Chindwin Futures

Natural resources, livelihoods, institutions and climate change in Myanmar's Chindwin River Basin

Edited by

Chayanis Krittasudthacheewa • Win Maung
Louis Lebel • Rajesh Daniel • Vanessa Hongsathavij

Chindwin Futures

Stockholm Environment Institute (SEI)

SEI is an international non-profit research and policy organization that tackles environment and development challenges. SEI connects science and decision-making to develop solutions for a sustainable future for all. SEI's approach is highly collaborative: stakeholder involvement is at the heart of our efforts to build capacity, strengthen institutions and equip partners for the long-term. SEI promotes debate and shares knowledge by convening decision-makers, academics and practitioners, and engaging with policy processes, development action and business practice throughout the world. The Asia Centre of SEI, based in Bangkok, focuses on gender and social equity, climate adaptation, reducing disaster risk, water insecurity and integrated water resources management, urbanization, and renewable energy. SEI is an affiliate of Chulalongkorn University, Thailand.

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Abbreviations

AIRBM	Ayeyarwady Integrated River Basin Management
ADB	Asian Development Bank
ARBRO	Ayeyarwady River Basin Research Organization
ASEAN	Association of Southeast Asian Nations
CRB	Chindwin River Basin
CRBO	Chindwin River Basin Organization
DEM	Digital Elevation Model
DMH	Department of Meteorology and Hydrology
DWIR	Directorate of Water Resources and Improvement of River Systems
EANET	Acid Deposition Monitoring Network of Southeast Asia
ECD	Environmental Conservation Department
ENSO	El Niño-Southern Oscillation
FAO	United Nations Food and Agriculture Organization
GCM	General Circulation Model
GIS	Geographic Information System
GMS	Greater Mekong Subregion
HEC-RAS	Hydrologic Engineering Center's River Analysis System
ID	Irrigation Department
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JAXA	Japan Aerospace Exploration Agency
KII	Key informant interview
MAI	Ministry of Agriculture and Irrigation
MEI	Myanmar Environment Institute
MONREC	Ministry of Natural Resources and Environmental Conservation
MOTC	Ministry of Transport and Communications
MPI	Multidimensional Poverty Index
MRC	Mekong River Commission
NARBO	Network of Asian River Basin Organizations
NDP	Net Domestic Product
NECCCCC	National Environmental Conservation and Climate Change

	Central Committee
NGO	nongovernmental organization
NLD	National League for Democracy
NWRC	National Water Resources Committee
RBO	River Basin Organization
TRMM	Tropical Rainfall Measuring Mission
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
WHO	World Health Organization
WMO	World Meteorological Organization
WRUD	Water Resources Utilization Department

Preface

The continued sustainability of the Chindwin River Basin is of primary importance to the people who are living in, and dependent upon, the river and other related resources for their livelihoods, and for Myanmar. We are becoming more aware that environmental degradation in the basin is affecting both natural ecosystems and livelihoods. We understand that there are many kinds of resource use in the basin, and there are many competing needs and interests, ranging from local communities needing water for agriculture and livelihoods, the use of the river for navigation, and timber and mining operations. All of this leads to increasing demands on the natural resources of the Chindwin Basin. At the same time, climate change is posing another huge challenge to natural ecosystems, water and livelihood security in the basin.

Urgent steps need to be taken to assess and understand the Chindwin Basin and to find solutions, including the conservation of ecosystems and helping local communities to maintain their livelihoods, while pursuing the development. I am very pleased to introduce this book on the Chindwin Basin which has come after many years of collaboration among the Union Government of Myanmar, the Sagaing Regional Government, and many partners including civil society, researchers, the private sector, local communities, and the media, with the continued support of the Stockholm Environment Institute (SEI) and Myanmar Environment Institute (MEI).

I believe the studies and findings in this book will help to highlight the many challenges facing the basin. This book will be especially useful to policymakers in Myanmar as well as university professors, students, researchers and others, and will support the building of strong partnerships so that together we can find solutions to the many key environmental and climate change challenges in order to achieve sustainable development of the Chindwin River Basin.

Dr Myint Naing
Chief Patron, Chindwin RBO
Chief Minister, Sagaing Regional Government

Foreword

Achieving sustainable development in the Chindwin River Basin requires building partnerships, improving scientific understanding, raising public awareness, and finding practical solutions to the many development and environmental challenges in the Chindwin Basin. The Chindwin River is a crucial mode of navigation, and provides water for agriculture, irrigation, livestock and domestic use for the people in the Sagaing Region. The regional economy of the Chindwin Basin depends heavily on boats for the trade of goods, including rice and fish, with the lower part of Myanmar. But basin-wide land-use changes including deforestation in the valleys are resulting in increased sedimentation, making it difficult for boats to navigate the shallower waters especially in the dry season. During the monsoon rains, the region faces the problem of extreme floods. Often many sections of the riverbanks are washed away, forcing families to relocate inland. Land erosion also affects the riverside gardens and fields, which provide food and support subsistence livelihoods.

One of the key factors affecting health and creating environmental problems in the Chindwin Basin is mining, which has been contributing to the degradation of water quality through pollution and contamination of the river and its streams and waterways. Water pollution poses serious health impacts for many thousands of people who continue to use the river for drinking, bathing and washing. The deterioration in water quality, combined with the lack of effective management of dry season water provision and allocation, affects the security of river-based livelihoods including farming, fishing and navigation. Effective solutions to these large-scale environmental problems require a basin-wide vision and understanding first and foremost. Deliberations on these challenges and their possible solutions should be made with multi-stakeholder engagement.

Towards this end, in 2017, the Sagaing Region government endorsed the establishment of the Chindwin River Basin Organization (RBO) to improve the management of basin-wide water and other related resources. The RBO provides an effective mechanism for different stakeholders to engage at the basin level to address environmental and development problems that are both interlinked and large-scale. The Chindwin RBO aims to improve collaboration among different sectors and people in the Basin, help share information about the water and environmental issues, and develop coherent policies and plans. The Chindwin RBO has strengthened partnerships across a range of groups and sectors, including government departments, regional governments, civil society, researchers, local communities and the media.

One of the key tasks of the Chindwin RBO is to achieve a better understanding of the ecosystems in the Chindwin Basin so that we can find solutions to the many development and environmental challenges. This will help us to benefit as well as conserve this important river basin of Myanmar.

As chair of the RBO, tasked with helping to guide its operation and development as well as provide strategic guidance to the work of the RBO, I sincerely welcome the efforts of the Stockholm Environment Institute and the Myanmar Environment Institute for their continuing work with our people here for several years now. Our joint work strengthens scientific understanding of the Chindwin River Basin and motivates many stakeholders from governmental and non-governmental agencies, and including the communities, to actively engage in saving the Chindwin River Basin.

This book *Chindwin Futures* is part of our collaboration. We believe the scientific studies and findings provided in this book can help support one of the most important objectives of the Chindwin RBO: to build better awareness and spread knowledge about the river basin's current condition, and related key health, environmental and livelihood issues. This book of assessments of the rich and diverse Chindwin River Basin can help us to not only better understand the complex environmental challenges, but also to find the solutions for improving the management of water and other related resources in the Chindwin River Basin that we love, for our next generations to grow and live in the future.

U Than Nyunt Win
Chair, Chindwin RBO
Minister, Ministry of Electricity, Industry, Roads and Transport
Sagaing Regional Government

1

Introduction

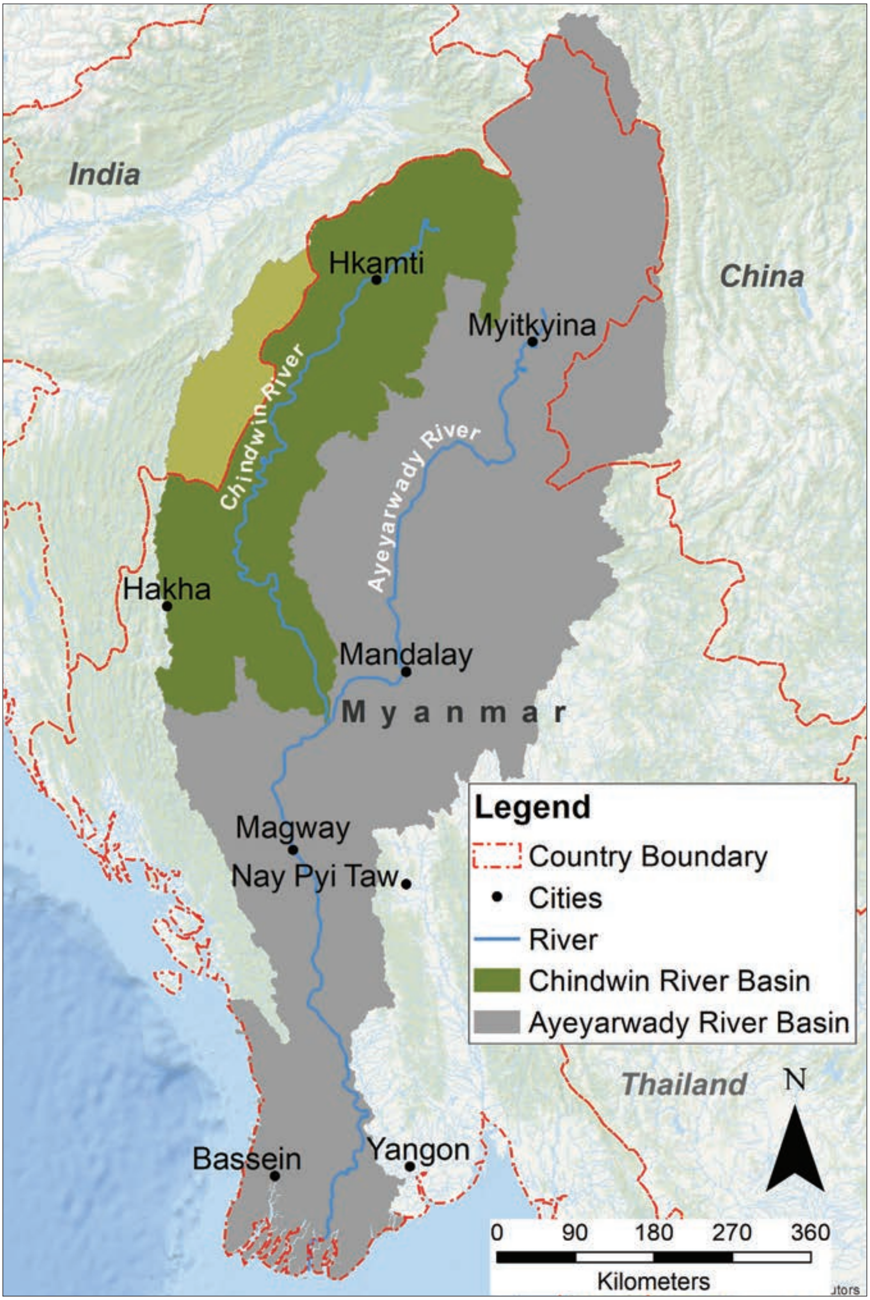
Chayanis Krittasudthacheewa, Rajesh Daniel, Louis Lebel, Vanessa Hongsathavij and Win Maung

When we, the book editors, began writing and compiling the chapters for this book in 2018, we did not imagine that the political situation in Myanmar would change dramatically in early 2021, just a few months after the general election in November 2020.

Between 2011 and 2020, Myanmar had been slowly opening up to the world once more. The country's progress towards political and economic liberalization, although gradual, was persistent. Many inside and outside Myanmar, especially the younger generation, looked forward to building their futures in a more open environment where science, knowledge and public participation could flourish. Yet, after the coup in February 2021, internal conflicts resurfaced, civil rights suppressed, and trust evaporated. Myanmar's political future once again became highly uncertain.

The work featured in this book was carried out primarily under three projects, namely, Ayeyarwady Futures (2013–14), Chindwin Futures (2015–20) and Chindwin Biodiversity and Ecosystem Services (2017–19). Several experts from organizations in Myanmar, including the Myanmar Environment Institute (MEI), cooperated closely with the international experts from the Stockholm Environment Institute (SEI) and other organizations worldwide to implement the various activities of these projects between 2013 and 2020.

Our cooperation with many colleagues in Myanmar to co-produce knowledge and find solutions for natural resource management problems has contributed to strengthening the country's scientific and environmental research capacity. The strong partnerships built with several organizations and stakeholders over the past several years enabled this process. The project teams interacted with the relevant government officials through making simple and direct appointments at the national, Map 1.1 The Chindwin River Basin



regional or local levels in the townships. These interactions frequently took place through discussions about work over lunch and tea. Through our partnerships, we were also able to routinely obtain permissions that were previously inaccessible, such as to hold workshops in rural villages and remote areas like the upper Chindwin valley. We accessed previously restricted areas to carry out environmental assessments through the support of local government bodies and communities. Both government and local communities warmly welcomed SEI and MEI and our colleagues in the Mekong Region, and some have become close working partners and good friends. Many partnerships and friendships that we have built remain strong until now.

From the Ayeyarwady to the Chindwin

The "Chindwin Futures" Project started in 2015 with funding from the BMF and SEI Core Support. While both the Ayeyarwady Futures and Chindwin Futures Projects focused on developing decision-support systems, water quality monitoring, capacity building and multi-stakeholder engagement, the latter project successfully developed a strong relationship with the Sagaing Regional Government, regional governmental departments, universities, civil society organizations, the private sector and local communities in the Chindwin River Basin. These local stakeholders played an active role in contributing to the establishment of the Chindwin River Basin Organization (RBO), the first RBO that was officially established through an approach involving local government and communities in the design of the RBO since the beginning. This was the first time in Myanmar's history that a regional government agreed to provide its own funding, and many organizations in the area agreed to contribute their time to support the establishment of the RBO to serve as a mechanism for integrated water resources management. This showed the feeling of ownership of the RBO by the Sagaing Regional Government and other local stakeholders and their realization of the urgency of improving water governance in this important basin.

Following the success of both projects, we continued our work in the Chindwin River Basin with funding support from the Critical Ecosystem Partnership Fund. This project, called "Chindwin Biodiversity and Ecosystem Services" focused on empowering government agencies

Our groundwork in Myanmar did not start in the Chindwin River Basin but actually began in 2013 with the Ayeyarwady River, Myanmar's largest river and its most important waterway, running from the north all the way to the southern delta region (see Map 1.1).

The Ayeyarwady Basin is expected to see massive changes in land- and water-use over next two decades. These changes have the potential to contribute to economic development, but could also result in environmental degradation and further marginalization of particular groups and their livelihoods. Identifying and understanding the key interactions among multiple water-related activities in the basin is critical to focus integrated water resources planning and management efforts as well as to widen public scrutiny where these conflicts, trade-offs and synergies are greatest.

In late 2013, with funding support from the Blue Moon Fund (BMF) and SEI Core Support and after a series of consultations with a wide range of stakeholders, SEI initiated the "Ayeyarwady Futures" Project. This project aimed to support Myanmar to move towards sustainable development through evidence-based participatory planning processes in water resources development and management. It succeeded in building new partnerships through formal agreements with the Directorate of Water Resources and Improvement of River Systems (DWIR) and MEI, two organizations in the core team that co-led various Ayeyarwady Futures Project activities. While SEI offered its technical expertise and capacity building support to all activities, DWIR contributed significantly in terms of coordination support and provided useful advice on the protocol related to engaging with governmental agencies. MEI worked on diagnostic institutional analysis and supported engagement with NGOs, universities and local communities, and fieldwork in Myanmar.

Subsequently, in 2014, impressed by our scientific research and participatory processes, the government requested the Ayeyarwady Futures Project team to focus its efforts on the Chindwin River Basin, a river basin facing multiple environmental and development challenges but little studied at that time.

and civil society organizations to mainstream biodiversity and ecosystem services into development plans. The project worked together with the Chindwin RBO to facilitate the incorporation of biodiversity conservation into development plans. Apart from conducting research and assessments to improve knowledge of the current status and challenges related to biodiversity, ecosystem services and ongoing plans and policies, the project has successfully cooperated with national and local media in raising public awareness on the important role of stakeholders, including local communities, in development planning and the management of the Chindwin River Basin.

The long-term goal of our work in Myanmar has always been to build and strengthen our partnerships and nurture existing collaborations with different state and non-state actors including line agencies and civil society. These three projects aimed to provide support to homegrown experts to take a leading role in their country's natural resource management while also helping to build capacity in science, planning and environmental assessment.

Our goal is ambitious and needs the long-term engagement of all concerned parties. Apart from SEI, MEI, DWIR and the Sagaing Regional Government that have been working together closely over the past seven years, our team engaged with other organizations in Myanmar including, but not limited to: the Environmental Conservation Department, Department of Meteorology and Hydrology, Irrigation Department, Ministry of National Planning and Economic Development, the Expert Group of the National Water Resources Committee, the Natural Resources and Environmental Conservation Committee, Asia Development Research Institute, Water Resources Utilization Department, Myanmar Maritime University, Sagaing University, Sagaing University of Education, Monywa University, Yangon University, and Mandalay Technological University.

The SEI team has also cooperated with experts from the Mekong Region associated with the Sustainable Mekong Research Network (SUMERNET) and internationally, such as those from the Murray-Darling Basin Authority in Australia and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) from Brazil, and to share and exchange the knowledge and experience with Myanmar stakeholders, so they can learn from past successes and avoid the mistakes that other countries have faced in their development pathways.

Our work in the Chindwin River Basin, and this book, represents one of the first efforts in the country to bring together Myanmar governmental agencies both at national and regional levels (Sagaing), civil society organizations, researchers, the private sector, and local communities to engage in, and co-produce, multi-stakeholder dialogues and scientific assessments on environmental issues.

What's in this book

This volume attempts to provide an overall socioecological understanding of the state of the Chindwin River Basin in Myanmar. The chapters provide assessments of the natural, socioeconomic and institutional features of the Chindwin River Basin, ranging from climate change, geography and economy to biodiversity, water-use, local livelihoods as well as multi-stakeholder dialogues and institutions.

The volume is divided into five sections.

Part 1: Biophysical conditions and resources provides a natural science assessment of the basin covering its geography, and hydro-climate conditions and climate change.

Part 2: Regional economic integration and social and environmental sustainability studies the risks and impacts of flooding using modeling, assessment of changes in sediments and geomorphology in both the Chindwin and Ayeyarwady Rivers, water quality in the Chindwin River and its key tributaries, and a brief assessment of the conservation of biodiversity in the basin, in particular, fish, bird and turtle species.

Part 3: Socioeconomic development and resource use gives an understanding of the Sagaing Region, the political and administrative unit of the Chindwin River Basin, and the changing patterns of water use in three townships in the Sagaing Region.

Part 4: Dialogues, stakeholder perspectives and institutional efforts assesses existing water governance institutions in Myanmar and provides the context and efforts undertaken in establishing the Chindwin RBO. As mentioned, the establishment of the Chindwin RBO was the highlight of our work, and the RBO chapter provides the range of perspectives of stakeholders on how to manage the Chindwin River Basin through a participatory process and how water governance can be undertaken and improved at the basin scale.

Part 5: Conclusion helps to synthesize these studies and assessments to make linkages between the different studies and enhance the understanding of both the efforts made and the challenges that lie ahead towards achieving ecological sustainability in the Chindwin River Basin.

Who will find this book useful?

This book will be of value to academics and researchers working on natural resources and water governance issues in Myanmar, and in particular, the Chindwin River Basin, who are undertaking socio-ecological assessments towards improving river basin governance. The book will also be useful for state agencies, development professionals, and environmental organizations in Myanmar, and also more widely, the Mekong Region, involved in planning and policy-making on natural resources management.

This book is written to also be of educational interest for university students, the media, donors and development partners and also the general public, who are interested in conserving and protecting natural resources while promoting sustainable development through multi-stakeholder engagement in Myanmar.

Part I

Biophysical conditions and resources

2

The geography of the Chindwin River Basin

Thein Soe and Khin Ma Ma

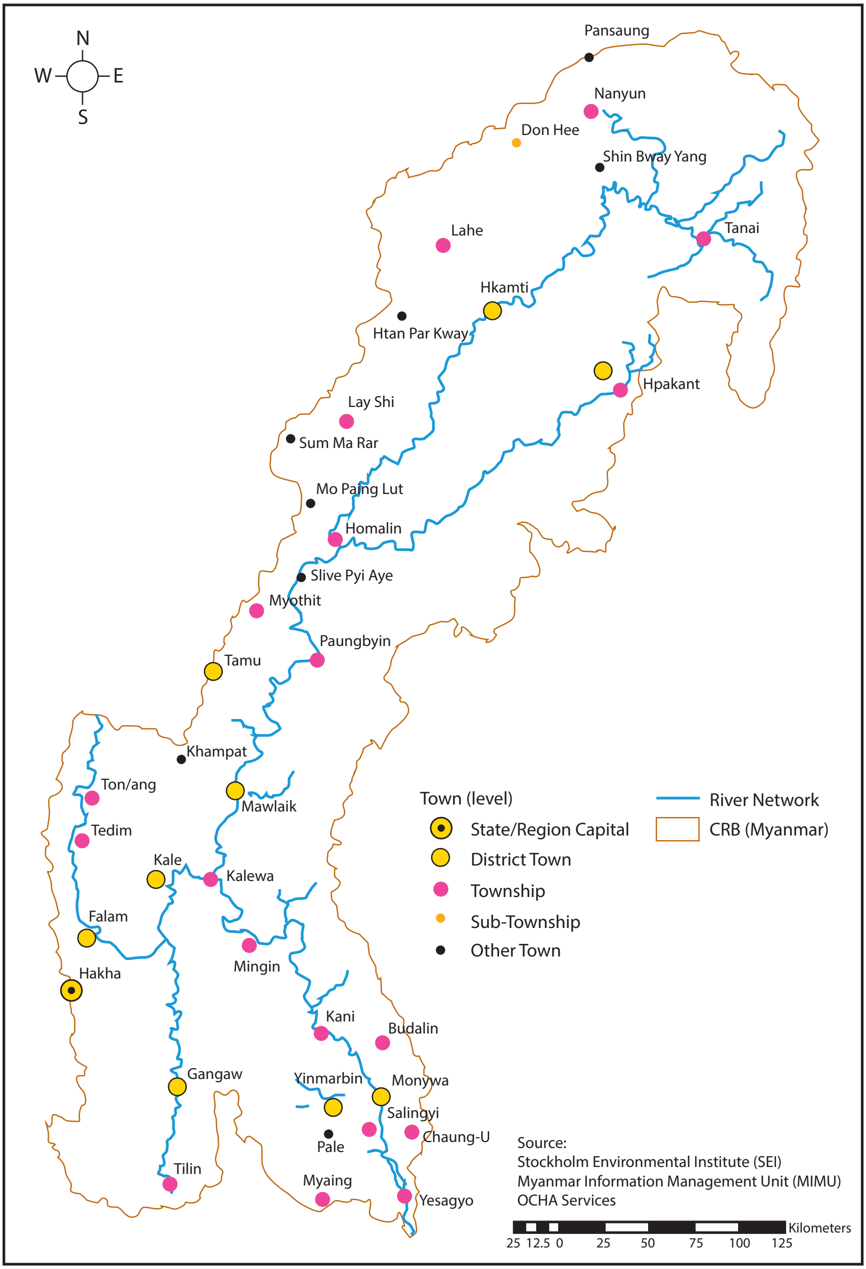
This chapter assesses how the physical and human geography of the Chindwin River Basin (CRB) in Myanmar (**Map 2.1**) supports and constrains the region's sustainable development. Special emphasis is placed on climate, topography, soils, demography and transport. Thorough knowledge of the climate, topography and soils, in turn, is important for evaluating and planning agricultural land-use. Topography is also important for assessing the costs of alternative transport options and the benefits of improved connectivity, for instance, for access to commodity markets and trade, as well as labor migration. Deforestation and land-use changes can seriously impact the topography, soils and river transportation in a river basin (IFC 2017). In the CRB, heavy rainfall occurs in the north (Grant Brown 1960). The water catchment is in the mountainous area upstream, while flooding and sedimentation are caused by deforestation, hydropower dams and mining (Van Meel et al. 2014). The climate of the upper CRB is different from that of the lower reaches, and it is determined mainly by geographical conditions (Grant Brown 1960; Aung et al. 2017).

Topography

The CRB is composed of mountainous forested terrain, with the exception of the vast plain in the south (Than 2005). Its northern and western border areas are mountainous, with an elevation of more than 1,000 m; the Patkoi Range has an elevation of over 2,400 m in the north. In the northwest is the Naga Highlands, where Mt Saramati, Myanmar's second highest mountain, has an elevation of about 3,800 m (see **Figure 2.1**).

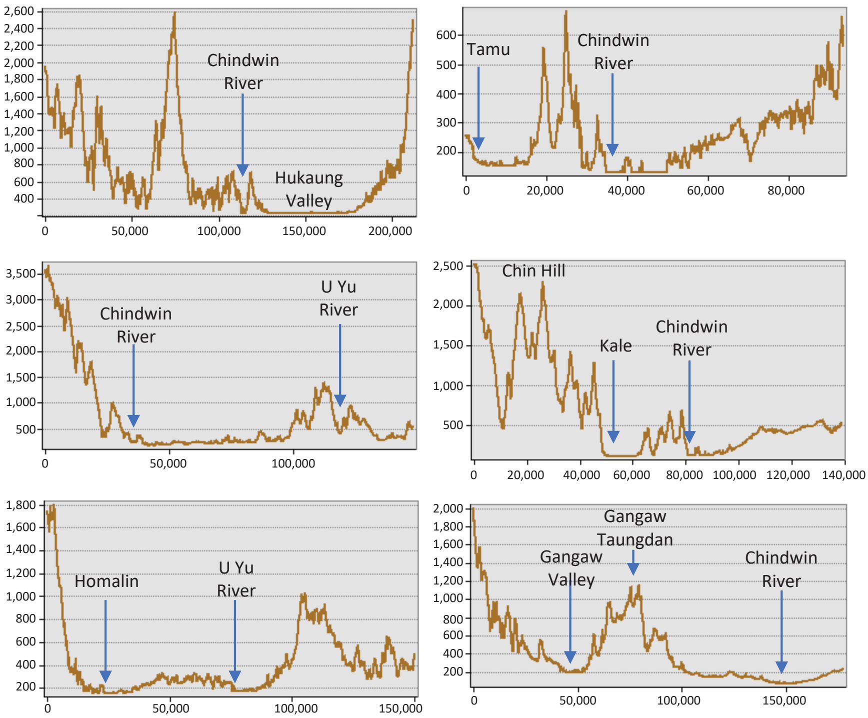
The Chindwin River radiates from the northern mountains, which is part of the Kachin Plateau. Tributaries flow into the Hukaung Valley, in the upper CRB.

Map 2.1 Chindwin River Basin: Towns



The U Yu Chaung (Creek) starts from the upland north of Hpakant, and is one of the river's largest tributaries in the upper CRB. Another large tributary is the Myittha River which meets the Chindwin at Kalewa. The Chindwin River then extends to the confluence of the Ayeyarwady River through the low plain east of Gangaw Taungdan (the Bago Yoma mountain chain). The Ma Ni Pur River from Chin Hills meets the Myintthar River and flows into the Gangaw Valley.

Figure 2.1 Elevation profiles: Chindwin River Basin



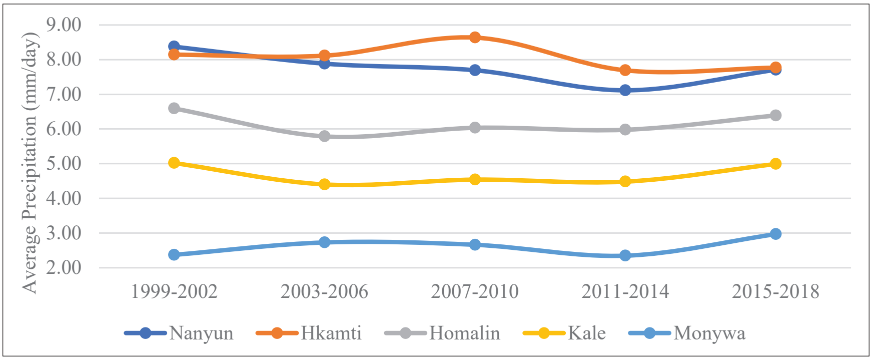
Source: TRIMM 3B42V7 precipitation products.

Climate conditions (2001–12)

The CRB stretches for 640 km from north to south and consists of high mountainous regions, valleys and vast plains. The lower right area is part of Myanmar's Central Dry Zone. This section explores precipitation in the CRB over a 20-year period from 1999 to 2018 by means of a probabilistic approach. A global dataset from TRMM[1] is used in a GIS analysis for five periods of four consecutive years.

Within this 20-year period, the average precipitation rate was between 2.4 to 9.5 mm per day. The northern region— including the towns of Tanai, Hpakant, Hkamti, Nanyun and Homalin—had a higher average precipitation of 7.5 to 9.5 mm per day. Lahe and Lay Shi in the Naga Highlands, Tamu, Mawlaik and Paungbyin received rainfall of 5.5 to 7.5 mm per day. The southern region, including the Chin Hills, Mawlaik, Kale, Kalewa, Mingin, Gangaw and Tilin, received 4 to 7.5 mm of rain per day on average. Kani and the Central Dry Zone of the Budalin-Monywa-Chaung-U-Salingyi-Myaung-Yesagyo area received less than 4 mm per day. The downstream part of the CRB falls in the Dry Zone, and the rainfall is lower in this area due to the subsiding lower layer of air and rain-shadow effects (Than 2005).

Figure 2.2 Average precipitation for selected areas, Sagaing Region



Source: TRIMM 3B42V7 precipitation products.

Figure 2.2 lists the five selected study areas of Sagaing Region from north to south. These temporal precipitation averages have mostly similar patterns, particularly in 2007–18. When comparing the average precipitation in 2015–18 to that of 1999–2002, two salient changes are found:

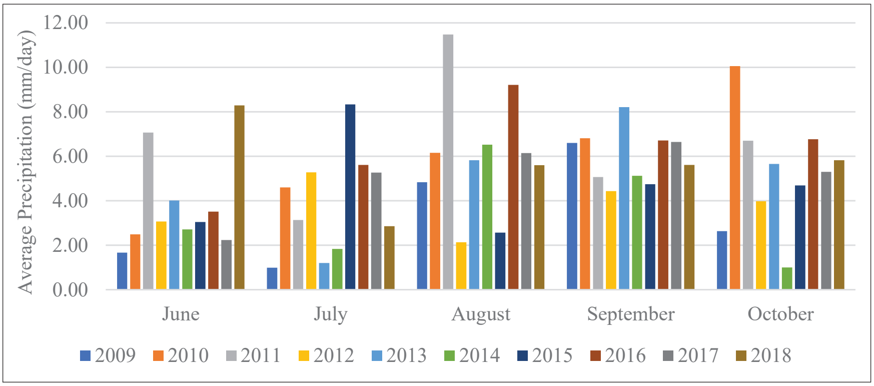
- Nanyun in the Naga Highlands had a reduction in precipitation of about 8 percent, due to temporal trends between 2003–06 and 2011–14.

- Monywa in the Central Dry Zone shows increased precipitation of about 25 percent, due to temporal trends between 2011–14 and 2015–18.

Case study: Rainfall variations in the Monywa area

For agriculture, crop selection and production depend on exogenous factors such as rainfall, humidity, soil nutrients and water availability. Both high and low rainfall could affect the cultivation cycle and production, especially during sowing and harvesting periods. Normally monsoon rice is sown at the end of June and early July, and harvested in mid-October. **Figure 2.3** presents the rainfall in Monywa during the moonsoon from June to September and post-monsoon in October.

Figure 2.3 Rainfall variation in Monywa area



Source: TRIMM 3B42V7 precipitation products.

The rainfall varies considerably in July, August and October year-by-year with unpredictable changes. These unpredictable patterns could strongly affect sustainable agricultural practices and crop cycles. The high rainfall and potential pluvial flooding (caused by extreme rainfall) in October may lead to greater damage to cash crops, and consequently have an adverse impact on the livelihoods of local farmers. When rainfall increases in October, the sowing of the winter crops will be delayed, affecting the whole agriculture cycle in the succeeding year.

Table 2.1 Soil types and soil characteristics

Soil type	Township	Soil depth[a]	Texture	Suitable crops
Yellow Brown Forest Soil	Hkamti, Homalin, Tamu, Paungbyin, Mawlaik, Kalewa, Kale, Mingin, Ye-U, Kani, Pale, Yinmarbin, Tani, Banmauk, Pinlebu, Hpakant, Mohnyin, Gangaw, Tilin, Myaing	Medium	Clay loam Silty clay Sandy clay	Forest products Orchards crops
Northern Hill Complex Soil	Tanai, Mogaung, Hkamti, Nanyun, Lahe, Lay Shi	Clay Clay loan Forest products	Clay Clay loan	Forest products
Chin Hill Complex Soil	Tonzang, Tedim, Falam, Hakha, Matupi, Mindat	Medium	Sandy loan Clay with gravel	Forest products
Alphic Complex Soil	Tanai, Nanyun	Medium	Clay Clay loan	Forest products
Meadow & Meadow Alluvial Soil	Tanai	Thick	Sandy loan Clay	Rice, pulses, sesame, sugarcane, vegetables
	Homalin, Paungbyin, Mawlaik, Kalewa, Kale, Mingin, Taze, Kani			Rice, sesame, ground nut, corn, cotton, vegetables
Alluvial Soil	Tanai	Thick	Loamy sand	Pulses, vegetables chillies, onions
	Mawlaik	Medium		Groundnut, sesame, vegetables
Red Brown Forest Soil	Hpakant, Tanai Hkmti, Homalin, Banmauk, Paungbyin, Pinlebu	Medium	Clay loan Silty clay Sandy clay	Forest products
	Falam, Tedim			Plantation crops and forest products
Light Forest Soil	Kani, Tabayin, Budalin, Monya, Ayadaw, Chaung-U, Yinmarbin, Pale, Salingyi	Medium	Sandy loan, Clay loan	Forest plantation, Upland crops
	Myaing, Yesagyo			Forest plantation, orchard crops
Savanna Soil on Slopes & Compact Soil in Depression	Budalin, Monywa, Chaung-U, Myaung	Tick	Sandy loan	Ground nut, sesame, sunflower, cotton, rice, sugarcane, chillies
	Yesagyo		Sandy loan Clay	Rice, chillies, pulses, sorghum, sugarcane, cotton, vegetables

Note: [a]Soil depth: Thick: >36 in; Medium: 20–36 in; Thin: <20 in.
Source: Soil types and characteristics of Myanmar (MOAI 2004).

Soil types

Most of the CRB is characterized by red-brown soils, dark compact soils and gravel soils having low fertility (Yee 2015; Grant Brown 1913). There are nine main soil types in the CRB area, with Yellow Brown Forest Soil being dominant. Northern Hill Complex Soil and Chin Hill Complex Soil are found on the northern mountainous region and on the high mountainous belt of the Chin Hills (see **Table 2.1**).

Demography

Historic records indicate the occurrence of diverse national ethnicities in the CRB including Bamar, Shan, Naga, Chin, Kachin and Kadu (Grant Brown 1960). There are 38 administrative townships in the CRB area: 24 townships in Sagaing Region, 4 townships in Kachin State, 6 townships in Chin State, and 4 townships in Magway Region. Along its western and northern boundaries, townships fall completely or mostly within the CRB area, while some townships in the east and south are partially contained in the CRB (**Map 2.2**). In this demographic analysis, the 27 townships which are completely or mostly within the CRB area were included.

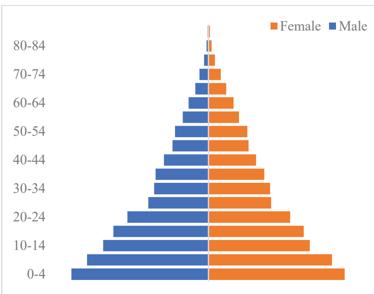
According to the 2014 Myanmar Census, there are a total of 3.1 million people living in these 27 townships, which is 6 percent of the total population of Myanmar. Altogether, 76 percent of this population lives in rural areas. Monywa, Kale and Homalin are the most populated townships. There are 37 towns of different administrative levels in the CRB, but only Monywa and Kalay have populations of over 100,000—about 200,000 and 130,000 respectively. Thus, Monywa and Kaly towns can be defined as the population-core cities of the CRB.

The population pyramids of the above three townships based on the 1973 and 2014 censuses are shown in **Figure 2.4**. The variation in the population pyramids during different periods in the same township, as well as between different townships during the same period, can be interpreted in terms of trends in migration and fatalities.

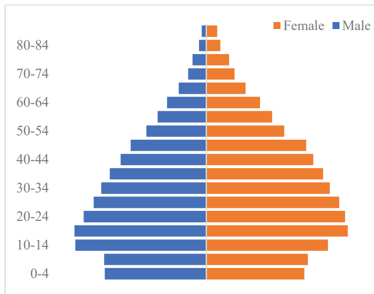
In 1973, the same patterns of high birth rates, high death rates and low life expectancy are found for all townships. For the aging population of 65 years and over, males had lower life expectancy compared to females in all townships. For young men aged 15 to 34 years, the decreasing trends could be an effect of emigration.

For Monywa, a contrast is found in the 2014 pyramid. The birth rate has been controlled within the past 10 years, which may be consistent with the township becoming more developed and urbanized, as well as the fatality rate likely declining. The number of those in the younger working-age group has been sustained compared to 1973, which may be due to the effects of immigration or because local young people are still working in the township due to job opportunities arising from economic development. Kale has the same pattern as Monywa.

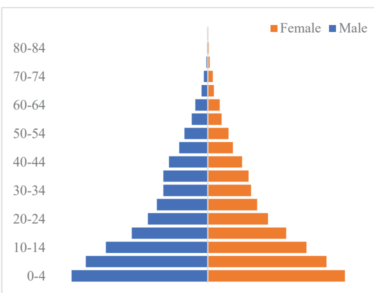
Figure 2.4 Population pyramids, 1973 and 2014



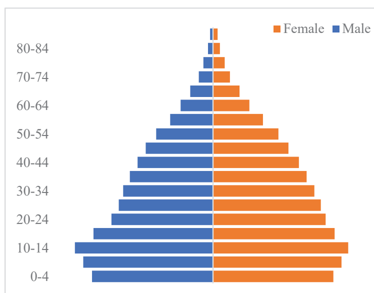
Monywa (1973)



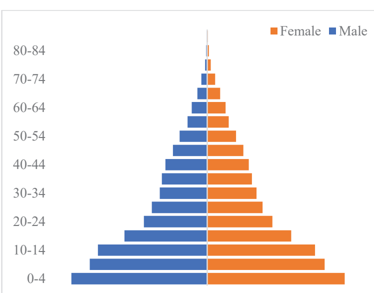
Monywa (2014)



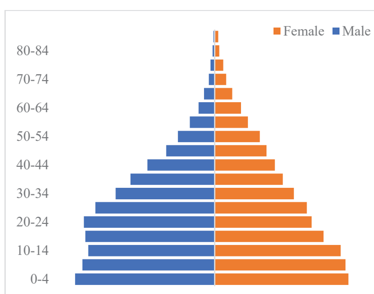
Kale (1973)



Kale (2014)



Homalin (1973)



Homalin (2014)

Sources: 1973 and 2014 Households and Population Census.

Homalin still has a high birth rate and a relatively high fatality rate. Outmigration may have been an issue in 2014; if so, this indicates that there were fewer job opportunities in Homalin than in Monywa and Kale. Homalin's patterns contrast with those in Monywa.

Transportation

Road transport is the primary mode of transport in the region. The Monywa-Kalewa-Kale-Tamu Road and Monywa-Kalaewa-Homalin Road are the major access roads. The Monywa-Kalaewa-Kale-Tamu road network is the strategic route for both the India-Myanmar-China corridor and India-Myanmar-Thailand corridor. Two railways exist—Sagaing-Monywa-Butalin branch line and Pakokku-Myaing-Gangaw-Kale railway—but trains are not a common mode of transport.

There are five operational airports in the CRB—in Monywa, Kalemyo, Homalin, Hkamti and Falam—with flights to Yangon and Mandalay international airports. There is also a direct flight from Monywa to Homalin.

People choose their mode of transport based on the price, time and other factors such as frequency, quality and reliability. Myanmar Railways charges 0.85 to 1.50 cents per km for passenger fares, which is the cheapest. But the trains are limited in frequency and destinations, and generally not on schedule, as they travel at low speeds at an average 30.5 km/hr (ADB 2016). Thus, most people prefer not to use the railway.

River transport is also relatively affordable, e.g. 2.61 cent per km for the Monywa–Kale route at a low speed of 16.9 km/hr (ibid.). The net navigation time for this route takes a minimum of 14 hours. According to interviews with local people, the Chindwin River is not navigable all year round, while boat safety is another issue to consider. Overall, river transport has been gradually declining. In addition, the river has become shallower due to the high sedimentation load, which has been attributed to deforestation and other activities, as well as soil types (IFC 2017). Boat safety is very low due to the high flood risk during the monsoons, particularly in the upper and middle parts of the basin (Hasman 2014; Latt 2015). Floods in the Chindwin River occur when intense rain falls for at least three days in the upstream area (UN Habitat 2015). Climate change is one of the factors which increases flood risks in the CRB (Ketelsen et al. 2017).

The road network covers the whole of the CRB with a wide variety of destinations. Buses are the most available form of transport. The average fare is 2.03 cents per km—less than river transport—and the average driving speed is about 40 km per hour, or approximately 7 to 8 hours driving time for the Monywa–Kale route. Field observation and travel indicates that the population of the CRB depends heavily on road transport.

While taking a flight saves travel time, the fares are much more expensive (about US$44 for Monywa to Homalin). Those who place value on the time saved and can afford the high fares prefer to use this travel mode.

Implications

The topographical and climate variations across the CRB have an impact on the modes of transport and agricultural practices, including crop selection and the cultivation cycle. Traditional agricultural practices have become unsuitable for current climate and soil conditions. Thus, agricultural institutions should study the deployment of new seed varieties, which may be more adaptable to the predicted climate change patterns.

Demography is one of the key indicators for human geography and regional socioeconomic development. Changes in the age structure of the population due to declining fertility and changes in spatial distribution due to migration need to be taken into account when undertaking long-term planning for education, employment and regional development.

Notes

1 The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) to study rainfall for weather and climate research. https://trmm.gsfc.nasa.gov/.

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3

Hydro-climatic conditions in the Chindwin River Basin

Thanapon Piman and Manish Shrestha

The climate of the Chindwin River Basin is tropical, and is driven by a number of complex large-scale atmospheric processes related to the Asian monsoonal systems. The monsoonal influence on the basin's climate has substantial effects on variations in the seasonal cycle of flows along the Chindwin River and, as a consequence, has implications for 80 percent of the six million people in the Chindwin Basin that depend directly on natural ecosystems for their livelihoods.

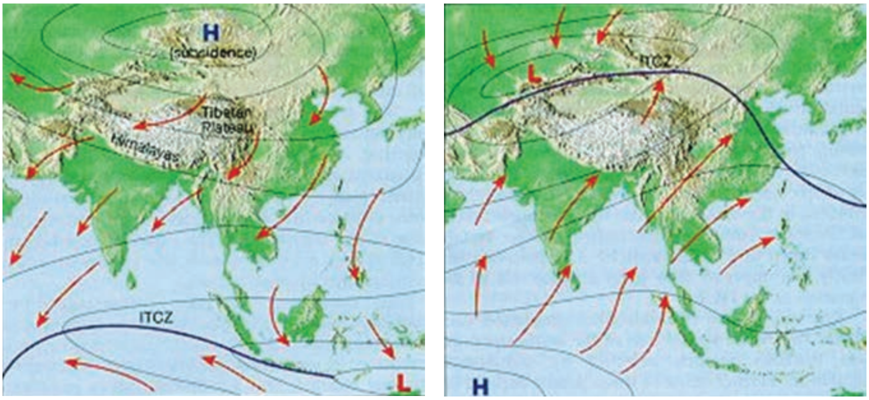
The basin experiences three seasons: winter (November to February), summer (March to mid-May) and rainy (mid-May to October). Floods associated with the monsoonal wet season usually occur from July to September with peak flows occurring in August (Kuntiyawichai et al. 2015). The lower part of the Chindwin River Basin lies in the Central Dry Zone of Myanmar where rainfall is less than 1,000 mm per year. It is located within a rain shadow area that is influenced by the Rakhine Yoma mountain range to the west (Drury 2017).

Drivers of climate in Myanmar and the Chindwin River Basin

Asian monsoon system

The Asian monsoon climate system is the largest climate system globally, playing a significant role in large-scale climate variability in Asia and providing a critical lifeline to billions of people living throughout the vast region. It is the dominant climate feature in Myanmar, modulating wet and dry season flows in the Chindwin River. The Asian monsoon system in Myanmar can be broadly divided into two identifiable sub-systems: the Southwest and Northeast Monsoons (**Figure 3.1**).

Figure 3.1 Schematic of the (a) Northeast and (b) Southwest monsoonal systems that dominate Myanmar's climate



(a) Winter moonsoon (b) Summer moonsoon

Source: Stott Laboratory, Department of Earth Sciences, University of Southern California, https://earth.usc.edu/~stott/Catalina/Regionalcirc.html.

The Southwest Monsoon that brings the rainy season to Myanmar and the Chindwin River Basin leads moisture-laden winds from the Indian Ocean into the subcontinent towards the Himalayas. The Himalayas acts like a high wall and forces these winds to rise, leading to a drop in cloud temperature and precipitation.

The Southwest Monsoon is divided into five periods: pre-monsoon (starting in mid-April), early monsoon (June), peak monsoon (July and August), late monsoon (September) and post-monsoon (October and November). The Southwest monsoon makes its appearance in Myanmar in mid-May and strengthens over the following months to peak during June to August with increased and intense rainfall events (Aung et al. 2017). The monthly rainfall distribution over 38 years (1979–2016) at five monitoring stations in the basin is presented in **Table 3.1**. The peak rainfall occurs in July (upstream stations) and August (downstream stations).

The Northeast Monsoon causes cold winds from the Himalayas to move southwards to the Indian Ocean, creating dry air streams which produce clear skies, low humidity and lower temperatures in the country. This occurs between November to February, which coincides with the winter season. Precipitation associated with this monsoon is limited, however, it is important for winter crops in northern Myanmar

Table 3.1 Monthly rainfall distribution at selected hydro-met stations, 1979–2016 (mm)

Month	Hkamti	Homalin	Mawlaik	Kalaywa	Monywa	Basin
Jan	5.6	6.6	3.8	2.6	0.9	4.5
Feb	14.2	13.0	4.7	4.4	1.9	9.5
Mar	21.7	23.1	16.6	14.7	5.9	18.1
Apr	44.5	42.3	37.6	33.4	28.9	39.2
May	230.4	172.8	142.8	163.3	82.2	175.1
Jun	813.3	450.1	283.2	269.1	90.6	477.1
Jul	1162.3	534.7	269.4	266.0	66.4	611.7
Aug	783.9	421.8	310.0	299.1	120.1	472.5
Sep	529.8	357.8	332.1	341.1	161.6	384.9
Oct	225.7	190.0	195.7	204.4	126.7	196.8
Nov	20.0	29.3	35.3	35.3	32.6	28.3
Dec	6.9	8.6	6.8	6.9	4.0	28.3

(Aung et al. 2017). In Myanmar's Dry Zone, over 90 percent of the annual rainfall occurs during the May to October monsoon period. The dry season therefore brings acute water shortages. Many villagers have to travel long distances to collect water from shallow ponds. The water shortages affect hygiene and sanitation and subsequently causes the spread of water-borne and other diseases (Drury 2017).

Tropical cyclones

A tropical cyclone is a large depression that forms over tropical oceans and moves away from the Equator. Tropical cyclones are intense rotating weather systems with organized cloud bands, thunderstorms and strong winds. Many of these can cause considerable damage to property and loss of life. They form over tropical oceans where temperatures are above 26.5 °C and have spheres of influence of between 100 and 1,000 km. Tropical cyclones persist for several days and move with irregular paths, usually dissipating over cooler oceans or once they reach land. Tropical storms tend to occur during the hottest times of the year – between May and November.

Myanmar has experienced a number of severe tropical cyclones in recent decades: Great Sittwe Cyclone in 1968, Pathein in 1975, Gwa in 1982, Maungdaw in 1994, Mala in 2006, Nargis in 2008, Giri in 2010, Komen in 2015, Roanu in 2016 and Mora in 2017 (Aung et al. 2017). They have caused severe floods in the Ayeyarwady Delta and the Chindwin River Basin. **Figure 3.2** shows the path of tropical cyclones since Nargis in 2008 and townships where people have been affected by major floods since 2012 (OCHA 2017). Many of the worst affected townships are located in the Chindwin River Basin and the Ayeyarwady Delta.

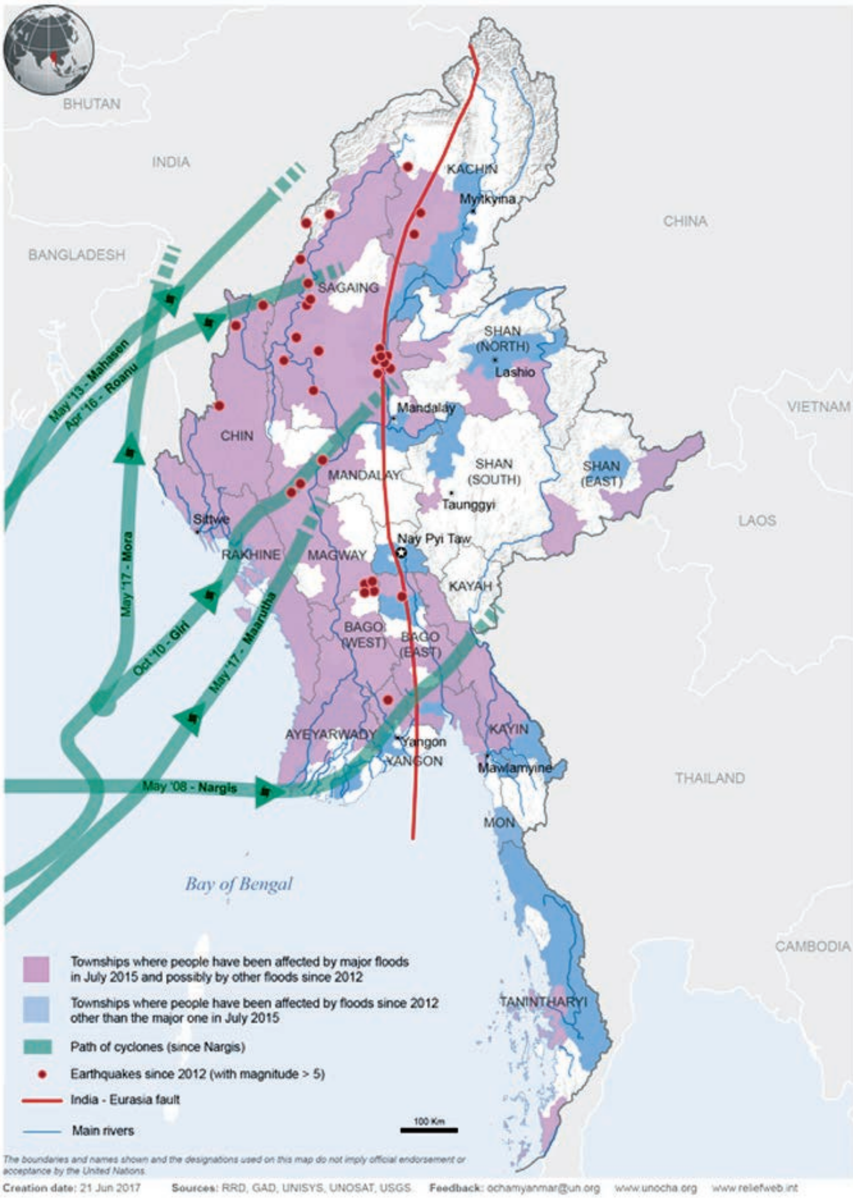
El Niño-Southern Oscillation

The El Niño-Southern Oscillation, or ENSO, is an interaction between ocean temperatures and large-scale atmospheric circulation, affecting much of the tropics and sub-tropics and, via global teleconnections, weather phenomena across the globe. The ENSO has two phases: El Niño (the warming phase) and La Nińa (the cooling phase). Across Southeast Asia, El Niño typically reduces precipitation and increases temperatures, whilst La Niña periods are characterized by both wetter and warmer conditions. Both have a return period of between three to five years, indicating that the ENSO is an interannual climate feature.

Atmospheric circulation across Myanmar and South Asia is modulated by the ENSO and Indian Ocean Dipole mode (IOD). These phenomena are linked to significant anomalies in rainfall and temperature (D'Arrigo and Ummenhofer 2014). Sen Roy and Sen Roy (2011) observed that the Pacific Decadal Oscillation (PDO) modulates precipitation during ENSO events across Myanmar, with drought during El Niños being more intense during the warm PDO phase, and with the reverse for La Niñas, bringing more intense floods.

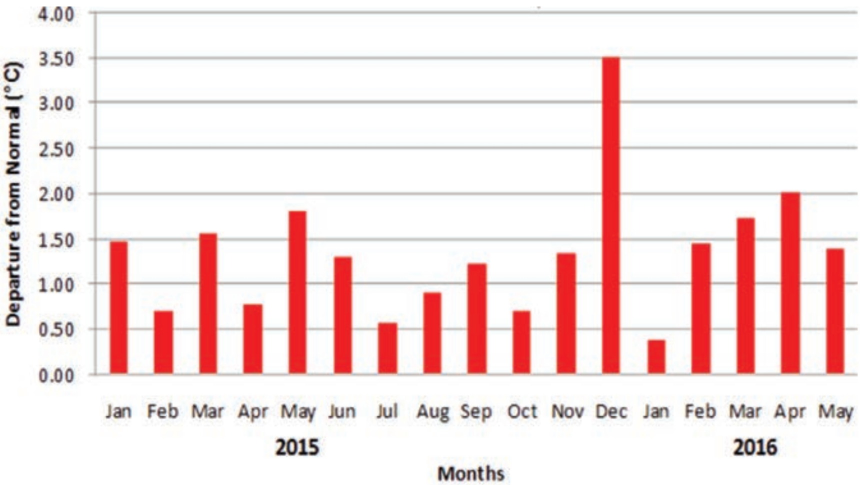
During a moderate El Niño event in 2010, record temperatures of 47.2 °C were experienced in Myinmu township in the Ayeyarwady Basin. During this year, the record low water levels in the Chindwin River (as recorded at the Monywa station) affected water supply, navigation and food production in the basin (Tin Yi et al. 2014). During the strong El Niño event in 2015–16, monthly mean temperatures in Myanmar were above normal when compared with the 30-year period from 1981–2010. The mean monthly temperature increased by between 0.6 to 3.5 °C in 2015, and from 0.4 to 2.0 °C in 2016 (**Figure 3.3**), increasing evaporation and worsening water shortages across the country, particularly in the Dry Zone and the lower Chindwin River Basin in Sagaing Region (ESCAP and UNDP 2016).

Figure 3.2 Path of tropical cyclones since Nargis in 2008 and townships affected by major floods since 2012



Source: UN Office for the Coordination of Humanitarian Affairs (OCHA). 2017. Myanmar: Recent Natural Disasters Overview,; https://reliefweb.int/map/myanmar/myanmarrecent-natural-disasters-overview-28-june-2017.

