SOBA 1.3: WATER POLLUTION SURVEY

AYEYARWADY STATE OF THE BASIN ASSESSMENT (SOBA)

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CSIRO AUSTRALIA AND HYDRONUMERICS

Disclaimer
"The Ayeyarwady State of the Basin Assessment (SOBA) study is conducted within the political boundary of Myanmar, where more than 93% of the Basin is situated."

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LIST OF ABBREVIATION

ADB	Asian Development Bank
ARB	Ayeyarwady River Basin
AIRBM	Ayeyarwady Integrated River Basin Management Project
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BOD	Biological Oxygen Demand
BMP	Basin Master Plan
CFU	Colony forming unit
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
COD	Chemical Oxygen Demand
DISI	Department of Industrial Supervision and Inspection
DoP	Department of Population
EC	Electrical conductivity
DWIR	Directorate of Water Resources and Improvement of River Systems
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIS	Geographic Information System
HEZ	Hydro-ecological Zone
IADS	Integrated Ayeyarwady Delta Survey
IPPS	Industrial Pollution Projection System
IWUMD	Irrigation and Water Utilization Management Department
km	Kilometre
LC_{50}	Lethal concentration, 50%
LD_{50}	Lethal dose, 50%
mg/L	Milligrams per litre
mL	Millilitres
MOALI	Ministry of Agriculture, Livestock and Irrigation
MoI	Ministry of Industry
NBSAP	National Biodiversity Strategy and Action Plan Myanmar
NTU	Nephelometric Turbidity Unit
SAR	Sodium Adsorption Ratio
SOBA	State of the Basin Assessment
TSS	Total suspended solids
US EPA	United States Environmental Protection Agency
WHO	World Health Organisation

EXECUTIVE SUMMARY

Reducing exposure to hazardous chemicals is essential to achieving Myanmar's Sustainable Development Goals (SDGs) for the Ayeyarwady Basin. In addition to substantially reducing the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination (SDG-Target 3.9), pollution control will help to alleviate poverty (SDG 1), improve access to clean water and improve sanitation (SDG 6), promote social justice (SDG 10), build sustainable cities and communities (SDG 11) and protect land and water (SDGs 14 and 15).

This project represents an initial, basin-scale assessment of water pollution within the Ayeyarwady Basin, with specific reference to the industrial, urban, mining and agriculture sectors of land use. There is a lack of reliable information on key parameters related to water pollution within the Ayeyarwady Basin. While this limited the water pollution assessment in some ways, the assessment has established that development in the four key sectors, without safety and protection measures, is likely to produce unacceptable risks to both ecosystem and human health.

In the industrial sector, loads of biological oxygen demand (BOD), total suspended solids (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. The lead load from industry, which presents severe health risks to both humans and ecosystems, was highest in the Middle Ayeyarwady zone (HEZ) 3) and Ayeyarwady Delta (HEZ 5). According to the World Health Organisation (WHO), more than one third of countries, including Myanmar, do not yet have in place legally binding controls on the production, import, export, sale and use of lead paints and this should be considered as the principal chemical of public health concern. The three main toxic industrial chemicals of concern in the Ayeyarwady Basin are ammonia, ethylene glycol and formaldehyde.

The production of industrial raw materials and construction materials are the leading source of pollution in industrial zones in the Chindwin (HEZ 2) and Middle Ayeyarwady (HEZ 3) zones. In the Lower Ayeyarwady (HEZ 4) and the Ayeyarwady Delta (HEZ 5), minerals and petroleum products, clothing and apparel, and food and beverage are the industry sectors which are the largest toxic chemical polluters. The lead load was the highest in the Middle Ayeyarwady and Ayeyarwady Delta. The highest loads of toxic chemicals and metals were identified as being produced in Mandalay, Yangon and Pathien.

Urban sector water pollutants were most prominent in the cities of Yangon (HEZ 5), Mandalay (HEZ 3), Magaway (HEZ 4) and Sagaing (HEZ 2). For drinking water, the acceptable concentration of *E. coli*, or coliform bacteria, is zero units per 100 mL (WHO 2011). This highlights the major health risk of waterborne diseases for those citizens, and particularly children under five, dependent on river water for their drinking or bathing. The poor sewage treatment and waste processing infrastructure within urban centres in the Ayeyarwady Basin are resulting in discharge of high levels of pollutants that harm their receiving waters. People using river water for drinking, bathing and washing of household utensils are exposed to significant risks, as microbial contamination of that water is above the relevant human health guidelines. With the highest population densities, the urban populations of the Middle Ayeyarwady and Ayeyarwady Delta are the most vulnerable to human health issues arising from urban water pollution.

Advanced reduction of wastewater pollution (using treatment plants) is present only in the largest cities of the basin. Excepting a limited sewerage system in Yangon city (in the old business district, and serving 40-50% of that population) there is no systematic collection and treatment of domestic wastewater. Thus, a significant area of the basin is reliant on septic tanks for wastewater treatment, or has negligible or no treatment – where open latrines and discharge of wastewaters into flowing waters is the norm. Most households in formal residential areas have some form of septic tank, but these receive insufficient maintenance, and the extracted sludge is not subjected to adequate treatment. The existing stormwater drainage has not been organised into networks with sufficient placement and capacity to carry monsoon season flows, which often results in severe flooding (itself a pollution source, among its impacts). Residents of informal settlements depend primarily on improvised latrines, and stormwater drains of these areas carry untreated sewage in open channels.

Mining, particularly of gold and jade, is widespread within the Upper Ayeyarwady (HEZ 1) and Chindwin zones of the Ayeyarwady Basin (HEZ 2). There are very few data available on the influences of such activities upon water pollution in the Ayeyarwady Basin, though many villagers have expressed concerns that it may be damaging. Mining activities are broadly responsible for high turbidity and sediment loads in rivers, and generation of wastewater that is discharged to natural waterways. Within the Ayeyarwady Basin, unregulated extraction practices and proliferation of small-scale mining (using ultra low-tech, and environmentally unsound methods) pose high risks to surface water quality. Discharges from mining activities, such those associated with microbial contamination in the Uyu River, also provide localised risks to people using river water for drinking, bathing and cooking. Developing a comprehensive database of mining activities and a monitoring framework regulating environmental and social aspects of mining development is recommended.

Agriculture is an important industry in Myanmar, and is experiencing increased attention regarding the extent to which it impacts upon water quality. Available data indicates that water pollution from agriculture resulted in high levels of microbial contamination in 17 sampled dams in HEZ 3 and HEZ 4, rendering their water unfit for human consumption. Agricultural activities utilise pesticides, and the unsafe use of pesticides leaves rural workers vulnerable to many health risks. They include leukaemia and cancerous tumours, infertility, liver and kidney dysfunction and neurological damage. For ecosystems, pesticide contamination can cause not only problems for their functioning, but can also have negative economic impacts (e.g. through tainting of produce) on potential export revenue. 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. Risks were also identified with aquaculture practices, specifically where low dissolved levels and high nutrients from ponds can result in localised impacts to fish stock and also adverse impacts on other aquatic organisms.

Information gaps presently limit our understanding of human and ecosystem impacts related to water pollution in the Ayeyarwady Basin. Two high priority monitoring activities are:

- For the protection of human health through monitoring and controlling faecal contamination, from the headwaters through to the Ayeyarwady Delta, and particularly where the risk of this pollution is seen to be increasing. To support this, adequate sanitation promotion (e.g. education and training of citizens most at risk; increasing: treatment, maintenance and infrastructure) is strongly recommended to protect both health and the environment. Additionally, we need more information/monitoring for the full assessment of the condition at basin level.
- Pollution arising from lead, arsenic, mercury, and pesticides is among the WHO top seven concerns for public health (where exposure is through drinking water or consumption of food that has been irrigated with contaminated water). Currently, the information base for the Ayeyarwady River Basin (ARB) is not sufficiently robust to explore and prioritise the required strategic and policy instruments to pursue national SDGs in the ARB. There is a need to create a secure and accessible database for current and future monitoring in industrial, agriculture, mining and urban sectors. This would include appropriate capacity building both in data handling and statistical analysis.

1 BACKGROUND AND INTRODUCTION

Running north to south over 2,170 km through Myanmar, the Ayeyarwady River is the country's most important commercial waterway and forms the cultural, economic and environmental backbone for the country. However, water pollution is a growing concern across the ARB, especially due to rapid economic development. This is particularly evident at the local level, where industrial development, mining and agriculture have transformed the landscape resulting in largely unknown and unquantified impacts on water quality.

CSIRO Land and Water and Hydronumerics Pty Ltd, Australia, have been engaged by the Australian Water Partnership (AWP) to undertake a package of works under project 360201.07 *Ayeyarwady basin water pollution survey.* A rapid assessment of polluting activities (considering economic, geospatial and hydrological aspects) of four key sectors - manufacturing, mining, agriculture and urban centres - was undertaken to characterise the nature and extent of surface water pollution in the ARB.

1.1 Project context

The heath and sustainability of the ARB are critically important for Myanmar. In order for the Government of the Republic of the Union of Myanmar (Government of Myanmar) to develop the institutions and tools needed to make informed decisions about the management of water resources, the Government of Myanmar received a USD $100 million loan from the World Bank to deliver the Ayeyarwady Integrated River Basin Management Project (AIRBMP). The project will contribute to the development of integrated river basin management through supporting basin development planning and institutional development, the development of monitoring and information systems, and the enhancement of riverine navigation.

1.1.1 *Project linkages: AIRBMP, SOBA and AWP activities*

The AIRBMP has five project elements, including developing State of the Basin Assessment (SOBA), a Basin Development Scoping Study, Stakeholder Engagement Platform, the development of a basin wide Decision Support System and Scenario Assessment. These activates will culminate in the delivery of a Basin Master Plan (BMP), which will provide a phased investment and prioritisation program for basin development.

In addition to AWP outputs, six (6) technical packages have been developed by the AIRBMP Project Management Unit (Myanmar) to deliver the SOBA report. Figure 1 describes the linkages between the Water Pollution Assessment (Activity 3) and other AWP activities, namely: *Data audit* [1] and *Surface water baseline assessment* (SOURCE Modelling) [2], as well as the applicable SOBA works packages - which are highlighted in blue in Figure 1.

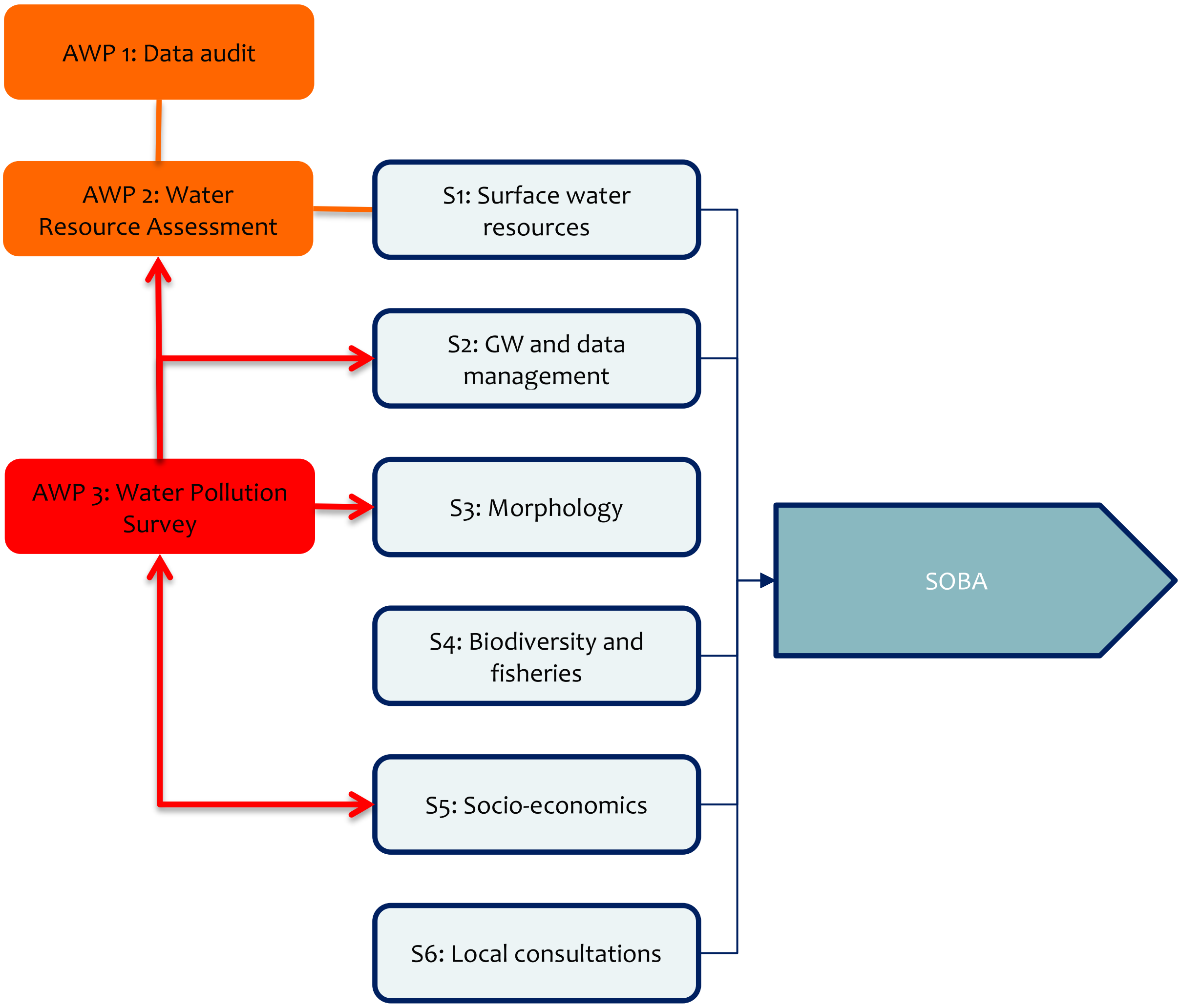

Figure 1 – Project Linkages for the AWP Water Pollution Assessment Project.
(This project is shown in red, and associated SOBA packages are shown in blue)

1.1.2 Activity objectives

Water pollution is of growing concern for water resources and people in the ARB, and ongoing development of the four key sectors continue to degrade water quality. Despite this, the magnitude and extent of pollution, and the impact on downstream environments is poorly understood. Water pollution monitoring across the basin is not systematic, often ad hoc, or absent; there is limited (but improving) spatio-temporal coverage of monitoring in major industrial zones.

To support the needs of the international partners, the objectives of the activity are to:

1) Contribute to a credible baseline analysis of pollution characteristics and issues in the basin;
2) Contribute a database on pollution sources and loading to the broader Water Information System for Data Management (WISDM); and
3) Outline how this pollutant database can be linked to other SOBA/AIRBM packages, particularly the AWP supported Activity 2 (SOBA 1.2), *surface water resources baseline assessment.*

1.2 Sectoral development in Myanmar

Myanmar is one of Asia's fastest-growing economies. Wide-ranging economic, social and governance reforms are promoting changes for both private and public sectors. Fundamentally important to national prosperity is the health and sustainability of the ARB. This basin houses some 66% of the population, six of the country's largest and most populous cities, large swathes of agricultural land, industrial zones, mining concessions, important biodiversity precincts (Simmance, 2013) and areas of international ecological significance.

Forecasted economic growth of 7.1 % for the three years from fiscal year 2017 (World Bank, 2016) is underpinned by continued agricultural intensification and expansion, infrastructure investment and expansion in the fast-moving markets for consumer goods, manufacturing, and food and beverage production. Unseasonal, or extreme weather conditions routinely affect economic prosperity across the ARB, particularly with the reliance on subsistence agriculture and underdeveloped supply chains attending to that sector (Asian Regional Integration Centre, 2017, Raitzer et al., 2015a). *El Nino* conditions in the central dry zone and unseasonable monsoon conditions in the delta regions negatively affect economic prosperity for similar reasons. However, they can be more acutely expressed in the remote or regional areas of the basin that have more limited market access.

The importance of each sector to the whole country can be examined through the national account, as shown in Figure 2. Agriculture contributed 26% to the national GDP, industrial sectors some 34% and services 38 % (including transport, communication and other soft services) [2016 figures: courtesy of the Central Statistical Organisation / Ministry of Planning and Finance (Government of Myanmar, 2016a)].

Contrary to the conventional understanding of the heavy industrial sector, mining (included in the 'Industry' sector) contributes only 1.3% to Myanmar's GDP. It is however, unclear how much of the economic activity associated with the mining sector remains off the national balance sheet, or is otherwise accounted for in processing, manufacturing (example, gem polishing) or in under other classifications figures (Government of Myanmar, 2016a).

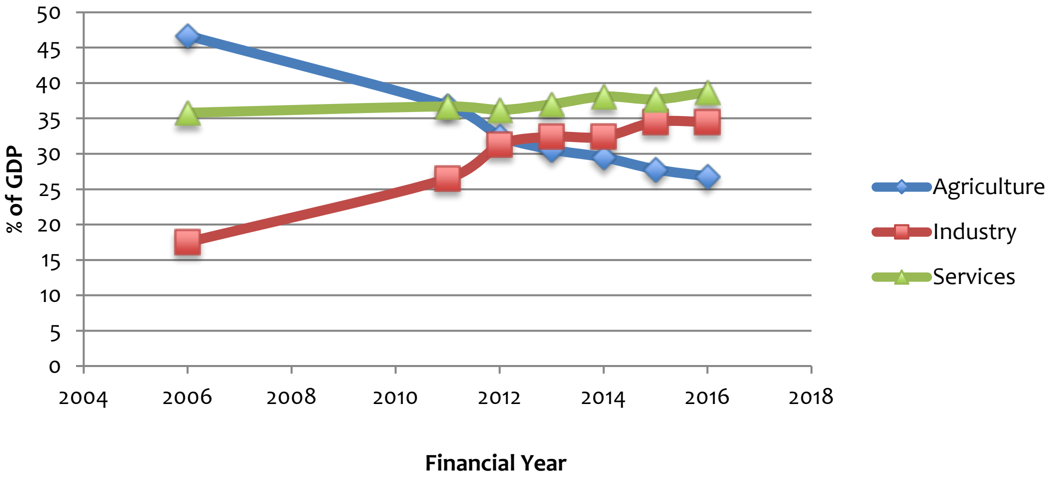

Figure 2 – Share of GDP at Current prices: Sector-wise break-down.
(Government of Myanmar 2016a)

More interesting to the sector-wise pollution assessment are the structural shifts that have occurred since the early 2000s. Myanmar's economy has historically been dominated by agriculture, and even as recently as 2005-06, agricultural output comprised 46.7% of GDP as compared to industry (17.5%), which includes energy, mining, processing and manufacturing, electrical power generation and construction. We observe in Figure 2 a rapid, then sustained steady decline in relative agricultural production, with the ~20% decline almost entirely matched by growth in industry over the same period. Figure 2 also demonstrates that services (i.e., transport, communications, finance, social and administrative services and trade) remained relatively stable over the same period.

Such changes have profound implications for local and regional water quality status. Moving from a predominantly low-tech, farming economy to one with intensive, urbanised processing and manufacturing mandates a shift from seasonal, low-to-medium intensity economic activities to high intensity, urban and peri-urban production year-round. This, in turn, changes contaminant types - from seasonally applied herbicides and pesticides to inorganic liquid and solid waste, heavy metals and toxicants exported from factories and industrial operations. Along with the shift in economic output is continued urbanisation of Myanmar's population, with increased population density, particularly in the industrial zones established throughout the ARB. The urban population across Myanmar grew from representing 24.8% in 1983 to 29.6% in 2014 (DoP, 2016).

We note that national statistics on urbanisation and migration are useful in highlighting longitudinal trends, but that they should be interpreted with some consideration to the contextual evidence supporting the results; for example changes in fertility and mortality rates, governance structures and regional reporting anomalies. The results, however, do provide evidence that urban areas within the industrial corridor of the ARB are experiencing increased urbanisation, which is relevant in the context of ongoing pollution management.

The following sections detail the sectoral development in the context of existing or emerging water quality risks to the ARB. Where possible, a high-level spatial assessment of the impacts to water quality is provided. There are a range of micro, and macro-economic factors that impact on the national accounts that are not considered in this report. The % GDP values reported in Figure 2 should not be considered in isolation, and should be explored with supporting contextual information. For example, despite a relative 50% contraction in agricultural contributions between 2005 and 2016, the total area under irrigation (irrigated and 'protected') increased over the same period and the total area sown (across all crops) increased by 12% (Government of Myanmar, 2016a). This suggests that water quality impacts are being expressed across a larger footprint. This may be attributed to lower farm-gate sales, increased international trade barriers and tariffs, acute environmental impacts, redundancies in invested capitals and disruptions to the domestic supply chain.

1.2.1 Industry sector

Myanmar is experiencing rapid changes in its economic structure, from a predominantly rural and agrarian society, to an urban, industrial economy (See for example the contraction in the agricultural sector described in Figure 2). Irrespective of the sector-wise contribution to GDP, the ARB remains of critical importance to the national economy. This section establishes the industrial framework and provides a high-level introduction to the industrial sectors in both Myanmar and the ARB. As with many other economic sectors in Myanmar (and as observed by counterpart studies), the lack of sub-national data is somewhat limiting for the success of this type of study. However, as detailed in the results section of this report, an innovative coefficient-based methodology has been applied to known industrial sectors in the ARB to estimate pollution hot-spots.

The industrial policy for Myanmar is revised at regular intervals by the Ministry of Industry (MOI) and it details the expected growth rates for each industrial sector, policy development for industrial zones and outlines current and future industrial opportunities for the Union. The current (MOI, 2016) policy sets down modest expectation for industrial sector growth to 2030, setting the target at 37%, only slightly higher than the 205-16 FY results of 34.5% (Government of Myanmar, 2016a; MOI, 2016).

The MOI (2016) Industrial Policy states Myanmar has >45,000 industrial operations, complemented by >19,000 cottage industries. Information provided by the Department of Industrial Supervision and Inspection (DISI) report indicates that 6,388 industrial operations exist within the major industrial centres of the ARB, employing some 213,900 people (out of an estimated population of 7.3 million in the greater city areas). Considering the population density, employment figures and reported industrial operations across the country, these figures appear considerably low, especially considering this includes some of the special economic zones – the majority of those in Myanmar being located in the ARB.

The Asian Development Bank (ADB) reports that approximately 61% of all manufacturing in Myanmar is devoted to food products (ADB, 2017). This figure conflicts somewhat with the DISI figures provided to this project, which suggest that only 24 and 15% of industrial operations in Yangon and Mandalay, respectively, are associated with food production.

Chapter 2, Section 2.1 details the methods used to estimate hot-spots of industrial pollution in the ARB. The results are based on a preliminary industrial classification provided by the Government of Myanmar, and can be used to scale pollution estimates across the country in future studies.

1.2.2 *Urban sector*

According to 2014 Government of Myanmar census data, Myanmar's population increased 46% between 1983 and 2014, but grew only at of 0.89% per annum between 2003 and 2014, making it one of the lowest annual growth rates in Southeast Asia. Further, 29.6% of the population were classified as living in urban areas in compared to 24.8% in 1983, suggesting that contrary to popular belief, the population of Myanmar remains predominantly rural (DoP, 2016). Myanmar stands out against other countries in Southeast Asia with its low life expectancy, high infant mortality rate and high incidence of waterborne disease in the urban sector.

Despite having the second lowest rate of urbanisation in all Southeast Asia after Cambodia (DoP, 2016), Yangon, Mandalay and Nay Pyi Taw (cities within the ARB) have densely populated, poorly serviced urban areas that have experienced positive migration in recent years. This is highlighted by figures from the city of Mandalay, which suggest that only 10% of the urban population receives piped, potable water and the majority of the 1500 industrial operations under the jurisdiction of the MCDC do not treat industrial wastewater, discharging it into adjacent waterways. A similar figure is floated in the urban areas of Yangon, where it is estimated only 15 – 20 % of the total population is connected to the sewer network, however; this is set to change in the future with large foreign-aid projects funding continued expansion of the sewerage network. Chapter 3 outlines the case studies undertaken in the urban sector as well as routine water quality samples assessed against relevant international standards.

1.2.3 *Mining sector*

Myanmar has long been recognised for its extensive deposits of tin, tungsten, copper, gold, silver, zinc, lead, jade, and other gemstones (Win and Myint 1998; Gardiner et al., 2014). The mining industry is currently small: accounting for less than 2% of Myanmar's GDP (Government of Myanmar, 2016a) and produces small amounts of copper, gold, lead, nickel, tin, tungsten and zinc (Fong-Sam, 2014; Gardiner et al., 2014). Figure 3 shows a map of primary metal areas and major mines in Myanmar after Gardiner et al., (2014).

The mining industry has become one of the country's key sectors for economic development, attracting considerable foreign investment (ADB, 2012). Sector-wide development has been attended by a proliferation of Artisanal and Small-Scale Mining (ASM). ASM operations are generally characterised by small groups of miners using ultra low-tech, and environmentally unsound methods to extract minerals and other materials at various scales. These operations are virtually impossible to quantify, other than to observe that such operations: routinely occur in the footprint of the regulated, larger mining operations, and are widespread and pervasive (Smith, 2007). Unregulated mines often take waste from the mines, re-processing the waste to extract remaining target materials, using unsafe and rudimentary processes.

The impact of the proliferation of the unregulated mining sectors has led to an increase in environmental degradation through habitat loss, reduction in water quality and land-use change along the main branches of the Ayeyarwady. Land is indiscriminately cleared for hydraulic and pit mining, and the natural flow regimes of the river, as well as environmental flows, experience severe changes (Simmance, 2013). Major sources of erosion/sediment loading at mining sites can include open pit areas, heap and dump leaches, waste rock and overburden piles, tailings piles and dams, haul roads and access roads, ore stockpiles, vehicle and equipment maintenance areas, exploration areas, and reclamation areas. A further concern is that exposed materials from mining operations (mine workings, wastes, contaminated soils, etc.) may contribute sediments with chemical pollutants, principally heavy metals. Hydraulic mining releases large quantities of sediment that can impact surface water for several miles downstream of the mining activity. Metals are particularly problematic because they do not break down in the environment. They settle to the bottom and persist in the stream for long periods of time, providing a long-term source of contamination to the aquatic insects that live there, and the fish that feed on them. These contaminants enter river systems, and the impacts on food security and water pollution are acutely evident in many downstream- areas associated with mining operations in the ARB (Burma Environmental Working Group, 2011).

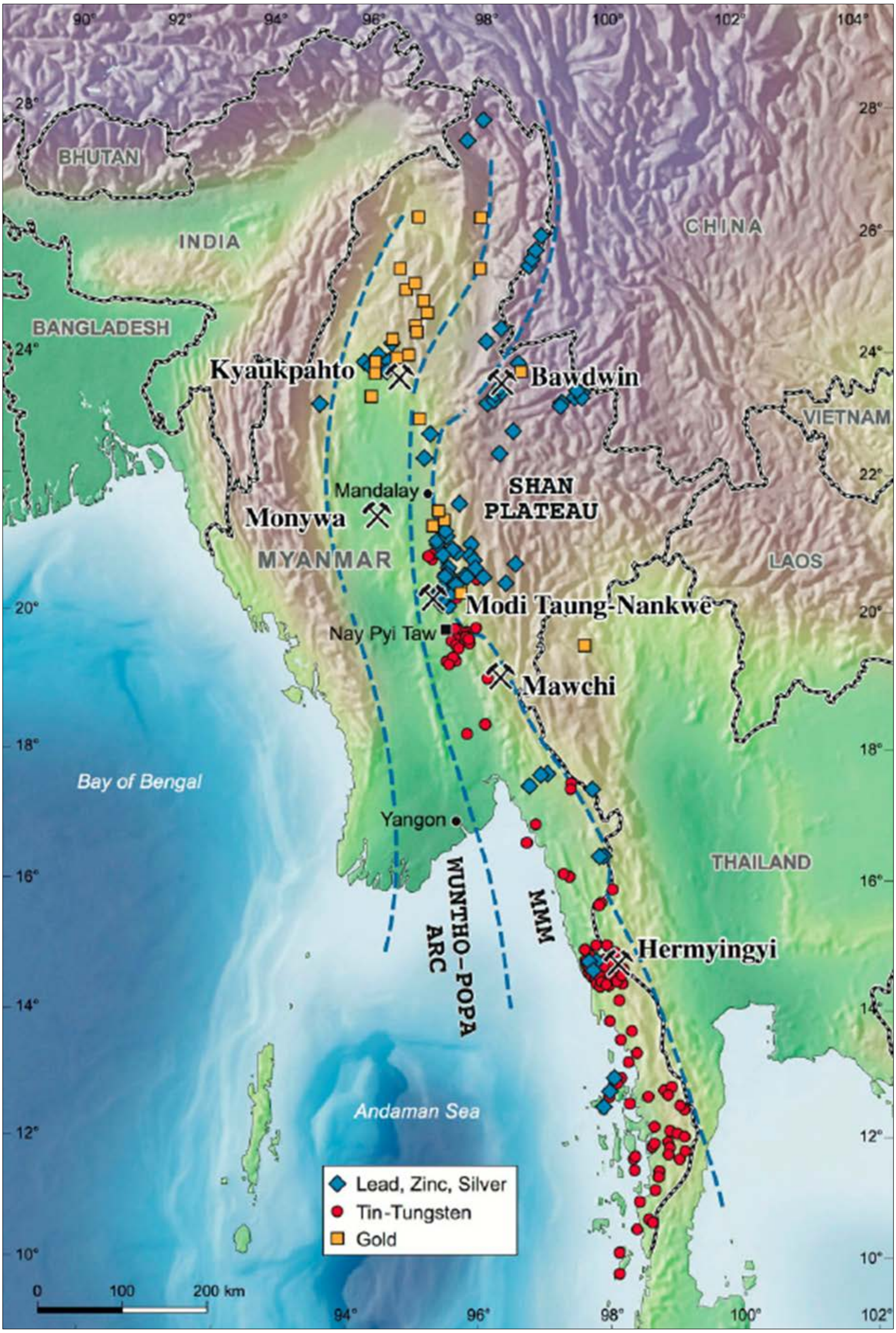

Figure 3 – Major mine locations in Myanmar.
(Gardiner et al., 2014)

1.2.4 *Agriculture sector*

Myanmar has developed as an agrarian society, and both within the ARB, and at the national level, agriculture has been fundamental for the Myanmar economy. Approximately 67% of the population live in rural areas, and agricultural sectors employ about 56 % of workers there, and up to 42% of employment in the urban areas (Government of Myanmar 2016b). Agriculture can also serve for future economic development. Myanmar's three principal agro-ecological zones, viz. the delta coastal zone, the central dry zone and the hilly, upper regions, enjoy a diversified, mature agricultural landscape. Agricultural production and population are largely concentrated in the central dry, delta and coastal zones. Monsoon (rain-fed) paddy rice dominates agricultural production, accounting for over 43% of agricultural output (FAO, 2017), but farming systems are much more diversified than what was commonly assumed. Myanmar is the second largest exporter of beans and pulses after Canada (World Bank, 2016); it has experienced strong growth in the production of: cotton; pulses; maize; fruits and vegetables; sunflower; meat; poultry, and fish. Farms across the country are routinely double cropped, with farmers generally growing a rice crop in the humid, rainy season, and a cereal or pulse crop in the dry, cool months. In the ARB central dry zone, irrigation is required to supplement the second crop's water requirement.

There were modest increases in total planted areas across the country between 2000 and 2016, from ~ 6,000,000 ha to 6,900,000 (Government of Myanmar, 2016a). However, the Asian Development Bank reports that there is capacity to double the area of agricultural land, and with access to plentiful labour, adequate water resources and powerhouse regional markets, agriculture can continue to underpin the country's economic expansion.

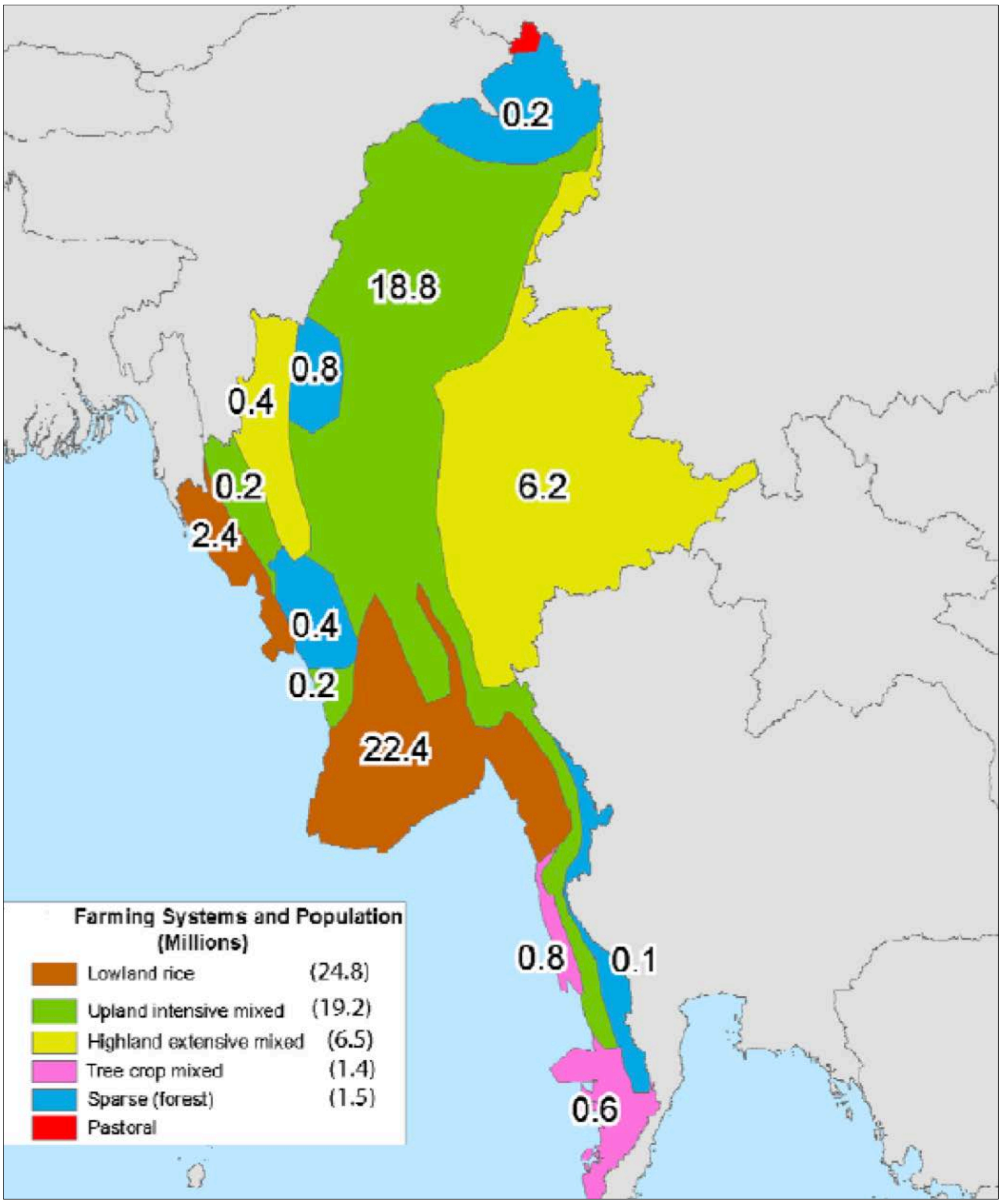

Figure 4 – Distribution of major farming systems in Myanmar.
(Source: *Raitzer et al., 2015b*)

Access to sub-regional farming data

Without access to data on crop production or cropping intensity in the ARB, estimation of the nature, extent and temporal pattern of pollution associated with agricultural production is highly complex. Other studies have estimated that approximately 60% of the agricultural land of Myanmar is located within the ARB, and assuming farming practices within the ARB are consistent with those outside of the ARB, we could infer production techniques, water demand and farming input use according to available national data. However, there is a large gap in the availability of data regarding: spatially disaggregated yields, capital and labour inputs, and basic crop husbandry.

The complexities are further illustrated by Figure 5, which shows the differing pesticide import figures provided by the Department of Statistics (blue) and the Ministry for Agriculture, Livestock and Industry (MOALI, in green). The graph shows that there is between a 50% and 90% difference in the recorded, aggregate, pesticide import figures provided by the two organisations, as well as some data appearing somewhat erroneous (i.e., 264,000 t reported to be imported in 2000-01 by the Government of Myanmar).

The ADB (2012) reported that statistical uncertainties generally hamper accurate assessment, but (for rice and other agricultural outputs): 'severely impedes planning of effective policy support and sharing of accurate market intelligence'. That there is little-to-no agricultural extension provided across the entire country (Simmance, 2013), and virtually no reporting of specific planting schedules across the regions, it is virtually impossible to spatially disaggregate the chemical import data[1].

Sub-regional data would also be useful for estimating pollution impacts of meat and livestock industries across the ARB. Disease concerns and biosecurity outbreaks appear regularly across Myanmar, including Foot and Mouth Disease, swine fever and avian influenza. This is coupled with the presence of poor hygiene practices at slaughterhouses. As the bulk of Myanmar's livestock production caters almost exclusively to the domestic market, water contaminants generated by the industry need to be better understood.

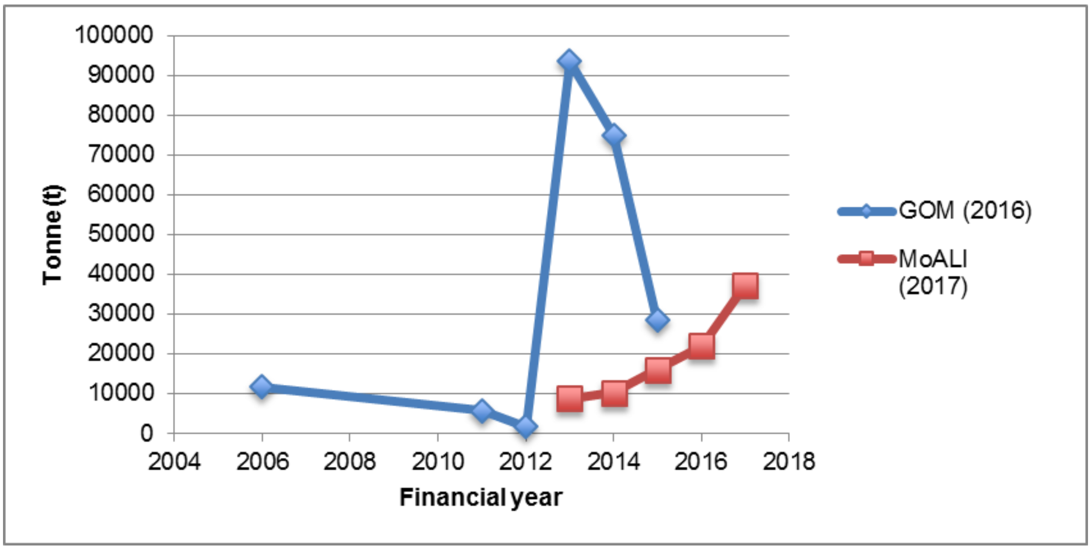

Figure 5 – Pesticide imports: 2000 to 2017.
(Government of Myanmar 2016/ MOALI 2017)

1.2.5 Aquaculture

The fisheries sector is crucially important in Myanmar, with fish making up the bulk of the population's protein intake, and fish is generally consumed at every meal in much of the lower delta regions. According to the United States Agency for International Development (USAID) approximately the same proportion of household income is spent on fish as it is on rice (14 vs 19% of food expenditure). The fisheries sector is spread across exclusive marine economic zones, riverine fisheries and inland fisheries, which comprise approximately 25% of the total fisheries in the country.

Approximately 900,000 t/y of fish are produced on inland fisheries per year (Figure 6) - 90% of which is produced in the Ayeyarwady Region and in Yangon, which are characterised by intensive shrimp farms. Despite differences in stocking rates, climate and species, it is generally agreed that rice-bran and oil cakes

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[1] Further complicating figures is the publication methods. The relevant departments only publish the maximum allowable import figures for each chemical category, not the actual figures. We also note the anecdotal reports that up to 90% of Myanmar's agricultural chemicals are illegally imported from neighbouring countries with little or no control of chemical type or guidance on application regimes. UN COMTRADE data also report a 20-fold increase in nitrogenous fertilizer imports in 2010 compared to official Government of Myanmar statistics, further highlighting the errors associated with this sector.

are the major food source for the aquaculture ponds, with organic fertilisers including cow manure and poultry waste often applied. Probiotics are routinely being imported as components of pelleted feedstock.

