

Ayeyarwady SOBA 2017: Synthesis Report

State of the Basin Assessment (Volume 1)

Ayeyarwady Integrated River Basin Management (AIRBM) Project



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DISCLAIMER	7
CITATION	7
PREFACE	9
ABOUT AIRBM PROJECT	10
ACKNOWLEDGEMENTS	12
LIST OF ABBREVIATIONS	15
EXECUTIVE SUMMARY	16
1. INTRODUCTION	18
1.1 Outline and Purpose	18
The Ayeyarwady River Basin	20
1.2 Structure of this Summary Report	20
2. SYNTHESIS	22
2.1 Introduction	22
2.2 Resources	22
2.3 Uses	29
2.4 Issues	37
2.5 Conclusions	39
SURFACE WATER	41
HIGHLIGHTS – Surface Water	42

TABLE OF CONTENTS

3. SURFACE WATER	44	GEOMORPHOLOGY AND SEDIMENTS	125
3.1 Introduction	44	HIGHLIGHTS – Geomorphology and Sediments	126
3.2 Ayeyarwady Setting	44		
3.3 Hydrological Regime of the Ayeyarwady Basin	47	6. GEOMORPHOLOGY AND SEDIMENTS	129
3.4 Surface Water Resources	53	6.1 Introduction	129
3.5 Status and Trends	54	6.2 Ayeyarwady Setting	129
3.6 Ecohydrology	57	6.3 Catchment Activities Affecting Geomorphology	129
3.7 Information Gaps	66	6.4 Sediment Transport and Characteristics	131
3.8 Conclusions	67	6.5 Issues Related to Geomorphology	135
WATER POLLUTION	69	6.6 Information Gaps – Sediment Monitoring	145
HIGHLIGHTS – water pollution	70	6.7 Conclusions	147
4. WATER POLLUTION	72	FISHERIES AND AQUACULTURE	149
4.1 Introduction	72	HIGHLIGHTS – Fisheries and aquaculture	150
4.2 Ayeyarwady Setting	72		
4.3 Status and Trends	72	7 FISHERIES AND AQUACULTURE	152
4.4 Information Gaps	91	7.1 Introduction	152
4.5 Conclusions	93	7.2 Fisheries Systems	153
GROUNDWATER	95	7.3 Fisheries Statistics	157
HIGHLIGHTS – Groundwater	96	7.4 Ecology of Fisheries Resources	164
5. GROUNDWATER	99	7.5 Fisheries Livelihoods	168
5.1 Introduction	99	7.6 Conclusions	172
5.2 Ayeyarwady Setting	99		
5.3 Groundwater Zones of the Ayeyarwady	101		
5.4 Status and Trends	117		
5.5 Conclusions	122		

BIODIVERSITY	177
HIGHLIGHTS – Biodiversity	178
8 BIODIVERSITY	180
8.1 Introduction	180
8.2 Ayeyarwady Setting	180
8.3 Species Distribution, Abundance, and Status	180
8.4 Areas of High Biodiversity Value	187
8.5 Trends	187
8.6 Threats	189
8.7 Opportunities for Conservation	193
8.8 Biodiversity Monitoring	195
8.9 Conclusions	197
SOCIO-ECONOMIC DEVELOPMENT	199
HIGHLIGHTS – Socio-Economic Development	200
9 SOCIO-ECONOMIC DEVELOPMENT	203
9.1 Introduction	203
9.2 Well-being and Livelihoods	205
9.3 Demography	206
9.4 Agriculture and Irrigation	211
9.5 Forestry and Watersheds	213
9.6 Ecosystem Valuation	214
9.7 Energy and Hydropower	217
9.8 Manufacturing	219
9.9 Mining	219
9.10 Conclusions	221

COMMUNITY PERSPECTIVES	223
HIGHLIGHTS – Community Perspectives	224
10 COMMUNITY PERSPECTIVES	227
10.1 Introduction	227
10.2 Ayeyarwady Setting	227
10.3 Methods and limitations	227
10.4 Status and Trends	229
10.5 Conclusions	24
11 CONCLUSIONS	247
11.1 Sustainable Use of Resources	247
11.2 Coordination of Strategies and Plans	249
11.3 Lessons Learnt About 'Doing' Assessments	249

DISCLAIMER

This document is a product of the Hydro-Informatics Centre of Myanmar (HIC) as one of the outputs of the Ayeyarwady Integrated River Basin Management (AIRBM) Project, on behalf of the National Water Resources Committee (NWRC).

The Ayeyarwady State of the Basin Assessment (SOBA) was a collaborative process including 25 international and Myanmar companies, NGOs, universities and research organisations. The views, conclusions, and recommendations of the SOBA process are the culmination of the field work and technical analysis of these groups and do not necessarily represent the views of the NWRC, HIC or AIRBM Project.

The Ayeyarwady SOBA is conducted within the political boundary of Myanmar, where more than 93% of the Basin is situated.

For further information please visit the AIRBM website: www.airbm.org.mm

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PREFACE

Dear Esteemed Reader,

It is with great pleasure that I welcome you to the first ever Ayeyarwady State of the Basin Assessment (SOBA) 2017 – the most comprehensive integrated environmental, social and economic baseline of our nationally important mighty mother Ayeyarwady River.

Rivers are the blood lines of the nation's economy, environmental sustainability, and cultural origins; they are an intrinsic part of our cultural, spiritual and national identity. The vision of the National Water Resources Committee (NWRC) is for *Myanmar to become a Water-Efficient Country* by implementing Integrated Water Resources Management (IWRM), and to bring benefits of income generation, better quality of life, a greener environment, and peace and stability for Myanmar people. In the words of our late Chairperson of NWRC Advisory Group and Retired Deputy Minister U Ohn Myint:

“Water is a natural legacy that we received from our ancestors.” We must also leave behind us a natural legacy for our future generations of clean and potable water guarded by National Water Policies and lawful practices”.

It has been two years since the NWRC signed an official agreement with the World Bank to implement the Ayeyarwady Integrated River Basin Management (AIRBM) Project. The AIRBM Project is unique in its aim to establish and maintain proper, sustainable management of water resources in their natural form. This extends to improving river systems, groundwater systems, coastal and marine water systems, water-related decision-making, hydro-meteorological data collection, storage and dissemination systems, water-related disaster risk reduction and management, water education, capacity building, and public participation in Myanmar.

We need to pay attention to conserving, managing and developing our water resources in an integrated manner. In doing so, the prioritisation of best development options needs to be informed by decision support systems, simulation models, optimisation methods, and environmental and social safeguard standards. Water bodies above and beneath the ground need to be monitored and conserved to prevent soil and water pollution. These are the most important tasks for the poverty alleviation and development of Myanmar's populace.

Thanks to the World Bank, Development Partners, Government of Myanmar and NWRC, these important tasks have finally received proper attention in the name of the AIRBM Project. While there remains much to accomplish, SOBA 2017 marks an important first step in this journey.

SOBA 2017 is an integrated environmental, social and economic analysis of past and present condition and trends in water and related resources in the Ayeyarwady Basin. It provides a major reference document for all development and conservation planners and managers working in the Ayeyarwady Basin.

The work underpinning SOBA 2017 was conducted by some 25 international and Myanmar commercial, research and NGO organisations. Grouped into six packages, each theme brought together leading Myanmar and international expertise in aspects of the Ayeyarwady's biophysical and socio-economic systems, with more than 100 individual experts engaged and working on this SOBA. SOBA 2017 will form the foundation of the future Ayeyarwady River Basin Master Plan.

It is my hope that this report will be a valuable resource for all those who want to join us in promoting and implementing IWRM in Myanmar, in using water to improve the livelihoods and economic conditions of all people in the basin; and in bringing cooperation and peace to our great nation.

I thank our leaders of NWRC, our partners from the World Bank and the Australian Government for their guidance of and support to the SOBA process. I thank our SOBA Coordinator and national SOBA Specialists for their hard work and intellectual contributions, and our AIRBM Director and all staff members for their kind support. I would also like to thank the SOBA teams for the effort, experience and commitment they brought to bear on the task. The quality of SOBA 2017 is testament to the dedication of all those involved.

Sincerely,



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Member of the NWRC

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ABOUT THE AIRBM PROJECT

The Government of Myanmar received USD 100 million in credit from the World Bank for the Ayeyarwady Integrated River Basin Management (AIRBM) Project. The project's objective is to empower good water governance through the development of institutional capacity and tools to improve decision-making in the context of integrated water management in the Ayeyarwady Basin. The project is led by the National Water Resources Committee (NWRC), with the Ministry of Transport and Communications (MoTC) as the focal ministry, and the Directorate of Water Resources and Improvement of River Systems (DWIR) as the implementing agency. The project is implemented under three components, as well as responding to potential crises and emergencies:

- Component 1 – Water resources management institutions, decision support systems, and Ayeyarwady River Basin Master Plan planning processes.
- Component 2 – Upgrading of the nation-wide hydro-meteorological data observation systems.
- Component 3 – Navigation enhancement on the Ayeyarwady River.

The main elements in the Ayeyarwady Basin development planning process include:

The Ayeyarwady State of the Basin Assessment (SOBA) represents the first major suite of technical outputs of the AIRBM Project, and will inform the development of an Ayeyarwady River Basin Master Plan. SOBA 2017 represents the most comprehensive, integrated environmental, social and economic baseline for the Ayeyarwady to date. It takes stock of the status and historic trends in key characteristics of the Ayeyarwady system, and how the people of Myanmar utilise and benefit from the river basin's water and related resources. SOBA 2017 combines rigorous technical assessments with inclusive consultation processes. It will inform the development of an Ayeyarwady Basin Master Plan in-keeping with international best-practice principles for integrated water resources management (IWRM). The work highlights issues, opportunities, risks and uncertainties, and tradeoffs that will need to be addressed in this planning process. Furthermore, SOBA 2017 provides an important baseline against which the impacts of future development pathways may be monitored and assessed.

The *Basin Scoping Study* (BSS) will act as a bridge between

baseline understanding of the Ayeyarwady system and the future Ayeyarwady Basin Master Plan by exploring: the sensitivity of the Ayeyarwady system to change; the inter-dependencies, synergies and tradeoffs between developments in the Ayeyarwady Basin; and the potential impacts of climate change.

The *Ayeyarwady Multi-Stakeholder Forum (MSF)* plays a critical role in the AIRBM Project's engagement with stakeholders, and underpins the success of its planning activities for the Ayeyarwady Basin. The AIRBM Project designed a MSF that comprises mechanisms and modalities like forums, working groups, liaison groups, and peer-review panels, for ensuring engagement of key stakeholders from the public and private sector involved in the management or use of the Ayeyarwady Basin's water and related resources. These stakeholders include Union and State/Region government agencies/departments, non-governmental organisations (NGOs), civil society organisations, and local communities. The design of the MSF includes a dedicated consultation process for the SOBA, the BSS and subsequent basin planning initiatives, notably the Ayeyarwady Basin Master Plan and the scope of the Decision Support System.

The *Decision Support System (DSS)* will serve as an integrated suite of tools and assessment methodologies designed to understand the hydrological, environmental, social and economic implications of development pathways and options for the Ayeyarwady Basin. In the first instance, a suite of linked hydrological models and databases covering flows, floods, water quality, sediments and saline intrusion will be developed, calibrated and tested.



The *Assessment of Basin-wide Development Scenarios* involves analysing existing water development pathways for the Ayeyarwady Basin (from the BSS) in the form of several alternative basin-wide development scenarios against a broad range of hydrological, environmental, social, and economic indicators, taking into account climate change. The resulting basin-wide distribution of the benefits, costs, impacts and risks of the various scenarios will enable basin-wide discussions with stakeholders to compare and identify acceptable scenarios or parts of scenarios. These scenarios aim to create high benefits, and acceptable adverse impacts, as well as provide water-related security in an equitable manner. It will also require close consideration of a range of complementary measures that may be needed to offset or mitigate the impacts of agreed development. The outcomes of these discussions will guide the formulation of the Ayeyarwady Basin Master Plan.

The *Ayeyarwady Basin Master Plan* will bring basin perspectives into Union and State/Region planning, decision-making and governance processes – steering the socio-economic and sector-based planning of relevant government agencies. Firstly, the Ayeyarwady Basin Master Plan will summarise the current water-related condition and trends, together with the plans for development. It will then describe the future water-related needs and opportunities, and associated risks and uncertainties. This will be followed by a basin development strategy that will balance a range of desired development outcomes that may be sustained in the long term (based on feedback from stakeholder discussions of the scenario assessment results). The plan will conclude with a phased investment program and supporting priority activities for basin development and management, which will need to be addressed in successive socio-economic and sector-based plans. The plan will be prepared in stages, starting with SOBA 2017 and the BSS.

While the above mentioned tasks are activities of component 1, they benefit from direct and indirect contributions and support from the component 2 and component 3 teams.



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HIC also extends its thanks to the Australian Water Partnership (AWP) for its support to SOBA and its establishment of the Ayeyarwady Murray-Darling twinning relationship. The twinning of the two basins has allowed for a rich peer-to-peer exchange between Myanmar and Australian experts throughout the SOBA design, implementation and review process.

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LIST OF ABBREVIATIONS

µg/L	micrograms per litre	Mt	million tonne
µS/cm	microsiemens per centimetre	Mt/yr	million tonne per year
99PGIP	99 Ponds GIP	MW	megawatt
ARI	annual recurrence interval	NGO	non-governmental organisation
BOD	biological oxygen demand	NT	near-threatened
CFU	colony forming unit	NTU	nephelometric turbidity unit
CPUE	catch-per-unit-effort	NTFP	non-timber forest product
CR	critically endangered	NWRC	National Water Resources Committee
DoF	Department of Fisheries	SAR	sodium adsorption ratio
EN	endangered	SME	small- and medium-sized enterprise
GDP	gross domestic product	SOBA	State of the Basin Assessment
GIP	Groundwater Irrigation Project	SOBA 2017	Ayeyarwady State of the Basin Assessment
GW	gigawatt	t/ha	tonne per hectare
GWD	Groundwater Division	TSS	total suspended solids
GWZ	groundwater zone	USD	United States dollars
ha	hectare	VU	vulnerable
HEZ	hydro-ecological zone	WISDM	Water Information System for Data Management
HIC	Hydro-Informatics Centre	WHO	World Health Organization
hm ³	cubic hectometre		
IPPS	Industrial Pollution Projection System		
IWMI	International Water Management Institute		
IWUMD	Irrigation Water Utilization Management Department		
KBA	Key Biodiversity Area		
km	kilometre		
km ²	square kilometre		
km ³	cubic kilometre		
km ³ /yr	cubic kilometre per year		
L/sec	litres per second		
m	metres		
m ³	cubic metres		
m/day	metres per day		
m/km	metres per kilometre		
m/yr	metres per year		
m ³ /yr	cubic metres per year		
mm	millimetres		
MOALI	Ministry of Agriculture, Livestock and Irrigation		
MONREC	Ministry of Natural Resources and Environmental Conservation		



EXECUTIVE SUMMARY

This report, *Ayeyarwady State of the Basin Assessment (SOBA) 2017: Synthesis Report*, together with a suite of companion reports, *Ayeyarwady State of the Basin Assessment (SOBA) 2017: Technical Reports*, are the first documents of their kind for the Ayeyarwady Basin. The assessment, convened by Myanmar's Hydro-Informatics Centre (HIC), brought together the research efforts and expertise of 25 entities from Myanmar and across the globe, including universities, institutes, and consulting companies, to collect and consolidate data about key aspects of the basin and establish a comprehensive evaluation of its current state. It also draws on the knowledge of officials and personal experiences of local citizens on the importance of the Ayeyarwady to their lives and to their livelihoods. More detailed technical data, information, and references underpinning this overview document are available in the companion technical reports.

SOBA 2017 aims to inform planning in the Ayeyarwady Basin by providing baseline information on the condition and trends in water and land resources as well as related ecosystem services. Eight thematic areas are covered, including Surface Water, Water Pollution, Groundwater, Geomorphology and Sediments, Fisheries and Aquaculture, Biodiversity, Socio-Economic Development, and Community Perspectives.

Overall, the current condition of the Ayeyarwady Basin is described as intermediate to good with respect to land and water resources in most hydro-ecological zones (HEZs). Surface water resources are abundant, but as the climate is highly seasonal and rainfall varies greatly among locations and years, sustainable use can still be challenging. The proportion of total annual runoff extracted is estimated at 2% and, in the dry season, at 8%. In the Mu Sub-basin, for example, dry season extraction was estimated at 48%.

Groundwater resources are extensive but are not well understood overall, because there is no detailed mapping outside the Central Dry Zone. Current extraction across the basin's nine groundwater zones (GWZs) ranges from 2% to 33%, with largest use in the Lower Ayeyarwady including much of the Central Dry Zone. These values are likely to be within the bounds of sustainable use and suggest that there may be opportunities to expand groundwater development if properly managed and regulated.

Mammal, bird, and reptile biodiversity is high, and large migratory fish species are still present in rivers that are extinct or endangered elsewhere in the world. Watershed ecosystems still provide many important ecological functions.

The key trends are much more worrisome than current condition. Key natural resources are in decline in several HEZs. Forest cover is declining rapidly in areas that, until recently, had relatively large areas of intact forest. Habitat loss and degradation is adversely affecting populations of many mammal, bird, and reptile species. Large areas of wetlands have been lost. Native fish populations are in decline. Surface water quality and river geomorphology are degrading as a result of mining activities in the catchment and in the riverbeds. Groundwater use in the Middle Ayeyarwady HEZ is extensive and may now be affecting fishery stocks.

These trends are important for society to consider, as many Ayeyarwady people remain highly dependent on the watershed and its ecosystems for clean drinking water, flood regulation, water storage, food, nutritional security, and livelihoods. The drivers of many of the negative trends appear to be strengthening, which raises several critical issues for sustainable development and future river basin planning and management in the Ayeyarwady.

Unregulated mining, illegal logging, and poorly managed concessions and fisheries are creating long-term social and environmental problems. Sand and gravel extraction from the river, for instance, affects the geomorphology of the river and impacts aquatic ecosystems. The growth of these natural resource management problems is attributable, in part, to ineffective management systems for land and water governance.

Development in the Ayeyarwady Basin is uneven, with large differences among HEZs, political jurisdictions, as well as rural and urban areas. For example, approximately 75% of households in the Ayeyarwady Basin had access to safe drinking water in 2014, whereas in the Upper Ayeyarwady HEZ only 26% had access. Targeting these differences represents opportunities for achieving more inclusive development of water-related resources.

Existing hydropower and irrigation dams already have small but detectable influences on river hydrology. There are 14 large hydropower plants in operation with 2.1 gigawatts (GW) of installed capacity, 3 under construction (1.4 GW) and 29 planned (25.6 GW); most planned plants are in mountainous areas in the Upper and Middle

Ayeyarwady. Implementation of all planned larger-scale infrastructure development would have major impacts on sediments, flows, and the flood pulse. These could have important adverse consequences on aquatic ecosystems, inland fisheries, and river island and bank agriculture.

Human settlements and associated economic activities are increasingly concentrated in floodplains and delta areas exposed to major flood events. Full protection is unrealistic given the associated costs and, in any case, space is needed into which flood waters can divert. This implies that steering new investments into less flood-prone areas should be part of future river basin planning alongside other efforts to improve monitoring and coordination of flood disaster risk reduction measures.

Unreliable and insufficient data on many key indicators for drivers, condition, and socio-economic consequences makes monitoring and projecting changes in the state of the basin difficult. The paucity of basic data on groundwater status, for instance, is a major barrier to setting and enforcing sustainable limits on extraction. Improved monitoring and data management are essential to sustainable development of resources in the Ayeyarwady Basin.

The Ayeyarwady Basin has significant natural resources. Ineffective governance and insecurities related to political conflicts remain the most significant obstacles to more inclusive and sustainable development. Addressing these issues will require cooperation among multiple stakeholders in strategic basin planning. Regular assessment of the condition and trends in natural resource stocks are key inputs to monitoring the effectiveness and adequacy of river basin planning.

1. INTRODUCTION

1.1 Outline and Purpose

The Ayeyarwady State of the Basin Assessment (SOBA) 2017 marks an important step in better understanding the conditions and trends of water and related resources of the Ayeyarwady Basin in Myanmar. It presents significant insights for guiding more sustainable development across the communities and environments of the Ayeyarwady Basin.

SOBA 2017 is the first comprehensive assessment of the Ayeyarwady Basin's environmental, social, and economic condition and trends and represents a major milestone in the river basin planning process. It presents a first-cut baseline within the constraints of available and reliable data for informing strategic policy settings at local-to-national scales that give effect to sustainable use and development of the Ayeyarwady Basin's natural resources. Importantly, the assessment process has identified significant gaps in data and highlighted the need for comprehensive and consistent monitoring of resource conditions and trends.

The assessment was initiated by the National Water Resources Committee and designed and managed by Myanmar's Hydro-Informatics Centre with the support of the World Bank and the Australian Water Partnership. The assessment was conducted by research teams in the following thematic areas:

- Surface water
- Water pollution
- Groundwater
- Geomorphology and sediments
- Fisheries and aquaculture
- Biodiversity
- Socio-economic development
- Community perspectives

The resulting SOBA 2017 is presented in two complementary forms: this Synthesis Report (Volume 1) and a series of theme-based Technical Reports (Volume 2). This report provides a synthesis across the technical themes, followed by an overview of findings and conclusions for each individual assessment. The Technical Reports document the body of evidence underpinning SOBA 2017 – the research literature, the methodologies applied, data sources and analyses, detailed findings, and conclusions.

Volume 1 is designed to inform readers with an interest in natural resource sustainability in the Ayeyarwady Basin. It may be read as a reference document or as a source of information to guide policy and planning decision-making. Each chapter opens with a suite of 'Highlights' as an entrée to its key facts and findings. Planners, researchers, donors, and others who require access to more detailed scientific information, including reference lists, should refer to the individual Technical Reports comprising Volume 2 (see breakout box). In addition, the Water Information System for Data Management (WISDM) is a web-based portal designed to provide secure access to a wide range of spatial and time series data, and other information relevant to managing and developing water resources in Myanmar's major river basins (<http://www.airbm.org>).

SOBA Technical Reports

SOBA 1.1: ALS Hydrographics, Alluvium and Hydronumerics (2017), Hydrological Data Audit and Rating Curve review (SOBA 1.1), as part of the Ayeyarwady State of the Basin Assessment, sponsored by Australian Water Partnership.

SOBA 1.2: eWater & CSIRO (2017), A Surface Water Resource Assessment of the Ayeyarwady River Basin (SOBA 1.2), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project, sponsored by the Australian Water Partnership.

SOBA 1.3: CSIRO Australia & Hydronumerics (2017), Water pollution survey (SOBA 1.3), as part of the Ayeyarwady State of the Basin Assessment, sponsored by the Australian Water Partnership.

SOBA 1.4: The Australian Rivers Institute, Griffith University & Truii Pty Ltd (2017), Ecohydrology assessment (SOBA 1.4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project, sponsored by the Australian Water Partnership.

SOBA 2a: International Water Management Institute & Aqua Rock Consultants (2017), Groundwater Resources of the Ayeyarwady River Basin (SOBA 2a), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 2b: International Water Management Institute (2017), WISDM Water Information System for Data Management (SOBA 2b), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 3: WWF Greater Mekong (2017), Sediments and Geomorphology (SOBA 3), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), Fisheries in the Ayeyarwady Basin (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), Consultations of fishers on fishery resources and livelihoods in the Ayeyarwady River Basin (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), Consultations on wild resources and livelihoods in the Ayeyarwady River Basin (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), Biodiversity of the Ayeyarwady Basin (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), Aquatic habitats in the Ayeyarwady Basin and their biodiversity (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 5: ICEM, CESD & MMRD (2017), Sectoral Development and Macroeconomics Assessment (SOBA 5), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 5.1: Natural Capital Economics, Alluvium International & Alluvium Consulting Australia (2017), Economic Valuation of Ecosystem Services in the Ayeyarwady Basin (SOBA 5.1), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project, sponsored by the Australian Water Partnership.

SOBA 6: Arcadis Nederland B.V., Wageningen University & Research, EMC (2017), Participatory 3D Mapping and Local Consultations (SOBA 6), as part of the Ayeyarwady State, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 6: Arcadis Nederland B.V., Wageningen University & Research, EMC (2017), Communities Atlas (SOBA 6) as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

The Ayeyarwady River Basin

The Ayeyarwady River is approximately 2,000 kilometres (km) long, and its catchment area of 414,000 square kilometres (km²) occupies 62% of Myanmar (Figure 1.1). Its largest tributary is the Chindwin River, representing more than a quarter of the total Ayeyarwady Basin (114,500 km²). The Ayeyarwady Basin has 13 sub-basins, encompassing all the major tributaries of the Ayeyarwady and Chindwin Rivers, each of which has distinct hydro-physical characteristics with respect to area, the main waterway, and elevation.

Based on river morphology, the Ayeyarwady Basin has five distinct hydro-ecological zones (HEZs), namely the Upper Ayeyarwady (HEZ 1), Chindwin (HEZ 2), Middle Ayeyarwady (HEZ 3), Lower Ayeyarwady (HEZ 4), and Ayeyarwady Delta (HEZ 5) (Figure 1.1). SOBA 2017 uses HEZ as its assessment framework, such that the research teams collected, analysed, and presented information according to each of the five HEZs wherever practicable.

1.2 Structure of this Summary Report

This report leads with a synthesis chapter that looks across the Technical Reports and provides an excellent entry point for readers who want an overview of SOBA 2017's key findings and talking points (Chapter 2). The chapters that follow are organised around the SOBA 2017 themes, which mirror the suite of Technical Reports.

Chapter 3 (Surface Water) outlines the hydrological regime of the Ayeyarwady Basin before providing an assessment of surface water resources. It concludes with an overview of the status and trends of surface water resources, including the impact of development on water resources to date and a summary of information gaps on surface water and climate modelling.

Chapter 4 (Water Pollution) is an initial assessment of water pollution from industrial, urban, mining and agricultural sectors in the Ayeyarwady Basin. The implications for ecosystem health and human health are also discussed. The chapter concludes with information gaps and suggested priorities for monitoring programs.

Chapter 5 (Groundwater) provides a synthesis of available data on groundwater quality, quantity, abstraction, and ecosystem values for each of the Ayeyarwady Basin's nine groundwater zones (GWZs). Data are highly variable for all GWZs so that some calculations are only indicative. This chapter concludes with an overview of the status and trends of groundwater, and key recommendations for future groundwater management, with emphasis on data gaps and governance.

Chapter 6 (Geomorphology and Sediments) provides an overview of the status and trends of key characteristics of the geomorphology and sediment dynamics of the Ayeyarwady Basin and outlines the implications for the Ayeyarwady Basin system. A conceptual design is recommended for a sediment and geomorphic monitoring program for the Ayeyarwady River.

Chapter 7 (Fisheries and Aquaculture) assesses the state of fisheries and aquaculture in the Ayeyarwady Basin. Monitoring data and statistics paint a comprehensive picture of the status of fisheries and the way forward for future monitoring efforts. The ecology of fisheries resources looks at biodiversity, species abundance, and fish migrations. It is followed by an outline of fisheries livelihoods, including consideration of nutrition, food security, and gender issues. Challenges and opportunities are outlined from a local perspective and that of a fisheries manager.

Chapter 8 (Biodiversity) summarises current knowledge of the status, trends, and threats to biodiversity in the Ayeyarwady Basin and outlines key opportunities for conservation and future monitoring. Its focus is primarily on a wide range of wetland habitats and species but also includes biodiversity of broader interest where information is available, such as for birds, most mammals, and selected reptiles.

Chapter 9 (Socio-Economic Development) summarises the key findings, conclusions, and recommendations related to socio-economic development. Special emphasis is placed on identifying key characteristics and trends and assessing their implications on development and water resources planning in the Ayeyarwady Basin.

Chapter 10 (Community Perspectives) analyses the present uses of the river and the values people attribute to it, whether pragmatic, spiritual, or cultural. It examines the threats people perceive and whether their causes are thought to be man-made or natural.

Chapter 11 (Conclusions) draws together the main insights arising from the collective assessment effort, with emphasis on key messages for planners and policy-makers to improve the sustainability of the Ayeyarwady Basin's water and related resources.

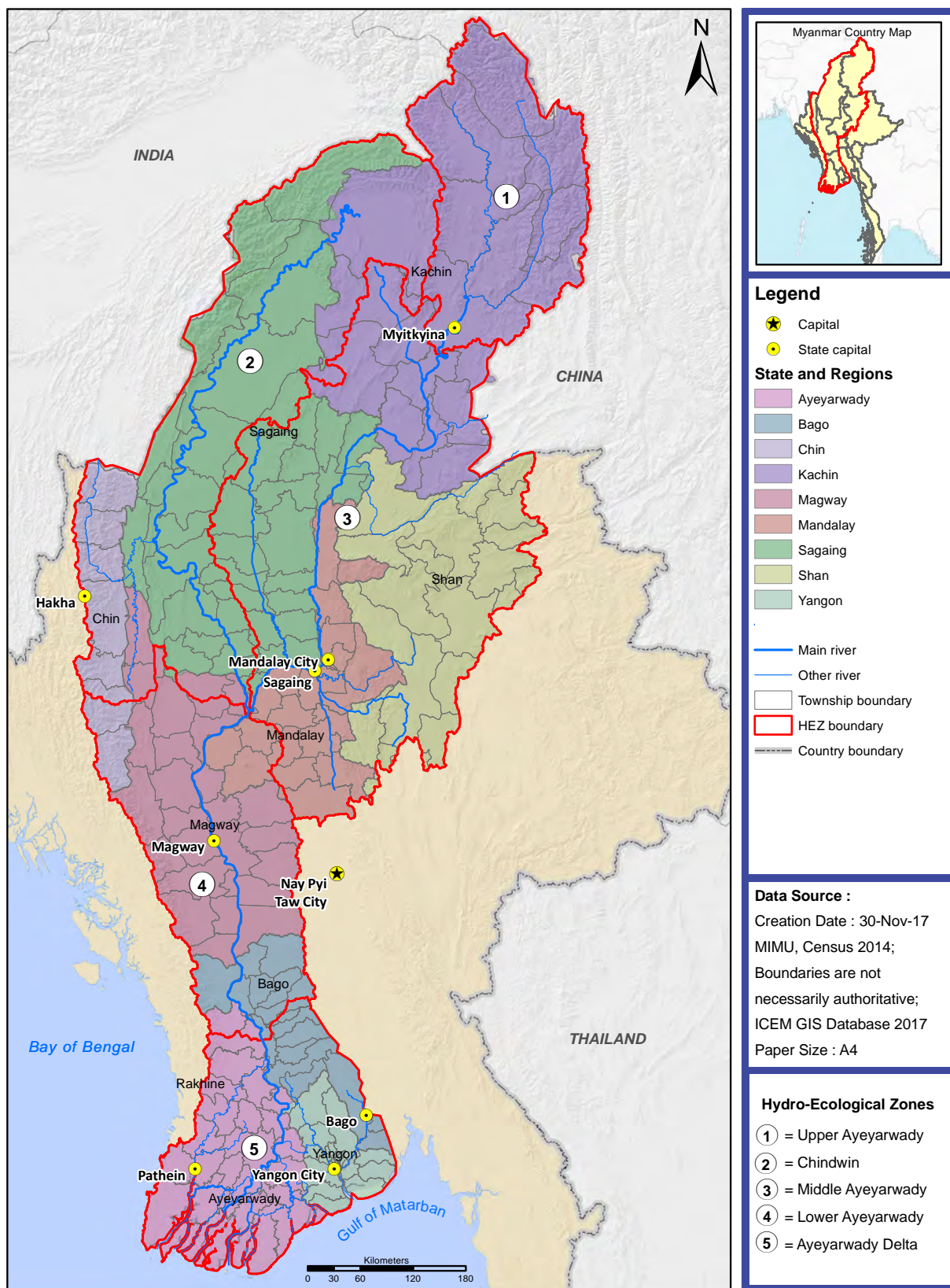


Figure 1.1 - Hydro-ecological zones and state–region–division in the Ayeyarwady Basin



2. SYNTHESIS

2.1 Introduction

This chapter provides an overview of SOBA 2017's main findings regarding condition and trends in the Ayeyarwady Basin and identifies a set of cross-cutting and emerging issues with potentially significant implications for the sustainable use of natural resources. It is framed according to:

- **Resources** — Surface water, groundwater, geomorphology and sediments, and biodiversity.
- **Uses** — Fisheries, hydropower, agriculture, forestry, navigation, mining, human settlements, manufacturing, industry, and ecosystem values.
- **Issues** — Ineffective land and water governance, uneven development and inequality, impacts of large-scale water infrastructure, protecting or redirecting at-risk floodplain assets, and inadequate monitoring and data management.

As this is the first iteration of SOBA, this chapter also identifies critical information gaps and makes recommendations on how these gaps could be addressed to improve monitoring changes in conditions.

2.2 Resources

In most HEZs, the condition of land and water resources in the Ayeyarwady Basin is intermediate to good (Figure 2.1). Surface water flow regimes have not been extensively modified by infrastructure operations, although the release of stored water in the dry season has detectable impacts on flows. Water quality is impacted by mining activities in the Chindwin HEZ, by multiple activities in the Middle Ayeyarwady, and by urban–industrial development in the Ayeyarwady Delta HEZ.

Groundwater is used most in the drier Middle Ayeyarwady HEZ and may be decreasing there. Groundwater use is low in the other HEZs and, in the absence of detailed information, stocks are assumed to be in good condition. Intact forests are only widespread in the Upper Ayeyarwady, and even here, they are in rapid decline. In most locations, the trend is for natural resources to be declining or, at best, stable (Figure 2.1).



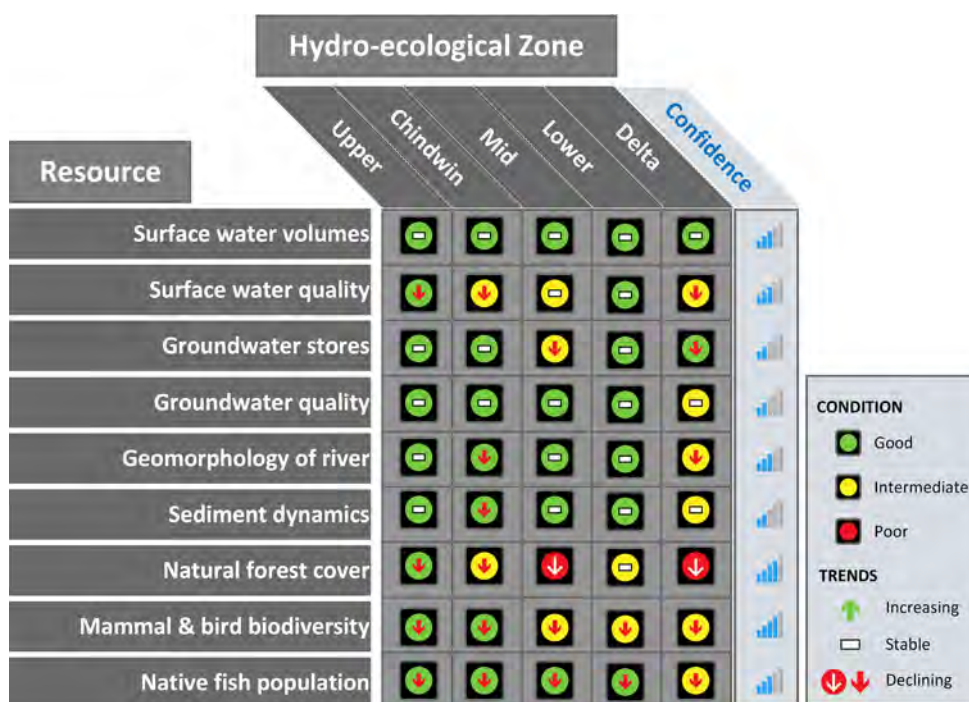


Figure 2.1 - Condition and trends of key resources in the hydro-ecological zones of the Ayeyarwady Basin

Rightmost column indicates level of confidence in condition and trend assessments with a stronger blue signal implying greater confidence

2.2.1 Surface water

The Ayeyarwady Basin is rich in surface water resources (Chapter 3), but the climate is highly seasonal, and rainfall varies greatly among locations. The highly seasonal nature of the rainfall gives rise to a flood pulse, which can be traced as it moves downstream through the basin. The onset and duration of the wet season varies year by year, with no apparent trend in either onset, duration, or cessation. The variability in the wet season affects water supply, navigation, and flooding. Analysis of climate data has revealed that, while parts of the Ayeyarwady Basin have showed a uniform climate since 1986, some areas have recorded extended periods of below average rainfall, resulting in potential water supply stress.

Significant natural drivers of basin hydrology include the monsoon in the wet season, cyclones, snowmelt in the lead up to the wet season, and groundwater flows to the surface water system.

The delta is particularly exposed to risk from cyclones, where storm surges exacerbate damage caused by rain-induced flooding. Approximately 60% of total flows upstream of the delta are generated from the upstream catchments of the Chindwin, Mali Hka, and N'Mai Hka Rivers. These rivers have their origins in the high rainfall regions of the Naga Hills and Eastern Himalayas.

At the scale of the entire Ayeyarwady Basin, most of the catchment runoff becomes end-of-system stream flow. The proportion of total annual runoff extracted in the Ayeyarwady Basin is estimated at 2.2%. The proportion of dry season runoff extracted in the Ayeyarwady Basin during the dry season is estimated at 8%. While the Ayeyarwady Basin is rich in water resources, heavily utilised tributaries have the potential to be stressed during the long dry season. The Mu Sub-basin in the Middle Ayeyarwady HEZ exploits a larger fraction of available flow volume than others (Figure 2.2). Water use is greatest in the Central Dry Zone, accounting for some 70% of surface water extraction. Risks posed by hydrologic alteration are thus highest within the Middle Ayeyarwady HEZ.

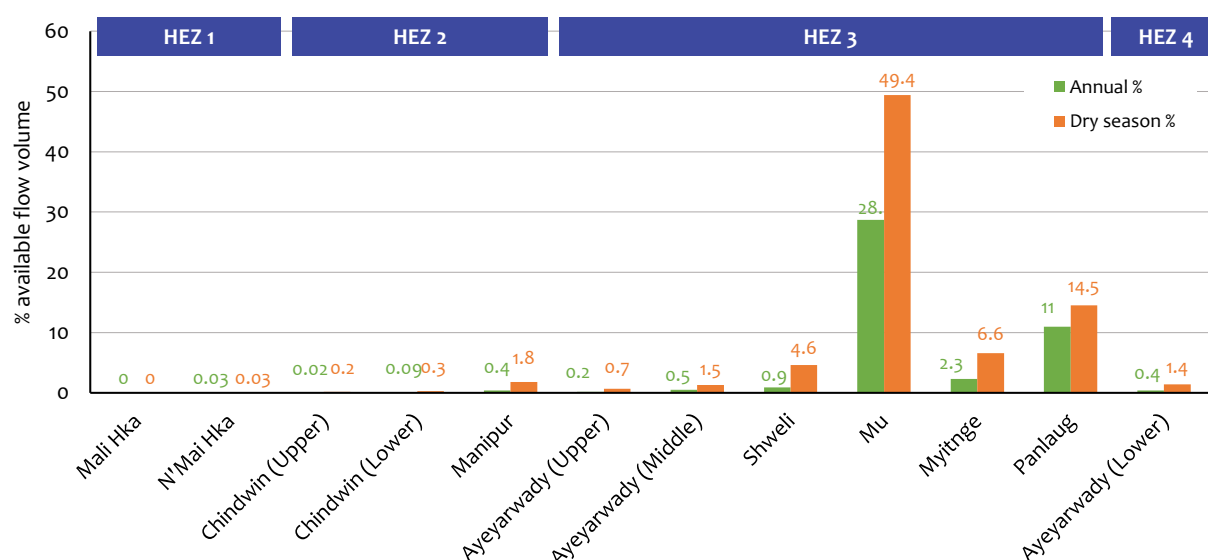


Figure 2.2 - Available water flow extracted in different sub-basins and hydro-ecological zones in the dry season and annually (SOBA 1.2)

Flows include mainstem flows in the Chindwin and Ayeyarwady rivers. These high flows in the mainstems can skew sub-basins of the Lower Ayeyarwady and Lower Chindwin to appear less impacted than they actually are if only considering localised sub-basin catchment runoff. Of the local sub-basin runoff, 7% is extracted in the Lower Ayeyarwady and 3.5% in the Lower Chindwin, putting them in a similar class to the Shweli and Myitnge river sub-basins.

There are nearly 300 man-made water storage structures in the Ayeyarwady Basin. The 30% of structures that provide only hydropower are mostly in China. The 46% classified as irrigation works are mostly in Myanmar. The remaining 24% are multi-purpose. During the dry season, water released from storage makes a detectable contribution to flow. The Upper Ayeyarwady HEZ has experienced no detectable hydrological changes from water resource development and extraction (Chapter 3). The most notable change in the Chindwin HEZ is the 15% increase in the duration of low flow spells. The Middle Ayeyarwady HEZ shows some major alterations in hydrology already: a 3% decrease in mean annual flow; 16% increase in the mean duration; and 25% decrease in number of low flow spells. Expanded monitoring of water flows, water storage structures, and climate would help manage the Ayeyarwady water system.

2.2.2 Groundwater

Groundwater resources (Chapter 5) are extensive but, outside the Central Dry Zone, have not been mapped in detail. Regulation and monitoring of industries and human activities are critical to the management of groundwater resources. Lack of groundwater legislation and regulation is a major hurdle.

Overall, a large volume of groundwater is stored in the aquifers underlying the Ayeyarwady Basin. Recharge is predominantly from direct rainfall. The assessment of groundwater resources defined nine GWZs by further subdividing some of the HEZ. Groundwater storage and recharge are highly variable between GWZs (Figure 2.3).

Quantification of the groundwater resources at a basin scale are order of magnitude estimates, because measurements of groundwater flow and levels are available only in limited areas. The exception is the Central Dry Zone, where a large body of data and the experience of local and international hydrogeologists are presented with high confidence. Detailed hydrogeological investigations in the Central Dry Zone have identified large areas with high-yield, low-salinity groundwater suitable for irrigation use. Identification of potential areas for expansion in the delta, Shan Plateau, and the upper reaches of the Ayeyarwady Basin will require similarly detailed hydrogeological mapping.

Current extraction is of the order of 7% to 15% of the renewable resource, with the largest use in the Central Dry Zone. Groundwater is the most important source for domestic and drinking water supplies nationally. According to census figures, tubewells provide water for drinking to 33% of households, and to 40% of households for other domestic uses.

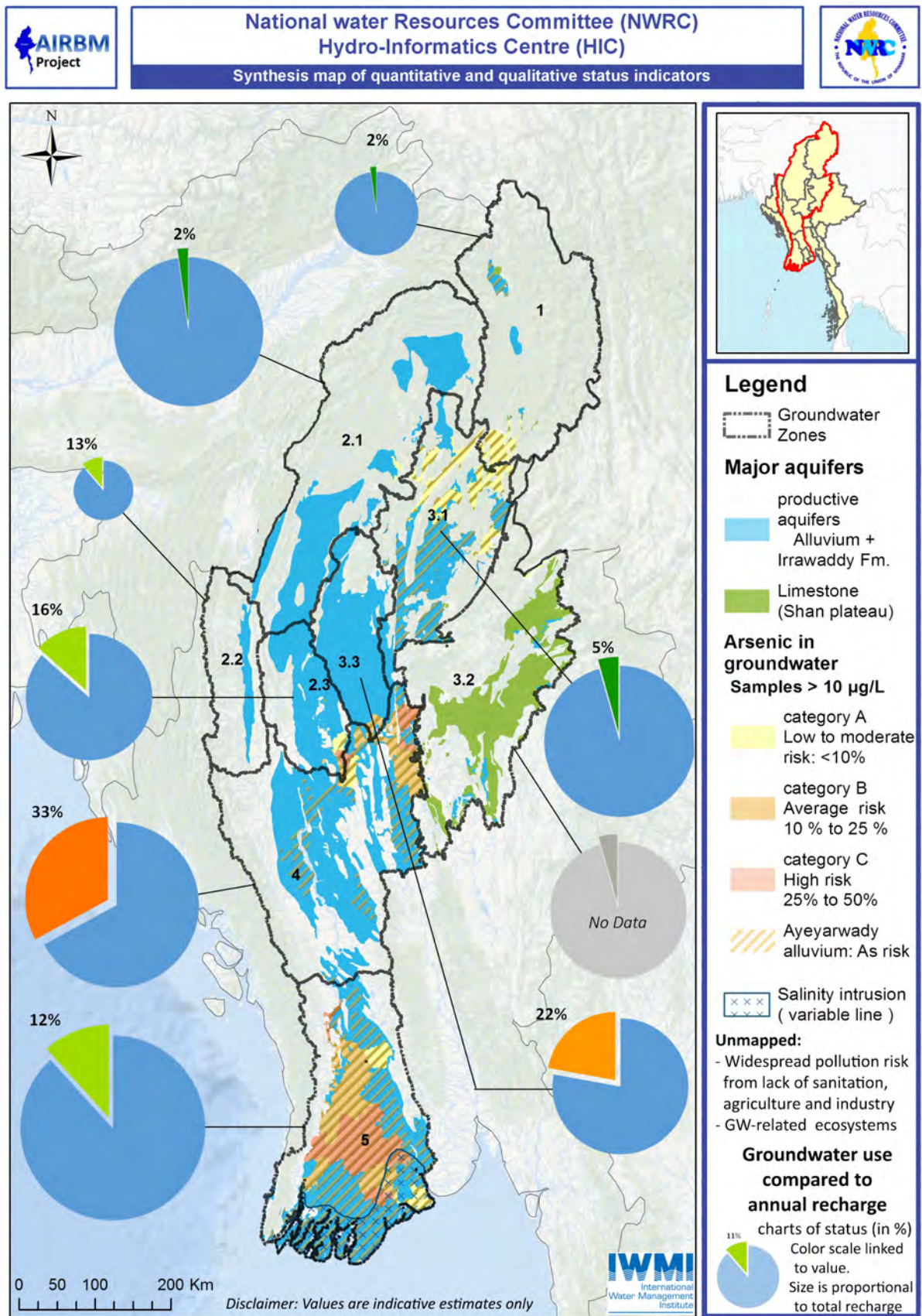


Figure 2.3 - Summary of main quantitative and qualitative status indicators for groundwater in the groundwater zones of the Ayeyarwady Basin (SOBA 3)

Except for salinity and arsenic, water quality issues are mainly localised, responding either to local geological conditions or local human pressures. Isolated occurrences of elevated fluoride, uranium, and metals are found in specific geological contexts, but data are scarce. Pumping from freshwater aquifers may cause groundwater from nearby saline aquifers to flow toward the pumped zone. No trend in arsenic occurrence is expected over time, and the current practices of drilling deeper or changing location for contaminated wells can be effective in preventing exposure to arsenic. Testing of wells for arsenic before use is critically important and should be mandatory for all new wells.

Large water-using industries, such as sugar, paper, and cement, use surface water, but towns and cities rely on groundwater wells to support smaller industries. As with other sectors, there are large uncertainties in attempting to estimate groundwater use for agriculture in Myanmar. What can be reported with confidence is that groundwater demand for irrigation in the Ayeyarwady Basin is increasing. It appears that the volumes of groundwater withdrawn for irrigation now approach or surpass volumes for domestic supply. This is an important shift and brings new management challenges to safeguard domestic supplies.

Groundwater discharge is important to dry season flows in the intermittent 'chaungs' (tributary streams) in the Central Dry Zone and the Ayeyarwady mainstream and must be taken into consideration in future planning. Pending further research, indications are that the Upper Chindwin, Middle Ayeyarwady, and the Ayeyarwady Delta GWZs represent the most important areas in terms of groundwater ecosystem values, as they host areas that are both highly reliant on groundwater and are considered a high priority for conservation.

There are two critical gaps in management of groundwater in the Ayeyarwady Basin. The first is the paucity of basic data on groundwater status and use, the absence of a systematic documentation of wells or extractions, and measurements of water levels and water quality. These data would provide the basis for establishing, monitoring, managing, and enforcing sustainable limits to groundwater extraction for each aquifer region and national groundwater quality standards to ensure that water is fit for purpose. The second critical gap is the lack of any legislative or regulatory framework for groundwater management. Establishing a suitable institutional and legislative base for groundwater management is a priority in the Government of Myanmar's National Water Policy. With improved information and institutions, there will be opportunities to use groundwater to support the expansion of agriculture and other economic activities.



2.2.3 Geomorphology and sediments

The geomorphology of the Ayeyarwady River (Chapter 6) is in moderate to good condition, owing to the lack of regulation of the mainstem and the flow and sediment inputs from the remaining unregulated tributaries (Figure 2.1). The pressures on the river are mounting at a rapid pace, and accelerating land use changes will impact the river at increased rates and severity if the linkages between land and river are not recognised and carefully managed.

The character of the Ayeyarwady River is strongly dependent on the geology of Myanmar. The river courses and catchment are formed from the active collision zone between the Indian Plate to the west and the Eurasian Plate to the east. The variability of rainfall in the Ayeyarwady Basin exerts a strong control on geomorphic processes. In the headwaters and along the western ranges of the Chindwin, monsoonal rainfall patterns dictate the flood pulse flow pattern. In the Lower Chindwin and Lower Ayeyarwady, rainfall is much lower due to the area being in a rain shadow, but the episodic high rainfall events that do occur are important for transporting large volumes of sediment from this arid landscape to the rivers. The Chindwin River, the largest tributary of the Ayeyarwady, is a major contributor to the sediment load of the Ayeyarwady Basin.

Land and river developments affect the geomorphology of rivers by altering the pattern and quantity of flow and sediment entering the river. Large areas of the Ayeyarwady have been and continue to be affected by deforestation and terrestrial mining. Observations suggest that there is a high likelihood that the characteristics and volumes of sediment entering the river are being altered by these activities.

The present scale of hydropower and irrigation activities is likely to be resulting in some modification of flows and reduction in sediment loads, as evidenced by geomorphic changes to the channel characteristics of tributaries. Present hydropower development is largely focused in the Upper Ayeyarwady, with irrigation developed in the Lower Ayeyarwady. The quantitative impact of these activities was not determined due to a lack of information regarding irrigation impoundments and operating regimes.

Sand and gravel extraction rates are estimated at approximately 10 million tonnes per year (Mt/yr) based on the responses of survey participants, although the actual volumes extracted are certainly higher. A comparison of possible bedload volumes being transported by the river suggests that extracting 10 to 20 Mt/yr of material from the river carries a high risk of having a geomorphic impact on the system. It is suggested that the extraction of material from the river and its tributaries is increasing, and the future trend will be for the extraction of even greater volumes to supply the construction industry.

Three types of geomorphic risks for the Ayeyarwady emerge from these changes in catchment and river activities.

1. First are changes to riverbanks and channels. The geomorphic zones most susceptible to change are the broad alluvial areas with low slope, in which sediment deposition and reworking are constantly occurring. This is especially so downstream of higher slope and energy zones that can deliver large loads of sediment that cannot be easily mobilised through the wider, low-slope reaches.
2. Second are altered flow and sediment regimes. There is evidence that low flows in the Ayeyarwady changed between 1986 to 2015. Additional flow changes associated with the implementation of additional hydropower development can be expected. Individual, large dams have the potential to dramatically alter the flow of rivers and trap large volumes of sediment. Collectively, these planned projects have the potential to substantially reduce sediment loads, alter flows, and reduce the connectivity of the Ayeyarwady through increased fragmentation.
3. Third is reduced delta stability. Recent investigations of the Ayeyarwady Delta conclude that the resilience of the delta may be decreasing, especially near the mouths of the main tributaries. The Ayeyarwady coastline is under stress due to land use pressures, and the proximity of the delta to the most populous area of the country will likely increase these pressures in the future. The management of sea-level rise due to climate change is best achieved through maintaining the resilience of river and coastal systems.



2.2.4 Biodiversity

The Ayeyarwady Basin is one of the most biologically diverse regions in the world (Chapter 8). It is home to approximately 1,400 mammal, bird, and reptile species, with more than 100 species that are globally threatened. This assessment confirms widespread declines in biodiversity of many mammal, bird, and reptile species. Key habitats have shrunk and are fragmented. Only 25% to 30% of former wetlands within the Ayeyarwady Basin still exist. The highest levels of remaining biodiversity are in the eastern areas of the Ayeyarwady Basin.

Several factors have contributed to biodiversity decline. Hunting and poaching is widespread even within Protected Areas. Mining and other activities have converted or degraded habitats. Only 50% of the Key Biodiversity Areas (KBAs) are protected. Stocked aquaculture fish have escaped from ponds and are now present in most rivers. Hydropower and irrigation dams disrupt water flows, sediments, and the ecology of the river with devastating impacts for many species. Little is known about trends in abundance or risks to the 85 to 101 freshwater mollusc species, including 8 or 9 species endemic to the Ayeyarwady Basin.

The overall number of fish species recorded in the Ayeyarwady Basin is 388, of which 311 are present in the Myanmar portion (Chapter 7). The others are found in India and China. Among these 388 fish species, 50% are endemic to the Ayeyarwady Basin, 26% of which are presently known only to Myanmar. Fish declining in the delta, according to interviewees, are valuable species, such as eel, hilsa, freshwater shrimp, and whiskered catfish. Shrimp as well as marine and coastal fish species like Barramundi are declining despite their usual higher resilience compared to freshwater species. Further up the basin, large catfish are among the top declining species. They are followed by other smaller, but commercially valuable catfish species. In the Upper Ayeyarwady, results are more site-specific.

Large and migratory species of commercial significance that have become rare in most tropical rivers are still relatively abundant in Myanmar rivers. However, stakeholders unanimously report declining abundance of such species. An analysis of HEZs, based on their ecological value from a fisheries protection perspective, shows that Hinthada Township has the highest ecological value, followed by Ingapu, Myanaung, Yandoon, and Twantay.

Urgent conservation measures are needed to protect species, like the riverine terns and the Irrawaddy dolphin. A resource management plan for the entire river should be developed as soon as possible, with no-take zones free of any fishing, mining, and dredging. The network of Protected Areas needs to be expanded and better staffed. Reaches of the Ayeyarwady could be listed as a World Heritage Site.

2.3 Uses

2.3.1 Fisheries

Second only to rice, fish is a major contributor to Myanmar's national diet, estimated to account for approximately 60% of animal protein intake, and supplying amino acids, oils, and essential micronutrients (Chapter 7). Assuring availability of and access to fish supplies remains critical to food and nutrition security in Myanmar. Research informants unanimously identified fish as the primary source of animal protein in all HEZs of the Ayeyarwady Basin.

Updated fisheries statistics indicate that Myanmar fish production comprises approximately 33% each of inland capture fish, marine capture fish, and aquaculture fish, collectively totalling 2.9 million tonnes (Mt) in 2015 (Figure 2.4). After a peak in 2005, there has been a decline in marine fish production, and the trend in inland fish production has plateaued. In contrast, aquaculture shows a steady increase over this period.

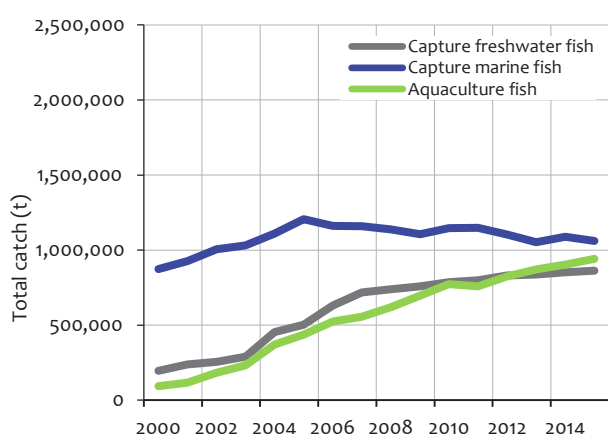


Figure 2.4 - Revised trends in marine capture fisheries, fresh water capture fisheries and aquaculture between 2000 and 2015 (SOBA 4) (FAO FIGIS, 2017)

According to national statistics, fisheries provide jobs for approximately 3.2 million people – 800,000 full-time and 2.4 million part-time jobs, including 1.6 million in inland fisheries. Approximately 12 to 15 million people in Myanmar generate income through fisheries. For 25% of landless households, fisheries provide the primary source of income through wage labour or fish sales. Fishing contributes to 10% of local incomes in the delta, compared with a few percent in Chindwin and the Upper Ayeyarwady. Migratory fish are essential to fishery livelihoods in the north, and less so, but nevertheless important, in the south of the Ayeyarwady Basin.

The gender distribution of fishers is approximately 75% men and 25% women when averaged between all five HEZs. The opposite is true in terms of involvement in fishing-related activities, such as processing and sales, where women make up at least 75% of the workforce. Women's rights to participate in sectoral decision-making are often ignored.

There are three main categories of freshwater capture fisheries systems in the Ayeyarwady Basin: leasable, tender lot, and open access. *Leasable fisheries* are areas of floodplains fished by the erection of barrage fences, with fish collected in pens or traps at the beginning of the flood recession. Leasable fisheries managers are compelled to spend 30% of the value of their lease on buying stock from government hatcheries. *Tender lot fisheries* are stretches of river where an operator has fishing rights for the use of a specific type and number of fishing gears (usually stow nets). Places that are not classified as either leasable or tender fisheries, and are not reserves, are considered *open access fisheries*. Entry to open access fisheries is free, but most fishing gears require a licence. These fisheries are extremely important to local populations, particularly the landless, for whom fishing requires little investment and represents a source of food and, possibly, income.

The Ayeyarwady Basin generated approximately 958,000 tonnes from aquaculture in 2017, representing 91% of the nation's total production. The total area dedicated to aquaculture within the Ayeyarwady Basin in 2017 is approximately 1130 km². The production and pond areas within the Ayeyarwady and Yangon Regions source 90% of Myanmar's farmed fish production. Rohu is the dominant production species, representing 70% of Myanmar's aquaculture production. This over-dependency on a single species, which has limited export potential, is perceived by experts as a constraint to further growth of the sector. Semi-intensive systems dominate the sector, using homemade and manufactured pelleted feeds.

Fingerling production is underdeveloped, with a small number of hatcheries operating with limited technology. In 2016, there were 26 active government hatcheries and 39 private hatcheries. Small-scale farmers depend on private hatcheries and a dense network of nurseries, which have boomed with the increasing demand for large-sized fingerlings. Intensive systems are limited to a small number of specialised marine fin fish, white shrimp farms, and a handful of farms producing *Pangasius* and *Pacu*. Increasing credit to the sector could be expected to create a less risky investment climate, increase farm productivity, and stimulate greater volumes of investment along the supply chain.



The economic value of Myanmar's freshwater aquaculture production was estimated at \$1.6 billion United States dollars (USD) in 2014, but declined to USD 1.3 billion in 2015, with a maximum 14% of the total production exported. Aquaculture has important spillover effects along the value chain for households and job creation. The sector in Myanmar has unique and competitive characteristics, but there are constraints on conversion of agricultural land to aquaculture and support systems are limited.

A sustainable fisheries sector in Myanmar is currently hampered by limited reliable data and inadequate monitoring, compliance, and enforcement. The tradition of using centralised targets, with the aim of maintaining or increasing government revenues, compromises data quality and creates conditions for misreporting. Non-compliance with regulations is widespread.

Fishers attributed the main causes of fish species decline to overfishing, destructive fishing, and fishing in spawning seasons. Fisher informants identified five primary solutions to improve the management of fish and wild resources: improve law enforcement, limit pollution, restrict destructive practices, improve coordination between parties, and undertake reclamation activities.

Research informants expressed strong interest in collaborating with the authorities to share knowledge and help with monitoring or control of illegal activities, especially during migration and spawning seasons and in the dry season when the reduced size of waterbodies can jeopardise fish survival.

The risks to fisheries from large-scale dam development are not well understood by local residents as impacts have yet to unfold and, thus, are not perceived by fishers. The absence of information on the possible impacts of development on the Ayeyarwady Basin fishery is a major knowledge gap.

2.3.2 Hydropower

Lack of adequate electricity remains a critical issue for the Ayeyarwady Basin and Myanmar as a country. Development of the energy sector is critical to socio-economic development in the Ayeyarwady Basin (Chapter 9). Annual energy consumption per capita grew at just 1.5% per year between 1990 and 2010. Since 2010, it has grown more rapidly at approximately 7.4% per annum. Per capita consumption remains comparatively low by regional and global standards. Fuelwood and charcoal, or biomass energy, still dominates energy consumption and production but is expected to eventually decline with rural electrification. Meanwhile, fuelwood harvesting from natural forests continues to grow and, thus, is a significant environmental concern.

The Ayeyarwady Basin has considerable energy resources, including oil, gas, coal, hydropower, and other renewables, that could be developed. Hydropower potential has been estimated at 58.3 GW. Approximately 300 projects have been identified with a combined potential of 46 GW. Fossil fuel production is important in the Ayeyarwady Basin. Most oil and gas reserves on land are in the Magway Region. Exploitation of fossil fuel resources raises important environmental as well as health and safety issues. Renewables like solar and wind are underdeveloped. Solar potential is high, particularly in the Middle Ayeyarwady HEZ. Wind resources are more limited, with plans for onshore wind projects in the Ayeyarwady and Yangon Regions by the China Three Gorges Company. Myanmar exports substantial amounts of energy to China and Thailand, mostly from offshore natural gas fields.

Total annual electricity generation at the national level doubled between 2000 and 2013. Almost all this increase has come from expansion of hydropower. There are 14 large hydropower plants in operation, with 2.1 GW of installed capacity. Three plants are under construction (1.4 GW) and 29 are planned (25.6 GW). Most planned plants are in the mountainous areas in the Upper Ayeyarwady in Kachin State, the Middle Ayeyarwady in Shan State, and the Mandalay Region (Figure 2.5). Impacts of large-scale hydropower development on flow regimes, sediment transport, and aquatic ecosystems could be substantial. Not much is known about transboundary impacts from the existing 174 hydropower projects in the small Chinese section of the Ayeyarwady, including the 875 megawatt (MW) Daying-4.

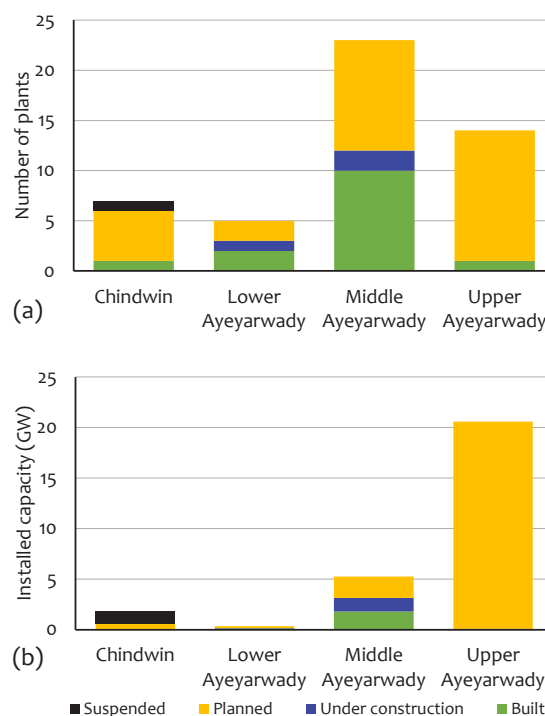


Figure 2.5 - Hydropower plants in the hydro-ecological zones, existing, under construction, planned and suspended by: (a) total number of plants and (b) installed capacity (SOBA 5) (ICEM, 2017)

The present scale of hydropower, primarily in the Upper Ayeyarwady, is likely to be causing some modification of flows and reduction in sediment loads, as evidenced by geomorphic changes to the channel characteristics of tributaries (Chapter 6). At present, the cumulative water storage volume in hydropower reservoirs is estimated at 10,542 cubic hectometre (hm³), which will increase sixfold if all projects are developed. The current reservoir area is estimated to increase from 661 km² to at least 2,251 km² (Chapter 9).

The core challenge is finding ways to meet diverse and growing energy needs across large parts of the Ayeyarwady Basin. Further large-scale hydropower development within Myanmar would have major environmental and social impacts but do little to increase access to electricity by rural households. A strategic basin-wide approach to hydropower development is needed to minimise adverse environmental and social impacts. A portfolio of energy sources, with a mix of on- and off-grid production, and selection of appropriate renewable technologies could support substantial increases in energy use and the inputs needed for rural electrification.

2.3.3 Agriculture

Agriculture accounts for approximately 27% of gross domestic product (GDP) and 60 to 70% of employment. In relative terms, the manufacturing and service sectors have grown in importance at the expense of agriculture.

The Ayeyarwady Basin has ample land and river water resources, but rainfall is unevenly distributed and seasonal. Most of the agriculture in the Ayeyarwady Basin is rainfed, with irrigated agriculture largely supported by extraction from storage in sub-basins of the Middle Ayeyarwady HEZ and Lower Ayeyarwady HEZ (Chapter 3).

In the dry areas and in the dry season, irrigation is essential for crop production. In wetter areas, supplementary irrigation helps deal with dry spells. Surface water runoff stored in reservoirs can irrigate approximately 1 million hectares. Water use for irrigation is less than 3% of total flow of the Ayeyarwady, suggesting possibilities for expansion (Chapter 3). The efficiency of existing irrigation, however, is low. The International Water Management Institute (IWMI) estimated that less than 5% of water extracted is used by crops.

Approximately 18% of the total area of Myanmar is cultivated. The most important crops cultivated by land area are paddy rice (42%), dry beans (19%), and sesame seeds (7%). The highest irrigation densities and areas of planted paddy rice occurred in the Ayeyarwady Delta HEZ (Figure 2.6). Livestock are more important in the Middle Ayeyarwady HEZ. Livestock are productive assets, which contribute directly to farm output through animal traction and indirectly as a savings for future investment. Finally, livestock production can contribute to soil fertility and recycling of agricultural waste. Swidden cultivation is still common in uplands and remote areas, especially in the Kachin, Chin, and Shan States.

The Irrigation Water Resources Utilization Department currently has more than 15,000 functioning shallow (<60 metres [m]) tubewells and more than 10,000 deep (60 to 200 m) tubewells. Mandalay, Sagaing, and Magway, in the Central Dry Zone, have received the most government support for development of groundwater- and river-pumped irrigation.

Irrigation from government pumping schemes is highly subsidised. Farmers pay modest fees for water. Private schemes charge more and, therefore, are only used by farmers growing high-value crops. Irrigation, along with flood protection in the coastal areas, is important to improve agricultural production for domestic food supply and export. This requires a number of inter-related actions, including improving power supply (so that river and groundwater pumping schemes are more reliable) and shifting to higher value crops (so that costs of irrigation can be recovered).



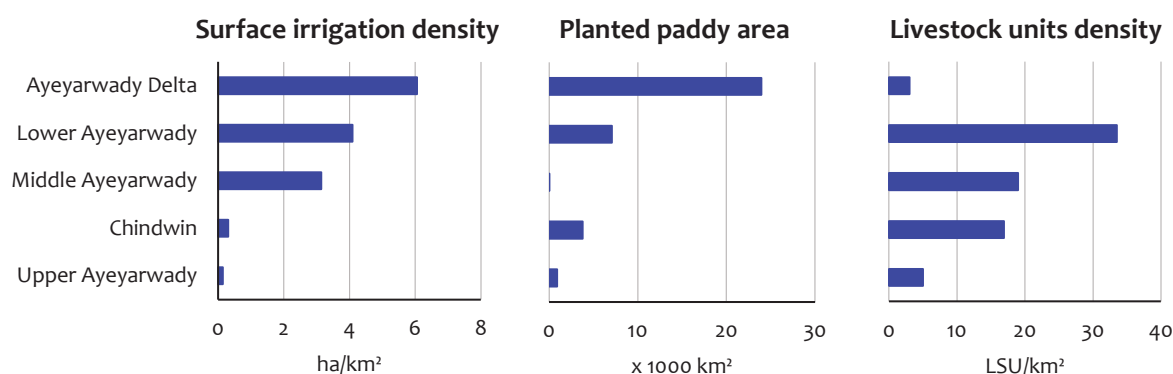


Figure 2.6 - Indicators of irrigation and key agricultural land uses according to hydro-ecological zones

LSU stands for livestock units

Although land is available for expansion of agriculture or to replace losses due to urbanisation, much of it has poor access to roads and electricity. Agricultural extension services, especially the provision of quality seed and low-interest credit, are limited and also a constraint on agricultural development.

Mechanisation is still low. Most ploughing, harvesting, and transport is done with bullocks and buffaloes. In areas with extensive waterways, transport is by canoes and boats, many still without motors. To access export markets, paddy rice harvesting, milling, and storage need to be mechanised further. Post-harvest losses of rice in Myanmar are high, and what is not lost is often of low quality and, thus, low value. Improved rural roads and electrification would benefit agricultural sector development.

The combination of increased productivity through irrigation and other inputs, with the expansion of agriculture into new areas, would substantially increase overall food production. This should reduce food prices for urban consumers but may not raise farm incomes if demand does not also increase. At the same time, there are many significant environmental issues associated with the expansion or intensification of agriculture. In the Central Dry Zone, a key problem is salinisation of soils. In the Hilly Zone, erosion and deforestation are concerns. Intensification of rice production could also have impacts on fisheries and other vegetable crops important to human nutrition. Water pollution from agriculture already contributes to high levels of microbial contamination in some dam reservoirs (Chapter 4). An alternative would be to encourage greater diversification, including low-chemical use agriculture that would be increasingly attractive to urban consumers.

2.3.4 Forestry

Myanmar is highly dependent on forest ecosystems for services and products (Chapter 9). Forested watersheds provide clean drinking water that helps prevent disease, in addition to many other regulating, provisioning, and cultural ecosystem services.

Myanmar still has significant forest resources, with 44% of the land area forested as of 2015. Much of the remaining intact, closed-canopy forest is in the Upper Ayeyarwady. Deforestation rates, however, are now the third highest in the world. Deforestation and degradation of existing forests are critical issues in the Kachin State and Sagaing Region in the Ayeyarwady Basin. This is mainly due to illegal logging and legal timber extraction associated with plantation and mining concessions. Many of the agribusiness concession areas have not been replanted as planned. In the Middle Ayeyarwady, there has been substantial loss of forest cover as well as significant areas of regeneration. Mangrove cover in the Ayeyarwady Delta is estimated to have decreased from 2,748 km² in 1980 to 450 km² in 2013 – mostly due to conversion to rice paddies.

Natural teak forests produce high-value logs. A log export ban reduced the volume of teak and hardwood extracted from forests and plantations in the Ayeyarwady Basin from 2015 to 2016, but even so, more than 690,000 cubic metres (m³) were harvested. There are major discrepancies in the trade data surrounding Myanmar's timber production, because it does not include illegal logging and cross-border smuggling.

There is a trend toward sourcing timber from plantations. Consequently, the area of teak plantation increased from 3,342 km² in 2008–2009 to 3,839 km² in 2015–2016, with 5.5 million new teak trees planted. The area of hardwood plantation increased from 4,813 km² to 4,972 km² in 2015–2016.

Fuelwood, charcoal, and many other non-timber forest products are harvested from forests. A recent study suggested that the economic value of non-timber forest products in 2012 was approximately USD 507 million from all types of forests. A study in 2012 estimated the current annual value of forest ecosystem services to be USD 7.3 billion. The Government of Myanmar's National Forest Master Plan (2002–2031) sets a target for community forestry of 1.4% of the total land area.

The National Forest Master Plan aims to maintain 30% of the land area within the permanent forest estate and 10% of the land area within Protected Areas by the year 2030. The Government of Myanmar has also made many global commitments to address deforestation and climate change. It also introduced policies to reduce illegal logging and deforestation.

Assessing past and projecting future trends for the forestry sector is challenging, as national statistics do not include large volumes of illegally exported wood. Remote sensing tools and international trade statistics provide important checks. Timber certification is needed to help ensure sustainable harvesting of teak and hardwoods in the Ayeyarwady Basin.

If the Ayeyarwady Basin is not well managed, there are significant risks to the physical integrity and condition of its natural capital. Ecotourism could provide opportunities for biodiversity conservation and livelihoods. The values of ecosystem services should be incorporated into prioritising basin management activities.

2.3.5 Navigation

Navigation is a highly valued use of the river. In the last few years there has been a significant reduction in waterborne freight transport. A number of factors are perceived to have contributed to this including a backlog of dredging works, slow loading and unloading times, and the growth of land-based transport.

Navigation may be impacted by modifications of river flows, sediment transport, seasonality of flow, and the variability in onset and duration of the monsoon impact (Chapter 3). The physical condition of riverbanks and the channel bed are important to safe and efficient navigation (Chapter 6). Activities on land impact activities in the river. Current navigation issues downstream of Mandalay, for instance, likely reflect landuse activities and regulation of tributaries as far upstream as Katha.

Concerns with navigation were high in community consultations because of its importance to livelihoods (Chapter 10). A common perception was that navigation is severely impacted by sedimentation and the solution is to dredge a fixed navigation channel. Dredging may not be the most appropriate or efficient solution in locations with highly dynamic sediments and naturally active channel. Improvements to navigation aids or using boats with smaller draft requirements may be an alternative solution for navigation in dry season. In the middle reach of the Ayeyarwady it is common to employ the service of pilots with local knowledge of position of sandbanks (Chapter 9).



2.3.6 Mining

Mining in the Ayeyarwady Basin is a growing and important part of the Myanmar economy (Chapter 9). According to official figures, mining accounted for 1.2% of the GDP from 2014 to 2015. Myanmar is well known for its deposits of jade, rubies, and other precious stones. It also has rich deposits of copper, nickel, lead, zinc, silver, tin tungsten, and gold.

According to official statistics, production of jade and gemstones appears to have declined in recent years. The decline may be a consequence of stockpiling, legislative changes, or failures to report actual production. Anecdotal evidence from mining locations suggests an upscaling of mining activity and an increased use of heavy equipment.

Small-scale or artisanal mining is ubiquitous throughout the Ayeyarwady Basin, with hundreds of thousands of pickers for jade and gemstones in the spoil heaps of Hpakant and Mogok. Small gold mines are dotted throughout the Mandalay Region and western areas of Shan State. The mining of alluvial gold deposits is a common sight along rivers and elsewhere.

Gold mining is widespread throughout the Ayeyarwady Basin. Myanmar's only copper mines are situated in the Monywa District of the Sagaing Region, close to the Chindwin River. The only nickel mine operating since 2011 is also in the Sagaing Region in Htigyaing Township. It obtains power from the Shweli 1 hydropower plant.

Sand mining on major rivers is widespread, with high demand for construction. The impacts on channel morphology, bank stability, and environment are major concerns (Chapter 6). Limestone production has also grown rapidly since 2010, due to demands in the construction industries.

Analysis of remote sensing data suggests that mining has expanded rapidly within the Ayeyarwady Basin and now directly affects more than 740 km². Much of this expansion is in the Chindwin River Basin or around Mandalay. The rapid expansion of mining has created significant environmental and social problems, including poor occupational health and safety, farmland appropriation or contamination, erosion and soil loss, deforestation and biodiversity loss, and water and land pollution. Gold mining, for instance, involves the use of mercury or cyanide. Artisanal miners use mercury, posing serious environmental issues (Chapter 9).

The mining sector is an important driver of economic growth and a source of employment. Artisanal mining is widespread throughout the Ayeyarwady Basin but is a particularly important income source for many people in the Upper Ayeyarwady, Middle Ayeyarwady, and the Chindwin Basin.

Mining activities, however, produce social, public, and occupational health problems (Chapter 9). Mining also causes various environmental problems, many of which impact water quality (Chapter 4). Regulation of the mining sector has proven difficult, making the expansion of mining a significant concern. Developing a comprehensive database of mining activities and a monitoring framework, as well as regulating the environmental and social aspects of mining development, should be a high priority.

2.3.7 Human settlements and manufacturing industry

The manufacturing sector is small but growing rapidly (Chapter 9). Development is likely to be centred in Yangon and Mandalay. The sector was initially dominated by small- and medium-sized enterprises in the food and beverage sector that served domestic markets. Recent growth and most foreign investment has been concentrated in the garment and footwear sectors for export. Development of the manufacturing sector will pose challenges for basin management in terms of flood risk, water use, and pollution. Industrial raw materials and construction materials are leading polluters in industrial zones in the Chindwin HEZ and Middle Ayeyarwady HEZ, while minerals and petroleum products, clothing and apparel, and food and beverage are the leading toxic chemical polluters in the Lower Ayeyarwady HEZ and Ayeyarwady Delta HEZ (Chapter 4). High loads of Biological Oxygen Demand and Total Suspended Solids in water samples were identified at the three major industrial zones of Yangon, Mandalay and Sagaing, with distilleries, pulp, leather and sugar identified as contributing industries. A more comprehensive evaluation of the manufacturing sector is not possible without more information.

The population of the Ayeyarwady Basin is approximately 33 million, a third of whom live in urban areas. Median township population density is lowest in the Upper Ayeyarwady and is highest to the south in the Ayeyarwady Delta. Urbanisation is an important component of economic re-organisation, bringing with it water supply opportunities and pollution challenges. It will become increasingly important to monitor and control faecal contamination of water supply sources. Approximately 75% of households in the Ayeyarwady Basin had access to safe drinking water in 2014, whereas only 26% had access in the Upper Ayeyarwady. Overall, the well-being of households in the Ayeyarwady Basin has improved and is higher in urban than in rural areas. Uneven spatial development is an important characteristic of the Ayeyarwady Basin that needs to be considered in basin-wide planning.

2.3.8 Ecosystem values

The natural ecosystems of the Ayeyarwady Basin are vitally important to the livelihoods of the people of Myanmar and the national economy (Chapter 9). Natural vegetation in the upper watersheds of the Ayeyarwady Basin, for instance, provide multiple and highly valuable ecosystem services, improving water quality supplies and reducing flood risks. In coastal areas, mangrove ecosystems provide similar protection services.

The economic value of a subset of ecosystem services was estimated; these are listed in Table 2.1 alongside qualitative comments on their importance. Ecosystem services are especially important to households directly dependent on natural resources for food and livelihoods. For many other important services, it was not possible to derive numerical values. Further studies of these unvalued and important services should be undertaken.



Table 2.1 - Annual value of ecosystem services (USD millions)

Numerical estimates provided for a small subset for which adequate information was available

Ecosystem service	Estimated values (USD millions)			Reliability of range of estimates
	Low	Medium	High	
Ecosystem services quantitatively estimated				
Agriculture (irrigation water supplies provisioning services)				
Yield gains in monsoon	29	40	50	
Ability to produce crops outside monsoon	62	91	121	
Freight (inland rivers – modal substitution provisioning services)				
Freight task savings	8	13	23	
Fisheries (protein replacement provisioning services)				
Freshwater capture	350	440	530	
Aquaculture	380	490	600	
Potable water supplies (water quality regulation services only)				
Treated tap water	57	91	125	
Local treatment	129	321	514	
Biodiversity (supporting services)				
Forests	1,300	2,645	4,418	
Wetlands	4	7	10	
Mangroves	146	297	497	
Ecosystem services not quantitatively estimated				
Agriculture (provisioning services excluding irrigation water supplies)				
Potable water supply (water provisioning)				
Flooding (regulating and provisioning services)				
Hydropower (intermediate provisioning service)				
Gravels and natural quarrying products (provisioning service)				
Ecotourism (cultural service)				

The analysis provides important insights and information. First, together with other chapters in the SOBA 2017 Synthesis Report, it shows that ecosystem services are important, valued, and at risk. Second, it demonstrates that some ecosystem services can be meaningfully valued. Further work is required to enhance and mainstream this economic knowledge into Ayeyarwady Basin planning.

2.4 Issues

Five critical emerging issues for the sustainability of society and the environment emerge from joint consideration of drivers of resource use as well as current condition and trends of key resources in the Ayeyarwady Basin. These issues include the following:

- Ineffective land and water governance.
- Uneven development and inequality.
- Impacts of large-scale water infrastructure.
- Protecting or redirecting floodplain assets at risk.
- Inadequate monitoring and data management.

2.4.1 Ineffective land and water governance

Unregulated mining, illegal logging, and poorly managed concessions are creating serious, long-term social and environmental problems at local and broader scales. Large mining concessions and vast numbers of artisanal mines pose threats to occupational and environmental health. Illegal logging, commercial fuelwood, charcoal production, and inactive plantation concessions contribute to the high rate of deforestation. This, in turn, is degrading valuable watershed ecosystem services. Sand and gravel extraction from the river is also affecting the geomorphology of the river and aquatic ecosystems. In lowland areas, land use changes related to agricultural intensification and urbanisation are also emerging as important issues. Weak administration and poor governance of land is also creating conflict, leading to dispossession and loss of access to resources important to the well-being of already marginalised groups.

Local perspective: Self-determination and good governance

Across the Ayeyarwady Basin, people are resilient and would like more opportunities for self-determination, whether it is improving their livelihoods or their living conditions. People want good governance. The current systems of governance are perceived as inadequate. Present opportunities for improvement, notably curtailing illegal fishing methods, require better law enforcement (Chapter 10).

To reduce the threats to the quality of groundwater and surface water as well as improve the stability of key floodplain areas and the delta, environmental protection and conservation laws need to be enforced and their effectiveness monitored. To achieve inclusive development, the rights of women and men to resources and a meaningful livelihood must also be respected and strengthened as part of institutional and socio-economic development.

2.4.2 Uneven development and inequality

Development in the Ayeyarwady Basin is uneven, with large differences among regions and HEZs. These differences represent significant risks and opportunities for the sustainable use and development of water resources. Only 26% of households in the Upper Ayeyarwady had access to safe drinking water in 2014 compared to approximately 75% of households across the whole Ayeyarwady Basin. For the Ayeyarwady Basin states and regions, 29% of children under 5 were stunted and 8% severely stunted. Many households still lack access to electricity.

Across the Ayeyarwady Basin, people are resilient Myitkyina Township: Insecurity, prosperity, and poverty

Myitkyina in Kachin State is a trading town with the northernmost river port and railway terminus in Myanmar. Key resources include jade, gold, and teak. There is potential for local river tourism. The military conflict in Kachin disrupts society, restricts access, and hinders inclusive development. Concerns in the community are high regarding planned hydropower development because of forced displacement and lack of local benefits, for instance, in the form of access to affordable electricity. There are also concerns about the impacts of gold mining on water quality in the river and on fisheries (Chapter 10).

There are also many differences between rural and urban areas, whereby wealthy and less well-off households have different needs. In some HEZs, there are high rates of landlessness – a very important consideration given the strong association between landholdings and household food security. According to government estimates, poverty in Myanmar declined from 25.6% in 2009 to 2010 to 19.4% in 2015. Urban poverty has declined more quickly than rural poverty. One of the challenges is that technological and institutional development in the agriculture sector has been slow, while extractive industries and urban centres have developed much more rapidly. Another challenge is energy poverty. Rural electrification is one of the keys to improving livelihoods and well-being.

2.4.3 Impacts of large-scale water infrastructure

Policy and planning needs to consider and reduce these large differences in social and economic conditions. Failing to do so may trigger the insecurities that have hindered and fragmented development in Myanmar in the past. More inclusive development would create many opportunities for adding value to production from basic livelihood activities, and if directed properly, include empowering women and improving the well-being of ethnic minority households.



Ecological assets in the Ayeyarwady Basin are facing increasing threats from hydrologic alteration, river impoundment, and longitudinal fragmentation. The cumulative impacts from these threats are unknown but may pose severe risks in the long term. Large-scale hydropower development or irrigation diversions, in particular, would have major impacts on sediments, flows, and flood regimes. This, in turn, would impact the replenishment of agricultural soils on floodplains and the productivity of wetlands and other aquatic ecosystems important to freshwater fisheries. The potential adverse impacts on fishery livelihoods and nutrition are of particular concern and underline the need for further detailed assessment.

Cultivation on riverbanks, islands, and sandbars in the dry season after floodwaters recede is an important practice for both subsistence and cash crops in the Ayeyarwady Basin. There are no estimates of their extent, but such types of farming would likely be vulnerable to infrastructure development that modifies river flows and sediment transport. Navigation may also be impacted.

There may be opportunities to expand sustainable use of groundwater in some regions, but detailed information to guide planning and monitoring is largely unavailable outside the Central Dry Zone. Not much is known about the potential consequences of large-scale investments in groundwater irrigation. Many households outside the Upper Ayeyarwady, it should be noted, depend on wells for drinking water supplies, and it would be important to ensure that agricultural activities do not compromise these sources.

The evaluation of water resource development strategies, whether for energy or agriculture, must carefully consider the impacts of migration, of a lower population fertility rate on population size and age structure, and of industrialisation on the attractiveness of farm work. All of these processes influence the availability of agricultural labour, and thus the longer-term viability and usefulness of large-scale and costly schemes.

The multiple interactions involved when introducing large-scale infrastructure underline the importance of considering cross-sectoral interactions in the water–energy–food and nature nexus. Basin planning should contribute to improving policy coordination. As pressures on natural resources increase with intensification of economic activities, it will become increasingly important to improve the efficiency or productivity of resource use and to introduce demand-side management strategies.

Local perspective: Information and concerns

People want to be better informed about the natural and man-made forces operating in the Ayeyarwady Basin. They have significant concerns about water quality, and put great value on clean river water for drinking, washing, bathing, irrigation, and for a healthy ecosystem. People have concerns about hard infrastructure – ranging from hydropower dams in the north to bridges and even hard flood protection measures in the south (Chapter 10).