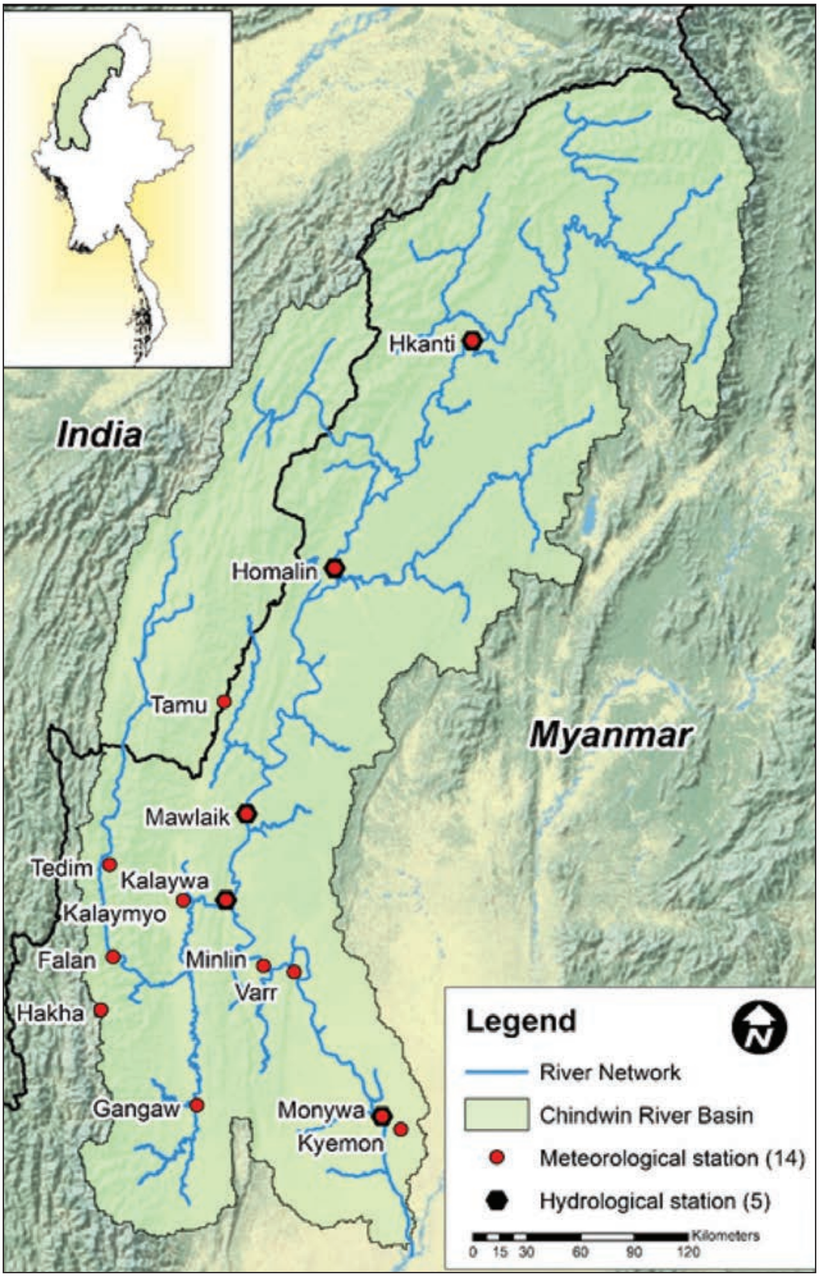
Figure 3.3 Change of monthly mean temperature 2015–2016 in Myanmar, relative to 1981–2010 (ESCAP and UNDP 2016)



Hydro-met network

Meteorological and hydrological observations in Myanmar are the responsibility of the Department of Meteorology and Hydrology (DMH), Ministry of Transport and Communications. **Figure 3.4** presents the location of the hydro-meteorological monitoring stations within the Chindwin River Basin. There are fourteen meteorological stations and five hydrological stations. The meteorological stations measure rainfall, and maximum and minimum temperatures whilst the hydrological stations record water levels, discharge and evaporation. Two stations, at Hkamti and Kalewa, record sediment loads. Further, the five hydrological stations along the Chindwin mainstream including Hkamti, Homalin, Mawlaik, Kalewa and Monywa stations are used for water level forecasting for providing early warning for floods (Htay Htay Than 2015). The meteorological and hydrological parameters are measured manually on a daily basis. Water level and rainfall records go back to the 1960s and 1970s respectively. Some meteorological stations in the lower part of the basin were installed only in the 1980s.

Figure 3.4 Hydro-met stations in the Chindwin River Basin



The density of rainfall and streamflow stations within the Chindwin River Basin are 8,128 and 22,760 km^2 per station, respectively, which is low according to WMO guidelines (WMO 1994). The minimum densities of rainfall and streamflow stations in the mountainous region for water resources planning are considered to be 2,500 and 1,000 km^2 per station. Only four stations are installed in the upper and middle part of the basin, and no hydrological stations are present in tributary rivers. This limitation is a critical issue affecting spatial accuracy in monitoring and analyzing climate and hydrological conditions across the basin. This is in part due to poor access and low population densities in the mountainous areas of the basin as well as financial and capacity limitations.

DMH is in the process of building capacity and improving the quality of weather, climate and hydrological information and services in Myanmar for disaster reduction, water resources management, agriculture, transport, environmental protection and other related sectors under the World Bank-funded Ayeyarwady Integrated River Basin Management (AIRBM) from 2015–20. This project aims to assist Myanmar develop the institutions and tools required to enable informed decision-making in the management of Myanmar's water resources and to implement integrated river basin management for the Ayeyarwady Basin (World Bank 2015). Eight Automatic Water Level Record stations are planned to be installed in the Chindwin River Basin under this project.

Climate: State, trends and extremes analysis

The analysis of climate and hydrological conditions across the Chindwin River Basin focuses on three parameters including temperature, precipitation and discharge. These variables typically control the water resources system across the basin. Five hydro-met stations that have long-term records and represent spatial distribution were selected to undertake a climate and hydrology assessment of the basin and to review the current status and trends. The data were collected from the selected five stations, Hkamti, Homalin, Mawlaik, Kalewa and Monywa, as shown in **Figure 3.4**. Daily time series datasets from 1979–2016 (38 years) were used for the analysis. The hydro-met data were obtained from DMH. Linear regression analysis was used to assess trends in the long-term hydro-met time series data. Extreme climate indices were examined based on WMO's guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation (WMO 2009).

Temperature

Current state

Figure 3.5 presents the spatial distribution of average annual temperature across the basin that varies between 24.4–27.4 °C. The temperature decreases from lowland downstream to highland upstream of the basin. **Figure 3.6** presents the relationship between the average annual temperature and elevation of the selected hydro-met monitoring stations. The elevation of the Hkamti station is 61 m higher than the Monywa station, with an average annual temperature 3.7 °C lower than at Monywa. Thes data indicate that the temperature in the basin is dependent on elevation. Apart from elevation, northerly distance is a significant influence on temperature. Hkamti station is at 26 degrees north and Monywa station is at 22 degrees north, with a distance between these two stations of about 440 km.

Figure 3.5 Average annual temperature and rainfall in the Chindwin River Basin, 1986–2005

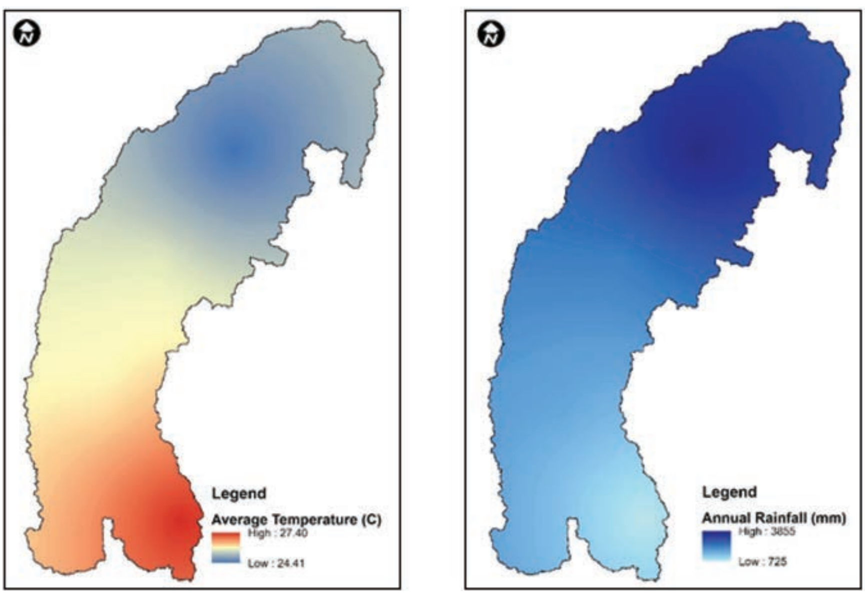
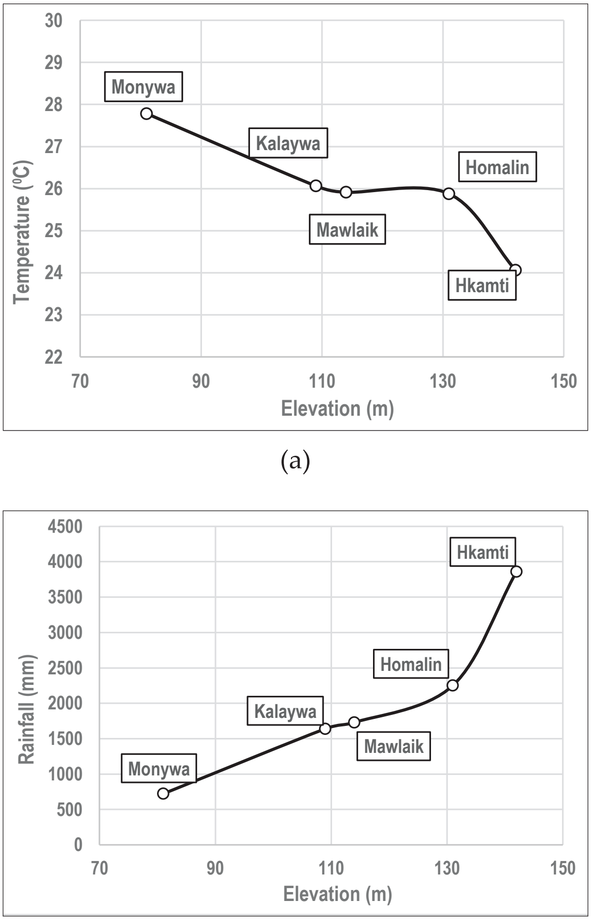


Figure 3.6 Relationship between (a) elevation and the average annual temperature of the selected hydro-met monitoring stations and (b) elevation and the average annual rainfall



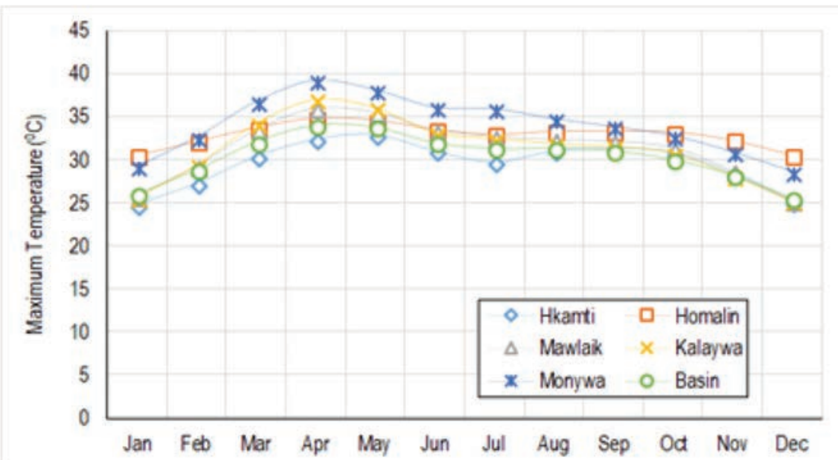
(a)

(b)

The average monthly distribution of maximum and minimum temperatures is calculated and plotted in **Figure 3.7**. Average monthly maximum temperatures vary from 24.8–39.2 °C and average monthly maximum temperatures 10.0–26.0 °C. Both maximum and minimum temperatures begin increasing from January to April and decrease thereafter. The hottest month is April and the coldest month is January.

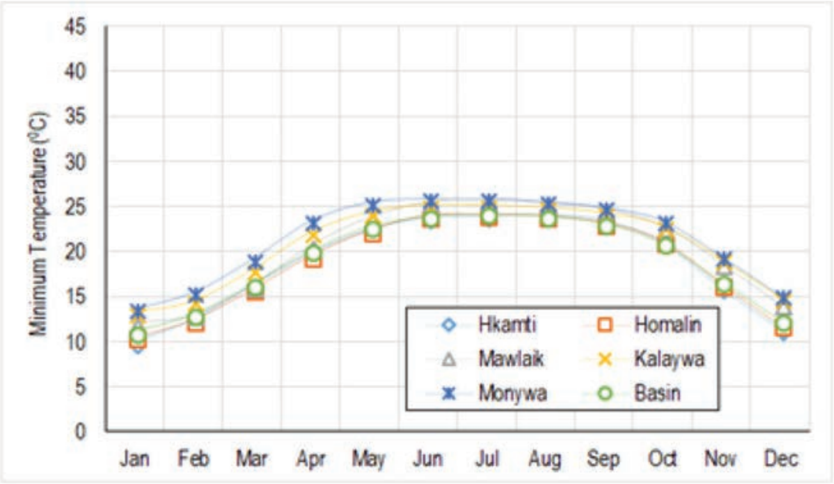
Figure 3.7 The average monthly maximum temperature (a) and minimum temperature (b) during 1979–2016 at selected hydro-met stations

Tmax						
Month	**Hkamti**	**Homalin**	**Mawlaik**	**Kalaywa**	**Monywa**	**Basin**
Jan	24.83	30.59	25.77	25.62	29.20	26.18
Feb	27.26	32.20	29.32	29.43	32.61	28.90
Mar	30.41	33.81	33.51	34.23	36.76	32.13
Apr	32.39	34.88	35.99	37.02	39.22	34.09
May	32.94	34.66	35.56	36.05	38.10	33.84
Jun	31.03	33.61	33.47	33.15	36.07	32.04
Jul	29.73	33.03	32.76	32.49	35.90	31.38
Aug	31.04	33.38	32.36	31.90	34.74	31.40
Sep	31.35	33.40	32.19	31.55	33.83	31.11
Oct	30.90	33.31	31.43	30.82	32.77	30.07
Nov	28.42	32.36	28.70	28.17	30.90	28.30
Dec	25.17	30.62	25.33	25.20	28.62	25.58



(a)

Tmin						
Month	**Hkamti**	**Homalin**	**Mawlaik**	**Kalaywa**	**Monywa**	**Basin**
Jan	9.98	10.54	12.14	13.29	13.64	11.13
Feb	12.48	12.47	12.98	14.51	15.48	13.00
Mar	16.19	15.79	16.25	17.95	19.13	16.39
Apr	19.82	19.52	20.66	22.11	23.40	20.13
May	22.44	22.32	23.75	24.37	25.51	22.81
Jun	23.84	24.03	25.49	25.17	25.90	24.01
Jul	23.98	24.08	25.71	25.12	25.99	24.28
Aug	24.12	23.98	25.40	24.88	25.59	24.02
Sep	23.49	23.19	24.74	24.27	24.93	23.22
Oct	21.02	21.23	22.86	22.89	23.46	20.95
Nov	15.95	16.44	18.71	19.13	19.49	16.75
Dec	11.41	11.88	14.17	14.95	15.17	12.38

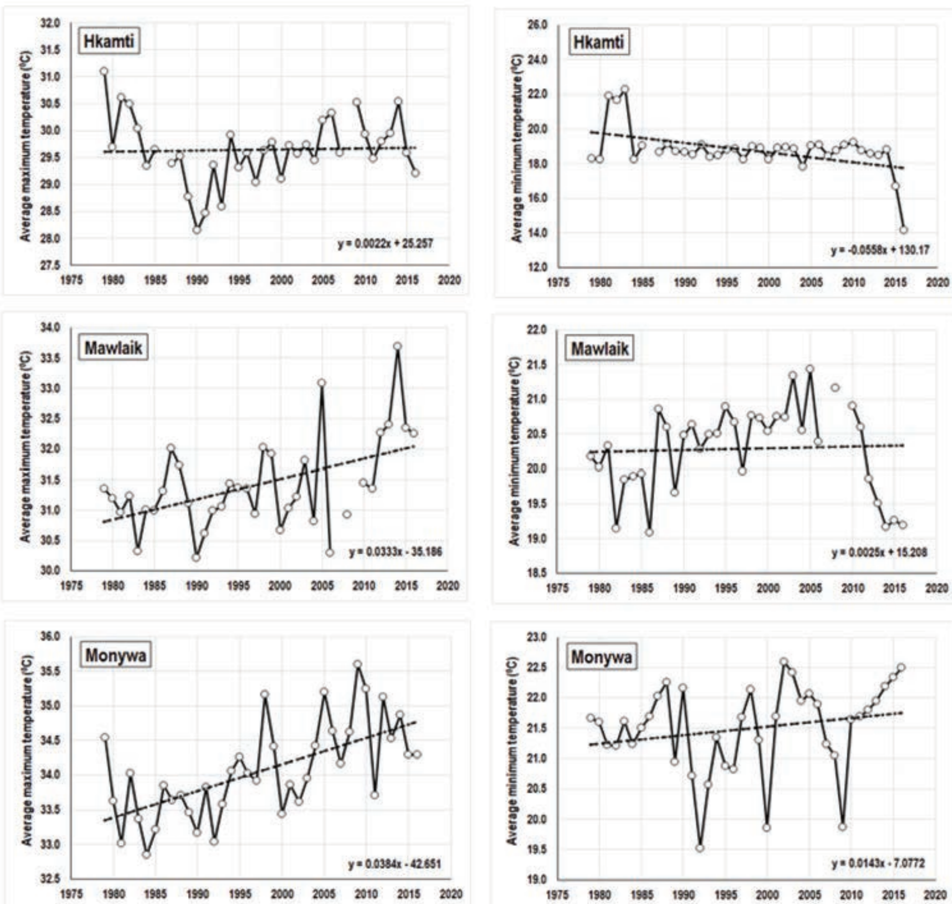


(b)

Trends

The average annual maximum and minimum temperature at the Hkamti, Mawlaik and Monywa stations were selected for trend analysis over 38 years (**Figure 3.8**). The average annual maximum temperature at Mawlaik and Monywa stations shows a significant increasing trend (averaging 0.33–0.38 °C/10-year) which is almost double the average global warming rate (~0.20 °C/decade) as reported by the IPCC (2018). At the Hkamti station, the average annual maximum temperature decreased during 1979–1990, but increased during 1991–2016 at an average rate of 0.36 °C/10-year.

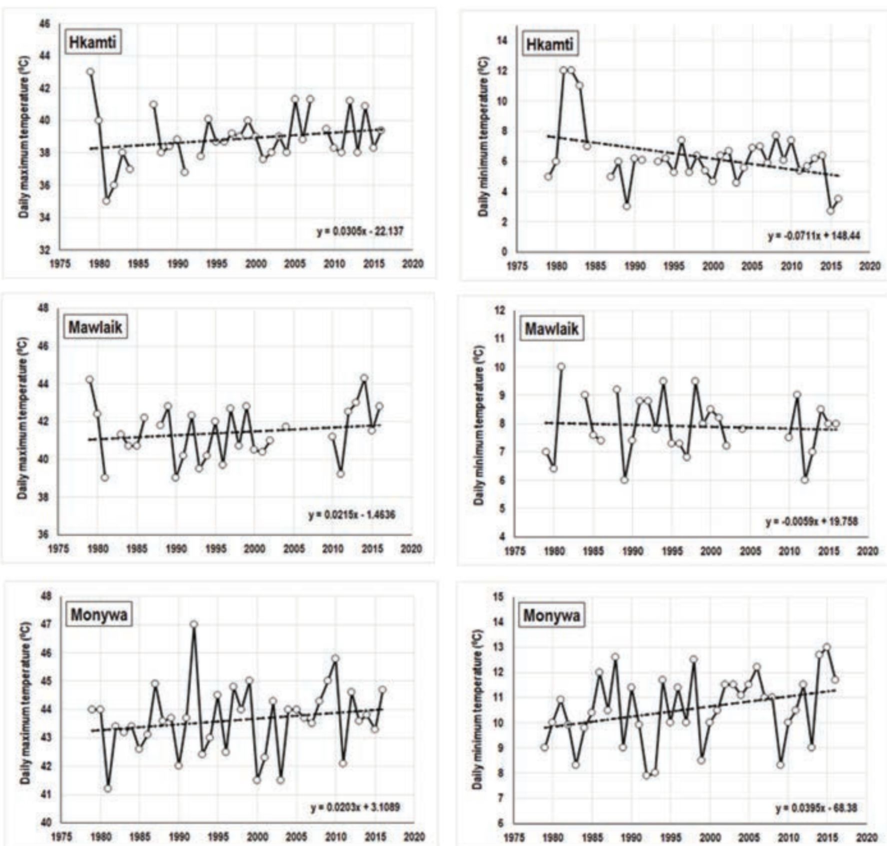
Figure 3.8 Annual trend analysis of the average maximum temperature (a) and the average minimum temperature (b) during 1979–2016 at selected hydro-met monitoring stations



(a) (b)

Overall across the basin, the average annual maximum temperature has increased by 1.37 °C since 1979. These results are consistent with the national report on climate change (Aung et al. 2017) and the IPCC Fifth Assessment Report (IPCCa 2014). The trends in average annual minimum temperature among the selected three stations are inconsistent. A decreasing trend is detected at the Hkamti station (averaging 0.56 °C/10-year) and an increasing trend at the Monywa station (averaging 0.14 °C/10-year). No clear trend was evident in data collected from the Mawlaik station over the period under review.

Figure 3.9 Annual trend analysis of two temperature extreme indices, the daily maximum temperature (a) and the daily minimum temperature (b) during 1979–2016 at selected hydro-met monitoring stations



(a) (b)

Table 3.2 Extreme climate and hydrological events at selected hydro-met stations, 1979–2016

Station	Temperature				Rainfall		Discharge			
	Maximum		Minimum		Maximum		Maximum		Minimum	
	°C	Date	°C	Date	mm	Date	m^3/s	Date	m^3/s	Date
Hkamti	43.0	3 Jun 1979	2.7	27 Dec 2015	527	29 Jun 1989	19,613	12 Jul 1991	0	Feb–Apr 2012
Homalin	43.0	5 Jun 1979	3.0	8 Feb 1980	415	1 Jul 2001	21,650	12 Jul 1968	40	29 Mar 1995
Mawlaik	44.3	22 Apr 2014	5.0	19 Jan 2003	225	28 Jul 2004	26,733	21 Jul 1976	152	29 Mar 2004
Kalewa	48.2	29 May 1979	1.2	25 Dec 1987	306	23 May 1981	26,220	18 Aug 2002	279	11 Apr 2006
Monywa	47.0	8 May 1992	7.9	6 Jan 1992	144	12 May 2007	27,300	9 Oct 1980	121	31 Mar 2010

Extremes

Table 3.2 presents the highest recorded daily maximum and minimum temperature at the five hydro-met stations. The Kalewa station recorded the highest daily maximum and minimum temperatures of 48.2 °C (29 May 1979) and 1.2 °C (25 Dec 1987), respectively. Two extreme indices, the maximum daily maximum temperature (TXx) and the minimum daily minimum temperature (TNn), are calculated for the Hkamti, Mawlaik and Monywa stations to assess trends of extreme events (**Figure 3.9**). The TXx tends to be rising over the period of 1979–2016 at all three stations. The TNn exhibits a decreasing trend at the Hkamti and Mawlaik stations (faster at Hkamti), but an increasing trend is detected at the Monywa station.

Rainfall

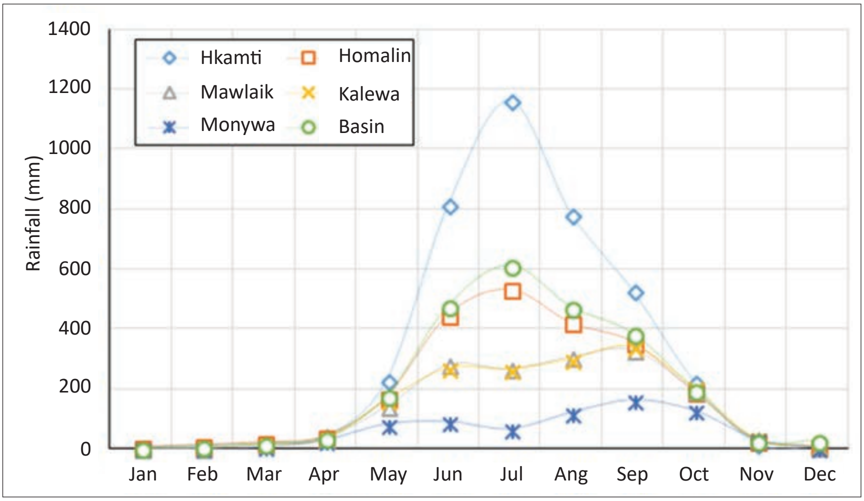
Current state

Figure 3.5 presents the spatial distribution of temperature and average annual rainfall across the basin. The variation in average annual rainfall is 725–3,855 mm. Rainfall increases from downstream to upstream of the basin. **Figure 3.6** presents the relationship between the average annual rainfall and elevation of the five stations. Similar to temperature, rainfall over the basin is strongly affected by elevation. It is observed that the increase in rainfall with elevation from Monywa to Homalin is on average

30.6 mm/m increase of elevation. Rainfall increases significantly from Homalin to Hkamti with the average of 146.2 mm/m increase in elevation due to moist air moving over the mountain range, where it lifts and cools. This results in the development of orographic clouds that result in heavy rainfall (Shige et al. 2017).

Average monthly rainfall distribution over 38 years (1979–2016) is calculated and plotted in **Figure 3.10**. The average monthly rainfall over the basin varies from 4.47–611.72 mm. The basin average rainfall of the wet season (May–Oct) is 2,318 mm, which is equivalent to 95 percent of the average annual rainfall. The average dry season (Nov–Apr) rainfall is 128 mm. The highest rainfall occurs in June, as reported at the Kalewa and Monywa stations. The highest rainfall recorded at Hkamti, Homalin and Mawlaik stations occurs in July. January has the lowest rainfall at all stations, less than 10 mm.

Figure 3.10 Average monthly rainfall at selected hydro-met monitoring stations, 1979–2016



Trends

The average annual rainfall at the Hkamti, Mawlaik and Monywa stations are selected for trend analysis, similar with the temperature analysis (**Figure 3.11**). The average annual rainfall at Mawlaik and Monywa stations shows an increasing trend (averaging 25–49 mm/10-year). At the

Figure 3.11 Annual trend analysis of the average annual rainfall at selected hydro-met monitoring stations

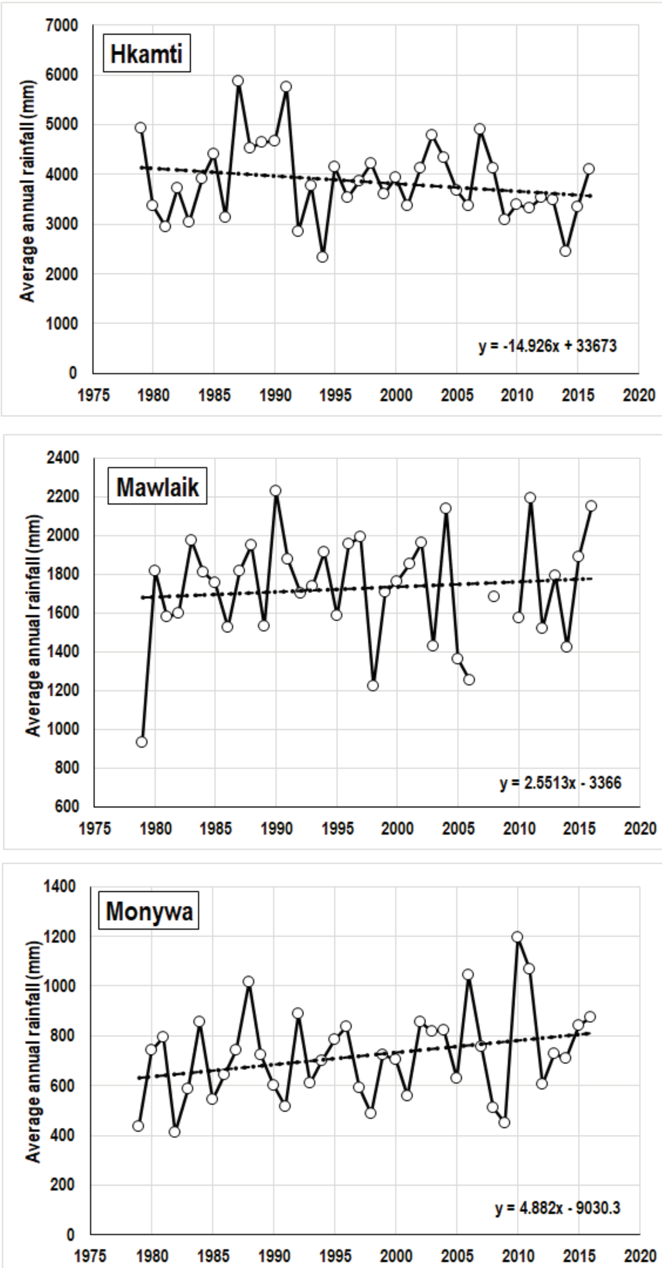
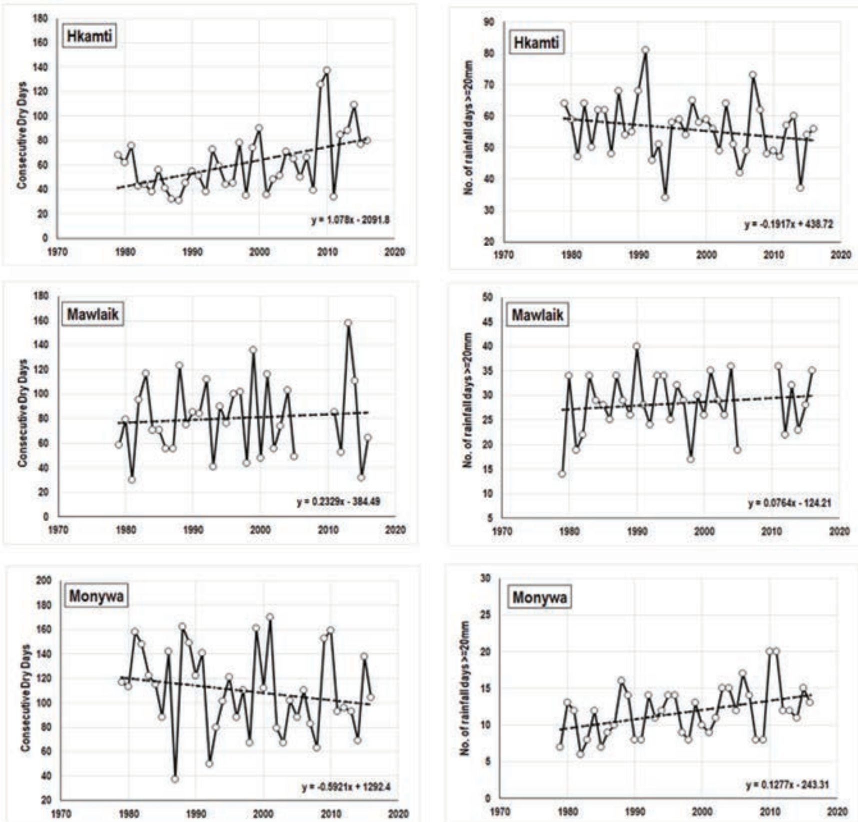


Figure 3.12 Annual trend analysis of consecutive dry days (a) and the number of rainfall days equal or more than 20 mm (b) at selected hydro-met monitoring stations



Hkamti station, the average annual rainfall has a decreasing trend with the average rate of 149 mm/10-year. Uncertainty in rainfall trends needs further investigation in correlation with changes in the monsoon and tropical cyclone systems.

Extremes

Table 3.1 presents the highest records of the daily maximum rainfall at the selected stations. The Hkamti station has the highest recorded daily maximum rainfall of 527 mm on 29 Jun 1989. Two extreme indices, the consecutive dry days (CDD) and the number of rainfall days that receive

≥ 20 mm (R20) were calculated for the Hkamti, Mawlaik and Monywa stations to analyze trends of extreme rainfall events (**Figure 3.12**). The CDD indicates an increasing trend at the Hkamti and Mawlaik stations. This would suggest that the annual maximum number of consecutive days with less than 1 mm of rain is rising. The upper and middle parts of the basin will therefore face drought or drier conditions more frequently in the dry season. In contrast, the CDD at Monywa is decreasing, suggesting a greater number of rainfall days in the lower part of the basin. This is consistent with an increasing trend in average annual rainfall at the Monywa station. With respect to R20, the number of rainfall days with ≥ 20 mm is decreasing at the Hkamti station whilst increasing at the Mawlaik and Monywa stations. This would suggest that the upper portion of the basin will exhibit drier conditions whilst the middle and lower parts of the basin will experience wetter conditions in the rainy season.

Discharge

Current state

Five hydrological stations, at the same locations as the rainfall and temperature stations, on the Chindwin River routinely measure water discharge. The average discharge at Monywa located downstream within the basin is 4600 $m^3 s^{-1}$. Average monthly discharge distribution associated with measurements made at each of the monitoring stations over 38 years (1979–2016) is presented in **Figure 3.13**. More than 90 percent of the total discharge occurs from May to November. The discharge is lowest in March with an average discharge of 700 $m^3 s^{-1}$. The highest discharge is observed during July to August with an average discharge of 12,200 $m^3 s^{-1}$ at Monywa Station.

Trends

The average annual discharge at the Hkamti, Mawlaik and Monywa stations was selected for trend analysis, similar with the temperature and rainfall analysis (**Figure 3.14**). The average annual discharge at these stations indicates a significant decreasing trend of 190, 91 and 165 m3 s-1 per year at the Hkamti, Mawlaik and Monywa stations, respectively. Similar decreasing trends can also be observed at Homalin and Kalewa.

Extremes

Table 3.2 presents the highest and lowest records of the daily discharge for the five stations. The highest discharge of 27,300 $m^3 s^{-1}$ was observed at the Monywa station on 9 October 1980, and the lowest discharge recorded at the same station was 121 $m^3 s^{-1}$ on 31 March 2010. During some years (2012, 2014 and 2015) in dry season, no discharge was observed at Hkamti.

Maximum annual discharge data at the selected five stations along the Chindwin River were used to calculate the extreme discharge value for 5, 10, 20, 50, 100 and 500 years' return period at the respective gauging stations (**Figure 3.15**). These extreme values were calculated using the Log Pearson Type III distribution method. The maximum annual discharge for Monywa was 6,488 $m^3 s^{-1}$ in 1991, and falls during the 50-year return period. The discharge for the 5-year return period at the Monywa station is 5,121 $m^3 s^{-1}$, and for the 100-year return period is 6,870 $m^3 s^{-1}$.

Figure 3.13 Average monthly discharge at selected hydro-met monitoring stations, 1979–2016

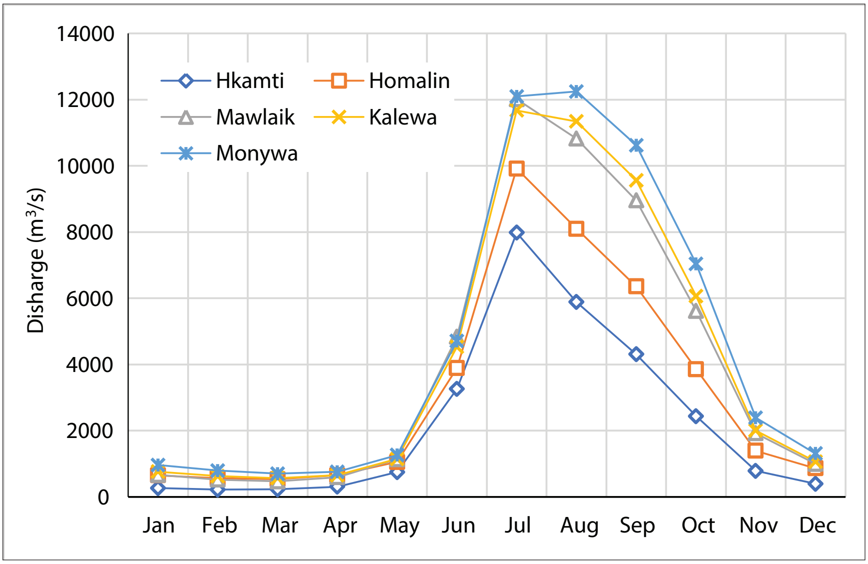
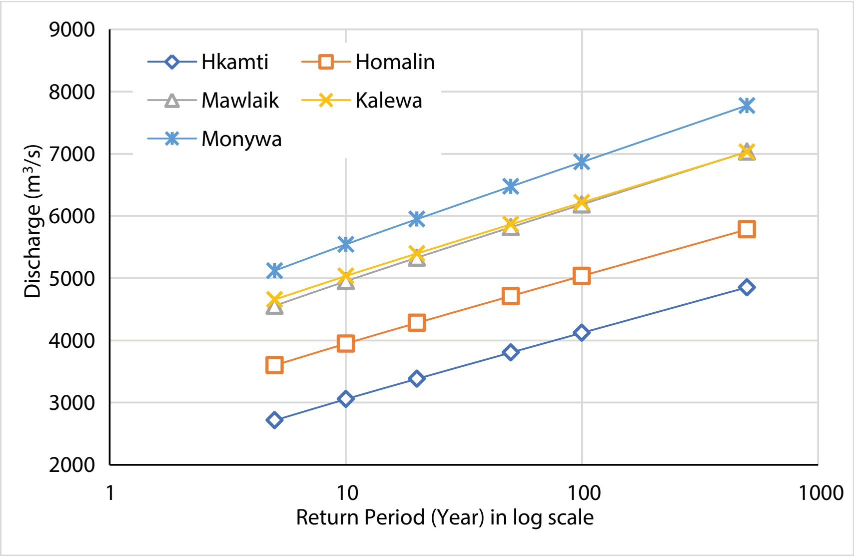


Figure 3.14 Extreme analysis of the maximum annual discharge at selected hydro-met monitoring stations



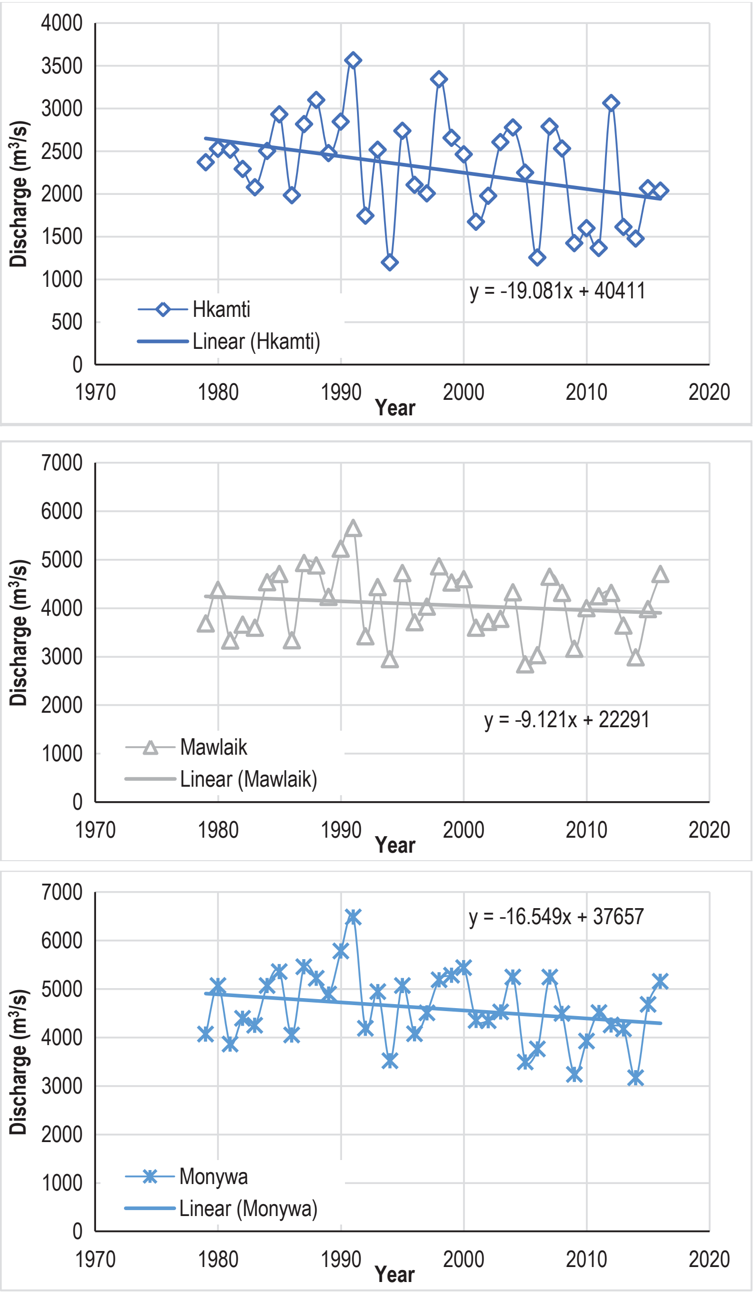
Climate change in Myanmar

Myanmar is exposed to various climate hazards include cyclones, intense rain events, floods, extreme temperatures, droughts and rising sea levels. Myanmar is one of the three countries in the world most affected by climate hazards over the past two decades (Kreft et al. 2016). This trend may be further complicated by changes in climate due to global warming. UNEP (2012) reports the observed climate change in Myanmar over the last six decades (1951–2007) as well as the projected climate change (2001–2100) as follows:

Observed climate change

- A general increase in temperatures across the whole country with an average increase of 0.08°C per decade, most notably in the northern and central regions.
- A general increase in total rainfall over most regions, however, with notable decreases occurring in certain areas, e.g. Bago Region.

Figure 3.15 Annual trend analysis of average annual discharge at selected hydro-met monitoring stations



- A decrease in the duration of the Southwest Monsoon season due to late onset and early departure times.
- Increases in the occurrence and severity of extreme weather events including cyclones, floods and droughts.

Projected climate change

- Increase in temperature particularly from December to May and significant increase projected for Northern and Central regions.
- Increase in rainfall variability during the rainy season. From March to November, the entire country is projected to experience an increase in rainfall (predominant in Northern region) while a decrease is projected between December to February.
- Shorter duration of monsoon (late onset and early end) creates higher risk of floods.
- Increase in extreme events (ibid.).

Ongoing climate change is expected to cause negative impacts on socioeconomic, environmental and natural resources across the country. Increases in temperature have major impacts on agricultural production and food security (Wassmann et al. 2009). In agriculture, the staple food crop of rice becomes sterile if exposed to temperatures above 35 °C for more than one hour during flowering and consequently produces no grain. Other effects of climate change on biodiversity are already evident in Myanmar. For example, shifts in the range as well as migration patterns of certain species of insects, marine/terrestrial mammals, birds and fish have been observed (UNEP 2012). Kovats and Akhtar (2009) indicate that higher temperatures and unpredictable precipitation will also increase the reproduction of mosquitoes and transmission rates of mosquito-borne diseases such as malaria and dengue as well as other pathogens. Shrestha and Htut (2016) have found that the impacts of climate change on streamflow in the Bago River Basin are more significant than that caused by changes in land use.

Climate change projections in the Chindwin River Basin

Emission scenarios

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) presents a set of emission scenarios, called Representative Concentration Pathways (RCPs), which are widely used for climate change projection around the world (IPCCb 2014). They describe the total radiative forcing that will occur by 2100, measured in Watts per square metre (W/m^2), and the forcing pathway that will be followed to get there. Four of these RCPs were developed, named according to their total radiative forcing by 2100: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. **Figure 3.16** presents projected global CO_2 emissions under each RCP (2.6, 4.5, 6.0 and 8.5), and corresponding historical emissions (Sanford et al. 2014). Also shown are the projected global mean surface temperature increases by 2100, and their 66 percent probability range (in brackets). The RCP 8.5 demonstrates the highest emission scenario and the RCP 2.6 is the lowest emission scenario.

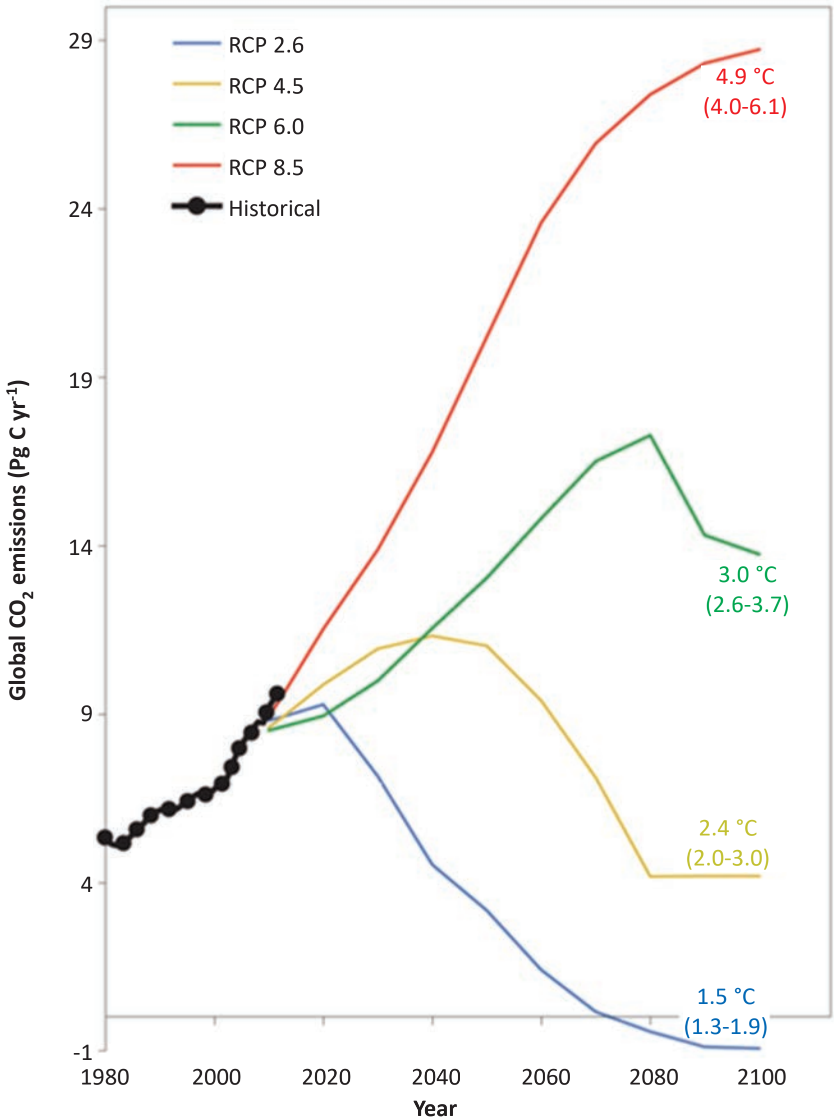
Climate change modelling

Information on future climate conditions in the Chindwin River Basin was obtained from the SimCLIM software,[1] which is supported by the Department of Water Resources, Thailand. SimCLIM contains the downscaled future climate data of 40 General Circulation Models (GCMs) from the Coupled Model Intercomparison Project, Phase 5 (CMIP5).

Models were processed using a so-called pattern scaling approach using historical data from 1986–2005 to downscale GCM data for the regional spatial resolution requirement which is 1km x 1km (Yin et al. 2013). Each climate model is typically run using multiple emissions scenarios and climate sensitivity parameters, generating many hundreds of equally plausible climate projections for adaptation planners to choose from.

In this study, we selected the RCP4.5 and RCP8.5 to represent medium and extreme changes of future climate conditions in the Chindwin River Basin. An ensemble of 40 GCMs is used to address the uncertainties associated with climate change modelling. The study focuses on analyzing changes in mean temperature and annual rainfall across the basin in Myanmar. Three future time periods including 2030s (averaged over the period 2021 to 2040), 2060s (averaged over the period 2051 to 2070) and

Figure 3.16 Observed and projected trends in global CO2 emissions under four RCP scenarios. Numbers on the top represent the median values of global mean surface temperature projections above pre-industrial levels in 2100 and numbers inside the bracket represent the 66% probability range of the ensemble projections for each RCP scenario (Sanford et al. 2014)



2090s (averaged over the period 2081–2100) were selected to determine changes against the baseline period (1986–2005), which are presented in **Figure 3.16**.

Future climate projections

Climate change projections of future mean temperature and annual rainfall in the Chindwin River Basin under the medium (RCP 4.5) and extreme (RCP 8.5) change scenarios are presented in **Figures 3.17** and **3.18**, respectively. **Figure 3.17** indicates that the temperature of the basin increases throughout until the end of the century. The average temperature over the basin is expected to increase by 0.75 °C by 2030s to 1.87 °C by 2090s under the medium change scenario (RCP4.5) compared to the baseline period of 1986–2005. Under the extreme scenario (RCP 8.5), the temperature is projected to increase by 1.00–1.40 °C by 2030s, 1.50–2.50 °C by 2060s and 1.80–3.75 °C by 2090s. Northern parts of the basin are predicted to experience greater changes in temperature.

The percentage change in annual rainfall under RCP 4.5 and RCP 8.5 scenarios is shown in **Figure 3.18**. Similar to temperature, rainfall in the basin increases throughout until the end of the century. Rainfall is expected to increase by 3.5 percent by 2030s to 13 percent by 2090s under the medium change scenario (RCP4.5) compared to the baseline period of 1986–2005. Under the extreme scenario (RCP 8.5), the rainfall is projected to increase by 3–5 percent by 2030s, 6–10 percent by 2060s and 10–22 percent by 2090. The highest increase in rainfall is predicted to occur in the middle portion of the basin.

Increased temperature and rainfall variability and change are projected to have huge impact on health in Myanmar. The Chindwin River Basin has been most vulnerable to flood, drought, and extreme dry temperature. Climate-induced shocks and stresses indiscriminately affect poor and marginalised people’s livelihoods (UNEP 2012). Employment and income in the basin are dependent on climate-sensitive sectors such as agriculture, livestock, forestry and natural resources.

Figure 3.17 Relative changes of the projected mean temperature in 2030s, 2060s, and 2090s under the medium change (RCP4.5) and extreme change (RCP8.5) scenarios compared to the baseline period in 1986–2005

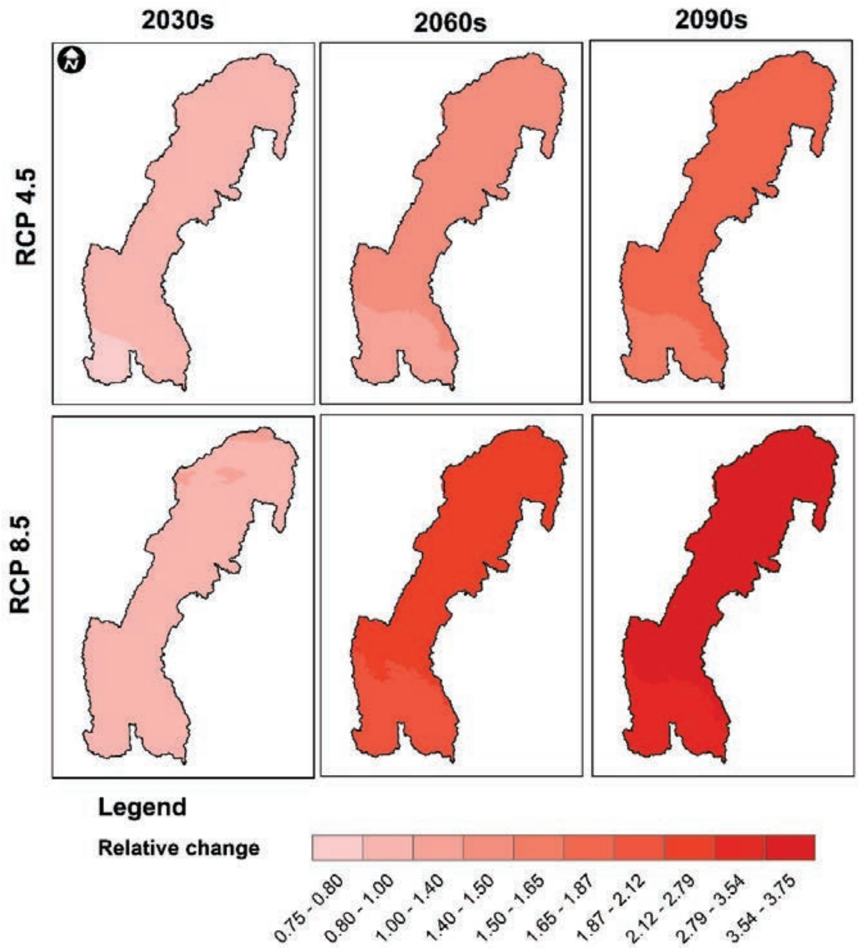
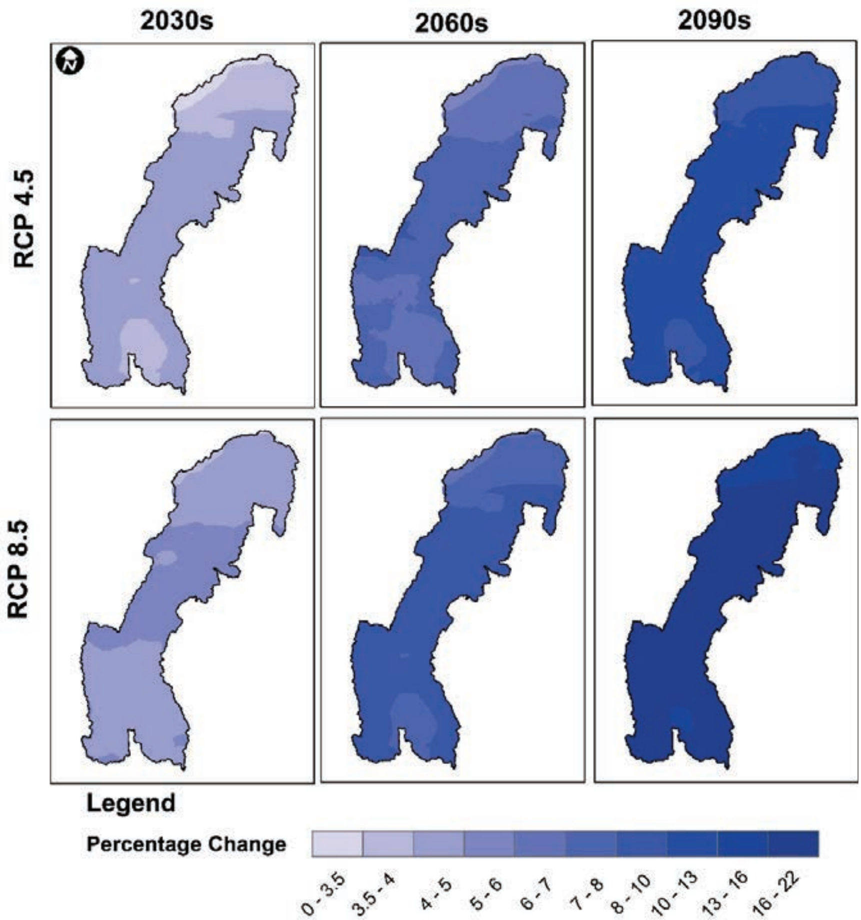


Figure 3.18 Percentage changes of the projected mean annual rainfall in 2030s, 2060s, and 2090s under the medium change (RCP4.5) and extreme change (RCP8.5) scenarios compared to the baseline period in 1986–2005



Conclusions and recommendations

Climate and hydrological systems in the Chindwin River Basin are dominated by three large-scale atmospheric processes including the Asian monsoons, tropical cyclones and El Niño-Southern Oscillation. The basin experiences three seasons: winter (Nov–Feb), summer (Mar–mid-May) and rainy (mid-May–Oct). Tropical cyclones cause severe floods in the basin, particularly Giri in 2010 and Roanu in 2016. ENSO has affected temperature and rainfall across Myanmar and the Chindwin River Basin. The strong El Niño event in 2015–16 caused severe drought and water shortages in the Central Dry Zone and the lower Chindwin River Basin in Sagaing Region. However, the densities of rainfall and streamflow stations in the Chindwin River Basin are low according to WMO guidelines. The current hydro-met network is not sufficient to monitor spatial distribution and variation over the basin, particularly in the north and the Chindwin tributaries. Given that six million people in the basin are dependent on the climate and natural ecosystems, there is a need for comprehensive information and regular monitoring of the status of the climate and hydrological conditions. We recommend enhancing the number of hydro-met stations to ensure appropriate coverage of the entire basin and key tributaries for effective water resources management and climate change adaptation planning in the basin.

Historical climate analysis indicates that temperature and rainfall over the basin are also controlled by elevation and latitude. The temperature decreases from the lowland downstream to the northern highland upstream areas of the basin, while rainfall patterns are the opposite. The average maximum temperature is increasing for the whole basin. The average minimum temperature is increasing in the middle and lower parts (the Mawlaik and Monywa stations) of the basin and decreasing in the upper part (Hkamti station) over the period 1979–2016. It can be concluded that the basin is warming but there are colder nights in the northern region. The average annual rainfall in the north is declining at an average rate of 149 mm/10-year, while the middle and lower parts of the basin show an increasing trend (averaging 25–49 mm/10-year).

The extreme rainfall indices also show similar trends. Drought or drier conditions in the dry season will become more frequent in the upper and middle basin, while the lower basin will have wetter conditions in the rainy season. The average annual discharge at these stations shows a significant decreasing trend of 190 $m^3 s^{-1}$, 91 $m^3 s^{-1}$ and 165 $m^3 s^{-1}$ per year at Hkamti, Mawlaik and Monywa stations, respectively. Improvement of flood and drought forecasting and warning systems by integrating remote sensing data is recommended to reduce the impacts of extreme climate events.

The future mean temperatures and annual rainfall across the basin are projected to increase until the end of the century. In the 2090s, the medium change scenario shows that the mean temperature is projected to increase by 1.87 °C and the annual rainfall is projected to increase by 13 percent compared to the baseline period of 1986–2005. The mean temperatures and rainfall under the extreme change scenario (RCP8.5) are projected to increase by double compared to the medium change scenario. In the 2090s, the mean temperature is expected to increase by 3.75 °C and the annual rainfall is projected to increase by 22 percent. An adaptation strategy and plan for climate-sensitive sectors, in particular for the agriculture, environment and natural resources and health sectors is required to manage future climate risks and increase resilience.

Notes

1 Produced by CLIMsystems in Hamilton, New Zealand; https://www.climsystems.com/simclim/.

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Part II

Regional economic integration and social and environmental sustainability

4

Modeling the risks and impacts of flooding in the Chindwin River Basin

Chusit Apirumanekul and Jayaram Pudashine

Over the last several decades, numerous natural hazards[1] have affected Myanmar, including floods, cyclones, earthquakes, landslides and periodic droughts (Reliefweb 2016). Floods are one of the most frequent hazards in Myanmar. Myanmar is one of the 15 countries that account for 80 percent of the global population exposed to flooding (Brakenridge et al. 2017). However, hazards become disasters only when an extreme natural event exceeds the capacity of local resources to manage hazards.