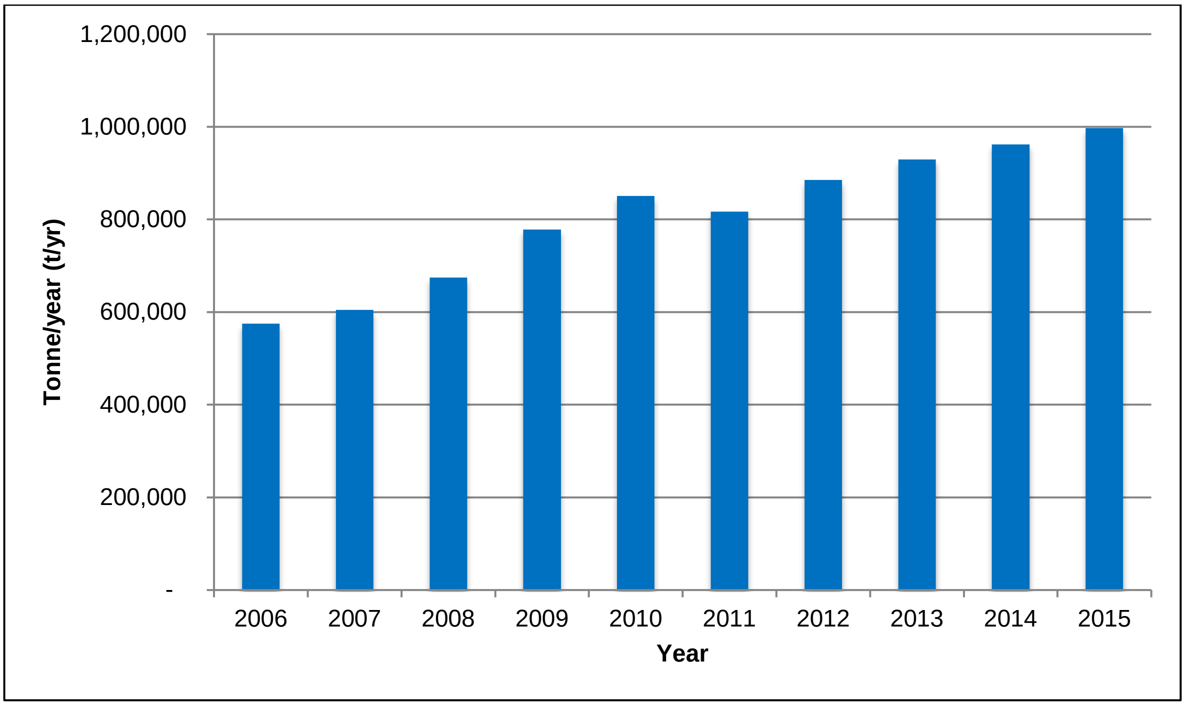


Figure 6 Aquaculture production development 2006 – 2015 (FAOSTAT, 2017)

Subsistence fish-farming is important for Myanmar's food security, especially in the delta, where the estimated number of fish farms is over 200,000 (Fish Agri-food Systems (FISH), 2015), and malnutrition rates are among the highest in the country. Small-scale fish farms, growing small species of indigenous carp using low-tech production methods (often in irrigation channels or disused rice-paddies) have the capacity to greatly improve household food budgets and household revenue, despite federal legislation prohibiting the conversion of rice paddies to fish ponds (United States Agency for International Development, 2015).

As previously highlighted with the broader agriculture data, there are no spatially disaggregated data available on the location and size of aquaculture farms across the ARB, even within the economically important delta region. Further mapping of this important sector would allow for the estimation of broad pollutant loads in the future.

1.3 Hydro-ecological zones (HEZ) of the Ayeyarwady

This section presents an overview of water quality from human and ecosystem health perspective for each of the HEZs - based on current knowledge, as available; in cases where there very little site-specific information was available, assessment was based on best judgement, and knowledge of similar issues in neighbouring countries. An initial, basin-scale assessment of water pollution within the five HEZs of Ayeyarwady Basin, with specific reference to the industrial, urban, mining and agriculture sectors of land use is discussed in this section (Figures 7 and 8)

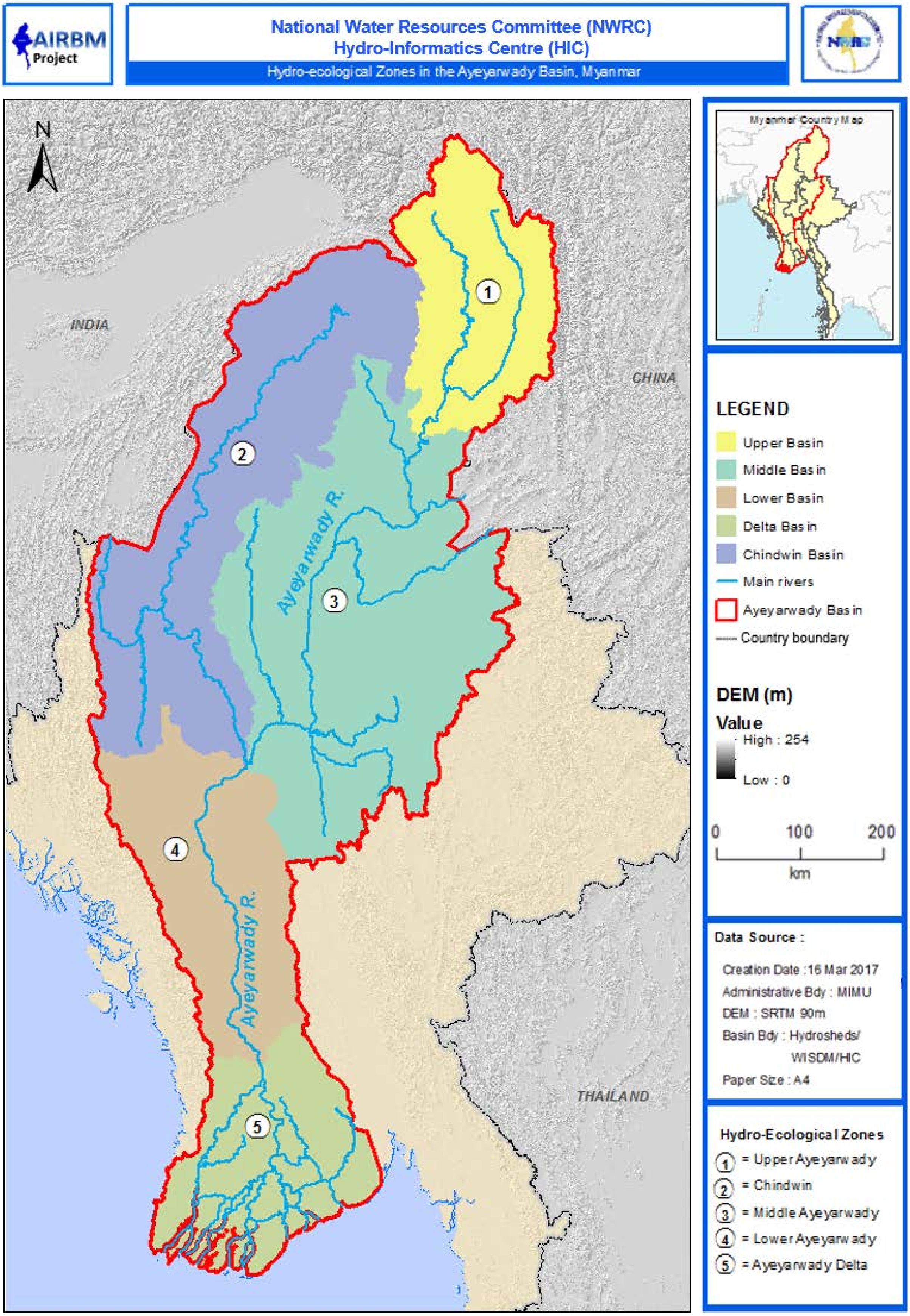


Figure 7 – Hydro-ecological Zones of the ARB.

Figure 8 – Segmentation of economic production for water pollution risk assessments.

1.3.1 Upper Ayeyarwady (HEZ 1)

Industry

There are no manufacturing industries reported from the Upper Ayeyarwady.

A concentration of hydropower generation in this Zone presents an additional risk for water quality maintenance. Dams, weirs and pipeline networks frequently reduced water flow, increase water residence time, promote thermal stratification, increase sedimentation rates and decrease dissolved oxygen concentrations – all of which are known to decrease water quality and disrupt the biota adapted to the natural conditions of a river.

Urban

This Zone has the lowest median township population density of the ARB. Its inhabitants use mainly river and groundwater for drinking and domestic purposes. Water pollution from household wastes into the river presents low and localised risks. Only 25% of the population has access to safe water quality. A 2015–16 survey found mortality of children under five was highest in Chin State (104 deaths per 1,000 live births). This raises concerns for high risks of infectious diseases and child morbidity due to unsafe water supplies.

There were no water quality monitoring data available regarding inorganic and organic contaminants.

Mining

Gold and jade mining is prominent in this Zone. Data on the contamination of the rivers from mining were not available. An assessment using monitoring studies from neighbouring countries indicates that contamination from mining activity is expected. It can result in significant impacts on the water quality, through deforestation, soil erosion, loss of biodiversity, acid mine drainage, and contamination from sediment, cyanide, mercury and other toxic metals. Mining activities may be responsible for high turbidity and sediment loads in surface waters.

Tailings and wastewaters are major aspects of gold extraction industries that can release high amounts of contaminants such as copper, zinc, nickel, cobalt, chromium, mercury, cyanide, and sulfate ions to catchments. Mercury is commonly used by ASM gold miners for the separation of gold from the mineral bearing rock to form an amalgam.

Agriculture

Teak and other forestry products are the major agricultural outputs, with deforestation and degradation of existing forests being seen as critical issues in Kachin State. Soil erosion leads to excessive sediment export, risking water reservoir siltation and the transportation of sediments and their particle-bound contaminants downstream. Agricultural intensification may increase pollution in the future. Fish populations could also be impacted by the chemical contamination, in addition to the practices such as electrofishing.

1.3.2 Chindwin Basin (HEZ 2)

Industry

There are intensive industrial areas in the Chindwin Basin. These are predominantly food and beverage which generate high Biological Oxygen Demand (BOD) loads. Also present are industrial operations concerning petroleum and mining bi-products, which are shipped up and down the river basin. The production of construction materials is heavily concentrated in this zone, generating water pollution through production of high TSS and toxic chemicals, with the industrial sites located near or adjacent to the Chindwin River.

Urban

Residents here experience low security of safe water supply, as there is extremely low connectivity to reticulated water or wastewater systems. Further, the discharges of urban waste, including those from light industry, are usually made usually to adjacent water bodies. There were no water quality monitoring data on inorganic and organic contaminants available for the Chindwin zone. Water pollution derived from household waste disposal into the river presents a low and localised risk.

Mining

Much of Myanmar's mining activity is focused on the Chindwin River Basin. Gold and jade mining is prominent there, and all of the copper mines in the Union are located exclusively within this zone - in the Monywa district, Sagaing region. Nickel is also mined in the Sagaing region. Water quality risks and outcomes associated with mining have been summarised in the preceding HEZ accounts.

Agriculture

The geology of the Chindwin zone mainly comprises soft sedimentary and meta-sedimentary rocks. These erode quickly when cleared of vegetation or excavated - releasing abundant quantities of finer-grained, readily-mobilised sediment (i.e., silts, muds and sands). Consequently, the HEZ is a major source of sediment loads to the basin. The Chindwin Basin is dominated by forestry in its lower, middle and upper catchments. Deforestation and degradation of existing forests are seen as particularly critical land management issues in Sagaing region, mainly due to illegal and legal timber extraction associated with plantation and mining concessions. Deforestation in the riparian zones to plant high value cash crops (i.e., bananas) has led to increased erosion and sediment loads in the surface waters.

Intensive cropping and paddy systems exist near the confluence of the Ayeyarwady River. At present, the livestock density is considered moderate. Expansion of grazing could lead to increases in biological and chemical contamination in surface waters in the zone.

1.3.3 Middle Basin (HEZ 3)

Industry

As in the Chindwin zone, a combination of intensive food and beverage production and petroleum refining is present within the Middle Basin, in Mandalay. The manufacture of construction materials, which is also heavily concentrated in the Middle HEZ, leads to water pollution from high TSS loads and toxic chemicals.

A large hydro-chemical investigation found that only 4.3% of water samples had arsenic concentrations higher than the World Health Organization (WHO) limit of 10 µg/L. There are no reports of other naturally-occurring groundwater contaminants in Middle Basin, but it must be noted that data are very limited.

Urban

Domestic water consumption at the village- and tract-level is predominantly from shallow (< 60 m) wells in the Middle Basin. The aquifers these wells access are generally of low salinity, but many aquifers - especially those along the main river channel have elevated arsenic levels. This represents a potential risk to human health, should any long-term exposure occur, particularly as approximately 77% of households in the zone rely on groundwater for domestic purposes. Large areas of Mandalay have urban, peri-urban and industrial activities.

Mining

Unregulated mining activities occur across the Alluvium and Irrawaddy Formation, as well as in the bed of the Ayeyarwady River in this HEZ. A separate study on mercury contamination near artisanal mining operations confirmed that mercury was present in river sediments in several locations in Myanmar, and in fish flesh from Indawgyi Lake, which is located in this HEZ.

Agriculture

Large areas of ground-water irrigation zones exist within the Middle basin. While chemical use is largely un-quantified at the HEZ-level (as per the rest of the country), as agriculture expands, and irrigation infrastructure prices decrease, we can expect pumping, consumables and chemical uses to increase, all of which will place increased pressure on water resources.

Given the predominance of irrigated paddy rice, pollution produced by supply-chain activities (from hulling, milling) is expected to be higher in this zone than others in the ARB. There is, however, little information on the small-scale processing industry, despite expectations it would be higher in this section of the ARB.

Mid-level risks are present for aquaculture activities (concerning biological and physicochemical contamination). This stems from the prevalence of small-scale aquaculture ponds in the zone, associated with the higher pumping rates observed there.

1.3.4 Lower Basin (HEZ 4)

Industry

Overwhelmingly (well over 63%), the industrial production of Yangon is concerned with intensive food and beverage production. These industries are associated with discharge of high loads of wastewater with high BOD concentrations into local waterways, especially as there is relatively little pre-treatment of wastewater prior to discharge. Similarly, high levels of industrial pollution (indicated by the parameters BOD and TSS) are expected at Pakokku and Myingyan, associated with production of industrial raw materials, as well as food and beverage products.

Urban

Small sections of the major cities of the Lower Basin (e.g. Pyay) have access to wastewater services, most towns and cities having no comprehensive wastewater treatment systems. Correspondingly, there is poor access to reticulated potable water services for Lower Basin residents.

Solid-waste pollution in dense urban areas is readily observable in the major urban areas, particularly in the port areas of Yangon.

Mining

There is virtually no mining in the Lower Basin, except for mining disturbances located in the north-east corner of the basin, closer to the Middle Basin mining zones.

Agriculture

Moderate risks from agricultural contaminants are likely. Irrigation is highly developed in the Lower Basin. Areas close to the major urban areas of Yangon have experienced increased areas of paddy, other agriculture, aquaculture and horticultural development in recent years. However, given the lack of sub-national information on chemical use in agriculture, it is unclear where the areas of high-risk for chemical pollutants from agriculture are likely to be located.

1.3.5 Delta Basin (HEZ 5)

Industry

Industrial areas in the urban and peri-urban areas have historically had no wastewater treatment systems (with virtually nothing constructed in Yangon before 2011). Major industrial zones located in Pathein and Myuang Mya are likely to present risks to human and ecosystem health. Toxic chemical pollution associated with industrial developments in the major cities is a challenge for water quality protection, but with increasing development in Pathein, industrial pollution to surface water is expected to increase.

Urban

The large urban settlements at Pathein and Myuang Mya have very poor urban infrastructure, inclusive of low connectivity to wastewater treatment systems. The projected growth in port developments at Pathein will exacerbate sources of urban surface water contaminants, and is likely to have a pronounced influence on the population in these zones.

Direct contamination of surface waters by animal and human wastes is common, and is likely to be reflected in poor bacteriological quality of the water.

Mining

There is no mining activity in the Delta (with the exception of un-reported and often illegal sand-mining) and therefore water quality issues from mining are considered not to pose any contribution to pollution.

Agriculture

The Ayeyarwady Delta is dominated by agriculture. The highest irrigation densities and areas of planted paddy for the ARB occur in the Delta, and therefore it is expected that the highest risk from chemicals entering the surface water network would be in this zone. The use of pesticides and fertilisers for paddy production could result in risks to both human and ecosystem health, due to increasing load of sediments, excessive discharge of household effluents as expansion of riverside settlements and increasing runoff agricultural pesticides.

Aquaculture risks are perceived to be highest due to the prevalence of very small-scale (even channelised) fish farms.

1.4 Urban and diffuse sources of pollution in the Basin

Surface waters can be contaminated by human activities in two ways: (1) by point sources, such as sewage treatment discharge and storm-water runoff; and (2) by diffuse sources such as runoff from urban and agricultural areas. Diffuse sources are especially difficult to detect since they generally encompass large areas in drainage basins and involve complex biotic and abiotic interactions (Table 1) outlines the classes of diffuse sources and relates their relative contributions to pollution loadings). Agriculture is only one of a variety of causes of diffuse sources of pollution, however it is generally regarded as the largest contributor of pollutants of all the categories.

Table 1 – Types of diffuse source pollution. (*FAO, 1996*)

Type	Description	Contaminants generated
Agriculture		
Animal feedlots **Irrigation** **Cultivation** **Pastures** **Dairy farming** **Orchards** **Aquaculture**	Runoff from all categories of agriculture leading to surface and groundwater pollution. Vegetable handling, especially washing in polluted surface waters in many developing countries, leads to contamination of food supplies. Growth of aquaculture is becoming a major polluting activity in many countries. Irrigation return flows carry salts, nutrients and pesticides. Tile drainage rapidly carries leachates such as nitrogen to surface waters.	Phosphorus, nitrogen, metals, pathogens, sediment, pesticides, salt, BOD [a], trace elements (e.g. selenium).
Forestry	Increased runoff from disturbed land. Most damaging is forest clearing for urbanization.	Sediment, pesticides.
Liquid waste disposal	Disposal of liquid wastes from municipal wastewater effluents, sewage sludge, industrial effluents and sludges, wastewater from home septic systems; especially disposal on agricultural land, and legal or illegal dumping in watercourses.	Pathogens, metals, organic compounds.
Urban areas		
Residential **Commercial** **Industrial**	Urban runoff from roofs, streets, parking lots, etc. leading to overloading of sewage plants from combined sewers, or polluted runoff routed directly to receiving waters; local industries and businesses may discharge wastes to street gutters and storm drains; street cleaning; road salting contributes to surface and groundwater pollution.	Fertilizers, greases and oils, faecal matter and pathogens, organic contaminants (e.g. PAHs [b] and PCBs [c]), heavy metals, pesticides, nutrients, sediment, salts, BOD [a], COD [d], etc.
Rural sewage systems	Overloading and malfunction of septic systems leading to surface runoff and/or direct infiltration to groundwater.	Phosphorus, nitrogen, pathogens (faecal matter).
Transportation	Roads, railways, pipelines, hydro-electric corridors, etc.	Nutrients, sediment, metals, organic contaminants, pesticides (especially herbicides).
Mineral extraction	Runoff from mines and mine wastes, quarries, well sites.	Sediment, acids, metals, oils, organic contaminants, salts (brine).
Recreational land use	Large variety of recreational land uses, including boating, campgrounds, parks; waste and "grey" water from recreational boats is a major pollutant, especially in small lakes and rivers.	Nutrients, pesticides, sediment, pathogens, heavy metals.
Solid waste disposal	Contamination of surface and groundwater by leachates and gases. Hazardous wastes may be disposed of through underground disposal.	Nutrients, metals, pathogens, organic contaminants.
Dredging	Dispersion of contaminated sediments, leakage from containment areas.	Metals, organic contaminants.
Deep well disposal	Contamination of groundwater by deep well injection of liquid wastes, especially oilfield brines and liquid industrial wastes.	Salts, heavy metals, organic contaminants.
Atmospheric deposition	Long-range transport of atmospheric pollutants (LRTAP) and deposition of land and water surfaces. Regarded as a significant source of pesticides (from agriculture, etc.), nutrients, metals, etc., especially in pristine environments.	Nutrients, metals, organic contaminants.

[a] BOD = Biological oxygen demand; [b] PAHs = Polycyclic aromatic hydrocarbons; [c] PCBs = Polycyclic chlorinated Biphenyls; [d] COD = Chemical Oxygen Demand

The use of contaminated water for human activities such as drinking, bathing, and agriculture pose serious threats to the health of local residents as well as aquatic and terrestrial ecosystems (Table 2) and some types of uses are more prone to be affected than others. This report reviews threats to water quality in order to identify and prioritise risks to inform management decisions.

Table 2 – Limits of water uses due to contamination.

Pollutants	Aquatic life and fisheries	Drinking water sources	Recreation	Agriculture	
				Irrigation	Livestock watering
General variables					
Temperature	xxx	0	x	0	0
Suspended solids	xxx	xxx	xxx	0	0
Turbidity/transparency	xx	xx	xx	0	0
Conductivity	x	x	0	x	
Total dissolved solids	x	x	0	xxx	x
pH	xx	x	x	xx	0
Dissolved oxygen	xxx	x	0	x	0
Salinity	xx	xx	0	xxx	xx
Nutrients					
Ammonia	xxx	x	0	0	0
Nitrate/nitrite	x	xxx	0	0	xx
Organic matter					
COD [a]	xx	0	0	0	0
BOD [b]	xxx	xx	0	0	0
Other inorganic variables					
Fluoride	0	xx	0	x	x
Boron	0	0	0	xx	x
Cyanide	x	x	0	0	0
Trace elements					
Heavy metals	xx	xxx	0	x	x
Arsenic/selenium	xx	xx	0	x	x
Organic contaminants					
Oils and hydrocarbons	x	xx	xxx	x	x
Organic solvents	x	xxx	0	0	x
Phenols	x	xx	0	0	x
Pesticides	xx	xx	0	0	x
Surfactants	x	x	x	0	x
Microbial indicators					
Faecal coliforms	0	xxx	xxx	xxx	0
Pathogens	0	xxx	xxx	x	xx

Low (x), medium (xx) and high (xxx) likelihood of water quality impairment; 0 – no impairment; [a] COD = Chemical oxygen demand; [b] BOD = Biological oxygen demand

WHO has published a list of the top ten contaminants of concern, from the perspective of human health (WHO, 2010). The list has no internal ranking. Seven of the substances are candidates for exposure to humans through drinking water or consumption of food that has been irrigated with contaminated water. Five of these serious risk substances are significantly present in the ARB (Table 3) as concern include lead, fluoride, arsenic, mercury, and pesticides.

Table 3 – Sources and exposure pathways of WHO priority contaminants of concern in the Ayeyarwady Basin (*Adapted from WHO, 2010*)

Contaminant	Source of contamination	Exposure pathway	Sector contributing to water pollution
Lead	Fuel, paint, plumbing and soldering	Drinking water and contaminated food	Industrial
Arsenic	No anthropogenic sources, naturally high in groundwater	Through the consumption of groundwater containing naturally high levels of inorganic arsenic, food prepared with this water, and food crops irrigated with high arsenic water sources.	Not applicable
Mercury	Coal-fired power stations, residential heating systems, waste incinerators and mining for mercury, gold and other metals.	Exposure occurs mainly through inhalation of elemental mercury vapours during industrial processes and through consumption of contaminated fish and shellfish	Mining and Industrial
Hazardous pesticides	Application to crops	Consumption of residues of pesticides in food and, possibly, drinking water	Agriculture
Fluoride	No anthropogenic sources, naturally high in groundwater	Drinking water and contaminated food	Not applicable

1.5 Microbial contamination a major concern for human health

Many bacteria occur naturally in freshwater. Some are found living in the water and sediments as photosynthetic autotrophs or saprophytes living on dead matter. Others exist in, or on, other organisms as mutual symbionts (providing some benefit to the host organisms in exchange for a place to live), commensals (neither helping nor harming the host), or parasites (utilizing the host in a way that causes harm). Certain bacteria that live in the intestinal tracts of animals are essential for the recovery of nutrients from digested food. Millions of these naturally occurring organisms are passed out of the body with faecal wastes.

When water is polluted by faecal material, pathogenic bacteria, viruses, and parasites may be introduced, posing a health hazard to those who come in contact with the water. Municipal and rural water supplies can transmit human diseases such as cholera (*Vibrio cholerae*), typhoid fever (*Salmonella typhi*), shigellosis (*Shigella*), salmonellosis (*Salmonella*), and gastroenteritis (*Campylobacter jejuni*, *Escherichia coli*, *Giardia lamblia*). The threat of such disease transmission becomes more serious as population density increases, and as more sewage pollutes public water supplies, carrying with it human intestinal pathogens. WHO (2017) considers waterborne diseases to be linked to a significant disease burden globally. Waterborne diarrhoeal diseases, for example, are responsible for 2 million deaths each year, with the majority occurring in children under 5.

Rather than test water directly for pathogens, which can be difficult, expensive and even hazardous, researchers use indicator organisms to assess the possibility of faecal contamination. Faecal coliform bacteria, members of the family Enterobacteriaceae, which include *Escherichia coli*, *Citrobacter*, *Enterobacter* and *Klebsiella* species, are often used as indicators.

The total and faecal coliform bacteria tests are primary indicators of ‘potability’, or suitability for consumption, of drinking water. It measures the density of coliform bacteria, which is associated with potential presence of disease causing organisms. *Escherichia coli* (*E. coli*) is the major species in the faecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only *E. coli* is generally not found growing and reproducing in the environment. Consequently, *E. coli* is the species of coliform bacteria that is the best indicator of faecal pollution and the possible presence of pathogens.

Faecal coliforms are sometimes associated with pathogens such as *Vibrio cholerae* bacteria or a form of Hepatitis virus that is found in the digestive tract. Other intestinal bacteria, such as streptococci or enterococci, may have a stronger correlation to human sewage, but no indicator has been identified that is exclusive to humans. Total coliform bacteria counts are sometimes used to test for water contamination also. These organisms are less precise as faecal contamination indicators because many can live and reproduce in soil and water, without having a human host.

Faecal coliform bacteria counts are often used to regulate surface waters for recreational use, shellfishing, and potability (ability to be safely consumed). Federal regulations stipulate maximum allowable numbers of these bacteria for various uses. The consumption of contaminated seafood, particularly shellfish, is a major public health problem. Shellfish are susceptible to bioaccumulating bacteria and viruses because they are filter feeders. In waters polluted by urban runoff, bacteria and viruses can be concentrated in the shellfish to much higher levels than those found in the surrounding waters. This becomes a public health concern because many potentially harmful bacteria and viruses can be ingested when people at contaminated shellfish.

1.6 Key indicators of water pollution

Water pollution indicators can be further classified into physico-chemical, organic matter, nutrients, inorganic and organic contaminants. The approach taken has been to address issues relevant to the ARB; in some instances, reference may be made to an aspect of water quality (e.g., treatment technologies) that may not be utilised within the ARB.

1.6.1 Physico-chemical indicators

Because of the multitude and complexity of interactions between landscape, geology, climate and biology with waters, a great many aspects of water quality have been derived to describe, diagnose and remediate water pollution. Important individual indicators of physical and chemical contamination comprise:

- **Turbidity** is used to quantify water containing silt, clay, organic, inorganic, and suspended materials. Particulate matter in water is generally not considered to pose a chemical health risk. The types of particles that are most frequently encountered are not regarded as significant chemical hazards. There are some indirect links between the chemical quality of particles and health that can be noted as a result of particles interacting with other chemical contaminants. Clay and natural organic matter particles can adsorb heavy metals as well as some pesticides. It is known that adsorbed chemicals can detach from particles upon experiencing a change in conditions, such as pH changes. Therefore, the possibility exists that when particles enter a different environment, such as the stomach, release of the adsorbed contaminants could occur. Excessive turbidity has often been associated with unacceptable tastes and odours. Turbidity in excess of 5 nephelometric turbidity units (NTU) also becomes visually apparent and may cause consumers to reject to the water (WHO, 2011). Increased turbidity in rivers increases suspended particles in the aquatic environment and this can lead to fish kills
- **Water temperature** is closely linked to other physical and chemical properties of water. The solubility of water soluble gases (such as oxygen, carbon dioxide, etc.), biological and microbial activity in water, non-ionic ammonia, salinity and pH, and other solutes are subject to water temperature changes. Higher water temperatures increase the adverse effects of low dissolved oxygen on fish. Because high temperature and low dissolved oxygen commonly occur together in natural environments, the additive or synergistic effect of these two potential stresses is an important consideration
- **Colour** indicates impurities, as pure water is often colourless and transparent. Clean water, when shallow, should be colourless, and light green or blue when deeper. The existence of humus, soil, plankton, iron and manganese and other metal ions in natural water can tinge water with colours. Waste water generated from textile, printing and dyeing, paper making,

food, organic synthesis industries often contains a lot of dye, biological pigments and coloured suspended particles. In the environment, coloured water interferes with sunlight penetration, disrupting many chemical and biological processes.

- **Odour** is absent from pure water, which is both odourless and tasteless. Absence of odour or taste does not, however, ensure that water is free from contaminants. Both organic and inorganic materials impart odours, and they may originate from domestic and industrial sewage, decomposition of natural materials, or the activities of micro-organisms and biological organisms. It can often be difficult to determine the composition of the material producing odours.
- **Transparency** refers to the clarity of sample water. Clean water is usually transparent, but when there is suspended matter and colloids in water, its transparency will be reduced. The transparency degree of groundwater is usually high which also changes constantly as its water supply conditions and environmental conditions are changing. Transparency is contrary to turbidity. The more suspended solids in water, the lower its transparency will be.
- **pH** values reflect the potential acid concentration of water. The pH value of natural water is usually between 6.5 and 8.5, which is also a controlled scope of the pH value for wastewater discharge. Not only is pH closely related to water solubility, chemical form, attribute, activities and effects, but it also has a significant impact on the activities of aquatic life.
- **TDS** (Total dissolved solids) measures the quantity of material remaining after the evaporation or drying of water at a standard temperature, including the ‘unfilterable residue’ (all the residues that is trapped in the filter, also known as suspended solids) and ‘filterable residue’ (all residues that can go through the filter, also known as soluble solids). The TDS of waters is related to its salinity, adsorptive capacity for nutrients and microorganisms, and optical properties.
- **Salinity** refers to the total amount of inorganic mineral content of water. Similar to temperature, salinity is a major driver of the physical and chemical activities in a water body. Regular consumption of low-mineral water will destroy the balance of alkali metals and alkaline earth metal ions in the human body, resulting in disease. Conversely, regular consumption of high-mineral water will lead to kidney stone disease. Salinity is an important indicator to determine the chemical compositions of water and is used in the evaluation of irrigation water applicability as a major indicator by evaluating the total water salinity.
- **EC** (Electrical conductivity) is a readily-measurable analogue of salinity that is also better suited for field-based and low cost measurement than is salinity. The conductivity of pure water is very low, but when the water contains an inorganic acid, alkali or salt, the conductivity increases. The conductivity of water depends on the nature and concentration of ions and the temperature and viscosity of the solution. Conductivity varies with temperature. Every increase of 1°C in the temperature causes an increase of the conductivity by 2% or so. The standard temperature for determination of the conductivity is set at 25°C.
- **Redox** (Reduction-oxidation potential) reflects the microscale electrical potentials that influence cellular and molecular processes that are responsible for energy cycling. The nature of the main solutes in the water depend to a large extent on the type, speed and balance of water oxidation. Simply put, reductive processes (such as respiration) consume dissolved oxygen, and oxidative processes liberate oxygen from molecules, and a healthy situation is where a balance is present. In relative terms, the oxidative supply of oxygen to water is negligible as compared to that which is introduced by turbulence. Quantities of organic matter that overcome the capacity of degrading microorganisms tip the balance in favour of reductive conditions. Under those conditions, toxic substances and bound nutrients can be ‘unlocked’ from sediments and anoxic (black water) conditions can cause fish kills and death of other aquatic species.
- **Acidity** measures all substances in water with the capacity of neutralizing alkalis, i.e., total amount of materials which release hydrogen ions (H^+) or generate H^+ through the hydrolysis, or reaction with water molecules. In the surface water, the integration of carbon dioxide or discharge of acid-containing wastewater by machinery, mineral processing, electroplating, pesticides, printing and dyeing, chemical production and other industries can increase acidity. Due to acid corrosion, living conditions for fish and other aquatic organisms and crops are

destroyed. Acid-containing wastewater can also corrode pipelines and ships and destroy buildings. Therefore, acidity is an important indicator in the measurement of the changes in water bodies.

- **Alkalinity** measures all substances in the water capable of neutralizing acid, i.e., total amount of materials which can accept protons. The alkalinity of surface water is basically determined by the concentrations of carbonate, bicarbonate and hydroxide it contains, with the total alkalinity is calculated by summing of these components. Alkalinity indicators are commonly used in the evaluation of the solubility and toxicity of metals in water and the buffering capacity of water. It is also an indicator in evaluating the process of water and wastewater treatment. If the alkalinity is mainly caused by an excessive amount of alkali metal salts, it becomes a major determinant of the suitability of water for use in irrigation.
- **Carbon dioxide** plays a unique part in the biochemical reactions between water and organisms. The main sources of CO_2 in surface water are the decomposition of organic matter in the water and sediment and aquatic respiration. It can also be absorbed from the air. Therefore, its content can be an indirect indicator of the water body subjected to organic matter pollution.

1.6.2 Composite indicators of biodegradable organic matter

- **Dissolved oxygen** concentrations of oxygen in clean surface water is generally close to saturation (at 100%). Because of the growth of algae, dissolved oxygen may become over-saturated (i.e., >100%). As described (see Redox) oxygen depletion degrades water quality and limits its suitability for supporting life. Concentrations of dissolved oxygen in wastewater is generally low, but varies widely. For fish growth, maintaining adequate oxygen at high temperatures is important, as fish normally attain high growth rates at these temperatures. Growth under fluctuating oxygen concentrations is almost always less than growth at a constant concentration equal to the mean concentration (US EPA, 1986). The toxicities of zinc, lead, copper, manganese, pentachlorophenol, cyanide, hydrogen sulfide and ammonia to aquatic organisms are enhanced by low dissolved oxygen.
- **COD** (Chemical oxygen demand) is a standardised test measuring the capacity of water to oxidise organic material via aqueous chemical reactions. The higher the demand, the greater the likelihood that all available O_2 is exhausted before all organic matter (‘organic load’) and other substances can be removed (or ‘processed’). Organic matter contained in water are complicated which makes it difficult to determine their ingredients one by one. For wastewaters, COD indicates their relative content of common contaminants (organic matter, nitrite, ferrous salt, sulfide etc.). Synthetic contaminants like PAHs, PCBs, dioxin-like pollution, etc., are not reflected in COD concentrations.
- **BOD** (Biological oxygen demand) is a standardised test measuring the capacity of water to oxidise organic material via biological reactions. In addition to the attributes of the COD test, BOD is employed as a high-level indicator of microbiological populations. Where the inference is strong that the organic matter gives rise to excessive BOD values (mostly from faecal matter or food wastes), they can be used to indicate the risk of the water bearing pathogenic organisms. For streams and rivers at high BOD levels, sediment-dwelling invertebrate species intolerant of low oxygen concentrations (i.e., caddisfly larvae and mayfly nymphs) cannot be supported, and those tolerant of lower dissolved oxygen (i.e., leeches and sludge worms) may proliferate and dominate the benthos.
- **TOC** (Total organic carbon) is a composite indicator of the total organic matter contained in water by testing the content of carbon. As the TOC is determined by combustion method where all the organic matter in water can be oxidised, making it a more direct method than BOD or COD in determining the total amount of organic matters. Therefore, it is often used to evaluate the degree of organic pollution in water.

1.6.3 Indicators of nutrient pollution

Nitrates and phosphates are plant nutrients and can cause algae and other plant life, as well as microorganisms to grow quickly. Although ecosystems need a certain amount of nutrients to thrive, the growth response has limits. If not managed properly, wastewater, in particular, can contribute an over-supply of nutrients to an ecosystem that can negatively impact it.

- **Total phosphorus** incorporates the various forms of phosphates, in combination with organic phosphorus (e.g., phospholipids, etc.).
- **TKN** (Total Kjeldahl nitrogen) is a test method which measures oxidised forms of nitrogen, which are considered to be bioavailable, and thus readily incorporated into biological tissues.
- **Nitrate** represents an inorganic and stable form of nitrogen. Ingestion of high amounts of nitrates in acute settings transforms haemoglobin to methemoglobin, which is unable to bind and transport oxygen as required by the body. This can result in a temporary blood disorder in infants called methemoglobinemia, commonly called ‘blue baby syndrome’. Symptoms include irritability, lack of energy, headache, dizziness, laboured breathing, and a blue-gray coloration around the eyes, mouth, lips, hands and feet and in extreme cases loss of consciousness and even death. Nitrate and nitrite poisoning or ingestion of large quantities can also cause violent gastroenteritis. Prolonged exposure to small amounts may produce anaemia and nephritis (kidney disease). Long-term exposure to nitrate and nitrite is associated with formation of nitroso compounds, many of which are carcinogenic, especially in the bladder.
- **Ammonia** reflects nitrogen in the form of ammonia or ammonium ions. The composition ratio between the two depends on the pH value and temperature of water. The main source of ammonia in water is the decomposition products of nitrogen-containing organic compounds under reaction of micro-organisms in some industrial wastewaters, such as coking wastewater and drainage from the ammonia fertilizer plants. Fish can be very sensitive to the ammonia in water, and high concentrations will lead to fish death.

  Total nitrogen is an aggregated nitrogen measure that represents both inorganic and organic nitrogen compounds. The discharge of excessive amounts of domestic sewage, agricultural drainage, or nitrogen-containing industrial wastewater into water bodies can cause the organic nitrogen and various inorganic nitrogen compounds to increase and result in a population explosion of organisms and micro-organisms. This over-abundance of organisms, in turn, depletes the dissolved oxygen in the water and leads to water quality deterioration (eutrophication). When there are excessive nitrogen and phosphorus substances in lakes and reservoirs, there will be an over-abundance of phytoplankton production that results in eutrophication of the water body. Therefore, total nitrogen is an important indicator in the assessment of water quality.

1.6.4 Individual indicators of heavy metal contaminants

- **Lead** is cited by the World Health Organization (WHO) as one of the ten leading chemicals of public health concern (WHO, 2010). Mining, milling and smelting of lead (and metals associated with lead, such as zinc, copper, silver; arsenic and antimony) as well as combustion of fossil fuels, deposits lead in the environment at rates above that of normal weathering. Although no concentration of lead is considered safe, for practical considerations the limit is set at < 0.01 mg/L. Many organ systems are affected by lead, significantly the nervous system, the haematological system and the gastrointestinal system. Others include the cardiovascular system, kidneys and the immune systems. Lead toxicity can occur as an acute, severe, clinically obvious poisoning to a slow, chronic, less obvious toxicity. The latter is far more common, and most often seen in children. Children are especially susceptible due to their much higher intake of food and water proportionate to their body weight, likelihood of greater absorption in case of mineral deficiencies and greater susceptibility of their immature body systems to the effects of lead. The most common route of human exposure is via ingestion, such as ingestion of contaminated ceramic glazes and paints, or through contaminated foods grown in polluted soil. In drinking-water, the principal source of lead is the use of lead solder in pipe fittings. Inhalation of small lead particles < 10 μm in size in occupational settings can also be an important route.

Lead is distributed to several organs such as the brain, kidneys, liver and bones. It gets stored in the teeth and bones from where it may be remobilized into the blood stream.

The typical effects of chronic exposure in children leads to neuro-behavioural deficits such as poor concentration, lower IQ and developmental milestone delays. An Anaemia or loss of red blood cells is also typical. In cases with exposure during fetal periods or early life when the immune system is developing, lead poisoning leads to defective immune functioning in infants. Adult exposure in women has been documented to cause adverse effects on pregnancy with pre-mature births, still births, low birth weight babies and abortions. Recurrent or intermittent abdominal pain, vomiting and constipation are other typical gastrointestinal symptoms of chronic lead exposure. Once exposure has occurred, it is uncertain if treatment can reverse many of the effects. Reversal of neurological deficits is not possible. Chelation therapy is suggested to limit the toxicity to other organs along with eliminating further exposure.

In order for a metal to be toxic to an aquatic organism, it needs to enter the body and interact with the surface or interior of cells. There are several pathways by which this happens. In addition to diffusion into the bloodstream via the gills and skin, fish can be exposed by eating sediments that are contaminated with the metal, or eating other animals or plants that have been exposed to the metal (ANZECC and ARMCANZ, 2000). Fish are more sensitive than algae to lead. When lead concentrations exceed 100 parts per billion (ppb), gill function is affected. Embryos and fry are more sensitive to the toxic effects of lead than adult fish. Lead is more toxic at lower pH values and in soft water (Wright and Welbourn, 2002).