2.4.4 *Protecting or redirecting floodplain assets at risk*

Human settlements, economic activities, and infrastructure assets with a low tolerance for even the normal seasonal flood pulse are increasingly located in floodplains. The Ayeyarwady Basin contains many flood-prone areas. Floods with a return period of 10 years were estimated in 2010 to affect 2.3 million people in the Central Dry Zone. Areas near the confluence of the Chindwin and Ayeyarwady Rivers, for example, are especially prone to flooding, with impacts on agricultural and built-up areas. The lower Ayeyarwady also frequently experiences higher flooding. In coastal areas, flooding is associated with high rainfall from cyclones and storm surges.

Protecting them all from floods is impossible, and even partial protection is costly. This is especially so in those reaches of the river with dynamic channels and riverbanks. Measures to protect particular locations need to consider the benefits of normal floods for replenishing soils and the productivity of wetlands and fisheries. To reduce the risks of catastrophic losses to extreme floods, new investment should be steered into less flood-prone locations, and elsewhere, good risk management practices should be followed.

Risk management is currently hampered by many factors, including lack of instrumentation for real-time monitoring, lack of coordination among government organisations, and insufficient knowledge about flood hydrology. These limitations in capacity and cooperation can and should be addressed.

2.4.5 *Inadequate monitoring and data management*

Unreliable and insufficient data on many key indicators for drivers, conditions, and socio-economic consequences makes monitoring and projecting changes in the state of basin difficult. The paucity of basic data on groundwater status, use, and water quality, for instance, is a major barrier to setting and enforcing sustainable limits on extraction or deploying national standards to ensure that water is safe for the purposes it is used. Contamination with arsenic and salinity are, in particular, major concerns. In other cases, the problem is more of unreliability of official statistics (arising from inadequate monitoring) and the difficulties in reporting negative trends (Chapter 7) or illegal activities (Chapter 9).

Many of this report's chapters conclude that improved monitoring and data management are essential to the sustainability of resources in the Ayeyarwady Basin. Monitoring and information gathering of sediments, for example, is recommended to include: repeat channel cross-sections in the river and delta; land use analysis based on satellite imagery; and the development of databases for hydropower, irrigation, forestry, and mining to track trends in these activities.

2.5 Conclusions

The Ayeyarwady Basin has significant natural and human resources. Ineffective governance of land, water, and rivers as well as insecurities related to political conflicts remain the most significant obstacles to more inclusive and sustainable development. Addressing these issues fairly across the diverse HEZs of the Ayeyarwady Basin will require cooperation among multiple stakeholders in the various states and regions in strategic basin planning.

Regular assessments of the conditions and trends in natural resource stocks is one of the key inputs into monitoring the sustainability of natural resource uses. Together with the analysis of the performance of institutional measures, assessments can also help identify shortfalls in governance of resources and, thus, identify areas requiring additional planning and coordination efforts.

3

SURFACE WATER



HIGHLIGHTS – SURFACE WATER



- This work represents the first integrated assessment of surface water resources for the Ayeyarwady Basin.
- The Ayeyarwady Basin has five hydro-ecological zones (HEZs), incorporating 13 major sub-basins.
- Significant natural drivers of basin hydrology include the monsoon in the wet season, cyclones, snowmelt in the lead up to the wet season, and groundwater flows to the surface water system.
- While the wet season typically ranges from mid-May to October, the actual onset and duration varies from year to year, affecting water supply, navigation, and flooding.
- Heavily utilised tributaries, such as the Mu and Panlaung Rivers, have the potential to be stressed during the long dry season.

- The proportion of total annual runoff extracted in the Ayeyarwady Basin is estimated at 2% and, in the dry season, at 8%.
- The Mu Sub-basin has the greatest proportional use of available water with 29% of total annual runoff being extracted. During the dry season, the estimate is 48%.
- Water use is greatest in the Central Dry Zone, accounting for approximately 70% of surface water extraction.
- Total annual domestic surface water demand for the Ayeyarwady Basin upstream of the Ayeyarwady Delta is estimated to be 0.07% of total available flows in the Ayeyarwady Basin.
- Total annual basin-observed outflow at Pyay is estimated to average 375,000 million cubic metres per year (m^3/yr) – an equivalent depth of approximately 1 metre per year (m/yr) of surface runoff across the Ayeyarwady Basin.



HIGHLIGHTS – SURFACE WATER

- There is little difference in the mean annual flows upstream of the delta between the 'without development' and 'baseline' of current development scenarios based on the SOURCE Basin Model.
- The greatest impact of water resource development occurs at the sub-basin level. In the Mu Sub-basin (within HEZ 3), for example, there is a 40% increase in flows from the 'baseline' compared with the 'without development' scenario.
- Risks posed by hydrologic alteration are highest within HEZ 3, particularly the Panlaung and Mu Sub-basins. The ecological assets, processes, and values assessed as being at highest cumulative risk from hydrologic alteration include flowing rivers and streams, floodplain wetlands, floodplain primary productivity, lateral connectivity, and migratory species.



- Risks from river impoundment are greatest in the Upper Ayeyarwady and, to a lesser extent, Mu Sub-basin (within HEZ 3). These were at substantially higher risk than all other sub-basins and contained the highest proportion of impounded area and a relatively high number of assets that were all highly vulnerable to this threat.
- The ecological assets, processes, and values assessed as being at highest risk from river impoundment include rare/endemic species, flowing rivers and streams, Key Biodiversity Areas (KBAs), and fisheries production.
- Risks from longitudinal fragmentation were highest in all sub-basins in HEZ 3, particularly the Shweli, Panlaung, and Mu Sub-basins. The ecological assets, processes, and values assessed as being at highest cumulative risk from longitudinal fragmentation include migratory species, longitudinal connectivity, and fisheries production.
- Augmented monitoring and measurement of water flows, stores, and climate in the Ayeyarwady Basin would improve the understanding and management of the Ayeyarwady water system.

3. SURFACE WATER

3.1 Introduction

This chapter provides an overview of the surface water resources within the five HEZs and 13 primary sub-basins of the Ayeyarwady Basin. It outlines the hydrological regime of the Ayeyarwady Basin, leading to an assessment of the status and trends of surface water resources, including the impact of development to date and ecological risks related to future development. It concludes with a summary of information gaps on surface water and climate modelling.

The findings presented in this chapter built on a baseline model that was established using the SOURCE water system planning software and based on historic climate data from 1981 to 2016.

SOBA Technical Reports

This chapter is a synopsis of the full assessment, which may be accessed by readers seeking more detailed information, including references:

SOBA 1.1: ALS Hydrographics, Alluvium and Hydronumerics (2017), Hydrological Data Audit and Rating Curve review (SOBA 1.1), as part of the Ayeyarwady State of the Basin Assessment, sponsored by Australian Water Partnership.

SOBA 1.2: eWater & CSIRO (2017), A Surface Water Resource Assessment of the Ayeyarwady River Basin (SOBA 1.2), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project, sponsored by the Australian Water Partnership.

SOBA 1.4: The Australian Rivers Institute, Griffith University & Truii Pty Ltd (2017), Ecohydrology assessment (SOBA 1.4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project, sponsored by the Australian Water Partnership.

3.2 Ayeyarwady Setting

The Ayeyarwady River is approximately 2,000 km long and has a basin area of 414,000 km², which represents 62% of Myanmar. The largest tributary of the Ayeyarwady River is the Chindwin River, which has a basin area of approximately 114,500 km², comprising approximately 25% of the total Ayeyarwady Basin. The Ayeyarwady Basin can be divided into 13 sub-basins, encompassing all the major tributaries of the Ayeyarwady and Chindwin Rivers and the delta (Figure 3.1). Each sub-basin has distinct hydro-physical characteristics in relation to area, the main tributary, and elevation (Table 3.1). All sub-basins are encompassed within five distinct HEZs, including the Upper Ayeyarwady (HEZ 1), Chindwin (HEZ 2), Middle Ayeyarwady (HEZ 3), Lower Ayeyarwady (HEZ 4), and Ayeyarwady Delta (HEZ 5).

Prior to this report, there had been no integrated surface water assessment of the Ayeyarwady Basin nor a water system model to enable planning for the future. This report provides essential baseline data and identifies gaps that currently limit the potential benefits of modelling.



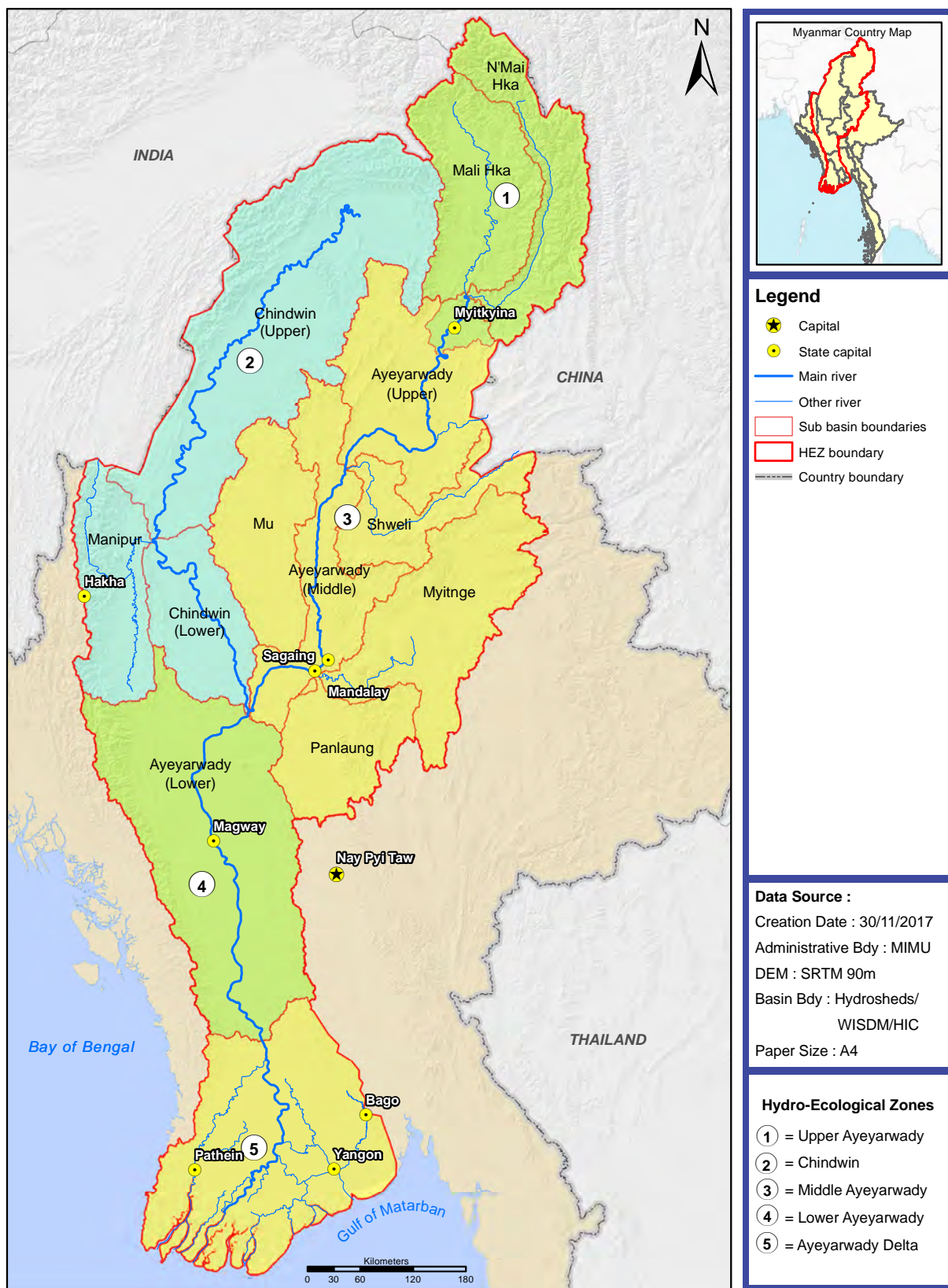


Figure 3.1 - Hydro-ecological zones and sub-basins of the Ayeyarwady Basin

Table 3.1 - Hydro-physical characteristics of each sub-basin

Sub-basin	HEZ *	Area **	Main river		Sub-basin Elevation ***			
		km ²	name	km	min	max	mean	med
Mali Hka	1	23,309	Mali Hka	312	119	4,759	1,093	855
n' Mai Hka	1	24,388	n' Mai Hka	469	119	5,583	2,512	2,466
Chindwin (Upper)	2	73,497	Chindwin River	818	69	3,795	686	421
Chindwin (Lower)	2	16,601	Chindwin River	318	32	1,300	253	190
Manipur	2	24,369	Manipur River	329	69	2,715	902	853
Ayeyarwady (Upper)	3	37,162	Ayeyarwady River	397	65	3,680	600	263
Mu	3	19,459	Mu River	376	36	1,666	227	194
Ayeyarwady (Middle)	3	22,250	Ayeyarwady River	385	31	2,198	308	177
Myitnge	3	30,682	Myitnge River	477	39	2,611	878	843
Panlaung	3	16,316	Panlaung River	139	55	2,338	501	290
Shweli	3	22,924	Shweli River	567	65	3,720	1,047	1,034
Ayeyarwady (Lower)	4	59,238	Ayeyarwady River	469	0	3,044	313	200
Delta	5	43,826	Ayeyarwady River	285	0	1,215	27	

The Ayeyarwady (Upper) Sub-basin is mainly situated within HEZ 3 with a small part in HEZ 1 near Myitkyina.

This slight misalignment is because sub-basins were chosen based on tributaries, while HEZs were identified on morphology.

* See Figure 3.1.

** River length based on Hydrosheds DEM stream basin threshold of 1,350 km².

*** Zone elevation based on Hydrosheds DEM.



3.3 Hydrological Regime of the Ayeyarwady Basin

This section presents an overview of each HEZ in the Ayeyarwady Basin followed by a description of the climate, hydrology, flood pulse, and the influence of extreme events.

3.3.1 Ayeyarwady Basin overview

Upper Ayeyarwady (HEZ 1)

The Upper Ayeyarwady incorporates the upper reaches of the Ayeyarwady River and the N'Mai Hka and Mali Hka Rivers from the most northern sections of the Ayeyarwady Basin to approximately 50 km downstream of Myitkyina. It is characterised by steep rocky slopes, alpine vegetation, and semi-evergreen forest. The headwaters rise more than 1,500 m above mean sea level. Most of the drop in elevation of the Ayeyarwady River occurs within the Upper Ayeyarwady. These upper reaches of the Ayeyarwady River are very steep with a drop of approximately 3 m/km in the 450 km upstream of the N'Mai Hka/Mali Hka confluence. Downstream of the N'Mai Hka/Mali Hka confluence the Ayeyarwady River flattens out to an average slope of 0.09 m/km for the remaining 1,550 km of the total river length.

Chindwin (HEZ 2)

The Chindwin River is predominantly fed by easterly flowing rivers arising from the Rakhine Yoma. A number of medium-sized tributaries, including the Myittha and Uyu Rivers, form significant floodplains at their confluences with the Chindwin. The geology is mainly comprised of relatively young, thrust and faulted sedimentary and meta-sedimentary rocks, which tend to erode quickly and produce abundant silts, muds, and sands. The Chindwin is a major contributor to the sediment load of the Ayeyarwady Basin. Although the headwaters of the Chindwin River are not as high or as steep as those of the Ayeyarwady River, the lower Chindwin River is steeper than the lower Ayeyarwady. The upper reaches of the Chindwin drop by approximately 1 m/km in its first 170 km. Thereafter, it flattens out to an average slope of 0.14 m/km for the remaining 985 km of the river's length.

Middle Ayeyarwady (HEZ 3)

The Middle Ayeyarwady is defined as the section of the Ayeyarwady Basin between the Upper Ayeyarwady (near Myitkyina) and the Ayeyarwady/Chindwin River confluence. The largest tributaries in this HEZ are the Tarpein, Shweli, Myitnge and Mu Rivers. The HEZ represents a largely flat reach, with the southern parts entering into the Central Dry Zone climatic area. The mainstem is interspersed by short reaches of confined rock-cut river channel, which partially constrains meandering and mobility. The right bank tributaries of the Middle Ayeyarwady generally comprise low-gradient,

moist-broadleaf forests with large floodplains. Left bank tributaries consist of higher-elevation, moist-broadleaf forests as well as karst formations and generally smaller floodplains.

Lower Ayeyarwady (HEZ 4)

The Lower Ayeyarwady extends from the Chindwin/Ayeyarwady confluence in the north to Myanaung in the south – approximately 100 km downstream of Pyay. This is the point in the Ayeyarwady River where tidal movement influences channel hydrology. Many of the tributary streams in this HEZ have a high variability index, illustrating their intermittent nature.

Both the Middle Ayeyarwady (HEZ 3) and Lower Ayeyarwady (HEZ 4) are dominated by flatter, cultivated landscapes, with higher population densities and a drier climate.

Ayeyarwady Delta (HEZ 5)

The southernmost HEZ is the Ayeyarwady Delta, made up by the division of the mainstem into a complex of low-gradient streams with mangroves along the southern edges. It is characterised by coastal processes, salinity gradients, high population densities and cultivated land.

3.3.2 Climate characteristics

Rainfall

Mean annual rainfall in the Ayeyarwady Basin varies significantly from between 500 mm in the Central Dry Zone to more than 4,000 mm in the north-western parts of the Ayeyarwady Basin and in the Ayeyarwady Delta. The Ayeyarwady Basin has a strongly monsoonal climate with definite wet and dry seasons. Wet season months start in mid-May and extend until the end of October, while the dry season months of November to mid-May are divided into a winter and summer period. During the winter months of November to February average rainfall across the whole Ayeyarwady Basin is very low. The Central Dry Zone in the rain shadow of the Arakan mountains receives less rainfall than any other part of the Ayeyarwady Basin at all times.

Temperature and evapotranspiration

Potential evapotranspiration is generally higher in the southern parts, decreasing northwards as altitude increases and temperature decreases. Calculated average annual evapotranspiration across the Ayeyarwady Basin ranges from less than 200 mm in the high elevation areas of the Ayeyarwady Basin, to more than 1,900 mm in the Central Dry Zone. Potential evapotranspiration is highest at the end of the dry season in the months of March, April, and May.

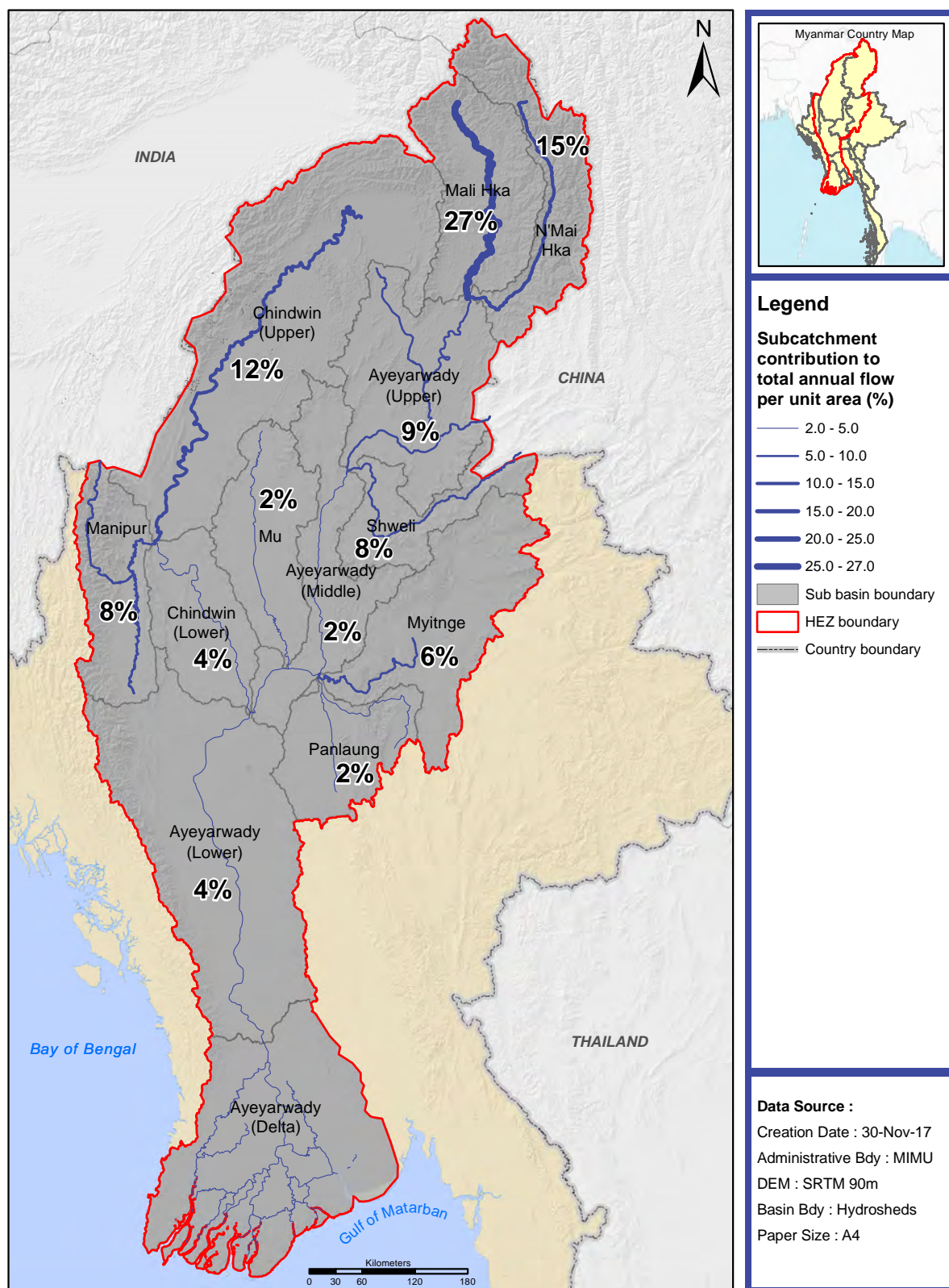


Figure 3.2 - Flow contributions per unit area per sub-basin upstream of the delta, as a proportion of annual outflow downstream of Pyay

3.3.3 Hydrology

Flows

The mean annual observed flow at Pyay, in the Lower Ayeyarwady (HEZ 4), is approximately 375 km³. The proportion of this flow contributed by each sub-basin varies across the Ayeyarwady Basin. Figure 3.2 shows the proportion of annual outflow downstream of Pyay contributed by each sub-basin, per unit area. Approximately 55% of total flows upstream of the delta are generated from the upstream sub-basins of the Chindwin (Upper), Mali Hka and N'Mai Hka Rivers. These rivers have their origins in the high-rainfall regions of the Naga Hills and Eastern Himalayas. The lower basin regions contribute a lower proportion of annual flow given their position in the Central Dry Zone with high rates of evaporation.

Streamflow in the Ayeyarwady Basin is influenced by snowmelt, monsoons, cyclones, and groundwater discharge. Groundwater discharge is generally toward the main rivers. Figure 3.3 uses 2010 data to show the contribution of snowmelt and the movement of the flood pulse in a downstream direction. This figure plots observed flows during the wet season of 2010 at six sites along the length of the Ayeyarwady River, from Myitkyina in the north (HEZ 1) to Pyay (within HEZ 4) in the south. The contribution of snowmelt is shown at Myitkyina, just prior to the onset of the wet season (May).

Snowmelt

The main snowmelt season is from June to September, largely coinciding with the wet season when monsoonal rains mask its impact. Given the right conditions, snowmelt can dominate flow in the Ayeyarwady leading up to the wet season, as seen by the flow at Myitkyina in April (Figure 3.3).

Flood pulse and high flows

The highly seasonal nature of rainfall in the Ayeyarwady Basin gives rise to a flood pulse that can be traced as it moves downstream through the Ayeyarwady Basin. Figure 3.3 shows that the first major flood peak of the season is observed at Myitkyina in the second half of June. Toward the end of the month, this peak can be observed downstream at Katha, and in early July, still further downstream at Sagaing. Flows at Nyaung U, Magway, and Pyay are influenced by early season inflows from the Chindwin River and begin to rise earlier in the season.

The period of high flows at a site can be defined as starting when flows rise above the average annual flow and finishing when the flows fall below average annual flow. In general, the high flow period starts earlier in the Upper Ayeyarwady than in other parts of the Ayeyarwady Basin.

Figure 3.4 shows the range (minimum, maximum, and mean) in monthly-observed flows for various locations in the Ayeyarwady Basin. The flows at Magway and Pyay (HEZ 4), downstream of the Chindwin River confluence, are significantly higher and have a greater range around the mean. Maximum flows at Myitkyina (HEZ 1) illustrate the contribution of pre-wet season snowmelt in March and April.

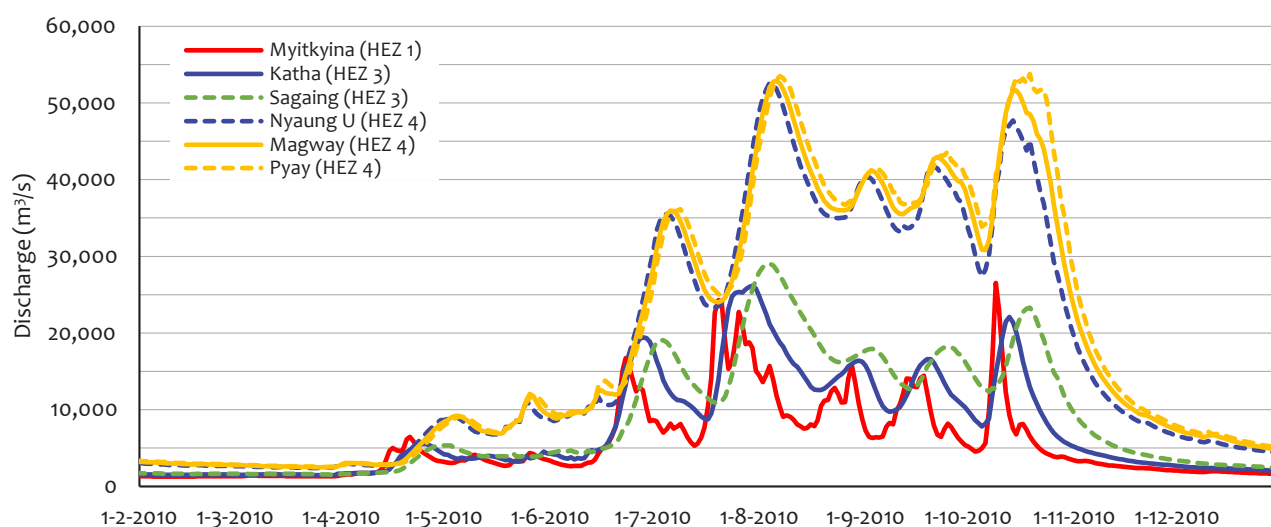


Figure 3.3 - Snowmelt and progression of flood peaks during 2010 down the length of the Ayeyarwady River

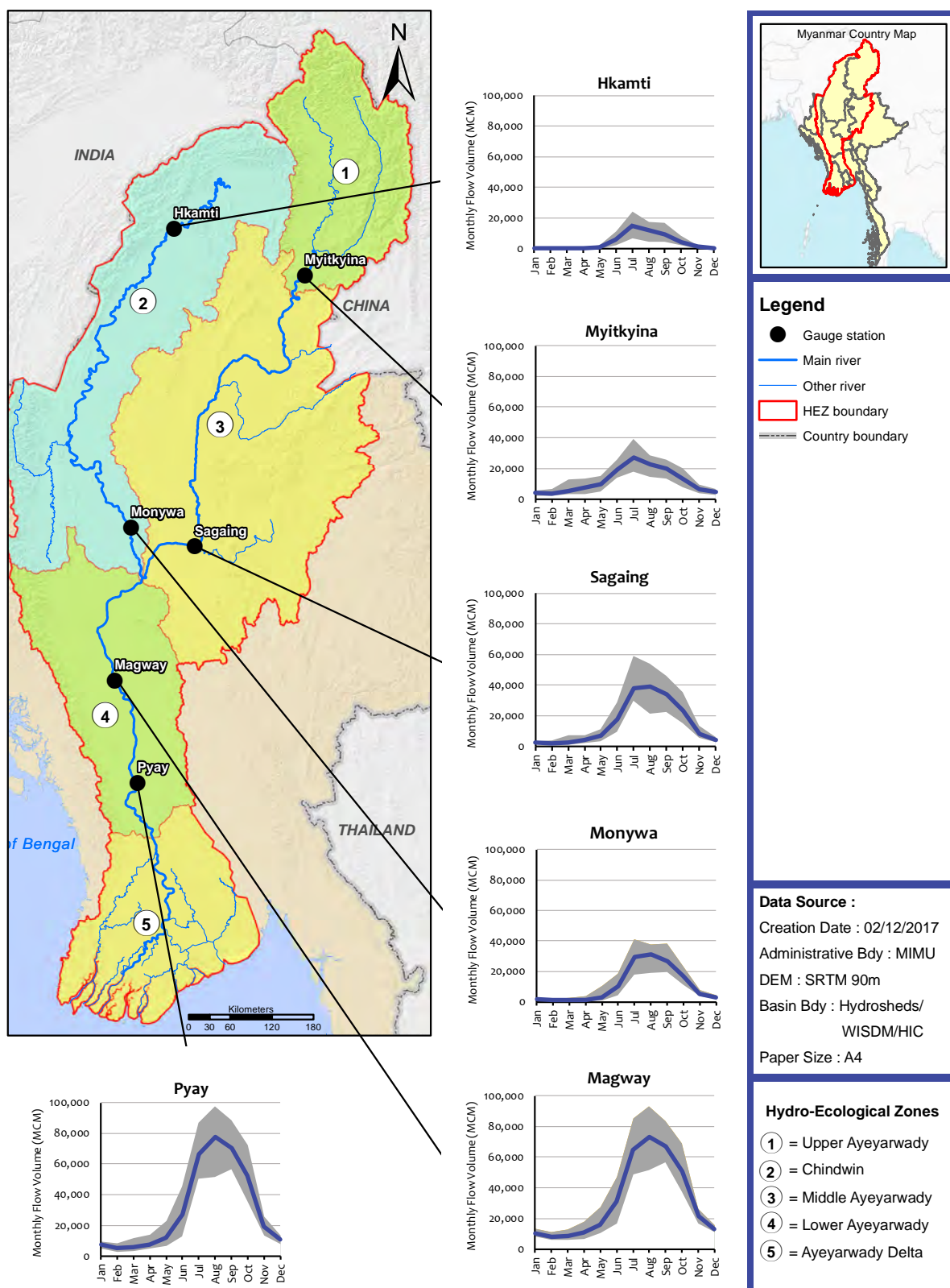


Figure 3.4 - Minimum, maximum and mean (blue line) observed monthly flows in the Ayeyarwady Basin

MCM = million cubic meters

3.3.4 Extreme events

Flood events

The annual recurrence intervals (ARI) for floods have been determined at each of six observed gauging station sites (Table 3.2). Nine years have been identified as representing particularly high flow, with ARIs exceeding the 1- in 10-year value at one or more sites across the Ayeyarwady Basin (namely 1988, 1991, 1997, 2001, 2002, 2004, 2008, 2009, and 2015). Events in 1991, 1997, 2004, and 2015 were associated with more widespread flooding across the Ayeyarwady Basin, with ARIs exceeding 1- in 20-year values. In 1997, two high flow events occurred in the Lower Ayeyarwady in late July and early October. Both these events were the result of the combined impact of high rainfall in the upper parts of both the Ayeyarwady and Chindwin Rivers. Similarly, in July 2004, extreme rainfall exceeded 400 millimetres (mm) and led to high flows in the northern Chindwin, which combined with high flows from upstream of Myitkyina to produce flooding downstream at Magway and Pyay.

This analysis indicates that sites in the Chindwin (HEZ 2) and the Lower Ayeyarwady (HEZ 4) experience higher flooding more often than the upper reaches in HEZ 1. It is unclear from climate change modelling whether changes in rainfall will lead to an increase or decrease in flooding intensity and frequency.

Table 3.2 - Years with high-flow events exceeding or equal to a 10-year annual recurrence interval

Gauge name	HEZ	No. of years	Years	
			10 - 20 year ARI	>20-year ARI
Myiktina	Upper Basin (1)	1		2004
Mawlaik	Chindwin Basin (2)	3	1997, 2015	2002
Monywa	Chindwin Basin (2)	4	2008	1988, 1991, 2015
Hkamti	Chindwin Basin (2)	2		1991, 1997
Sagaing	Middle Basin (3)	2	1988	2004
Magway	Lower Basin (4)	2		2004, 1997
Pyay	Lower Basin (4)	3		1997, 2004, 2015

The Ayeyarwady Delta is particularly exposed to risk from cyclones, where storm surges caused by low atmospheric pressure exacerbate damage caused by rain-induced flooding. For example, in May 2008, Cyclone Nargis killed more than 100,000 people in the delta region. Other cyclones can cause intense rain in other parts of the Ayeyarwady Basin, although the flow response might not be as significant compared with that caused by monsoonal rains.

Flood extent

Examining flooded extent across the Ayeyarwady Basin in the 9 high flow ARI years makes it possible to assess areas most often subjected to flooding. The Chindwin and Ayeyarwady confluence and sections downstream in the Lower Ayeyarwady and the Ayeyarwady Delta were identified as being temporarily inundated during the wet season for 5 or more years out of the 9 high flow years listed above. Figure 3.5 shows the total extent of this inundation at the Chindwin and Ayeyarwady confluence and in the Lower Ayeyarwady (HEZ 4) upstream of Magway.



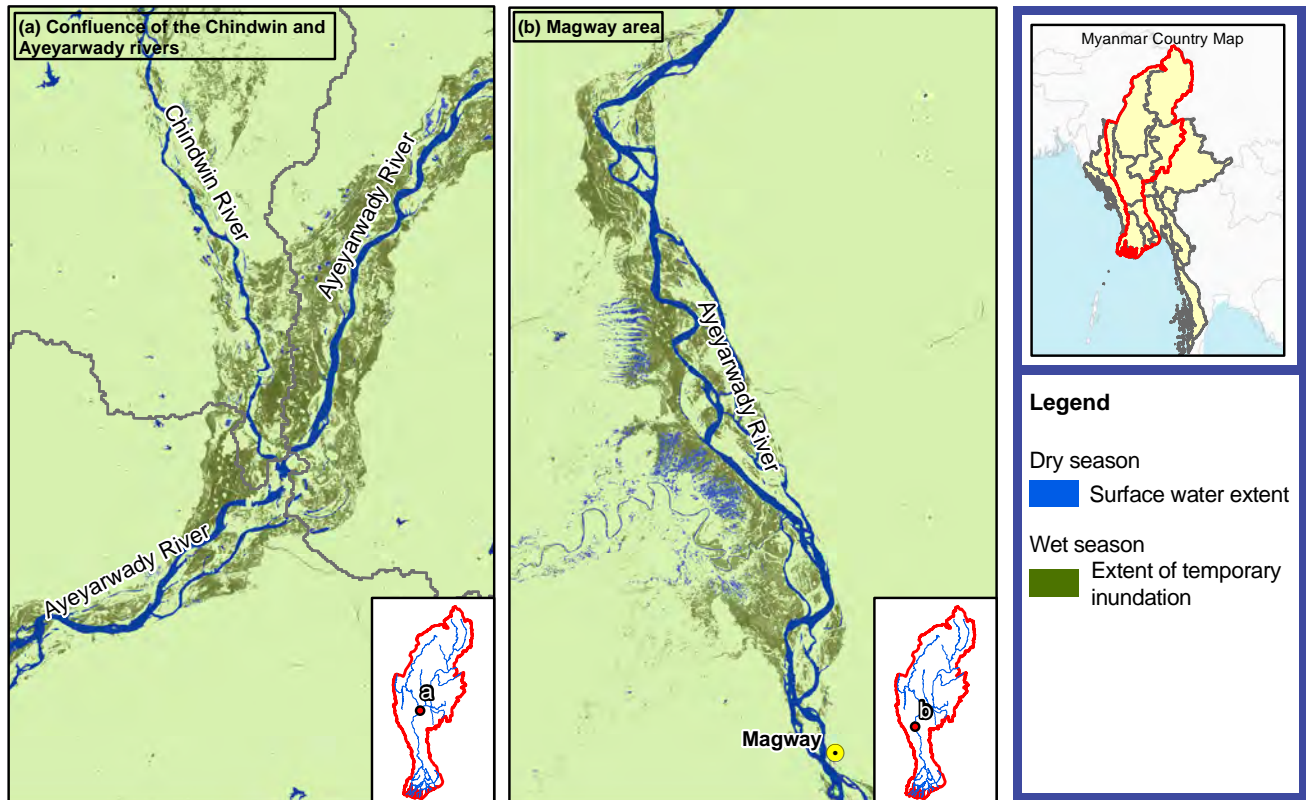


Figure 3.5 Extent of areas inundated in at least five of the following years: 1988, 1991, 1997, 2001, 2002, 2004, 2008, 2009 and 2015
Areas of temporary paddy rice might be incorrectly identified as riverine flooding in the analysis of satellite images

3.4 Surface Water Resources

Storages

By the end of 2016, there were nearly 300 man-made storages for irrigation and hydropower in the Ayeyarwady Basin. Of the storages, 30% provide only hydropower, 46% support only irrigation works, and 24% are for both hydropower and irrigation works. While most of the irrigation works and multi-purpose storages are within Myanmar, most of the hydropower storages are in the Chinese sections of the Middle Ayeyarwady (HEZ 3). The total storages vary by each HEZ and according to storage type (Table 3.3). Similarly, storage varies in each sub-basin as a percentage of upstream available runoff (Table 3.4). The Upper Ayeyarwady (HEZ 1), containing the N'Mai Hka and Mali Hka Rivers, includes the lowest total storage volume; however, this could change with several new dams planned in the N'Mai Hka River.

Table 3.3 - Total capacity (km³) of storage types per hydro-ecological zone

HEZ	Irrigation works	Hydro power	Multi-purpose	Total
Upper Ayeyarwady (1)		0.001		0.001
Chindwin Ayeyarwady (2)	0.361		0.082	0.443
Middle Ayeyarwady (3)	6,968	8,259	5,915	21,142
Lower Ayeyarwady (4)	4,255	0.571	0.832	5,658
Ayeyarwady Delta (5)	1,618			1,618
Total	13,202	8,831	6,829	28,862

Table 3.4 - Storage volume as a percentage of sub-basin available runoff

Sub-basin	HEZ	Storage Total Full Supply Capacity (km ³)	%
Ayeyarwady (Upper)	1	2,396	4.9
Mali Hka	1	0	0.0
N'Mai Hka	1	0.001	0.0
Chindwin (Upper) **	2	0	0.0
Chindwin (Lower)	2	0.294	3.0
Manipur	2	0.149	0.5
Mu	3	7,314	82.6
Ayeyarwady (Middle)	3	1.048	6.4
Myitnge	3	3,752	16.0
Panlaung	3	4,390	65.6
Shweli	3	2,242	17.4
Ayeyarwady (Lower)	4	5,658	14.7
Ayeyarwady Delta *	5	1,618	-

MCM = Million cubic meters

*Sub-basin runoff in the Ayeyarwady Delta could not be ascertained.

**Actual full supply capacity of storages in the Chindwin Upper Sub-basin could not be ascertained.

Water requirement – domestic and irrigation extractions

Much of the Ayeyarwady Basin is characterised as rural, with most areas having a population density of less than 250 people/km². The largest urban areas within the Ayeyarwady Basin are Yangon, with a population exceeding 5 million people, and Mandalay, with a population of approximately 1.2 million.

Domestic surface water requirements in the Ayeyarwady Basin upstream of the Ayeyarwady Delta (which does not include Yangon) are small by comparison to the available flows. Total annual domestic surface water demand upstream of the Ayeyarwady Delta (HEZ 5) is estimated to be 0.07% of total available flows in the Ayeyarwady Basin.

Most of the agriculture in the Ayeyarwady Basin is rainfed, with irrigated agriculture largely supported by storage extractions in the sub-basins of the Middle Ayeyarwady (HEZ 3) and Lower Ayeyarwady (HEZ 4). The Mu and Panlaung Sub-basins (HEZ 3) extract the highest proportion of available flows (Figure 2.2). The highest levels of extraction are in the Mu Sub-basin, where average annual net extraction is approximately 29% of available flows and 48% in the dry season. Much of this extraction is made possible by the Thapenseik 2 Reservoir on the Mu River and the Kinda Reservoir in the Panluang Sub-basin.

3.5 Status and Trends

3.5.1 Water balance

A baseline run of the SOURCE Model calculated a water balance for the whole Ayeyarwady Basin, including unmonitored sub-basins. The baseline represents the level of development from 2014 to 2016, particularly in terms of storages, irrigation areas, and population. The model is run with historic climate data from 1981 to 2016. The water balance accounted for catchment runoff, net evaporation, change in storage volume over time, and total extractions. It shows how water is accounted for within a basin and provides an overview of where and when water is most or least available in the context of water use.

Using available information on known storage volumes, the total storage capacity of major reservoirs (i.e., volume greater than 250 x 106 m³, crest height greater than 40 m, or installed capacity > 100 MW, if hydropower) in the Ayeyarwady Basin has increased from approximately 1 cubic kilometre (km³) to nearly 13 km³ since 1980, with 27 major reservoirs built. Including major and all minor storages, there was a total of approximately 20 km³ of known storage volume in the Myanmar portion of the Ayeyarwady Basin in 2016.

Figure 3.6 shows the inflows and losses across the whole Ayeyarwady Basin for baseline conditions, for the whole year, and for the dry season only. When considering annual flows for the whole Ayeyarwady Basin, approximately 98% of catchment runoff becomes end-of-system streamflow, with approximately 2% extracted and a minimal loss to evaporation. The dry season catchment runoff is approximately 15% of annual flows. This is supplemented by water released from storages for hydropower or irrigation extractions, increasing the total dry season flows to 19% of annual flows. Approximately 7.5% of total dry season flows are extracted.

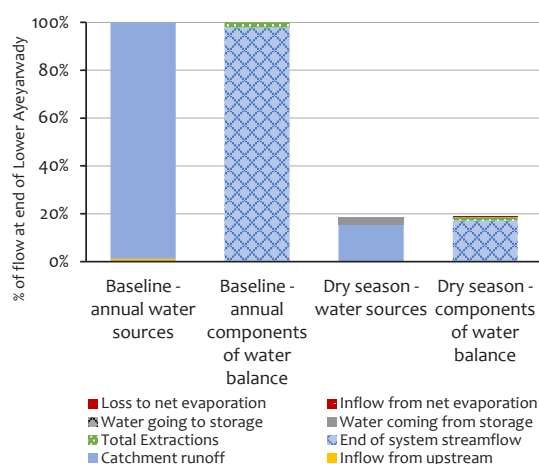


Figure 3.6 – Total water balance and dry season water balance of the Ayeyarwady Basin north of the delta – baseline run

In flows from the sections of the Ayeyarwady Basin in China are accounted as ‘In flow from upstream,’ and make up about 1% of total in flows to catchment runoff at an annual scale.

It is important to consider these values in the context of the location of the extractions and the source of basin flow. As previously noted, approximately 55% of average annual flow comes from the upper sub-basins of the Upper Ayeyarwady (HEZ 1) and the Chindwin (HEZ 2). It is these vital sub-basins that sustain the flows further down in the mainstems of the Chindwin and Ayeyarwady Rivers and down into the Ayeyarwady Delta.

Much of the current water use occurs in the Mu and Panlaung Sub-basins of the Central Dry Zone. This is where rainfall is lower, and contribution to total flows is much smaller. While 2% extraction might appear small at a whole-basin scale, the localised sub-basin impacts are more significant, such as in the Mu Sub-basin (Figure 3.7). Annually, 71% of catchment runoff becomes sub-basin outflow. Considering only the dry season, even though flows are supplemented by releases from the Thapansaik 2 Reservoir, sub-basin outflow is reduced to less than the contribution from catchment runoff.

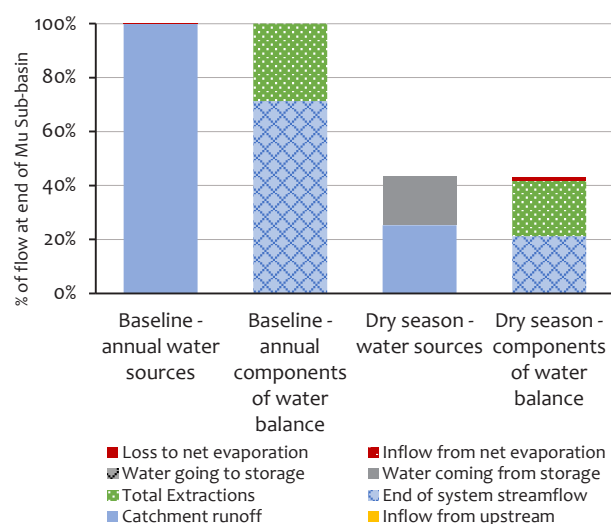


Figure 3.7 – Total water balance and dry season water balance of the Mu River Sub-basin – baseline run

3.5.2 Impacts of development

The potential impact of development on water resources in the Ayeyarwady Basin was evaluated using daily discharge data from the SOURCE Model, covering the period from 1981 to 2016, upstream of the delta. Two flow scenarios were compared: the ‘without development’ scenario and the ‘baseline’ scenario of current levels of development in the Ayeyarwady Basin. These two scenarios are identical in all aspects except for the anthropogenic water resource development and extraction activities. They provide a good basis for comparing the effects of water resource development on the flow regime.

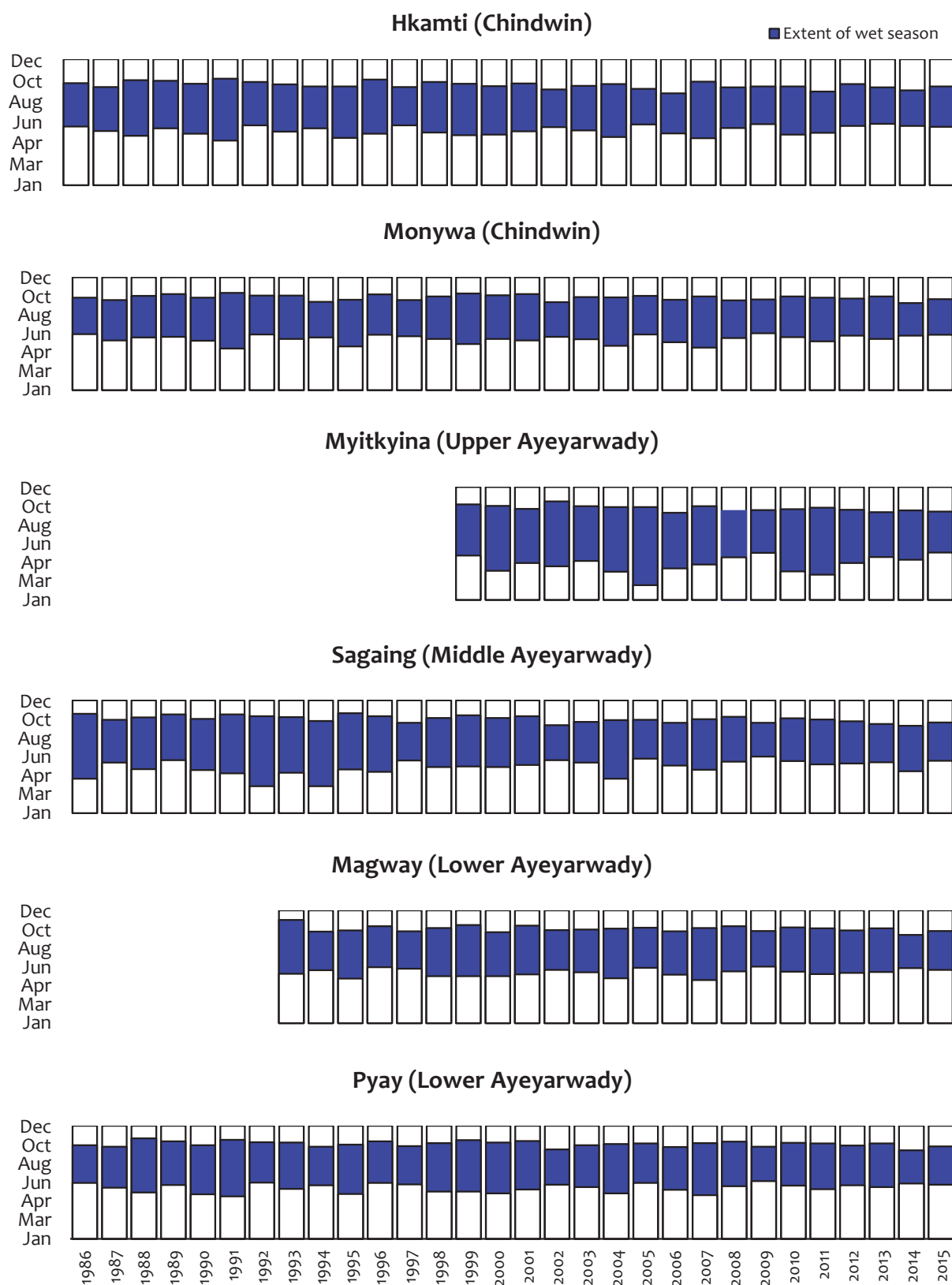


Figure 3.8 - Duration of wet season from 1986 to 2015 based on available observed flows

Gaps indicate where data was unavailable



On a whole-basin analysis, there was little difference between the 'without development' and 'baseline' scenarios. Comparing annual values, there was a 2% increase in flows from the 'baseline' to the 'without development' scenario. Comparing dry season values, there was a 1% increase in flows from the baseline to the 'without development' scenario. The dry season showed less impact because of water released from storages.

On a sub-basin scale, the impacts of development become more obvious. In the Mu Sub-basin, there was a 40% increase in annual flows from 'baseline' conditions to the 'without development' scenario. Comparing dry season values in the Mu Sub-basin, there was a 20% increase in flows from the 'baseline' to the 'without development' scenario.

While it appears that the impact of development is less during the dry season, it is important to consider the impact of dry season return flows from irrigated areas in the 'baseline' scenario. These return flows are dependent on assumptions concerning irrigation efficiencies and can cause the baseline dry season flows to be higher than expected and result in less difference between the two scenarios for this period. A 50% irrigation efficiency is currently assumed, with all lost water returned to the system.

3.5.3 Consistency of the monsoon

The start of the wet season may be defined as when the flows at that site rise above the mean annual discharge. The finish of the wet season is when the flows fall below the mean annual discharge. Typically, flows cross this threshold at the beginning and end of the wet season. While the arrival of a wet period after a dry period is predictable every year, there is a range in the start and end dates and the length of the wet season. This impacts the reliability of water supply, navigability, and the arrival of flooding.

Figure 3.8 shows the range in the onset and duration of the wet season based on observed flows at various sites across the Ayeyarwady Basin. These extend from the northern sites of Myitkyina (in HEZ 1) and Hkamti (in northern HEZ 2), to the central sites of Sagaing (HEZ 3) and Monywa (southern HEZ 2), and to the southern sites of Magway and Pyay (HEZ 4).



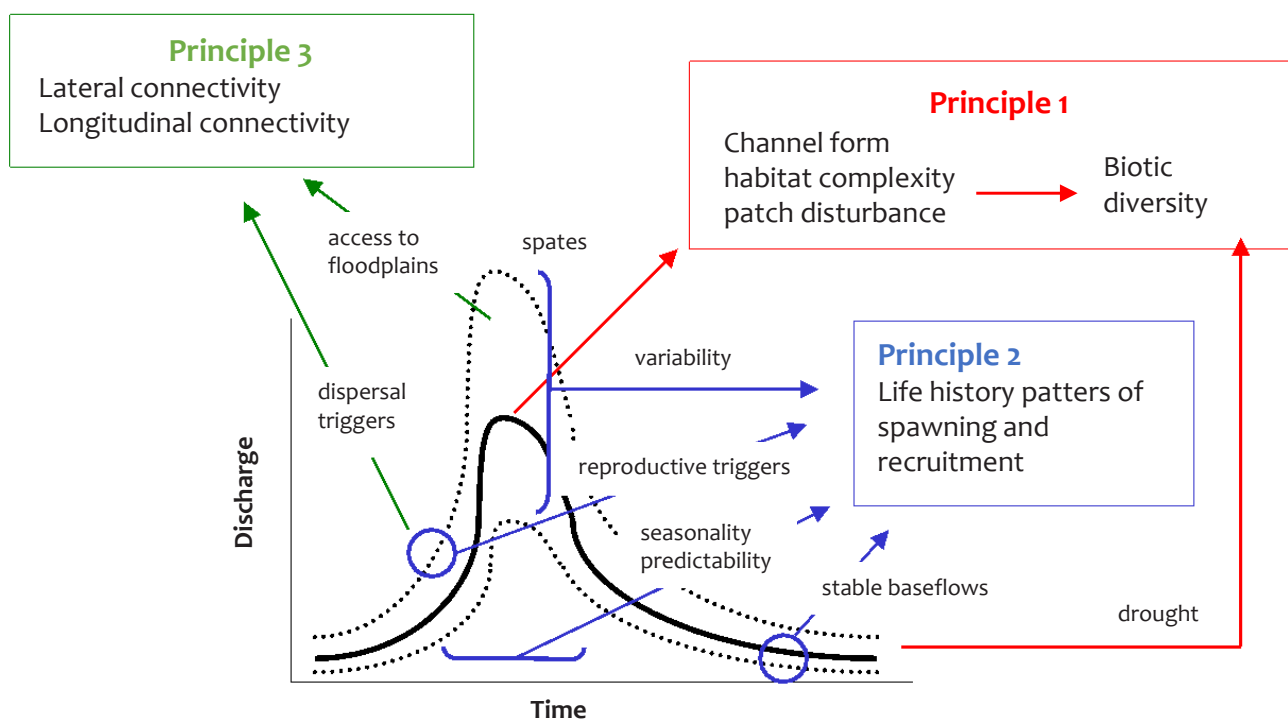


Figure 3.9 - Three of the guiding principles on the influence of flow regimes on aquatic biodiversity
(Bunn and Arthington, 2002)

3.6 Ecohydrology

An ecohydrological assessment was undertaken to characterise the status and trends in the key attributes of the flow regime of the Ayeyarwady Basin. This assessment is likely to be of importance to biodiversity, fisheries, and the ecological processes that sustain them. It explored the associated risks to these environmental assets from water infrastructure development, including hydrologic alteration, river impoundment, and longitudinal fragmentation by large dams. This was not intended to be a comprehensive assessment of environmental flow needs. No attempt was made to recommend sustainable water extraction and diversion limits or to provide assessments of critical flow needs for specific species.

3.6.1 Review of key principles and existing knowledge

Hydrological regimes and ecological responses

The flow regime is regarded as the key driver of river, floodplain, and wetland ecosystems. High flows interact with the surrounding landform and geology to shape the channel form and disturb the substrate of the river bed and banks. This creates a high level of physical habitat complexity, which is a major determinant of aquatic biodiversity (Figure 3.9; Principle 1). Many features of the flow regime influence the life history patterns of

aquatic and riparian species – not only the seasonality and predictability of the overall pattern, but also the timing of particular flow events (Figure 3.9; Principle 2). Critical life events of many aquatic species are linked to these flow patterns.

The long-term viability of populations of many riverine species depends on the natural patterns of connectivity along the channel network and, in some migratory species, to the sea (longitudinal connectivity). Populations of many riverine species are sustained by the massive subsidy of resources available during periods of floodplain inundation and connection of associated lowland wetlands. Larger flow events trigger and facilitate longitudinal dispersal of migratory aquatic species and allow access to otherwise disconnected floodplain and wetland habitats (Figure 3.9; Principle 3).

This simple conceptual view of a hydrograph (Figure 3.9) understates the complexity of intra- and inter-annual variation in hydrology (Figure 3.10). It is important to be able to quantify these key components of the flow regime across these temporal scales. It is worth noting that several attributes of the flow regime, particularly the low flow characteristics and timing of smaller flow events, may be of critical ecological importance, even though they are of little importance from a water resource development perspective.

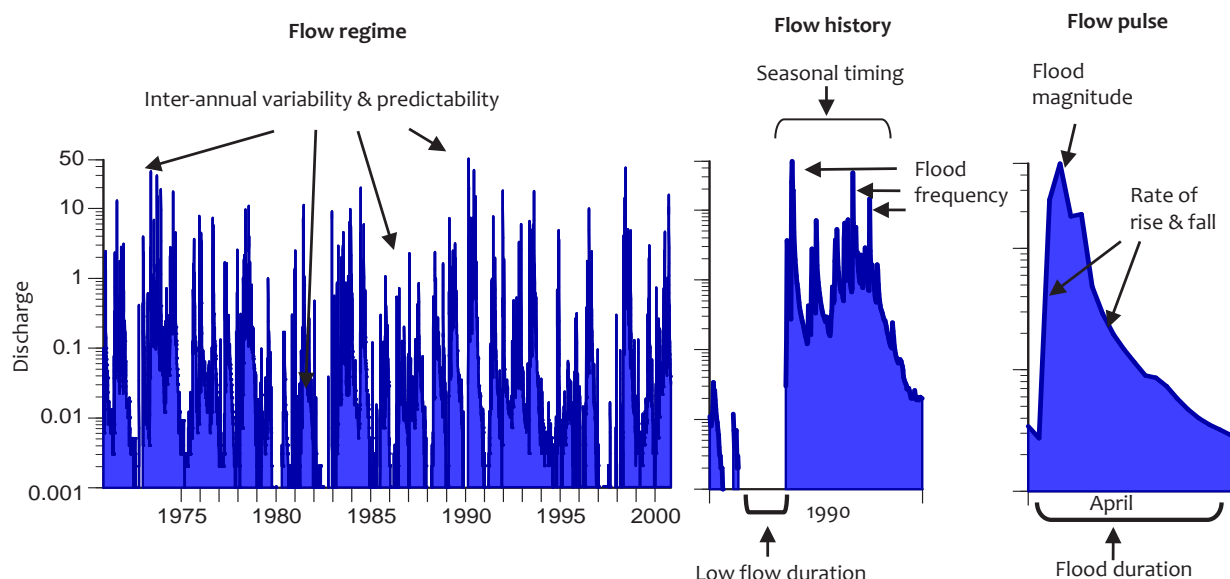


Figure 3.10 - Components of flow variability may be characterised over various temporal scales, including the long-term flow regime, the short-term history of flow events, and individual flow pulses (Olden et al., 2012)



Ecological responses to risks associated with water resource development

The alteration of flow regimes is one of the most serious and continuing threats to ecological sustainability of rivers and their associated floodplain wetlands. It is important to understand how attributes of the flow regime are affected by water resource development and the likely risks to ecological assets and values associated with these changes.

The ecology of aquatic ecosystems in the Ayeyarwady Basin is fundamentally linked to the seasonality of the climate and the natural flow regime. The Ayeyarwady River can be described as having a highly rhythmic flood pulse. Tropical floodplain rivers with these features are associated with higher fish species richness, more stable avian populations, and elevated rates of riparian forest production compared with those river systems with arrhythmic flood pulses. Water resource and hydropower development that alters the hydrologic rhythmicity is likely to have significant long-term consequences for both biodiversity and productivity.

The movement of water and associated nutrients, carbon and energy, and aquatic biota between different habitats of the river are essential to sustain biodiversity, maintain productive fisheries, and support other essential ecosystem services. Maintenance of connectivity between these components, both longitudinal and lateral, is vital for natural ecosystem function. In-channel or floodplain development in the Ayeyarwady Basin that diminishes or severs these links is likely to diminish these values.

3.6.2 Ecohydrological risk assessment

Ecological assets in the Ayeyarwady Basin are facing increasing threats from a range of processes related to water resource development, including hydrologic alteration, river impoundment, and longitudinal fragmentation. The cumulative impacts from these threats are unknown but may pose severe risks in the long term. An ecological risk assessment was undertaken to estimate the cumulative impacts of current threats to ecological assets in the Ayeyarwady Basin, including risks to aquatic biodiversity, ecological processes, and ecosystem values from cumulative effects of flow alteration, riverine impoundment, and longitudinal fragmentation. The risk assessment was based on a widely accepted approach to ecological risk assessment that combines spatially explicit information on threat exposure, the occurrence and relative importance of aquatic biodiversity assets, ecological processes and ecosystem values, and their potential vulnerability to threats. These analyses allowed areas (e.g., sub-basins) to be ranked on their overall risk to each threat.

Assessment of hydrologic alteration

Twelve hydrologic metrics were used to characterise ecologically relevant components of the flow regime of rivers, including variation in the magnitude, frequency, duration, timing, and inter-annual variability of high and low flows. These metrics describe components of the flow regime known to be sensitive to hydrologic alterations caused by human activities and are potentially amenable to management through ecologically sensitive dam operations and constraints on abstraction.

The extent of hydrologic alteration for the 12 sub-basins in the Ayeyarwady Basin (excluding the Delta Sub-basin) was based on analysis of modelled daily discharge data from the SOURCE Model using the 'without development' and 'baseline' scenarios. The magnitude of hydrologic alteration was calculated as the percentage difference between modelled flow scenarios for each of the 12 hydrologic metrics. An overall measure of flow alteration was also calculated for each sub-basin using the Gower dissimilarity metric, which ranges from 0 to 1. Changes in individual hydrologic metrics between modelled flow scenarios are presented in Table 3.5. Maps of overall hydrologic alteration and differences between modelled flow scenarios for each metric are shown on Figure 3.11.

The Upper Ayeyarwady (HEZ 1) has experienced no detectable hydrological changes from water resource development and extraction. Similarly, the Chindwin (HEZ 2) has had relatively minor hydrological changes overall. The most notable change in the Chindwin is the 15% increase in the duration of low flow spells. Upstream sub-basins within the Chindwin have experienced more pronounced changes in flows, particularly the Manipur Sub-basin in which low flow magnitude has decreased by 9.8% and the duration of low flow spells has increased by 42%.

The Middle Ayeyarwady (HEZ 3) shows some major alterations in hydrology, with a 3% decrease in mean annual flow and < 10% decrease in the magnitude, frequency, duration, and variability in timing of high flows. Major changes in the mean duration (16% increase) and number (25% decrease) of low flow spells occurred, and minor changes (< 5% absolute difference) in the timing and variability of low flow spells is evident. Upstream sub-basins within the Middle Ayeyarwady experienced more dramatic changes in most flow regime characteristics, particularly the Mu, Panlaung, Myitnge and Shweli Sub-basins, which have had a 29%, 22%, 7%, and 2% decrease in mean annual flow volume, respectively. The magnitude and frequency of high flow spells has decreased substantially across these sub-basins (e.g., a 38% reduction in high spell frequency in the Panlaung Sub-basin) (Figure 3.12). Low flows have also changed considerably, with a maximum decrease in low flow magnitude of 38.7% (Mu Sub-basin), maximum increase in low flow spell duration of 106.3% (Panlaung Sub-basin), and maximum increase in low flow spell frequency of 104% (Mu Sub-basin). The timing and variability of high and low flow spells have also changed considerably in these sub-basins (up to 29% difference from 'without-development' flows).

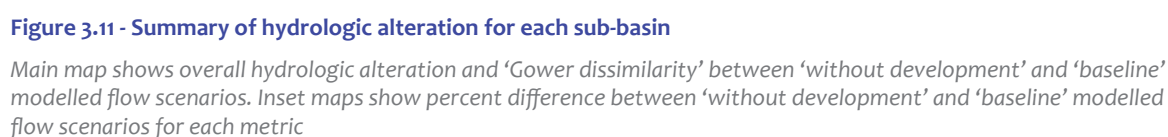
The Lower Ayeyarwady (HEZ 4) shows an overall decline of 2% flow volume, 8% decline in the average duration of high flow spells, and a > 20% difference in the mean duration and frequency of low spells.

Table 3.5 - Percentage change in hydrologic metrics from the ‘baseline’ scenario to the ‘without development’ scenario for each sub-basin

		HEZ 1		HEZ 2			HEZ 3						HEZ 4
Flow class	Metric	N'Mai Hka	Mali Hka	Chindwin (Upper)	Manipur	Chindwin (Lower)	Ayeyarwady (Upper)	Shweli	Myitnge	Panlaung	Mu	Ayeyarwady (Middle)	Ayeyarwady (Lower)
Flow volume	Mean annual flow	0%	0%	0%	-1%	0%	0%	-2%	-7%	-22%	-29%	-3%	-2%
High flows	High flow magnitude	0%	0%	0%	0%	0%	-1%	0%	-7%	-31%	-25%	-2%	-2%
	Mean duration of high spells	0%	0%	0%	0%	0%	-0%	2	4%	-4%	-22%	-1%	-8%
	Mean annual number of high spells	0%	0%	0%	0%	0%	-4%	-2%	-20%	-38%	-29%	-9%	-1%
Low flows	Low flow magnitude	0%	0%	0%	-10%	-2%	5%	-30%	-21%	-23%	-39%	2%	1%
	Mean duration of low spells	0%	0%	4%	42%	15%	-21%	90%	56%	106%	-9%	16%	21%
	Mean annual number of low spells	0%	0%	0%	13%	-1%	-38%	13%	0%	-8%	104%	-25%	-20%
Timing and variability	Timing of high flow	0%	0%	0%	0%	0%	1%	1%	4%	12%	21%	0%	0%
	Variability in timing of high flow	0%	0%	0%	0%	0%	-2%	-9%	-26%	-42%	-16%	-5%	-1%
	Timing of low flow	0%	0%	0%	-3%	-1%	5%	-9%	-7%	-12%	29%	4%	3%
	Variability in timing of low flow	0%	0%	1%	2%	1%	14%	-9%	27%	37%	-6%	-5%	-6%
Seasonality	Proportion flow driest 6 months	0%	0%	0%	-3%	-1%	4%	-7%	-5%	-1%	19%	1%	0%
Overall flow alteration	Gower dissimilarity*	0.00	0.00	0.02	0.02	0.01	0.05	0.05	0.09	0.18	0.19	0.03	0.04

Negative value indicates that the metric has decreased for the ‘baseline’ compared to ‘without development’ scenario

*Gower dissimilarity – Reflects the overall degree of hydrologic alteration for each sub-basin (calculated using the ‘Gower dissimilarity’ between hydrologic metrics calculated for ‘without development’ and ‘baseline’ scenario development flow regimes). The Gower metric ranges from 0 to 1, where higher values indicate greater divergence of the ‘baseline’ flow regime from the ‘without development’ flow regime.



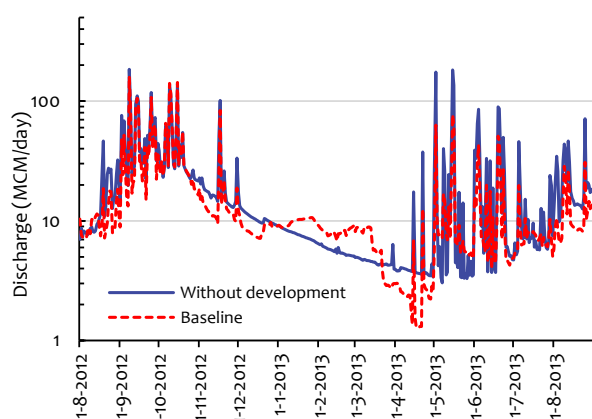


Figure 3.12 - Panlaung Sub-basin example hydrographs for each modelled flow scenario.

Differences shown in high flow magnitude and post-wet season recession flows between 'baseline' and 'without development' scenarios.

Assessment of exposure to river impoundment and longitudinal fragmentation

The relative exposure of each sub-basin to two other ecological threats caused by water resource developments include 1) the spatial extent of river impoundment, and 2) the degree of longitudinal fragmentation. The spatial extent of impounded rivers and streams in each sub-basin was calculated using available datasets and expressed as the proportion of total sub-basin area covered by reservoirs. Longitudinal fragmentation was calculated using an index (ranging from 0 to 1) that quantifies the cumulative impact of the number and location of barriers to longitudinal connectivity of a river network.

The relative exposure of each sub-basin to the threat of river impoundment and longitudinal fragmentation is presented in Table 3.6 and Figure 3.13. River impoundment was highest in the Ayeyarwady (Upper), Mu and Panlaung Sub-basins. The Ayeyarwady (Middle), Ayeyarwady (Lower) and Manipur Sub-basins had lower exposure to river impoundment. The remaining sub-basins had little or no impoundment of riverine habitat. The sub-basins most severely affected by longitudinal fragmentation (River Fragmentation Index Scores > 0.5) were Shweli, Panlaung, and Mu Sub-basins. The Ayeyarwady (Upper), Ayeyarwady (Middle), Ayeyarwady (Lower) and Myitnge Sub-basins were also affected by fragmentation, with index scores between 0.1 and 0.5.

Table 3.6 - Relative exposure in each sub-basin to threats posed by river impoundment (proportion of sub-basin area) and longitudinal fragmentation (River Fragmentation Index)
Each threat can have a maximum exposure score of 1 at a given sub-basin

HEZ	Sub-basin	Ecohydrological threat	
		River impoundment	Longitudinal fragmentation
Upper Ayeyarwady (1)	N'Mai Hka	0.0000	0.0324
Upper Ayeyarwady (1)	Mali Hka	0.0002	0.0000
Chindwin Ayeyarwady (2)	Chindwin (Upper)	0.0002	0.0000
Chindwin Ayeyarwady (2)	Manipur	0.0032	0.0155
Chindwin Ayeyarwady (2)	Chindwin (Lower)	0.0007	0.0000
Middle Ayeyarwady (3)	Ayeyarwady (Upper)	0.0457	0.3640
Middle Ayeyarwady (3)	Shweli	0.0004	0.7298
Middle Ayeyarwady (3)	Myitnge	0.0002	0.1320
Middle Ayeyarwady (3)	Panlaung	0.0076	0.5816
Middle Ayeyarwady (3)	Mu	0.0184	0.4996
Middle Ayeyarwady (3)	Ayeyarwady (Middle)	0.0038	0.2665
Lower Ayeyarwady (4)	Ayeyarwady (Lower)	0.0032	0.1878

Ecological risks from hydrologic alteration, river

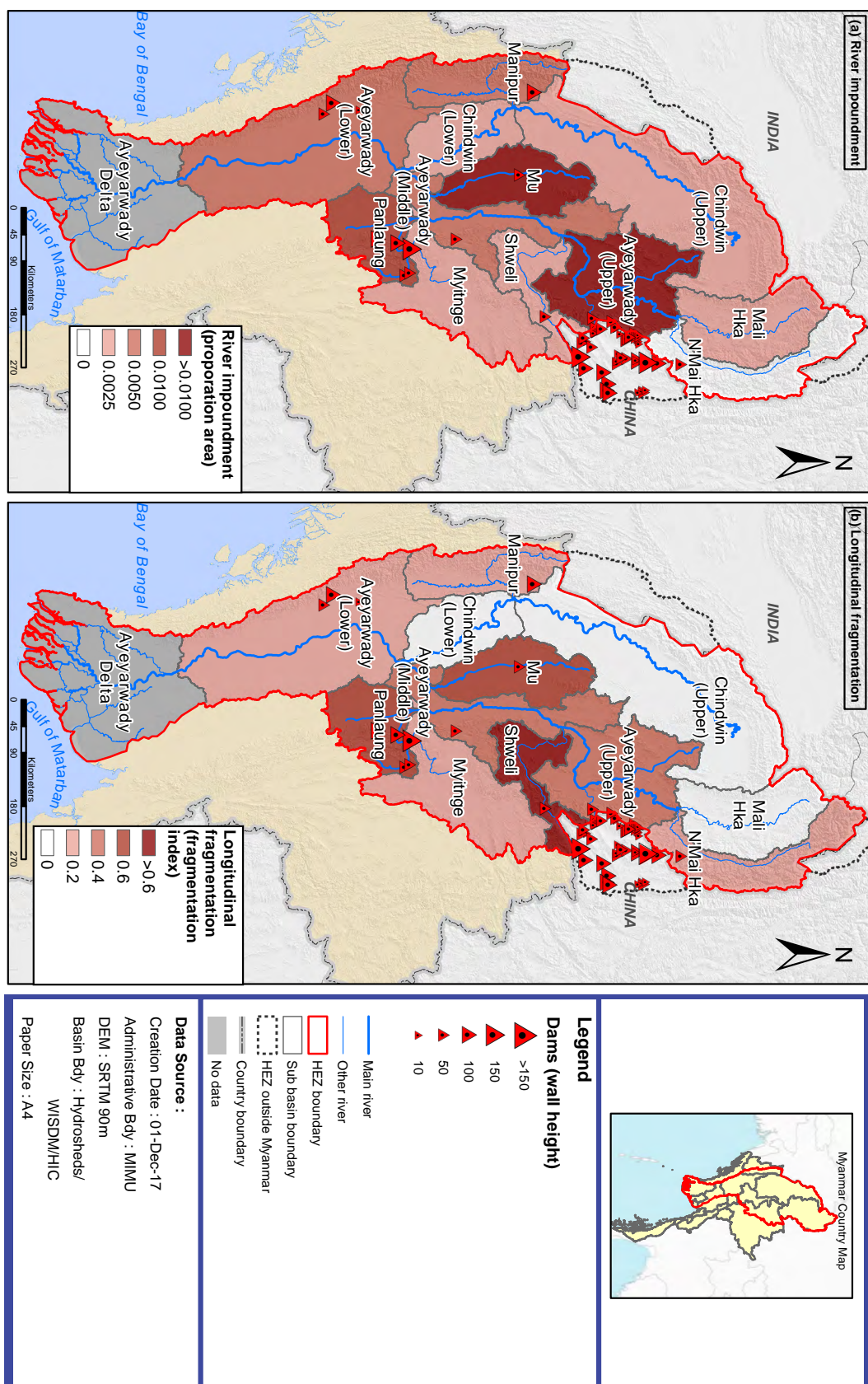


Figure 3.13 - Spatial variation in relative exposure to threats posed by river impoundment (a; proportion of sub-basin area), and longitudinal fragmentation (b; River Fragmentation Index), for each sub-basin. Each threat can have a maximum exposure score of 1 at a given sub-basin.

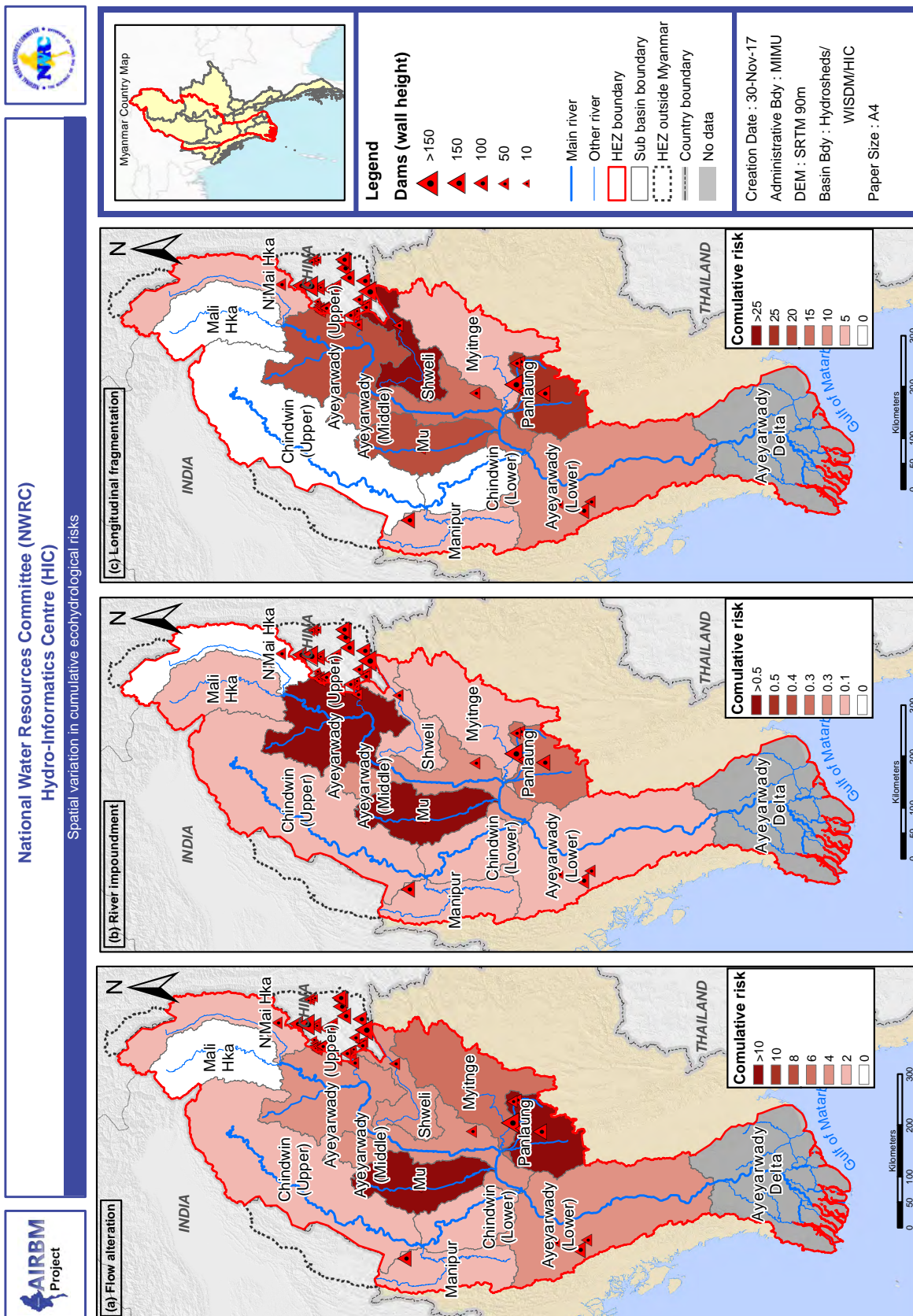


Figure 3.14 - Spatial variation in cumulative risks from (a) flow alteration, (b) river impoundment, and (c) longitudinal fragmentation, across all assets, processes, and values in each sub-basin

Cumulative risk combines threat exposure data with the occurrence/importance of each asset, process, and value and their vulnerability to threats for each sub-basin. A high-risk score for a given sub-basin could be attained by that sub-basin having high exposure to a threat and containing a high occurrence/importance of highly vulnerable assets/processes/values

impoundment, and longitudinal fragmentation

The ecological risk assessment revealed that existing hydrologic alteration and associated threats from river impoundment and fragmentation are currently posing serious risks to aquatic ecosystems in some parts of the Ayeyarwady Basin. Key findings from the risk assessment are summarised below and on Figures 3.14 and 3.15.

Hydrologic alteration – The assessment of risks posed by hydrologic alteration revealed that the sub-basins in HEZ 3, particularly the Panlaung and Mu Sub-basins, were at highest cumulative risk. Overall, ecological assets, processes, and values assessed as being at highest cumulative risk from hydrologic alteration include flowing rivers and streams, floodplain wetlands, floodplain primary productivity, lateral connectivity, and migratory species. Hydrologic alteration from current development poses a lower, but still substantial, risk to rare/endemic species, longitudinal connectivity, and fisheries production.

River impoundment – The loss of riverine habitat and its associated effects on biodiversity and ecosystem processes is not offset by the creation of lentic (stationary or relatively still water) habitat through construction of impoundments. Assessment of the cumulative risks from river impoundment revealed that the Ayeyarwady (Upper) Sub-basin and, to a lesser extent, the Mu Sub-basin in HEZ 3 were at substantially higher risk than all other sub-basins. These sub-basins contained the highest proportion of impounded area and contained a relatively high number of assets that were all highly vulnerable to this threat. Ecological assets, processes, and values assessed as being at highest cumulative risk from river impoundment included rare and endemic species, flowing rivers and streams, KBAs, and fisheries production.

Longitudinal fragmentation – Assessment of cumulative risks from longitudinal fragmentation revealed that all sub-basins in HEZ 3 were at high risk, particularly the Shweli, Panlaung, and Mu Sub-basins. Other sub-basins at relatively lower risk included the Ayeyarwady (Middle) and the Ayeyarwady (Lower). Ecological assets, processes, and values assessed as being at highest cumulative risk from longitudinal fragmentation include migratory species, longitudinal connectivity, and fisheries production. KBAs and rare and endemic species were assessed as being at moderate risk, with all other assets at relatively low risk.

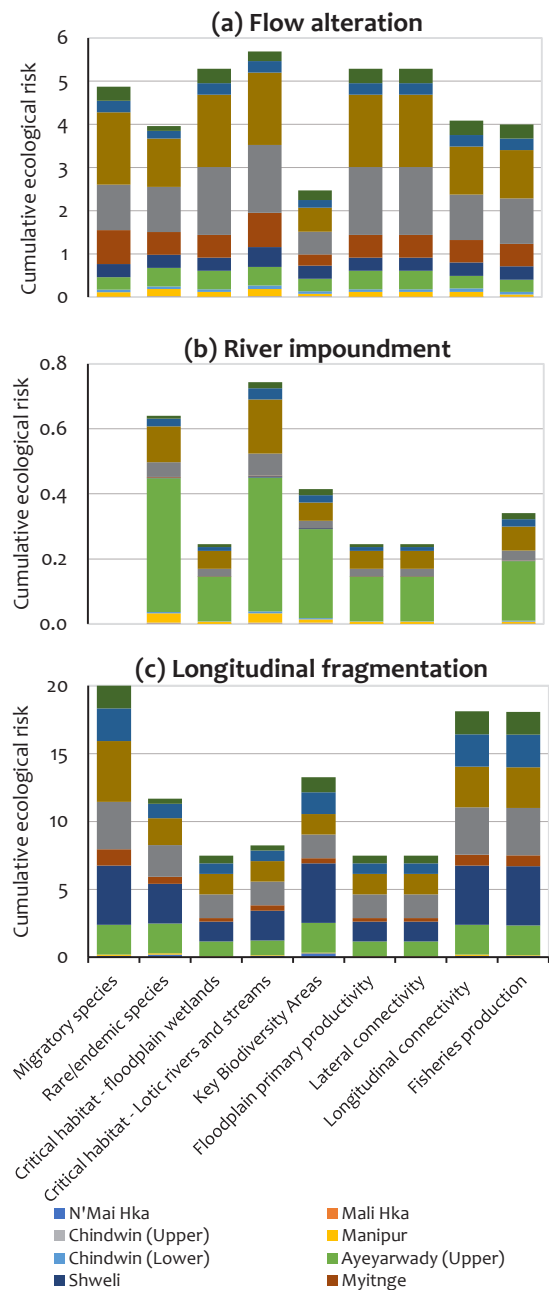


Figure 3.15 - Cumulative ecological risks from (a) flow alteration, (b) river impoundment, and (c) longitudinal fragmentation for each asset, process, and value in each sub-basin, indicated by colours

3.7 Information Gaps

This section outlines a number of information gaps identified by the surface water resources and eco-hydrologic assessments.

3.7.1 Surface water and climate monitoring

There was insufficient reliable data to undertake a comprehensive assessment of surface water research and, in some cases, insufficient time to access what was available. Issues related to data quality and coverage include the following:

- Data from only 18 recorded rainfall gauges were available for modelling and analysis, which were too few to adequately describe rainfall inputs for such a large and variable landscape.
- Publicly-available, remotely-sensed precipitation data were used to attain the required spatial coverage; however, this data did not always concur with observed data.
- Data from only one recorded evaporation gauge were available. Remotely-sensed temperature was used to calculate evapotranspiration, but there was no capacity to validate this against observation.
- Remotely-sensed temperature data were also used for the snowmelt modelling; however, the accuracy of these data for the Ayeyarwady Basin are not known.
- Data from nine observed discharge sites were available for model calibration; however, there is uncertainty about the reliability of the rating curves used to calculate discharge.
- The size and height of storages could be accessed; however, detailed information on storage operations was difficult to obtain.
- Extensive cropping information is collected in Myanmar; however, much of this is not yet digitised at an appropriate scale.

The lack of reliable input data leads to greater uncertainty in the modelled outputs. However, the SOURCE Model was designed as a platform to which data may be added as it becomes available. The most important issue to address is the uncertainty in discharge measurements, since this will continue to impede adequate modelling of the system.

3.7.2 Ecohydrologic risk assessment

Several assumptions and associated limitations arose in the cumulative risk assessment approach used, including the following:

- Accuracy of characterisation of threat exposure – The assessment was dependent on the accuracy, currency, and spatial grain-size of the individual threat data layers and the methods used for integration of individual data layers within each threat type and their subsequent transformation.
- Accuracy of estimations of distributions and importance of assets, processes, and values – The assessment was based primarily on expert opinion, with reference to literature sources. Future assessments could be improved by more quantitative, spatially-explicit, and spatially-comprehensive data on species distributions, fisheries production, and the like. Some of this data are already available and could be modelled.
- Linear response of species to threats – The assessment relied on assumptions of linear and additive responses of assets, processes, and values to increasing intensity of threats.
- Accuracy of vulnerability weights – Extremely limited available knowledge required the use of expert judgement to estimate vulnerability assets, processes, and values to threats. While the estimates are assumed to be representative and accurate, they could be refined and improved through surveying a broader pool of experts and by estimating and representing uncertainty in assessment.

3.8 Conclusions

This chapter has provided an initial assessment of surface water resources and ecohydrological risk in the Ayeyarwady Basin, with a specific focus on the five HEZs and 13 sub-basins.

