EVALUATION OF AN EXISTING AND FUTURE WATER BALANCE IN THE BAGO RIVER BASIN, MYANMAR

HNIN THIDAR PHUE

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Master of Engineering in (Civil Engineering)
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has been approved by the Graduate School as partial fulfillment of the requirements for the Master of Engineering in Civil Engineering of Naresuan University

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ABSTRACT

In recent years, frequent flood to the Bago Township area was serious problems during the rainy season, however, drought occurs during the late of wet season and the dry season normally. In this study, Water Evaluation and Planning (WEAP) model was implemented in the Bago River Basin (BRB), Myanmar to evaluate an existing and future water balance, based on five different scenarios: Reference (RS), High Population Growth Rate (HPG), Higher Living Standard (HLS), Climate Change (CC), and Water Supply Management (WSM). The existing scenario was set for the year of 1999-2018, however, the model calibration in surface hydrology at the Bago gauging station in the Bago Township within the period of 2011-2015 and model verification during the period of 2016-2018 were carried out. The observed data during these periods were fitted to the coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Root mean square error (RMSE) with the values of 0.97, 0.84, 9 m^3/s and 0.98, 0.92, 4 m^3/s, respectively. The mean annual water supply based on releasing flow from the existing five dams and actual rainfall-runoff during the period of 1999-2018 was 1,208 MCM, while the demand of water for domestic and agricultural as well as the diversion from BRB was 1,225 MCM. The existing results indicated that currently the basin has sufficient water to meet the water demands except in 2014 and 2018.

The simple statistics were adapted as forecasting of population in next 22 years (2019-2040) with the growth rate of 1.85 % with no changes for the others such as industrial, and agricultural area. The future annual water supply of projected reference scenario will be 1,097 MCM, and water demand will be 1,237 MCM. However, the annual unmet water demand will be started in 2021 due to shortage water. The future average monthly unmet demand under reference Scenario, high population growth and higher living standard scenario to be 7.88 MCM, climate change scenario impacted at 25.8 MCM, and WSM Scenario showed enormous improvement of a 0.03 MCM. The results show that, by reducing the water use rate of the summer crops, reducing transmission losses in the water supply site, and proper demand site management (DSM), unmet demand can be reduced expressively. The results further indicate that the WEAP model showed highly capable and the recommendation of WEAP should be applied in management agencies and local authorities in decision making for the improvement of Bago River Basin water demand and supply system efficiency in the future.

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ABBREVIATIONS

BRB = Bago River Basin

BRBWSS = Bago River Basin Water Supply System

DALMS = Department of Agricultural Land Management and Statistics

DEM = Digital Elevation Model

DHPI = Department of Hydropower Implementation

DMH = Department of Meteorology and Hydrology

DRD = Department of Rural Development

EDWS = Engineering Department (Water and Sanitation)

FAO = Food and Agriculture and Organization

GCM = General Circulation Model

ID = Irrigation Department

IWRM = Integrated Water Resources Management

IWUMD = Irrigation and Water Utilization Management Department

MIP = The Ministry of Immigration and Population

MOALI = Ministry of Agriculture, Livestock and Irrigation

MOECAF = Ministry of Forestry and Environmental Conservation

MOT = Ministry of Transport

GIS = Geographic Information System

SRTM = Shutter Radar Topography Mission

TDC = Township Development Committee

CHAPTER I

INTRODUCTION

1.1 Background of the Study

Water is an important natural resource for all living things in this world. Water is a four-factor for human consumption as well as used in various agricultural and industrial sectors, including water transport, prevention of intrusion saltwater, and wastewater dilution. Besides, water also has a social and economic cost for human beings, and population growth and economic development put constant pressure on the ecosystems of water resources (Alcamo et al., 2007). There is a durable positive correlation between water demand and urbanization or population growth. Consequently, this leads to implementation of effective water resource management which becomes particularly important in defining how much water is obtainable for human use and economic activities, so that water should be shared between users in the process of planning. The increasing water demand relates to water availability particular during the dry season and has also increased water conflicts at upstream in the watershed. Without proper management, increasing demand for scarce water resources in each region will have a huge impact on users and the environment (Hellström et al., 2000).

The poor management of water resources, the increasing, challenging water demand for livelihood and lack of strong administration and coordination among sectors is expected to exasperate the water scarcity challenges of the basin (Gadain and Mugo, 2009). The suggests that there is a need for suitable the utilalization of water from the available resources and development. This requires empirical evidences on current and future water availability and demand in Bago River watershed. This study aims to simulate water resources in the Bago River Basin and evaluate the water balance under increased service levels due to increased population and irrigation activities among users which are important for decision makers engaged in water related sectors.

1.2 Statement of the Problem

Recently, water resource management in Myanmar has become more complicated and contentious due to impacts of various parameters affecting its water systems. For instance, increasing demands due to rising from human activity, changing of socio-economic situations, growing industrialization and urbanization conditions, climate change, environmental considerations, and hydrologic and hydraulic conditions can be mentioned. In the case of Myanmar, adverse effects of this issue can be seen in an increase in strong droughts in the dry season, huge floods during the rainy season and unseasonable weather. Currently, the rate of population growth and urbanization as well as industrial development in the large cities of Myanmar has grown rapidly. As a result, the demand for water has increased in the water sector, household appliances, industry, agriculture and hydropower production. All the problems, along with the fact that water plays a dynamic role in almost every aspect of human life, make water sources an important source of conflict. Therefore, decision makers need to have reliable models to manage water resources between different stakeholders efficiently and effectively (Zarghami et.al., 2015).

Nowadays, water shortage is one of the real challenges facing many countries in the world. Water surplus and shortages forced many countries to reconsider the management options of their water resources and its infrastructure. As a result, water resource management (WRM) have undergone a drastic change world-wide, moving from a supply-oriented, engineering based approach towards a demand oriented and multi-sectorial approach. Myanmar has abundant water resources comprising four principle river basins including Ayeyarwady, Chindwin, Sittaung, and Salween. However, about 80 percent of abundantly water flows during May - October due to the monsoon season. The rest is in the dry season, which is lacking water resources, especially in the arid regions of the central region, such as Bago and Yangon regions, as well as in Kachin and Shan states (FAO, 2016).

The Republic of the Union of Myanmar (Myanmar) is one of the Southeast Asian countries and surrounded by the Andaman Sea, the Bay of Bengal, Bangladesh, India, China, Laos, and Thailand. Its total area is 6,53,290 km^2, its population has increased from 18.8 million in 1955 to over 54 million in 2019. Moreover, water requirement for domestic consumption, tourism and industrial activities are continuously growing at an increasing rate. Total water extract from available water resources in Myanmar are around 89% for agriculture, 10% is for municipalities and 1% is for industries. 91% of the total water extract comes from surface water and 9% from groundwater (ADB, 2013). Groundwater is mostly used for domestic purposes. As the difference between water resources and demand is ever increasing, the government is faced with the increasingly difficult task of water managing and delegating the available water resources among the competing demands.

Water managers and policy makers require tools in order to achieve a balance in water supply and demand, to ensure equitable use of water resources, protect the environment, and develop priorities in shared water resources (Loon and Droogers, 2006). In the literature, there are many hydrological and hydraulics models for the water management and water balance. For example, EPA's Storm Water Management Model (**SWMM**) is promising for urban flood planning (Jiang, 2015), Water Balance Model **(WBalMo)** Model is an interactive simulation tool for river-basin management by balancing the respective time series with monthly water use demands and reservoir storage changes (Loucks, 2006), SEI's Water Evaluation And Planning model (**WEAP**) can be applied for accounting of water supply and demand in the Upper Chattahoochee River Basin of Georgia (Johnson, 1994), the Catchment Water Allocation Tool (**CaWAT**) was used for water resource planning; it is based on water balance accounting. It also simulates the water storage, which is a model of the balance of water (Cai, 2014). Among them, **WEAP** has been used worldwide in order to evaluate an existing and future water balance, scenario analyses, and reporting data tool for water resource management in this study area.

The Bago River Basin (BRB) is the sub-basin of the Sittaung River and it is located 91 km from the northeast of Yangon. **Figure 1** shows the location map of the Bago River Basin (Shrestha, 2014). The Bago River originates from the south of Bago mountain range, which flows toward the south and finally confluence into the Yangon River, which drains to the sea and also connects to the Sittaung River. The Bago Basin has faced several floods and droughts in recent years because of poor water management. Consequently, floods and droughts have caused degradation of natural and water resources (Hlaing et al., 2008). It has been reported that annual rainfall has decreased and seasonal stream flows are reduced to this watershed, particularly during the summer season. In many areas of the Bago Basin, water is scarce during the dry season due to insufficient rainfall for water use and the development of unstable renewable energy from dams and reservoirs in upstream areas. Water yields declined at the basin outlet during the summer and winter, but increased during the rainy season. The outflow from this area is insufficient for the downstream area (Kawasaki, 2017).