Table 4.1 Natural disasters in Myanmar, 1900–2017

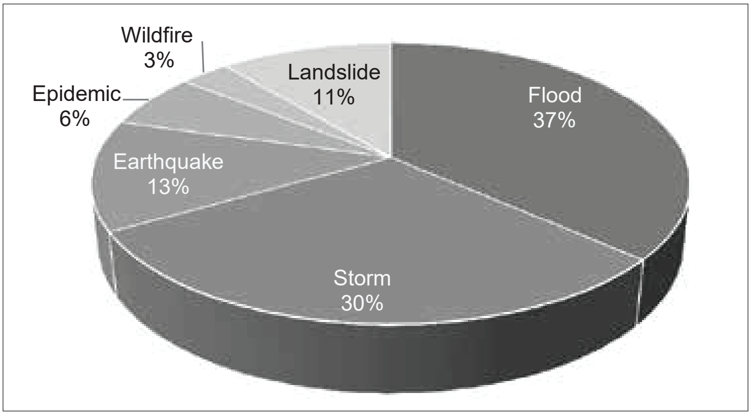
Disaster type	Disaster subtype	No. of events	Total deaths	Total affected	Total damage (US$1,000)
Storm	Tropical cyclone	18	144,663	4,043,364	4,079,388
Flood	Riverine flood	16	293	3,916,393	198,840
Flood	Others (e.g. coastal flood, urban flood)	9	180	1,239,215	57,115
Earthquake	Ground movement	8	667	24,075	14,770
Landslide	Landslide	7	205	147,582	n.a.
Flood	Flash flood	4	279	85,734	1,700
Storm	Convective storm	3	35	99,956	4,600
Wildfire	Forest fire	2	8	78,588	11,000
Epidemic	Bacterial disease	2	10	800	n.a
Epidemic	Viral disease	2	64	n.a.	n.a.
Earthquake	Tsunami	1	71	15700	500000
Mass movement (dry)	Landslide	1	17	n.a	n.a.

Sources: Centre for Research on the Epidemiology of Diasters (CRED), Université catholique de Louvain, Brussels, EM-DAT: The Emergency Events Database.

A summary of natural disasters[2] in Myanmar from 1900 to 2017 is presented in **Table 4.1**. Storms are the most frequent cause of natural disasters, while riverine floods and other types of floods are ranked second and third, respectively.

Myanmar is highly vulnerable to the effects of storms and cyclones, particularly during the months of April and May, and in October and November (National Disaster Management Committee 2017). This reflects the bimodal distribution pattern of storm frequency across Myanmar according to the data from the Department of Meteorology and Hydrology for 1977–2010 (RIMES 2018). Cyclonic storms bring torrential rainfall which causes extensive flooding. An assessment of natural disasters from 1900 to 2017 clearly indicates the predominance of water-related disasters; among these disasters are those associated with storms and floods, which make up a total of 67 percent of all recorded disasters (**Figure 4.1**).

Figure 4.1 Disaster occurrences in Myanmar, 1900–2017 (%)



Source: Centre for Research on the Epidemiology of Diasters (CRED), Université catholique de Louvain, Brussels, EM-DAT: The Emergency Events Database.

Myanmar has a monsoon climate, which produces three main seasons: the summer, rainy, and winter seasons (CFE-DMHA 2017). The monsoon season starts from June and lasts until October, with the biggest threat occurring in July or August due to the peaking of the monsoon, which generates heavy rain. The central Ayeyarwady Region, which includes parts of the Chindwin River Basin, is most affected by floods (National Disaster Management Committee 2017). There has been a rise in disaster losses over the past decades primarily due to the increased exposure of the population and assets in hazardous zones (ibid.). The top ten hazards in Myanmar based on total economic damage are associated with storms, floods and earthquakes (**Table 4.2**).

Table 4.2 Top 10 hazards ranked on total economic damage

Rank	Type of hazard	Date	Total damage (US$1,000)
1	Storm	May 2008	4,000,000
2	Earthquake	Dec 2004	500,000
3	Flood	Jul 2015	119,000
4	Flood	Jul 1991	79,840
5	Storm	Oct 2010	57,000
6	Flood	May 1992	55,115
7	Wildfire	Feb 1979	11,000
8	Storm	May 1994	10,000
9	Earthquake	Aug 2016	10,000
10	Storm	May 1967	5,000

The level of disaster risk is further exacerbated by climate change and variability, and greater exposure from inappropriate development (Kawasaki et al. 2017).

Table 4.3 presents the occurrence of natural hazards in Myanmar from 1970 to 2017. There is evidence from this data set that Myanmar has been impacted by a greater number of hazards in the last decade. This pattern accords with the increasing exposure of people and assets to flood hazards among emerging and developed economies (Mochizuki et al. 2014).

Flooding was identified as one issue of most concern among villagers who were consulted in the Chindwin Basin (see Chapter 9). The Chindwin River Basin is prone to floods, for e.g., as caused by Cyclone Komen in 2015 (Vasconcelos et al. 2016). Consultation meetings with villagers in Kalay and Monywa Townships indicated that extreme weather conditions, together with increasing rates of sedimentation of the main river and of deforestation, are perceived to be the main causes of flooding (Arcadis Nederland B.V. 2017).

Table 4.3 Reported occurrence of natural hazards in Myanmar, 1970–2017

Year/Hazard	Flood	Storm	Earthquake	Landslide	Drought	Wildfire	Epidemic
1970	x						
1971							
1972							
1973							
1974	x						
1975		x					
1976	x						
1977	x						
1978		x					
1979	x						
1980							
1981						x	
1982		x					
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2006	x	x					
2007	x						x
2008		x					
2009				x			
2010		x		x			
2011	x		x				
2012	x		x				
2013	x			x			
2014	x						
2015	x	x		x	x		
2016	x	x	x	x	x		x
2017	x	x					

Modeling of flooding in the Chindwin River Basin

In January 2014, the Directorate of Water Resources and Improvement of River Systems (DWIR) and Stockholm Environment Institute (SEI) jointly organized the First Joint Committee Meeting for the Ayeyarwady Futures Project to discuss technical support to Myanmar governmental agencies involved in managing the water resources of the Ayeyarwady River Basin, of which the Chindwin Basin is part. DWIR requested SEI to provide support for strengthening the capacity of DWIR staff to undertake hydraulic modeling. SEI's work focused on building the capacity of DWIR and relevant agencies, such as the Department of Meteorology and Hydrology (DMH), Irrigation Department (ID) and Myanmar Maritime University (MMU), use modeling to support water resources management and planning. Other recent flood models for the Chindwin River Basin include the Development and Implementation of User-Relevant End-to-End Flood Forecast Generation for Myanmar Project, which was completed in 2017, and Improving Flood Forecasting Capacity of DMH to Strengthen Flood Early Warning System in Myanmar Project, which was finished in 2017.

The Chindwin River is a large river with high variability in its river flow and water level. Setting up flood models for the whole Chindwin River Basin requires significant resources. The basin poses a challenge due to the lack of ground data and limited studies on flood topics. Most of the previous flood models on the Chindwin River Basin were developed for research purposes (Geoinformatics Center 2013; Naing 2013; SEI 2015).

A flood hazard map is typically used to identify areas at risk of flooding and to support flood risk management and disaster preparedness. Flood hazard maps typically include information related to the expected extent and depth of flooding at a specific location based on different situations or scenarios (Climate Technology Centre and Network 2020). However, there was no basin-scale flood hazard mapping for the Chindwin River Basin available at the beginning of this project. Given the limited ground-truth data related to basin floods, satellite data was used as an alternative source of flood monitoring and mapping.

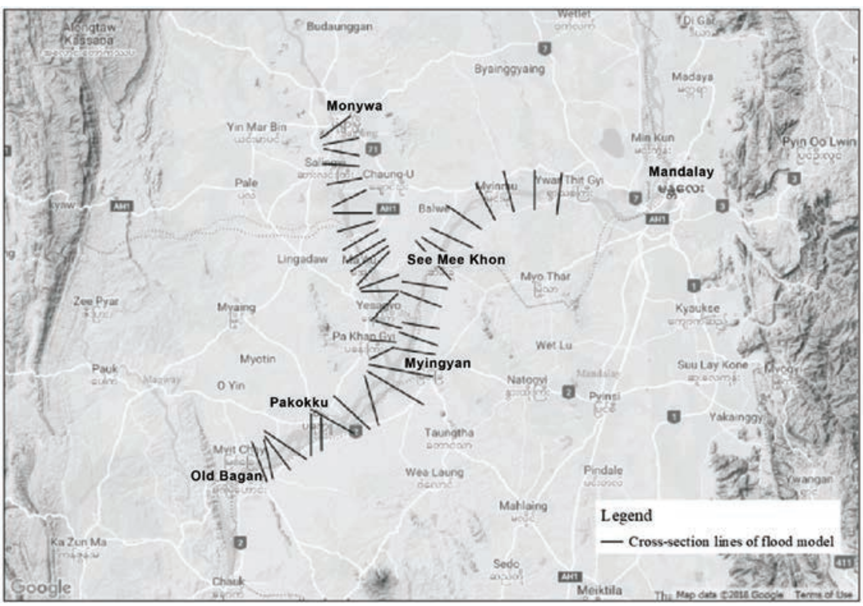
This chapter demonstrates the process and methodology for setting up flood models in a data-scarce area through a combination of ground observation, survey information and satellite-based information to support flood management. This chapter also presents the results of the application of satellite data for flood hazard mapping across the Chindwin River Basin to better understand the flood prone areas at the macro-scale given the limited ground data.

Study area and methodology

Geographical area

The hydraulic model covers an area around the confluence of the Chindwin and Ayeyarwady Rivers which is prone to flooding (**Figure 4.2**) and important for waterway transport and navigational purposes (Van der Velden 2014). The focus area is located near three regions, Sagaing, Magway and Mandalay, and includes a section of the Chindwin from the Monywa to the confluence, approximately 73 km and two sections of the Ayeyarwady, about 74 km from the northeast to the confluence and 55 km from the southwest to the confluence (**Figure 4.2**).

Figure 4.2 Geographical area of the hydraulic model around the confluence of Ayeyarwady and Chindwin Rivers (black lines represent locations of cross-sections included in the model)



In the Chindwin River Basin, the rainy season starts in June and ends around September and October with peak rain occurring around July and August. River discharges reach their peaks around July, except at Monywa, the most downstream part of the basin, where peak discharge occurs in August. Based on ground observation (**Figure 4.3**) from 1979 to 2016, the Chindwin River has an average annual flow volume ranging from 70,465 million m3 at Hkamti to 144,236 million m^3 at Monywa. **Table 4.4** presents the river flow volumes from upstream to downstream of the Chindwin River during the wet and dry seasons. Flow accumulates from upstream to downstream with significant side flow occurring between the Hkamti-Homalin reach and Homalin-Mawlaik reach during the wet season, at 34.6 percent and 31.5 percent, respectively (**Table 4.4**). During the dry season, flow in the Chindwin River mainly takes place in the upstream, with a 97 percent side flow from the Hkamti–Homalin reach, while the side flow downstream of Mawlaik station is minimal in both dry and wet seasons.

To improve understanding of flow variations along the Ayeyarwady and Chindwin Rivers to support flood management and navigation, a hydraulic model was set up to simulate the flow along the Ayeyarwady and Chindwin Rivers around the confluence areas in this study.

Figure 4.3 Averaged monthly river discharge at hydrological stations along the Chindwin River, 1979–2016

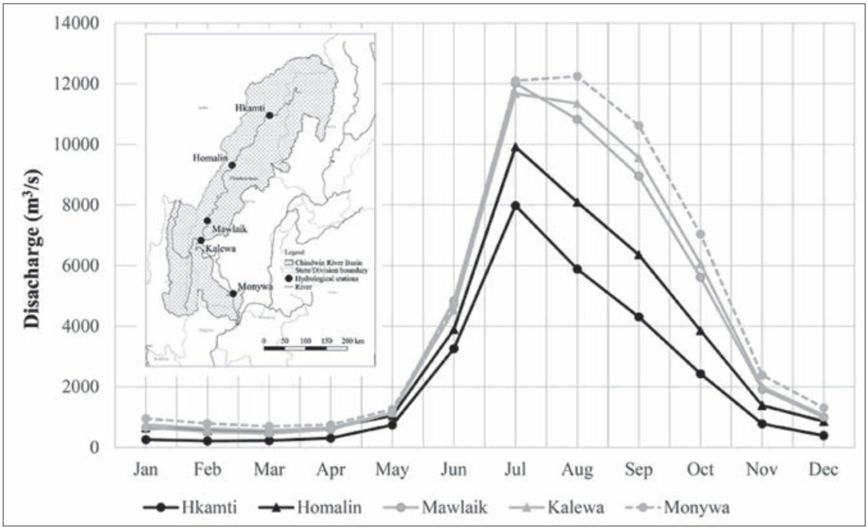


Table 4.4 Average flow volume along Chindwin River based on discharge data, 1979–2016

Description	Hkamti	Homalin	Mawlaik	Kalewa	Monywa
Annual flow volume (million m^3)	70,465	99,418	127,605	131,397	144,236
Wet season flow volume (million m^3)	63,109	84,927	111,716	114,158	123,505
Dry season flow volume (million m^3)	7,356	14,490	15,888	17,239	20,731
Percentage of wet season flow to annual flow	89.6	85.4	87.5	86.9	85.6
Percentage of wet flow increased from upstream	-	34.6	31.5	2.2	8.2
Percentage of dry flow increased from upstream	-	97.0	9.7	8.5	20.3

Data used

The data used in the hydraulic model was obtained from a range of sources, including ground observation (e.g. hydro-meteorological data from hydrometer stations, river cross-sections from boat surveys, etc.) from various government agencies and secondary source data in the public domain (e.g. Digital Elevation Model, land-use maps, etc.). **Table 4.5** summarizes the types of data and sources used in the study.

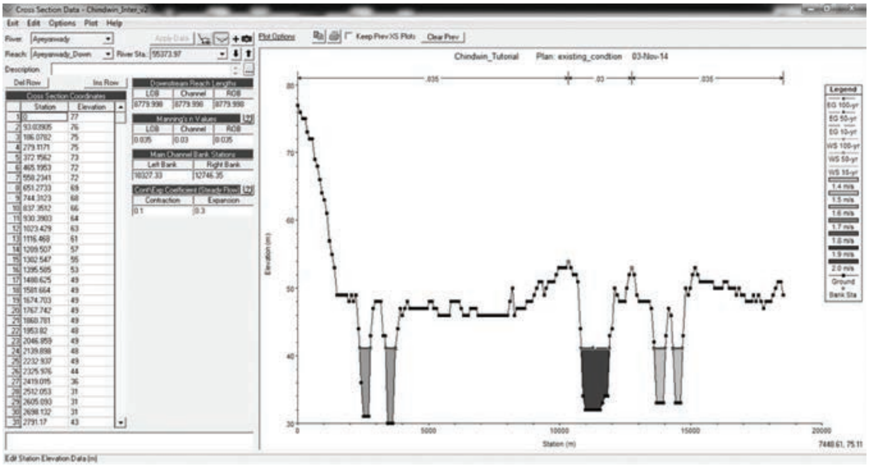
Table 4.5 Input for flood model

Type of data	Source
Water level and discharge at stations along Chindwin and Ayeyarwady Rivers	DMH
Survey river cross-sections along Chindwin and Ayeyarwady Rivers	DWIR
River cross-sections and floodplain topography	Secondary source (ASTER GDEM)
River network and floodplain conditions	Secondary source (Google Earth)

The geometry of the river network is presented in **Figure 4.4**. River cross-sections, roughness coefficients and river bed conditions form an important input of the hydraulic model. These parameters require regular updating (e.g. every three to five years depending on river flow conditions) to reflect up-to-date river conditions. River cross-sections are usually obtained from river surveys which require time and effort. Existing river cross-sections are available for only a few locations along the Ayeyarwady River (e.g. only at bridges across the river). Additional cross-sections along the Ayeyarwady and Chindwin Rivers are required for flood model inputs. River cross-sections used in this preliminary model were obtained from the river survey carried out by DWIR and from the ASTER Global Digital Elevation Model (ASTER GDEM) with a horizontal resolution of 30 m. **Figure 4.5** shows examples of cross-sections extracted from the ASTER GDEM at a location downstream of the confluence of the Ayeyarwady and Chindwin Rivers.

Figure 4.4 HEC-RAS schematic network with river cross-sectional lines

Figure 4.5 Example of river cross-section profile extracted from ASTER GDEM downstream of Ayeyarwady and Chindwin confluence



Model set up

The modeling tool used in this study is the Hydrologic Engineering Center's River Analysis System (HEC-RAS[4]) software developed at the US Army Corp of Engineers' Hydrologic Engineering Center (HEC) in Davis, California. HEC-RAS, which is available to the public, is a one-dimensional hydraulic model that can perform steady and unsteady flows to simulate flow conditions in the channel. The results of the model in terms of water level, discharge and velocity at each cross-section along the channel can be used for channel flow analysis and hydraulic structure design.

HEC-RAS requires geometric data (e.g., river geometry, cross-section profiles, Manning's coefficients, information about hydraulic structures, etc.), flow data (flow regime and discharge data) and water level data. For steady flow regime calculations, HEC-RAS uses the energy equation to compute the water surface level between river cross-sections using an iterative procedure. HEC-RAS requires water level hydrographs to apply boundary conditions at the downstream end of river system for a subcritical flow regime or the upstream end for supercritical flow (Brunner 2010).

Following the evaluation of decision support tools for integrated water resources management in the Ayeyarwady River Basin in 2014 (SEI 2015), the HEC-RAS model was selected in this study based on the fact that the constraints on data availability in Myanmar as noted above (i.e. only a few cross-sections are available along the Chindwin and Ayeyarwady Rivers). HEC-RAS is freely available at no charge, and it can be used to set up a hydraulic model to estimate the flow condition in rivers with limited data to carry out the feasibility of applying a one-dimensional hydraulic model in this region.

The physical laws which govern the flow of open channels under unsteady flow are the principle of conservation mass (continuity) and the principle of conservation momentum. The derivations of the equations of continuity and momentum presented by Ligget and Cunge (1974) are applied in HEC-RAS to perform the unsteady flow conditions.

Unsteady flow simulation was performed in this study to capture the large flow contribution from the Chindwin River to the Ayeyarwady River at the confluence point. Discharge hydrographs in 2007 at the Chindwin and Sagaing stations are used as upstream boundary conditions for the Chindwin and upper Ayeyarwady reaches, respectively. The river stage hydrograph of 2007 at Nyaung U station is used as the downstream boundary condition.

Model calibration

To address concerns regarding navigation during the dry season, flow conditions in 2007 were selected for the model calibration, as 2007 is considered a normal year with some unusual peak flows during the wet season. Five peak flows occurred during the wet season in 2007, while discharges in the year 2017 were selected for calibration to examine the performances of the model on peak flow simulations.

Roughness coefficients represent the resistance to flood flows in channels and flood plains. Roughness characteristics depend on various factors, such as the size and type of bed and bank materials, shape of cross-section, amount and type of vegetation at the bed and bank, and longitudinal variation in cross-sectional shapes and cover types. The roughness coefficient is one of the important factors that influence the simulated discharge, and thus is used for model calibration. Approximate Manning's n values (roughness coefficients) can be estimated from the river bed and bank conditions, which can be obtained from photographs taken during field surveys (e.g., **Figure 4.6**). The guided Manning's n values for the main channel and floodplain under different land covers can be obtained from the HEC-RAS reference manual (Brunner 2010). In this study, the approximate Manning's n value of 0.03 is applied for the main channel part, while the Manning's n value of 0.035 is used for the floodplain part as a guided value for the model calibration.

Figure 4.6 River bank conditions along the Ayeyarwady River (photo: SEI)

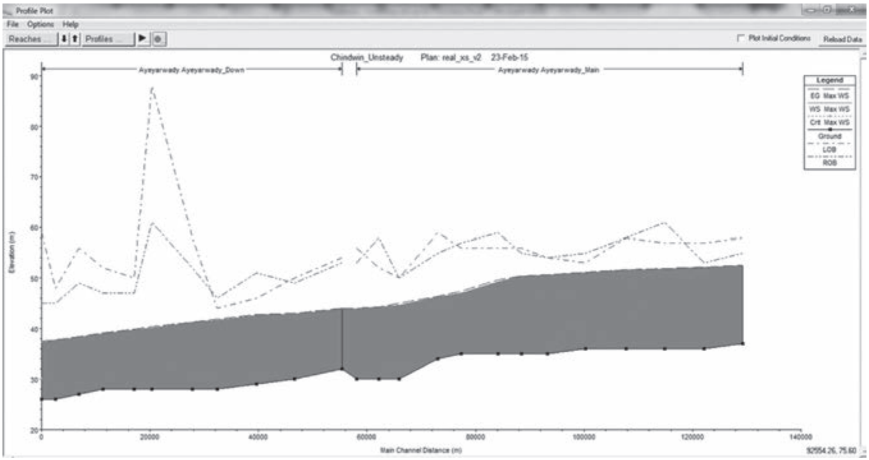
Using remote-sensing information for flood detection

Flood risk assessment requires various information, including the likelihood of a hazard event, the exposure of the population and the vulnerability of populations. With limitations on data availability and a lack of a regional systematic flood risk assessment, the application of remote-sensed information to detect surface water occurrence has been studied at continental and sub-continental scales (Prigent et al. 2012, Yamazaki et al. 2015, Mueller et al. 2016, Pekel et al. 2016 and Tulbure et al. 2016). The European Commission's Joint Research Centre developed the global surface water dataset[5] to map the spatial and temporal distribution of water surfaces, including permanent waterbodies, at the global scale based on the past 32 years of satellite images. The dataset was produced from Landsat imagery between 1984 to 2015 and was validated with ground observation.[6] The global surface water dataset provides statistics on the extent and change of those water surfaces across the world. Historical patterns of surface water can potentially inform users about flood frequency and associated risk. Water occurrence with its frequency can then be interpreted as proxy for flood frequency or flood hazard. The application of remote sensing information is thus important in the detection of the flood frequency and associated risk at a regional level.

Results and discussion

HEC-RAS is a one-dimensional hydraulic model. The outputs of the one-dimensional model at each cross-section, in terms of stage, discharge and velocity, are averaged values (i.e. only one water level and one discharge at each cross-section). Flood model calibration, a comparison between observed discharge/water level and simulated results from flood model, is carried out at a specific period, 2007 in this case. After calibration, the flood model will normally be validated to check its performance by selecting another flood event. This study carried out only flood model calibration by comparing discharge measurements; validation has not been performed yet due to limited data availability. The simulated maximum water level profile along Ayeyarwady reaches (Sagaing to Nyaung U) is presented in **Figure 4.7**. The maximum longitudinal water profile was below both left and right river banks, leading to no overbank flow.

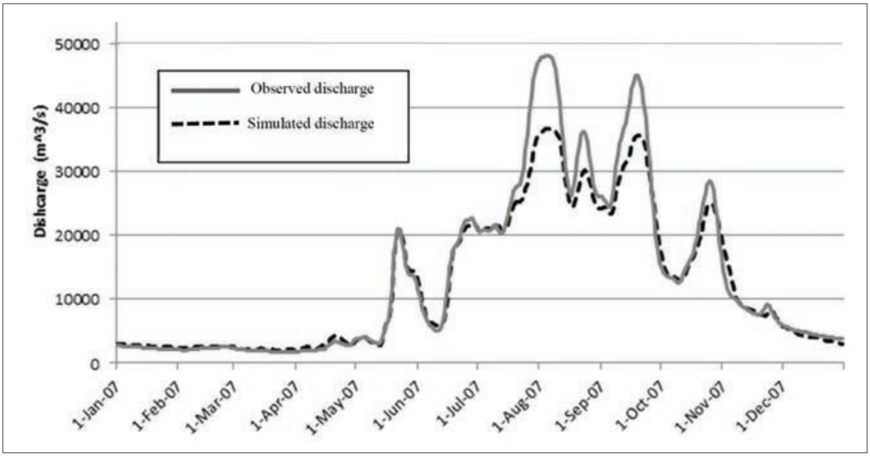
Figure 4.7 Simulated maximum water level profile along Ayeyarwady River for 2007 flow conditions. Dotted lines represent left and right river bank profiles



A comparison of simulated and observed discharges was carried out at Nyaung U station (**Figure 4.8**). The simulated discharge from the HEC-RAS model is in good agreement with the observed discharge from the dry season to beginning of the wet season (July 2007), even to the peak in June 2007. The simulated peak flow in June corresponded with heavy rainfall from Cyclone Akash making landfall on 15 May affecting central Myanmar. However, the model results underestimate the three flood peaks between August to the middle of September (**Figure 4.8**).

In general, the flood modeling system consists of a hydrological model (rainfall-runoff model) and hydraulic model (flood routing model). The results from this study, in terms of discharge and water level, were calculated based on a hydraulic model without integration of the hydrological (rainfall-runoff) model into the simulation due to limited resources at that time. During the wet season, there may be side flows from tributaries along the main river; it is thus necessary to apply the hydrological model to capture the side flows from tributaries contributing to the mainstream flow. The lack of a hydrological model to simulate side flows along the mainstream could be one of the reasons for the underestimated peak flows during the wet season.

Figure 4.8 Comparison between observed and simulated discharge hydrographs at Nyaung U station for 2007 conditions



The maximum flood depth map (**Figure 4.9**) and maximum flood velocity map (**Figure 4.10**) for conditions in 2007 are developed based on simulated results from HEC-RAS. Water levels simulated from each river cross-section are extrapolated and laid over the Digital Elevation Model (DEM) to estimate the flood extent and flood depths. The same concept is applied to develop the flood velocity map. Flood hazard is quantified by considering flood depth and velocity in combination. A shallow flood moving at a high velocity could be dangerous for people and vehicles. **Figure 4.11** displays the flood hazard vulnerability curve (Australian Institute for Disaster Resilience 2014) showing different vulnerability at various flood depths and flood velocities. Once the flood hazard has been quantified, the vulnerability of the community and its assets can be described by comparing flood hazard thresholds related to the vulnerability of people as they walk or drive through floodwaters or to the stability of houses in flooded areas. The flood hazard map showing the vulnerability of people and assets in different zones can be used for land-use planning to identify appropriate land development and identifying priorities for river training zones. In addition, the flood hazard map can also be used for flood zoning to prepare for flood mitigation and management.

Figure 4.9 Maximum flood depth map for 2007 from simulated HEC-RAS results

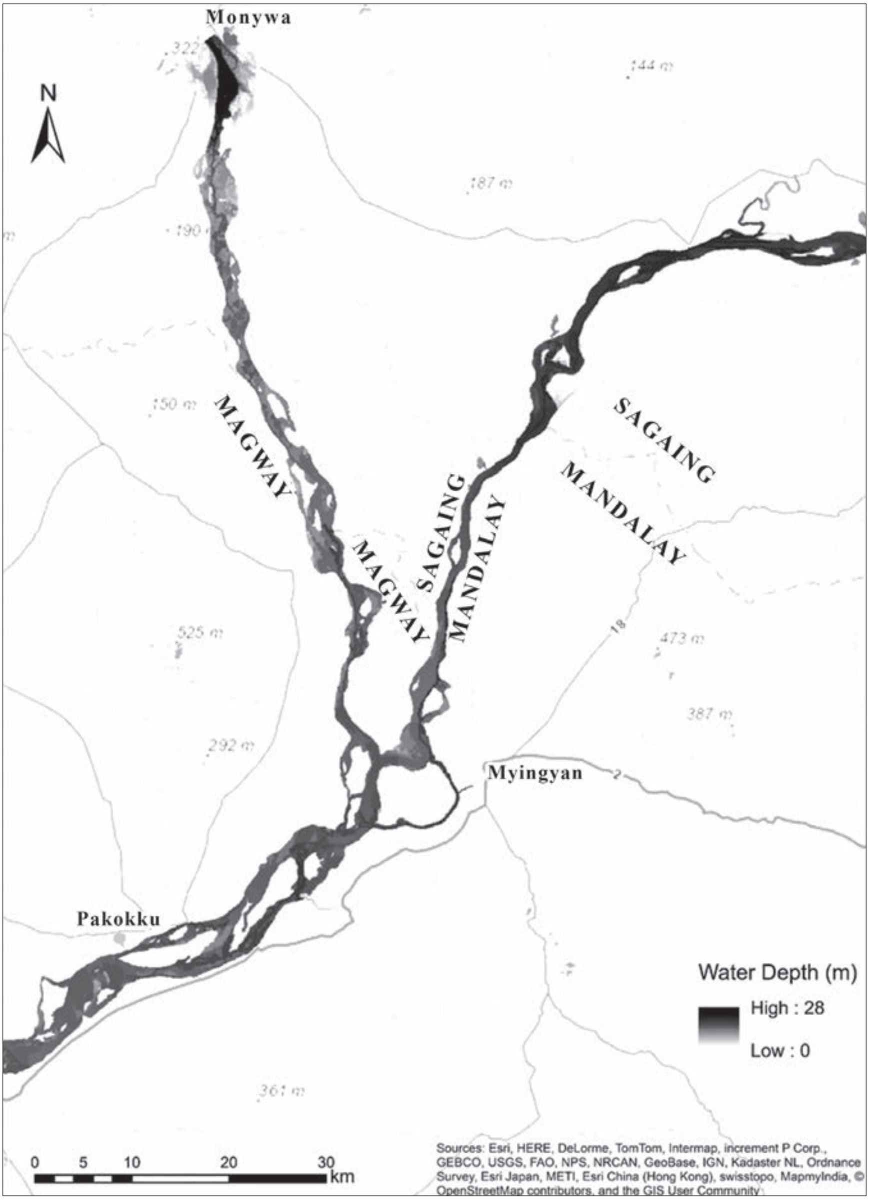


Figure 4.10 Maximum flood velocity map for 2007 from simulated HEC-RAS results

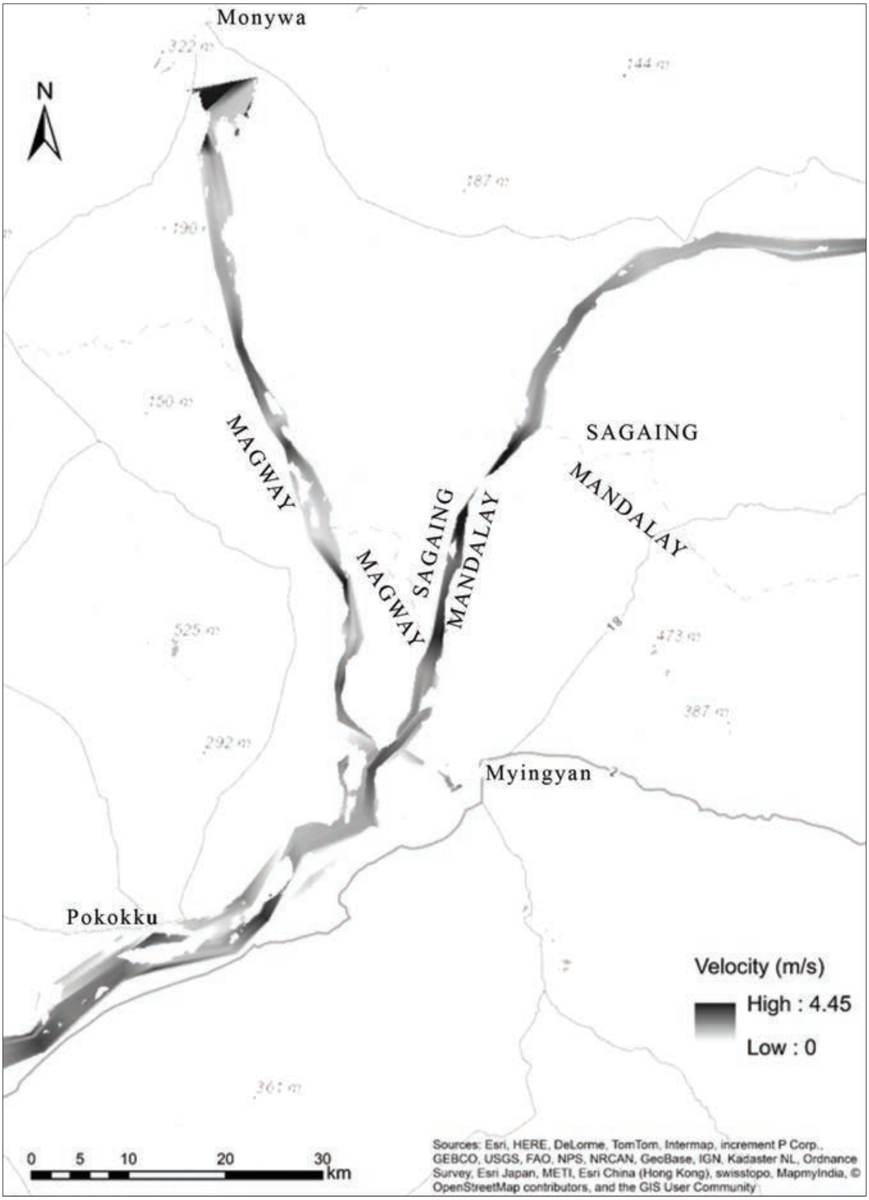
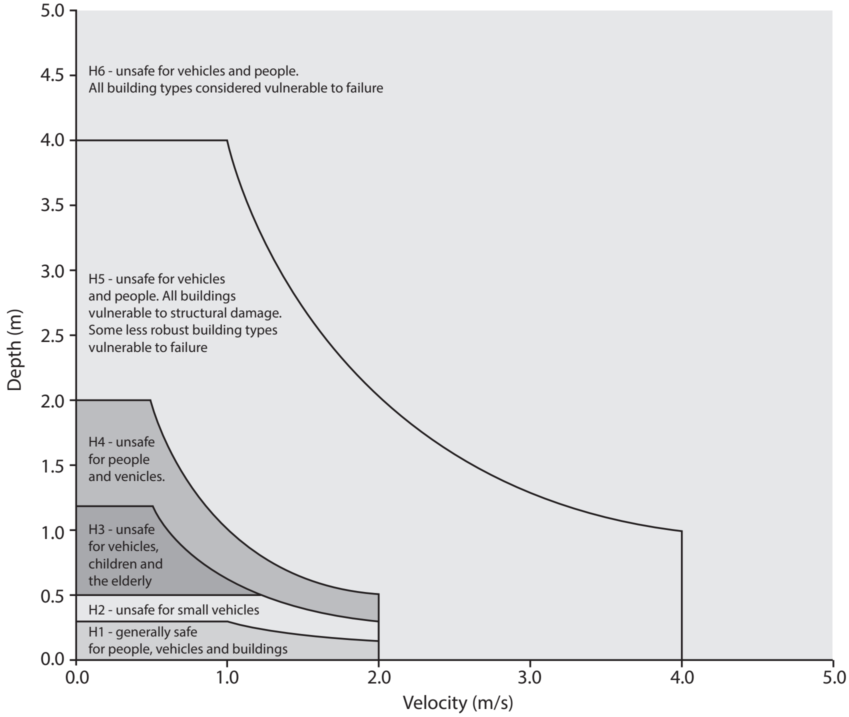


Figure 4.11 General flood hazard vulnerability curve



Source: Australian Disaster Resilience Guideline 7-3: Technical flood risk management guideline: Flood hazard (Australian Institute for Disaster Resilience 2014).

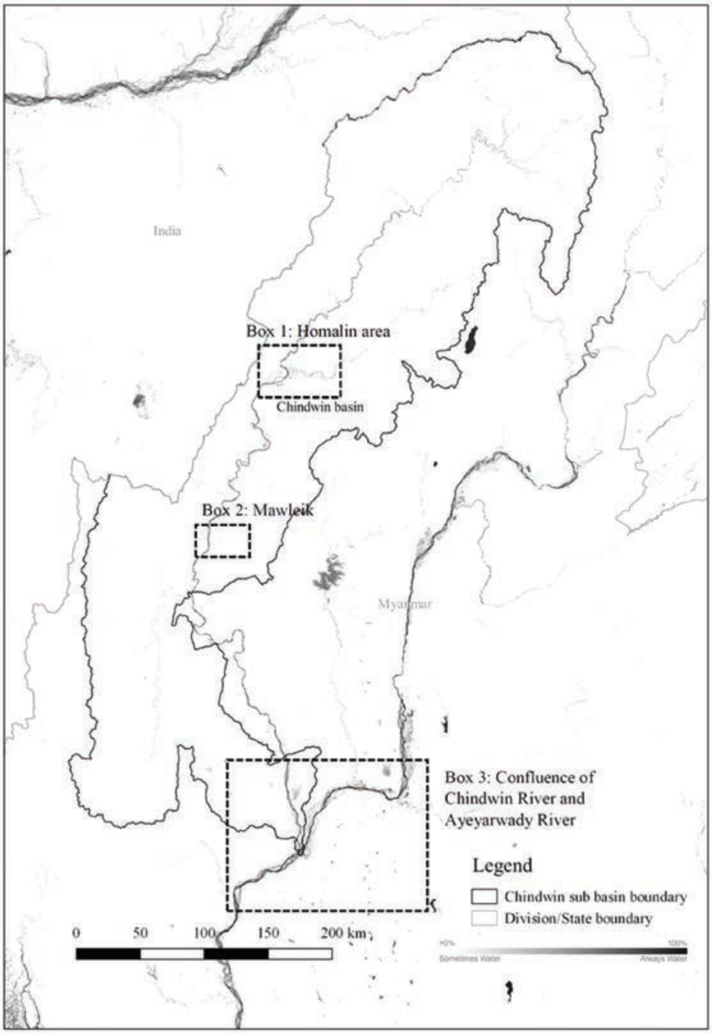
Flood depths and flow velocity are heterogeneously distributed along the river reach with high variability due to the complex river morphology. Both the Chindwin and Ayeyarwady are meandering rivers characterised by non-linear dynamics and other conditions affecting flow, including topography, roughness, obstacles, vegetation, and human intervention. Along the Ayeyarwady, the vulnerable areas for riverbank erosion are Si Mee Khon, the confluence point, and Pakkoku and its downstream due to high flood velocity. Along the Chindwin, areas downstream of Monywa, Ma Au and Yesagyo are also prone to riverbank erosion because of the river's high velocity during peak flows. In some areas, the depth of water is low while the velocity is quite high (downstream of the confluence to the Pakkoku area), a combination that can also cause riverbank erosion.

Assuming a one-dimensional flow for the Chindwin and Ayeyarwady Rivers may not be appropriate for a braided river with meandering dynamics. However, applying a one or two-dimensional model depends on the objective of the model and available resources. A two-dimensional flood model requires more input data and technical skills compared with a one-dimensional model (Braud et al. 2010). A two-dimensional flood model is appropriate for flows in a floodplain, urban area or in a channel, which requires an appropriate understanding of flows in the plane geometer (i.e. flood flows in urban areas or river flows in wide channels).

With limited data available for flood model simulation, the surface waters captured by the long-term Landsat imagery are presented in **Figure 4.12**. Dark areas represent high frequent water occurrences (i.e. 100 percent represents a permanent waterbody) while light areas represent lower surface water occurrence, which could represent a seasonal flood. It is necessary to understand the concept of surface water detection through long-term Landsat imagery. The water occurrence areas estimated from 30 years of Landsat imagery attempt to capture the area where surface water is detected by the satellites when they pass over the areas. Landsat has a 15-day orbit time, meaning that the satellite passes the region twice per month. Therefore, the surface water occurrence from the global surface water dataset is not data representing a specific flood event; the satellite might not be able to capture all flood events, especially flash floods and short-termed riverine floods, since what it captures is contingent on orbit time and path. However, the water occurrence maps may be used as a proxy to preliminarily define the space and frequency of water surfaces which can be applied for disaster risk management (prevention and mitigation) and water resources planning. **Figure 4.12A**, **Figure 4.12B** and **Figure 4.12C** display the flood prone areas around Homalin, Mawlaik and Ayeyarwady-Chindwin confluence areas, respectively.

In 2015, Myanmar was hit by Cyclone Komen which brought heavy rainfall and landslides in several parts of the country, including Homalin township. UNOSAT detected the flood extent in September 2015 from satellite-based information (Sentinel-1), and the flood extent map of September 2015 (**Figure 4.13**) around Homalin shows similar flooded areas as obtained from the global surface water dataset as a proxy of flood prone area. Notably, the flood extent from UNOSAT is based on Sentinel-1, and it is an event-based flood extent. However, the flood frequency map of the global surface water dataset is derived from long-term Landsat images to represent a proxy of flood-prone areas. Therefore, the flood extent map and global frequency cannot be qualitatively compared, in terms of flood extent.

Figure 4.12 Water occurrences in the Chindwin River Basin from Landsat images, 1984–2015



Source: European Commission, https://global-surface-water.appspot.com/.

Figure 4.12A Water occurrences from Landsat images during 1984–2015 over Homalin area (Box 1 of Figure 12)

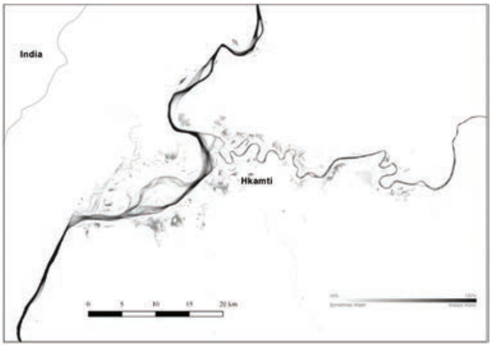


Figure 4.12B Water occurrences from Landsat images 1984–2015 over Mawlaik area (Box 2 of Figure 12)

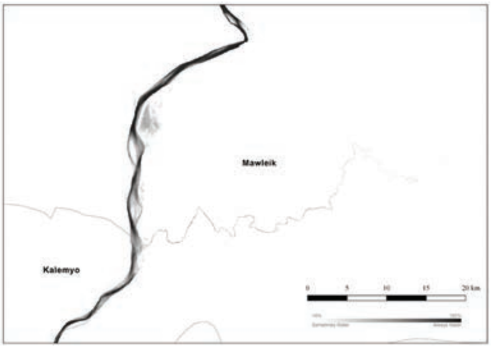


Figure 4.12C Water occurrences from Landsat images 1984–2015 over confluence between Ayeyarwady and Chindwin Rivers (Box 3 of Figure 12)

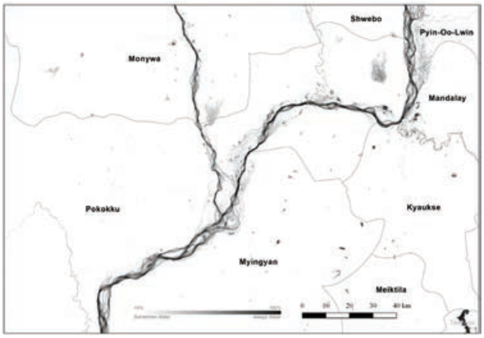
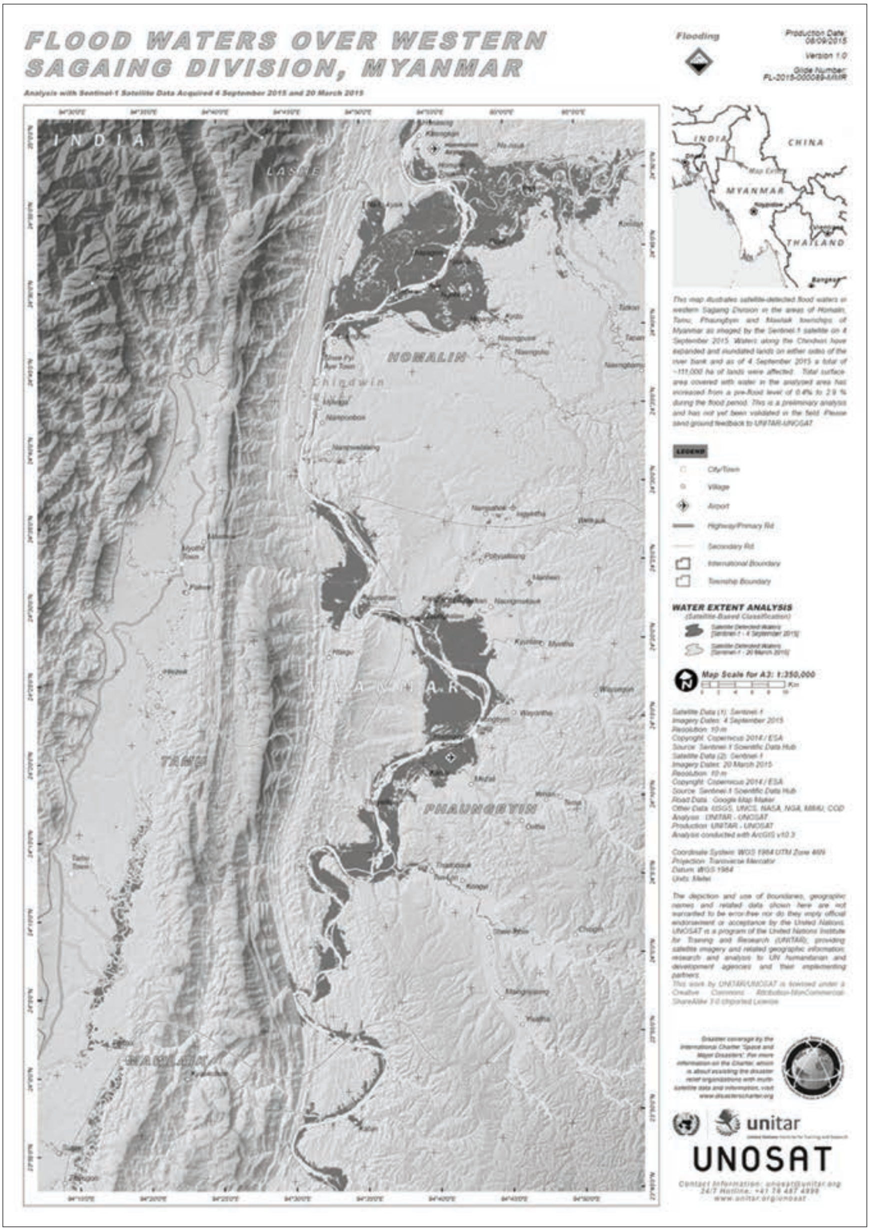


Figure 4.13 Flood extent around Homalin in September 2015 by UNOSAT (Sentinel-1)



Conclusions and recommendations

The flood model was set up for the confluence between the Ayeyarwady and Chindwin Rivers to simulate river flow conditions as a decision support tool for water management, including river transportation. Results from the flood model in terms of the depths of the river and velocity distribution in the river reaches can be used for river transportation and river training (i.e. planning for river bank protection in the areas which encounter high discharge with high velocity). The flood map produced from the one-dimensional flood model could be used to develop flood hazard (combination of depth and velocity) projections which are important for assessing flood risk and flood impacts. It should be noted that simulated flood peaks are likely underestimated for the August to September period, because the current flood model does not integrate side flows into the main river system.

Given the limitations on data availability, the application of remote-sensing information can be used to detect historical surface water patterns, which can be applied as a proxy for flood frequency. It is found that flood frequency maps, estimated from multiple Landsat images over 30 years, are useful in identifying flood prone areas at the macro scale and for preliminary analysis of flood risk at the national and sub-national levels.

It is recommended that the issues below should be taken into consideration for future work:

Model improvement

- Surveyed river cross-sections are important inputs and have a major impact on the model's accuracy. With support from DWIR, real surveyed cross-sections along the Chindwin and Ayeyarwady Rivers should be carried out, and the surveyed data should be included in the model in the future.
- Consultation with local experts from the regional government, DWIR and DMH who have a good understanding of flow conditions should be carried out. Lateral flows or tributary flows along the Chindwin and Ayeyarwady Rivers could contribute to changes in flow regime of the main channel, and hence important to include as an input in the model.

- Major infrastructure across the river have an influence on river flow conditions. Details of the infrastructure (e.g. dimensions, upstream and downstream flow conditions of those infrastructures) should also be included in the model.
- Integrating the hydrological model (rainfall-runoff) into the flood model is necessary to improve the model's performance for flood peaks.
- The Chindwin and Ayeyarwady Rivers are generally characterized by wide meanders with extensive sandbanks. These dynamic processes cause changes in river courses, such as thalwegs, banks and floodplains. The results from a one-dimensional hydraulic model which can only estimate the averaged flow condition at a specific cross-section along the river should be interpreted carefully when used for the design of a hydraulic structure.

Application

- To have a systematic flood risk and flood impact assessment, more information related to vulnerability and coping capacity is important. It is recommended that information about the socioeconomic, livelihood, infrastructure conditions, capacities of the population for disaster risk management, and loss and damage should be collected through surveys or interviews to be used as inputs for the vulnerability and capacity assessment.
- Consultation meetings with agencies related to flood management and local communities are necessary to demonstrate how to use a satellite-based flood frequency map for flood disaster risk management. The consultation meetings could also provide an opportunity to validate the results of flood frequency maps and obtain feedback as well.
- By varying the timelines in the flood hazard map generation, the results in terms of flood frequency maps can be used to assess the impacts of specific types of development in the study area. For instance, if we know that a flood dyke was developed in 2010, satellite-based flood frequency maps at the regional scale can be generated before 2010 and after 2010 to assess the impacts of flood dyke construction on river water levels and velocity upstream and downstream of the construction site.

- The flood model can be used for impact assessment of different policies and development projects, e.g. infrastructure (e.g. river training, flood dyke, bridge, etc.), land-use change and water policies. The findings of the impact assessment such as probable changes in water levels and river flows, can also contribute to project feasibility studies in terms of engineering soundness and cost-benefits.

Notes

1 A natural hazard is defined as a natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNDRR 2009).

2 A disaster is defined as a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources (UNDRR 2009).

3 The ASTER Global Digital Elevation Model (ASTER GDEM) is a joint product developed and made available to the public by the Ministry of Economy, Trade, and Industry (METI) of Japan and the U.S. National Aeronautics and Space Administration (NASA).

4 U.S. Army Corps of Engineers, Hydraulic Engineer Center (HEC), http://www.hec.usace.army.mil/software/hec-ras/.

5 European Commission, Global Surface Water Explorer, https://global-surface-water.appspot.com/.

6 See U.S. Geological Survey and NASA, Landsat Science, https://landsat.gsfc.nasa.gov/; https://earthobservatory.nasa.gov/world-of-change.

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5

Assessment of fluvial geomorphological change in the confluence of Chindwin and Ayeyarwady Rivers using remote sensing

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The main goal of this chapter is to understand the fluvial geomorphological processes in the area surrounding the confluence of the Chindwin and Ayeyarwady Rivers. This is an area that has not received due attention in scientific studies of Myanmar mainly due to the lack of field-level data. In this chapter, we analyze remote sensing imagery to explore perceived impacts from riverbank erosion. The erosion impacts were verified with consultation among stakeholders in the Chindwin Basin. Through observed changes in the river channels, including to the water level and sandbanks, this study sheds light on ongoing riverbank erosion and sedimentation, as well as the subsequent re-stabilization of riverbanks through re-vegetation. A special focus is given to assessing the vulnerability of villages to bank erosion.

The erosion of riverbanks along the Chindwin and Ayeyarwady Rivers has been of recurring concern in Myanmar, and highlighted by the country's media (Lwin 2013; Bowles 2013). There are frequent media reports, especially in the rainy season, about hundreds of villagers and farmers losing their houses and farmlands due to riverbank collapses caused by surging river flows. During our fieldwork and household surveys in 2015, bank erosion risks to public infrastructure, such as roads, water pumping stations, bridges and irrigation canals, were identified as major concerns in the Chindwin Basin (**Figure 5.1**).

Figure 5.1 A. Bank erosion along the Chindwin River (photo: Chayanis Krittasudthacheewa, Apr. 2014); B. Pumping station of irrigation canal where farmers reported risk of bank erosion, Chindwin River, downstream from Monywa. (photo: Chusit Apirumanekul, May 2015); C. Sandbags and cement plates being placed to protect bridge from bank erosion, Homalin (photo: Vitor Vasconcelos, May 2015).

In the household survey in 2015, farmers reported that the river water had become more turbid in the past ten years. While riverbank erosion could be caused by several factors including climate change (Shrestha et al. 2020), the farmers perceived mining activities and deforestation as the two main factors increasing sedimentation (linked with the perception of greater turbidity and sandbank extensions) and riverbank erosion. Some of them explicitly expressed that the new sandbanks caused by these land-use changes would change the natural dynamics of the rivers, forcing it to erode its banks. Other farmers also reasoned that the increasing amount of sediment in the riverbed would make it easier for the water to overflow its natural channel during rainstorms, and the overflowing water would hit the banks and cause more erosion. Due to a constraint on the availability of long-term observed data in the basin, this chapter does not intend to test whether farmers' perceptions on the causes of bank erosion are accurate. Instead, it addresses the following key questions to enhance understanding about bank erosion in the basin:

- Which areas near the confluence of the Chindwin and Ayeyarwady have a higher risk of bank erosion?
- What are the historical interrelationships between trends in the processes of bank erosion, deposition and re-vegetation?
- Where and how are the hazards of bank erosion faced by the villages in the rivers' valley?

Methodology

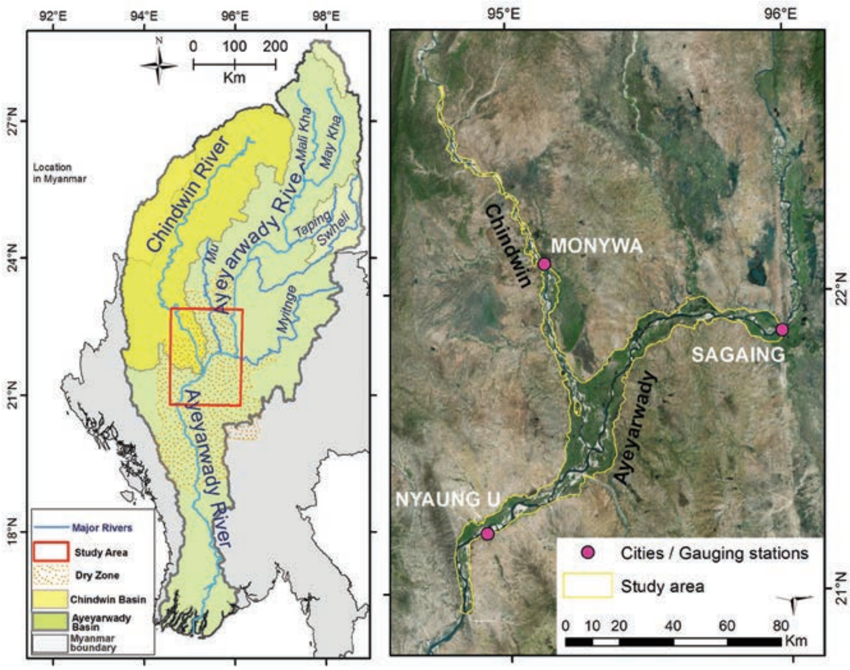
Study area

In consultation with the Directorate of Water Resources and Improvement of River Systems (DWIR), the research selected the region of the confluence of Chindwin River and Ayeyarwady River (**Figure 5.2**) as its priority area of study. The main reason for this choice of site is the constant demand on DWIR to perform river improvement works, including dredging, in order to enable navigation in this area. The presence of stream gauging stations in each branch and downstream of the confluence also helps to integrate the remote sensing studies to hydrological and hydraulic studies in the river basin.

Braided rivers like the Chindwin and Ayeyarwady develop under conditions of low-cohesive substrate, high seasonal variation of stream flow, and abundant sediment sources from upstream (Piégay et al. 2005). The Chindwin-Ayeyarwady confluence lies within the Central Tertiary Cenozoic Belt, subdivided by the central magmatic belt (Sew 2013). The Central Cenozoic belt consists of sedimentary rocks, comprised predominantly of sandstone, together with shale and mudstone (Myanmar Geosciences Society 2014). The central magmatic belt divides the Central Cenozoic belt, creating a tray of volcanoes and magmatic rocks.

This area has relatively homogeneous environmental characteristics, such as plain landscape and oxysols (highly weathered lateritic clay soils) over sandy unconsolidated sediments, the lowest sections lying

Figure 5.2 Location of study area and gauging stations (left) and Chindwin River Sub-basin in Ayeyarwady River Basin, and state borders in Myanmar (right)



on sandstone or Holocene alluvium (USGS 2007; Lee Hadden 2008; Pramumijoyo et al. 2010; Myanmar Geosciences Society 2014). Near the rivers, there is a predominance of luvisols (soils with a subsurface clay layer, covered by sandy loam), with gleisols (saturated sediments) in the floodplains (FAO and UNESCO 1974). There is also occurrence of vertic soils (cracking soils, whose clay has shrink-swell potential) along the “Central Magmatic Belt”. The original vegetation was brushland (Stamp 1924; Davis 1960), but later was almost entirely replaced by rainfed agriculture, which was rotated with cattle raising (UNEP 1994; Forestry Department FAO 2010). The sandy banks of the river have increased its susceptibility to fluvial erosion, while the removal of the natural vegetation may have also increased this susceptibility.

Chein (1961) and Coleman (1969) describe how the dynamic changes in the multiple channels of braided rivers are intrinsically linked to their seasonal flow changes: when the flow is increasing, the channels widen and deepen to accommodate the additional flow; afterwards, when the flow is decreasing, abundant sediments are deposited and bars grow rapidly within the channels.