The assessment provides baseline knowledge of water resources and flows in the Ayeyarwady Basin. The estimated average annual discharge above the delta is 375 km³/yr – an equivalent depth of approximately 1 m/yr of surface runoff across the Ayeyarwady Basin. While this would appear to be a considerable amount of flow, it occurs predominately during the 6 months of the wet season, with smaller tributaries ceasing to flow in the dry season.

The assessment identified that, beyond the monsoonal wet season, important drivers of hydrology in the Ayeyarwady Basin include the cyclonic systems, groundwater flows to the streams, and snowmelt. The onset and duration of the wet season varies year by year, with no apparent trend in either onset, duration, or cessation. The variability in the wet season could, however, affect water supply, navigation, and flooding.

The assessment identified that while water supplies from the mainstream of the Ayeyarwady should be reliable year-round, sub-basin tributaries, such as the Mu and Panlaung Rivers, show greater signs of being stressed. During the dry season, ephemeral streams naturally cease to flow, and heavily regulated sub-basins can potentially be subjected to stress. More data on extractions, deliveries, and return flows are required to better understand these risks.

While only 2% of the basin's total available surface water is extracted, an estimated amount equivalent to 7.5% of available water is extracted during the dry season. Location plays a key role in the sustainability of extractions. In the Mu Sub-basin (in the Central Dry Zone), it is estimated that 29% of available surface water is extracted on an annual basis, with an amount equivalent to 48% of available water extracted during the dry season.

Acknowledging data limitations, the ecohydrological assessment identified that current flow alteration and associated threats from river impoundment and fragmentation are already posing potentially serious risks to aquatic ecosystems in some parts of the Ayeyarwady Basin. These comprised most sub-basins in HEZ 3, namely the Mu, Panlaung, Ayeyarwady (Upper), and Shweli Sub-basins. These areas could be prioritised for more detailed on-the-ground assessment of potential ecological impacts and options for threat management and risk mitigation.

A number of key strategies could be considered in the future for minimising the negative ecological impacts of water resource development and associated flow regime changes in the Ayeyarwady Basin, especially environmental flow management, water infrastructure management, and strategic water resource planning and adaptive management.

The prospect of dramatic environmental changes over the coming years underscores the need for tools to efficiently manage and conserve freshwater ecosystems in Myanmar. This will enhance the capacity of natural resource managers to implement effective mitigation and adaptation programs and should aid environmentally sustainable economic and social development. There is a need to develop spatially explicit scenario evaluation tools for Myanmar's river catchments to evaluate tradeoffs of different development and climate scenarios. These should be underpinned by gathering new knowledge with respect to the following:

- Risk management – Some sub-basins and their ecological assets and values are already at high risk. Strategic, coordinated, and inclusive management is required to address current and future threats.
- Environmental flows – Information on the environmental flow requirements of freshwater biota and ecological processes is urgently required to inform planning and management.
- Ecological responses – Targeted assessment is required on ecological responses to development and the benefits of management actions.
- Geophysical representation – Quantifying changes in floodplain inundation and sediment is needed.
- Data collection – Augmented monitoring and measurement of water flows, water stores, and climate in the Ayeyarwady Basin would assist the understanding and management of the Ayeyarwady water system, including streamflow; reservoir water storage; reservoir releases for consumptive use and hydropower generation; groundwater levels; water extractions; water deliveries; returns of extracted water to the system; and rainfall, temperature, and other climate data.

4

WATER POLLUTION



HIGHLIGHTS – WATER POLLUTION

- This work represents an initial assessment of water pollution within the Ayeyarwady Basin, with specific reference to four sectors: industrial, urban, mining, and agriculture.
- There is a lack of reliable information on key parameters related to water pollution within the Ayeyarwady Basin. While this limited the assessment of water pollution, available data established that development in the four key sectors, without safety and protection measures, is likely to produce unacceptable risks to ecosystem and human health.
- A preliminary estimate of industrial pollution identified BOD and TSS loads as concerns in the three major industrial zones of Yangon, Mandalay, and Sagaing.
- Industrial raw materials and construction materials are leading polluters in industrial zones in the Chindwin (HEZ 2) and Middle Ayeyarwady (HEZ 3).



- Minerals and petroleum products, clothing and apparel, and food and beverages are the leading toxic chemical polluters in the Lower Ayeyarwady (HEZ 4) and the Ayeyarwady Delta (HEZ 5).
- Lead load was the highest in the Middle Ayeyarwady (HEZ 3) and the Ayeyarwady Delta (HEZ 5).
- The 3 main toxic chemicals of concern in the Ayeyarwady Basin are ammonia, ethyl glycol, and formaldehyde. The highest loads of toxic chemicals and metals were identified in Mandalay, Yangon, and Pathien.
- The areas of highest population density, particularly in the Middle Ayeyarwady (HEZ 3) and the Ayeyarwady Delta (HEZ 5), are the most vulnerable to human health issues arising from urban water pollution.

HIGHLIGHTS – WATER POLLUTION

- Urban environments produce pollutants that are harmful to receiving waters and water users, if above the relevant guideline levels.
- Untreated private water supplies present significant health risks to urban populations. Poor sewerage treatment in cities results in faecal levels above those appropriate for human health.
- Significant data gaps exist in relation to the scale and impact of mining activities on water pollution.
- Continued expansion of mining activities, particularly unregulated artisanal and small-scale mining, are likely to pose increased human health risks and contribute to environmental degradation through erosion, habitat destruction, and forest loss.



- Available data indicate that water pollution from agriculture resulted in high levels of microbial contamination in 17 sampled dams, such that the water was unfit for human consumption.
- Little information is available on the impact of pesticide and insecticide use; however, available data indicate they present a moderate risk to ecosystems and human health in the Ayeyarwady Basin.
- Low dissolved oxygen levels and high nutrients from aquaculture ponds impact adversely on aquatic organisms.
- Information gaps related to water pollution limit our understanding of human and ecosystem impacts within the Ayeyarwady Basin.
- Two priority monitoring activities are to protect human health through monitoring and controlling faecal coliforms, particularly where the risk increases at the headwaters through to the Ayeyarwady Delta (HEZ 5), and to create a secure and accessible database for current and future monitoring. This would include appropriate capacity building in data handling and statistical analysis.

4. WATER POLLUTION

4.1 Introduction

This chapter provides a summary of work undertaken to establish a credible baseline analysis of water pollution characteristics within the Ayeyarwady Basin. It outlines the current water pollution risks posed by development activities within four key sectors – industrial, urban, mining, and agriculture – with reference to the five HEZs of the Ayeyarwady Basin. The chapter assesses the consequences of potential pollution and identifies significant information gaps.

SOBA Technical Reports

This chapter is a synopsis of the full assessment, which may be accessed by readers seeking more detailed information, including references:

SOBA 1.3: CSIRO Australia & Hydronumerics (2017), *Water pollution survey* (SOBA 1.3), as part of the Ayeyarwady State of the Basin Assessment, sponsored by the Australian Water Partnership.

4.2 Ayeyarwady Setting

The Ayeyarwady Basin is Myanmar's most important commercial waterway and forms the cultural, economic, and environmental backbone for the country. The Ayeyarwady Basin is home to approximately 66% of Myanmar's population, including six of Myanmar's largest cities, large swathes of agricultural land, industrial zones, mining concessions, and a number of KBAs. The health and sustainability of the Ayeyarwady Basin are important to the country's future development and is expected to be subject to further pressure from development based on continued resource use.

Water pollution is a growing concern in the Ayeyarwady Basin, where agriculture, mining, industrial, and urban development all have an impact. This is evident at the local level where landscapes have been transformed, resulting in largely unquantified effects on water quality.

Despite the clear risks, systematic water pollution monitoring is often absent or ad hoc within the Ayeyarwady Basin, with a growing, but still limited, spatio-temporal coverage in major industrial zones. There is a poor understanding of the magnitude and extent of water pollution and its impact on downstream environments. The SOBA water pollution assessment is an initial attempt to define the current status of water quality within the Ayeyarwady Basin, with specific reference to the four key sectors. Significant data limitations mean that the

information presented here is not a comprehensive assessment of water pollution in the basin. The findings of the assessment should be reviewed and revised on an ongoing basis as more and better data become available.

4.3 Status and Trends

This section presents an overview of the influence of agriculture, mining, industrial, and urban development on water pollution in the Ayeyarwady Basin and its implications for human and ecosystem health.

4.3.1 Industrial sector

Myanmar's industrial sector has grown rapidly in recent decades. Most of the industrial activity is located close to the major urban and transport centres in the Ayeyarwady Basin, especially the large cities of the Middle Ayeyarwady (HEZ 3), the Lower Ayeyarwady (HEZ 4), and the Ayeyarwady Delta (HEZ 5).

Pollution loading from the industrial sector is determined by the type and scale of industrial activity. Myanmar's industrial sector is diverse and includes activities, such as food and beverages; clothing and apparel; construction materials; personal, electrical, and household goods; printing and publishing; industrial raw materials; minerals and petroleum products; agricultural and industrial machinery/equipment; transport vehicles; and electrical goods.

Food and beverages are the major industrial sub-sector in Myanmar, accounting for approximately 62% of the national industrial operation. Major food and beverage developments are located in Yangon and Mandalay, garment manufacturing in Patheingyi and Yangon, and mineral and petroleum product manufacturing in Monywa and Mandalay.

Small-scale enterprises make up 80% of the industrial sector within the Ayeyarwady Basin (Figure 4.1). While small-scale industry dominates smaller population centres, it is also prominent in urban centres, making up 42% of the total industry in Yangon and 50% in Mandalay. Small-scale industries can cause significant water pollution risk due to inadequate treatment processes and lack of knowledge to mitigate pollution risks.

Industrial pollution load

A preliminary estimate of industrial pollution load was conducted in 10 industrial zones in the Ayeyarwady Basin using the World Bank's Industrial Pollution Projection System (IPPS). The assessment focused on three key industrial pollutants (see Box, pg 75).

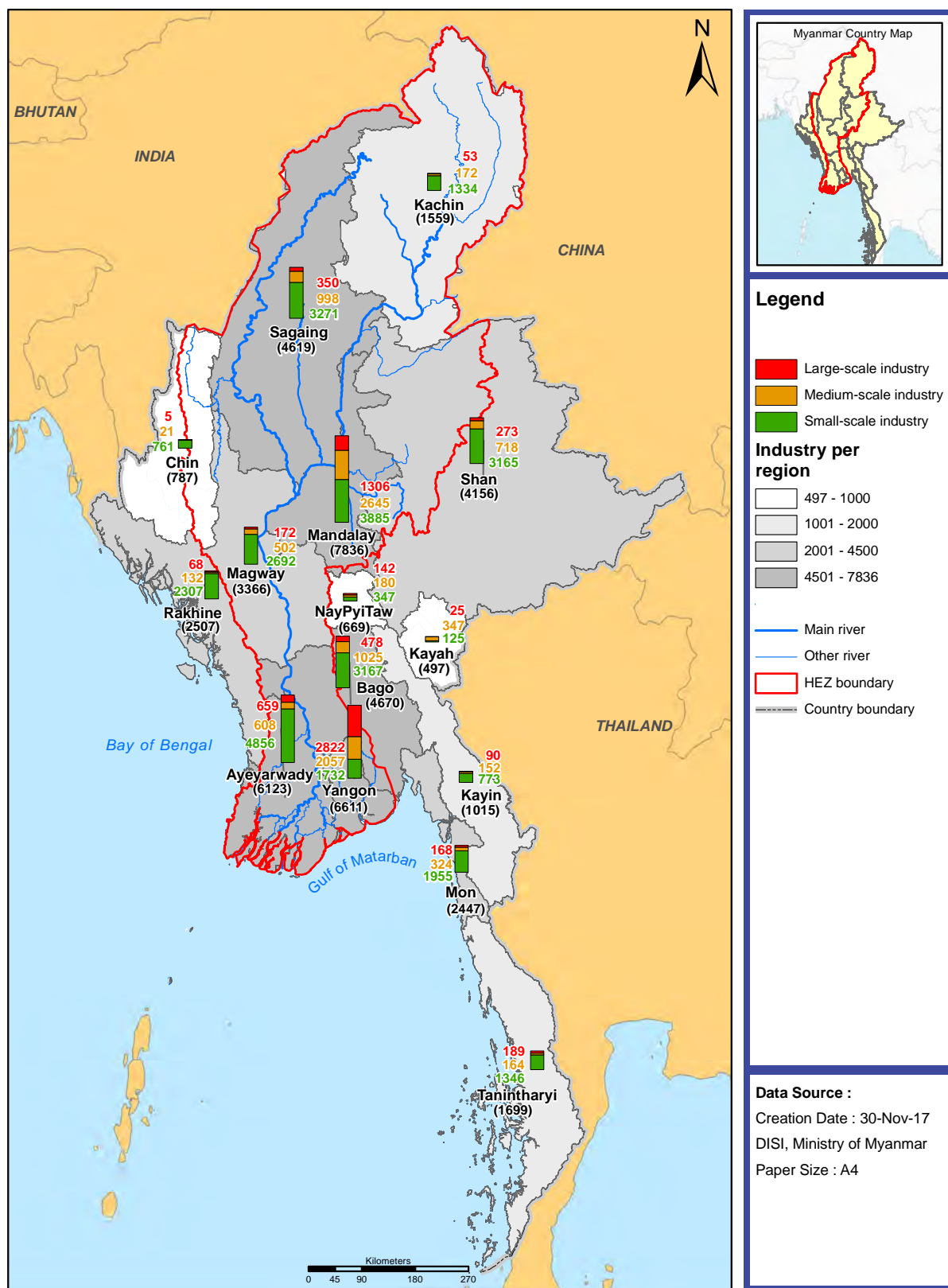


Figure 4.1 - Scale of industrial sectors in Myanmar

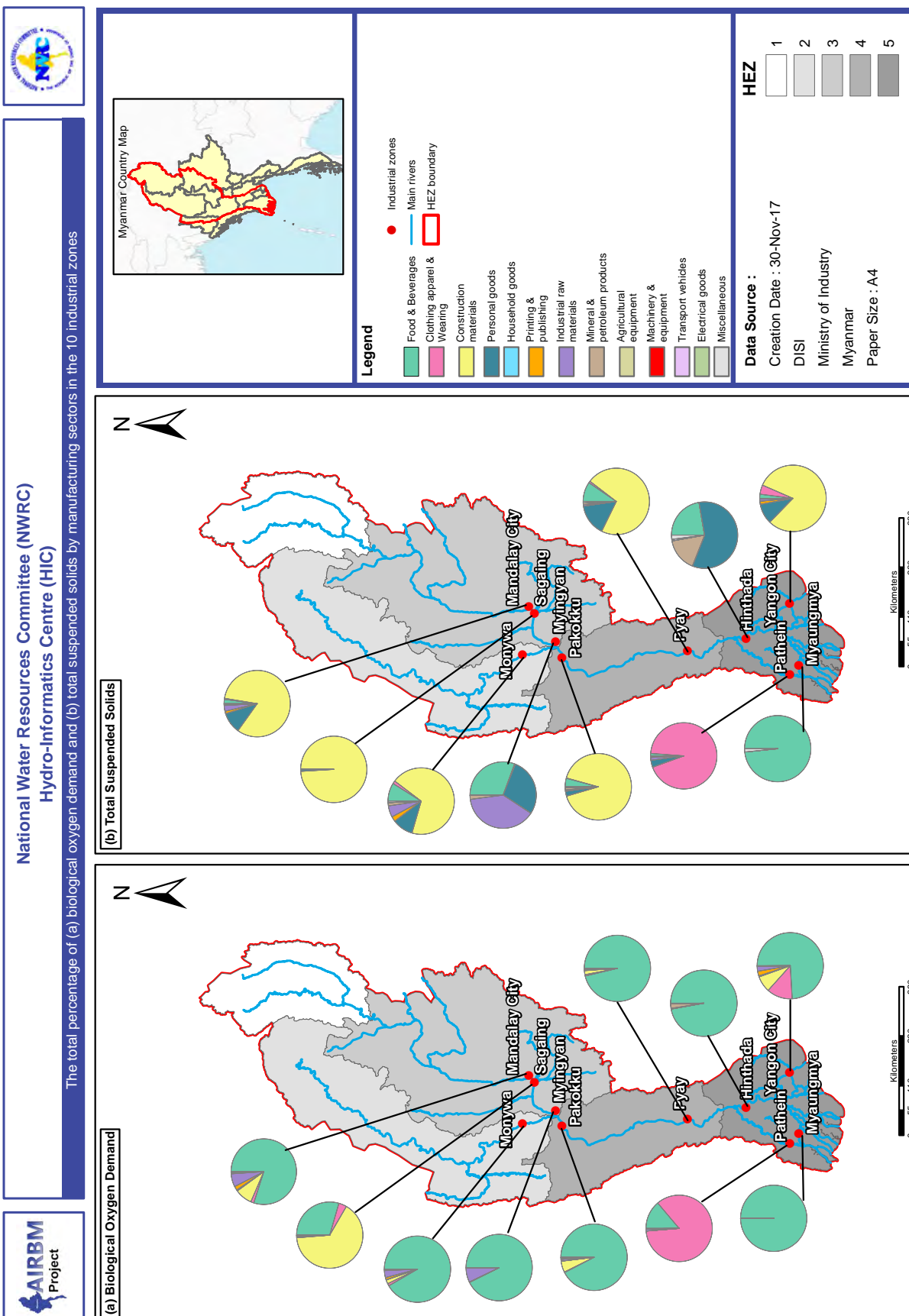


Figure 4.2 - The total percentage of (a) biological oxygen demand and (b) total suspended solids by manufacturing sectors in the 10 industrial zones, based on the Industrial Pollution Projection System

Key industrial pollutants

Biological oxygen demand (BOD) – Industrial wastewater contains large amounts of organic matter in various forms. When the waters are polluted, the decomposition of organic matter in the water consumes dissolved oxygen, thereby upsetting the balance of oxygen in water, deteriorating water quality, and causing death to fish and other aquatic organisms from hypoxia. BOD is used to indirectly test the content of organic matter in water.

Total suspended solids (TSS) – TSS is a measure of the mass of fine inorganic particles suspended in the water. High concentrations of TSS can block light from reaching submerged vegetation, slowing down photosynthesis. Suspended solids can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development.

Toxic chemicals and metal pollutants – Industrial chemical waste consists of organic waste (e.g., pesticide residues, solvents and cleaning fluids, dissolved residue from fruit and vegetables, and lignin from pulp and paper), effluents (e.g., inorganic wastes, such as brine salts and metals), chemicals (influencing taste, odour, and colour) and metals (sometimes barely detectable). Many of the organic chemicals, such as polychlorinated biphenyls (PCBs), and polychlorinated phenols (PCPs), carbon tetrachloride, formaldehyde, plasticisers, and metals that enter the water are, even in minute amounts, toxic to human, plant, and animal life.

Ten industrial zones were assessed using the IPPS, which provide a snapshot of the industrial sector within the Ayeyarwady Basin (Table 4.1). All zones are close to urban centres, connected by the main inland waterway and road transport routes, and near the rivers, streams, and waterways of the Ayeyarwady Basin.

Table 4.1 - Industrial zones assessed with the Industrial Pollution Projection System

HEZ	Industrial zone
Chindwin (2)	Monywa
Middle Ayeyarwady (3)	Mandalay, Sagaing, Myingyan
Lower Ayeyarwady (4)	Pakokku, Pyay
Ayeyarwady Delta (5)	Hinthada, Yangon, Patheingyi, Myaungmya

Biological oxygen demand and total suspended pollutants

The three major industrial zones of concern in relation to BOD and TSS are Yangon, Mandalay, and Sagaing (Figure 4.2). High BOD loads are driven by the food and beverage industry (Mandalay and Yangon) and the construction materials industry (Sagaing). Food and beverage dominate BOD loading in all industrial zones, except for clothing and apparel in Patheingyi. High TSS loads are dominated by the construction industry, with significant contributions from clothing and apparel (Patheingyi), personal goods (Hinthada, Myingyan, and Pyay), and food and beverage (Myaungmya and Hinthada) (Figure 4.2).

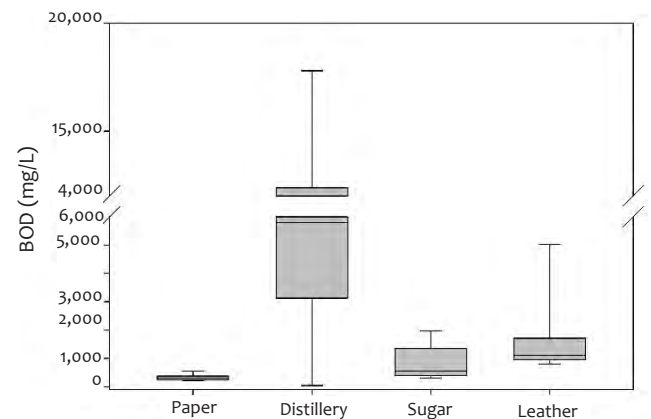


Figure 4.3 - Biological oxygen demand concentration of industrial effluents from the factories located in the Mandalay industrial zone

Findings from using the IPPS were confirmed by additional water quality monitoring data for Mandalay. Snapshot monitoring of three sites identified high BOD levels in the wastewaters of the city's distilleries (up to 15,000 milligrams per litre [mg/L]) and in sugar and leather factories (ranging from 200 to 2000 mg/L and 700 to 5000 mg/L, respectively). Other sub-sectors, like pulp factories, exhibited BOD levels from 220 to 560 mg/L (Figure 4.3). These recordings are all beyond what is deemed acceptable by guidelines for drinking water, protection of aquatic life, and irrigation (Table 4.2).



Table 4.2. Indicative water quality guidelines for drinking, protection of aquatic life, and irrigation

A Short-term trigger value; b: For taste only; c: For groundwater system; d: For surface water system; e: Moderately tolerant crops; f: Tolerant crops; g: Raw human food crops in direct contact with irrigation water (e.g. via sprays or irrigation of salad vegetables); h: Raw human food crops not in direct contact with irrigation water; i: Values at the high end of the range would be found in rivers draining from slightly disturbed catchments during high flows of the monsoon season

Pollutant	Drinking water guideline (World Health Organization, 2011)	Freshwater guideline (ANZECC and ARMCANZ, 2000a)	Irrigation water guideline ^a (ANZECC and ARMCANZ, 2000b)
Arsenic (micrograms per litre [µg/L])	10	24	2,000
Cadmium (µg/L)	3	0.2	50
Copper (µg/L)	2,000	1.8	5,000
Cobalt (µg/L)			100
Chromium (µg/L)	50	1	1,000
Cyanide (µg/L)	500	7	
Lead (µg/L)	10	3	5,000
Mercury (µg/L)	6	0.6	2
Nickel (µg/L)	70	11	2,000
Fluoride (µg/L)	1,500		2,000
Uranium (µg/L)	6		100
Zinc (µg/L)	4,000 ^b	8	5,000
Physico-chemical, nutrients, and microbial pollution indicators			
pH	6.5 to 8.5	6.5 to 8.5	6 to 8.5 ^c 6 to 9 ^d
Electrical conductivity (microsiemens per centimetre [µS/cm])	- ^b	500 to 1,500	1,300 to 2,900 ^e 2,900 to 5,200 ^f
Dissolved oxygen (mg/L)		>5	
Biological oxygen demand (mg/L)	0-6	<15	Good for soil
Faecal coliform (colony forming unit per 100 millilitre [CFU/100mL])	0		<10g
Turbidity (nephelometric turbidity unit [NTU])	5	6-50i	
Nitrate (mg/L)	50		
Nitrite (mg/L)	3	0.197	
Ammonia (mg/L)		0.9	

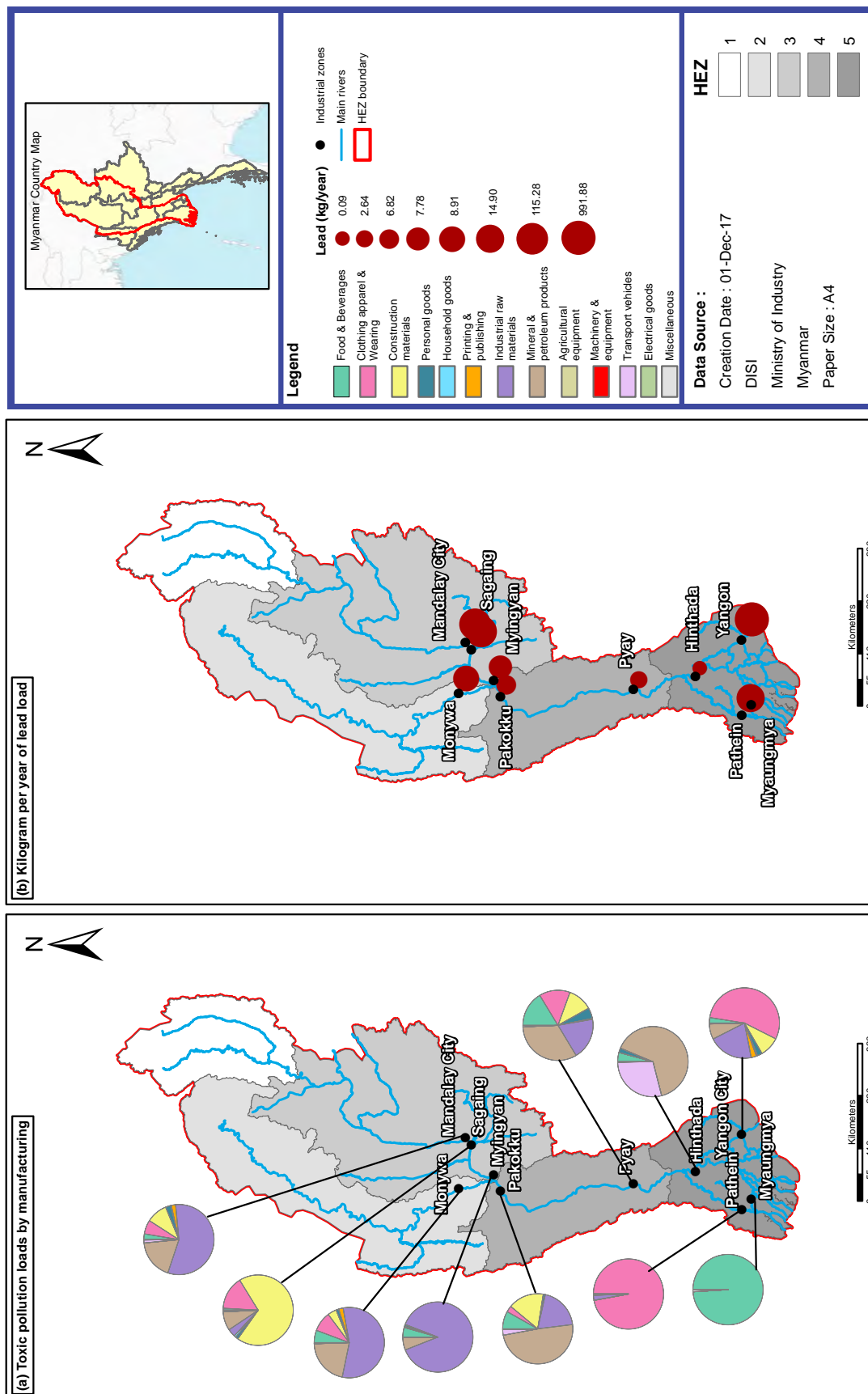


Figure 4.4 - The total percentage of (a) toxic pollution loads by manufacturing and (b) kilogram per year of lead load in the 10 industrial zones within the Ayeeyarwady Basin, based on the Industrial Pollution Projection System

Toxic chemicals and metal pollutants

The contribution of toxic chemical loads to the Ayeyarwady Basin is spread among a wide range of sub-sectors, including construction materials, food and beverages, clothing and apparel, industrial raw material, minerals, and petroleum products (Figure 4.4).

Industrial raw materials and construction materials are the leading polluters in industrial zones in the Chindwin (HEZ 2) and Middle Ayeyarwady (HEZ 3). Minerals and petroleum products, clothing and apparel, and food and beverages are the leading toxic chemical polluters in the industrial zones in the Lower Ayeyarwady (HEZ 4) and the Ayeyarwady Delta (HEZ 5).

High loads of highly toxic chemicals and metals are found in Mandalay, Yangon, and Pathien (Figure 4.4 A). According to IPPS, the lead load is the highest in the Middle Ayeyarwady (HEZ 3) and Ayeyarwady Delta (HEZ 5) (Figure 4.4). Copper and lead record the highest loads in Sagaing, chromium in Pathien, and zinc in Pakokku (Figure 4.5). Construction materials contribute to approximately 60% of the load of cadmium, copper, lead, and arsenic, while the contribution from the industrial raw materials industries are mostly associated with mercury load.

The three main toxic chemicals of concern in the Ayeyarwady Basin are ammonia, ethyl glycol, and formaldehyde (formaldehyde is seen in Figure 4.5). The food and beverage sector influences formaldehyde load the most, with the highest levels identified in Myaungmya (Figure 4.5). Construction material contributes the most to high levels of ammonia, with the highest load identified in Pakokku (Figure 4.5). Mineral and petroleum products are responsible for 76% and 15% of the ethyl glycol load in the Yangon and Mandalay industrial zones, respectively.

The industrial raw material sector contributes to high levels of carbon tetrachloride, while personal goods are responsible for high loads of dichloromethane. Plasticisers, such as dibutyl phthalate, are major components of industrial raw materials (43%) and mineral and petroleum products (57%). Household goods contribute to 50% of the diethyl phthalate load.

Among salts and acids, sodium hydroxide is associated with the industrial activities producing clothing apparel, and hydrochloric acid with construction material and personal goods. The construction material sector is responsible for high ammonia and phenol (70% to 90%).

Findings from the IPPS in relation to BOD, TSS, toxic chemicals, and metal pollutants were validated by water quality monitoring data for Mandalay. Snapshot monitoring of three sites in August 2017 assessed the influence of industrial wastewaters on the Dokhtawaddy River. It identified that dissolved oxygen concentrations,

faecal coliform, turbidity, and BOD all exceeded relevant water quality guidelines. At all sites, dissolved oxygen concentrations were below 4 mg/L and did not meet guidelines for fresh and marine water quality. Turbidity (ranging from 14 to 34 NTU) and BOD (30 to 45 mg/L) also failed to meet these guidelines. Levels of faecal coliform sampled varied between 1,000 and 2,000 CFU/100 mL and were well above the World Health Organization (WHO) guidelines for drinking water quality (0 CFU/100 mL). At all three sites, copper, zinc, lead, and arsenic did not exceed the water quality guidelines set out in Table 4.2

Ecosystem health implications

The 10 industrial zones assessed are concentrated in two ecologically important areas of the Ayeyarwady Basin: 1) the Central Dry Zone confluence of the Ayeyarwady and Chindwin Rivers, and 2) the delta inland and coastal zones. While species richness and diversity are lower compared to the upland areas of the Ayeyarwady Basin, these areas comprise important riverine and marine aquatic habitats that are highly productive. Areas of significance include the Sarus Crane Nesting Site (HEZ 5); sites at Mehon, Myaleik Taung, Pyu Lake, Shinmataung, Wetthikan Lake, and Man Chaung (HEZ 3); and the Bagan stretch of the Ayeyarwady KBA.

The impacts from BOD, TSS, and metals load in industrial effluent present the greatest risks for river stretches downstream of Yangon, Mandalay, and Sagaing (including the Pyu Lake, Shinmataung, and Ayeyarwady–Bagan stretch KBAs). While metals pollution loads at these sites are small compared to BOD and TSS, the relative toxicity of these substances makes them a high priority.

In Pathien, marine shrimp species and estuarine fish species are at risk from use of surfactants, solvents, high BOD, and toxic metals. Within delta towns, catfish are at risk from the sediment bound metals and other organic chemicals characterised by high turbidity.

The use of IPPS identified particular areas at risk from certain water pollutants. High formaldehyde loads were identified in Myaungmya, in association with high BOD and TSS loads. At high concentrations, these pollutants can reduce fish growth rates, decrease resistance to disease, and prevent egg and larval development of aquatic organisms. High loads of toxic metals, such as copper and lead, could threaten ecosystem health in Pyu Lake, a small lake in the Sagaing Region, south of Mandalay, that regularly hosts the remaining wintering numbers of Baer's pochard (*Aythya baeri*). Discharges of high BOD and high TSS loads from factories are expected to have acute adverse effects on fish in the dry season, including fish kills. Areas at greatest risk include those downstream of large industrial facilities or clusters around large urban areas, such as Yangon and Mandalay.

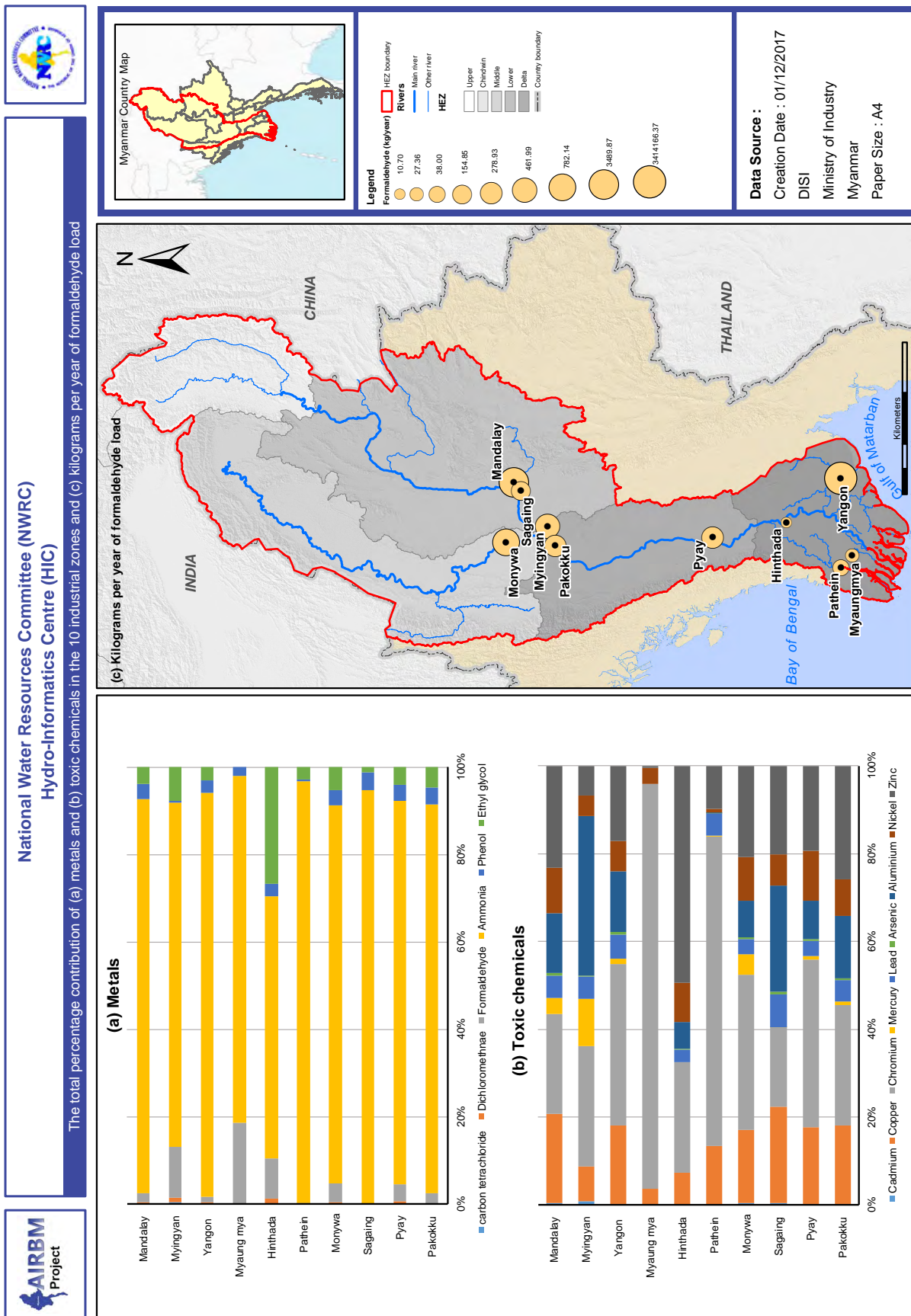


Figure 4.5 - The total percentage of (a) metals and (b) toxic chemicals in the 10 industrial zones, and (c) kilograms per year of formaldehyde load in the 10 industrial zones, based on the Industrial Pollution Projection System

Human health implications

High levels of dissolved pollutants and organic matter discharged from industrial activities can lead to severe health issues. Risks from organic matter, such as high BOD loads, are of greatest concern in high population density areas, such as Yangon and Mandalay.

Industrial water pollution can affect communities where fish is a significant part of the local diet. There is high risk of metals and other toxic chemicals from industrial effluents bioaccumulating in fish that, when consumed, may cause human health risks. Risks are particularly high in the Middle Ayeyarwady (HEZ 3), where fish is eaten on average 2 to 3 times per week, and in the Ayeyarwady Delta (HEZ 5), where it is eaten daily.

In the Ayeyarwady Basin, wastewater from factories presents clear health risks related to pathogens and toxic chemicals. At-risk populations include those who use river water near factories for drinking, washing, and agriculture. For example, the villages of Amarapura Township in the Mandalay industrial zone are presented with particular risks from a range of factories (including a distillery, an indigo colouring washing powder factory, and a leather tannery) that discharge waste into the river.

4.3.2 Urban sector

The urban population of the Ayeyarwady Basin is 10.8 million people. This accounts for 73% of Myanmar's total urban population. Urban populations are most highly concentrated in the Ayeyarwady Delta (HEZ 5), with Yangon the most populous city (approximately 5 million). Mandalay (HEZ 3) has the second highest urban population (approximately 2 million), followed by Magaway (HEZ 4) and Sagaing (HEZ 2).

Population density is highest in the southern parts of the Ayeyarwady Basin. The Upper Ayeyarwady (HEZ 1) has a township median population density of 2.2 persons/km², increasing to 100 persons/km² in the Lower Ayeyarwady (HEZ 4) and 334 persons/km² in the Ayeyarwady Delta (HEZ 5).

Common urban pollutants

Urban environments produce large numbers of pollutants that are harmful to receiving waters. The most common urban pollutants include: TSS (as a measure of turbidity); oxygen-demanding substances (e.g., BOD); nitrogen and phosphorus; pathogens (e.g., faecal coliform); petroleum hydrocarbons and inorganic contaminants (e.g., copper, lead, zinc); and synthetic organics.

Microbial contamination and public health

Urban-based public health impacts are mainly related to bacteria and disease-causing organisms carried by untreated sewage discharges, the overflow of untreated sewage from open latrines, and urban stormwater runoff. These pose risks for people using river water for drinking, bathing, and washing household utensils, if the pollutants are not below the relevant guideline levels.

Sewerage treatment and processing with urban centres in the Ayeyarwady Basin is not comprehensive. The only sewerage system in Yangon is limited to the old business district and serves 40% to 50% of the population. There is no systematic collection and treatment of domestic wastewater and, as a consequence, effluent and seepage from septic tanks and latrines in most parts of the city flows into open rainwater drainage and natural waterways. In urban areas of the Ayeyarwady Basin, existing stormwater drainage has not been organised into networks with sufficient placement and capacity to carry monsoon-season flows, often resulting in severe flooding and pollution.

In Mandalay, only 10% of the urban population receives piped, potable water. Currently, the majority of the 1,500 industrial operations under the jurisdiction of the Mandalay City Development Corporation do not treat industrial wastewater and discharge the water into adjacent waterways. This might be set to change in the future with large foreign-aid projects funding expansion of the sewerage network.

While there are limited data available on microbial contamination in the Ayeyarwady Basin, data from the Government of Myanmar provide an insight into the occurrence of water pollutants in urban environments. Based on water quality taken from 10 locations during the dry seasons of 2011 to 2015, there have been variable results when compared to the water guidelines (Table 4.2). For example, while 2014 monitoring identified that pH varied from 4.4 to 8.9 (beyond the acceptable range for drinking water, protection of aquatic life, and irrigation), 2015 monitoring results were 6.5 to 8.5, which were within the acceptable range. Turbidity levels were above the recommended guideline values at all sites, with Twantee Township (HEZ 5) recording turbidity ranging from 120 to 200 NTU, compared to the 5 NTU considered safe for human consumption (Figure 4.6).

Based on water quality data from Yangon City Development Corporation, in 2016, the quality of wastewater treatment plant effluent in Yangon exhibited temporal variation in BOD load, ranging from 10 to 60 mg/L (Figure 4.7A). However, the wastewater treatment plant was efficient in producing effluent quality with a pH from 6.5 to 8.5 before discharging into the Yangon River (Figure 4.7B).

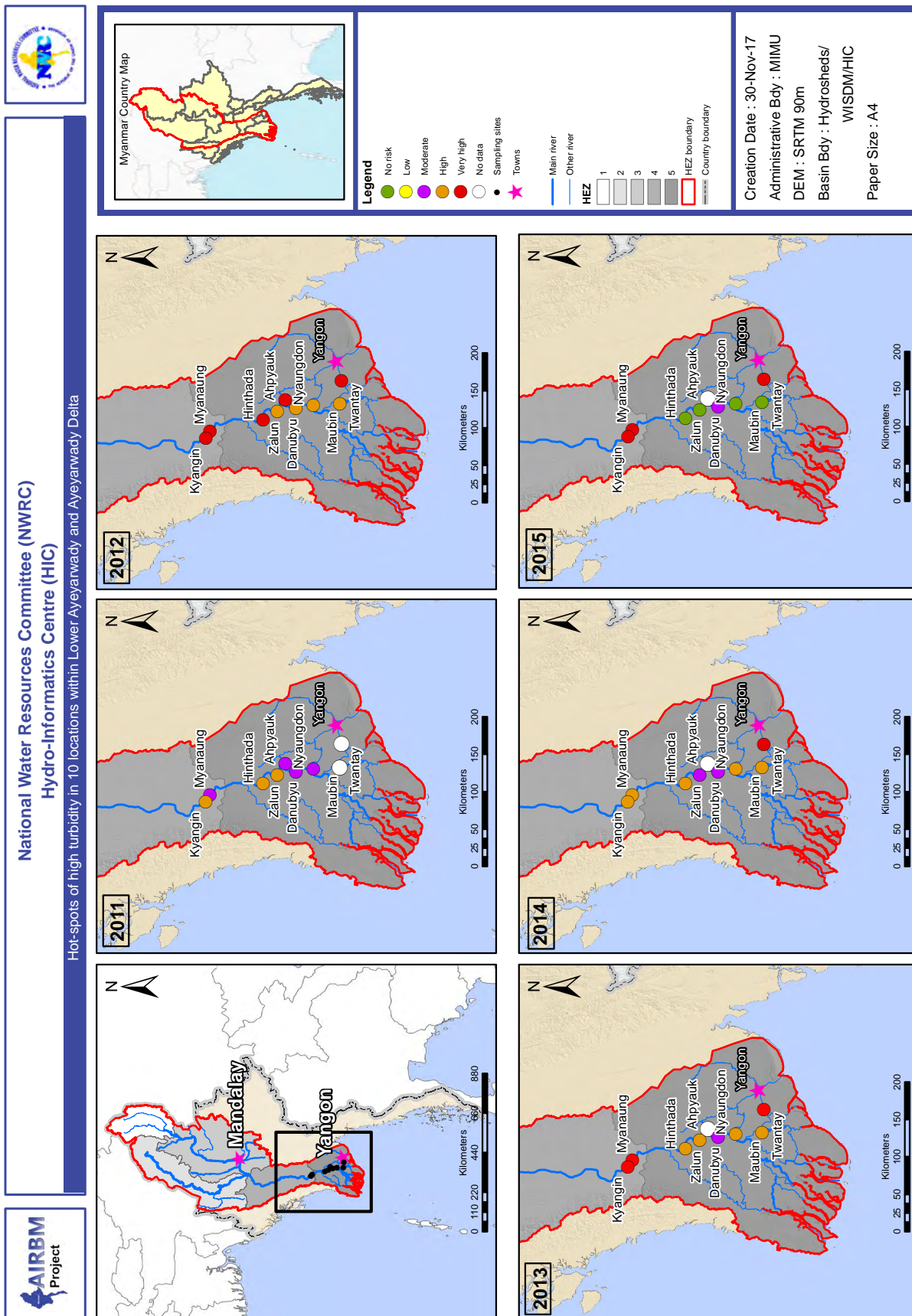


Figure 4.6 - Hot spots of turbidity in 10 locations within Lower Ayeyarwady and Ayeyarwady Delta from 2011 to 2015

A snapshot monitoring of three sites of the Yangon River in June 2017 (near the outfall of the wastewater treatment plant), in addition to two sites downstream and one upstream, provided insight into the influence of wastewater discharges on the river. It identified that dissolved oxygen concentrations, measured at all sites, were below 4 mg/L, suggesting a high risk to aquatic organisms. Turbidity levels from 250 to 300 NTU were recorded, which are 50 to 60 times higher than the level specified as safe for human consumption. The BOD loads were recorded at 29 mg/L at the outfall and 22 mg/L at the downstream site. Both readings were substantially higher than what is considered appropriate for human consumption or aquatic ecosystems.

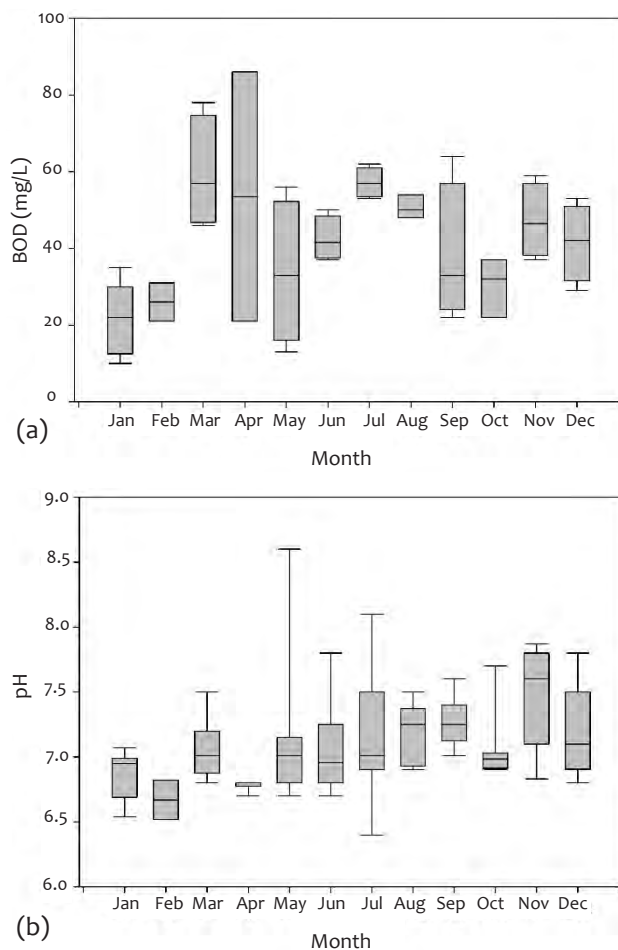


Figure 4.7 - Monthly variation of (a) biological oxygen demand and (b) pH in the treated wastewater effluent from the Yangon wastewater treatment plant in 2016

In Mandalay, snapshot monitoring was undertaken in August 2017 at an urban stormwater drain to understand the contribution of urban stormwater to water pollution. Sampling indicated metal levels much higher than those recommended for aquatic life and human health. For example, when compared to the guideline values for

aquatic life protection, samples indicated levels of zinc eight times higher than acceptable and lead twice the acceptable limit. Levels of manganese were reported five times higher than drinking water quality guidelines. In contrast, nickel, copper, lead, cadmium, and uranium were within the limits for freshwater and drinking water protection levels. The site also reported low nutrient and salinity but high BOD (60 mg/L), low dissolved oxygen (3.3 mg/L), high total coliform (> 1,000 CFU/100 mL), and high turbidity (75 NTU).

Ecosystem health implications

Urban environments present threats to ecosystem health in the Ayeyarwady Basin. Aquatic life surrounding Yangon and Mandalay is under a major threat due to the stormwater discharges and the discharges of untreated or partially-treated domestic waste with high BOD and low dissolved oxygen levels into the river system. Water quality issues in the Middle Ayeyarwady (HEZ 3) and the Ayeyarwady Delta (HEZ 5) could also be exacerbated by increased industrial activities and the discharge of their outputs (e.g., heavy metals, organic micro-pollutants, and oils).

With increasing urbanisation in the Ayeyarwady Delta (HEZ 5), anthropogenic sources of pollution present moderate levels of risk to the new KBAs, such as the Outer Delta Islands. Other areas of biodiversity interest, such as isolated river populations of the Irrawaddy dolphin, could also be at risk from water pollution as a result of urbanisation.

Urban water discharges present a challenge for fish species. For example, based on using IPPS and the snapshot monitoring, native fish populations in the Hinthada Township are at risk from urban stormwater discharges with high metals, BOD, and TSS loads.

Human health implications

With the highest population densities, people of the Middle Ayeyarwady (HEZ 3) and the Ayeyarwady Delta (HEZ 5) are the most vulnerable to human health issues arising from urban water pollution.

Reliance on untreated private water supplies that are unlikely to meet bacteriological guidelines for drinking presents significant health risks to urban populations. High faecal coliform (> 1,000 CFU/100 mL), in the Yangon River and in the urban stormwater drain of Mandalay, highlights potential issues in the densely populated urbanised areas if the water is not treated.

While improvements in access to safe water and adequate sanitation have been reported in Myanmar, there is still significant scope to improve performance in this area.

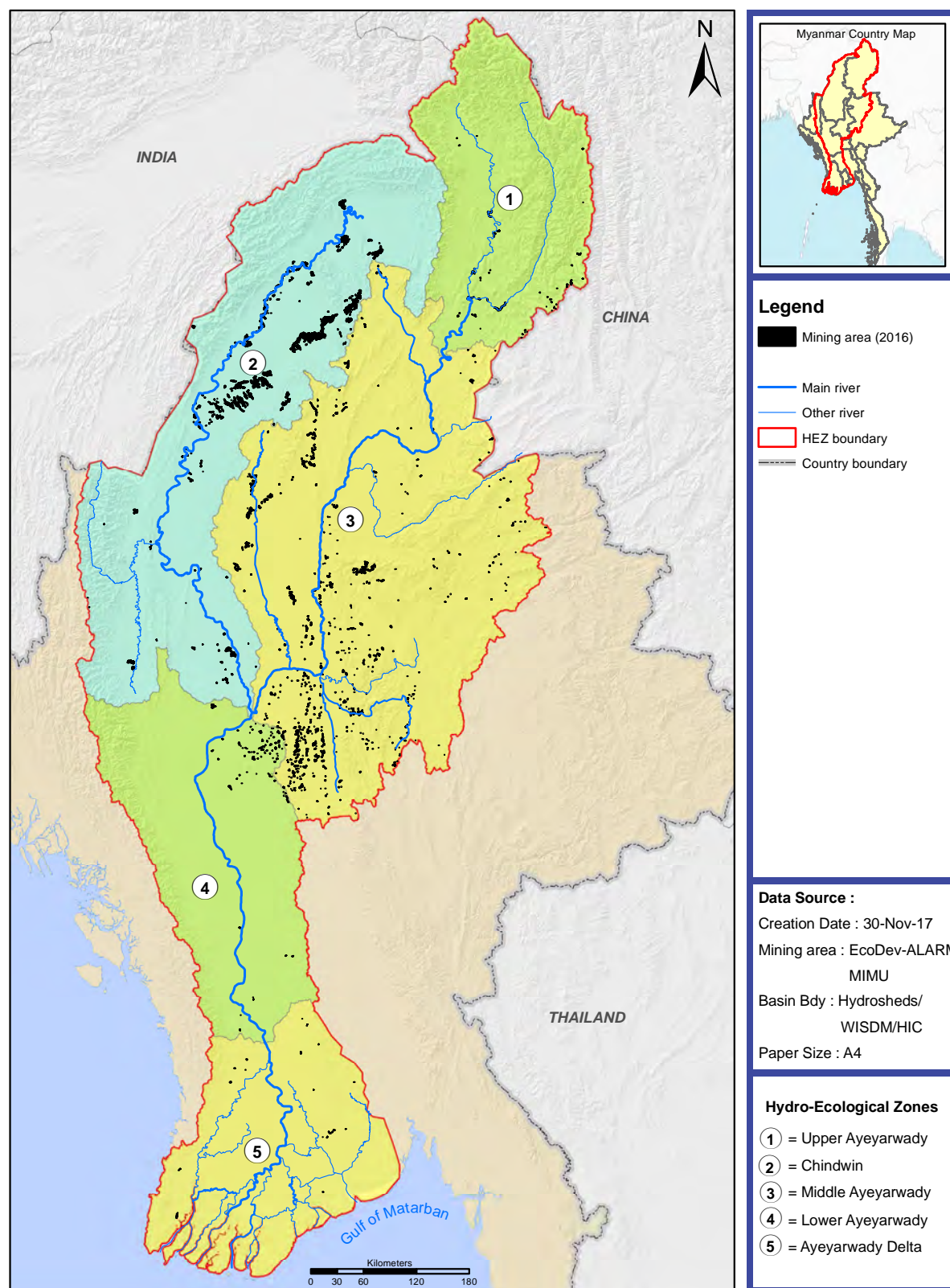


Figure 4.8 - Distribution of the mining sector in the Ayeyarwady Basin

4.3.3 Mining

In 2014 to 2015, mining accounted for 1.2% of GDP in Myanmar. Myanmar produces 90% of the world's jade and is among the top producers of rubies and sapphires. Gold and jade mining are widespread across the Ayeyarwady Basin and are particularly prominent in the Upper Ayeyarwady (HEZ 1) and Chindwin (HEZ 2) (Figure 4.8). Myanmar also has rich deposits of copper, nickel, lead, zinc, silver, tin tungsten, and gold.

The country hosts mineral deposits of global significance at Bawdwin (lead, zinc, and silver) and Monywa (copper) in the Ayeyarwady Basin, and also at Mawchi (tin tungsten). While Htigyaing has the only nickel mine in current operation, pebble and sand mining are increasing in the large rivers, like the Ayeyarwady and Chindwin.

The areas being disturbed by mining have increased at a high rate over the past decade and this is likely to continue in the future. Remote sensing data supports this, suggesting that mining disturbances directly affect an area of 740 km² in the Ayeyarwady Basin, much of which is in the Chindwin (HEZ 2). These large increases in mining activities in the upper Chindwin have led to forest loss and exacerbated other pressures on biodiversity in the region.

Artisanal and small-scale mining are pervasive in the basin and, as it is unregulated, the environmental impacts are extremely difficult to quantify. This is made especially difficult as these mines often operate in the 'shadow' of regulated mining operations.

Mining pollution

Despite well-developed mining operations and supply chains across the Ayeyarwady Basin, there is relatively little information on the scale of mining operations, their nature and extent, their production methods, and their waste management strategies. There is an urgent need to properly catalogue and characterise mining operations in the Ayeyarwady Basin to identify potential environmental hotspots. This is important in the context of pollutant transport, as small-scale alluvial mining is common, and the extraction methods and environmental footprint are virtually unknown.

Mining activities tend to be responsible for high turbidity and sediment loads in the river. Tailings and wastewaters are major outputs from gold extraction, including containing high contaminant loads (such as copper, zinc, nickel, cobalt, chromium, mercury, cyanide, and sulfate ions). However, data limitations constrain the assessment of mining-related water pollution in the Ayeyarwady Basin.

At two sites in the Uyu River, snapshot water monitoring was conducted in August 2017. This identified that high turbidity and microbial contamination are the major risks in the Upper Ayeyarwady (HEZ 1). Nutrient levels were low and do not pose a threat in these environments. Metals, such as copper, zinc, manganese, and nickel, exceeded the water quality guidelines for the protection of aquatic life. Levels of mercury and uranium were below the drinking water guidelines.

Ecosystem health implications

In the absence of increased land management and regulations regarding the storage of mining waste, mining activities are likely to increase sediment loads to the river in localised areas and increase pressure on biota. Copper, zinc, manganese, and nickel; high BOD; and turbidity in the river water due to mining activities pose moderate-to-high risks to ecosystem health.

Gold and sand mining have serious ecosystem implications for ground-nesting birds, freshwater turtles, and the fish community. High turbidity due to mining frees sediments into the river, removes spawning areas, and reduces food availability of the benthic fauna. Decline in the population of waterbirds is also related to sand and mineral mining in the Upper Ayeyarwady (HEZ 1) and Chindwin (HEZ 2). Fauna in the KBAs in the Upper Ayeyarwady could also be at high risk due to mining activities.

Pebble suction motorboats in the river between Pyay and Bagan are highly destructive to the river ecosystem and can lead to adverse effects on Irrawaddy dolphin populations. Aquatic habitat destruction due to deforestation, erosion, and gold and sandstone mining poses threats to fish populations in the floodplains and wetlands.

Anthropogenic pollution of shallow groundwater from mining is an increasing risk, although little information is available on the extent and severity.

Human health implications

There are a number of human health risks that emerge as a result of mining activities. Gold mining involves the use of mercury or cyanide. This presents the risk that people consume fish with potential mercury bioaccumulation, due to pollution from current and past alluvial gold mining operations in the Upper Ayeyarwady (HEZ 1) and Chindwin (HEZ 2).

Localised moderate risk to human health is expected from metals, such as nickel, lead, tin, and mercury. There is a clear need for further research to determine loads and the potential impacts of these on human health within the Upper Ayeyarwady (HEZ 1) and Chindwin (HEZ 2). Microbial contamination in the Uyu River also highlights localised risk to people.

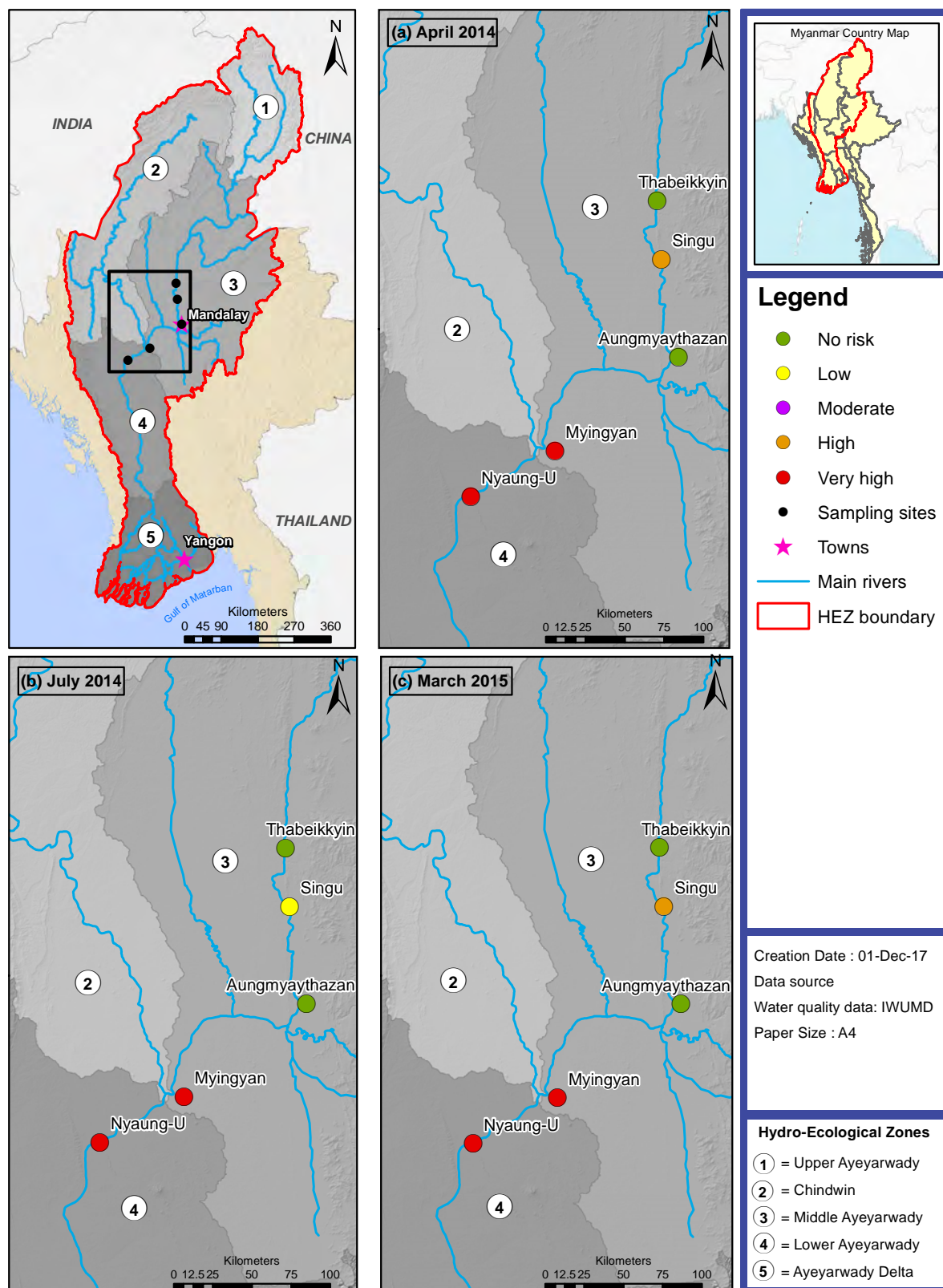


Figure 4.9 - Hot spots for lead pollution risk in the selected towns in the Middle Ayeyarwady and Lower Ayeyarwady, based on Irrigation and Water Utilization Management Department data in (a) April 2014, (b) July 2014 and (c) March 2015

4.3.4 Agriculture

In 2015 to 2016, agriculture (including crops, livestock, and fisheries) contributed 28.6% to the GDP. At a country level, nearly 75% of all households are engaged in subsistence farming activities in some capacity. In 2010, there was almost 7.5 million ha of agricultural land in the Ayeyarwady Basin, a 13% increase since 2003, mostly located in the Lower Ayeyarwady (HEZ 4), Middle Ayeyarwady (HEZ 3), and Ayeyarwady Delta (HEZ 5).

In general, agronomic inputs to agriculture are low compared to regional standards. Reliable data for fertiliser use are unavailable. The most generous approximation of use in Myanmar is 306,000 tonnes per annum, or approximately 15 kilograms per hectare. Highlighting the problems associated with verifying this information, official records suggest that between 2010 and 2014, pesticide imports increased from 6,186 to 10,205 metric tonnes (approximately 30 times less than estimates of use), but were only reported at 4,472 in 2015.

In the Ayeyarwady Basin, aquaculture is carried out in fish ponds (fresh water) and shrimp ponds (brackish/salt water). Fish ponds are found in all states/regions but mainly in the Ayeyarwady Delta and Yangon, whereas shrimp ponds are only located in the Ayeyarwady Delta.

Agriculture pollution

While there are limited data available on agriculture-related water pollution, water quality data made available by the Irrigation and Water Utilization Management Department provide some insights into agricultural water pollutants. Based on data from five towns in the Ayeyarwady Basin, collected in April 2014, July 2014, and March 2015, a number of water pollutants registered higher levels than recommended guidelines. For example, lead was above the guideline levels at Sinktu, Myichan, and Nyaung-U (Figure 4.9). The highest concentrations were reported at Nyaung-U where lead levels were six times higher than guidelines for human consumption.

Data for the years 2016 to 2017, for 17 dams across 30 water quality parameters, validated the risk presented by agricultural pollutants. The results highlighted that trace metals, such as copper, lead, and zinc, in these dams were below the drinking water and aquatic ecosystem guidelines. All dams reported microbial contamination, with total coliform values of > 16 CFU/100 mL. Based on this dataset, water from all dams is unfit for drinking and for irrigation on leafy vegetables.

High salinity of irrigation water with excess amounts of sodium can adversely impact soil structure and affect crop yield. Sodium adsorption ratio (SAR) is an indicator of the suitability of water for use in agricultural irrigation, a ratio below 3 being suitable. High salinity in the dams corresponded with high SARs, with values of 7.6 measured

at Taungthar Dam and 17 at Natthardaw Dam – highlighting that the water quality was unsuitable for irrigation (Figure 4.10).

Water quality data from aquaculture ponds in the delta region from 2014 to 2016 provide further insight into the extent of water pollutants. The samples showed that while dissolved oxygen concentrations were in the healthy range for samples from 2014 and 2015, the risk of anoxia was greater in 2016, with more than 50% of values below the minimum human health guideline. In 2014 and 2016, 50% of nitrate samples were at levels more than three and five times the upper guideline value, respectively.

Ecosystem health implications

Lead pollution was localised in selected towns and, at some locations, represented a high risk to aquatic life in the Lower Ayeyarwady (HEZ 4) and Middle Ayeyarwady (HEZ 3). Risk is increased where lead is associated with particulate matter and can cause toxicity to benthic inhabitants and leave a lasting legacy of pollution.

Use of insecticides can impact the early life stages of fish, and current application could be reducing fish reproduction rates. This is of concern given the high level of risk that many insecticides have on aquatic organisms (Table 4.3); however, further investigation on fish health should be conducted to confirm the severity of this issue. Copper, zinc, and arsenic do not pose any risk to aquatic organisms inhabiting rivers and tributaries in the rural setting.

The quality of irrigation water available to farmers has a considerable impact on which plants can be successfully grown, the productivity of these plants, and water infiltration and other soil physical conditions. High SAR of irrigation water also affects crop health by increasing potential for diseases, weeds, soil erosion, lack of oxygen, and inadequate nutrient availability. Long-term, high SAR in dams has implications for agricultural productivity and affects the livelihood of farmers relying on this water for irrigation in the Middle Ayeyarwady (HEZ 3) and the Lower Ayeyarwady (HEZ 4).

Wastewater discharge from small-scale aquaculture systems presents variable risk throughout the Ayeyarwady Basin (Figure 4.11). The highest risk is concentrated in the Ayeyarwady Delta (HEZ 5), particularly through waste that is discharged without treatment and with high concentrations of nitrogen and phosphorus nutrients. This may produce chronic elevations of total organic matter contents, especially in poorly managed or located sites. Low dissolved oxygen levels and high nutrients in effluents from aquaculture ponds can lead to localised risk for aquatic fauna and can cause 'brown-blood' disease in fin fish.

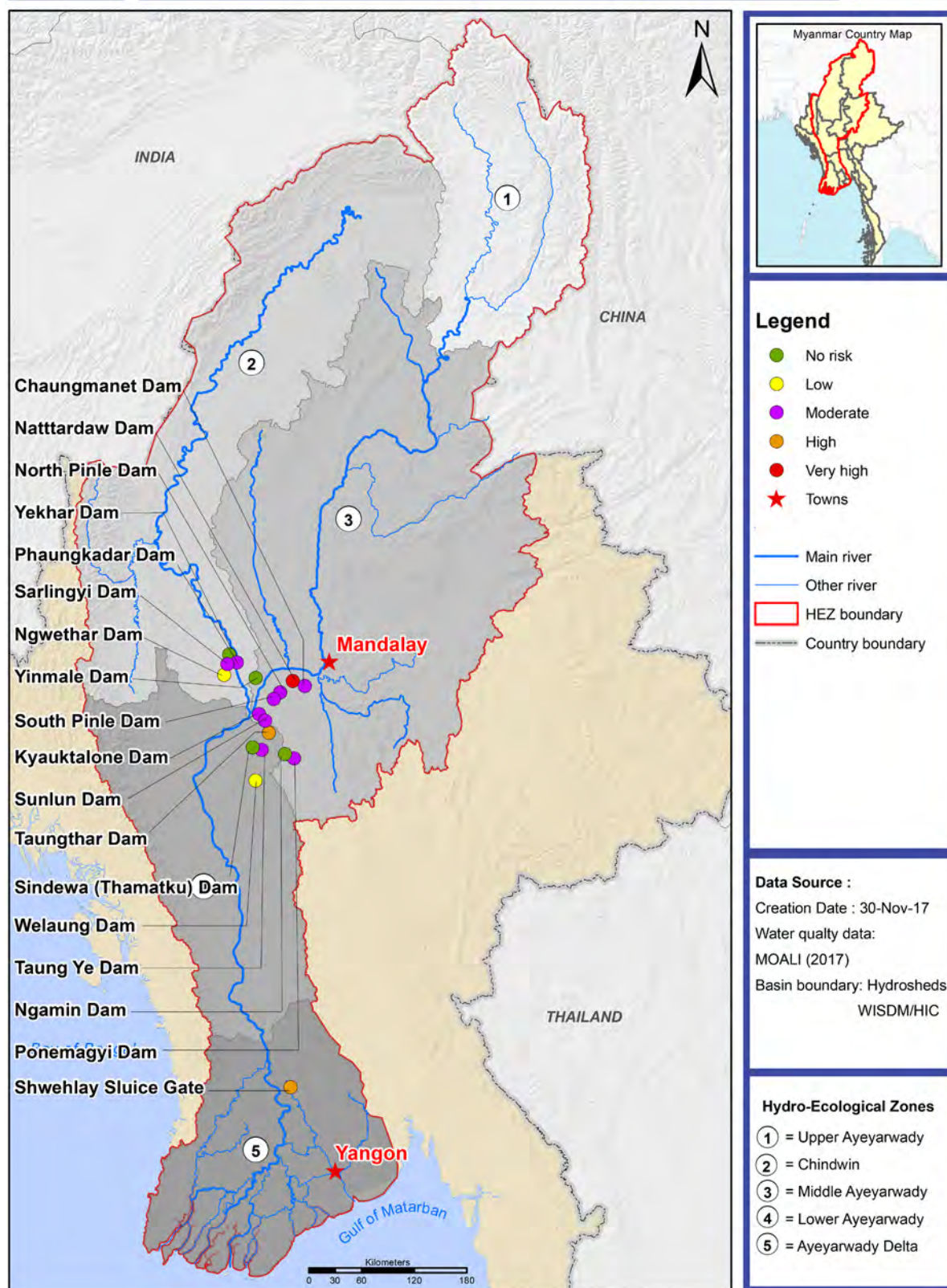


Figure 4.10 - Sodium adsorption ratio related irrigation water risk for selected dams in the Middle Ayeyarwady and Lower Ayeyarwady

Table 4.3 - Risk categorisation based on insecticide use in Myanmar based on their toxicity

	Human health	Aquatic organisms	Aquatic organisms	Aquatic organisms	Terrestrial organisms	Terrestrial organisms	Terrestrial organisms
Insecticides	Mammals	Fish	Crustaceans	Algae	Birds	Honey bees	Earthworms
Chlorpyrifos	Very High	Very High	High	Moderate	High	High	Moderate
Acephate	Moderate	Moderate	Moderate	Low	Low	Moderate	Low
Cypermethrin	Moderate	High	High	Moderate	Low	High	Moderate
Carbofuran	High	Moderate	High	Moderate	High	High	Moderate
L a m b d a - Cyhalothrin	High	High	Moderate	Moderate	Low	High	Moderate
Dimethoate	Moderate	Moderate	Moderate	Low	High	High	Moderate
Chlorpyrifos + Cypermethrin	Very High	Very High	High	High	High	High	High
Imidacloprid	Moderate	Moderate	Moderate	Low	High	High	Moderate

Human health implications

While data was limited, agriculture paralleled other sectors in showing levels of pollutants higher than those indicated in guidelines for safe human consumption and use. At localised sites, this included lead, which has serious human health implications, as well as copper, zinc, and levels of nitrate.

Greater levels of insecticide use in the future would increase risks to human health, depending on the type used. Of the top eight registered insecticides for use in Myanmar, four pose high or very high levels of risk to humans (Table 4.3).

While there is little information available on the domestic use of pesticides in the Ayeyarwady Basin and their impacts, they could present a moderate risk to ecosystems and human health. Further research is required to determine loads and potential impacts on rural communities.

There is a risk to future food security, especially in the Ayeyarwady Delta (HEZ 5), due to reduced wild fish stocks as a result of degraded water quality, new pathogens, and changed abundance of food available to fishery species.

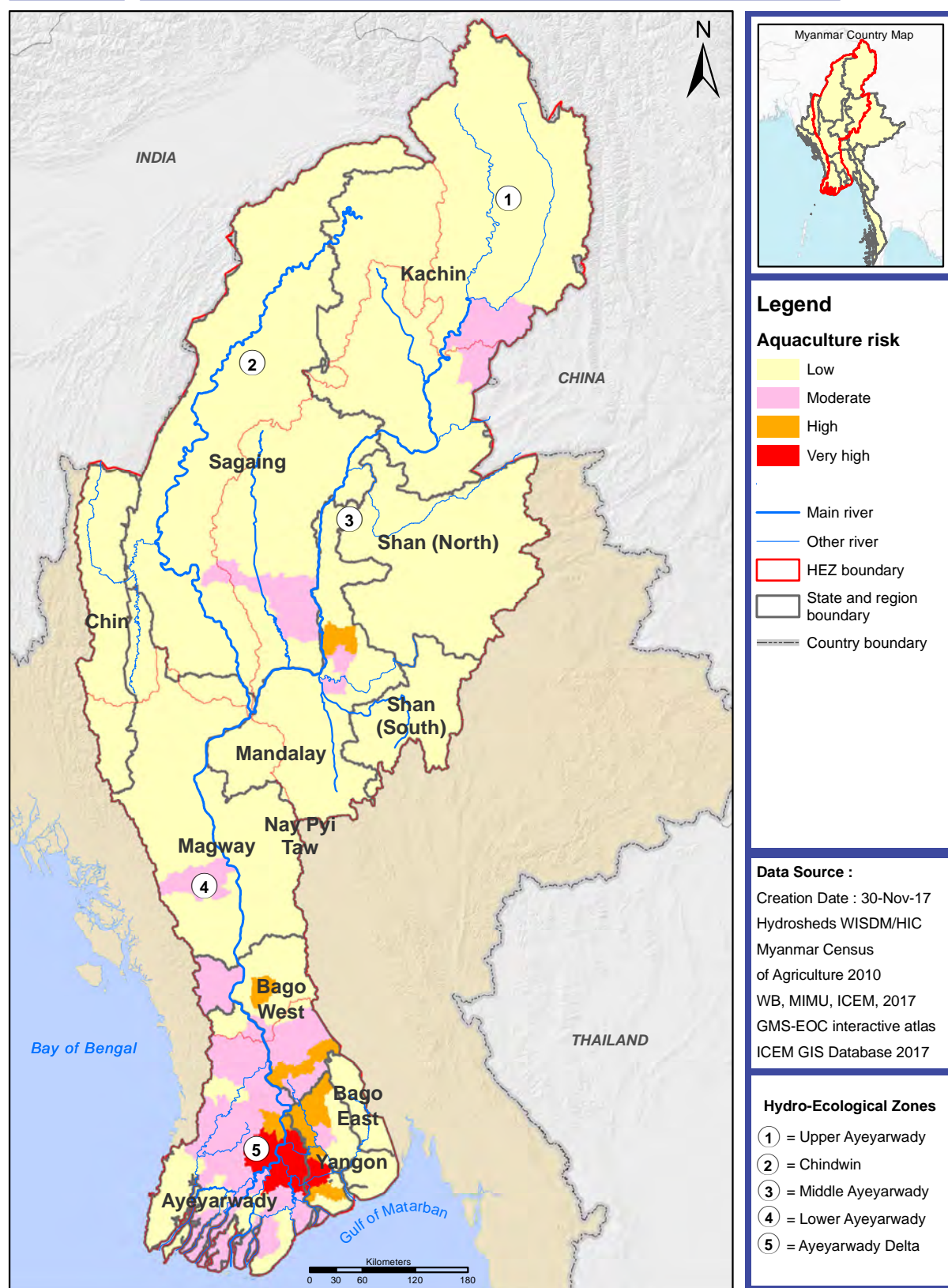


Figure 4.11 – Level of risk from wastewater discharges from the aquaculture ponds in the Ayeyarwady Basin

4.4 Information Gaps

Limited water quality data provides a challenge to a comprehensive assessment of water pollution.

4.4.1 Sectorial information gaps

Industry – A better understanding of the geographical position of industrial enterprises would provide an opportunity to identify areas of greatest risk. On a local level, possible sources of contamination should be investigated in industrial zones to assist managing the contamination and the direct or indirect impact on receiving waters. Better modelling of industrial pollution projections could be achieved through accessing more and better data. This will likely require engagement with industry managers to collect and integrate actual data into the estimates and modelling.

Mining – Understanding mining sector impacts on water quality is limited, and there are many information gaps. Where high levels of heavy metal contamination have been identified, possible local sources of contamination should be investigated. At a broader level, environmental monitoring programs and water management strategies are urgently required by mining companies in Myanmar to assess and minimise the impacts of water contamination. Water quality monitoring should also occur during different seasons to better understand the differences in heavy metals distribution in the river due to mining activities under different rainfall/flow conditions.

Urban – A full assessment of urban water pollution at a basin level requires monitoring of microbial pollution, organic and inorganic pollutants, and the presence of faecal coliforms. Raising the awareness of citizens most at risk as well as increasing the treatment, maintenance, and infrastructure should be considered to protect health and the environment.

Agriculture – Existing data are insufficient for determining the relative polluting impact of agriculture compared with other anthropogenic impacts. There are specific information gaps around pesticide, insecticide, and fertiliser use at the basin scale, especially in the Upper Ayeyarwady (HEZ 1), the Middle Ayeyarwady (HEZ 3), and the Ayeyarwady Delta (HEZ 5).

4.4.2 Priorities for monitoring programs

Future monitoring should be targeted geographically and follow strict protocols. Potential activities could include the following:

- Describing production methods, output type, timing, capital invested, and labour use at each factory for more accurate estimates of industrial water pollution.
- Quantifying the impacts of mineral processing by identifying the exact locations of mines and production estimates.
- Establishing a basin-scale database system that records monitoring point GIS coordinates and local information, timing of sampling, and results of analyses.
- Integrating into the database system information obtained from government agencies and private enterprises with a measure of the data quality.





4.5 Conclusions

This chapter has provided an initial assessment of water pollution characteristics within the Ayeyarwady Basin. Notwithstanding the lack of reliable information on key parameters related to water pollution, this chapter establishes that future developments in the four key sectors, without mitigating measures, are likely to produce unacceptable risks to ecosystem and human health.

In the industrial sector, BOD, TSS, and lead were all identified as issues of concern. High loads of BOD and TSS were identified at the three major industrial zones of Yangon, Mandalay, and Sagaing, with distilleries, pulp, leather, and sugar identified as contributing industries. Lead load, which presents severe health risks to ecosystem and human health, was highest in the Middle Ayeyarwady (HEZ 3) and the Ayeyarwady Delta (HEZ 5). The three main toxic chemicals of concern in the Ayeyarwady Basin are ammonia, ethyl glycol, and formaldehyde.

In the industrial zones of the Chindwin (HEZ 2) and Middle Ayeyarwady (HEZ 3), the leading polluting sectors were industrial raw materials and construction materials. In the Lower Ayeyarwady (HEZ 4) and the Ayeyarwady Delta (HEZ 5), the leading toxic chemical polluters were minerals and petroleum products, clothing and apparel, and food and beverages. Risks of human bioaccumulation of mercury through fish consumption were particularly high in the Middle Ayeyarwady (HEZ 3) and the Ayeyarwady Delta (HEZ 5).

Urban sector water pollutants were most prominent in the cities of Yangon (HEZ 5), Mandalay (HEZ 3), Magaway (HEZ 4), and Sagaing (HEZ 2). High levels of pollutants from poor treatment and processing of sewerage are harmful to receiving waters near these urban centres. For people using river water for drinking, bathing, and washing household utensils, microbial contamination above the relevant human health guidelines poses significant risks. With the highest population densities, communities living in the Middle Ayeyarwady (HEZ 3) and the Ayeyarwady Delta (HEZ 5) are the most vulnerable to human health issues arising from urban water pollution.

Mining activities are widespread in the Ayeyarwady Basin, particularly gold and jade in the Upper Ayeyarwady (HEZ 1) and Chindwin (HEZ 2); however, there are little data available on the impacts of such activities. Mining activities are broadly responsible for high turbidity and sediment loads in the river and the production of wastewater in the receiving environment. Within the Ayeyarwady Basin, unregulated extraction practices and small-scale mining pose high risks to surface water quality from mining disturbances. Discharge from mining activities, such as the issues of microbial contamination in the Uyu River, can also provide localised risks to people using river water for drinking, bathing, and cooking.

Agriculture is an important industry in Myanmar that is coming under increased pressure for its potential impact on water quality. There is little information available on the domestic use and impact of pesticides that could present a moderate risk to ecosystems and human health in the Ayeyarwady Basin. Risks were also identified with aquaculture practices, specifically where low dissolved oxygen levels and high nutrients from ponds can result in localised risk and adversely impact aquatic organisms.

This chapter has identified the need for information gaps to be filled to better understand water pollution in the Ayeyarwady Basin. In the future, water quality monitoring and management should assess the sources of pollution rather than consider only the current state. However, it is important to maintain existing monitoring sites to provide credible baseline levels of pollution data in the basin and to estimate trends in pollution.

In relation to the monitoring activities identified above, there are two key priorities. First, is to protect human health through monitoring faecal coliforms, particularly where the risk increases from the headwaters to the Ayeyarwady Delta. Second, is to create a database to organise current and future monitoring results in a safe, accessible, and transparent manner. This would include appropriate capacity building both in data handling and statistical analysis.



5

GROUNDWATER



HIGHLIGHTS – GROUNDWATER

- This work represents the first detailed assessment of the status and dynamics of the groundwater resources of the Ayeyarwady Basin.
- Current extraction is likely to be within the bounds of sustainable use and suggests that there may be opportunities to expand groundwater development. On average, 13% of the renewable resource is used annually and rates range from 2% to 33% across the groundwater zones (GWZs), with the largest use in the Central Dry Zone.
- Detailed hydrogeological investigations in the Central Dry Zone have identified large areas with a high well yield and low salinity that are suitable for irrigation use. Other potential areas for expansion include the Ayeyarwady Delta, Shan Plateau, and the Upper Ayeyarwady. These areas will require similarly detailed hydrogeological mapping.
- It seems that the volumes of groundwater withdrawn for irrigation approach or surpass volumes for domestic supply. This is an important shift from the past and brings new management challenges to safeguard domestic supplies.



- The importance of groundwater discharge to dry season flows in the intermittent streams of the Central Dry Zone and the Ayeyarwady mainstream, both for livelihoods and for ecosystems, must be taken into consideration in future planning.
- Substantial water savings could be made through capping and appropriate management of artesian wells within the Lower Ayeyarwady, Lower Chindwin, and Mu GWZs. Currently, these wells flow freely year-round, with productive use as low as 10% of the flow.
- The study confirms the existence of a sizable renewable groundwater resource within the Ayeyarwady Basin. Estimates of groundwater storage in the Ayeyarwady Basin indicate an enormous volume of the more than 2,000 km³, but with an annual recharge of less than 1.5% (approximately 27 km³).

HIGHLIGHTS – GROUNDWATER

- Indications are that the Upper Chindwin, Middle Ayeyarwady, and Ayeyarwady Delta GWZs represent the most important areas of groundwater ecosystem support function, because they host Key Biodiversity Areas that are both highly reliant on groundwater and are considered of high priority for conservation. Dry season contribution to baseflow of the Ayeyarwady River and its tributaries is significant and is key to supporting these ecosystems.
- Water quality constrains groundwater use over large areas of the Ayeyarwady Basin. High levels of arsenic are a risk in the recent (Holocene) alluvial aquifers, though the problem seems to be limited to the sediments of the Ayeyarwady mainstream and does not affect the Chindwin and Mu systems.



- Salinity is mostly associated with aquifers of the marine Pegu Group sedimentary rocks and with intrusion of seawater in the Ayeyarwady Delta.
- Isolated occurrences of elevated fluoride, uranium, and metals are found in specific geological contexts, but data are scarce.
- Anthropogenic pollution of shallow groundwater from industry, sewage, mining, and agriculture is an increasing risk, although little information is available on the actual extent and severity.
- There are two critical gaps in management of groundwater in the Ayeyarwady Basin. First is the paucity of basic data on groundwater status and use, the absence of systematic documentation of wells or extractions, and measurements of water levels and water quality. Secondly, the establishment of a suitable institutional and legislative base for groundwater management is a priority in the National Water Policy, but it will require both political will and community commitment to formulate and implement.