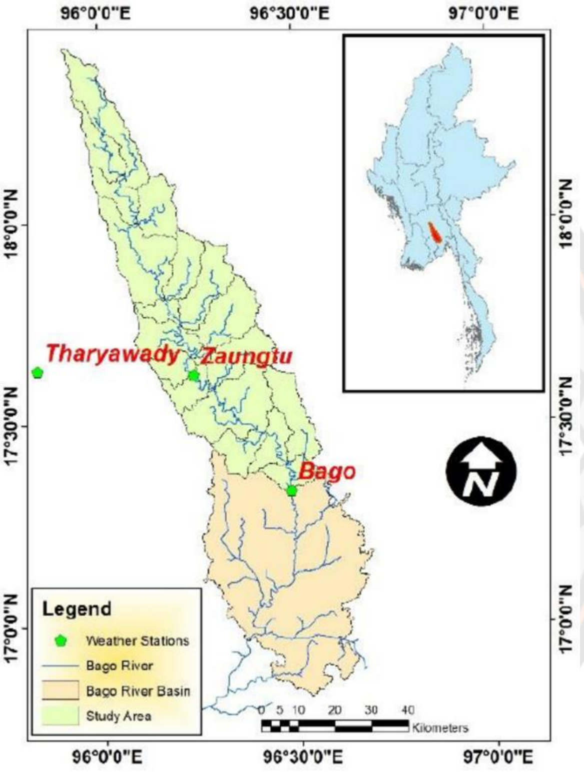


Figure 1 Location of Bago River Basin, Myanmar

Source: Shrestha, M., 2014

In 2011, the water level in the Bago River at the city's hydrology site rises to 9.6 meters above average sea level (M.S.L), causing damage to paddy and many farms in Bago Township (Win et al.,2018). Moreover, in 2015, a major flooding occurred in this basin, causing damage to buildings and structures. Resulting in the loss of life and property, as well as the impact that damage to agricultural products, paddy, and farms in the area of Bago Township (Kawasaki, 2017). Bago area has a major irrigation scheme; rice is practically the only crop and is exported through Yangon. The Bago River Basin plays an important role in agricultural production of paddy rice in Myanmar and its socioeconomic development is impacted by flood and drought disasters. It is one of the most useful river basins in lower Myanmar for hydropower generation in the country, the use of water for agriculture, irrigation, fishery and navigation.

However, Bago river basin suffers water problems such as floods, drought, many water disasters because of poor water resource management and lack of technical information and expertise to support planning, management and innovation in the water sector (Shrestha, 2014). The increased water demand during the dry season and has also increased water problems in the study area. The water balance of a basin is the key aspect in water resources development and management programs. The components of water balance of a basin are influenced by water supply source and water demand activities and the physical characteristics of the watershed. Until now, the author has not seen any results of studies on water balance and effective water resource management with WEAP model in the Bago Basin. Therefore, the main objective of this study is to assess the current surface water availability and demand situation and future water balance in the Bago Basin, Myanmar. The outcome of this study is expected to improve water management decisions, to develop the WEAP model, better adaptation, and preparation for a protective plan to reduce water resource problems for the future.

1.3 Objectives of Research

The objectives of the research are:

1.3.1 To describe the overview of the existing situation of water resource availability, include water demand and supply in the study area.

1.3.2 To evaluate the existing water balance with an application of the Water Evaluation and Planning System version (WEAP) for the development of water resources of the study area.

1.3.3 To evaluate future water balance with the different scenarios by using the WEAP model in the study area.

1.4 Scope and Limitation of Research

This study was carried out in the Bago River Basin (from the upstream of Bago River to Bago Township). This is covering the local consumption of water resources to the domestic and agriculture to build future scenarios to enable the possible impact of water resource. This study uses the WEAP model to assess current and future water balances for key water use sectors in the Bago Basin. With the current condition being evaluated for water balance between 1999-2018. Due to lack of data of demand for crop water at the local level, including lack of groundwater use data which cannot be collected. This study, therefore, evaluates the water demand of major plants from the 4 groups of crop calendar, namely rainy season rice, dry season rice, field crops, and orchards in the study area. In addition, this study also uses the relationship between rainfall-runoff model from the simplified coefficient method.

1.5 Structure of the Thesis

The thesis is organized and presented in five parts. They are as follows:

Chapter 1: Introduction

This chapter provides background of the thesis, statement of the problem, objectives of the study, the limitations and the scope of the study.

Chapter 2: Literature Review

The literature review chapter describes the general knowledge of hydrology, water resources management models, CROPWAT 8.0 software, WEAP model software and applications and scenarios with WEAP model.

Chapter 3: Methodology

This chapter describes the overview of the study area, overview of the study methodology, development of Water Evaluation and Planning (WEAP) model, data entry in the current accounts, calibration and validation of WEAP Model, and the creation of scenarios in WEAP of the study research.

Chapter 4: Results and Discussion

This chapter presents WEAP model performance results, a description of the findings of the existing water balance situation and simulation and evaluation of future scenario results.

Chapter 5: Conclusions and Recommendations

The final chapter addresses conclusions based on the findings in relation to the research objectives and gives recommendations on the effectiveness of the WEAP model used for water balance.

CHAPTER II

LITERATURE REVIEW

This chapter discusses the background knowledge of hydrology, geographic information system (GIS) and remote sensing, water resources, water allocation, the water resources management models, and WEAP model.

2.1 Hydrological Balance

Water is an essential resource and a primary requirement of all living things. There is an ever-increasing demand for the supply of fresh water to the various sectors of need. Hydrology plays a fundamental role in the development and management of water resources as well as in the protection of the environment (Patra, 2001). In the present research, the main focus is to understand the existing and future water balance of Bago River Basin by an in-depth study of the concept of water balance and by using the Water Evaluation and Planning (**WEAP**) model as a water balance tool to assist water planners and policy makers in decision making for future management of the water resource problems.

A related concept commonly utilized in hydrology is the hydrologic cycle. Several aspects of water related to the Earth can be described in terms of a cycle known as the hydrologic cycle. **Figure 2** presents a schematic description of the hydrologic cycle and the natural world hydrological balance.

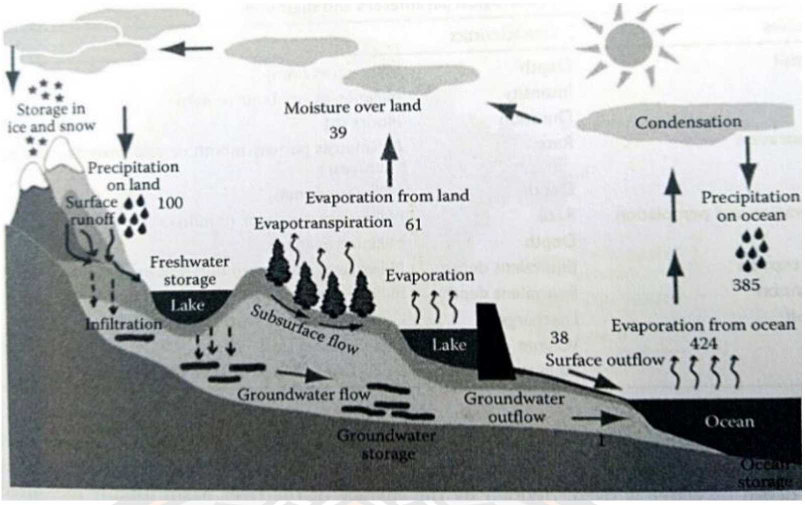


Figure 2 The Hydrological cycle and the annual world hydrological balance

Source: Mimikou, M. A., 2016

There is a genuine need in hydrology to define the whole area that receives the rainfall, and surface runoff is produced and tops up to a specific location or point of the drainage system. The area is called a drainage basin or watershed. To manage the water supply and estimates of water scarcity, a water balance method can be used. It is also used in irrigation, runoff calculation, flood control and pollution control. Numerous monthly water balance models have been developed for several conditions and purposes. The water balance of a river basin is expressed by equating the variance between inputs and outputs with the rate of change of the water storage ΔS in a defined time interval Δt. If the watershed or a reservoir, is considered as the hydrological balance, it can be expressed as follows:

$$\frac{\Delta S}{\Delta t} = \bar{I} - \bar{O} \tag{2.1}$$

Where $\bar{I}$ and $\bar{O}$ are the average inflow and outflow (m^3) in the time interval Δt (s). The rainfall, the snow, the hail and the other forms of precipitation could be considered as inflow for a catchment area. The most communal forms of outflow could be measured by the surface runoff, intermediate runoff, underground runoff, evaporation, transpiration, and percolation.

Water Balance Equation

$$P - R - G - ET = \Delta S \tag{2.2}$$

where,

P = precipitation (mm)

R = surface runoff (mm)

G = net groundwater flow out of the catchment (mm)

ET = evapotranspiration (mm)

ΔS = change in storage (mm).

The storage S consists of three components as

$$\Delta S = \Delta S_s + \Delta S_{sm} + \Delta S_g \tag{2.3}$$

where,

ΔS_s = surface water storage

ΔS_{sm} = water in storage as soil moisture and

ΔS_g = water in storage as groundwater.