The braided channels of the Chindwin and Ayeyarwady face extreme seasonal changes. According to data provided by the Department of Meteorology and Hydrology (DMH) of Myanmar (from 1991 to 2010), the Ayeyarwady River at Nyaung-U gauging station changes from an average discharge of 2,448 m^3/s in February to 25,585 m^3/s in August. On average, 74.2 percent of the discharge flows in the rainy season (May to October). These seasonal changes in the water level allow large boats to travel only in the rainy season, bogging down even the small boats on the sandbanks during the dry season. On the other hand, the heavy flows in the rainy season may cause significant bank erosion (Bowles 2013). Heavy flows may also create further sandbank slumping due to the undercutting and saturation of the non-cohesive sand grains (Nasermoaddeli and Pasche 2010).

Measuring the balance of sediments transported through the Ayeyarwady and Chindwin Rivers is also crucial to understanding the dynamics of its fluvial processes. During the rainy season, the discharged sediments of the Ayeyarwady River at Sagaing station, which is located upstream of the studied area, is almost 3 times lower than at Chauck station (which is located downstream of the studied area), reflecting the contribution of sediments from the Chindwin River and from riverbank erosion in the Ayeyarwady River (Velden 2015).

Data used

This study uses Landsat images[1] as the main reference for evaluating the changes in the course of the Chindwin and Ayeyarwady Rivers (**Table 5.1**). For the earliest period (1973), scenes from the Tri-Decadal Global Landsat Orthorectified Overview from Landsat 1 were selected. Sequentially, an annual series of Landsat images for 1988 to 2020 (orthorectified and atmospherically corrected) were used for an inter-annual scale evaluation of the rates of erosion, deposition and vegetation re-stabilization. Notwithstanding, a visual inspection of the relatively plain landscape of the studied area did not show any significant parallax displacement. Scenes of the dry season (November to April) were preferred, due to clearer skies and for depicting sandbanks adjacent to the river surface.

Table 5.1 Primary data for this study

Data	Spatial resolution	Temporal resolution	Year(s)
Landsat 1, 2, 3	60m	1 image (dry season)	1973
Landsat 4, 5	30m	Yearly (dry season)	1988–2012
Landsat 7	30m	4 images (dry season)	2001–03, and 2013
Landsat 8	30m	Yearly (dry season)	2014–20
High Resolution Image (Spot, from ArcGIS basemap and Bing maps "arcbrutile")	2.5m	2 images	2012 and Mosaic 2008/2010
High Resolution Image (digital globe – World View)	0.5m	2 images	Mosaic (2008–2010) and 2020
SRTM (elevation)	15m	1 image	1994
Discharge and Water Level at Monywa, Sagaing and Nyaung-U gauging stations	3 stations	Daily data	1966–2010 (Monywa and Sagaing) 1991–2010 (Nyaung)
Location of towns and villages (MIMU)	Points		4 Dec 2013

An important conceptual model in order to understand the river channels of the Chindwin and Ayeyarwady is the distinction between the natural levee (inner banks) bordering the dry season channel (minor riverbed), the major riverbed where the water flows during the rainy season (covering the sandbank areas), and the bluffs (outer banks) that delimit the river valley (Wilkerson 2012). During the evolutionary history of these river channels, they may keep changing their courses within the bluffs, and may cause bluff erosion when the channels migrate close to the bluffs. The limits of the embedded river valley (between the bluffs) were extracted through visual interpretation of:

- Satellite imagery
  - Red, green, blue (RGB) combination of Landsat Imagery;
  - Principal Component analysis (PCA) of Landsat Imagery;
  - Natural color for high-resolution imagery;
- Elevation derived from Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM);[2]
- Slope derived from SRTM DEM;
- Vertical distance to rivers.

The vertical distance to rivers was obtained through the homonymous algorithm in SAGA 2.1.2, using the SRTM DEM and the SRTM water mask as inputs, according to the HAND (Height to the Nearest River) method (Rennó et al. 2008).

For each Landsat scene of each year, a supervised classification was used for the river valley, comprising three classes: Water, Exposed Sandbanks, and Others. The class "Others" includes mainly agriculture areas, often seasonally rotated with cattle raising in the dry season, with fragments of native vegetation and villages. The visual interpretation of the training polygons for supervised classification was straightforward from the Landsat images, although fieldwork and ground truth from May and September 2015 and high-resolution images helped to ensure its reliability. Subsequently, the class "Water" was separated manually between river surface and lake surface. The spurious (scattered) pixels of exposed soil not associated with river channels were also separated through visual interpretation. Constraining the classification within the river valley area (instead of classifying the entire Landsat scene) and maintaining few classes (three), was important to increase the reliability of the maximum likelihood classification algorithm (Strahler 1980).

For the Landsat 7 image of 2013, with void strips due to the SLC (Scan Line Corrector) failure after 2003, in the present study, three images were combined in order to fill the voids of each other. Sequentially, the respective three classes of land cover (water, exposed sandbanks and others) were vectorized based on visual interpretation. The supervised classifications by maximum likelihood developed in this study for the years of 2012 and 2014 were used as an additional reference for the visual interpretation, in order to ensure the same classification pattern for 2013. This method of void filling, followed by visual interpretation of Landsat 7 images, has been validated previously by Hossain et al. (2015).

After the maximum likelihood classification of each scene, they were overlaid in order to identify the areas that were subjected to active changes from 1973 and 1988–2020. In this manner, the areas that faced bank erosion were discriminated from the ones that remained safe from it during this period. For that operation, the changes in the river and adjacent sandbanks in the dry season were considered together, as they would correspond to the wider river surface of the previous rainy season. The overlaid map also identified which sections of the rivers' channel (minor riverbed) in

2020 have remained stable since 1973 and which ones have been subject to recurrent changes. The frequency of land-use change in each pixel was mapped to infer the overall instability of the land cover in the river valleys.

High-resolution images from Open Street Map from May to September 2012 and from Digital Globe for 2020 were used to delimit the villages within the river valley and on the top of the borders of the bluffs. The location of the villages within the river valley was compared with the land cover classification from Landsat images, in order to discover which village areas were destroyed by riverbank erosion from 2012 to 2020. Existing villages in 2020 that are in areas that faced riverbank erosion from 1973 to 2019 were also identified, as they would be in sites that are more vulnerable to future river erosion.

The villages on the border of the bluffs were classified in a progressive scale of bluff erosion hazards: bluff on stable land (lowest hazard), bluff on stable river channel (low hazard), and bluff on area of unstable river channel (possible hazard). For this study, it was not possible to evaluate the hazards faced by the villages on bluffs adjacent to unstable river channel to be affected by bank erosion in the future, because it would demand a detailed fieldwork assessment of the resistance of the riverbanks. Nevertheless, some of these villages were selected for a detailed remote sensing study, to evaluate the bluff erosion during this studied period, as per suggestion by DWIR.

The annual time series of land cover maps from 1988 to 2020 was used to compare the erosion and deposition by two different approaches:

1. Comparing the changes in the river surface (minor riverbed) over the remaining land cover classes (sandbanks and “others”). The advance of the river surface over the remaining land cover classes is classified as erosion, while the advance of the remaining classes on the previous river surface is classified as deposition (Khan et al. 2003; Goshal et al. 2010; Sarkar et al. 2012; Das 2012;, Nath et al. 2013; Ahmed and Fawzi 2011).
2. The approach proposed by Uddin et al. (2011) for braided rivers, considers the stabilization versus erosion of vegetated areas adjacent to exposed sandbanks and river surface. The assumption underlying this approach is that the wider (major) riverbed in the rainy season is approximately the same as the union of the classes corresponding

to the river surface and exposed sandbanks in the dry season (because the river flow will cover the sandbanks in the rainy season).

Results and discussion

Land cover change

The map of **Figure 5.3** presents the combination of the classifications (1973, and yearly classifications from 1988–2020) to evaluate the extent of these changes. In the red areas of the map of **Figure 5.3**, the river keeps shifting its course through processes of bank erosion and sediment deposition (or dancing) through the years. From 1973 to 2020, 34 percent (668 km^2) of the river valley suffered bank erosion. Only 38 km^2 of the river surface (minor riverbed) in 2020 has been stable since 1973, which corresponds to 13 percent of total river surface and 2 percent of the river valley area. The Chindwin River (which is upstream from the border between Monywa and Butalin townships) concentrates most of the stable sandbanks in the studied area, and long stretches of stable river course as well. A long continuous stretch in the Ayeyarwady River, just upstream from its confluence with Chindwin River, was also stable during the whole period.

Figure 5.4 shows the frequency of the land cover change (i.e., how many times the land cover type of a pixel changed along the time series), comparing the land classification of 1973, and the yearly classifications from 1988 to 2020. The areas with higher frequency of land-use change within the river channel would face higher susceptibility to recurrent riverbank erosion.

The graph of **Figure 5.5a** shows the evolution of the river valley when divided between two classes: major riverbed (river water surface plus sandbanks in dry season, matching the river surface in rainy season) and stable land (including temporary lakes). Both classes remained stable along the time series, with a slight decrease in the river channel area from 1989 to 2020. Thus, the data in this graph does not contribute to the hypothesis that increasing riverbank erosion and sedimentation would widen the river channel area.

Figure 5.3 Changes in the river channel, 1988–2020

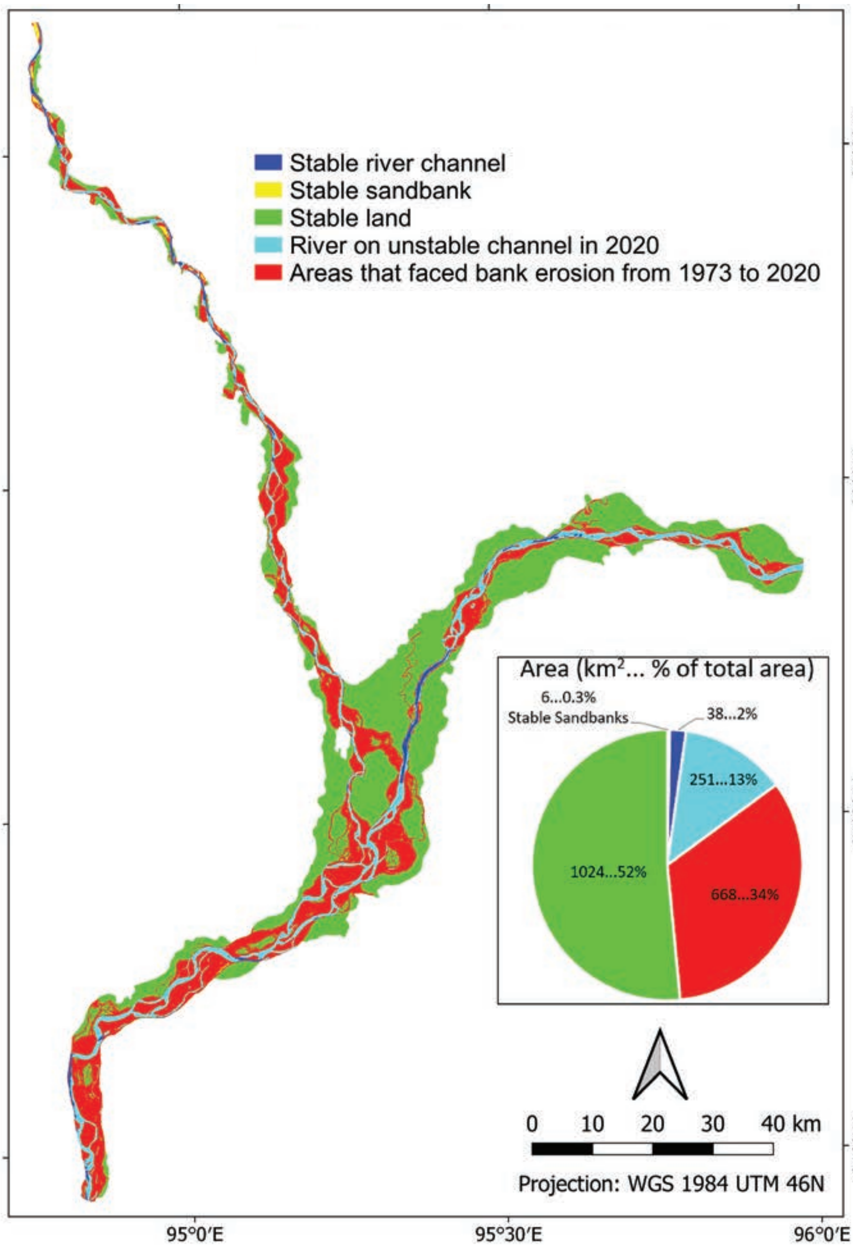


Figure 5.4 Frequency of changes in the Chindwin and Ayeyarwady, 1988-2020, with reference to 1973 land-use classification

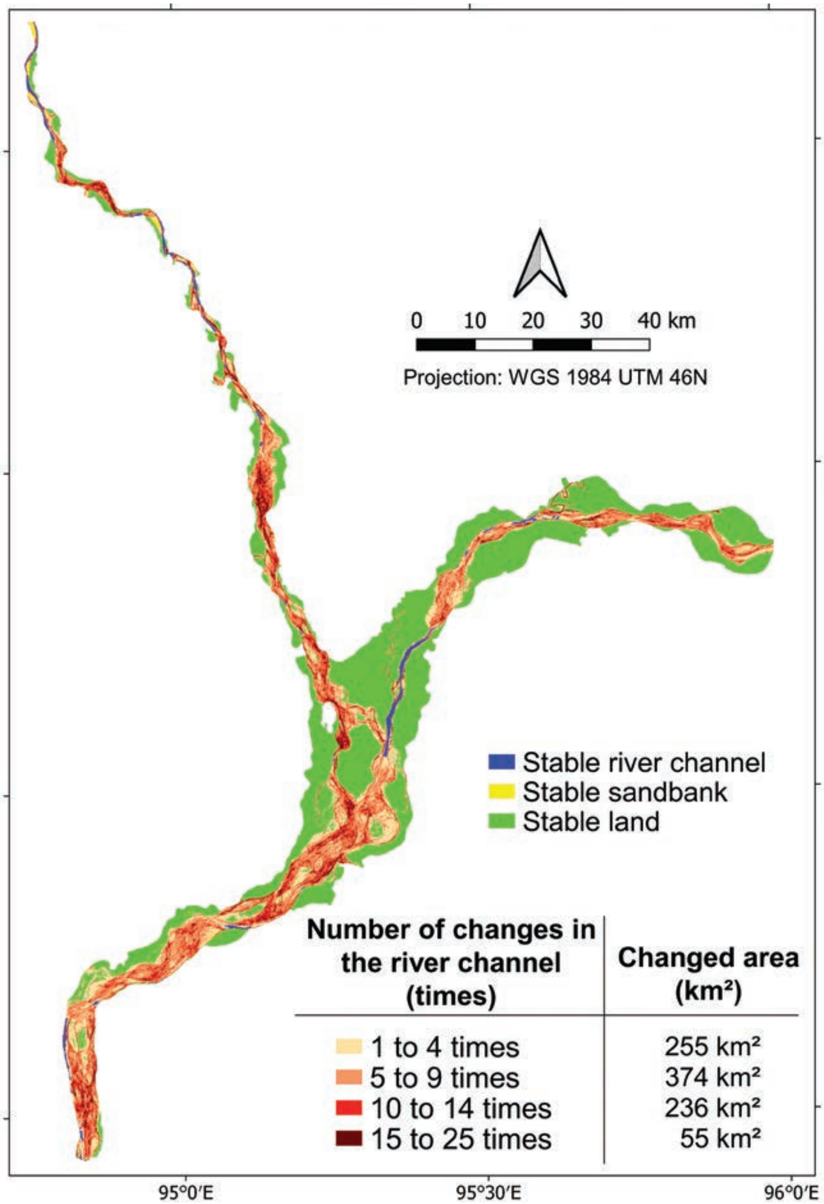
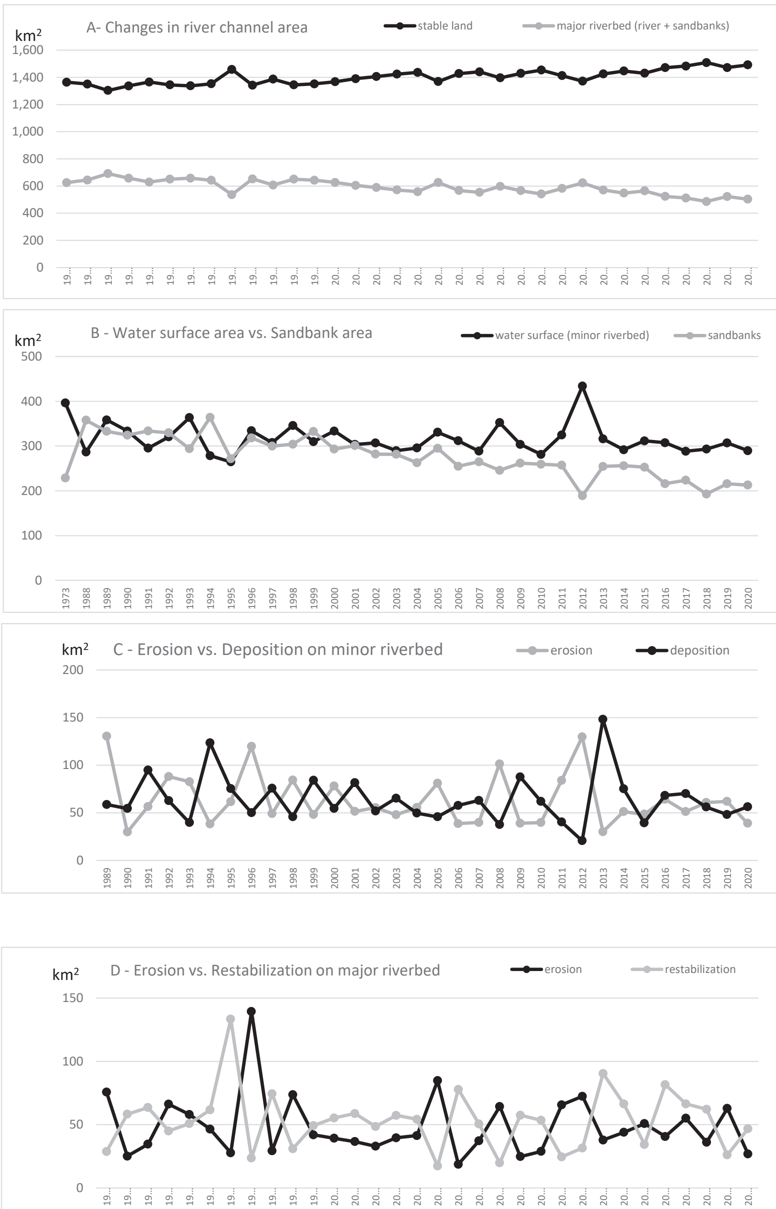


Figure 5.5 Annual time series for changes in river channel area, including (A) areas of stable land vs. major riverbed (river water + sandbanks), (B) river water surface (minor riverbed) versus sandbanks, (C) bank erosion versus deposition on minor riverbed, and (D) bank erosion versus vegetation restabilization on major riverbed



In **Figure 5.5b**, it is possible to infer that, despite some peaks of river surface area in 1973, 1993, 2008 and 2012, the river surface in the dry season (minor riverbed) has been maintained at around 300 km^2 from 1988 to 2020. Part of the interannual variations of the river surface may be related to variations in the river water level, due to the distinct intensity of the drought season in each year. On the other hand, the exposed sandbank area has decreased gradually, since 2003, from 300 km^2 to approximately 200 km^2 in 2018–2020, being partially restabilized by vegetation. This trend is consonant with the long-term trend (1973–2020) identified in the graph **Figure 5.5a**, where the wider (major) riverbed (sandbanks plus river water surface) gradually lose space for stabilized land across the decades.

The annual time series of the areas of bank erosion versus deposition (minor riverbed in the dry season) and erosion versus vegetation restabilization (major riverbed in the rainy season) is presented in **Figures 5.5c** and **5.5d**, respectively. It is possible to infer that, in both approaches (inner and wider riverbed) the rates were higher from 1989 to 1997, then relatively stable from 1998 to 2004, but from 2004 to 2012 there were higher cycles of erosion every 1 to 2 years, followed by cycles of deposition and vegetation restabilization every 1 to 2 years. Just after 2012, these cycles tended to progressively decrease in magnitude. This cyclic pattern corroborates the hypothesis that, in a systemic approach, the river system tries to recover its balance after a disturbance (erosion event). The cycles of erosion and deposition/restabilization are in temporal agreement in both graphs for the inner and the wider riverbed, although to very dissimilar degrees of intensity for each year. From 1989 to 1997, first there was a period with increased minor riverbed erosional-depositional cycles, accompanied by major riverbed erosional and restabilization cycles at the end of this period. For the minor riverbed, these cycles of erosion and deposition become progressively higher from 2004 onwards. On the other hand, for the major riverbed, the high erosion rates and subsequent vegetation restabilization from 2004 to 2006 were followed by lower cycles of restabilization and erosion, with a predominantly higher rate of vegetation restabilization from 2013 onwards.

These patterns of erosion and deposition depicted in **Figure 5.5c** and **Figure 5.5d** are in consonance with historical trends of land use in Myanmar. The period 1988 to 1995 corresponds to the ceasefire during the civil war, with a policy of granting land concessions for logging and agricultural projects funded by foreign investment (Woods 2011; Alban et al. 2019), and corresponding to increased cycles of erosion of the inner and major riverbeds. From 1996 to 2003, the re-emergence of civil conflicts and foreign economic sanctions hampered rural investment projects in Myanmar (Andréasson 2008), and corresponds to the period with less erosion in **Figure 5.5** (c and d). From 2003 onwards, there was an increased acceleration in the transition from native vegetation to agricultural land up to 2012 in Myanmar according to FAO statistics (2019), which was linked to the policy of land confiscation for large-scale agricultural projects (Woods 2015).

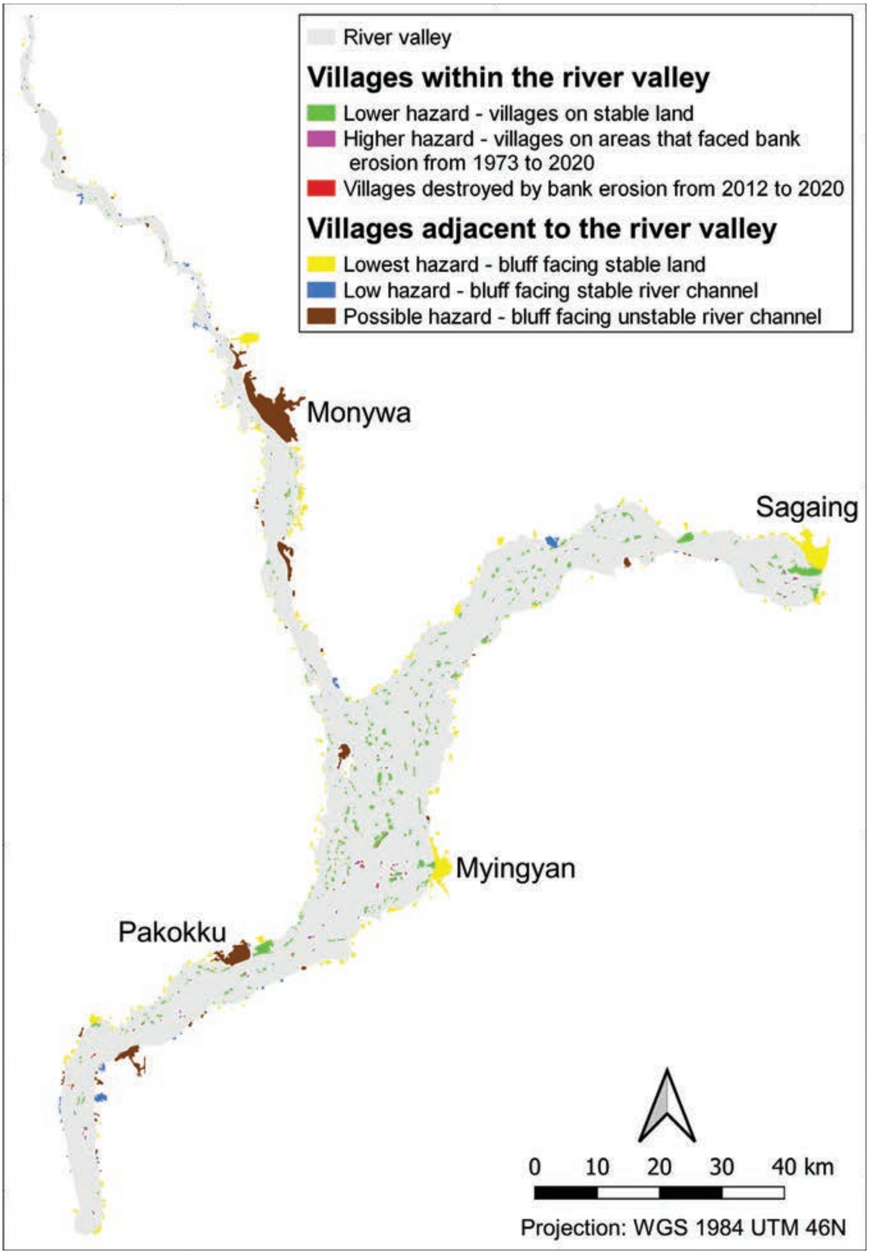
These events also correspond to the gradually increasing magnitude and frequency of cycles of riverbank erosion. After 2013, conversion to new agricultural areas deaccelerated (FAO 2019), according with the decrease in erosion cycles in **Figure 5.5** (c and d); meanwhile the policy of land confiscation for agricultural projects was halted by increasing supervision by government commissions (Thein et al. 2017), which was reinforced by the new democratically elected government after 2015 (NLD 2015; Weir 2018). This coherence between erosion cycles and general trends of conversion from native vegetation to agricultural land support the hypothesis of this impact of land-use change on riverbank stability. However, further remote sensing studies on detailed land-use change within the area could evaluate these causal relationships more accurately.

Village areas

The locations of 447 villages (79 km^2) in 2012, and 509 (86 km^2) in 2020, were identified within the river valley, besides 302 villages (139 km^2) located uphill on the borders of the bluff, i.e., adjacent to the river valley. The largest urbanized sites (Monywa, Sagaing, Myingyan and Pakokku) are outside the river valley, adjacent to the bluff.

The map in **Figure 5.6** shows the classification of villages that have suffered bank erosion or are in areas that faced erosion in the past. Most of the village area within the bluffs (91 percent, 78km^2) have not faced bank erosion since 1973, while 9 percent (7.6 km^2) are in vulnerable areas that faced erosion before 2020. Bank erosion destroyed 3.5 percent (2.8 km^2) of the villages from 2012–20. Practically all the destroyed village areas are downstream from the confluence of the Chindwin and Ayeyarwady Rivers.

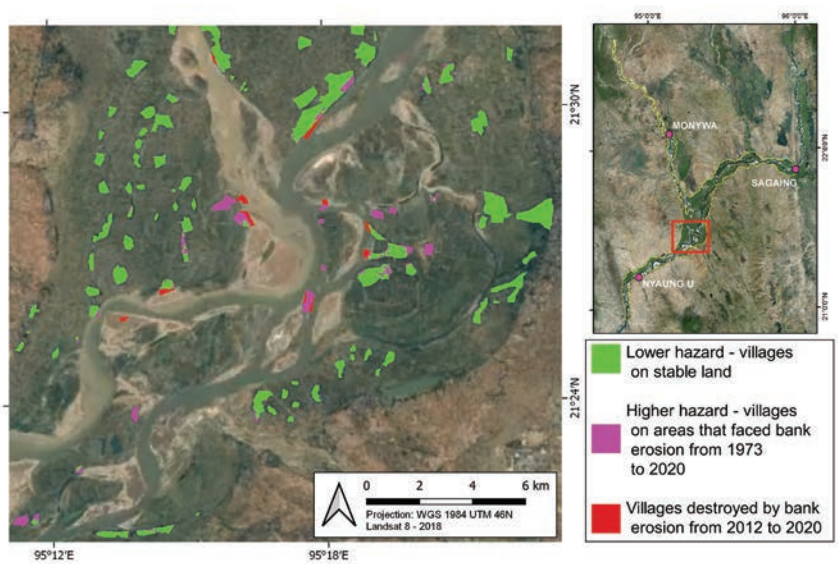
Figure 5.6 Impact/hazards of riverbank erosion on villages in the studied area



In **Figure 5.6**, approximately half of the village area (51 percent, 90 km^2) adjacent to the bluff (outside of river valley) were facing stable land since 1973 (lowest hazard), while 6 percent (11 km^2) were facing stable river channel (low hazard) and 43 percent (76 km^2) were facing areas of unstable river channel (possible hazard). As for the biggest urban sites in the studied area, Monywa and Pakokku face areas of unstable river channel, while Sagaing and Myingyan are safer, facing areas of stable land.

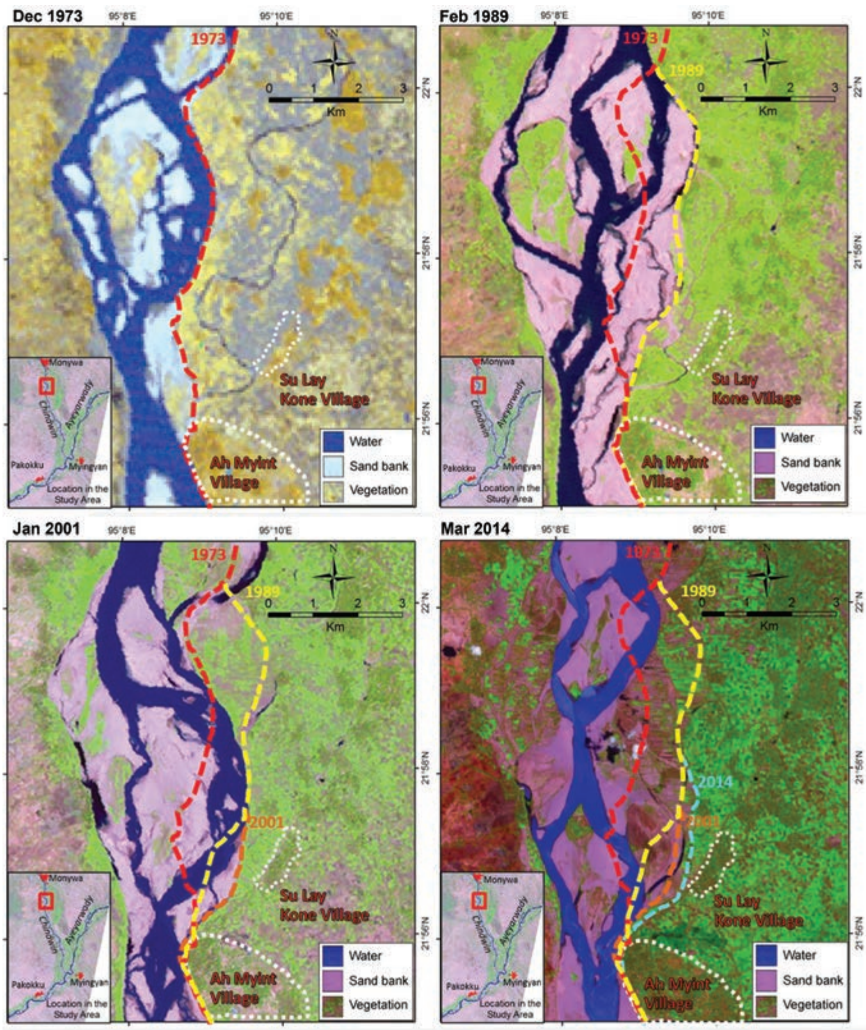
The map of **Figure 5.7** zooms into an area just downstream of the confluence of the Chindwin and Ayeyarwady Rivers where there is a higher occurrence of eroded villages and also villages placed in hazardous areas that were part of the river channel in the past.

Figure 5.7 Assessment of impacts and hazards of bank erosion on selected area downstream of the Chindwin and Ayeyarwady confluence



In **Figure 5.8**, a time series of satellite images is interpreted to detail the hazards of bank erosion near Su Lay Kon and Ah Myint villages, in Chaung-U Township, Monywa District, Sagaing Region. From 1973 to 2014, the river channel (inferred from surface and sandbanks in the dry season) widened progressively due to bank erosion, posing greater hazards to those villages.

Figure 5.8 Bank erosion in the Chindwin River, near Ah Myint and Su Lay villages, interpreted on Landsat Images of 1973, 1989, 2001 and 2014. The lines depict the progression of riverbank erosion in each year. Note how the riverbank line advances toward the villages



Use of remote sensing studies for planning purposes

The assessment of bank erosion proposed in this chapter is valuable for land-use planning. It is better to build infrastructure (bridges, pumping stations, etc.) on the borders of river stretches that have been stable over many decades. Stable channels are also important for navigation planning in the Ayeyarwady and Chindwin Rivers. Velden (2015) proposes that, in the stretches of higher instability in the Chindwin and Ayeyarwady Rivers, the structures for navigation improvement should be flexible and adjustable to the changes in the active river channel. Conversely, large and fixed infrastructure would face higher risks. Furthermore, any infrastructure or activity that affects water and sediment flow in the river channels, such as dams, weirs, dredging and diversions, may have consequences on the geomorphological evolution of the channels downstream from the intervention.

The areas previously occupied by the riverbed are very fertile for agriculture. However, if the farmers build their villages or infrastructure there, the river may come back again and destroy these. Although all villages within the river bluffs suffer some risk with the changes of the river channel, this study shows that most of them remained relatively safe from 1973 to 2015. The exceptions are villages located just downstream from the confluence of the Chindwin and Ayeyarwady Rivers (**Figure 5.7**), which deserve closer attention.

Many people voiced concern during our stakeholder consultations that the rivers are becoming shallower with more sandbanks. This perception should be carefully considered in the results of this study. The results presented in the previous section point that, although the river surface area is not increasing (therefore, maybe the rate of width versus depth did not increase), the dynamics of erosion and deposition seems to have intensified since 2004. In this context, with less stability in the riverbed, it may become more common to find sandbanks along previously stable navigation routes, although the river compensates by becoming deeper in other parts of the cross-section. Nevertheless, remote sensing studies just provide clues based on visual interpretation; more precise answers about these trends require analysis of time-series bathymetric studies.

The trend of vegetation restabilization on the sandbanks in the last decades, inferred from **Figure 5.5**, also has some implications on land use. According to previous land-use mapping (UNEP 1994; Forestry Department FAO 2010), fieldwork ground truth in May and September 2015, and interpretation of high-resolution images, most of this vegetation is agricultural, including some seasonal rotation with cattle raising. On the one hand, the vegetation helps to stabilize the sandbanks against fluvial erosion. On the other hand, the culivation of these hazardous areas of unstable sandbanks may be a long-lasting risk to the farmers, as they are vulnerable to erosion. This risk variable should be kept in mind in planning at the farm level. In addition, the remote sensing methodology used in this chapter did not assess the conversion of riparian forests to agriculture, which could potentially increase the hazards of bank erosion.

Limitations of remote sensing of river channels

One of the limitations of the methodology used in this study is that the river is assessed only in terms of its 2D shape, i.e., not including its depth. Therefore, remote sensing studies cannot replace bathymetric studies, especially coupled with hydraulic and hydrological studies. Moreover, the spatial resolution of 30 m of the Landsat images could not evaluate the existence or absence of narrower strips of riparian vegetation that often protect riverbanks from erosion.

The extensive cloud cover in the studied area in the rainy season brings significant difficulties for the systematic use of satellite images when the rivers are at their highest water levels. On the other hand, the availability of annual images in the dry season enabled a better interpretation of the sedimentation patterns of sandbanks.

The maximum likelihood supervised classification of the river valley was adequate for the land-use classification used in this methodology when compared to fieldwork validation and visual interpretation, but required additional cleaning of spurious pixels. If the study method required more detailed classification (for example, discriminating the class “Others” into more classes, such as agriculture, villages and natural vegetation types), then more advanced classification techniques and/or more extensive fieldwork validation would be advisable.

As the methodology required a delimitation of the river valley prior to the land use classification, the changes in the shape of the river valley over the years (through erosion of the bluffs) were not evaluated quantitatively. When studying the erosion hazards faced by the villages adjacent to the bluffs (outside river valley), an alternative approach was to evaluate if there was any bank erosion close to the bluff during the analyzed time series. The detailed case study on Su Lay Kon and Ah Myint villages showed that bluff erosion can be a real hazard for adjacent villages.

Conclusion

This study helps us to understand the spatial and temporal magnitude of changes in the channels of the Ayeyarwady and Chindwin Rivers. From 1973 to 2020, 47 percent of the river valley in the area faced riverbank erosion. Development within these areas of recurrent bank erosion should proceed cautiously, both for agriculture and settlement. The identified stable stretches of Chindwin and Ayeyarwady Rivers should be prioritized for infrastructure projects such as bridges, water pumping stations and electricity lines.

The studied area of the river channel remained relatively stable during this period, showing that the river channels have not been widened by bank erosion, because the river system recovers its balance after erosional events. However, the rates of bank erosion versus bank restabilization were higher from 1988 to 1996, followed by a relatively stable period, which was succeeded by an increasing frequency of erosion cycles after 2004, which gradually decreased after 2012. This pattern is coherent with the main historical trends of conversion of native vegetation to agriculture in Myanmar, supporting the hypothesis that the increasing destabilization of riverbanks was influenced by deforestation; however, this has not been directly assessed in this study, and therefore, needs to be further explored in future research.

Since 1973, 7.6 km^2 of villages (9 percent of the village area within the bluff zone) have been built on unstable areas of recurrent bank erosion and face higher hazards. Most of these villages are located in the area just downstream from the confluence from the Ayeyarwady and Chindwin Rivers. The villages of Ah Myint and Su Lay beside the Chindwin River are also highly susceptible to bank erosion. The urban areas facing the bluffs, adjacent to the river valley, on stretches of unstable river channels, deserve more detailed studies to evaluate their risks to bluff erosion, especially at Monywa and Pakokku, which are large urbanized sites adjacent to unstable stretches of river channel.

Recommendations

Further studies could compare the results of this research to hydrological data from the Monywa, Sagaing and Nyaung-U gauging stations, as well as with hydrodynamic models based on the hydrological data and bathymetry cross-sections. Land cover change models based on cellular automata could be developed to detect areas with a higher probability of bank erosion in the future.

On the river bluffs, the villages bordering unstable channels should have a higher priority for future detailed investigations about riverbank erosion. Analysis of the stability of soil and rocks on the natural levees and bluffs should be implemented. Complementary detailed analysis of historical changes in the river channel, such as done in this chapter for Ah Myint and Su Lay villages, are useful as well.

Vendel (2015) proposes that the revegetation of the Ayeyarwady and Chindwin bluffs and sandbanks could increase channel stability, thus decreasing infrastructure losses and improving navigability. These revegetation buffers could include both areas of natural vegetation and agriculture for economic and ecological purposes. A detailed study could advise the appropriate plants for revegetation for each stretch of the Ayeyarwady and Chindwin Rivers, based on their soils, rocks, land use, hydrology and hydraulic characteristics.

The development of more detailed survey maps for geology, soil, geomorphology and land cover for Myanmar would be extremely useful for future research and planning regarding susceptibility to riverbank erosion. These maps could be overlaid with the results of the remote sensing methodology proposed in this study, in order to understand the causes of these erosional processes and the viability of planned interventions.

Finally, it is also recommended that other areas with braided patterns along the Ayeyarwady River, downstream from the studied area, be studied using the methodology applied in this study. The remote sensing study provides an initial framework for planning purposes. A further detailed geomorphological and remote sensing zoning, coupled with extensive fieldwork, would be helpful to advise government and people about areas with higher risks for building houses and other infrastructure such as bridges, pumping stations and river navigation facilities. Maintaining or recovering stable vegetation on vulnerable riverbanks may be a possible strategy to cope with erosion. Moreover, land-use planning for living in this dynamic riparian system, such as sustainable agriculture on areas newly created by deposition, may be a possible complementary approach.

Notes

1 Retrieved from U.S. Geological Survey, Earth Explorer, https://earthexplorer.usgs.gov/. On Landsat satellites, see U.S. Geological Survey, Landsat Missions, http://landsat.usgs.gov/.

2 NASA, Shuttle Radar Topography Mission, http://www2.jpl.nasa.gov/srtm/; U.S. Geological Survey, Shuttle Radar Topography Mission, http://srtm.usgs.gov/.

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6

Water quality in the Chindwin River Basin

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Myanmar has one of the least developed economies in the world (UN 2018). Water quality assessments conducted by Sagai et al. (2013) from various water sources in Myanmar, such as urban areas, rivers, dams, lakes, and wells, found them to be of generally good quality. However, water pollution in the country has been increasing due to ongoing development activities and the degradation of water quality will become more critical in the future. The main sources of water pollution in Myanmar are sewage, solid waste, and industrial, mining and agrochemical wastes (FAO 2018). The country has limited capacity to monitor water quality across the country, particularly that of the main rivers, the Ayeyarwady, Chindwin and Sittuang.

To date, limited published studies related to water quality in Myanmar are available in the public domain. Re et al. (2018) conducted an assessment at a catchment scale in Inle Lake to understand its surface and groundwater dynamics. Their study highlighted the lack of awareness of the potential water quality and pollution issues due to population growth, agriculture and tourism in the catchment area. Su Thet Hninn et al. (2017) evaluated a water quality improvement policy package for the floating settlements on Inle Lake. The results showed that the average surplus gain from an improvement in the lake's water quality was at least as large as 5.9 percent of the average annual per capita income of those living on the lake.

Water quality and sedimentation are intrinsically linked with land-use changes, climate change and water use within the Chindwin River Basin. Over the last two decades, water users have seen noticeable changes in water quality and increased sedimentation and turbidity. Concerns over water quality are mainly related to low dissolved oxygen, high turbidity, and heavy metal contamination in water sources (SEI 2015a, 2015b). Intensified commercial activities along the Chindwin River, especially mining (**Figures 6.1 and 6.2**), deforestation, agriculture and other industries, are assumed by the stakeholders in the basin to be the main drivers behind a decline in water quality (SEI 2015a, 2015b). However, to date, there have been no scientific studies of the Chindwin Basin to adequately quantify the extent of its water quality problems.

Study objectives

This chapter assesses the current state of water quality in the Chindwin River Basin (CRB) and identifies the gaps that need to be addressed for future water quality management and research. The chapter aims to answer the following three questions:

- Which existing institutions are responsible for monitoring and managing water quality in the CRB?
- What is the current condition of water quality in the CRB when compared to international standards?
- How may stakeholders address the current challenges related to water quality issues in the CRB?

Figure 6.1 Remote sensing image of the Uru River and confluence with the Chindwin River. The spectral signature distinguishes the areas that have been cleared for mining activities.

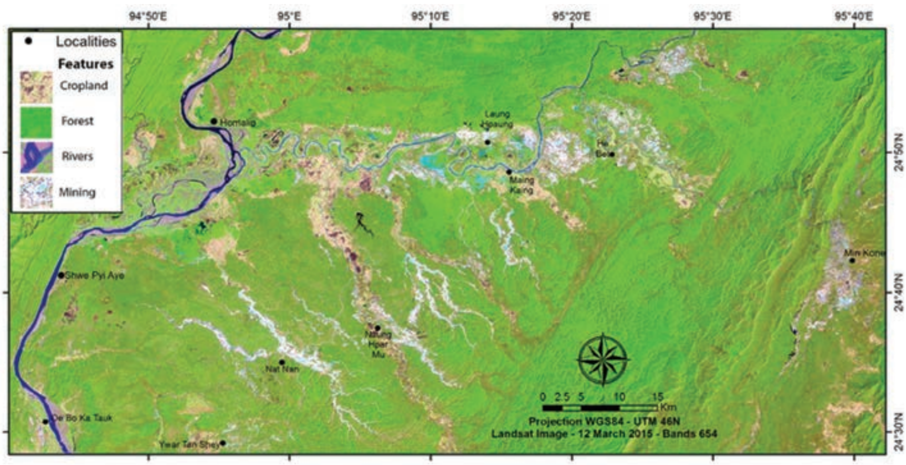


Figure 6.2 Bank hill mining along the Uru River, Chindwin River Basin

Methodology and data

This study used mixed methods to assess the state of water quality in the basin and related issues, as listed in **Table 6.1**.

Table 6.1 Activities for assessment of water quality in the Chindwin Basin

Activity	Purpose	Period
Literature and data review	To understand current state of knowledge and existing water quality data	2015–18
Stakeholder consultations	To define water quality problems in terms of specific concerns, issues, targeted locations, concerned agencies and potential solutions	2015–16
Interviews with key actors	To improve understanding of water quality problems and associated governance structure currently in place	2015
Household survey	To improve understanding of the use of water, livelihoods, and concerns and impacts of water users in targeted area	2015
Water sampling and analysis	To collect water quality data at targeted areas using different methods and conduct measurements of specific water attributes	2015–17

Literature and data review

The study team reviewed past literature available in the public domain to understand the CRB's bio-physical characteristics, and key activities and livelihoods of the people living there that are connected to water quality. The secondary data from various agencies (e.g., Irrigation Department, Department of Meteorology and Hydrology, and University of Monywa) were collected to improve understanding of the spatial and temporal water quality parameter ranges in the Chindwin River, with a focus on Homalin and Monywa townships, where there is a greater concentration of mining activities.

Stakeholder consultations

Five stakeholder consultations were held to contribute to an integrated assessment of water quality in the basin, and were conducted in April 2014, November 2014, May 2015, October 2015, and October 2016. These consultations contributed to defining the problem in terms of the specific concerns, issues, targeted locations, responsible line agencies and potential solutions. The inputs were useful in guiding the design of follow-up activities, e.g., interviews with key actors, household surveys, water quality sampling and testing, and the formulation of policy recommendations.

Interviews with key actors

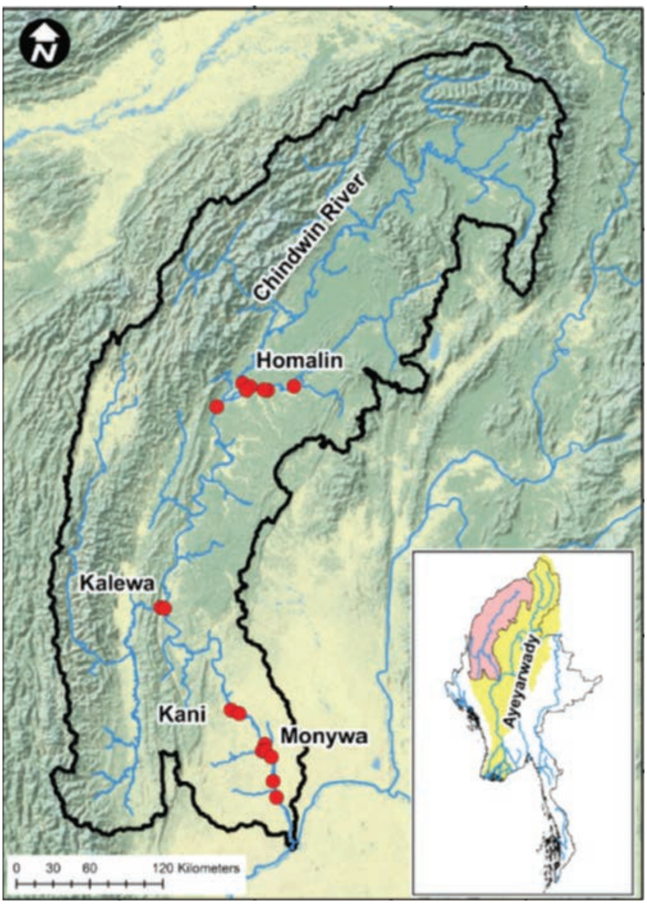
Several agencies are responsible for water quality monitoring and management in Myanmar. To better understand the challenges, available data, and institutional arrangements related to water quality in Chindwin, the study team conducted semi-structured interviews in August and September 2015 with six line agencies that have oversight of water quality.

Water sampling and quality testing

Several government agencies are responsible for water quality monitoring at different locations in the Chindwin River Basin. The water quality data collected by these agencies are not freely accessible by the public. It is also difficult to compare these data since they were collected at different locations at different times, using different parameters and monitoring techniques. Following discussions with line agencies and stakeholders, the study team conducted water quality sampling and testing in the basin as summarized below.

Seventeen locations in the upper, middle and lower parts of the Chindwin River Basin were selected for water quality monitoring. These sites are located near Homalin, Kalewa, Kani and Monywa townships where human activities and interventions are assumed to have impacted water quality (**Figure 6.3**). Selected cross-sections for sampling sites were identified considering the criteria proposed by the US Geological Survey (2006).

Figure 6.3 Water quality sampling sites in the Chindwin River Basin: samples collected 2015–17



Water quality sampling and testing in the Chindwin River was undertaken biannually: in the dry season (May–June) and in the wet season (September–October) of 2015 and 2017. The identified sampling points were in many cases remote and not easily accessible; therefore, three water equality testing methods were used to enhance the accuracy and quality of data generated. These included in situ measurement (8 monitoring parameters), laboratory measurement (14 monitoring parameters) and the use of portable test kits (5 monitoring parameters) as detailed in **Table 6.2**.

Table 6.2 Water quality evaluation methods and parameters at selected sites on the Chindwin River and tributaries

Testing methods	Measuring parameters
In situ measurement (8 parameters)	1. Water Temperature 2. Air Temperature 3. Rugged Dissolved Oxygen (RDO) 4. pH 5. Oxidation Reduction Potential (ORP) 6. Electrical Conductivity (EC) 7. Salinity 8. Total Dissolved Solids (TDS)
Laboratory measurement	1. Oil and grease 2. Total Nitrogen (TN) 3. Total Phosphorus (TP) 4. Chemical Oxygen Demand (COD) 5. Total Suspended Solid (TSS) 6. Turbidity (NTU) 7. Total hardness 8. Total Dissolved Solids (TDS) 9. Arsenic (As) 10. Cyanide (CN) 11. Lead (Pb) 12. Mercury (Hg) 13. Copper (Cu) 14. Iron (Fe)
Portable test kits (5 parameters)	1. Bacteria, 2. Lead (Pb) 3. Mercury (Hg) 4. Copper (Cu) 5. Iron (Fe)

Figure 6.4 Measuring water quality using an in situ hand-held instrument (upper left) in 2015, collecting water samples (upper right) in 2015 and preservation of water samples in 2016 (lower figure)

In situ measurements were undertaken using a multiprobe to obtain measurements to compare with historical datasets. The multiprobe model used in the present study is a Smartoll^{TM}MP from In-Situ Inc. Water sampling was undertaken via a horizontal water sampler using the grab sampling method positioned at the middle depth of the deepest point of the cross-section of the river. The 1,000 ml High Density Polyethylene (HDPE) and glass bottles with clear labels were used to store the water samples for laboratory measurements. Samples used to evaluate the levels of heavy metals were preserved at a pH < 2 through the addition of the chemicals such as nitric acid (HNO3) to each sample collected (**Figure 6.4**). All samples were preserved in ice boxes at a temperature < 4 ^{0}C to maintain the biological and chemical characteristics of the water samples until the samples reached laboratories in Yangon and Bangkok.

Portable test kits can be purchased commercially for rapid testing for a number of parameters, including bacteriological testing and heavy metals. The disposable test kit is for single use and evaluates a signal parameter on a sample after which it is discarded. The test kits were considered useful for testing as an alternative to costly laboratory analysis of selected parameters. These test kits were compared against the results from the laboratory analyzed samples.

Household survey

Household surveys on livelihoods and water-related issues were conducted in three locations along the Chindwin River in May 2015. A total of 600 households were surveyed in Homalin, Kani and Monywa townships (200 in each location) (see Aung and Resureccion, this vol.). These three locations are located in the upper, middle and lower Chindwin River Basin, respectively.

Results and discussion

Several interviews were conducted with government departments during August and September 2015, in order to understand which line agencies are responsible for particular governance areas and geographical boundaries regarding water management. Information was gathered about water quality and river health, current governance interactions and how each agency views the potential establishment, role and function of a Chindwin River Basin Organization (RBO) (Krittasudthacheewa et al., this volume). Only findings related to water quality are discussed in this chapter. **Table 6.3** includes a classification of the ministries, departments, their responsibilities with regard to water management (including water quality) and the geographical boundaries over which their responsibilities stretch.

Table 6.3 Summary of line agencies in Myanmar with responsibilities related to water quality

Ministry	Department/ Institution	Main responsibility	Water quality monitoring
Ministry of Agriculture and Irrigation (MOAI)	Irrigation Department (ID)	Water for irrigation supply (gravity fed) and flood protection (dykes) in rural areas; maintenance of storage infrastructure such as reservoirs, dams and artificial lakes	Regular monitoring in reservoirs and project-based monitoring on rivers
	Water Resources Utilization Department (WRUD)	Water delivery infrastructure; irrigation channels, pumps, tube wells. Developing drinking water standards for national adoption (except for municipalities).	Water quality monitoring within irrigation channels, and for drinking water in urban areas including groundwater supplies
Ministry of Transport and Communications (MOTC)	Directorate of Water Resources and Improvement of River Systems (DWIR)	River channels, including water quality, dredging, bank erosion and general water management	Water quality monitoring in river channels
	Department of Meteorology and Hydrology (DMH)	Rainfall/runoff data; gauging river levels	Regular monitoring water quality of rainfall at gauging stations. Project based monitoring of sediments at gauging stations.
	Myanmar Maritime University (MMU)	Road maintenance (Ministry of Transport). MMU is the research arm of MOTC and collaborates with DWIR.	Research driven and flexible.
Ministry of Health	Department of Public Health	Occupational and environmental health risks (hazards).	Measuring water quality of drinking water and waste water, in identified places with health hazards
Ministry of Environment, Conservation and Forestry (MOECAF)	Environmental Conservation Department	Deforestation, mining and industrial pollution; Environmental Impact Assessments.	Water quality for environmental standards. Needs to rely on Department of Health for sampling but submitted a budget proposal to set up its own laboratory.
Ministry of Livestock Fisheries and Rural Development	Department of Rural Development	Rural infrastructure, including roads, bridges, housing. Electrification.	Unable to interview in 2015
Ministry of Science and Technology	Universities (including Monywa and Mandalay universities)	Research and Development for the improvement of the National Economy	Research based mainly in PhD and Masters projects in the universities, on water quality and fish biodiversity
Ministry of Information		Public announcements for disaster evacuations (e.g. floods), as part of informing the public on policy plans	Action based on information provided by the other government institutions

Water quality management in Myanmar: Institutions

DWIR, Ministry of Transport and Communications

The Directorate of Water Resources and Improvement of River Systems (DWIR) is responsible for monitoring water quality in the river channels. In the Chindwin River Basin, DWIR has been measuring water quality at 34 sites since 2010, although not all sites were measured every year. The sites are located along the Chindwin River, from Homalin to the confluence with the Ayeyarwady River, including a number of the main tributaries such as Uru and Myinthar. The parameters measured were temperature, dissolved oxygen, iron, chloride, chlorine, alkalinity, hardness, ammonia, nitrite, nitrate, fluoride and turbidity.

Since 2013, DWIR has served as the Secretariat of the National Water Resources Committee (NWRC) and thus is progressively assuming a broader role on integrated water resources management in Myanmar. This linkage with NWRC would make DWIR a key institution in the inter-institutional coordination of water resources management, including on water quality issues in Myanmar.

Irrigation Department (ID)

The Irrigation Department (ID) in the Ministry of Agriculture and Irrigation (MAI) is responsible for irrigation water supply and flood protection. Its role is to maintain water quality for agriculture in modified lakes and reservoirs; to that extent, it collects samples from reservoirs routinely (twice a year, once during the dry season and once during the wet season) and from the river periodically but not regularly. ID data on river water quality is project-based, and is used as an input for irrigation planning and management. FAO standards are used to assess water quality.

ID had a project from 2008 to 2011 in the Chindwin River Basin to measure water quality in Monywa, Kalewa and Homalin (Ra 2011), for pH, conductivity, temperature, total hardness, total dissolved solids, salinity, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), calcium, magnesium, sodium, potassium, carbonates, sulfur and chlorine. From 2012 to 2014, ID monitored water quality in five sites near Monywa, for temperature, pH, conductivity, total dissolved solids, turbidity, arsenic, lead, mercury, iron, copper, sodium, SAR, soluble sodium percentage

(SSP), chlorine, carbonates, sulfur, calcium, magnesium, potassium, total cations, total anions, and RSC. The monitoring results indicate that there were no significant problems with water quality for agriculture, except for instances of excess sodium carbonate content.

ID has one investigative branch that employs scientists and agronomists. They undertake water quality monitoring and socio-economic surveys. ID uses its own laboratory, which is set up to measure routine water parameters that are of interest to the Department. Collaboration between ID and DWIR is limited to some data sharing; DWIR uses agricultural data and also monitors groundwater for water quality purposes.

Water Resources Utilization Department (WRUD)

While ID is responsible for gravity-fed water supply, dams, weirs and reservoirs, and dykes along with flood protection (including maintenance), the Water Resources Utilization Department (WRUD) of MAI is responsible for all irrigation pumping (including energy) using surface water and groundwater and for irrigation channels. The main responsibility for WRUD regarding water quality is twofold:

- Water quality monitoring for irrigation water in the delivery channels. WRUD is responsible for river pumping projects, and delivery of irrigation water (from the Ayeyarwady, Chindwin and Salween), whereas DWIR has the responsibility for improvement of the river channel.
- Water quality monitoring for drinking water in urban areas; regular testing is conducted. WRUD has a small laboratory for water quality testing, for parameters that include total cations, total anions, pH, EC, etc. (physical and chemical parameters) but this does not include testing for heavy metals.