- **Arsenic** effects, once initiated in the human body, are irreversible. Prevention of further exposure is a key recommendation by the WHO (2010). No case of arsenicosis or chronic arsenic poisoning has so far been reported from the Ayeyarwady Basin, though this may be due to the absence of surveillance. Human exposure to elevated levels of inorganic arsenic occurs through drinking contaminated water (including naturally contaminated water), using contaminated water for crop irrigation and food preparation, industrial exposure and smoking tobacco grown in arsenic contaminated soils. By far the greatest risk of exposure is from drinking contaminated water. Arsenic has no smell and no taste; and it is not possible to tell if it is present in food, water or air without special tests. Adverse health effects of arsenic can occur in acute or chronic settings, though chronic exposure is of greater public health importance. Acute poisoning due to arsenic leads to abdominal pain, vomiting, diarrhoea, muscular pain and weakness, with flushing of the skin. These symptoms are often followed by numbness and tingling of the extremities, muscular cramping and the appearance of rash. Death can also follow in extreme cases. Chronic effects are most often seen after long term exposure to high levels via drinking water and food for over five years at the minimum. The occurrence of these effects is influenced by the status of nutrition of the exposed individuals; with malnourished individuals showing greater adverse impacts

  Chronic effects can be both carcinogenic and non-carcinogenic. A far greater proportion of the population that shows any effects presents with non-carcinogenic impacts. The signature symptoms are related to the skin, with pigmentation changes and hyperkeratosis (thickening of the skin). Dermal lesions include hyper-pigmentation and hypo-pigmentation, roughened and thickened patches on palms and soles, and peripheral neuropathy. The arsenic-related skin lesions may also be a possible precursor to skin cancer. Other effects of long term exposure that have been reported include lung cancers and peripheral vascular disease, bladder cancer, cardiovascular disease, diabetes and neurotoxicity.
- **Cadmium** exposure to humans occurs mostly via food. Crops irrigated with polluted water or grown on contaminated soil contain increased concentrations, as does meat from animals that graze on contaminated grasslands. The main foodstuffs containing high cadmium are leafy vegetables, potatoes, grains, peanuts and soybeans. In comparison, the intake from contaminated drinking water forms a much less significant source. Galvanized pipes can be a source of contamination to some extent in drinking water. The ability of the body to both convert the metal to this harmless form and excrete it, are overcome when exposed to high concentrations; overloading the liver and kidney with the toxic metal form. Cadmium is a non-essential element with a slow excretion rate, and can become toxic at lower concentrations.

Cadmium has been labelled a human carcinogen by the International Agency for Research on Cancer and a probable human carcinogen by the US EPA. The type of cancer seen due to the metal is usually lung cancer after exposure via inhalation route. Oral exposure via food or water is known to lead to deposition in the kidney with renal disease. Bone disease with increased brittleness and fractures are also seen. Some recent studies also implicate the metal in the development of diabetes or impaired sugar tolerance. Acute oral exposure to very high levels via food or drinking water can lead to severe gastric problems with vomiting, diarrhoea, and occasionally even death.

Cadmium effects on aquatic organisms are analogous to those in humans, and include skeletal deformities and impaired functioning of kidneys in fish. Cadmium is more toxic in freshwater than in saltwater because cadmium combines with chlorides in saltwater to form a molecule that is less available from solution (Wright and Welbourn, 2002).

- **Chromium** exposure to humans in their drinking water is usually is a very minor route. Moderate amounts of the metal are naturally present in fruits, vegetables, nuts, beverages and meats. This form of exposure increases when these foods are grown in soil contaminated with high concentrations of the metal or irrigated with polluted water. Food prepared in utensils that contain chromium may have increased concentrations. Acute oral exposure or poisoning can cause gastrointestinal upset with vomiting, haemorrhage, convulsions and even death. Chromium compounds have been categorized as human carcinogens by the International Agency for Research on Cancer and particularly lung cancers have been seen in those exposed occupationally via inhalation route.

  Low concentrations of hexavalent chromium cause sub-lethal toxic effects in aquatic plants and animals. (Wright and Welbourn, 2002).
- **Nickel** exposure at high levels, either in food or drinking water, is uncommon. There is also no evidence linking this form of exposure to carcinogenesis in humans. The primary cause of toxicity of the metal in humans is through its effect on proteins at the molecular level.
- **Selenium** may be toxic to the human body when present in excess, with small quantities of selenium essential for normal functioning. It is thus an essential trace element. The main route of human exposure is via foodstuff such as cereals, meat and fish. Humans can also be exposed to selenium dust via burning coal or oil. Selenium can be absorbed into the human body via the gastrointestinal tract, the skin or the respiratory tract. WHO guidelines for drinking water quality for selenium are marked 'provisional' and set at 0.04 mg/L due to the lack of definite certainty in the levels that cause adverse health impacts. Short-term exposure to high levels can cause vomiting and diarrhoea. Oral exposure to high levels over long periods has been found to cause dermatologic changes with hair loss and nail pathology. Neurologic changes with odd sensations (paraesthesia) are also known to occur. Occupational exposure via air can lead to respiratory illness with bronchitis and difficulty breathing.
- **Iron** is an essential trace element and its presence is critical for normal functioning of the human body. It is required by haemoglobin in the blood for transporting oxygen to all cells in the body. High levels of iron in the body from drinking water or other oral routes are not usually a problem except in genetic disorders characterized by increased iron absorption (hemochromatosis) or diseases requiring frequent blood transfusions. The guideline limit is for reasons of palatability, aesthetics and smell rather than any health concerns.
- **Fluoride** exposure to humans occurs mostly from drinking water contamination. Fluoride is rapidly absorbed in the body and distributed throughout, with deposition in the teeth and bones. Infants and young children absorb proportionately greater amounts. WHO has established a guidance value of 1.5 mg/L for naturally occurring Fluoride in drinking water, based on consumption of 2 L water/day. Levels higher than these over a prolonged period lead to dental and bone problems. Dental fluorosis develops early, and is associated with damage to the enamel and consequent staining, pitting and opacity of teeth. Continued and higher levels lead to skeletal fluorosis with deposition of the metal in the bones leading to brittle bones, increased fractures, denser bones, calcification of ligaments, stiffness of joints, joint pains, loss of mobility of joints and a rigid spine. Once exposure has occurred, these effects cannot be reversed.

- **Mercury** is an urban/industrial pollutant that is released into the atmosphere and enters water runoff via atmospheric deposition. Mining activities and impurities in the fertilisers contribute to mercury in the environment. The US EPA has found mercury in water has the potential to cause kidney damage from short-term exposures at levels above the maximum contaminant level (MCL). No health advisories have been established for short-term exposures. However, on a chronic basis, mercury has the potential to cause kidney damage from long-term exposure at levels above the MCL. The EPA has not discovered sufficient evidence to state whether mercury in drinking water has the potential to cause cancer over a lifetime.

1.6.5 *Pesticides*

Pests, weeds and diseases can have significant impacts on crop growth. Pesticides are therefore widely used in modern agriculture. While they offer benefits, they also have potential to bring deleterious effects. Pesticides are further classified into groups such as insecticides, herbicides, fungicides, rodenticides, fumigants and insect repellents. Depending on the mode of action, pesticides are further classified into sub-groups (Table 4). Among insecticides, organophosphates, pyrethroids, carbamates are the most common groups used for controlling insects.

Toxic effects arise from improper application, consumption of foods with residues, or environmental exposure. Pesticide residues transported into surface and groundwater can have profound effects on non-target organisms in the environment and human health.

Table 4 – Pesticide classification.

Insecticides	Herbicides	Fungicides	Rodenticides	Fumigants	Insect repellents
Pyrethroids	Bipyridyls	Thiocarbamates	Warfarines	Aluminium and zinc phosphide	Diethyltoluamide
Organophosphates	Cholorophenoxy	Dithiocarbamates	Indanodiones	Methyl bromide	
Carbamates	Glyphosate	Cupric salts		Ethylene bromide	
Neonicotinoids	Acetanilides	Triazoles			
Organochlorines	Triazines	Tiabenzadadole			
		Dinitrophenols			

Water pollution stems from both the active ingredient, and efficacious additives (wetting agents, diluent, solvents, extenders, adhesives, etc.) used to deliver the pesticide for its intended effect. Following their application, pesticides may degrade or metabolise into forms which retain some potency of the active ingredient potency.

Ecosystem health effects of pesticides

Organophosphorus and carbamate insecticides exhibit considerable toxicity to mammals and invertebrates, whereas pyrethroids are highly toxic for insects and fish, but exhibit low toxicity potential for mammals. Contaminated runoff is the principal pathway for ecological impacts. Pesticide transfer to aquatic organisms is via bioconcentration and biomagnification. Bioconcentration often involves active ingredients binding to ’fatty tissue‘ (lipid molecules). Some pesticides, such as organochlorines, are ‘lipophilic’ - being soluble in and accumulate in meat such as fish, and in human tissue. Others (e.g., glyphosate) are more readily metabolized and excreted. Biomagnification refers to increasing concentrations (as opposed to *mass*) of a pesticide as it advances through a food chain, and is more common for pesticides that are lipophilic. Very high concentrations can be observed in top predators, including humans.

Human health effects of pesticides

There is a growing body of evidence coming from research (using animal exposure, and epidemiologic approaches) suggesting links between long-term exposure of a person to pesticides and health impacts - including abnormal growth and development, impairment of neurobehavioural development and/or functions, cancers and increased susceptibility to infection. Human embryos and foetuses are especially vulnerable to pesticide exposure - with increased risks of infertility, perinatal death, spontaneous abortion, premature birth, foetal growth retardation, congenital malformations and early childhood cancers. There is a growing body of evidence coming from research (using animal exposure, and epidemiologic approaches) which suggest there may be links between long-term exposure of an individual to pesticides and the human health impacts including abnormal growth and development, impairment of neurobehavioural development and/or functions, cancers and increased susceptibility to infection. Human embryos and foetuses are especially vulnerable to pesticide exposure with increased risks of infertility, perinatal death, spontaneous abortion, premature birth, foetal growth retardation, congenital malformations and early childhood cancers.

1.6.6 *Toxic industrial chemical contamination*

Many of the chemicals, such as PCBs, and PCPs (polychlorinated phenols) contained in industrial wastewaters are, even in minute amounts - toxic to human, plant and animal life. There is a large group of common toxic organic chemicals among the key industrial chemicals; which include formaldehyde, benzene, ethylbenzene, chloroethane, chloromethane, dichloromethane, di(2-ethylhexyl)phthalate, hexachlorobutadiene, pentchlorophenol, tetrachloroethane, toluene and xylene.

Environmental pathways of toxic chemical exposure

These chemicals are used in small industrial zones within human settlements, and, particularly where such units are found in groups of similar enterprises, they may represent a significant source of contaminants. Petroleum oils are widely used in human settlements, and improper handling or disposal can lead to significant pollution of surface water and groundwater (WHO, 2011). Toxic industrial chemical exposure to humans occurs through direct contact or through inhalation and intake as food. Humans can ingest severely damaging or fatal quantities through repeated exposure, or by consuming plants or animals in which these compounds have accumulated.

Health effects of toxic ***chemicals for humans and environment***

When exposed to toxic chemicals, fish and wildlife can experience reduced fertility, generic deformities, immune system damage, increased incidence of tumors, and even death. Toxic chemicals may cause damage to internal organs and neurological functions, result in reproductive problems and birth defects, and can be carcinogenic Benzene and asbestos are known carcinogens linked to leukemia and lung cancer (WHO, 2011). Chemicals with a Lethal concentration, 50% (LC_{50}) of 0.1 milligram per litre (mg/L) and lethal dose, 50% (LD_{50}) < 10 milligram per kilogram (mg/kg) are considered highly hazardous (Table 5). Human and ecosystem hazard of key chemicals are given Annex I. The concentrations and lengths of exposure necessary to cause these effects vary widely. The drinking water guidelines of the industrial chemicals are given in Table 6 (WHO, 2011).

Table 5 – Categories of chemical hazard.

Category	Air (mg/L)	Land (mg/kg)	Water (mg/L)
High hazard	If $LC_{50} \le 0.1$	$LD_{50} \le 10$	If $LC_{50} \le 0.1$
Moderate hazard	If $0.1 < LC_{50} \le 0.5$	$10 < LD_{50} \le 25$	If $0.1 < LC_{50} \le 0.5$
Low hazard	If $LC_{50} > 0.5$	$LD_{50} > 25$	If $LC_{50} > 0.5$

Table 6 – Guideline values for organic chemicals from industrial sources and human dwellings that are of health significance in drinking-water. (*WHO, 2011*)

Chemicals	Guideline values	
	micrograms per litre (µg/L)	milligram per litre (mg/L)
Benzene	10[a]	0.01[a]
Caron tetrachloride	4	0.004
1,2-Dichlorobenzene	1000[c]	1[c]
1,4-Dichlorobenzene	300[c]	0.3[c]
1,2-Dichloroethane	30[a]	0.03[a]
1,2-Dichloroethene	50	0.05
Dichloromethane	20	0.02
Di(2-ethylhexyl)phthalate	8	0.008
1,4-Dioxane[1]	50[a]	0.05[a]
Edetic acid (as free acid)	600	6
Ethylebenzene	300[c]	0.3 [c]
Hexachlorobutadiene	0.06	0.0006
Nitrilotriacetic acid	200	0.2
Pentachorophenol	9[a, p]	0.009[a, p]
Styrene	20[c]	0.02[c]
Tetrachloroethene	40	0.04
Toluene	700[c]	0.7[c]
Trichloroethene	20[p]	0.02[p]
Xylenes	500[c]	0.5[c]

[1] derived using total daily intake (TDI) approach as well as linear multistage modelling; [a] For non-threshold substances, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional case of cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10; [c] concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints; [p] provisional guideline value because of uncertainties in the health database

2 METHODS

The data presented in this report draw on published and unpublished reports, workshops and interviews with key experts, and compilation of other data sources, together with snapshot sampling conducted in 2017.

For baseline monitoring of pollution in the basin, we applied the following approaches:

1) Use of IPPS (International Pollution Projection System) to predict pollution loads in the ten industrial zones. [Some information on water pollution was available. However, that has not been collected on a systematic and comprehensive basis and does not cover as many pollutants or sectors as in the IPPS]
2) Assessment of available historical water quality data.
3) Snapshot sampling was conducted at selected sites in the urban, industrial and mining areas within ARB.
4) Characterisation of pollution in ARB was conducted using the following two approaches:
    i. Conducting risk assessment for each major type of pollutant using impact/risk registers, as well as guidelines values of key contaminants.
    ii. Developing hot-spot maps of loads and hazards, based on guideline values

2.1 Industrial Pollution Projection System (IPPS)

The overall objective of this study was to estimate the pollution loads from sectoral industrial activities in the ARB based on the IPPS. The specific objectives were:

1) To estimate pollution loads at major industrial zones, and estimate their contribution to the overall industrial pollution load.
2) To compare estimated pollution load (given the limited available data) and develop hot-spot using spatial GIS modelling.
3) To develop a database for this estimation and mapping process for future updates as information grows.

The IPPS tool estimates pollution loads based on production and employment patterns in manufacturing sub-sectors (Hettige et al., 1995). BOD, TSS and toxic chemical loads were estimated for the ten industrial zones within the Ayeyarwady Basin (Table 7) using employment data provided by DISI. Experience with the use of IPPS approach in other countries has shown this employment-based pollution intensity to have lower variation across different technologies, for both developed and developing countries (Dasgupta et al., 2002). All industrial 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 7 – Industrial zones assessed with the IPPS.

Hydro-ecological zone	Industrial zone
Chindwin (HEZ 2)	Monywa
Middle Ayeyarwady (HEZ 3)	Mandalay, Sagaing, Myingan
Lower Ayeyarwady (HEZ 4)	Pakokku, Pyay
Ayeyarwady Delta (HEZ 5	Hinthada, Yangon, Pathein, Myaungmya

In Myanmar there are 13 manufacturing industries in Myanmar (Table 8). The IPPS converts industrial production or employment data to pollution load using coefficients (developed from employment and pollution data from over 200,000 industries in the United States). The IPPS includes pollution intensities for over 240 priority *chemicals* and *metals* released to air, water, and land. Table 7 lists some of those priority chemicals which are well-known to be toxic to human health, as well as metals known to be bio-accumulative.

Table 8 – Major manufacturing categories in Myanmar.

Manufacturing sectors	
Food & beverages	Mineral & petroleum products
Clothing apparel and wearing	Agricultural equipment
Construction materials	Machinery & equipment
Personal goods	Transport vehicles
Household goods	Electrical goods
Printing and publishing	Miscellaneous
Industrial raw materials	

IPPS provides a lower bound value for the pollution intensity coefficients, an upper bound value, and an inter-quartile mean value. For this study, estimates of pollution load utilised the lower bound value of pollution intensity. It was decided to adopt the more conservative measure of pollution intensity. Therefore, pollution release estimates presented in this report are to be interpreted as under-estimates of actual pollution releases. However, both in the context of this study, and for priority setting in general, what matters most are the relative rankings of one sector or area over another.

To factor toxicity into the analysis, load estimates were weighted by a relative toxicity factor (or Threshold Limit Values (TLV)) produced by an internationally recognised source (American Conference of Governmental Industrial Hygienists (ACIGH). These toxicity factors are a culmination of epidemiological evidence and occupational health and safety standards typically adopted across the US and throughout the world. The calculation procedure essentially multiplies the estimated pollution load by the relative toxicity factor (TLV) of the substance, to yield a toxicity-weighted pollution load. For example, if a substance were more toxic, the pollution load would receive a greater weight than if the substance were relatively benign. Thus, substances that are relatively more toxic would rank higher.

Table 9 – Outputs of the IPPS of greatest relevance to water quality

IPPS outputs	Water quality parameters				
Pollution Load Coefficients	Biological oxygen demand (BOD) Total suspended solids (TSS)				
Toxic Metals/ Toxic Inorganic Compounds	Arsenic	Copper	Cadmium	Cyanide	Lead
	Chromium	Nickel	Mercury	Zinc	
Toxic Organic Compounds	Benzene	Chloroethane	Chloromethane	Toluene	xylene
	Formaldehyde	Ethyl glycol	Dichloromethane	Phenol	Carbon tetrachloride
Other Water Pollutants	Aluminium Boron Manganese Titanium	Ammonia Chlorine Phosphorus Chemical oxygen demand (COD)	Iron Cobalt Sulfur	Barium Fluoride Hydrogen sulfide	

2.2 Historical water quality data for baseline pollution survey

Temporal and spatial data water quality data sources used for the baseline pollution survey are outlined in Table 10.

Table 10 – Historical water quality data for baseline pollution survey

Data	Source	Locations	Time period covered	Parameters analysed	HEZ covered
Dams	IWUMD	18 dams[a]	2016-2017	30 including metals and microbials[c]	Lower (HEZ 4) and Middle (HEZ 3)
Five towns in the ARB	IWUMD	Thabeikkyin), Sintku, Mandalay, Myinchan, Nyaung-U	April and July 2014 and March 2015	pH, EC, turbidity, BOD, COD, heavy metals	Lower (HEZ 4) and Middle (HEZ 3
Ten towns in the ARB	IWUMD	Kyankhinn, Mynaung, Hinthada, Zalun, Aphauk, Zakargi, Danuphyu, Nyaungdone, Maubin, Twantee	2011-2015	pH, DO, Ammonia, Nitrite, Nitrate, Fluoride and turbidity	Delta (HEZ 5)
Selected distilleries, leather, sugar, pulp factories	MCDC[a]	Mandalay industrial zone	Variable (2012-2017)	BOD, COD, pH, TSS of effluents	Middle (HEZ 3)
Wastewater treatment plant	YCDC	Yangon	Daily data for 2016	BOD, COD, pH and TSS of influent and effluent	Delta (HEZ5)
Anonymous [a]	Aquaculture ponds	Exact location and ID of these aquaculture was not accessible	2014-2016	pH, DO and unionised ammonia	Delta (HEZ5)

[a] Data-set required translation; [b] details in the Annex II, [c] details in Annex III; BOD-Biological oxygen demand; COD-Chemical oxygen demand; DO-Dissolved oxygen; EC-Electrical conductivity; HEZ-Hydro-Ecological Zone; IWUMD-Irrigation and Water Utilization Management Department; MCDC- Mandalay City Development Corporation; TSS-Total suspended solids; YCDC-Yangon City Development Corporation

Water quality assessment from all these data sources will be discussed in the sub-sections addressing specific sectoral baseline survey, and within pollution assessment in the Results Section.

2.3 Snapshot sampling programme

Water samples were collected from Yangon, Mandalay and the upper Ayeyarwady region. The sampling location, date of sampling are given in Table 11, Table 12 and Table 13). All water samples were analysed for general physico-chemical parameters, nutrients, faecal coliform and heavy metals.

Table 11 – Sampling site locations in Yangon, Ayeyarwady Delta.

	Sites in Yangon	Latitude	Longitude	Date of collection
1	Upstream- 100 m from the outfall	16°45'58.01"N	96°11'26.04"E	23 June 2017
2	Discharge point- Wastewater treatment plant in Yangon	16º45'58"	96º11'27"	23 June 2017
3	Downstream 0.3- 30 m from the outfall	16°45'57.90"N	96°11'28.06"E	23 June 2017
4	Downstream 2- 200 m from the outfall)	16°45'57.84"N	96°11'29.00"E	23 June 2017
5	Pazaung Taung Creek- tributary of Yangon River	16º46'41"	96º10'45"	23 June 2017
6	Kandowgi Lake- Urban stormwater discharge point	16º47'46"	96º9'44"	24 June 2017
7	Field blanks			23 June and 24 June 2017

Table 12 – Sampling site locations in Mandalay, Middle Ayeyarwady.

	Sites in Mandalay	Latitude	Longitude	Date of collection
1	Drinking water supply- Mandalay	22º 0'13"	96º 6'29"	7 August 2017
2	Urban stormwater drain- Mandalay	21º 55'40"	96º 3'60"	7 August 2017
3	Taungthaman Lake sampling, near U Bein Teak Bridge	21º 53'39"	96º 3'6"	7 August 2017
4	Amarapura- Rural stormwater drain	21º 50'11"	96º 6'7"	7 August 2017
5	Amarapura- River samples upstream	21º 50'11"	96º 6'6"	7 August 2017
6	Amarapura - River sample, 150m downstream of Point 5, Downstream 1	21°50'12.29"N	96° 6'0.76"E	7 August 2017
7	Amarapura- River sample, 350 m downstream of Point 5, Downstream 2	21°50'11.68"N	96° 5'53.93"E	7 August 2017
8	Field blanks, tap water	Not applicable		7 August 2017

Table 13 – Water sampling sites in the Upper Ayeyarwady.

Location	Sites	Sample collection
Uyu River	Naung Po Aung Village	30 August 2017
Uyu River	Nyaung Pin Thar Village	30 August 2017

2.4 Guideline values for water quality assessment in the Ayeyarwady Basin

Control of water pollution has reached primary importance in developed and a number of developing countries. The prevention of pollution at source, the precautionary principle and the prior licensing of wastewater discharges by competent authorities have become key elements of successful policies for preventing, controlling and reducing inputs of hazardous substances, nutrients and other water pollutants from point sources into aquatic ecosystems.

Environmental values' are those values or uses of water that the community believes are important for a healthy ecosystem - for public benefit, welfare, safety or health. In the current project, for risk assessment of water pollution in Ayeyarwady, we included the following environmental values:

- Drinking water
- Primary and secondary recreation
- Protection of aquatic ecosystems
- Agricultural water for irrigation and
- Aquaculture

There is a range of water standards or guidelines. Three relevant documents considered in the report were the Australian guidelines (Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand; ANZECC and ARMCANZ, 2000 a) for protection of freshwater organisms and guidelines for irrigation water and aquaculture (ANZECC and ARMCANZ, 2000 b). World Health Organisation guidelines (WHO, 2011) drinking water guidelines were applied for human health risk assessment (Table 14). The ANZECC guidelines provide a framework for assessing water quality, based on whether the physical, chemical and biological characteristics of a waterway support these community environmental values. In effect, the guidelines help to define the water quality needed to protect these values. For each environmental value, the guidelines identify particular water quality characteristics or 'indicators' that are used to assess whether the condition of the water supports that value. The presence of faecal coliforms, for example, is used as an indicator for recreational and drinking water quality, because this directly puts those uses at risk, but it is not an indicator for the protection of aquatic ecosystems.

Microbial contamination is an important indicator of drinking water. If drinking water is contaminated with faeces, bacterial pathogens are likely to be widely and rapidly dispersed, posing a health hazard to those who come in contact with the water. According to the WHO guidelines (WHO, 2011), water intended for human consumption should contain no detectable faecal indicator organisms (must not be detected in 100 mL sample of drinking water). It is recognized that in the great majority of rural water supplies, especially in developing countries, faecal contamination is widespread. The occurrence of disease is also related to the relative level of immunity in the community. If, for example, the water supply has been repeatedly contaminated, the community may have become immune to some waterborne pathogens. Such a situation can be seen in some developing countries such as Myanmar where the prevalence of pathogens is high and the standard of tap water is less than optimal. The immunity of the local population may, however, be acquired at the expense of the health of more susceptible individuals in that community, including children, the aged and people already in poor health. For primary contact activities including swimming and bathing, the ANZECC guidelines recommends the median bacterial content in fresh and marine waters taken over the bathing season should not exceed 200 faecal coliform organisms/100 mL.

Some water pollutants which become extremely toxic at high concentrations are, however, needed in trace amounts. Copper, zinc, manganese, boron and phosphorus, for example, can be toxic or may otherwise adversely affect aquatic life when present above certain concentrations, although their presence in low amounts is essential to support and maintain biological functions in aquatic ecosystems. The same is true for certain elements with respect to drinking water. Selenium, for example, is essential for humans but becomes harmful or even toxic when its concentration exceeds a certain level.

Poor quality water may affect irrigated crops by causing accumulation of salts in the root zone, by causing loss of permeability of the soil due to excess sodium or calcium leaching, or by containing pathogens or contaminants which are directly toxic to plants or to those consuming them. Sodium adsorption ratio (SAR), measuring the ratio between sodium ions and calcium and magnesium ions, is an indicator of whether irrigation water may lead to decline in soil quality. Depending on the structure of a soil, a high SAR indicates relatively high concentrations of sodium to other ions and ongoing exposure of soils to high SAR irrigation water could lead to long-term damage to soils.

Table 14 – Indicative guidelines for drinking water, protection of aquatic life, and irrigation

Pollutant	Drinking water guideline (WHO, 2011)	Freshwater guideline (ANZECC and ARMCANZ, 2000 a)	Irrigation water guideline[a] (ANZECC and ARMCANZ, 2000 b)
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	6.5-8.5	6.5-8.5	6 - 8.5[c] 6-9[d]
Electrical conductivity (microsiemens per centimetre [µS/cm])	- [b]	500-1500	1,300-2,900[e] 2,900-5,200[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/100 mL])	0	-	<10[g] <1,000[h]
Turbidity (nephelometric turbidity unit [NTU])	5	6-50[i]	-
Nitrate (mg/L)	50	0.7	-
Nitrite (mg/L)	3	0.197	-
Ammonia (mg/L)	-	0.9	-
Sodium Adsorption Ratio (SAR)	-	-	<3

Notes: [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, 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.

2.5 Methods used for risk assessment of water pollution in ARB

Pollutants in water can pose a significant risk to human health and ecosystem health. Risk was defined as concentrations of pollutants exceeding their guideline levels for protection aquatic life and drinking water.

The ANZECC guidelines are a powerful tool that allows ambient water quality management to be an important element in decision-making for environment protection, land-use planning and natural resource management. Where an indicator is below the threshold value or within the desirable range for this trigger value in a particular waterway, the risk to the protection of the environmental value is low. Where an indicator is higher than the threshold value or outside the desirable range for its trigger value in a particular waterway, there may be a risk that the environmental value will not be protected

Risk characterisation of key physicochemical parameters for protection of aquatic life are given in Table 15. Ecological risk for heavy metals and inorganic contaminants was estimated numerically using the Hazard Quotient (HQ) approach. The HQ is a ratio, which can be used to estimate if risk to harmful effects is likely or not due to the contaminant in question. The HQ is calculated as predicted environmental concentration/guideline value. Guidelines for interpreting HQ calculations are:

1) HQ < 0.1 no risk
2) HQ 0.1–1 low risk
3) HQ 1–5 moderate risk
4) HQ 5-10 high risk and
5) HQ >10 very high risk.

For drinking water guidelines, measured water quality values were classified as ‘no risk’ (less than 0.5 the guideline value), ‘low risk’ (between 0.5 and 0.75 of the guideline value), ‘moderate risk’ (between 0.75 the guideline and the guideline value), ‘high risk’ (between guideline and twice the guideline value), and ‘very high risk’ (more than twice the guideline value). The outcomes are listed in Table 16. Some of the toxicants have harmful effects at levels less than the guideline values – for example, the effect of arsenic at 0.0075 mg/L has been considered harmful by McGrory et al. (2017). Low levels of lead are also known to be harmful for young children. For example, children under two years will be at risk at 4 µg/L of lead in drinking water with water intake of 1 L/day and body weight of 10.5 kg. For consistency, the same approach was used for each toxicant. We give some weight to toxicants as they approach 0.75 of the guideline value and consider them of low risk and a toxicant in the range 0.75 to 1.0 guideline value is considered to be moderate risk. The risk classification proposed was also used for plotting GIS maps, tables and graphical presentations.

The summary guidelines for interpreting water SAR values are:

1) SAR <3: no risk as the water is non sodic
2) SAR 3 -4: low risk to soil structure and penetration on clayey soils if ECw[a] is <1.5
3) SAR 4 to 6: medium risk to soil structure and penetration on clayey soils if ECw[a] is <1.5
4) SAR 6-9 has increasing effect on all soils at low to moderate salinity (up to 2.5 dS/m[b]) and starts to reduce growth of most crop and pasture plants
5) SAR >9 - severe risk of increasing soil sodicity on most soils.

[a] ECw - Electrical conductivity of the applied irrigation water; [b] dS/m - deciSiemens/meter.

Large uncertainties regarding human and ecological risk (HERA) remain because much of the information identified as necessary to complete the HERA was not available at the time this project was carried out. We have used precautionary principle to deal with such uncertainties in this process.

Table 15 – Risk characterisation of key physicochemical parameters for protection of aquatic life.

Water quality parameter	Water quality ranking				
Risk	**No**	**Low**	**Moderate**	**High**	**Very high**
pH	6.5 to 7.5	6.6 - 8.5	5-6.4	3 -5 and 9-11	<3 and >11
Dissolved oxygen (mg/L)	>8	7 - 8	5.5-7	4 - 5.5	<4
Biological oxygen demand (BOD) (mg/L)	<5	5-15	15-30	30 to 60	>60
EC µS/cm	<500	500 -1500	1500-3000	3000 to 4000	>4000
Turbidity (NTU)	<6	6-50	50-100	100-200	>200

Table 16 – Risk characterisation of metals and inorganic contaminants from human health perspective.

Contaminants	Water quality ranking				
Risk	**No risk**	**Low**	**Moderate**	**High**	**Very high**
Range	**<50% GL**	**50%-75% GL**	**75%-GL**	**GL-2xGL**	**>2GL**
Arsenic (µg/L)	<5	5-7.5	7.5-10	10-20	>20
Cadmium (µg/L)	<1.5	1.5-2.25	2.25-3	3-6	>6
Chromium (µg/L)	<25	25-37.5	37.5-50	50-100	>100
Fluoride (mg/L)	<0.5	0.5-0.75	0.75-1.5	1.5-3	>3
Lead (µg/L)	<5	5-7.5	7.5-10	10-20	>20
Mercury (µg/L)	<0.5	0.5-0.75	0.75-1	1-2	>2
Nickel (µg/L)	<10	10-15	15-20	20-40	>40
Uranium (µg/L)	<15	15-22.5	22.5-30	30-60	>60

GL- Guideline value

2.6 Geographic Information System for hot-spots

Effective analytical tools, such as geographical information systems (GIS) and multivariate statistics, can deal with spatial data and complex interactions, and are coming into common usage in watershed management. However, their effectiveness depends on the quality and quantity of data collected in the field, which tend to be sparse, especially when dealing with entire watersheds.

A geographic information system (GIS) database was populated with the following data:

- GIS layers for (as a minimum) land use, population density, topography and soil type
- Townships in the 5 HEZ of the basin
- Locations and descriptions of weirs/dams and associate water quality data
- Pollutant type and load estimates using IPPS
- Locations of water quality monitoring stations and their associated monitoring data
- Locations where any water quality standards where water quality standards were not met

Water quality data were limited. All data were rasterised and placed within the same projection in ArcGIS before the information was synthesized to develop meaningful and accurate results. The data layers were then overlaid (with different weights if needed). GIS information was shared between various SOBA packages.

2.6.1 *Selection of contaminants for GIS Modelling*

Whilst there are a variety of contaminants that could be addressed by modelling, the following criteria were used in the selection of a provisional list of contaminants:

- Distribution and occurrence of contaminants with impact on receiving waters
- Potency/toxicity
- Potential for impairment of beneficial use of receiving waters, and
- Failure in the guideline values at a specific site based on the existing water monitoring data and risk categorisation as described in Tables 15 and 16.

3 STATUS AND TRENDS-INDIVIDUAL ECONOMIC ACTIVITY

3.1 Industry

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), Lower Ayeyarwady (HEZ 4) and Ayeyarwady Delta (HEZ 5).

3.1.1 Industrial sectors in Myanmar

Small scale industries are prevalent in Myanmar. Small-scale enterprises make up 80% of the industrial sector within the Ayeyarwady Basin (Figure 9). While small-scale industry dominates smaller population centres, it is also in prominent in urban centres, making up 42% of the total industry in Yangon and 50% Mandalay. Small scale industries can cause significant water pollution risk due to inadequate treatment processes and lack of knowledge to mitigate pollution risks.

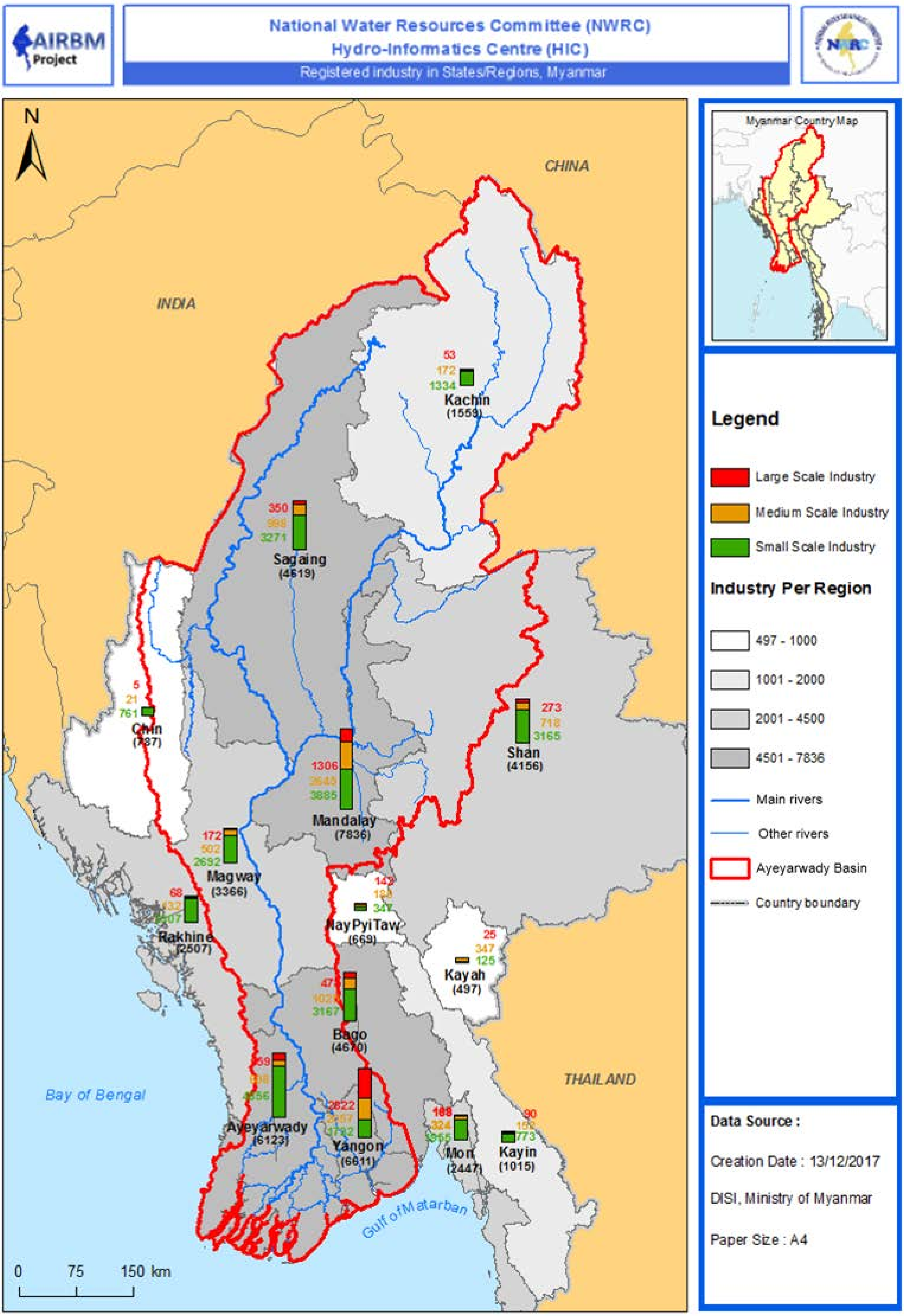


Figure 9 – Scale of industrial sectors in Myanmar.

3.1.2 *Water pollution assessment using Industrial Pollution Projection System (IPPS)*

A preliminary estimate of industrial pollution load was conducted in 10 industrial zones in Ayeyarwady Basin using the World Bank's Industrial Pollution Projection System (IPPS). The use of IPPS approach was used to provide a comprehensive picture of Industrial pollution in Ayeyarwady Basin. The assessment focused on three types of key industrial pollutants – BOD, TSS and toxic industrial chemicals.

BIOLOGICAL OXYGEN DEMAND (BOD)

Domestic sewage and industrial wastewater contains large amount of organic matters in various forms. When the waters are polluted, the decomposition of organic matter in the water would consume a lot of dissolved oxygen, and thereby undermining the balance of oxygen in water, deteriorating water quality and causing death to fish and other aquatic organisms because of hypoxia. Organic matter contained in water is complex which makes it difficult to determine their ingredients one by one. People often use the oxygen consumed by organic compounds in water under certain conditions to indirectly test the content of organic matters in water, and BOD is one of the important indicators fall into this category.

TOTAL SUSPENDED SOLIDS (TSS)

Total suspended solids (TSS) are solids in water that can be trapped by a filter. It is a measure of the mass of fine inorganic particles suspended in the water. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, sediments from soil erosion, industrial wastes, and sewage. High concentrations of TSS can block light from reaching submerged vegetation, slowing down photosynthesis. This causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die. As the plants are decomposed, bacteria will use up even more oxygen from the water. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even further. Suspended solids can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development.

By assuming a constant pollution/labour ratio for each sector (Hettige et al., 1997) in terms of kg BOD and TSS discharged/worker, it is possible to calculate the value of BOD and TSS loading in each manufacturing sector and the industrial zone. However, this only holds if the underlying hypothesis is correct, namely that the pollution/labour ratio remains constant for a given industrial sector, regardless of the level of technological development. This is assumed to be the case, as plant-level studies have shown that the pollution per unit of output, and employment per unit of output, decrease at almost exactly the same rate as income increases.

Based on 13 manufacturing sectors, BOD and TSS were used as indicators to illustrate hot spots as % and kg/year in the ten industrial zones (Figures 10 and 11). Food and beverages was the major contributor to BOD load and construction material was responsible for the highest TSS load (Figures 10 and 11) Sagaing industrial zone exhibited high BOD due to construction material whereas clothing, wearing and apparel sector was contributing to high BOD in Pathien (Figure 12). TSS load was high in Mandalay, Yangon and Manyowa industrial zones.