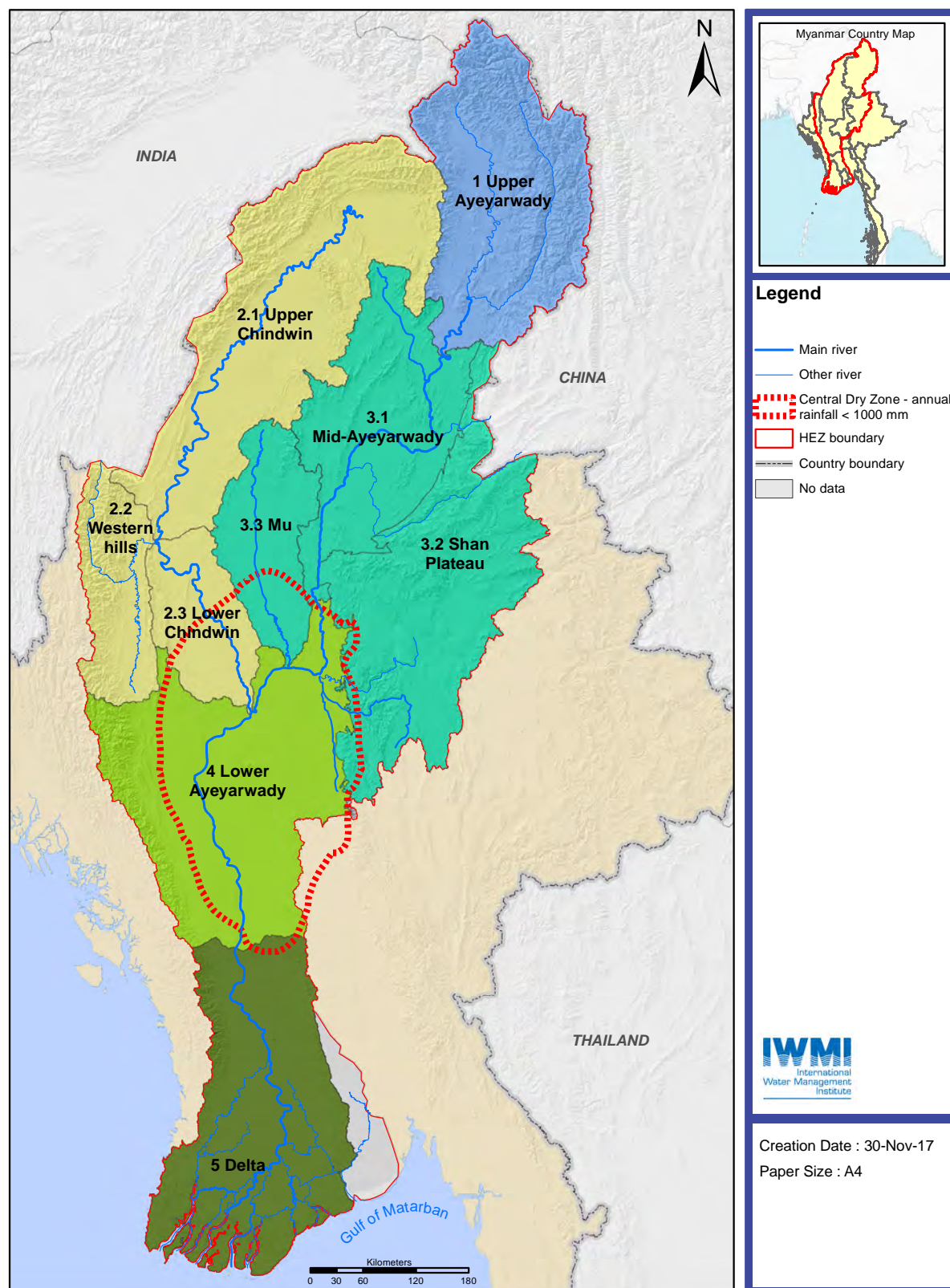


Figure 5.1 – Groundwater zones of the Ayeyarwady Basin

Refer to Table 5.1 for descriptions

5. GROUNDWATER

5.1 Introduction

This chapter provides a synthesis of available data on groundwater quality, quantity, abstraction, and ecosystem values for each of the Ayeyarwady Basin's nine GWZs, as defined in this study. It concludes with an overview of the status and trends of groundwater, a summary, and key recommendations focused on data gaps and governance to improve future groundwater management efforts.

SOBA Technical Reports

This chapter is a synopsis of the full assessment, which may be accessed by readers seeking more detailed information, including references:

SOBA 2a: International Water Management Institute & Aqua Rock Consultants (2017), *Groundwater Resources of the Ayeyarwady River Basin* (SOBA 2a), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 2b: International Water Management Institute (2017), *WISDM Water Information System for Data Management* (SOBA 2b), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

5.2 Ayeyarwady Setting

Groundwater is a vital resource for human and environmental purposes. More than 50% of all households in the Ayeyarwady Basin use groundwater for drinking and domestic supplies, and in some areas, this use exceeds 90%. As pumping technologies become more affordable, the use of groundwater for irrigation is increasing rapidly, with increased investments from public and private sectors. Groundwater contributes significantly to dry season flows in rivers and streams and plays an important role in supporting ecosystems in a range of contexts from Ayeyarwady Delta marshes to riverine wetlands and upland springs.

The Ayeyarwady Basin has nine major GWZs (Figure 5.1 and Table 5.1) based on its five HEZs, which are subdivided to reflect the dominant geology and aquifers. Groundwater storage and recharge are highly variable between GWZs (Figure 5.2). The Ayeyarwady Basin is known to host substantial groundwater, but there is considerable uncertainty around the extent of the renewable resource, links between surface and groundwater, and limits to sustainable extraction. Issues of population density and access to safe sanitation are a further challenge for future groundwater management.

Table 5.1 - Groundwater zones of the Ayeyarwady Basin
(Drury 2017)

HEZ	GWZ	Geology	Main aquifers	Drury (2017)*
1	1. Upper Ayeyarwady	Dominantly Precambrian, Palaeozoic and Mesozoic metamorphics, Mesozoic granites. Small alluvial floodplains.	Dominantly low yielding fracture hard rocks. Alluvial aquifers in floodplains.	
2	2.1 Upper Chindwin	Dominantly Paleocene to Holocene sediments, including Irrawaddy Formation and Pegu Group; some metamorphics of Western Ranges	Mostly sandstones of variable age including Miocene Pegu group formation with salinity risk. Limited alluvial aquifers and some Irrawaddy formation.	
	2.2 Western Ranges	Cretaceous flysch units in Western Ranges; Paleocene – Eocene molasse and flysch in river valleys	Older alluvium in river valleys	DZ5 (Pale) and DZ6 (Budalin)
	2.3 Lower Chindwin	Irrawaddy Formation and Younger Alluvium	Irrawaddy Formation and Younger Alluvium	
3	3.1 Mid Ayeyarwady Lowlands	Miocene to Holocene alluvial sediments	Alluvial aquifers including Younger Alluvium, Irrawaddy Formation, and Pegu Group	
	3.2 Shan Plateau	Ordovician to Cretaceous sediments, including large areas of Perma-Triassic Plateau Limestone Group.	Limestone aquifers, fractured hard rock aquifers	
	3.3 Mu	Irrawaddy Formation and Younger Alluvium with small areas of Pegu Group, Cretaceous Volcanics and Mesozoic granites	Irrawaddy Formation and Younger Alluvium	DZ7 Shwebo / Monywa
4	4 Lower Ayeyarwady	Dominantly Miocene to Holocene alluvial sediments (Part of DZ10)	Pegu Group, Irrawaddy Formation, Younger Alluvium	DZ1, DZ2, DZ3, DZ4, DZ9, (DZ10 (part)), DZ11
5	5 Delta	Recent alluvial deposits	Younger Alluvium with underlying Irrawaddy	

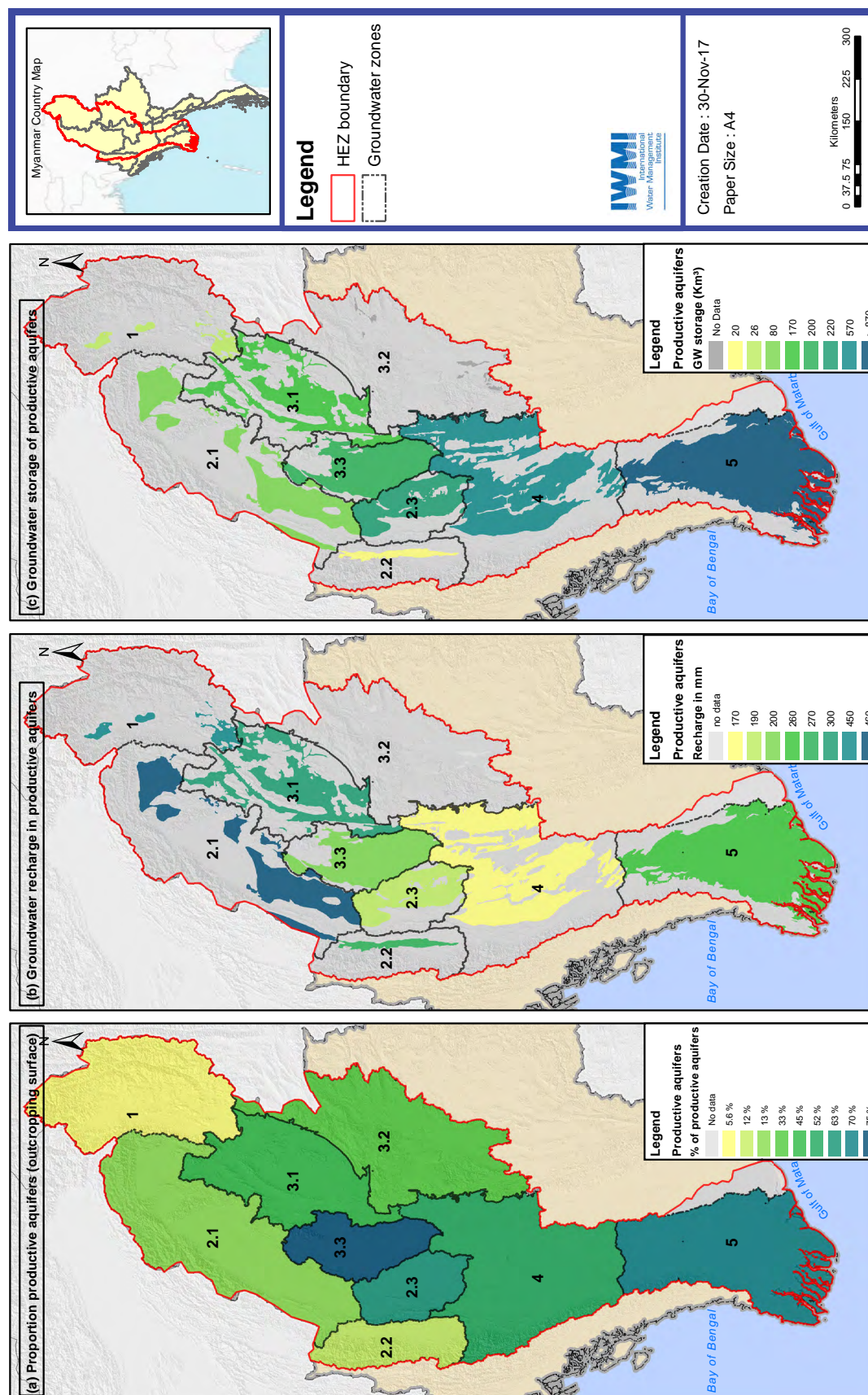


Figure 5.2 – The (a) proportion of productive aquifers, (b) groundwater recharge in productive aquifers, and (c) groundwater storage in productive aquifers, for each groundwater zone

Methods and limitations

The data presented throughout this chapter draws on published and unpublished reports, workshops and interviews with key local experts, analysis of data held by the Groundwater Division (GWD) of the Irrigation Water Utilization Management Department (IWUMD), a compilation of other data sources, and field verification visits. Sections on the Central Dry Zone are drawn mostly from Drury (2017), a major report on the hydrogeology of the Central Dry Zone (for further details, refer to the SOBA Technical Report).

Two major workshops and separate consultations discussed data analysis with regional and international experts. Field visits examined irrigation and water supply, facilitated expert discussion, and accessed state and regional records.

In the absence of well monitoring data, three surrogate indicators for GWZ-scale groundwater quantity were used:

- The proportion (by area) of productive aquifers (providing significant tubewell yields).
- The annual recharge of productive aquifers.
- The total storage in productive aquifers.

Groundwater monitoring is limited throughout the Ayeyarwady Basin, including in the Central Dry Zone. Few organisations conduct pump-out tests to obtain hydrogeological aquifer characteristics. There are no groundwater laws or regulations that require developers or users to monitor and manage the groundwater resource. Government agencies and non-governmental organisations (NGOs) are not obliged to record hydrogeological data. Drillers, local governments, and farmer organisations have provided some information on groundwater level behaviour and overall hydrogeological trends.

Information on groundwater use is sparse. Water abstraction calculations used census data, population maps, and derived consumption rates for urban and rural areas. The 2014 Census has data on the number of households using groundwater for domestic and agricultural supplies. The Ministry of Agriculture, Livestock, and Irrigation (MOALI) has some data on irrigation extractions by formal schemes, but there appears to be no reliable data on pumping by the private sector or individual farmers. GWD has compiled data for some, but not all, townships on the number of tubewells, dugwells, rainfall collection points, and the volumes pumped for their town water supply.

Due to the paucity of reliable data and the assumptions made in the process, the estimates of aquifer storage recharge and abstraction should be considered only as indicators of the order of magnitude.

5.3 Groundwater Zones of the Ayeyarwady

This section presents an overview of the geology and aquifers, storage and recharge, water quality, usage, and groundwater-related ecosystems for each GWZ. Data varied widely between GWZs, and some estimates (e.g., recharge and storage) are highly uncertain.

5.3.1 Upper Ayeyarwady GWZ

The Upper Ayeyarwady GWZ comprises the catchment of the N'Mai and Mali Rivers, the headwaters of the Ayeyarwady. It covers approximately 50,700 km² in the Kachin State, with a population of 0.51 million. Small plains around the major rivers are more densely populated. Remote villages are found scattered over the hills, and the northern mountains are mostly uninhabited.

Geology and aquifers

This region has limited groundwater systems, mostly in the lowland plains. The greatest potential for groundwater is in small areas of alluvial and unconsolidated aquifers. Other aquifers, including sandstones, siltstones and equivalents, metamorphic and meta-sedimentary aquifers, and granitic aquifers hold much less potential for groundwater.

Storage and recharge

Storage and recharge (Table 5.2) for the alluvial and unconsolidated aquifers are derived from limited data and assumptions about aquifer size, specific yield, and rainfall/recharge coefficient.

Water quality

There are no data on natural or anthropogenic pollutants in the groundwater in this GWZ. Within the urban zone of Myitkyina, urban waste and sewage are potential pollutants. Low populations outside the city pose little pollution risks. Agricultural intensification may increase pollution in the future. Alluvial gold mining poses threats, as the mercury and cyanide used in the gold mining process may end up in natural systems.

Table 5.2 - Summary of estimations of extent, recharge, and storage in productive aquifers in the Ayeyarwady Basin

Ground Water Zone (GWZ)	Aquifer group	Area km ²	% of productive aquifers	Rain (mm) average	Storage (km ³)	Recharge (km ³)	Recharge (mm)
1 Upper Ayeyarwady	Alluvial and unconsolidated aquifers	2,559	6%	3,011	2,559	1,166	452
2.1 Upper Chindwin	Alluvium	8,018	13%	3,094	8,018	3,721	464
2.2 Western hills	Alluvium and colluvial fans	2,068	12%	1,793	2,068	556	269
2.3 Lower Chindwin	Alluvial and Irrawaddy Formation	10,487	63%	1,242	22,280	2,068	186
3.1 Mid-Ayeyarwady	Alluvial and Irrawaddy Formation	17,044	45%	2,025	17,044	5,176	304
3.2 Shan Plateau	Alluvial aquifer and Plateau Limestone	17,913	33%				
3.3 Mu Shwebo	Alluvial and Irrawaddy Formation	14,510	74%	1,364	20,058	3,032	205
4 Lower Ayeyarwady	Alluvial and Irrawaddy Formation	33,572	52%	1,132	46,389	5,750	170
5 Delta	Alluvial and Irrawaddy formation	38,323	71%	2,578	93,3150	6,093	258

Human use and ecosystem value

In the alluvial plains around Myitkyina and Putao, most households use groundwater for domestic supply, drawing on small alluvial aquifers. Total area of irrigation in the GWZ is small (less than 30,000 hectares [ha]), and irrigation is mostly from surface water. There is some use of groundwater from alluvial aquifers in the floodplains. Each year, the State and National Governments of Myanmar allocate a budget for drilling tubewells to support irrigation for farmers.

There are nine Key Biodiversity Areas (KBAs) in this GWZ. Most are located in the steep mountains of mostly metamorphic and igneous rocks. Groundwater plays an indirect role in buffering climate variability and supporting springs. In general, groundwater in the GWZ is not a key factor for conservation.

Summary of assets and issues

- Alluvial aquifers provide important domestic supplies and small-scale cash crop irrigation opportunities.
- Locally, unregulated artisanal mining poses a potential pollution source to shallow aquifers.

5.3.2 Upper Chindwin GWZ

The Upper Chindwin GWZ comprises the Chindwin catchment within Myanmar. It is north of the junction with the Myittha River at Kalewa, an area of approximately 62,900 km². It has a population of approximately 700,000 people.

Geology and aquifers

There are three main physiographic regions: the Western Ranges, the Central Chindwin River Valley, and the Upper Catchment.

The major low-salinity and high-yield groundwater aquifers are located in the Irrawaddy Formation and Quaternary Alluvium of the Chindwin Valley. Low yield and brackish aquifers are generally encountered in the sandstones of the Pegu Group and Eocene rocks.

The Irrawaddy Formation aquifers are mainly semi-consolidated brown and blue sand and gravel with clay aquitard bands. Groundwater yield ranges from 1 to 10 litres per second (L/sec), with hydraulic conductivity less than 15 metres per day (m/day).

There are some extensive alluvial flats on the Uru River with shallow dugwells. Depth to the groundwater is shallow. Groundwater yields up to 20 L/sec are anticipated in tubewells close to the river. Hydraulic conductivity is likely in the order of 100 to 200 m/day. The thickness varies from 70 m at Kelewa to less than 40 m in the Upper Catchment.

The hydrogeology of the fractured volcanic and metamorphic rocks is poorly documented. Groundwater yields are typically low, at less than 5 L/sec.

Storage and recharge

There is limited understanding of the recharge, storage, and discharge processes in this GWZ. Volumes, storage properties, and recharge rates are estimates only, based on broad assumptions (Table 5.2). Appropriate groundwater studies should be carried out to refine these values.

Water quality

Salinity in this GWZ is usually low, but limited areas of higher salinity may occur immediately downstream of the more saline Pegu Group outcrops. There are possible future risks from artisanal gold and jade mining and small-scale coal and oil mining; however, impact on groundwater is likely to be limited and localised, as groundwater flow is toward the river. Approximately 25% of households have no access to sanitation, posing a moderate risk of localised pollution where population density is high.

Human use and ecosystem value

Water abstraction is estimated to be 0.021 cubic kilometres per year (km³/yr) for all four aquifers in this GWZ. Given small population density and abundant surface water, groundwater demand for urban use and irrigation is low. All towns are on the river, and there are no major industries using the groundwater. In rural areas, a high proportion of households use groundwater, notably in the uplands where 70% of households use wells, springs, or tubewells. Small areas of intensive irrigation occur near towns; however, it is unclear if this water is sourced from groundwater or surface water resources.

This GWZ hosts 10 KBAs, some of which have high conservation value. Most of these are forested hills with low groundwater ecosystems. Two of the 10 KBAs are closely related to groundwater resources. These include the marshes in the Tanai River and the wetland areas in the Hukaung Valley Wildlife Sanctuary.

Summary of assets and issues

- Large recharge to alluvial aquifers, which provide important domestic supplies, small-scale cash crop irrigation opportunities, and high-priority KBAs.
- Potential pollution of shallow aquifers from unregulated artisanal mining and unsafe sanitation around towns.





5.3.3 Western Hills GWZ

This GWZ encompasses the catchment of the Myittha River within Myanmar, which has an area of 17,600 km² and a population of 620,000 people. Large colluvial fans emanate from the Chin Hills.

Geology and aquifers

The Myittha River Valley is formed within a major Horst-Graben structure, with elevated mountains bordered by major fault zones to the west and east (Kabaw Fault) and a dropped valley centre.

The major geological features are the elevated western Chin Hills (Western Ranges), the central valley consisting of extensive heterogeneous alluvial fluvial sediments and colluvial fans, and elevated eastern mountain ranges of the Thit Chauk Reserve Forest.

The most abundant aquifer units are sandstones and sediments with alluvial aquifers of various types, including colluvial fans with artesian zones that outcrop in 12% of the GWZ.

Colluvial fans form heterogeneous aquifers that are highly permeable in the west. They become less permeable in the inter-tonguing alluvial sediments to the east, as silt content increases. Within the colluvial fans there is a large amplitude in water level fluctuation, with dry season levels being 10 m deeper than in the wet season. Tubewells are abundant in colluvial fans and are used for domestic and irrigation purposes.

There are two extensive artesian zones located near the base of the colluvial fans. North of Tahan-Kalay Town, drilling depths are usually from 25 to 100 m, with artesian flow commencing at approximately 30 m. Some tubewells are equipped with small hydro-generators for household power supply. A less extensive artesian area is found to the south of Kalay in Sithar Village, where artesian flows have reduced since initial drilling, at least partly on account of owners not closing control valves after use. No artesian aquifers are intersected in the Kalay and Tahan Townships area, even though the area is on the centre of a major colluvial fan.

Storage and recharge

The aquifers are annually recharged by rainfall and surface water runoff along the western Chin Hills. There is likely to be considerable recharge, particularly through the highly permeable colluvial fans. High groundwater yields are available from deep, correctly designed and constructed production tubewells within the colluvial fans. There is poor potential of obtaining high-yield aquifers in the fine-grained alluvium along the eastern edge of the valley.

Groundwater stored in the Myittha River Valley cannot be transferred to the lower drainage system but must discharge either into the Myittha River and associated chaungs (intermittent streams), from natural springs, or from pumping and flowing tubewells.

Water quality

Groundwater in this GWZ is consistently low in salinity. No other groundwater quality issues have been reported. There is some risk of aquifer pollution from agrichemicals as agriculture intensifies on the colluvial fans.

Human use and ecosystem value

Dependence on groundwater is low in the uplands of the Chin Hills but high along the river valley, where there are large numbers of tubewells and dugwells. In the main towns of Kalay and Tahan, there is no reticulated water supply system, but many households have a dugwell or tubewell. Domestic abstraction for the alluvium and colluvial fans is estimated to be 0.0125 km³/yr and 0.0063 km³/yr in the sedimentary and meta-sedimentary. Industrial use is currently limited but is expected to expand in the Kalay area, along with government-promoted irrigation with groundwater.

The Government of Myanmar has promoted irrigation using groundwater by installing 28 artesian tubewells in the valley. There are now approximately 500 private tubewells. Land cover mapping (IWMI, 2016) indicates approximately 42,500 ha of intensive cropping system in the Myithha River Valley on the colluvial fans or along the river floodplain. It is not clear what proportion is drawn from groundwater — pumping from both groundwater and surface water sources is likely.

Groundwater is not expected to be an important component of ecosystems in the Western Hills, as most of the GWZ is located in steep, mountainous terrain. Aside from springs, groundwater plays an active role in supporting the dry season flow in the inter-montane valley.

Summary of assets and issues

- Productive aquifers in the colluvial fans abutting the Chin Hills, extensively used for town and domestic supply as well as irrigation.
- Artesian zones north and south of Kalay.
- Difficulties with drilling in colluvial aquifers.
- Decline in groundwater pressure in artesian zones due to a failure to cap flowing tubewells.

5.3.4 Lower Chindwin GWZ

The Lower Chindwin GWZ comprises the catchment of the Chindwin, downstream of the junction with the Myittha, and above the junction with the Ayeyarwady, south of Yesagyo. There are two significant groundwater sub-basins.

- **Monywa Sub-basin:** The alluvial plain of the Lower Chindwin is bounded to the west by the Pale Sub-basin and east by the Kyaukka Range. To the south, the flats become swampy near the confluence with the Ayeyarwady River and are flooded for several months. Due to the presence of shallow, low-salinity groundwater few villages use surface ponds for domestic water supplies. Under the Monywa Groundwater Irrigation Project (GIP), hundreds of government and thousands of private tubewells and dugwells have been constructed. Some shallow dugwells need to be progressively deepened due to groundwater extraction for irrigation purposes.
- **Pale Sub-basin:** The North Yama Chaung and Nga Kon Yama Chaung traverse west to east through the area and are the only water discharge points from the sub-basin into the Chindwin River Valley. Dams on these rivers are used for irrigation and were designed for groundwater recharge. The Pale Sub-basin contains the 99 Ponds GIP (99PGIP).

Geology and aquifers

The northern part of the GWZ, east of Kalewa, is dominantly Irrawaddy Formation, loosely cemented sandstones outcropping over large areas as forested hills. Significant groundwater resources could be present and warrant further investigation since recharge conditions over the Irrawaddy Formation outcrops are favourable. The southern part of the GWZ comprises the Monywa and Pale Sub-basins and is dominated by recent alluvium underlain by Irrawaddy Formation. These areas have been extensively developed for groundwater irrigation.

The Monywa Sub-basin's main geological units are Pegu Group outcrops, Irrawaddy Formation, igneous rocks, and alluvium. Faulting and folding has strongly influenced the distribution of the various formations. The main geological units of the Pale Sub-basin are Eocene and Pegu Group sediments, Irrawaddy Formation, and Quaternary Alluvium. Sediments are folded and faulted, and these structures play an important role in groundwater movement.

Major high-yield groundwater aquifers are located in the Quaternary Alluvium and Irrawaddy Formation (Table 5.3). A large percentage of the Quaternary Alluvium and Irrawaddy Formation could be potential sources of high-yield and low-salinity groundwater for irrigation purposes.

Table 5.3 - Summary of aquifer depth and characteristics in the Lower Chindwin groundwater zone

Aquifer-type	Sub-basin	Specific location	Drill depth/ average (m)	SWL range (m)	Yield (L/ sec)	Quality ($\mu\text{S}/\text{cm}^{-1}$)	Hydraulic Characteristics		
							Trans-missivity (m^2/day)	Hydraulic conductivity (m/day)	Storage co-efficient
Alluvium	Monywa	Monywa	15 - 70/45	3 - 18	10 - 50	500 - 2,500	200 - 15,000	18-44 / 24	8.4×10^{-3}
Irrawaddy Fm.	Pale Monywa	Kokko-gon Fm	270	+ 5 - 20	5 - 50	600 - 1,900			5×10^{-4}
		Y/A	30 - 310	+ 10 - 30	18 - 100	< 1,000	100 - 1,700	1-65 / 30	2×10^{-4}
		Kyaukka	200	5 - 10	1 - 25	< 1,500	2 - 170	30-260/100	
Pegu Gp.	Monywa	Kyaukka	100	50	0.5 - 5	2,000 -10,000	0.5 - 70		
Eocene	Pale		280		0.5 - 5	> 1,500		1-10	
Volcanics	Monywa	Cu Mine Area	30 - 240	2 - 30	0.5 - 4	500 -> 10,000		3×10^{-4} - 7×10^{-2}	

*Y/A - Ywatha/Aungban Formation.



Storage and recharge

Storage in this GWZ is estimated at 223 km³ and recharge at 2.07 km³. Estimates for the Pale Sub-basin place storage at 54.1 km³ and at 84.2 km³ for the Lower Chindwin River Valley.

The extent to which groundwater flow occurs between the Quaternary Alluvium and Irrawaddy Formation aquifers is controlled by the presence of clay layers (aquicludes). In the Pale Sub-basin, regional groundwater movement is from the recharge areas in the surrounding hills toward the centre of the basin. Groundwater discharge is mainly to Zidaw Springs (along the anticline), the North Yama River, and the artesian tubewells.

Water balance

Monywa Sub-basin: Modelling suggests that more groundwater could be extracted, but caution is required with respect to impacts on shallow tubewells, water quality, and environmental requirements.

Pale Sub-basin: The water balance model indicates that there is some water level decline, probably due to constantly flowing tubewells. If the artesian tubewells were closed when not used for irrigation, then aquifer repressurisation could be expected with subsequent flow increase in springs, tubewells, and river discharge. Alternatively, additional groundwater development may be possible elsewhere in the basin.

Water quality

The aquifers of the Quaternary Alluvium and Irrawaddy Formation usually have low salinity. Water from the Ywatha/Aungban Aquifer is better suited for irrigation than the Kokkagon Aquifer, because they have a lower sodium absorption ratio and generally lower hardness.

Only the aquifers along the Ayeyarwady mainstream have elevated levels of arsenic. Monywa generates municipal and industrial waste and permits unregulated volumes of pesticides and fertilisers to be applied to crops. Where dugwells and tubewells are poorly sealed at the surface, urban and rural pollutants may contaminate the soil and the underlying shallow aquifers. No chemical analysis of such contamination has been undertaken. There is potential for soil and groundwater contamination from mining projects.

Human use and ecosystem value

Approximately 77% of all households in the GWZ rely on groundwater for drinking, and total annual abstraction for domestic use is estimated at 0.068 km³.

Total abstraction for agriculture is estimated at 0.236 km³ annually within the Monywa and Pale Sub-basins. This level provides an indicative lower threshold for abstraction for the GWZ.

The Monywa GIP has been operational for 30 years, with 141 tubewells but no hydrogeological monitoring. Water level decline is reported in some shallow aquifers, but no overall decline is observed. It is important that a groundwater monitoring system be installed to assess how best to manage the Monywa GIP.

The 99PGIP has been operating since 1995 in the Pale Sub-basin. There has been a steady decline in flow and effective command area. By 2016, the potentiometric pressure in the Ywatha/Aungban Aquifer declined from 131 to 121 m above mean sea level because of uncontrolled groundwater flow by both government and private irrigators. Hundreds of private artesian irrigation and domestic tubewells have been drilled, but there is no control of artesian flow in non-irrigation periods and no effective water management strategy.

Only two areas have been identified as important for conservation in this GWZ, both of which have low reliance on groundwater – the Alaungdaw Kathapa National Park, in thickly forested hills, and the Twintaung KBA, where groundwater influences springs within the Cenozoic Volcanic Aquifer.

Summary of assets and issues

- A large percentage of the Quaternary Alluvium and Irrawaddy Formation is a potential source of high-yield and low-salinity groundwater for irrigation purposes.
- There are potential resources in the Irrawaddy Formation, north of GWZ, that have not been exploited.
- The Pale Sub-basin is fully developed, with a small net annual loss that could potentially be corrected by improved management.
- There is a high dependence for drinking and domestic water supplies.
- There are artesian irrigation systems at 99PGIP and Monywa GIP.



5.3.5 Mid Ayeyarwady GWZ

This GWZ comprises the lowlands of the middle reaches of the Ayeyarwady, bounded on the east and west by hills along major fault zones. Within this range are two parallel, long, narrow intra-montane alluvial valleys.

South of Myitkyina, the Ayeyarwady River cuts through a series of hills and then widens to form an alluvial plain that is fed by numerous streams descending from the Shan Plateau. Following a second constriction at Naungmo, the river opens into a 30-km wide alluvial plain. It then flows for 90 km along the Sagaing Fault until it is diverted by the hard rocks of the Chaung Gyi volcanics, which form the southern boundary.

Geology and aquifers

The two dominant geological features bounding the GWZ are:

1. The Sagaing Fault, in the west, has Miocene rocks of the Pegu Group that outcrop westwards and metamorphic rocks that form a wedge-shape range that extends 200 km along the fault from Myitkyina southwards.
2. Mesozoic granites, in the east, outcrop to form hills at the foot of the uplifted Shan Plateau.

In between the two older ranges, Upper Miocene and Quaternary, alluvial deposits are found, intercalated with sedimentary formations of Cretaceous and granitoid and volcanic intrusion of variable age.

This complex geology provides numerous groundwater systems; however, these have not been studied in depth. Significant quantities of groundwater are assumed to be found only in the semi-unconsolidated aquifers of the Quaternary Alluvium and Irrawaddy Formation.

Alluvial aquifers are found in three major areas:

1. The intra-montane valley, extending within the Katha-Gangaw Range.
2. The recent alluvium from the Ayeyarwady River and smaller streams draining from Shan State.
3. The Ayeyarwady River alluvium and associated older sediments of the Irrawaddy Formation in the central area and on the eastern bank of the river in the channel along the Sagaing Fault.

The groundwater flow has not been studied in the area; however, topography and aquifer properties can be used to broadly map the flow patterns.

Storage and recharge

It is estimated that the largest aquifers, the Quaternary Alluvium and Irrawaddy Formation, have a combined total storage volume of 170 km³ and recharge is estimated at 5 km³/yr. These results must be treated with caution as there are no ground-based studies to support these indicators.

Water quality

A large hydrochemical investigation found that only 4.3% of water samples had arsenic concentrations higher than the World Health Organization (WHO) limit of 10 micrograms per litre (µg/L). There are no reports of other naturally-occurring groundwater contaminants in this GWZ, but data are limited.

Use of chemical fertilisers and pesticides is generally low, but this might increase as agriculture intensifies. Unregulated mining activities occur across the Quaternary Alluvium and Irrawaddy Formation, as well as in the bed of the Ayeyarwady River in this GWZ. A study on mercury contamination near artisanal mining operations confirmed mercury in river sediments in several locations in Myanmar and in fish from Indawgyi Lake.

Human use and ecosystem value

Approximately 75% of households in this GWZ use groundwater for domestic supply. There is little industrial use.

Cropping is mostly near the Indawgyi Lake and along major tributaries and floodplains of the Ayeyarwady River, where groundwater is not likely to be a major source of irrigation water.

It is likely that groundwater in this GWZ plays a major role in ecosystem functions in two major zones of wetlands. The first is Indawgyi Lake and its surrounding wetland, which is now classified under the Ramsar Convention as a 'wetland of international importance.' Second is a major zone of riverine wetlands and small lakes that stretch along the length of the Indaw and Ayeyarwady Rivers in this GWZ and have been identified as KBAs. These areas are poorly studied, but are likely to provide high supporting roles, notably during the dry season. Quaternary alluvial deposits present in the area are most likely connected to the meanders and marshes, actively supporting ecosystem function.

Summary of assets and issues

- There are important alluvial deposits 50 m deep and actively recharged.
- Groundwater is used for domestic and small-scale irrigation.

- There are groundwater inputs to the Ramsar-listed Indawgyi Lake, and riverine wetlands.
- There is a potential for mercury pollution from current and past alluvial gold mining operations.

5.3.6 Shan Plateau GWZ

The main geomorphological features of this GWZ are the plateau, with gently undulating hills, and mountain ranges. In between ranges, some intra-montane valley flats have developed. The main river is the Myitnge, running for 440 km before reaching the Ayeyarwady River. Although perennial rivers are rare in the plateau, springs and intermittent streams are abundant.

Geology and aquifers

The geology of the Shan Plateau is particularly complex and is under-studied, partly due to political unrest over the last 50 years. The Shan Plateau consists of mostly Late Precambrian to Cretaceous sedimentary, metamorphic, and plutonic rocks. The fault zone, which uplifted the plateau, originated during the Mesozoic or earlier and reactivated during the Cenozoic, inducing vertical movements of more than 1,000 m. Sedimentary formations (sandstones, mudstones, and limestones) are the most abundant types of rock, covering 69% of the area, with thickness varying from hundreds to thousands of metres. Alluvial deposits are limited to approximately 2% of the total area.

Six aquifer groups exist in the Shan Plateau:

- 1. Alluvial aquifers (2%) are found as small pockets along rivers and intra-montane basins and are usually not thick (< 50 m). They support the local communities' water supply.
- 2. Plateau limestones (31%) are deep with karst development and structures, including fractures, sink holes, and caves. Little is known about these units; however, limestone springs have historically been used by communities for domestic supply. Interest has increased as adequate drilling technology has become available; however, results are difficult to predict due to aquifer heterogeneity.
- 3-4. Sandstone and limestone units (12%) are differentiated from the Plateau Limestone by their mountainous topography. This lowers their potential for groundwater, but they may play an important role in groundwater recharge.
- 5-6. Hardrock aquifers (igneous and metamorphic rocks) have limited water-bearing capacity except in fracture zones. No data on these aquifers are available.

Storage and recharge

The geological complexity of the Shan Plateau and fragmented data make storage calculations unreliable. These aquifer units are likely to host a significant amount of groundwater. The storage of groundwater in the Shan Plateau Limestone is also expected to be high as recharge water percolates quickly vertically and is stored in fractures and conduits – a hypothesis supported by the paucity of perennial rivers on the plateau.

Water quality

No naturally occurring groundwater pollution has been reported; however, given the extreme data scarcity in the area, it is difficult to assess the current situation.

Organic pollution and waste from industry are potential risks for groundwater quality near towns and villages. Intensive horticulture is developing in the Shan Plateau, and unregulated use of agrichemicals and poor knowledge of best practices pose significant water quality hazards. Over many centuries, this GWZ has been home to mining activities, including the world-renowned Mogok Gem Deposit and the lead, silver, nickel, copper, and antimony of the Namtu Bawdin Mine. These mines are mostly located in hard rock areas where groundwater contamination, if occurring, should be reasonably contained.

Human use and ecosystem value

Groundwater use has historically been from springs flowing from mountain ranges and shallow wells in the alluvial aquifers in valley bottoms and along rivers. Approximately 57% of households depend on groundwater for domestic supply. Rural areas use dugwells, while larger towns have a much higher use of tubewells.

Land cover maps indicate approximately 180,000 ha of intensive cropping systems, mostly in alluvial valleys and using surface water. Groundwater is used mainly for home gardening and small-scale irrigation. No information is available on water use for urban industries.

The ecosystem value of the Shan Plateau is hard to evaluate due to the complex geological setting and the large size of the GWZ. Springs are numerous in the hills, where they support many rural communities and possibly high-value ecosystems. Only three KBAs are located in this GWZ, of which two are terrestrial, with low connection to the groundwater. The remaining one, the Doke-Hta River in the centre of the Karstic Plateau, is potentially highly reliant on groundwater, but there is little or no documented evidence to support this.



Summary of assets and issues

- Deep tubewells drilled in limestone can provide all-year, safe water supplies to communities.
- Annual recharge rates of the Shan Plateau Limestone are expected to be high. Total storage is unknown, but possibly high.
- Springs constitute an important part of the water supply on the plateau.
- Alluvial aquifers are limited in extent but can support small-scale irrigation using water-saving technologies.
- Limestones are highly variable aquifers, sensitive to pollution, and both expensive and technically demanding to drill.
- There is a pollution risk from the unregulated use of agrichemicals.

5.3.7 Mu GWZ

This GWZ comprises the catchment of the Mu River to its junction with the Ayeyarwady near Myinmu, draining densely forested mountains. The Lower Mu River Valley consists of undulating peripheral hills and the central alluvial plain. Multiple diversion weirs on the Mu River supply water for rice. A major transformation in irrigation development was the 2001 construction of Thaphanseik Dam. This multi-purpose dam, one of the largest in Southeast Asia, enables year-round irrigation of over 500,000 ha with feeder canals extending to eight townships. Due to the availability of perennial surface water, there is little need to develop groundwater irrigation areas. An artesian scheme was developed near Ayadaw. Most villages rely on groundwater for domestic purposes.

The southern Mu Valley has been studied in detail, but only limited information is available for the north of the GWZ.

Geology and aquifers

In contrast to the Mid Ayeyarwady GWZ and Upper Ayeyarwady GWZ, the Mu GWZ is not tectonically active and has no major fault zones. The Upper Mu River Valley centres on the Wuntho Massif, an area of significant intrusive and extrusive volcanics. Sedimentary rocks are located south of the igneous rocks. The Lower Mu River Valley consists predominantly of Quaternary Alluvium and the Lower Pleistocene-to-Upper Miocene Irrawaddy Formation. The western hydrogeological boundary is the easterly dipping Pegu Group and the Lower Pleistocene-to-Upper Miocene basalt along the Kyaukka Range. The eastern boundary includes the Lower Palaeozoic-to-Precambrian metamorphics, igneous intrusions, and

Eocene rocks associated with the Sagaing Fault. To the south, the hydrogeological boundary is the northern extensions of the Bago Yoma. All the boundaries and internal geological structures have an impact on groundwater occurrence and quality.

The major low-salinity and high-yielding groundwater aquifers suitable for irrigation are located in the Quaternary Alluvium and Irrawaddy Formation. This is especially the case in the deep gravels and sand along the Ayadaw Syncline and, to a lesser extent, along the Shwebo Syncline. Most high groundwater yields and low salinities are located within the synclinal structures and close to the Ayeyarwady River. Artesian aquifers at depths of 55 to 240 m occur along the full length of the syncline.

Storage and recharge

Groundwater recharge is from direct rainfall, infiltration of surface irrigation and surface runoff, and upward leakage from underlying aquifer systems. Discharge is toward the watercourses, shallow alluvial aquifers, and artesian tubewells. Flow is complex, with vertical leakage between the more permeable layers being as important as lateral flow toward the discharge areas. The overall gentle groundwater gradient beneath the Mu River Valley is indicative of high permeability. Radiocarbon dating indicates that recharge takes place in the Irrawaddy Formation near the Kyaukka Range and moves slowly down-gradient to the deep sediments in the Ayadaw Syncline. Order of magnitude estimates of annual recharge are 44 km³ for the Quaternary Alluvium and 1,170 km³ for the Irrawaddy Formation.

The Lower Mu Valley has been studied in detail enabling better estimates of water balance for that area.

Water quality

Aquifers of the Quaternary Alluvium and Irrawaddy Formation have low salinities, except immediately downstream of the Pegu Group outcrops.

Hot saline artesian tubewells near the ancient City of Halin appear to be associated with the Halin Fault complex. It appears that high arsenic in groundwater is associated only with the Ayeyarwady River sediments.

Approximately 30% of the population in the Mu GWZ does not have access to safe sanitation. There is, therefore, some risk of bacterial contamination of shallow groundwater that is coupled with relatively high reliance on groundwater for drinking. Monitoring of water quality in village supplies should be a priority, particularly if drawn from dugwells.

Large-scale irrigation occurs in the Mu Valley. Use of agrichemicals is not yet widespread; however, this will likely change in the future with potential for agrichemical pollution of the groundwater.

Human use and ecosystem value

Reliance on groundwater for domestic supplies is high, with tubewells much more common than dugwells. Community dugwells in villages and urban/market areas show signs of bacterial pollution. There is some extraction of groundwater for industrial purposes in Shwebo Township.

Surface water is provided for irrigation from Thapanzeik Dam and the associated network of canals and small reservoirs. Artesian groundwater is exploited for irrigation around Ayadaw Taze and Ye-U, but extraction is limited due to the abundance of surface water.

The Mahanandar Kan, a freshwater lake and marsh located near Shwebo, adjoins a large artesian flow area and is likely to have high reliance on groundwater. A second KBA, the Chatthin Wildlife Sanctuary, is located in the Quaternary Alluvium, includes a large wetland and flooded forests, and is also likely to be partially groundwater fed in the dry season.

Summary of assets and Issues

- Ayadaw and Shwebo Artesian Zones.
- High dependence on groundwater for domestic supply.
- High potential for groundwater irrigation development in the Quaternary Alluvium and Irrawaddy Formation.
- Current use is approximately 22% of estimated recharge.
- Hot saline springs at Halin.
- Recharge from Thapanzeik Dam and from irrigation areas below Thapanzeik.
- Potential for salinisation of shallow groundwaters in irrigation area.



5.3.8 Lower Ayeyarwady GWZ

The Lower Ayeyarwady GWZ comprises the Ayeyarwady floodplain and catchment, incorporating the Ayeyarwady River corridor, the adjacent higher areas of the Bago Yoma, and the floodplains of the Samon River (which joins the Dokthawaddy and then the Ayeyarwady). The Quaternary Alluvium commences 65 km upstream of Mandalay and is joined by extensive sedimentary deposits from the Mu and Chindwin Rivers. The overall flat morphology of the central area is interrupted by a series of tectonically-induced, elongated anticlinal ridges, which rise sharply over the surrounding plains and break the continuity of the wide alluvial deposits.

Although the Central Dry Zone is endowed with abundant surface water from the Ayeyarwady River and its major tributaries, these sources are unevenly distributed. Most of the flow occurs in the wet season, with more than 70% of annual discharge occurring during the monsoon period. For the remainder of the year, river flow is maintained by groundwater discharge and, more recently, from hydropower and irrigation dams.

Groundwater is critical to the livelihoods of communities in the Central Dry Zone. Most villages, towns, and cities rely on groundwater for potable water supplies – some partially, most fully. Groundwater is also used extensively for industrial and irrigation purposes. Villagers without tubewells travel great distances to collect small quantities of water from shallow dugwells and polluted earth ponds. This water shortage causes the people to suffer from waterborne and related diseases.

Tree felling to provide fuel has resulted in much of this area being denuded of vegetation. Serious soil erosion has occurred over large areas. Erosion is particularly dominant in areas of thin, sandy soil cover. This area has the lowest rainfall and highest potential evaporation and temperature in Myanmar, resulting in a considerable soil moisture deficiency and a lack of significant surface water availability.

A combination of low rainfall, high potential evaporation, low humidity, consistently high temperature, sandy soil, saline base flow, sparse vegetation, scarcity of shallow groundwater (in some areas), and tectonically-complex geological features all combine to produce a semi-arid, barren region.

Geology and aquifers

The Lower Ayeyarwady GWZ is in an active tectonic region with a complex system of faults, anticlinal folds, and multiple sub-basins influencing groundwater occurrence.

The major productive aquifers include the following:

- **Quaternary Alluvium** – A sequence of geologically recent, unconsolidated river and lake sediments deposited on alluvial flats, river terraces, and piedmont plains. It comprises unconfined, semi-confined, and confined aquifers of variable thickness and yield in different areas. High groundwater yields are encountered in thick alluvial sediments. Where a superficial alluvial cover is present, groundwater potential is usually poor, except in the immediate vicinity of the rivers. Colluvial sand, gravel, and cobble deposits, along the foothills of Western Range and Shan Plateau, act as recharge zones and have high-yield and low-salinity groundwater but variable extent and thickness.
- **Irrawaddy Formation**: – A thick sequence of continental sediments that includes partially cemented sands and gravels with high groundwater yield as well as aquitard clay beds. Both confined and semi-confined aquifers occur. In some areas, deep drilling is required to access good-quality water.
- **Tertiary marine sediments of the Pegu Group and Eocene Formations**: – Contain aquifers, but groundwater is commonly brackish to saline and yield is mostly low.
- **Piedmont Sediments**: – Thick accumulation of colluvial sediments, mainly along the base of the Shan Plateau.
- **Volcanics**: – Fractured rocks of the Central Volcanic Belt may also yield good-quality water locally but are restricted in extent.

Storage and recharge

Throughout the Lower Ayeyarwady GWZ, the direction of groundwater flow is from the elevated aquifer recharge areas directly or indirectly toward the Ayeyarwady River. Major natural groundwater recharge areas include exposed areas of alluvium, elevated Piedmont Colluvial Sediment along the western edge of the Shan Plateau, sandstones along the Western Fold Belt, and sandy intermittent flowing chaungs. Induced artificial groundwater recharge may occur directly where the radius of influence of pumping tubewells intersect with the Ayeyarwady River and its tributaries. Groundwater discharge occurs to the down-gradient watercourses from evapotranspiration, from the large number of artesian and sub-artesian tubewells and dugwells, and continuously along the Ayeyarwady River. The extent to which groundwater flow occurs between the Quaternary Alluvium and Irrawaddy Formation aquifers is controlled by the vertical permeability and thickness of the clay aquicludes and head differences.

Tritium analysis and radiocarbon dating indicate that groundwater moves at only several metres per year.

Due to the lack of long-term monitoring of the potentiometric surface and the geological complexity, aquifer recharge and discharge cannot be estimated accurately. With that caveat, water balance calculations suggest that expansion of groundwater utilisation is viable, especially close to the Ayeyarwady River. However, issues of appropriate hydrogeological locations and aquifer sustainability need to be considered in any basin-wide water planning and management strategy. Groundwater and surface water need to be viewed as one integrated resource and mutually interdependent.

Water quality

Groundwater salinity is strongly controlled by the mode of sediment deposition and geological structure of the aquifers. Although variation in quality occurs over short distances, groundwater salinity is quite predictable. Low salinity usually occurs within the Quaternary Alluvium and Irrawaddy Formation aquifers.

High concentrations of arsenic occur in the Ayeyarwady River alluvial sediments and the Lower Samon Chaung. There is no evidence of arsenic in Mu and Chindwin Rivers, based on a limited number of samples.

Testing for other contaminants in groundwater is not common. The few analyses available show that elevated levels of dissolved metals occur, some exceeding WHO standards.

Elevated groundwater temperature is found in deep aquifers along the Sagaing Fault, indicating magma intrusion.

Approximately 25% of households living in this region do not have access to safe sanitation, and bacterial contamination of shallow groundwaters in the vicinity of villages is a potential threat. Oilfields in the Magway and Minbu Districts pose a potential threat of groundwater contamination; however, analysis of four wells in the Mann oilfield at Minbu found no evidence of contamination.

Human use and ecosystem value

Groundwater is critical to livelihoods in the Central Dry Zone, with more than 70% of people depending on groundwater for drinking and domestic use. Communities access groundwater for domestic and irrigation supplies through wells of different types. Villagers without tubewells collect small quantities of water from distant, shallow dugwells and polluted earth ponds. The water shortage contributes to waterborne and related diseases. Shallow dugwells and tubewells with hand, air, and solar pumps are common for domestic supplies. Tubewells with diesel centrifugal pumps are more common for irrigation purposes. Shallow dugwells, in many areas, dry out as the regional groundwater level drops during the dry season, and village use shifts to tubewells. National, international, and NGO funds have conducted numerous drilling activities.



The Lower Ayeyarwady includes major agricultural areas, with more than 80% of production being rainfed. Land cover mapping showed that 315,000 ha are irrigated, largely sourcing water from the Ayeyarwady River. Water access is limited to the areas close to the river or canals, and operational problems mean that water delivery is unreliable. Many farmers in the GWZ use groundwater that is accessed through individually-managed tubewells. The Government of Myanmar has invested in groundwater irrigation schemes. Small-scale irrigation also takes place from thousands of shallow, small-diameter tubewells equipped with centrifugal pumps. Artesian and sub-artesian tubewells occur in some areas, mainly in the Piedmont Complex along the base of the Shan Plateau. Deeper tubewells are used to access the Irrawaddy Formation in some areas.

Mandalay, other towns, and many industries in the Central Dry Zone rely on groundwater for potable water supplies – some partially, most fully.

Several large alluvial plains are within KBAs and, in these cases, groundwater is likely to support ecosystems, particularly through dry season flow contribution. This is particularly true for the Ayeyarwady River, which is classified as high priority, and where groundwater contribution to baseflow has been estimated to be particularly important.

Summary of assets and issues

- Large reserves of low-salinity groundwater are available along the Ayeyarwady corridor.
- The water balance indicates that expansion of groundwater use appears viable, especially close to the Ayeyarwady River.
- Groundwater discharge from the Lower Ayeyarwady GWZ alone represents at least 20% of the Ayeyarwady River dry season baseflow – considering inputs from the upper basin, the total input could be much higher.
- Groundwater is important for village and urban supplies.
- Small artesian systems in the Piedmont Fringe of the Shan Plateau require careful management.
- There are high concentrations of arsenic in the alluvial aquifers along the Ayeyarwady River and Lower Samon Chaung River.

5.3.9 Ayeyarwady Delta GWZ

The Ayeyarwady Delta GWZ is bounded by the hills of the Rakhine Yoma in the west and the Pegu (Bago) Yoma in the east. Below Hinthada, a broad delta opens out, with a maze of distributary channels. The Ayeyarwady Delta divides into three zones: the tidal coastal front, a brackish estuarine zone, and a freshwater floodplain. These zones shift with seasons and tides, with intrusion of seawater most pronounced during the dry season. Paddy rice is cultivated across much of the delta, with varying degrees of irrigation and water management. The monsoon crop is rainfed but requires protection from saline intrusion through embankments, sluice gates, and drainage systems. Dry season cropping draws on irrigation from canals and from groundwater.

The delta is densely settled, with a total population of 15 million, including approximately 5.2 million in Yangon city. There is high groundwater potential in the area, and with growing industrial and agricultural use, it is likely to be an important resource in the future.

Geology and aquifers

The groundwater systems of the delta are constrained by the Pegu (Bago) Yoma hills in the east and the Rakhine Yoma in the west, formed of pre-Upper Miocene sedimentary rocks, which have undergone compression and block-faulting. The central delta is between 25 to 150 km in width and is flat. The plain is composed of recent and Quaternary fluvial sands, gravel, and clay deposits underlain by an important sequence of continental deposits (the Irrawaddy Formation).

The two major aquifer systems are the Quaternary Alluvium and Irrawaddy Formation, which together cover 93% of the Ayeyarwady Delta. The Quaternary Alluvium aquifer is made up of recent unconsolidated sediments. It varies in thickness and contains a number of unconfined, semi-confined, and confined aquifers of different thicknesses and yield in different areas. Alluvial fans in the vicinity of the hills of Rakhine Yoma, in the west, and Bago Yoma, in the northeast, might provide higher yields due to lower clay content.

The Irrawaddy Formation is composed of sandstones, sands, and gravels. Rather than being a single aquifer, it comprises a succession of sedimentary beds of varying extent and thickness. The thickness of the Irrawaddy Formation is approximately 3,000 m, and it could be expected that huge groundwater resources are available within this aquifer system.

Storage and recharge

Estimates, from the limited stratigraphic data, give potential volumes of storage in the order of thousands of cubic kilometres. These estimates give an insight into the quantity of water but are of limited value for groundwater management since the aquifer depth is great and recharge processes are poorly understood.

The lack of a continuum between the aquifers of the Lower Ayeyarwady and the Ayeyarwady Delta GWZs limits groundwater inflow from the north. Rainfall is the dominant source of recharge, either through direct infiltration in the delta or surface and sub-surface runoff from the Rakhine Yoma and Bago Yoma. In the lowlands, the presence of clays could make direct rainfall infiltration recharge limited and might restrict the opportunity for groundwater and surface water interaction.

Water quality

Arsenic contamination is an issue in the delta, notably in the upper Holocene Alluvium. Tubewells drilled between 10 to 60 m are the most likely to contain high levels of arsenic, with lower concentrations at greater depth. Deep aquifers may have elevated arsenic where poorly constructed tubewells allow leakage from upper aquifers.

Salinity affects wells in the Lower Ayeyarwady Delta due to seawater intrusion, while the Upper Ayeyarwady Delta is less saline. Salinity caused by seawater intrusion is an important issue in the Ayeyarwady Delta and is common to several deltas in the world. Salty and brackish water is found in the channels of the delta under tidal influence and in the groundwater systems. Catastrophic events, such as Cyclone Nargis, also cause seawater to flood and then infiltrate through the soil and contaminate shallow groundwater resources. As a consequence, wells located in the south of the delta are more affected than in the upper area. In some locations, populations rely exclusively on rainwater harvesting or shallow lenses of freshwater locally found above brackish groundwater. Elevated iron levels have been recorded, with at least 33% of tubewells having high iron concentration.

Bacterial pollution of shallow groundwater is common, because access to safe sanitation is low, particularly in the southern areas. Coupled with animal waste and poor sanitation, shallow groundwater is at risk of ongoing pollution. Other potential sources of pollution include industries in the Yangon area; however, no evidence of pollution from this source has been reported. Increasing agricultural intensification may create greater pollution through increased use of pesticides and fertiliser.



Human use and ecosystem value

In the Ayeyarwady Delta, 52% of households use groundwater for drinking and domestic water supplies. The Yangon city water supply uses a mix of surface water from reservoirs and groundwater from tubewells. The latter causes aquifer stress (with drawdown of up to 60 m), intrusion of saline water into shallow aquifers, and pollution from vertical seepage from industrial and urban wastewater. Irrigation in the delta comes mostly from surface water. There are no reliable estimates of current groundwater use for agriculture.

Groundwater is expected to play an important role in supporting ecosystems in the delta due to the low, flat topography; shallow groundwater levels; and deltaic geomorphology. Five KBAs are located in the groundwater-reliant mangrove forest and are recognised as high priority for conservation.

Summary of assets and Issues

- A large resource of high-yielding, low-salinity groundwater could be available in the Irrawaddy Formation underlying the Ayeyarwady Delta.
- There is potential for much greater use of groundwater.
- Salinity intrusion generally affects groundwater quality in shallow aquifers in the Lower Ayeyarwady Delta.
- Arsenic contamination occurs in shallow tubewells. Testing of all new wells is essential.
- Faecal contamination occurs, particularly in the 0 to 10 m range.
- Recharge dynamics in the delta are poorly understood. If most of the recharge is from the Rakhine Yoma (rather than the Ayeyarwady River), the renewable resource may be much more limited than the storage volume.

5.4 Status and Trends

This section summarises groundwater status and trends with respect to quantity, quality, abstraction, ecosystem support function, and groundwater management and institutions.

5.4.1 Quantity

Overall, a large volume of groundwater is held in storage in the aquifers underlying the Ayeyarwady Basin, mostly within the productive Quaternary Alluvium and Irrawaddy Formation aquifers. Recharge is dominantly from direct rainfall.

Unregulated flow from artesian tubewells in the Pale Sub-basin has resulted in loss of groundwater pressure. Without appropriate management and regulation of groundwater, this pattern is likely to recur in other artesian areas.

Radioisotope dating across the Ayeyarwady Basin would be of value for understanding recharge rates and patterns, as demonstrated by the limited data available for the Central Dry Zone.

Land cover in Myanmar has changed significantly over the last 50 years. Forest loss and degradation has been widespread, particularly in the dry forests around the margins of the Central Dry Zone. At the same time, crop area increased by more than 20,000 km². The impacts on total recharge are difficult to predict. Increased crop area should increase recharge, but the loss of forest cover in sloping lands may result in increased runoff and decreased infiltration.

Impacts of climate change on recharge are similarly difficult to quantify; consequently, it is not clear what the overall impacts on recharge will be.

The quantitative status of groundwater resources should be monitored using regular measurements of static water level or pressure in wells as an indicator of availability and resource depletion. Seasonal monitoring of water levels provides immediate, local information on the impacts of pumping. A network of wells, monitored over time, can build an understanding of the regional and long-term dynamics, particularly when combined with groundwater models. Monitoring networks should be designed considering the aquifer conditions and patterns of withdrawal. Although critically needed for sustainable management, there is currently no coordinated long-term well monitoring program in Myanmar.



5.4.2 Quality

With the exception of salinity and arsenic, water quality issues are mainly localised, responding either to local geological conditions or local human pressures (such as faecal contamination).

In the Pegu Group, pumping from freshwater aquifers may cause groundwater from nearby saline aquifers to flow toward the pumped zone. Variations in salinity in the Central Dry Zone have been studied in detail, identifying zones with high probability of brackish water. Saline intrusion of seawater occurs in unconsolidated sediments in the delta. Irrigation-induced salinity is not widely reported in Myanmar, although use of marginal-quality groundwater has resulted in problems in some areas. These issues are directly related to human pressures placed on groundwater systems.

Elevated arsenic levels are observed in aquifers in recent (Holocene) alluvium in the Ayeyarwady River, particularly in the delta but also in other areas. Elevated arsenic is not found in the Chindwin and Mu Rivers. Because of the strong geogenic control, no trend in arsenic occurrence is expected over time, and the current practices of drilling deeper or changing location for contaminated wells (for local drillers) can be effective in preventing exposure to arsenic. Testing of wells for arsenic, before use, is critically important and should be mandatory for all new wells.

There is insufficient data to accurately describe the status and trends of most sources of anthropogenic groundwater contamination. Currently, there is no systematic monitoring of groundwater pollution from industry, mining, or agriculture, and little monitoring of bacterial contamination. However, it is likely that the risk of contamination from anthropogenic sources is widespread and increasing.

5.4.3 Abstraction

To monitor sustainability of groundwater use, an estimate of total withdrawals is a key indicator, but the extent of use is difficult to quantify accurately. Groundwater use is unregulated, with no requirement to register wells or report withdrawals. As a result, estimates of intensity of abstraction and calculation of the total volumes per GWZ have been made using different assumptions to provide upper and lower bounds for extraction (Table 5.4).

Table 5.4 - Comparison of total abstractions and recharge in groundwater zones

	Recharge (km ³)	Total abs. low (km ³)	Total abs. low (% of R) ¹	Total abs. high (km ³)	Total abs. high (% of R) ¹
Upper Ayeyarwady	1,156	0.015	1%	0.027	2%
Upper Chindwin	3,721	0.026	1%	0.070	2%
Western Hills	0.556	0.022	4%	0.071	13%
Lower Chindwin	2,068	0.307	15%	0.321	16%
Mid Ayeyarwady	5,176	0.84	2%	0.235	5%
Shan Plateau	Not determined	0.154	Not determined	0.124	Not determined
Mu	3,032	0.110	4%	0.671	22%
Lower Ayeyarwady	5,750	0.653	11%	1,894	33%
Delta	6,093	0.518	8%	0.715	12%
Total/average	27,552	1,890	7%	4,128	15%

¹Abstraction as percentage of estimated recharge

Domestic use

Groundwater is the primary source for domestic and drinking supplies for more than 50% the population nationally. In rural and remote areas, this proportion is much higher, with almost 67% of the rural population drawing drinking water and village water supplies from wells.

There is no nationally-consistent data on groundwater abstraction for domestic use. Using 2014 Census data on the proportion of population using groundwater, the current estimate is 1.004 km³/yr, of which approximately 70% is from the Lower Ayeyarwady and Ayeyarwady Delta GWZs. This is based on MOALI's assumption of the per capita use of 135 L/day in rural areas and 150 L/day in urban areas. This is relatively high compared to estimates of rural use in other countries in the region and probably overestimates domestic demand. However, as the population grows, and pumping technology improves, groundwater extraction is increasing and is likely to continue to do so. The important exception may be in Yangon, where urban development plans recommend a shift away from groundwater.

Industrial use

Large water-using industries, such as sugar, paper, and cement, use surface water. Towns and cities rely on groundwater wells to support smaller industries. Estimated total extraction for industrial use is 0.153 km³/yr, almost entirely in the Lower Ayeyarwady and Ayeyarwady Delta GWZs. As with domestic, this use is likely to be increasing due to population growth and changes in technology, but perhaps partly offset by newly developed industrial zones providing centralised services, including water.

Mining

Groundwater is used in the mining sector in mineral and oil extraction, but data on the extent of use for mining is almost non-existent. Future use for mining could grow significantly, because there is a high potential for expansion in the oil and minerals sectors, which are likely to rely on groundwater.

Agriculture

As with other sectors, there are large uncertainties in attempting to estimate groundwater use for agriculture in Myanmar. There are currently no records collected on the number or size of privately-drilled wells and even estimation of the area irrigated is problematic. Based on several assumptions and sources of information, a range for current total annual withdrawals for the Ayeyarwady Basin is 0.536 to 2.325 km³/yr. What can be reported with confidence is that groundwater demand for irrigation in the Ayeyarwady Basin is increasing. A major constraint on expansion of groundwater pumping has been the costs involved, such as investment in wells, pumps, and energy. Solar pumping is gaining ground as a cost-effective method of accessing shallow groundwater and could accelerate the existing trend for adoption of farmer-managed groundwater pumping.

Results indicate that total groundwater extraction in the Ayeyarwady Basin is in the order of 13% of current recharge, ranging from minimal use in the Upper Catchment (2%) to as much as 33% in the Lower Ayeyarwady (Figure 2.3).



5.4.4 Ecosystem support values

Shallow groundwater and surface water are dynamically interconnected by recharge and discharge processes. Where groundwater tables meet the surface, groundwater can play an important role in aquatic ecosystems, providing a proportion of water to support springs, marshes, and streams. The relative contribution of groundwater and surface water may vary seasonally. In a monsoonal climate, such as in the Ayeyarwady Basin, baseflow in rivers during the dry season may be substantially groundwater-derived. Conversely, wetlands and streams may act as recharge zones to replenish shallow groundwater.

Pending further research, indications are that the Upper Chindwin, Middle Ayeyarwady, and Ayeyarwady Delta GWZs represent the most important areas in terms of groundwater ecosystems support function, because they host KBAs that are highly reliant on groundwater and are considered of high priority for conservation. The Lower Ayeyarwady GWZ hosts 20 KBAs, although some are small areas, of which 50% have a high or average level of groundwater reliance.

The important conservation values of wetlands have not been fully recognised in land use planning in Myanmar, and a large percentage of wetlands and mangroves in the Ayeyarwady Basin have been lost or degraded, through clearing, drainage, and conversion to farming land. This is particularly true in the delta, where the area of mangrove forest has declined from more than 2,600 km² in 1978 to less than 1,000 km² in 2011.

5.4.5 Groundwater management and institutions

There is no specific legislation or regulations specifically directed to monitor and manage the groundwater resource. Multiple government agencies are involved in water development and management, but there is no single authority responsible for groundwater management.

Existing laws appear to give proprietary rights for groundwater to the landowner. Groundwater is still perceived as an individual's property and is exploited inequitably and without any consideration to its sustainability. The *Burma Underground Water Act of 1930* mandated the collection of information to manage underground water supplies and to prevent aquifer contamination, with guidelines and procedures for groundwater litigation problems. It appears that all of the databases have been lost and the Acts and regulations have been abandoned.

There is an urgent need to establish coherent groundwater monitoring and management systems tailored to the different contexts in Myanmar. As a starting point, there needs to be a clear definition of the low-salinity groundwater resource in terms of volume, storage, and availability. This baseline can provide a starting point for setting limits for sustainable extraction.

Regulation and monitoring of industries and human activities is critical to the management of groundwater resources. Lack of groundwater legislation and regulation is a major hurdle. Although it is identified as a priority in the *National Water Policy*, establishing a suitable institutional and legislative base for groundwater management will take time and political will.

5.5 Conclusions

This report summarises the current understanding of the significance and role of groundwater in the Ayeyarwady Basin, and it presents some quantitative and semi-quantitative indicators to describe the status and dynamics of the resource.

Because measurements of groundwater flow and levels are available only in limited areas, quantification of the resource at a basin scale relies on assumptions and represents order of magnitude estimates. While the overall patterns and relative size of different components are likely to be robust, it is critically important that all estimates and indicators be seen as first-pass approximations and used with appropriate caution. The exception is the Central Dry Zone, where a large body of data and experience of local and international hydrogeologists is presented with high confidence.

The study confirms the existence of a sizable renewable groundwater resource within the Ayeyarwady Basin. Current extraction across the basin is 13% of the renewable resource on average, with the largest use in the Central Dry Zone. This seems to be well within the bounds of sustainable use and suggests that there are important opportunities to expand groundwater development. Detailed hydrogeological investigations in the Central Dry Zone have identified large areas with high-yield, low-salinity groundwater suitable for irrigation use. Potential areas for expansion in the Ayeyarwady Delta, Shan Plateau, and the upper reaches of the Ayeyarwady Basin will require similarly detailed hydrogeological mapping.

In planning and implementing expansion of groundwater use, it is essential that issues of aquifer sustainability are considered as well as broader social, economic, and environmental concerns, such as ownership, community expectations, impact on dry season surface water availability and environmental demands, and the needs of future generations.



Although estimates of agricultural use have high uncertainty, it seems that volumes of groundwater withdrawn for irrigation now approach or surpass volumes for domestic supply. This is an important shift and brings new management challenges to safeguard domestic supplies.

Throughout the Ayeyarwady Basin, groundwater flow direction is predominantly toward rivers and streams. Groundwater discharge contributes significantly to dry season flows both in the intermittent chaungs of the Central Dry Zone and the Ayeyarwady mainstream. The importance of these flows for livelihoods and for ecosystems must be given serious consideration in future planning. The Upper Chindwin, Middle Ayeyarwady, and Ayeyarwady Delta host KBAs that are highly reliant on groundwater and are high priority for conservation. However, given the complexity of the interactions and the scarcity of groundwater resources data, there is an urgent need for further research into the importance of groundwater for ecosystem support in each GWZ.

A significant component of current withdrawals within the Lower Ayeyarwady, Lower Chindwin, and Mu GWZs is from artesian wells, which flow freely year-round. Productive use from these wells may be as low as 10% of the flow. Substantial savings could be made through capping and appropriate management of these wells.

Estimates of groundwater storage in the Ayeyarwady Basin indicate an enormous volume in the order of 2,000 km³. However, current annual recharge is less than 1.5% of this. Radiocarbon dating indicates that this resource has accumulated over a long period and may represent a “fossil” resource, with minimal replenishment. In addition, much of this volume may not be technically or economically accessible. Planned exploitation should work within the limits of the renewable resource until resource dynamics are more fully understood.

Water quality constrains groundwater use over large areas of the Ayeyarwady Basin. High levels of arsenic are a risk in the recent (Holocene) alluvial aquifers, though the problem seems to be limited to the sediments of the Ayeyarwady mainstream and does not affect the Chindwin and Mu Rivers.

Salinity is mostly associated with aquifers of the marine Pegu Group sediments and with intrusion of seawater in the delta. Isolated occurrence of elevated fluoride, uranium, and metals are found in specific geological contexts, but data are scarce.

In general, geogenic contaminants cannot be managed, and users can only be protected by identifying contaminated sources and either restricting access or treating the water before use.

Anthropogenic pollution of shallow groundwater from industry, sewage, mining, and agriculture is an increasing risk, although little information is available on the actual extent and severity. Man-made pollution can and should be managed and mitigated. Protection of shallow aquifers is an important priority, given the high dependence on groundwater for domestic supply.

There are two critical gaps in management of groundwater in the Ayeyarwady Basin:

- The first is the paucity of basic data on groundwater status and use, the absence of systematic documentation of wells or extractions, and measurements of water levels and water quality. These data would provide the basis for setting, monitoring, managing, and enforcing sustainable limits to groundwater extraction for each aquifer region. National groundwater quality standards need to be established to ensure that water is fit for purpose. Recommendations for monitoring and terms of reference for a national monitoring system are presented within the full assessment report on the groundwater resources of the Ayeyarwady Basin).
- The second critical gap is the lack of any legislative or regulatory framework for groundwater management. Establishing a suitable institutional and legislative base for groundwater management is a priority in the National Water Policy (NWRC, 2014), but this will require both political will and community commitment to formulate and implement.

GEOMORPHOLOGY AND SEDIMENTS



HIGHLIGHTS – GEOMORPHOLOGY AND SEDIMENTS



- The overall finding is that the geomorphology of the Ayeyarwady River is in moderate to good condition, owing to the lack of regulation of the mainstream and the flow and sediment inputs from the remaining unregulated tributaries.
- The geomorphology of the Ayeyarwady is controlled by the unique geological and tectonic setting of the river, combined with the variable hydrology across the Ayeyarwady Basin and land use impacts.
- Sediment transport in the Ayeyarwady Basin is characterised by fast sediment delivery from steep tributaries combined with the slow movement of material through the low-sloped Ayeyarwady; consequently, sediment transport is like two conveyor belts moving at different speeds.
- Sediment input has been altered due to land use changes that increase the delivery of sediment to the river, especially in the Sagaing Fault Zone, which is highly modified by mining activities, and in the Central Dry Zone, where episodic rainfall events can deliver large volumes of sediment to the system.

- Trend analysis completed on land and river use changes shows accelerating rates of land disturbance associated with deforestation and mining. These localised land use changes have a high likelihood of increasing sediment inputs at discrete points in the river.
- The trend analysis for hydropower found that the past level of hydropower development was moderate, but the number and size of projects under development and planned over the next two decades reflects a large increase in the potential river fragmentation and regulation of the river.
- Planned development of numerous mega-dams have the potential to dramatically alter the flow of rivers and trap large volumes of sediment.
- The concentration of hydropower in the Upper Ayeyarwady presents an additional risk, because this area provides a large proportion of the flow in the river, so flow regulation will have basin-wide impacts. There is evidence that hydropower regulation has altered flows in the Middle Ayeyarwady, but the data, upon which the analysis is based, are of low quality.



HIGHLIGHTS – GEOMORPHOLOGY AND SEDIMENTS

- Less clear are the trends in irrigation due to a lack of information, but the focus on economic growth and investment in Myanmar and the importance of agriculture to the economy suggest that regulation for irrigation is likely to increase in the future.
- The present rate of sand and gravel extraction is near or beyond the bounds of sustainability (recognising the lack of a reliable sediment budget).
- The resilience of the Ayeyarwady Delta may be decreasing with increasing erosion being recorded near the mouths of the distributaries.



- If land use changes continue to increase at the present rates of change, additional geomorphic impacts to the river are inevitable and will affect the ecological and social uses of the river system.
- The primary recommendation is to implement sediment and geomorphic monitoring and interpret the results in a catchment context.
- An approach for a sediment monitoring system that collects representative and accurate information is presented as a starting point for discussion.



6. GEOMORPHOLOGY AND SEDIMENTS

6.1 Introduction

This chapter provides an overview of the status and trends of key characteristics of the geomorphology and sediment dynamics of the Ayeyarwady Basin and outlines the implications for the Ayeyarwady Basin system. A conceptual design is recommended for a sediment and geomorphic monitoring program on the Ayeyarwady River.

SOBA Technical Reports

This chapter is a synopsis of the full assessment, which may be accessed by readers seeking more detailed information, including references:

WWF Greater Mekong (2017), *Sediments and Geomorphology* (SOBA 3), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

6.2 Ayeyarwady Setting

The character of the Ayeyarwady River is strongly dependent on the geological and tectonic features of Myanmar. The river catchment is developed on the active collision zone between the Indian Plate to the west and the Eurasian Plate to the east, with the course of the river, sediment types, and sediment input rates all influenced by this unique setting (Figure 6.1). The northern half of the Ayeyarwady Basin is roughly divided in half by the active Sagaing Fault. East of this collision zone, the geology is characterised by older resistant crystalline igneous and metamorphic rocks, including the Shan Plateau, the southernmost extension of the Tibet Plateau. West of the Sagaing Fault, the geology consists of relatively young, thrust and faulted rocks, where high rainfall has led to deep weathering of the tectonically weakened strata. This area is drained predominantly by the Chindwin River, the largest tributary of the Ayeyarwady, and a major contributor to the sediment load of the Ayeyarwady Basin. Downstream of the confluence, the river continues to flow through this younger 'western' style geology before reaching the wedge-shaped, flat-laying, depositional Ayeyarwady Delta.

The variability of rainfall in the Ayeyarwady exerts a strong control on the geomorphic processes operating in the system. In the headwaters and along the western ranges of the Chindwin River, monsoonal rainfall patterns dictate the flood pulse flow pattern of the system. In the lower Chindwin and Lower Ayeyarwady, rainfall is much lower due to the area being in a rain shadow, but the episodic high rainfall events that do occur are important

for transporting large volumes of sediment from this arid landscape to the rivers. The characteristics of the river system were used to identify geomorphic zones within which sediment transport processes are considered to be similar (Figure 6.1).

The characteristics of the Ayeyarwady River include steeply sloping headwater and tributary rivers, but an overall low (although variable) slope to the river downstream of the confluence of the Nmai Hka and Mali Hka Rivers. The width of the Ayeyarwady reflects the landscape, with predominantly broad alluvial valleys joined by single channel reaches where it cuts through resistant strata. The variability in river slope and valley width combines to control the transport and deposition of sediment along the river and accounts for areas of the river in which sediment reworking and active channel migration occur.

6.3 Catchment Activities Affecting Geomorphology

Land and river developments affect the geomorphology of rivers by altering the pattern and/or quantity of flow and sediment entering the river. Land use changes were identified and, where possible, quantified. These changes are associated with deforestation, mining, hydropower, irrigation, and the extraction and dredging of sand and gravel in the Ayeyarwady. Deforestation and terrestrial mining can increase sediment inputs to rivers due to land disturbance. Large areas of the Ayeyarwady have been and continue to be affected by these activities (Figure 6.2), and observations suggest there is a high likelihood that the characteristics and volumes of sediment entering the river are being altered by these activities.



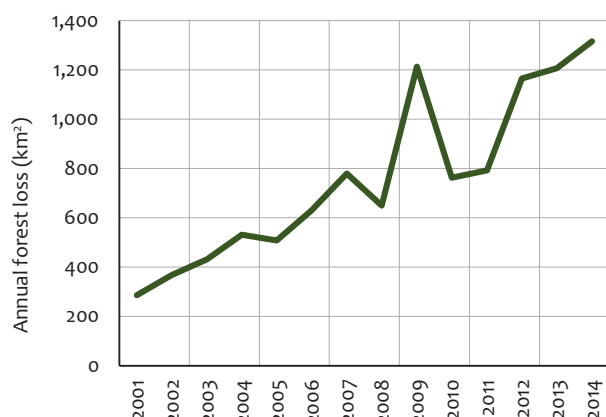


Figure 6.2 - Increasing rates of deforestation in the Ayeyarwady
(Hansen et al. 2013)
Mining derived from satellite image analysis completed by project researchers

Hydropower and irrigation activities can alter the flow regime of rivers and affect sediment budgets by reducing sediment inputs and altering sediment transport patterns. The present scale of these activities (Figure 6.3) is likely to be resulting in some modification of flows and reduction in sediment loads, as evidenced by geomorphic changes to the channel characteristics of tributaries. Present hydropower development is largely focused in the Upper Ayeyarwady, with irrigation developed in the Lower Ayeyarwady. The relative impact of these activities was not able to be determined due to a lack of information regarding irrigation impoundments and operating regimes.

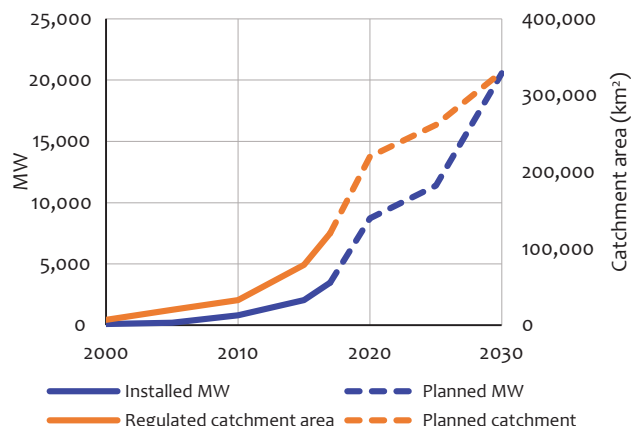


Figure 6.3 - Existing and planned hydropower projects in the Ayeyarwady
(IFC, MOEE, and MONREC, 2017)
HP-Hydropower; MW-Megawatts

Satellite image analysis was combined with ground-based surveying of sand and gravel distributors to ascertain the locations, methods, and volumes of construction materials extracted from the river. The investigations focused on the lower river near large population centres and documented extraction rates of approximately 10 Mt/yr of sand and gravel based on the responses of survey participants (Figure 6.4). The actual volumes extracted are higher than this value, due to the large number of operators, including those upstream of Mandalay/Sagaing, who were not accounted for in the survey, and the number of operators who did not report volumes. A back of the envelope comparison of possible bedload volumes transported by the river suggests that extracting >10 to 20 Mt/yr of material from the river carries a high risk of having a geomorphic impact on the system. The recent concerns expressed by local communities about riverbank erosion in areas exploited for sand and gravel mining are consistent with these findings, as are recent investigations concluding that the resilience of the delta may be decreasing with increasing erosion recorded near the mouths of the distributaries.



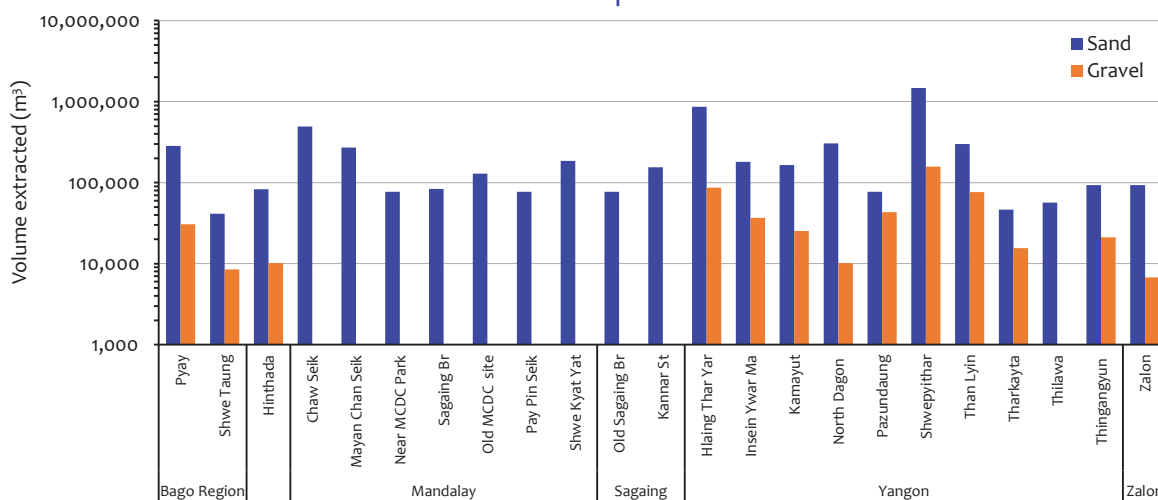


Figure 6.4 - Summary of volumes of sand and gravel extracted from different areas based on the survey results

The length of operations of the distributors included in the survey ranged from 1 year to 37 years, with the average values for each township

6.4 Sediment Transport and Characteristics

Sediment delivery is governed by several processes in the Ayeyarwady. The monsoonal rains induce a large seasonal input of sediments from the upland areas throughout the catchment. In the Central Dry Zone, the episodic rain events result in pulses of material entering the river at uneven intervals. Land use activities, such as mining and forestry, also contribute to pulses of material entering the river. These processes combine to result in a complex sediment transport system characterised by both a relatively constant sediment input superimposed by episodic high-input events. The geology of the catchment affects the sediment composition, with the more resilient crystalline rocks in the western basin producing predominantly sands, and the softer sediment-rich strata of the western basin producing predominantly silt-sized material.

Field observations and investigations documented the grain-size characteristics of sediment moving through the system, and identified key areas of sediment input, transport, and deposition. The Ayeyarwady is not only a flood pulse system with respect to flow, but is also a sediment pulse system. The investigations found that the alluvial banks of the river are dominated by fine to medium sand and the bed of the river is dominated by medium to coarse sand. There is a general trend of coarser sediment size downstream, which is unusual in rivers. This is shown on Figure 6.5, where the percentage of fine sand decreases, and medium and coarse sand increases, with distance downstream. Based on field observations and the sediment data, it is suggested that the increased presence of coarse sand and gravel is attributable to: sediment input from the Sagaing Fault zone, where mining activities have altered the landscape and sediment budgets of the tributaries; and from the Lower Ayeyarwady in the Central Dry Zone, where episodic high rainfall events are likely to transport large volumes of material from the arid exposed landscape. Coarse-grained inputs from the Chindwin are also likely, but the sediment results did not reflect a major shift in grain-size immediately downstream of the confluence.

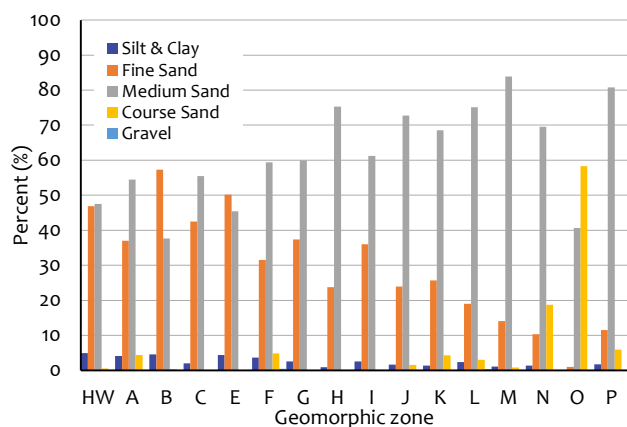


Figure 6.5 - Grain-size distribution of active banks by geomorphic zone

Geomorphic zones are shown on Figure 6.7

A conceptual model of sediment transport includes a relatively steady input of sediment from high-rainfall areas in the Ayeyarwady and Chindwin headwaters overlain by episodic inputs of high volumes of sediment from the Central Dry Zone, and areas disturbed by mining and forestry. The steep nature of the tributaries promotes rapid delivery of sediment into the mainstem Ayeyarwady, with transport within the Ayeyarwady dependent on high flows due to the low slope of the river channel (Figure 6.6). Within the Ayeyarwady, the variable but generally low slope of the river results in sediment pulses that are transported through some areas of the river, but stored in other areas. This is especially relevant when land use activities such as mining produce coarse-grained sediments that require high river energy for transport, thus limiting the window for these materials to move through the system to peak flow times. The progressive implementation of hydropower and irrigation impoundments that have the potential to reduce these peak flow periods poses long-term risks to sediment transport in the river. In turn, areas that become choked with sediment can experience bed aggradation and high rates of channel migration, increased river braiding and bank erosion. Understanding the inseparable linkages and feedback between land use, sediment characteristics, and transport are fundamental to the long-term sustainable management of the river, and highlight that management of the river is contingent on management of the land (Figure 6.6).