WRUD is responsible for the village pumping stations to supply water from the Chindwin River to farmland and for domestic use. This includes improving surface water and groundwater supplies. In Monywa (Sagaing region) there is a problem for irrigation with the levels of sodium (Na) in the groundwater; therefore, the water in this area is being tested. During the last decades, groundwater irrigation for paddy fields has caused land salinization in some irrigation projects, and areas with high groundwater salinity can no longer be used for rice growing; instead, other seasonal crops that require less intensive water use such as groundnut are being planted.

WRUD's responsibilities for groundwater include all the tube wells. About 200 tube wells are sampled and tested for drinking water once a year. Twenty-five years ago, with the aid of UNICEF and the Government of the Netherlands, water yield and quality were monitored every month for selected tube wells (including in the Sagaing area), hence historical data exists. During this project, WRUD provided test kits for every well that was drilled, but this did not include testing for heavy metals, which may need to be considered in the future. Since the aid program was discontinued, measurements have been undertaken once a year (funded by the Myanmar government). The water quality in some tube wells has deteriorated due to salinity intrusion and can no longer be used (over the past 5–30 years of use, the water quality has changed). However, there is no evidence of tube wells drying up. Also, some of the tube wells have artesian flow and do not need pumping.

Some exploration drilling for groundwater has been undertaken at selected locations across the country. The purpose is for government-funded irrigation projects, as well as locating new sources of drinking water supplies. Data for groundwater aquifers related to water quality exist from 1953, including for artesian tube wells. A hydrogeological assessment of the lower Chindwin River (in the Dry Zone) was also elaborated.

In 1996 the department handed over responsibility for the supply of drinking water to municipalities to the Department of Rural Development (DRD). Township municipalities are now responsible for using water from the rivers for domestic use, not WRUD. Therefore, WRUD is sharing its groundwater data with the Department of Rural Development. Water quality results are also reported to the Ministry of Health. However, DRD and WRUD have overlapping responsibilities for groundwater, including for issuing warnings that drinking water must be boiled as required.

Department of Meteorology and Hydrology (DMH)

The Department of Meteorology and Hydrology (DMH), Ministry of Transport and Communications, monitors the quality of rainwater with a particular focus on rainfall pH (acid deposition). DMH has 60 stations (rainfall gauges) in Myanmar that measure precipitation and collect samples for water quality testing of the first rainfall of every month. The data are sent to the Acid Deposition Monitoring Network of Southeast Asia (EANET). The main office for water quality is in Yangon. DMH also collects information on sedimentation and water temperature from their hydrology gauging stations, but this is event (project) based, and not a routine activity of the Department. Pedometers are used to measure sediment discharge. The hydrology stations measure water levels and water temperatures on a daily basis. In the past, DMH conducted projects that measured the water quality of the Chindwin River from 1999 to 2004 (called "Base line study"), including pH, conductivity, turbidity, nitrite, nitrate, chloride, hardness, alkalinity, ammonia, chlorine (free and total), iron and dissolved oxygen. In addition, a project collected water samples between 2004 and 2007 including in the Chindwin River Basin (Chapman et al. 2015), measured the presence and levels of calcium, sodium, potassium, silicon, chlorine, sulfur, fluorine, carbonate, strontium-87 and strontium-86.

Environmental Conservation Department (ECD)

The Environmental Conservation Department (ECD), MONREC has existed only since October 2012 and is still building its capacity. The Department is interested in monitoring deforestation and timber harvesting, as well as mining and industrial pollution. ECD has initiated several activities on the state of the environment (including water quality). There are 14 regional ECD offices; the Department has expressed a willingness to extend its jurisdiction from the national to regional level; in addition, it aims to extend its capacity to the district and township level.

Currently, ECD has limited capacity for undertaking laboratory analysis for water quality, and therefore is reliant on the Department of Health. ECD has submitted a budget proposal, which includes building and staffing a water quality laboratory as the Department will assume responsibility for water quality in the future.

Occupational and Environmental Health Division (OEHD)

The Occupational and Environmental Health Division, Department of Public Health, Ministry of Health, is responsible for measuring water quality, formulating national drinking water quality standards, assessing wastewater and drinking water, and collaborating with other health divisions with respect to the health of workers who handle pesticides and other chemicals in factories. The department has its own laboratory and technical staff to measure water quality. A representative from the Occupational and Environmental Health Division expressed concern about cyanide pollution in the Chindwin River, which can lead to cyanide poisoning. There is a need for systematic checking of this parameter, and also for monitoring air pollution resulting from mining activities (causing acid rain) in the Chindwin Basin.

Mandalay Technological University

The main research link of the Zoology Department of Mandalay Technological University (MTU) to water safety is to measure fish biodiversity and correlate this with water quality. The Department has several PhD students working on this research topic. In the Chindwin River Basin, two PhD students recently conducted research on the correlation between fish biodiversity and water quality. One PhD student studied three locations on the Chindwin River, while the other student was based in Kale and studied a tributary of the river.

MTU has two laboratories for water quality testing. They are able to detect and measure water pollution parameters such as biological oxygen demand (BOD), pH, turbidity, chemicals, heavy metals and pesticides. The Department is also able to undertake a PCA analysis of DNA. Whilst the Zoology Department has an interest in heavy metal analysis, the high cost associated with conducting analyses and the lack of funds remain constraints.

Improving water governance

Institutional arrangements within Myanmar are complex. Ministries may have overall responsibility over an area, however they devolve these responsibilities to different government departments (see Chapter 10). Thus, compartmentalization may be occurring not only between ministries, but also within them (resulting in two decision-making levels), and between different locations (e.g. Yangon and Nay Pyi Taw offices). In addition, responsibilities are now being devolved to the lowest decision-making levels: from federal to state to local governments, a trend that will continue as part of the reforms in Myanmar. However, local governments often lack adequate financial and other resources to undertake these additional responsibilities.

One of the proposals to counter this problem of governance is to establish a multi-stakeholder body or institution that will help with the coordination, data sharing and ensuring the coherence of relevant policies formulated by different agencies, e.g. Chindwin RBO.

While discussion on the Chindwin RBO is beyond the scope of this chapter, several governance shortcomings were observed from interviews with government departments:

- Responsibilities for water management are mostly divided based on water use functions, with some overlapping and unclear delineations of geographical boundaries. These boundaries are based on in-channel river hydraulics and are further confused when extreme events occur, such as floods or droughts.
- Collaboration and data sharing are limited. Reporting occurs vertically through the ministries up to the central government, which then prioritizes the policies, budgets and decision-making powers of the Ministers in the Cabinet. This is exemplified by the fact that all departments require the resources for their own activities, and most of them have their own laboratories to analyse water quality data. Myanmar does not have yet a national data sharing policy, and the release of data for public use requires a complex and time-consuming process for approval.
- Water quality sampling activities that were undertaken regularly by various departments depended not only on the designated responsibilities of each department, but also on the available budgets from external sources. For example, 25 years ago, water sampling for drinking water was done monthly by WRUD with funding from international aid (UNICEF, the Netherlands). A further example is a current plan of ECD to put forward a proposal for its own laboratory, and for integrating data collection under a national research centre as part of the Ministry of Science and Technology. However, collaboration on monitoring activities and laboratories across the departments and ministries is still very limited.

Different departments and agencies have dedicated laboratories to analyse water quality for specific parameters, locations and time periods that are of their interest and focus; however, it is always useful to coordinate or at least share information/data among relevant agencies related to measurement methods, parameters, locations, frequency, and other details for effective water quality management in the area. Moreover, it would be useful if this information and data is shared with national institutes or centres that are mandated to coordinate across the agencies at the national or river basin level (e.g. the National Hydro-Informatics Centre that will be established by the World Bank's loan to the Myanmar Government under the Ayeyarwady Integrated River Basin Management Project).

It is hoped that decentralisation will provide the opportunity for the decision-makers at the regional or local level who understand local priorities to make appropriate and effective decisions related to water quality monitoring and management. To maximise the benefits of this decentralization trend, adequate support in terms of resources and capacity to regional and local government or emerging RBOs is necessary, especially for river basins that are situated in more than one region, state and country such as the Chindwin Basin. To improve data sharing and coordination among different levels, any data monitored and collected at the regional and local levels should also be linked with the national level.

Water quality status in Chindwin River and its tributaries

The present study undertook water quality sampling during the dry and wet seasons over a period of three years (2015–17) at 17 locations in four townships including Homalin, Kalaewa, Kani and Monywa. River water quality status in these townships was compared with international water, sanitation and health quality standards set by the World Health Organization (WHO 2011), which are summarized in **Table 6.4 below**.

Homalin Township

Heavy metals including arsenic, iron and mercury were detected in the dry and wet seasons at all locations. The observed values of mercury via the portable test kit were higher than the WHO acceptable standard for drinking water in 2015 (see **Figure 6.5** for mercury in 2015) and lower than the standard in 2016–17 via laboratory. It is noted that the accuracy of the

Table 6.4 Results of laboratory test of heavy metal parameters in water samples during 2016–17 in the Chindwin River Basin (Red indicates values above the WHO standard)

Parameters		Mercury				Iron				Lead				Arseenic			
WHO standard		<0.006 mg/l				<0.3 mg/l				<0.01 mg/l				<0.01 mg/l			
No	Site	2016		2017		2016		2017		2016		2017		2016		2017	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	Homalin Town	0.00001	ND	0.00002	0.00002	3.10	5.62	2.28	0.40	ND	ND	ND	ND	0.00002	0.00159	0.00000	0.00000
2	Nam Taw	0.00002	ND	0.00002	ND	7.25	8.55	5.56	0.80	ND	ND	ND	ND	0.00001	0.00000	0.00000	0.00000
3	Nansakar	0.00002	ND	0.00001	0.00002	7.57	18.60	6.78	2.60	ND	ND	ND	ND	0.00002	0.00008	0.00000	0.00000
4	Naung Po Aung	0.00001	ND	0.00001	0.00002	7.80	9.60	3.30	1.60	ND	ND	ND	ND	0.00001	0.00000	0.00002	0.00000
5	Uru River downstream	0.00001	0.00001	0.00001	0.00002	7.95	13.50	4.87	1.60	ND	ND	ND	ND	0.00002	0.00167	0.00000	0.00000
6	Mokekalae	0.00001	ND	0.00002	0.00003	7.44	8.33	5.03	2.08	ND	ND	ND	ND	0.00002	0.00183	0.00001	0.00000
7	Shwe Pyi Aye Town	0.00001	ND	0.00000	0.00002	3.28	4.31	2.67	0.20	ND	ND	ND	ND	0.00002	0.00178	0.00000	0.00000
8	Kalewa upstream	ND	ND	0.00001	0.00001	4.68	5.60	4.88	5.48	ND	ND	ND	0.000004	0.00002	0.00167	0.00003	0.00000
9	Kalewa downstream	ND	ND	0.00001	0.00001	6.72	3.77	4.96	5.70	ND	ND	ND	0.000002	0.00002	0.00170	0.00004	0.00171
10	Kani upstream	0.00002	ND	0.00002	0.00002	5.78	3.28	4.95	8.00	ND	ND	ND	ND	0.00002	0.00163	0.00001	0.00002
11	Kani downstream	0.00001	0.00001	0.00001	0.00002	5.33	6.25	4.70	8.70	0.01683	ND	ND	ND	0.00004	0.00154	0.00000	0.00002
12	Monywa upstream	0.00002	ND	0.00001	0.00002	5.89	7.70	4.34	8.90	ND	ND	ND	ND	0.00004	0.00174	0.00000	0.00001
13	Ya Mar River Bridge	0.00002	ND	0.00000	0.00002	8.10	8.23	4.20	7.70	0.09949	ND	ND	ND	0.00005	0.00134	0.00006	0.00002
14	Ya Mar River downstream	0.00002	0.00002	0.00001	0.00002	7.78	7.62	4.10	3.00	0.09956	0.00002	0.00002	0.00000	0.00005	0.00130	0.00000	0.00004
15	Monywa Town	0.00002	0.00001	0.00003	0.00001	6.28	8.20	4.80	7.90	ND	0.00004	0.00000	0.00001	0.00005	0.00129	0.00000	0.00001
16	CHR down2	0.00003	ND	0.00002	0.00002	6.50	5.86	4.90	6.88	ND	0.00001	0.00000	0.00000	0.00006	0.00132	0.00001	0.00001
17	Monywa downstream	0.00002	ND	0.00001	0.00001	8.23	6.23	4.88	8.60	ND	ND	ND	ND	0.00005	0.00135	0.00001	0.00000

portable test kit is lower than the laboratory test. However, the portable test kit is useful for initial detection and monitoring, but a laboratory test is still required to validate the results from the portable test kit. The source of mercury is likely to stem from the intensive gold mining activities in the upstream of the Uru River and Homalin. However, a more detailed study is required to provide evidence of the pollution sources.

The observed values of iron were higher than the WHO standard in both dry and wet seasons during 2015–17. The observed values of turbidity and total suspended solids were higher than the standard at all locations, particularly in the dry season. The observed values of total phosphorus were higher than the standard at most locations, while it was found that the observed values of total nitrogen in the dry season in 2017 were higher than the standard at all locations. E. coli bacteria were detected at all locations in both dry and wet seasons. The observed values of other parameters were much lower than international standards.

Figure 6.5 presents maps of the spatial analysis of water quality parameters measured around Homalin Township in September 2015 compared to the threshold values of WHO international standards.

Kalewa Township

Heavy metals including arsenic, iron and mercury were detected in the dry and wet seasons. However, the observed values of arsenic

Figure 6.5 Map of values of water quality parameters (Hg, NTU, pH, RDO, TP, and TN) at Homalin in September 2015 compared to WHO standards

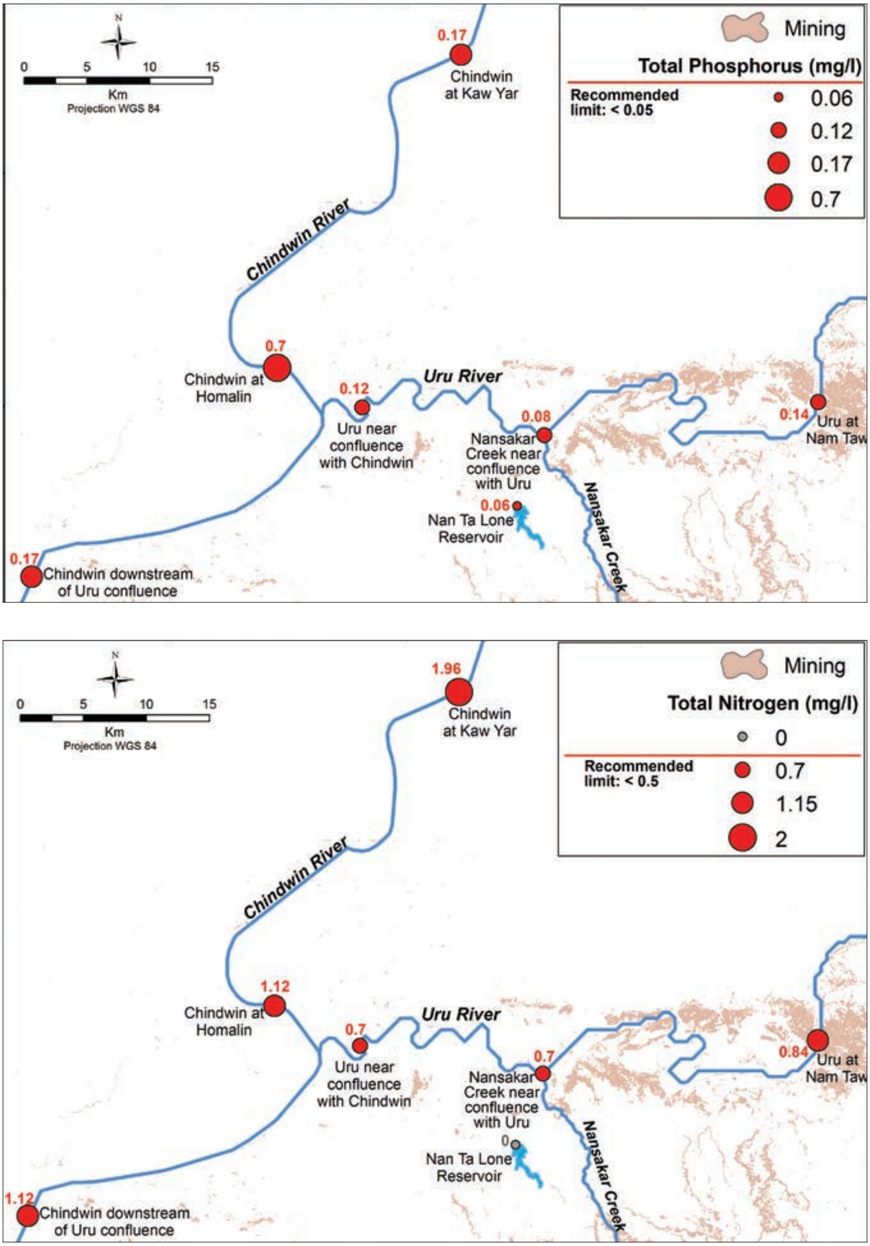
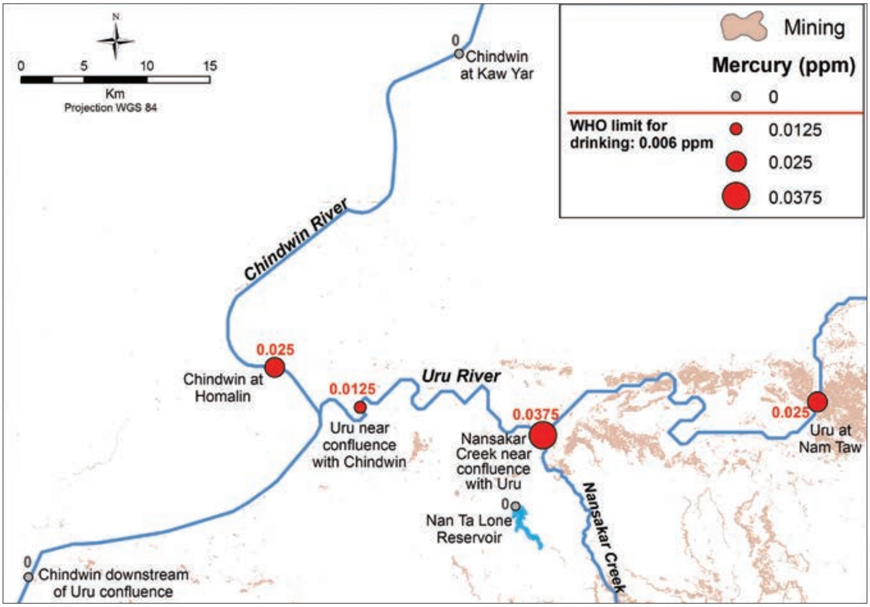
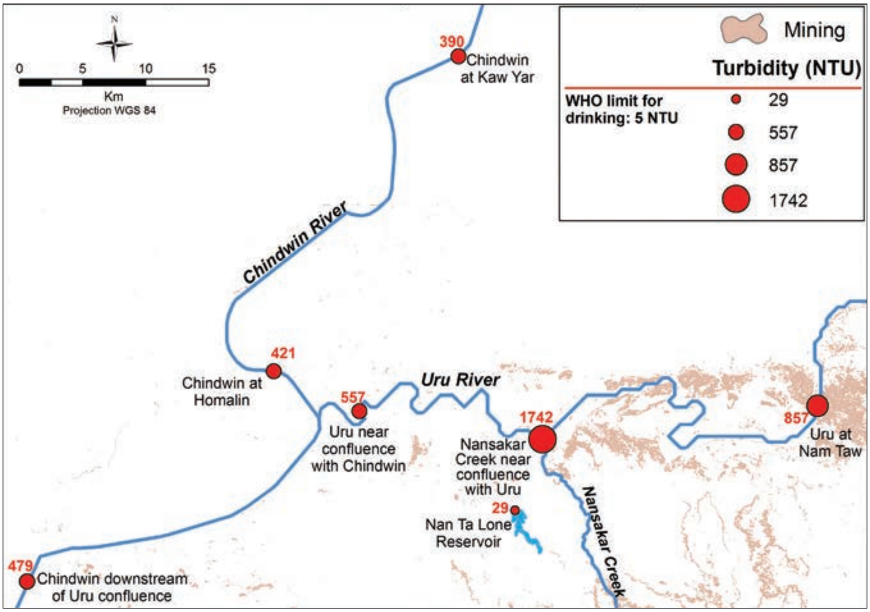


Figure 6.5 continued





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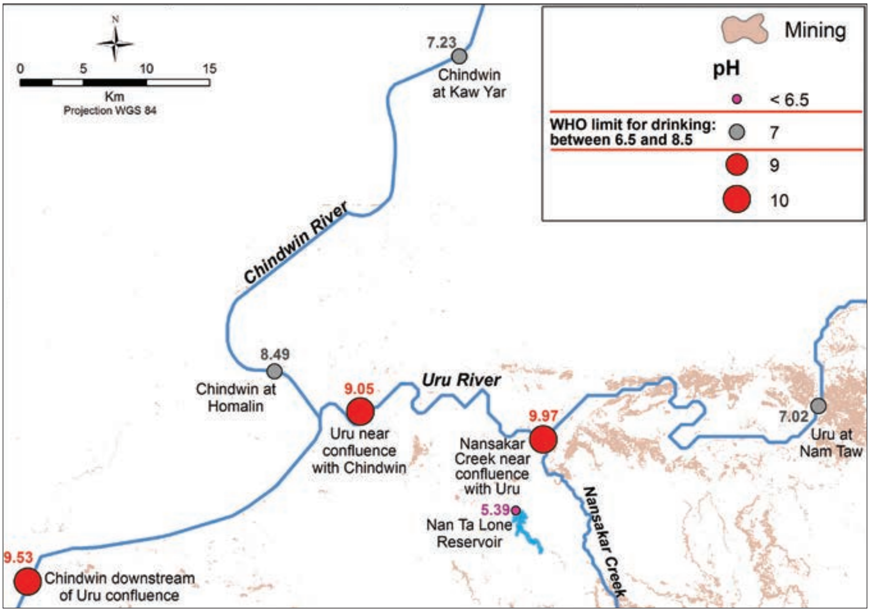
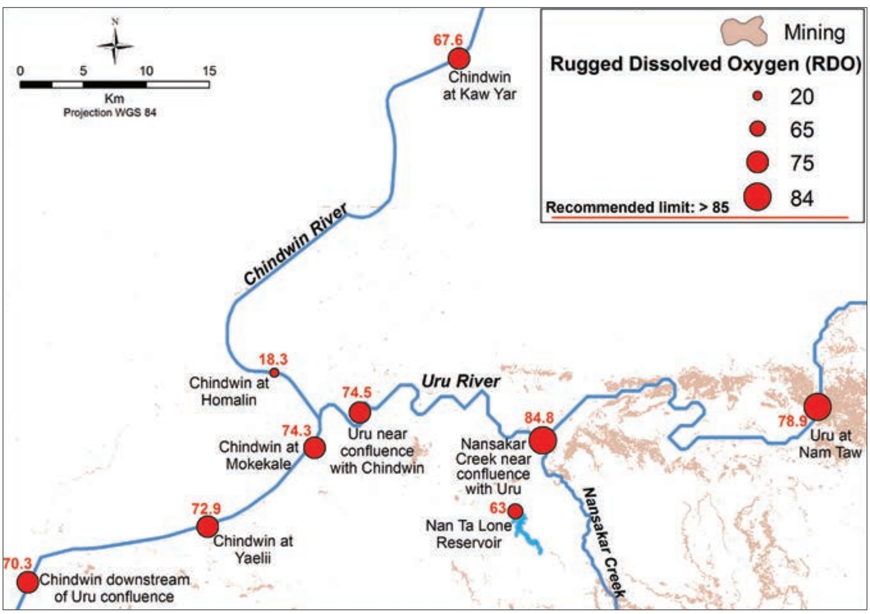




and mercury were much lower than the WHO acceptable standard of drinking water, but observed values of iron were higher than the standard in the dry and wet seasons. The observed values of turbidity and total suspended solids were higher than the standard at all locations, particularly in the dry season. The observed values of total phosphorus were higher than the standard at most locations, while it was found that the observed values of total nitrogen in the dry season 2017 were higher than the standard at all locations. E. coli bacteria were detected at all locations in the dry and wet seasons. The observed values of other parameters were much lower than the standards.

Kani and Monywa Townships

Heavy metals including arsenic, iron and mercury were detected in the dry and wet seasons at all locations. However, the observed values of arsenic and mercury (from laboratory tests) were much lower than the WHO acceptable standards for drinking water, but observed values of iron were higher than the standard in the dry and wet seasons. Lead was detected at Monywa and Ya Mar River, and the observed values in the dry season in 2016 were higher than the standard. In Ya Mar River, the observed values of (electrical) conductivity in the dry season were higher than the WHO acceptable standard for drinking water. The observed values of turbidity and total suspended solids were higher than the standard at all locations, particularly in the dry season. The observed values of total phosphorus for the dry and wet seasons of 2016 were higher than the standard at all locations in Monywa, while the observed values in the dry season of 2017 was lower than the standard at most locations. It was found that the observed values of total nitrogen in the dry season in 2017 were higher than the standard at most locations. E. coli bacteria were detected in the water at all locations in both dry and wet seasons. The observed values of other parameters were much lower than the WHO standards.

Household survey results related to water quality

From the responses of all 600 households in three townships to the survey, it is apparent that water use for drinking water varies considerably depending on location. There was a high dependency on river water for drinking purposes in Kani (40 percent). The differences in value of water quality parameters between Homalin and Monywa suggest that the local point and non-point pollution sources can significantly influence the concentration levels detected of measured parameters. In addition, the results from field sampling suggest that water from the Chindwin River is currently contaminated with pathogenic organisms (total coliform), which exposes users to high risk of infectious diseases.

There is no data on the presence and levels of heavy metals in the water systematically collected by any government department. However, there are reasons for concern, given the levels of mercury detected at some sites in the basin in the present study. In addition to using the river water for drinking, the household survey also highlights that fishing is an important economic activity in all three townships. Whereas all three locations make use of river water for a variety of activities, including washing (clothes and bathing) and agriculture, Kani appears to have a higher dependency on the river for drinking water than the other locations (**Figure 6.6**).

The level of concern among communities on issues related to river conditions are presented in **Figure 6.7**. The highest level of concern among local communities living along the river was over impacts from industrial and mining pollution in Kani, and Monywa, followed closely by bank erosion. Most of the categories of concern scored in the middle of the scale, indicating that people are somewhat concerned with conditions of the river.

Pollution from mining activities is one of the key concerns for residents from Kani and Homalin (**Figure 6.7**). In Kani, a large percentage of people obtain drinking water from the river (**Figure 6.6**). This group is at risk of exposure to water contamination, but also potential infections from pathogens. In Homalin, 25 households (17 percent) in the survey have family members working in gold mining. Fourteen acknowledged using mercury, however, there was no indication that cyanide was being used (see Chapter 9, this vol.).

Figure 6.6 Household drinking water sources

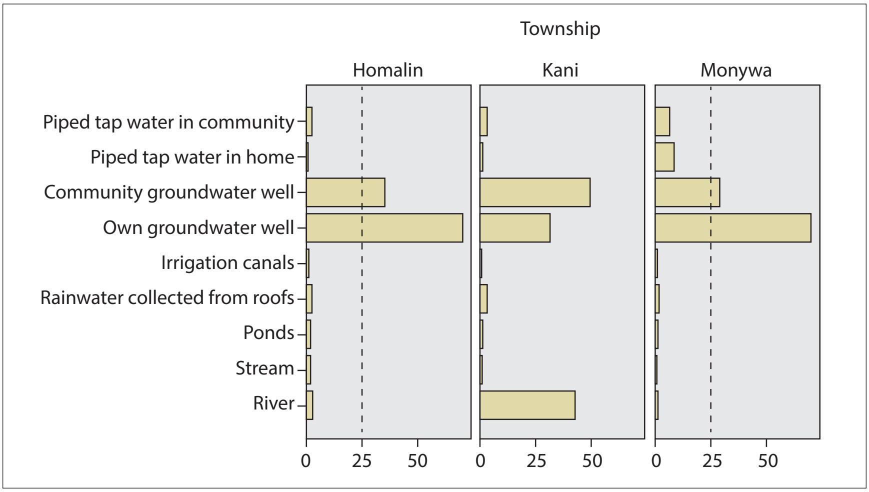
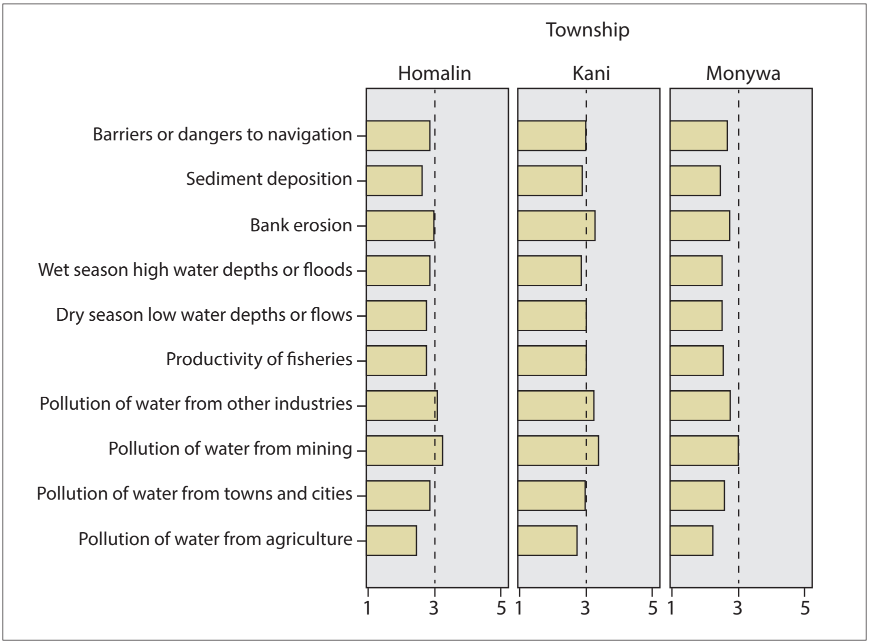


Figure 6.7 Average level of concern with river conditions. Based on scores of respondents on a scale of 1 (not at all concerned) through 3 (somewhat concerned) to 5 (very concerned).



Limitations of the present study

The findings of this chapter were drawn from the results of various activities conducted on a basis of limited sample sizes of surveyed households in three townships and a limited number of interviewed agencies and participants who attended the consultation meetings. They may therefore not be able to truly represent the perspectives of all concerned stakeholders throughout the basin.

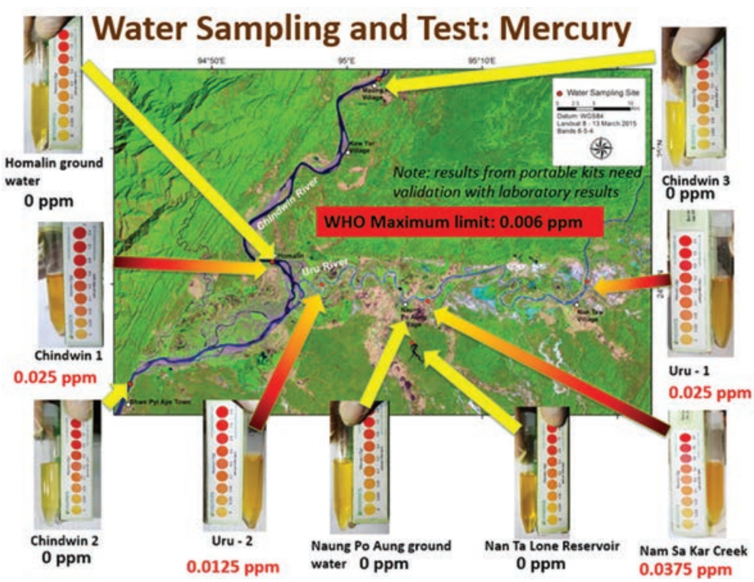
While several other agencies have collected water quality data, this data cannot be directly compared with the results generated in this assessment because different parameters were collected using different testing techniques and at different locations. Testing methods, exact locations, and sampling dates of some water quality data collected from other agencies could not be identified. Therefore, mainly the data from the water quality sampling and testing conducted at only 17 stations along the rivers in three years (the period of this study) have been utilized in this chapter. However, it should be noted that some data collected from other agencies are in line with the results of the present study. The river water was found to be contaminated with mercury at only two points of data recorded by the Irrigation Department in March 2015, at the Northern Ya Mar Chaung Bridge (close to a copper mine site) and Nan Shaung Jetty in Monywa.

Different methods and procedures of water sampling, preservation and laboratory standards can produce different results. The portable test kits tend to give higher values for mercury contamination compared to the results from laboratory analysis, which could be observed from several sampling locations in the dry and wet seasons in 2016. On-site testing using portable test kits have allowed water quality testing to be a possibility in developing countries. This is particularly important in the Myanmar context because several remote areas are far from the laboratories. Homalin is about 700 km from the laboratories and only accessible by air once or twice a week (depending on the season). It would take about 5–7 days until water samples could be transferred to laboratories after their collection. In addition to being cheaper another advantage of using portable kits is that tests are carried out on freshly collected water samples in which the quality has not changed as a result of being stored and transported over long distances (CAWST 2013).

While portable test kits are simpler, the accuracy of their results depend on the testers' skill (**Figure 6.8**). Concentrations are determined by comparing the test tube results against a color chart manually, which could be subjective. If key personnel involved in the laboratory and portable kit tests are well-trained and the preservation of all water samples are adequately preserved, laboratory tests would in general provide more accurate results as compared to the results from portable test kits (CAWST 2013). Due to funding constraints, a test was conducted only for heavy metal parameters in 2017.

Despite commercial laboratories using international standards for testing, which can provide more consistent, accurate and precise results, different laboratories may also give different results for water samples collected at the same locations. These results depend on various factors, e.g. water samples, laboratory testing techniques, and skills of the laboratory staff. The results of mercury contamination received from two laboratories for water samples from the same locations are different and have no correlation. Therefore, it is important to use water quality testing results with caution.

Figure 6.8 Test kits used to determine concentrations of mercury (Hg). Yellow arrows indicate zero presence; red arrows indicate mercury detection



Conclusions and recommendations

From the water quality sampling results, there is a clear evidence that the Chindwin River Basin is facing a problem of water pollution and declining water quality. The communities living along the river are concerned about water pollution as a result of chemicals discharged by mining and various industrial operations, but their knowledge of the severity of the problem is limited. Since hundreds of households living along the river still rely on river water for their drinking and other domestic uses, it is therefore very important to raise public awareness about water quality, associated health risks and feasible measures for water treatment among the Chindwin Basin residents.

The following recommendations are made to governmental line agencies and the general public to consider in addressing these problems and improving water quality management in the basin in the long term, namely through improving the existing water governance structure, enhancing water quality monitoring and studies, engaging with local universities and communities and raising public awareness.

Improvement of existing governance

- The governance architecture for water quality management should be formally reviewed and adjusted to reduce overlap among different agencies as well as close institutional gaps. Clear data sharing procedures or guidelines should be developed for all concerned agencies.
- Increased responsibilities and capacities of the governmental agencies at the regional level and emerging Chindwin RBO should be promoted.
- Future water quality database management in the Chindwin River Basin from different responsible agencies should also be linked with national institutes or centres that are mandated to coordinate across the agencies at the national or river basin level (e.g. the National Hydro-Informatics Centre) in order to provide overall results across the country.
- Water quality standards for surface and groundwater as well as water quality monitoring guidelines should be developed to control water pollution from different sectors and maintain good water quality. These should be developed based on international standards

and through a participatory approach including the representatives of all water user groups and stakeholders, with attention to the perceived or real risks of exposure to pollution issues. To maximize chances of success, all actors will need to have ownership and play their part. Participatory decision-making may also require some education on water quality issues, so users can make an informed choice.

- Water quality management strategy should be developed and integrated into sector development plans from the beginning stage to protect water bodies from toxic waste and pollution.

Enhancement of water quality monitoring and studies

- Water quality monitoring should continue at strategic locations, particularly for detected heavy metals (e.g. arsenic, iron, mercury, and lead) and other parameters such as turbidity, total suspended solids, total phosphorus and total nitrogens which have values higher than the WHO acceptable standards for drinking water.
- Future studies related to water quality should be designed in a way to explicitly help assess the causes (e.g. which activities or investments are resulting in water quality degradation and how) and risks or impacts of water quality on different sectors or components of concern, such as through testing of flooded rice, fish, and human body tissue samples (hair, nails and urine, etc.)
- Public water wells should be tested at least twice a year (once during the wet season and once during the dry season) for the following parameters: coliform bacteria, mercury, lead, copper, iron and arsenic.
- Use the test kits as an early warning signal for testing in water wells; if any heavy metals are detected, further laboratory testing can be carried out by engaging government officials responsible for drinking water.
- Further analysis should be conducted on the benefits and limitations of using portable test kits and a combination of laboratory analysis and portable test kits for monitoring during normal conditions as well as extreme events such as floods and droughts. The factors to be considered include priorities for use, frequency, locations, logistics of purchase, dissemination, capacity building, and costs.

Engagement with local universities and communities

- Future efforts in water quality monitoring and studies should allow faculty members and students from local universities in the basin to be involved more. Through this involvement, they can develop research and knowledge related to water quality issues in the basin such as the impact of water quality degradation on fisheries, biodiversity and ecosystem services.
- Explore the opportunity to strengthen the relevant capacities of local communities to engage in water quality monitoring activities. This would be useful especially for communities living in remote areas in addition to raising public awareness and building ownership of the communities with respect to the water resources in the basin.

Awareness raising

- Since a large proportion of the population in the Chindwin River Basin are using water directly from the rivers and other sources without any treatment, it is important that they are aware of the state of water quality in the basin, as well as information on water uses and also basic household-level water treatment methods. Water treatment systems for drinking water are required at all locations to remove turbidity, total suspended solids, total phosphorus, iron, arsenic and mercury from raw water sources in the Chindwin, Uru and Ya Mar Rivers.
- Agencies that are responsible for monitoring water quality and possess relevant data should inform the general public (e.g. websites, publications), and provide access to educational information on water quality issues.
- Follow-up the knowledge gained from this study to improve the water quality in the basin, especially for the parameters that are beyond the acceptable threshold of international standards that could be detrimental for human health and the environment. These follow-up actions could include providing means for testing, communications, education and awareness, and management strategies to improve the quality of water from different sources.

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7

Conservation of fish, birds and turtles in the Chindwin River Basin

Win Maung

The Chindwin River Basin, particularly the upstream areas of the river around Mahar Myaing, Hatmanthi and Hukaung valleys, possesses diverse ecological conditions, habitats and biological components vital for the basin's healthy ecosystem functioning. This chapter documents previously unpublished observations of fish, bird and turtle species made at sites along the Chindwin River over a period of 16 years (2002–18) and compares these with other published reports (e.g. Win Maung and Win Ko Ko 2002). The chapter also assesses the current understanding of existing and emerging threats to these components of riverine biodiversity, with an emphasis on the impacts of deforestation, mining and illegal fishing. The chapter concludes with a brief review of ongoing conservation efforts to protect rare and endangered species and their habitats.

Biodiversity conservation is important for the functioning of ecosystems, and thus species extinction may have dramatic effects on broader environmental health. According to the United Nations (2010), one-third of wild vertebrate species declined between 1970 and 2006, of which 41 percent were from freshwater ecosystems. Southeast Asia is listed as an important region in the world for conservation (Myers et al. 2000). Habitat loss and forest degradation are the main causes for the decline of biodiversity value (Sodhi et al. 2004). Myanmar is rich in biodiversity due to its varied geography and ecology, and further study is still needed to explore new species of flora and fauna in the country (Corbett and Hill 1992; Avibase 2015). The biodiversity of the Chindwin River Basin and other biodiversity hotspots in Myanmar are potentially threatened by economic growth and climate change (Rao et al. 2013; Nijman and Shepherd 2015; Donald et al. 2015).

Fish

The fishes of Myanmar were previously studied in some parts of the country by international and local scientists (Jayaram 1981; Day 1989; Kottelat 1990; Ferraris 1999; Talwar and Jhingran 1991; Vidthayanon et al. 2005; Fan 2000). However, many freshwater habitats remain to be explored and the species lists for the country remain incomplete. In the present study of the Chindwin River, a total of 52 fish species belonging to 18 families were recorded (**Table 7.1**). The members of the family Cyprinidae was the largest in number, followed by those of the family Bagridae. Among the recorded species, the species *Notopterus notopterus*, *Cirrhinus mrigala*, *Labeo boga*, *Osteobrama alfrediana*, *Mystus aor*, *Wallago attu*, and *Ompok bimaculatus* are commercial fish species in the community. An important species for conservation, *Tenulosa ilisha*, was previously found around the Monywa segment of Chindwin River, although this species has not been observed in recent years.

Table 7.1 Fish species composition in Chindwin River

Sr. No.	Scientific name	Local name	Family	Order
1	*Notopterus notopterus*	Nga phe	Notopteridae	Osteoglossiformes
2	*Labeo boga*	Nga lu	Cyprinidae	Cypriniformes
3	*Labeo angra*	Nga lu myikwet	Cyprinidae	Cypriniformes
4	*Labeo calbasu*	Nga net pya	Cyprinidae	Cypriniformes
5	*Labeo stoliczkae*	Nga lu	Cyprinidae	Cypriniformes
6	*Labeo rohita*	Ngagyin	Cyprinidae	Cypriniformes
7	*Cirrhinus mrigala mrigala*	Nga gyin lon	Cyprinidae	Cypriniformes
8	*Catla catla*	Nga thaing	Cyprinidae	Cypriniformes
9	*Garra lamta*	Kyauk nga lu	Cyprinidae	Cypriniformes
10	*Osteobrama alfrediana*	Nga phan ma	Cyprinidae	Cypriniformes
11	*Osteobrama cotio*	Nga phan ma	Cyprinidae	Cypriniformes
12	*Osteobrama belangeri*	Nga phaung	Cyprinidae	Cypriniformes
13	*Osteobrama feae*	Nga phe aung	Cyprinidae	Cypriniformes
14	*Puntius chola*	Nga khon ma	Cyprinidae	Cypriniformes
15	*Puntius sarana*	Nga khon ma	Cyprinidae	Cypriniformes
16	*Salmostoma sardinella*	Ngayinbaunzar	Cyprinidae	Cypriniformes
17	*Esomus altus*	Ngamautort	Cyprinidae	Cypriniformes

Sr. No.	Scientific name	Local name	Family	Order
18	*Psilorhynchus balitora*	Nga din lon	Psilorhynchidae	Cypriniformes
19	*Botia histrionica*	Nga kya ma	Cobidae	Cypriniformes
20	*Botia berdmorei*	Nga kya ma	Cobidae	Cypriniformes
21	*Rhinomugil corsula*	Ngazinlone	Mugilidae	Cypriniformes
22	*Tachysurus jatius*	Nga yaung	Arridae	Siluriformes
23	*Ompok bimaculatus*	Nga nu than	Siluridae	Siluriformes
24	*Wallago attu*	Nga butt	Siluridae	Siluriformes
25	*Mystus aor*	Nga gyaung	Bagridae	Siluriformes
26	*Mystus seenghala*	Nga gyaung	Bagridae	Siluriformes
27	*Mystus gulio*	Nga yway	Bagridae	Siluriformes
28	*Mystus leucophasis*	Nga pet let	Bagridae	Siluriformes
29	*Mystus microphthalmus*	Nga ike	Bagridae	Siluriformes
30	*Mystus cavasius*	Nga zin yine phyu	Bagridae	Siluriformes
31	*Mystus bleekeri*	Ngazinyine kwe	Bagridae	Siluriformes
32	*Mystus pulcher*	Ngazinyine kyetchee	Bagridae	Siluriformes
33	*Silonia silondia*	Nga myin	Schilbeidae	Siluriformes
34	*Clupisoma gaura*	Nga myin oke phar	Schilbeidae	Siluriformes
35	*Pseudotropius atherinoides*	Ngasuegote	Schilbeidae	Siluriformes
36	*Eutropiichthys vacha*	Nga myin kunsar	Schilbeidae	Siluriformes
37	*Gagata gagata*	Nga sue gote	Sisoridae	Siluriformes
38	*Gagata gasawyuh*	Nga sue goat	Sisoridae	Siluriformes
39	*Bagarius bagarius*	Nga maung ma	Sisoridae	Siluriformes
40	*Bagarius yarrellii*	Nga maung ma	Sisoridae	Siluriformes
41	*Xenentodon cancila*	Nga phoung yoe	Belonidae	Beloniformes
42	*Rhinomugil corsula*	Nga zin lone	Mugilidae	Mugiliformes
43	*Channa striatus*	Nga yant	Channidae	Perciformes
44	*Channa marulius*	Nga yant daing	Channidae	Perciformes
45	*Channa punctatus*	Nga panaw	Channidae	Perciformes
46	*Parambassis ranga*	Nga zin zat	Ambassidae	Perciformes
47	*Trichogaster fasciatus*	Nga phyin tha let	Osphronemidae	Perciformes

Sr. No.	Scientific name	Local name	Family	Order
48	*Mastacembelus armatus*	Nga mwe doe gyar	Mastacembelidae	Synbranchiformes
49	*Macrognathus acudiocellatus*	Nga mway naga	Mastacembelidae	Synbranchiformes
50	*Mastacembelus zebranus*	Ngamwedoe baygyar	Mastacembelidae	Synbranchiformes
51	*Glossogobius giuris*	Kathaboe	Gobiidae	Perciformes
52	*Gudusia variegate*	Ngalabi	Clupeidae	Clupeiformes

Birds

Birds were previously studied by ornithologists from universities in Myanmar, but most of these findings were unpublished. The first book on the birds of Myanmar was published in 1940 by B.E. Smythies. The handbooks by Smythies (1940) and Robson (2000) are used by most ornithologists for bird species identification in Myanmar. In the present study, a total of 53 bird species were recorded along the Chindwin River and related terrestrial habitats (**Table 7.2**). Among the recorded species, the species *Aceros nipalensis* (rufous-necked hornbill) was listed as a threatened species in IUCN's Red List. There were fourteen water bird species and the remaining species were terrestrial. The Wildlife Conservation Society (2007) recorded the endangered black-bellied Tern (*Sterna acuticauda*) along the Chindwin River between Monywa and Khamti. This species is protected in Myanmar. The threats to this species include the loss of their sandbank nesting habitat. The white-bellied Heron *Ardea insignis* and white-rumped vulture *Gyps bengalensis*, which are found at the furthest upstream reaches of the Chindwin, are listed as Critically Endangered species. The threats to these bird species are habitat loss, hunting and disturbances caused by development projects.

Table 7.2 Bird species of the Chindwin River and related terrestrial habitats

Sr. No.	Scientific name	Common name	Family	Order	IUCN status
1	Ardea intermedia	Intermediate egret	Ardeidae	Pelecaniformes	LC
2	Egretta garzetta	Little egret	Ardeidae	Pelecaniformes	LC
3	Bubulcus ibis	Cattle egret	Ardeidae	Pelecaniformes	LC
4	Ardeola grayii	Indian pond heron	Ardeidae	Pelecaniformes	LC
5	Ardea cinerea	Grey heron	Ardeidae	Pelecaniformes	LC
6	Microcarbo niger	Little cormorant	Phalacrocoracidae	Suliformes	LC
7	Phalacrocorax carbo	Great cormorant	Phalacrocoracidae	Suliformes	LC
8	Vanellus duvaucelii	River lapwing	Charadriidae	Charadriiformes	NT
9	Charadrius dubius	Little ringed plover	Charadriidae	Charadriiformes	LC
10	Actitis hypoleucos	Common sand piper	Scolopacidae	Charadriiformes	LC
11	Chroicocephalus brunnicephalus	Brown-headed gull	Laridae	Charadriiformes	LC
12	Sterna aurantia	River tern	Laridae	Charadriiformes	NT
13	Tadorna ferruginea	Ruddy shelduck	Anatidae	Anseriformes	LC
14	Dendrocygna javanica	Lesser whistling duck	Anatidae	Anseriformes	LC
15	Tachybaptus ruficollis	Little grebe	Podicipedidae	Podicipediformes	LC
16	Gallus gallus	Red jungle fowl	Phasianidae	Galliformes	LC
17	Francolinus pintadeanus	Chinese francolin	Phasianidae	Galliformes	LC
18	Milvus migrans	Black kite	Accipitridae	Accipitriformes	LC
19	Aviceda leuphotes	Black baza	Accipitridae	Accipitriformes	LC
20	Streptopelia chinensis	Spotted dove	Columbidae	Columbiformes	LC
21	Columba livia	Rock pigeon	Columbidae	Columbiformes	LC
22	Centropus sinensis	Greater coucal	Cuculidae	Cuculiformes	LC

Sr. No.	Scientific name	Common name	Family	Order	IUCN status
23	Eudynamys scolopaceus	Asian koel	Cuculidae	Cuculiformes	LC
24	Aerodramus brevirostris	Himalayan swiftlet	Apodidae	Caprimulgiformes	LC
25	Upupa epops	Eurasian hoopoe	Upupidae	Bucerotimformes	LC
26	Anthracoceros albirostris	Oriental pied-hornbill	Bucerotidae	Bucerotimformes	LC
27	Aceros nipalensis	Rufous-necked hornbill	Bucerotidae	Bucerotimformes	VU
28	Alcedo atthis	Common kingfisher	Alcedinidae	Coraciiformes	LC
29	Halcyon smyrnensis	White-throated kingfisher	Alcedinidae	Coraciiformes	LC
30	Merops leschenaulti	Chestnut-headed bee-eater	Meropidae	Coraciiformes	LC
31	Coracias benghalensis	Indian roller	Coraciidae	Coraciiformes	LC
32	Psilopogon asiaticus	Blue-throated barbet	Megalaimidae	Piciformes	LC
33	Aegithina tiphia	Common iora	Aegithinidae	Passeriformes	LC
34	Lanius tephronotus	Gray-backed shrike	Laniidae	Passeriformes	LC
35	Oriolus xanthornus	Black-hooded oriole	Oriolidae	Passeriformes	LC
36	Dicrurus macrocercus	Black drongo	Dicruridae	Passeriformes	LC
37	Dicrurus aeneus	Bronze drongo	Dicruridae	Passeriformes	LC
38	Dendrocitta vagabunda	Rufous treepie	Corvidae	Passeriformes	LC
39	Corvus macrorhynchos	Large-billed crow	Corvidae	Passeriformes	LC
40	Corvus splendens	House crow	Corvidae	Passeriformes	LC
41	Delichon dasypus	Asian house-martin	Hirundinidae	Passeriformes	LC
42	Pycnonotus cafer	Red-vented bulbul	Pycnonotidae	Passeriformes	LC

Sr. No.	Scientific name	Common name	Family	Order	IUCN status
43	Pycnonotus jocosus	Red-whiskered bulbul	Pycnonotidae	Passeriformes	LC
44	Pycnonotus flaviventris	Black-crested bulbul	Pycnonotidae	Passeriformes	LC
45	Orthotomus sutorius	Common tailor bird	Cisticolidae	Passeriformes	LC
46	Copsychus saularis	Oriental magpie-robin	Muscicapidae	Passeriformes	LC
47	Acridotheres tristis	Common myna	Sturnidae	Passeriformes	LC
48	Acridotheres burmannicus	Vinous-breasted starling	Sturnidae	Passeriformes	LC
49	Acridotheres cristatellus	White-vented myna	Sturnidae	Passeriformes	LC
50	Acridotheres cristatellus	Crested myna	Sturnidae	Passeriformes	LC
51	Motacilla cinerea	Gray wagtail	Motacillidae	Passeriformes	LC
52	Motacilla alba	White wagtail	Motacillidae	Passeriformes	LC
53	Passer montanus	Eurasian tree sparrow	Passeridae	Passeriformes	LC

Note: In the IUCN Red List of Threatened Species, LC = Least Concern; NT = Near Threatened; VU = Vulnerable.

Turtles

The Burmese roofed turtle (*Batagur trivittata*) is one of the endemic and critically endangered turtle species found in the upper Chindwin Basin. This species was previously found along the Ayeyarwady, Thanlwin, and Sittaung rivers. However, at present, the species can be found only in the upper Chindwin area of Khamti District. The population of this species dramatically declined in Myanmar due to local consumption, habitat destruction and the wildlife trade. The Wildlife Conservation Society (Myanmar), Turtle Survival Alliance and Forest Department are now undertaking a conservation project at Lin Phar village area, Khamti District. Some threatened species like the Myanmar peacock soft shell turtle (*Nilssonia formosa*) and Myanmar eyed turtle (*Morenia ocellate*) were recorded upstream. Research on the tortoises and turtles of Myanmar is fragmented; however, the chelonian population has drastically declined in the country. The first book on Myanmar chelonians was published in 1931 by Smith. Most of the tortoises in Myanmar are protected species since they are listed in IUCN's threatened species list. There are some helpful works on the conservation status and distribution of some chelonians in Myanmar (e.g., Vandijk 1997; Platt et al. 2014, Win Maung and Win Ko Ko 2002; Platt et al. 2000).

Threats

Fish populations in the Chindwin River are declining due to illegal fishing, gold mining, the degradation of breeding grounds and habitat loss. The fishers in the area have to find other jobs to generate family income because they cannot fully rely on fishing for their livelihood any longer. The fisheries and fish populations of the Chindwin Basin have been affected by water pollution caused or otherwise adversely affected by gold mining, logging and agricultural expansion. River water quality is important for primary production of the aquatic ecosystem, which supports the food availability of aquatic organisms, including fish. Another problem is that of illegal fishing methods, including the use of electric shocks, poisons and explosives as well as the practice of fishing during the spawning season. The Chindwin's spawning and breeding grounds, including wetland areas, are degraded because of unchecked human activities such as river-bed mining and agricultural expansion in the wetlands. An important food fish species is *Tenulosa illisha*, which was observed in the lower Chindwin River segment until 2004; however, the species has not been found in more recent years. This species is a migratory fish species that moves between brackish water and freshwater habitats to breed. Conservation activities are critically needed for much of the riverine fauna along the Chindwin River.

The Chindwin Basin is also rich in avifauna. The population of birds, particularly that of water birds, is declining in parallel with the economic development of the river basin. Major threats to water birds are human disturbance and habitat loss along the Chindwin River. The food sources for water birds include aquatic invertebrates and fishes, some of which are not available as before due to the degradation of the aquatic environment. The development of river transportation, gold mining and agricultural expansion are the main disturbances affecting the water bird species.

All turtle species of the Chindwin River are threatened, and are protected in Myanmar by the Protection of Wildlife and Wild Plants and Conservation of Natural Areas Law (1994). Illegal fishing methods like electrofishing and the use of toxic materials have negative impacts on almost all aquatic animals, including turtle species. Gold mining along the Chindwin River and its tributaries like the Uyu River causes water pollution and the destruction of foraging and nesting areas. Turtles are adversely impacted by some local activities on sandy beaches, for example, some turtle nesting beaches are used by local farmers for groundnut and maize cultivation. Turtle hunting and turtle egg collection by local people are also reducing the Chindwin's turtle population.

Conclusions

All stakeholders need to collaborate in conserving the Chindwin River ecosystem and biodiversity, because physical, biological and social environments are inter-connected and the proper functioning of the ecosystem depends on their interaction. Effective conservation of fish, birds and turtles along the Chindwin River can be achieved only by multi-stakeholder engagement, with community participation playing an important role. The findings of scientific studies should be integrated into the policy-making process, in which the Chindwin River Basin Organization will be a platform for all stakeholders.

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Part III

Socioeconomic development and resource use

8

Socioeconomic development in the Sagaing Region

Dolly Kyaw and Kaung Htike Thu

Rivers provide a range of essential ecosystem services such as a water supply, food supply, drought mitigation, and, most importantly, livelihood support. This is particularly true for countries with agriculture-dominated economies such as Myanmar. In 2014, more than 65 percent of Myanmar's population lived in rural areas and worked in agriculture or related activities, according to the United Nations Food and Agriculture Organization (FAO 2014).

This chapter will focus on the Chindwin River Basin, which has 16 percent of Myanmar's total catchment area and provides 21 percent of its total estimated annual surface water. The Chindwin River, which rises in the Kumon Range in northern Myanmar, and joins the Ayeyarwady River near Myingyan in central Myanmar, is the largest tributary of the Ayeyarwady (Taft and Mariele 2016). The Chindwin River is 900 km in length with 730 km of navigable waterway. It flows through many townships, including Hkamti, Homalin, Mawlaik, Kalewa, Kani, Mingin, and Monywa in the Sagaing Region, which represent one-fifth of the total population of Sagaing. In short, at least one-fifth, or 1.02 million people in 2016–17, depend directly on the Chindwin River for their livelihoods, food, transportation and, most importantly, irrigation. Since the mainstay of the local economy is agriculture, the River is a lifeline for the residents of the Chindwin Basin.

This chapter describes the social and economic state of the Chindwin Basin using available secondary data such as the Myanmar Living Condition Survey and the Myanmar Housing and Population Census of 2014. Some indicators from the Multidimensional Poverty Index (MPI) are used to analyze social and economic conditions of the Basin's population. The data used throughout refers to seven townships in the basin: Hkamti, Homalin, Mawlaik, Kalewa, Kani, Mingin, and Monywa. The chapter begins by discussing MPI briefly and explains the rationale behind using only some of its indicators. It will then move on to a comparison of selected MPI indicators between the Chindwin area and the Sagaing Region as a whole to explore the former's unique contribution in terms of ecosystem services. The following section presents the Chindwin Basin's economy and trade. The chapter ends with some recommendations for the future programs and projects to support sustainable socioeconomic development in the river basin.