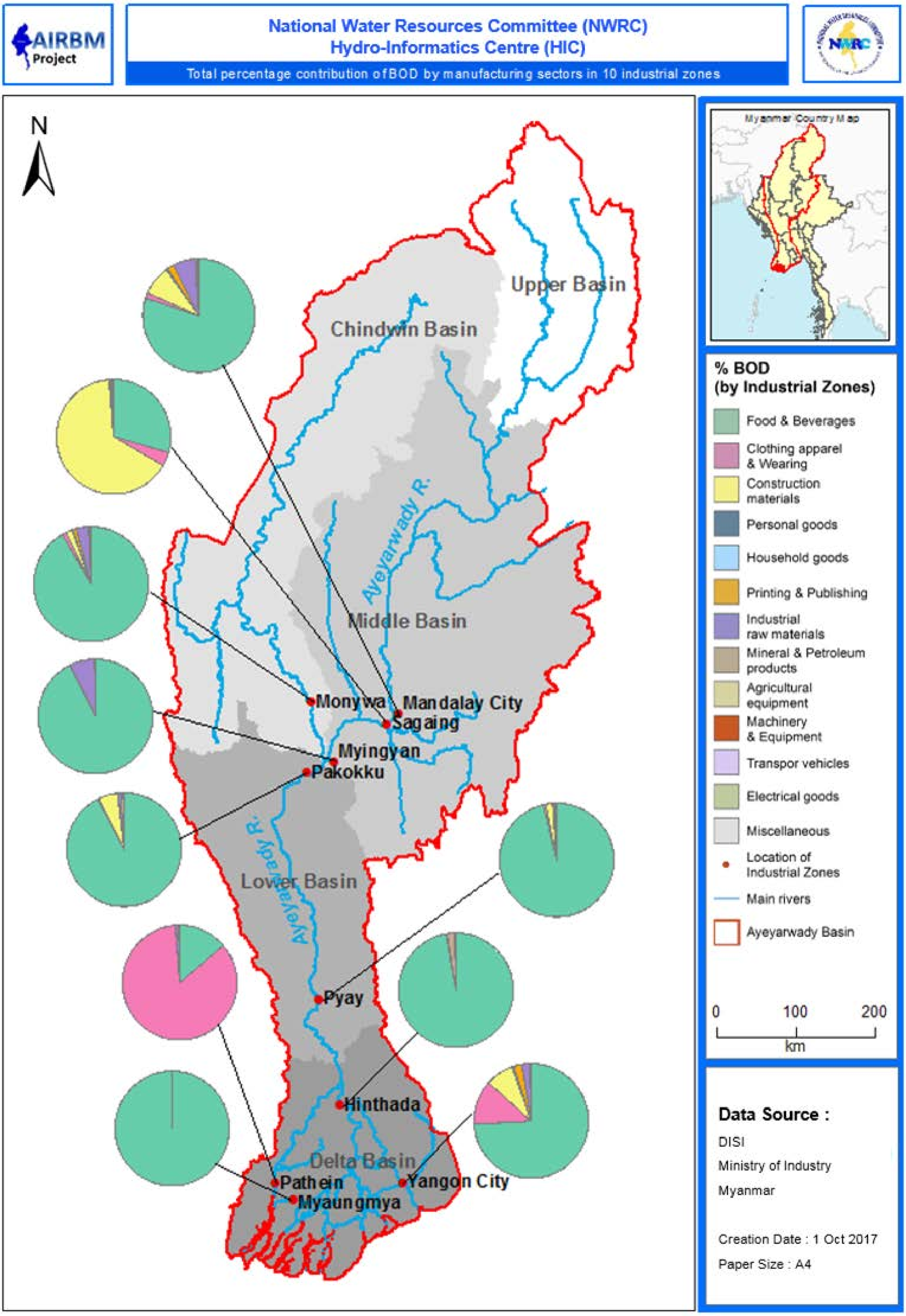


Figure 10 – The total percentage of biological oxygen demand (BOD) load by manufacturing sectors in the 10 industrial zones, based on IPPS.

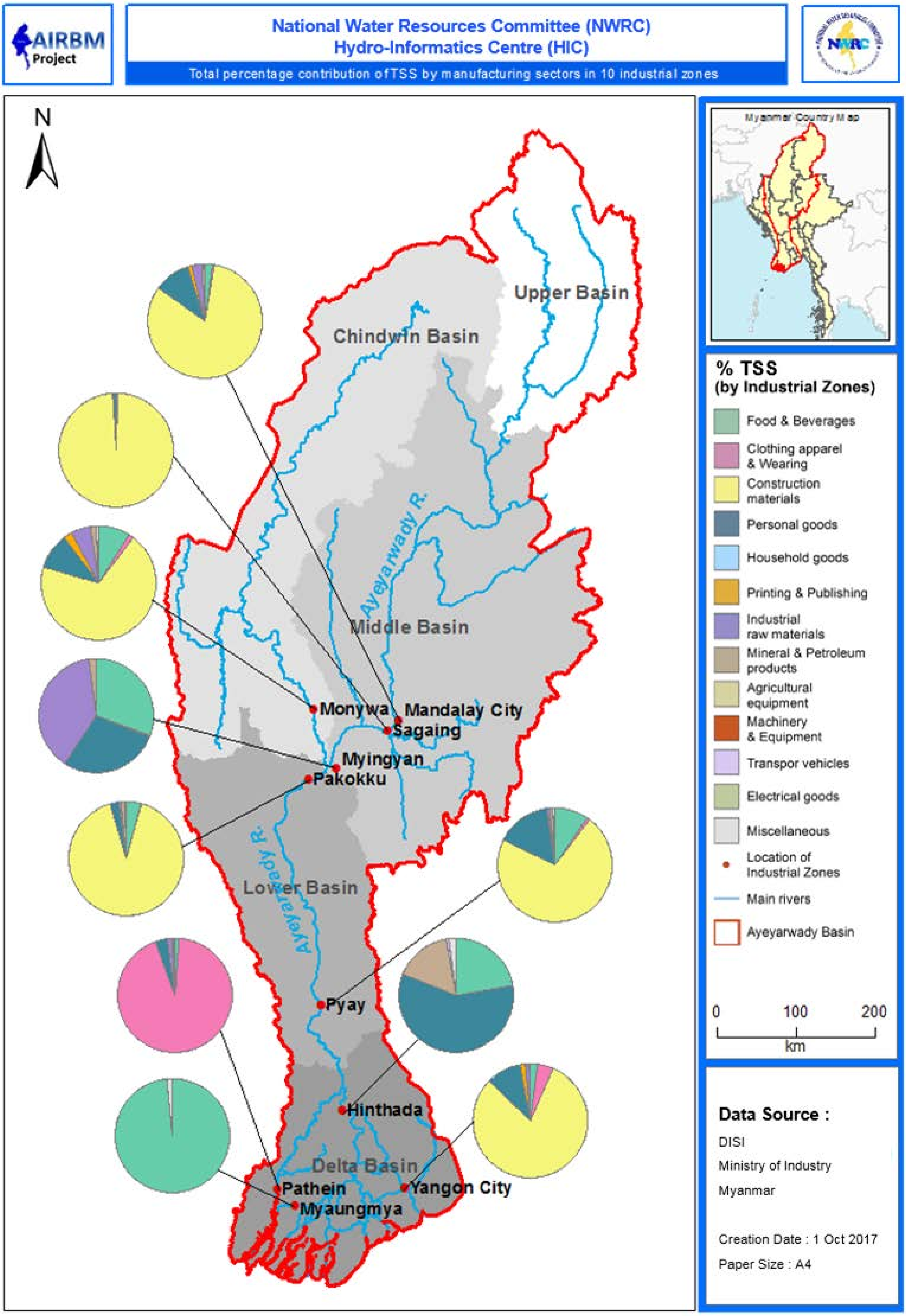


Figure 11 – The total percentage of total suspended solids (TSS) by manufacturing sectors in the 10 industrial zones, based on IPPS.

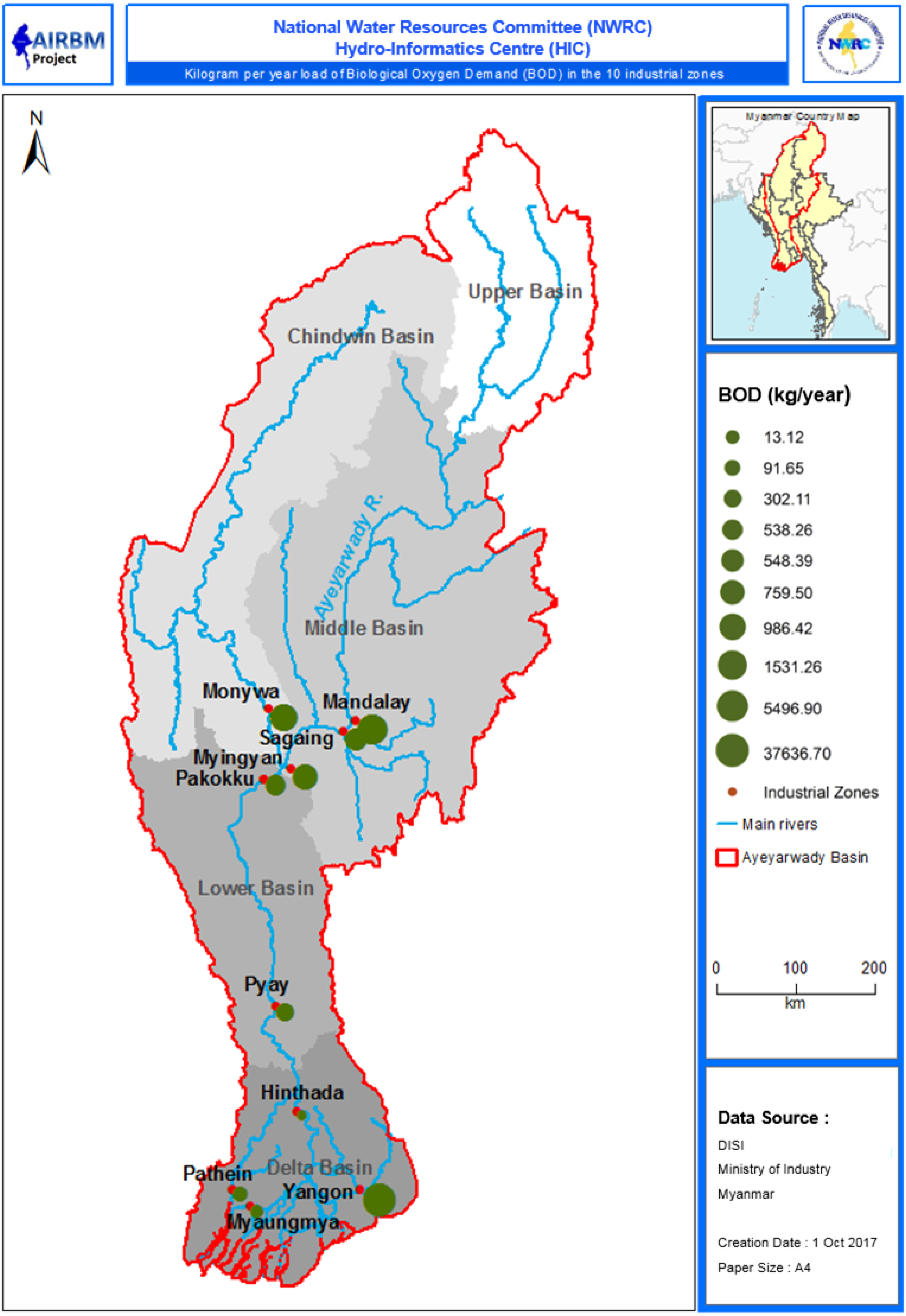


Figure 12 – Kilogram per year of biological oxygen demand load in the 10 industrial zones within Ayeyarwady Basin, based on IPPS.

TOXIC INDUSTRIAL CHEMICALS

Industrial chemical waste consists of both organic and inorganic substances. Organic wastes include pesticide residues, solvents and cleaning fluids, dissolved residue from fruit and vegetables, and lignin from pulp and paper to name a few. Effluents can also contain inorganic wastes such as brine salts and metals. Chemicals can cause problems with the taste, odour and colour in water. Metals may not be detectable, but can be harmful in high concentrations. Fish and wildlife can experience reduced fertility, generic deformities, immune system damage, increased incidence of tumours, and even death. Many of the chemicals, such as pesticides, PCBs, and PCPs, and metals that enter the water are, even in minute amounts, toxic to human, plant and animal life.

Toxic industrial chemicals represented the highest loads in Mandalay, Yangon and Pathien (Figure 13). Hotspots in the industrial zones for individual metals and organics such as phthalates are given in Figure 14 to Figure 19. Maximum load of cadmium, copper, lead and arsenic load was contributed by the construction materials (approx 60%, Table 17). Chromium load was related to mainly clothing, apparel and wearing industry in HEZ 3 (Figure 16) and. Mercury load was associated with the industrial raw materials (Table 17) and was dominant in HEZ 3 (Figure 17).

Table 17 – Metal contribution (as %) in Yangon based on thirteen manufacturing sectors.

	Yangong industrial zone (% contribution by industrial sector)					
Name of enterprise	Cadmium	Copper	Chromium	Mercury	Lead	Arsenic
Food & beverage	0.0	0.0	17.7	0.0	0.0	0.0
Clothing apparel & wearing	0.0	20.9	56.6	0.0	27.5	0.0
Construction material	66.9	59.9	21.4	0.0	59.5	61.7
Personal goods	0.0	13.5	0.0	0.0	1.5	35.0
Household goods	0.0	0.0	0.8	0.0	0.6	0.0
Printing and publishing	0.0	2.7	2.4	0.2	0.0	0.0
Industrial raw materials	30.6	0.0	0.4	99.8	1.3	3.2
Mineral & petroleum products	2.5	0.0	0.5	0.0	1.7	0.0
Agricultural equipment	0.0	0.0	0.0	0.0	0.0	0.0
Machinery & equipment	0.0	0.0	0.0	0.0	0.0	0.0
Transport vehicles	0.0	0.0	0.1	0.0	0.2	0.0
Electrical goods	0.0	0.9	0.0	0.0	7.8	0.0
Miscellaneous	0.0	2.0	0.0	0.0	0.0	0.0

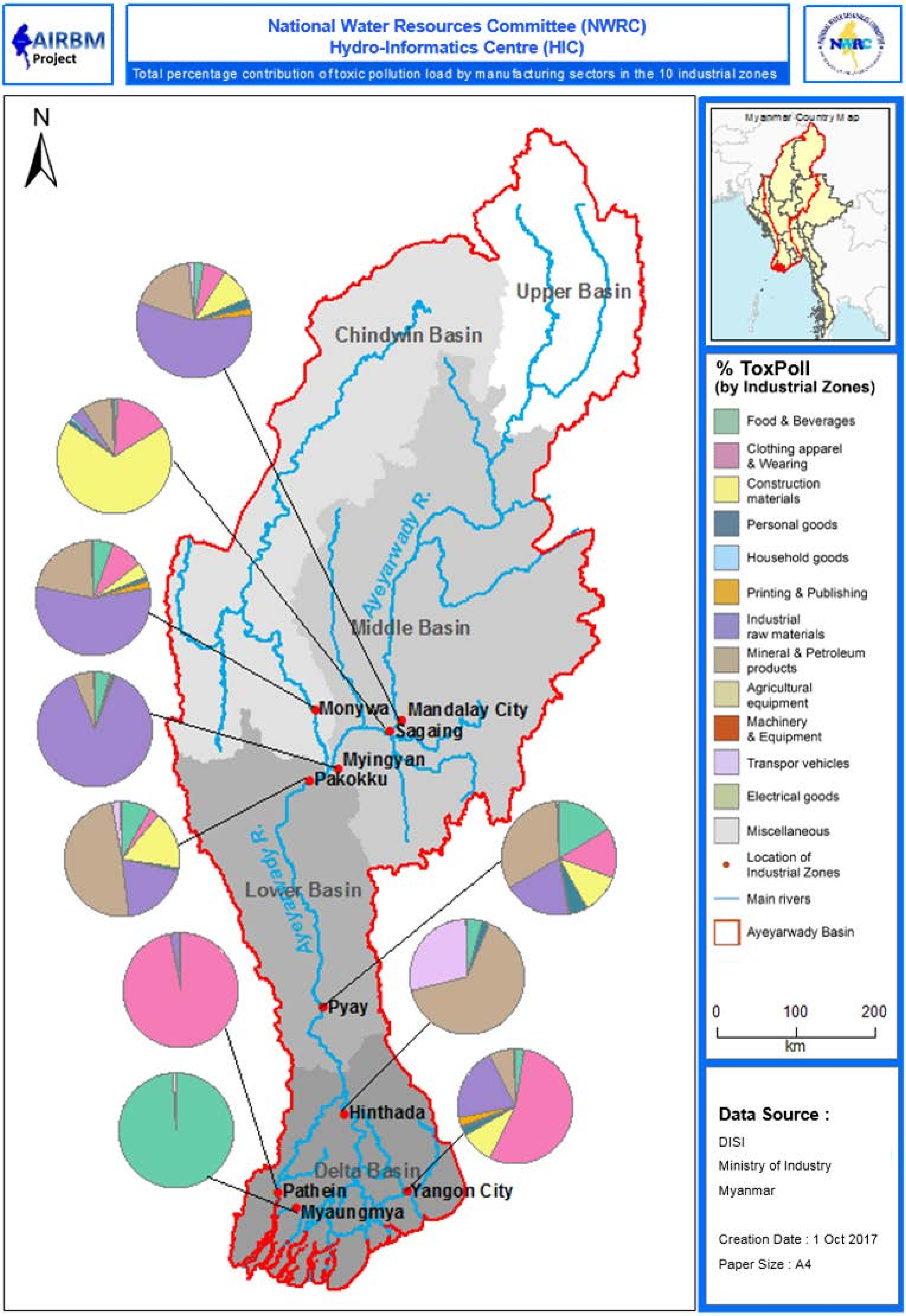


Figure 13 – The total percentage of toxic chemicals by manufacturing sectors in the 10 industrial zones, based on IPPS.

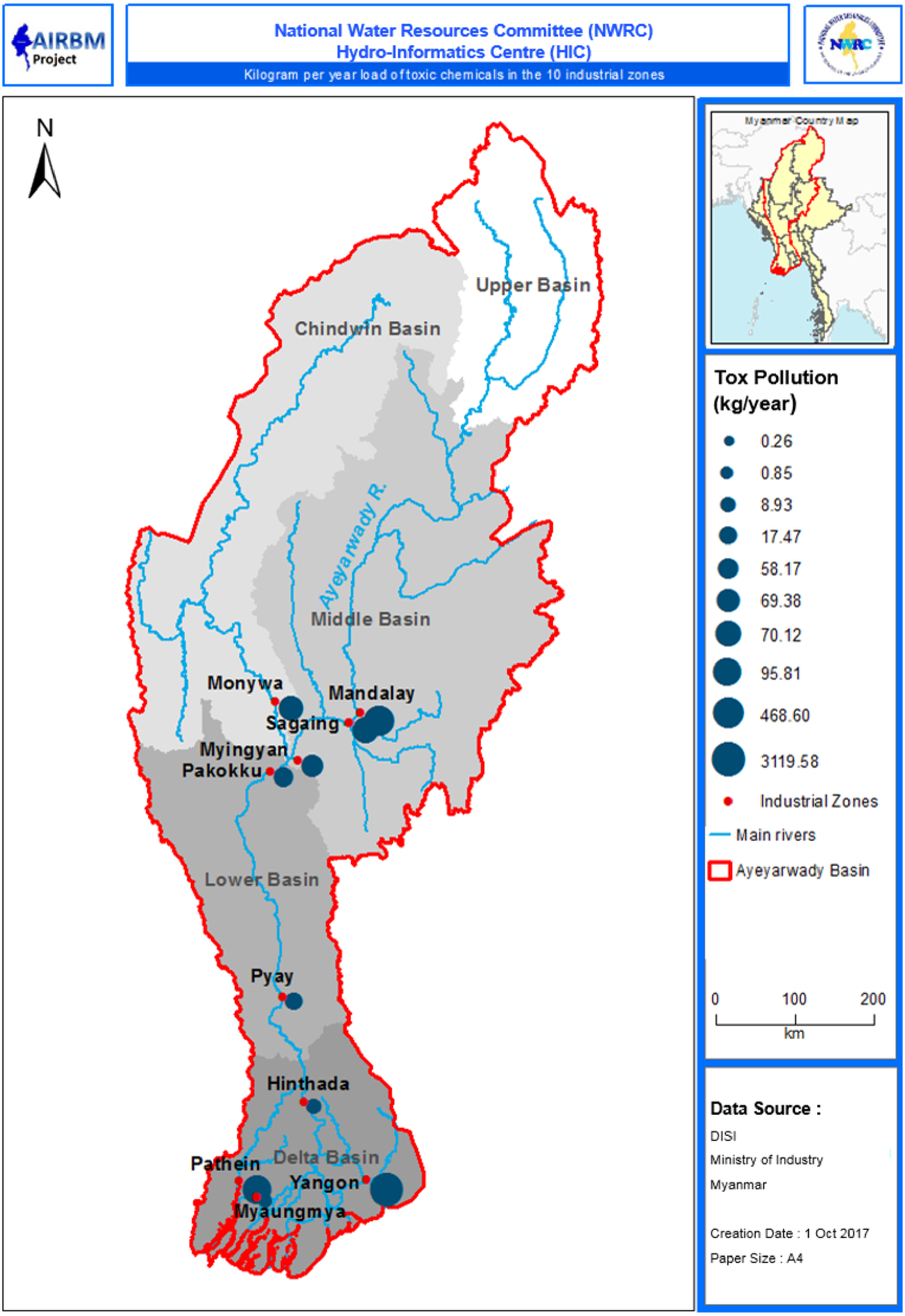


Figure 14 – Kilograms per year of toxic chemicals in the 10 industrial zones within the Ayeyarwady Basin, based on IPPS.

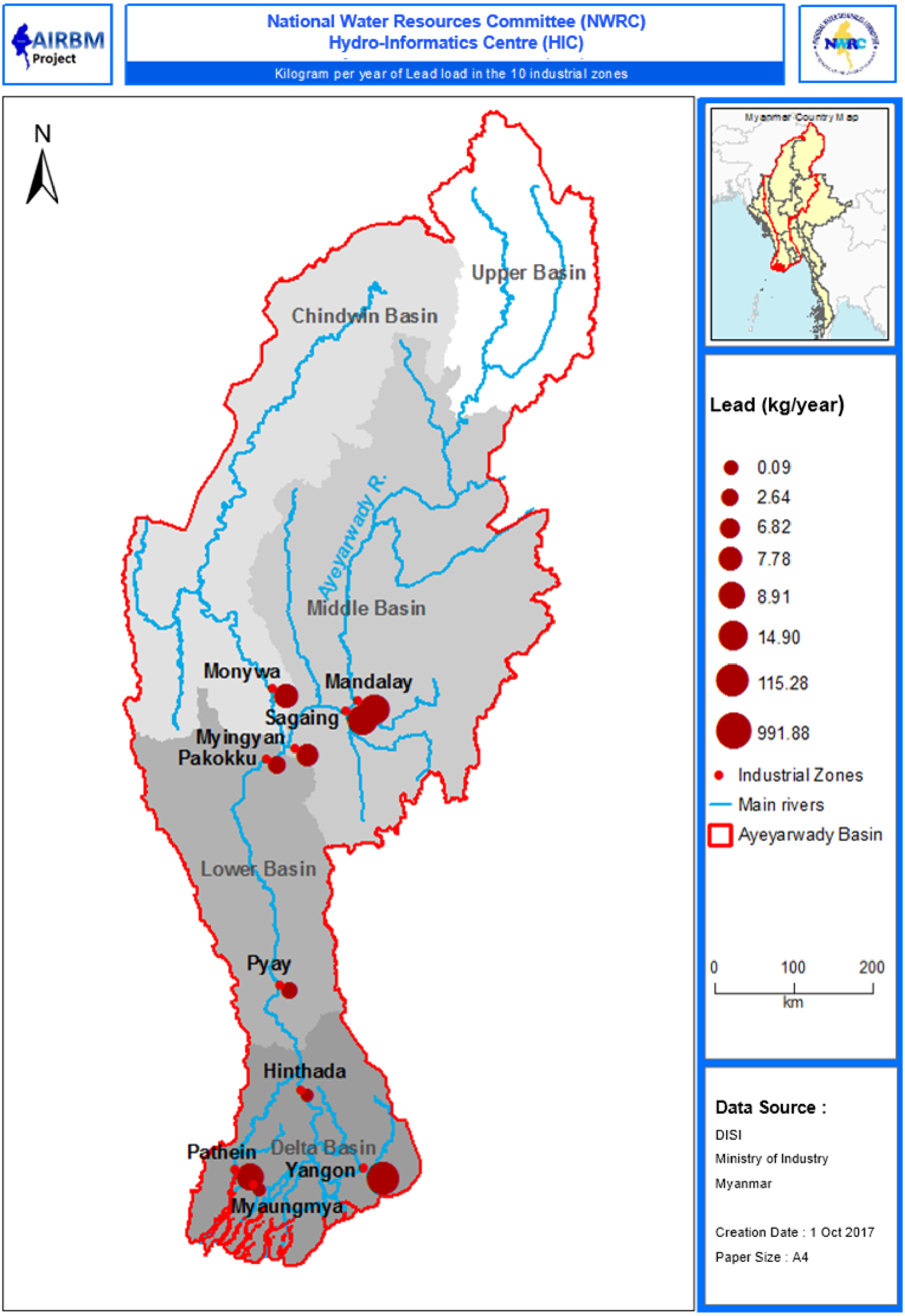


Figure 15 – Kilograms per year of lead load in the 10 industrial zones within the Ayeyarwady Basin, based on IPPS.

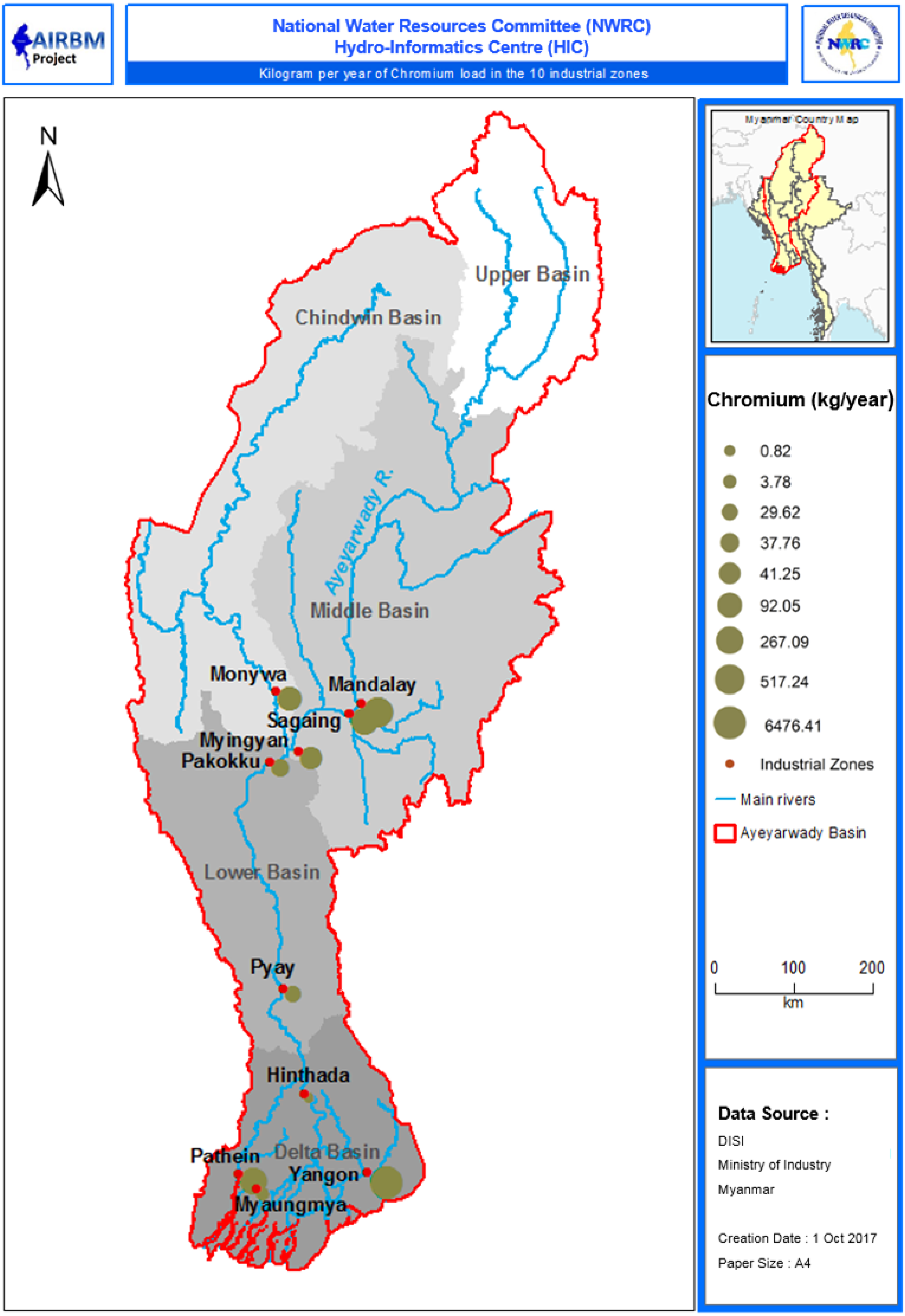


Figure 16 – Kilograms per year of chromium load in the 10 industrial zones within the Ayeyarwady Basin, based on IPPS.

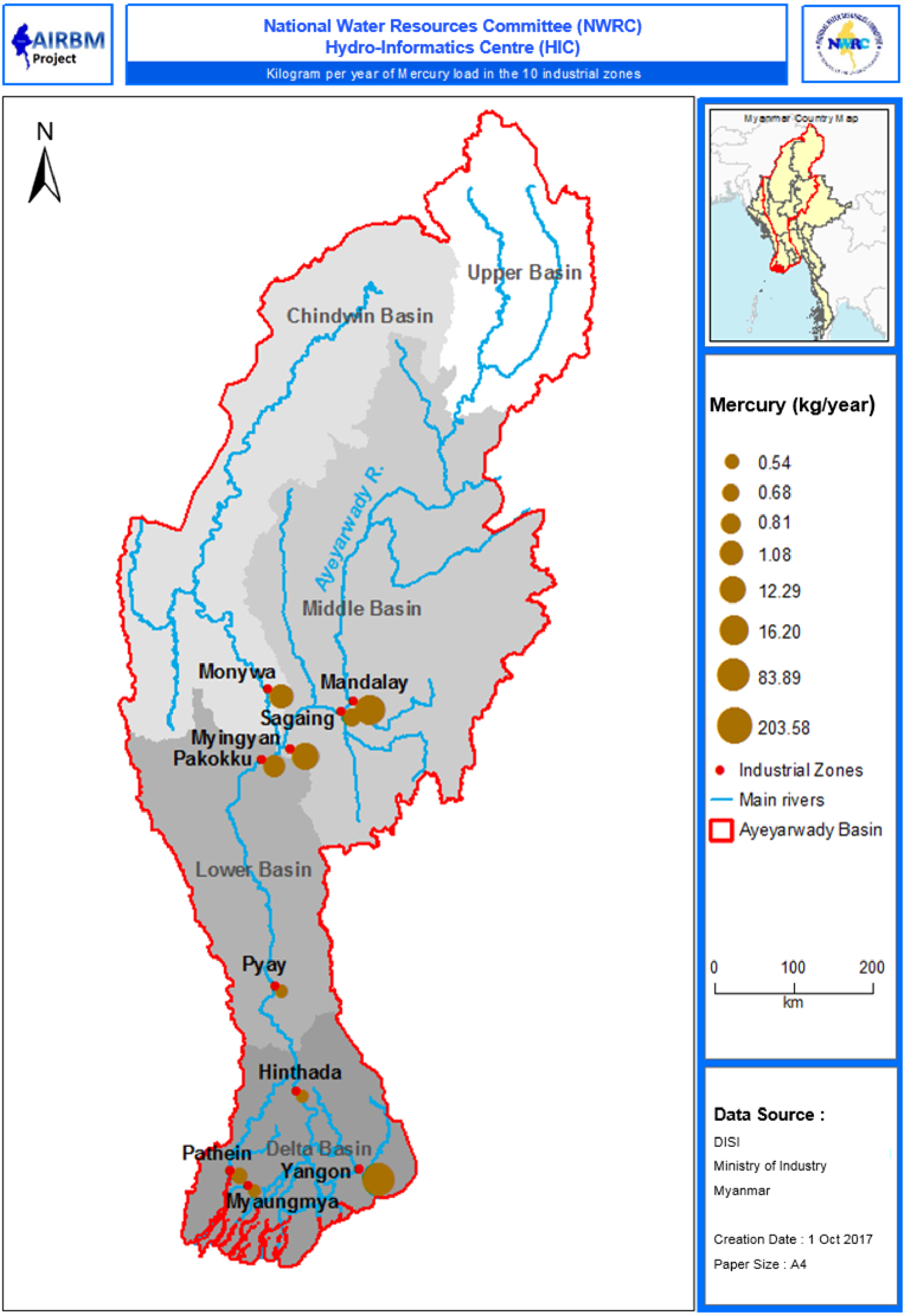


Figure 17 – Kilograms per year of mercury load in the 10 industrial zones within the Ayeyarwady Basin, based on IPPS.

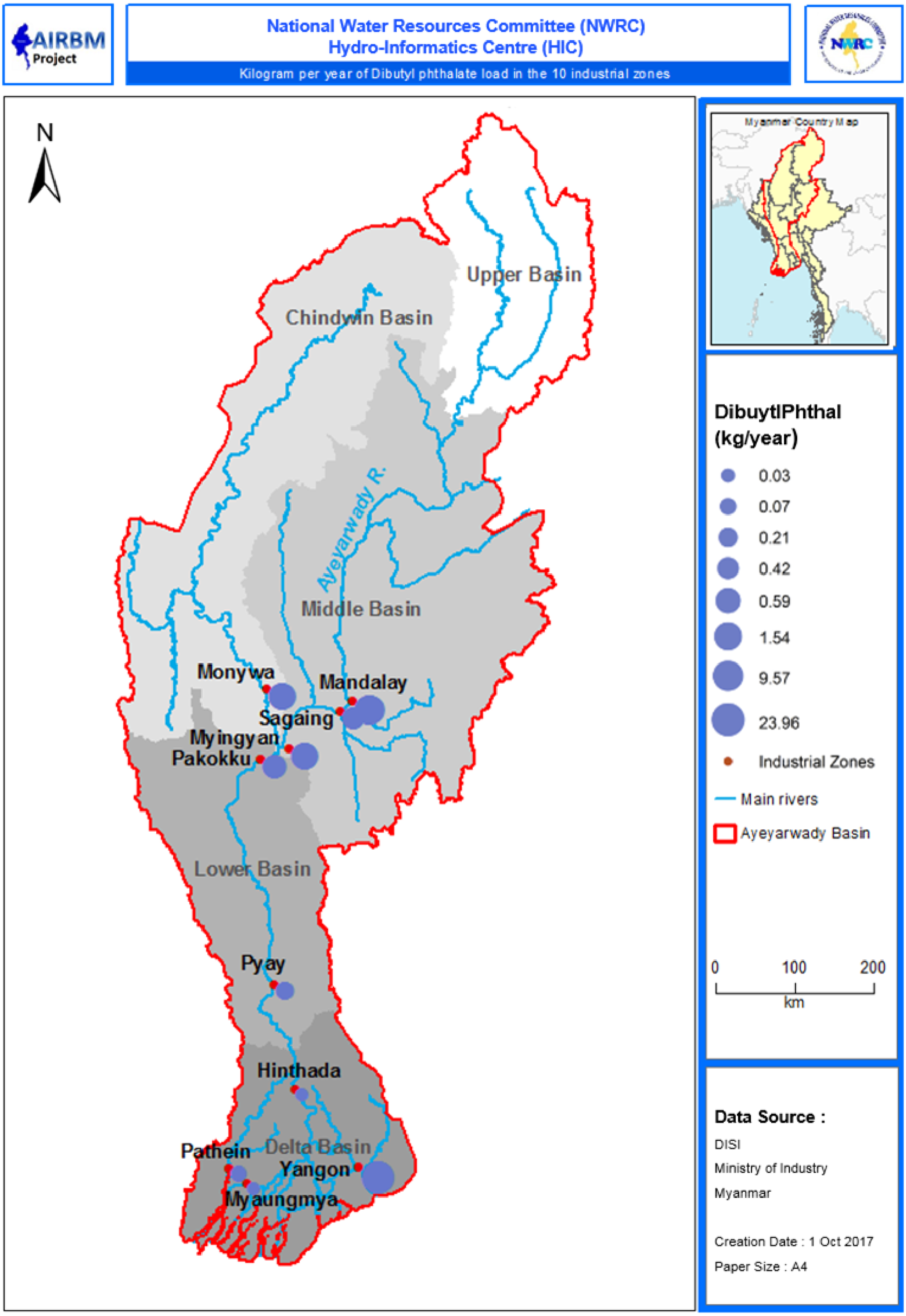
Among salts and acids, sodium hydroxide was contributed by the clothing apparel and wearing sector and hydrochloric acid by construction material and personal goods. Ammonium nitrate was associated with the Miscellaneous sector (Table 18). Construction material sector was responsible for high ammonia and phenol (70-90%). Industrial raw material sector was contributing to high carbon tetrachloride and personal good for high dichloromethane (>85%, Table 19)

Table 18 – IPPS output for percentage contribution of ammonium nitrate, hydrochloric acid and sodium hydroxide as toxic chemicals in the thirteen manufacturing sectors of the ARB.

Name of enterprise	Ammonium nitrate (%)	Hydrochloric acid (%)	Sodium hydroxide (%)
Food & beverages	0.0	4.0	5.1
Clothing apparel & wearing	0.0	0.0	91.6
Construction materials	0.0	47.0	0.5
Personal goods	0.0	16.3	0.9
Household goods	0.0	0.7	0.0
Printing and publishing	0.0	7.4	0.0
Industrial raw materials	9.0	2.4	0.6
Mineral & petroleum products	0.0	4.7	0.5
Agricultural equipment	0.0	0.0	0.0
Machinery & equipment	0.0	0.0	0.0
Transport Vehicles	0.0	0.6	0.0
Electrical goods	0.0	0.3	0.8
Miscellaneous	91.0	16.6	0.0

Table 19 – IPPS output for percentage contribution of key organic chemicals based on thirteen manufacturing sectors of the ARB.

Name of enterprise	Dibutyl phthalate (%)	Diethyl phthalate (%)	Carbon tetrachloride (%)	Dichloromethane (%)	Formaldehyde (%)	Ammonia (%)	Phenol (%)	Ethylene glycol (%)
Food & beverages	0.0	0.0	0.0	0.0	53.1	2.0	0.0	0.0
Clothing apparel & wearing	0.0	25.7	0.0	0.0	0.2	15.5	0.0	13.8
Construction materials	0.0	3.3	0.0	0.0	0.3	74.4	93.1	19.2
Personal goods	0.0	0.0	0.0	93.8	1.5	0.9	0.1	3.4
Household goods	0.0	47.5	0.0	2.5	0.0	0.1	0.0	17.8
Printing and publishing	0.0	1.1	0.0	0.2	5.3	0.7	0.0	1.9
Industrial raw materials	42.9	0.0	86.7	2.9	15.8	2.9	0.4	2.9
Mineral & petroleum products	57.1	22.4	13.3	0.3	20.1	1.0	1.1	39.8
Agricultural equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Machinery & equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Transport Vehicles	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Electrical goods	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.9
Miscellaneous	0.0	0.0	0.0	0.1	3.7	2.5	5.2	0.0



National Water Resources Committee (NWRC)
Hydro-Informatics Centre (HIC)
Kilogram per year of Dibutyl phthalate load in the 10 industrial zones

Data Source :
DISI
Ministry of Industry
Myanmar

Creation Date : 1 Oct 2017
Paper Size : A4

Figure 18 – Kilograms per year of plasticisers (as dibutyl and diethyl phthalates) load in the 10 industrial zones within Ayeyarwady Basin, based on IPPS.