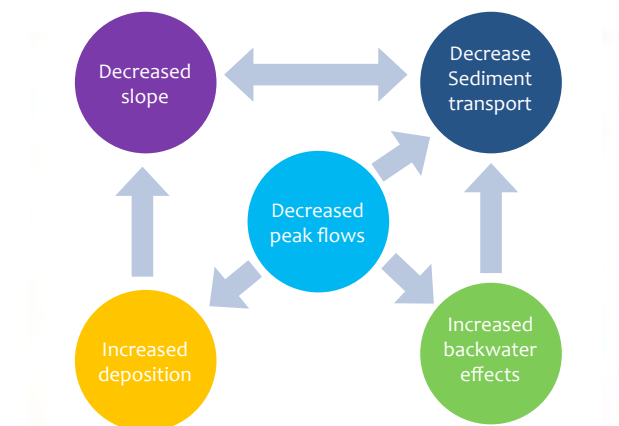
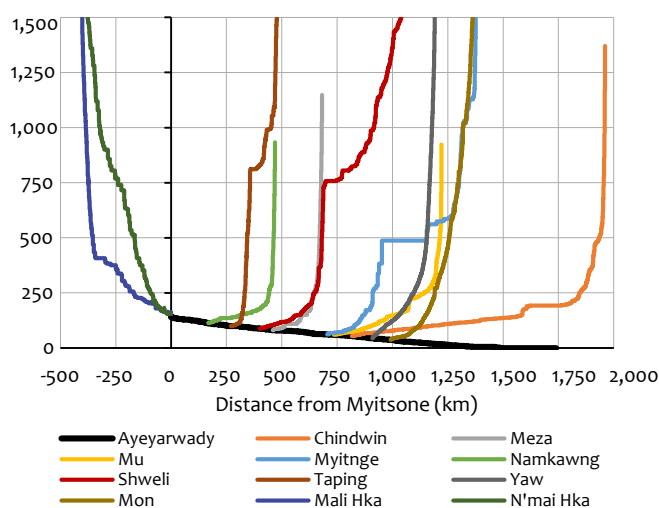


Figure 6.6 - Slope of the Ayeyarwady and major tributaries (a), and potential feedback mechanisms leading to increased deposition in the river channel (b)

The slope of the Ayeyarwady is shown by the solid dark line on the graph. See Figure 6.7 for the location of the geomorphic zones

A hypothetical sediment budget for fine- and coarse-grained sediments was derived based on the characteristics and distribution of physiographic and geomorphic units in the Ayeyarwady Basin. An overall sediment budget of ~220 Mt/yr was achieved, with approximately 50% of the sand derived from the Upper Ayeyarwady, and the remaining input split between the Chindwin and the Lower Ayeyarwady. A little less than 50% of the silt was derived from the Chindwin, with approximately 25% sourced from the Upper Ayeyarwady. The exercise highlights the different sediment yields required to satisfy the field observations and data regarding the provenance and abundance of silt in the Chindwin. These values should not be considered definitive, as the derivation of a reliable sediment budget suitable for use in management requires accurate and long-term monitoring of the river.

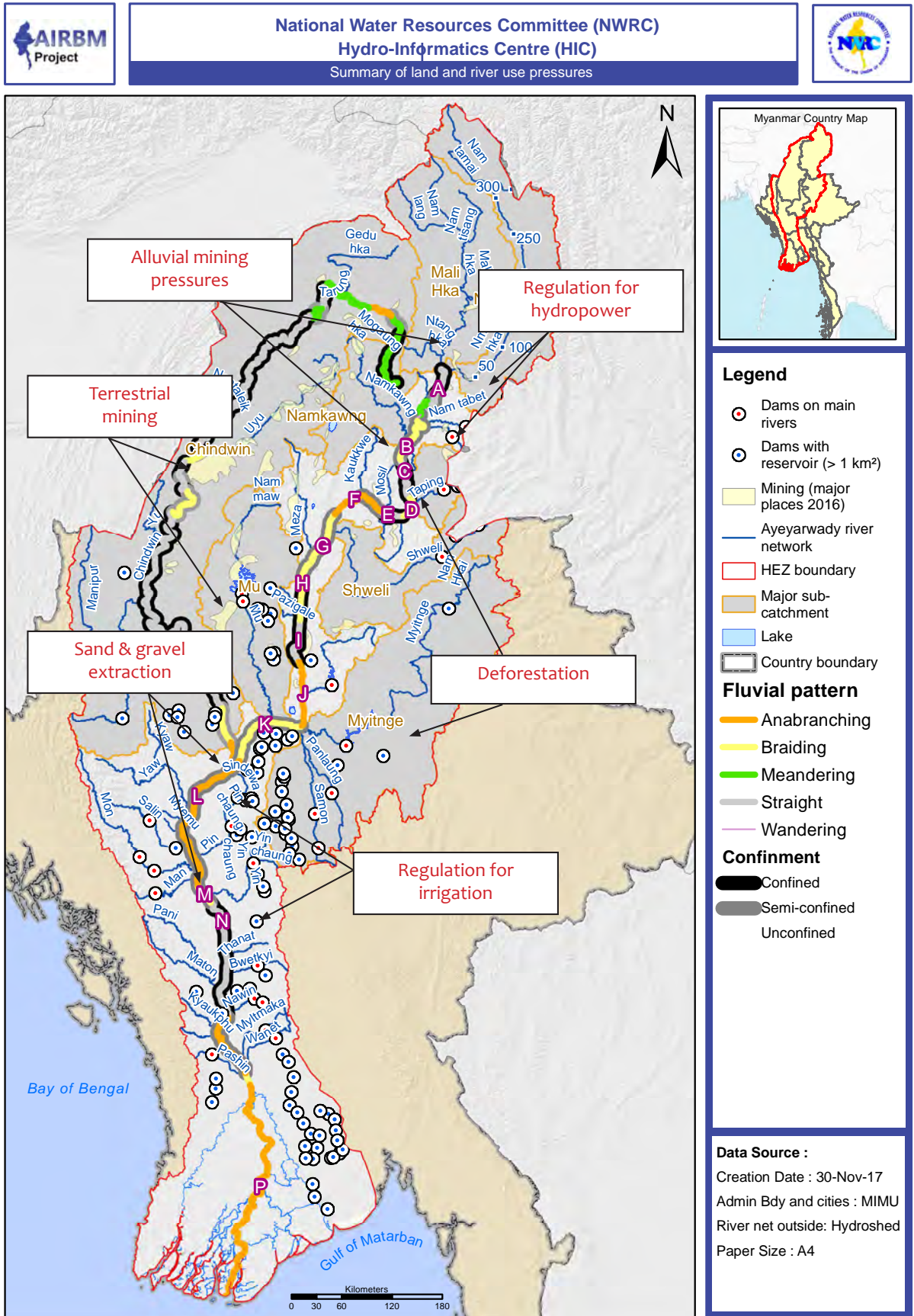


Figure 6.7 - Summary of land and river use pressures in the Ayeyarwady Basin

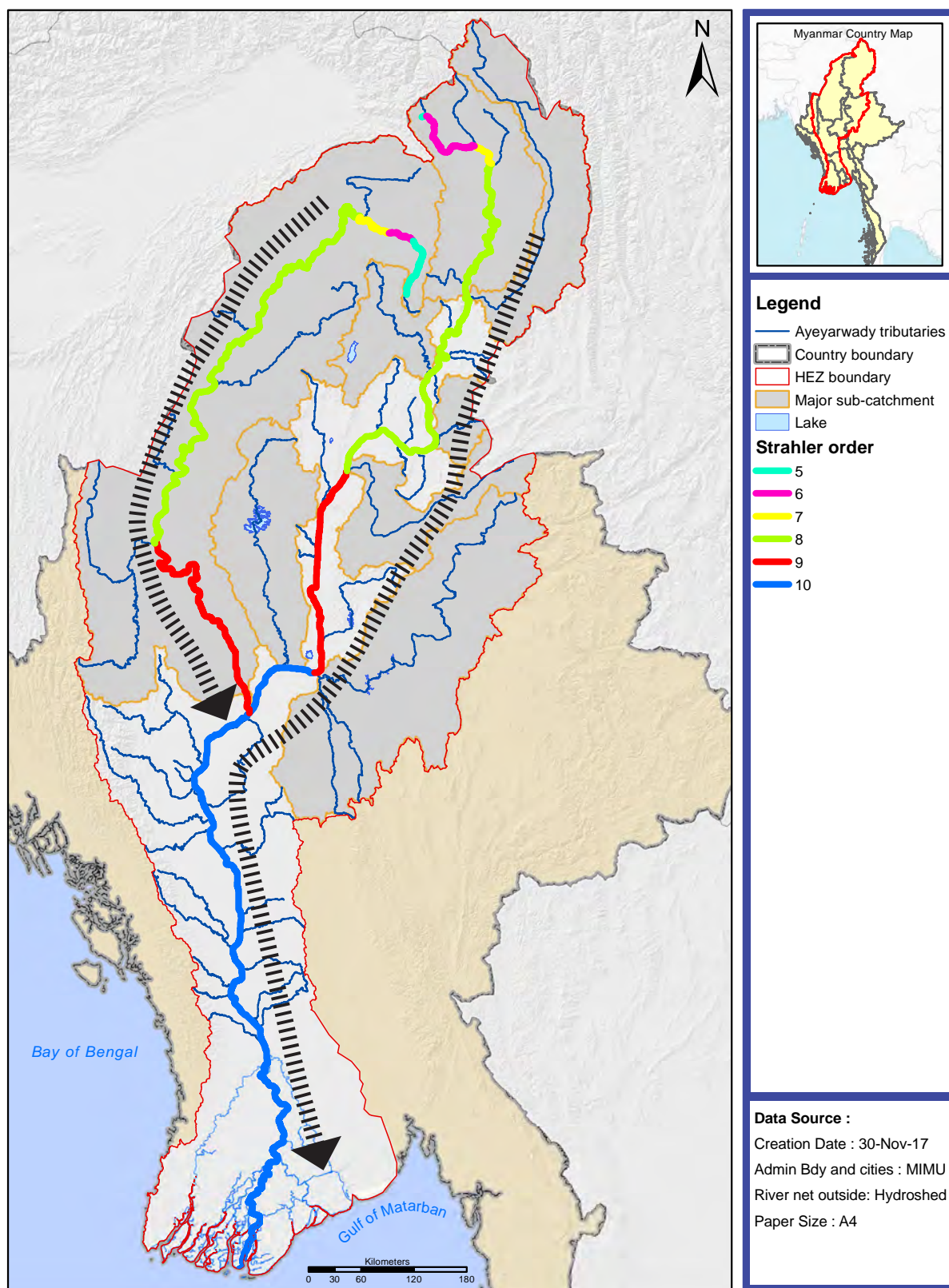


Figure 6.8 - Connectivity throughout the high Strahler Order rivers of the Ayeyarwady

Strahler Order is a measure of the complexity of river systems based on the number of tributaries feeding into a river reach

6.5 Issues Related to Geomorphology

6.5.1 Overview of issues and risks

All physical aspects of the Ayeyarwady River and its catchment are related to the geomorphology and sediment transport of the river. Rivers will adjust to any change to the magnitude, frequency, duration, rate or seasonality of water or sediment inputs. These adjustments include changes to the elevation or slope of the riverbed, alteration to riverbanks (erosion or deposition), changes to the shape of channels and mid-stream bars, and even changes to the large-scale course of the river. Under natural conditions, rivers continually adjust to the inherent variability of interactions between the climate and the landscape. The dynamic equilibrium between the land and climate creates an ever-changing riverscape that hosts a wide variety of physical attributes that underpin the habitats supporting biological diversity. Any change to the physical (land use, tectonics, and channel alterations), climatic (climate change, and the El Niño Southern Oscillation), or hydrological attributes (flow regulation, irrigation, and alteration to runoff and infiltration) of a river will alter the geomorphology and sediment transport processes occurring within the system.

Landscape and hydrologic changes alter rivers continuously, but these natural responses are considered impacts when they alter the way that humans use and interact with river systems. Changes such as bank erosion, channel filling or deepening, delta instability, or subsidence are all geomorphic changes that reflect the natural response of the river system, but can also affect the ecological, social, economic, and cultural uses of the waterway. The three broad, overlapping categories of geomorphic issues and risks identified for the Ayeyarwady are described next.

Bank and channel morphology and stability

The physical attributes and condition of the banks and bed are important for maintaining the connectivity of the river channel, and for supporting and protecting the infrastructure developed along the river (roads, bridges, irrigation pumps, and shipping facilities), as well as critical for safe and efficient navigation. The maintenance of bank stability and channel capacity is also vital for flood prevention and the continued connectivity between floodplains and river channels. The Ayeyarwady is recognised as a highly active waterway, and this work has mapped channel changes throughout the river. The geomorphic zones most susceptible to change are the broad alluvial areas with low slope in which sediment deposition and reworking are constantly occurring. This is especially the case downstream of higher slope and energy zones that can deliver large loads of sediment that cannot be easily mobilised through the wider, low-slope reaches. Indicators associated with monitoring and managing these issues include accurate flow and sediment measurements

(including grain-size), repeat channel cross-sections, and land use changes associated with deforestation, mining, sand and gravel extraction, hydropower, and irrigation (Figure 6.7).

Sediment transport and river connectivity

This second category overlaps with the first, but reflects a larger, basin-wide consideration of changes and connectivity. The continuous movement of material through the river controls the channel and bank characteristics and nutrient dispersal and availability, which have relevance to biodiversity, fisheries, and the important economic sectors of agriculture and construction. Nutrient transport is not a geomorphic process per se; however, the inextricable link between sediment and nutrients needs to be recognised and considered in basin planning. Monitoring the condition and sediment transport throughout the high Strahler Order rivers (Figure 6.8) is required to understand processes and, in turn, manage development in ways that maintain these important links. Long-term indicators are needed to monitor aspects of flow, sediment, channel, and nutrients.

Delta stability

The final category of major geomorphic risk is associated with the maintenance of the Ayeyarwady Delta. River deltas are the culmination of all processes occurring in the upstream catchment, and the interface between the terrestrial, fluvial, and marine environments. On a physical level, deltas are maintained by rivers, with physical stability and coastal productivity dependent on the continuous delivery of material from the upstream catchment. Deltas and resilient coastlines provide protection against floods and typhoons, host a wide range of ecological habitats, and provide fertile land for agriculture and coastal areas for urban development and recreation. Recent investigations of the Ayeyarwady Delta conclude that the resilience of the delta may be decreasing, especially near the mouths of the main distributaries (Figure 6.9).

Activities that have the potential to affect the geomorphology of the delta include the alteration of sediment supply due to trapping in upstream dams and sediment extraction, alterations to the pattern of flow delivery, including groundwater extraction, channelisation of the distributaries, and climate change.

Similar indicators for flow, sediment transport, land use, and channel change are required to understand the linkages between the river system and the delta. Monitoring should include cross-sections and channel long-sections through the delta and periodic assessment of changes to the delta front based on satellite imagery.

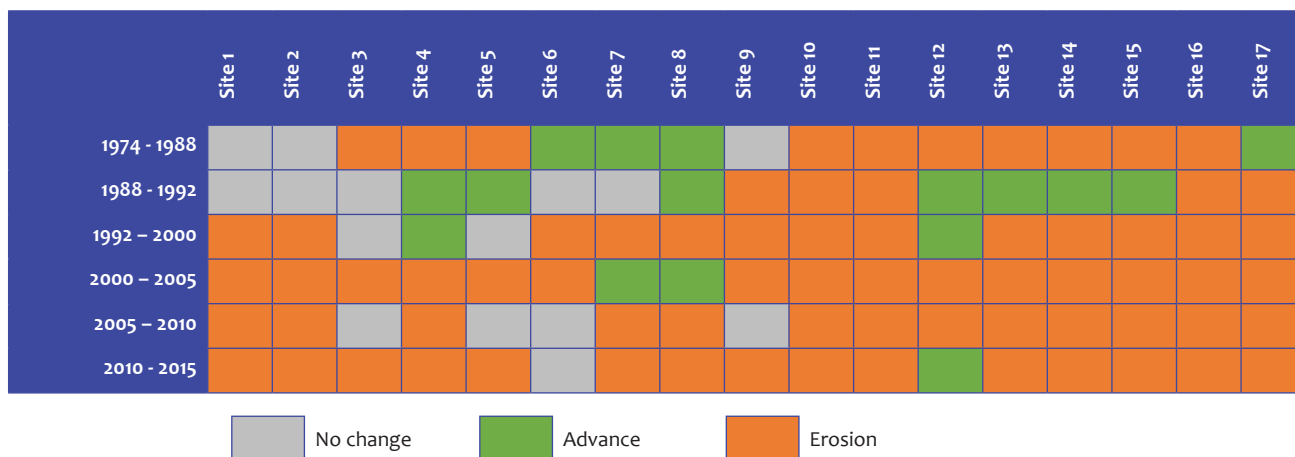


Figure 6.9 - Results of a vulnerability assessment of the Ayeyarwady Delta showing trends in erosion and advance
 Sites 10 through 17 are located at the mouths of the distributaries of the Ayeyarwady River; the other sites are located toward the east of the delta front (Anthony et al. 2017)



6.5.2 Trend assessment

The assessment of trends is outlined here in terms of: hydrologic changes; channel migration; flow regulation (hydropower); irrigation; land use changes (separately for deforestation and for terrestrial mining); sand and gravel mining from the river; coastline evolution and mangrove loss; and climate change and sea level rise. Completing a trend analysis for parameters such as flow and sediment transport was not possible due to the accuracy of the available monitoring results.

Hydrologic changes

Hydrology is a major driver of sediment transport and geomorphic change. Evaluating whether flow rates or the timing of flow delivery has been altered will assist in understanding whether and how geomorphic processes might change. For example, a decrease in peak flows has the potential to reduce transport of coarse sediment, resulting in channel aggradation. Because the flow records are considered to have a low reliability, water levels provided by the Department of Meteorology and Hydrology at the Sagaing and Pyay gauging stations were analysed for changes over the period of record (Figures 6.10 and 6.11). At both sites, there is a substantial increase in the frequency of low flow levels (200 to 400 cm at Sagaing and 1700 to 1800 bins at Pyay) in the 2006 to 2015 data compared to the earlier time periods, and a large decrease in the frequency of low to moderate flows (400 to 600 cm at Sagaing and 1900 to 2100 bins at Pyay). Both datasets also show reductions in medium to high flows in the 1996 to 2005 period.

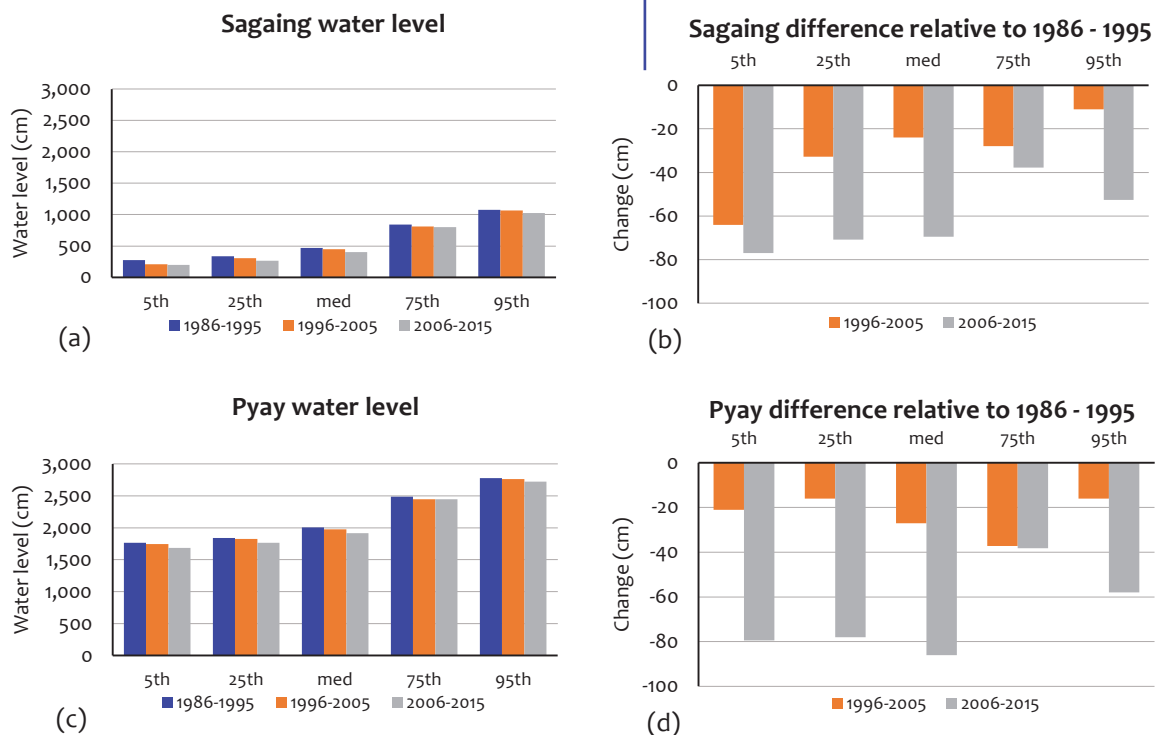


Figure 6.10 - Comparison of daily water levels at Sagaing (a and b) and Pyay (c and d) showing 5th, 25th median, 75th, and 95th percentile flows for each site, and the differences between the values between the groups

The top graphs represent Sagaing, while the bottom graphs represent Pyay (Department of Meteorology and Hydrology)

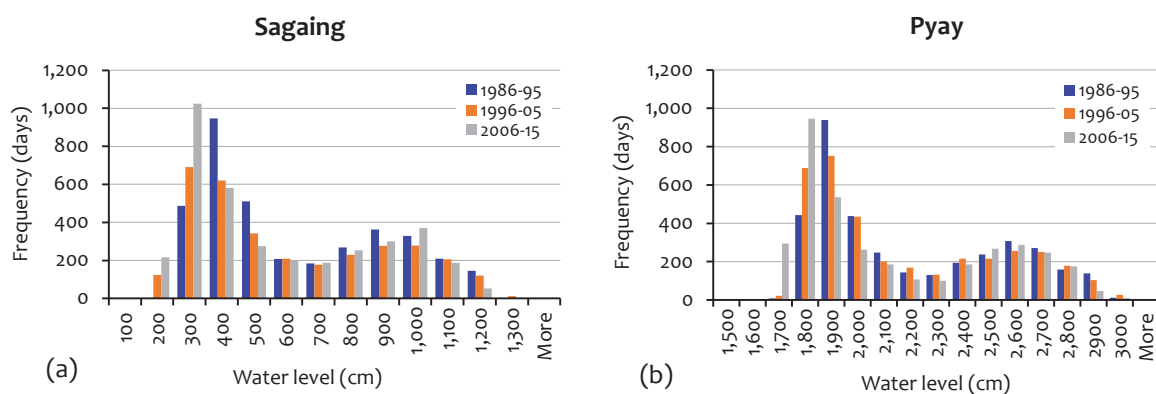


Figure 6.11 - Caption: Histograms of daily water level at (a) Sagaing and (b) Pyay by 100 cm water level 'bins'

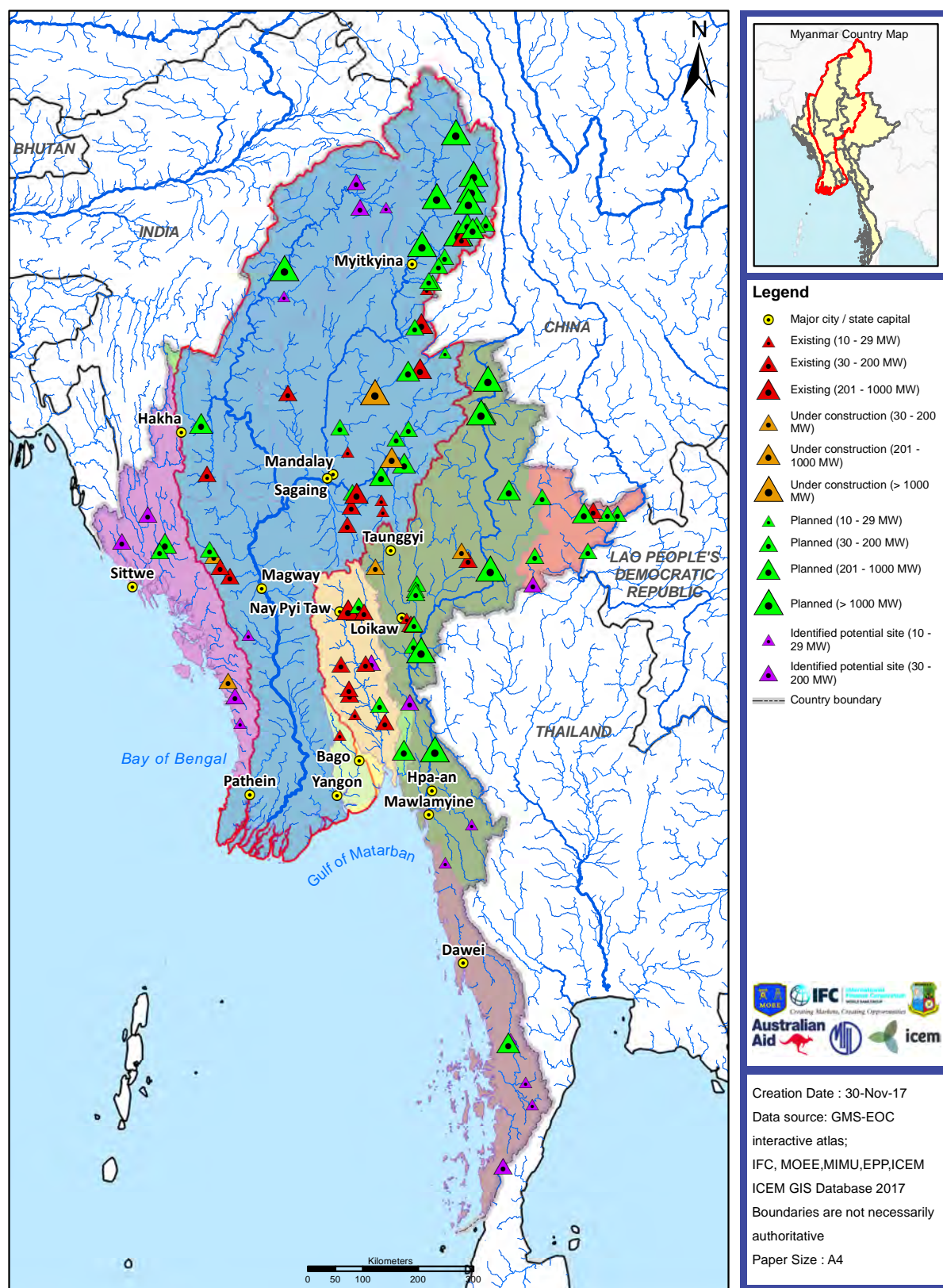


Figure 6.12 - Status of hydropower development in Myanmar

(IFC, MOEE, and MONREC, 2017)

These changes could represent climatic shifts, but climate models suggest the area will become wetter over time, rather than drier. These changes could also be consistent with regulation due to hydropower and/or irrigation dams, but additional detailed analysis of hydrologic data is warranted to better understand any potential flow changes. This is especially relevant when considering additional development within the catchment.

Channel migration

Tracking the rate of channel migration could, in principle, provide valuable information about whether the geomorphic attributes of the river are changing. In reality, channel migration occurs at a very local level, and natural rates include small annual incremental changes as well as major episodic events, so quantifying rates is difficult. Mapping of channel changes between 1988 and 2016 based on satellite imagery at some of the sites monitored in April to May 2017, show varying results between locations, and present a snapshot of changes over the past two decades. Analysis of the braiding of the Ayeyarwady between 1988 and 2016 shows that the alluvial reach upstream of the Sagaing Fault zone and downstream of the confluence with the Chindwin show increases in braiding over the period, with the Middle Ayeyarwady from Singu to the Chindwin confluence showing small to moderate decreases. These changes are consistent with hydropower development reducing and altering flows in the middle catchment, combined with land use changes increasing sediment inputs. It is recommended that this type of indicator monitoring be incorporated into a larger landscape-based monitoring design, and targeted to specific areas based on the distribution of existing or planned land-based changes (e.g. some sites upstream and downstream of regulated or free-flowing tributaries, areas upstream and downstream of mining zones, areas upstream and downstream of intensive sand mining activities, etc.).

Flow regulation – hydropower

The disruption to flow and sediment transport caused by the physical obstruction of rivers has potential to alter river systems at both a local and large scale. There is no readily accessible list of all structures that alter water or sediment movement in the Ayeyarwady. The lack of this resource is an information gap, and the compiling of such a database is recommended.

Figure 6.12 shows the total megawatts and catchment area of hydropower projects both installed and under construction in the Ayeyarwady, with a trajectory showing hydropower development if all planned projects are implemented. The summary shows that at present up to approximately 25% of the catchment area of the Ayeyarwady (based on 404,000 km²) could be affected by dams. This is reasonable considering the large developed

tributaries: Shweli, Taping, Myitnge, Ma Gyi Chaung, Mali Creek, and Tampak. If all planned developments proceed, the regulated area and proportion of regulated flow in the Ayeyarwady would increase substantially.

International experience shows a significant decrease in sediments at the mouths of the rivers as the number of mega-dams (>100 m in height, with reservoir volumes >1 km³) increases. There are currently two mega-dams commissioned in Myanmar (Shweli 3 and Yewya) with the dam heights associated with 20 of the planned projects exceeding 100 m, and very large but unquantified storage volumes. Dams other than mega-dams will also trap sediment and regulate flow.

The trend analysis concluded that, at present, there is a level of flow regulation in the Ayeyarwady that is likely affecting flow and sediment movement to some degree. This is consistent with the findings of the hydrologic analysis suggesting changes to the flow regime in the dry season. It is also consistent with the findings of recent delta investigations suggesting its resilience may be reducing, especially near the mouths of the distributaries. Myanmar is entering an era of increased hydropower development and the future trend is a large increase in the regulation of flow and sediment trapping within the catchment. Many of the future planned developments include high dams and very large storages, increasing the capacity for flow alterations and sediment trapping. Collectively, these projects have the potential to substantially reduce sediment loads, alter flows, and reduce the connectivity of the Ayeyarwady through increased fragmentation.

Irrigation

The Lower Ayeyarwady has undergone substantial irrigation-related water development, with both permanent and non-permanent waterbodies developed between 1984 and 2015 (Figure 6.13). The analysis suggests that most development has occurred on the floodplains and along the distributaries of the river in the delta. These types of water resource development projects have the potential to alter the timing and delivery of flow and sediment to the delta and the delta front, where the timing of sediment introduction as well as the magnitude is important for maintaining its stability.

The extraction of groundwater for irrigation is another activity that can alter the hydrology of the river and delta. Changes to the hydrology of the river and delta can also affect the extent of saltwater intrusion and, in turn, affect the usability and productivity of large areas (Chapter 3).

The trend analysis concluded that the existing level of irrigation development likely has an impact on flow and sediment regimes within tributaries, and collectively may be altering the flow in the Ayeyarwady, especially in the Central Dry Zone and lower river system where irrigation

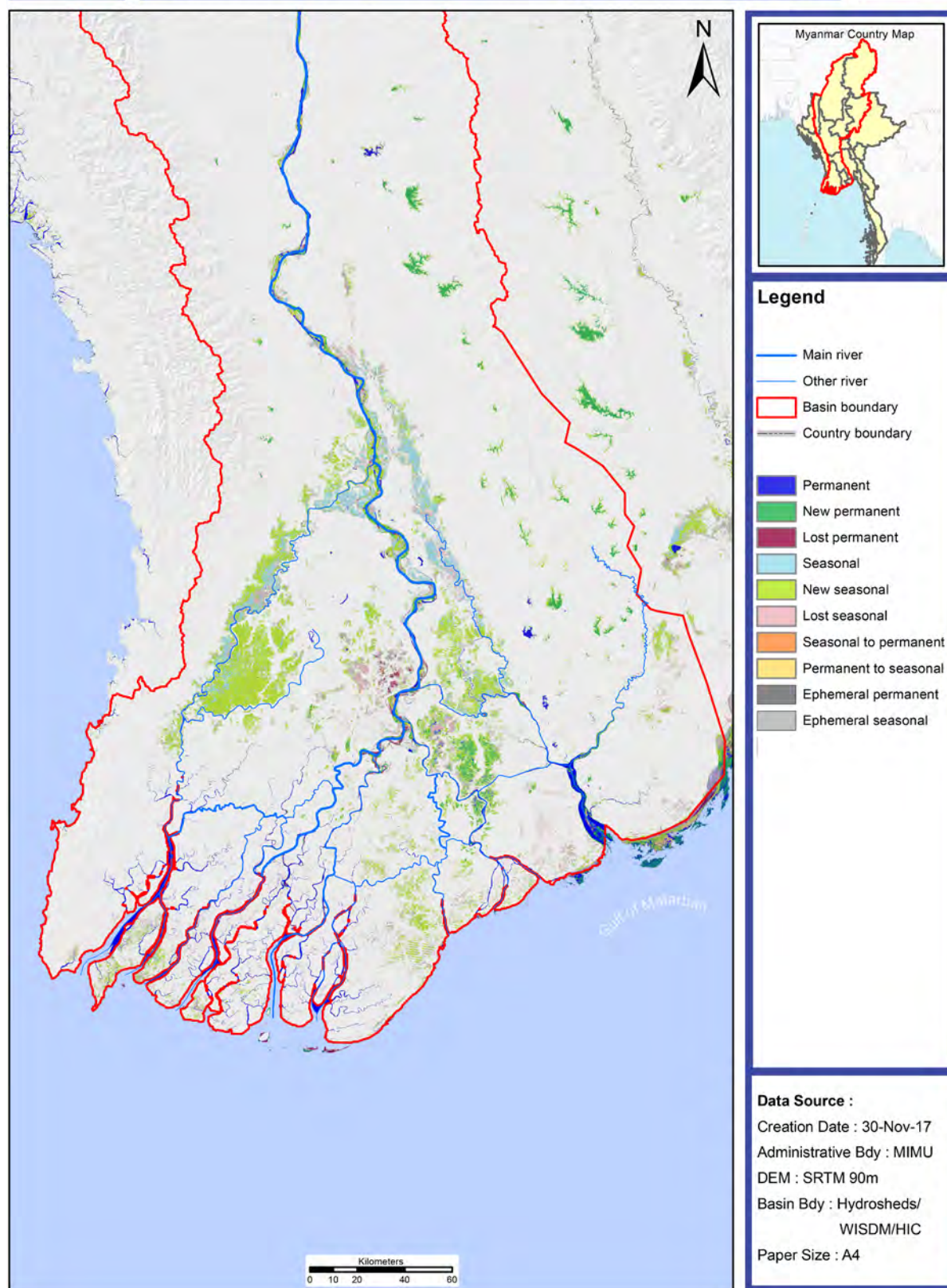


Figure 6.13 - Development of new seasonal (light green) and permanent (dark green) waterbodies in the Ayeyarwady Delta between 1984 and 2015
(Global Surface Water Explorer)

is concentrated. There is no long-term plan available for future irrigation developments as exists for hydropower, despite the likely increase in irrigation pressures in the future from population growth and the drive to lift the productivity of agricultural regions in the Ayeyarwady. These developments, and their potential changes on the system need to be considered on a cumulative basis, and in conjunction with flow and sediment changes associated with hydropower development. There is a high risk that the flow, sediment delivery, and connectivity of the Ayeyarwady could be irrevocably altered due to development and implementation of individual projects, without consideration of the overall system.

Land use changes: deforestation

Deforestation affects rivers by increasing the availability of sediment and altering rainwater runoff. The removal of vegetation from landscapes increases the susceptibility of the underlying soils to physical erosion through exposure to direct raindrop attack, runoff, or wind. Deforestation can also alter the hydrologic balance within catchments as evapotranspiration is reduced, altering soil moisture properties and the potential for physical erosion and runoff. Removal of vegetation from riparian zones increases the susceptibility of the bank face to erosion. The destabilisation of banks and hillslopes through deforestation can increase the occurrence of episodic sediment input events such as landslips, owing to a reduction in stability provided by the root systems of plants.

The annual rate of forest loss in the Ayeyarwady is increasing, resulting in a large cumulative loss (Figure 6.14). The reduction is spread among the tributaries, with the larger catchments (Chindwin, Myitnge, Shweli, and Taping) recording the largest areas of deforestation. Deforestation maps suggest that clearing may be a transboundary issue, with high concentrations of tree cover loss occurring near both the eastern and western national borders in northern Myanmar (Figure 6.15).

The trend analysis concluded that rates of deforestation have been increasing over the past decade in the Ayeyarwady, and unless land management policies change, deforestation is likely to continue to increase into the future. As the more accessible forested areas are reduced, there is an increased risk that clearing will be concentrated on steeper areas, which could have large detrimental impacts on rivers as steeper slopes are more prone to erosion and mass-failure. An increasing trend in deforestation will likely increase the sediment input to rivers in some areas.

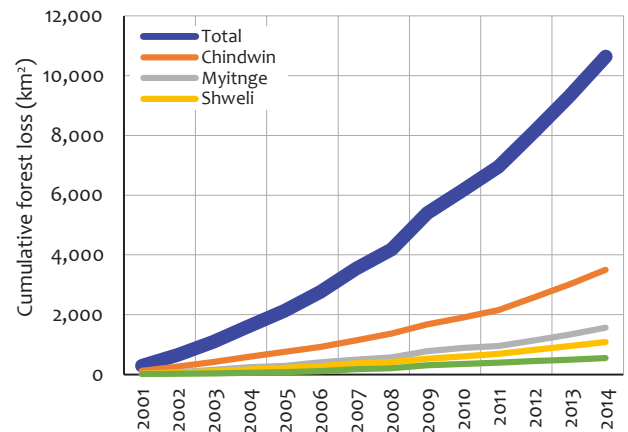


Figure 6.14 - Cumulative area of forest loss in the Ayeyarwady showing contributions from four major tributaries (Hansen et al., 2013)

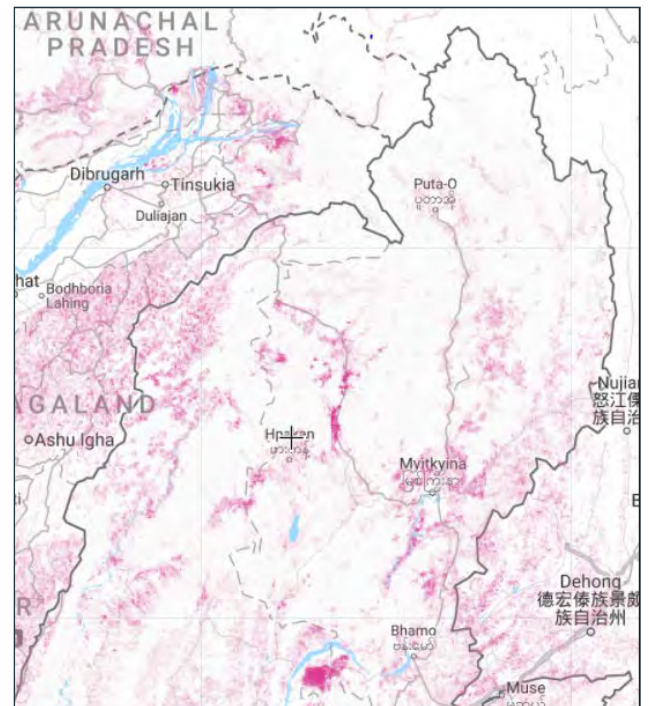


Figure 6.15 - Map of northern Myanmar showing areas of deforestation between 2001 and 2015

Pink areas indicate areas of tree loss (>30% canopy cover) and are more intense near the eastern border with China and the western border with India (<http://www.globalforestwatch.org>)

Land use changes: terrestrial mining



Mining activities have the potential to increase sediment inputs to river systems through the large-scale disturbance of land surfaces that can increase erosion and alter flow patterns. Reshaping the land surface is often required to remove large volumes of overburden to access the underlying mineral resource. These piles of waste rock can provide high sediment inputs, as well as alter other water quality parameters. Mines that post-process ores and generate mine tailings pose an additional sediment input risk if these materials are not stored in long-term secure repositories. Alluvial mining, where unconsolidated sediments are processed to extract mineral particulates, poses a substantial risk to river systems, as the target material is frequently located in active alluvial deposits along the banks or floodplains of rivers, and the waste is typically deposited within the river channel or along the banks where it is mobilised in subsequent high flow events. If mining areas are not rehabilitated, such that the landscape is returned to a stable configuration, mining inputs and impacts can persist for decades after the cessation of mining activities.

In recent years, the disturbed areas associated with mining have increased, with an especially large increase occurring between 2010 and 2016 in the Ayeyarwady River (Figure 6.16). Field observations included abundant small mining waste piles near the bank of the river in the Upper Ayeyarwady, and increased sediment input into the Ayeyarwady where the river occupies the Sagaing Fault zone, attributable to mining activities.

The trend analysis concluded that areas disturbed by mining in the Ayeyarwady have increased at a high rate over the past decade, and that the rate is likely to continue to increase in the future. In the absence of increased land management and regulations regarding the storage of mining waste, mining activities are likely to increase sediment inputs to the river in localised areas.

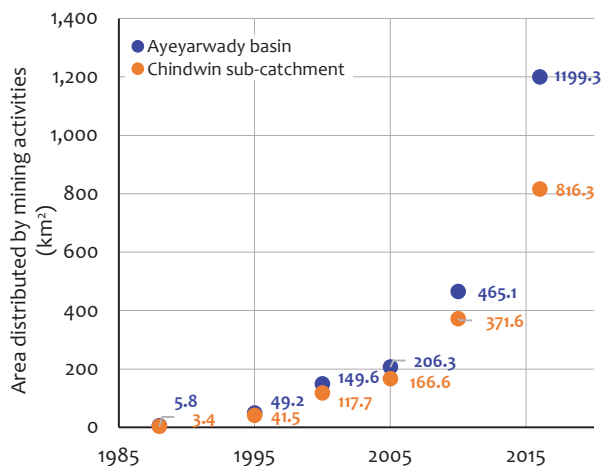


Figure 6.16 - Mining affected land in the Ayeyarwady between 1986 and 2020

Sand and gravel mining from the river

Sediment extraction impacts the geomorphology and sediment transport of rivers in a number of ways. Locally, the removal of material can deepen channels that in turn can destabilise the local riverbanks as the channel adjusts to the deeper conditions. The local extraction of material will also alter the morphology of the bed, leading to alterations in the local river currents. Deeper and steeper channels can increase the flow velocity, which exacerbates erosion. Once the morphology of a channel is changed in one location, these changes can propagate upstream through head-cutting and downstream due to the reach adjusting to the change in slope, flow velocities, and sediment delivery.

Typically, coarse sand and gravel is targeted for extraction, as these are the most desirable construction materials. These sediment sizes tend to be transported as bedload, and in the Ayeyarwady make up a small proportion of the overall sediment load, based on the grain-size distribution of more than 300 bank and bed samples collected. The disproportionate removal of this coarse material will alter the characteristics of the sediment load moving downstream, potentially affecting the stability of the downstream channel, and increasing the risk of channel incision. A reduction in the delivery of material to the delta channels and delta front can promote delta instability and subsidence.

There is little information available regarding sand and gravel extraction from the Ayeyarwady. This assessment has provided a snapshot that can be used to develop a more complete surveying and monitoring system. However, given the volumes of materials recorded during the survey, the level of development in Myanmar, and the large volumes of sand and gravel required for construction, road building and dam building, it is highly likely that the extraction of material from the river and its tributaries is increasing, and the future trend will be the extraction of even greater volumes.

Mangroves provide stability to the delta front and protect it from wave, wind, and storm surge erosion. A decrease in the forest cover of the delta has been documented since 1978. Deforestation is projected to continue due to the importance of agriculture to the growing Myanmar economy, the introduction of new investors, insufficient land tenure agreements, and governance issues. Resilience of the delta may also be declining, which could be linked to deforestation, as well as to sediment delivery changes and hydrologic changes.

The trend analysis concluded that the Ayeyarwady coastline is under stress due to land use pressures. The proximity of the delta to the most populous area of the country will likely increase these pressures in the future without the implementation of sound land and water management policies.

Climate change and sea level rise

Climate change is a risk to the Ayeyarwady Basin and delta because it has the potential to substantially exacerbate impacts associated with other activities, such as increased erosion from deforestation (including mangroves), or decreased flows in the dry season associated with higher temperatures increasing evaporation. Recent climate risk profiles list the following projections of change:

- An increase in 0.5° to 5.5°C in temperature by 2100.
- Reduced duration and increased variability of the south-west monsoon.
- Increased frequency and intensity of extreme weather events.
- An increase in sea level of 0.2 to 0.6 m by 2100 (at the lowest end of 2014 IPCC global projections, and with the possibility of much higher sea level rise).
- An increase in rainfall variability during the wettest months (May to October) with rainfall ranges predicted to range from a decrease of 45 mm per month to an increase of up to 200 mm per month compared to present.

The above predictions identify the expected future trends in climate change. To be useful as a management indicator, good climate data is required, together with an understanding of how climate change will interact with other catchment changes and geomorphic processes. The management of the impacts of climate change is best achieved through maintaining the resilience of river and coastal systems. This resilience is linked to the inherent variability of river systems, maintenance of key flow and sediment pathways, and protection of natural assets, such as riparian and coastal vegetation, that provide first lines of defence against extreme events.



Overview of trend assessment

An analysis of water levels during the dry season suggests that flow changes consistent with regulation for hydropower and irrigation may be occurring, but the instability of the river cross-sections at the monitoring points makes these findings questionable. Trend analysis was completed on land and river use changes, and the analysis shows accelerating rates of land disturbance associated with deforestation and mining. These localised land use changes have a high likelihood of increasing sediment inputs at discrete points in the river. The trend analysis for hydropower found that the past levels of hydropower development has been moderate, but the number and size of projects under development and projected over the next two decades reflect a very large increase in the potential river fragmentation and regulation of the river. Of particular note is the planned development of numerous mega-dams, with heights more than 100 m and storage capacities in excess of 1 km³. These projects have the potential to dramatically alter the flow of rivers and trap large volumes of sediment. The concentration of hydropower in the Upper Ayeyarwady presents an additional risk, as this area provides the majority of flow in the river, so flow regulation will have basin-wide impacts.

Less clear are trends in irrigation due to a lack of information, but the focus on economic growth and investment in Myanmar and the importance of agriculture to the economy suggest that regulation for irrigation is also likely to increase in the future. Finally, the present rate of sand and gravel extraction is considered to be near or beyond the bounds of sustainability, recognising the lack of a reliable sediment budget. The rate of sand and gravel extraction generally parallels construction trends due to the dependence of the construction industry on this commodity. The projected increased investment and growth in Myanmar into the future will likely translate into an increase in the demand for sand and gravel, placing an additional stress on the river.

6.6 Information Gaps – Sediment Monitoring

The findings of the investigations and trend analysis highlight the need for improved monitoring. Some overall benefits of monitoring sediments include:

- Understanding channel stability to reduce impacts on communities and infrastructure.
- Assisting the long-term design and maintenance of navigation channels, as boat transport continues to be critical in the Ayeyarwady Basin.
- Understanding and managing the Ayeyarwady Delta, which will continue to support ecosystems and industry, and provide protection from inevitable future cyclones.
- Managing and protecting ecosystems, which provide important food sources and biodiversity values to the country.
- Accurately predicting the associated impacts of large developments such as hydropower dams, and informing the identification of mitigation measures.
- Understanding how Myanmar's landscape changes through time, and improving the predictive capacity for the future.

An approach for a sediment monitoring system is presented as a starting point for discussion (Figure 6.17). The proposed monitoring is integrated with discharge monitoring and includes an initial two-year development period, during which time physical samples would be collected. The information will give an immediate snapshot of sediment transport in the river and sediment characteristics, as well as provide the basis for the calibration of other remote sensing techniques, such that physical monitoring may be reduced in the future. Data management and capacity building are important components of the strategy. Sediment monitoring is proposed to be completed as part of a larger monitoring strategy to fill the identified data gaps. Monitoring and information gathering is recommended to include: repeat channel cross-sections in the river and delta, land use analysis based on satellite imagery, and the development of databases relating to hydropower, irrigation, forestry, and mining to track trends in these activities.

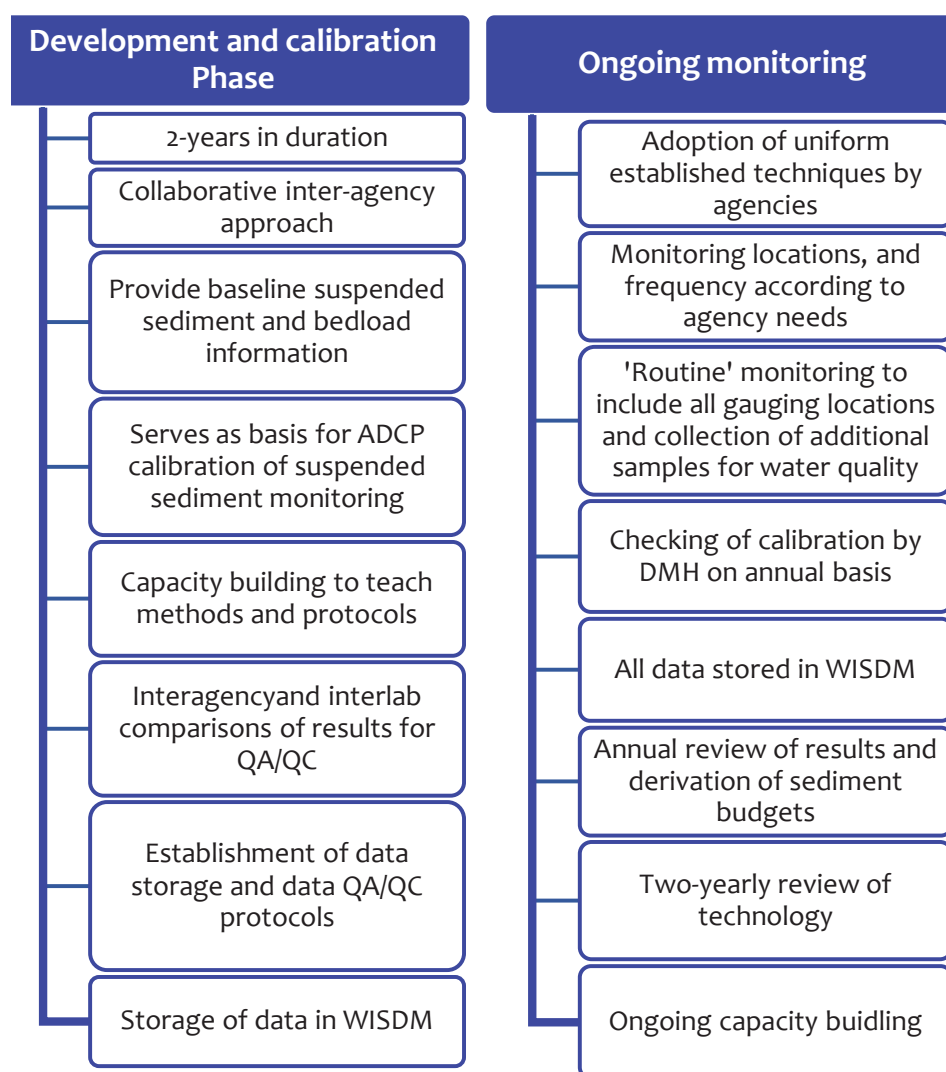


Figure 6.17 - Summary of proposed two-phased monitoring program

ADPC = Acoustic Doppler Current Profiler, DMH = Department of Meteorology and Hydrology, QA/QC = Quality Assurance/Quality Control

6.7 Conclusions

Sediment transport is complex in the Ayeyarwady owing to multiple processes contributing to the introduction and transport of sediment into the system. The steep nature of the tributaries, combined with land use practices, contribute high sediment loads to the mainstem Ayeyarwady, with sediment input punctuated by episodic inputs from the arid Central Dry Zone. The slope of the Ayeyarwady is generally low, and sediment transport is highly dependent on high flows. Small variations in the slope of the river govern where and when sediment is transported or stored. These characteristics combine to increase the sediment grain-size of bank and bed deposits in a downstream direction, which is unusual in rivers systems.

The overall finding is that the geomorphology of the Ayeyarwady River is in moderate to good condition, owing to the lack of regulation of the mainstem, and the flow and sediment inputs from the remaining unregulated tributaries. The pressures on the river are mounting at a rapid pace, and accelerating land use changes will impact the river at increased rates and severity if the linkages between land and river are not recognised and more appropriately managed.

Recognising, understanding and managing these land and river relationships is the first step toward sustainable development. For example, the navigation issues widely recorded downstream of Mandalay are likely linked to land use activities and regulation of tributaries as far upstream as Katha. Implementing land use policies that control runoff from mining and forest operations, and require hydropower plants to provide appropriate flows for the maintenance of geomorphic processes, are the best first steps toward sustainable use of the resources of the Ayeyarwady. Sustainable development can only be based on accurate and up-to-date information about the river and its flow, sediment transport, and channel characteristics. The primary recommendation is to implement sediment and geomorphic monitoring, and to



FISHERIES AND AQUACULTURE



HIGHLIGHTS – FISHERIES AND AQUACULTURE

- The Ayeyarwady Basin features at least 388 fish species. Of these, 311 are present in the Myanmar portion of the basin, with 50% (193) endemic to the basin and 26% (100) only known to Myanmar.
- Myanmar fish production, based on 2017 updated fisheries statistics, comprises approximately 33% each of inland capture fish, marine capture fish, and inland aquaculture fish, collectively totalling 2.9 Mt in 2015.
- After a peak in 2005, there has been a decline in marine fish production, and the trend in inland fish production has plateaued. In contrast, aquaculture shows a steady increase over this period.
- Large and migratory species of commercial significance that have become rare in most tropical rivers are still relatively abundant in Myanmar rivers; however, stakeholders unanimously report declining abundance of such species.



- Fish declining in the Ayeyarwady Delta include eel, hilsa, freshwater shrimp, and whiskered catfish, while large catfish are among the top declining species further up the Ayeyarwady Basin.
- Fishers attributed the main causes of fish species decline to destructive fishing (electrofishing and poisoning), followed by destruction of aquatic habitats, and gold or sand mining. Hydropower development is a threat they are not yet aware of.
- Hinthada Township has the highest ecological value from a fisheries protection perspective, followed by Ingapu, Myanaung, Yandoon, and Twantay.



HIGHLIGHTS – FISHERIES AND AQUACULTURE

- Second only to rice, fish is a major contributor to Myanmar's national diet. It accounts for approximately 60% of animal protein intake and supplies amino acids, oils, and essential micronutrients (such as calcium, iodine, and some vitamins).
- Assuring the availability of and access to fish supplies is critical to food and nutrition security.
- Fishing provides full-time and part-time jobs for approximately 3.2 million people, and the whole fisheries sector, including trade, processing and related sector activities, generates income for approximately 12 to 15 million people in Myanmar.
- The gender distribution of fishers is approximately 3:1 in favour of men when averaged for all five Ayeyarwady Basin zones. The opposite is true for involvement in fishing-related activities, such as processing and sales, where women make up at least 75% of the workforce.



- Fisheries provide the primary source of income for 25% of landless households through wage labour or fish sales.
- Migratory fish are essential to fishery livelihoods in the north. They are less essential, but still important, in the south of the Ayeyarwady Basin.
- The economic value of freshwater aquaculture production was estimated at USD 1.3 billion in 2015.
- An aquaculture feed sector is emerging with total production capacity nationally increasing fivefold between 2000 and 2010, from 200 to 1,000 tonnes per day.
- Overall, the aquaculture value chain functions at a sub-optimal level, with substantive input, access, and quality issues as well as risks linked to a focus on a single species (rohu).



7 FISHERIES AND AQUACULTURE

7.1 Introduction

This chapter comprises six sections on the state of fisheries and aquaculture in the Ayeyarwady Basin. The first section describes the three main systems of freshwater fisheries, together with fishing methods, stocking, and aquaculture. Next, monitoring data and statistics paint a comprehensive picture of the status of fisheries and the way forward for future monitoring efforts. In Section 7.4, the ecology of fisheries resources looks at biodiversity, species abundance, and fish migrations. This is followed by an outline of fishery livelihoods, including consideration of nutrition, food security, and gender issues. Section 7.6 takes the perspective of a fisheries manager and asks: what are the challenges and opportunities? Finally, the chapter concludes with a local perspective in terms of trends, issues, options, and recommendations.

SOBA Technical Reports

This chapter is a synopsis of the full assessment, which may be accessed by readers seeking more detailed information, including references:

SOBA 4: Worldfish & FFI (2017), *Fisheries in the Ayeyarwady Basin* (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), *A brief review of the aquaculture sector in the Ayeyarwady Basin* (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), *Consultations of fishers on fishery resources and livelihoods in the Ayeyarwady River Basin* (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), *Consultations on wild resources and livelihoods in the Ayeyarwady River Basin* (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.



7.2 Fisheries Systems

This section introduces the fisheries systems of the Ayeyarwady Basin in terms of the different types of systems (leasable fisheries, tender lots, and open access fisheries), fishing methods (like gill nets and traps), stocking of ponds, wetlands and rivers with culture fish, and aspects of aquaculture.

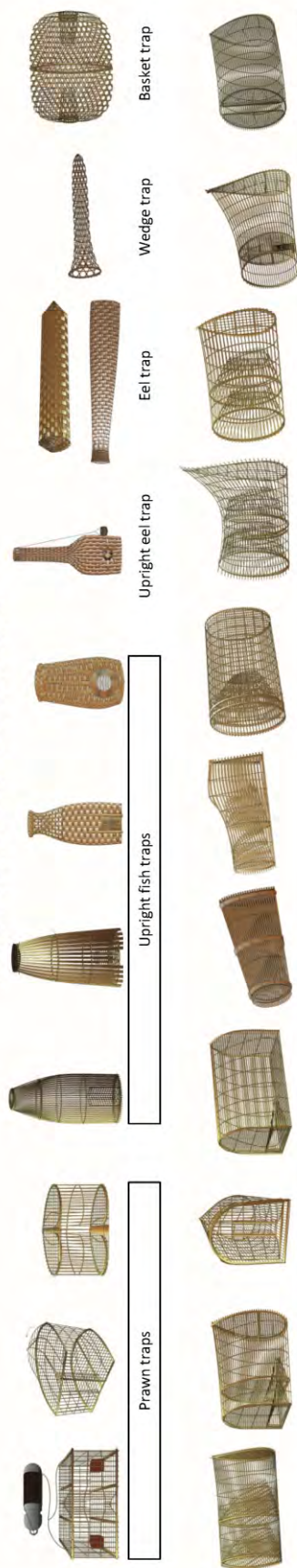
7.2.1 Types of freshwater fisheries systems

There are three main categories of freshwater fisheries systems in the Ayeyarwady Basin:

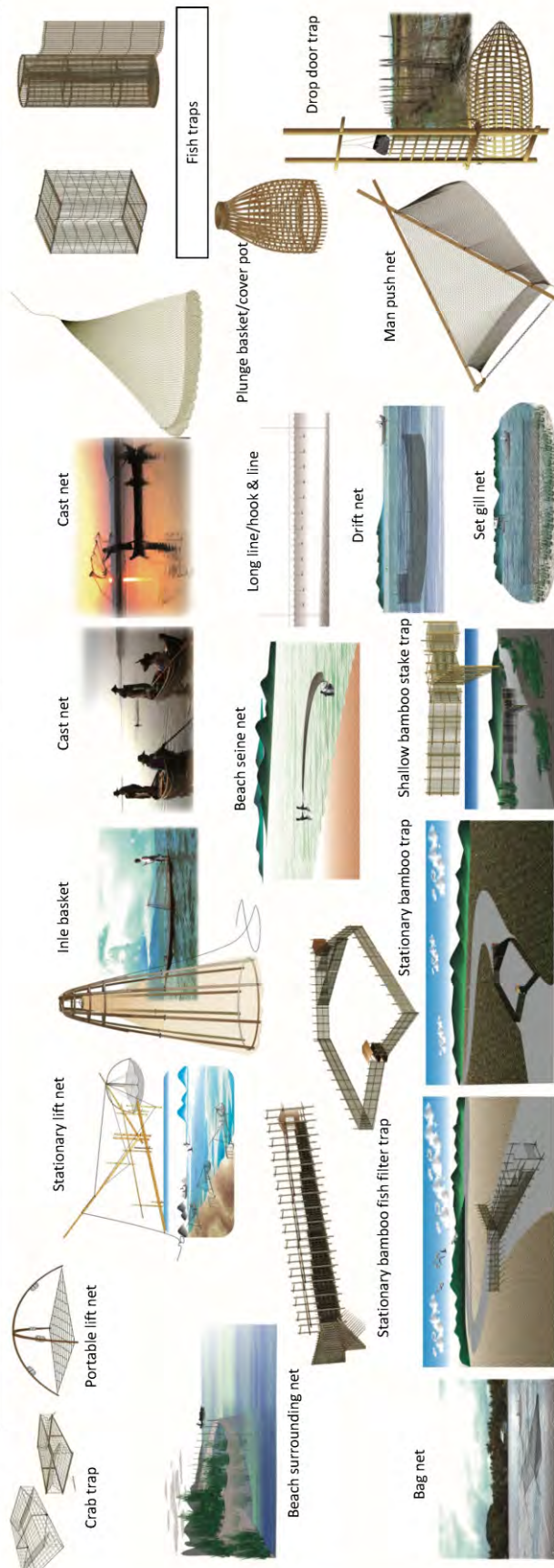
- *Leasable fisheries* are areas of floodplains fished by the erection of barrage fences, with fish collected in pens or traps at the beginning of the flood recession.
 - There were 3,304 leasable fisheries from 2014 to 2015.
 - Ninety-six percent of the leases in the Ayeyarwady and Yangon Regions are associated with large rivers, river channels, or wetlands.
 - Leases are granted for 1, 3, or, exceptionally, 5 years by the Department of Fisheries (DoF).
 - Lease prices vary from USD 50 to USD 165,000 per unit, which reflects the diversity in size, fish productivity, and species composition of each lot.
 - The majority of leases are affected by water withdrawal for purposes other than fisheries, such as agriculture and domestic uses.
 - Leases are usually an important source of employment to nearby villagers, and large operations can support up to 100 families.
- *Tender lot fisheries* are stretches of river for which an operator has fishing rights for the use of a specific type and number of fishing gears (usually stow nets).
 - Tender licences are commonly issued by DoF to business operators who sub-lease fishing rights to fishery operators.
 - The number of stow nets in the river stretch is usually fixed as part of the tender agreement.
 - Tender lot owners may give access (for remuneration) to small-scale fishers who can operate between stow nets.
- *Open access fisheries* are found all over the country in places that are not classified as either leasable or tender fisheries and are not reserves.
 - Access is free, but most fishing gears require a licence issued by DoF for a yearly fee.
 - There are 16 types of small fishing gear that, for a limited number of gear units, do not require a licence.
 - Fishing is often conducted using non-motorised, traditional wooden crafts.
 - Open access fisheries are extremely important to local populations, particularly the landless, for whom fishing requires little investment and represents a source of food and possibly income.
 - There is an increasing tendency to auction some parts of open water areas as tender sites.

7.2.2 Fishing methods

The most common fishing techniques used in inland fisheries are drift nets, gill nets, traps and pots, pole and lines, stationary traps, and bamboo stake traps. Gill nets, stationary bamboo traps, and stationary bamboo fish filter traps are used across various fishing grounds. Stow nets are more common in main rivers and river channels, while filter traps are more adapted for seasonal wetlands. The types of inland fishing gears are shown in Figure 7.1.



Fish traps



စီးပွားရေးနှင့် ဖွံ့ဖြိုးရေး ဝန်ကြီးဌာန

Illustration and Layout by
WIN KO KO
Institute of Fisheries Technology (I.F.T.)
Department of Fisheries, Myanmar.

Figure 7.1 - Inland fishing gears of Myanmar
(U Win Ko Ko, Department of Fisheries, Myanmar)

7.2.3 Fish stocking

The practice of stocking inland waters in Myanmar started in 1967 and is done at a uniquely high level. The intention of stocking ponds, wetlands, and rivers with cultured fish is to enhance natural fish production and recruitment. Leasable fishery managers are compelled to follow stocking practices and must spend 30% of the value of their lease to buy fingerlings. Approximately 79% of leaseholders in the Ayeyarwady Delta stock their area with fish fingerlings.

The majority of seed stock production comes from government hatcheries. The most common species are rohu (*Labeo rohita*), silver barb (*Barbonymus gonionotus*), and catla carp (*Gibelion catla*, formerly known as *Catla catla*). Fishers return possible breeders to government hatcheries to sustain adequate genetic diversity. However, fishers complain about frequent reductions of the wild stock from competition for food and habitat between stocked fish (a few species introduced in massive quantities) and native fish.

Research on the benefits or adverse impacts of stocking natural water bodies with cultured fish is scant, with different outcomes likely for open waterways (floodplain areas, rivers, and creeks) compared to enclosed water bodies (closed lakes and reservoirs). Further research is needed with respect to the potential benefits of stocking, how to optimise production and cost effectiveness, species to be stocked, optimal density and size of stocked individuals, target water bodies, and timing of stocking. For stocking programs to contribute to poverty alleviation, an examination of their social aspects and main beneficiaries is essential. Better monitoring and testing of the stocking process would help increase productivity, reduce costs, and minimise harmful impacts.

7.2.4 Aquaculture

The state of aquaculture in the Ayeyarwady Basin is discussed here in terms of levels of production, its spatial distribution, and the species that are used. An overview of value chains, economic value, and barriers to aquaculture development is provided, together with an outline of aquaculture's competitive edge and some stand-out opportunities for industry development.

Production and spatial distribution

The Ayeyarwady Basin generated approximately 958,000 tonnes from aquaculture in 2017, representing 91% of the nation's total aquaculture production. The economic value of Myanmar's freshwater aquaculture production was estimated at USD 1.6 billion in 2014 but declined to USD 1.3 billion in 2015, with a maximum 14% of the total production exported.

Although the sector's average fitted growth is ostensibly 8.7%, based on DoF data between 2004 and 2014, Myanmar's aquaculture statistics need to be treated with caution. Unlike capture fishery statistics (Section 7.3), aquaculture statistics have not been overhauled. Researchers who compared production figures with national fish consumption and fish trade, estimate that over-reporting of aquaculture production can reach 164%.

The total area dedicated to aquaculture within the Ayeyarwady Basin in 2017 is approximately 113,000 ha, which constitutes 57% of Myanmar's total aquaculture area. The production and pond areas within the Ayeyarwady and Yangon Regions provide 90% of Myanmar's farmed fish production. Twantay Township, in Yangon Region, and Maubin, Pantanaw, and Nyaungdon Townships in the Ayeyarwady Region account for nearly 52% of the Ayeyarwady Basin's estimated pond area.

Recent studies paint a more complex picture than previously described. They show that the aquaculture sector is not only made of large farms but also of numerous small- and medium-size farms that contribute significantly to the sector and which are not generally acknowledged.

Species and production systems

Rohu (*Labeo rohita*) is the dominant aquaculture species, representing 70% of Myanmar's aquaculture production. This over-dependency on a single species is perceived by experts as a constraint to further growth of the sector. Rohu has limited export potential, and production mainly targets the domestic market. Other important species are mrigal, catla, pangasius, tilapia, silver barb, puntius, common carp, and grass carp. Major aquaculture species in Southeast Asia that are absent in the Ayeyarwady Basin include walking catfish, sea bass, climbing perch, stinging catfish, and striped snakehead.

Carp polyculture, in semi-intensive systems, dominates the sector, using external homemade and manufactured pelleted feed. Intensive systems are limited to a small number of marine fin fish, white shrimp farms, and a handful of farms producing pangasius and pacu. Productivity is limited and ranges from as little as 1 tonne per hectare (t/ha) to a maximum of 10 t/ha, with a mean of 3.7 t/ha. Feed represents 70% of operation costs, followed by fingerlings, non-feed inputs (fuel and fertiliser), and labour. Sub-optimal pond management practices are common.

Fingerling production is underdeveloped, with a small number of hatcheries operating with limited technology. In 2016, there were 26 active government hatcheries, producing approximately 644 million fish fingerlings, of which 68% were rohu. In addition, there are 39 private hatcheries, producing 1,875 million fry and fingerlings to support the sector. Small-scale farmers depend on private hatcheries and a dense network of nurseries, which have boomed with increasing demand for large-sized fingerlings.



Recent productivity gains are mostly due to improved management practices, with stocking of larger fingerlings reducing the culture period from 12 to 9 months and increasing the use of manufactured feeds. At least 33% of the output growth that occurred over the past 10 years is thought to be attributable to these productivity improvements.

An aquaculture feed sector is emerging in Myanmar. Until recently, feed was mainly homemade and composed of locally-available agricultural by-products, particularly rice bran and peanut oil cake. The total production capacity nationally increased fivefold, from 200 to 1,000 tonnes per day, between 2000 and 2010. Until recently, a single company dominated sectoral production and distribution. The lack of competition for manufactured pellet drove costs 10% to 30% higher than for other countries in the region. Commercial feed pellets are not commonly used due to their high price.

Value chains

Fish marketing channels are short, with the majority of farms selling to a single fish trader for later trade in San Pya Market in Yangon. There is rapid development of small and medium enterprises in off-farm segments of the supply chain (e.g., ice manufacture and rural transport) or in fish farming intensification (e.g., pond digging services, hatcheries and nurseries, and feed traders). Yet, access to credit is limited for small- and medium-scale fish farmers who borrow from informal lenders. Increasing credit to the sector could create a less risky investment climate, increase farm productivity, and stimulate greater volumes of investment along the supply chain.

Aquaculture has important spillover effects along the value chain for households and job creation:

- Generates a higher return per hectare than for crops, with an average gross margin of USD 1,600/ha in the Yangon and Ayeyarwady Regions.
- Creates four times more labour demand per hectare than crop farms, especially for small fish farms – with fish farm wages higher than for crop farms and more beneficial for women when compared to wages in the crop sector.
- Contributes significantly to household incomes for small-scale aquaculture systems in the Delta Region.

Barriers to aquaculture development

The conversion of any paddy land or other agricultural land into aquaculture (as a non-agricultural land use) is forbidden in Myanmar. Failure to cultivate agricultural land can result in its confiscation. Although enforcement is uneven from place to place, this regulatory barrier is the primary constraint to aquaculture development within the Ayeyarwady Basin. In addition, there are legal barriers to trading fish between states.

Support systems for aquaculture development, including private and public extension services, are still weak and have limited capacity and inadequate coordination with the development aid sector. The overall value chain functions at a sub-optimal level, with substantive input access and quality issues. The sector lacks diversification, making it vulnerable, less resilient to shocks (e.g., markets and diseases), and limiting prospects for export. Access to water is also a constraint in certain parts of the Ayeyarwady Basin, notably in the Central Dry Zone.

Development opportunities

Drivers of change and interventions for the development of a more competitive, spatially-diversified and smallholder-inclusive sector include the following:

- Enacting regulatory reform and creating a less restrictive legal framework for land and reservoir use for aquaculture and inter-state trade.
- Supporting feed and input sector development to facilitate access by small-scale farmers.
- Investing in fingerling production, hatchery infrastructure, and capacity to diversify production.
- Increasing access to formal sources of credit for fish farmers and small and medium enterprises in the aquaculture supply chain. This can be achieved through the development of tailored lending instruments.
- Training a skilled workforce to meet future industry needs through a structured approach to educational curriculum development and capacity building, with coordination between universities, the private sector, DoF, and civil society.
- Improving hard (e.g., road and electricity) and soft (e.g., extension services) infrastructure.

7.3 Fisheries Statistics

This section on fisheries statistics examines monitoring tools and the data sources currently available. An ongoing reassessment of the capture fisheries statistics is presented, and updated fisheries statistics are summarised, which is followed by a proposed way forward for fisheries monitoring. The section closes with a synopsis of the economic values of inland fisheries.

7.3.1 Tools required for fisheries monitoring

Monitoring fisheries resources in the Ayeyarwady Basin, particularly its inland fisheries, is an essential requirement for its long-term management. Multiple studies emphasise the need to monitor the following aspects of the fisheries sector:

- Resource exploitation – total yield, fishing effort, catch-per-unit-effort (CPUE), and fishing exploitation modalities (intensity, mortality, and selectivity).
- Biological aspects – composition of the catch (value of dominant species), monitoring of target species (maximum size and size at maturity), and monitoring of habitat health.
- Socio-economic aspects – monitoring at the household level (benefits from fisheries) and of fisheries governance modalities and effectiveness.

7.3.2 Main data available from fisheries monitoring

Statistics until 2016

Fisheries produced 5.59 million metric tonnes in 2015 to 2016, according to DoF, which comprised 1.58 million metric tonnes of freshwater fish from inland capture fisheries, 1.01 million metric tonnes from freshwater aquaculture, and 3 million metric tonnes of marine fish.

These central statistics indicate that approximately 50% of the production comes from marine fisheries, with approximately 30% from freshwater fisheries and less than 20% from aquaculture. The long-term trend shows a steady increase of both inland and marine capture fisheries, with an average annual growth of 11% in inland capture fisheries and 8% in both marine fisheries and aquaculture.

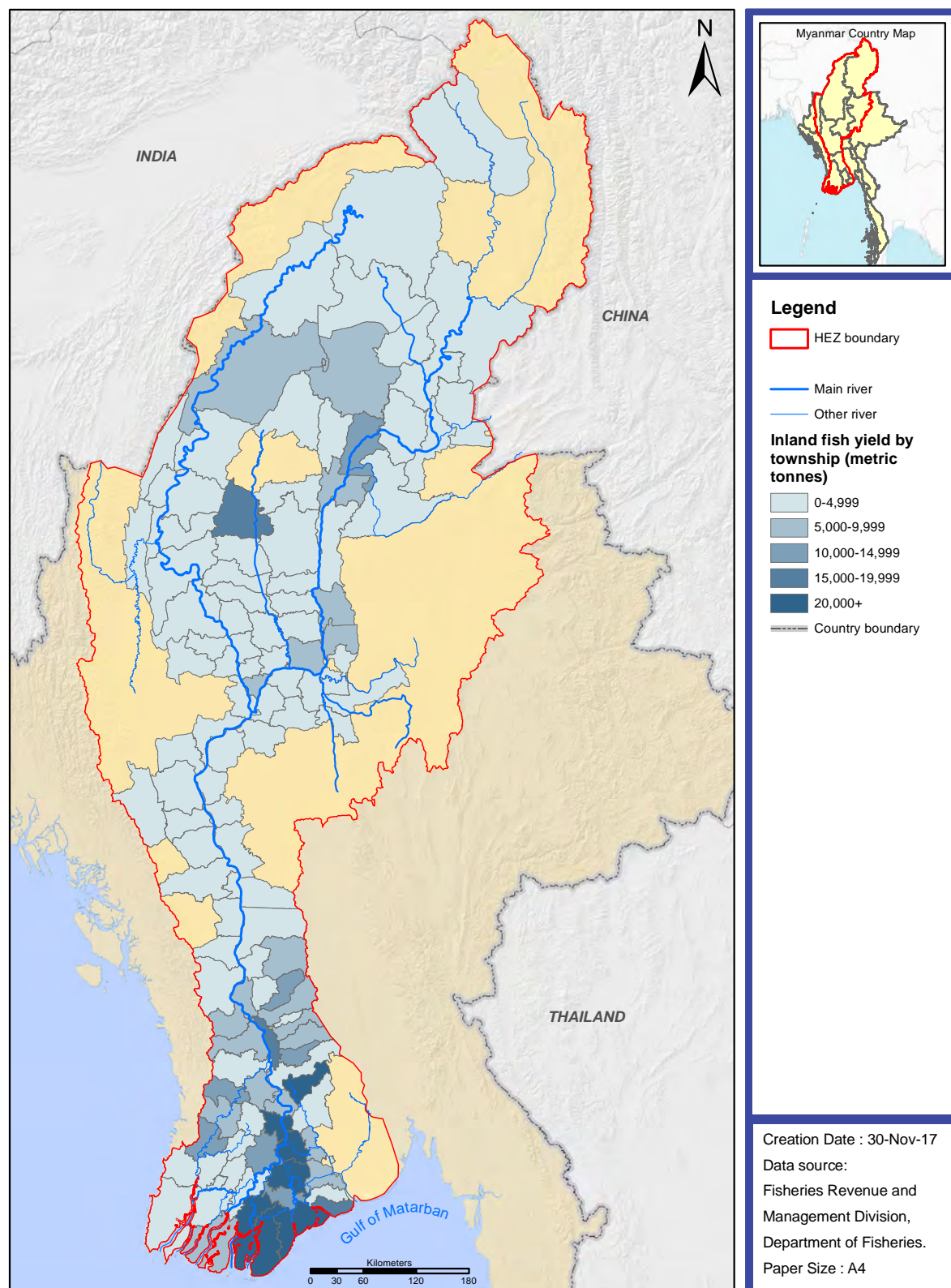


Figure 7.2 - Inland fish yields by township in 2015 to 2016, according to statistics gathered at the township level
(Fisheries Revenue and Management Division)

At the township level, the data compiled from DoF offices along the Ayeyarwady River (2015 to 2016 data gathered and digitised) show the spatial distribution of total yield (Figure 7.2), with a majority of catches in the delta in the Bogale, Danubyu, Dedaye, Maubin, Mawlamyinyun, Nyaungdon, Pyapon, and Thayarwady Townships. This distribution of catches aligns with the distribution of fishing gears for registered, leasable, and tender fisheries in the Ayeyarwady Basin on the basis of DoF township data (2015 to 2016 season).

The share of each type of fishery in the total catch, using the same township data compiled by the Fisheries Revenue and Management Division, is 49% from open access fisheries, 32% from leasable fisheries, and 19% from tender lot fisheries. However, for the same 2015 to 2016 period, statistics from DoF's Planning Division indicate that leasable and tender lot fisheries combined contribute 21% of the freshwater fish yield, while open access fisheries contribute 79% of the total.

Data on species caught are gathered at the township level but have never been published. Shrimp is the dominant taxon identified in catches, according to township data (Figure 7.3), followed by whiskered catfish (*Wallago attu*), rohu carp (*Labeo rohita*), snakehead (*Channa striata*), hilsa (*Tenualosa ilisha*), featherback (*Notopterus notopterus*), catla carp (*Gibelion catla*), mystus catfish (*Mystus spp.*), and walking catfish (*Clarias batrachus*).

Seasonal distribution of catches could not be determined as there are no monthly data, while time constraints precluded digitisation of past township-level records of catches and the assessment of trends.

The data presented in this report should be used with caution. Notably, there are some unusual geographic patterns in the data and conflicting statistics between central and township data about leasable and open access fisheries. That said, these local data (once digitised) could provide substantial value in the process of prioritising planning and management activities in the Ayeyarwady Basin, on the basis that biases between townships are made constant. Therefore, a peer-reviewed assessment, with a view to validating or amending the data, is recommended, using the expertise of both DoF officers and fisheries statisticians.

7.3.3 Reassessment of capture fisheries statistics in 2017

In 2017, a major reassessment of catch statistics for capture fisheries in Myanmar was undertaken by DoF and international partners including the Food and Agriculture Organization of the United Nations (FAO). The resultant figures differ from those compiled up until 2016, as reflected in FAO FIGIS statistics for the 2003 to 2014 period (Figure 7.4). Although the total estimate of Myanmar's freshwater fish catch declined significantly to 863,000 metric tonnes (from 1.58 million metric tonnes), this figure still represents 7.2% of the world's total inland fish yield. Aquaculture statistics, as opposed to capture fish statistics, have not been questioned and modified.

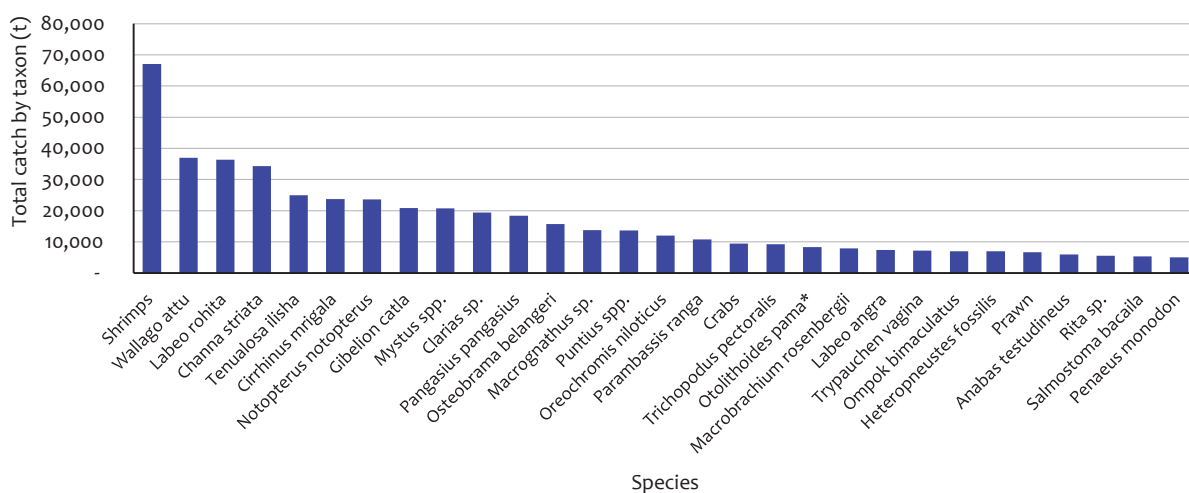


Figure 7.3 - Fish species distribution in the Ayeyarwady River for the 2015 to 2016 season

(Department of Fisheries, Myanmar)

* including *Polynemus paradiseus*.

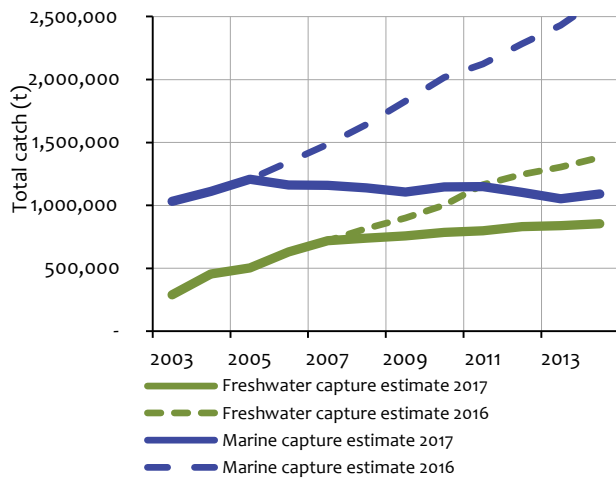


Figure 7.4 - Reassessment in 2017 of catch statistics for capture fisheries in the 2003 to 2014 period

Former data (dotted lines) up until November 2016 and data revised (plain lines) in September 2017 (FAO FIGIS)

Why reassess fish catch statistics?

In recent years, several studies and individual scientists have flagged the need to reassess central capture fisheries statistics because the ever-increasing catch statistics do not match with observations from the field. This mismatch arises in large part because the annual yield of inland fisheries is estimated at the central level rather than measured. This creates two major problems.

- Firstly, declining resources are masked because the catch statistics are estimated based on the number of licensed gears multiplied by a constant biomass per gear, regardless of the actual yield. In case of declining resources, each gear harvests less, resulting in an increasing number of gears, which is reflected in statistics by a misleading constant or higher yield.
- Secondly, national-level catch per species data are not compiled, and overall trends among individual species, like high-value hilsa, are not monitored (they are only available from export statistics, not from landing statistics).



Figure 7.5 shows the discrepancy between catch statistics and fish exports or employment in the fisheries sector.

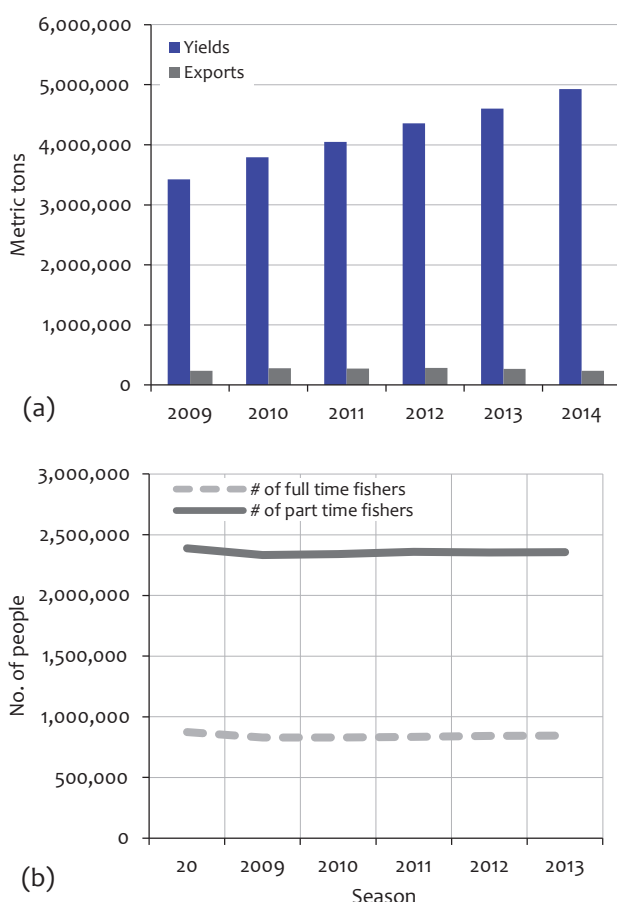


Figure 7.5 shows the discrepancy between catch statistics and fish exports or employment in the fisheries sector.

(DoF 2011, 2013, 2014, and 2015 publications)

Historical trends in fisheries statistics

Three distinct reporting phases can be observed in Myanmar's historical fisheries statistics: pre-2000 (under-reporting), 2000 to 2016 (over-reporting), and post-2016 (reassessment).

Prior to 2000, there was limited incentive to assess and evaluate catch information, and the low catch volumes recorded during this period likely reflect substantial under-reporting. A 2002 assessment concludes that the reported annual catch was probably underestimated by as much as 2.5 to 3.8 times the actual total.

In 2000, the government laid out a 30-year plan for fisheries development, which included total fisheries production reaching 41.5 million metric tonnes by 2030 (a 10% annual increase). Rapid linear growth observed in officially reported catch volumes (8% to 11% per year depending on the fishery) is most likely related to these targets rather than to actual production levels.