Overview

The 1,200 km long Chindwin River Basin in northwestern Myanmar is over 115,300 sq km, almost 47 percent of which is forested. The basin consists, in general, of mountainous forested terrain with the exception of its lowest southern part, which is a vast plain. The highest mountains are to be found to the west and north of the basin where they reach up to 3,049 m. From the east, the watershed passes a mountain chain of 915 m to 1,524 m.

The largest tributaries of the Chindwin River are the Uru, Yu-wa and Myittha. Four miles below Homalin, the river receives an important tributary on the left bank: the Uru River, which rises in Myitkyina district. On the right bank, it receives the Yu-wa at Yu-wa and the Myittha at Kalewa, from which it receives rainfall from the Chin Hills. The main stream is navigable by light vessels throughout the year; in the rainy season vessels can ply up to Homalin. The Chindwin River flows southward through the Naga Mountains, and past many villages and towns in Sagaing Region. The river can be used by regular boats and jetties up to the town of Homalin, which is located about 640 km from its confluence with the Ayeyarwady.

Naga Self-Administered Zone in Sagaing Region

In August 2010, the Naga Self-Administered Zone, covering Lahe, Leshi and Nanyun, was announced officially. Those three townships were previously parts of the Hkamti District, Sagaing Region. The estimated population of the minority Naga was around 2.2 percent of the total population Sagaing, and they mainly resided in Lahe (where 99 percent of the total population is Naga), Nanyun (96 percent) and Leshi (87 percent). Some Naga also live in Hkamti (45 percent). The Naga Self-Administered Zone is situated in hilly areas of the northwest.

The major constraints for their livelihood activities are difficulty in transportation and communication (thus they have low access to market), soil erosion, uncertain customary land-use right (due to their practice of shifting cultivation), and limited access to social services, social networks and credit. Naga households also face shrinking land frontiers and ecological pressures on the land due to an increasing population, forest clearing, and natural disasters such as floods and landslides. Their livelihoods traditionally relied on forest products such as fuelwoods, bamboo, bark, resin, and honey; non-agricultural income-earning opportunities are very limited, and therefore some have resorted to migration to find work to support their households.

The needs of the Naga for sustainable livelihoods differ significantly from those living in lower lying areas in the Chindwin Basin in terms of their livelihood assets, vulnerability, and existing institutions. Keeping the above in mind, future development programs and projects for the Naga Uplands should be prepared separately while recognizing that there is limited available data. The government should provide an adequate budget and resources for data collection in the uplands.

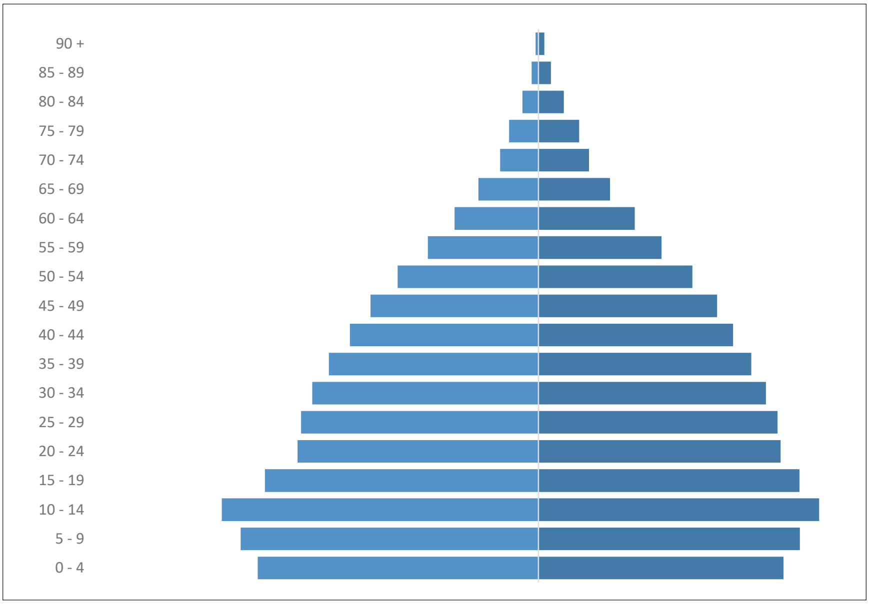
Population in Sagaing Region and selected townships

Sagaing Region is the second-largest constituent unit of Myanmar, after Shan State. The total population of Sagaing (5.3 million) represents 10.3 percent of the total population. Of the 5.3 million, the 911,335 is urban and 4,414,012 is rural (Myanmar Population Census 2014). Thus, approximately 83 percent of the total population resides in rural areas. The regional population is growing, as it was estimated at 3.1 million in 1973 and 3.9 million in the 1983 census. It has the fifth largest population, among other states and regions, after Yangon, Ayeyarwady, Mandalay and the Shan State.

The population pyramid of the Sagaing Region in 2014 has a similar shape to that of the Union as a whole. Thus, Sagaing, like the Union, has an expansive population pyramid, which depicts the population having a larger percentage of young people. Out of 5.3 million, the working age population (15 to 64 years old) is nearly 3.5 million or approximately 66 percent. Only 6.21 percent of the total population is over 65, which means Sagaing has a young population, similar to the Union's (**Figure 8.1**). In terms of population density, the region ranks ninth, with 56.8 persons per sq km in 2014, compared to other state or regions. This population density is lower than the Union average, which is 76 persons per sq km.

More than half of the total population (66 percent) of townships in the Basin can be classified as part of the labour force, i.e. between 15 and 64 years old (**Table 8.2**). Like the region's population, the Basin's population also has a larger percentage of young people. In **Table 8.2**, there are 675,537 persons aged between 15 to 64 living in the basin area, representing 13 percent of Sagaing as a whole. There are 295,386 persons aged 0 to 14, and 53,686 persons aged over 65, representing only 6 percent and 1 percent, respectively. It can be concluded that the Basin, like the Sagaing Region as a whole, has an expanding population that has a larger percentage of youth.

Figure 8.1 Sagaing Region population pyramid



Source: Myanmar Population and Housing Census 2014.

Table 8.1 Population of Chindwin River Basin townships by gender

Township	Total	Male	Female	Sex Ratio
Monywa	372,095	171,951	200,144	85.9
Kani	134,541	62,465	72,076	86.7
Kalewa	56,432	27,715	28,717	96.5
Mingin	104,363	50,171	54,192	92.6
Mawlaik	51,314	25,055	26,259	95.4
Hkamti	47,658	26,916	20,742	129.8
Homalin	258,206	133,750	124,456	107.5
Total for 7 townships	1,024,609	498,023	526,586	94.9
Proportion of regional population	19%	20%	19%	

Source: Myanmar Population and Housing Census 2014.

Table 8.2 Population of basin townships by age group

Township	0–14	15–64	65+
Monywa	87,869	259,250	24,976
Kani	39,463	86,404	8,674
Kalewa	16,475	37,224	2,733
Mingin	31,665	67,252	5,446
Mawlaik	16,390	32,274	2,650
Hkamti	14,071	32,333	1,254
Homalin	89,453	160,800	7,953
Total 7 towns	295,386 (29%)	675,537 (66%)	53,686 (5%)
Proportion to the regional total	6%	13%	1%

Source: Myanmar Population and Housing Census 2014.

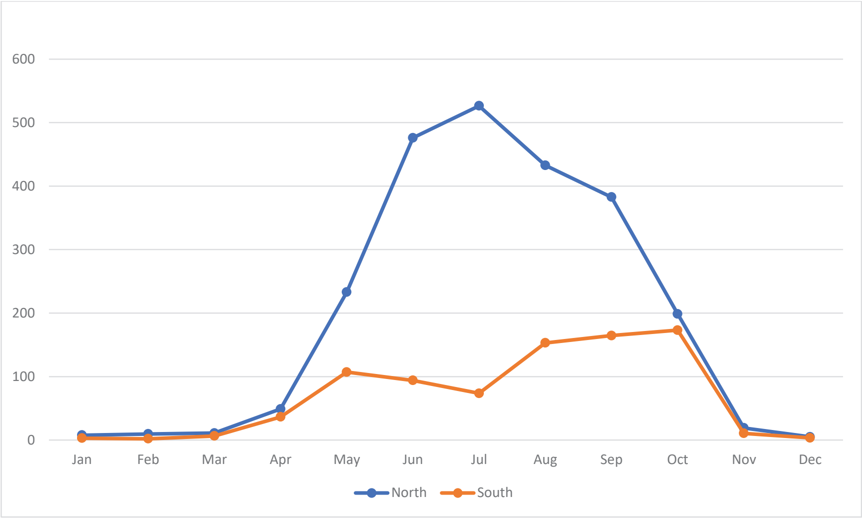
Climate

Sagaing Region varies topographically with mountains in the north and plains in the south. Therefore, the region has two main climates: a hilly climate in the northern mountain ranges, and an arid climate in the southern flat plains. **Figure 8.2** shows the monthly average rainfall of the weather stations in the north (Hkamti, Mawlaik and Katha) and south (Monywa and Shwebo). The average rainfall in the north is considerably higher than that of the south. The townships located in the north where there is a hilly climate received significantly higher average rainfall than those in the south's arid climate. Rainfall in the north is also a significant water contributor for the entire Chindwin Basin.

The heavy rainfall during the monsoon season causes the river to flood, and the flood waves move downstream, damaging crops and property. There have been several flood incidences in recent years. In 2015 Cyclone Komen brought heavy rainfall and strong winds to the region. At that time, Sagaing Region, along with Chin State, Rakhine State and Magway Region, was declared a disaster zone. A total of 229,600 people were affected by the floods and over 1.1 million acres (445,000 ha) of farmlands were inundated, with more than 872,000 acres (353,000 ha) destroyed, as of 4 October 2015.

In terms of temperature, the region can also be divided into the chilly northern hill climate and hot arid southern climate. The monthly mean temperatures during 2006 to 2015 shows that weather stations in the south recorded higher mean temperatures compared with the weather stations in the north (**Table 8.3**).

Figure 8.2 Average monthly rainfall in Sagaing Region, 2005–15 (mm)



Source: CSO Myanmar Statistical Yearbook 2016.

Table 8.3 Monthly mean temperature in Sagaing, 2006–15 (°C)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Average
Hkamti	17.1	19.6	23.1	26	27.8	27.4	27	27.6	27.6	25.8	21.8	17.9	24.06
Mawlaik	19.4	21.5	25.1	28.5	29.7	29.6	29.5	28.9	28.6	27	23.9	20.1	25.98
Katha	18.7	21	24.3	26	26.8	26.7	26.6	26.4	26.3	24.8	22.1	18.6	24.03
Ave. for North	18.4	20.7	24.17	26.83	28.1	27.9	27.7	27.63	27.5	25.9	22.6	18.8	24.69
Monywa	22.1	24.7	28.6	31.5	31.8	31.3	31.4	30.3	29.6	28.1	25.7	22.1	28.10
Shwebo	21.7	23.6	28	30.6	30.0	29.7	29.5	28.8	28.6	27.3	24.7	21.5	27.00
Ave. for South	21.9	24.15	28.3	31.05	30.9	30.5	30.45	29.6	29.1	27.7	25.2	21.8	27.55

Source: CSO Myanmar Statistical Yearbook 2016.

Moreover, the average lowest temperature in the region in January (18.4 °C) was also recorded in the north. For the south, the average lowest temperature in January was still above 20 °C (**Table 8.3**). Therefore, the hilly north enjoys a brisk climate, whereas the southern plains are relatively warm.

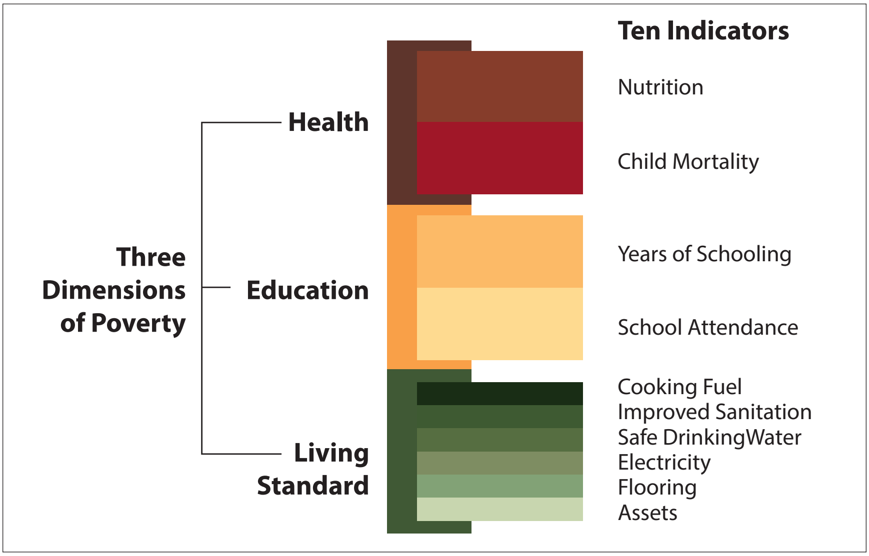
Multidimensional Poverty Index (MPI)

According to the *Myanmar Living Conditions Survey 2017: Poverty Report* (Central Statistical Organization 2019), the percentage of people in Myanmar living in poverty has decreased from 48.5 percent in 2005 to 24.8 percent in 2017. The national poverty line in 2017 is 1,590 kyat per adult per day, and it is estimated that 24.8 percent of the population (11.8 million) in Myanmar is considered to be poor. Among the regions, the highest number of poor inhabitants (about 1.8 million people) is found in Ayeyarwady region, followed closely by Shan and Sagaing regions.

The findings of the report strongly support the correlation between poverty incidence and geo-spatial differences in Myanmar. The highest poverty rate is observed in Chin State where 58 percent of the population (six out of ten persons) are poor, followed by Rakhine with 41.6 percent. Rural residents are 2.7 times more likely to be poorer than their urban counterparts. Thus poverty is lowest in households whose members work exclusively in sectors other than agriculture (13.2 percent). Despite the increase in adult expenditure, there are many non-poor with consumption levels very near to the poverty line, which makes them very vulnerable in the face of negative shocks. Therefore, it can be concluded that despite the significant decline in Myanmar's poverty rate, there is a large vulnerable population which could fall under the poverty line in the face of unanticipated negative shocks such as loss of employment.

The MPI, which is currently being used in the United Nations Development Program's Human Development Reports (see, e.g. UNDP 2018), measures acute global poverty by using a set of ten indicators in three dimensions (**Figure 8.3**). Those three dimensions are health, education, and living standards. Then the data are summarized to produce the poverty profile with a weighted deprivations score. The households or individuals can be identified as multidimensionally poor if more than three of the ten indicators are below the relevant poverty cut-offs (Alkire et al. 2013). In the figure below, the ten indicators with the three dimensions of poverty are illustrated. The MPI can be used to illustrate a comprehensive socioeconomic situation of people living in poverty, and allows comparisons across countries and regions and the world, and within countries as well.

Figure 8.3 The Multidimensional Poverty Index



Source: OPHI and UNDP 2018, Global Multidimensional Poverty Index 2018.

It is the authors' intention to use 9 out of 10 indicators, i.e, all except nutrition because nutrition data are only available at the regional and not at the township level. To create a comprehensive socioeconomic overview of the Chindwin Basin, these indicators are compared with the regional average, using available data from the 2014 Housing and Population Census (Ministry of Irrigation and Population 2014).

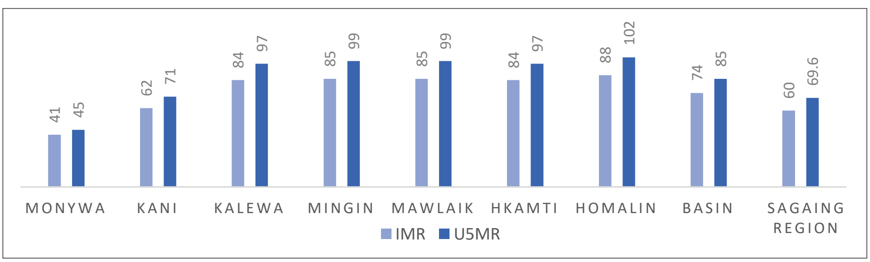
Comparative social indicators: Chindwin Basin and Sagaing

In this section, a multidimensional analysis will be used to illustrate the current status of the population of the Chindwin Basin, focusing on the three main dimensions: health, education and living standards. The relevant indicators of each dimension will be used to describe and to compare each indicator with the regional average to fully understand the basin's current social and poverty profile.

Health

Myanmar has the second-highest rate of infant and child mortality in ASEAN. Of every 1,000 newborns, 62 die before their first birthday and 72 die before their fifth (Ministry of Population 2014). Currently, the infant and under-5 mortality rates for the Sagaing Region stands at 60 and 69.6 per 1,000 births, respectively (**Figure 8.4**).

Figure 8.4 Infant and under-5 mortality rate in the Chindwin Basin (deaths per 1,000 births)



Source: Housing and Population Census 2014.

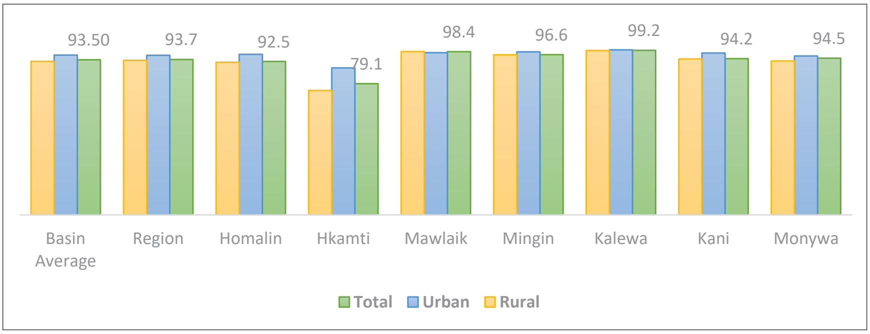
The infant and under-5 mortality rates in the Chindwin Basin is illustrated in **Figure 8.4**. It is evident that the basin rate is higher than the regional rate in both categories. The infant mortality rate of the basin is 74, whereas that of the region is 60 per 1,000 live births. The under-5 mortality rate of the basin is 85, whereas the rate of the region is sitting at 69.6 per 1,000 live births. Among townships in the basin, Homalin has the highest rate in both categories with 88 for the infant mortality rate, and 102 for the under-5 mortality rate. Mawlaik and Mingin are tied at the second place with 85 for the infant mortality rate and 99 for the under-5 mortality rate. Monywa has the lowest rate in both categories, which is not a surprise, since it is the most developed township. Therefore, out of the seven main townships in the river basin, four (Mingin, Mawlaik, Hkamti, Homalin) have higher infant and under-5 mortality rates; their abortion and maternal mortality rates are also higher.

Education

Education also plays a vital role in the social situation of households in Sagaing Region. The literacy rate, school attendance rate, and school completion rate for high school and university are excellent indicators in illustrating the social characteristics of a region. First, the literacy rate of people aged over 15 years is described in **Figure 8.5**. According to the 2014 Census data, the adult literacy rate for Sagaing Region is at 93.7 percent. Sagaing's literacy rate (93.7) is higher than that of the Union, which is 89.52 for adults aged 15 years and over, with urban areas having a higher literacy rate than rural areas in the region.

Figure 8.5 shows the literacy rates in urban and rural areas in the Chindwin Basin and the Sagaing Region on average. Except for Hkamti and Homalin, the literacy rate in all townships is higher than that of the average literacy rate of Sagaing. Hkamti has the lowest adult literacy rate (79.1 percent) among the townships. Kalewa has the highest literacy rate among the selected townships (99.2 percent), which is higher than the basin average literacy rate (93.5 percent). The literacy rate for urban areas is significantly higher than the literacy rate in rural areas, especially in Hkamti.

Figure 8.5 Literacy rate in Chindwin River Basin (% urban, rural)



Source: Housing and Population Census 2014.

The basin population school/college attendance rates are very similar to that of the regional overall (**Table 8.4**). The highest proportion of the total population who have attended school (60 percent) is in Monywa and the lowest proportion of former school attendees (42 percent) is in Hkamti. In fact, the highest proportion of those who have never attended school (10 percent) is in Hkamti. On average, for the seven basin towns, 5 percent of both males and females aged 5 to 29 have never attended school.

Table 8.4 School/college attendance (5–29 year olds) in Chindwin Basin (%)

	Both Sexes			Male			Female		
	Currently attending	Attended previously	Never attended	Currently attending	Attended previously	Never attended	Currently attending	Attended previously	Never attended
Whole Region	42	53	5	42	53	5	40	55	5
Monywa	35	60	5	35	60	5	34	61	5
Kani	47	49	4	49	47	4	45	51	4
Kalewa	41	56	3	41	55	4	41	56	3
Mingin	46	51	3	47	49	4	44	53	3
Mawlaik	44	52	4	45	51	4	43	53	3
Hkamti	48	42	10	46	44	10	50	39	11
Homalin	49	45	6	49	45	6	49	46	5
Basin Overall	43	52	5	43	52	5	42	53	5

Source: Housing and Population Census 2014.

Comparing the basin and the region, there is a higher percentage of people with no formal education and a relatively lower rate for completion of primary school in the Chindwin Basin (**Table 8.5**), particularly in Hkamti. On the other hand, Monywa has the highest percentage of university graduates (13.09 percent) in the region and basin. Among the townships, Monywa has the highest rate of tertiary education, which is not surprising, given that it is the capital of the region and its most developed township.

When it comes to education, women are clearly disadvantaged (**Table 8.6**). The proportion of the female population without any degree is higher across all the townships. In some cases, the figure is nearly double. For example, the proportion without education in Mingin is 4.01 percent for males, and 8.26 percent for females. In Hkamti, the proportion of males with education is 15.9 percent and that of females is 30.92 percent (the highest gender gap amongst the townships). Thus, the uncompleted education rate for women is nearly double that for men in Mingin and Hkamti. Women also have lower school completion rates, especially in middle school (grades 6–9) and high school (grades 10–11) levels, in all the townships.

Table 8.5 Completed education level in Chindwin Basin (%)

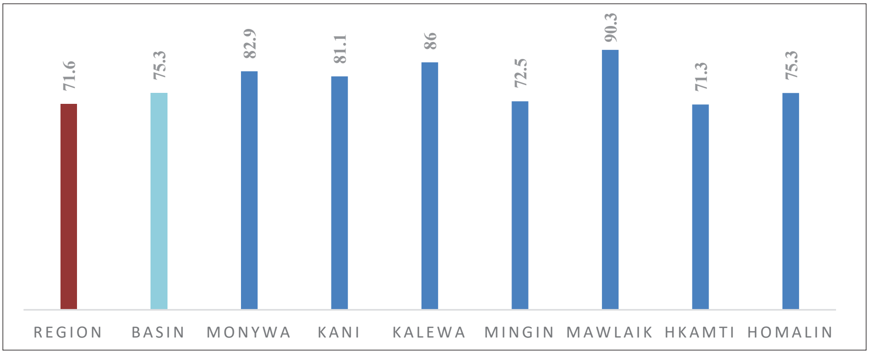
Town	None	Primary school	Middle school	High school	Diploma	University/ College	Post-graduate & above	Vocational training	Other
Region	11.9	55.2	15.6	7.4	0.2	6.6	0.3	0.1	2.6
Monywa	9.0	46.2	17.9	11.2	0.4	13.1	1.1	0.1	1.1
Kani	12.0	62.4	13.9	5.5	0.1	4.9	0.1	0.1	1.9
Kalewa	1.2	62.6	14.1	7.2	0.2	6.6	0.1	0.1	8.0
Mingin	6.3	61.9	13.7	6.7	0.2	5.4	0.1	0.0	5.6
Mawlaik	5.3	66.7	13.4	6.8	0.2	5.3	0.1	0.2	2.1
Hkamti	22.3	33.1	25.0	11.9	0.2	6.2	0.3	0.2	0.6
Homalin	12.7	47.7	22.1	8.8	0.2	5.1	0.2	0.0	3.2
Basin Overall	9.0	49.2	19.5	10.1	0.3	8.8	0.5	0.1	2.4

Living conditions

The final dimension in the Multi-dimensional Poverty Index is living conditions, which include household sanitation, access to electricity (for lighting), cooking fuel, home construction materials, transportation modes and household assets. **Figure 8.6** shows the safe sanitation rate for the basin, and the region overall. The overall Sagaing Region rate is 71.6 percent, which means that 7 out of 10 households have access to either flush toilets or water seal improved latrines. In the basin, 75.3 percent or 8 out of 10 households have access to either one of these. Among the townships, Hkamti has the lowest rate, with 71.3 percent, followed by Mingin, with 72.5 percent. The highest is Mawlaik with 90.3 percent, followed by Monywa. Overall, the basin has a relatively high rate of access to safe sanitation facilities compared with the regional average. Among the townships, 9 out of 10 households in Mawlaik has access to safe sanitation facilities, which are either flush toilets or water seal improved latrines.

In Sagaing Region, a typical house has a corrugated sheet roof, with bamboo walls and a wooden floor. Out of 1,096,857 houses in Sagaing, nearly 60 percent have a corrugated sheet roof, 66 percent have bamboo walls and half (51.73 percent) have wooden floors (**Table 8.7**). The same

Figure 8.6 Safe sanitation availability in the Chindwin Basin (%)



Source: Housing and Population Census 2014.

Table 8.6 Completed education level by gender (%)

Township Name	Sex	None	Primary school	Middle school	High school	Diploma	University/ College	Post-graduate & above	Vocational training	Other
Monywa	Male	5.5	42.1	22.3	14.1	0.6	13.3	0.7	0.2	1.3
	Female	11.7	49.5	14.5	8.9	0.2	12.9	1.4	0.1	0.9
Kani	Male	8.9	59.4	17.9	7.3	0.1	5.0	0.1	0.1	1.1
	Female	1.7	65.7	11.7	5.9	0.1	7.0	0.1	0.0	7.8
Kalewa	Male	0.8	59.3	16.6	8.6	0.2	6.1	0.1	0.1	8.2
	Female	1.7	65.7	11.7	5.9	0.1	7.0	0.1	0.0	7.8
Mingin	Male	4.0	58.7	17.0	8.3	0.2	5.4	0.1	0.0	6.1
	Female	8.3	64.6	10.8	5.3	0.1	5.4	0.1	0.0	5.2
Mawlaik	Male	4.3	62.9	16.8	7.9	0.3	4.9	0.1	0.2	2.4
	Female	6.1	70.1	10.2	5.7	0.1	5.7	0.1	0.1	1.9
Hkamti	Male	15.9	33.8	29.1	13.1	0.2	6.4	0.4	0.2	0.8
	Female	30.9	32.1	19.6	10.3	0.3	6.1	0.2	0.1	0.4
Homalin	Male	9.6	44.2	26.4	10.1	0.2	4.9	0.1	0.0	4.4
	Female	15.9	51.4	17.6	7.5	0.1	5.3	0.2	0.0	2.0

Source: Housing and Population Census 2014.

Table 8.7 Housing materials used in Sagaing Region and the Chindwin Basin

Roof, wall & floor material		Region (no. / %)		Basin (no. / %)	
Roof	Total	1,096,857	100	235,973	100
	Dhani/Theke/In leaf	344,862	31.44	42,564	18.04
	Bamboo	59,659	5.44	21,428	9.08
	Wood	2,226	0.20	1,405	0.60
	Corrugated sheet	652,925	59.53	165,280	70.04
	Tile/Brick/ Concrete	5,258	0.48	2,134	0.90
	Other	31,927	2.91	3,162	1.34
Wall	Total	1,096,857	100	235,973	100
	Dhani/Theke/In leaf	14,640	1.33	2,839	1.20
	Bamboo	724,484	66.05	140,204	59.42
	Earth	1,026	0.09	221	0.09
	Wood	231,515	21.11	61,028	25.86
	Corrugated sheet	1,575	0.14	512	0.22
	Tile/Brick/Concrete	113,305	10.33	29,503	12.50
	Other	10,312	0.94	1,666	0.71
Floor	Total	1,096,857	100	235,973	100
	Bamboo	121,462	11.07	12,270	5.20
	Earth	289,354	26.38	35,296	14.96
	Wood	567,381	51.73	154,094	65.30
	Tile/Brick/Concrete	110,837	10.10	32,128	13.62
	Other	7,823	0.71	2,185	0.93

Source: Housing and Population Census 2014.

typical house can also be found throughout the Chindwin Basin. Out of 235,973 houses in the basin, 70 percent have corrugated sheet roofs, nearly 60 percent have bamboo walls and 65 percent have wood floors. Therefore, in Sagaing and in the river basin area, a typical house would have a corrugated sheet roof, bamboo walls and wooden floors, with a water seal improved pit latrine.

Compared with the regional overall (24 percent), all selected townships (except Monywa) have a lower rate of access to electricity for lighting (**Table 8.8**). Once the data is further broken down by township, not more than 10 percent of total households in Mingin (4.3) and Kani (5.8) have electricity. Not surprisingly, towns with poor access to the grid will turn to alternative solutions. For example, in Mingin, about 44 percent of households use batteries as their main source of electricity, and 24 percent have their own private generator. Therefore, it can be concluded that households in all the townships, except Monywa, have their own source of power, in the form of private generators or batteries or just simple candles, for lighting.

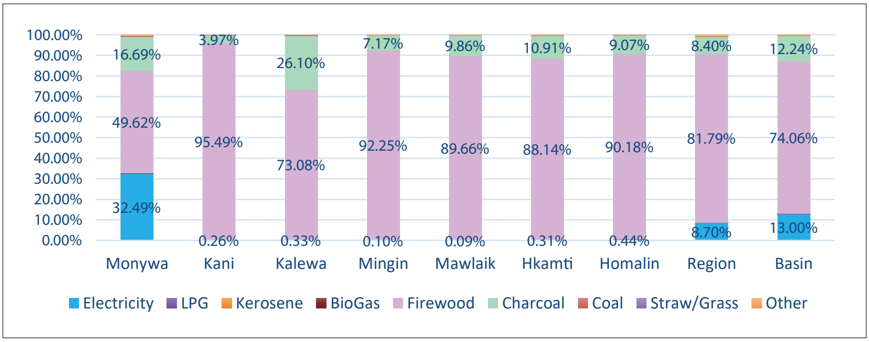
Table 8.8 Sources of household lighting in selected townships (%)

Township	Electricity grid	Kerosene	Candle	Battery	Generator (private)	Water mill (private)	Solar system/ energy	Other
Monywa	67.3	0.1	4.6	17.4	4.0	0.1	2.9	3.6
Kani	5.9	0.3	11.5	34.2	25.2	0.2	12.9	10.0
Kalewa	16.8	3.0	11.5	21.0	36.8	1.0	6.8	2.9
Mingin	4.3	0.4	14.7	43.7	23.7	0.2	7.3	5.7
Mawlaik	12.2	0.8	14.9	36.1	16.2	0.3	16.0	3.5
Hkamti	21.8	0.3	38.2	5.4	13.3	1.0	16.3	3.7
Homalin	10.3	0.7	50.4	7.5	18.0	0.2	11.3	1.6
Region	**24.2**	**0.9**	**15.7**	**24.6**	**16.5**	**0.8**	**11.8**	**5.4**
Basin	**27.5**	**0.7**	**16.1**	**18.2**	**23.0**	**1.2**	**9.8**	**3.4**

Source: Housing and Population Census 2014.

The major sources of energy for cooking are firewood, charcoal and electricity. Given that access to the grid is low, the usage of electricity for cooking is also low in both Sagaing Region and the Chindwin Basin, at 8.7 percent and 13 percent respectively (**Figure 8.7**). The highest rate of electricity use for cooking is 32.49 percent, in Monywa, while that of other basin towns is less than 1 percent. Even in Monywa, nearly half of the households use firewood as their main cooking fuel. By the same token, 92 percent of households in Mingin use firewood as their main source of energy, since Mingin has the lowest number of households connected to the grid. In summary, the main source of fuel for cooking is firewood, with 81.79 percent for the region as a whole, and 74.06 percent in the Chindwin Basin. Among the selected townships, charcoal is in relatively higher use, e.g. 26 percent of households in Kalewa.

Figure 8.7 Cooking fuels in Chindwin Basin townships (%)



About half of the households (47 percent) obtain their drinking water from boreholes or tube wells (**Table 8.9**). Protected wells supply nearly 25 percent of households. The same pattern can also be observed in the basin as well. Households in the Chindwin Basin use tube wells or boreholes as their main water source, with protected wells as a second. Due to their location near Chindwin River and its tributaries, about 11 percent use river, stream or canal water for drinking. A similar pattern is observed when the data is further broken down by townships: the borehole is the main source of drinking water, followed by either protected wells or rivers and streams, depending on the location. The only outlier is Hkamti, where the river and its streams and canals are used as the main drinking water source, followed by protected wells/springs. The use of tubewells is quite low, with only about 5 percent of households using it as their drinking water source in Hkamti. Among the selected townships, a higher percentage of households in Kalewa (44.7 percent) and Hkamti (38.4 percent) use river water as their main source for drinking.

The major modes of transportation in the Chindwin Basin are presented in **Table 8.10**. Kalewa, Hkamti, Mawlaik and Homalin have a higher rate of both canoe and motorboat availability (**Table 8.10**). On the other hand, Monywa, which is located on the highway, has a higher rate of vehicle use (5 percent cars, 73 percent motorcycles). It is followed by Homalin (1.5 percent cars) and (54 percent motorcycles), although as a township with a basic transport infrastructure, the rate for vehicle use should be higher since it is the main mode of transport. When compared with the whole region, however, there is a higher rate of use of waterways in the Chindwin Basin.

Table 8.9 Access to drinking water in Chindwin Basin towns (%)

Township	Piped water	Tube well	Protected well	Unprotected well	Pool/ Pond/ Lake	River/ stream	Rain water	Water purifier	Tanker/ Truck	Other
Monywa	12.2	48.9	20.0	1.1	2.0	1.0	0.8	11.4	0.6	2.1
Kani	1.7	49.2	27.8	1.6	4.7	13.4	0.2	0.0	0.0	1.3
Kalewa	15.9	16.5	14.3	2.3	4.8	44.7	0.6	1.0	0.0	0.0
Mingin	2.0	50.4	18.6	1.6	0.0	24.2	2.6	0.0	0.0	0.5
Mawlaik	2.6	44.1	30.8	2.5	0.0	19.2	0.6	0.1	0.0	0.0
Hkamti	9.5	5.0	18.4	12.4	4.1	38.4	7.8	4.2	0.0	0.2
Homalin	2.5	51.1	15.1	3.8	1.0	22.6	2.2	0.3	0.0	1.4
Region	**7.5**	**47.0**	**24.1**	**3.2**	**5.1**	**7.2**	**1.4**	**2.5**	**0.3**	**1.6**
Basin	**6.4**	**41.5**	**27.3**	**4.1**	**1.2**	**11.4**	**1.2**	**4.8**	**0.2**	**1.8**

Source: Housing and Population Census 2014.

Table 8.10 Transportation in the Chindwin Basin (%)

Township	Car/Truck/ Van	Motorcycle	Bicycle	4-Wheel tractor	Canoe/ Boat	Motor boat	Cart (bullock)
Monywa	5.3	73.2	62.7	2.1	1.3	0.5	14.1
Kani	0.9	48.7	27.4	0.6	3.6	1.5	56.4
Kalewa	1.3	37.3	16.4	0.6	15.8	4.9	45.3
Mingin	0.3	33.7	16.5	0.5	9.0	4.2	67.9
Mawlaik	0.6	38.3	22.9	0.8	15.9	7.9	54.8
Hkamti	1.2	33.3	10.8	0.6	10.6	16.0	8.6
Homalin	1.5	54.2	15.9	4.8	17.6	6.9	42.3
Region	**1.7**	**55.8**	**40.5**	**1.8**	**3.5**	**1.5**	**42.2**
Basin	**2.8**	**57.6**	**44.6**	**2.0**	**6.1**	**2.8**	**30.8**

Source: Housing and Population Census 2014.

Household assets, in this case a radio, television, landline phone, mobile phone, computer, and internet access, can be used as proxy indicators for the economic situation of households (see **Table 8.11**). If the percentage of households owning none of these items is high, it could indicate household poverty. For example, 40 percent of households in Hkamti do not own any of these items, which is the highest rate in the river basin. This perhaps reflects the Hkamti's lack of income-generating opportunities. Households in Monywa have twice as much household assets as those of Hkamti because Monywa is the most developed town with more income-generating and economic opportunities than Hkamti. Moreover, the number of households with this bundle of assets in the capital is significantly higher than in all the other townships. If Monywa was excluded, the basin has a higher percentage of households owning none of the items (33) and a lower percentage of household owning all items (0.05) than for Sagaing Region as a whole.

Table 8.11 Ownership of household assets in the Chindwin Basin

Township	Conventional households	Own Radio	Television	Land line phone	Mobile phone	Computer	Internet at home	with none of the items	with all of the items
Monywa	75,962	31,197	46,306	5,218	38,578	4,169	5,721	18.9	0.7
Kani	29,223	19,056	7,202	1,337	2,637	175	231	27.7	*
Kalewa	11,735	5,405	4,581	495	1,865	114	145	33.2	*
Mingin	22,058	12,165	6,123	558	354	123	16	35.2	*
Mawlaik	10,345	5,211	4,779	199	1,840	134	306	27.8	0.1
Hkamti	7,361	2,282	3,330	166	1,418	172	71	40.8	0.1
Homalin	35,743	12,251	19,432	1,289	4,005	546	331	32.6	0.1
Basin	**192,427**	**87,567**	**91,753**	**9,262**	**50,697**	**5,433**	**6,821**		
Region	**1,096,857**	**469,946**	**462,064**	**44,285**	**238,163**	**17,500**	**29,006**	**31.5**	**0.2**

Source: Housing and Population Census 2014.

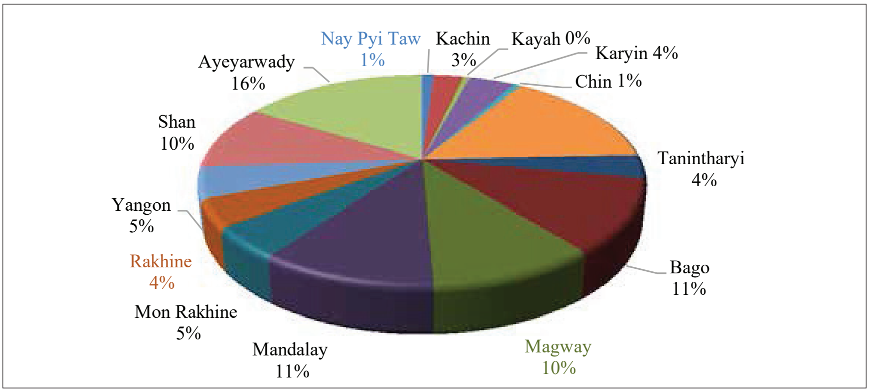
Comparative economic indicators: Chindwin Basin and Sagaing Region

This section compares the economies of the Chindwin Basin and Sagaing Region as a whole. Sagaing is one of the three main regions in the upper Myanmar Dry Zone that contributes significantly to the national economy due to its agricultural output and developed markets. Sagaing Region mainly produces wheat for the country and also rice (it is the third-largest producer of rice after Ayeyarwady and Bago regions). One-third of the total groundnuts and sesame seeds, and 20 percent of the total green gram (mung bean) and maize seeds, are produced in the region (Myanmar Agricultural Statistics 2017).

One-third of the total land area under paddy cultivation in the country, or 2.9 million ha, is found in the Ayeyarwady region, which is called the "rice bowl" of the country, followed by 1.43 million ha in the Bago region and 1.33 million ha in Sagaing Region (Agriculture Census 2014). Approximately 80 percent of the total wheat cultivated area is in Sagaing, while the Mandalay Region, Shan (north) and Shan (south) states reported percentages of 7.52, 6.66 and 4.80, respectively, of the total land area planted with wheat. Maize is mainly cultivated in Shan (North), and parts of Sagaing, Shan (South) state, Ayeyarwady Region and Chin State, with percentages of 19.43, 17.62, 7.24 and 7.12, respectively.

The total land area of Sagaing is 9,374,000 ha, constituting 13.8 percent of the country's land and the second largest after Shan State. The share of total land under agriculture, as well as the share of the net sown area (15 percent of total), is also the second highest after Ayeyarwady (**Figure 8.8**). It is obvious that agriculture plays a critical role in food and livelihood security of households at the state, regional and national levels.

Figure 8.8 Net sown area by state/region in 2015–16



Source: Myanmar Agricultural Statistics, 2017.

Several types of land use are seen in the Sagaing Region: *Le*, *Ya*, *Kaine*, *Ma Yoe Lae* and garden plots. *Le* is where mainly paddy is grown on generally wet, muddy and flat land, whereas *Ya* is considered as dryland in hilly landscape. *Le* can be found in areas with good rainfall, and *Ya* can be found in areas with insufficient rainfall to grow paddy. On *Ya* land, crops such as groundnuts, sesame, mungbean, cotton and maize are grown. *Kaine* and *Ma Yoe Lae* are seasonal farming methods on the silted land along riverbanks. The former is on sandy soil, whereas the latter is on wet silted land on the riverbanks. As in the case of *Le*, paddy can be grown on *Ma Yoe Lae* once the tide recedes in the late monsoon season. The sandy soils in *Kaine* plots is used to grow vegetables such as onions, tomatoes, and chillies. In Sagaing, more *Ya* land can be found compared to other regions such as Mandalay or Magway.

In fact, Sagaing expanded its *Le* cultivation only after the irrigation schemes (such as the Thaphanseik, Karboe and Kintat dams on the Ayeyarwady and Mu rivers) were implemented during the 1990s and 2000s. The government investment in dams, river water pumping and underground water pumping schemes of the Chindwin and Mu rivers enabled the region to become one of Myanmar's major rice-producing areas in the mid-1990s. The water pumping scheme for the Chindwin River provides water for cropping in Monywa, Budalin, Chaung U and Salingyi. There are 22 river water pumping stations on the Chindwin River, which provided irrigation for 39,358 ha of crops, including rice in 2016 (**Table 8.12**) (IWUMD 2017).

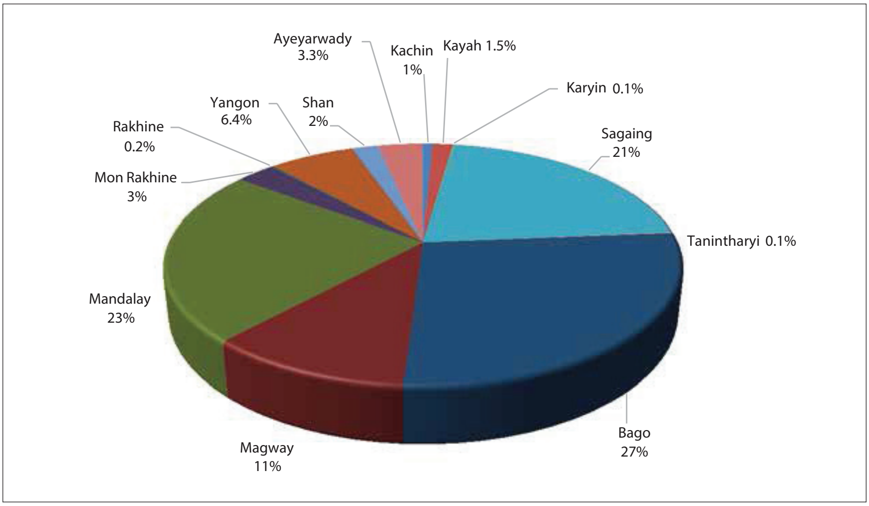
Table 8.12 River water pumping stations in Myanmar

River name	Ayeyarwady	Chindwin (Sagaing)	Thanlwin	Sittoung	Mu (Sagaing)	Dokehta-wady	Others	Total
No. of station	86	22	6	29	24	27	196	390
Estimated crops area (ha)	118,794	39,358	3,474	11,150	13,072	7,632	109,280	302,760

Source: IWUMD 2017.

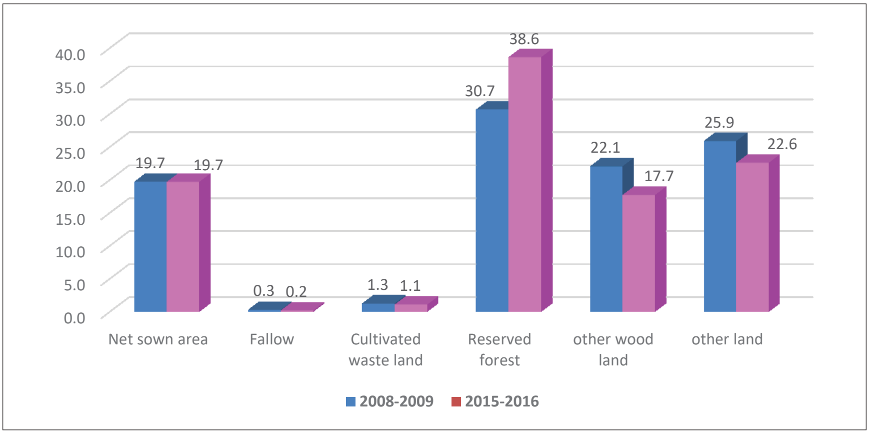
The southern part of Sagaing has transformed its farming system from *Ya* (dry land) to *Le* (wet land) mainly through the construction of dams and irrigation canals. The total irrigable land in the country was 1,214,000 ha in 2015–2016 (Myanmar Agriculture Statistics 2017). Sagaing possessed 258,000 ha of irrigable land or 21 percent of the country's total (**Figure 8.9**). The highest share of irrigable land area is in Bago Region (27 percent of total irrigable land) followed by Mandalay Region (23 percent).

Figure 8.9 Myanmar: Irrigable land by state/region, 2015–16



Source: Myanmar Agriculture Statistics 2017.

Figure 8.10 Land-use pattern changes in Sagaing Region (%)



Sources: Myanmar Agriculture Statistics 2011 and 2017.

Land-use patterns, especially cropped or net sown areas, remained unchanged during 2008–09 and 2015–16 in the Sagaing Region (**Figure 8.10**). Forest and related land decreased by 4.4 percent and 3.3 percent, respectively within the same periods. The proportion of current fallow and cultivable wasteland to total land decreased by less than 1 percent. On the other hand, the share of reserved forest to total land area increased by 7.9 percent.

Land-use patterns for the seven townships in the Chindwin River Basin differ from the general pattern for the region. The total land area of the seven townships (3,327,000 ha) located along the Chindwin River comprises some 35.5 percent of the total land area of Sagaing. Among these, Hkamti and Homalin are larger, occupying about half of the total area. Unfortunately, cultivated wasteland constitutes only 33 percent of the total land of Hkamti and only 7 percent in Mawlaik (**Figure 8.11**). The share of cultivated wasteland to total land is 4 percent in Kani, Kalewa and Mingin, respectively.

The proportion of the net sown area to the total is the largest in Monywa (61 percent of total land) followed by Kanni (21 percent). The proportion of the net sown area is the lowest in Hkamti (1 percent) followed by Mawlaik (3 percent). The highest percentage of virgin land is also found in Monywa (34 percent of total land) and Kanni (7 percent). The proportion of virgin land is negligible in Mingin and Hkamti.

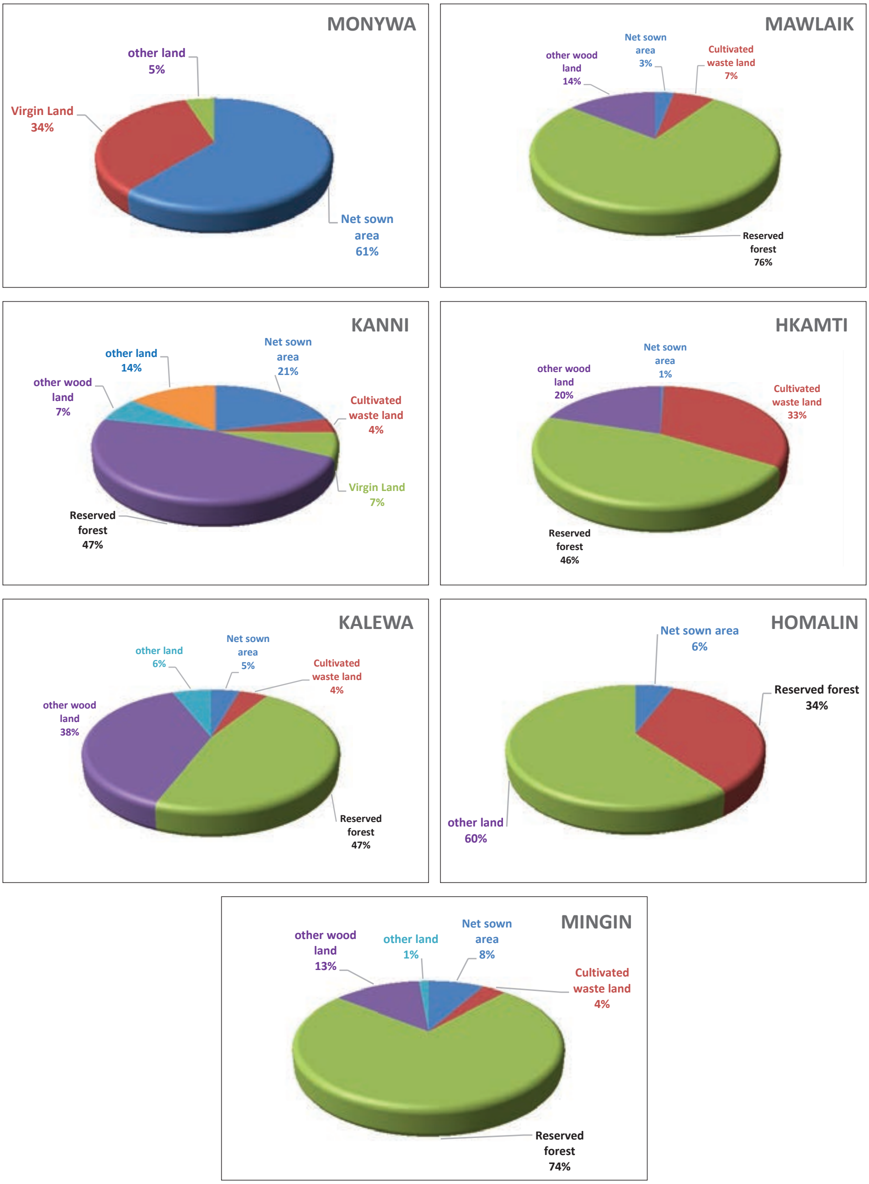
Nearly half of the land area of Hkamti, Kalewa and Kani is forested. More than 70 percent of the total land in Mingin and Mawlaik is forested, and 34 percent in Homalin. The forested area of Sagaing Region constitutes 22 percent of the country's total forest area, and is concentrated in six of the surveyed townships in this study (all except Monywa).

Sown acreages and selected crops

Sagaing Region is at the forefront of groundnut and sesame production in the country, producing 34 percent and 32 percent of the country's production of these two crops in 2015–16 (CSO 2017). Sagaing Region contributes 12 percent of Myanmar's annual output of 25.57 million metric tons of paddy.

A similar picture can be seen in the Chindwin Basin. As shown earlier, the Chindwin is a key area for paddy, oil-crops and pulses, where the share of sown acreage reaches 34 percent in the case of paddy, 22 percent for sesame, 17 percent for groundnut and 10 percent for green gram (**Table 8.13**). Among the 37 townships of Sagaing Region, the 7 townships in Chindwin Basin contribute 12 percent each of the annual regional crop of groundnut and sesame, 10 percent of green gram and 9 percent of paddy.

Figure 8.11 Land use in selected townships in Chindwin Basin



Source: General Administration Department's Township Profiles (2016–17).

Morever, agriculture is mainly practiced under rain-fed conditions in this area. Cropping systems therefore depend on adequate rainfall and suitable geomorphology. Rice is grown in lowland rainfed areas and oil seed crops and pulses are grown in the uplands. The common farming practice is crop diversification with intercropping (especially of sesame and pigeon pea) and mixed cropping. However, overall production is rather low because of low crop yields per unit of land (compared to other states and regions).

This area is important in terms of its location on the border trade route with India. The Monywa-Yagyi-Kalewa road is part of the ASEAN highway (AH1, from the border of Thailand to the border of India) that connects Monywa to the Indian border. Rice and other food crops are transported from this area to rice-deficit areas of Chin State and the Naga Self-Administrated Zone. In addition, pulses produced in this area are sent to the Mandalay wholesale market for export.

Monywa is the capital and the chief commercial city of Sagaing Region, located 136 km northwest of Mandalay on the eastern bank of the Chindwin River. It is an important transport hub with important connections to the south, including Magway and Ayeyarwady regions via road, to the Mandalay region by train and car, and to the India–Myanmar border trading town of Tamu by car, and north to Kalewa, Mawlaik, Homalin and Hkamti by boat. Therefore, Monywa city has been designated as a 'commercial hub' as it is close to highways heading to Mandalay and India, and is well connected to other townships in Sagaing Region by road, railway and boat.

An India–Myanmar border entry port opening ceremony was held on 8 August 2018 at Tamu Border Bridge in Sagaing Region. An MOU was signed between India and Myanmar, and people can apply for a border pass and stay up to two weeks within the area stipulated by the two countries.

According to the Department of Trade (Ministry of Commerce), the trade volume for four months (1 April to 3 August 2018) at the Tamu border point was USD43.36 million, a nearly fourfold increase in trade compared with the same period in 2017. Increasing both internal and external trade provides opportunities for income-generating activities in the region and river basin, as well as helps to develop better transportation and connectivity among the townships.

Table 8.13 Sown acreage and production of selected crops in selected townships in 2015–16

Township	Paddy Sown Area (acre)	Paddy Production ('000 ton)	Groundnut (acre)	Groundnut Production ('000 ton)	Sesame (acre)	Sesame Production ('000 ton)	Maize (acre)	Maize Production ('000 ton)	Blackgram (acre)	Blackgram Production ('000 ton)	Greengram (acre)	Greengram Production ('000 ton)
Monywa	4,217	6.87	5,752	4.14	21,781	4.94	1,460	1.63	773	0.31	15,704	6.05
Kani	24,473	35.50	42,165	27.37	64,006	10.76	565	0.63	6,973	3.00	22,547	8.09
Kalewa	18,646	30.49	3,371	2.73	1,296	0.26	958	1.17	1,908	0.88	1,513	0.56
Mingin	36,325	59.50	21,266	15.98	32,126	7.27	1,616	2.17	3,720	1.61	14,582	6.03
Mawlaik	21,639	33.55	4,112	3.46	838	0.27	458	0.58	255	0.09	328	0.16
Hkamti	8,030	11.04	1,591	1.14	121	0.02	475	0.57	31	0.01	0	0.00
Homalin	73,541	-	14,236	0	10	0.00	202	0.24	710	0.00	310	0.00
Total	186,871	176.96	92,493	54.83	120,178	23.52	5,734	6.99	14,730	5.90	54,984	20.90
% of CRB	34%		17%		22%		1%		3%		10%	
Regional	2,126,415		762,043		1,036,262		210,875		190,309		570,416	
% of region	9%		12%		12%		3%		8%		10%	

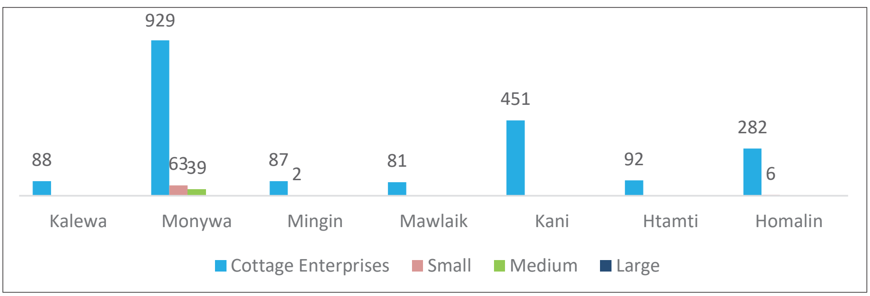
Source: General Administration Department's Township Profiles (2016-2017).

SME development

The UNDP's *One Pager Business Census 2013–2014* on Myanmar concludes that there were no firms with 100 or more employees in the 10 townships surveyed (UNDP 2014). Most firms had between 1 and 15 employees, and there were only a few with more than 100 employees in the surveyed townships (UNDP 2014). Therefore, the new SME definition, which is more aligned with the OECD definition, was used in the Small and Medium Enterprises in Myanmar Report. It was found that out of 2,490 sampled firms, 67 percent were microenterprises, with 5 to 9 employees, and 31 percent can be categorized as small enterprises with 10 to 49 employees. Only 2 percent were categorized as medium enterprises, with 50 to 99 employees (Amine and Stockman 2015).

By using the above definition for small and medium enterprises, most firms in the selected townships in Chindwin Basin can only be categorized as cottage enterprises (**Figure 8.12**). Cottage enterprises employ between 1 to 4 employees. Apart from Monywa, which has an industrial zone, large enterprises that employ more than 100 employees are not found in the selected townships. Monywa has businesses of all sizes, including two large enterprises (a sawmill and a traditional medicine manufacturing plant).