A linear program (LP) is used to make the best use of approval of requirements for demand sites, user specified instream flows and hydropower, subject to demand priorities, supply preferences, mass balance and other constraints. Mass balance equations are the basis of WEAP's monthly water accounting: total inflows equal total outflows, net of any change in storage. Every node and link in WEAP has a mass balance equation. Each mass balance equation becomes a constraint in the linear Program (LP).

2.2 Geographic Information System (GIS) and Remote Sensing

A geographic information system (GIS) is a system intended to capture, store, manipulate, analyze, manage, and present all types of geographical data. GIS is a useful tool in water resource engineering if it is used effectively and efficiently.

Geographic Information System (GIS) and Remote Sensing (RS) is an integral tool of water resource strategy (Kumar,1999). GIS is the most complete information system for modeling, analyzing spatial data and displaying community. In this study, GIS can be used to create a background map of the study area which clearly and quickly illustrates specific areas of a community. Landcover refers to the physical condition of the earth's surface such as forest, water, grassland, bare land and so forth, while land-use corresponds to the human activities. The classification process of land cover can be done based on the purpose of the user, the spatial and spectral resolution of remote sensing data, etc. In the remote sensing technique, either supervised or unsupervised classification can be applied to land use and land cover classification. In this study, supervised classification will be applied to extract land-use and landcover classes from multispectral images using image processing techniques.

2.3 Water Supply Sites

Water resources are natural resources of water that are hypothetically useful. Sectors of water use include: agricultural, industrial, household, recreational and environmental activities and so forth. Surface water is water that amasses at ground level and can be collected by precipitation and is naturally lost through discharge to the oceans, evaporation, evapotranspiration and groundwater recharge. This water is naturally open to the atmosphere and may come from: Streams, Rivers, Lakes, Wetlands and Oceans. Groundwater is renewed water located in the subsurface pore space of soil and rock foundations and it is flowing within aquifers below the water table.

The water supply comes from surface water, groundwater, rainwater and wastewater treatment and reuse. Water supply is the provision of water from public utilities, commercial organizations, community endeavors or by individuals, usually via a system of pumps and pipes. Understanding the balance or imbalance of all water allocations in a region is a critical first step toward effective water resource planning and management. The task is of developing a water balance, or a weather center for a number of years. The computer program Water Evaluation and Planning System (WEAP) has been developed to model all supply and demand in a region and to provide information on the balance of the water resources under a variety of future conditions.

2.3.1 Reservoir and Weir

Reservoirs are constructed for two main functions. The first function is to store water in the lake behind the dam to even out the variations in river flow and to match the availability with demand. The storage water and head allow reservoirs to generate electricity, to supply water for agriculture, industries and households, to control flooding, and to support river navigation by providing consistent flows and drowning rapids. A reservoir contains a number of other structural features than the main wall itself. Spillways are used to discharge water when the reservoir level becomes dangerously high. Weirs and dams are constructed to distract the river flow and they do not have substantial storage and cannot effectively regulate flows. Reservoir operation is a vital element in water resource development and management. Data of rainfall and runoff are used to predict the pattern of supply to a reservoir. It consists of several control variables that define the operation strategies for controlling a sequence of releases to meet a large number of demands from stakeholders.

2.4 Water Demand Sectors

Water Resources that comprise surface water (river, lakes, and reservoirs), groundwater, floodwater, and with the advent of new technologies, desalinated water, are an essential input for various allocation sectors, such as municipal, industrial, agricultural, hydropower, and so forth. With increased population growth rates, improved lifestyle, dwindling supplies (both in terms of quantity and quality), the competition over scarce the water resources is increasing.

2.4.1 Domestic Demand Sector

Domestic water use is water used for indoor and outdoor household purposes: drinking, preparing food, bathing, washing clothes and dishes, and so forth. In the domestic sector, population growth is one of the key factors affecting water demand through increased consumption of water demand for domestic purposes. In this study, arithmetic progression method was used to calculate the population growth rate and to estimate the future population size of the study. These were the simplest methods of population forecast.

Population Growth Rate percentage

$$PR=\frac{(V_{present}-V_{past})}{V_{past}}\times 100 \tag{2.4}$$

Source: Bob, 2002

where, PR = Percent growth rate of population

$V_{present}$ = Present or future value of the population (No.)

V_{past} = Past value of the population (No.)

N = Year from present to past population (No.).

Estimating the population size between two census periods

$$P_{estimate}= P_1+\frac{n}{N}(P_2-P_1) \tag{2.5}$$

Source: https://www.measureevaluation.org/

where, $P_{estimate}$ = population estimate for a given year (no.)

n = the number of months from P_1 census to the date of estimate

N = the number of months between census periods

P_2 = last census taking (no.)

P_1 = second to last census taking (no.).

2.4.2 Agricultural Demand Sector

1) Crop Water Requirement

Crop water requirements are defined as the required water depth of the crop to meet the water loss through evapotranspiration, increasing in large fields under non-restricting soil conditions, including soil, water and fertility and reaching full production potential under the given growing environment. The crops require a certain quantity of water through their growth period.

2) Reference Crop Evapotranspiration (ET_o)

The evapotranspiration from a reference surface in order not to have a shortage of water is called the reference crop evapotranspiration and is denoted by ET_o. The ET_o was proclaimed to study the evaporative demand of the atmosphere self-sufficient of crop type, crop development stage and management practices. To calculate the reference crop evapotranspiration (ET_o), there are (i) Blaney-Criddle method, (ii) Radiation method, (iii) Pan evaporation method, (iv) Penman method or Modified Penman method and (v) Penman-Monteith method. In this study, Penman-Monteith Method was used to calculate crop evapotranspiration.

3) FAO Penman-Monteith Method

Nowadays, the most recommended method for determining reference crop evapotranspiration (ET_o) becomes the FAO Penman-Monteith method. This method overcomes the limitations of all other previous empirical and semi-empirical methods and provides ET_o values that are more reliable in terms of actual crop water use data in all regions and climates.

The **Penman-Monteith equation** is given by the following equation;

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{2.6}$$

where,

ETo = reference evapotranspiration (mm day^{-1})

R_n = net radiation at the crop surface (MJ m^{-2} day^{-1})

G = soil heat flux density (MJ m^{-2} day^{-1})

T = mean daily air temperature at 2m height (°C)

u_2 = wind speed at 2m height (ms^{-1}) = $u_z \frac{4.87}{\ln(67.8z - 5.42)}$

where z isheight of measurement above ground surface (m)

e_s = saturation vapour pressure (kPa)

e_a = actual vapour pressure (kPa)

$e_s - e_a$ = saturation vapour pressure deficit (kPa)

Δ = slope vapour pressure curve (kPa °C^{-1})

γ = psychrometric constant (kPa °C^{-1})

4) Crop Evapotranspiration (ET_c)

The crop evapotranspiration under standard conditions is the evapotranspira-tion from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions. The crop evapotranspiration differs distinctly from the reference evapotranspiration (ET_o) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (K_c). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ET_o by K_c (FAO, 1977).

$$ET_c = K_c \times ET_o \tag{2.7}$$

Where, ET_c = crop evapotranspiration (mm / day)

K_c = crop coefficient (unitless)

ET_o = reference crop evapotranspiration (mm / day)

5) CROPWAT 8.0 Software and Application

CROPWAT was developed by the Land and Water Development Division of FAO for planning and management of irrigation as a decision support system. It is a practical tool that is used to transmit out standard calculations for reference evapotranspiration, crop water requirements and irrigation requirements (Savva, 2002). For estimating crop evapotranspiration, CROPWAT 8.0 uses the recommended FAO Penman Monteith method.

In similar studies conducted in Zambia on promoting water use efficiency revealed that allocating water based on crop water requirement reduces water demand as opposed to allocating water based on a fixed quantity. In a correlated study on reasonable water allocation (Mtshali, 2001) concluded that using crop water requirement in water allocation gives scope to accommodate new water right applicants. In the present study, CROPWAT 8.0 model will be used as a tool for calculating crop water requirements.

2.5 Water Resources Management Models

Water resource planning and management was usually an exercise based on previous engineering considerations. Currently, it gradually occurs as a part of a complex, multi-disciplinary analysis that brings together a wide range of individuals and organizations with different interests, technical skills, and selections (Yates et al., 2005). To select the appropriate models for solving specific problems, the classification of models depending on the spatial scale and physical detail of the model are important to know the determination of model behavior as required data, required expertise, expected accuracy and user-friendliness (see **Figure 3**) (Immerzeel, & Droogers, 2008). Podium, STREAM, SLURP, and WSBM are IWRM models for national scale, SWAT, and WEAP are the basin and system analysis IWRM model, and SWAP, WaterMod and FutureView are small scale IWRM tools.