Around 2013, the reporting issues of the second phase progressively emerged. Three independent stock assessments and consumption surveys indicated production levels far lower than those reported in national statistics. This led to the post-2016 reassessment. A recent in-depth review concluded that there seemed to be "two parallel statistical systems in Myanmar" (BOBLME 2014):

- DoF's Planning Division – "mainly based on target levels. This data cannot be used to support fisheries management or policy development."
- That of DoF at the township and district level – "some of the collected data is reliable and some is based on target level." Although this system collects catch statistics per species, the species data are unavailable at the national level. Major constraints are described as: "the system is not standardized for the whole of the country," and "it is almost completely paper-based."

Data gathered from different DoF sources for the same townships or districts during the same period in the course of this work also exhibited significant discrepancies. This confirms the need for "a standardized data collection system for fisheries and aquaculture, with appropriate data collection forms, correct and transparent raising and estimation procedures, and guidelines for data collection."

7.3.4 Updated fisheries statistics

According to 2017 revised statistics, Myanmar fish production comprises approximately 33% each of inland capture fish, marine capture fish, and aquaculture fish, collectively totalling 2.9 million metric tonnes in 2015 (Figure 2.4). More specifically, Myanmar's fish production comprised approximately 863,000 metric tonnes of inland capture fish, 1,062,000 tonnes of marine capture fish, and 942,000 tonnes of aquaculture fish.

After a peak in 2005, there has been a decline in marine fish production, whereas inland fish production has plateaued. Overall, inland capture yield represented 42% of the marine fish yield in 2005 and 81% of it a decade later, due to the combined growth in inland fisheries and decline in marine catches. This underlines the increasing role of inland fisheries for food security in Myanmar.

Aquaculture shows a steady increase over this period, of which 99% of production is from inland waters.

Importantly, these updated figures reflect an adjustment of previous statistics based on external and independent evidence (stock status and consumption surveys). In the future, proper assessments based on actual fish catches are needed, as detailed below.

7.3.5 Fisheries monitoring: the way forward

As identified by the Myanmar Fisheries Partnerships in its review of the inland fisheries sector BOBLME (2014):

“The way annual fishery yields are estimated leads to large biases in estimates, and data are not detailed enough to inform management (e.g. catch per species are absent in national landing statistics). A monitoring system is required at least for some target species (e.g. Hilsa) to ensure sustainable exploitation. There is considerable potential in bringing together the Department of Fisheries, Universities, NGOs and the private sector for coordinated knowledge generation. The research capacity of the Department of Fisheries needs to be strengthened and a formal mechanism is required to ensure that policy and decision-makers receive and utilize updated information and scientific evidence. If no initiative is taken, knowledge of the resource will remain insufficient to protect it; the resource will remain exploited without status monitoring, i.e. until it is fishers who send a socially critical signal of overexploitation to authorities.”



The reassessment of fisheries statistics highlights the need for tools to ensure effective fisheries monitoring. DoF has a strong administrative structure in all townships, which provides the basis for regular monitoring. There is a need in the Ayeyarwady Basin for the following:

- An assessment of yields based, not only on estimates per fishery, but on actual sampling – the monitoring could be designed in representative townships.
- An assessment of the fishing effort, particularly for marine fisheries, in order to assess the evolution of the CPUE.
- Monitoring, in some target sites, of the species composition of catches (all species identified), and of the biological parameters (size/weight, sexual maturity, etc.) of some target species among all identified species.
- Socio-economic monitoring at the household level to assess the benefits derived from fisheries (income, occupational benefit, and nutrition).
- Monitoring of fisheries governance to assess the effectiveness of the new modalities being put in place, in particular co-management modalities based on *Community Fishing Groups*.
- Monitoring critical fish habitat health, following the principles of the *Ecosystem Approach to Fisheries Management*.

Monitoring does not need to apply to each township but can be implemented at selected sites that are representative of the whole system. It should focus on generating status indicators, trends, and warning signals, rather than on producing comprehensive statistics. Developing better data collection systems to improve data quality and interpretation are critical steps to ensuring the sustainable development of the fisheries resources in the Ayeyarwady Basin.

7.3.6 Inland fisheries values: an economic perspective

The economic values of inland fisheries are discussed here in terms of existing statistics and fish value chains.

Existing statistics

National statistics identify three main categories of fish export commodities: Fish, Prawn/shrimp, and Other. These statistics indicate that the total volume of freshwater, marine, and aquaculture items exported reached 338,000 metric tonnes in 2014 to 2015, for a total value of USD 483 million. Exported Myanmar inland capture fish products are said to contribute 1% to 3% of total exports, worth USD 8.5 million per year. However, this figure is a dramatic underestimate arising from a classification anomaly. Actual figures reach at least USD 60 million per year (i.e., 10% of national fishery exports and probably much more given the reassessment detailed in Section 7.3.3). The 'Other' export category includes specific freshwater fisheries items of high value, like eels, such that the contribution of all inland fisheries products is not fully reflected in current national fisheries statistics. The value of inland fisheries products would multiply by a factor of five if export statistics accounted for three freshwater commodities (eels, dried gourami, freshwater prawn) under the category of inland fisheries products.

Fish value chains

Five main fish value chains can be distinguished in Myanmar:

- Fresh fish supply chain, including for the fishers' own consumption – This value chain usually involves small quantities and low profit margins, but it plays a crucial role in the food security of the poorest consumers and fishing communities.
- Dried and processed fish chain – Essential for the food security of upland areas in Myanmar where processed fish is often the only source of fish.
- Urban fresh fish chain – A relatively new but fast-growing chain driven by traders.
- Animal-feed chain – A flourishing exploitation and transformation chain despite frequent spoilage due to poor preservation, processing, and transportation.
- Export value chain, by far the most lucrative – Fishers' involvement is limited to providing fish or working in processing activities.

The urban fresh fish market has the highest potential for small-scale fishers. Enhancing the role of small-scale fishers in these value chains will require the following:

- Facilitating fishers' access to fish resources and structured processes aimed at increasing the volume of fish directly reaching higher levels in the value chain.
- Improving infrastructure conditions (landing, preservation, and transportation) to ensure good fish quality up to the end consumer.
- Strengthening fishers' bargaining capacity and reducing their dependence on traders (through community institutional development, access to ice and markets, and to credit).
- Building the capacity of staff of relevant government agencies, such as DoF.
- Promoting sustainable and equitable fisheries policies.





7.4 Ecology of Fisheries Resources

A taxonomic review done for the present study shows that the overall number of fish species recorded in the Ayeyarwady Basin is 388. Of these, 311 are present in the Myanmar portion of the basin and the others are found in India and China. Among these 388 fish species, 50% (193) are endemic to the Ayeyarwady Basin and 26% (100) are presently known only to Myanmar. Species lists compiled in DoF township offices generated a list of 514 fish species within 60 families, but scientific taxonomic validation is yet to be completed.

7.4.1 Most abundant species

The most abundant species described for each of five Ayeyarwady Basin zones were identified through interviews of groups of fishers in 14 townships throughout the Ayeyarwady Basin:

Ayeyarwady Delta HEZ

Shrimp (either marine or freshwater) and crab (i.e., arthropods) are dominant species in the delta, particularly in the Labutta District, according to fishers consulted. Marine species are dominant in Patheingyi. Estuarine species, such as mullets or Sciaenids, are also dominant in catches throughout the delta. Catfish and hilsa are among the top 10 most abundant species in the delta. From an economic perspective, crab and shrimp are the most important taxa. Of fish, hilsa is foremost, followed by catfish (*Silonia silondia*, *Wallago attu*, and *Sperata sp.*). Among other commercially important species are mullets, threadfins, otoliths, silver pomfret (*Pampus argenteus*), and false trevally (*Lactarius lactarius*).

Lower and Middle Ayeyarwady HEZs

In terms of fish abundance, Pyaw is part of the same cluster as the other cities of the delta, while Magway is part of the Middle Ayeyarwady cluster; the latter also includes Myittha. Magway, in particular, features a large abundance of species used in aquaculture systems. Catfishes remain present in all of its districts. Whiskered catfish (*Wallago attu*), a sensitive and valuable species, is part of the top 10 in Magway and Shwebo, indicating good fishery conditions. Economically speaking, *Silonia silondia*, *Wallago attu*, and *Sperata sp.* are considered the most important commercial species. Freshwater shrimp (*Macrobrachium rosenbergii*) is also important to the income of fishers in this zone, followed by featherbacks (e.g., *Notopterus notopterus*).

Upper Ayeyarwady HEZ

Putao Region harbours endemic species and species typical of rapid rivers (e.g., *Garra sp.*). Catfishes are the most economically significant species for fishers. Introduced tilapia (*Oreochromis niloticus*) is considered one of the top three species.

Chindwin HEZ

This zone features several large catfishes (*Wallago attu* and *Bagarius*, *Silonia*) typical of healthy rivers. From an economic perspective, common and valuable catfish (*Silonia silondia*, *Wallago attu*, and *Sperata sp.*) are dominant. Myitkyina and Monywa are characterised by the significant economic role of the Sardinella razorbelly minnow (*Salmostoma sardinella*).

7.4.2 Species decreasing and increasing in catches

Fish declining in the delta, according to interviewees, are valuable species, such as eel, hilsa, freshwater shrimp, and whiskered catfish. Shrimp and marine and coastal fish species (hilsa, *Polynemus sp.*, and sea bass) are declining despite their usual higher resilience compared to freshwater species. Further up the Ayeyarwady Basin, large catfishes (*Silonia silondia*, *Sperata acicularis*, and *Wallago attu*, 1.8 to 2.4 m in size) are among the top declining species. They are followed by other smaller, but commercially valuable catfish species. In the Upper Ayeyarwady, results are more site-specific.

In the delta, the beginning of the decline of most species has taken place, according to most observers, during the last decade. Up to Pyay, the last 5 years in particular (2012 to 2016) seem to be characterised by an accelerated decline for a number of species. No generic timing patterns appear in the other districts. In contrast, fishers indicated that a few species seem to increase in catches. Among these are tilapia (*Oreochromis niloticus*), a catfish resistant to electrofishing (*Pangasius pangasius*), and some mystus catfish (*Mystus sp.*) of low commercial interest.

7.4.3 Documented fish migrations

Large and migratory species of commercial significance that have become rare in most tropical rivers are still relatively abundant in Myanmar rivers. However, stakeholders unanimously report declining abundance of such species.

The migratory status, migration routes, and breeding sites of 30 species were recently surveyed through the Ayeyarwady Delta and Central Dry Zone. The study is based on local ecological knowledge of 200 fishers surveyed in 42 sites from the delta up to Katha and Kalewa.

Fishers interviewed did not know the migratory status of 14 species. Most of these species are quite rare and have no known breeding sites in the places surveyed.

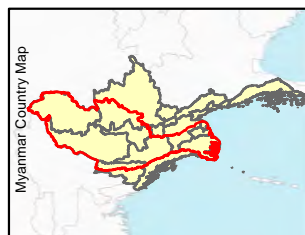
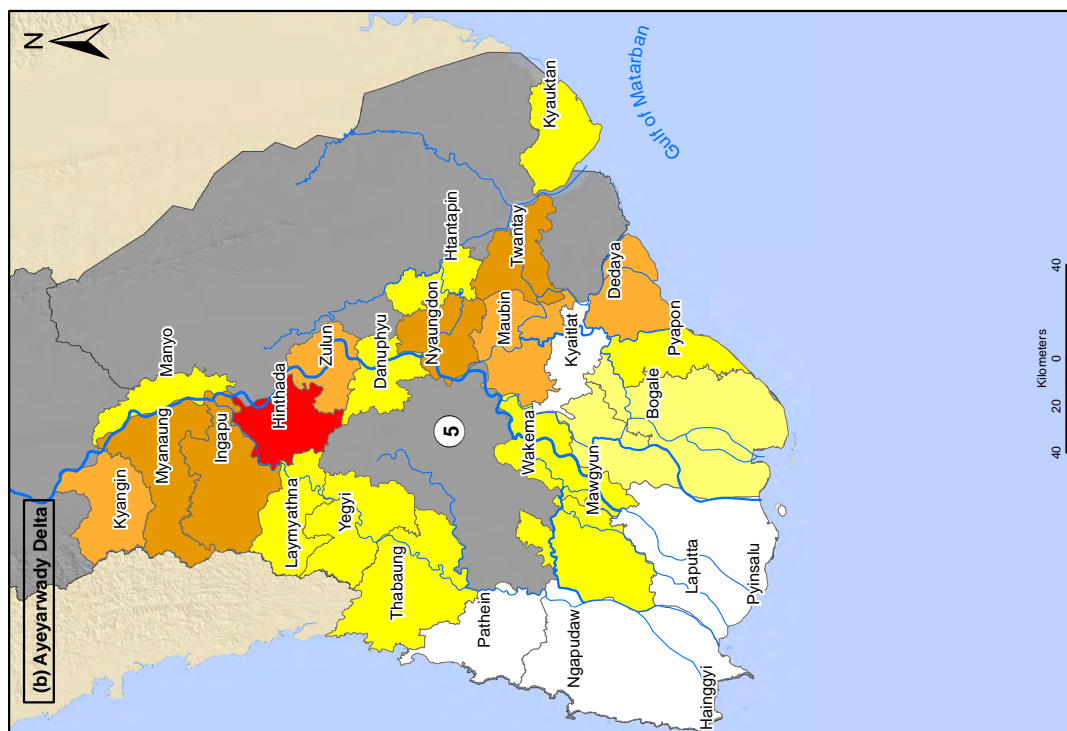
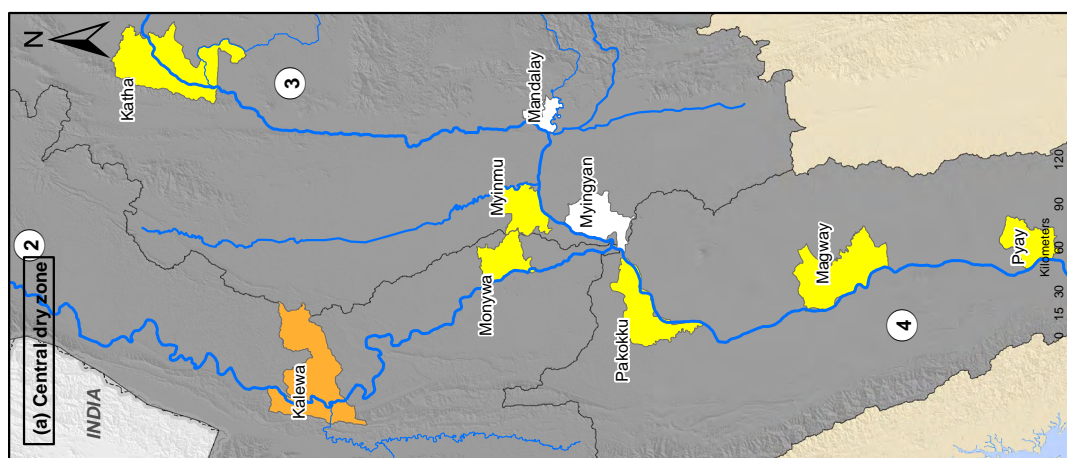
The five migratory species dominant in catches are *Pangasius sp.*, *Tenualosa ilisha*, *Rita sp.*, *Pangasius pangasius*, and *Hemibagrus microphthalmus*. Three of the five are catfishes. These species are followed by less abundant migratory species, including *Wallago attu*, *Cirrhinus cirrhosus/mrigala*, *Bagarius bagarius*, *Gibelion catla*, *Labeo calbasu*, *Sperata aor*, and *Silonia silondia*. The remaining species are rare in catches.

Among these species, two are considered migratory with no known breeding sites (*Hilsa kelee* and *Ilsha megaloptera*). Five species are considered non-migratory with known breeding sites in the Ayeyarwady system (*Bagarius bagarius*, *Cirrhinus mrigala*, *Gudusia variegata*, *Hemibagrus microphthalmus*, and *Sperata sp.*). Lastly, there are nine migratory species, also with known breeding sites (*Gibelion catla*, *Cirrhinus cirrhosus*, *Labeo calbasu*, *Lates calcarifer*, *Pangasius sp.*, *Pangasius pangasius*, *Rita sp.*, *Silonia silondia*, and *Wallago attu*).

Two species are characterised by a high number of breeding sites in multiple townships. These species are hilsa (*Tenualosa ilisha*) and whiskered catfish (*Wallago attu*).

Five species are characterised by a limited number of known breeding sites (1 to 3 maximum). These species are *Bagarius bagarius*, *Gudusia variegata*, *Sperata sp.*, *Hemibagrus microphthalmus*, and *Silonia silondia*. All five species require special management attention through the protection of their breeding sites.

An analysis of zones based on their ecological value from a fisheries protection perspective shows that Hinthada Township has the highest ecological value, followed by Ingapu, Myanaung, Yandoon, and Twantay Townships (Figure 7.6). Hinthada Township is, therefore, a priority place for fisheries resources protection and management measures. This ecological value is a combination of the number of species breeding, surface area of breeding sites, and the importance of species to fisheries.



Legend

Main river
Other river

Ecological value from fishery perspective

0 Low
1
2
3
4
5 High

HEZ boundary
Country boundary

Hydro-Ecological Zones

① = Upper Ayeyarwady
② = Chindwin
③ = Middle Ayeyarwady
④ = Lower Ayeyarwady
⑤ = Ayeyarwady Delta

Data Source :

Creation Date : 30-Nov-17
Administrative Bdy : MIMU
DEM : SRTM 90m
Basin Bdy : Hydrosheds/
WISDM/HIC
Paper Size : A4

Figure 7.6 - Ecological value of townships in the Central Dry Zone (a) and in the delta (b) from a fish resource protection perspective

7.4.4 *Hilsa migrations in the Ayeyarwady system*

Hilsa (*Tenualosa ilisha*) is of particularly high commercial value and is a major migratory fish resource in the Gulf of Bengal. For the first time, a recent study assessed the migration and breeding sites of this species in the Ayeyarwady.

In the delta, there is no fishing from July to August, which corresponds to the monsoonal or flooding season. In general, the greatest abundance and yield of hilsa is from October to May. The coastal zone shows a consistently high yield throughout the year. This zone is characterised by adult fish rather than by juveniles. Juveniles are observed inland, together with large-sized individuals, probably breeders.

In the Patheingyi River, abundance is highest and largely constant at the mouth of the river. Abundance decreases with distance from the sea, as does the size of the individuals. Large individuals migrate upstream in the first half of the year, while smaller individuals migrate upstream during the second half.

Along the Ayeyarwady River, four patterns of hilsa abundance and distribution were identified:

- There is relatively high abundance along the coast and in large estuaries, and hilsa is found throughout much of the year in these areas.
- Away from the coast and in the smaller rivers the abundance is low and diminishes in proportion to the distance from the coast.
- Dedaye and Twantay Townships display a high abundance compared to other estuarine sites – they are based on the Toe River and linked to the Yangon River by the Twantay Canal, which are two important migration routes.
- Upstream of the confluence of the Ayeyarwady and Toe Rivers, hilsa abundance is consistently high up to Hinthada and then suddenly drops.

Hilsa breeding sites were identified in 15 out of the 32 locations surveyed. The largest breeding site was around Hinthada Township. The most important hilsa breeding zone was in the section stretching from Zalun to Monyo. This leads to two main recommendations:

- Given the importance of the convergence of the Toe River, Twantay Canal, and the mainstream of the Ayeyarwady to the migration and breeding of hilsa, this zone should be a priority location for protection and regulation measures.
- The section of the Ayeyarwady centred on Hinthada and stretching from Zalun to Monyo is the most important hilsa breeding zone and should also be considered a priority location for protection and regulation measures.

7.4.5 *The threat of climate change*

Myanmar is one of the countries most vulnerable to climate change on a global basis. In terms of fish resources, the anticipated changes imply the following:

- Reduced availability of wild fish stocks due to degraded water quality, new predators and pathogens, and changes in abundance of food available to fishery species.
- Changes in fish migration, recruitment patterns, and fisheries success.
- Reduced wild fish stocks, intensified competition for fishing areas, and more migration by fisherfolk.
- Alteration to freshwater capture fisheries due to saline influence.

Late arrival of the monsoon already affects fish migration and spawning, according to the informants consulted. The challenges posed by climate change will require early decision-making about adaptation strategies to minimise impacts on the livelihoods and food security of the poorest fishers in particular.

7.4.6 The threat of dam development

The absence of information on the possible impact of hydropower development on Ayeyarwady Basin fisheries is striking. Extensive studies in the neighbouring Mekong, similarly characterised by huge yields and large-scale fish migrations, have concluded that mainstream hydropower developments will have major negative impacts on fisheries resources. Two main mechanisms are involved, namely:

- River fragmentation and subsequent disruption of fish migrations (in particular, loss of access to breeding sites).
- Significant loss of nutrients due to sediment retention by dams (resulting in an overall loss of water productivity).

The scale of hydropower development plans calls for an urgent and detailed analysis of their possible impacts on Myanmar's fishery resources.

7.5 Fisheries Livelihoods

Livelihoods are examined in this section with respect to employment, the role of fisheries from a local perspective, fish consumption, and gender.

7.5.1 Livelihoods and employment

According to national statistics, fisheries provide jobs for approximately 3.2 million people – 800,000 full-time and 2.4 million part-time jobs, including 1.6 million in inland fisheries and 1.4 million in marine fisheries (Figure 7.7).

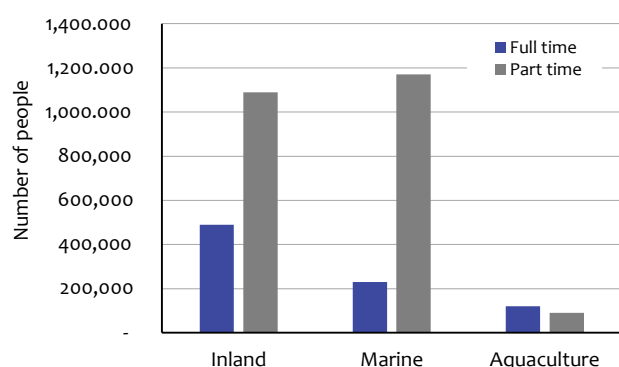


Figure 7.7 - Number of people involved in aquaculture and capture fisheries

(2008 to 2014 average) (DoF, 2015)

Approximately 12 to 15 million people in Myanmar generate income through fisheries. For 25% of landless households, fisheries provide the primary source of income through wage labour or fish sales.

7.5.2 Local perceptions of the role of fisheries in livelihoods

The perceptions below result from a consultation of 14 focus groups of 12 persons each and 80 key informants in 14 districts of the Ayeyarwady Basin from July to August 2017. Agriculture is perceived as the main source of local income. Fishing, hunting, and collecting wild resources is perceived to account for approximately 10% of income when including processing and trading. Aquaculture is perceived to contribute a few percent on average. Fishing alone represents approximately 67% of the combined income from fish and wild resources. However, the differences between zones are significant (Figure 7.8). Fishing is perceived as contributing approximately 10% of local incomes in the delta, compared with a few percent in Chindwin and the Upper Ayeyarwady.

In many cases, fishing is an opportunity to obtain food and a small income on a daily basis. For instance, fishing will pay for children's schooling and for medicine needed in the rainy and winter seasons.

Research informants estimate that the proportion of fishers in the delta is 10% to 20% of the population, compared to less than 5% of fishers in the Lower and Middle Ayeyarwady. Opinions diverged about the situation in the Upper Ayeyarwady and Chindwin Basin, from a few percent to as high as 20%.

Fishers depend primarily on migratory fish species, according to every participant consulted in the Lower, Middle, and Upper Ayeyarwady, as well as nearly every group in the Chindwin Sub-basin. In the delta, approximately 50% of the groups expressed their dependency on migratory species but with high variability. Overall, migratory fish are essential to fishery livelihoods in the north. They are less essential, but still important, to livelihoods in the south of the Ayeyarwady Basin.

In the delta, all groups agreed that fishing is not a desirable livelihood. The three primary reasons given are that fishing is a dangerous activity, better income can be obtained elsewhere, and people do not want to kill fish for religious reasons. These reasons also apply in the Chindwin Basin and, to some extent, in the Lower Ayeyarwady. The consulted fishers considered fishing to be a desirable livelihood in the Middle and Upper Ayeyarwady. In these places, fishing is still perceived as a good traditional activity to support a livelihood.

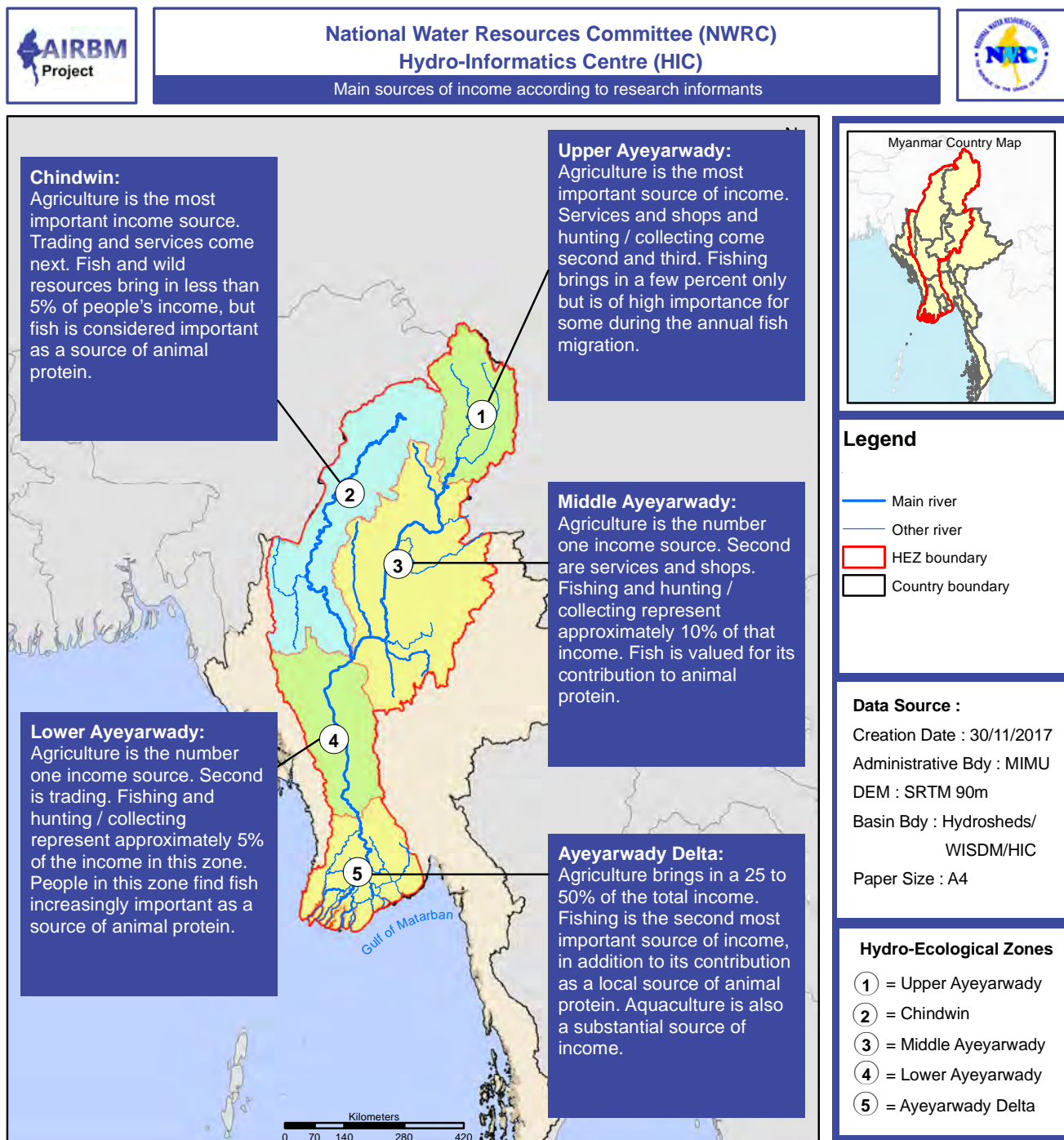


Figure 7.8 - Main sources of income according to research informants

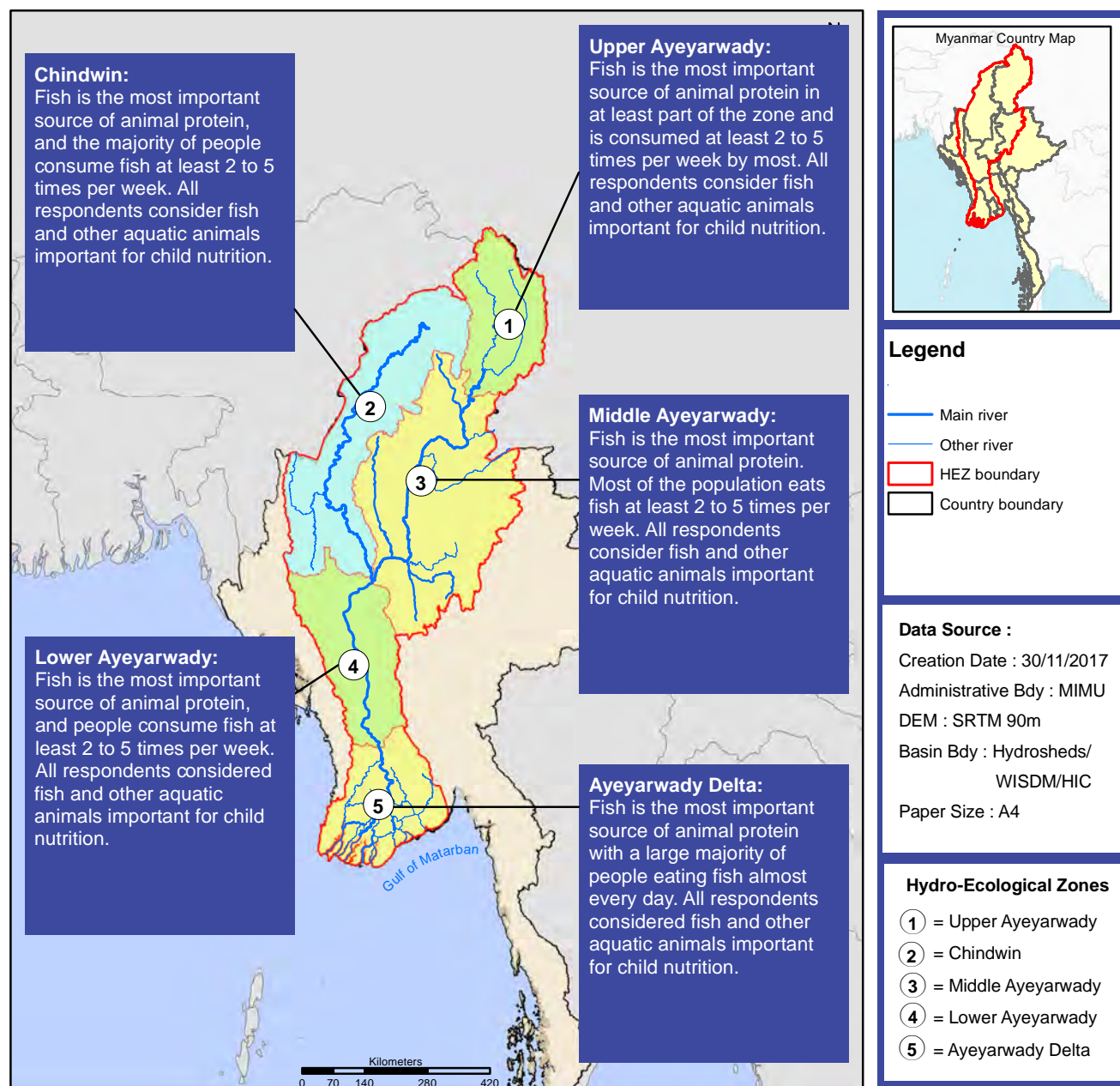


Figure 7.9 - Importance of fish and wild resources for nutrition according to research informants

Alternative livelihoods identified comprise four main categories, each with similar frequency: waged labour, agriculture, livestock farming, and services. Fish trade is a fifth category that was cited less often (specifically in the Lower Ayeyarwady). In the delta, the livelihood option most often considered is waged labour, followed by livestock farming (usually poultry), and services. Districts of the Middle Ayeyarwady, as well as Monywa and Myitkyina, focus almost exclusively on agriculture, complemented by livestock farming. The two most remote districts mentioned limited livelihood alternatives, namely taxi driving or casual labour, in the case of Putao, and dead wood gathering, in the case of Kale.

Most groups of fishers consulted considered that aquaculture will be more significant in the future. Overall, aquaculture fish are welcome and already widely consumed because of their lower cost compared to wild fish, chicken, and pork, and because they are perceived as a better option than wild fish for religious reasons.

7.5.3 Fish, nutrition, and food security

Second only to rice, fish is a major contributor to Myanmar's national diet. Fish was estimated to account for approximately 60% of animal protein intake in Myanmar. Fish is rich in essential micronutrients, such as calcium, iodine, and some vitamins, as well as amino acids and oils. Consuming fish also contributes to the bioavailability of nutrients from other food items in the meal.

In 2000, fish consumption per capita was estimated to be triple that of meat consumption for the population. A study in Labutta and Bogalay Townships showed that 54% of fishing households consume half their catch, while 14% consume all of their catch. However, there is a lack of quantified documentation on the inter-regional differences in fish consumption.

Research informants unanimously identified fish as the primary source of animal protein in all zones of the Ayeyarwady Basin (Figure 7.9). Prawn and shrimp were also considered important in almost all zones. The role of fish in nutrition is relatively less important in the Upper Ayeyarwady, where access to wildlife provides an alternative food source. In all zones, fish and other aquatic animals are considered important for the nutrition of children and believed to aid in their development, including strengthening of bones and brain development. They are also seen as contributing to infection prevention. Respondents expressed appreciation that fish resources are widely available at a fair price, making them accessible to most people. The large majority of those surveyed stated that people consume fish and/or other aquatic animals either almost every day or two to five times per week.

The species most often consumed are the climbing perch (*Anabas testudineus*), mola carplet (*Amblypharyngodon mola*), pool barb (*Puntius sophore*), spotted snakehead (*Channa panaw*), bronze featherback (*Notopterus notopterus*), Philippine catfish (*Clarias batrachus*), stinging catfish (*Heteropneustes fossilis*), striped snakehead (*Channa striata*), tilapia (*Oreochromis niloticus*), and rohu (*Labeo rohita*).

National fish statistics about fish consumption are simply calculated as (Landings - Exports) / Population. Such a calculation, biased by misestimated landings (Section 7.3.3) and underestimated fish exports (Section 7.3.6), is inaccurate and cannot be used for monitoring. A large-scale and rigorous reassessment is needed to address current inconsistencies in fish consumption estimates and unrealistic growth in official fish consumption patterns.

7.5.4 Gender in fisheries

Although fishing and aquaculture are male-dominated activities, women play significant roles in fisheries. A number of small-scale fishers around Inle Lake, for example, are women. Around the Gulf of Mottama, there is evidence of women taking an active part in fishing, especially in the inland water bodies. Depending on circumstances, women may fish along with their husbands, with other women, or on their own. They may go fishing in a boat or by wading in shallow waters. Women manage many small-scale aquaculture ponds and hatcheries or are engaged in routine management operations, such as feed preparation and feeding. Beyond catching and farming fish, women play a dominant role in processing and marketing fish.

According to focus groups and key informants, the gender distribution of fishers is approximately 75% men and 25% women when averaged between all five zones. The opposite is true in terms of involvement in fishing-related activities, such as processing and sales, where women make up at least 75% of the workforce. Participation in fishing seems less separated by gender in Chindwin and the Lower Ayeyarwady, where approximately 40% of the fishers are women according to the focus groups surveyed. However, the overall picture remains one of a relatively clear division of work between the genders.

Despite their integration in fisheries, women's contribution is often overlooked and undocumented. For instance, interviews reveal that fisheries laws require registration of fishing gears and that most families register only the male household head. Therefore, official numbers largely exclude women from being identified and counted as fishers.

Gender data on fisheries in Myanmar are limited, and women's rights to participate in sectoral decision-making are often ignored. The development of a network of women in fisheries in Myanmar would present a promising opportunity.



7.6 Conclusions

Overall conclusions are presented here from two vantage points – that of a fisheries manager and that of fishers and communities at the local level.

7.6.1 A manager's perspective

The main challenges and opportunities are outlined here from the perspective of a fisheries manager.

Main challenges

The efforts of DoF to develop a sustainable fisheries sector are hampered by the lack of reliable data and inadequate monitoring, compliance, and enforcement. The tradition of using centralised targets, with the aim of maintaining or increasing government revenues, compromise data quality and create conditions for misreporting. Recommendations to address these monitoring issues include the following:

- De-link data collection and statistics from the target planning process.
- Raise the capacity of DoF in fisheries statistics, data collection, and analyses at all levels (headquarters, regional, districts, and townships).
- Replace the current paper-based system for data collection with a digital system.
- Put in place a standardised and sample-based data collection system for fisheries and aquaculture with guidelines, appropriate data collection forms, and transparent procedures.
- Revise published data, if possible, to provide more accurate insights about the real trends in catches since 1994 to 1995.
- Implement a pilot project in one or two regions.

Non-compliance with regulations is widespread, and the lack of monitoring and enforcement of regulations poses a self-evident problem for the sustainable management of the sector. Recommendations to improve compliance and enforcement include the following:

- Establish dedicated provisions for fisheries monitoring, compliance, and enforcement within the legal system.
- Update fines to a level that reflects the severity of the impact of the infringement on resources, supports voluntary compliance, and acts as a deterrent.
- Introduce some form of regulation for the 16 types of gear that do not presently require licensing by DoF.

Main opportunities

A great deal can be achieved through communication, agreements, and cooperation between government line agencies, even in the absence of a national policy mandate. This is illustrated by the National Water Resources Committee, which was set up in July 2013 and brought together representatives from 23 government agencies with the task of integrating their efforts.

Co-management provides a mechanism to help complement the efforts of government agencies to manage the inland fisheries sector:

- They can contribute to data collection and monitoring.
- They can help the enforcement of fisheries regulations.
- They would facilitate communication between DoF and fishing communities.

A step-by-step approach is recommended for the introduction of a fisheries co-management system in Myanmar, with lessons and models to be drawn from forestry co-management and from community fisheries established in nearby countries.

Many countries have established active fisheries in reservoirs with little environmental impact. In Myanmar, the Department of Irrigation banned the practice in 1995, based on perceptions that fishing in reservoirs is environmentally unsound, while DoF has continued stocking reservoirs with carps for 'conservation purposes'. There need not be a conflict between the creation of reservoirs for irrigation purposes and their utilisation for fish production. In 2003, it was estimated that reservoir fishing could provide employment for 20,000 to 30,000 people. It is, therefore, suggested that reservoir fishing be reintroduced slowly, initially on a small scale, in conjunction with the irrigation authorities, and while including research to assess suitable strategies, cost-effectiveness, and sustainability. A unit could be created within DoF to manage these responsibilities.

7.6.2 The local perspective

Taking a local perspective, this section outlines the main perceived trends and issues and concludes with options and recommendations.

Main trends perceived

Focus groups and key informants perceived a downward trend in the economic importance of income sources related to fishing. However, people generally reported improved living standards, in terms of economic and social well-being, and expected this trend to continue. Physical infrastructure improvements, including roads, bridges, and telecommunication, are the most commonly cited major positive socio-economic changes that occurred during the last decade, followed by improved health and education infrastructure and the transformation from traditional to mechanised farming.

Throughout the Ayeyarwady Basin, fish and other aquatic animals are widely perceived as more important for animal protein now than compared to 10 years ago. Reasons for this include improved knowledge about the health benefits of fish, livelihood dependency on fish, and increased demand from a growing population.

The most common negative change experienced is a decline in yields, especially reduction in quantities, sometimes sizes, of fish, shrimp and prawn. Such decline characterises the last decade. Likewise, people expect fish abundance to decrease further in the coming decade.

Floods, shallowing of creeks and rivers, and an increase in illegal fishing – together with the proliferation of drugs – were perceived as downsides of development of the past decade.

Issues perceived

Almost every group consulted was concerned that fish, like shrimp and prawns, are decreasing in abundance. Electrofishing, poisoning (from agriculture or intentionally), and destruction of aquatic habitats were the most commonly mentioned issues in all zones surveyed, followed by gold mining, and organisational or land sharing issues in leasable fisheries. Electrofishing and pesticide fishing were reported at an alarming scale across the entire Ayeyarwady Basin.

Informants attributed the main causes of fish species decline to overfishing (linked to a reduction of mesh sizes, human population increase, and a rising number of trawl boats in the delta), destructive fishing (electrofishing and fishing using pesticides) and fishing in spawning seasons. The perceived causes of aquatic habitat destruction were identified as deforestation, erosion, gold or sand mining, extension of farms into floodplains, and clearing of natural vegetation that normally benefit fish in floodplains and wetlands. Among other causes identified was the demand for multiple uses of floodplains (fishing vs. farming), rivers (fishing vs. mining), and some organisational aspects (timing in water management and licensing).



It is noted that dam development (hydropower or irrigation dams) was not mentioned during consultations as a possible threat to fish resources, although the negative impact of dams on fish production is well known to scientists, particularly in neighbouring Mekong. This may be attributed to the fact that:

- Dam density is still relatively low in Myanmar, with low visibility at this stage.
- Impacts will be fully experienced several years after dam construction.
- People at the local level often do not perceive the diffuse or distant impacts of dams (e.g., reduced migration and breeding success).

This underlines biases inherent in consulting local communities, and the need to complement people's perceptions with predictive scientific studies and lessons from other countries.

Options and recommendations

Fisher informants identified five primary solutions to improve the management of fish and wild resources:

- Improve law enforcement – Finding ways to stop illegal fishing is among the top recommendations. Although there are sufficient provisions in the law for good management, law enforcement was repeatedly mentioned as being weak, with people consulted often calling for increased cooperation between the authorities and the resource users as well as between different government departments.
- Limit pollution – By imposing restrictions (on the use of pesticides and on the release of pollutants) and by improving environmental awareness and education.
- Restrict destructive practices – Practices, such as sand mining, waste dumping in rivers and floodplains, and use of harmful pesticides, need to be restricted by upgrading and improving current laws and regulations.
- Improve coordination between parties – Either between fishers and DoF (management of leasable fisheries) or between fishers and farmers (reaching compromises about land and water uses).
- Undertake reclamation activities, in particular replanting mangrove forests – Stocking fingerlings into waterways was perceived by informants as a way to boost fish production in the wild, but scientists do not necessarily agree with this assumption.

At the local level, some recommendations are more specific, including:

- Ayeyarwady Delta – Impose an effective ban on electrofishing, pesticide use as a poison, and cage farming in forested areas. Focus on mangrove reforestation.
- Lower Ayeyarwady – Impose an effective ban on electrofishing, pesticide use as a poison, and extraction of sand, stone, or gold from rivers.
- Middle Ayeyarwady – Impose an effective ban on fishing during the breeding season (April to June), allow for three-year leases for more sustainable management of leasable fisheries, and facilitate negotiation and compromise between farmers and fishers.
- Upper Ayeyarwady – Impose an effective ban on electrofishing and illegal fishing.
- Chindwin – Impose an effective ban on electrofishing and the use of poison and focus on reforestation.

In all cases, research informants expressed strong interest in collaborating with the authorities in order to share knowledge and help with monitoring or control of illegal activities, especially during migration and spawning seasons, and in the dry season when the reduced size of water bodies can jeopardise the fish survival chances.

BIODIVERSITY





HIGHLIGHTS – BIODIVERSITY

- Predictions of rapid economic growth across Myanmar will be tightly linked to natural resource exploitation; this creates new and additional challenges for biodiversity in the Ayeyarwady Basin, which is already under enormous environmental stress, and should be addressed as a matter of urgency.
- The Ayeyarwady Basin is one of the most biologically diverse regions in the world; it is the 19th richest region in bird diversity globally and home to 1,400 mammal, bird, and reptile species, with more than 100 species that are globally threatened.
- Little is known about trends in abundance or risks to the 85 to 101 freshwater mollusc species, including 8 or 9 species endemic to the Ayeyarwady Basin.
- The state of biodiversity in the Ayeyarwady Basin is fragmented, declining, precarious, and very fragile.



- It is estimated that only 25% to 33% of former wetlands still exist within the Ayeyarwady Basin.
- The overall trend in biodiversity is declining across all taxa, some of which are declining sharply and rapidly.
- There is a clear gradient from the less biodiverse coast to richer biodiversity at higher elevations, and outstandingly high diversity in the eastern area of the Ayeyarwady Basin.
- Trend data in population sizes are unavailable for most taxa (other than waterbirds) and declines are almost entirely illustrated by the absence or loss of a species or species group.
- Urgent conservation measures are needed to protect some species, including the last remaining riverine terns and the Irrawaddy dolphin river population, which is in a critical but stable state.





HIGHLIGHTS – BIODIVERSITY

- The threats and reasons for the declines range from large-scale industrial ventures to increasing sand and mineral mining, and precipitous hunting and poaching across the entire Ayeyarwady Basin.
- Hydropower and irrigation dams have devastating impacts on many species.
- Stocked aquaculture fish have escaped from ponds and are beginning to invade most river stretches.
- Uncontrolled hunting and wildlife trade occurs in approximately 70% of Protected Areas.
- Urgent attention should be given to the 89 KBAs, of which only approximately 50% are officially protected.
- It is highly recommended to expand the Protected Area network and increase the level of KBA coverage by Protected Areas to at least 80% of Key Biodiversity Areas (KBAs).



- UNESCO Biosphere Reserve recognition could be extended in the Ayeyarwady Basin beyond Myanmar's two existing reserves.
- Listing the Ayeyarwady River between Mytkyina and Bagan (or even further downstream) as a World Heritage Site could protect the river and contribute to local livelihoods.
- Ecotourism could provide opportunities for biodiversity conservation alongside economic growth.
- Stress on the biodiversity in the Ayeyarwady Basin could be addressed through policy and institutional reform and the integration of environmental safeguards into economic development planning.
- A resource management plan for the entire river should be developed as soon as possible, with no-take zones free of any fishing, mining, and dredging.
- Waterbird monitoring could act as a good indicator for monitoring the health of the river basin wetlands.



8 BIODIVERSITY

8.1 Introduction

This chapter summarises current knowledge of the status, trends, and threats to biodiversity in the Ayeyarwady Basin and outlines key opportunities for conservation and future monitoring. Its focus is primarily on a wide range of wetland habitats and species, but also includes biodiversity of broader interest where information is available, such as for birds, most mammals, and selected reptiles. Overall, the state of biodiversity in the Ayeyarwady Basin is fragmented, declining, precarious, and very fragile.

SOBA Technical Reports

This chapter is a synopsis of the full assessment, which may be accessed by readers seeking more detailed information, including references:

SOBA 4: Worldfish & FFI (2017), **Biodiversity of the Ayeyarwady Basin** (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

SOBA 4: Worldfish & FFI (2017), **Aquatic habitats in the Ayeyarwady Basin and their biodiversity** (SOBA 4), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project.

8.2 Ayeyarwady Setting

The Ayeyarwady Basin is a vast network of riverine and lake wetlands that provides a host of ecosystem services to Myanmar's population. Its river and wetland habitats are shown in Figure 8.1.

With a total area of 413,674 km², the Ayeyarwady Basin has a cascade of 12 ecoregions (Table 8.1), from Hkakabo Razi Mountain, with an elevation at 5,881 m and an alpine shrub and meadow system, down to the delta mangroves at sea level. The Ayeyarwady Basin can be described in three parts: the mountainous Upper Ayeyarwady that extends to the Himalayas; the hilly and floodplain zone in the Middle Ayeyarwady; and the delta landscape of the Lower Ayeyarwady. The Chindwin Basin feeding the Ayeyarwady also has a diversity of ecosystems shaped largely by elevation and geology.

Table 8.1 - Ecoregion representation in the Ayeyarwady Basin

Ecoregions	Basin area coverage (%)
Chin Hills–Arakan Yoma montane forests	2.8
Eastern Himalayan alpine shrub and meadows	2.0
Irrawaddy dry forests	11.4
Irrawaddy freshwater swamp forests	4.3
Irrawaddy moist deciduous forests	31.1
Mizoram–Manipur–Kachin rainforests	7.7
Myanmar Coast mangroves	3.0
Myanmar coastal rain forests	3.1
Northern Indochina subtropical forests	18.2
Northern Triangle subtropical forests	12.1
Northern Triangle temperate forests	2.3
Nujiang Langcang Gorge alpine conifer and mixed forests	1.7
Total Values (<0.1% omitted)	99.8

8.3 Species Distribution, Abundance, and Status

Data on biodiversity is scattered and in many cases non-existent. For most taxa, little information is available on a basin-wide scale. Best-studied groups are birds, mammals, reptiles, and fish. However, even in those taxa there are gaps, and data by sub-basin is scattered. Information on invertebrates is scarce and does not exist for many taxa, such as insects of the order *Odonata* or *freshwater crabs*. *Previous assessments focused more on the Himalayan Region, but the large majority of the Ayeyarwady Basin was not included in the International Union for Conservation of Nature (IUCN) assessment. Hotspots analysis presented in this report used species distribution data provided by IUCN. This data has also been used in combination with other published information to portray the general distribution for some species with that recently observed based on KBA information.*

8.3.1 Mammals

Most of the >300 species of mammals recorded in Myanmar are found also in the Ayeyarwady Basin, including at least 5 endemic mammal species. However, many large mammals may have either disappeared from the Ayeyarwady Basin or declined in population significantly. Several species, including both rhinoceros species (*Dicerorhinus spec.*) and the wild water buffalo (*Bubalus arnee*), have not been recorded recently, while others are very rare and their current status uncertain. In total, 41 species listed as globally threatened are present in the Ayeyarwady Basin.

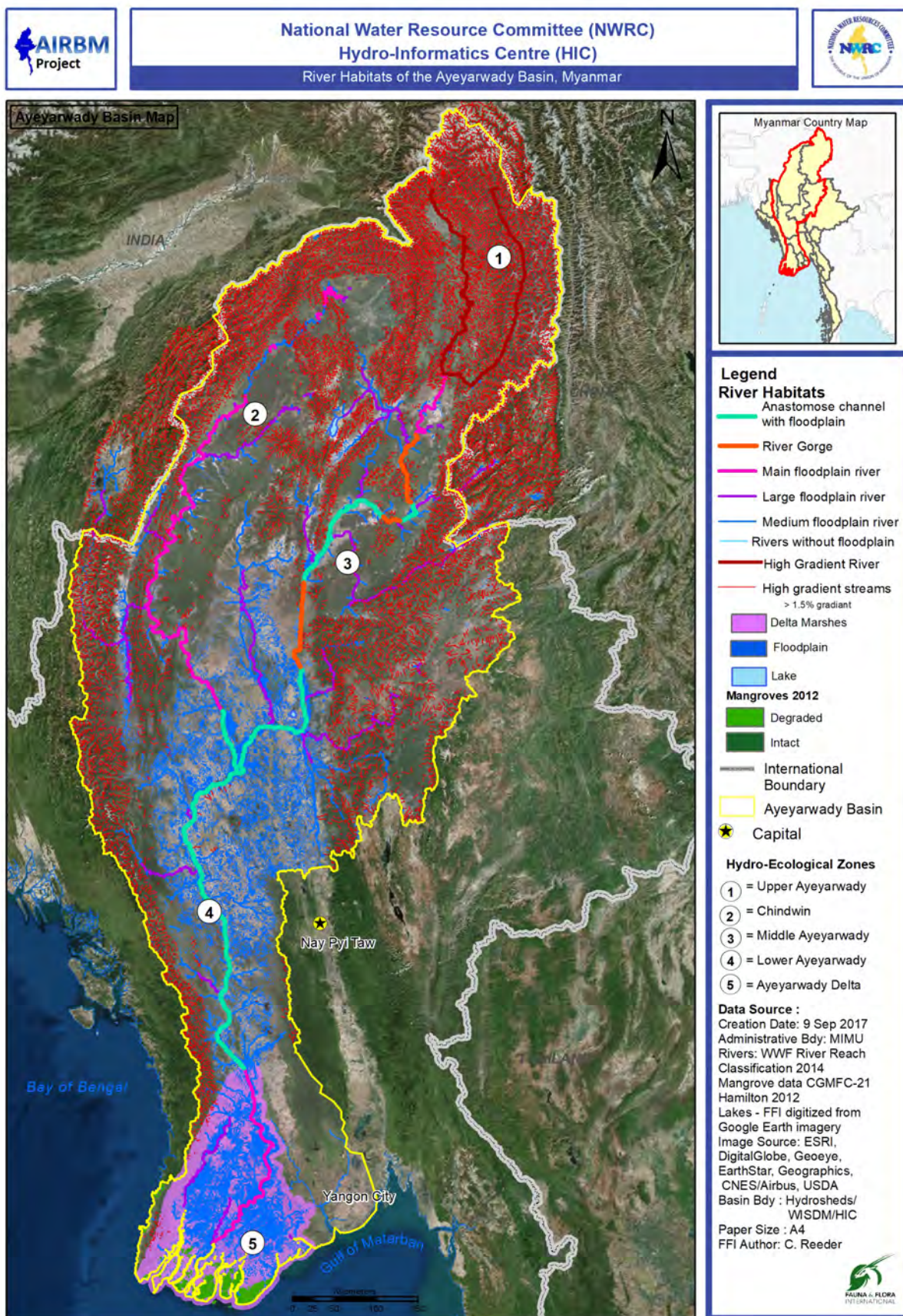


Figure 8.1 - River and wetland habitats in the Ayeyarwady Basin

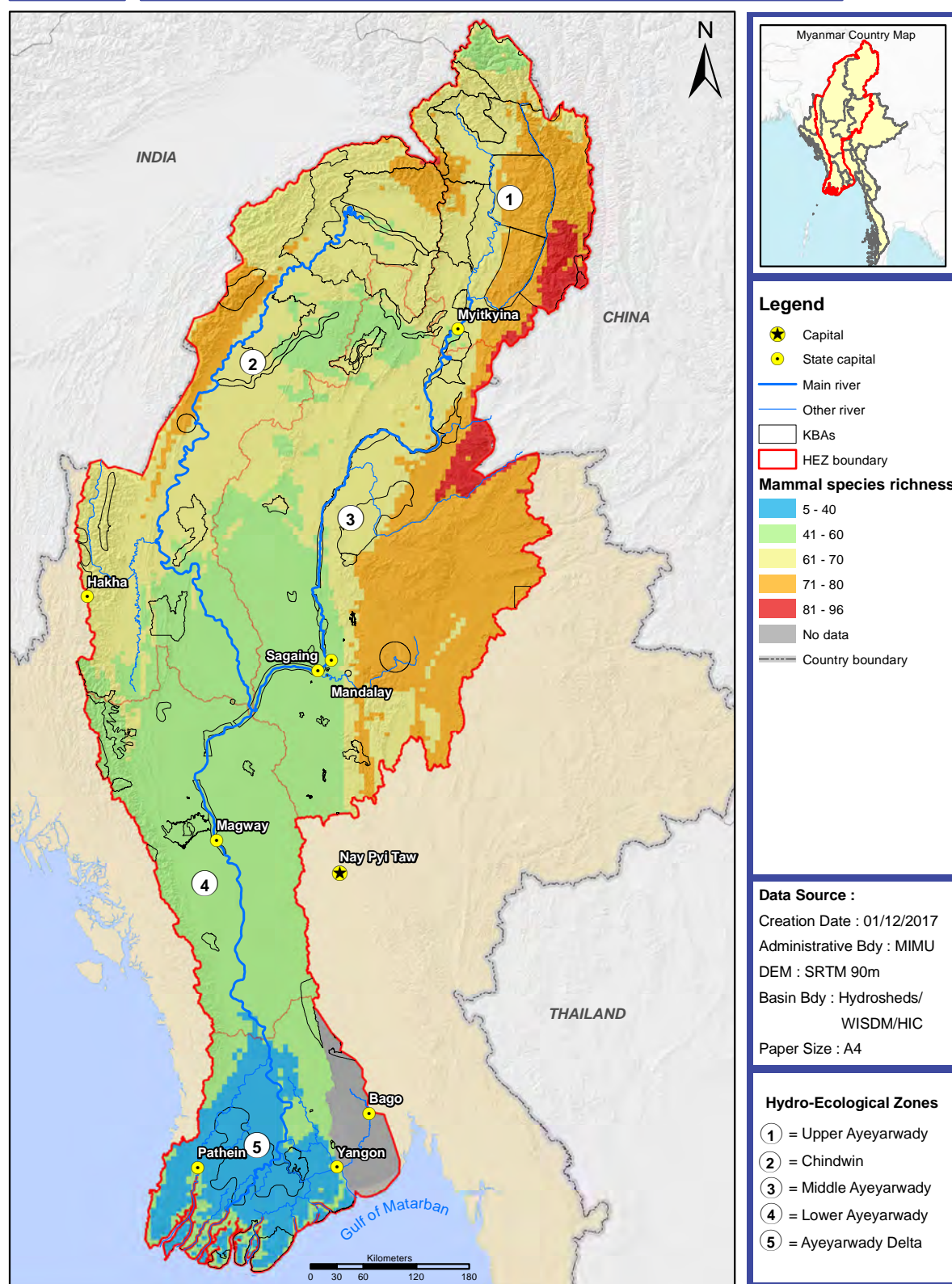


Figure 8.2 - Mammal species richness within the Ayeyarwady Basin

In addition to the Sumatran Rhinoceros, last recorded in the Ayeyarwady Basin in 1980, five are listed under the IUCN's Red List as critically endangered (CR), 15 as endangered (EN) and 23 as vulnerable (VU).

Only the wild water buffalo (*Bubalus arnee*), fishing cat (*Prionailurus viverrinus*) and four other species have a distinct affinity to wetland habitats. The Wild Water Buffalo is restricted to the Hukaung Valley, but there are no recent surveys to confirm its presence. The elusive fishing cat is now confined to Meinmahla Kyun Wildlife Sanctuary where, according to forest rangers, several dozen animals are thriving. Three of the four other species are listed as globally threatened (one EN, two VU) and the fourth as near-threatened (NT), reflecting the precarious status of these wetland-inhabiting mammal species.

There is a healthy coastal population of the Irrawaddy dolphin (*Orcaella brevirostris*) in the Ayeyarwady Delta, but the species is considered VU under the IUCN Red List due to an estimated 30% or more reduction in the range-wide population. The small river population of less than 50 mature individuals is considered CR. The recent sighting of a solitary dolphin south of Bagan is the first record in this area after 139 years and confirms the original range of the Irrawaddy dolphin, including the lower Mandalay Region.

It is important for river populations to maintain occasional demographic interaction with other groups for long-term persistence. Groups can become completely isolated if others located in between are eradicated, with potential cascading conservation impacts for the species or populations. This is particularly valid for the isolated river populations of the Irrawaddy dolphin, as well as for other taxa in the Ayeyarwady River.

Figure 8.2 shows the overall distribution of mammal species in the Ayeyarwady Basin.

8.3.2 Birds

Birds have been comparatively well studied in the Ayeyarwady Basin, with 906 bird species recorded (Figure 8.3). There are only 18 countries globally that list more species than the Ayeyarwady Basin. Four of these species have not been recorded for some time and are feared as locally, and one even globally, extinct. Of the 906, 41 are listed as globally threatened, 8 globally CR, and 24 are globally VU. Another 46 species are classified as globally NT.

Seventy-three percent are resident birds that breed or have bred until recently in the Ayeyarwady Basin, the others migrants or vagrants that winter in the Ayeyarwady Basin or stop over on their migration further afield. There are nine bird species endemic to Myanmar, seven of which are endemic to the Ayeyarwady Basin.

A total of 173 waterbirds have been recorded in the Ayeyarwady Basin, including waterfowl, divers, grebes, cormorants, shorebirds, egrets, and related birds. For this subgroup of birds that live on or near river and wetland habitats, distributional and trend data are available. Other species from different families are also mentioned, especially when globally threatened or range-restricted. Among the CR- and EN-listed species are many whose range or populations have declined. The black-bellied tern (*Sterna acuticauda*; EN) graphically depicts the status of the Ayeyarwady River; this species is exclusively distributed along large rivers consisting of extensive sand bars, but today it is confined to only three or four sites in the Ayeyarwady River.

It is striking to also see common waterbirds declining, with almost all species affected. In many river sections the numbers of the common ruddy shelduck were declining compared to surveys of previous years. In some instances, the decline at some observation sites might reflect a redistribution of waterbirds along the river. It is not clear what has caused the decline, but prevailing hunting and loss of riverine habitats might be a major contributor.

Another common resident species, the small pratincole (*Glareola lactea*), has declined by approximately 25% in the past 14 years. Considering this decline across one of the species' main distribution areas in the Ayeyarwady Basin, a listing of the species to globally NT or even VU might be warranted, subject to further assessments from neighbouring countries.



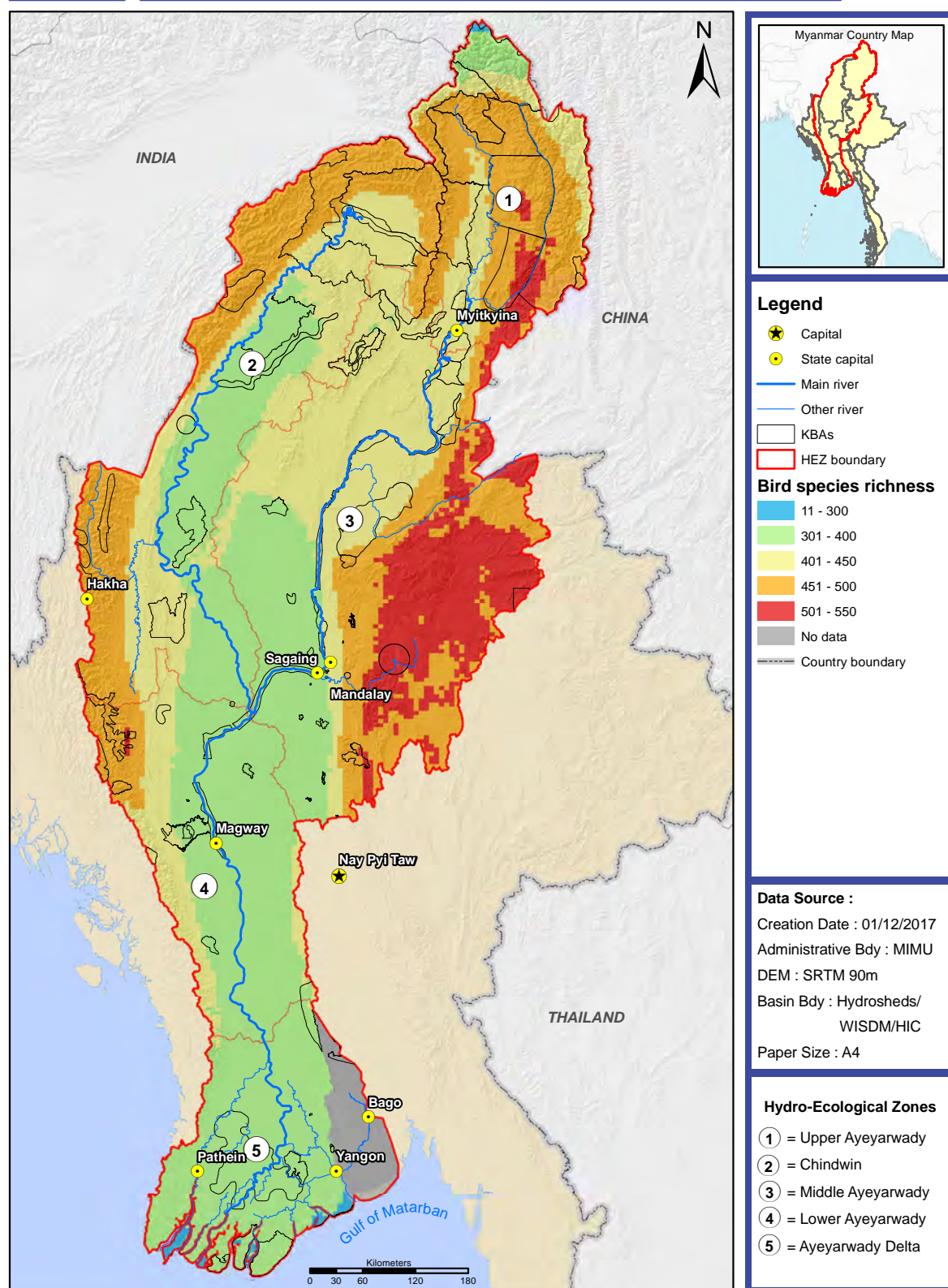


Figure 8.3 - Hotspots of bird distribution in the Ayeyarwady Basin

8.3.3 Reptiles

The Ayeyarwady Basin is estimated to have approximately 200 species of reptiles; 21 are endemic to Myanmar and 24 are globally threatened. It is likely that many of the threatened species (mainly turtles) will have their level of threat lifted to a higher category.

The distribution of 134 species has been digitised, forming the basis of Figure 8.4.

Freshwater turtles rely entirely on ecologically healthy river systems and, in some cases, lakes. Most freshwater turtles have declined and the two endemic species, the mangrove terrapin (*Batagur baska*) and Burmese roofed turtle, have suffered from heavy poaching and habitat destruction. Freshwater turtles are still not well studied, which is alarming given the threats faced by turtle populations throughout the Ayeyarwady Basin from commercial and subsistence harvesting and habitat destruction.

Many of these endangered reptiles, which include the saltwater crocodile (*Crocodylus porosus*), have been rescued from local extirpation by breeding programmes at zoos and wildlife sanctuaries.

8.3.4 Marine Turtles

Five species of marine turtles were known to nest in the Ayeyarwady Delta at well-known island and mainland beaches, known locally as turtle-banks. Two of these, the hawksbill (*Eretmochelys imbricate*) and leatherback (*Dermochelys coriacea*), are considered CR and were already extremely rare in 1999 and are possibly already gone. The green turtle (*Chelonia mydas*) is considered EN under the IUCN Red List, while the other three species are VU.

Regular monitoring of selected turtle nesting sites on the Outer Delta Islands shows that numbers have continued to drop dramatically since 2000.

8.3.5 Amphibians

According to IUCN, there are approximately 120 amphibian species occurring in Myanmar. These comprise of 116 frogs and toads, two caecilians, and two salamanders. Within the Ayeyarwady Basin, there are 102 species; however, this is very likely an underestimate of the real diversity of amphibians present, which has not been studied in detail. Of these 102 species in the Ayeyarwady Basin, two of the frogs and toads are classified as EN, and a further three of four as NT, 57 are least concern, and 14 data deficient.

8.3.6 Fish

Information on fish diversity, distribution, and numbers is scattered. For the Ayeyarwady Basin, 388 fish species have been recorded so far; 311 are in the Myanmar area, while the others are in India and China. Fifty percent of these species are endemic to the Ayeyarwady Basin. A number of endemics are in that portion of the Ayeyarwady Basin that is within India and China, but the vast majority are expected to be present in Myanmar, at least close to the border.

Since 2000, a number of additional species (new to science) have been discovered in Lake Indawgyi basin. Of them, *Mastacembelus pantherinus* is widespread and abundant in the lake and its tributaries. That a large fish, abundant, easily identifiable, of a genus frequently seen on markets, has not been recorded outside the lake suggests it is potentially endemic to the lake.

Assessing the conservation status of many species is difficult because their taxonomy is insufficiently studied and the limited data cannot be unambiguously linked to valid names. A serious problem is that a number of studies have been uncritical, geographically restricted, and/or sometimes confined to reiterating earlier studies with only limited new data; the result is that many of these studies add further confusion to the situation.

8.3.7 Other aquatic fauna and flora

The Ayeyarwady Basin and Chindwin River Basin are considered to have freshwater mollusc species richness of between 85 and 101 species, and eight to nine endemic species. It is very likely that levels of threat status among the molluscs in the Ayeyarwady Basin will be similar to the global profile.

Freshwater crabs, dragonflies and damselflies and aquatic plants have not been surveyed to date in the Ayeyarwady Basin. Currently, the best estimates are based on extrapolation from neighbouring regions that have been better surveyed.

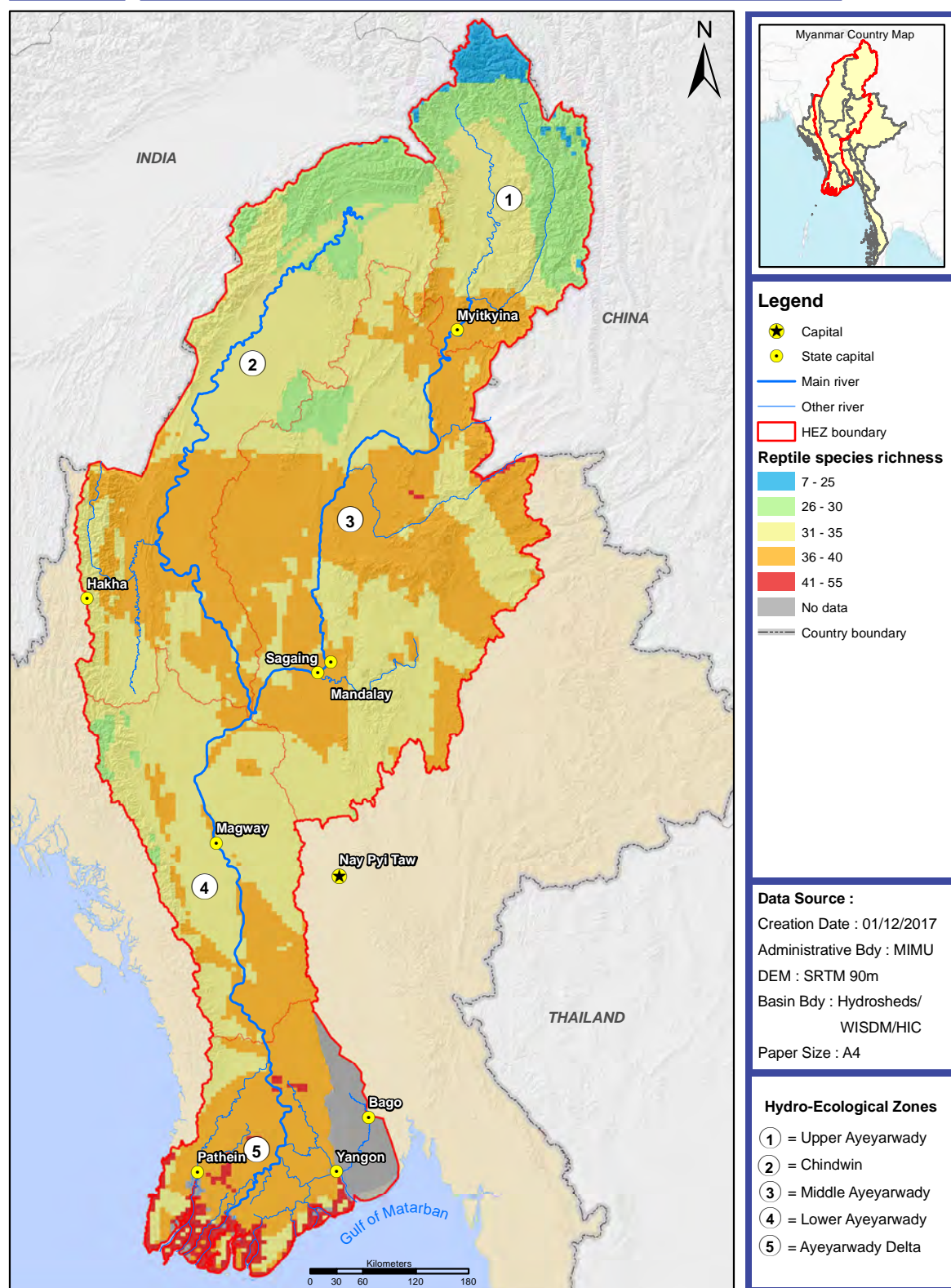


Figure 8.4 - Hotspots of reptile distribution in the Ayeyarwady Basin based on 134 species

8.4 Areas of High Biodiversity Value

Areas of high biodiversity in the Ayeyarwady Basin are described here with respect to biodiversity hotspots and areas of fish species endemism, KBAs, and Ramsar international wetland sites.

8.4.1 Biodiversity hotspots and areas of fish species endemism

Figures 8.2 to 8.4 show a clear gradient from less biodiversity at the coast to richer diversity at higher elevations, both in birds as well as in mammals. It is striking though to see the outstanding high diversity in the eastern area of the Ayeyarwady Basin for both mammals and birds, but less pronounced for reptiles. Very few hotspot areas coincide with the KBA networks (Section 8.4.2). This might be an artefact of species range mapping; however, it is highly recommended that this issue is investigated further in order to obtain more details about potential future KBAs.

In the Ayeyarwady Basin, the highest level of fish endemism is in its mountain tributaries along the Rakhine Yoma and Chin Hills, the Bago Yoma, and its northern tributaries around the Chinese border. But Myanmar requires further surveys and Red List assessments to fully understand the endemic distribution of fish and freshwater molluscs, crabs, and Odonata. This is illustrated by recent ichthyological surveys around Lake Indawgyi and in the Putao Region with 34 species recorded for the first time, of which one genus and about five species were new to science.

8.4.2 Key Biodiversity Areas

KBAs are based on an internationally agreed set of criteria for globally threatened and range-restricted species. Figure 8.5 shows all 89 sites and their coverage by Protected Areas, including six sites added based on new information gathered through this assessment and proposed as a new KBA within the Ayeyarwady Basin.

While the Upper Chindwin is relatively well protected, the Upper Ayeyarwady is less so, although recent new Protected Areas, such as Imawbum, are not incorporated in the map. Of the new KBAs, the Outer Delta Islands are already designated as a Ramsar site (Section 8.4.3) and protected, but all other new proposed areas, alongside several of the older KBAs, still need formal protection.

8.4.3 Ramsar designated sites

Myanmar has four designated wetlands of international importance under the Ramsar Convention on the Protection of Wetlands. In the Ayeyarwady Basin, two KBAs have been added recently, namely Lake Indawgyi, and Meinmahla Kyun and the Outer Delta Islands.

8.5 Trends

The overall trend in biodiversity is declining across all taxa, some of which are declining sharply and rapidly. Trend data in population sizes are unavailable for most taxa other than waterbirds, and declines are almost entirely illustrated by the absence or loss of a species or species group.

Waterbirds have been monitored irregularly, but repeatedly over a period of 30 years. Although the data has not always been collected systematically, waterbird counts and trends are an ideal indicator to show the state of wetlands in the Ayeyarwady Basin. The data can be used for comparison and errors can be reduced by comparing many years and looking at similar patterns in neighbouring sites and different species.

Several decades of monitoring data for two different sites in the Middle Ayeyarwady indicate trends and suggest potential shifts. In addition, for selected and mostly rare species, additional monitoring data from different sites have been referenced to help validate observed trends in the Ayeyarwady Basin.

For any trend analyses it is crucial to understand the migratory status and origin of the species, and also the seasonal changes of waterbirds. Taking all these caveats and limitations into account, it is possible to identify some trends in some species.

For Lake Indawgyi, a total of 44 species have been assessed for trends in population over a period of 10 years, for which monitoring data for some years is available for analyses. Of these 44 species, trend information can be derived for 31 species: 11 are declining, 11 are increasing or possibly increasing, and eight are stable.

Of the 11 declining species, the red-crested pochard (*Netta rufina*) has disappeared altogether and has not been seen in the 2016 to 2017 winter. This corresponds with the absence of this duck on the Ayeyarwady River in the same period. In contrast, the Ferruginous Duck is sharply declining and almost disappearing from the Ayeyarwady River, but only declining marginally or even maintaining a stable population in Lake Indawgyi.

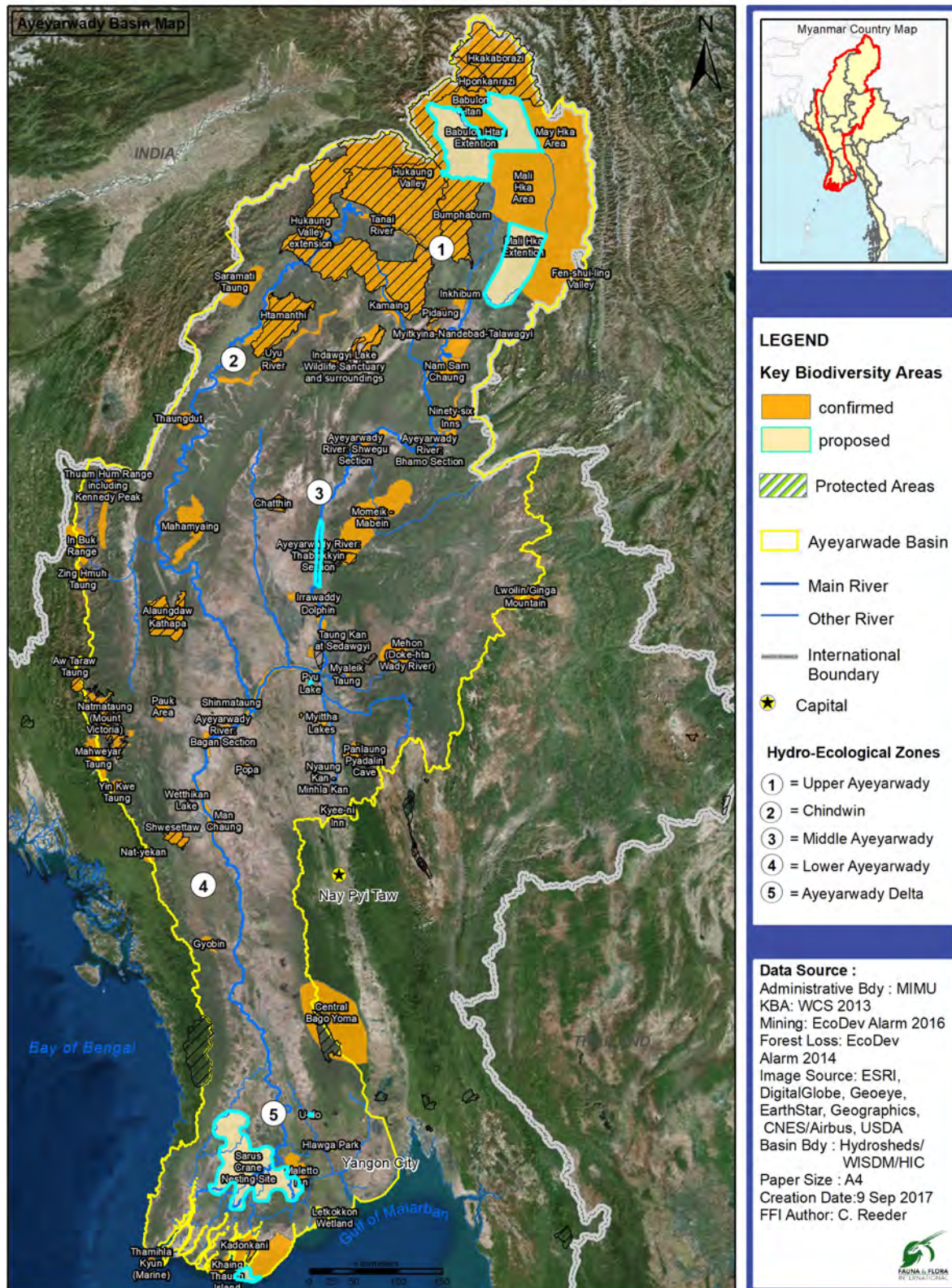


Figure 8.5 –Key Biodiversity Areas (confirmed and proposed) and Protected Areas in the Ayeyarwady Basin

The overall number of waterbirds in the river stretch between Myitkyina and Simbo has declined fourfold from more than 21,000 individuals to only 5,500. These declines range between the species and cover rare and common species, and resident as well as migrant birds from different geographical regions. In this context, it is also important to note that the survey could not find any spot-billed pelican, lesser adjutant stork, black-necked storks, wholly-necked storks, any of the two jacana species, or any of the cotton pygmy goose to name a few. All of these species were present in 2001 to 2003, with some in large numbers. The absence of jacana species and the cotton pygmy goose shows a strong decline and degradation of more vegetated riverbanks and floating vegetation at nearby wetlands in the Ayeyarwady Basin.

Adding to the sharp decline of most waterbirds on the river is the partial disappearance of riverine terns and other sand bank breeding birds. Although the black-bellied tern (*S. acuticauda*) has never been common in the Ayeyarwady Basin, this is almost its last refuge globally. Disappearance from the Ayeyarwady Basin could mean the black-bellied tern would follow the alarming path of extinction like too many others already. It is also striking to see the sharp decline in river terns (*S. aurantia*) in the Ayeyarwady River from 69 birds in 2003, to zero in 2017 along the Myitkyina to Sinbo stretch and from 83 birds in 2006, to only two in 2017 along the Bhamo to Mandalay stretch. Both tern species signal stress and are in serious trouble. Any additional stress by human interference or through further development could push either species to local extirpation, and in the case of black-bellied tern, to global extinction. Urgent conservation measures are needed to protect the last remaining riverine terns.

8.6 Threats

8.6.1 Hydropower and irrigation dams

Hydropower and irrigation dams, as well as any kind of interruption of flow, disrupts the hydrology, sedimentology and ecology of the river with devastating impacts for many species, crucial components of the river ecosystems and, ultimately, the people who live by the river. Dam construction has been mentioned in the IUCN Red List as a significant hazard for globally threatened species.

Mammals

The IUCN Red List specifically mentions that the Irrawaddy dolphin has been affected by various dam projects in several large rivers, including the Mekong. Major threats to Asian otter populations are loss of wetland habitats due to construction of large-scale hydroelectric projects, reclamation of wetlands for settlements, and agriculture.

Birds

All ground-nesting birds are affected by hydropower projects when sand banks and other habitats disappear as nesting sites. Hydropower dam development along the flyway can also impact the biodiversity of migratory birds in the Ayeyarwady Basin. In Mongolia, two recently completed hydroelectric dams were severely disrupting water levels in Great Lakes Basin, potentially affecting all sites frequented by migrants from Myanmar, such as bar-headed geese, ruddy shelduck, pallas' fish eagle, and several others.

Turtles

The recently rediscovered Burmese roofed turtle (*Batagur trivittata*) population at the Dokthawady in Shan State is now thought to be extinct after the construction of a hydropower dam inundated nesting beaches and brought an influx of fishers.

Fishes

Dams impact fish diversity in several ways. They block migration routes and adult fishes are unable to reach their spawning sites. Fish ladders, designed to allow passage, have largely failed in Southeast Asia where a very large number of species have their own requirements with respect to flow, position in the water column, and upstream and downstream passage. Dams also block the downstream movement of the young. Floating eggs and larvae, which normally drift until metamorphosis, sink to the bottom because of the lack of currents and die in the accumulating sediments. Since dams are built where there is sharp gradient, rapids are flooded and with them disappear those species specialised for this habitat, among which are many endemics with narrow ranges. Fluctuations in water levels, water temperature, and flow rates create an uninhabitable zone between maximum and minimum operation levels.

Schemes involving a cascade of dams entirely eradicate the fast-water fauna of a river, and hence the native fish diversity. Although often perceived as a minor problem, the accumulation of micro- and pico-hydropower (small turbines placed directly in small streams) may seriously impact these streams by creating long successions of weirs and silted ponds.

Invertebrates

The dramatic decline of bivalves and other molluscs globally have been attributed to modifications and destruction of watercourses, dam construction, and channelisation.



8.6.2 Loss of wetlands

The global ‘Wetland Extent Trend Index’, based on 1,100 global datasets, found that Asia has lost 67% of its inland wetlands since 1945. There is no data to compare these figures for Myanmar and the Ayeyarwady Basin, but it is likely that they are very similar, meaning that roughly 25% to 33% of former wetlands still exist within the Ayeyarwady Basin. These wetlands are not only important for biodiversity or feeding an increasing population, but are vital in buffering storm surges and extreme weather events, which are predicted to increase in force with global warming.

Lakes, especially in the Central Dry Zone of the Ayeyarwady Basin, are exposed to increasing demands from irrigation and other natural resource uses. Water levels have fallen in response to deforestation, as shown by the example of Indaw Lake, which local people claim has lost approximately 10% of its coverage in the past 10 to 15 years. Of 19 lakes in the Ayeyarwady Basin previously surveyed for waterbirds, reinspection found two lakes to be completely dried out and one with very little open water. Lakes like Yewai and Yit Lake, which supported significant numbers of waterbirds and fish for local communities until 1993, were both completely dry when visited in 2001.

Irrigated agriculture is likely to increase in Myanmar. Further consideration of the ecological consequences of such development is needed, especially heightened pressures on the few remaining wetlands and risks to the fragile ecological balance.



8.6.3 Deforestation

Deforestation is a significant problem for the entire Ayeyarwady Basin. The greatest forest loss has occurred in the Middle Ayeyarwady, which has been diminished by 5,560 km² from 2001 to 2014.

KBAs seem to be less affected on average by deforestation, but some have still lost up to 17%, and 10 KBAs are above the Ayeyarwady Basin average of 2% (Table 8.2).

The top three KBAs affected are very important for several globally threatened turtles, but some of the information about turtles is old and out-dated.

Forest loss is not only contributing to the loss of forest biodiversity, such as large mammals and birds – intact forests protect rivers and their biodiversity from increased sedimentation due to erosion, following exposure of soil after logging and land clearance.