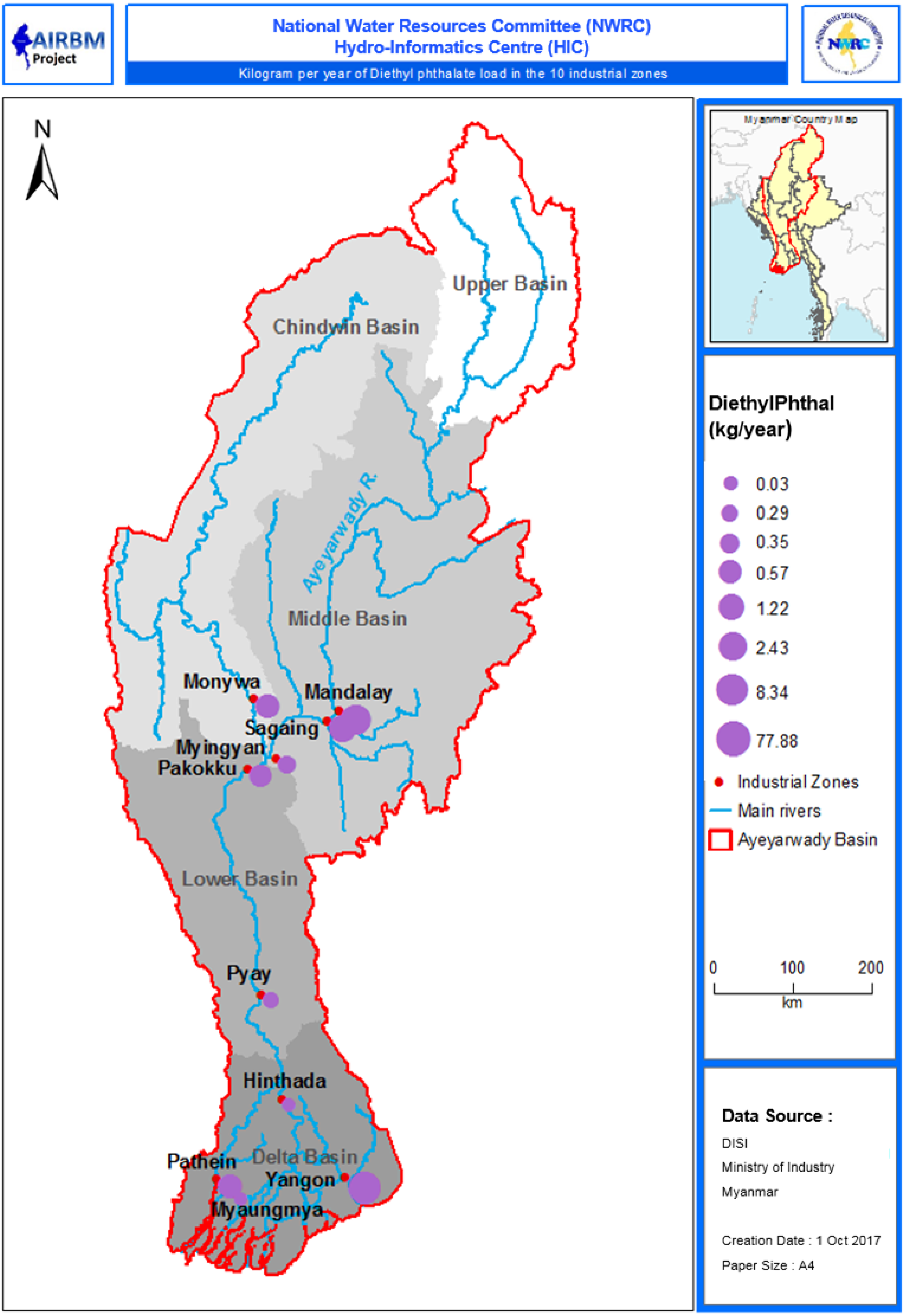


Figure 19 – Kilograms per year of plasticisers (as dibutyl and diethyl phthalates) load in the 10 industrial zones within Ayeyarwady Basin, based on IPPS.

Ranking of HEZs in ARB for each sector

The IPPS model indicated that Yangon industrial zone generates the dominant pollution load for 11 of the 12 industrial activities considered, the exception being the miscellaneous industries, 45% of which are located in the Mandalay zone. The strong majority of BOD loading came from the food and beverage industrial sector, and the dominant source of TSS resulted from construction materials industry. Factories releasing the highest chemical toxic loads were in the construction materials, food and beverages, clothing, apparel and wearing, industrial raw material, minerals and petroleum products. Mandaly, Pathien and Yangon are recommended as hot spots from toxic chemicals perspective.

Ammonia, ethyl glycol and formaldehyde were the three main toxic chemicals of concern in the ARB (Figure 20). Formaldehyde load was the highest in Myaung mya and ammonia in the Pakoku industrial zone. Among toxic metals, copper and lead was the highest in Sagaing, chromium in Pathien and zinc in Pakokku (Figure 21). These results should be further validated by conducting systematic monitoring studies in the ARB.

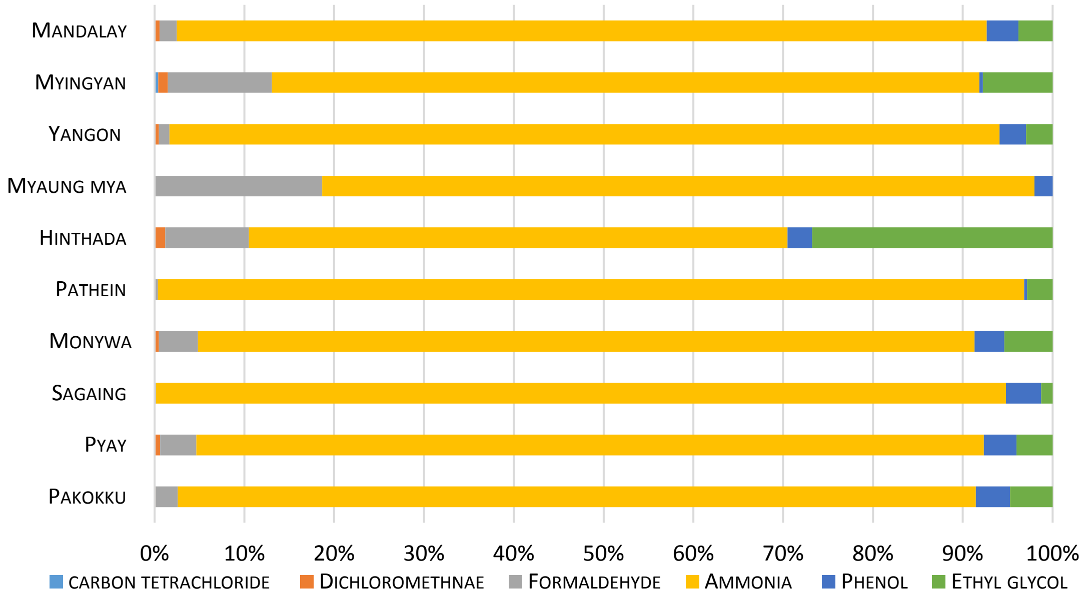


Figure 20 – IPPS output for percentage contribution of toxic chemicals in the ten industrial zones.

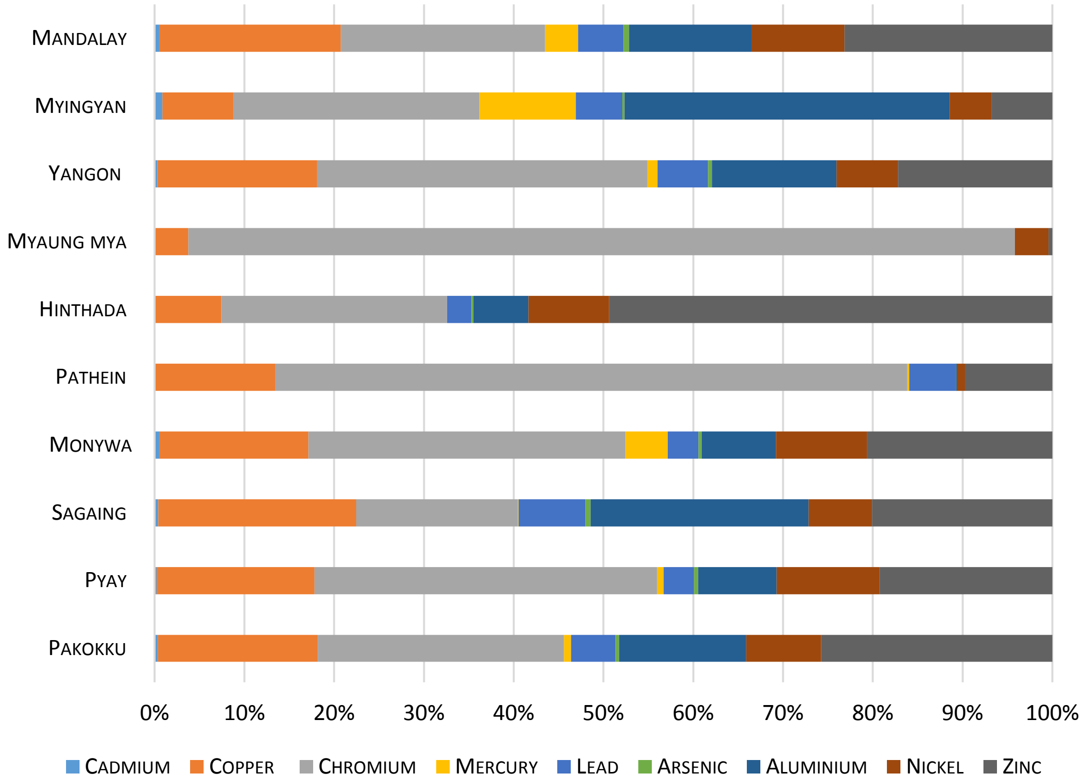


Figure 21 – IPPS output for percentage contribution of toxic metals in the ten industrial zones.

Yangon had the highest chemical load (6239 kg/year), BOD load (37,637 kg/year) and TSS load (198,077 kg/year, Table 20). Total loads/year for BOD, TSS and chemicals for a given industrial zone were ranked from 1-3 with ranking of 1 given to the highest load and 3 to the lowest load (Table 20). Industrial chemical contribution to the pollution load was highest in Pathien (19%) and Yangon (16%). Contribution of TSS to the pollution load was the highest in Sagaing (97%), in contrast only 3% of BOD and 1% of toxic chemicals contributed to the total pollution load (Table 20).

Table 20 – IPPS output for Total loading of BOD, TSS and chemicals in ARB industrial zones.

	Total loads, kg/year			% composition of total load			Load ranking		
	Chemicals	BOD	TSS	Chemicals	BOD	TSS	Chemicals	BOD	TSS
Pakokku	35	548	1759	1	23	75	3	2	1
Pyay	18	538	783	1	40	58	3	2	1
Sagaing	140	760	27118	1	3	97	3	2	1
Monywa	139	1531	2278	4	39	58	3	2	1
Pathein	192	302	519	19	30	51	3	2	1
Hinthada	2	13	8	7	57	36	3	1	2
Myaung mya	1	92	13	0	87	13	3	1	2
Yangon	6239	37637	198077	3	16	82	3	2	1
Myingyan	116	986	430	8	64	28	3	1	2
Mandalay	937	5497	30762	3	15	83	3	1	2

Chemical loads were generally quite small when compared to BOD and TSS loads (Table 20). As the relative toxicity and hazards of industrial chemicals make them a high priority for authorities to address, they were given the highest hazard ranking (Table 21). Based on this assessment, a water pollution index was calculated for each of the ten industrial zone by combining relative ranking of % contribution of toxic chemicals, BOD and TSS. Water pollution index of 1 represented the highest concern in comparison to 10 being the lowest concern. The top 5 industrial zones of major concern are located in HEZ5, HEZ3 and HEZ 2 (Table 22).

1. Yangon (HEZ 5)
2. Mandalay (HEZ 3)
3. Sagaing (HEZ 3)
4. Monya (HEz 2)
5. Pathien (HEZ 5)

Table 21 – Hazard ranking of industrial zones based on toxic chemicals, BOD and TSS loads in the industrial zones.

Industrial zones	Hazard rank		
	Chemicals	BOD	TSS
Pakokku	1	3	3
Pyay	1	3	3
Sagaing	1	3	3
Monywa	1	3	3
Pathein	1	3	3
Hinthada	1	3	3
Myaung mya	1	3	3
Yangon	1	3	3
Myingyan	1	3	3
Mandalay	1	3	3

Table 22 – Water pollution index ranking for industrial zones.

Industrial zones	BOD	TSS	Toxic chemicals	Water pollution index
Pakokku	5	5	7	5.7
Pyay	6	6	8	6.7
Sagaing	3	3	4	3.3
Monywa	4	4	5	4.3
Pathein	7	7	3	5.7
Hinthada	10	10	9	9.7
Myaung mya	9	9	10	9.3
Yangon	1	1	1	1.0
Myingyan	8	8	6	7.3
Mandalay	2	2	2	2.0

The toxic chemical and toxic metal pollution load estimated using IPPS must be interpreted with extreme caution. Information regarding technologies, process and raw materials used in the relevant industries and data on actual measurement of toxic pollution are needed to support the validity of the IPPS.

3.1.4 *Validation of IPPS results*

Wastewater quality of the factories in middle Ayeyarwady HEZ3

Evaluation of the water quality monitoring data from the factories in the industrial zone of HEZ3 further validated the high BOD input from food and beverages sector, based on IPPS (Section 3.1.2). The effluent quality data identified high BOD levels in the wastewaters of the city's distilleries (up to 15,000 mg/L) and in sugar and leather factories (ranging from 200-2000 and 700-5000 mg/L respectively). Other sub-sectors like pulp factories exhibited BOD levels from 220-560 mg/L (Figure 22). These recordings are all beyond what is deemed acceptable by guidelines for drinking water, protection of aquatic life, and irrigation (Table 14). In addition. The pH of the effluent discharged from distilleries and sugar factories was acidic while the pH of leather factories was alkaline (Figure 23).

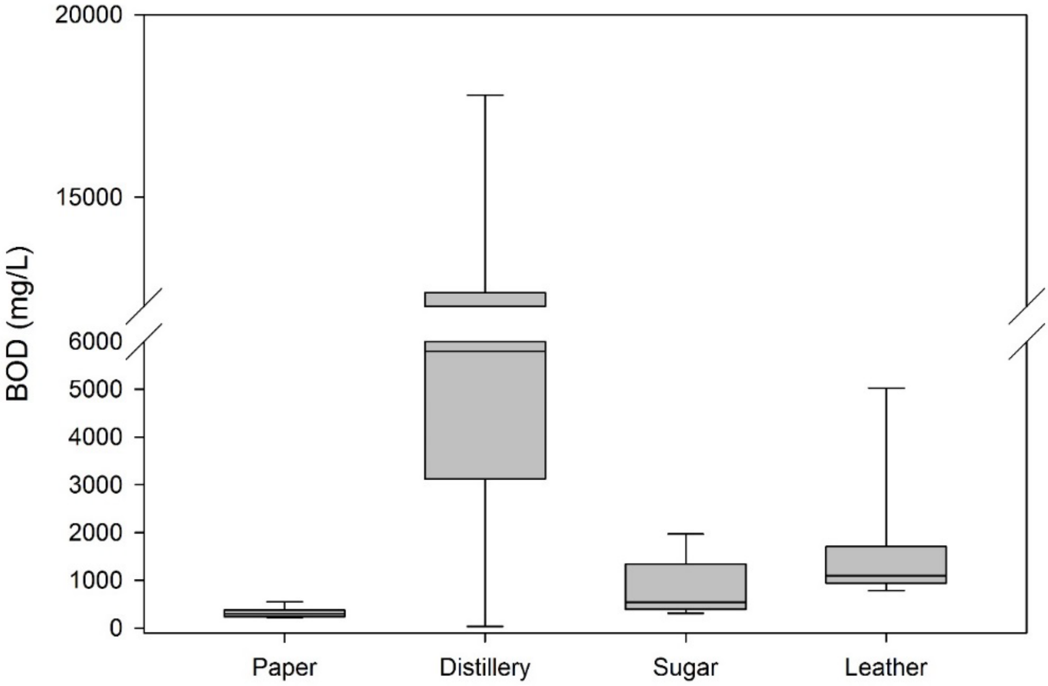


Figure 22 – Biological oxygen demand (BOD) of industrial effluents from the factories located in the Mandalay industrial zone.

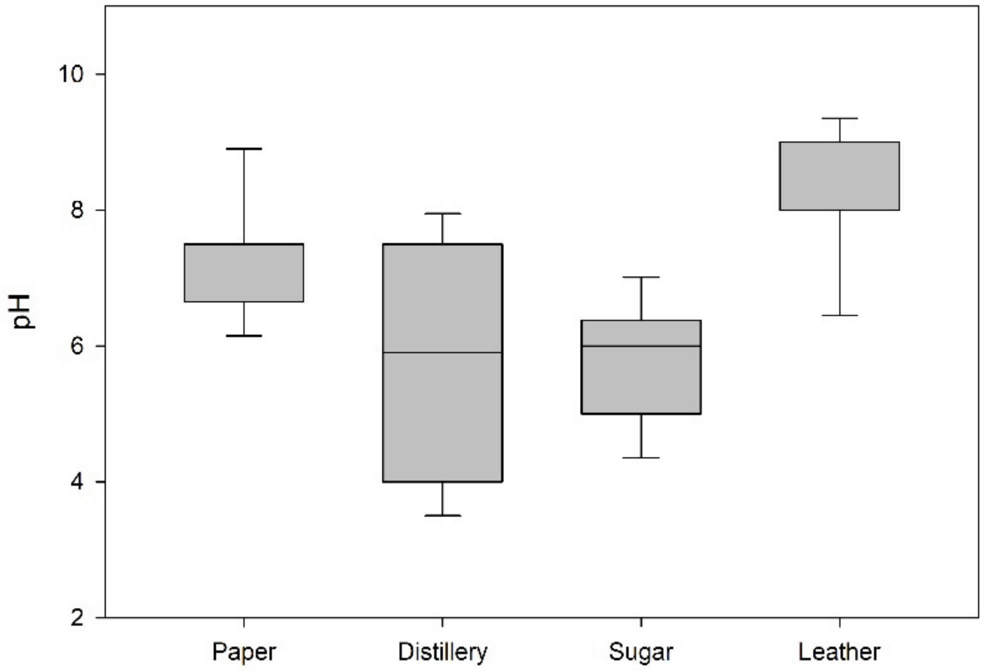


Figure 23 – pH of industrial effluents from the factories located in the Mandalay industrial zone.

Snapshot monitoring in the Dokhtawaddy River receiving industrial wastewater

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 coliforms, 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 coliforms sampled varied between 1000 and 2000 CFU/100 mL) and were well above the 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 14.

3.1.5 Ecosystem health implications

The 10 industrial zones assessed are concentrated in two ecologically important areas of the Ayeyarwady Basin: the Central Dry Zone confluence of the Ayeyarwady and Chindwin Rivers, and 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 which 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 greatest risks for river stretches downstream of Yangon, Mandalay and Sagaing, including the Pyu Lake, Shinmataung and Ayeyarwady-Bagan stretch KBA Like BOD, TSS is an indicator of threat to the aquatic system, and in high concentrations can lead to massive dead zones, where no fish or plant life can survive for long. If the water source is used for higher purposes that serve the food chain, the impacts of high TSS loadings can be severe. While metal pollution loads at these sites were 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. A high formaldehyde load was identified in Myaung mya, 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 in aquatic organisms. High loads of toxic metals, such as copper and lead, could threaten the ecosystem health in Pyu Lake, a small lake in 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 the factories are expected to have acute adverse effects on fish in the dry season, including fish kills. Areas at greatest risk include those down-stream of large industrial facilities or clusters around large urban areas, such as Yangon and Mandalay.

3.1.6 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 are a significant part of the local diet. There is a high risk of metals and other toxic chemicals from industrial effluents bioaccumulating in fish which, 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 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 water, 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, indigo colouring washing powder factory and leather tannery) which discharge waster into the river.

From a human health perspective, the effect of intense BOD on extinguishing microbial populations is of low priority, relatively speaking. However, high levels of organic matter in water be accompanied by severe health issues such as diarrhoea and serious bacterial infections, if left untreated. The size and flow rate of the water body dictate the assimilative capacity to absorb organic matter, as do the nature of the organic loadings. In high population density areas, such as Yangon, BOD is a significant concern.

3.1.7 Recommendations

After the identification of 'hotspot' areas, such as Delta and the middle Ayeyarwady basin to be at high risk from industrial pollution, there is a need to monitor these HEZs to calibrate the model further and perform a trends analysis in sector pollution and area-based pollution over time. This will enable regulators to track the progress in these hot spots and help identify those where efforts are most needed. The industrial pollution projections model needs to be 'filled in' through feedback from industry managers and the development of a plan to collect and integrate actual data into the estimates and analysis on an ongoing basis.

Systematic access and use of this dataset by environmental authorities could guide and greatly facilitate the setting of priorities for the collection of environmental data (monitoring) and for management planning. In particular increased coverage would be most useful in locations of environmental concern, including expanding industrial zones and craft villages. This would serve to focus resources in areas of higher pollution intensity and where calibrating the IPPS model to the local context would be of greatest benefit. Future monitoring efforts would be most effective in sectors where there is a current dearth of systematic pollution monitoring information.

Validation of the IPPS model should be with actual pollution-intensity observations in the basin.

There is a need to prepare pilot pollution profiles and management plans for high priority areas. This action would identify for high priority communes and geographic areas throughout the basin the sectors and plants that need to change, the pollutants to be tackled first. The pilot profiles would initiate a dialogue with the right authorities on alternative methods to be adopted to manage the pollution problems within the existing regulatory and institutional framework and to prepare pilot pollution management plans

To make manufacturing sector based toxic reduction strategies work the government needs to:

- define priority "toxic" substances which must be phased out of all industrial processes.
- categorize all industrial chemical substances for their potential for exposure to workers and the public, or for their inherent toxicity and persistence or bioaccumulation
- promote environmental agreements between HEZs which share polluted natural areas, targeting the elimination of specific toxic pollutants

3.2 Urban sector

The urban population of the Ayeyarwady Basin is 10.8 million. 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 (urban population of almost 5 million). Mandalay (HEZ 3) has the second highest urban population (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) reports a township median population density of 2.2 persons/km^2, increasing to 100 persons/km^2 in the Lower Ayeyarwady (HEZ 4) and 334 persons/km^2 in the Ayeyarwady Delta (HEZ 5).

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 coliforms), petroleum hydrocarbons, inorganic contaminants (e.g., copper, lead and zinc), and synthetic organics.

3.2.1 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 as drinking water, bathing and washing household utensils if the pollutants are not below the relevant guideline levels.

Sewage treatment and processing at urban centres in the Ayeyarwady Basin is not comprehensive. The only sewage system in Yangon is limited to the old business district and serves 40-50% of the population (ADB, 2013). 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.

Water quality data on microbial contamination are very limited within ARB. A report prepared by (ADB, 2016) on the Initial Environment Examination for the 4 hectare plot in the Yangon City reported faecal coliform levels in two wells MW3 and MW4, at 30,000 CFU/100 mL and 500 CFU/100 mL, respectively.

3.2.2 Water pollution assessment in the Ayeyarwady Delta

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 2011-2015, there have been variable results when compared to the water guidelines (Table 14). 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 was within the acceptable range reporting 6.5 to 8.5 (Figure 24 –Hot-spots of pH changes in 10 locations and associated ecosystem health risks within Lower Ayeyarwady and Ayeyarwady Delta). Turbidity levels were above the recommended guideline values at all sites, with Twantay Town (HEZ 5) recording turbidity ranging from 120 to 200 NTU, compared to the 5 NTU considered safe for human consumption and protection of aquatic life (Figure 25).

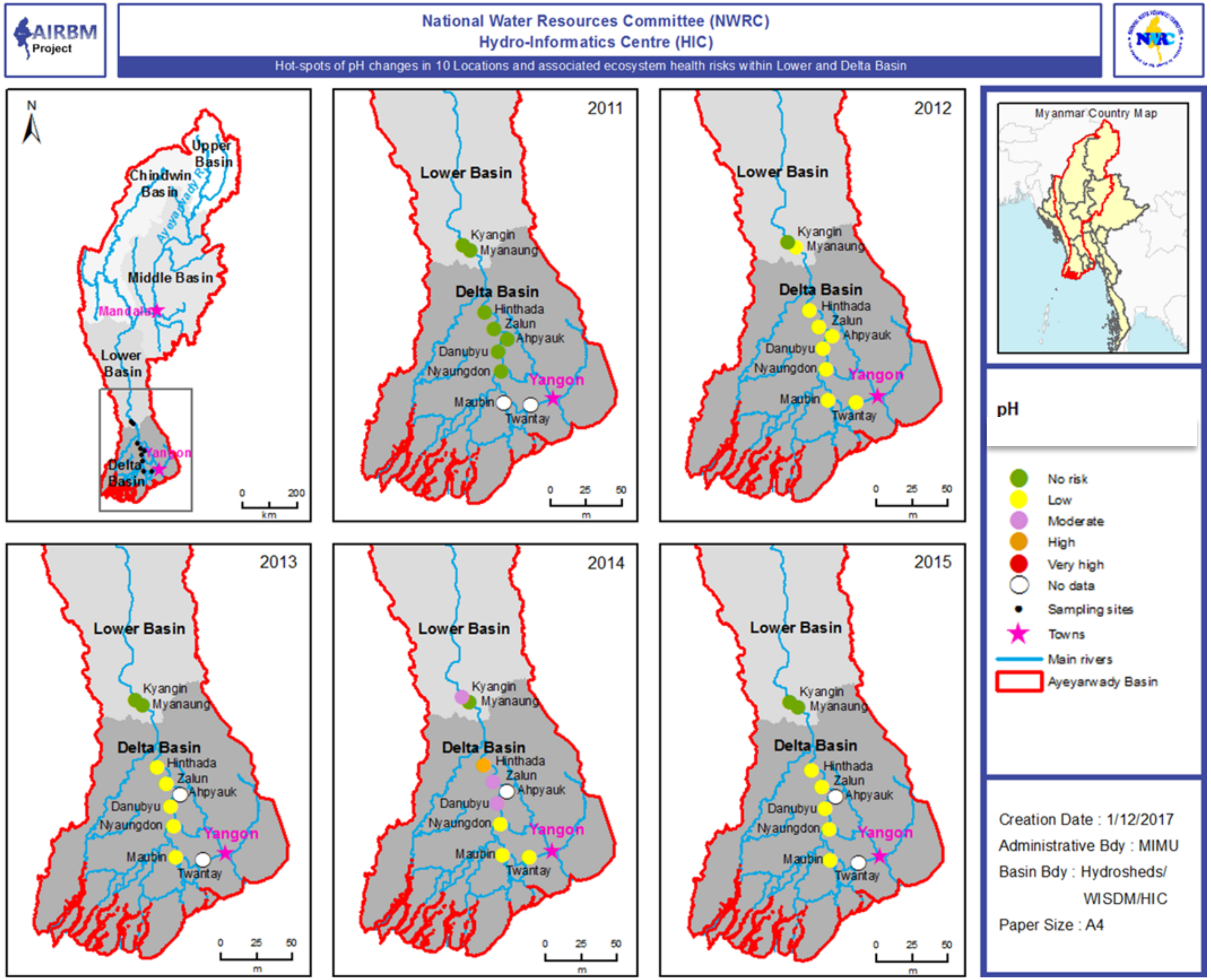


Figure 24 – Hot-spots of pH changes in 10 locations and associated ecosystem health risks within Lower Ayeyarwady and Ayeyarwady Delta.

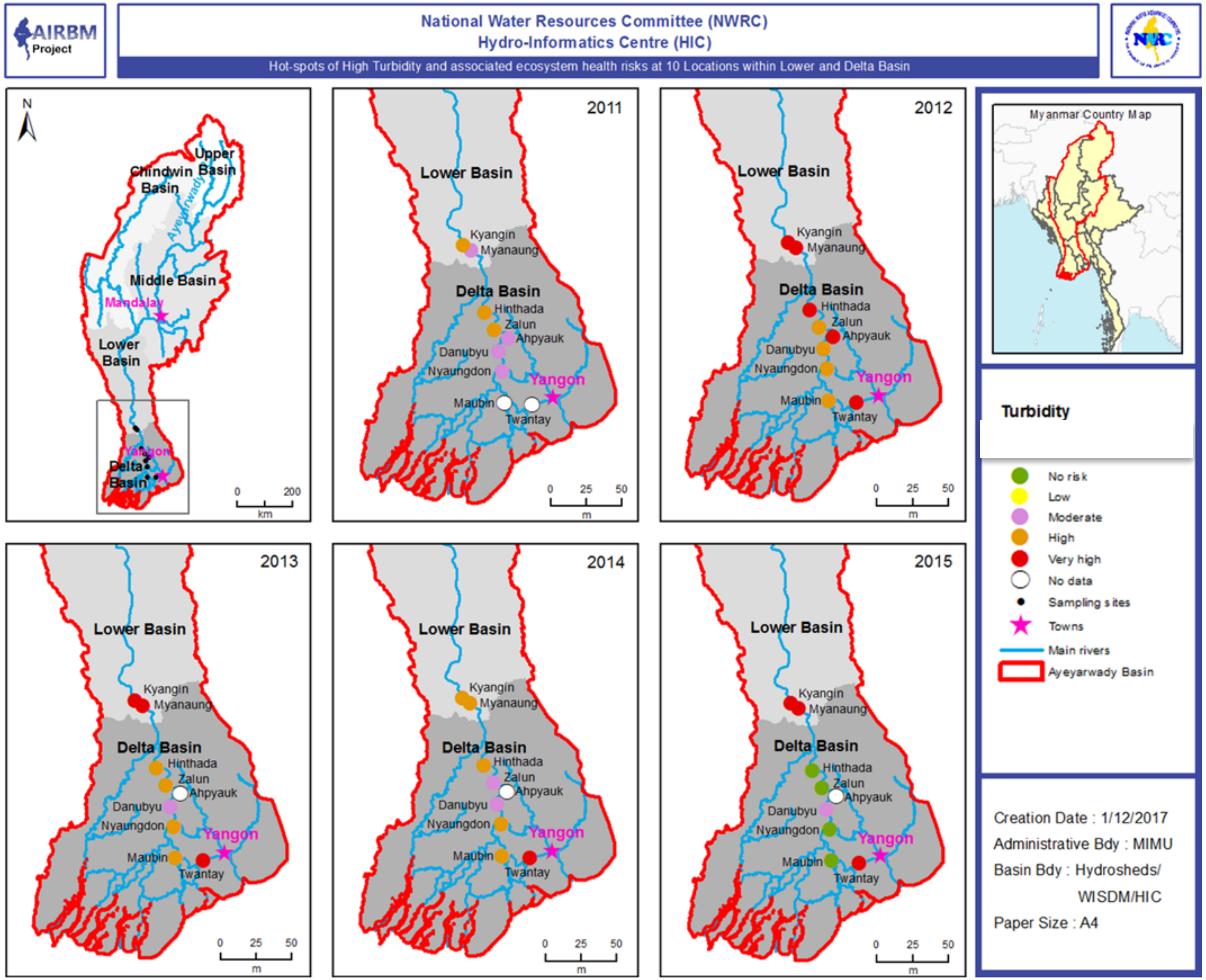


Figure 25 – Hot-spots of turbidity changes in 10 locations and associated ecosystem health risks within Lower Ayeyarwady and Ayeyarwady Delta.

85% of the water samples tested exhibited fluoride concentration above (1 mg/L) and these levels are approaching WHO drinking water quality guideline (1.5 mg/L).

The Integrated Ayeyarwady Delta Strategy (IADS) in 2017 in their atlas have documented a study on water quality in the delta reporting high phosphate concentrations (PO4) in the deltaic water most probably because of lack of wastewater treatment (Tun and New, 2010). Also, high nitrate concentrations were found near settlements indicating that decomposition of home waste disposals has already affected shallow water aquifers near settlements (Hilang et al., 2013). Currently there are no data available on the concentrations of the toxic chemicals in the delta region.

3.2.3 Effluent discharges from the Yangon City Wastewater Treatment Plant (WWTP)

Based on water quality data from Yangon City Development Corporation, in 2016 quality of wastewater treatment plant effluent in Yangon exhibited a temporal variation in BOD load, ranging from 10 to 60 mg/L (Figure 26). However, the wastewater treatment plant was efficient in producing effluent quality with pH from 6.5 to 8.5 before discharging in to the Yangon River (Figure 26).

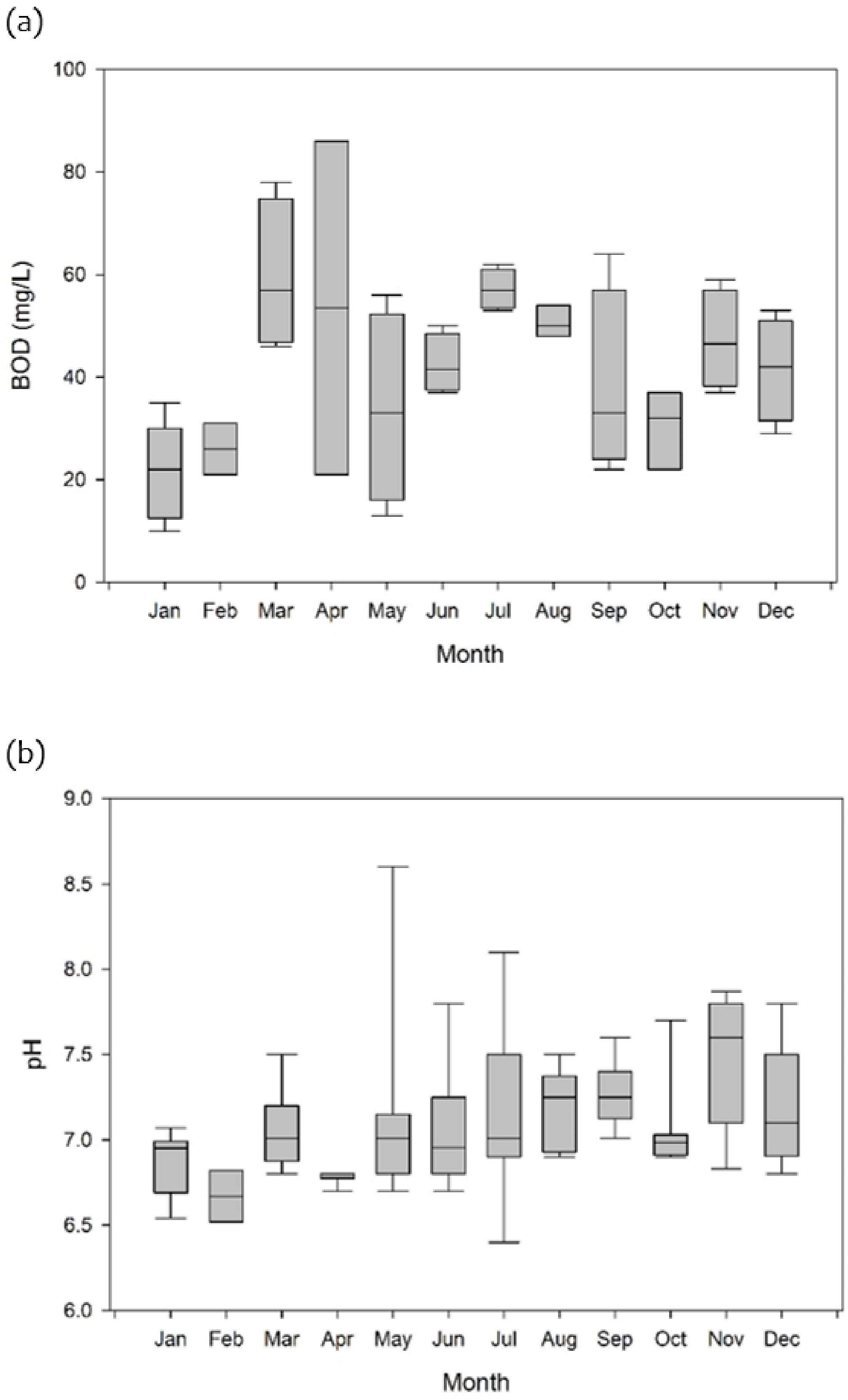


Figure 26 – Monthly variation of (a) BOD and (b) pH in the treated wastewater effluent from the Yangon wastewater treatment plant in 2016.

3.2.4 Snapshot monitoring in Yangon and Mandalay

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 downstream and one upstream site, provided insight into the influence of wastewater discharges into the river. It identified that dissolved oxygen concentration measured at all sites was below 4 mg/L, suggesting very high risk to aquatic organisms (Figure 27). 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. BOD load was recorded at 29 mg/L at the outfall and 22 mg/L at the downstream site, both readings substantially higher than what is considered appropriate for human consumption or aquatic systems (Figure 27). Ammonia levels were also above the guideline values (Figure 28).

In Mandalay, snapshot monitoring was undertaken in August 2017 at the 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 guidelines 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 very high BOD (60 mg/L), low dissolved oxygen (3.3 mg/L), high total coliform (>1000 CFU/100 mL) and high turbidity (75 NTU) (Figure 27).

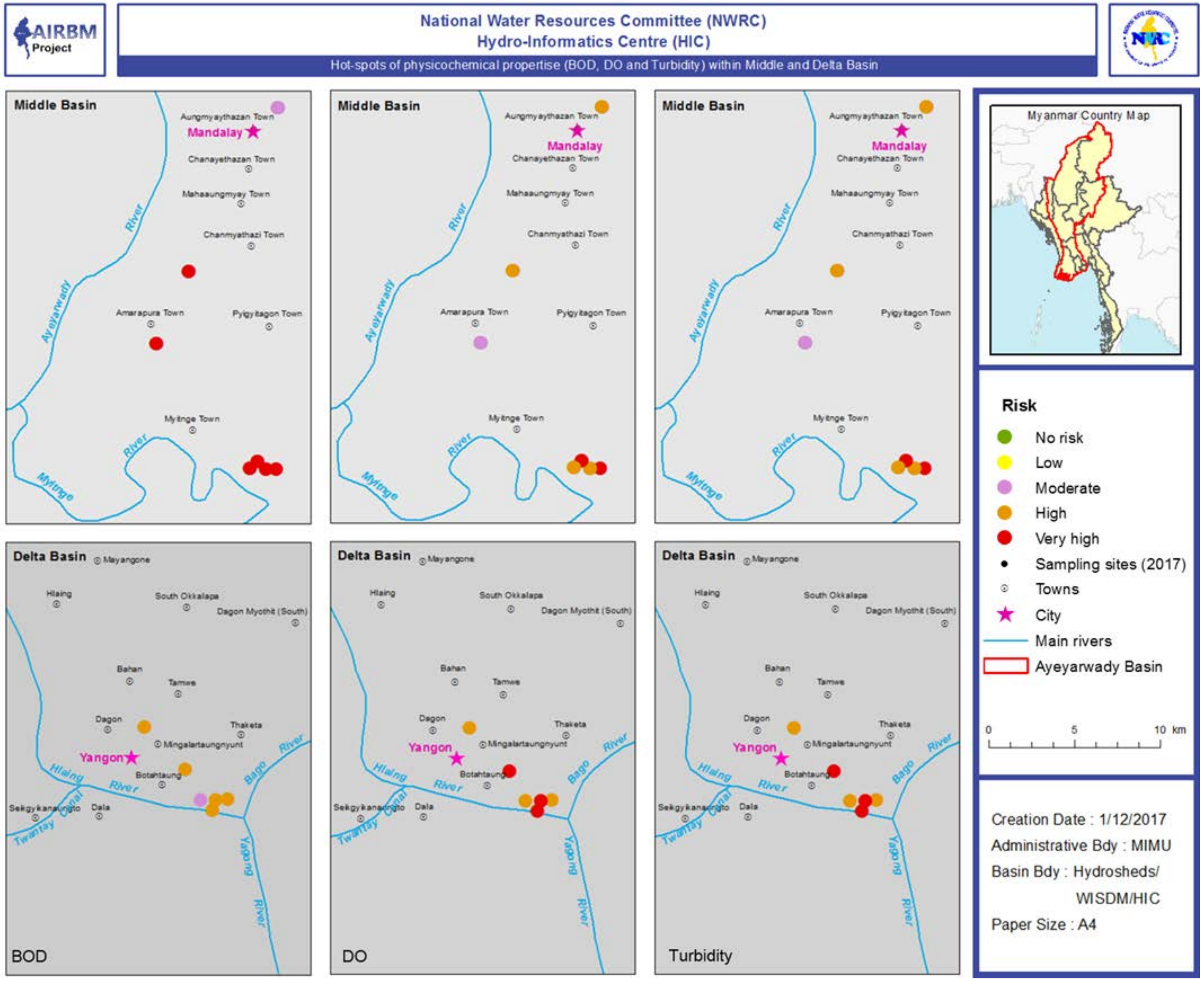


Figure 27 – Hot-spots of dissolved oxygen (DO), biological oxygen demand (BOD) and (turbidity) levels in the Yangon and the Mandalay City.