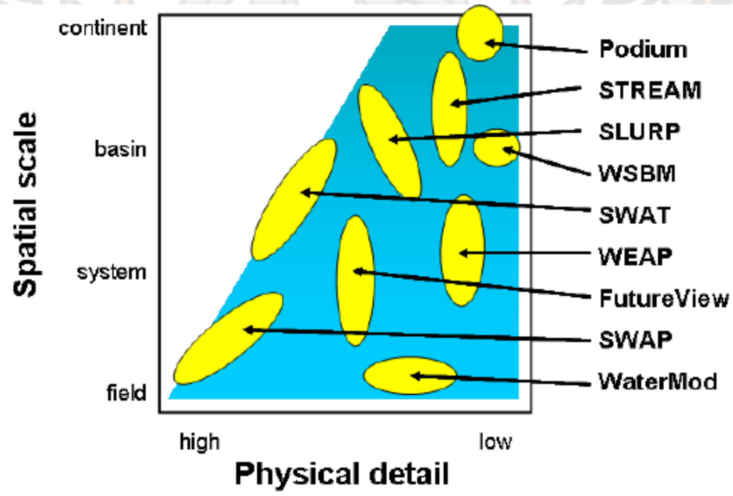


Figure 3 Spatial and physical detail of hydrological model

Source: Immerzeel, & Droogers, 2008

SWAT (Soil and Water Assessment Tool) includes complex physical hydrology modules as rainfall-runoff, irrigated agriculture, and point and non-point catchment dynamics, but it is a relatively simple reservoir operation module (Srinivasan, 1998; Neitsch et al., 2002). This model is originating from United States Environmental Protection Agency’s research program, and it might have the potential to be a de-facto standard in basin scale modelling.

WBalMo (Water Balance Model) is an interactive imitation tool for river basin management, and it simulates the natural processes of runoff and precipitation stochastically by balancing the particular time series with monthly water use demands and reservoir storage deviations (Loucks, 2006; Mugatsia, 2010). It can identify management guidelines for river basins, design reservoirs and their operations, and perform scenario analysis and environmental impact analysis for development projects, but it requires detailed data for design.

The Water Evaluation and Planning System (**WEAP**) helps to integrate these values into a practical tool for water resources planning. It is famed due to its integrated approach to simulating water systems and by its policy orientation. It is complete, straightforward and easy-to-use, and attempts to assist rather than substitute for the expert planner. As a strategic analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (SEI, 2015). It can also analyse multiple scenarios such as technical changes, social-economic changes, and policy changes. WEAP is a new generation of water planning and management software, and due to the powerful capability of today’s personal computers, it can be easily used everywhere to access to the appropriate tools.

2.6 WEAP Model

The WEAP modelling software developed by the Stockholm Environmental Institute (SEI) is an object-oriented computer-modelling package and IWRM tool, designed for simulation of water supply system and demand analysis (SEI, 2015). The basic principle of WEAP is a water balance accounting operation with monthly time steps, and it can be applied in a single catchment to a complex trans-boundary river basin. In WEAP, Current Accounts and Reference scenario or business-as-usual scenario need to be created first, and then other alternative policy scenarios can be developed for comparison of their effects on the system against the business-as usual scenario.

WEAP has a user-friendly interface with graphical drag-and-drop GIS-based inputs and outputs as maps, charts, and tables. WEAP can link to other models and software, such as QUAL2K (surface-water quality model), MODFLOW (groundwater flow model), MODPATH (a particle-tracking model for MODFLOW), PEST (parameter estimation tool), GAMS (general algebraic modelling system), Excel, and Google Earth (SEI, 2015; WEAP, 2014). WEAP computes water and pollution-mass balances for every node and link in the system at every time step, however, each step is autonomous of the previous step, except about reservoir storage, aquifer storage, and soil moisture (Yates et al., 2005). Therefore, all of the water entering the system in a given period is stored in the soil, an aquifer, a reservoir, or leaves the system at the end of that period.

2.7 WEAP Model Software and Application

WEAP model was formed in 1988 as a flexible IWRM tool for the current water supply and demand system evaluation and future scenario exploration (WEAP, 2014). It has an extensive history of development and use in the water-planning field. The first application of WEAP was in 1989 to study the water development strategies and water supply and demand analysis in the Aral Sea region in 1989 with the sponsorship of SEI (Raskin et al., 1992). The version of WEAP at that time had several limitations, such as an allocation scheme, demand sites priorities and water allocations.

WEAP software has been a support to water planners from global organization and institutions, especially, freely transferred to governmental and academic users from developing countries, and WEAP has been applied in several countries and river basins over two decades. The application of WEAP models to main agricultural regions in Argentina, Brazil, China, Hungary, Romania, and the US, was analyzed by simulating future scenarios about climate change, agricultural yield, population, technology, and economic development (Rosenzweig et al., 2004).

The study about water evaluation and the planning system in Kitui-Kenya obviously verified that WEAP is a powerful framework in evaluating current and future options of water resources, and the evaluation can be completed within a few minutes by adding more accurate data to increase the accuracy of the analysis and validation of results (Loon, & Droogers, 2006). As population growth, urbanization, and current policies and water management practices highlight water resources and urban infrastructure, urban water management tools are becoming essential for urban water planners to see an overview of their water system (O'Connor et al., 2010).

Aung, 2014 evaluated the water supply options for the growing megacity of Yangon, Myanmar under different external driven scenarios and management scenarios by using the application WEAP modelling. Mansouri, 2017 used WEAP for inter-regional planning and analysis of water resources to estimate water demand and analysis of multiple and competing uses of the hydro-system in Seybouse's Wadi Basin and to make a comparison with proposed water storage estimations. This model was applied under five different scenarios which reflect the best and worst conditions of the supply and demand, not only to evaluate water demand shortage, but also to help planners to use different management options.

Leong, & Lai (2017) investigated integrated water resources management in the Langat River Basin, Malaysia by using WEAP modelling, the objective of this research is to evaluate current and future water management systems in that study area under different scenarios, due to the effects of climate change and the increasing demand for water. Hassan, 2017 researched future water resources management for the Sindh Province in Pakistan by using WEAP modeling water demand and supply and the aid of that research was to examine complex water resources systems and to examine supply and demand management strategies in that study area. Metobwa, 2018 applied WEAP model for water demand simulation to manage water resources for present and future uses in a case study of the Mara River Basin, Kenya. Modelling water demands and resources at the MRB showed that the basin is projected to experience strain and pressure increases on its resources; water and land. The application of WEAP models to develop a calculation environment, a decision support system for the management of surface water resources in the Ivory Coast basin of Aghien Lagoon analyzed the ability of the WEAP model to evaluate quantitative water management scenarios, by comparing the evolution of the demand with that of supply in terms of water availability (Djibril et al., 2019).

2.8 Application of WEAP Model in the Study Area

According to the WEAP literature provided on the official website, WEAP is applied effectively in multi-criteria in WRM field all over the world, including water supply and demand management issues in the river basin to achieve multi-benefit goals. The aim of the study is to evaluate current and future water balance, based on Water Evaluation and Planning (WEAP) for a case study of the Bago River Basin in Myanmar. Firstly, the model was run for twenty years and illustrated the application of the WEAP model as a water balance tool for the development of water resources, described the overview of the existing situation of water availability, demand and water resource planning within the study area, evaluated future water balance under different scenarios on the water resources management and made recommendations for these different future scenarios by the year 2040 in the Bago River Basin. Finally, the model performance was evaluated by model evaluation statistics.

2.9 Scenario with WEAP model

WEAP model as designated above allows for the analysis of numerous global change and water management scenarios. Scenarios are self-consistent storylines of how a future system might develop over time. These can address a broad range of "what if" questions like what if population increases?’, ‘What if ecosystem requirements are tightened?’ and so on.

This permits us to evaluate the implications of different internal and external drivers of change, and how the resulting changes may be mitigated by policy and/or technical interventions. For instance, WEAP can be used to assess the water supply and demand impacts of a variety of future changes in demography, land use, and climate. The results of these analyses can be used to attend the development of adaptation portfolios, which are combinations of management and/or infrastructural changes that enhance the water productivity of the system. In several basins around the world increasing water demand is leading to the over exploitation of limited water resources and more recurrent and more pronounced periods of extreme water scarcity

(Falkenmark and Molden, 2008). Modeling can be used to determine possible implications of water demands and provide a useful contribution to how the water resources of the Bago River basin might be best utilized in the future.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Overview of Study area

Bago River basin is shared by both Bago Township of Bago Division and Yangon Division of Myanmar and lies within the latitude 16° 40’ 30”and 18° 25’ 48” N, and longitudes 95° 54’ 39.6” and 96° 44’ 38.4” E. The total drainage area of the Bago River Basin is **3,220 km^2** and the total river length is about 331 km long, however, the study was conducted only up to Bago Township shown in **Figure 4** Therefore, the basin area of the study is **2,660 km^2** (based on SRTM-DEM) and the river length is about **245 km**. The study area was divided into two catchments: namely, upstream catchment with the area of **1700 km^2** and downstream catchment with the area of **960 km^2**.