Table 8.2 – Forest loss in Key Biodiversity Areas ranked by impact of forest loss in percent from 2002 to 2014*(Based on Bhagwat et al., 2014)*

Ranking	KBA site name	Forest loss (ha)	Forest loss (%)
1	Uyu River	14,688	17.40
2	Myaleik Taung	282	7.61
3	Mehon (Doke-ha Wady River)	6,224	7.07
4	Lwoilin/Ginga Mountain	3,219	5.87
5	Upper Chindwin River: Kaunghein to Padumone section	158	3.81
6	Ayeyarwady Delta (including Meinmahla Kyun)	21,888	3.34
7	Kennedy Peak	3,486	3.20
8	Panlaung Pyadalin Cave	921	2.64
9	Tanai River	1,419	2.23
10	Pauk Area	433	2.22
11	Paunglaung Catchment Area	4,727	1.85
12	Central Bago Yoma	7,101	1.80
13	Saramati Taung	17,978	1.69
14	Minzontaung	26	1.53
15	Upper Mogaung Chaung basin	221	1.17
16	Kamaing	444	1.12
17	Hlawga Park	67	1.10
18	Myitkyina-Nandebad-Talawagyi	499	0.90
19	Indawgyi Lake Wildlife Sanctuary and surroundings	623	0.85
20	Zeihmu Range	63	0.78

8.6.4 Conversion to plantations

Rubber plantations in the northern part of the Ayeyarwady Basin, especially Kachin and Shan States cover approximately 70,000 ha. Myitkyina Township in Kachin experienced large-scale conversion to plantations (rubber, banana, and cassava), resulting in the loss of approximately 25,000 ha of intact forest between 2002 and 2014.

8.6.5 Gold and jade mining

Myanmar accounts for 90% of the world's jade production and is among the top producers of rubies and sapphires. Gold and jade mining is widespread across the Ayeyarwady Basin and particularly prominent in the Upper Ayeyarwady and Chindwin. A large increase in mining activities in the Upper Chindwin has led to forest loss of more than 6%. Both drivers exacerbate the pressure on biodiversity in the region, which still has 68% forest cover.

8.6.6 Pebble and sand mining

An increasing problem for the large rivers like the Ayeyarwady, but also the Chindwin, is the dredging for minerals, mostly gold, but also pebble and sand mining. The latter is widespread and increasing, with devastating impacts on ground-nesting birds and freshwater turtles. Fish communities are similarly adversely affected, including removal of spawning areas and benthic fauna. Free sediment that is launched into the river smothers spawning and algae-grazing areas, especially rapids and riffles, fills deep holes, and changes the chemistry of the river.

8.6.7 Overfishing

Electric shock contributes to unsustainable fishing in that it catches fish of all kinds and sizes in large quantities in a very short period of time. Many fishers understand that electric fishing is drastically affecting the environment and the ecosystem, but they have indicated an unwillingness to stop unless everyone else does. Environmentally, and even economically, this is a race to the bottom that can only be stopped by the government implementing and enforcing strict fishing regulations.

Finless porpoises, Irrawaddy dolphins and all marine turtles are extremely susceptible to entanglement in gill nets, and large numbers have been, and continue to be, killed in many parts of their range.

Most turtles in Myanmar have been poached to local extirpation and near extinction due to subsistence hunting and collecting for illegal trade. Notably, River terrapins like *Batagur baska* and *Batagastur trivittata* have suffered heavy losses, but other river turtles like the Softshell Turtle (VU) are heavily poached and are predicted to be reclassified as CR in the coming decade.



8.6.8 Hunting and illegal wildlife trade

Hunting and poaching is widespread across the Ayeyarwady Basin and is affecting all habitats and all taxa. A survey in 2008 to 2009 found all mammal species were hunted, and skins, horns, or scales left in villages in the Upper Chindwin. Elephants are hunted for ivory and to deter them from increasingly encroaching crops. Otters have been poached to local extinction in many places in the belief that they will prey on fish and invade fish farms.

Uncontrolled hunting and wildlife trade occurs in approximately 70% of Protected Areas, with large quantities of wildlife and wildlife products transported across the border to China's Yunnan Province and to Thailand. The wildlife trade along international borders is creating large areas of silent forest, where species such as elephants, Asiatic bears, sun bears, tigers, leopards, clouded leopards, turtles, tortoises, pangolins, and many species of songbirds are being eliminated.

The Asian elephant (*Elephas maximus*) and tiger (*Panthera tigris*) are threatened, mainly due to illegal trafficking and habitat loss. Softshell turtles are in high demand by Chinese wildlife markets and populations of most species have been decimated throughout much of Myanmar.

Bird hunting is prevalent throughout the Ayeyarwady Basin and documented at the river during the field surveys between Myitkyina and Bagan, as well as in the delta. Waterbirds and forest birds are hunted for food, trophies, and wild bird trade. Bird hunting is even practised in most Protected Areas, and there is little law enforcement. There is hardly any wetland or reserve, protected or not, that is not subject to persistent and heavy trapping by nets or snares.

8.6.9 Invasive species

Stocked aquaculture fish have escaped from ponds and are now present in most rivers. Some were introduced so long ago that few people realise that they are not native. Introduced fish species from the Upper Shweli in China are beginning to swim downstream and invade Myanmar rivers.

The very invasive South American sucker catfish (*Pterygoplichthys* sp) was recorded during the field survey in June 2017. Another upcoming threat is the invasive Chinese pond mussel (*Sinanodonta woodiana*) that was found for the first time near Bhamo in 2017 and could impact native mussels including the Myanmar freshwater mussel that presents a high level of endemism.

8.7 Opportunities for Conservation

This section outlines opportunities for conservation in the Ayeyarwady Basin in terms of sustainable development, KBAs and Protected Areas, ecotourism, local schemes, international conservation agreements, and biodiversity surveys.

8.7.1 Sustainable development

Predictions of rapid economic growth across Myanmar will be tightly linked to natural resource exploitation. This creates new and additional challenges for biodiversity in the Ayeyarwady Basin, which is already under enormous environmental stress. This is an important issue that should be addressed as a matter of urgency, potentially through policy and institutional reform and the integration of environmental safeguards into economic development planning. Some of these safeguards must be a comprehensive network of Protected Areas and sustainable resource management that is negotiated and led by communities and supervised by an Integrated River Basin Management Committee and local subsidiaries.

8.7.2 KBAs and Protected Areas

Only 50% of the identified KBAs are officially protected. It is highly recommended to expand the Protected Area network and urgently increase the level of KBA coverage by Protected Areas to at least 80% of KBAs. This will safeguard the most precious remains of biodiversity in the Ayeyarwady Basin. New forms of Protected Areas, such as Biosphere Reserves, should be more widely explored. The recent inclusion of Lake Indawgyi into the list of Biosphere Reserves is encouraging. The design and implementation of management plans together with local communities are crucial in the long-term protection of biodiversity.

The Management Plan for the Ayeyarwady Dolphin Protected Area has been prepared to dramatically reduce or eliminate illegal fishing activities. However, enforcement was particularly weak from 2010 to 2014, there is poor inter-agency cooperation, funds and equipment are limited, and there has been a surge in electric fishing. The Ayeyarwady Dolphin Protected Area can also benefit other species like freshwater turtles, and should also be expanded to include the newly discovered population south of Bagan. These Protected Areas can serve as a platform for implementing conservation measures, such as no gill net fishing zones, but also for providing alternative economic opportunities such as dolphin watching and other touristic activities.

8.7.3 Ecotourism

There are now bodies promoting ecotourism in the Bagan to Bamaw section of the Ayeyarwady, the Meinmahla Kyun Wildlife Sanctuary and the Outer Delta Islands. In 2016, for the first time, bird tour operators included visits to the Sarus Crane areas in the delta region in their programme. The potential for expansion is huge and important in providing an alternative to hunting and wildlife poaching as a source of local income.

8.7.4 Local schemes

Head-starting and breeding programmes have been established for the Saltwater Crocodile (*Crocodylus porosus*). In the Meinmahla Kyun Wildlife Sanctuary in the delta region, the Burmese Roofed Turtle in the Chindwin River, and Softshell Turtles near Bago. The original assurance colony of Burmese Roofed Turtle at the Mandalay Zoo continues to serve as the bulwark of the ex situ conservation effort.

The Burmese Star Tortoise will only survive through a successful captive breeding and reintroduction scheme, but reintroduction is hampered by persistent and rampant poaching of the tortoise. Local communities and their traditional beliefs must be incorporated in any conservation scheme. The Burmese Star Tortoise has demonstrated this necessity as every successfully released tortoise has been tattooed with a sign of the spirits of the forest to deter any collector.

Several nest-guarding schemes involving local community members in return for direct payment have been successful at the local scale.

8.7.5 International Conservation Agreements

There are two Ramsar sites within the Ayeyarwady Basin and several more should qualify. The Alliance for Zero Extinction, an international effort led by IUCN, focuses on areas and sites where 95% of one particular species resides or spends a large proportion of its life cycle. There have been two such sites formally defined in the Chin Hills and the Fen-shui-ling Valley. The Rakhine Yoma Elephant Sanctuary on the western edge of the Ayeyarwady Basin would qualify through the frog *Leptobrachium rakhinensis*, which occurs only in this area. The site is currently reviewed for inclusion into the Alliance for Zero Extinction.

Myanmar has identified potential World Heritage Sites, including natural river and wetland sites. This effort should receive full support and include the river stretches to the north of Bhamo up to Myitkyina, and also in the south where Irrawaddy dolphins have been sighted.

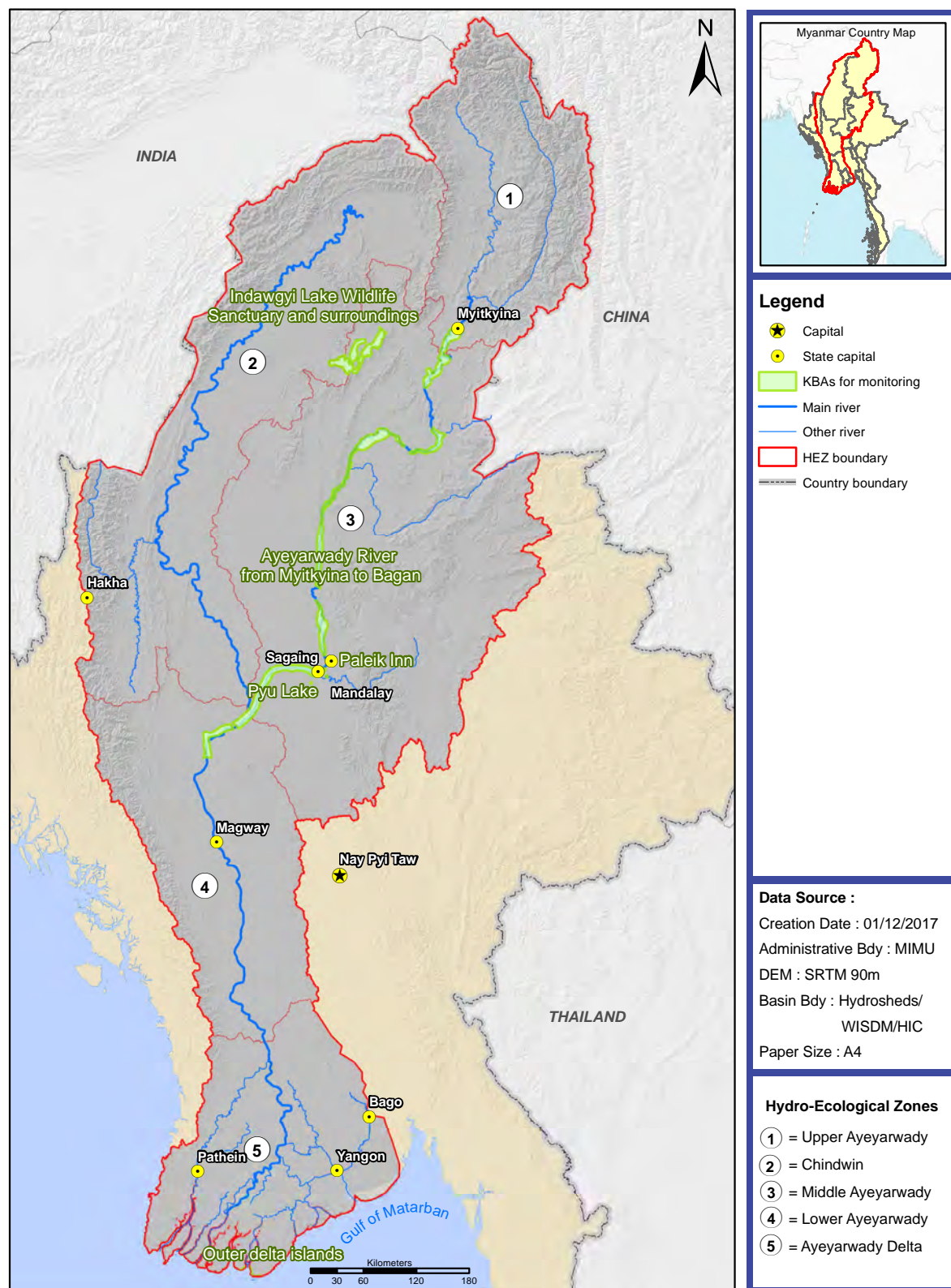


Figure 8.6 - Proposed regular waterbird monitoring sites in the Ayeyarwady Basin

8.7.6 Biodiversity surveys

Many areas within the Ayeyarwady Basin have never been surveyed or have not been surveyed in the past 10 years. In particular, the Chindwin and many sections of the Upper Ayeyarwady are under-surveyed. Many sections and tributaries in the Middle Ayeyarwady have not been surveyed for fish and for many freshwater invertebrates. Many of the areas in the Upper Ayeyarwady and Chindwin are currently inaccessible due to insurgent activities.

8.8 Biodiversity Monitoring

Ecosystem integrity can be assessed from a suite of biodiversity indicators that are regularly monitored. Across the Ayeyarwady Basin these indicators will cover forest through to wetland and aquatic ecosystems.

In an ideal world, the monitoring would encompass a large suite of indicators: chemical, physical, and biotic. However, the capacity and resources available for monitoring demand a more focused and down-scaled approach. Biological indicators tell most about the state of the living environment rather than the physical or chemical state of the river or wetland at a random point in time. It is therefore important to choose the right suite of species and sites to measure these indicators, which should reveal the environmental stress and the effect of management and conservation measures.

Choice of indicators should enable comparison with historic data. Observer bias, time, and frequency of the monitoring can mar these comparisons; however, increased frequency of time series can smooth out discrepancies. The multitude of different species with similar ecology can reinforce the message one species is indicating, and prompt investigation of different geographical issues. Waterbirds are ideal, indicating at local level and through their migratory habits that vary from species to species. However, when all waterbird species are declining regardless of their migratory origin, as in the case of the river stretch between Myitkyina and Sinbo, the issues must be examined locally.

Waterbird monitoring should be conducted approximately simultaneously at different sites and habitats across the Ayeyarwady Basin, in order to understand and distinguish between local, regional, and flyway issues. Ideally, this would coincide with the mid-winter counts that Wetlands International organises globally. Wetland areas such as Lake Indawgyi and the Ayeyarwady River between Myitkyina and Bagan should be included. The latter could also serve to monitor Irrawaddy dolphins. Some of the most important lakes in the Central Dry Zone (e.g. Paleik Inn or Pyu Lake) should be included, in addition to the inter-tidal mudflats of the delta region near Nga Mann Thaug, building on the 2013 monitoring.

These four major monitoring sites, split into several sub-sites, cover a wide geographical range and different wetland types (Figure 8.6). The Upper Ayeyarwady and Chindwin are excluded on account of current insurgent activities and the remoteness of these sites. Future monitoring should include suitable sites when circumstances allow.

Mammals are difficult to monitor, but the charismatic and critically endangered Irrawaddy dolphin needs to be included. At least the proposed river stretches and the delta region should include this species in the regular monitoring scheme.

It is highly recommended that freshwater turtles and marine turtles be included in a monitoring scheme. The Forest Department of the Ministry of Natural Resources and Environmental Conservation (MONREC) is already regularly monitoring the Saltwater Crocodile and the Department of Fisheries, of MOALI, is regularly monitoring the marine turtles in the Outer Delta Islands. Most freshwater turtles have become so rare that a meaningful monitoring programme is hardly possible, but Wildlife Conservation Society (WCS) is ready and equipped to undertake regular monitoring of selected sites, especially the release sites for globally threatened species in the Chindwin.

It is crucially important to include fish diversity into the monitoring. Currently, the state of fish knowledge within the Ayeyarwady Basin is still too fragmented to recommend a detailed monitoring programme for fish diversity.



8.9 Conclusions

This assessment draws the following high-level conclusions:

8.9.1 The Ayeyarwady Basin has high biodiversity values for mammals, birds, fish, and reptiles

The Ayeyarwady Basin is one of the most biologically diverse regions in the world. It is the 19th richest region in bird diversity globally. It is home to 1,400 mammal, bird, and reptile species, with more than 100 species that are globally threatened. At least 388 fish species are known to occur in the region, but the total is estimated to be near 550 when all areas have been surveyed. Similarly, amphibians and many invertebrates are little studied and might match the better-studied taxa in numbers.

8.9.2 The Ayeyarwady Basin is experiencing a dramatic decline in biodiversity

The findings in this assessment confirm widespread decline in almost all taxa and across almost all regions. Several species of mammals, birds, and reptiles have already disappeared from the Ayeyarwady Basin and many others could follow if conservation actions are not taken seriously and with proper resourcing. The declines are pronounced and sharp, in particular for comparatively well-monitored waterbirds on many river stretches and lakes. The threats and reasons for the declines range from large-scale industrial ventures, to increasing sand and mineral mining, and precipitous hunting and poaching across the entire Ayeyarwady Basin.

8.9.3 More Key Biodiversity Areas need protection

The Ayeyarwady Basin is home to 89 different KBAs, highlighting the huge importance for biodiversity. Of these, only approximately 50% are officially protected. Increased effort is needed to enhance the Protected Areas network, along with capacity building and training to ensure that biodiversity is protected in practice. Increased resources are needed to enforce existing laws. The Lake Indawgyi Wildlife Sanctuary has now been recognised by UNESCO as the first Biosphere Reserve in the Ayeyarwady Basin and the second in Myanmar. There are many more candidates in the Ayeyarwady Basin and hopefully these can be expanded.

8.9.4 Rivers and wetlands need comprehensive protection from development pressures

The fragile river system and its wetlands are under enormous and increasing pressure from hydropower development, sand and pebble extraction, mining for gold and other minerals, and over-exploitation of its biological resources. It is a unique ecosystem, a lifeline for millions of people, and deserves full protection and stricter control over its resource management. A resource management plan for the entire river should be developed as soon as possible, with no-take zones free of any fishing, mining, and dredging.

8.9.5 Further World Heritage listings would be beneficial

The World Heritage Convention lists sites that have unique and exceptional cultural and natural value to the world, and which encapsulate the beauty and history of both human civilisation and the planet. Bagan qualifies as a site of cultural distinction. The Ayeyarwady River may also qualify on the basis of its natural and possibly also its cultural qualities. It is suggested that listing the river between Myitkyina and Bagan (or even further downstream) as a World Heritage Site would not only boost the conservation of the region's rich cultural and natural history, but also could protect the river in the long term. Local communities could build their livelihoods on an economy that includes ecotourism as well as sustainable use of the river's natural resources.

8.9.6 Monitor indicators of environmental health

In addition to waterbird populations, the river dolphins act as key sentinels for the health of the river ecosystem in Asia. The Irrawaddy dolphin river population is in a critical but stable state. The Yangtze dolphin is extinct and the Mekong River population of the Irrawaddy dolphin is on the brink of extinction due to human impacts on the river ecosystem. Myanmar has the choice now about whether to follow the destructive path of the Yangtze and Mekong Rivers, where biodiversity has suffered and dolphins have been lost or almost lost, or to embrace sustainable development in balance with biodiversity and people.



HIGHLIGHTS – SOCIO-ECONOMIC DEVELOPMENT



- Since 2000, the Myanmar economy overall has grown steadily, with GDP per capita rising more than seven-fold.
- Poverty in Myanmar declined from 25.6% in 2009 - 2010, to 19.4% in 2015.
- In the Upper Ayeyarwady, 30% of the population above 25 years of age has had no formal education, and only 26% had access to safe drinking water in 2014.
- In 2015 - 2016, approximately 29% of children under-five were stunted and 8% severely stunted in the states and regions with territory in the Ayeyarwady Basin.



- The Ayeyarwady Basin contains many flood-prone areas; floods with a return period of 10 years were estimated in 2010 to affect 2.3 million people.
- The national annual population growth rate has decreased, from 2.4% in 1970 to 0.9% in 2017.
- The 2014 Census suggests a net migration out of the Ayeyarwady Basin, but migration to and within the urbanising region around Yangon has grown dramatically and not all movements within the country are well captured by the census.

HIGHLIGHTS – SOCIO-ECONOMIC DEVELOPMENT

- Agriculture accounts for approximately 27% of GDP and 60 to 70% of employment
- Myanmar still has significant forest resources with 44% of the land area forested in 2015, and most of the remaining closed forest in the Upper Ayeyarwady, but vast areas of high value timber have already been logged.
- Annual energy consumption per capita grew at just 1.5% per year between 1990 and 2010, while since 2010 it has grown more rapidly, at approximately 7.4%.



- There are 14 large hydropower plants in operation with 2.1 GW of installed capacity, 3 under construction (1.4 GW) and 29 planned (25.6 GW); most planned are in mountainous areas in the Upper and Middle Ayeyarwady.
- The rapid expansion of mining has created significant localised environmental and social problems.
- Division of responsibilities and coordination among states and regions regarding development and conservation of natural resources will be a key governance issue.





9. SOCIO-ECONOMIC DEVELOPMENT

9.1 Introduction

The purpose of this chapter is to summarise the key findings, conclusions, and recommendations related to socio-economic development in the Ayeyarwady Basin. Special emphasis is placed on identifying key characteristics and trends, and assessing their implications for development and water resources planning.

Since 2000, the Myanmar economy overall has grown steadily with GDP per capita rising more than sevenfold. In relative terms, the manufacturing and service sectors have grown in importance at the expense of agriculture (Figure 9.1).

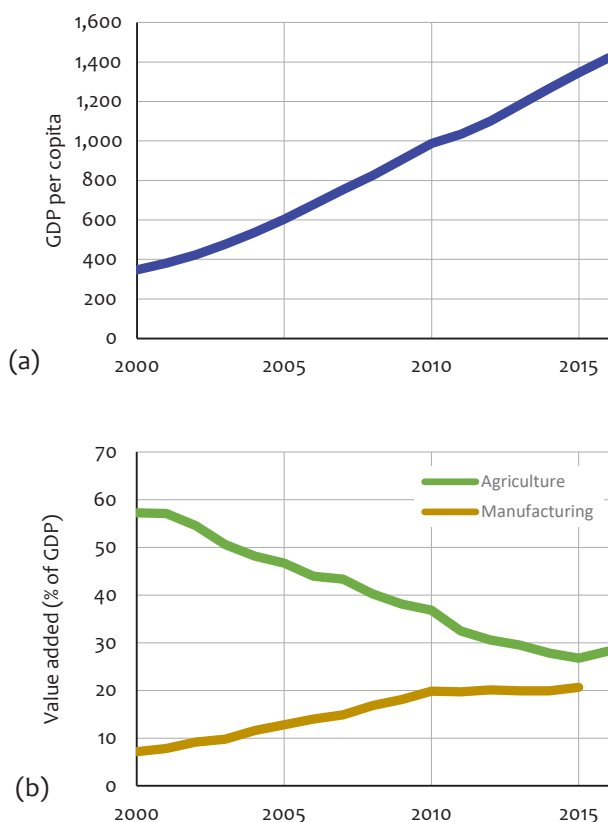


Figure 9.1 - Growth of the national economy of Myanmar (a) and decline in the relative importance of agriculture (b)
(World Development Indicators)

In the last decade, another key change has been the opening of the formal economy to trade in 2011 (Figure 9.2). Foreign Direct Investment started to grow later. These aggregate statistics reflect important socio-economic transformations underway in the Ayeyarwady Basin, but they do not capture the large spatial differences in economic activities, or the large informal or illegal extraction and trade of natural resources.



Figure 9.2 - Recent trends in indicators of the openness of the Myanmar economy
(World Development Indicators)

It should be noted at the outset that the assessment of trends and spatial patterns in socio-economic indicators by HEZs within the Ayeyarwady Basin was limited by the low resolution, short time series, or low reliability of available data. Addressing these data limitations will be important to provide better foundations for planning and monitoring in the future. Despite these limitations in coverage, this chapter shows that sustaining improvements in well-being will strongly depend on careful management of land and water resources in the Ayeyarwady Basin.

SOBA Technical Reports

This chapter is a synopsis of the full assessment, which may be accessed by readers seeking more detailed information, including references:

SOBA 5: ICEM, CESD & MMRD (2017), *Sectoral Development and Macroeconomics Assessment* (SOBA 5), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project

SOBA 5.1: Natural Capital Economics, Alluvium International & Alluvium Consulting Australia (2017), *Economic Valuation of Ecosystem Services in the Ayeyarwady Basin* (SOBA 5.1), as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project, sponsored by the Australian Water Partnership

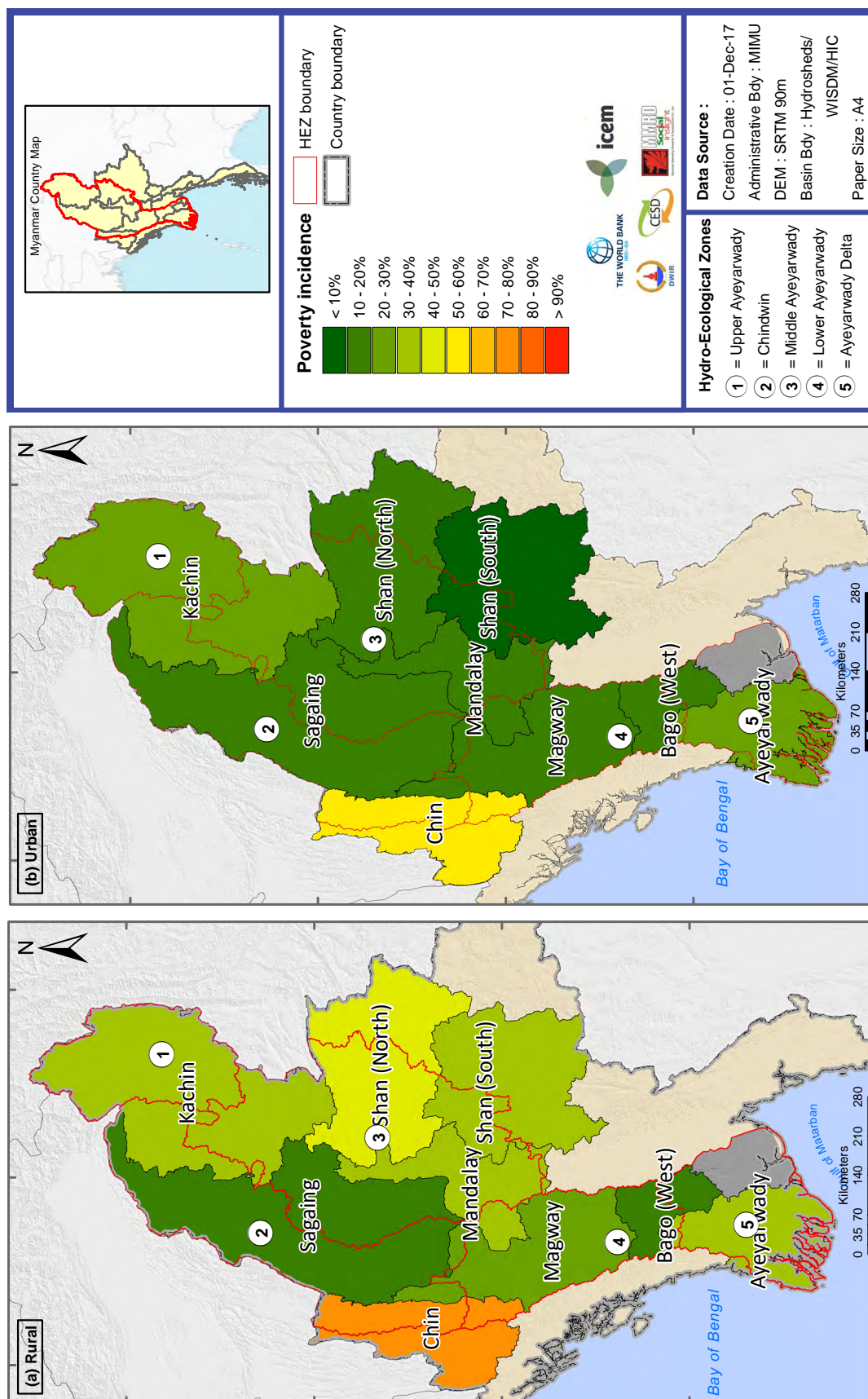


Figure 9.3 – Poverty incidence by (a) rural and (b) urban settings in 2010 by state or region, overlaid on hydro-ecological zones

9.2 Well-being and Livelihoods

Overall, the well-being of households in the Ayeyarwady Basin has improved and is higher in urban than in rural areas. Economic development, infrastructure investment, and urbanisation are contributing to these trends. Well-being and socio-economic development indicators for the Upper Ayeyarwady are lower than for other HEZs.

9.2.1 Poverty

According to government estimates, poverty in Myanmar declined from 25.6% in 2009–10 to 19.4% in 2015. World Bank calculations suggest slightly higher values for 2015, with rural poverty estimated at 28.8% and urban poverty at 19.2%. Poverty incidence was highest by far in Chin State, at 73% (Figure 9.3). Urban poverty has declined more quickly than rural poverty.

Available data does not allow analysis by HEZ or the Ayeyarwady Basin as a whole. Taking household television ownership by townships as a proxy indicator for poverty suggests poverty is higher in the Upper Ayeyarwady (24%) than in other HEZs (44% to 54%). The status of many households fluctuates around the poverty line, with transitory poverty affecting 28% of households.

9.2.2 Education and family

In the Upper Ayeyarwady, 30% of the population above 25 years of age has had no formal education, whereas in the delta this population is only 7%. The delta has the highest rate (15%) of attainment of high school or higher degrees,

reflecting the influence of Yangon. In the Burmese language, the literacy rate of males (95%) is higher than that of females (89%), while the rate of literate urban residents (95%) is higher than that of rural residents (76%).

Mean household size in the Upper Ayeyarwady (5.6 members) was higher than in other HEZs (4.0 to 4.9 members), reflecting ethnic differences and socio-economic conditions leading to larger families and households. Household dependency ratios (number of young and elderly divided by the number of working age members) vary substantially among townships, but on average are higher in the Upper Ayeyarwady (74%) and Chindwin (60%) than in other HEZs. Approximately 24% of households are female-headed. Census data shows no relationship between rates of female-headed households and poverty indicators at the township level. Other studies suggest female-headed households are more common in urban (27%) than rural (19%) areas.

9.2.3 Health

Approximately 72% to 78% of households in each HEZ had access to safe drinking water in 2014, except in the Upper Ayeyarwady, where only 26% had such access. Sources of non-drinking water are diverse with high dependence overall on wells (Figure 9.4). Access to safe sanitation is reasonably high (83% to 90%) in all HEZs in the Ayeyarwady Basin.

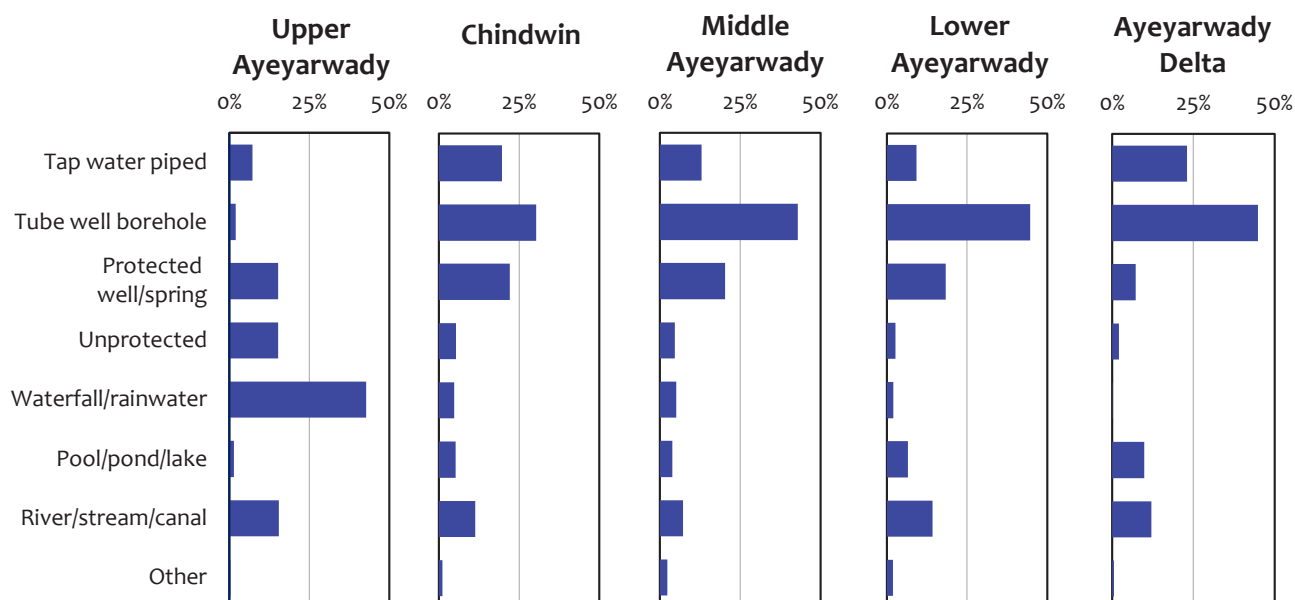


Figure 9.4 - Sources of non-drinking water

Child health is an important indicator of socio-economic development. Available data does not allow for analysis of infant and child mortality for the Ayeyarwady Basin or by HEZ, but relevant results are available by state and region. A 2015–2016 survey found that mortality of children under five was highest in Chin State (104 deaths per 1,000 live births), while infant mortality was highest in Bago Region (80 deaths per 1,000 live births). In 2015 to 2016, 29% of children under five were stunted and 8% severely stunted in the states and regions with territory in the Ayeyarwady Basin. Six years earlier, the figures were 35% and 8%, suggesting some improvement in the stunted category.

Deficiencies of iodine, iron, and vitamin A impede the development of children in Myanmar, costing approximately 2.4% of the country's GDP (Win, 2016)¹. Public expenditure on health and education has historically and comparatively been very low, at less than 1.0% of GDP (Findlay et al., 2016)². Taken together, these statistics highlight the continuing importance of access to viable fisheries for food security and nutritional health (Chapter 7).

9.2.4 Livelihoods

Agriculture, on own land or as hired casual labour, is by far the most important economic activity for most households in the Central Dry Zone, delta, and Hilly Zone. The average area of land owned was much higher in the delta (16.8 acres), than in the Central Dry Zone (6.3), or Hilly Zone (3.5). Land ownership in the delta is particularly skewed, with a small proportion of the population owning most of the land. Land ownership is a strong predictor of household food security: landless and near-landless households are much more likely to be food and nutrient insecure (Rammohan and Pritchard, 2014)³.

Extreme floods and droughts have substantial impacts on the livelihoods and economic well-being of households, and are a factor in transitory poverty. Large agricultural areas and human settlements in the Central Dry Zone and areas near the confluence of the Chindwin and Ayeyarwady are prone to flooding. Floods with a return period of 10 years were estimated in 2010 to affect 2.3 million people.

It is clear from Figure 9.5 that, apart from Yangon, the majority of the population is involved in forestry, agriculture, or fisheries.

Mobility generates livelihood options. The mean percentage of households in townships in the Ayeyarwady Basin that own a motorcycle was 38%; less than 5% owned cars or trucks, four-wheel tractors, or motorboats. Ownership of boats is higher in the delta and Chindwin, whereas motorcycles are more common outside the delta. Road access indicators vary among states and regions from low in Chin State to high in Mandalay Region.

9.2.5 Opportunities and risks

Improving well-being is multi-faceted and for rural poor closely linked to the quality of governance and uses of natural resources (described elsewhere in this chapter), water for irrigation, forests, and energy. Improved infrastructure and services such as education and health will lead to livelihood options that provide better returns to labour.

Peace is essential to human well-being and security. Ongoing armed conflicts in Kachin State (partly in the Upper Ayeyarwady HEZ) and Shan State (partly in the Middle Ayeyarwady HEZ) have hampered social development and come at a huge human cost. Politically negotiated solutions for these conflicts should be a high priority in cooperation across states and regions in strategic planning of development and conservation of the Ayeyarwady Basin as a whole.

9.3 Demography

The demographic changes underway in Myanmar are potentially an important development opportunity.

9.3.1 Population distribution

The population of the Ayeyarwady Basin is approximately 33 million, a third of whom live in urban areas. Median township population density is lowest in the Upper Ayeyarwady, increases to the south, and is highest in the delta (Figure 9.6). The main ethnic minority groups in the Ayeyarwady Basin are Shan, Kachin, Chini, and Karen.

¹ Win, A.Z. (2016). Micronutrient deficiencies in early childhood can lower a country's GDP: The Myanmar example. *Nutrition*. 32(1):138-140.

² Findlay, R., C.-Y. Park, and J.-P.A. Verbiest. 2016. Myanmar: building economic foundations. *Asian-Pacific Economic Literature*. 30(1):42-64.

³ Rammohan, A. and B. Pritchard. 2014. The Role of Landholding as a Determinant of Food and Nutrition Insecurity in Rural Myanmar. *World Development*. 64:597-608.

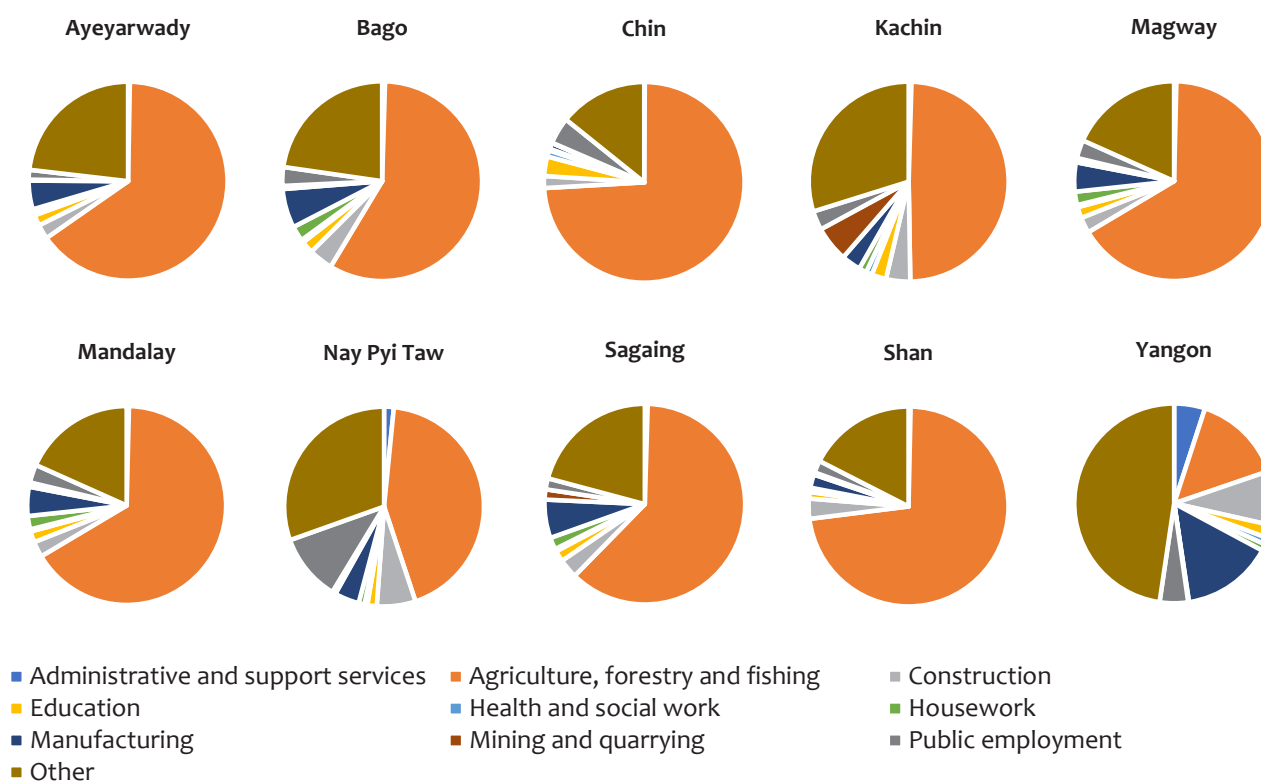


Figure 9.5 - Occupation by industry: percentage of both sexes by state or region
(Myanmar Census, 2014)



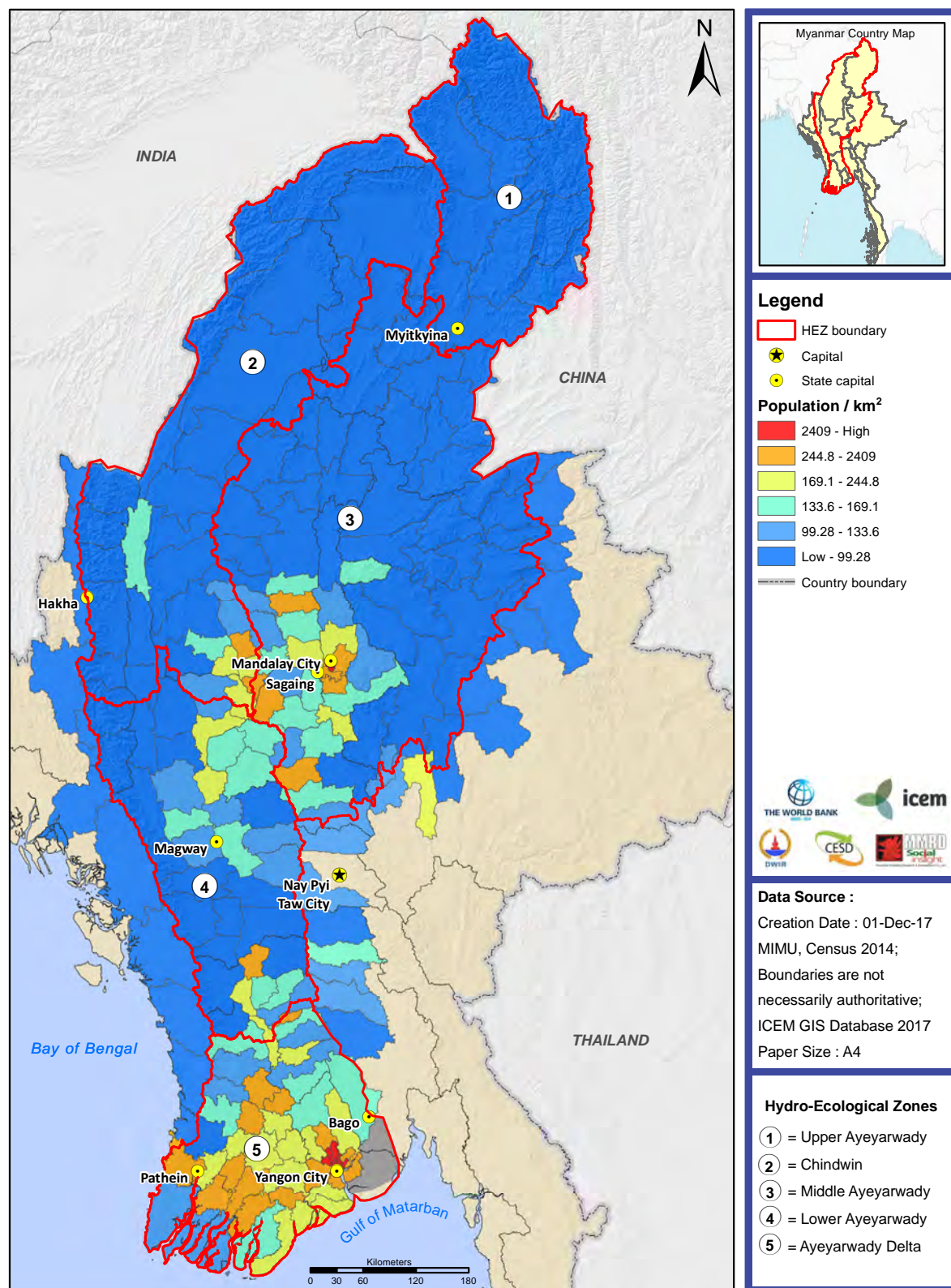


Figure 9.6 - Population density overlaid on hydro-ecological zones

9.3.2 Fertility transition

The national annual population growth rate decreased from 2.4% in 1970 to 0.9% in 2017. In some states and regions, populations will decline in absolute numbers. In the Ayeyarwady Region, the growth rate according to the 2014 Census will be -0.07% in 2020 and -0.23% in 2025, implying a decrease in its population by approximately 130,000 people between 2015 and 2030.

This is a consequence of the steady declines in fertility rate over the past four decades (Figure 9.7). Another consequence is that the age structure of the population is shifting, with the working age population growing (Figure 9.7). The 15- to 24-year-old cohort, in particular, is large and represents a significant development opportunity over the next few decades for Myanmar but much depends on their education and skills training (Findlay et al., 2016)².

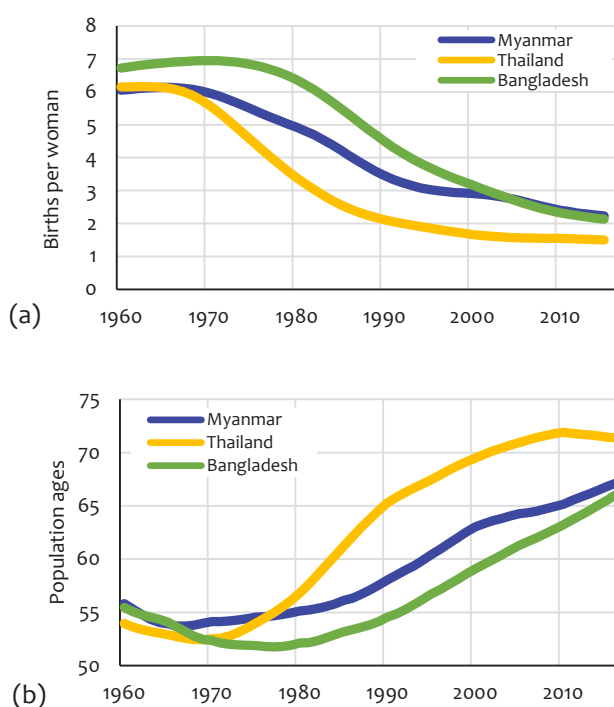


Figure 9.7 - Demographic transition in Myanmar compared with selected neighbouring countries Total fertility rate (a) and working age population (b), from 1965 to 2015 (World Bank)

9.3.3 Migration

The 2014 Census suggests a net migration out of the Ayeyarwady Basin, though the accuracy of these findings is questionable. Migration to and within the urbanising region around Yangon now dominates migration within the Ayeyarwady Basin (Figure 9.8). Sex ratios in some townships are skewed due to dominant economic activities (e.g. jade mining), out-migration for work, and higher male mortality.

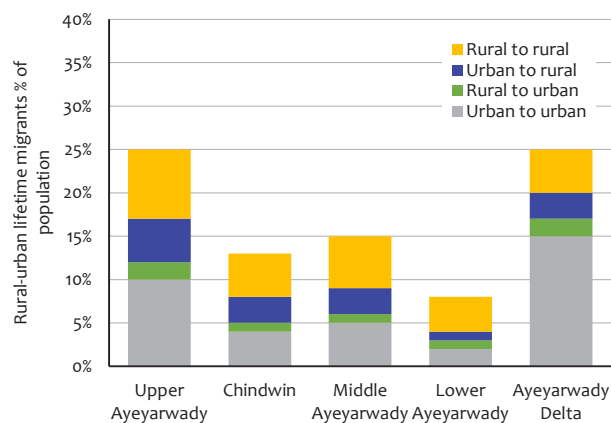


Figure 9.8 - Rural-urban migration flows – lifetime migrants as mean percentage of district populations in hydro-ecological zones

9.3.4 Opportunities and risks

The transition to lower fertility has consequences for future population size and age structure in the coming decades in the Ayeyarwady Basin. Migration is much more dynamic and less predictable, but will also have important interactions with and consequences for spatial development. There are significant opportunities for sustainable development in these trends, for example, the possibility of maintaining a growing workforce for decades. In 2014, approximately 1 million emigrants left the Ayeyarwady Basin with most going to Thailand, Malaysia, or China. As the Myanmar economy grows, it is possible that qualified emigrants may return.

These demographic shifts also pose some risks for development strategies based on long-lived infrastructure. The evaluation of water resources development strategies, for instance, must carefully consider the impacts of migration, fertility transition, and industrialisation on the availability of agricultural labour in different locations, otherwise there is the risk of costly schemes being built, which quickly fall into disuse.

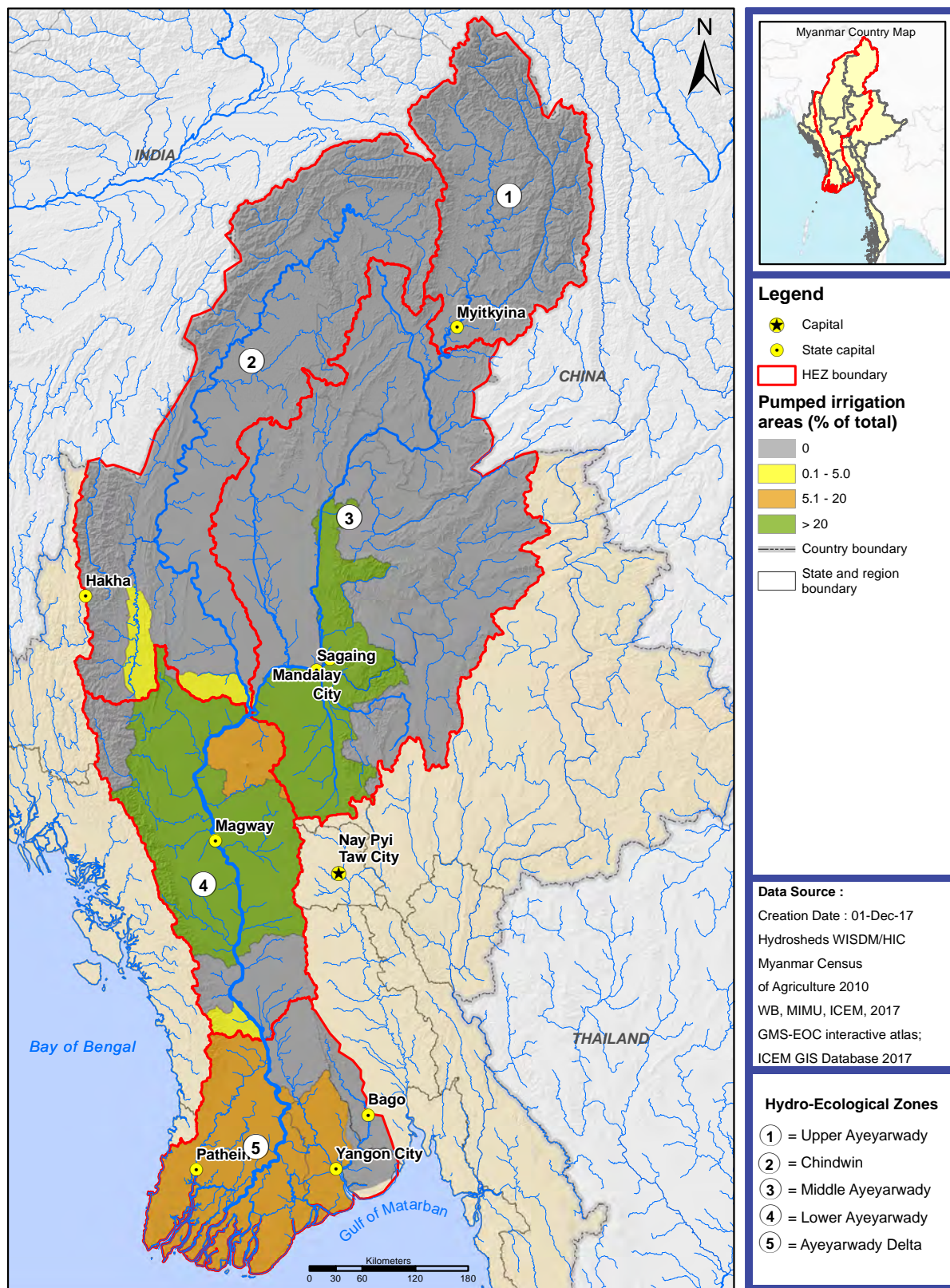


Figure 9.9 - Pumped irrigation areas in hydro-ecological zones

9.4 Agriculture and Irrigation

Agriculture accounts for approximately 27% of GDP (Figure 9.1) and 60% to 70% of employment.

9.4.1 Land and water uses

The Ayeyarwady Basin has ample land and river water resources, but rainfall is unevenly distributed and seasonal. In the dry areas and seasons, irrigation is essential for crop production. In wetter areas, supplementary irrigation helps deal with dry spells. Surface water runoff stored in reservoirs can irrigate approximately 1 million hectares.

Approximately 18% of the area of Myanmar is cultivated. The most important crops by land area cultivated are paddy rice (42%), dry beans (19%), and sesame seed (7%). The highest irrigation densities and areas of planted paddy occur in the delta. Livestock are more important in the three middle HEZs. Livestock are productive assets that contribute directly to farm output through animal traction and indirectly as a saving for future investment. Finally, they can contribute to soil fertility and recycling of agricultural waste. Swidden cultivation is still common in remote upland areas in Kachin, Chin, and Shan States.

The Irrigation Water Resources Utilization Department currently has more than 15,000 functioning shallow (<60 m) tubewells and more than 10,000 deep (60 to 200 m) tubewells. Mandalay, Sagaing, and Magway in the Central Dry Zone have received the most government support for development of groundwater- and river-pumped irrigation (Figure 9.9). Irrigation from government pumping schemes is highly subsidised; farmers pay very modest fees for water. Private schemes charge more and so are only used by farmers growing high value crops.

Cultivation on riverbanks, islands, and sandbars in the dry season after floodwaters recede is an important practice for both subsistence and cash crops in the Ayeyarwady Basin. There are no estimates of their extent, but such types of farming would likely be vulnerable to infrastructure development, which modifies river flows and sediment transport (Taft and Evers, 2016)⁴.

9.4.2 Constraints

Although land is available for expansion of agriculture, much of it has poor access to roads and electricity. Insecure land tenure is also a significant issue as it hinders access to credit. Agricultural extension services, especially provision of quality seed and low-interest credit, are limited and a constraint on agricultural development.

Mechanisation is still low: most ploughing, harvesting, and transport is done with bullocks and buffaloes. In areas with extensive waterways, transport is by canoes and boats, many still without motors. Post-harvest losses of rice in Myanmar are high, and the remaining crop is often of low quality and thus low value.

Floods in the Chindwin River Basin frequently have significant impacts on agricultural areas. Risk management is hampered by many factors, including lack of instrumentation for real-time monitoring, lack of coordination among government agencies, and insufficient knowledge about flood hydrology.

9.4.3 Opportunities and risks

Irrigation, along with flood protection in the coastal areas, is important to improve agricultural production for domestic food supply and export. This requires a number of inter-related actions, including improving power supply so that river and groundwater pumping schemes are more reliable, and shifting to higher value crops so that costs of irrigation can be recovered.

The combination of increased productivity through irrigation and other inputs, with expansion of agriculture into new areas, would substantially increase overall food production. This should reduce food prices for urban consumers, and under conditions of rising demand, may also raise farm incomes (Findlay et al., 2016)².

There are, however, some significant environmental issues associated with intensification and expansion. In the Central Dry Zone, a key problem is the salinisation of soils; in upland areas, erosion and deforestation are concerns. Intensification of rice production could also have impacts on fisheries and other vegetable crops important to human nutrition. An alternative would be to encourage greater diversification including low-chemical use agriculture that would be increasingly attractive to urban consumers.

⁴ Taft, L. and M. Evers. 2016. A review of current and possible future human–water dynamics in Myanmar’s river basins. *Hydrology and Earth System Sciences*. 20(12):4913–4928.

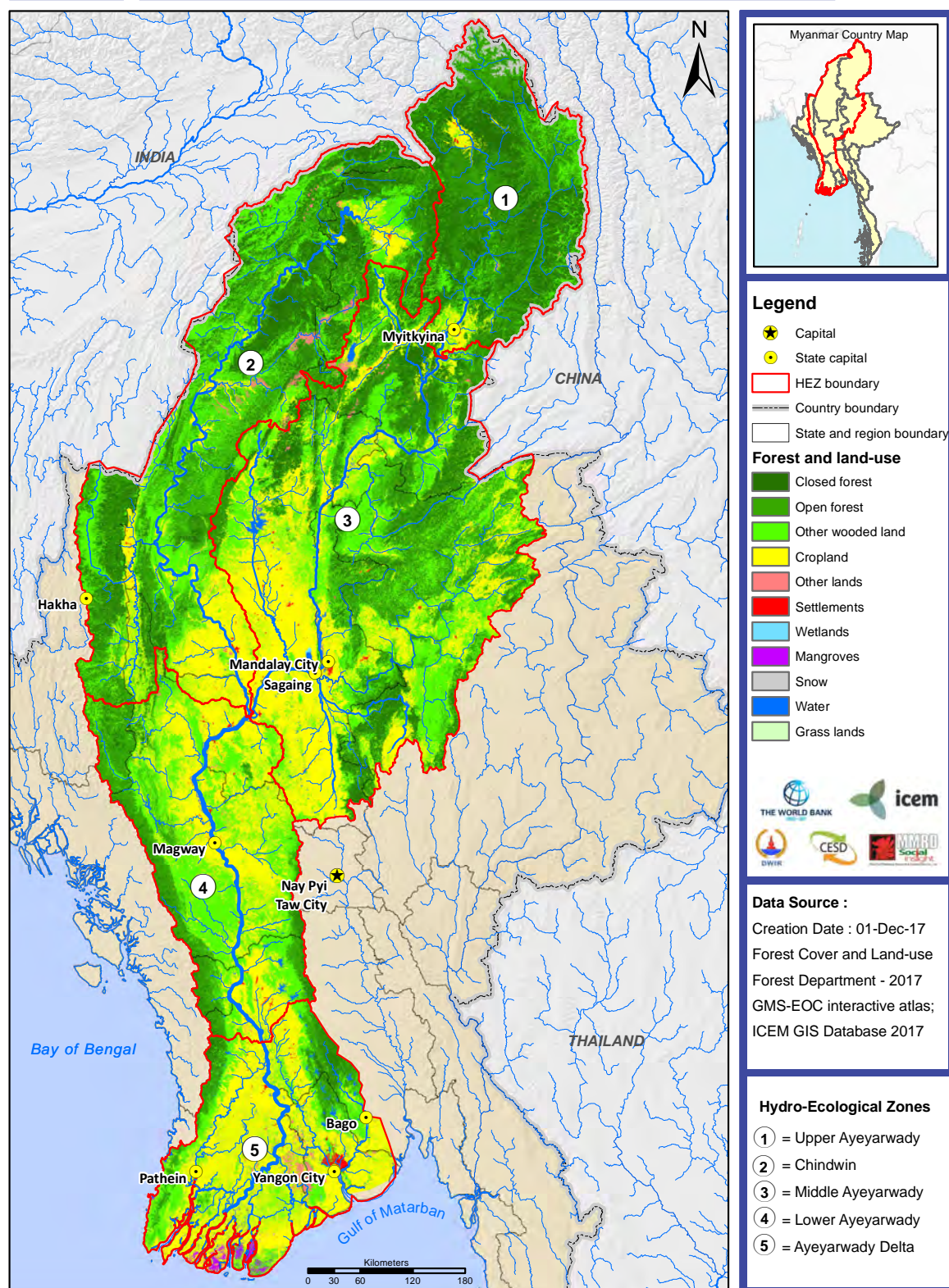


Figure 9.10 - Forest cover and land-use in the Ayeyarwady Basin, in 2015

9.5 Forestry and Watersheds

Myanmar is highly dependent on forest ecosystem services and products.

9.5.1 Forest cover

Myanmar still has significant forest resources, with 44% of the land area forested in 2015. Much of the remaining closed (or intact) forest is in the Upper Ayeyarwady (Figure 9.10).

Deforestation rates at the national level, however, are now the third highest in the world. Deforestation and degradation of existing forests are seen as critical issues in Kachin State (in the Upper Ayeyarwady HEZ) and Sagaing Region (in the Chindwin HEZ) in the Ayeyarwady Basin (Figure 9.11). This is mainly due to illegal and legal timber extraction associated with plantation and mining concessions. Moreover, many of the agribusiness concession areas have not been replanted as planned. The largest changes in forest cover in relative terms were in the Middle Ayeyarwady and related to the expansion of croplands (Figure 9.11).

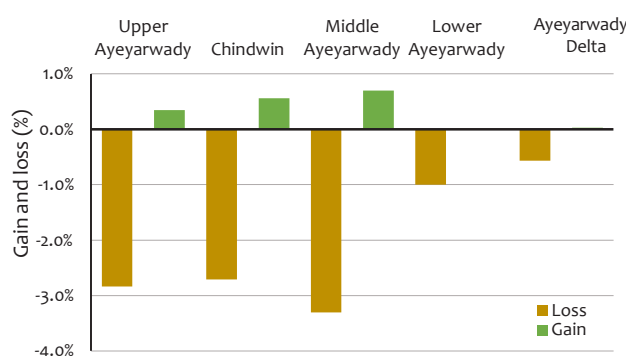


Figure 9.11 - Relative areas of loss and gain in forest cover in the hydro-ecological zones of the Ayeyarwady Basin from 2000 to 2015

Mangrove cover in the Ayeyarwady Delta decreased from 2,748 km² in 1980, to 450 km² in 2013, mostly due to conversion to rice paddies (Figure 9.12). Mangroves protect communities from flooding and storm surges, as well as provide habitat.

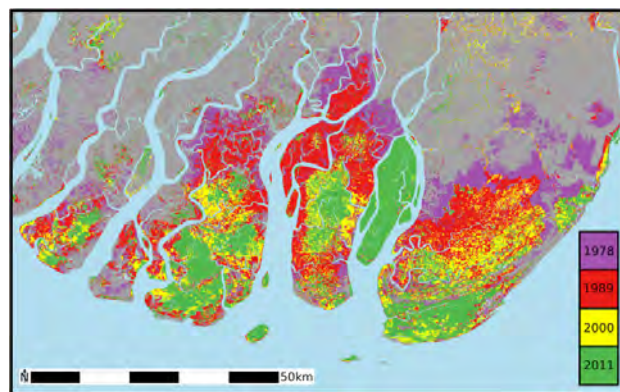


Figure 9.12 - Change in mangrove forest cover in 1978, 1989, 2000 and 2011

9.5.2 Forest products

Natural teak forests produce high-value logs. A log export ban reduced the volume of teak and hardwood extracted from forests and plantations in the Ayeyarwady Basin from 2015 to 2016, but even so more than 690,000 m³ were harvested. There are major discrepancies in the trade data surrounding Myanmar's timber production, as it does not include illegal logging and cross-border smuggling.

Myanmar's illegal wood trade includes timber, fuelwood, and charcoal. Demand from the wood processing industries and plantation sectors in China, Vietnam, and Thailand exerts pressure on Myanmar's forests. These demands are intensified by logging controls in these countries' own forests and Myanmar's stock of valuable species. Some estimates suggest that almost half of the logs imported into global markets from Myanmar in 2001 to 2013 were illegally harvested. Unsustainable logging practices have also substantially contributed to deforestation.

There is a trend toward sourcing timber from plantations. Thus, the area of teak plantation increased from 3,342 km² in 2008–2009 to 3,839 km² in 2015–2016. The area of hardwood plantation increased from 4,813 to 4,972 km² in 2015–2016.

Fuelwood, charcoal, and many other non-timber forest products are harvested from forests. A recent study suggested that the economic value of non-timber forest products in 2012 was approximately USD 507 million from all types of forests. A study in 2012 estimated the current annual value of forest ecosystem services at USD 7.3 billion. The Government of Myanmar's *National Forest Master Plan (2002–2031)* set a target for community forestry of 1.4% of total land area.



9.5.3 Opportunities and risks

The *National Forest Master Plan* also aims to maintain 30% of the land area within the permanent forest estate, and 10% of the land area within Protected Areas by the year 2030. The Government of Myanmar has also made a number of global commitments to address deforestation and climate change. It also introduced policies to reduce illegal logging and deforestation, including a logging ban for the period of about 1 year commencing in 2016. Timber certification is needed to help ensure sustainable harvesting of teak and hardwoods in the Ayeyarwady Basin. Small plantations may support livelihoods and reduce pressure on natural forests, provided they are established on already degraded lands. Assessing past and projecting future trends for the forestry sector is challenging, as national statistics do not include large volumes of illegally exported wood. The annual value of forest ecosystem services from the entire country has been estimated at USD 7.3 billion.

9.6 Ecosystem Valuation

The natural ecosystems of the Ayeyarwady Basin are vitally important to the livelihoods of the people of Myanmar and the national economy. Natural vegetation in the upper tributary watersheds of the Ayeyarwady Basin, for instance, provides multiple and highly valuable ecosystem services, improving water quality supplies and reducing risks of floods. In coastal areas, mangroves provide protection services.

9.6.1 Aggregate value

The value of a few key ecosystem services was estimated quantitatively, while for others only qualitative summary was possible (Table 9.1). The estimates are indicative only and care should be taken in using them. The estimated aggregate value for the subset of services for which valuation was possible underlines the importance of ecosystem services.

Table 9.1 - Annual value of ecosystem services

9.6.2 Opportunities and risks

If the Ayeyarwady Basin is not well managed, there are significant risks to the physical integrity and condition of its natural capital. Declines in ecosystem services may be expensive to replace with technologies or lead to a loss of economic opportunities. Well-managed ecosystems provide opportunities to use natural infrastructure rather than built infrastructure to achieve some objectives.

The values of ecosystem services should be incorporated into decision-making, for instance, in analyses

Ecosystem service	Estimated values (USD millions)			Reliability of range of estimates
	Low	Medium	High	
Ecosystem services quantitatively estimated				
Agriculture (irrigation water supplies provisioning services)				
Yield gains in monsoon	29	40	50	Intermediate
Ability to produce crops outside monsoon	62	91	121	High
Freight (inland rivers – modal substitution provisioning services)				
Freight task savings	8	13	23	Intermediate
Fisheries (protein replacement provisioning services)				
Freshwater capture	350	440	530	High
Aquaculture	380	490	600	High
Potable water supplies (water quality regulation services only)				
Treated tap water	57	91	125	Intermediate
Local treatment	129	321	514	Intermediate
Biodiversity (supporting services)				
Forests	1,300	2,645	4,418	Low
Wetlands	4	7	10	Low
Mangroves	146	297	497	Low
Ecosystem services not quantitatively estimated				
Agriculture (provisioning services excluding irrigation water supplies)				
Soil retention and fertility, nutrient cycling, pollination, pest control and non-irrigation water.	Insufficient data to value. Likely to be significant across irrigated cropping, dryland cropping and stock.			n/a
Potable water supply (water provisioning)				
Supply of groundwater and surface water (volume) for consumptive use in households (drinking, cooking, personal hygiene, clothes washing etc.).	Insufficient data on consumption volumes and economic values of alternative water sources (including replacement costs) to develop estimates. Insight from international water supplies suggests these values would be very significant (greater than the regulating ecosystem services that have been estimated).			n/a
Flooding (regulating and provisioning services)				
The Basin's natural flooding regime (frequency, extent etc.) results in risks (lives and crops etc.) as well as soil replenishment. Basin management will change the flooding regime and the marginal benefits and costs attributable to flooding.	Data on locations and extent of flooding available is insufficient to estimate economic values. Values are likely to be very significant.			n/a
Hydropower (intermediate provisioning service)				
River flows in conjunction with built capital (dams, turbines, etc.) provide an intermediate provisioning service to electricity generation. These values would ideally be assessed against any trade-offs relating to specific hydro projects (communities etc.).	Insufficient data available on costs of electricity to be supplied and costs of next best substitute to estimate marginal benefit of hydropower. Values will be project specific and are likely to be very significant.			n/a
Gravels and natural quarrying products (provisioning service)				
These products are often extracted from riverbeds in the Ayeyarwady Basin for use in building of homes, other buildings and public infrastructure such as roads and bridges, etc.	Insufficient data on both extraction rates, costs of extraction and costs of substitutes to establish credible estimates at this stage. Values are likely to be significant.			n/a
Ecotourism (cultural service)				
The Basin's natural beauty will be one of the drawbacks for the emerging tourism industry. This provides a major cultural ecosystem service.	There is insufficient data on tourism and ecotourism in particular, although the sector has significant potential to be a major contributor to economic activity.			n/a
Total ecosystem services	> 2,464	> 4,435	> 6,888	

aimed at prioritising basin management activities. The development, understanding, and use of economic knowledge to better inform decision-making is a long-term strategy. This will require improving data collection as well as building the capacity of Ayeyarwady Basin managers.

Tradeoffs were not assessed in this analysis, but may be significant. Priority areas for maintaining ecosystem services and conserving biodiversity overlap, but are far from identical (Mandle et al., 2017)⁵.

The analysis nevertheless provides important insight and information. First, together with other chapters in the SOBA Report, it shows that ecosystem services are important, valuable, and at risk. Second, it demonstrates that some ecosystem services can be meaningfully valued. Further work is still required to enhance and mainstream this economic knowledge into Ayeyarwady Basin planning

9.7 Energy and Hydropower

Lack of adequate electricity provision remains a critical issue for the Ayeyarwady Basin, and Myanmar as a country.

9.7.1 Energy consumption and sources

Development of the energy sector is critical to socio-economic development in the Ayeyarwady Basin. Annual energy consumption per capita grew at just 1.5% per year between 1990 and 2010, while since 2010 it has grown more rapidly, at approximately 7.4% per annum. Per capita consumption still remains comparatively low by regional and global standards. Fuelwood and charcoal, or biomass energy, still dominates energy consumption and production (Figure 9.13).

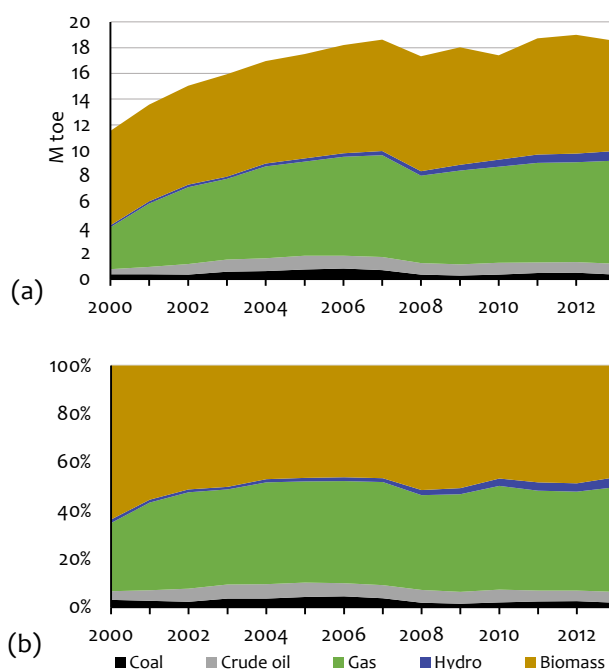


Figure 9.13 - Total primary energy production in Myanmar for 2000 - 2001 to 2013 - 2014

Toe = tonn of oil equivalent

Few households have access to grid electricity for lighting, most of which are in urban areas of larger towns (Figure 9.14). Candles are still important in many townships, in particular in the Upper Ayeyarwady, whereas kerosene is more common in the delta. Biomass burning indoors also has major impacts on human health. Meanwhile, fuelwood harvesting from natural forests continues to grow and thus is a significant environmental concern.

Fossil fuel production is important in the Ayeyarwady Basin. Most oil and gas reserves on land are in the Magway Region. Exploitation of fossil fuel resources raises important environmental as well as health and safety issues. Myanmar exports substantial amounts of energy to China and Thailand, mostly from offshore natural gas fields.

Renewables like solar and wind are under-developed. Solar potential is high, particularly in the Middle Ayeyarwady. Wind resources are more limited, though there are plans for onshore wind projects in the Ayeyarwady and Yangon Regions by the China Three Gorges Corporation.

⁵ Mandle, L., S. Wolny, N. Bhagabati, et al. 2017. Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar. PLOS ONE. 12(9): p. e0184951

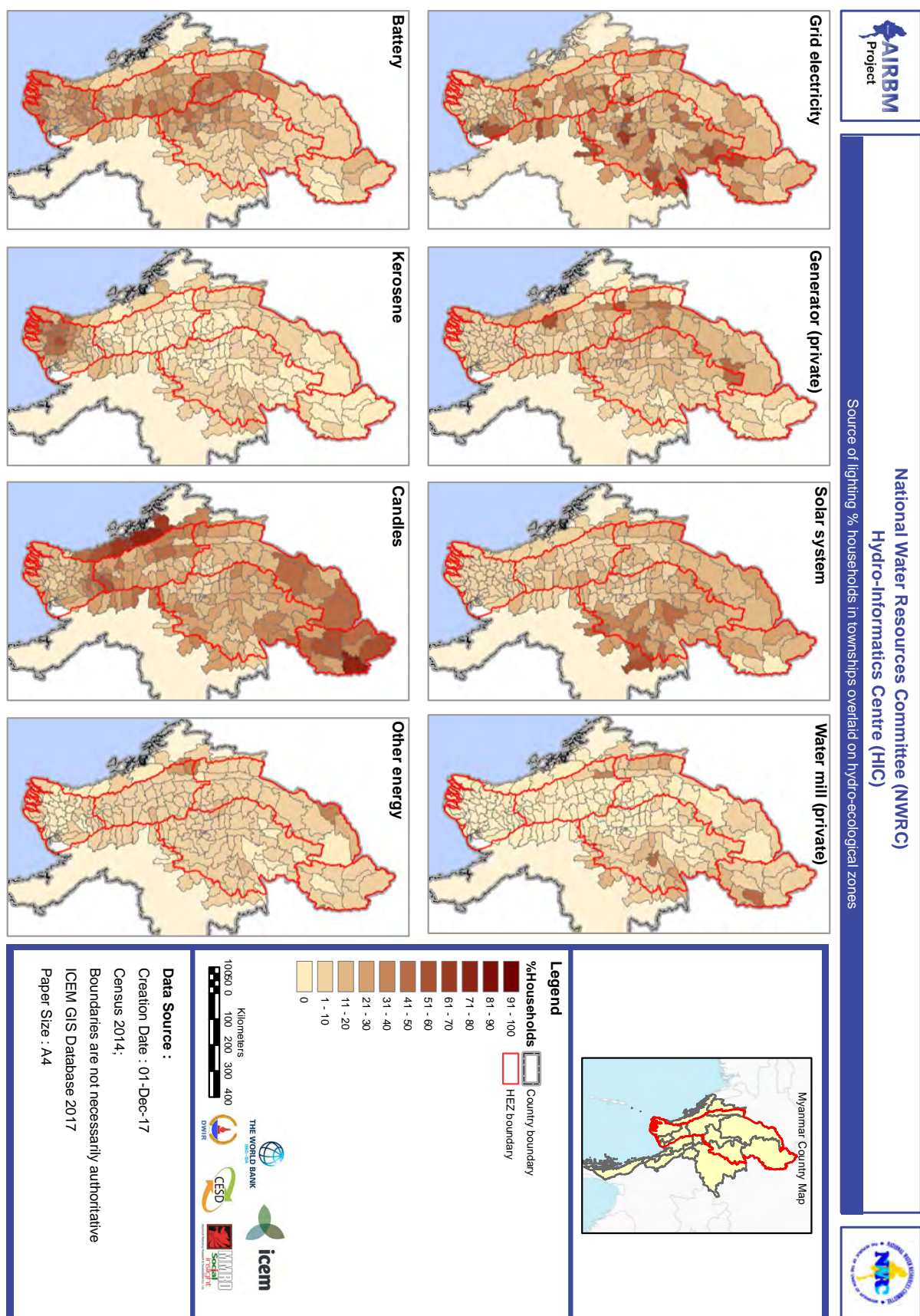


Figure 9.14 - Sources of lighting of households in townships overlaid on hydro-ecological zones in 2014 (2014 Census)

9.7.2 Hydropower

Total annual electricity generation at the national level doubled between 2000 and 2013. Almost all of this increase has come from the expansion of hydropower (Figure 9.15).

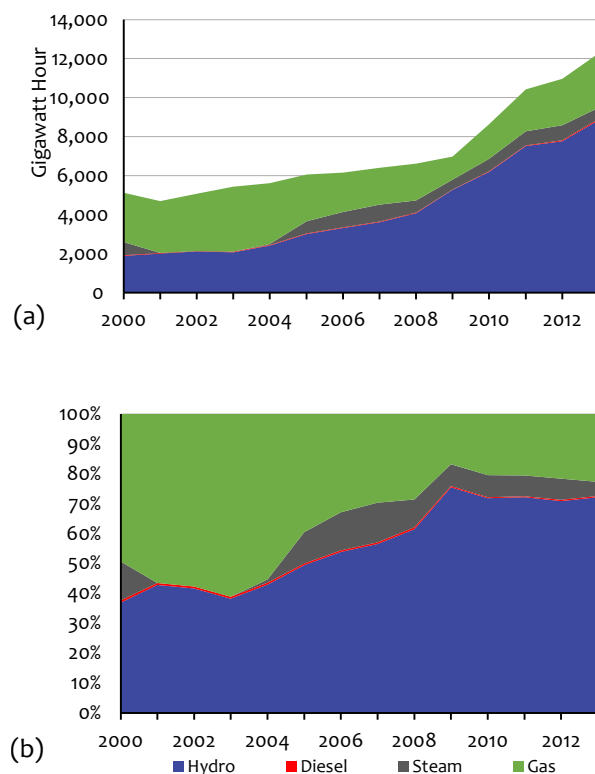


Figure 9.15 - Electricity production by generation technology by total GWh produced (a) and total share of energy produced (b) for 2000 - 2001 to 2013 - 2014

(IES and MMIC, 2015)

There are 14 large hydropower plants in operation, with 2.1 GW of installed capacity, three under construction (1.4 GW) and 29 planned (25.6 GW) in the Ayeyarwady Basin. Most planned are in mountainous areas in the Upper and Middle Ayeyarwady (Figure 2.5). Impacts of large-scale hydropower development on flow regimes, sediment transport, and aquatic ecosystems could be substantial.

Not much is known about transboundary impacts from the existing 183 hydropower projects in the small Chinese section of the Ayeyarwady, including the 875 MW Daying-4 (Hennig, 2016)⁶. Of the 52 hydropower projects proposed, in the pipeline, or built in Myanmar, more than 30 are fully or partly owned by Chinese State Enterprises, including the 790 MW Yewya and 600 MW Shweli-1 near the border with China.

9.7.3 Opportunities and risks

The Ayeyarwady Basin has considerable energy resources, including oil, gas, coal, hydropower, and other renewables that could be developed. Solutions that improve access to energy and are more sustainable exist (Sovacool, 2013)⁷. To address energy needs in remote locations, planners should consider microfinancing and skills training, as well as women's empowerment (Pascale et al., 2016)⁸. Improved cooking stoves are healthier and would reduce fuel needs. Biomass rice husk power plants have the potential to provide grid-quality power (Pode et al., 2016)⁹.

Power sector development in the Ayeyarwady Basin is a critical issue given rapid growth in demand, and the need for stable supply to attract industry and investment. Large-scale hydropower development would have major environmental and social impacts. This underlines the importance of comprehensive assessment of options to meet diverse energy needs across the Ayeyarwady Basin.

⁶ Hennig, T. 2016. Damming the transnational Ayeyarwady basin. Hydropower and the water-energy nexus. *Renewable and Sustainable Energy Reviews*. 65:1232-1246.

⁷ Sovacool, B.K. 2013. Confronting energy poverty behind the bamboo curtain: A review of challenges and solutions for Myanmar (Burma). *Energy for Sustainable Development*. 17(4):305-314.

⁸ Pascale, A., T. Urme, J. Whale, and S. Kumar. 2016. Examining the potential for developing women-led solar PV enterprises in rural Myanmar. *Renewable and Sustainable Energy Reviews*. 57:576-583.

⁹ Pode, R., G. Pode, and B. Diouf. 2016. Solution to sustainable rural electrification in Myanmar. *Renewable and Sustainable Energy Reviews*. 59:107-118.

9.8 Manufacturing

The manufacturing sector is small, but growing rapidly. In the coming decades it is likely to become a significant source of employment within the Ayeyarwady Basin.

9.8.1 Growth trends

The manufacturing sector is small but growing rapidly. Small- and medium-sized enterprises in the food and beverage sector serving domestic markets initially dominated (Figure 9.16). Recent growth and most foreign investment have been concentrated in the garment and footwear sectors for export.

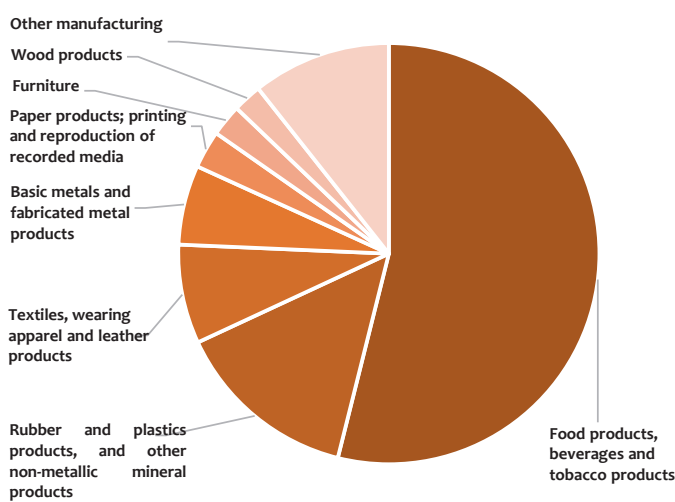
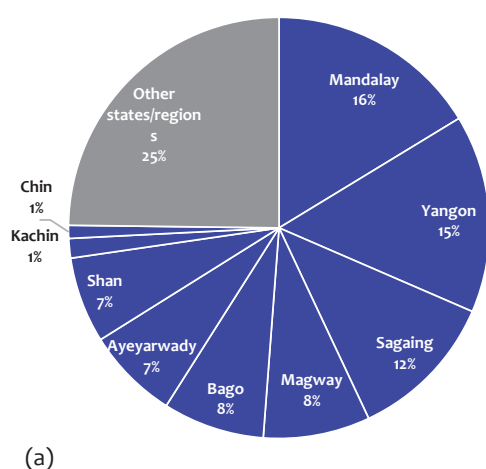


Figure 9.16 - Share of industrial and manufacturing enterprises, nationally and by state or region in the Ayeyarwady Basin (a) and by manufacturing sub-sector (b), 2014 to 2015
(CSO, 2016)

9.8.2 Opportunities and risks

Foreign Direct Investment has been low for the past two decades (Figure 9.2), but has the potential to significantly increase in the next few decades. This, in turn, could result in rapid growth of the manufacturing sector, given the large and cheap labour force, and proximity to large domestic as well as foreign markets like China and Thailand.

Development of the sector will pose challenges for basin management in terms of flood risk, water use, and pollution. A more comprehensive evaluation of the manufacturing sector is not possible without more information. An important next step is to develop a comprehensive database of the manufacturing industry in the Ayeyarwady Basin. This should include information on water use, potential pollutants, and expected energy demand.

9.9 Mining

Mining in the Ayeyarwady Basin is a growing and important part of the Myanmar economy. According to official figures, mining accounted for 1.2% of GDP in 2014 to 2015. Mining statistics, however, are notoriously unreliable as illegally traded products are not included.

9.9.1 Minerals and sites

Myanmar has very rich deposits of jade, sapphire, ruby, and limestone, as well as rich deposits of copper, lead, nickel, zinc, tin, tungsten, gold, coal, and barites. Important minerals that are mined include copper, lead, nickel, and limestone (Figure 9.17A).

According to official statistics, production of jade and gemstones appears to have declined in recent years. The decline may be a consequence of stockpiling, legislative changes, or failures to report actual production. Some estimates suggest as much as 80% of jade and rubies are illegally traded. Anecdotal evidence from mining locations suggests an upscaling of mining activity and increased use of heavy equipment.

Small-scale or artisanal mining is ubiquitous throughout the Ayeyarwady Basin, with hundreds of thousands of pickers for jade and gemstones in the spoil heaps of Hpakant and Mogok. Small gold mines are dotted throughout the Mandalay Region and western areas of Shan State, and the mining of alluvial gold deposits is a common sight along rivers and elsewhere. Artisanal mining is an important income source for many people.