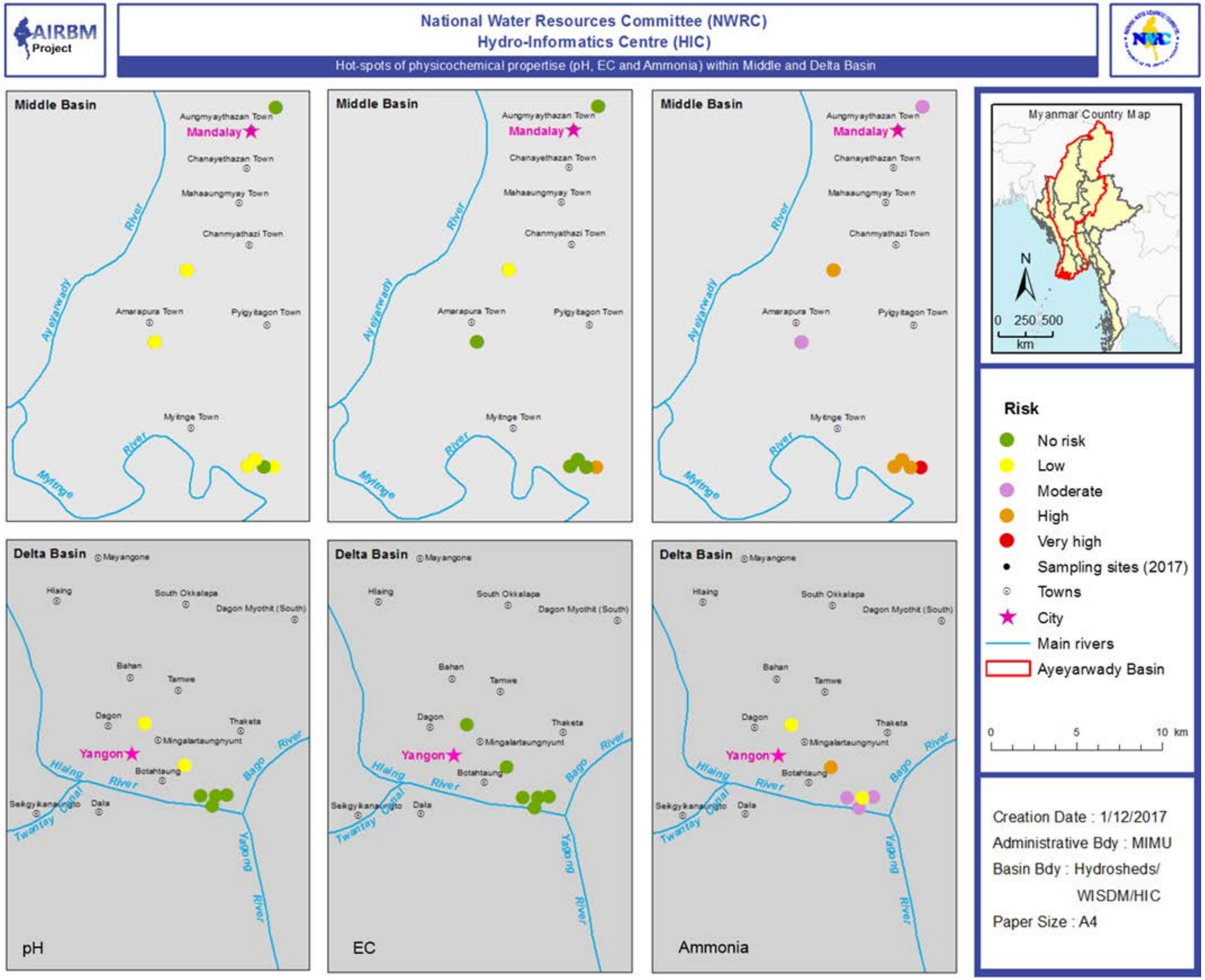


Figure 28 – Hot-spots of pH, EC (electrical conductivity) and ammonia levels in the Yangon and Mandalay City.

3.2.5 Ecosystem health implications

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

With increasing urbanisation in the Ayeyarwady Delta, anthropogenic sources of pollution present moderate levels 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 load.

3.2.6 Human health implications

With the highest population densities, people of the Middle Ayeyarwady (HEZ 3) and Ayeyarwady Delta (HEZ 5) are the most vulnerable to human health issues arising from urban water pollution. Most people in urban areas rely on untreated private water supplies, which are unlikely to meet bacteriological guidelines for drinking. An additional risk is arsenic contamination, which occurs in the groundwater of the Ayeryarwady delta (ADB 2013).

The reliance on untreated private water supplies which are unlikely to meet bacteriological guidelines for drinking presents significant health risks to urban populations. High faecal coliforms (> 1000 CFU/100 mL) in the Yangon River and in the urban stormwater drain of Mandalay highlight potential issues in the densely populated urbanised areas if water is not treated.

In Myanmar, improvements in access to safe water and adequate sanitation have been reported. However, diarrhoea remains among the top five causes of death and among children under five. In addition, 22.6% children under the age of 5 years are underweight and infant mortality rate is equal to 67.24 deaths/1,000 live births. This situation indicates the need to further investigate how “safe” the drinking water is and how “sanitary” the sanitary facilities that people accessed. WHO stated that 88% of diarrheal diseases is attributed to an unsafe water supply and inadequate sanitation and hygiene (WHO, 2004). 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.

3.2.7 Recommendations

Adequate sanitation promotion (e.g., education and training of citizens most at risk, and increasing treatment, maintenance and infrastructure) is strongly recommended to protect both health and the environment. We need more information/monitoring for the full assessment of the condition at basin level.

The following recommendations are proposed for future investigations:

- Where there are high levels of heavy metal contamination, possible local sources of contamination should be investigated with a view to managing the contamination.
- For human health risk assessment, arsenic speciation and bioavailability are critical and should be determined as arsenic species vary in their toxicity and bioavailability. This may also apply to other contaminants (e.g., chromium)
- Contaminants can also enter the food chain from natural or anthropogenic sources and uptake by plants and crops from groundwater used for irrigation. This study focussed on human health risk assessment based on the drinking water as a source of exposure to the contaminants. All exposure pathways/sources should be integrated to assess the potential ecosystem and human health risks.

3.3 Mining

In 2014-2015, mining accounted for 1.2% of gross domestic product 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 particularly prominent in the Upper Ayeyarwady (HEZ 1) and Chindwin (HEZ 2) (Figure 29). 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-silver) and Monywa (copper) in the Ayeyarwady Basin. While Htigyaing has the only nickel mine in current operation, pebble and sand mining is increasing in the large rivers like the Ayeyarwady and Chindwin.

Mining and production practices in Myanmar are in general small-scale and labour intensive. The mining industry still relies on dated geological data, which often results in imprecise resource estimates and grades. Much of the country still requires geological mapping and exploration using contemporary techniques.

The potential for Myanmar's mining industry has recently been highlighted by the rapid growth in tin production Myanmar is now the third largest global tin producer, after China and Indonesia, producing over ten per cent of the worlds mined tin (Gardiner et al., 2015). Myanmar is on the verge of a mining boom with many as yet untapped primary and secondary minerals. The challenge for Myanmar is how to access these natural resources in a manner (e.g. effective policies and regulations and community acceptance) that ensures growth is sustainable and important natural and cultural resources are conserved for current and future generations. If appropriate measures are not taken to proactively manage and monitor the expansion of the mining sector there is potential for economic growth to be threatened (e.g. decreased international investment and exports) and irreversible impacts occur to human and environmental health.

Despite obtaining high-resolution information on the likely zones of mining disturbances in the ARB, this program has been unable to access individual mine sites, government agencies dealing with mining or associated industries. As such, point-source production figures (from individual mines), processing technologies and expected environmental pollution loads at both the union level and more specifically with the ARB are unavailable. Union-level data are available on the total number of registered ferrous and non-ferrous mines across the country, however, no sub-regional data are available. The results show that there are large increases in overall mine numbers (from 19 to 2,943) between 2000 and 2015. It does however appear unlikely that there were only 19 mines in the whole country in 2000 (Government of Myanmar, 2016)In lieu of this information, the following sections of this report outline the environmental impacts that may occur due to major mining and extractive operations in sensitive ecosystems in Myanmar.

3.3.1 Gemstone mining

Myanmar is recognised globally for high quality gemstones such as rubies, jadeites, sapphires, peridot and spinel. The mining of gem stones can have significant environmental, social and cultural impacts. Alluvial deposits, where gemstones have been transported from their original parent rock by weathering into streams and rivers, are the source of most of the gemstones that have been mined in Myanmar. In recent years, new technologies are increasing being used more to penetrate primary deposits and increase the footprint (impacts) of mine sites.

The majority of gemstones in Myanmar are sourced from artisanal and small scale mining operations. Small-scale operations in theory have a smaller environmental footprints than larger mines; however, when there is a large number of poorly run mines in a small location there is potential for significant environmental impacts to occur at local and regional scales, especially in ecological sensitive areas. The washing of gemstones in rivers and streams can erode river banks and pollute water ways with silt and sediment thereby impacting aquatic habitats. The influx of labourers into highly environmental sensitive areas can have significant impacts on soils, waterways and forests e.g. deforestation (e.g., fire wood and timber for mines), loss of biodiversity (e.g. hunting for food), weed invasion, and soil and water pollution (e.g., oil spills, etc.).

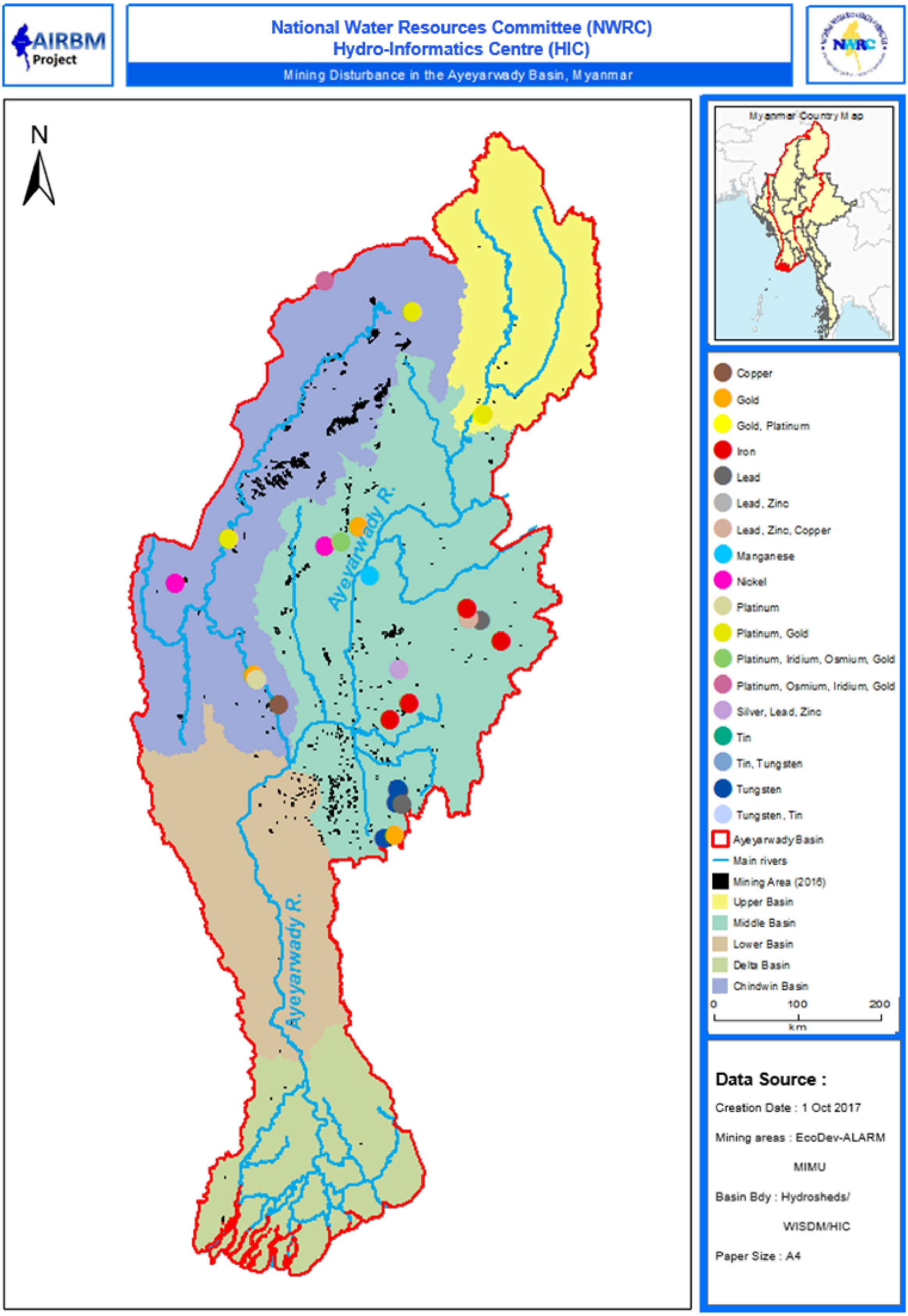


Figure 29 – Distribution of mining activities in the Ayeyarwady Basin.

(*Government of Myanmar, 2016*)

Erosion and siltation of the river is accelerated by gemstone mining activities and can damage habitats, reduce oxygen availability for aquatic species, and affect water temperatures leading to a loss of biodiversity (DeLeon, 2008). Since the ecological structure of the river is much of what allows it to provide food and a clean, continuous supply of water for local people and animals, the effects of changing this structure can be disastrous. The growth of gem mining to larger operations could have significant impacts on land and water environments, if not adequately managed. For example, environmental impacts (e.g. erosion, siltation and sedimentation) from gemstone (e.g., rubies) mining is known to occur on rivers and streams in the north western regions of Myanmar (DeLeon, 2008). Large amounts of waste rock could also lead to air pollution (e.g. dust) and water contamination through acid rock drainage.

If the continued development in gemstone mining is not managed in sustainable manner there is potential for significant environmental, social and cultural impacts to occur as experienced in other countries such as Sri Lanka, Vietnam and West Africa (Merem et al., 2017; Dissanayake and Rupasinghe, 1996; Mekong River Commission State of the Basin Report, 2010).

3.3.2 Gold mining

Gold mines can be open-pit or deep shaft and depending on the geology and location can range from artisanal & small-scale to large-scale scale operations. Surface mines produce significantly more waste than subsurface operations because of the greater amount of topsoil, overburden and waste rock that has to be removed and managed. The location of mines and quality of ore will determine the type of mining process to be used in extraction and the amount of wastes that will be generated.

Gold mining can result in significant impacts on the environment including deforestation, soil erosion, loss in biodiversity, acid mine drainage and contamination of surface and ground waters by cyanide, mercury and other toxic metals (e.g. Omotola Fashola et al., 2016; Abdul-Wahab and Marikar, 2012). Tailings and waste waters are major products from gold extraction that can contain high amounts of contaminants such as copper, zinc, nickel, cobalt, chromium, mercury, cyanide, and sulfate ions. Mercury is commonly used by artisanal and small-scale gold mining operations for the separation of gold from the mineral bearing rock to form an amalgam (Omotola Fashola et al., 2016; Telmer et al., 2006).

Gold is also commonly extracted/leached from ores using cyanide by converting the gold to a water-soluble complex (Kuyucak and Akcil, 2013). Environmental pollution from gold mines is associated mainly with the release of harmful chemicals such as mercury from tailings into aquatic and terrestrial ecosystems. Sulfidic mine tailings may also generate acidic-metal-laden waters that can have significant environmental consequences for generations (Dold, 2014). For example, artisanal and small-scale gold mining operations have been shown to have significant environmental impacts such as deforestation, sedimentation, and surface and ground water contamination in countries such as Ghana, Kenya and Brazil (Hilson, 2002; Ogola et al., 2002; Pfeiffer et al., 1993).

Tailings dam beaches from gold mining operations (WISE, 2016) have resulted in large scale toxic waste releases to aquatic and terrestrial ecosystems and significant human and environmental health effects, e.g., Mount Polley mine, British Columbia, Canada (2014); Karamken, Magadan region, Russia (2009); and Zhen'an County, Shangluo, Shaanxi Province, China (2006). The partial tailings dam breach at the Mount Polley gold and copper mine in British Columbia in 2014 resulted in the release of approximately 10 million cubic meters of contaminated water and 4.5 million cubic meters of slurry into Polley Lake. The spill poisoned water supplies, killed fish, and harmed local tourism. The economic, environmental and social impacts will be felt for generations.

3.3.3 Impact of mining on forest ecosystems

Myanmar is one of the most forested countries in the region with a cover of approximately 42,366,000 ha (63% of Myanmar) (Bhagwat et al., 2017). Myanmar's remaining dense intact forests are found mostly in the far north and south of the country, connecting to other extensive forests in India and Thailand. These forested areas are considered biodiversity hotspots (Myers et al., 2000), that support numerous important and endangered species, including tigers (*Panthera tigris*), Asian elephants (*Elephas maximus*), Gurney's pitta (*Pitta gurneyi*) and Asian tapir (*Tapirus indicus*) (NBSAP, 2011). Many new species have also been identified in these areas, such as mammals, including the leaf deer (*Muntiacus putaoensis*) and the Kachin woolly bat

(*Kerivoula kachinensis*); several new species of frog (such as toad, *Duttaphrynus (Bufo) crocus*); and new species of reptiles, the Mandalay spitting cobra (*Naja mandalayenis*) (Bhagwat et al., 2017; NBSAP, 2011).

Between 2002 and 2014, intact forests in Myanmar declined at a rate of 0.94% annually, totalling more than 2 million ha of forest loss (Bhagwat et al., 2017). Drivers of deforestation include agriculture, legal and illegal logging, and various types of mining. The opening up of forested areas to small- and large scale mining will have significant directs and indirect impacts on forested ecosystems and local communities.

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 km^2 in the Ayeyarwady Basin, much of which is in the Chindwin Basin (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.

Mining is a major contributor to economies and livelihoods around the world, particularly in developing countries (Langston et al., 2015; Kotsadam and Tolonen, 2016). However, the economic benefit can be quickly offset by negative direct and indirect economic, social and environmental impacts on forested ecosystems (Figure 30).

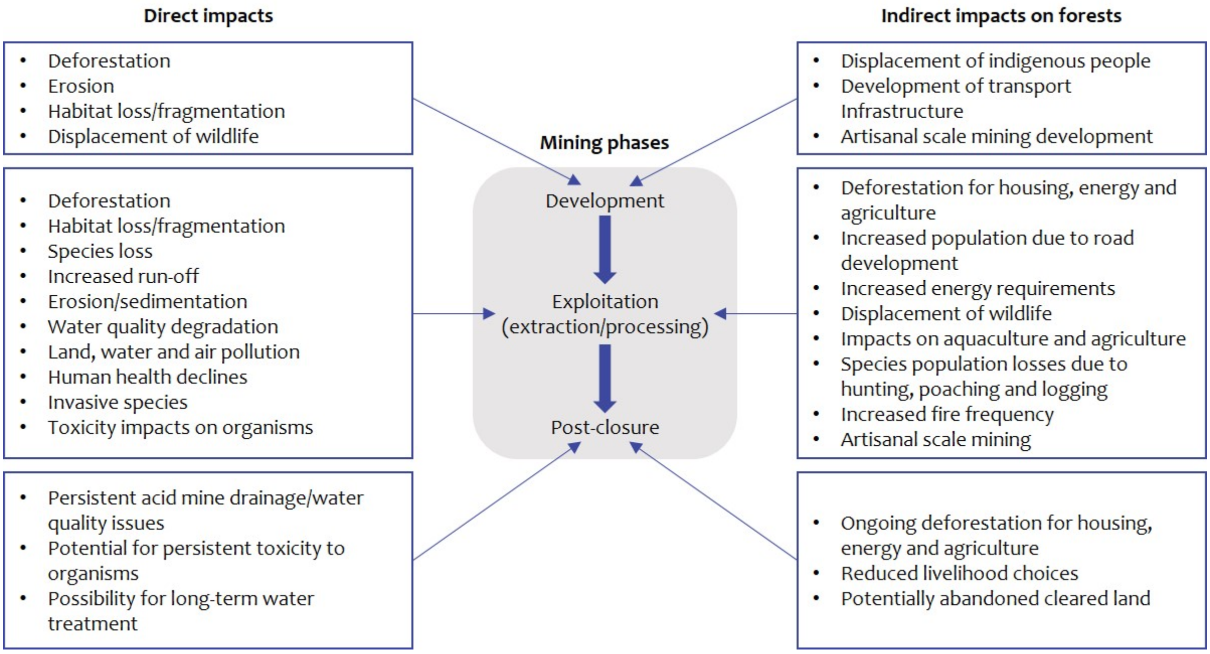


Figure 30 – Direct and indirect impacts on forests and forest based communities from mining activities.

3.3.4 Mining pollution in the Ayeyarwady Basin

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 hot-spots. This is important in the context of pollutant transport, because 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 (and typically contain high contaminant loads such as copper, zinc, nickel, cobalt, chromium, mercury, cyanide, and sulfate ions). However, data limitations currently constrain the assessment of mining related to 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.

3.3.5 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 the biota. Copper, zinc, manganese and nickel, high BOD and turbidity in the river water due to mining activities poses moderate to high risk to ecosystem health. Water contaminated with high concentrations of metals, sulphide minerals, dissolved solids, or salts can negatively affect surface water quality, aquatic ecosystems, and groundwater quality. Impacts on aquatic life can include increased mortality, health or reproductive problems, and a reduction in the number of species present. Impacts on human health can occur where the quality of water supplies used for irrigation, drinking, and/or industrial applications is affected.

Gold and sand mining have serious ecosystem implications for ground-nesting birds, freshwater turtles and fish community. High turbidity, due to mining increasing sediment inputs into the river, eliminates spawning areas and reduces food availability of the benthic fauna. Decline in the population of water birds is also related to sand and mineral mining in the Upper Ayeyarwady (HEZ 1) and Chindwin (HEZ 2) Basins. Fauna in the KBAs in the Upper Ayeyarwady could also be at very 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, threatens sediemntpopulations 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.

3.3.6 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) Basins.

A 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 potential impacts of these on human health within the Upper Ayeyarwady (HEZ 1) and Chindwin (HEZ 2) Basins. Microbial contamination in the Uyu River also highlights localised risk to people.

3.3.7 Recommendation

Water contamination can result in a need for water treatment or the adoption of a different water source. Environmental monitoring programs and water management strategies are urgently required by mining companies in Myanmar to assess and minimize the impacts of water contamination.

Mining has been shown to have a significant impact on forest ecosystems in a number of countries and regions, including Indonesia, Brazil, Ghana, the Peoples Republic of Congo, and Peru (Chatham House, 2015). Although individual mining companies are often required to perform environmental impact assessments and develop rehabilitation plans, they are often inadequate and do not assess cumulative impacts, regulations and policies vary between countries and regions and there is little monitoring or enforcement

In the short-term, Myanmar will likely rely heavily on its natural resources (including oil and gas reserves) to boost its economy, and to provide energy and livelihoods for its population. However, if unchecked industries such as mining have the potential to negatively impact many environmental assets (e.g. forests, soils and water catchments) that can affect the economy and human health for current and future generations. There needs to be increased national leadership on the development of policies and regulations and appropriate monitoring and enforcement to ensure sustainable growth and protection of natural assets and human and environmental health.

A monitoring program to measure trace metal levels in water, sediment and biota should be implemented to assess the risk of mining activities on ecosystem and human health. In general, studies on heavy metals can be important in two main aspects: 1) the public health point of view, and 2) the aquatic environment point of view. Heavy metals are present in the aquatic environment where it can accumulate along the food chain. Moreover, small amounts of adsorbed heavy metals are either stored in a metabolically available form for essential biochemical processes or detoxified into metabolically inert forms or held in the body either temporarily or permanently. Consequently, small fish and prawns in polluted aquaculture will become contaminated with the accumulated substances. Predatory fish generally displays higher levels than their prey. Eventually, humans consuming the fish and prawns, inevitably suffer from the results of bioaccumulation of contaminants taking place at each trophic level. For this reason, determining the chemical quality of aquatic organisms, particularly their content of heavy metals, is extremely important to human health.

It is recommended that sampling should be done during wet and dry seasons to assess effects of temporal variation in heavy metal distribution in rivers associated with mining activities. Biological samples, water and sediment samples should be collected together in an area that is polluted and in other areas where the level of pollution is expected to reflect undisturbed waterways. This will help scientists observe and interpret accumulation of metals and compare them with the concentration of pollutants at different locations. The importance of characterising heavy metal pollution in the river system is increasing, as aquaculture is growing in Myanmar due to fish making up the bulk of the population’s protein intake.

3.4 Agriculture

In 2015-16, agriculture, including crops, livestock and fisheries, contributed 28.6% to 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 hectares of agricultural land in the Ayeyarwady Basin, a 13% increase since 2003, mostly located in the Lower Ayeyarwady (HEZ 1), 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 is unavailable, the most generous approximation of use in Myanmar is 306,000 tonnes per annum, or approximately 15 kg/ha. 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 tons (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 and regions, but mainly in Ayeyarwady Delta and Yangon, whereas shrimp pond are only located in the Ayeyarwady Delta.

3.4.1 Use of Pesticides in Myanmar

Myanmar’s agriculture has (to recent years) involved comparatively low use of pesticides. However, this rapidly changed, with high imports and large increases in application rates. Official statistics reflect a 1,000% increase in quantities applied between 2005 and 2010 (Government of Myanmar, 2012). Current pesticide application levels are beginning to approach those of other countries in the region. However, imported pesticides are poorly documented, barely regulated, and not well understood by the farming population. This is likely to lead to problems of operator health impacts, environmental contamination, and ecological disruption in the long-term. More effective pesticide regulation is needed to avoid long-term costs to the sector and to the health of farmers and consumers (Raitzer et al., 2015b).

A considerable portion of the formulations are indigenously compounded from imported technical grade active ingredients (TC) and various companies engage in import and formulating activities. These include international companies such as Syngenta, Bayer Crop science, Dow AgroScience, Dupont and Sumitomo. In addition, several local companies are active in the market. Approximately 90% of the products are imported by local Myanmar companies, the balance imported by multinational agrochemical companies. Products from multinational companies are approximately 30-40% more expensive than products from Myanmar companies. From 2006 to 2009, importation varied from 4,000 to 6,000 tonnes, whereas after 2011 importation stabilized at around 10,000 tons. The volume and percentage of herbicides steadily increased while that of insecticide decreased thereafter. This fast change can be ascribed to massive importation from China and poor supervision of imports crossing the Myanmar border.

Trends in pesticide use and Import

The pesticide consumption data for Myanmar indicate that national usage was very low compared to many neighbouring countries. Values in tonnes (t) are: fungicides (633.45 t); herbicides (142.57 t); others (including plan growth regulators and fumigant) (250.00 t). A detailed breakdown of the import of pesticides is shown in Figure 31. The agricultural sector is where 90 percent of total pesticide use occurs (Annex IV). Pesticides are also in Myanmar including ARB for growing vegetables and fruit (Annex V). Many years ago, organochloride pesticides such as aldrin, endrin, lindane, and dichlorodiphenyltrichloroethane (DDT) were used for agriculture and public health purposes, but this has ceased. There are now plans to ban endosulfan, the last organochlorine compound being used in Myanmar. Among insecticides, chlorpyrifos and acephate are the top two imported insecticides (Table 23).

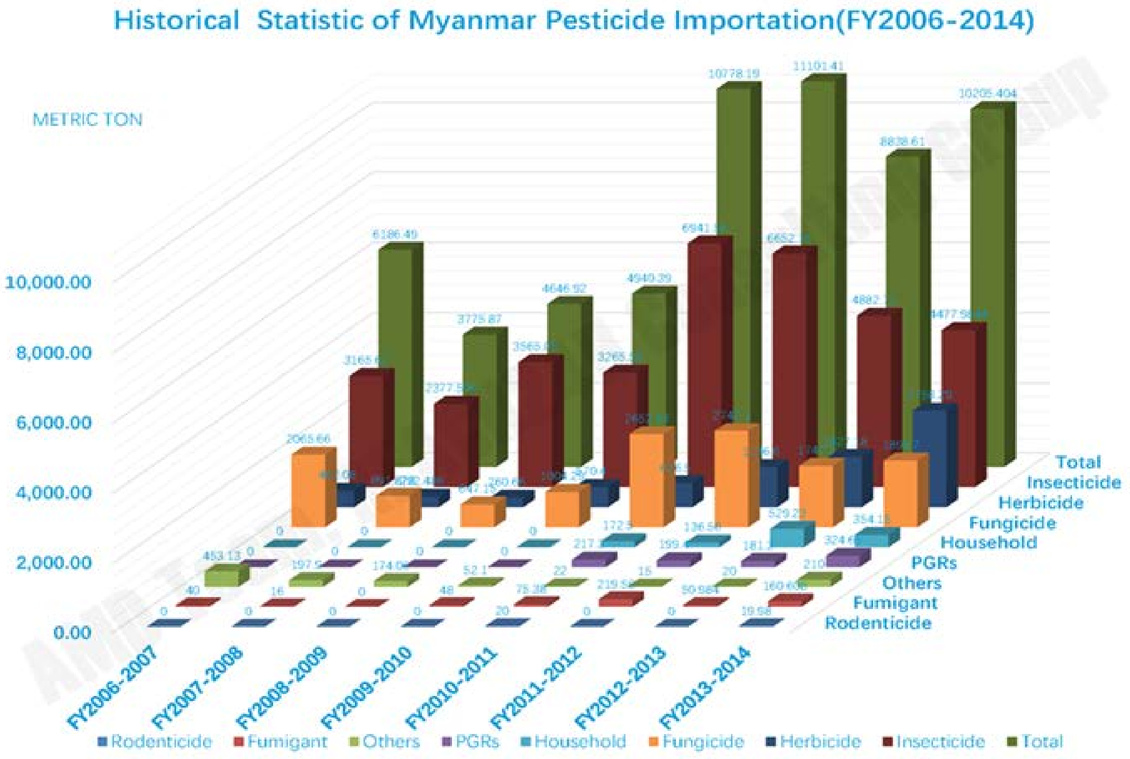


Figure 31 – Myanmar, trends in pesticide use and imports, 2006 to 2014 (*Source: Fang, 2017*)

SEASONAL APPLICATION PATTERNS

In the monsoon paddies, insecticides, herbicides and fungicides used by farmers is known, but their use of molluscicides or rodenticide is not reported. The percentage of growers using insecticide was <20% and, for herbicides, <6%. In comparison, the percentage of users and average cost for both insecticides and herbicides were lower for dry season cropping. The second largest crop after paddy, pulses have a shorter growing period than rice and are thus more able to accommodate shorter wet periods. They are grown more densely in regions with hasher climate conditions, including regions where rainfall is characteristically erratic. Pulse production constitutes an important source of revenue and the percentage of users and average costs are quite high and varied among regions. Maize, despite its growing importance, is still a minor crop in Myanmar. Total maize area was only 10% of pulses area and 6% of rice area. Herbicide use was almost none and large amount of the labour was for weed control. Groundnut possess the largest user percentage and expenditure of the top 3 oilseeds and the percentage of insecticide users ranged from 61 in river area to 14 in dryland area for sesame. Refer to Annex IV and Annex VI for detailed seasonal use statistics.

There are no existing pesticide monitoring data to assess the contamination of rivers in ARB due to pesticide and fertiliser use. The most commonly used pesticides in paddy are organophosphates and organochlorines, particularly dimethoate, phenthoate and endosulfan (Annex VI). Tomatoes, cabbages and cauliflowers are the top three vegetables grown in Myanmar (Annex V). To control insects in cauliflower crop, farmers generally apply insecticides such as cypermethrin, chlorpyrifos and monocrotophos. Imidacloprid is used to control thrip in green gram crop (Appendix VI). Insecticides are used by 50% of the farmers for dryland and irrigated off-season rice production in Sagaing region (Annex VII). Organophosphate pesticides such as malathion, diazinon, profenofos and chlorpyrifos are registered for use in Myanmar (Appendix VIII).

Table 23 – Highest-volume pesticides imported to Myanmar (Tonne, t). *(Adapted from Fang, 2017)*

Insecticides		Herbicides		Fungicides	
Chlorpyrifos	859	**Glyphosate**	407	**Mancozeb**	535
Acephate	847	**2,4 D Amine salt**	257	**Benomyl**	370
Cypermethrin	797	**Pretilachlor**	135	**Sulfur**	347
Carbofuram	687	**Fomesafen**	60	**Carbendazim**	263
Lambda-Cyhalothrin	665	**Quinchlorac**	40	**Propiconazole**	190
Dimetoate	454	**Paraquat dichloride**	36	**Metalaxyl**	175
Chlorpyrifos + Cypermethrin	345	**Altrazine**	35	**Copper hydroxide**	134
Imidacloprid	310	**Quinchlorac + Fenoxyprop-P-ethyl + Pyrazosulfuron**	35	**Kasugamycin**	124
Abamectin	202			**Dimethomorph**	70

3.4.2 *Aquaculture in Myanmar*

Aquaculture poses the following contamination risks to the quality and values of water resources:

- increase in nutrients, organic material, pathogens, pharmaceuticals and suspended solid concentrations
- vegetation loss adjacent to waterways and wetlands
- loss of embankments and pond contents during storm events
- release of exotic species from different genetic populations into local waters threatening the local aquatic ecology
- turbid stormwater from earthworks during pond construction
- pond discharges with increased salinity resulting from solar evaporation effects

Myanmar's inland fisheries yielded 2.24 million metric tons in FY2012 – approximately half of the national fishery production (i.e., from coastal waters) Raitzer et al., (2015b). Major fish species cultured include Roho (*Labeo rohita*), Catla (*Catla catla*), Common carp (*Cyprinus carpio*), Grass carp (*Ctenopharyngodon idellus*), Mrigal carp (*Cirrhinus mrigala*), Silver carp (*Hypophthalmichthys molitrix*), Tilapia (*Tilapia* spp.), Striped catfish (*Pangasius sutchi*), Philippine catfish (*Clarias batrachus*). Recently, Ministry of Livestock and Fisheries successfully cultivated another three species of freshwater fishes, namely *Piratus branchatus*, clown knifefish (*Notopterus chitala)* and giant gouramy (*Osphronnemus gouramy*).

Fingerling production

Government hatcheries in 2004 to 2005 produced about 5,868 million freshwater fingerlings. The main species were roho (434 million), common carp (58 million), grass carp (6 million), catla (5.5 million), mrigal (7 million), tilapia (12 million), silver carp (3 million), big head (2 million), catfish (1 million), striped catfish (16 million), tapian (41 million) and freshwater pomfret (2.5 million). In 2004 to 2005, DoF replenished 109 million fish seed into reservoirs and dams, 63 million fish seed into lakes and rivers, and 0.7 million fish seed for national organizations. There were are 59 million fish seed supplied to governmental organizations to replenish rice fields and natural water bodies to increase inland fish production and to maintain a sound biodiversity balance. In 2002 to 2003, DoF replenished 236.5 million fish seed (113% of target) into dams, reservoirs and natural water bodies.

The main group of ornamental fish produced are cyprinids. The common names of exported ornamental fishes are pearl danio, spotted danio, Stoliczka's barb, pink microrasbora, emeraid dwarfrasbora, Sawbwa rasbora and (Asian rummy nose), all of which are exported by the fish trading aquarium companies under control of Department of Fishery, DoF.

Belton et al. (2005) surveyed aquaculture enterprises in Myanmar using satellite images. They Identified and catalogued all pond clusters in every township in the delta region (Ayeyarwady, Yangon, Bago), focussing on freshwater aquaculture only. Their findings on farm logistics were: In terms of production volumes, aquaculture was dominated by large scale operations – from the low 100s-1000s of acres; there were also large numbers of 'medium-sized' farms, from 5-50 acres, including integrated poultry-fish operations; there existed several specialized seed production hubs with private hatcheries and large numbers of nurseries (mainly 1-5 acres); there were ~200,000 'backyard' ponds (whose main purpose is drinking water supply, but increasingly stocked with fish), the existence of these small and medium operations being rarely recognised or considered (though of great importance to individual resident groups). Among their conclusions were:

- Aquaculture in Myanmar has grown rapidly despite an unfavourable policy environment which increases the cost of adoption and, in some areas, prevents it completely
- Aquaculture practiced on a small and medium scale is more widespread than generally recognized – this is a testament to how attractive it is to farmers
- Commercial aquaculture is a high value activity, which can be viable at small/medium scale, and contributes to food and nutrition security goals
- Demand for farmed fish will continue to grow as incomes rise, capture fisheries output declines, and markets become better integrated
- As Myanmar's economy grows and urbanizes, rice will account for an increasingly smaller share of food expenditures, and fish will account for more. Aquaculture will account for an increasingly large share of the fish consumed.

A summary of Win (2004): The dominant species cultured is Rohu. Most farmers practice polyculture, using major carps, and common carps. Farmers in upper Myanmar prefer to stock fingerling 2 to 5 cm but those in lower Myanmar especially in Yangon and Ayeyarwady Division, prefer stocking yearlings of 12 to 15 cm so that the fish can reach marketable size in a short time. A common practice is to put 3,000 yearlings into an acre of pond. Culture period is 10-12 months and the average yield 5 tons per acre (or 12 tonne per hectare). The most successful culture industry is found in Twantee Township, near Yangon where 50% of the total fishpond area is situated. The sizes of the ponds vary from four to eight hectares with an average water depth of 1.5 m. Tilapia cage culture has been demonstrated successfully by DOF in the Ayeyarwady River in Magwe Division, situated in the dry zone where there is not only poor soil condition but also scarce water resources for fish culture. Altogether over 300 cages of 5 x 5 x 3 m size are stocked with 2,000 fish seed per cage. One company, the Yuzana Company has cage culture operations in Ayeyarwady River in the Delta region. *Pangasius* species are grown in cages of 2 x 8 x 8 m at a rate of 110,000 fish 10 cm size per cage.

In conclusion, inland fisheries deliver half of national fishery production. Most of this production comes from large facilities in excess of several hundred acres in area. Half of the national fishpond area is in Twantee Township, near Yangon. As would be expected of a fish-eating nation, some fish raising is part of many landowners' enterprises, even if it is only for subsistence. The future will see more fish consumption, higher prices for fish, and aquaculture delivering an increasingly large share of production.

3.4.3 Water quality data from aquaculture ponds in the Delta Ayeyarwady

Monitoring data collected from 2014 to 2016 from aquaculture ponds as part of this project are summarised in Figures 32-34. Dissolved oxygen concentrations were in the healthy range for samples from 2014 and 2015, but in 2016 the risk of anoxia was greater, with more than 50% of the values below the minimal health guideline of 5.0 mg/L (Figure 32).

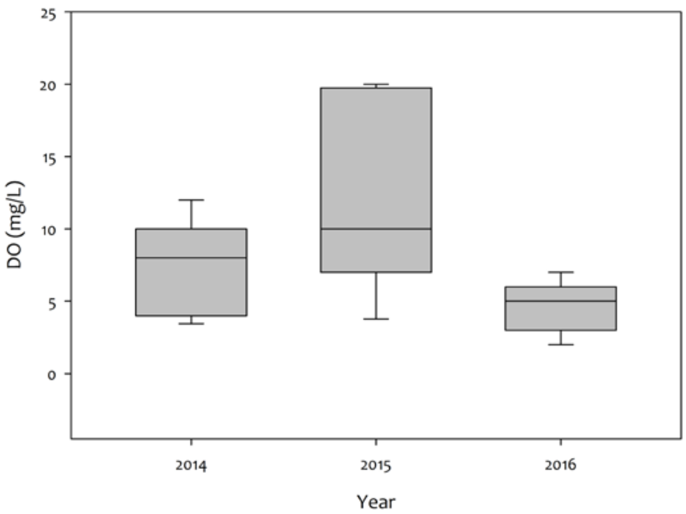


Figure 32 – Dissolved oxygen in selected aquaculture operations in the Delta Ayeyarwady.

Over the period investigated, the acidity progressively decreased. There were high risks owing to acid water conditions in 2014, but in 2015 and 2016, pH values moved into, and then well within the recommended range of 6.5-8.5 (Figure 33).

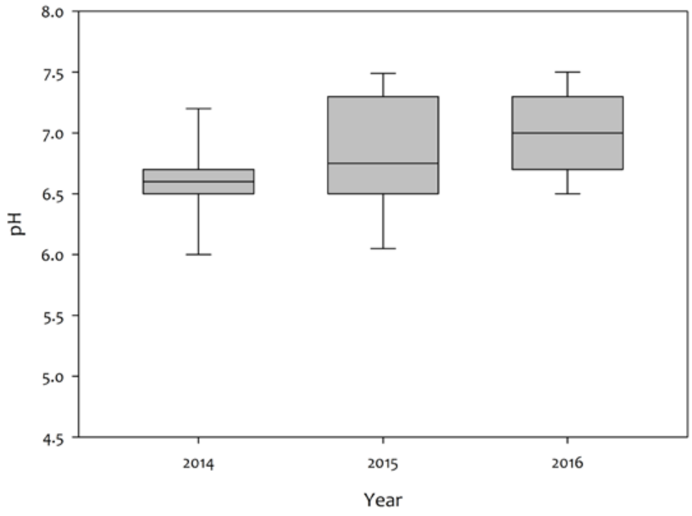


Figure 33 – pH in selected aquaculture operations in the Delta Ayeyarwady.

The accumulation of ammonia in the water is known to be one of the major causes of functional and structural disorders in aquaculture. Ammonia toxicity is greatly affected by the water chemistry. The toxicity of total ammonia nitrogen (TAN: being the sum of ammonium [NH_4^+] + unionised ammonia [NH_3]) depends on the fraction that is unionised (i.e. NH3), since this is the most toxic form and is pH dependent. The ionised form, $NH4^+$, may also be toxic, but only at very high concentrations. The Canadian Water Quality Guidelines for the protection of freshwater aquatic life recommends a guideline for un-ionised ammonia NH_3 of 0.02 mg/L. High ammonia concentrations affect bodily functions and can damage gills. Chronic exposure to ammonia increases susceptibility to disease and reduces growth (Colt & Armstrong, 1979).

Water quality data from the selected aquaculture ponds in 2014-2016 in the Delta Ayeyarwady documented ammonia levels as NH3. The very low sample size (4) in 2015 may mean that the data are not representative. In 2014 and 2016, 50% of sample were more than three and five times more, respectively than the guideline value (Figure 34).