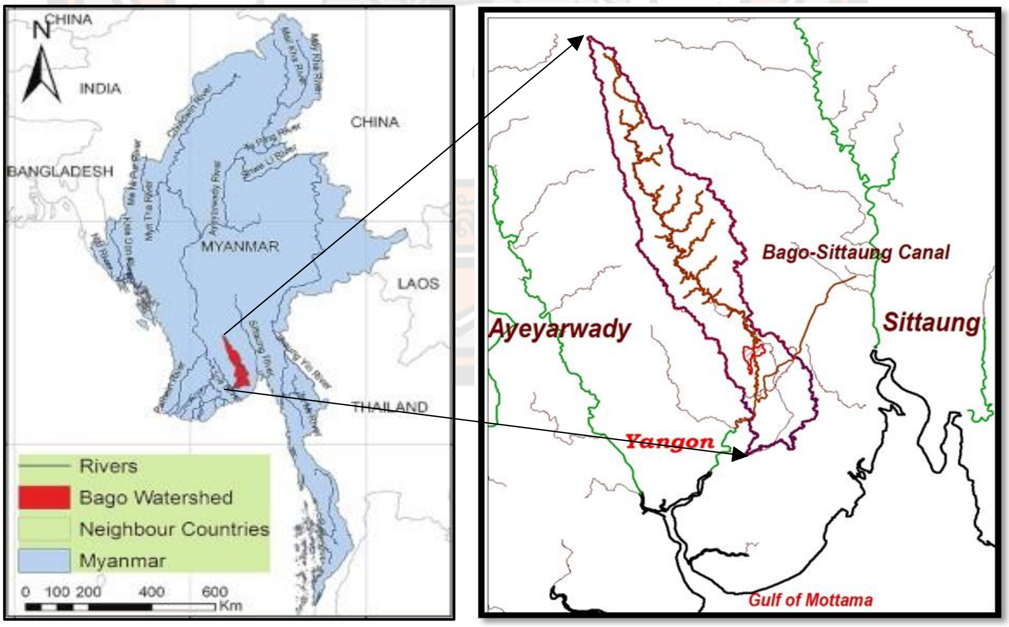


Figure 4 Location map of the study area

Source: Shrestha, 2014; MIMU, 2013

The Bago River is one of the most important and useful river basins in lower Myanmar for hydropower generation, irrigation, fisheries, and navigation. Since Bago Region topographies and the neighboring of Sittaing Basin contain mountains and floodplains, the region has both forest cover for teak production, while the flood plains are important for rice production and other agricultural products. The BRB has only two meteorological stations: namely Bago and Zaung Tu, which are managed by DMH (Myanmar). Bago and Zaung Tu are located at (17°20.250'N, 96°29.082'E; 15 m AMSL), and (17°37.812'N, 96°13.734'E; 36 m AMSL). For the purpose of irrigation and power generation, the Zaung Tu Hydropower dam (storage capacity 407 MCM, catchment area 1,120 km2, built in 1994) was constructed about 65 km upstream from Bago City, is the uppermost dam on the Bago River. Mazin dam was constructed in 1998 and completed in 1999 for the purpose of domestic and irrigation use for Bago Township. Three earthen dams namely kodukwe, Shwe laung, and Salu dam, which located on tributaries connected to the left bank of the Bago River by the Zaungts Weir (built in 1994) were constructed in 2011 and opened in May, 2012 for the purpose of flood control and the irrigation. The Zaung Tu weir has a function as the regulator with 18 MCM of the storage capacity, for which the released water from Zaungtu (296 MCM/-: total storage/effective storage), Kodukwe (183 MCM/170 MCM), Shwelaung (145/117 MCM) and Salu (112/97 MCM) reservoir (Main Report, 2014). Moreover, the flood diversion canals from the Zaung Tu weir to the Zaung Tu-Moe Yoon Gyi, Zaung Tu-Sun Pi, and Zaung Tu-Kyike Hla were also completed in 2012. At the down reach, the water flows into the Sittaung-Bago Canal, as supplying water to four (4) irrigation areas planned in the eastern bank of Bago River. **Figure 5** shows the location of the dams, weir and the weather station.

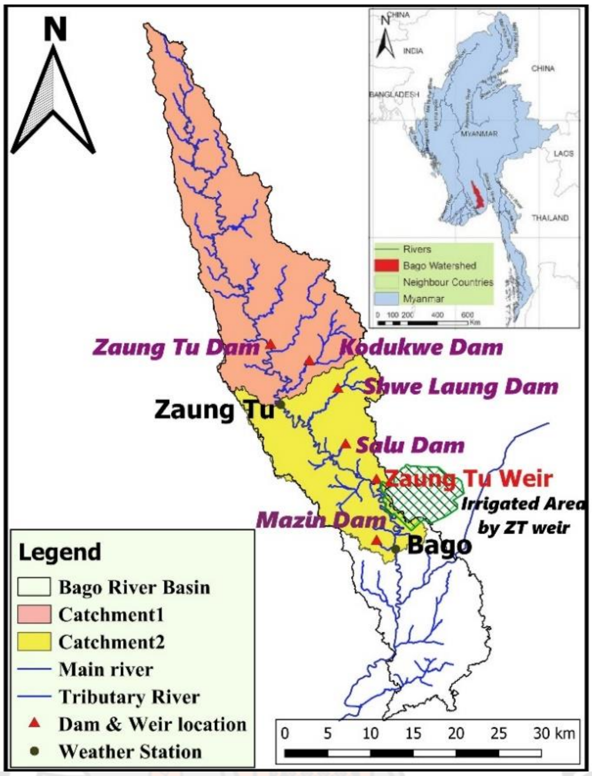


Figure 5 Location map of dams, weir and weather station in the study area

Source: MIMU, 2018

The Bago River originates from the south of the Bago mountain range, then flows south ward and drains into the Yangon River near Yangon city. The peak elevation of the sources of the Bago River is about 800 m above sea-level in the southern Bago mountain range. Therefore, the whole river system is located in Lower Myanmar between the two larger systems of the Sittaung River (**420 km**) on the east and the Ayeyarwaddy (**1550 km**) and the Myintmakha Rivers on the west (Htut, A. Y., 2014).

The total population in the whole BRB is 491,434 (MIP, 2014(Bago Region)), but it is 353,816 in this study area. The historical population trend along with the average population growth rate of 1.85% of the study area is shown in **Figure 6**. There were two types of soil in the BRB: Nitosols (Ne) covering 62% and Eutric Gleysols (Ge) covering 38% of the total area. In the different landuse types, most of the areas upstream of BRB is forested. **Figure 7** shows the soil type and landcover map of BRB (Eriksen et al., 2017).