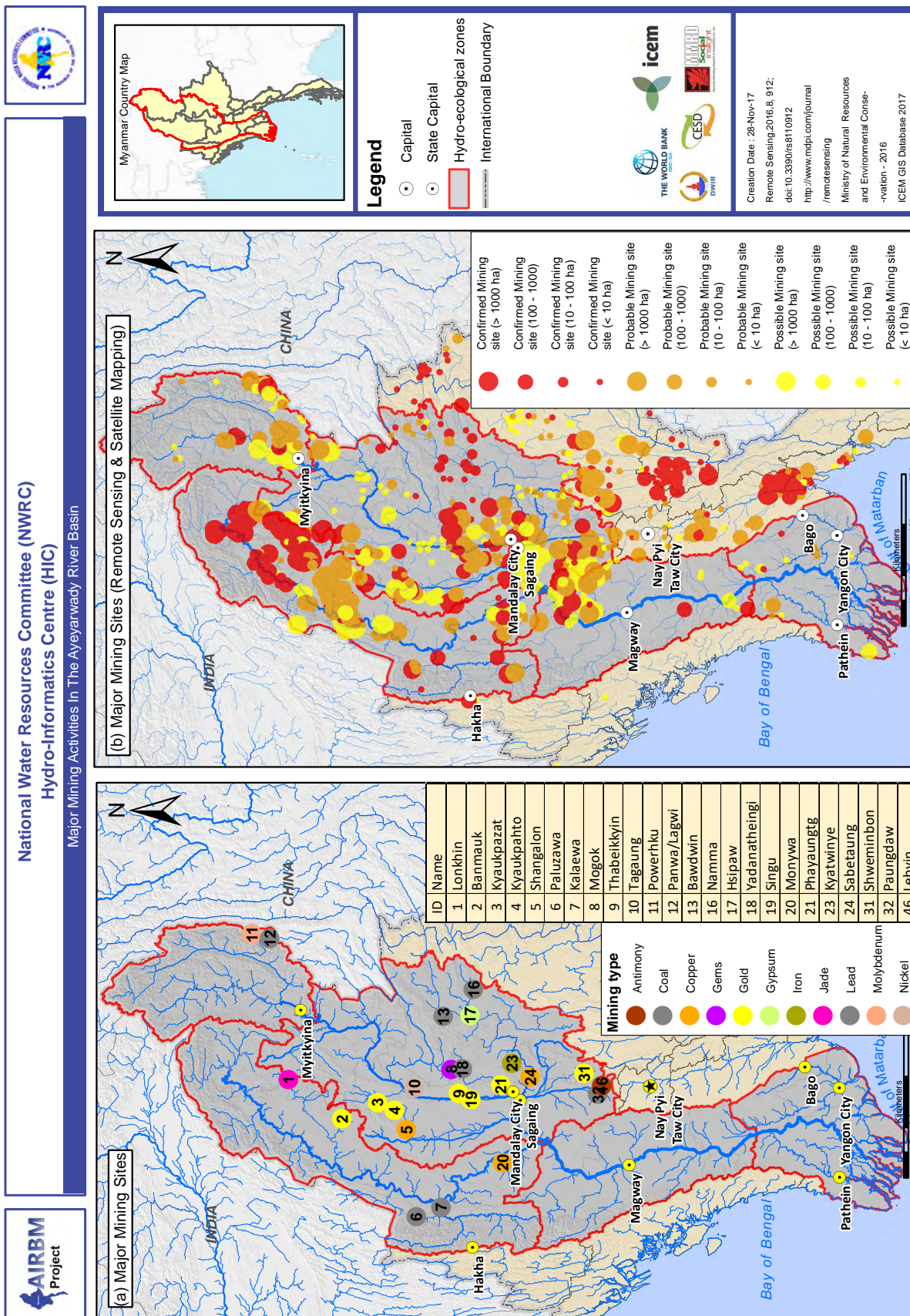


Figure 9.17 - Major mining activities in the Ayeyarwady Basin (a) Kywa Kywa, n.d., and ground disturbance due to mining, 2015 (b) Eco-dev/ALARM, 2016

Analysis of remote sensing data suggests mining has expanded rapidly and now directly affects more than 740 km² in the Ayeyarwady Basin, much of which is in the Chindwin River Basin or around Mandalay (Figure 9.17B).

Gold mining is widespread throughout the Ayeyarwady Basin. Myanmar's only copper mines are situated in the Monywa District of the Sagaing Region, close to the Chindwin River. The only nickel mine operating since 2011 is also in the Sagaing Region, in Htigyaing Township. The mine obtains power from the Shweli 1 hydropower plant.

Sand mining on major rivers is widespread with high demand for construction. The impacts on channel morphology, bank stability, and environment are major concerns. Limestone production has also grown rapidly since 2010.

9.9.2 *Environmental and social problems*

The rapid expansion of mining has created significant environmental and social problems. These include: poor occupational health and safety; farmland appropriation or contamination; erosion and soil loss; deforestation and biodiversity loss; and water and land pollution. Gold mining, for instance, involves the use of mercury or cyanide. Artisanal miners use mercury, posing serious environmental issues.

9.9.3 *Opportunities and risks*

The mining sector is an important driver of economic growth and source of employment. Mining activities, however, produce social, public, and occupational health problems. Regulation of the mining sector has proven very difficult, making the expansions of mining a significant concern for the future.

9.10 Conclusions

Recent trends in social and economic development indicators imply an acceleration of economic activity and increasing pressures on natural resources in the Ayeyarwady Basin in the medium term.

On the one hand, if unsustainable, exploitative practices persist, then the contributions to inclusive development will be negligible, and the prospects for much of the rural and remote populations especially bleak. The unevenness of development increases the likelihood that resource insecurities will prolong ongoing conflicts and renew others. Peace is essential to human well-being and security.

On the other hand, ample natural resources managed sustainably could provide the foundations for developing a more diversified economy with agricultural exports and larger manufacturing and service sectors. Cultural- and nature-oriented tourism, for instance, could grow into a significant source of foreign exchange. Across sector after sector, this assessment finds that to realise these positive outcomes, more equitable and responsible resource governance is key. Division of responsibilities and coordination among states and regions regarding development and conservation of natural resources will be essential.

The changes in population age structure and mobility are an opportunity. To benefit from these 'demographic gifts,' policy changes will be required, to place much more emphasis on raising the education and skills of the workforce.

A river basin perspective on the challenges of development is of special relevance in the case of Myanmar, as the Ayeyarwady River physically links many of these activities. Changes in upper catchments have important implications for the river channel and its floodplains downstream; while manufactured goods travel upstream or along the banks. Activities in one economic sector frequently impact on the water and land resources used by another sector implying that the key benefits of river basin planning would be better coordination, fewer tradeoffs and more synergies.

COMMUNITY PERSPECTIVES





- The consultations in 32 villages delivered data about perceived assets, hot topic issues, and development trends that can be aggregated to the 14 townships across the Ayeyarwady Basin.
- Throughout the entire Ayeyarwady Basin, people remain resilient and adaptive; they cope with the downsides of living close to the river, and would like to be more in charge of their destinies, whether they are improving their livelihoods or living conditions.
- People want to be better informed; they are very eager to understand the morphological forces operating in the Ayeyarwady Basin.
- People want good governance; current systems of governance were perceived as inadequate and present opportunities for improvement through better law enforcement, notably of illegal fishing methods.



- People have significant concerns about water quality; they expressed concerns about these issues, and put great value on clean river water for drinking, washing, bathing, and irrigation, as well as for a healthy ecosystem.
- People have concerns about hard infrastructure; they worry about these structures, ranging from hydropower dams in the north, to bridges and even hard flood protection measures in the south.
- The five hydro-ecological zones (HEZs) of the Ayeyarwady Basin represent different natural resources, industries, enterprises, and a range of cultures and beliefs, and also pose different threats and challenges.



HIGHLIGHTS – COMMUNITY PERSPECTIVES

- Strengthening the peace process is the first priority in the Upper Ayeyarwady HEZ; opportunities for the region are then plentiful, as it is beautiful and extremely rich in natural resources.
- There is a general lack of awareness of the environmental and social impacts of industries in the Upper Ayeyarwady HEZ, particularly within the gold mining sector.
- The Chindwin HEZ is a mountainous area, vulnerable to flash floods, erosion, and sedimentation; resilience could be improved by raising awareness, supporting preparedness training, mitigating causes, and promoting good governance.



- Bank erosion is the main issue in Monywa Township, which could be addressed through raising awareness of the risks of settling close to the river, especially on the outer bends.
- The main issues in Singu and Mandalay, in the Middle Ayeyarwady HEZ, are floods (in Singu) and erosion, navigability, unsustainable fisheries practices, and weak law enforcement (in Mandalay).
- The Lower Ayeyarwady HEZ would benefit from a combination of hard flood protection measures, shelters, better data, monitoring and warning systems, and spatial planning through the prohibition of building in dangerous areas, to reduce the impact of typhoons and flash flooding.
- Clear trends in the Ayeyarwady Delta HEZ are the decline in fish (especially saltwater species) and the increase in flooding over the last decade.



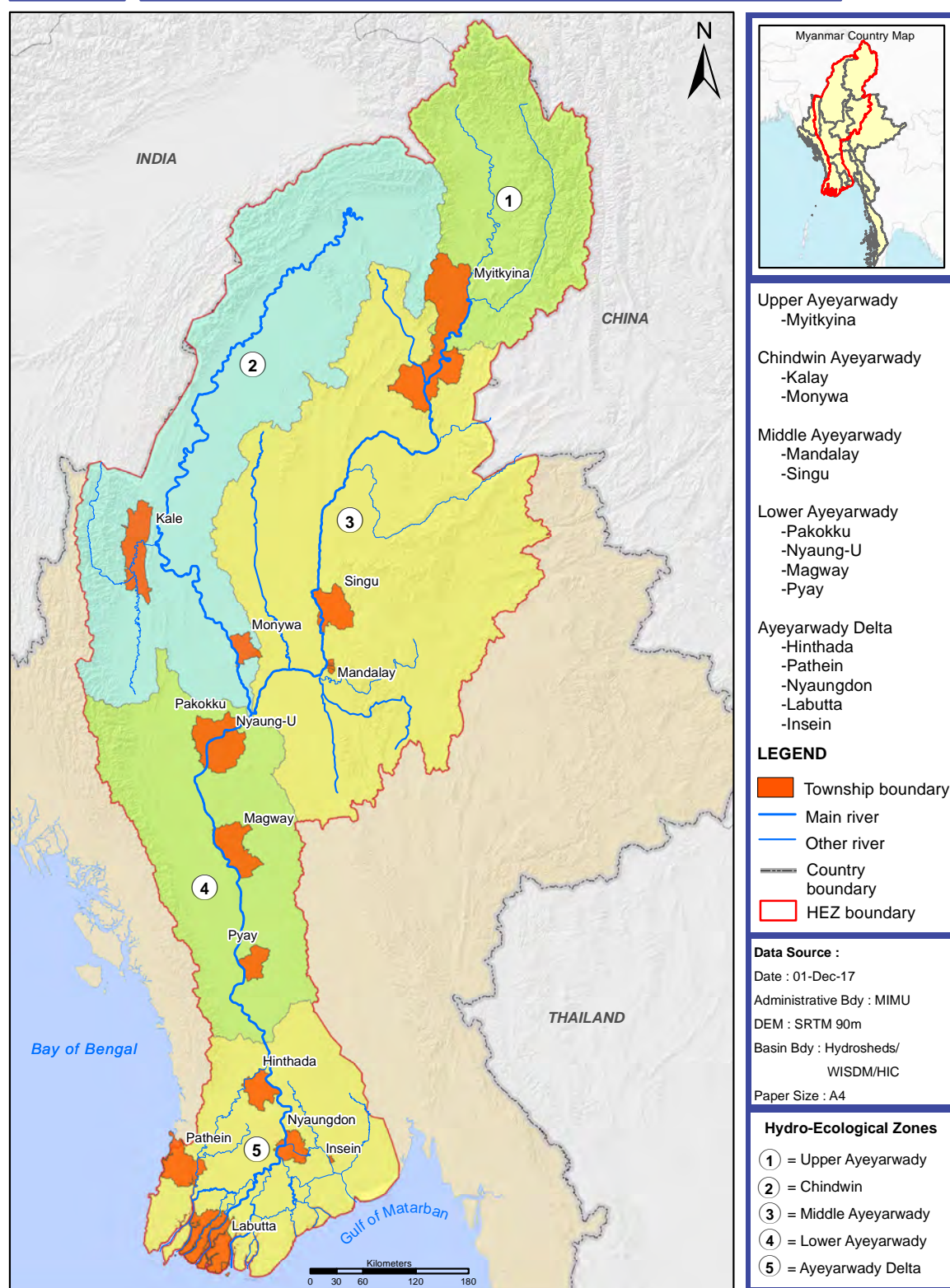


Figure 10.1 -The five hydro-ecological zones of the Ayeyarwady Basin

Townships consulted are shown in orange

10 COMMUNITY PERSPECTIVES

10.1 Introduction

This chapter analyses the present uses of the river, and the values people attribute to it, pragmatic spiritual and cultural. It examines the threats people perceive and whether their causes are thought to be man-made or natural.

SOBA Technical Reports

This chapter is a synopsis of the full assessment, which may be accessed by readers seeking more detailed information, including references:

SOBA 6: Arcadis Nederland B.V., Wageningen University & Research, EMC (2017), *Participatory 3D Mapping and Local Consultations* (SOBA 6), as part of the Ayeyarwady State, product of the Hydro-Informatics Centre, AIRBM Project

SOBA 6: Arcadis Nederland B.V., Wageningen University & Research, EMC (2017), *Communities Atlas* (SOBA 6) as part of the Ayeyarwady State of the Basin Assessment, product of the Hydro-Informatics Centre, AIRBM Project

10.2 Ayeyarwady Setting

The Ayeyarwady Basin has five HEZs (Figure 10.1), each of which has different natural resources, industries, and enterprises (Figure 10.2), and a range of cultures and beliefs. They also represent different threats and challenges.

- In the Upper and Chindwin HEZs, the population is largely Christian and the religious and cultural assets are dominated by churches. Land use consists of evergreen forest, some dry mixed deciduous forest in the upper part, and some scrubland in the Chindwin.
- In the Middle and Lower HEZs, there are many pagodas along the Ayeyarwady River and in the consulted villages. Land use is extremely diverse including forest, scrubland, and considerable agricultural land (Figure 10.2).
- The Ayeyarwady Delta is dominated by agriculture, particularly paddy fields.

10.3 Methods and limitations

Community consultation involved meetings in 32 villages in 14 different townships across the Ayeyarwady Basin, ensuring that each HEZ was equally represented (Figure 10.1). Township selection also took account of ethnic and cultural representativeness.

Those invited, although not identical from session to session, included local and regional authorities, regional politicians, members of the local communities (main water users, such as farmers, fishers, manual labourers, and local entrepreneurs), religious leaders and NGOs.

Consultation was based on the principles of 3D participatory modelling, where the agreed issues and assets were displayed and discussed on a large physical relief model of the Ayeyarwady Basin. This was used to explain the river system and possible upstream and downstream causes and consequences. This model catered to and encouraged:

- Participants with different levels of education and literacy;
- Expression of emotion, frustration, hopes for the future, and perceived trends and tradeoffs; and
- Heightened understanding of the integrated workings of a river system for both participants and researchers.

The 3D model was supported by large traditional 2D satellite maps of regional areas and townships.

These sessions were designed to:

- Test and validate the assumptions/hypotheses in the scoping report, about communities with respect to cultural, spiritual, ecological, social, and livelihood assets.
- Collect information about community priorities, aspirations, issues, challenges, concerns, and best practices.

Listening to, rather than talking at the communities, was emphasised in the consultations. At the same time, an overall database was compiled of participants' village, occupation, role in the community, and gender, as part of the SOBA Communities Atlas.

The townships were chosen with care and are highly informative on hot topics in the main catchment areas of the Ayeyarwady; however, the research remains qualitative, and is not intended to be statistically representative.

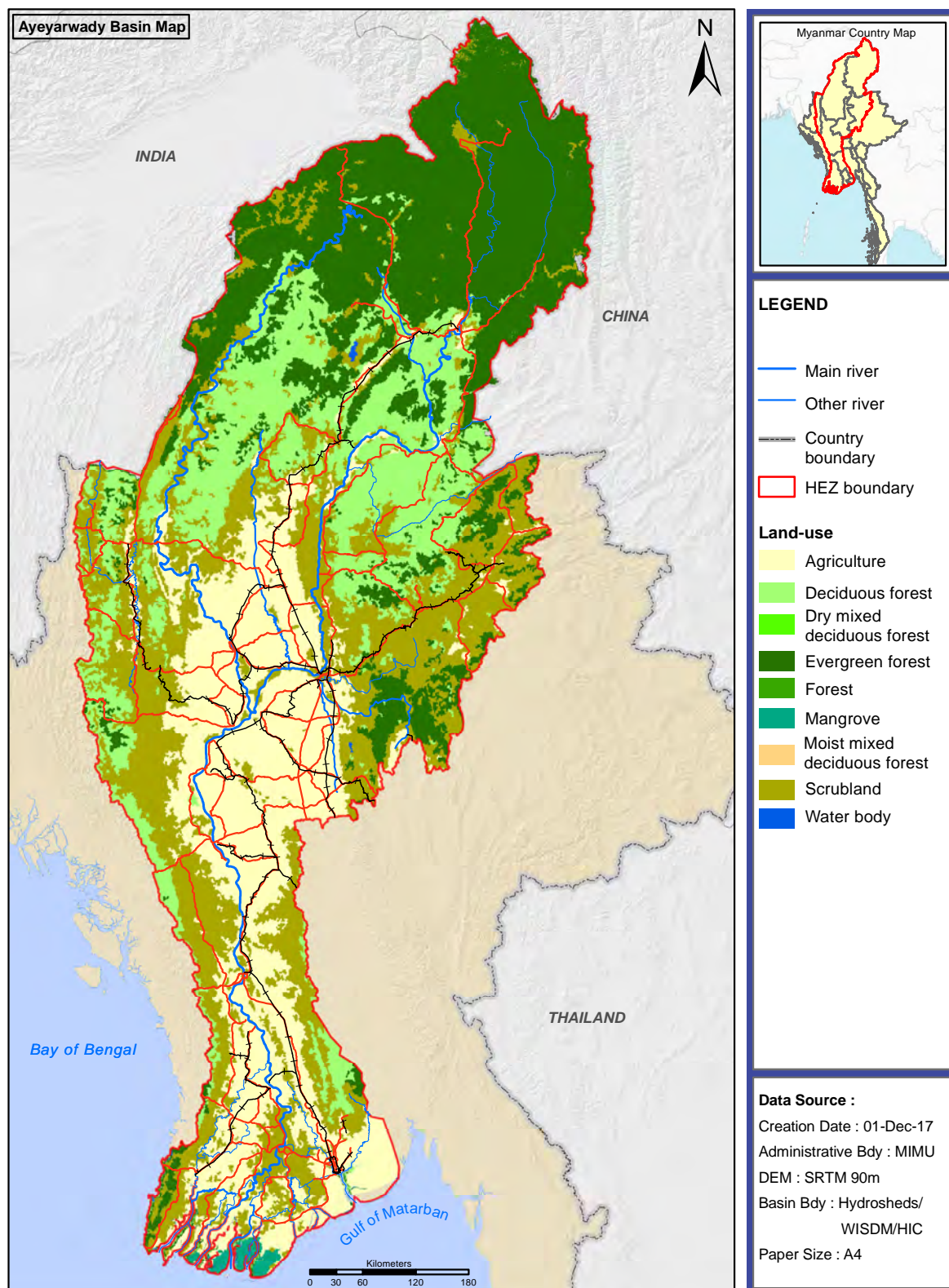


Figure 10.2 - Land use in the Ayeyarwady Basin

Community data was collected through sticky notes placed on maps, quotes and storylines, questionnaire responses, testimonials, and site visits. Myanmar language was used and local assistance was available where illiteracy might have been an impediment. Geographic Information System-based software packages (QGIS and ArcGis) were used for data management and geospatial data visualisation by creating various maps.

Gender

Specific care was taken to make sure that women could participate equally. This was done by:

- Having a female team leader and female experts (alongside their male colleagues) leading the sessions and the interviews.
- Ensuring that women were invited to participate in discussions and interviews, and were enabled in those processes, sometimes through further prompting.
- Registering how many women were present, and whether or not specific remarks were gender-based.

10.4 Status and Trends

10.4.1 Upper Ayeyarwady HEZ

Myitkyina Township

Assets

Myitkyina is the northernmost river port and railway terminus in Myanmar, a business centre of Kachin State, and an important trading town between China and Burma since ancient times. Myitkyina is home to Kachin, Lisu, Chinese, and Burmese people, while most of its population is Christian.

Local resources include jade, gold, teak, forestry products, and agricultural products, while the river environment around Myitkyina is picturesque, with considerable potential for local river tourism.

Issues

Figure 10.3 depicts the issues indicated by villagers in the Upper Ayeyarwady HEZ. The current civil war in Kachin disrupts society, creates uncertainty, restricts access, and hinders development. The people want a federal system based on shared power and better educational opportunities. They might then be open to small-scale developments that meet their needs.

Gold mining employs many locals, but exploitation leads to abuse of opiates and a resulting impact on local society. The industry is said to discharge toxic waste into the river so that few fish remain, water is unsuitable for drinking or bathing, and tourism is deterred in the river's current state.

There is community concern about six planned hydro dams. An existing dam on the N'Mai Kha lacks transparency with respect to energy yield, the benefitting groups, revenue sharing between Kachin State and the Government of Myanmar, environmental impacts, social impacts, and blocked essential river transportation routes. Landholders are uninformed of plans and often abruptly forced to leave their lands, creating tensions between villages and a decline in trust in the state government. There is frustration that electricity is exported while local communities go without the resource.

Values

Local communities value the Ayeyarwady Basin as it has existed for centuries: not exploited for energy and natural resources far beyond what is necessary for a reasonable living. The potential for mining and hydropower is clear, but awareness of impacts on environment and society is lacking, as is knowledge on mitigation. Business owners and managers from the gold mining industry indicate that they need and would welcome guidance on these matters.

The river is vital for transportation, especially with the lack of good roads in the north. Traditionally, fisheries were of great value and today still have potential, but currently suffer from the polluted river.

Development trends in Myitkyina

The river is more polluted since 2000, due to gold mining, dam construction, and waste from domestic and miscellaneous industrial sources. People are now using wells and water from creeks for drinking water, following the decline in river water quality. Large fish are absent from the river, as a result of pollution from gold mining and fishing with chemicals and battery stunning.

Flood risk has increased, possibly due to deforestation upstream leading to erosion and increased runoff.

Conclusions for Upper Ayeyarwady HEZ

The need for peace is the fundamental and paramount issue in the Upper Ayeyarwady HEZ. Opportunities to improve the circumstances of communities in this HEZ begin with the government strengthening its relationship with the people. This can be propelled by government policies aimed at avoiding and mitigating the adverse impacts experienced to date.

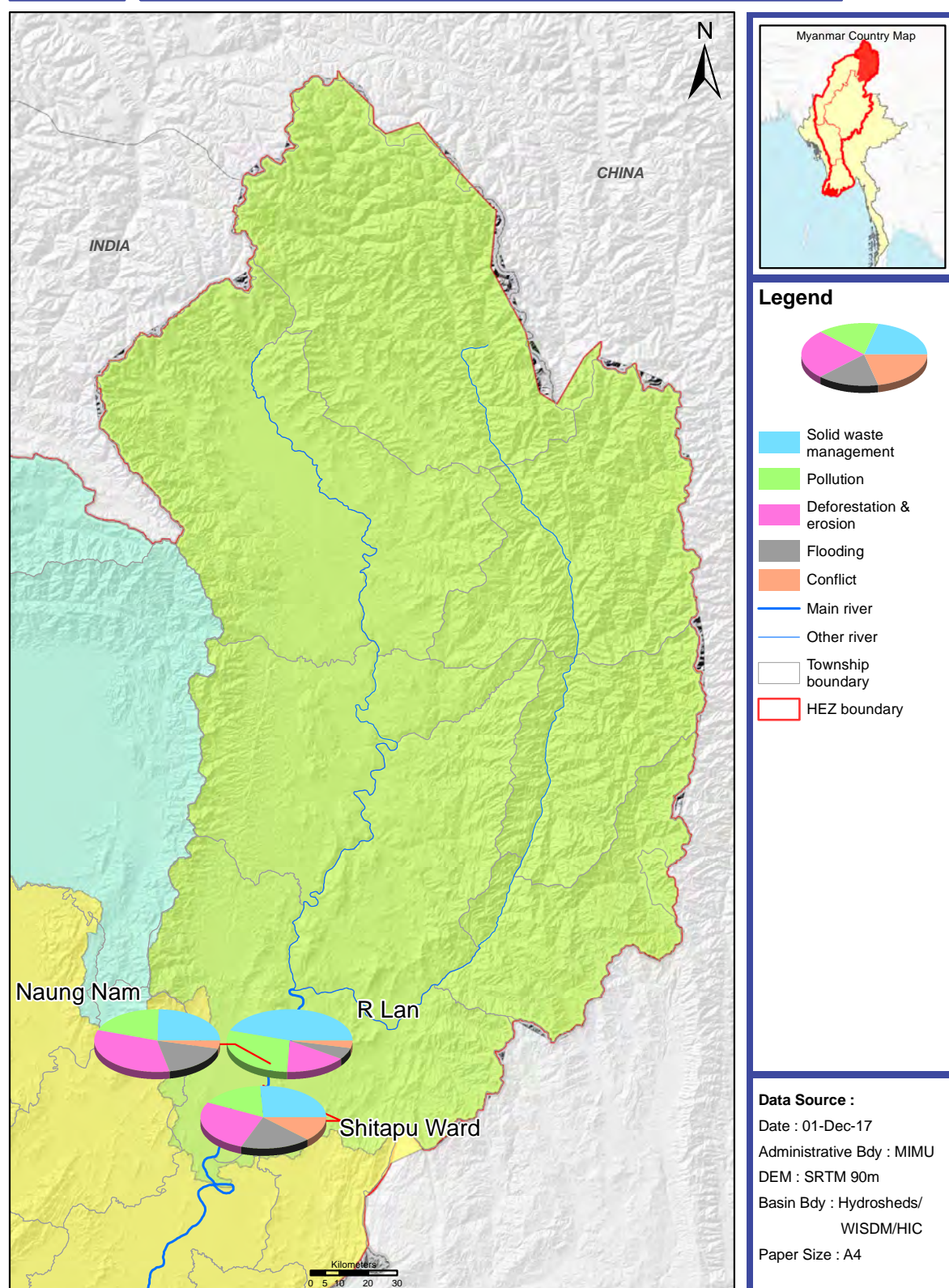


Figure 10.3 - Issues in the Upper Ayeyarwady hydro-ecological zone, as indicated by the villagers in Myitkyina Township

There is a general lack of awareness of the environmental and social impacts of industries, particularly within the gold mining industry, which is a major offender. Dams also have a profound impact and should be planned with the utmost care and transparency, and conform to international standards on human rights, environmental preservation, and protection of local communities. River water quality could be improved with increased awareness and enhanced technical knowledge of water treatment within polluting industries.

10.4.2 Chindwin HEZ

Two townships in the Chindwin HEZ are discussed, Kalay and Monywa.

Kalay Township

Assets

Kalay, on the Myit Tha River tributary of the Ayeyarwady, is a trading hub along the strategic road between India and Myanmar. The township is both an agricultural and industrial town with an estimated population of 400,000, most of whom are devout Christian.

Forestry, mainly for plywood, is practised in the Chin Hills very near to many tributaries of the main river. These have steep upstream sections that can result in flash flooding following heavy rainfall in the catchment.

Issues

Figure 10.4 depicts the issues indicated by villagers in the Chindwin HEZ. A major flash flood in 2015 caused significant casualties and family displacements in two of the three villages and crop damage in all three. This was the result of extreme weather conditions combined with deforestation in the mountains, leading to sedimentation of the main river. There is concern that with climate change and continuing deforestation these events will recur, perhaps more often and with greater intensity. These flooding events occur more often than in flatter areas further down the Ayeyarwady Basin.

Deforestation also results in landslides on mountain slopes and deposition of sediments and waste in villages below. Drainage systems then become almost entirely dysfunctional, flow stops, and irrigation of rice paddies ceases, the effects of which are still obvious two years after the floods. These low flows also put some small hydropower generators out of operation. Unique to this section of the Ayeyarwady Basin, these sediments are mostly large rocks and gravel which, unlike fine sediment deposited during regular seasonal floods, is of no opportunistic value to agriculture.

Drinking water is perceived as problematic, partly on account of pollution as a result of waste and poor hygiene, and also due to concern that the aquifer has been disrupted by the flooding.

Around Kalay, the morphological behaviour of the river sometimes causes outer and inner bends to swap over every 10 or so years. This requires a high level of flexibility from the farmers who own and work the adjacent lands, which adds to local resilience and adaptiveness. Disputes occasionally arise over ownership rights, but these are usually readily resolved at the village level.

In general, local people expressed frustration that top-down structures are an impediment to their voices being heard by government at the national level.

Values

Resilience is a key value, expressed as a capacity to deal with crises and a willingness to help each other under all circumstances and unconditionally. This togetherness is very evident in the villages in Kalay Township, perhaps because of their vulnerability. Kalay villagers say government should also play a role during hardship, to provide protection, relief, and renewed opportunities after a natural disaster.

Farming and, to a lesser extent, fisheries are valued as significant sources of income, along with irrigation, which is important for farming.

Drinking water and navigation are important water values, the latter particularly because farmers often own land on both sides of the river.

Development trends in Kalay

Climate change and deforestation are feared, particularly in light of the severe flash floods of 2015. Fisheries have diminished since the 2015 floods due to sedimentation and access to fishing grounds, while agriculture has suffered from damage to irrigation infrastructure.

Groundwater, traditionally a source of drinking water, is no longer used. Apparently, the quality of the aquifer deteriorated as a result of a small earthquake in 2015; consequently, there is greater dependence on polluted river water.

Erosion and sedimentation occur on both sides of the river, as the inner and outer banks of the river swap every 10 to 15 years.

Communities are developing ever greater resilience and there is some optimism as education and health care facilities improve.

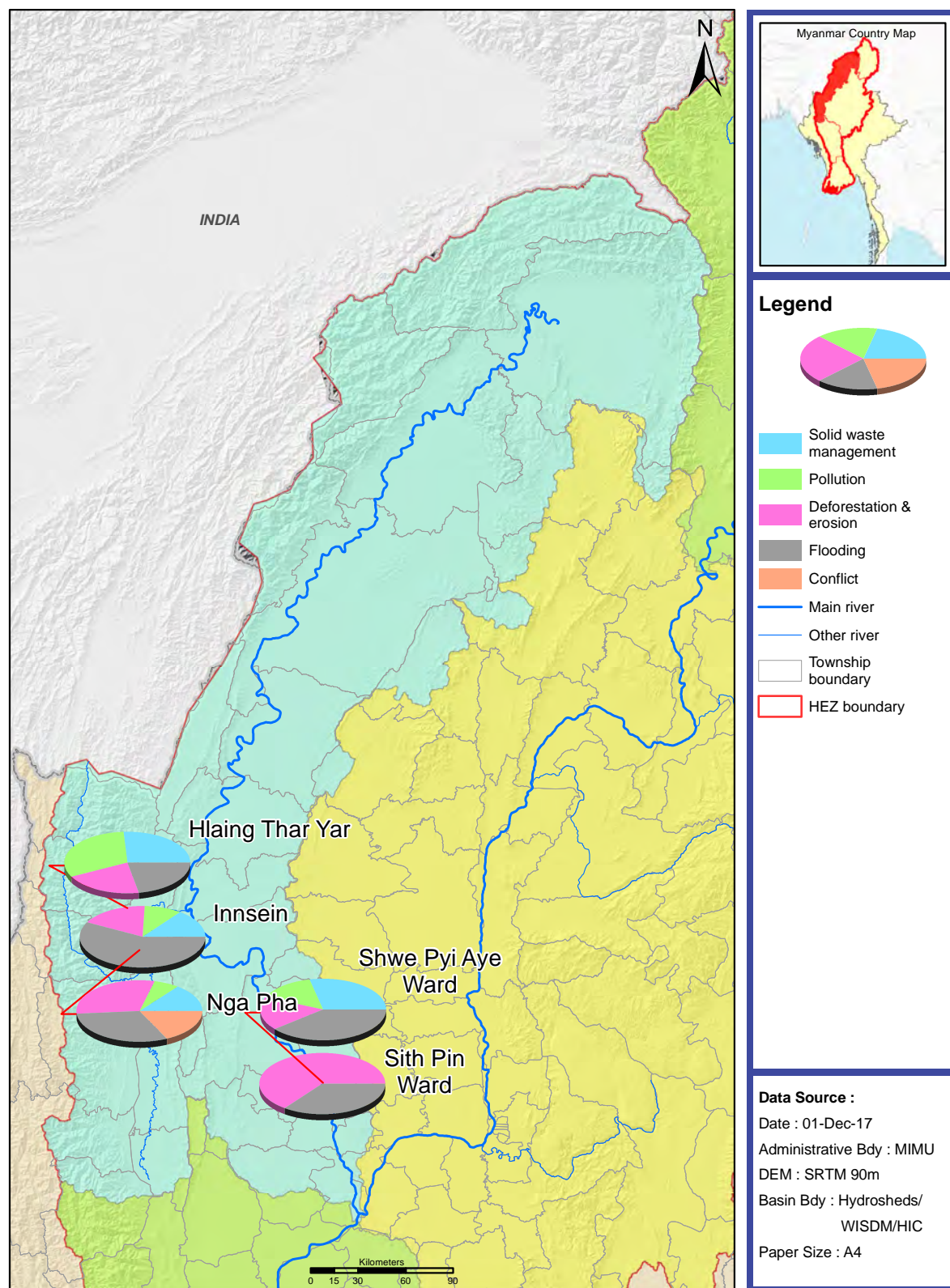


Figure 10.4 - Issues in the Chindwin hydro-ecological zone, as indicated by the villagers in the townships of Kalay and Monywa

Monywa Township

Assets

Monywa is a major centre for trade and commerce in agricultural produce, especially beans, oranges, pulses, and palm sugar, while also milling produce cotton, flour, noodles, and edible oils. The processing and transportation of bamboo is a significant and growing industry, together with clay brick production. Monywa also has tourist attractions and can be reached from Mandalay by road or rail.

Good quality drinking water is accessed from wells.

Issues

Stream bank erosion is an ongoing process with little infrastructure to mitigate the issue. This threatens many dwellings built on outer river bends, and there is apparently little understanding of morphological processes rendering these areas vulnerable. Villagers mainly attribute erosion to wave action from passing boats, dredging, and gold and clay mining upstream.

Sedimentation is a related issue when it creates navigational uncertainty during the dry season, when the water level is very low.

Values

The Chindwin River is essential for the transport of bamboo products, hence the importance of uninterrupted navigation. Fisheries resources are mainly from a lake near the river, and yields have been constant for decades.

The importance of good governance is highlighted when one village is the beneficiary of roads and electricity, whereas another struggles for assistance with embankments. Good quality drinking water from wells is valued across the township.

Development trends in Monywa

Bank erosion and sedimentation have worsened since dredging activities started upstream.

Conclusions for Chindwin HEZ

In the Chindwin HEZ there are concerns that major flash floods will recur more often and with greater intensity due to trends such as climate change and deforestation. Associated erosion and sedimentation severely impacts livelihoods, particularly with respect to drinking water, irrigation, and river navigability. Despite this, adaptiveness, social cohesion, and sharing are deeply embedded characteristics of Chindwin communities.

Bank erosion, the main issue in Monywa, could be addressed through raised awareness of the risks of settling close to the river, especially on the outer bends. There is an obvious need for data, monitoring and decision support systems.

The villages of Monywa display a self-reliance mentality with great potential to contribute economically. Government support should provide relief during floods, stronger law enforcement, infrastructure development, navigability on the river, and protection against bank erosion.

10.4.3 Middle Ayeyarwady HEZ

Two townships in the Middle Ayeyarwady HEZ are discussed, namely Singu and Mandalay.

Singu Township

Assets

Just upstream of a vast inland delta north of Mandalay, Singu depends mainly on small-scale farming and fisheries that benefit from a relatively healthy section of the river. Drinking water is still taken directly from the river and flooding brings some benefits with deposition of relatively fertile soil on farming land.

Issues

Figure 10.5 depicts the issues indicated by villagers in the Township of Singu, as well as in Monywa and Mandalay, in the Middle Ayeyarwady HEZ. The monsoon is a regular and expected event, and yet life stops for two months per year as villagers cannot farm or fish, and have great difficulty getting children to school.

The township manages solid waste with a collection service for some areas, but for many people this is too far away, and garbage mostly ends up in the river, particularly in the wet season. Plastic is becoming more prevalent in the waste stream.

Values

The river in Singu is valued for its contribution to farming, fisheries, drinking water, and sanitation, and has a unique spiritual and religious value.

Development trends in Singu

There is some evidence that drinking water from the river is becoming more turbid and that the fish catch is declining. However, there is general optimism about the future and a belief that young people will stay in the community.

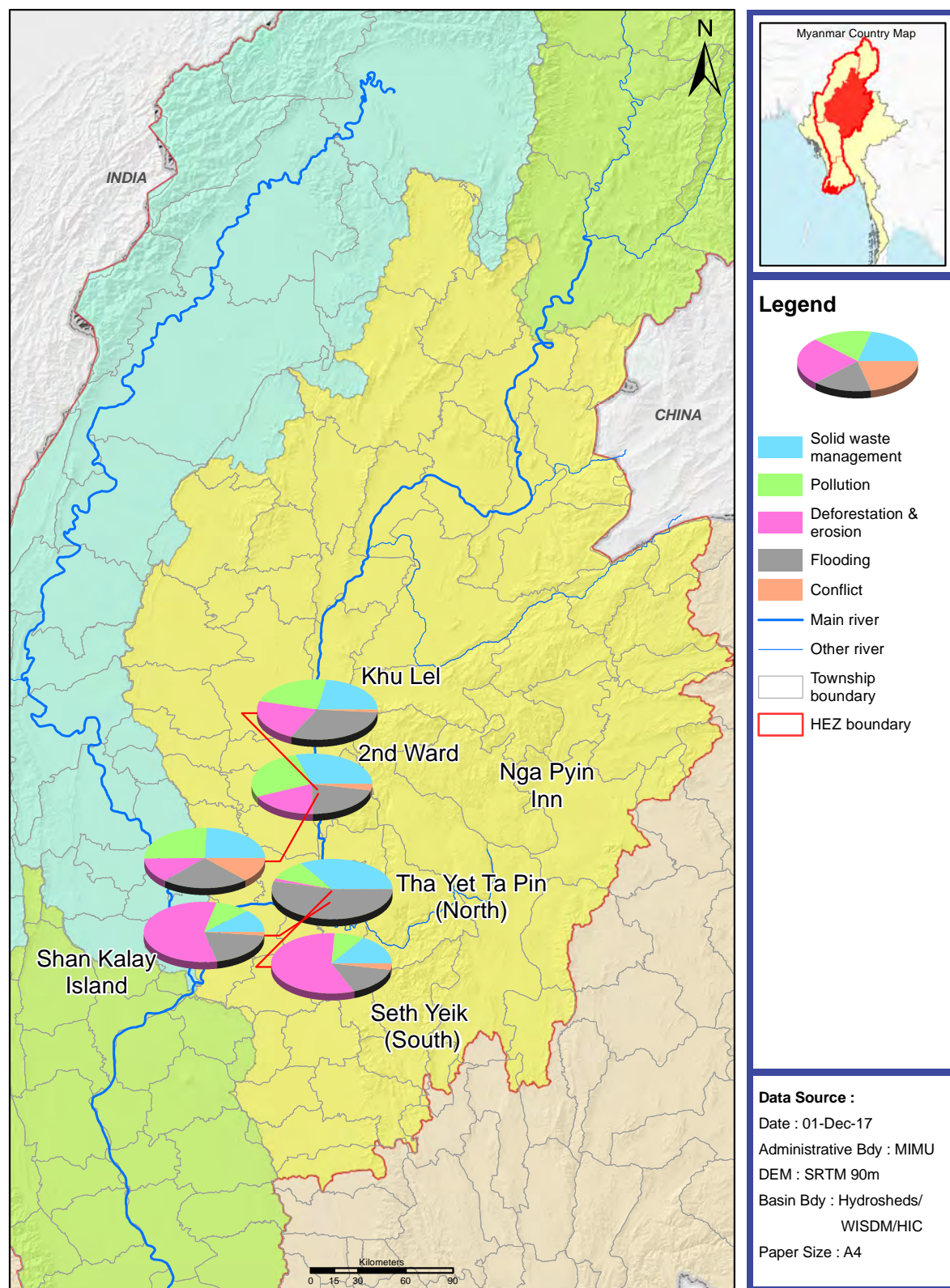


Figure 10.5 - Issues in the Middle Ayeyarwady hydro-ecological zone, as indicated by the villagers in the Townships of Singu and Mandalay

Mandalay Township

Assets

Mandalay is an important transport hub, connected to other parts of the country, China, and India. The Ayeyarwady River remains a significant route for transporting farm products, pottery, bamboo, and teak. Mandalay is the major trading, communications, and cultural centre for northern and central Myanmar, with the Ayeyarwady as a beautiful and crucial artery. Such is the morphology of the river that vast quantities of productive soil are eroded from stream banks, with much of it deposited further downstream with agricultural potential.

Issues

Figure 10.5 depicts the issues indicated by villagers in the Township of Mandalay, as well as in Singu and Monywa, in the Middle Ayeyarwady HEZ. Bank erosion poses a real threat to farming communities who see their homes and lands being eaten away. The sedimentation impedes navigability, making business difficult for boat owners and fishers. Sand mining and dredging practices are blamed, as locals are able to detail the coincidence of mining and dredging activities with periods of erosion. To prevent undesired morphodynamical behaviour, the villagers believe that a fixed navigation channel should be dredged.

The other aspect is that due to sedimentation, new land emerges, and is often very fertile. People are eager to start cultivation on those lands, but it is difficult to obtain the necessary permissions.

Local fisheries suffer from illegal fishing methods, such as electrical battery fishing, forcing local fishers to travel further for a reasonable catch. People are losing faith that fisheries can continue to be profitable when law enforcement is weak and, as a consequence, are leaving the industry.

Values

The most important values of the river are farming and fishery, particularly the potential for farming on new fertile lands if licensing procedures speed up. Fisheries are losing value as a result of illegal electrical battery fishing.

Drinking water is a value, directly from the river in certain places, and in others from groundwater wells.

Seasonal floods are of great value to villages in the Central Dry Zone, which receive limited rainfall. Farmers are highly dependent on floods for agricultural production, especially those without irrigation systems.

Development trends in Mandalay

Erosion is increasing due to wave action from additional and larger ships, and from dredging and sand mining operations. Changing depths and shallow areas in the river make navigation more difficult.

Fisheries are also becoming much more difficult due to unregulated and illegal fishing.

Less drinking water is taken from the river and groundwater with the move to rainwater and bottled water.

People are generally optimistic about the future, seeing opportunities for diversification of their jobs, and better education for their children. Improved microfinance schemes would further widen their options.

Conclusions for Middle Ayeyarwady HEZ

The main issues in Singu and Mandalay are floods (in Singu) and erosion, navigability, unsustainable fisheries practices, and weak law enforcement (in Mandalay). Some of the issues can be addressed by raising awareness and supporting adaptability improvements. Careful government planning is also required, based on knowledge of the river's hydraulic and morphologic behaviour. In some places, protective dykes and improved channel navigation are needed.

Law enforcement should be addressed, which could require more manpower, capacity, and adjustment of work procedures of the enforcers and their managers.

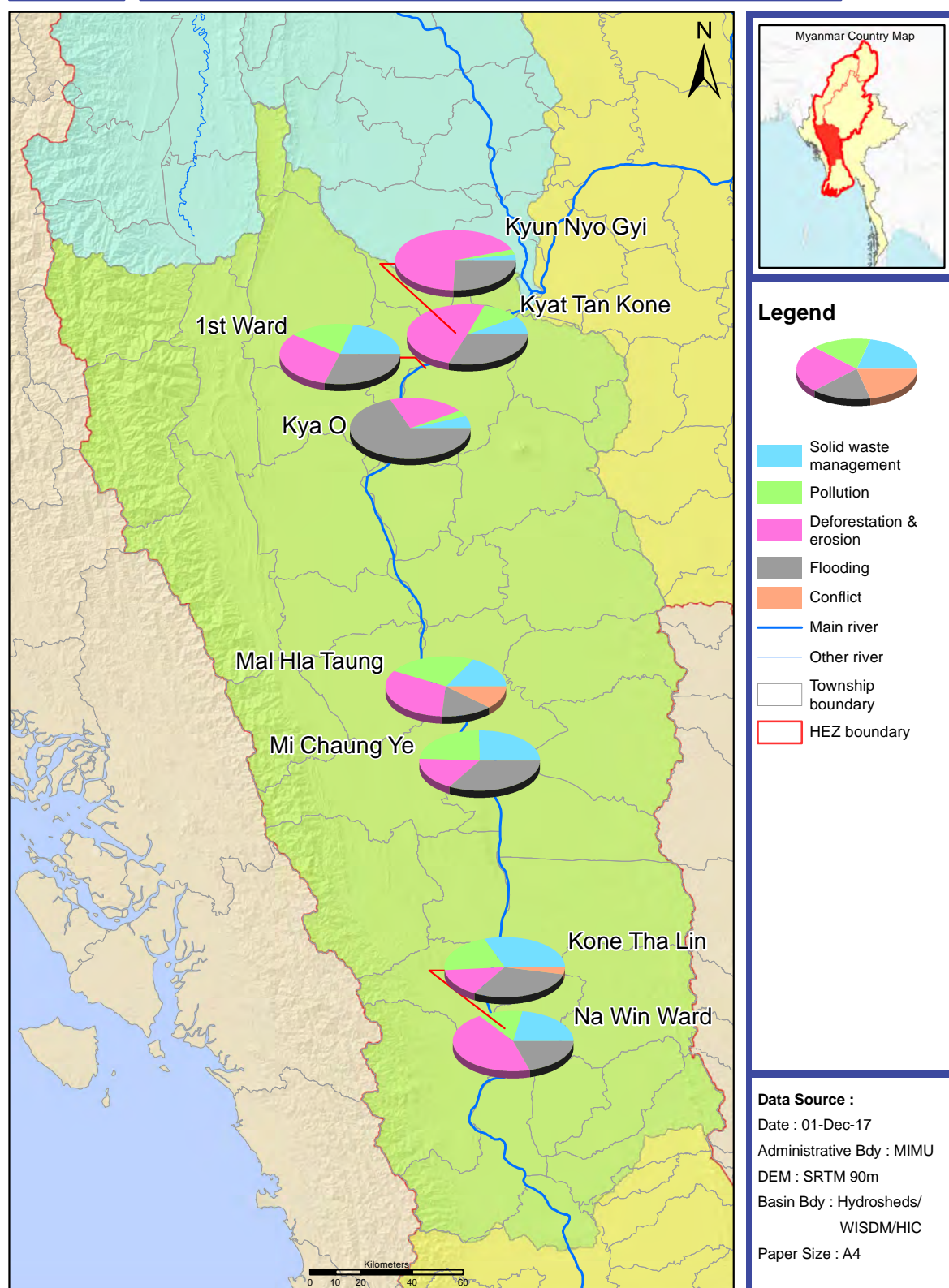


Figure 10.6 - Issues in the Lower Ayeyarwady hydro-ecological zone, as indicated by the villagers in the Townships of Pakokku, Nyaung U, Magway, and Pyay

10.4.4 Lower Ayeyarwady HEZ

Four townships in the Lower Ayeyarwady HEZ are discussed, namely Pakokku, Nyaung U, Magway, and Pyay.

Pakokku Township

Assets

Pakokku is a quiet and traditional town on the banks of the Ayeyarwady River, 25 km north of Bagan, where some residents work. The main local industry is agriculture.

Issues

Figure 10.6 depicts the issues indicated by villagers in the Township of Pakokku, as well as in Nyaung U, Magway, and Pyay, in the Lower Ayeyarwady HEZ. Flooding is a problem perceived by the community as largely the result of the government mismanagement of infrastructure. Associated erosion manifests as ‘walking islands’ (islands that, due to erosion and sedimentation, move every year) in the middle of the river and damage to riverside roads.

Values

Values of the river in Pakokku relate particularly to navigation, irrigation, erosion control, and sanitation.

Development trends in Pakokku

Erosion has become much worse since 2012, when a new bridge was built.

Nyaung U

Assets

Agriculture is the main source of income; however, being only 4 km from old Bagan tourism is becoming a significant employer.

Issues

Figure 10.6 depicts the issues indicated by villagers in the Township of Nyaung U, as well as in Pakokku, Magway, and Pyay, in the Lower Ayeyarwady HEZ. Seasonal flooding in the monsoon season is accepted as normal, but there is great concern about flash floods after heavy rainfall in the pre- and post-monsoon time periods. The dykes are poorly maintained, flood mitigation dams are dysfunctional, and there is a lack of coordination to manage flooding across the township. There is a community consensus that the whole village should be moved to a safer area, but they cannot afford the land. There is a perception of collusion between some landowners and government officials.

Values

The villagers see emerging opportunities in river tourism, but mostly they look to employment in the garment industry to escape the ravages of flooding.

Development trends in Nyaung U

The villagers believe that rain events are heavier than before and that the water cannot escape, leading to ever worsening flooding events. Navigation has become more difficult due to sedimentation.

A decline in fishery is perceived as a result of the use of battery stunning upstream and unregulated fishing in the spawning season.

The uncertain future is prompting a general emigration of young people to Mandalay.

Magway

Assets

The Ayeyarwady River is the major transportation system in Magway. The riverfront is potentially attractive but for the garbage floating in the river and accumulating on the riversides. Agriculture is important on the higher ground and the alluvial islands.

Issues

Figure 10.6 depicts the issues indicated by villagers in the Township of Magway, as well as in Pakokku, Nyaung U, and Pyay, in the Lower Ayeyarwady HEZ. Seasonal flooding is a dominant issue and many villagers would move to a safer location but are too poor to do so. Associated with flooding is the impact on sanitation, many unusable toilets, and solid waste being swept into the river.

The most important issue is a conflict around ownership of farmland. Prior to the last elections, farmland was sold to the regional government who provided it to others, who are apparently not using it. The villagers wish to buy their land back to grow vegetables on this very fertile river-related soil, but they have no proof of previous ownership. Communication with the government is difficult and time-consuming. Conflict also arises over the right to till the alluvial islands that move every year, so it is difficult to establish which village owns them, or is entitled to use them.

Values

Drinking water from the river is an important value, particularly because groundwater is often too saline. The river is also valued for navigation and irrigation.

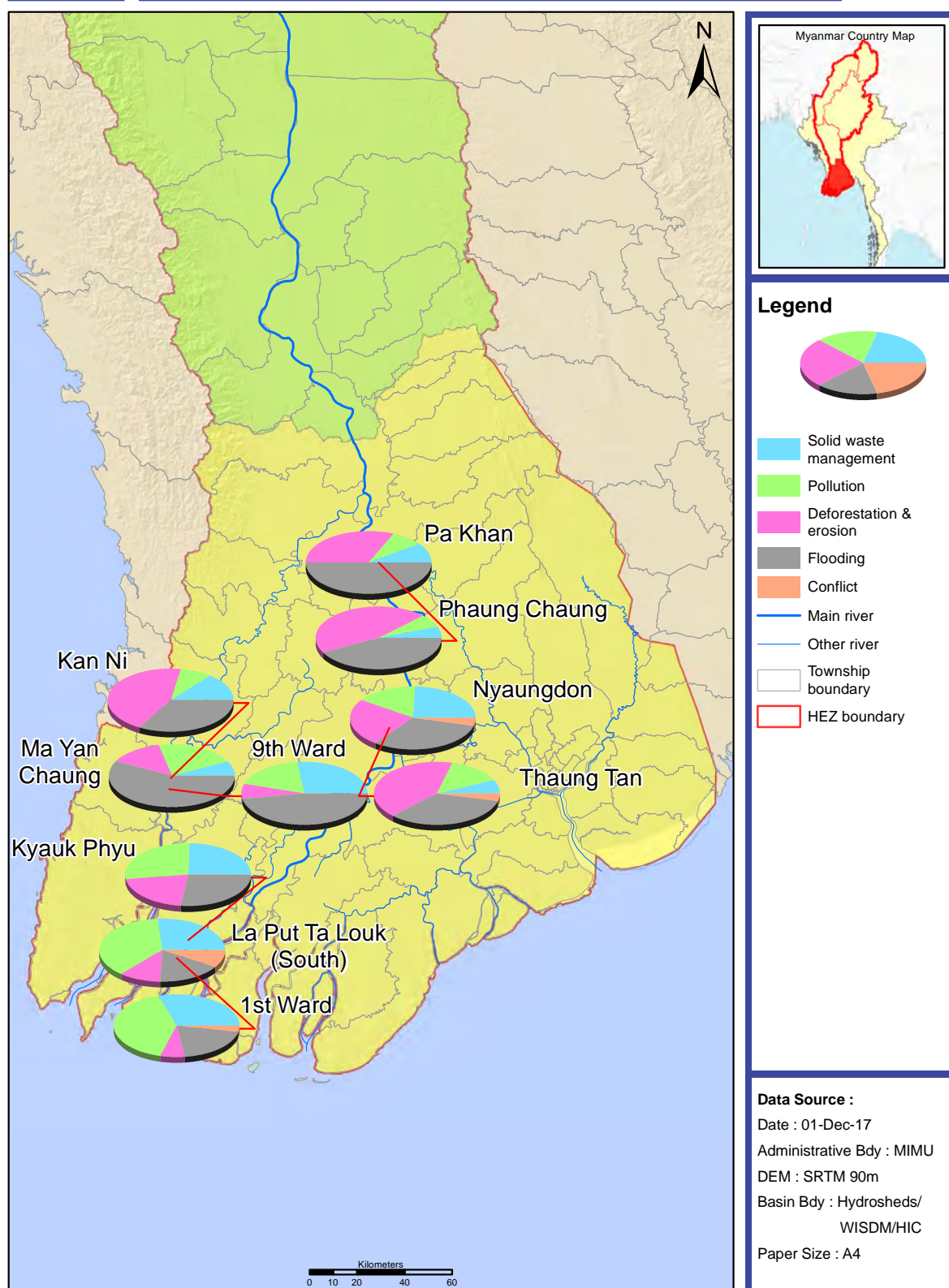


Figure 10.7 - Issues in the Ayeyarwady Delta hydro-ecological zone, as indicated by the villagers in the Townships of Hinthada, Nyaungdon, Pathein, and Labutta

Development trends in Magway

Seasonal flooding is becoming worse and more frequent. This impacts water quality in the river, particularly turbidity and pollution related to poor management of solid waste.

Fisheries are deteriorating due to overfishing and taking of fish during spawning season.

Pyay

Assets

Pyay is on the Naweng River, at the convergence of numerous mountain streams. With a tropical savanna climate, agriculture is important; based on rice, cotton, tobacco, and custard apple. The river is the main source of drinking water, as groundwater is too saline.

Issues

Figure 10.6 depicts the issues indicated by villagers in the Township of Pyay, as well as in Pakokku, Nyaung U, and Magway, in the Lower Ayeyarwady HEZ. Seasonal flooding is described as becoming worse in some villages but not others, though certainly the impacts, such as erosion and pollution, have worsened. Most people want to relocate; some were offered less flood-prone land, but it is poorer farmland with bad road access. Some villages are isolated during the period of seasonal floods, because they cannot use the road. The river is then the only means of transport.

Fisheries are facing reduced catches due to fishing in the spawning season, the use of battery stunning by other villagers, and the river becoming shallower. There is a need for well-researched soil conservation measures to assist agriculture and reduce offsite damage.

Values

The most important water value in Pyay is drinking water.

Development trends in Pyay

Erosion and pollution, the consequences of flooding, are worsening. The people of Na Win Ward would relocate if it were possible.

Fish takes are declining due to fishing in the spawning season, the use of battery stunning, and the river becoming shallower, which influence fish habitat.

Conclusions for Lower Ayeyarwady HEZ

Good governance or its absence lies behind many of the issues in this HEZ. Whereas seasonal floods are seen as inconvenient but natural, flash floods are perceived to be man-made and should be dealt with by local governments. Villagers have clear ideas about fair judgement and conflicts of interest by local governors when dealing with water issues and related developments. When a community lives in a flood-prone area and wants to relocate, they should be able to buy land at a fair market-conforming price. Or when several land owners are asked to maintain a dyke, all should be bound to comply.

The HEZ has economic potential through tourism in and around Bagan and the petroleum industry around Magway. However, there is a gap in perception between entrepreneurs and, for example, farmers or garment industry workers. Entrepreneurs are eager for change and development; farmers and workers are more reluctant.

10.4.5 Ayeyarwady Delta HEZ

Five townships in the Ayeyarwady Delta HEZ are discussed, namely Hinthada, Nyaungdon, Pathein, Labutta and Yangon, Insein.

Hinthada

Assets

Hinthada, a city of 170,000 people, is an agricultural trading town, a port for the surrounding agricultural area, and is connected by road and rail with Pathein and Yangon. East of the town is a low-lying irrigation scheme protected by embankments along the Ayeyarwady. Artisanal fishing on the river has been an important industry in many of the villages.

Issues

Figure 10.7 depicts the issues indicated by villagers in the Township of Hinthada, as well as in Nyaungdon, Pathein, and Labutta, in the Ayeyarwady Delta HEZ. The villages in the Hinthada Township are close enough to big urban developments to experience the impacts of sand mining, domestic and industrial waste pollution, and excessive commercial fishing, but too remote to access higher education or professional health care.

Bank erosion and sand mining upstream cause sedimentation, which in turn hinders navigation and exacerbates flooding. Industrial and domestic solid waste is being dumped in the river upstream, thereby polluting the river, which has been the main source of drinking water. Groundwater in much of the delta has arsenic levels exceeding WHO limits.

Values

People value their own resilience and sense of community. They do not wish to live elsewhere but argue that everyone should share the benefits of government-subsidised development.

Development trends in Hinthada

Local fishers are licensed but claim that bigger ships from the nearby cities abuse these licences using gear that is becoming ever larger and more overwhelming.

Community-based floodgate management would provide better protection for communities that grow rice in paddies behind the dykes.

Nyaungdon

Assets

Nyaungdon is a port city at the junction of the Ayeyarwady and the Pan Hlaing and is protected by flood-control embankments. Rice growing, vegetables, and fishing are the major industries along with transport and communication services. Of 216,000 people, 90% live in rural areas.

The fertile soil is replenished by seasonal flooding, a fundamental property of the delta.

Issues

Villagers believe that seasonal flooding has increased in duration and severity and the cause is man-made. Unlike other parts of the Ayeyarwady Basin, Nyaungdon benefits from occasional flooding, but it does inflict damage. Sluices associated with the Mezali weir are considered the source of their problems and they believe that the tradeoff between the advantages of the sluices upstream (providing water to Yangon) and the problems they face with erosion and flooding is unbalanced against them.

Values

Villagers depend on the river for their livelihood and value the silt that it delivers.

Development trends in Nyaungdon

Flooding has worsened since 2012; however, overall confidence is high and young people are staying.

Patheingyi

Assets

Patheingyi has significant growth potential due to its position on the main thoroughfare to the coast, and the beach toward the west. Expectations for national and international tourism are high.

Issues

Seasonal flooding lasting up to three months is the main issue, which has been significantly worse since 2004. As a result, people who have to stay in shelters cannot work and are highly dependent on charity. The pylons of two bridges close together are considered the cause of the increased siltation along with sand mining, which is at such a scale as to alter the course of the river.

People use the river as a garbage chute, partly in ignorance and partly through lack of opportunities for proper disposal. Drinking water is almost entirely from wells.

Decline of fisheries is a concern, and the blame is usually shifted to other villages or to fishers on the other side of the river taking illegally or using equipment considered too heavy. Government enforcement of regulations is lax and under resourced.

Values

The river is of immense value for transportation, irrigation, and fish.

Development trends in Patheingyi

Since 2004, floods have become more frequent, longer lasting, and deeper. The worsened floods are thought to be caused by the disappearance of forests upstream, while siltation is increasing as huge quantities of sand are mined for large-scale construction in Patheingyi.

A significant decline in fish stocks is the result of factors such as overfishing and heavy equipment, but also the build-up of barriers from deposited sand and debris in the wet season. This might explain the particular decline in saltwater fish.

Labutta

Assets

Labutta was hit very hard by Cyclone Nargis in 2008. The economy is based mainly on agriculture (rice) and aquaculture (fish ponds).

Issues

Climate change and the risk of cyclones are still priority issues in this region, but there is little that villages can do. Salt intrusion to rice paddies is seen as evidence of rising sea levels associated with climate change and the clearance of coastal mangroves.

Fisheries are very important, but the closed season means there are long periods of no income. As a result, fishers increasingly have to go to sea.

Fish ponds are important for food security and economic development, but most are owned by foreign investors (particularly Thailand and Singapore) who bring in their own labour. Little benefit flows back to the local communities left to deal with the resulting pollution and erosion.

Values

Risk management, navigation, fishing, and irrigation are key values in river use by the villagers.

Development trends in Labutta

Fishing is still a major industry, but fishers are caught in a poverty trap, as they are restricted by law as to where and when they can fish. During the off-season they borrow money, often from the people to whom they sell the fish (probably at a discount), at high interest rates. Microfinancing might assist fishers to escape this poverty trap. Fishers have not seen several species of fish since Cyclone Nargis.

Salination in the paddy fields is reducing crop yields at an ever-increasing rate.

Yangon, Insein Township

Assets

The community provided accommodation for former labourers during construction of a bridge. They were supposed to leave after the bridge was finished, but never did.

Issues

Sanitation and overall living conditions are poor, as houses do not have toilets and are prone to flooding. It is unclear who is responsible for maintenance or upkeep. A dry walkway has been co-funded by the inhabitants and a political party.

Values

The inhabitants want to be sure about their place of living (as they risk being evicted) and want to improve their living conditions and livelihoods. They hope for better jobs and further education for their children, so they can take charge of their lives and move to less flood-prone areas.

Development trends in Yangon, Insein

This township illustrates planning issues along the riverbanks that are seen in other urban centres along the river, when a township is in close proximity to a booming large city. People live in a gray zone between being squatters and having some official rights to their homes.

Conclusions for Ayeyarwady Delta HEZ

The Ayeyarwady Delta HEZ is a flood- and cyclone-prone region. Communities attribute recent increased seasonal flooding and salinity to climate change and locally to causes such as deforestation and erosion.

Communities understand processes such as erosion and sedimentation and can relate these to events and likely causal factors. Seasonal flooding is an accepted part of their lives, and they are far more concerned about the effect on their livelihoods, their earning capacity, and the educational opportunities for their children, than about risk reduction or more technical hard measures of control. With job opportunities, economic development, law enforcement, microcredit, and education they contend that they can take care of themselves.

As in other HEZs, recurring issues are solid waste, sanitation, and drinking water.

10.5 Conclusions

This section presents conclusions in four parts. Firstly, basin-wide status and trends are summarised in terms of flooding, erosion, sedimentation, water quality, fisheries, solid waste, and cultural differences. Next, opportunities and tradeoffs are described for each HEZ. Overall conclusions are then drawn in Section 8.4.3, which is followed by specific conclusions that relate to the methodological approach used in this work.

10.5.1 Basin-wide status and trends

The status and trends of the Ayeyarwady Basin, according to the communities consulted in 32 villages across 14 townships, may be summarised as:

Flooding

- Flash floods, particularly in mountainous areas, are more frequent and extreme; reported causes include climate change, deforestation, and river sedimentation.
- Seasonal floods are higher and last longer; farming operations are on hold for a longer period creating economic stress, which needs to be addressed by adaptation and children's education is disrupted.

Erosion

- Good agricultural land and infrastructure are disappearing or at risk, sometimes resulting in disputes over accountability and land ownership.
- Research is needed to validate perceived causes.
- Increased turbidity reduces water quality for drinking and irrigation.
- People understand the relationship between deforestation and erosion, and hence the concept of the larger river system.
- More awareness is required on local hydrodynamics to foresee that outer river bends erode more rapidly than inner bends.
- Soil conservation measures are needed in upland areas to reduce erosion and loss of water holding capacity.

Sedimentation

- Navigation for transportation of goods and for reaching agricultural lands are severely impacted by sedimentation.
- Villagers relate sedimentation to flooding as riverbeds rise and drainage systems block.

- Sedimentation also creates new land, some very fertile; the 'walking islands' around Magway cause disputes among villages vying to cultivate the new land.
- Where rocks and gravel are deposited, they destroy good agricultural land.
- Sedimentation makes the river water turbid and spoils drinking water quality.
- Local communities well understand the relationship between erosion and sedimentation.
- The meandering quality of the river is less well understood, resulting in unwise settlements on unstable riverbanks.

Water quality

- Water quality is generally decreasing, particularly during the rainy season.
- In the Upper Ayeyarwady HEZ, people use mainly river and groundwater for drinking and domestic use; in the Middle and Lower Ayeyarwady HEZs people use the river water and tubewells, where the quality is poor in the rainy season and people depend on bottled water, rainwater, or their neighbours.
- In the Lower Delta, people use groundwater as the river is too salty, and in the Upper Delta they use river water as the groundwater is too deep.
- Mercury and cyanide from gold mining, industrial waste, agricultural pesticides, and solid waste including plastics, all contribute to the declining river ecology and water quality.
- The river has a sanitary function for many villagers.
- In many villages people use special traditional clay pots, seeds, and crystals to 'clean' the water.
- The ecological condition of the river is perceived only indirectly; fishers worry about the decrease in biodiversity and bio volume, while in the Upper Ayeyarwady HEZ villagers describe the river as 'dead', which they attribute to gold mining.

Fisheries

- There is a general decline in traditional fish catches, coinciding with the increase in illegal electrical battery fishing, the use of chemicals, and fishing in the spawning season.
- Conflicts occur among fishers on fishing methods and zoning, and a perceived lack of law enforcement.
- High investment costs for equipment, boats, and licences combined with high loan interest rates create a poverty trap for many fishers.

Solid waste

- Garbage in the river is on the rise, and is increasingly composed of plastic and other non-degradable waste; this blocks irrigation canals, deters bathing, domestic use and drinking, and discourages tourism.
- Much of the waste problem reflects a lack of awareness, absence of waste management programs, and lack of appropriate regulations.

10.5.2 Opportunities and tradeoffs

Upper Ayeyarwady HEZ

Myitkyina Township

- The area around Myitkyina is very picturesque with significant touristic potential, which would be greatly enhanced if the river was returned to a reasonably unpolluted natural state.
- Reducing environmental pollution from gold mining would decrease the disruption of river morphology and could reduce adverse social impacts, such as working conditions and substance abuse. This would require working with stakeholders and the industry on awareness raising, capacity building, exchange of technical know-how, and the introduction of best practices on waste treatment.
- The increasing demand for hydropower needs the development of enhancements or alternatives by incorporating stakeholders, national, regional, and local interests and by conforming to international standards regarding environmental protection.
- Improving solid waste management.
- Improving protective measures against bank erosion.
- Social cost-benefit analyses are needed, with respect to:

- potential for tourism under the current condition versus improved conditions, such as peace, prosperity, and reduced pollution;
- the future of the gold mining industry under the current condition, versus those that meet international standards on sustainability and socio-economic impacts; and
- extraction of hydropower under the current condition, versus an all-inclusive, more sustainable approach.

Conclusions for the Upper Ayeyarwady HEZ — The first priority is a strengthening of the peace process in the Upper Ayeyarwady; opportunities for the region are then plentiful, as it is beautiful and extremely rich in natural resources. Tradeoffs relate to how the natural resources are protected, reinforced, and used, and to how the people of the north are involved and share in the benefits. There are great potential gains, some already in the short term, in the sectors of tourism, gold mining, and hydropower.

Chindwin HEZ

Kalay Township

- Raise awareness of governors and villagers on the effects of deforestation and climate change, and how to prepare for flash floods.
- Base mitigation measures on the scientific understanding of the role that climate change and deforestation play in flash floods.
- Improve government efficiency in providing relief during and following natural disasters.
- Investigate the reasons for the decline of drinking water quality and formulate alternative supply options.
- Raise awareness of the effects of erosion and sedimentation on livelihoods, farmlands, and irrigation systems, and how to better adapt.
- Develop a waste collection system and raise awareness among villagers.

Monywa Township

- Raise awareness about the causes of flooding and erosion, and how to better adapt.
- Protect against bank erosion for short-term relief.
- Improve solid waste management and follow up with proper law enforcement.

Conclusions for the Chindwin HEZ – The Chindwin HEZ is a mountainous area, vulnerable to flash floods, erosion, and sedimentation. In the Township of Monywa bank erosion and sedimentation are the main issues. Resilience could be improved by raising awareness, supporting preparedness training, mitigating causes and promoting good governance. Tradeoffs are defined by the short-, medium-, and long-term benefits.

Middle Ayeyarwady HEZ

Singu Township

- Improve drinking water quality.
- Improve irrigation and water retention during the dry season, with potential for installation of a regulating sluice at the inlet near Khul Lel.
- Improve solid waste management.

Mandalay Township

- Raise awareness of the impacts of ever-changing river morphology and how to deal with erosion (landowners, farmers, villagers living near the banks of the river) and sedimentation (fishers, boat owners).
- Investigate the effects of sand mining and dredging on river morphology.
- Investigate the status of local fisheries, identify those using battery fishing, and offer alternatives or create restricted zones, as well as improve law enforcement.
- Improve solid waste management.
- Improve microfinance schemes to diversify village-level business.

Conclusions for the Middle Ayeyarwady HEZ – The opportunities and tradeoffs in the different townships of this HEZ are so diverse that general conclusions cannot be drawn. Refer to the above sections on individual townships.

Lower Ayeyarwady HEZ

Pakokku Township

- Design a more affordable system for river transportation in Pakokku for use during floods.
- Improve spatial planning and planning rules under the 'disaster code' to enable people to relocate to less flood-prone areas, and that the government achieves this in a transparent and fair way.
- Improve livelihoods by capacity building with regard to good farming practices, irrigation options, and crop diversification.
- Increase community involvement and good transparent governance, enabling villagers to be active participants and agents of change.
- Improve monitoring, data management, and modelling so that local people are warned of potentially disastrous floods and can prepare themselves.

Nyaung U Township

- In the long term, relocate the village or provide protection by dams to deal with flash floods. In the short term, support the community to collaborate in the development and maintenance of the dry wadi as an emergency canal.
- Increase waste collection points and raise awareness of solid waste management.

Magway Township

- Provide more information about the monitored quality of the water for domestic and drinking water use.
- Raise awareness of the effects of littering, and consider the need for regulation.
- Enforce the law on illegal fishing, but also explore other job opportunities, given there are too many fishers.
- Develop and enforce codes of practice for gold mining, and sand and gravel extraction to reduce downstream sedimentation.
- Clarify and decide on land ownership with respect to alluvial islands.

Pyay Township

- Introduce water quality monitoring for industries discharging into the river.
- Improve solid waste management.
- Address relocation and land ownership issues.
- Investigate microcredit to enable improved livelihoods on the river.

Conclusions for Lower Ayeyarwady HEZ – Much can be achieved by investing in villager participation and in strengthening their resilience. A combination of hard flood protection measures, shelters, better data, monitoring and warning systems, and spatial planning (prohibition to build in dangerous areas) can reduce the impact of typhoons and flash flooding. The inconveniences of annual flooding can be mitigated by involving people in decision-making and helping them improve their livelihoods so they are better able to fend for themselves.

Ayeyarwady Delta HEZ

Hinthada Township

- Investigate the role, if any, of trees on falling groundwater levels, and provide the community with reliable information on arsenic levels.

Nyaungdon Township

- Improve and expand the local council's program to collect waste.
- Alter the regime of the Mezali sluices so that farmers also have fresh water.
- Increase the responsibility of villages and township upstream with regard to protecting the river; the villagers in Nyaungdon will maintain the system if the regional/national government take responsibility for the budgets, law enforcement, and awareness raising.
- Patheingyi Township
- Build a new bridge in view of the rapid growth of Patheingyi.
- Improve the solid waste management program with the help of local communities.
- Decrease the amount of fish caught and illegal fishing by improving law enforcement by the Department of Fisheries, channelising certain river sections, and removing blockages in the river system.
- Regulate sand mining, which is changing the course of the river and causing erosion.

- Influence perceptions that development of the coastline is more important than local erosion and flooding.
- Improve livelihoods by introducing competition to provide cheaper and better fertilisers.
- Labutta Township
- Enable people to determine equitable fishing rights between fishing associations, including monitoring of outcomes.
- Address the poverty gap among fishers by introducing microcredit.
- Enforce existing laws for solid waste management, as well as establish and enforce new laws to address regulatory deficiencies.
- Yangon, Insein Township
- Establish residential rights for the people still there, so they may decide whether to stay and improve their living conditions or to move away.

Conclusions for Ayeyarwady Delta HEZ – Clear trends are the decline in fish (especially saltwater species) and the increase in flooding over the last decade. In this HEZ, people would like to be more in charge of their destinies, whether they are improving their livelihoods or their living conditions. Fishers would be more enabled in caring for themselves and their families through improved collaborations with officials and money lenders.

10.5.3 Overall conclusions

People remain resilient and adaptive

Throughout the entire Ayeyarwady Basin, people show resilience and adaptiveness in coping with the downsides of living close to the river. In countries like the Netherlands, annual flooding would lead to demand for extensive government intervention, but this is not the case in the Ayeyarwady Basin. Local people expressed a desire to improve their livelihoods in order to better care for themselves and their families. However, this resilience should not be taken for granted in the light of growing socio-economic pressures and increasing stresses on the natural systems, upon which these local communities depend.

People want to be better informed

People are seeking information and knowledge. They are very eager to understand the forces operating in the Ayeyarwady Basin, whether man-made or natural. When discussing flood risk management, they expressed a need for practical information, like weather forecasts, flood predictions and routes to shelters. When deciding on measures applicable to the mid- or long-term, they want to be informed about the available alternatives, including best practice. People would like to better understand the risks of declining water quality and the implications of current poor management of solid waste. They also want to know what they can do themselves and what should be done by others, including how to address perceived sources of pollution like industry or mining. In addition, they expressed a desire to contribute information to a broader system of data collection and interpretation through the conduct of grassroots-level monitoring.

People want good governance

Current systems of governance were perceived as inadequate. Aspects of governance perceived as having deficiencies extended to, inter alia, data management, capacity development, water law, water policy improvement, rules and regulations, and finance and investment priorities.

People have significant concerns about water quality

People expressed concerns about water quality issues, whether it is the 'dead river' in the north or the steep decline of fish in the south. They put great value on clean river water for drinking, washing, bathing and irrigation, as well as for a healthy ecosystem. The latter, for example, was expressed by their concern about the steep decline in fish or mangroves. They blame several sources for the decline in water quality, and requested more regulation and law enforcement for tackling these issues.

People have concerns about hard infrastructure

People do understand the workings of the Ayeyarwady Basin; they can pinpoint the causes of erosion and sedimentation upstream, and relate that to their downstream problems. These causes might range from hydropower dams in the north, to bridges and even hard flood protection measures in the south. A more holistic, inclusive planning process is needed that much more adequately accounts for their perspectives.

10.5.4 Conclusions on methodology

The 3D participatory modelling methodology proved a suitable method for research of this kind. This was particularly so for the first phase of the work, which involved asking informants to rank hot topics by placing a limited number of stickers on pictures of these hot topics. This simple technique was an effective conversation starter, and well suited to people with little formal education.

The 3D model was a highly effective tool for communicating the connections and dependencies across the entire basin. However, it is quite cumbersome to transport.

Maps and aerial photos provided excellent reference points, and were easy to transport. These materials need explanation though, and therefore more engagement time. Furthermore, the mapping of locations and experiences is not something that all informants will find straightforward. Separating local experts, including farmers and local inhabitants, from the rest of the group can allow for more in-depth map-based conversations, while the remainder are assisted with questionnaire completion.

The meta-analysis of this methodology is considered a valuable technique in that it has given a voice to the people surveyed. In doing so, it has tapped into local knowledge and experience, like traditional ways of improving the quality of water for drinking by using crystals or nuts. It may be argued that it has extended the licence to operate of those responsible for future developments along the Ayeyarwady on the basis that people tend to be more supportive of developments if they understand the issues and options, and see the bigger picture. This is especially so when they perceive that their points of view and interests have been heard and taken seriously. The resultant database from this work will inform the design and implementation of future stakeholder engagement, as a core requirement of projects with most donors and financial institutes. Regular updating of the database will add new insights about local perspectives and interests. Ongoing engagement and interactive dialogue with local communities of the Ayeyarwady Basin is essential.

11 CONCLUSIONS

This final chapter summarises the lessons learned from the *Ayeyarwady State of the Basin Assessment* (SOBA 2017) process and outlines the key messages for future river basin planning activities.

11.1 Sustainable Use of Resources

Most SOBA technical reports identified ways to address shortcomings in current monitoring and/or management of the uses of natural resources. These suggestions are a valuable output of the process and an important input to river basin planning activities.

Overall, use of **surface** water resources is modest, with 2% of total annual runoff extracted in the Ayeyarwady Basin. In the Mu Sub-basin, however, there is potential for stress in the dry season, during which time as much as 48% of surface water is extracted. The ecohydrological assessment suggests that current flow alteration and associated threats from river impoundment and fragmentation are already posing significant risks to aquatic ecosystems in parts of the Ayeyarwady Basin. Given plans for many other interventions that are likely to increase ecological risks, it will be important for planning and management to gain an improved understanding of environmental flows and ecological responses and to expand monitoring of water flows, water stores, and climate. To minimise the negative ecological impacts of water resources, development strategies are needed, like environmental flow management and scenario evaluation tools to explore tradeoffs under different development scenarios.

On average, approximately 13% of renewable **groundwater** resources are exploited, with highest usage in the Central Dry Zone at around 33%. To date, hydrogeological mapping is mostly confined to the Central Dry Zone, pointing to the need for more systematic documentation of groundwater status and use across the broader Ayeyarwady Basin. Expansion of groundwater use will require careful planning to ensure sustainability. Groundwater discharge, for instance, contributes significantly to dry season flows, which are essential for livelihoods and ecosystems in the intermittent side and tributary channels in the Central Dry Zone and the main river channel. The institutional and legal framework for groundwater management needs further development and comprehensive implementation.

The **geomorphology** of the Ayeyarwady River is in moderate to good condition, but pressures on the river are increasing and multiplying. Sediment transport is complex. In low-slope areas, most transport occurs in periods of high flows. Recognising the links between land and river are essential to effective management of sediments and the sustainable use of resources in the Ayeyarwady Basin. Mining and forest operations, for instance, influence runoff and sediment delivery to streams. Large

hydropower dams trap **sediments**. Improved monitoring of sediments would help understand channel stability and assist in maintaining navigation channels and in managing the Ayeyarwady Delta.

With respect to **fish** resources, it is suggested that data collection and statistics be separated from responsibilities to set targets for fisheries production. Standardised protocols to collect information and capacities to enable their implementation by the Department of Fisheries should be strengthened. To improve compliance and enforcement with fisheries laws, dedicated provisions could be integrated within the existing legal framework, including higher fines that better reflect adverse impacts and the inclusion of gears that do not currently require a licence. Destructive fishing practices, like using electrofishing or poison, should be prohibited. More detailed studies are urgently needed on the potential impacts of planned hydropower development on fisheries in the Ayeyarwady Basin.

In 2015, 44% of the land area of Myanmar was **forested**, with much of the remaining closed forest in the Upper Ayeyarwady HEZ. Deforestation rates, however, are high. While there is some evidence that recent log export bans helped reduce illegal logging, timber certification is needed to help ensure the long-term sustainable harvesting of teak and other hardwoods in the Ayeyarwady Basin. Additional investment in the timber industry is needed to stimulate the export of value-added wood products rather than unprocessed logs. The Government of Myanmar's *National Forest Master Plan (2002–2031)* aims to maintain 30% of the land area within the permanent forest estate and 10% of the land area within Protected Areas by the year 2030. Given the high dependence of society on ecosystem services and products from forests, a more detailed assessment of the Ayeyarwady Basin would be highly valuable for forest conservation planning. This should take into account the future impacts on forests from the development of roads, hydropower projects, transmission lines, pipelines, and special economic zones.

Myanmar is rich in biodiversity with more than 1,400 mammal, bird, and reptile species. At least 388 fish species are known to occur. Populations of many taxa are in decline. Although a *Management Plan for the Ayeyarwady Dolphin Protected Area* has been prepared to reduce illegal fishing activities, a history of weak enforcement has hindered its effectiveness with the population now in a critical but stable state. Only 50% of KBAs are officially protected. The assessment recommends that the Protected Area network should be expanded to cover at least 80% of the KBAs. Additional biosphere reserves, Ramsar sites, and World Heritage listings could be used to help conserve river and wetland areas that need urgent protection from development pressures.



11.2 Coordination of Strategies and Plans

River basin planning has an important role in horizontal **coordination** of strategic and spatial planning among sectors – in particular, for dealing with interactions among sector plans or policies that impact the condition and use of natural resources. In Myanmar’s federal system, river basin planning can also contribute to vertical coordination by strengthening alignment of state and regional watershed policies and priorities with nationally negotiated strategic objectives for the Ayeyarwady Basin.

River **fisheries**, in many ways, are at the nexus of various impacts and, thus, an integrative measure of river health. Fisheries, for example, are adversely impacted by destructive practices like sand mining, dredging, waste dumping into rivers, and runoff of pollutants from catchment activities. They are also vulnerable to large-scale modification of flows and barriers to migration arising from dam infrastructure. A more detailed assessment of the impacts of land-based and within-river activities on inland capture fisheries is warranted given the high importance of this sector to nutrition and livelihoods.

The **links** between land use and river water quality need to be managed carefully, requiring coordination in planning among agencies in different ministries. Mining and forestry operations, for instance, influence runoff and sediment inputs to streams with impacts on fisheries and navigation uses of rivers. Scenario models or other future-oriented planning tools are needed to explore the potential combined effects of sectoral development strategies and identify synergies and ways to reduce tradeoffs among sectors and places.

River basin planning is also important to the management of floods and reducing the risks of flood disasters. Planning for new human settlements and industry should direct investments into areas outside of high-risk floodplains. Measures to protect particular locations from flooding should take into account the benefits of normal flood pulse for replenishing soils, recharging groundwater, and the productivity of wetlands and fisheries. Cooperation among disaster, land use planning, and water management agencies is key to improving risk management.

11.3 Lessons Learnt About ‘Doing’ Assessments

SOBA 2017 was the first iteration of a recurrent or ongoing process of monitoring and evaluating to inform river basin planning. The assessment had some important limitations that future iterations should address.

First, assessment teams experienced difficulties in obtaining access to existing data. Streamlined data sharing agreements and mechanisms between Hydro-Informatics Centre (HIC) and other government agencies would make the assessment process more straightforward to carry out. Improved **data management** systems could support higher resolution datasets that would allow analysis by HEZs in the Ayeyarwady Basin rather than only conventional state and region categories.

Second, there was high involvement of consultants and experts from outside Myanmar. **Building capacity** of Myanmar nationals to undertake and lead assessment activities would increase ownership of assessments. If also prepared in local languages, it would make the findings more accessible to officials at different levels and to the wider public. Future iterations of SOBA should more actively engage a wider range of stakeholders in the assessment process, not just as targets for communication activities or as sources of data, but also in the definition of assessment criteria and interpretation of the implications of changes in indicators for planning.

Third, there was a lack of **observations or measurements** for many indicators necessary to more accurately assess condition and trends in the Ayeyarwady Basin. Additional monitoring and observation networks are clearly needed, for example, in relation to groundwater stocks and use as well as surface water flows, storage, and climate. Time series for key drivers of resource use are also important to understanding trends and pressures.

Fourth, there was a lack of an explicit **framework** to guide the assessment from the start of the assessment process. A clearer system of organisation would make it easier for reports of different teams to be combined into a coherent analysis and to make sure that critical areas received sufficient attention, such as irrigation in the agriculture sector and hydropower in the energy sector.

Future assessments of condition and trends in natural resource stocks and the drivers and consequences of resource use should build on the experiences of SOBA 2017.

This Ayeyarwady State of the Basin Assessment (SOBA) 2017: Synthesis Report is one of the major knowledge outputs of the Ayeyarwady Integrated River Basin Management (AIRBM) Project prepared by the Hydro-Informatics Centre (HIC). It is designed to inform readers with an interest in natural resource sustainability in the Ayeyarwady Basin. It may be read as a reference document or as a source of information to guide policy and planning decision-making.

SOBA 2017 represents the most comprehensive integrated environmental, social and economic baseline for the Ayeyarwady to date. It takes stock of the status of and historic trends in key characteristics of the Ayeyarwady system, and how the people of Myanmar utilise and benefit from the water and related resources of the Ayeyarwady River and its tributaries.

SOBA 2017 combines rigorous technical assessments with inclusive consultation processes. It will inform the development of an Ayeyarwady Basin Master Plan in-keeping with international best-practice principles for integrated water resources management (IWRM). The work highlights issues, opportunities, risks and uncertainties, and tradeoffs that will need to be addressed in this planning process. Furthermore, SOBA 2017 provides an important baseline against which the impacts of future development pathways may be monitored and assessed.