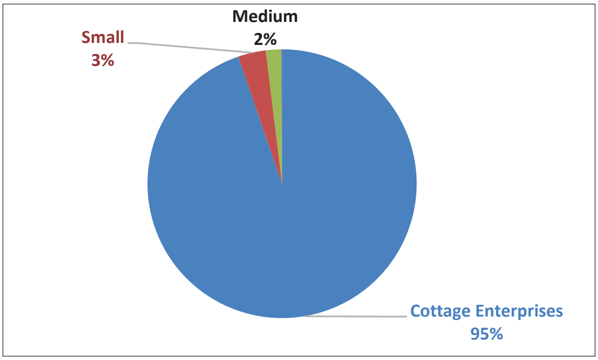
Figure 8.12 Cottage, small, medium and large enterprises in selected townships



Source: General Administration Department's Township Profiles (2016–17).

Among the selected townships, 95 percent of businesses are cottage enterprises, employing less than 5 employees. Kani has the second highest number of cottage enterprises, after Monywa, with 451 and Homalin follows in third place with 282 (see **Figure 8.12**). Apart from Monywa, there are no medium or large enterprises in the other townships. It is clear that there are few SMEs in the basin (**Figure 8.13**): the percentage of small enterprises in the basin is just 3 percent, and that of medium enterprises is just 2 percent. Therefore, the cottage industries are significant in terms of employing a large proportion of labour.

Figure 8.13 Types of business in selected townships in Chindwin Basin (%)



Source: General Administration Department's Township Profiles (2016-2017).

Net Domestic Product

The estimated total Net Domestic Product (NDP) value for the selected townships is 1,457,717 million Kyats or USD1,214 million in 2016–17. The total NDP value of the seven townships contributes 20.4 percent of the NDP value of Sagaing Region. The NDP value can be divided into (i) goods, (ii) services and (iii) trade. The agriculture sector (including livestock raising, fishing and forestry) and industry (including mining, energy, power, manufacturing, construction) is under the NDP value of goods. The service sector includes transport, communication, financing, social and administration, rental and other services.

The share of NDP of the goods sector to total NDP value is more than 70 percent in Mingin, Kalewa, Homalin and Mawlaik (**Table 8.14**). Mingin produces a surplus of paddy and pulses and sends those crops to Monywa and Kale. Kalewa produces not only a surplus of paddy and oil seed crops but also coal and timber. Nine private companies produce coal valued at around 1,660 million Kyats, which is sent to Mandalay and Kyaukse in Mandalay Region. The NDP of Homalin is mainly from paddy and oil seed crops, and gold mining. Gold mining is also concentrated in Hkamti. Pulses from Monywa are sent to Mandalay, while oil seed crops from Kani are sent to Monywa. In addition, food processing and copper mining contribute to the NDP of the goods sector in Monywa. Most of the SMEs, such as wheat and rice noodle factories, pulse grading and processing factories, are located in Monywa.

The share of NDP of the service sector in selected townships to total NDP value is the highest (22 percent) in Monywa and Hkamti. The lowest share of NDP value of the service sector to total NDP value (4–6 percent) is found in Mingin and Kalewa. The highest share of NDP value of the trade sector in selected townships to total NDP value (19 percent) is found in Monywa. The NDP from the agriculture sector has been gradually replaced by the share of trade and services over time in Monywa.

Overall, the share of goods, services and trade to total NDP value of the selected townships is 65, 17.5 and 17.3 percent, respectively (**Table 8.14**). The contributions of the selected townships to Sagaing Region's NDP were 19 percent in goods, 33 percent in services, and 20 percent in the trade sector, in 2016–2017.

Income

Myanmar, with a GNI per capita of US$1,455 in 2017, has one of the fastest growing economies in the Asia Pacific region and globally. The GDP growth rate for 2016/2017 was 6.4 percent. Among the selected townships, the highest annual per capita income is received in Monywa (2,318,033 Kyats or USD$1,932) in 2016–17 (**Figure 8.14**). The annual per capita income in Monywa is more than double the income in Mawlaik and Hkamti, and it is nearly five times that of Homalin. According to the Ministry of Planning and Finance (2018), the per capita income for Sagaing Region is 1,952,000 Kyats, which is higher than the river basin average income (1,249,000 Kyats).

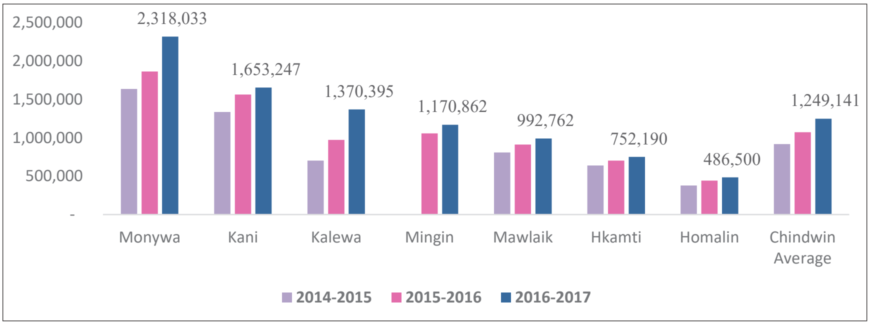
However, the per capita income growth rate is uneven among the townships (**Figure 8.15**). Per capita income increased in Kalewa by 38 percent during 2014/15 and 2015/16, and by 41 percent during 2015/16 and 2016/17. During 2015/16 and 2016/17, per capita income increased at an annual growth rate of 24 percent in Monywa. However, the per capita income increased at a lower growth rate of 6 percent in Kani, 9 percent in Mawlaik, and 7 percent in Hkamti during 2015/16 and 2016/17.

Table 8.14 Net Domestic Product of the selected townships, 2016–17

Township	Value & share	Good	Service	Trade	NDP
Monywa	Value (million Ks.)	390,034	149,312	129,975	669,321
	Share (%)	58.3	22.3	19.4	
Kani	Value (million Ks.)	227,993	72,649	55,800	356,442
	Share (%)	64.0	20.4	15.6	
Kalewa	Value (million Ks.)	135,435	10,252	28,757	174,444
	Share (%)	77.6	5.9	16.5	
Mingin	Value (million Ks.)	79,639	4,464	15,520	99,623
	Share (%)	79.9	4.5	15.6	
Mawlaik	Value (million Ks.)	28,781	4,339	5,776	38,895
	Share (%)	74.0	11.1	14.8	
Hkamti	Value (million Ks.)	17,888	6,156	3,618	27,661
	Share (%)	64.7	22.2	13.1	
Homalin	Value (million Ks.)	68,613	9,185	13,532	91,330
	Share (%)	75.1	10.1	14.8	
TOTAL	**Value (million Ks.)**	**948,386**	**256,358**	**252,979**	**1,457,717**
	Share to region's NDP (%)	**65.1**	**17.6**	**17.3**	

Source: General Administration Department's Township Profiles (2016–17).

Figure 8.14 Trends of per capita income in selected townships (kyats)



Source: General Administration Department's Township Profiles (2016-17).

On average, the per capita income of the seven townships increased by 16 percent during 2015/16 and 2016/17. Except in Monywa and Kani, the per capita income growth rate in the rest of the selected townships is lower than the average income growth rate of the basin.

Conclusion

Overall, health services and indicators are lower in the Chindwin Basin than for the Sagaing Region. Average infant mortality and under-5 mortality rates are significantly higher than the regional average, possibly due to poor access to heath services and the difficulties (in both the rainy season and summer) of traveling to the nearest medical facilities. The priority for health sector development in the basin area should be expanding health service provision, but also awareness raising on how to lower infant and under-5 mortality rates.

Among the education indicators, there is a gap in the percentage of people who completed education and the completion rate for primary school between the region and basin average. Further study should be conducted to explore the factors hampering access to universal education (especially increasing completion rates for primary education) in the basin. Moreover, women have less opportunity and access to education in the river basin as there is a higher percentage of women with uncompleted education, especially in middle school (grades 6–9) and high school (grades 10–11). Future projects for the socioeconomic development in the river basin should aim to achieve gender equality in access to education.

Both the region and the Chindwin Basin rely on tube wells for drinking water, but some townships (Kalewa and Hkamti) also rely on river water. On the other hand, there is a gap in access to electricity between the region and the basin townships (except Monywa). Some have very poor access to electricity (less than 10 percent of total households), which should be a priority for the development of the river basin. The majority of selected townships, about 88 percent (except Monywa), use firewood for cooking and the rest (12 percent) use charcoal. Thus, the promotion and supporting of community forestry should be planned for sustainable ecosystem and livelihoods in the basin.

A gap is found in the ownership of households assets (radio, television, land line, mobile phone, computer, internet) between the region and the majority of the townships (excluding Monywa). Therefore, regional development plans should give priority to the socioeconomic development of vulnerable households in the river basin.

The Myanmar Living Condition Survey (2017) shows that the Coastal zone and the Hills and Mountains zone have the highest poverty rates (32 percent and 31 percent respectively). Unsurprisingly, given its largely hilly terrain, a higher poverty incidence of 30.7 percent is found in the Sagaing Region. Except for Monywa, the selected townsh*ips in this study had lower per capi*ta incomes when compared with the regional average. The poverty incidence could be more than 30 percent in some townships. Important drivers for increasing income in these lower-income townships are the development of services (not only access to health and education, but also transportation and telecommunications to expand internal and external trade and improve mobility for jobs and access to markets), and industries (such as energy, power, manufacturing, cottage enterprises and construction).

The landless and marginal farmers and people who live along the rivers in Sagaing Region are vulnerable to floods, river bank errosion, water pollution and sedimentation due to gold mining and logging upstream and stagnant waterways in the summer. These external threats directly affect not only the socioeconomic development of households, but also the interrelated biodiversity and ecosystem services of the river basin as a whole.

The awareness and participation of local people in the development of Chindwin River Basin is a must, and the participation of the Chindwin RBO is essential to improve water quality and river health. Future strategic planning and development projec*ts for the river basin s*hould be considered from various angles and aspects (including lowland and upland agro-ecosystems, community forestry, forest reserves, biodiversity, and the negative environmental impacts of mining) to enhance and sustain the socioeconomic status and improve the incomes of vulnerable households in the river basin.

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9

Changing water use in the Chindwin River Basin: A case study of three townships

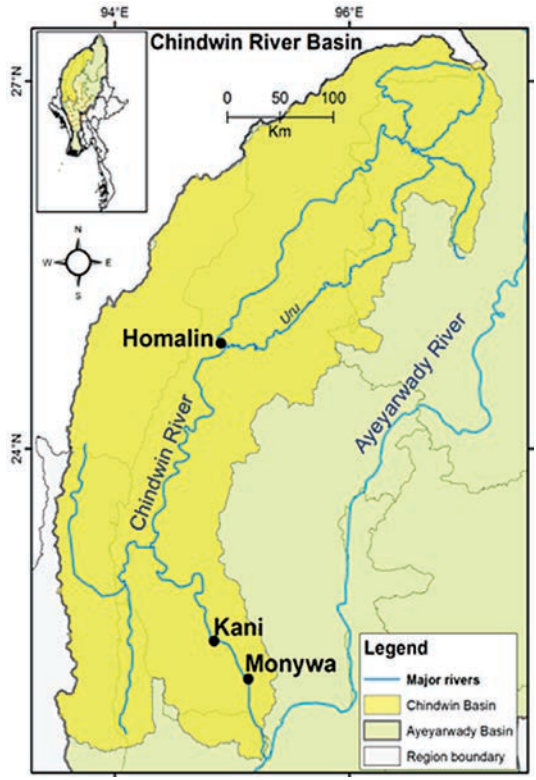
May Thazin Aung and Bernadette P. Resurrección

The Chindwin River as it is today has been shaped by the forces of nature, as well as politics that determined the access and control of the Chindwin River. Historical and present-day political decisions have shaped the landscape and the river's geomorphology, which in turn shape the livelihoods and water uses of basin residents. Recognizing the importance of politics to access to water resources, this chapter attempts to shed light on the effects of governance on communities' access to and control of water resources. To do so, we combine insights from a literature review of the political economy of natural resource management in Myanmar with qualitative and quantitative field data on households' water use within three townships in the Chindwin River Basin, Monywa, Homalin and Kani, which are areas under the jurisdiction of the Sagaing regional government (see **Figure 9.1**).

The chapter is divided into six sections. The first section discusses the political economy of natural resource governance in Myanmar and the Chindwin River Basin, and provides background into the history of natural resource extraction that is shaping biophysical changes in the basin. The second section on livelihoods and water use draws from results of household surveys and key informant interviews (KIIs) to shed light on water use within the basin. This section is divided into three subsections: methodology, household profiles of the three townships and perceptions, and water use and management for communities in the three townships. The third section addresses basin residents' perceptions of domestic and agricultural water use based on the results from key informant interviews. This is followed by the fourth section, on social and institutional relations from discussions with informants on the need for improved water governance.

The final two sections of the chapter summarize the data and present the key results of the study, and offer concluding thoughts on the future of water management for the Chindwin Basin.

Figure 9.1 Three study sites: Homalin, Kani and Monywa



Political economy of natural resources in Myanmar and the Chindwin Basin

Political economy recognizes the integral relationship between politics and economics in which the policies and the behavior of politicians influence the development of a country (De Almeida 2018). Since the early 1960s, the ruling Myanmar military junta has controlled politics through its control over land and the extraction of natural resources, ensuring its dominance over the economy[1] (HIC 2017). Before 1988, the Socialist state had total control of the economy. However, after the Socialist state went bankrupt, it began siphoning off its control to military-linked firms, such as the Myanmar Economic Holdings Ltd (MEHL), the Myanmar Economic Corporation (MEC), and to a select group of entrepreneurial individuals or 'crony capitalists.' These 'crony capitalists' or 'cronies' included wealthy businessmen and some foreign firms, who wielded a considerable amount of power over the economy and politics (Jones 2014: 148–51).

The junta set up mechanisms to control land through agricultural land concessions throughout the country. Agriculture was touted as a way to increase national food security and reduce dependence on foreign food imports (Scurrah et al. 2015: 19). Large tracts of land were allocated for agriculture; for instance, along the Chinese–Myanmar border, the junta allocated large areas in Kachin and Shan States to agribusinesses for establishing rubber plantations (Scurrah et al. 2015: 5). In a study by Papworth et al. (2017), two agricultural concessions of 4,047 ha each were awarded to two domestic companies with close ties to the military for developing agribusinesses in Kachin State. The main crops cultivated in one of the concessions were jatropha and cassava for biofuels (ibid.: 2).

The practice of allocating large tracts of land for agribusinesses continued with the Thein Sein administration, which took office in 2011. New laws such as the Vacant, Fallow and Virgin Lands Management Law (2012) and Foreign Investment Law (2012) enabled 'legal' land acquisitions. These laws allowed land to be deemed as 'wasteland'[2] so that it could be leased to domestic and foreign private sector entities supposedly for agriculture (McCarthy 2018: 228–46). Agricultural concessions increased from 3 million acres to 5.2 million acres (1.2 million ha and 2.10 million ha) within two years of Thein Sein taking office (Woods 2015: 2). In 2013, 6,400 companies were granted land concessions, totaling 1.6 million hectares (Henley 2014: 5).

Similar practices of providing patronage to junta-linked individuals and companies occurred in the extractive sector. Joint ventures and licenses for energy and mining investments, particularly in the border areas, were awarded to companies and individuals linked to the junta (Scurrah et al. 2015: 6). In one notable example, top military personnel and military-owned companies, like MEHL and MEC, and military-linked individuals held major stakes in the jade industry, with an estimated worth of US$13 billion in 2014, which is equivalent to 48 percent of Myanmar's official GDP for that year (Global Witness 2015: 26).

The Chindwin River Basin falls under the jurisdictions of the Sagaing, Mandalay, and Magway regional governments and the Kachin State Government. Kachin State and the Sagaing and Tanintharyi Regions have both the highest numbers of agricultural land concessions per hectare and the lowest proportion of cultivated land. All three regions have experienced a significant number of disputes between local populations displaced by land concessions and the companies that received them (O'Toole 2013a).

Within the Chindwin River Basin, concessions for mining and agriculture were especially prevalent. Kachin State possessed the largest area of land concessions with around 0.56 million ha allocated in 2012 (O'Toole 2013a). The majority of these lands were for agribusinesses (both foreign and domestic), although the percentage of areas planted with crops was only 12 percent of the concession areas. This suggests that the land was acquired for purposes of land speculation or to act as entry points for accessing other natural resources, for example, timber (Scurrah et al. 2015: 12). The large number of agricultural concessions in Kachin State may be due to the ease at which the junta could reclassify land that had been let to lie fallow as wasteland. This reclassification also discounts the farming practice of shifting cultivation in which land is left to lie fallow for several cropping cycles, which is the most common form of agriculture in the uplands, accounting for 30 to 40 percent of all cultivation in Myanmar (McCarthy 2018: 236).

Between 2010 and 2013, an estimated 533,000 acres (215,697 ha) of land in Sagaing had been given out as agricultural concessions although only 3.7 percent has been planted with crops since (O'Toole 2013b). A highly controversial mining land concession also took place within this period when the expansion of the Lepadaung copper mine owned by MEHL and the Wan Bao Co. Ltd, a subsidiary of China North Industries Corp, led to the forced removal of communities from three villages in the Sagaing Region (McCartan 2013). The villagers have continued to resist the terms of compensation from the company for farmlands seized for the project (Wai 2017).

The junta's land concessions continue to impact the lives of residents in the Chindwin River Basin. There is little evidence to show that the development model of large-scale land concessions has improved the lives of the citizens of Myanmar. The granting of land concessions instead has resulted in many citizens, particularly farmers, being dispossessed of their land (Scurrah et al. 2015: 13). At the time of writing, the NLD administration was making efforts to make amends for past actions. For instance, the Ministry of Agriculture, Livestock and Irrigation in 2016 announced plans to return 2,500 acres of confiscated land to farmers in the northwestern Sagaing Region after more than 35 years (Toe and Gerin 2016).

Thus, the political economy of natural resource governance has shaped the social and economic circumstances of the households within the Chindwin River Basin. The proceeding sections, with data from household surveys, will shed light on how the junta's policies and actions have affected, and continue to affect, livelihoods in the basin.

Livelihoods and water use in the Chindwin River Basin

Methodology

Three townships in the Chindwin River Basin, Homalin, Monywa, and Kani, were selected as study sites. Villages within the townships were selected based on their proximity to the Chindwin River and its tributaries, levels of urbanization, and diversity of livelihoods. Earlier desk reviews and key informant interviews with local regional and national officials indicated that in these areas, people engage in a mix of agriculture, fishing, river transport, and mining activities. In Monywa, respondents were selected from three villages, Zee Taw, Nyaung Hpyu Pin and Thae Pon Kaing; in Kani, three villages, Aing Taung, Ka Ne and Nyaung Wun; and in Homalin, five villages, Nan Sa Kar, Kaw Yar, Maing Kaing, Nyaung Po Aung and Nan Taw.

A mixed methods approach was conducted through 600 randomly sampled surveys (200 respondents within each township) from all three study sites and semi-structured key informant interviews (KIIs) with 120 individuals. Key informants were selected based on their knowledge of water resources or natural resource management, experience as water users and leadership roles in community water resource management. They included representatives of public institutions who were knowledgeable about peoples' livelihoods in the study areas, and the changes in water use and management practices. Thirty additional KIIs[3] were conducted with water users and relevant water resource management stakeholders at the national and regional level, including government representatives of water institutions, civil society, members of academia and business associations, to learn about current water governance and for understanding gaps in water management.

Household profiles within three townships

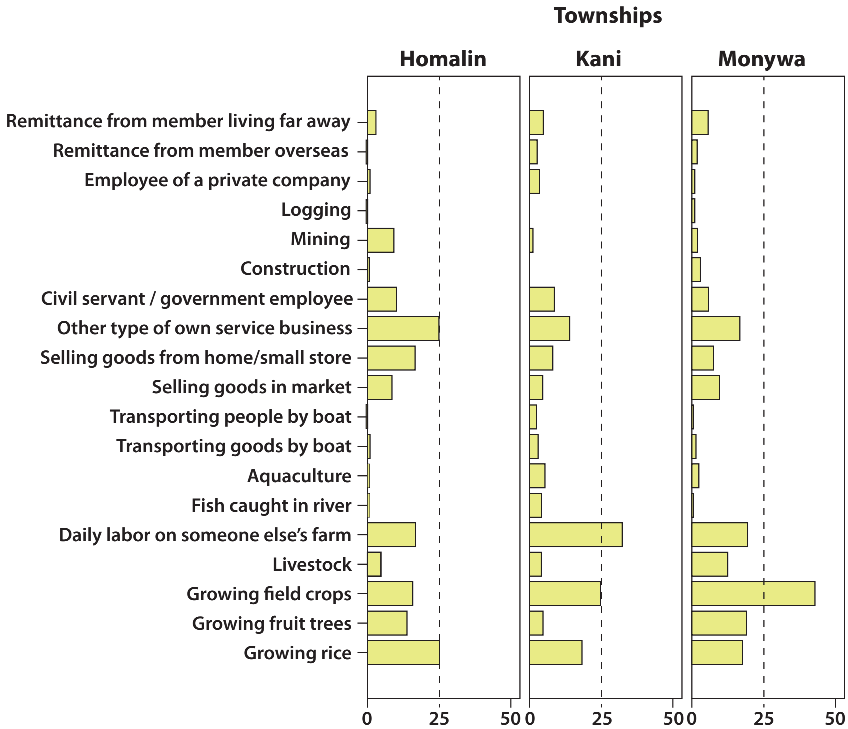
This section provides a summary profile of the respondents in Kani, Monywa and Homalin townships. Women comprised 54 percent of the total number of sampled respondents. Only 13 percent of households in all townships were headed by single women. The majority of the respondents in all townships had completed at least primary and secondary education (79.3 percent).

The most common average monthly income group (30.7 percent) was in the income bracket between US$7 to US$18. Kani township had the highest percentage of persons (30 percent) in the lowest income bracket (per capita income less than 7 US$/month) compared to Homalin (26 percent) and Monywa (24 percent). Kani also had the lowest percentage (10 percent) of people in the highest income bracket (per capita income more than 53 US$/month) compared to higher percentages in Homalin (19 percent) and Monywa (20 percent). The majority of persons in all three townships (84 percent) were under the World Bank's global per capita income for extreme poverty threshold of US$57 a month (or US$1.90 a day).[4]

Of the total surveyed households, 17 percent were engaged in agriculture, which included being daily wage laborers, keeping livestock, and growing field crops, fruits and vegetables. The percentage of households with income from agricultural sources was highest in Monywa at around 21 percent. Growing cash crops such as musk melons and watermelons was the most common income source for households in Monywa (40 percent) compared to 25 percent for households in Kani and 15 percent in Homalin. In Kani, income from being a day laborer on someone's farm was the main source of income for 30 percent of households. This was less common in Monywa (20 percent) and Homalin (16 percent). In Homalin, rice farming was the most common income source for most households (25 percent). In Kani and Monywa, 15 percent of households relied on rice farming as an income source.

An average of around 12 percent of households also owned small stores or market stalls. In Homalin, owning a small business was the most common income source for households (25 percent). This was less common in Monywa (21.2 percent) and Kani (15 percent). Homalin households also had the highest percentage of households making an income from selling goods (18 percent).

Figure 9.2 Household income sources 2015 (%, N = 600)



Other income sources included mining, civil service, fishing and transporting people and goods by boat (**Figure 9.2**). The percentage of households (12 percent) with income from mining was most prevalent in Homalin compared to Monywa and Kani where there were almost no households with incomes from mining. It is possible that gold mining may be declining. One resident from Naung Po Aung village in Homalin observed, "Farmers changed from farming to gold mining and rented their farm land to other people. The economy, health, and social activities of this village depended on gold mining, but I think the income which comes from gold mining, it is decreasing." A resident of Kyaw Yar village in Homalin also noted, "The local people here used to plant green tea, then they went off to work in the gold mining and metal mining areas. Yet now, the income from gold mining is decreasing and so the local people are changing back to growing green tea." The average number of income sources per respondent was similar in the three townships: Monywa (1.68), Homalin (1.50), and Kani (1.43).

Most households in all three townships had limited connectivity to a stable electricity supply and piped water. Only 24.3 percent of households were connected to a stable electricity supply and 11 percent on average were connected to municipal piped water. Monywa stood out amongst the other townships as having the highest connectivity to municipal services, with 60 percent of households having an electricity connection and 26 percent with access to piped water. Kani had the lowest connectivity rate, as no households had access to electricity, and only 1 percent was connected to piped water. In Homalin, 13 percent of households were connected to electricity and 6 percent were connected to piped water.

Perceptions, uses and management of water resources

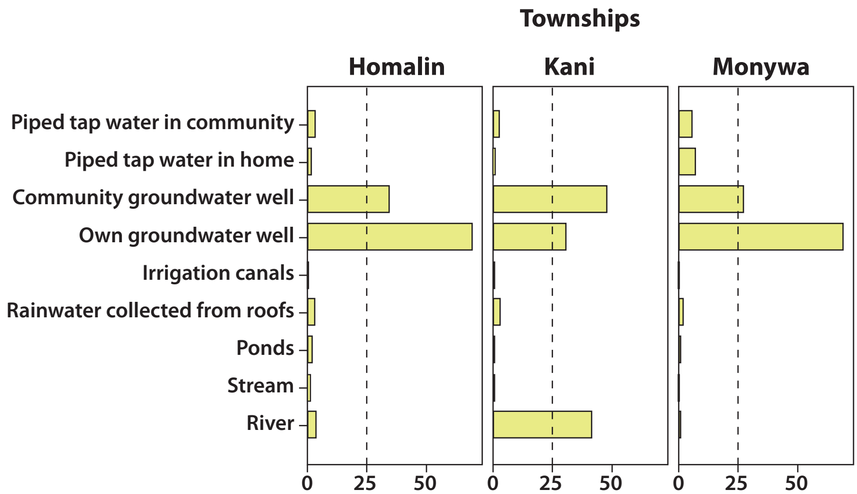
This section will describe the drinking, domestic and agricultural uses of water from different sources and their changes over time in the three study sites. It will also highlight the respondents' observations and perceptions of changes in the Chindwin River and the sources of these changes.

Domestic water use

In all three sites, water for domestic use came primarily from groundwater, although in Kani, river water was also an important source. According to **Figure 9.3**, all households relied most heavily on groundwater from community or household tube wells in all three townships for drinking water use. Kani had the highest potable water sourced from community groundwater wells at 50 percent followed by Homalin (35 percent) and Monywa (25 percent). In Homalin and Monywa, over 90 percent used their own tube wells for drinking water while in Kani, about 30 percent used personal wells.

Kani households had the highest reliance for drinking water from the Chindwin River (40 percent). Very few households in Homalin and Monywa relied on the Chindwin River for drinking water.

Figure 9.3 Potable water sources for households, 2015 (%)



In terms of non-potable, domestic water use (**Figure 9.4**), the profile was also similar, with households in Kani relying heavily on community tube wells and those in Monywa relying heavily on personal tube wells. Kani once again had the highest community tube well use (50 percent) followed by Homalin (27 percent) and Monywa (25 percent). Monywa had the greatest reliance on personal tube wells (75 percent), followed by Homalin (63 percent) and Kani (30 percent). Kani households (50 percent) relied the most on the Chindwin River for non-drinking water, followed by Homalin (20 percent). Monywa households did not use river water, most probably due to their easy access to household and community tube wells.

Most respondents from Homalin and Kani perceived that the availability of water resources had declined while those from Monywa perceived that water availability had declined slightly (**Figure 9.5**).

There was a preference amongst households within the basin for the convenience and in terms of water quality of having tube wells for drinking and domestic use. One resident in Zee Taw village, Monywa explained, "I don't use river water because I am too lazy to go there. The tube wells are full of water and every house has one." In Homalin, only residents without access to tube wells relied on other sources of water. In

Nan Taw village, Homalin, a resident observed, "Some people do not have tube wells, so they use the water from hand [dug] wells that contains oil. Washing clothes with this water turns them red."

Figure 9.4. Domestic water supply sources for households, 2015 (%)

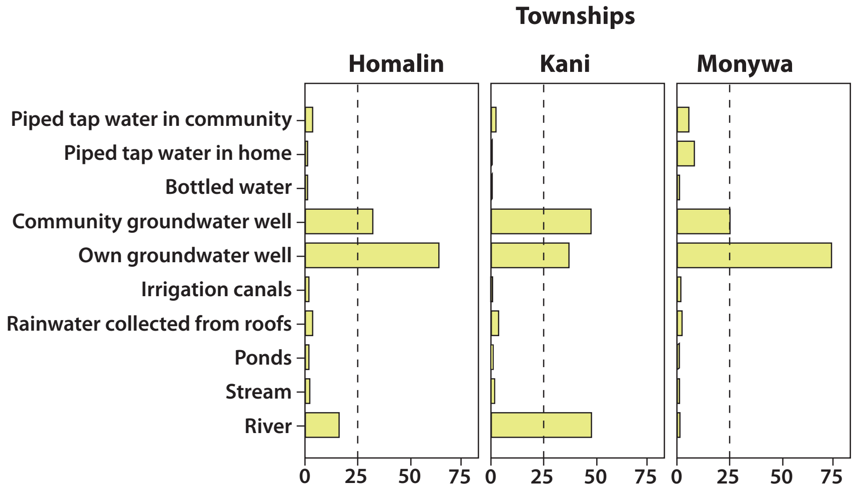
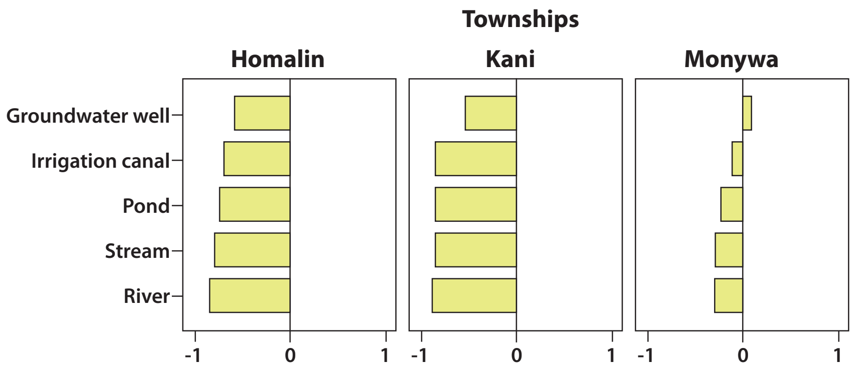


Figure 9.5 Perceived changes in water availability from various sources



Note: -1 (decreased), 0 (stayed about the same), 1 (increased).

Even in Kani, which had the highest number of residents relying on the Chindwin for drinking water, households also preferred to use tube wells. A resident of Aing Taung village in Kani stated, "In the past, we drank river water. Now we drink well water since it is easier to access compared to river water." Another resident of Aing Taung explained, "In the past, the river water was clear, and it was easy to reach the river, but now it is muddy and the water level in there is low. Now we are using tube well water."

The preference for tube well water was due to noted changes in the river's color, water availability and increased turbidity. Residents attributed these changes to upstream deforestation and gold mining. A resident from Kaw Yar village in Homalin explained, "The river water is shallower compared to ten years ago. Because of gold mining, the river water color has changed completely, and the water has become turbid." From Nan Taw village, Homalin, a resident observed, "The river is shallower due to sediment from gold mining. The water is dirtier, and the color has changed to red. Gold mining has degraded soils and has also caused deforestation. There are no trees left in the gold mining areas."

Residents of Homalin in particular were concerned about changes to the U Ru River, one of the Chindwin's tributaries. In Maing Kaing village, located by the U Ru, one resident compared the U Ru to how it had been ten years ago: "There is change in the depth of water and its quantity. It used to be quite deep before, but it is silted up now. There is less water and it is polluted." In Nan Taw village in Homalin, a resident reflected, "We used to be able to use this river for transportation and it was full of fish. The water was clean up until 1992. After 1993, the water could no longer be used for drinking."

The health impact of the river's poor water quality has been observed amongst some residents in all three townships, leading many to drink well water. In Nan Taw village, another resident said, "Women who work in gold mining and fisherwomen suffer from goiters and skin diseases." In Aing Taung village, Kani, one resident observed that "When the river water becomes muddy, children suffer from stomach issues. We used to drink river water but now, we do not. When we were young, about ten years ago, we drank the water. Now we drink well water." A community health officer in Nyaung Hpyu Pin, Monywa, spoke about health concerns associated with drinking river water: "We are afraid of chemicals used by gold miners at the river's origin. The water's color is not natural—sometimes it is red, blue or green. This impacts people's health. That is why we changed our drinking water source from river water to tube wells."

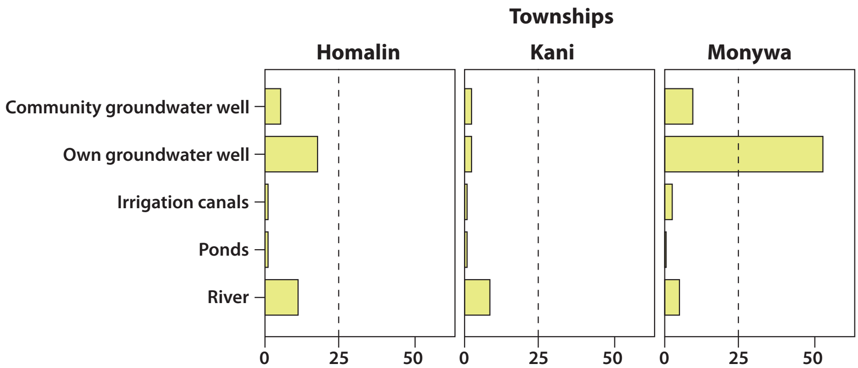
Despite a preference for tube wells, residents were also concerned about the decline in water quality from tube wells. The problem of salinity within tube wells affected residents of Zee Taw village in Monywa. One resident explained, "We have plenty of water resources, but the well in our village is saline and we can't drink it. That well is only used for bathing. For drinking and cooking, we draw from another well outside of the village." Another resident of the village shared, "There is saline water in the wells [in their village] so the villagers have to use water from elsewhere. If water from the village well is used for cooking rice, the color of the rice changes to yellow."

For other residents of the basin, the reliability and availability of water within tube wells were concerns. In Kaw Yar village, Homalin, one resident explained, "People here store rain water and tube well water in the rainy season because about 50 percent of tube wells dry up after the rainy season, especially in April and May." A teacher from the same village explained, "In the summer, during April and May, there is not enough water [from tube wells in the school] so the water has to be carried from neighboring houses. Oil for pumping water from the tube well is very expensive." A resident of Nyaung Hpyu Pin village in Monywa shared, "Ten years ago, some villagers started using underground water for drinking. Now there are many tube wells. If the water quality [from wells] is not good, we dig in another place. However, the quantity of water both in river water and underground water resources is a lot less compared to ten years ago. There is less water in the river and less ground water. We now experience water shortages every April and May."

Agricultural water use

Groundwater was the key source for irrigation. As shown in **Figure 9.6**, groundwater use for irrigation from personal tube wells was highest in Monywa (50 percent), followed by Homalin (20 percent) and very little in Kani. Less than 10 percent of households in all townships used community groundwater for agriculture. Homalin had the highest river water use for agriculture at 13 percent, followed by Kani at 10 percent and Monywa at 5 percent.[6]

Figure 9.6 Irrigation water sources for households, 2015 (%)



Some farmers relied on water from traditional water sources: the Chindwin River and its tributaries, its flood plains and rainwater. A resident from Kaw Yar village, Homalin, said, "Rain water is mainly used for agriculture and stored in a small embankment around the farm. Some people pump water from river and stream." In Nan Sa Kar village, Homalin, a resident stated, "Rain water as well as river water is used for agriculture. Some people also use water from the U Ru river while others use water from Nan Sa Kar stream." In Ka Ne village, Kani, one resident mentioned, "We take water for agriculture from the river. This only works when the water level within the Chindwin is high."

Yet this practice and reliance on the Chindwin River for agricultural uses appeared to be changing and farmers were turning to groundwater. In Monywa's Nyaung Hpyu Pin village a resident observed, "Cultivation on these lands has occurred since 1980. Thirty years ago, we had to hand dig wells. Now we pump up water with motors and we can expand the cultivated area and transport two trucks of fresh vegetables and flowers to the town market daily. The difference in crop productivity of using manual versus mechanical water supply systems is very significant." In Kani too, farmers were turning to tube wells. A resident of Kani's Ka Ne village observed, "We used river water for agriculture ten years ago. Now, water from the tube wells is mainly used."

One reason for switching their water sources for agriculture was due to uncertainties surrounding water availability from the Chindwin and with rainfall. A resident of Nyaung Hpyu Pin village in Monywa said, "There used to be a small tributary of the Chindwin River near our village. It has been nearly two to three years since river water has not reached that tributary during the rainy season." Another resident of the same village stated, "About ten years ago, river water was mainly used in for agriculture but these days, it is quite difficult to grow rice in our village because of lower river water levels. River water is still used only for lowland paddy, but groundwater is used for everything else."

In Kani too, there has been a change towards using groundwater for agriculture due to its greater reliability compared to rainwater. In Nyaung Wun Village, Kani, one farmer had switched to tube wells, stating, "Agriculture depends too much on rain which can cause a delay in the growing period. People who have wells can cultivate crops on time." A resident from Ka Ne village in Kani stated, "Ten years ago, river water was used for agriculture, now water from tube wells is mainly used because of irregular weather conditions." In Maing Kaing village, Monywa, one resident explained, "We have to use the water from tube wells for agriculture because of climate change. Ten years ago, we used rain water for agriculture. Now, we use water from the well."

Despite high reliance on groundwater, for some farmers in Monywa, the reliability of groundwater was declining. In Nyaung Hpyu Pin village, Monywa, there were concerns about soil salinity due to groundwater use: "There is a soil salinity problem: because of this soil problem, we cannot grow rice. As flooding has not occurred in the floodplain for six years, we can't grow rice." In Zee Taw village in Monywa, one resident remarked, "There is a salinity problem with some wells. I think the groundwater resources in our area have a lot of dissolved salts."

The government had provided surface water irrigation schemes for some villages in Monywa such as Zee Taw, Nyaung Hpyu Pin and Thar Pon Kaing, but these systems were not consistently reliable. In Zee Taw village, another resident stated, "For agriculture we get water from Inntaw dam (a nearby reservoir) for irrigation. The water [supply] is not regular, so we cannot grow rice." Another farmer from the same village explained, "We use water from wells [for agriculture]. Ten years ago, we got connected to irrigation water supplies. As the water pump . . . . by the irrigation department broke down, we had to start digging our own wells. We asked the irrigation department to fix the pump, but they could not. The tube wells have also started to run dry." In Nyaung Hpyu Pin village, a resident noted, "We received irrigation water supply ten years ago but [the pump] has been damaged and has not been repaired yet."

Social and institutional relations: RBO participation

At the national level, high-level water resources management committees like the National Water Resources Committee (NWRC) have taken a keen interest in integrating bottom-up approaches to water management. This is reflected in Myanmar's National Water Policy (2014), which was formulated by the NWRC and calls for the institutionalization of basin level, community-based water management mechanisms (Tun et al. 2016: 32). A type of mechanism that is widely used for water management globally is a river basin organization (RBO),[7] which draws from the principles of inclusive and participatory approaches to water resources management outlined in Agenda 21 of the Earth Summit in Rio de Janeiro (1992) and in the Principles from the Dublin Conference on Water and the Environment (1992) (Bandaragoda 2000: 11–26).

A key driver behind forming a Chindwin RBO is to engage multiple stakeholders for improving water resource governance and managing threats to the watershed such as deforestation, mining and agricultural expansion. Thirty KIIs were conducted to identify key issues around water management within the Chindwin River Basin and gather recommendations about forming a Chindwin River Basin Organization (RBO). For the Chindwin River Basin, KIIs identified navigation, water quality and riverbank erosion as primary environmental concerns.

In Myanmar, establishing cooperative governance amongst natural resource-related agencies to comprehensively and effectively manage environmental issues is a challenge. Today, natural resource-related government line agencies, without any laws defining an overarching goal towards sustainability or environmental conservation, operate independently and are guided by their own agency mandates. The creation of the Environmental Conservation Department (ECD) under the Ministry of Natural Resources and Environmental Conservation (MONREC) in 2011 is an attempt to mainstream environmental conservation into the activities of various departments. Yet, based on key informant interviews, mainstreaming has been challenging in the water sector. Water-related agencies such as the Directorate of Water Resources and Improvement of River Systems, the Department of Irrigation and the Department of Hydropower Planning are under separate ministries, where they continue to carry out their mandated activities (e.g., dam, weir and reservoir construction) without consultation about the impact of one department's activity on that of another nor joint decision-making on water allocation per sector (i.e. agriculture and energy).

Indeed, KIIs with key actors in water resources management revealed that there is currently no entity within the Sagaing Region to manage all aspects of water use. Informants recommended cooperation as a key need for the operation of a functional RBO. One informant from the government commented, "[The RBO would be] better if there are those within the RBO who can connect with various government institutions to facilitate cooperation. We [the government] don't have strong cooperative management. Members of the RBO should not only be government departments, it should cover all those concerned, especially people from the most affected areas." Another government informant added, "Systematic cooperation is necessary to overcome any difficulties. The process must be transparent and cooperative."

A question of importance is how a multi-stakeholder basin authority like an RBO can function within the current system of governance. Within the water sector, there is continued reliance on a top-down approach. Most policies and directives are issued from the national level to be implemented at the subnational level. For example, NWRC's National Water Policy calls for an inclusive and bottom-up approach to basin management, but it is unclear how the necessary financial, technical and human capacity support will be dispatched to ensure implementation of this goals. The desire for integrated and inclusive water management at the national level is not reflected in the practices at the regional level.

Despite inclusive governance not being reflected in the current practices, there is a strong desire from the regional government, as well as other stakeholders, to engage with basin communities, particularly through public awareness raising. An informant from the government remarked that in order for an organization like the RBO to be successful, it "must meet with local communities and business people; they should be invited to meetings to raise awareness to encourage their cooperation." An informant from civil society suggested specific mechanisms for the management of the Chindwin Basin, "There should be river conservation teams in each township. Those who are interested in volunteering should take part, it will be better [for water governance] if they are involved. If [the RBO] has only one main office in Monywa, it is not that good. There should be its branches in each township as well. It will be more effective and the local people along the river will be more convinced to be a part of it."

Thus, the main benefit of the RBO in Sagaing would be to establish stronger links between the regional government and communities, as well as businesses, around the issue of conserving the Chindwin River. Under a unified goal of raising public awareness to conserve the Chindwin River, the interactions amongst public, private and civil society will over time strengthen to form a truly integrated, bottom-up approach to manage the Chindwin River and overcome the current siloed and top-down approach to governance.

Discussion

Based on the household profiles, households in the study sites were extremely poor, with per capita incomes of less than US$1.90 per day, and rural, with extremely limited access to electricity and piped water. Our findings also show that in addition to carrying the burden of poverty, households were also facing water-related hardships, particularly declining water quality and water availability in the Chindwin as well as groundwater.

Land-use decisions have increased activities, like mining, that have caused environmental degradation in the watershed areas. Many individuals and households observed that compared to the previous ten years, the Chindwin's water quality had declined, citing the changes in the river's color, sicknesses from drinking river water, and muddiness or high sedimentation. Many also attributed mining and deforestation as the causes of these changes.

Indeed, mining and deforestation have increased in the basin in recent decades. Some areas within the Chindwin River Basin are rich in mineral resources, primarily jade and gold, but also copper and coal. Sagaing and Kachin states, based on satellite imagery, have the largest areas of mining in Myanmar. Over 60 percent of the mining areas in these states had been added between 2002 and 2015 (LaJeunesse Connette et al. 2016: 9). Mining is associated with increased sedimentation, due to the removal of forest cover (Latrubesse et al. 2009: 239–52) and poorer water quality (Obiri et al. 2016). Studies have found that even small-scale artisanal gold mining has a range of negative social and environmental impacts, including deforestation, water contamination, mass migration and illness among miners (Papworth et al. 2017: 1). In the upper Chindwin River in Kachin State, jade mining has resulted in forest clearing for hydraulic and pit mining operations and has also caused soil erosion, leading to floods and landslides in the state (Global Witness 2015: 9–79).[8] In Kachin State, gold mines have also been associated with tree cover loss (Papworth et al. 2017: 5–6).

Large-scale agricultural concessions also have significant impacts on forest cover. Indeed, a study of two agricultural concessions granted in Kachin State in 2006 were strongly associated with tree cover change (Papworth et al. 2017: 3–4).

Another concern raised by households was the decreasing availability of river water. The survey results showed that most households perceived a decline in water quantity. KIIs also reveal that water availability within the Chindwin River had changed, with informants noticing that the river was "shallower" as compared to ten years before. Communities living within the vicinity of the U Ru River noted that they could no longer use the river for transportation and that it had too much "silt." In some areas like Nyaung Hpyu Pin, tributaries no longer extended to the villages they used to reach. Elsewhere, the floodplains where farmers used to cultivate crops no longer existed. Lastly, residents were noticing changes in rainfall, citing late rains and weather irregularities.[9]

Less reliance on river water

The changes in water quality and quantity places the burden on households to find reliable and clean sources of water for drinking and domestic use. Households have responded to these conditions by switching from river water to groundwater. Ten years ago, many households, particularly those in Homalin and Kani townships, relied solely on the Chindwin River for all their water needs, yet many households were now resorting to groundwater.

For drinking and domestic water, Monywa and Homalin in particular relied on groundwater from household tube wells. In Kani, the poorest of the townships, the water use profile was slightly different, with about half of households relying on groundwater from community wells for drinking and domestic use, while the other half relied on water from the Chindwin. Households cited accessibility and better quality as reasons for preferring groundwater.

Though farmers were switching to using groundwater for agriculture, KIIs reported water availability and quality issues related to agricultural water. In Monywa, households in Zee Taw reported salinity in tube well water, as well as decreased water supply from both tube wells and Chindwin tributaries. Despite being the only township out of the three surveyed that had access to irrigation, households in Monywa reported that there was poor local government maintenance of these structures, so they could not use them. In Kani and Homalin, farmers relied on water from the Chindwin River and its tributaries, floodplains and rainwater; however, farmers preferred to use groundwater as they felt it was more reliable and predictable than rainfall and river water. Some farmers here who had switched encountered new challenges: in Kaw Yar village households reported that half of the wells dried up in the summer months.

Diversification of income sources

The declining water quality and supply in the Basin was especially hard on farming households who depended on a consistent water supply to support their livelihoods. Agricultural-based income sources were still the most common in the region. Although farmers have chosen to use groundwater for agriculture, the cost of owning wells is high. As the interviews revealed, the cost of diesel for the pump was expensive and perhaps prohibitive for many farmers. Indeed, Pavelic et al. (2015) found that the greatest challenge for farmers owning wells for agricultural purposes in Monywa and surrounding areas was the high cost of fuel for running their diesel pumps. A fair amount of financial investment was therefore necessary to irrigate crops using groundwater and hence it is beyond the reach of the poorest farmers (Pavelic et al. 2015: 19).

Thus, a diversification of income sources allowed households, particularly poor farming households, to ensure greater financial security. The diversification of income sources to non-farm income has been observed in other rural contexts (Deininger and Olinto 2001: 455–65; Escobal 2001: 497–508). Households were diversifying their income options to non-agriculture-based occupations that included mining, working for the government, operating a small business, or buying/selling goods at the market. Indeed, on average, all households had more than one income source.

The chain reaction of environmental degradation caused by the agricultural and mining concessions has led to a decline in water quality in the Chindwin. For all these communities that have long relied on the Chindwin River for all their water needs, this has directly impacted their lives. While households were changing their water use and diversifying their income sources to cope with their hardships, these strategies are temporary and short-lived. As we have seen, farmers invested in tube wells to switch to groundwater to continue cultivating crops, yet groundwater is also becoming unreliable in quantity and quality. Households may diversify their income sources to include mining, but this solution, too, is short-lived, ending when the resource is depleted or when the demand for the commodity declines. This has happened in Homalin where some farmers who switched to gold mining were now going back to farming.

The underlying cause of the systemic poverty and water stress in this region is the lack of alternative livelihoods for communities within a degraded environment. Without government interventions to relieve communities of water stress through the provision of electricity supplies and piped water, communities were forced to continue relying on their degraded environment through participation in environmentally destructive mining and the excessive extraction of groundwater.

Conclusion

This study uses KIIs and household surveys to understand water use and perceptions around water use within three townships in the Chindwin River Basin. We also consider how the political economy of natural resource governance in Myanmar has shaped the social and physical landscape of the Chindwin River Basin.

Through this study, we have been able to provide a snapshot of the changing circumstances in three townships that affect water use. One key observation is the drastic decline in the water quality and quantity of the Chindwin River within a very short space of time in the early to mid-2000s. Poor water quality is certainly linked to the large-scale land concessions for mining and agribusiness during the junta era. Declining water availability within the Chindwin was also a concern, although we did not explore its causes in detail.

Households coped with water stress by changing to groundwater. The main reasons for this change were greater convenience, accessibility, better quality and availability. Households also had to diversify their income sources to reduce the hardships from poverty and cope with changes in their environment and uncertain water resources. We argue that farming households have more reason to change as they are the poorest and experience the greatest water stress.

Myanmar is undergoing tremendous political and economic change. Under the National League for Democracy (NLD) administration from 2015 to early 2021, there were efforts towards greater decentralization and authority to state and regional governments. For the Chindwin River Basin whose boundaries lie primarily within the jurisdiction of the Sagaing regional government and Kachin state government, decentralization and greater subnational government authority bring possibilities to shape the direction of development towards progressive, social and environmentally minded reforms. Additionally, NWRC, the apex water body, has identified inclusive, bottom-up approaches to water governance as a key development strategy for the country. At the regional level, there is a keen interest amongst stakeholders in government and civil society alike to engage local people in managing the basin. With so much interest in inclusive and multisectoral water governance, there is much potential for forming a Chindwin River Basin Organization as a priority to ensure sustainable livelihoods opportunities are created for communities within the basin.

Notes

1 Junta rule began in 1962 when General Ne Win came to power and ended in 2016 when the NLD government came to power (Schreiner 2017: 3–6).

2 The classification of land as wasteland since British colonial times has been more for political purposes than for the actual value of land as the word literally applies. Historically, lands have been labelled as ‘waste land’ for not generating enough revenue for the state or for being used by people considered enemies of the state (Ferguson 2014: 306–7).

3 Interviews were conducted with national and regional stakeholders in 2015, 2016 and 2018. *Public entities*: representatives from Ministry of Agriculture, Livestock and Irrigation; Ministry of Natural Resources and Environmental Conservation; Ministry of Transport and Communications; Ministry of Energy and Ministry of National Planning and Economic Development and Members of Parliament; *private entities*: Members of Water Transportation Association and Gold Mining Businesses; *civil society*: Youth associations and women’s associations; *educational institutions*: academics.

4 The World Bank International Poverty Line to define extreme poverty is

US$1.90/day. See: https://datahelpdesk.worldbank.org/knowledgebase/articles/193308-there-are-multiple-international-poverty-lines-wh.

5 Farmers in all townships typically grew pulses and legumes such as sesame, peanuts, soybeans, chickpeas and mung beans. Farmers in Homalin typically had tea bushes while farmers in Monywa grew musk melons and watermelons as cash crops.

6 Direct rainfall is important in all locations, particularly in the wet season based on KIIs, but this was not asked in the survey.

7 Examples include the Mekong River Commission (MRC), the Okavango River Basin Water Commission (OKACOM) and International Commission for the Protection of the Rhine (ICPR) (Schmeier 2010: 9–26).

8 Casualties caused by landslides in mines are common in Kachin. See e.g.: https://www.mmtimes.com/national-news/mandalay-upper-myanmar/24926-nine-killed-in-kachin-jade-mine-landslide.html.

9 The reasons for decreasing groundwater availability are not explored in this chapter.

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Part IV

Dialogues, stakeholder perspectives and institutional efforts

10

Water governance institutions in Myanmar

May Thazin Aung and Bernadette P. Resurrección

Rapid economic development in Myanmar since the country opened up in 2011 has placed great pressure on its existing water resources. The Ayeyarwady River Basin, home to Myanmar's most culturally significant river, is a site of competing uses for mining, hydropower, navigation and agricultural expansion. Meanwhile, increasing deforestation and mining activities have increased sediment loads within the river, making it difficult for the transport of manufactured goods and raw materials. Increased industrial and mining activities also threaten water quality, affecting drinking and domestic water uses for communities (HIC 2017: 16–249).

Water governance institutions are integral to ensuring that water quality and quantity needs are met for all water users: villagers, farmers, townsfolk and industry alike. There have been many efforts to formulate an integrated and comprehensive water governance policy in Myanmar since 2011, and there have also been some institutional reforms. The most notable of these is the establishment of National Water Resources Commission (NWRC), an apex body formed to formulate water laws and coordinate all water-related activities in Myanmar. It was originally formed by former president Thein Sein's Presidential Decree in July 2013 and remains as the apex water institution to date. Under the NLD administration there were also improvements in areas of water governance, as evidenced by the acceptance of foreign assistance from the World Bank, Australian, Norwegian and Dutch governments to improve scientific understanding, building technical capacity, enhancing public participation and building collaborative partnerships in the water sector. Though reform efforts are taking place, obstacles remain as water management in Myanmar is convoluted, being characterized by myriad laws, policies, and overlapping agency mandates and agencies.

Thus, the overall aim of this chapter is to provide a comprehensive overview of water governance in Myanmar, which includes the various water-related institutions, their roles in water management and the framework of water laws and policies. The chapter summarizes key findings based on a literature review and key informant interviews (KIIs), conducted between 2015 and 2018, with key water agencies, non-profits and civil society on the status of and challenges to water governance.

The chapter is organized in the following way: the first section on policies, legal frameworks and institutional arrangements provides an overview of laws and policies on water governance in Myanmar. This is followed by a section on key actors and institutions which describes the functions of relevant national level committees, line agencies, civil society and international institutions who play a role in water management. The next section discusses key challenges to water governance and constraints faced by water institutions. The conclusion offers insights on the future of water governance in Myanmar and some recommendations based on the findings of the studies about the Chindwin River Basin in this book.

Policies and legal frameworks

Authorities and rights over natural resources

The 2008 Constitution of Myanmar stipulates that the state, particularly the national government, has the ultimate authority over the ownership and exploitation of natural resources: "The Union government is the ultimate owner of all lands and all-natural resources above and below the ground, above and beneath the water and in the atmosphere in the Union" (Government of Myanmar 2008: 10).

State and regional governments have some discretion in natural resource management; Myanmar is sub-divided into seven states and seven regions, as well as six predominantly ethnic, self-administered zones. A chief minister, appointed by the President, leads the region and coordinates the functions of departments and sub-departments. The chief minister selects a minister to head each line agency as members of the Cabinet (Nixon et al. 2013: 9–55). A 2015 amendment to the Constitution, Law 45, provides state and regional governments discretion to manage their natural resources, provided that their activities are compliant with Union level laws (Pyidaungsu Hluttaw 2015: 1–5).

Laws

The Water Law has been under discussion by the NWRC since 2013 (Thant 2016). In 2017, the government announced plans to begin public consultations for the water law with assistance from the World Bank (Phyu 2017). In the absence of a water law, the most important pieces of legislation for controlling pollution and managing impacts from development projects are the Environmental Conservation Law (2012), which requires Environmental Impact Assessments (EIAs), and a subsequent set of laws formulated under it, including the Environmental Conservation Rules (2014), Environmental Impact Assessment Procedures (2015), and Environmental Quality (Emission) Guidelines (2015).

Further, sectoral agency mandates govern each water-related line agency's day-to-day functions and include a variety of other specialized laws that are also important for water management. A selected list of laws and their purposes are summarized in **Table 10.1**.

Policies

The National Water Policy was approved in 2014 and is the first integrated policy addressing all bodies of water, including underground water. The document speaks to both substantive and procedural aspects of water management. Procedurally, it emphasizes water as a common pool resource to be managed by the state at the basin scale through basin authorities, and by following the principles of good governance such as transparency, informed decision-making and public participation (IFC 2017: 39; Tun et al. 2016: 1–55). It compels all levels of government to act to provide access to clean water to all citizens: "The Union, the Regions and States, and local bodies (governance institutions) must ensure access to minimum quality of portable water for essential health and hygiene to all its citizens, available within easy reach of each household" (Oo 2015: 33). It also highlights bottom-up approaches, calling for the institutionalization of community based water management: "Community based water management should be institutionalized and strengthened not only for water utilization but also for technology transfer " (Tun et al. 2016: 32). Substantively, the document highlights the interdependent nature of water bodies and calls for consideration of maintaining minimum ecological functions and climate change impacts in water planning (IFC 2017: 40).

Table 10.1 Laws related to water governance in Myanmar

Law	Year	Description
The Burma Canal Act	1905	Authorizes the overall control of water; regulates irrigation, navigation and drainage, and the use and control of water in rivers, streams, lakes and other water bodies for public purposes
Underground Water Act[a]	1930	The conservation and protection of groundwater resource supplies
Factory Act	1951	Manages waste and effluence from factories
Territorial Sea and Maritime Zone Law	1977	Defines maritime boundaries and gives Myanmar exclusive jurisdiction over the preservation and protection of the marine environment within its territories and prevention of marine pollution
Marine Fisheries Law	1990	Conserves marine fisheries to ensure production
Forestry Law 1992	1992	Conserves natural forests and biodiversity
Protection of Wildlife and Wild Plants and Conservation of Natural Areas Law	1994	Protects wildlife and wild plants, and conserves natural areas
Myanmar Mines Law	1996	Regulates mining activities to minimize impact of mining on the environment
Conservation of Water Resources and Rivers Law	2004	Conserves and protects water resources and river systems to benefit public users by ensuring safe navigation along rivers and creeks and prevent serious environmental impacts in waterways
Environmental Conservation Law	2012	Provides the Ministry of Environmental Conservation and Natural Resources (MONREC) the authority to establish systems for environmental protection such as Environmental Impact Assessments (EIAs)
Environmental Conservation Rules	2014	Further clarifies MONREC's mandate for environmental protection and specifies the types of projects which must conduct EIAs
National Environmental Quality Emissions Guidelines	2016	Provides a basis for controlling noise, air emissions and water pollution
Environmental Impact Assessment Procedures	2016	Outlines procedures conducting EIAs as required in the Environmental Conservation Rules

Note: [a] An updated law for conservation of groundwater is in progress. See: https://www.mmtimes.com/news/law-drafted-save-underground-water.html.