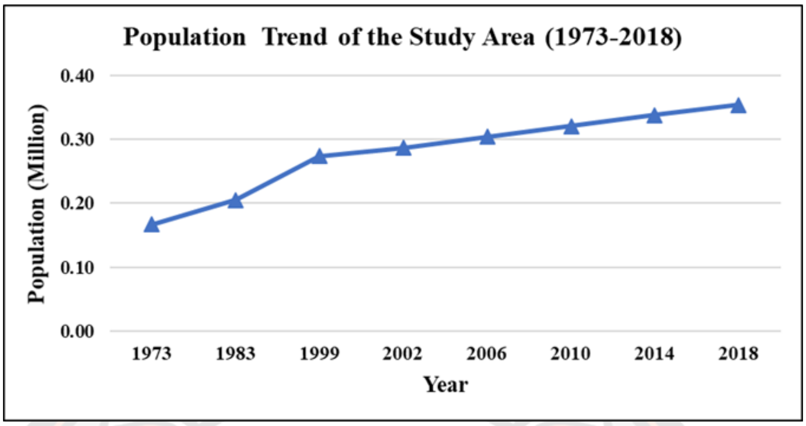


Figure 6 The historical population trend in the study area from 1973 to 2018

Source: MIP, 2014

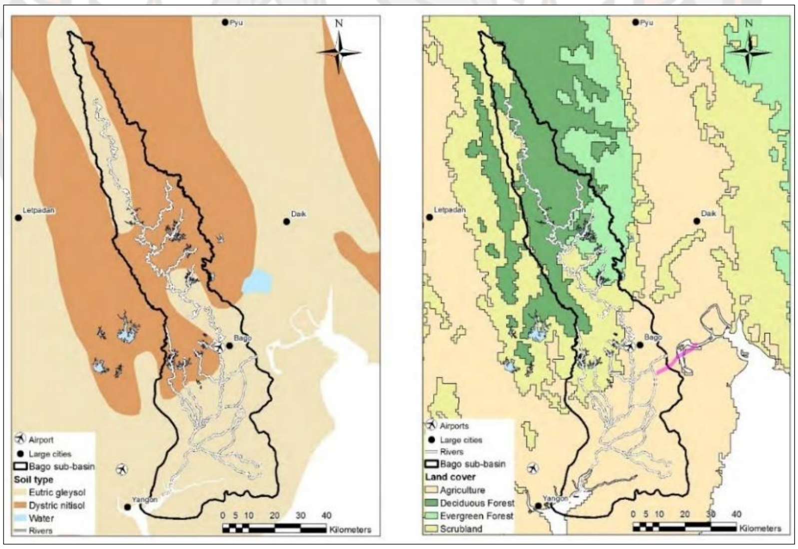


Figure 7 Soil type and land cover map of Bago River Basin

Source: Eriksen et al., 2017

3.1.1 Climatology

The Bago River basin is a tropical monsoon climate zone in southern Myanmar and there are three seasons: summer, winter and rain. In long-term analysis, the maximum mean daily temperature of BRB is 38ºC (in April) and the minimum is 16ºC (in January). The mean relative humidity of BRB is high in the rainy season, moderate in the winter season and low in the summer season. The maximum mean wind speed of BRB is 4.9 miles per hour (mph) in April and the minimum is 3.65 mph in October. The maximum mean monthly evaporation of BRB is 176 mm in April, and the minimum is 109 mm in July. In BRB, the average monthly rainfall is high by 825 mm at Bago station and 725 mm at the Zaung Tu station in July, especially in the rainy season. The average annual rainfall of Bago and Zaung Tu stations are 3365 mm and 3022 mm, respectively. The long-term monthly average values of all climate data except rainfall are shown in **Figure 8 and 9** shows the rainfall data by analysing the data at Bago and Zaung Tu Station for the period 1999 to 2018.

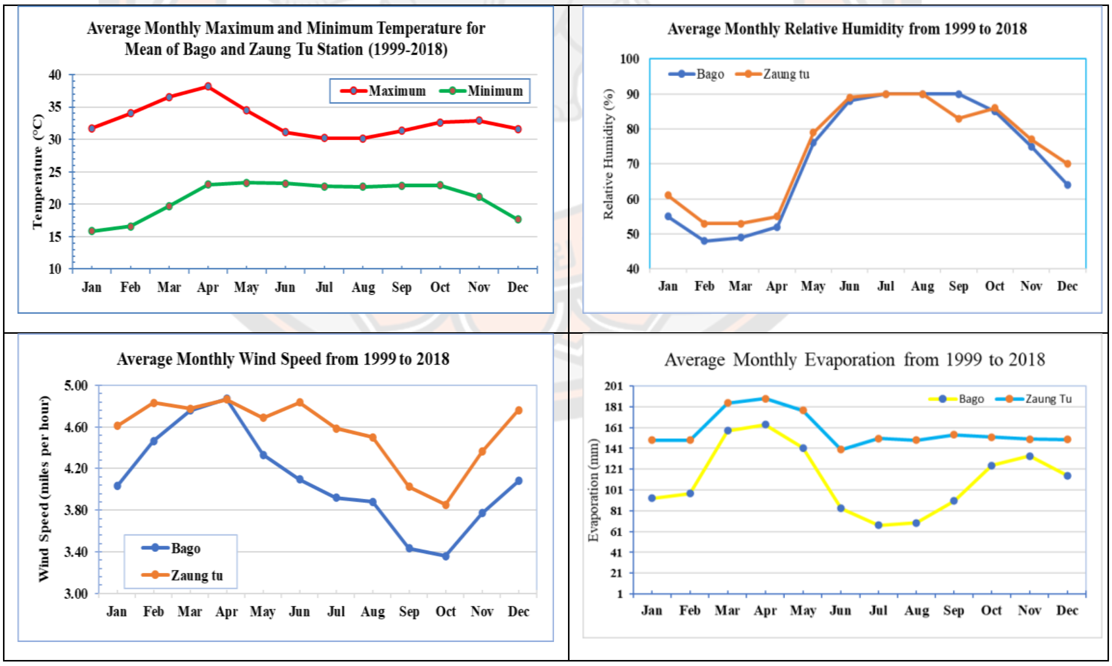


Figure 8 Average monthly maximum and minimum temperature, relative humidity, wind speed and evaporation at gauging station of BRB (1999 to 2018)

Source: DMH (Myanmar), 1999-2018

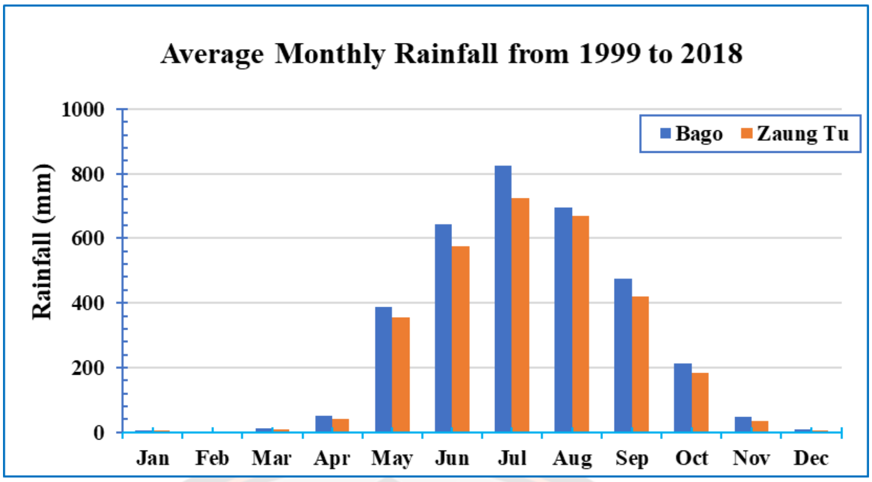


Figure 9 Average monthly rainfall at Bago and Zaung Tu station from 1999 to 2018

Source: DMH (Myanmar), 1999-2018

3.2 Research Methodology of the Study

In this study, GIS has been used to produce the background map of the study area with SRTM (DEM) data, Remote sensing techniques have been used for the landuse classification with Landsat8 image. The CROPWAT 8.0 software will be used to calculate water requirement of crops and WEAP model software will be used to evaluate an existing and future water balance under different possible scenarios. The overall methodology of this study is shown in **Figure 10** and **11.**