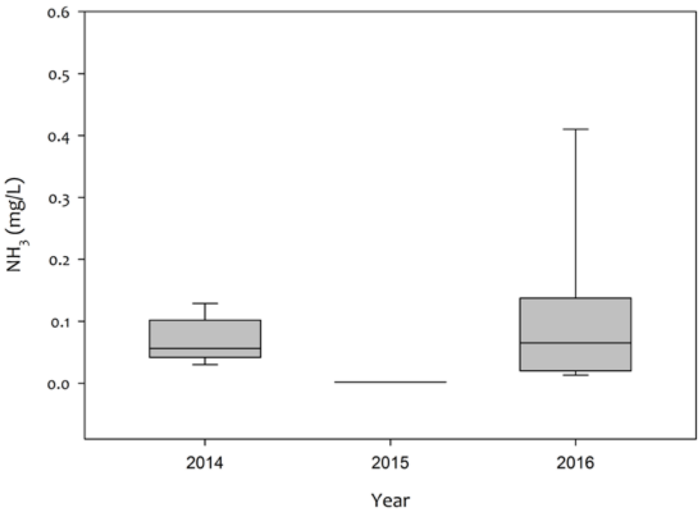


Figure 34 – Nitrate levels in selected aquaculture operations in Delta Ayeyarwady.

3.4.4 Water quality of 18 dams in Middle and Lower Ayeyarwady

Data, for the years 2016 to 2017 for 18 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

Low dissolved oxygen in the dams corresponded with high BOD (Figure 35 and Figure 36). All dams reported microbial contamination with total coliform values of >16 CFU/100 mL (Figure 37). Based on this data set, water from all dams is unfit for drinking and for irrigation on leafy vegetables.

High salinity of irrigation water (Figure 38) with excess amounts of sodium can adversely impact soil structure and affect crop yield. The sodium adsorption ratio 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 sodium adsorption ratios, with values of 7.6 measured at Taungthar Dam and 17 at Natthardaw Dam highlighting water quality unsuitable for irrigation (Figure 39).

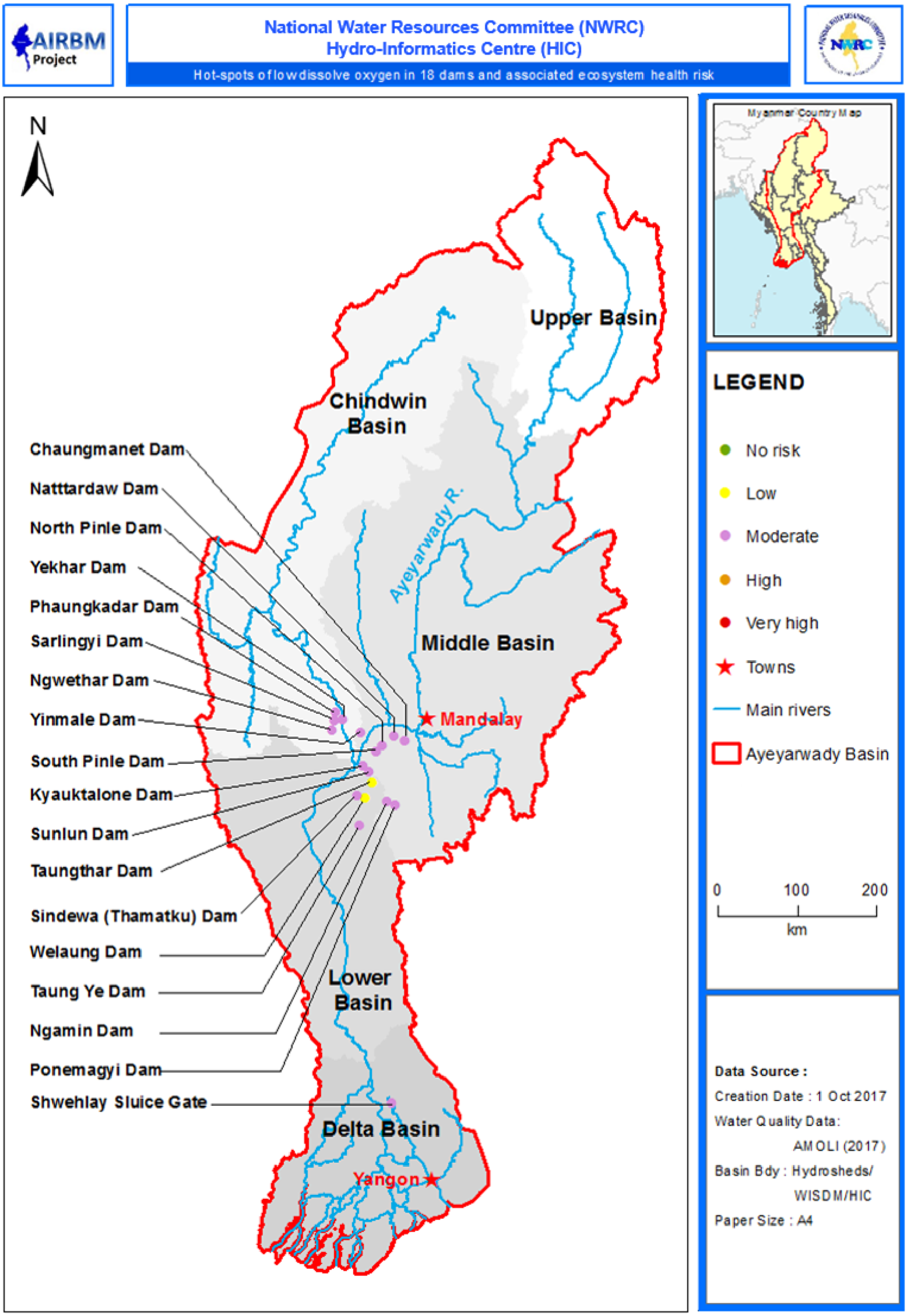


Figure 35 – Hot-spots of low dissolved oxygen in 18 dams and associated ecosystem health risk in the Ayeyarwady Basin, Myanmar.

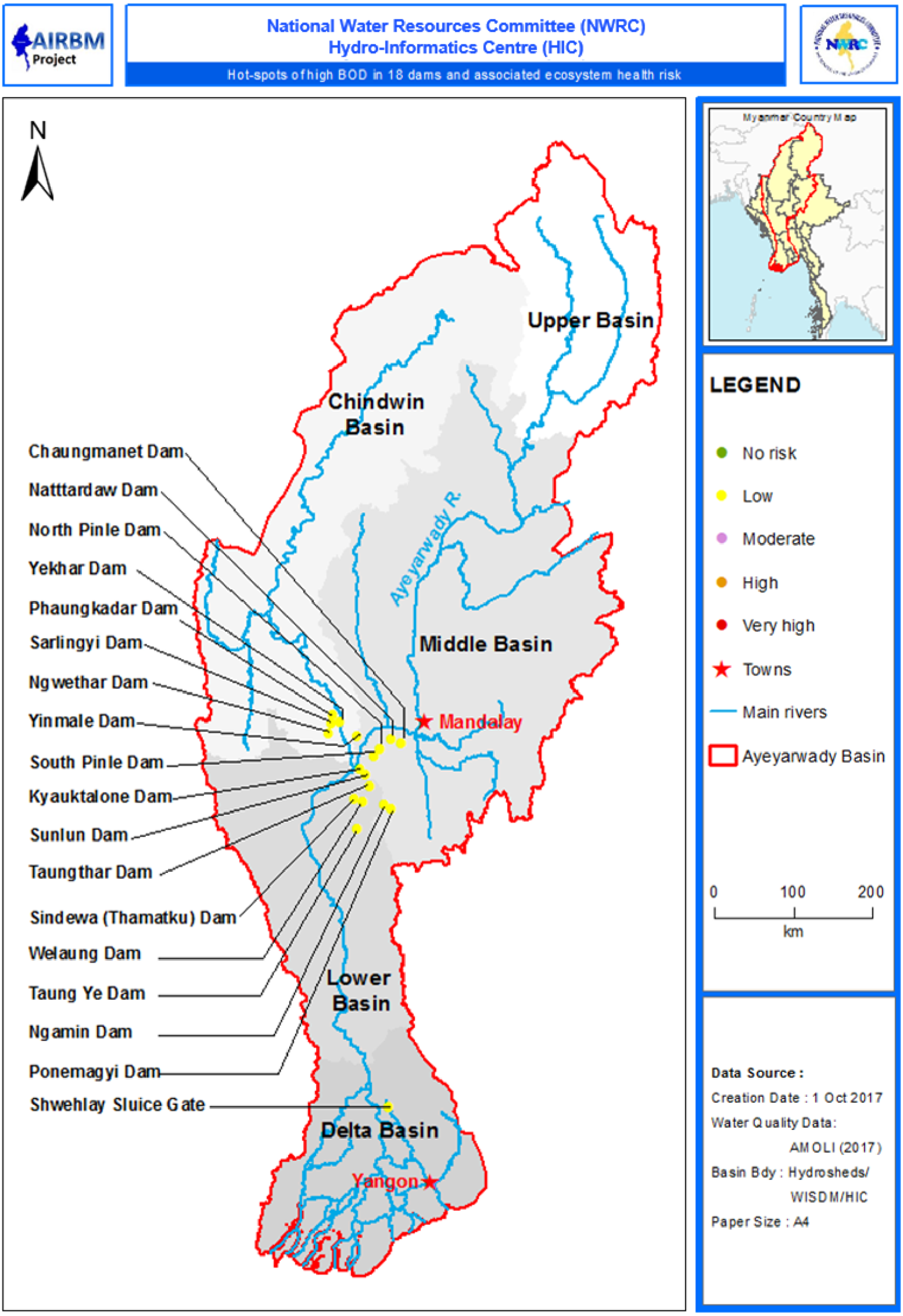


Figure 36 – Hot spots of high biological oxygen demand in 18 dams and associated ecosystem health risk in the Ayeyarwady Basin, Myanmar.

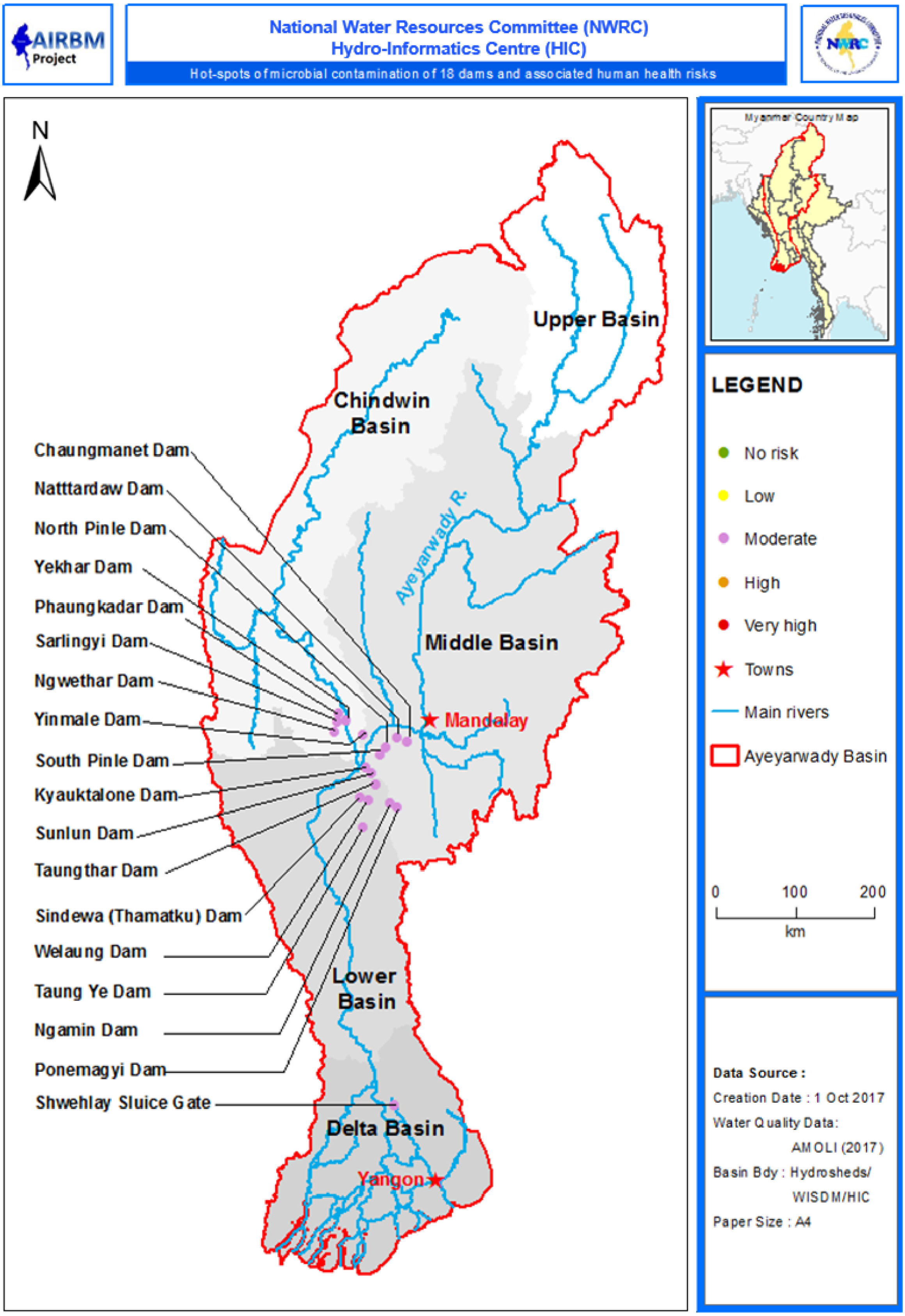


Figure 37 – Hot-spots of microbial contamination of 18 dams and associated human health risks, in the Ayeyarwady Basin, Myanmar.

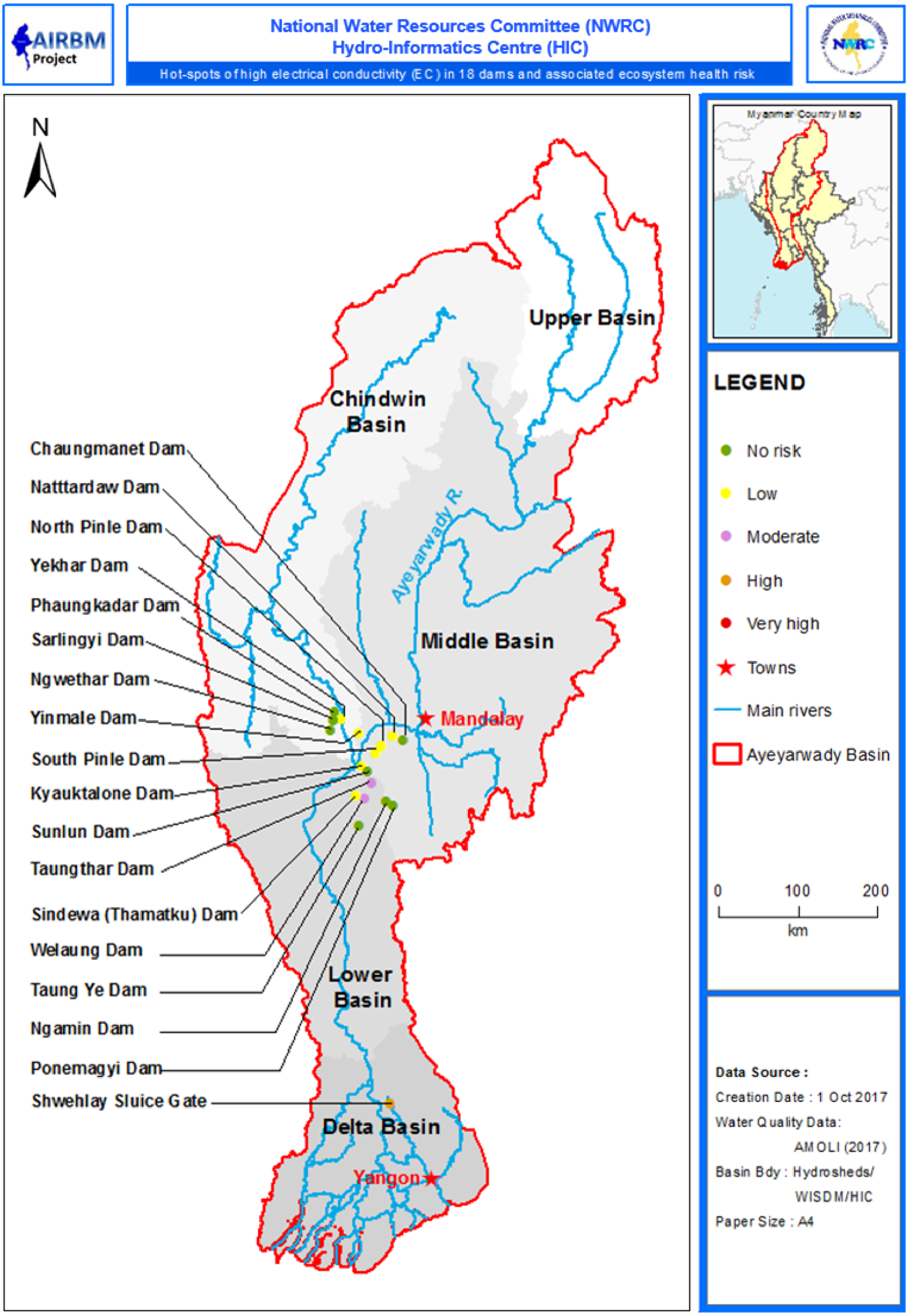


Figure 38 – Hot spots of high electrical conductivity (EC) in 18 dams and related irrigation water risk in the Ayeyarwady Basin, Myanmar.

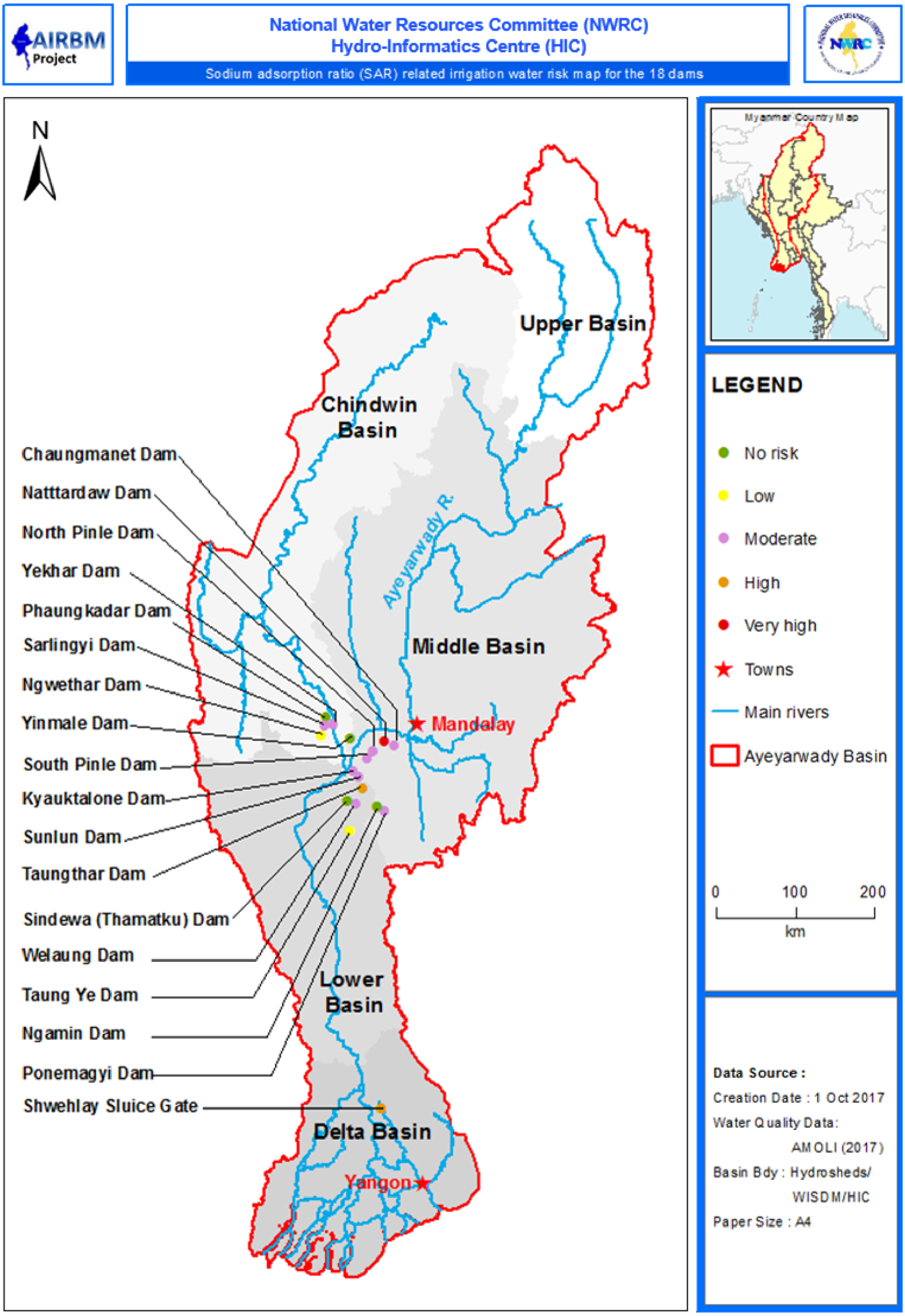


Figure 39 – Sodium adsorption ratio related irrigation water risk for selected dams in the Middle and Lower Ayeyarwady Basin.

3.4.5 Assessment of Water Pollution in five towns in Lower and Middle Ayeyarwady

While there are few data available on agriculture related water pollution, water quality data made available by the Irrigation and Water Utilization Management Department (IWUMD) 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, turbidity ranged between 70 to 150 NTU and was reported to be the highest at the Nyaung-U (Figure 40).PH values were within the range of 6.5 to 8.5 (Figure 41). Lead was above the guideline value at Sinktu, Myichan and Nyaung-U (Figure 42). The highest concentrations were reported at Nyaung-U where lead levels were six times higher than the WHO recommended drinking water guideline. There were no seasonal differences in the water quality parameters analysed during this investigation. Arsenic, mercury and copper were reported to be below the detection limits.

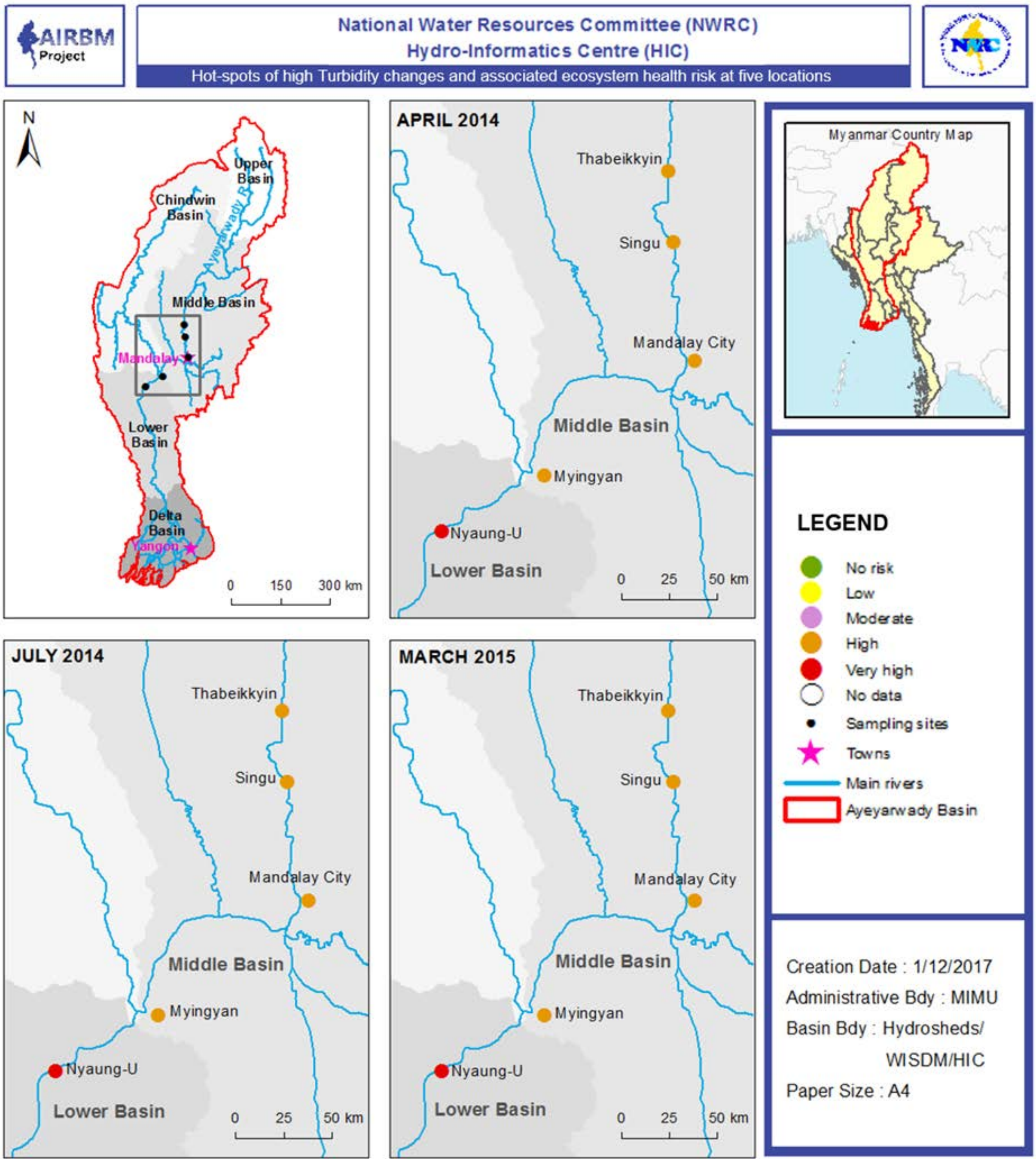


Figure 40 – Hot spots of high turbidity in the selected towns of the Middle and Lower Ayeyarwady.
(Based on the IWUMD data in April 2014, July 2014 and March 2015)

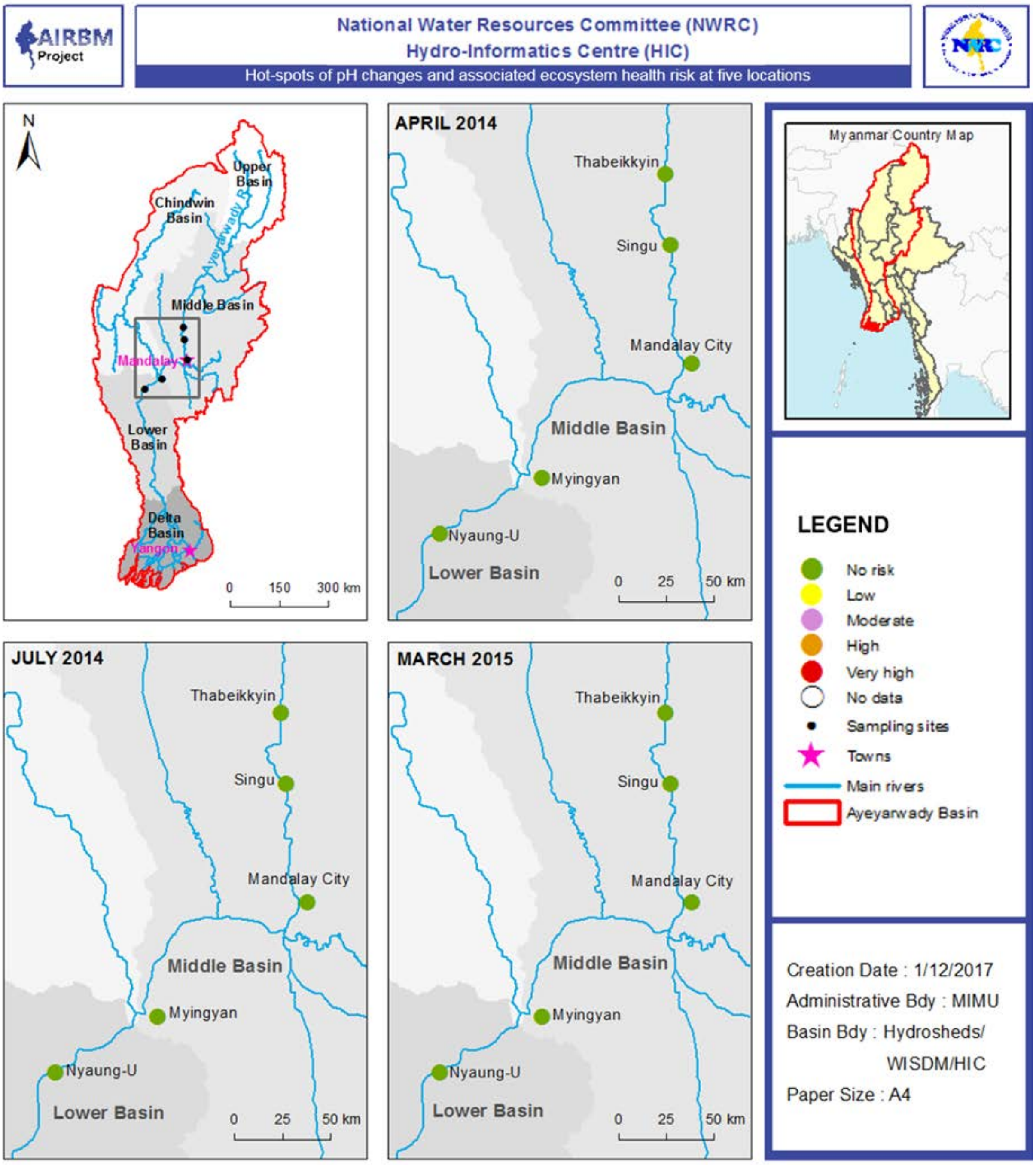


Figure 41 – Hot spots of pH changes in the selected towns of the Middle and Lower Ayeyarwady.
(*Based on the IWUMD data in April 2014, July 2014 and March 2015*)

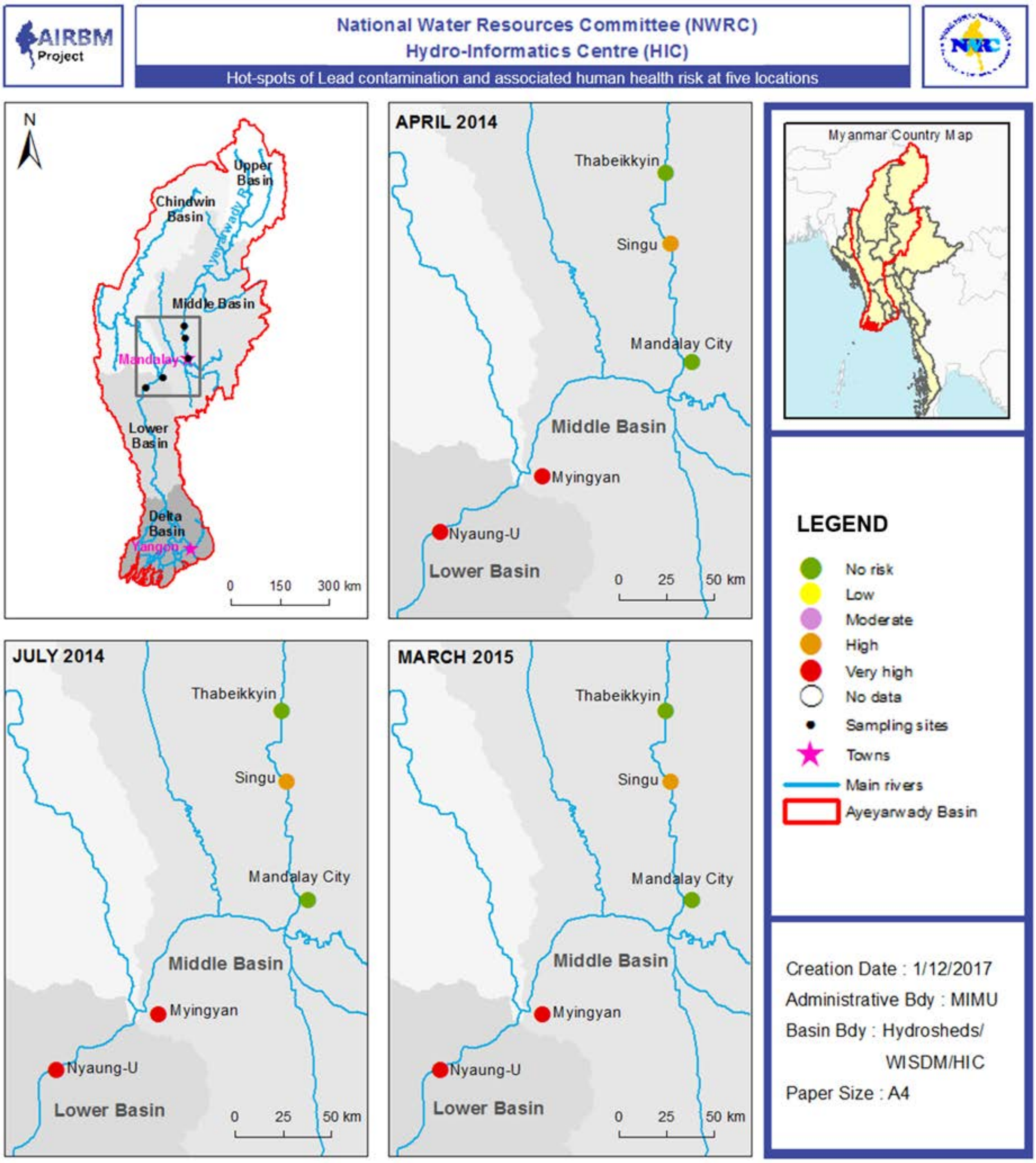


Figure 42 – Hot spots for lead pollution in the selected towns of the Middle and Lower Ayeyarwady.
(Based on the IWUMD data in April 2014, July 2014 and March 2015)

3.4.6 Ecosystem health implications

Lead pollution was localised in selected towns and at some locations represents a very high risk to aquatic life in Lower Ayeyarwady (HEZ 1) 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 24). Risks to fish and aquatic organisms from fungicides and herbicides is much lower than from insecticides (Tables 24- 26). Further investigations of fish health should be conducted to confirm the severity of this issue. Copper, zinc and arsenic concentrations 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 livelihood of farmers relying on this water for irrigation in HEZ 3 and HEZ 4.

The wastewater discharge from small-scale aquaculture systems presents variable risk throughout the Ayeyarwady Basin (Figure 43). 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 elevation of the total organic matter content, 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 finfish.

3.4.7 Human health implications

While data were limited, agriculture paralleled other sectors in showing levels of pollutants higher than the 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. Risk form the use of herbicides and fungicides is significantly lower the insecticides. Of the top eight registered insecticides for use in Myanmar, four pose high or very high levels of risk to humans (Table 24) in comparison to low to moderate risk associated with fungicides and herbicides (Tables 25 and 26).

While there is little information available on the domestic use of pesticides and their impacts in the Ayeyarwady Basin, 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, due to reduced wild fish stocks as a result of degraded water quality, new pathogens, and changed abundance of food available to fishery species.

Table 24 – Risk categorisation of insecticides used in Myanmar based on their toxicity to mammals, aquatic organisms and terrestrial organisms.

	Human health	Aquatic 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
Lambda-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

Table 25 – Risk categorization of herbicides used in Myanmar based on their toxicity to mammals, aquatic organisms and terrestrial organisms.

	Human health	Aquatic organisms			Terrestrial organisms		
Herbicides	**Mammals**	**Fish**	**Crustaceans**	**Algae**	**Birds**	**Honey bees**	**Earthworms**
Glyphosate	Low	Moderate	Moderate	Moderate	Low	Low	Moderate
2,4 D Amine salt	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Pretilachlor	Low	Moderate	Moderate	Moderate	Low	Moderate	Moderate
Fomesafen	Moderate	Low	Moderate	Moderate	Low	Moderate	Moderate
Quinchlorac	Low	Moderate	Moderate	Moderate	Low	Low	Moderate
Paraquat dichloride	Moderate	Moderate	Moderate	High	High	Moderate	Low
Altrazine	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate
Quinchlorac + Fenoxaprop-P-ethyl	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate
+ Pyrazosulfuron	Low	Low	Low	Low	Low	Moderate	Low

Table 26 – Risk categorization of fungicides used in Myanmar based on their toxicity to mammals, aquatic organisms and terrestrial organisms.

	Human health	Aquatic organisms			Terrestrial organisms		
Fungicides	**Mammals**	**Fish**	**Crustaceans**	**Algae**	**Birds**	**Honey bees**	**Earthworms**
Mancozeb	Low	High	High	Moderate	Low	Low	Moderate
Benomyl	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Sulfur	Low	High	High	Moderate	Low	Low	Low
Carbendazim	Low	Moderate	Moderate	Moderate	Low	Low	High
Propiconazole	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Metalaxyl	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Copper hydroxide	Moderate	High	High	High	Moderate	Moderate	Moderate
Dimethomorph	Low	Moderate	Moderate	Low	Low	Moderate	Moderate

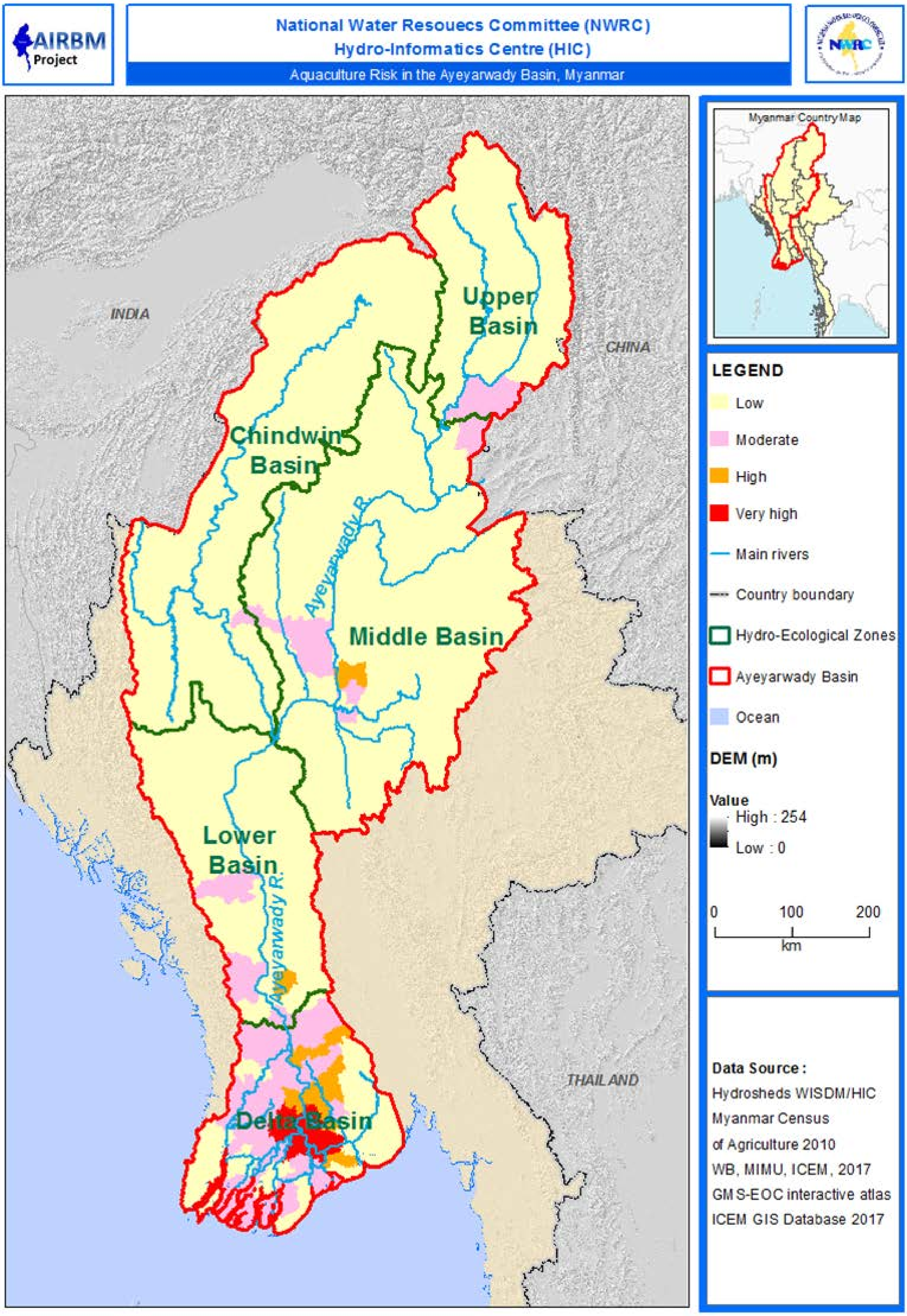


Figure 43 – Level of risk from wastewater discharges from the aquaculture ponds in the Ayeyarwady Basin.