Sources: Nyunt 2008: 299–300; Soe and Kyi 2016; ADB 2017: 1–8; Gutter 2001: 5.

Guided by the water policy, the National Water Directive, adopted by the NWRC in 2014, provides a framework for drafting a National Water Law. This document is important for water management in Myanmar as it emphasizes a holistic rather than sectoral approach. This policy framework, inspired by the EU Water Framework Directive, includes seven important principles for an integrated water management approach, including the prioritization of water quality for humans and ecosystems, use of the river basin management approach and national and subnational government cooperation (Nesheim et al. 2016: 22–23).

Other natural resource-related policies are also important for water management. The draft National Environmental Policy serves as a guiding principle for the environmental sector, which replaced the previous version from 1994.[1] The document provides guidance for the development of the environmental sector and covers three priority areas: health, ecosystems, and sustainable development (Hnin 2017). The subsequent draft of the National Environmental Strategic Framework, which falls under the National Environmental Policy, is notable for its provisions on water management requiring the establishment of inclusive and transparent institutional processes to ensure integrated water management (IFC 2017: 40).

Planning documents such as sectoral master plans and strategic action plans formulated by ministries and minister's directives also affect water resources management.[2]

Key actors and institutions

Apex bodies

NWRC is an apex water governing body which was originally formed in July 2013 by former president Thein Sein. In 2016, NWRC was reformed under the leadership of former vice president U Henry Van Tio. NWRC is responsible for the development of water policies, and strategies for water resources management (IFC 2017: 41–2).

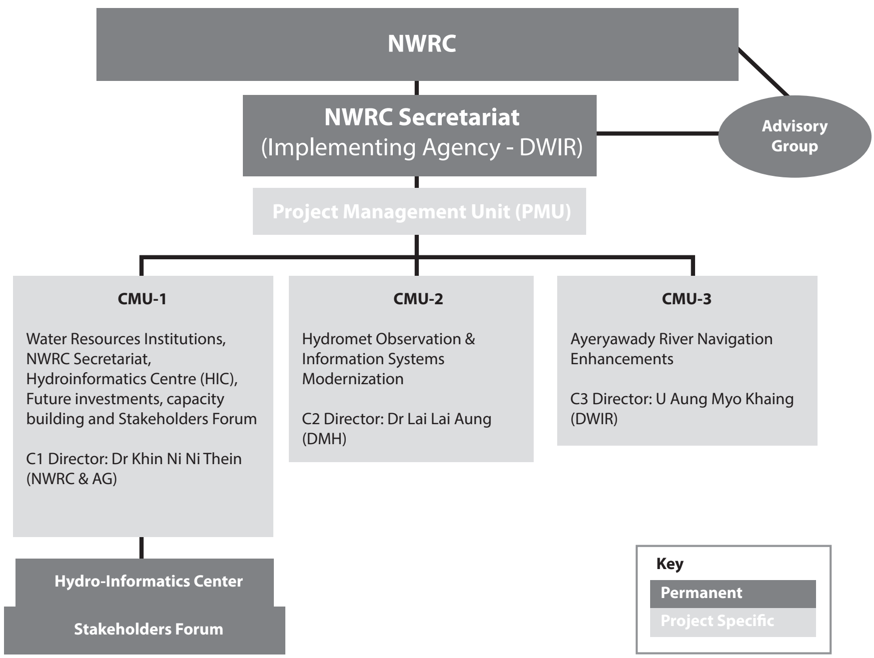
The membership of NWRC is comprised of 20 members with representatives from the ministries of: Border Affairs; Agriculture, Livestock and Irrigation; Transportation and Communications; Natural Resources and Environmental Conservation; Electric Power and Energy; and Planning and Finance. The committee also includes the mayors of

Nay Pyi Taw, Mandalay and Yangon, and nongovernmental water experts (Phyu 2016; IFC 2017: 41–2).

NWRC is organized into three main entities: the Secretariat, Hydro Informatics Center, and the Advisory Group (see **Figure 10.1**). The Ministry of Transportation and Communications serves as the focal ministry, with the Director General of Directorate of Water Resources and Improvement of River Systems (DWIR) serving as the secretary. The Advisory Group of thirteen full-time members and ten part-time members advises the secretariat and NWRC. HIC supports the NWRC's decision-making in fulfilling its mandate (AIRBM 2016).

Another high-level committee of importance is the National Environmental Conservation and Climate Change Central Committee (NECCCCC) formed in 2016. NECCCCC is a reiteration of the National Commission for Environmental Affairs (NCEA) which was

Figure 10.1 National Water Resource Committee organization chart (AIRBM 2016)



formed in 1990 under the Ministry of Environmental Conservation and Natural Resources. NCEA's original responsibilities were ensuring the sustainable use of environmental resources and coordination amongst government agencies on various aspects of environmental and natural resources management, including water (Kattelus et al. 2014: 89–90).

The current NECCCCC has similar responsibilities to NCEA and is now responsible for formulating policies, strategies and work plans related to climate change and the sustainable use of natural resources. NECCCCC also has sub-committees at subnational government levels. The committee is chaired by the minister of MONREC. The committee is supported by six sub-committees on policy and laws, industry and development, climate change, conservation, capacity building and education, and green economy and growth (Myanmar President Office 2017; MONREC 2017).

Line agencies

There is currently no single ministry overseeing water resource management in Myanmar. Instead, several departments under different ministries engage in different aspects of the water sector for navigation, energy, household use and agriculture. The main ministries housing departments with a major share of water-related responsibilities are the Ministry of Agriculture, Livestock and Irrigation (MOALI), Ministry of Electricity and Energy, Ministry of Transport and Communications, and Ministry of Natural Resources and Environmental Conservation (see **Table 10.2**).

Under MOALI, the Department of Irrigation and Water Management (IWUMD) and the Department of Rural Development (DRD) are responsible for the management of irrigation canals, groundwater and rural water supplies. IWUMD's priority is the provision of water for irrigation. The consolidated IWUMD was formed in 2015, and is a merger of the former Irrigation Department (ID) which was responsible for supplying efficient and increased irrigation for agriculture, and the Water Resources Utilization Department (WRUD), which developed irrigation for agriculture, providing pump irrigation and rural water supply. The Department of Rural Development (DRD), also under the ministry, is primarily responsible for poverty reduction, but also for rural household water supply (Van Meel et al. 2014: 73)

Table 10.2 Selected government agencies with key roles in water management

Government agencies	Mandates and responsibilities
Ministry of Agriculture, Livestock and Irrigation Department of Irrigation & Water Management Department of Rural Development	Provision of water for irrigation dams and canals, recording water levels; rural water supply. Water quality for agriculture. Installation of flood protection embankments
Ministry of Electricity and Energy Department of Hydropower Implementation	Oversees electricity generation and the provision of water for hydropower; oversees planning, construction and operation of hydropower dams
Ministry of Transport and Communications Directorate of Water Resources and Improvement of River Systems Department of Meteorology and Hydrology	Monitoring water quality, sediment flows and salt intrusion on main rivers and tributaries; maintaining waterways for safe navigation of water vessels. Bank erosion control
Ministry of Natural Resources and Environmental Conservation Environmental Conservation Department Department of Mines Forest Department	Rehabilitation and conservation of forests and watersheds; environmental conservation and management; promulgating environmental policy, industrial pollution control and water quality

Sources: KIIs; Nesheim et al. 2016: 21; IFC 2017: 40–41.

Under the Ministry of Electricity and Energy (MOEE), the Department of Hydropower Implementation (DHPI) is responsible for hydropower development. According to the department's mandate, based on informants, the department has jurisdiction over waterways which are five miles upstream and downstream of large (over 100MW) dams. Beyond this, the authority of waterways falls to DWIR. Before 2016, when the Ministry of Energy and Ministry of Electrical Power (MOEP) were merged to form MOEE, MOEP was under two sub-ministries, Ministry of Electric Power 1 and 2. MoEP 1 was responsible for generation of electricity and hydroelectric power implementation, including developing new hydroelectric power projects and the operation and maintenance of existing ones, while MoEP 2 was responsible for transmission and distribution of electricity (MOEE 2018).

The Ministry of Transport and Communications houses the two departments with key responsibilities in water management. These two departments, the Directorate of Water Resources and Improvement of River Systems (DWIR) and the Department of Meteorology and

Hydrology (DMH), have jurisdiction over river systems which includes the mainstems of major rivers and large tributaries. Based on KIIs, DWIR is mandated to conserve and protect inland waterways for smooth and safe navigation, although more recently, they have expanded the scope of their activities from waterways into river systems more broadly. Their primary responsibility is to ensure safe navigation in rivers, and they do so by conducting river engineering, or "river training" and dredging for improvement of waterways and new navigation channels (DWIR 2014; van Meel et al. 2014: 41). Yet, they also fulfill obligations to protect river systems by protecting riverbanks from erosion, surveying water quality and conducting hydrological surveys and plans. The other department under the ministry, the Department of Meteorology and Hydrology, is responsible for issuing flood warnings and water monitoring activities such as measuring discharge, sediment flows, water quality and salt intrusion in major rivers and large tributaries (Nesheim et al. 2016: 21; van Meel et al. 2014: 36).

Lastly, under the Ministry of Natural Resources and Environmental Conservation (MONREC), the Environmental Conservation Department (ECD) serves as the main policy arm of the ministry which has promulgated environmental standards. From KIIs, their responsibilities include formulating environmental policies and strategies, reviewing environmental impact assessments and mainstreaming environmental plans and measures across other line agencies. The Forest Department (FD) is responsible for watershed protection and protects banks by planting native tree species. The Department of Mines was absorbed by the ministry after the Ministry of Mines was dissolved in 2016 (Gleeson and Lynn 2016).

Other actors

Based on KIIs, regional and national civil society are increasingly becoming more active in water resources management. The Myanmar NGOs are mainly volunteer non-profit groups. In the realm of environmental governance, these NGOs focus primarily on enhancing public participation through Environmental Impact Assessments (EIAs) and are active in other areas of natural resource management, such as building capacity for natural resource management within the public and community, and increasing awareness through advocacy against environmentally and socially impactful projects such as hydropower and coal projects.

Some notable environmental organizations like EcoDEV have emerged as a major non-state player in the environmental arena, especially as it began its advocacy activities to halt the construction of the controversial Myitsone Dam in the upper Ayeyarwady Basin. There are also networks of environmental NGOs such as the Myanmar Environment Rehabilitation-Conservation Network (MERN),[3] a consortium of 16 NGOs, "working for environmental rehabilitation and conservation activities linking with the development of local communities for their livelihood and food security." Some of the 16 NGOs have strong experience in forestry and environment, some in community development, capacity building and social mobilization, while others are strong in agriculture, livestock and fisheries.

The international community has also taken an interest in promoting a national integrated water resource management (IWRM) approach in Myanmar. Various bilateral and loan programs in the water sector have focused on establishing strong water institutions, producing reliable data and providing technical support to help work towards an integrated water management system. One example is the bilateral cooperation agreement between the governments of the Netherlands and Myanmar, which envisages technical assistance and support for developing an IWRM strategy in Myanmar (van Meel et al. 2014: 99–107). The Government of Norway through the Norwegian Institute for Water Research (NIVA) plans to implement an IWRM approach for inland waters at the national level. Plans also include establishing a national laboratory for analyzing water quality, and monitoring of the Inle Lake (Nesheim et al. 2016: 18–27; Tun et al. 2016: 1–54).

The most high-profile project is the World Bank's Ayeyarwady Integrated River Basin Management (AIRBM) project. This began in 2015 when the World Bank provided a US$100 million loan package to strengthen water resource management institutions, particularly NWRC, and build decision support systems and capacity. The project allowed for the creation of the Ayeyarwady River Basin Research Organization (ARBRO), which under the guidance of NWRC in 2012, undertook intensive assessment of various components of the river system, including surface water, groundwater, sediment and geomorphology. This State of the Basin assessment provides the information for comprehensive planning and management of the river basin (HIC 2017).

Gaps and constraints in water governance

As explained, there have been efforts to formulate an integrated and comprehensive policy on water governance in Myanmar since 2011. Yet, these efforts have not adequately addressed some of the major underlying issues behind water resources management in Myanmar. The first major issue is that water institutions are inherently not integrated. This is true of natural resource management in the country more broadly. Without an overarching goal for conservation or sustainability, line agencies in natural resource management continue to operate as if the activities of one department have no impact on those of another: as earlier mentioned, DHI and DWIR chop up authority over the river instead of managing it as a system. Similar instances of fragmentation are observed elsewhere. Water quality data is collected by DWIR from the river, DRD from tube wells and ECD for industrial waste water, and the information is not shared amongst departments (Nesheim et al. 2016: 21).

ECD is tasked with the role of environmental protection across all sectors and ministries. ECD, created in 2011, is yet to demonstrate whether it has the capacity to marshal inter-agency cooperation in addressing degrading water resources in an integrated manner. Instead, environmental protection continues to proceed in fragmented ways within the Ayeyarwady Basin: FD oversees forest and watershed conservation issues, DWIR oversees water navigation and water quality concerns, and IWRUD oversees surface water irrigation in irrigation canals. As a result of this fragmentation at the departmental level, water professionals tend to approach watersheds as individualized sectors rather than as a system.

This leads us to question the efforts of NWRC. There are both positives and negatives to having an institution like NWRC that uses a top-down approach to reform water resources management. On the plus side, having a multisectoral apex body comprised of high-level ministers and a vice president can help to speed along regulatory processes, and ensure that all ministries have input into decision-making.

However, as the water institutions themselves are set up to be siloed and separate, implementing high-level decisions to establish basin authorities and integrated, bottom-up approaches as defined in the National Water Policy and Framework Directive require systems-scale thinking and coordination. This poses a major challenge for subnational-level governments and implementing agencies that are constrained by their own agency mandates. Further, without a binding water law to compel all ministries to action, NWRC lacks clout and faces challenges in implementing integrated water management, as it remains statutorily separate from line agencies without an institutional and policy foundation to support and enforce its decisions.

Conclusion and recommendations

Integrated water governance requires building new capacities for multi-stakeholder policy dialogues, and research and support tools for decision-making on water use that are compatible with social inclusion and water security norms. Various efforts for integrated water management are growing from various state and non-state actors; these need to be consolidated on the basis of a more solid and shared understanding amongst all levels of government on the benefits of integrated and inclusive water governance, as well as decision-making on the use of water resources for economic development.

Collective action is critical not only for working towards an IWRM approach, but also for bringing together relevant government departments to collectively adopt an integrated and coherent policy on water governance for the Ayeyarwady Basin that is premised by shared environmental and social norms on inclusive sustainable development. This policy needs to be integrated into national and economic policies that include land-use planning, use of forest resources, and protection of mountain slopes and riverbanks.

Current and ongoing efforts in the water sector show that there is strong motivation and commitment in the NWRC towards water sector reform, as reflected in high-level policy prioritizing bottom-up and integrated approaches to water management. Now, it is up to the NWRC to ensure that these policies and integrated methods filter from its headquarters to all levels of government, as well as citizens, to ensure that they can work in practice.

As Myanmar continues to open up to international trade and investment, economic growth and development is expected to bring massive changes to forest, land and water use, and place additional pressures on the Ayeyarwady River Basin. A well-functioning and coordinated system for water management to deal with the impacts of investment on the water sector is more necessary now than ever.

Notes

[1] The discussion here is based on the draft of the final policy issued in 2019. See *National Environmental Policy of Myanmar*, June 5, 2019. https://www.mm.undp.org/content/myanmar/en/home/library/environment_energy/national-environmental-policy-of-myanmar.html.

[2] According to a key informant, the Minister of Mining issued a directive in 2004 requiring better inspection and environmental impact mitigation measures from mining operations country-wide, and regional mining departments were obliged to follow. Similarly, in 2015, the Minister of the Ministry of Hotels and Tourism issued an order to a district administrator to stop sand mining at Ngapali beach in Rakhine State.

[3] See: http://www.mernmyanmar.org.

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11

Towards a Chindwin River Basin Organization

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The need for River Basin Organizations in Myanmar

In July 2013, Myanmar established the National Water Resources Committee (NWRC) to address water management challenges and promote integrated water resources management (IWRM) in the country. Formed by a Presidential Decree under the chairmanship of Myanmar's vice president, NWRC is a multisectoral apex body comprised of high-level ministries and other governmental bodies. Since its establishment, this body has contributed to improving a range of water-related policies in the country and supported the preparation of the National Water Policy and the National Water Framework Directive, both of which were officially launched in 2014.

However, despite its achievements, NWRC is a national-level body that uses a top-down approach to undertake reforms in water resources management. In order to adequately monitor and address water-related problems and challenges, there is a need to focus closely also at the basin level. Basin-level water governance challenges are not only complex but also need regional actors and appropriate solutions, tasks that a national body may not have enough local knowledge or practical mechanisms to undertake.

A dedicated institution at the basin level can also help coordinate collaboration among different sectors (i.e. ministries and departments), groups (i.e. government, non-government, politicians, private sector, local community), and areas (i.e. upstream and downstream) in each specific river basin.

It is, however, a challenge in the Mekong Region and particularly in Myanmar, to establish this type of institution in the country as water institutions in Myanmar are usually designed to work in their own respective bureaucratic siloes. Local governments at the subnational (i.e. provincial) level and relevant implementing agencies in charge of water issues at the river basin scale are often constrained by their own national agency's mandates (see Chapter 10, this volume).

Myanmar is aware of this need for more localized water governance that can support national-level actors and goals. The National Water Policy of 2014, for example, recommended that related governmental agencies at the central, regional or state levels should be restructured and made to become more multi-disciplinary. This is also in line with a recommendation from a study on water institutions in the Ayeyarwady River Basin (SEI 2015) for Myanmar to "convene, create and sustain a vibrant constituency for inclusive water governance by forging meaningful partnerships among champions and key stakeholders from state, non-state, and international organizations operating at community, sub-national and national scales."

In order to cope with multi-disciplinary and inter-sectional issues, river basin organizations (RBOs) have been promoted in many parts of the world (Ganjanapan and Lebel 2014) by both state and civil society actors. Myanmar's Director General of the Directorate of Water Resources and Improvement of River Systems (DWIR), the Secretary of the NWRC also highlighted a similar point in the National Water Policy (2014) that "RBOs are needed to be established in order to enable the active participation of all people of Myanmar in the implementation process of IWRM." Although there is political support to the general idea of having RBOs in Myanmar, there are many challenges in practice given questions that remain about the design, establishment, operation, and sustainability of RBOs that are appropriate for the country.

Water governance at the basin scale

The Chindwin River Basin faces several water-related problems, ranging from floods and excessive sedimentation to declining water quality and supporting local livelihoods. Before the Stockholm Environment Institute (SEI) initiated work in the basin, there was no specific local institution to help coordinate collaboration among various stakeholders and find water management solutions in the basin. Subsequently, when SEI undertook work in Myanmar, and especially in the Chindwin Basin, many concerned stakeholders voiced the need for a basin-level institution. These concerns were taken up by SEI and the Myanmar Environment Institute (MEI) in November 2014. This request resulted in the Ayeyarwady Futures Project (the first phase of the Chindwin Futures Project, funded by the Blue Moon Fund Foundation) to draw on the experience from other countries worldwide to move forward in supporting the establishment of the Chindwin River Basin Organization (Chindwin RBO).

The purpose of this chapter is to describe the efforts of multi-stakeholders in the establishment of the Chindwin RBO with the technical support of the Chindwin Futures Project Team from SEI and MEI, to help manage water and other related resources in the basin over the past six years, from 2014 until the present.

This chapter focuses on the participatory processes used in the design and establishment of the Chindwin RBO, as well as its successes so far, challenges faced, and recommendations for the future development and operation of the Chindwin RBO.

Stakeholder engagement

The Chindwin RBO is envisaged to serve as an IWRM mechanism by ensuring the environmental and social sustainability of development within this nationally important basin. Six key principles were used in the design and establishment of the Chindwin RBO, which were agreed upon by stakeholders in the basin:

- **Inclusiveness**: Ensure the inclusion of stakeholders in the design, establishment and operation of the Chindwin RBO through suitable activities.
- **No duplication**: The Chindwin RBO will not compete but will work complementarily with current mechanisms. The functions of the Chindwin RBO will not duplicate but will add value to the mandates of relevant departments and other concerned agencies.
- **Local ownership**: Myanmar's home-grown leaders will lead the process in the design, establishment and operation of the Chindwin RBO.
- **Realistic expectations**: Subject to available resources and capacity, the Chindwin RBO will begin with smaller tasks at the start, and its contributions may grow over time.

- **Learning process**: The design of the Chindwin RBO will be based on learning and sharing knowledge with national and international experts working on basin-scale water issues in Myanmar and beyond.
- **Communications**: To ensure that the stakeholders in the basin can engage effectively in the design and establishment process, communications related to the Chindwin RBO with the stakeholders will be conducted in the local language.

In response to the request of the stakeholders in 2014, the Ayeyarwady Futures/Chindwin Futures Project Team from MEI and SEI has worked in close collaboration with the Sagaing Regional Government, Directorate of Water Resources and Improvement of River System (DWIR), Monywa University, Sagaing University of Education, and other governmental and non-governmental agencies in Myanmar and international experts from Australia, Brazil, and the Mekong Region in conducting intensive consultations with a wide group of stakeholders in Chindwin in 2015 to explore appropriate design and other options for the Chindwin RBO. The activities included two major stakeholder consultations in Monywa (in May and October 2015), a survey of 600 households in the Chindwin (during June to July 2015) and 30 in-depth interviews of concerned agencies (from August to September 2015).

A working group to design the Chindwin RBO was formed following an agreement during the stakeholder consultation in Monywa in October 2015. This working group consisted of representatives from government (DWIR, WRUD, ID), academic institutes (Sagaing University of Education), civil society organizations (MEI, ADRI), and a community leader (the parliamentarian from Homalin township). With facilitation from SEI and technical support from the experts on RBO in Thailand, the Chindwin RBO design working group gathered together in Bangkok in December 2015 to brainstorm and interact with the members of Tha Chin RBO in Thailand. Tha Chin RBO is well-known in Thailand for comprising of strong civil society agencies and individuals who are actively contributing to the management and conservation of the river basin.

The outputs from this working group meeting were the draft Chindwin RBO design, tentative work plan and estimated budget for the establishment and startup of Chindwin RBO during the first two years (April 2016–March 2018). The draft documents were subsequently improved after the working group meeting in December 2015 and their formal submission to the Sagaing Regional Government in January 2016. Follow-up meetings among the team from MEI, Chief Minister of Sagaing Regional Government, and other concerned agencies, led to further minor adjustments on the draft design of the Chindwin RBO.

In February 2016, the Sagaing Regional Government approved the establishment of the Chindwin RBO with funding committed for its first year. The design of the Chindwin RBO was also submitted to the Union Government in the same month.

The change of government in April 2016 interrupted the process of establishing the Chindwin RBO. The Chindwin Futures Project team put considerable effort to introduce a plan to establish the Chindwin RBO through several informal and formal consultations with the new government. In August 2016, MEI and SEI experts held several meetings with high-level officials from the new government, including the Chairman of the Parliamentarians on Natural Resources and Environment Committee, the Director General (DG) of DWIR representing the Minister of Union Ministry of Transport and Communications (MOTC) and the Sagaing Regional Government Ministers. All parties expressed an interest to support ongoing efforts to establish the RBO in the Chindwin River Basin.

The Sagaing Regional Government through its new Chief Minister reaffirmed a strong commitment to support the establishment of the Chindwin RBO. To seek public opinion on the RBO, the Sagaing Regional Consultation Meeting on the Chindwin RBO was convened on 4 October 2016. The event was attended by more than one hundred representatives from the Sagaing Regional Government (e.g. Regional Chief Minister, Ministers), Parliamentarians, government agencies, universities and NGOs (**Figures 11.1** and **11.2**). The participants actively shared their opinions on the design of the RBO and the next steps towards its establishment. There was overwhelming and unanimous support at the meeting for the current proposal for the Chindwin RBO. Valuable suggestions from the participants, especially on the composition of the Chindwin River Basin Committees (RBCs), were used to update the design of the Chindwin RBO before it was submitted to the Sagaing Regional Government in late 2016 (**Figure 11.3**).

Figure 11.1 and 11.2 A number of stakeholder consultations were held across the Chindwin Basin to discuss the establishment of the Chindwin RBO

Figure 11.3 The Sagaing Regional Consultation Meeting discussed the Chindwin RBO at Parliament House, Monywa, Sagaing Region, Myanmar on 4 October 2016

In February 2017, the Sagaing Regional Government issued an official letter confirming their strong intention to support the establishment and operation of the Chindwin RBO with funding approved from the regional budget for the 2017 fiscal year, starting from April 2017 onwards. This was the first time in Myanmar's history that the regional government had agreed to provide its own funding to support the establishment of the RBO to serve as a mechanism for integrated water resources management. This commitment demonstrated the feeling of ownership of the RBO by the Sagaing Regional Government and other stakeholders to improve water governance in this important basin.

It took about three years to finalize the design and get the proposal on the establishment of Chindwin RBO officially endorsed by the Sagaing Regional Government following five formal stakeholder consultations. The central and regional government bodies and line agencies, civil society, universities, business groups and local communities actively participated and shared their views and concerns in these consultations. Several of them continue to engage in RBO activities as the members of the Chindwin River Basin Committee (CRBC) until the present day.

Design of the Chindwin RBO

The design of the Chindwin RBO, which was agreed by multi-stakeholders through the three-year consultation process, is described below.

Aim and objectives

The Chindwin RBO was set up to achieve sustainable development in the Chindwin River Basin by improving the management of water resources and river health. The objectives of CRBO were also formulated:

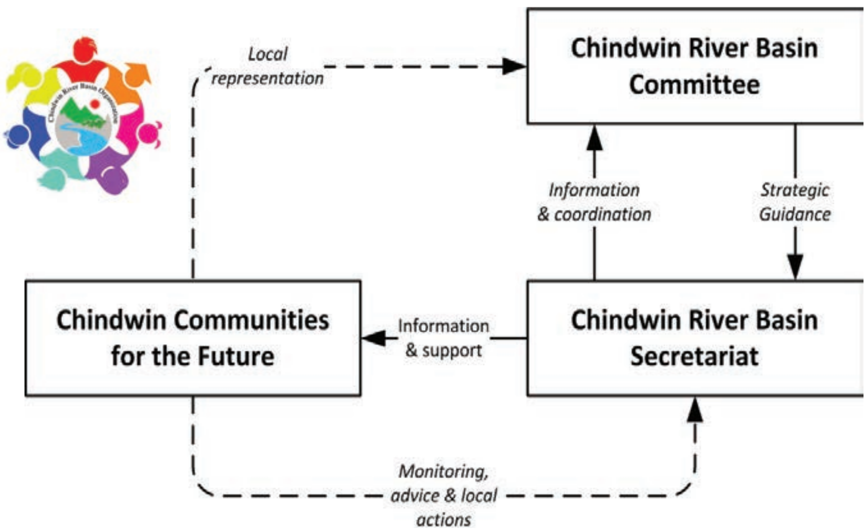
1. to help improve the gathering and sharing of information among all stakeholders about opportunities and threats;
2. to help coordinate collaboration among different sectors, groups and areas;
3. to help achieve reconciliation and solve problems across different sectors, groups and areas; to support the development of more coherent policies and plans;
4. to encourage and recognize local initiatives that can provide bottom-up inputs to the Chindwin RBO;
5. to build public awareness and education about river conditions and integrated water resources management;
6. to coordinate trainings of communities for monitoring water resources considering different seasons, locations and sources and other concerned topics; and
7. to approve new membership of the Chindwin River Basin Committee (CRBC), set up the River Sub-Basin Organizations and nominate sub-committees or working groups to handle tasks as assigned by the CRBC.

Structure

RBOs have different governance structures. All RBOs consist of at least two organizational bodies: a high-level decision-making body and a secretariat. The proposed structure of the CRBO after its full establishment is as shown in **Figure 11.4**.

The CRBO will include three main bodies: the Chindwin River Basin Committee (CRBC), Chindwin River Basin Secretariat (CRBS), and Chindwin Communities for the Future (CCF). In the future, River Sub-basin Organizations (RBOs) will also be formed in respective sub-basins of the Chindwin River Basin.

Figure 11.4 Structure of the Chindwin River Basin Organization



Chindwin River Basin Committee (CRBC). A River Basic Committee (RBC) is a high-level decision-making body representing the different management levels of the organization and fulfilling different functions. The RBC normally consists of representatives of all concerned agencies (governmental and non-governmental), private sectors and local communities. To ensure effectiveness of the RBO (e.g. convening power in engaging the RBC members, political power for implementation of RBO activities, and funding support), the chair or head of the RBC is often a very senior government official.

Chindwin River Basin Secretariat (CRBS). The RBS is important for the effectiveness of river basin management. A secretariat body operates by rendering administrative and other services to the organization. Apart from these two bodies, most of the RBOs also have an intermediary body, consisting of technical experts from RBC agencies and translating high-level policy decisions into operationalized strategies. The Chindwin RBS coordinates directly with the National Hydro-Informatic Centre (HIC) for activities related to data, information, knowledge, decision-support tools and capacity building.

Chindwin Communities for the Future (CFF). The CFF comprises locally formed groups of people who live along the Chindwin or its major tributaries as well as communities geographically located away from banks of the Chindwin and major tributaries, and in more upland watersheds. Groups included in the CFF are interested in supporting the goals of the RBO through their own activities, including monitoring and other local actions. This is the main mechanism for bottom-up inputs and public engagement in RBO activities.

River Sub-Basin Organizations (RSBO). The Chindwin is a very large river basin. In the future, it may make sense to create other formal river-sub-basin organizations (RSBO) with a similar structure to the parent body. Considering existing challenges, the first few RSBO that should be considered for establishment include the Myittha and Uru Rivers. The second set of the RSBOs can be established for the Yu and Muu Rivers.

Function of Chindwin River Basin Committee

Under the CRBC, the Chindwin River Basin Secretariat (RBS) is responsible for preparation of an annual report summarizing the activities, achievements, challenges, expenditures, and proposed work plan and budget for the Chindwin RBC's consideration and comments. The RBC led by the Sagaing Regional Government submits the annual report, including the proposed annual work plan and budget of the Chindwin RBO to the Sagaing Regional Parliament for approval before a formal submission to the Union Government and NWRC for endorsement.

Successes so far

It took almost three years to complete the design of the Chindwin RBO that could be agreed by its stakeholders. Progress towards the establishment of the Chindwin RBO was made through a step-by-step approach based on available resources and the capacity of parties involved. We describe the achievements made to date.

Formation of the RBC and RBS

Key positions of the Chindwin RBC and RBS were appointed in December 2017 and these positions regularly updated. The Chindwin RBO is formally chaired by the Sagaing Regional Minister for Industry, Electricity and Transportation. To share the workload, the Chindwin RBO has two secretaries, which are the Regional Head of DWIR and Regional Head of Environmental Conservation Department (ECD). The Chief of Sagaing Regional Government serves as the Chief Patron of the Chindwin RBO. The RBC membership consists of 68 representives of government agencies, NGOs, universities, private sectors, and communities.

Formation of the Chindwin RBC Sub-committee

Five RBC sub-committees were formed in early 2018 to carry out the tasks assigned to each one.

- Sub-committee on management and legal issues (16 members)
- Sub-committee on finance and fund raising (22 members)
- Sub-committee on information and communication (11 members)
- Sub-committee on external coordination (11 members)
- Sub-committee on research and development (16 members)

Each RBC member must join at least one sub-committee. Some RBC members joined two sub-committees because tasks under these sub-committee are highly relevant to their responsibility in their respective organizations. Apart from the RBC members, resource persons outside the Chindwin RBC could be engaged and contribute to the tasks of sub-committee time to time.

Each sub-committee selected a chair among its members to take a lead on assigned tasks and a secretary to help coordinate the meetings and compile all inputs from the sub-committee members for reporting progress and results to the Chindwin RBC members and the RBC Chair at a later stage.

Progress towards Chindwin RBO's mandates

An RBO Secretariat Office was set up in Monywa with the support of the Sagaing Regional Government and sub-committee meetings have been held since 2018. Although the Chindwin RBO has not been fully established as per the recommended governance structure, some good progress has been made towards Chindwin RBO's mandates, as summarized in Table 11.1.

Table 11.1 Successes measured against the Chindwin RBO's mandates

Chindwin RBO's mandates	Achievements so far
1. To help improve the gathering and sharing of information among all stakeholders about opportunities and threats	Water quality data collection, water sampling and data analysis have been funded by the Chindwin Futures project since 2015 until 2016. From 2017–19, this activity has been funded by the Sagaing Regional Government with in-kind contribution from DWIR, MEI and SEI as part of Chindwin RBO activities. Other data has been collected for implementation of Chindwin Biodiversity and Ecosystem System (CBES) project to mainstream biodiversity conservation and ecosystem services into planning. Knowledge products were published to the public in 2017–19. Organized an exhibition to share the research findings from local universities and local knowledge produced by local NGOs to the public in May 2019.
2. To coordinate collaboration amongst actors within water-related sectors, groups and areas	Successful coordination and organization for several events: RBC meetings, stakeholder consultations, policy dialogues and trainings with active participation of various actors (2017–20).
3. To help achieve reconciliation and solve problems across different sectors, groups and areas	The Chindwin RBO supports research implementation and dissemination of research findings to the public and facilitated discussions among various actors representing different interests through RBC meetings and stakeholder consultations for joint solutions to the problems (2017–20).

Chindwin RBO's mandates	Achievements so far
4. To support development of coherent policies and plans	Research project e.g. CBES supported by Chindwin RBO provided policy recommendations for concerned agencies to consider them for further development and improvement of their policies and plans. Initial draft action plans have been jointly prepared in 2019 by concerned agencies through policy dialogues for addressing fisheries decline, illegal mining and land degradation, and agricultural expansion into protected forest areas. Chindwin RBC members actively engaged in the stakeholder consultations for the design of GCF Climate-resilient Agriculture, Forestry and Land-use in Chindwin river basin project of the Food and Agriculture Organization of the United Nations (FAO), ECD and MOALI with facilitation support by MEI and SEI (2019–20).
5. To encourage and recognize local initiatives that can provide bottom-up inputs to Chindwin RBO	Engaged various stakeholders including the communities through research and consultations with the Chindwin RBCs in 2017–2020. These have resulted in the cooperation among the governmental agencies, universities and NGO on joint water quality monitoring.
6. To build public awareness and education about river conditions and integrated water resources management	Supported the design and implementation of Saving Chindwin's Campaign co-led by Monywa University with almost 200 participants from the universities, local communities, CSOs, and governmental agencies in February 2019. Supported a series of Public Talk Shows led by Information and Public Relation Department (IPRD) to raise public awareness about river conditions, biodiversity and water management in 2019–20.
7. To coordinate trainings of communities for monitoring water resources considering different seasons, locations and sources and other concerned topics	Through funding support from CBES and Chindwin Futures, supported the organization of trainings on various subjects, e.g. on water quality data monitoring, INVEST model, GIS, media training. Key training materials have been made available to the public (2017–19).
8. To approve new membership of the Chindwin RBC, set up the River Sub-Basin Organizations and nominate sub-committees or working groups to handle tasks as assigned by the Chindwin RBC.	Five sub-committees have been set up in 2018 to support various tasks related to the work of Chindwin RBO: (1) management and legal issues, (2) finance and fund raising, (3) information and communication, (4) external coordination, (5) research and development.

Challenges faced

Change of governments and delay in approval

There was major transition in the political system when the former government prepared for the election in 2015 and the new elected government came to power in April 2016. The former government approved Chindwin RBO with committed funding support in February 2016. The change in the government unavoidably delayed the funding process of the Chindwin RBO from the regional government.

The Chindwin Futures Project team from SEI and MEI had to start over again with the introduction and discussion with the new government on the justification and current state of the RBO design and establishment. Because of the strong relationships and trust that the team built with concerned local partners in the basin with a common interest in establishing this RBO quickly, the new government at that time reaffirmed their interest to continue supporting this initiative. The political support gained during this process allowed the establishment of RBO to proceed despite some delay to the original schedule.

Personnel and financial constraints

Establishing a new RBO requires the long-term commitment of many parties and sufficient funding and human resources to support such efforts are critical. Following intensive consultations with the stakeholders on the design of the Chindwin RBO (SEI 2016), ideally, funding support for the staff and direct costs related to core activities and functions of the RBO should be made available from four sources, including the regional government, Union Government, large, commercial, water river users and international and domestic donors.

The Sagaing Regional Government has committed funding to support RBO activities since 2017. They have also submitted the request for funding support for the operation of Chindwin RBO to the Union Government in the past years, but this has yet to be approved. Currently, the RBO activities mainly rely on the Sagaing government's fund, which is approved annually, plus limited funding from a number of small projects that could be raised externally through competitive calls by support from SEI and MEI. Both funding sources, however, are rather uncertain. In-kind contributions from RBC members and their organizations have been critical to the progress of RBO activities so far.

Officials play important roles in the RBO as members in the RBC and RBS. Because of the current workload in their departments, this responsibility made it difficult for them to allocate their time for RBO activities effectively. They needed to pay attention to their work, particularly during times of crisis, such as floods, droughts or the COVID-19 pandemic. In addition, governmental officials are moved to other locations in different regions every few years of service. Because the RBC members representing the governmental agencies were appointed by their positions, the RBC members from the government were frequently replaced. New RBC members often need to be briefed and consulted on the Chindwin RBO, how this mechanism can support their work, and how they can contribute to RBO activities in their capacity as RBC members and Secretaries.

To address these issues, engagement and regular meetings with high-level governmental in Sagaing in the early stage was a top priority for the project team when the new government was on board. The plan towards the establishment and operation of RBO had been reviewed and updated realistically in consultation with the stakeholders. In addition, the project team also relied on the local universities and CSOs (in the river basin), who have been engaged in the design of RBO and were part of the RBCs, to keep up regular communications with the regional government and departments as well.

Selection of approaches in the formation of the RBO in Myanmar

Myanmar has undergone significant political reform in the past decade. Public participation in natural resources management has been more welcome. However, how this participation should be translated into practice at the local, regional and national levels still need to be seen, considering the limited capacities of key personnel, governmental system, as well as the power relations and balance among concerned parties. Similarly, the idea of establishing the Chindwin RBO was generally supported by many stakeholders, including high-level officials. However, the best approach to fully implement the RBO remains a question.

A bottom-up approach was used throughout the process since the designing stage in 2014 to ensure that the Chindwin RBO would serve local needs and be sustained in the long-term. With strong support from the regional government and stakeholders in the river basin, significant progress on the Chindwin RBO was made despite the limited resources and changes in government.

In 2015, Myanmar received a US$100 million loan from the World Bank for the implementation of the Ayeyarwady Integrated River Basin Management (AIRBM) project. This project aimed to help Myanmar develop the institutions and tools needed to enable informed decision-making in the management of Myanmar's water resources and to implement integrated management of the Ayeyarwady Basin. The AIRBM project helped develop the master plan and decision support system to inform the development decisions in the Ayeyarwady Basin where the Chindwin River Basin is located. This master plan, once completed, aimed to provide a top-down direction on river basin development for local and regional stakeholders to follow. Since the AIRBM's master plan had not yet been completed, some concerns were raised by key officials associated with the AIRBM project that the design and establishment of the Chindwin RBO through a bottom-up approach may have been completed too quickly. Another concern was related to the fear that the Chindwin RBO would suggest different development paths in the basin that were not fully in line with a top-down plan that the Union Government would want to implement following the recommendations made by the AIRBM.

To address the above concerns, the design of the Chindwin RBO was updated from 2016 to 2017 to emphasize the intention of the Chindwin RBO to "help coordinate collaboration among different sectors, groups and area" and "support the development of more coherent policies and plans," including those that may be suggested from the Union Government in the future. In short, the Chindwin RBO would help facilitate stakeholder engagement on the plans and policies by bridging the top-down and bottom-up approaches together, based on an improved understanding on the local needs and state of the basin. To strengthen the relationship among stakeholders from the local, regional and national levels, at least one member from NWRC would join as a formal member of the Chindwin RBC. In addition, the Chindwin RBS has a responsibility to coordinate directly with the National HIC on future cooperation related to data, information, decision-support tools and capacity building for the Chindwin River Basin.

Looking to the future

While the design of Chindwin RBO was officially endorsed by the Sagaing Regional Government in 2017 and some achievements on its mandates have been recognized, it is still in the early stages. Further enhancement in many areas is needed.

As pointed out by Meijerink and Huitema (2017), the capacity to generate funding and institutional stability are crucial to the success of an RBOs in realizing its roles in terms of coordination and environmental effectiveness. Sustainable and secured financing is a necessary condition for the efficient work of an RBO.

Currently, funding support for the Chindwin RBO activities from the Sagaing Regional Government needs to be considered year by year. High uncertainty in budget allocation could be expected, especially in the years when the region faces crises such as flood, drought, or a pandemic. For example, because of competing priorities, the regional government could not allocate funds for water quality monitoring and analysis in 2020, unlike the situation in 2017–19. Continued effort in securing additional fund from other sources to support further development and operation of the Chindwin RBO is necessary.

Apart from potential funding from the regional and Union Government, there have been ongoing discussions among the stakeholders on how to establish necessary mechanisms to allow the private sector, which is a large water user, to contribute funding for conserving water and related resources in the river basin. This opportunity is being explored partially under the potential project "Climate-resilient Agriculture, Forestry and Land-use in Chindwin River Basin (CAFOLU-Chindwin)" (FAO 2019). The FAO, with technical support from UNIQUE, SEI, MEI, RECOFTC, and Mercy Corps, have been supporting the Government of Myanmar on the design of this project for future submission to the Green Climate Fund (GCF). The Chindwin RBC members have been actively engaged in various consultations for the full proposal development throughout 2020.

To enhance further development and operation of the Chindwin RBO, so that it can fulfill its mandates in improving the management of water resources and river health in the river basin, the Chindwin RBC members and its supporters should target the following areas:

- Seeking additional funding support from international and domestic donors to build relevant capacities (i.e. human, technical and finance) necessary for the development and operation of Chindwin RBO in the long-term. To ensure the institutional stability of the Chindwin RBO, there should be a dedicated fund to support key personnel to perform their core functions of the Chindwin RBO despite changes in personnel from time to time.
- Maintaining regular communications and raising public awareness on the status and progress of Chindwin RBO activities among concerned governmental agencies associated with the regional government and the wider public to motivate multi-stakeholder engagement. For the government, this could be done through routine meetings of the parliamentarians and the Sagaing Regional Government. For the public, the IPRD and local media could support the dissemination of related information in the local language.
- Keeping NWRC regularly informed on the progress, achievements and challenges of the Chindwin RBO's establishment and operation to ensure the recognition of the Union Government on the contributions of the Chindwin RBO to water resources management in the river basin. This could be done through reporting to NWRC by the Chief Minister of Sagaing Regional Government (as the Chindwin RBO's Chief Patron) and the Regional Head of DWIR (as the Chindwin RBO Co-secretary).
- Establishing a formal link of the Chindwin RBO with HIC, so that the Chindwin RBO can benefit from capacity support related to technical aspects of river basin management and at the same time, can contribute to HIC's activities that need to be done locally within the basin, such as data collection and river monitoring.
- Engaging with community leaders including the parliamentarians in the river basin who might want to contribute to the Chindwin RBO as the members of Chindwin Communities for the Future (CFF), the body that has not been filled yet in the current government structure of Chindwin RBO. This body is critical to demonstrate strong local ownership of this RBO.
- Promoting the role of local universities in the river basin more as knowledge providers to reach the decision makers and the public via Chindwin RBO's activities. A recent example is the 'Saving

Chindwin Campaign' that was co-led by Monywa University in 2019. More initiatives of this kind could be done since local universities conduct research on the Chindwin River Basin.

- Seeking the opportunity to exchange the knowledge and experience with other initiatives related to the RBOs in Myanmar and internationally. For Myanmar, this includes, but is not limited to, the Ayeyarwady River Basin Research Organization (ARBRO), which has been established voluntarily by academics, consulting sectors and administration to promote IWRM in the Ayeyarwady River Basin (NARBO 2013) and Bago Sub-basin Area Committee that has been established as part of the project "Piloting river basin management in the Bago Sub-basin, experiences and recommendations" (Niva 2019). At the international level, the Chindwin RBO could explore a partnership with the Network of Asian River Basin Organizations (NARBO), established in 2004 to promote IWRM in monsoon Asia.
- The Chindwin River Basin is spread across four regions of Myanmar (Sagaing Region, Kachin State, Chin State, and Magway Region), and part of the basin is in India. For the sustainable management of water resources in the river basin, there is a need to expand engagement with the stakeholders beyond the Sagaing Region, to include representatives from other regions of Myanmar and from India in the Chindwin RBO activities in the future.

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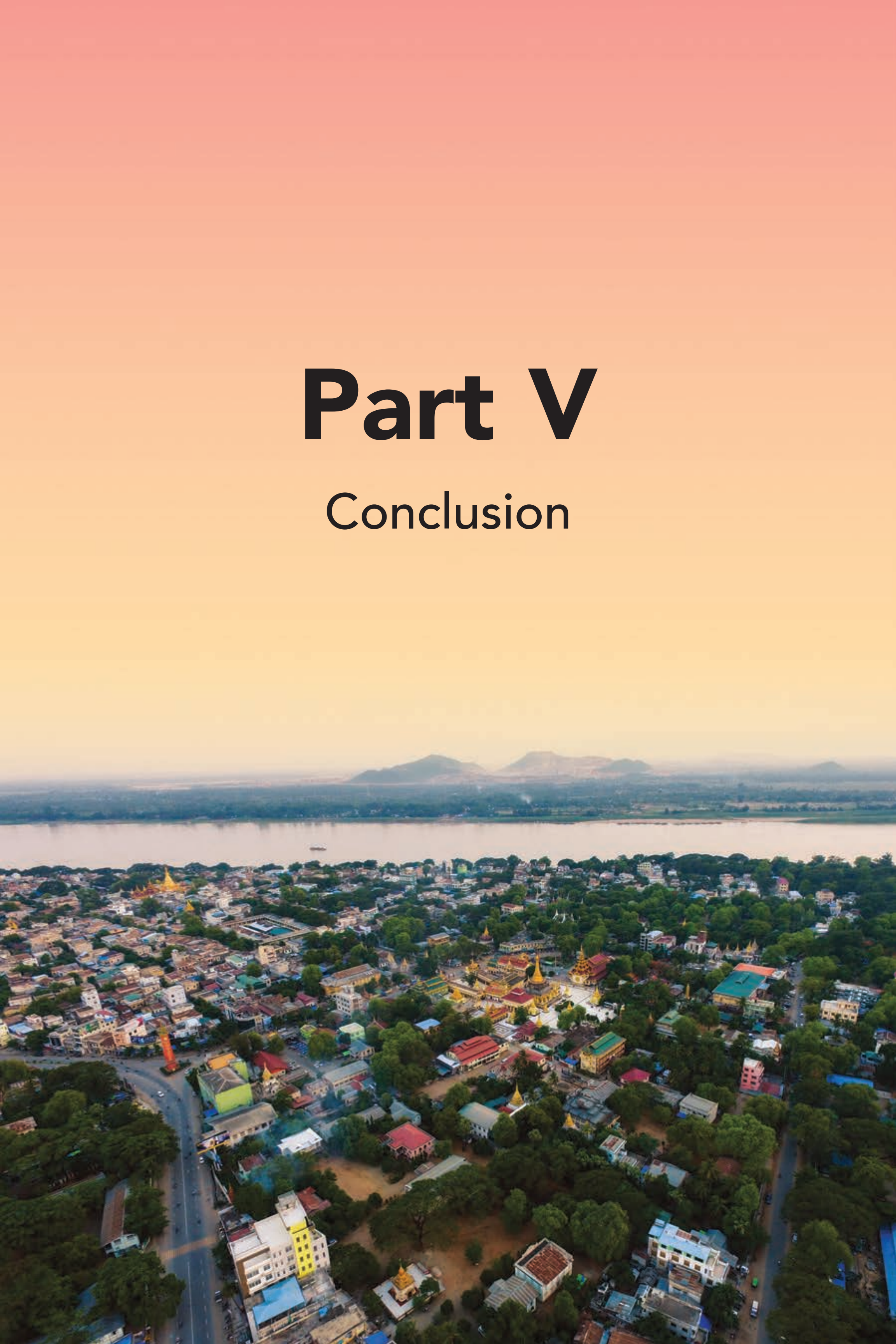
Part V

Conclusion



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Synthesis

Louis Lebel, Chayanis Krittasudthacheewa, Rajesh Daniel, Vanessa Hongsathavij and Win Maung

The physical geography of the Chindwin River Basin (CRB), with its hills and valleys and the winding Chindwin River, both supports and constrains the development of the basin (Chapter 2). Topography, soils and climate vary with implications for road or river access (Chapter 4), the suitability of alternative crops (Chapter 2), water and river management options (Chapter 11), and the importance of habitats for conservation (Chapter 7).

The climate, for instance, is highly seasonal with winter (November to February), summer (March to mid-May) and rainy (mid-May to October) seasons (Chapter 3). Flooding usually occurs between July to September (Chapter 3). The 2015 flood was particularly severe, destroying crops and killing livestock, and underlining the need for flood forecasting systems that work for areas with limited observation networks (Agarwal et al. 2020).

Climate changes observed over the past couple of decades include rising temperatures, reduced rainfall in the north and increased rainfall in the south, shorter monsoon seasons, and more frequent extreme events (Chapter 3). Projected changes are similar to observed trends with overall increases in annual rainfall (Chapter 3). Increases in mean annual discharges are likely to be accompanied by more severe and frequent extreme flood events (Shrestha et al. 2020). The infrastructure and capacity to forecast flood events, as well as project longer-term changes in river flow and flood regimes, will be a key to ongoing river management and riparian development planning.

Modeled impacts on river flow conditions at the confluence of the Chindwin River with the Ayeyarwady River were used to derive flood hazard and risk maps (Chapter 4). Despite many data limitations, the analysis produced useful results for river navigation and 'river training' plans (Chapter 4). Remote sensing imagery was also used to better understand the impacts of riverbank erosion (Chapter 5). In some decades, erosion dominates, whereas in other periods riverbanks have restabilized, following a pattern consistent with periods of replacement of forests by agricultural land (Chapter 5).

Large-scale river water pumping stations operated by the state have historically played an important role in visions for irrigation in the CRB (Chapter 8), but running costs and maintenance problems mean many farmers switched to tube wells (Chapter 9). The storage of water in reservoirs for gravity-fed irrigation is the responsibility of the Irrigation Department, whereas pumps, wells and water supply infrastructure are with the Water Resources Utilization Department (Chapter 6). Both departments are in the Ministry of Agriculture and Irrigation, while livestock and fisheries until 2016 had their own Ministry. Coordination of water use for producing food presumably became easier after the merger.

The allocation of large-scale agricultural land concessions to agribusiness companies, often with close ties to the military, has led to disputes with local communities (Chapter 9). Only a small fraction of the land acquired is planted, suggesting their real purpose was to access other resources such as timber. Land has also been seized for mining concessions (Chapter 9). Land-use and land-cover changes for agricultural development, timber and fuelwood extraction, and mining have significant biophysical and socioeconomic impacts further downstream (Chapter 5).

Water quality in the CRB is declining (Chapter 9). Riparian communities are concerned with the impacts of mining and other industrial activities on river water quality (Chapters 6, 9). Some households still rely on river water for drinking and other domestic uses (Chapter 6), whilst many others have switched to pumping from groundwater wells (Chapter 9). At the same time, the capacity to monitor the water quality of the Chindwin and its tributaries is currently limited (Chapter 6). Water quality standards need to be adopted and data on water quality shared among agencies (Chapter 6) and the public.

The CRB is rich in biodiversity. However, in recent years, many fish, bird and turtle species along the Chindwin River have been declining (Chapter 7). Fish and turtle populations have been adversely impacted by illegal fishing and gold mining (Chapter 7). In addition, habitat loss to agriculture impacts avifauna as well as threatens turtle species (Chapter 7). In a study of fish biodiversity across the Ayeyarwady basin, the western CRB was prioritized for fish conservation because of a high level of threats to endemic species in the area (Li et al. 2021). Conservation actions that involve local communities and businesses are urgently needed for many important riparian species (Chapter 7).

River-based livelihoods include farming in seasonal gardens on the riverbanks, moving goods and people by boat, and fishing. This book, unfortunately, has not explored the habitats and movement of wild capture fisheries in the CRB. This is a significant omission given the high importance of fish in the Myanmar diet (Khin et al. 2020). Apart from being a critical source of protein, fish are also a key nutrient source. Even in the Central Dry Zone, in which the lower CRB falls (Chapter 2), small-scale aquaculture production is widespread (Khin et al. 2020).

In the 2014 census, the population of the Sagaing Region was 5.3 million (Chapter 8). The total estimate for the CRB is approximately 6 million (Chapter 3). Demographically, the Sagaing Region has a high proportion of young people (Chapter 8). Falling fertility and mortality rates and migration are changing the age structure, size and spatial distribution of the workforce (Chapter 2). Health care issues are of concern, with infant mortality rates across the CRB averaging a high of 74 deaths per 1,000 live births (Chapter 8). Internal and international migration is also driving changes in the spatial distribution of the population. Long-term development planning needs to consider the implications of these demographic transitions (Chapter 2).

Households are diversifying their sources of income beyond agriculture, including working in mining and becoming market traders (Chapter 9). Road transportation has become the most important mode of travel, replacing boat and rail transport (Chapter 2). Nevertheless, some remote parts of the CRB, such as the Naga Self-Administered Zone, remain relatively more isolated and need special support to improve their access to markets and livelihood sustainability (Chapter 8).

In 2013, a presidential decree established the National Water Resources Committee (NWRC) to coordinate water-related activities in Myanmar (Chapter 10). The NWRC and regional government stakeholders in the CRB were keen to engage local communities in basin management (Chapter 9), consistent with the 2014 National Water Policy (Chapter 10).

In 2017, after extensive consultations, the Sagaing Regional Government officially endorsed the establishment of the Chindwin RBO, but much still needs to be done to make it fully operational and sustainable (Chapter 11). The hydro-meteorological observation network, for instance, is inadequate, with major gaps in the northern part of the CRB (Chapter 3). A modest year-by-year budget is a starting point (Chapter 11), but remains too short-term for strategic team building, multi-stakeholder consultation and planning to be undertaken in earnest.

Various assessments conducted in partnership with multi-stakeholders over the past seven years have helped to improve our understanding of the CRB's natural, socioeconomic and institutional features (Chapter 1). These findings, as presented in this book, underscore the importance of the quality of river basin governance for sustainable development. Evidence of problems arising from land allocations and water use, environmental threats to fish, bird and other wildlife populations, declining water quality, and climate change point to the need for improvements in transparency, accountability and capacity in river basin governance. Nevertheless, local and multi-stakeholder support for a Chindwin RBO has remained strong despite political changes. At the end of 2019, many advances seemed possible.

The COVID-19 pandemic starting in early 2020, and the February 2021 coup, together have disrupted years of economic and institutional development in Myanmar and delayed the arrival of a more inclusive Chindwin Futures. In the shorter term, technical assistance and investment seems likely to contract, whilst political unrest seems likely to continue. The pressing need to coordinate responses to the COVID-19 pandemic with neighboring countries, for example, with respect to migrant labor and tourism, may become a channel for addressing other issues. In the medium term, we expect the needs for integration and coordination with respect to water resources development and management in the Chindwin River Basin will once again create demand for partnership building and multi-stakeholder processes. The experiences of the last decade, as reported in this book, provide a starting point.

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Page numbers in italics indicate illustrations

Nestled among dense forests and high mountains, the Chindwin River Basin lies in Myanmar's remote northwestern region.

This assessment of the Chindwin Basin shows that it is facing huge changes in land- and water-use that can contribute to economic development but also cause environmental degradation and the further marginalization of vulnerable communities.

Identifying and understanding the interactions among multiple development and water-related activities in the Chindwin Basin, and the impacts of climate change, geography and economic transformation on biodiversity, water-use, and local livelihoods, is critical for integrated water resources planning and management.

The work in the Chindwin Basin was not restricted to research but also multi-stakeholder dialogues and building supportive institutions for water management. As a result of this assessment, which took almost three years to complete, the Sagaing Regional Government established the Chindwin River Basin Organization (RBO), the first RBO in Myanmar, supported with funding from the local government in partnership with a range of state and non-state actors, including local communities.

This volume will prove of value to academics and researchers as well as media, donors and development partners working on natural resources and water governance issues in Myanmar, and in particular, the Chindwin River Basin, and especially for those studying river basin governance in the Mekong Region.

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