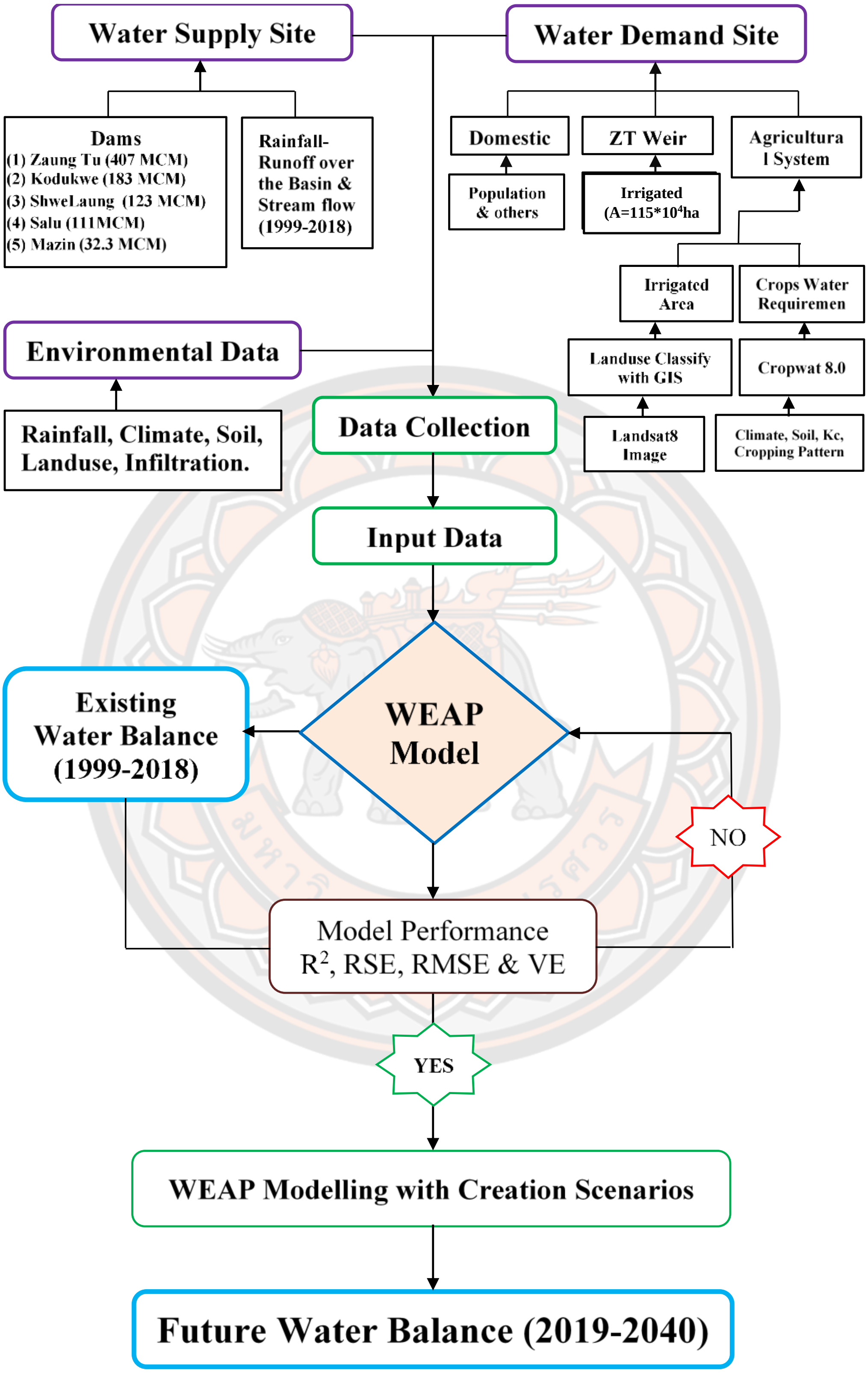


Figure 10 Flow Chart of the Study

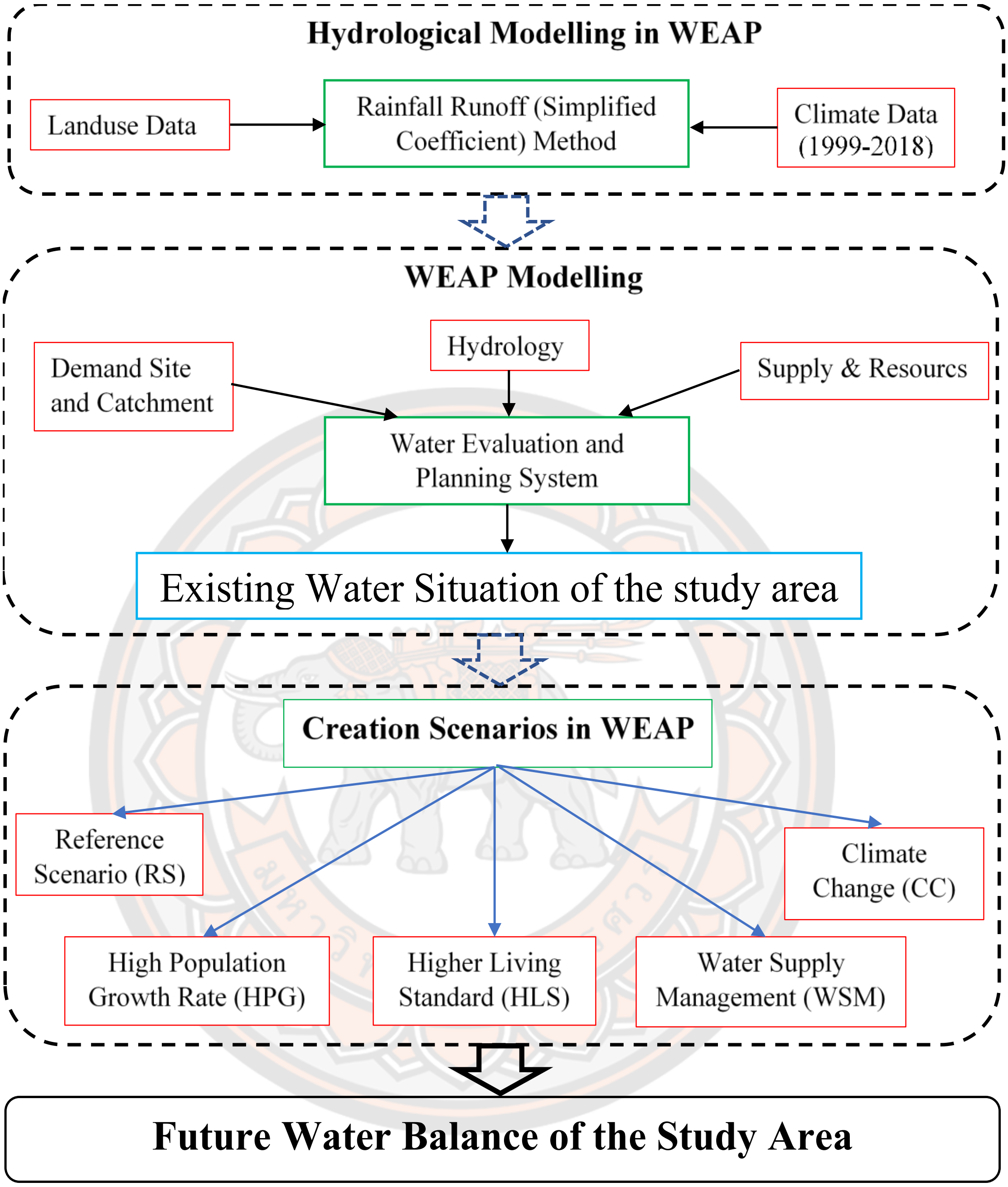


Figure 11 Schematic Diagram in WEAP

3.3 Data Acquisition

To generate the existing and future water balance of the BRB by using WEAP Model, the following data will be collected from different sources. **Table 1** indicates the list of required data and different sources for this study area.

Table 1 List of required data and Source of Data

No.	Data	Source	Year
1.	Digital Elevation Model (SRTM) (30 m resolution), Satellite Image Landsat.	EarthExplorer-USGS https://earthexplorer.usgs.gov/	-
2.	Discharge, Water level, Rainfall, Wind speed, Relative Humidity, Evaporation, Maximum and Minimum Temperature	Department of Meteorology and Hydrology (DMH), Myanmar. Bago station, Zaung Tu station.	1999-2018
3.	Population and Population Growth Rate	Department of Population Ministry of Immigration and Population (MIP), Bago Region.	-
4.	Domestic Water use rate	Engineering Department (Water and Sanitation) (EDWS), Bago Township Development Committee (Bago TDC).	
5.	Irrigation area, Water use and Soil data	Ministry of Agriculture, Livestock and Irrigation (MoALI), Bago.	
6.	Landuse data	Department of Agricultural Land Management and Statistics (DALMS), Bago.	-
7.	Dams and weir data	Irrigation and Water Utilization Department (IWUMD), Bago.	-
8.	Zaung Tu Hydropower Dam	Department of Hydropower Implementation (DHPI), Bago.	
9.	CROPWAT 8.0 software	http://www.fao.org/land-water/databases-and-software/cropwat/en/	
10.	WEAP Model Software	https://www.weap21.org/	

3.4 Development of Water Evaluation and Planning (WEAP) Model

In order for the water supply sources in the future will be sustainable and of quantity to meet many purposes of the growing demand. WEAP model has been developed and applied to evaluate the existing and future water balance under different scenarios. **Figure 12** shows the flow chart of the WEAP model, which is modified by own creation based on SEI, 2015.

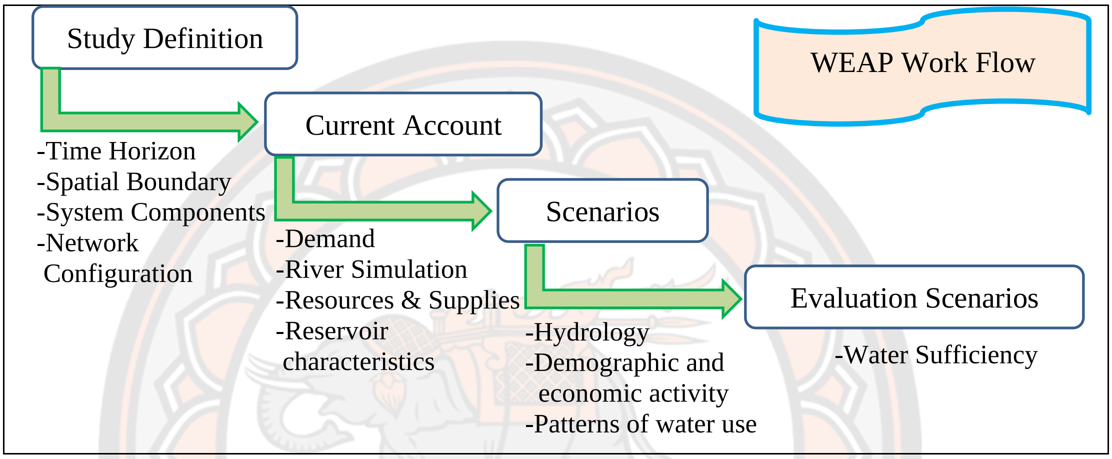
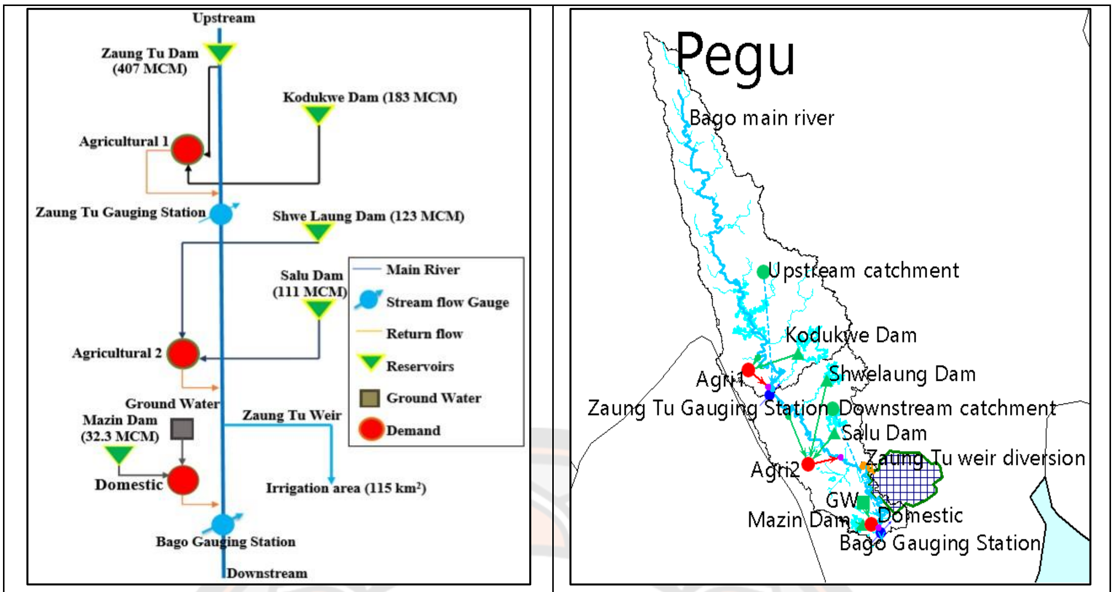