4 CONCLUSIONS AND RECOMMENDATIONS

This project represents an initial assessment of water pollution within the Ayeyarwady Basin, with specific reference to the industrial, urban, mining and agriculture sectors. There is a lack of reliable information on key parameters related to water pollution within the Ayeyarwady Basin. While this limited the water pollution assessment, available data established that development in the four key sectors, without safety and protection measures, are likely to produce unacceptable risks to both ecosystem and human health.

In the *industrial* sector, biological oxygen demand (BOD) and total suspended solids (TSS) loads 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. The three main toxic chemicals of concern in the Ayeyarwady Basin are ammonia, ethylene glycol and formaldehyde. Lead load, which presents severe health risks to both ecosystem and human health, was highest in the Middle Ayeyarwady (HEZ 3) and Ayeyarwady Delta (HEZ 5). According to WHO, more than one third of countries including Myanmar do not yet have in place legally binding controls on the production, import, export, sale and use of lead paints and should be considered as the top most chemical for public health concern,

Industrial raw materials and construction materials are leading polluters in industrial zones in the Chindwin (hydro-ecological zone (HEZ) 2) and Middle Ayeyarwady (HEZ 3), while minerals and petroleum products, clothing and apparel, and food and beverage 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 Ayeyarwady Delta (HEZ 5). The 3 main toxic chemicals of concern in the Ayeyarwady Basin are ammonia, ethylene glycol and formaldehyde, and highest loads of toxic chemicals and metals were identified in Mandalay, Yangon and Pathien.

Urban sector water pollutants were most prominent in the cities of Yangon (HEZ 5), Mandalay (HEZ 3), Magaway (HEZ 4) and Sagaing (HEZ 2). With poor sewage treatment and processing with urban centres in the Ayeyarwady Basin, high levels of pollutants are harmful to receiving waters. 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, the populations of the Middle Ayeyarwady (HEZ 3) and Ayeyarwady Delta (HEZ 5) are the most vulnerable to human health issues arising from urban water pollution.

Advanced reduction of wastewater pollution (using treatment plants) is present only in the largest cities of the basin. A significant area of the basin is reliant on septic tanks for wastewater treatment, or has negligible or no treatment, in the cases of open latrines and discharge of wastewaters into flowing waters. In urban areas of the 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 (itself a pollution source, among its impacts). Excepting a limited sewerage system in Yangon city (in the old business district, and serving 40-50% of the population) there is no systematic collection and treatment of domestic wastewater. Consequently, effluent and seepage from septic tanks and latrines in most parts of the city flows into open rainwater drainage and natural waterways. Most households in formal residential areas have some form of septic tank. However, these receive insufficient maintenance, and the extracted sludge is not subjected to adequate treatment. Residents of informal settlements depend primarily on improvised latrines, and stormwater drains of these areas carry untreated sewage in open channels.

The acceptable level of *E. coli* or coliform bacteria in drinking water is 0 CFU per 100 mL (WHO, 2011).This highlights the major health risk of waterborne diseases for those citizens, and particularly children under five, dependent on river water as source of drinking water/bathing.

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 very few data available on the impact 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. In these regions, activities such as flooded rice production, development of river navigation, and aquaculture (e.g. shrimp farming) potentially contribute nutrients, and organic compounds (pesticides, antibiotics) to the basin's waters. The unsafe use of pesticides leaves farmers vulnerable to many health risks. They include leukaemia and cancerous tumours, infertility, spontaneous abortions, genetic damage, liver and kidney dysfunction and neurological damage. Pesticide contamination can cause not only problems for human health and the environment, but can also have negative economic impacts (e.g. tainting of produce) on potential export revenue. 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. Available data indicates that water pollution from agriculture also resulted in high levels of microbial contamination in 18 sampled dams, meaning water was unfit for human consumption. Risks were also identified with aquaculture practices, specifically where low dissolved levels and high nutrients from ponds can result in localised risk and adversely impact aquatic organisms.

Recommendations

This project was undertaken based on analysis using the best available data. We have identified a number of areas that require further information and propose the following recommendations:

1) The geographical positions of industrial enterprises (as coordinates) are not available. Possible local sources of contamination should be investigated in the industrial zones with a view to managing the contamination.
2) Public health effects should be confirmed through integrated monitoring programmes and epidemiological studies.
3) Ecosystem health should be protected through investing in treatment technologies, controlling sources and the enforcement of regulations for the discharge of industrial effluents.
4) The social perception of a monsoon season removal of pollution is also erroneously applied to industrial discharges. Greater knowledge among citizens and decision makers should be promoted through strategies to extend and enhance education and communication.
5) Developing a comprehensive database of mining activities and a monitoring framework regulating environmental and social aspects of mining development is recommended.
6) Data quality and quality assurance/quality control (QA/QC) approaches should implemented in the monitoring studies- this should be considered as a capacity building objective.

Ways forward to manage water pollution

1) Water quality is best managed by regulating the sources of contamination.
2) Treatment of industrial effluent should be designed using 'fit for purpose' approaches.
3) Monitoring programmes (surface water, groundwater) based on the risk assessment approach should be established.
4) Institutional coordination is required for public health surveillance and food security.
5) Community and stakeholder engagement is critical to raise awareness and encourage positive behavioural change.

Acceptable water quality levels may be guaranteed only if wastewater containment and treatment are fully operational when floods or extreme rainfalls occur, thus treatment must be resilient to high flows and climate extremes. Prevention is usually the most cost effective means of delivering the requirement for safe water; to do this we require knowledge of the hazards. However, for many countries the technical, financial and governance capacity is inadequate and investment in the means for building capacity is essential to move forward to delivering 'fit for purpose water' to meet the sustainable development goals (SDGs).

Reducing exposure to hazardous chemicals is essential to achieving the SDGs in the Ayeyarwady Basin, as well as ensuring a sustainable and properly utilised water resource base. In addition to substantially reducing the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination (SDG-Target 3.9) pollution control will help to alleviate poverty (SDG 1), improve access to clean water and improve sanitation (SDG 6), promote social justice (SDG 10), build sustainable cities and communities (SDG 11), and protect land and water (SDGs 14 and 15).

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ANNEX I – LIST OF COMMONLY USED INDUSTRIAL CHEMICALS AND THEIR HAZARD RATING

Toxics Release Inventory (TRI) list of toxic chemicals (US EPA 2017). Hazards are defined according to their Lethal dose, 50% (LD_{50}) and Lethal concentration, 50% (LC_{50}) values.

Chemical Abstract Service (CAS)	Substance	LD_{50}	LC_{50}	LD_{50} Hazard	LC_{50} Hazard
56382	**PARATHION**	2.00	0.08	High	High
74908	**HYDROGEN CYANIDE**	4.00	0.18	High	High
7440280	**THALLIUM**	5.71	-	High	Low
534521	**4,6-DINITRO-O-CRESOL**	7.00	0.00	High	High
151564	**ETHYLENEIMINE**	15.00	0.10	High	High
62737	**DICHLORVOS**	17.00	0.02	High	High
75558	**PROPYLENEIMINE (2-METHYLAZIRIDINE)**	19.00	1.17	High	Low
463581	**CARBONYL SULFIDE**	23.00	2.63	High	Low
107028	**ACROLEIN**	26.00	0.02	High	High
87865	**PENTACHLOROPHENOL**	27.00	0.36	High	Moderate
7440473	**CHROMIUM**	27.50	-	High	Low
51285	**2,4-DINTROPHENOL**	30.00	-	High	Low
79107	**ACRYLIC ACID**	33.50	11.78	High	Low
132659	**DIBENZOFURAN**	36.00	-	High	Low
76448	**HEPTACHLOR**	40.00	0.15	High	High
7439976	**MERCURY**	43.00	0.04	High	High
120832	**2,4-DICHLOROPHENOL**	47.00	-	High	Low
7440417	**BERYLLIUM**	51.00	-	Moderate	Low
624839	**METHYL ISOCYANATE**	51.50	0.01	Moderate	High
79118	**CHLOROACETIC ACID**	55.00	0.18	Moderate	High
7440622	**VANADIUM (FUME OR DUST)**	59.00	-	Moderate	Low
302012	**HYDRAZINE**	60.00	0.75	Moderate	Moderate
75218	**ETHYLENE OXIDE**	72.00	1.44	Moderate	Low
111444	**BIS (2-CHLOROETHYL) ETHER (DICHLOROETHYL ETHER; 2,2-DICHLORODIETHYL ETHER)**	75.00	0.33	Moderate	Moderate
58899	**LINDANE (HEXACHLOROCYCLOHEXANE-gamma)**	76.00	0.12	Moderate	High
107131	**ACRYLONITRILE (VINYL CYANIDE)**	78.00	0.72	Moderate	Moderate
106503	**PHENYLENEDIAMINE (P-ISOMER)**	80.00	0.92	Moderate	Moderate
569642	**C.I BASIC GREEN 4**	80.00	-	Moderate	Low
87683	**HEXACHLORO-1,3-BUTADIENE**	82.00	0.37	Moderate	Moderate
106898	**EPICHLOROHYDRIN (1-CHLORO-2,3-EPOXYPROPANE)**	90.00	0.95	Moderate	Moderate
50000	**FORMALDEHYDE**	100.00	0.20	Moderate	High
91087	**TOLUENE-2,6-DIISOCYANATE**	100.00	0.00	Moderate	High
90948	**MICHLER'S KETONE**	100.00	-	Moderate	Low
55630	**NITROGYLCERIN (NG)**	105.00	-	Moderate	Low
74953	**METHYLENE BROMIDE**	108.00	40.00	Moderate	Low
106934	**1,2-DIBROMOETHANE (EDB) (ETHYLENE DIBROMIDE)**	108.00	14.30	Moderate	Low
95487	**CRESOL (O-ISOMER)**	121.00	1.22	Moderate	Low

Chemical Abstract Service (CAS)	Substance	LD_{50}	LC_{50}	LD_{50} Hazard	LC_{50} Hazard
57147	**1,1-DIMETHYL HYDRAZINE**	122.00	0.62	Moderate	Moderate
79061	**ACRYLAMIDE**	124.00	-	Moderate	Low
62566	**THIOUREA**	125.00	-	Moderate	Low
106514	**QUINONE (P-BENZOQUINONE)**	130.00	-	Moderate	Low
7664417	**AMMONIA**	132.00	1.39	Moderate	Low
156627	**CALCIUM CYANAMIDE**	158.00	0.15	Moderate	High
7439921	**LEAD**	160.00	0.00	Moderate	High
1344281	**ALUMINIUM OXIDE (FIBROUS FORM)**	164.00	0.62	Moderate	Moderate
7429905	**ALUMINIUM (FUME OR DUST)**	164.00	0.62	Moderate	Moderate
606202	**2,6-DINITROTOLUENE**	177.00	0.24	Moderate	High
156105	**NITROSODIPHENYLAMINE (P-ISOMER)**	178.00	-	Moderate	Low
7440393	**BARIUM**	198.00	-	Moderate	Low
135206	**CUPFERRON**	199.00	-	Moderate	Low
793206	**1,1,2,2-TETRACHLOROETHANE**	200.00	4.50	Moderate	Low
57749	**CHLORDANE**	200.00	0.10	Moderate	High
88891	**PICRIC ACID (2,416-TRINITROPHENOL)**	200.00	-	Moderate	Low
60093	**4-AMINOAZOBENZENE**	200.00	-	Moderate	Low
100027	**4-NITROPHENOL**	202.00	-	Moderate	Low
77781	**DIMEHTYL SULFATE**	205.00	0.05	Moderate	High
106445	**CRESOL (P-ISOMER)**	207.00	0.71	Moderate	Moderate
79210	**PERACETIC ACID**	210.00	0.45	Moderate	Moderate
542881	**BIS(CHLOROMETHYL) ETHER (DICHLOROMEHTYL ETHER) (BCME)**	210.00	0.03	Moderate	High
74839	**METHYL BROMIDE (BROMOMETHANE)**	214.00	1.17	Moderate	Low
63252	**CARBARL (SEVIN)**	230.00	0.39	Moderate	Moderate
108394	**CRESOL (M-ISOMER)**	242.00	0.71	Moderate	Moderate
62533	**ANILINE**	250.00	0.95	Moderate	Moderate
120809	**CATECHOL (PYROCATECHOL)**	260.00	-	Moderate	Low
121142	**2,4-DINITROTOLUENE**	268.00	-	Moderate	Low
25376458	**DIAMINOTOLUENE (MIXED ISOMERS)**	270.00	-	Moderate	Low
541413	**ETHYL CHLOROFORMATE**	270.00	0.84	Moderate	Moderate
9633	**METHYL ACRYLATE**	277.00	4.75	Moderate	Low
10049044	**CHLORINE DIOXIDE**	292.00	0.72	Moderate	Moderate
123319	**HYDROQUINONE (DIHYDROXYBENZENE)**	302.00	-	Moderate	Low
77474	**HEXACHLOROCYCLOPENTADIENE**	315.00	0.02	Moderate	High
108952	**PHENOL**	317.00	0.32	Moderate	Moderate
95807	**2,4-DIAMINOTOLUENE**	325.00	-	Moderate	Low
91225	**QUINOLINE**	331.00	-	Moderate	Low
88755	**2-NITROPHENOL**	334.00	-	Moderate	Low
98953	**NITROBENZENE**	349.00	2.80	Moderate	Low
94757	**2,4-D (DICHLOROPHENOXYACETIC ACID)**	375.00	-	Moderate	Low
75569	**PROPYLENE OXIDE (1,2-EPXOYPROPANE)**	382.00	9.50	Moderate	Low
80159	**CUMENE HYDROPEROXIDE**	400.00	1.37	Moderate	Low
108316	**MALEIC ANHYDRIDE**	430.00	-	Moderate	Low
7697372	**NITRIC ACID**	430.00	0.17	Moderate	High
75274	**DICHLOROBROMOMETHANE (BROMOCHLORO.)**	450.00	-	Moderate	Low
126998	**CHLOROPRENE (BETA-CHLOROPRENE; NEOPRENE)**	450.00	11.80	Moderate	Low
52686	**TRICHLORFORN**	460.00	1.30	Moderate	Low
107051	**ALLYL CHLORIDE**	460.00	11.00	Moderate	Low
615054	**2,4-DIAMINOSANISOLE**	470.00	-	Moderate	Low

Chemical Abstract Service (CAS)	Substance	LD_{50}	LC_{50}	LD_{50} Hazard	LC_{50} Hazard
542756	**1,3-DICHLOROPROPYLENE**	480.00	4.54	Moderate	Low
621647	**N-NITROODODI-N-PROPYLAMINE (NDPA)**	490.00	-	Moderate	Low
91203	**NAPHTHALENE**	500.00	0.34	Moderate	Moderate
1310732	**SODIUM HYDROXIDE (SOLUTION)**	500.00	-	Moderate	Low
75014	**VINYL CHLORIDE**	500.00	459.84	Moderate	Low
1163195	**DECABROMODIPHENYLY OXIDE**	500.00	-	Moderate	Low
95501	**DICHLOROBENZENE 1,2-(O-ISOMER)**	500.00	4.93	Moderate	Low
106467	**DICHLOROBENZENE 1,4-(P-ISOMER)**	500.00	72.11	Moderate	Low
25321226	**DICHLOROBENZENE (MIXED ISOMERS)**	500.00	72.11	Moderate	Low
593602	**VINYL BROMIDE (BROMOETHENE)**	500.00	218.58	Moderate	Low
106887	**1,2-BUTYLENE OXIDE (1,2-EPOXYBUTANE)**	500.00	1.17	Moderate	Low
92671	**4-AMINODIPHENYL (P-isomer)**	500.00	-	Moderate	Low
101779	**4,4-METHYLENE DIANILINE (4,4-DIAMINODIPHENYLMETHANE)**	517.00	-	Low	Low
7723140	**PHOSPHORUS (YELLOW OR WHITE)**	550.00	0.58	Low	Moderate
115322	**DICOFOL**	575.00	5.00	Low	Low
10034932	**HYDRAZINE SULFATE**	601.00	0.01	Low	High
111422	**DIETHANOLAMINE**	620.00	-	Low	Low
108883	**TOLUNE (TOLUOL)**	636.00	49.00	Low	Low
90437	**2-PHENYLPHENOL (SODIUM SALT)**	656.00	-	Low	Low
75070	**ACETALDEHYDE**	661.00	23.95	Low	Low
107062	**1,2-DICHLOROOETHANE (ETHYLENE DICHLORIDE)**	670.00	4.05	Low	Low
95534	**TOLUIDINE (O-ISOMER)**	670.00	3.78	Low	Low
67663	**CHLOROFORM**	695.00	47.70	Low	Low
79469	**2-NITROPROPANE**	720.00	1.46	Low	Low
101804	**4,4-DIAMINODIPHENYL ETHER (4,4-OXYDIANILINE)**	725.00	-	Low	Low
134327	**NAPHTHYLAMINE (ALPHA or 2-NAPHTHYLAMINE)**	727.00	-	Low	Low
120821	**1,2,4-TRICHLOROBENZENE**	756.00	-	Low	Low
7440382	**ARSENIC**	763.00	-	Low	Low
540590	**1,2-DICHLOROETHYLENE**	770.00	0.12	Low	High
71363	**N-BUTANOL (N-BUTYL ALCOHOL)**	790.00	24.24	Low	Low
140885	**ETHYL ACRYLATE (ACRYLIC ACID & ETHYL ESTER)**	800.00	5.79	Low	Low
79005	**1,1,2-TRICHLOROETHANE**	836.00	2.73	Low	Low
64675	**DIETHYL SULFATE**	880.00	1.58	Low	Low
110861	**PYRIDINE**	891.00	28.50	Low	Low
7647010	**HYDROCHLORIC ACID (HYDROGEN CHLORIDE)**	900.00	4.66	Low	Low
141322	**BUTYL ACRYLATE (ACRYLIC ACID & N-BUYTL ESTER)**	900.00	14.30	Low	Low
71432	**BENZENE**	930.00	31.93	Low	Low
121597	**DIMETHYLANILINE (N,N-DIMETHYLANILINE)**	951.00	0.25	Low	High
78842	**ISOBUTYRALDEHYDE**	690.00	23.58	Low	Low
842079	**C.I SOLVENT YELLOW 14**	1000.00	-	Low	Low
541731	**1,3-DICHLOROBENZENE (M-ISOMER)**	1062.00	-	Low	Low
108907	**CHLOROBENZENE (CHLORINATED BENZENE)**	1100.00	13.64	Low	Low
139139	**NITRILOTRIACETIC ACID**	1100.00	-	Low	Low
82688	**QUINTOZENE (PENTACHLORONITROBENZENE)**	1100.00	1.40	Low	Low

Chemical Abstract Service (CAS)	Substance	LD_{50}	LC_{50}	LD_{50} Hazard	LC_{50} Hazard
1314201	THORIUM DIOXIDE	1140.00	-	Low	Low
101144	4,4'-METHYLENE BIS(2-CHLOROANILINE) (MBOCA)	1140.00	-	Low	Low
75150	CARBON DISULFIDE	1200.00	25.00	Low	Low
100447	BENZYL CHLORIDE	1231.00	0.78	Low	Moderate
98828	CUMENE	1400.00	39.30	Low	Low
123386	PROPIONALDEHYDE	1410.00	18.99	Low	Low
120718	CRESIDINE (P-ISOMER)	1450.00	-	Low	Low
2164172	FLUOMETURON	1450.00	-	Low	Low
1319773	CRESOL (ALL ISOMERS)	1454.00	-	Low	Low
97563	AMINOAZOTOLUENE, O-ISOMER (C.I. SOLVENT YELLOW 3)	1500.00	-	Low	Low
7664382	PHOSPHORIC ACID	1530.00	0.85	Low	Moderate
85449	PHTHALIC ANHYDRIDE	1530.00	0.21	Low	High
75092	DICHLOROMETHANE (METHYLENE CHLORIDE)	1600.00	52.00	Low	Low
74873	METHYL CHLORIDE	1800.00	5.30	Low	Low
51796	URETHANE (CARBAMIC ACID, ETHYL ESTER)	1809.00	-	Low	Low
86306	N-NITROSODIPHENYLAMINE	1825.00	-	Low	Low
96457	ETHYLENE THIOUREA (2-IMIDAZOLIDINETHIONE)	1832.00	-	Low	Low
12122677	ZINEB	1850.00	0.80	Low	Moderate
72435	METHOXYCHLOR	1855.00	-	Low	Low
1336363	POLYCHLORINATED BIPHENYLS (CHLORODIPHENYLS, 54% CHLORINE)	1900.00	-	Low	Low
98884	BENZOYL CHLORIDE	1900.00	-	Low	Low
1582098	TRIFLURALIN (2,6-DINITRO-N,N-DIPROPYL-4-(TRIFLUOROMETHYL) BENZENAMINE)	1930.00	2.80	Low	Low
78875	1,2-DICHLOROPROPANE (PROPYLENE DICHLORIDE)	1947.00	14.00	Low	Low
90040	ANISIDINE (O-ISOMER)	2000.00	-	Low	Low
96093	STYRENE OXIDE	2000.00	2.46	Low	Low
104949	ANISIDINE (P-ISOMER)	2000.00	-	Low	Low
108101	METHYL ISOBUTYL KETONE (HEXONE)	2080.00	100.00	Low	Low
110805	2-ETHOXYETHANOL (ETHYLENE GLYCOL MONOETHYL ETHER; CELLOSOLVE)	2125.00	7.37	Low	Low
7664939	SULFURIC ACID	2140.00	0.51	Low	Moderate
92524	BIPHENYL (DIPHENYL)	2140.00	0.20	Low	High
78922	BUTYL ALCOHOL (SEC-BUTANOL)	2193.00	48.48	Low	Low
6484522	AMMONIUM NITRATE (SOLUTION)	2217.00	-	Low	Low
85687	BUTYL BENZYL PHTHALATE	2330.00	-	Low	Low
7440439	CADMIUM	2330.00	0.03	Low	High
56235	CARBON TETRACHLORIDE (TETRACHLOROMETHANE)	2350.00	50.30	Low	Low
109864	2-METHOXYETHANOL (ETHYLENE GLYCOL MONOMETHYL ETHER; METHYL CELLOSOLVE)	2370.00	4.67	Low	Low
75058	ACETONITRILE	2460.00	12.67	Low	Low
123728	BUTYRALDEHYDE	2490.00	23.58	Low	Low
127184	TETRACHLOROETHYLENE (PERCHLOROETHYLENE)	2629.00	34.20	Low	Low

Chemical Abstract Service (CAS)	Substance	LD_{50}	LC_{50}	LD_{50} Hazard	LC_{50} Hazard
100425	**STYRENE (PHENYLETHYLENE; VINYL BENZENE)**	2650.00	12.00	Low	Low
1313275	**MOLYBDENUM TRIOXIDE**	2689.00	5.84	Low	Low
78933	**METHYL ETHYL KETONE (MEK; 2-BUTANONE)**	2737.00	23.50	Low	Low
75650	**BUTYL ALCOHOL (TERT-BUTANOL)**	2743.00	30.30	Low	Low
7783202	**AMMONIUM SULFATE (SOLUTION)**	2840.00	-	Low	Low
108054	**VINYL ACETATE**	2900.00	11.40	Low	Low
12427382	**MANEB**	3000.00	-	Low	Low
101611	**4,4'-METHYLENE BIS(N,N-DIMETHYL) BENZELAMINE**	3160.00	-	Low	Low
108781	**MELAMINE**	3161.00	3.25	Low	Low
105679	**2,4-DIMETHYLPHENOL**	3200.00	0.03	Low	High
98873	**BENZAL CHLORIDE**	3249.00	0.40	Low	Moderate
80057	**4,4'-ISOPROPYLIDENEDIPHENOL (BISPHENOL A)**	3250.00	1.70	Low	Low
100414	**ETHYL BENZENE**	3500.00	17.36	Low	Low
133904	**CHLORAMBEN (3-AMINO-2,5-DICHLOROBENZOIC ACID)**	3500.00	-	Low	Low
91941	**3,3'-DICHLOROBENZIDINE (AZO DYE)**	3820.00	-	Low	Low
1634044	**METHYL-TERT-BUTYL ETHER**	4000.00	84.95	Low	Low
961115	**TETRACHLORVINPHOS (STIROFOS)**	4000.00	1.50	Low	Low
39156417	**2,4-DIAMINO ANISOLE SULFATE**	4000.00	-	Low	Low
123911	**1,4-DIOXANE (1,4-DIETHYLENE DIOXIDE**	4200.00	165.66	Low	Low
1330207	**XYLENE (MIXED ISOMERS)**	4300.00	21.70	Low	Low
67721	**HEXACHLOROETHANE**	4460.00	57.09	Low	Low
3844459	**C.I. ACID BLUE 9, DISODIUM SALT**	4600.00	-	Low	Low
2650182	**C.I. ACID BLUE 9, DIAMMONIUM SALT**	4600.00	-	Low	Low
107211	**ETHYLENE GLYCOL**	4700.00	0.20	Low	High
79016	**TRICHLOROETHYLENE**	4920.00	25.78	Low	Low
7440020	**NICKEL**	5000.00	-	Low	Low
95636	**1,2,4-TRIMETHYLBENZENE (PSEUDOCUMENE)**	5000.00	18.00	Low	Low
108383	**XYLENE (M-ISOMER)**	5000.00	34.72	Low	Low
106423	**XYLENE (P-ISOMER)**	5000.00	19.75	Low	Low
95476	**XYLENE (O-ISOMER)**	5000.00	26.58	Low	Low
67630	**ISOPROPYL ALCOHOL (MANUFACTURING, STRONGACID PROCESS ONLY, NO PROCESS)**	5045.00	31.44	Low	Low
106990	**1,3-BUTADIENE**	5480.00	285.00	Low	Low
67561	**METHANOL (METHYL ALCOHOL)**	5628.00	83.82	Low	Low
67641	**ACETONE**	5800.00	50.10	Low	Low
584849	**TOLUENE-2,4-DIISOCYANATE (TDI)**	5800.00	0.10	Low	High
7757826	**SODIUM SULFATE (SOLUTION)**	5989.00		Low	Low
98077	**BENZOIC TRICHLORIDE (BENZYL TRICHLORIDE; TRICHLOROMETHYLBENZENE)**	6000.00	0.15	Low	Low
7440484	**COBALT**	6171.00	-	Low	Low
100210	**TEREPHTHALIC ACID**	6400.00	-	Low	Low
7782492	**SELENIUM**	6700.00	0.03	Low	High
131113	**DIMETHYL PHTHALATE**	6800.00	9.30	Low	Low
7440360	**ANTIMONY**	7000.00	-	Low	Low
60355	**ACETAMIDE**	7000.00	-	Low	High
84742	**DIBUTYL PHTHALATE**	7499.00	4.25	Low	Low
94360	**BENZOYL PEROXIDE**	7710.00	-	Low	Low

Chemical Abstract Service (CAS)	Substance	LD_{50}	LC_{50}	LD_{50} Hazard	LC_{50} Hazard
80626	METHYL METHACRYLATE (METHACRYLIC ACID METHYL ESTER)	7872.00	78.00	Low	Low
84662	DIETHYL PHTHALATE	8600.00	1.00	Low	Moderate
7439965	MANGANESE	9000.00	0.00	Low	High
133062	CAPTAN	9000.00	-	Low	Low
103231	BIS(2-ETHYLHEXYL) ADIPATE	9100.00	-	Low	Low
101688	METHYLENE BISPHENYL ISOCYANATE (DIPHENYLMETHANE-4,4'-DIISOCYANATE; MDI)	9200.00	0.18	Low	High
71556	1,1,1-TRICHLOROETHANE (METHYL CHLOROFORM)	9600.00	98.12	Low	Low
7440508	COPPER (FUME OR DUST)	9930.00	0.82	Low	Moderate
1897456	CHLOROTHALONIL	10000.00	0.31	Low	Moderate
118741	HEXACHLOROBENZENE	10000.00	3.60	Low	Low
7440224	SILVER	10000.00	-	Low	Low
110827	CYCLOHEXANE	12705.00	89.60	Low	Low
120127	ANTHRACENE	17000.00	-	Low	Low
81072	SACCHARIN (MANUFACTURING ONLY, NO PROCESSOR REPORTING)	17000.00	-	Low	Low
117817	DI (2-ETHYLHEXYL) OR (SEC-OCTYL) PHTHALATE (DEHP)	30000.00	-	Low	Low
76131	1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE (FREON 113)	43000.00	294.87	Low	Low
117840	DI-N-OCTYL PHTHALATE	47000.00	-	Low	Low
7440666	ZINC (FUME OR DUST)	-	0.12	Low	High
1332214	ASBESTOS (FRIABLE)	-	0.00	Low	High
7782505	CHLORINE	-	0.85	Low	Moderate
75003	ETHYL CHLORIDE (CHLOROETHANE)	-	152.00	Low	Low
74851	ETHYLENE	-	1089.38	Low	Low
115071	PROPYLENE	-	86.00	Low	Low
7664393	HYDROGEN FLUORIDE (HYDROFLUORIC ACID)	-	1.04	Low	Low
7550450	TITANIUM TETRACHLORIDE	-	0.40	Low	Moderate
75445	PHOSGENE (CARBONYL CHLORIDE)	-	0.36	Low	Moderate
107302	CHLOROMETHYL METHYL ETHER (CMME)	-	0.18	Low	High

Lethal dose, 50% (LD_{50}); Lethal concentration, 50% (LC_{50})

ANNEX II – SELELCTED DAMS FOR WATER QUALITY ASSESSEMENT (2016-2017)

(From Irrigation and Water Utilization Management Department)

DAMS MONITORED FOR WATER QUALITY			
1	**TaungYe Dam**	10	Sindewa (Thametku) Dam
2	**Welaung Dam**	11	North Pinle Dam
3	**Taungthar Dam**	12	South Pinle Dam
4	**Kyauktalone Dam**	13	Sunlun Dam
5	**Ponemagyi Dam**	14	Phaung kadar Dam
6	**Natthardaw Dam**	15	Yinmale Weir
7	**Chaungmanet Dam**	16	Ngwethar Dam
8	**Ngamin Dam**	17	Yekhar Dam
9	**Sarlingyi Dam**	18	Shwehlay Sluice Gate

ANNEX III – WATER QULITY PARAMETERS SELECTED FOR MONITORING DAMS

(Data from Irrigation and Water Utilization Management Department)

WATER QUALITY PARAMETERS MEASURED		
Calcium	Dissolved oxygen	Temperature
Magnesium	Total dissolved solids	Arsenic
Sodium	Soluble sodium percentage	Lead
Potassium	Sodium adsorption ratio	Mercury
Carbonate	Residual sodium carbonate	Cadmium
Bicarbonate	Suspended solids	Chromium
Sulfate	pH	Copper
Chloride	Electrical conductivity	Iron
Total hardness	Turbidity	Cyanide
Chemical oxygen demand	Salinity	Biochemical oxygen demand

ANNEX IV – STATISTICS OF CROP PLANTATION AREA, REPORTED PESTS AND UTILISED PESTICIDES IN MYANMAR (FANG 2017)

Plantation and production of major crops in Myanmar								
Rank	Crop	Area (1000 ha)			Crop	Production (1000 MT)		
		2012/13	2013/14	2014/15		2012/13	2013/14	2014/15
1	Paddy	7241	7284	7172	Paddy	27704	28322	28193
2	Sesame	1553	1622	1581	Sesame	9564	10473	11307
3	Green gram	1087	1123	1173	Maize	1526	1626	1721
4	Black gram	1108	1102	1098	Black gram	1548	1574	1580
5	Ground nut	912	931	949	Green gram	1387	1452	1536
6	Rubber	581	610	641	Ground nut	1451	1488	1525
7	Pigeon pea	613	639	619	Onion	1161	1224	1265
8	Sunflower	496	481	484	Sesame	863	909	930
9	Maize	422	441	459	Pigeon pea	803	847	841
10	Chick pea	362	384	378	Chick pea	525	571	580
11	Cotton	278	299	304	Potatoes	560	549	551
12	Sorghum	218	226	235	Cotton	467	509	533
13	Sugarcane	154	169	181	Sunflower	468	463	473
14	Oil palm	144	148	153	Sorghum	214	229	243
15	Soy bean	158	155	151	Soy bean	238	235	229
16	Chilli (dried)	113	110	112	Garlic	212	215	212
17	Sultapya	108	112	110	Rubber	164	177	198
18	Wheat	99	101	99	Wheat	180	186	185
19	Onion	72	77	78	Onion	134	138	145
20	Butter bean	64	63	64	Oil Palm	134	136	135
21	Garden pea	53	54	54	Sultapya	119	117	123
22	Potatoes	37	36	37	Butter bean	82	84	86
23	Garlic	29	29	28	Garden pea	68	71	71
24	Coffee	20	20	20	Coffee	8	8	8
25	Tobacco	3	3	3	Tobacco	4	4	4
26	Jute & fibres	2	1	2	Jute & fibres	2	1	1

ANNEX V – STATISTICS OF TOP 10 FRUIT AND VEGETABLES IN MYANMAR (FANG 2017)

Production of the top 10 fruits and vegetables in Myanmar

Rank	Fruit	2012/13 (t)	2013/14 (t)	2014/15 ((t)	Vegetable	2012/13 (t)	2013/14 (t)	2014/15 (t)
1	Mango	524654	530813	557070	Tomato	1380512	1379874	1343172
2	Orange	316115	341237	353050	Cabbage	474803	471512	476976
3	Jujube & plum	306942	311125	306677	Cauliflower	377310	369572	387662
4	Pineapple	252477	244897	250182	Radish	258884	252679	272855
5	Tamarind tree	145115	144094	154395	Bottle gourd	263519	282311	267095
6	Pummelo	82300	86589	77113	Mustard	280717	299987	239570
7	Cashew nut	56215	56416	51317	Watermelon	185794	230794	236226
8	Lemon & lime	52218	55131	50793	Lettuce	76840	78519	74008
9	Durian	42564	41585	42153	Beet	23555	21648	16599
10	Custard apple	21740	20268	20377	asparagus	2482	3705	3332

ANNEX VI – CROP PESTES AND MOST FREQUENCTLY UTILISED PESTICIDE IN MYANMAR (FANG 2017)

	Major crop pests and most frequently utilized pesticide in Myanmar
Crop	Major Reported Pests and Utilized Pesticides
Paddy	In paddy two important plant parasite nematodes were reported of causing a lot of yield problems: *Ditylechus angustus* and *Hirschemaniella oryzea*. The golden nematode, *Globodera rostrochiensis* is declared absent in Myanmar. The most common insects were planthoppers, leaf folder, stem borer (*Scirpophaga incertulas*), paddy gall midge (*Orseolia oryzae*), Jassid (*Nephotettix apicalis*) and paddy ear bug (*Leptocorisa spp*). **Pesticides used:** The range of pesticides used in Myanmar was narrow. The most commonly used pesticides were organophosphates and organochlorines, particularly dimethoate, phenthoate and endosulfan.
Tomato	Main diseases and pest are late blight (*Phytophthora infestans*), early blight (*Alternaria solani*), fusarium wilt (*Fusarium oxysporum*) and white fly. **Pesticides used:** Late blight: mancozed, chlorothalonil, dimethomorph, cymoxanil, copper hydroxide Early blight: chlorothalonil, tebuconazole, propiconazole Powdery mildew: hexaconazole Root diseases: thiram, carbendazim
Cauliflower	Main pests are blight (*Peronospora parasitca*), damping-off (*Pythium spp., Fusarium spp., and Rhizoctonia solani*) and insects. **Pesticides used:** Blight: copper oxychloride Insects: cypermethrin, chloropyrifos, monocrotophos Damping-off: carbofuran (furadan). The use of this toxic insecticide is questionable because damping-off is usually caused by fungi and not pests.
Potato	Main pests and diseases mentioned are: late blight, bacterial wilt, aphids, tuber moth, cutworm, and beetle. **Pesticides used:** Late blight: mancozed, metalaxyl (Ridomil) Insects: systemic insecticides
Green gram	Main diseases and pests are powdery mildew, downy mildew, damping-off, Mung Bean Yellow Mosaic Virus (MYMV), thrips, army worms, pod borers, aphids and leaf miners. **Pesticides used:** Damping-off: seed is treated with fungicides & insecticides Thrips: imidacloprid Wee control: paraquat, glyphosate, 2,4 D, oxadiazole Fungicides: mancozed, carbendazim, thiophanate-methyl

ANNEX VII – PERCENTAGE OF USERS AND AVERAGE COSTS FOR RICE PRODUCTION IN MYANMAR

	Monsoon rice (in MMK/acre)				Off-season rice (in MMK/acre)			
	Insecticides		Herbicides		Insecticides		Herbicides	
	% Users	Costs	% Users	Costs	% Users	Costs	% Users	Costs
By region								
Ayeyarwady	12.2	702	7.6	263	-	-	-	-
Brackish water	8.2	139	12.6	620	-	-	-	-
Freshwater	1.3	91	9.4	283	-	-	-	-
Saltwater	27.6	1439	0.6	1	57.6	3741	7.9	193
Bago	0.3	68	1.6	52	-	-	-	-
East alluvial	-	-	3.1	150	-	-	-	-
West alluvial	-	-	0.8	1	-	-	-	-
River area	0.8	184	0.8	11	-	-	-	-
Sagaing	37.4	3690	12.8	1028	-	-	-	-
Dryland	47.1	2782	13.7	1144	48.1	3908	63.3	4775
Irrigated tract	50.6	4706	18.8	1060	59.2	8573	40.8	3509
River area	-	-	-	-	-	-	-	-
Shan state	27	1328	0.6	5	-	-	-	-
Border area	22.2	1135	0.9	9	62.9	4671	0	0
Northern interior	25.7	2466	-	-	-	-	-	-
Southern interior	54.5	606	-	-	-	-	-	-
By farm size								
Ayeyarwady								
Small	7.1	276	8.7	860	63.3	5443	6.7	241
Medium	8.7	258	5	197	66	4579	8.0	143
Large	18.8	996	9.1	178	49.3	3186	8.5	206
Bago								
Small	-	-	1.1	2	-	-	-	-
Medium	-	-	1.5	42	-	-	-	-
Large	0.6	113	1.9	66	-	-	-	-
Sagaing								
Small	26	3027	8.7	624	57.6	5331	55.9	3700
Medium	44	4553	16.4	2039	48.1	8748	55.6	5771
Large	44.1	3322	13.7	413	54.1	3176	43.2	3159
Shan state								
Small	23	1308	0.7	8	62.9	4671	-	-
Medium	21.7	2041	-	-	-	-	-	-
Large	68.8	612	-	-	-	-	-	-
By gender								
Male	17.2	881	6.7	276	55	4381	27.2	1427
Female	16.7	1324	3.7	208	65.8	4467	26.3	1041
Overall	17.1	1025	6.3	269	56.3	4389	27.1	1393

Myanmar kyat (MMK)

ANNEX VIII – CROSS-REFERENCE LIST OF COMMON, TRADE AND CHEMICAL NAMES OF ORGANOPHOSPHATE PESTICIDES USED IN MYANMAR

Common name	Trade names*	Chemical name
Acephate	Acephate®, Orthene®,	O,S-dimethyl acetylphosphoroamidothioate
Chlorpyrifos	Chlorpyrifos®, Govern®, Lorsban®, Nufos®, Warhawk®, Whirlwind®	O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate
Diazinon	Diazinon®	O,O-diethyl O-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate
Dimethoate	Dimethoate®, Cygon®	O,O-dimethyl S-methylcarbamoylmethyl phosphorodithioate
Disulfoton	Di-Syston®	O,O-diethyl S-[2-(ethylthio)ethyl] phosphorodithoate
Ethoprop	Mocap®	O-ethyl S,S-dipropyl phosphorodithioate
Malathion	Fyfanon®, Malathion®	Diethyl (dimethoxythiophosphorylthio)succinate
Methamidophos	Monitor®	O,S-Dimethyl phosphoramidothioate
Methidathion	Supracide®	S-2,3-dihydro-5-methoxy-2-oxo-1,3,4-thiadiazol-3-ylmethyl O,O-dimethyl phosphorodithioate
Naled	Dibrom®	1,2-dibromo-2,2-dichloroethyl dimethyl phosphate
Oxydemeton-methyl	MSR®	S-[2-(Ethylsulfinyl)ethy]O,O-dimethyl phosphorothioate
Phorate	Phorate®, Thimet®	O,O-Diethyl S-[(ethylthio)methyl] phosphorodithioate
Phosmet	Imidan®	S-[(1,3-dihydro-1,3-dioxo-2H-isoindol- 2-yl)methyl] O,O-dimethyl phosphorothioate
Profenofos	Curacron®	O-4-bromo-2-chlorophenyl O-ethyl S-propyl phosphorothioate

*Does not include manufacturers' prepackaged mixture