Figure 12 The flow chart of WEAP

The main schematic component of WEAP model that required various parameters and variables to carry out its simulation are illustrated in **Figure 13(a)** and **(b)**.



(a) (b)

Figure 13 (a) Schematic of the main components of the Model (b) Schematic illustration in WEAP application

3.4.1 Rainfall-Runoff Modelling in WEAP

Different methods are available in WEAP for rainfall-runoff modelling of the basin, which include rainfall-runoff (simplified coefficient method), irrigation demands only (simplified coefficient method), rainfall-runoff (soil moisture method), MABIA (FAO 56, dual KC, daily), and plant growth (daily; CO_2, water and temperature stress effects). In this model, there are two catchments: Upstream catchment (from Upstream to Zaung Tu gauging station) and Downstream catchment (from Zaung Tu gauging station to Bago Township). Based on data availability for the BRB, **rainfall-runoff with the simplified coefficient method** was employed for this study based upon the hydrological processes in the water cycle as shown in **Figure14.**

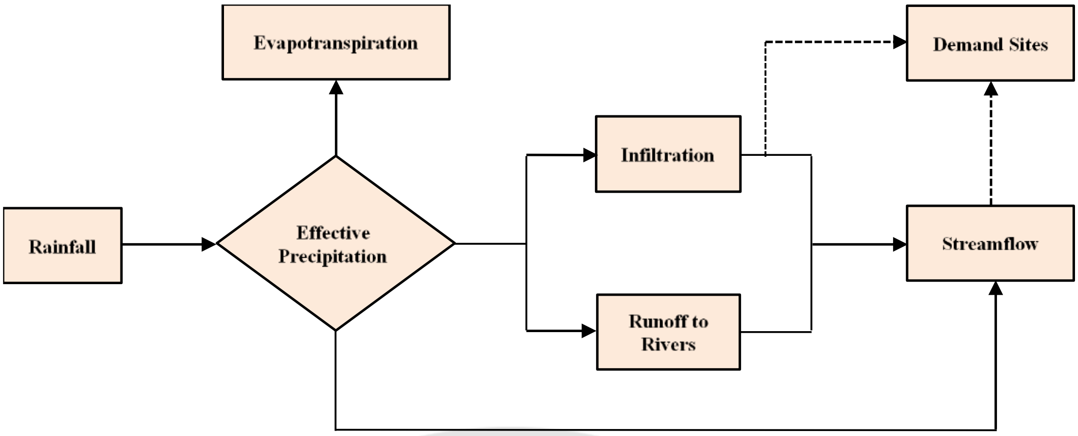


Figure 14 Flow chart of rainfall runoff sub-model with simplified coefficient Method

Source: LeRoy, 2005

The parameters which can be used for model calibration in WEAP using rainfall-runoff (simplified coefficient method) include **runoff coefficient**, **crop coefficient**, **reference crop evapotranspiration**, and **effective rainfall**. The model calibration was done manually for these parameters. The value of the runoff coefficient for the two sub-basins was estimated by dividing the runoff generated from rainfall into surface runoff (compared with the observed streamflow data).

3.4.2 Demand Sites

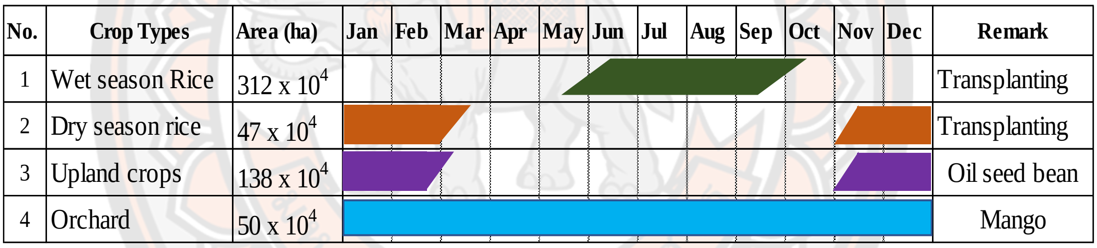
A demand site defined as a set of water users sharing a physical distribution system or an important withdrawal supply source in a defined region (**SEI, 2015**). Agricultural and domestic sites were major demand sites for this study. Domestic demand site was considered as one demand node for all township and village areas and agricultural demand site was divided into two demand nodes, which are: the agricultural node 1 in the upstream catchment and agricultural node 2 in the downstream catchment. Water demand was calculated by multiplying the activity level, by a measure of social and economic activity such as population or households for cities and hectares in an agricultural area, with the water use rate (SEI, 2015). Domestic water usage rate per capita per day is considered as 0.114 cubic meters (Bago, TDC).

In the calculation of crop water demand, the reference crop evapotranspiration (**ET₀**) is estimated by using the FAO Penman-Monteith Method (CROPWAT) because it has been recommended as the appropriate and the sole standard method of standard. According to the regions of the study area, U.S. Bureau of Reclamation Method was used for calculation **effective rainfall** as shown in the following equations:

Effective Precipitation, $P_e = 120.6$ mm, if Monthly precipitation $(P) \geq 150$mm
Effective Precipitation, $P_e = 0.8\,P$, if 50mm $<$ Monthly precipitation $(P) < 150$mm
Effective Precipitation, $P_e = P$, if Monthly Precipitation ≤ 50mm

The main crops of the study basin are wet season rice, dry season rice, upland crop and orchard and the cropping pattern as shown in **Table 2**.

Table 2 Cropping pattern and the area of the main crops



No.	Crop Types	Area (ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Remark
1	Wet season Rice	312×10^4					🟩	🟩	🟩	🟩	🟩	🟩			Transplanting
2	Dry season rice	47×10^4	🟧	🟧	🟧								🟧	🟧	Transplanting
3	Upland crops	138×10^4	🟪	🟪	🟪								🟪	🟪	Oil seed bean
4	Orchard	50×10^4	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	Mango

Source: MOALI, 2018

The cropping period for wet season rice is from mid-May to mid-October (Win et al., 2014 & 2020), dry season rice is from mid-November to mid-March (Shrestha et al., 2014), upland crops are from mid-November to the first week of March, orchard are from June to May (MOALI (Bago), 2018). Crop growth stages were divided into four: initial, development, mid and late stages. According to the landuse classification and MOALI (Bago) for the agricultural area, most of the upland crops were oil seed beans and the calculation of water demand for orchard in this study represented mango trees. There are two types of cultivating paddy within the study area - by spreading seeds of paddy and by transplanting one-month old paddy plants. In this study, transplanting method of cultivating paddy was used because cultivating by transplanting requires a lot of agricultural labour to grow it in time. Moreover, it may lead to better yields and high quality rice than that of spreading seeds (Win et al., 2018).

3.4.3 Hydrology section

In this study model, the Water Year Method was used for classification of normal, wet, and dry years based on the hydrological method by Yoo (2006; Khalil, 2018). For an assessment of climate variability of the study basin, the years from 1999 to 2018 were classified as wet, dry, or normal years as shown in **Figure 15**. Data from the two rain gauges were used to compute the mean annual rainfall for the period 1999–2018 using **Thiessen** mean method. Annual precipitation is more than $P_{mean} + 0.75SD$ ($P \geq P_{mean} + 0.75SD$) can be considered as the wet years, whereas periods with annual precipitation less than $P_{mean}-0.75SD$ can be considered as the dry years ($P \leq P_{mean} - 0.75SD$). Annual precipitation of more than $Pmean - 0.75SD$ but less than $Pmean + 0.75SD$ can be considered as the normal years ($Pmean - 0.75SD < P < Pmean + 0.75SD$).

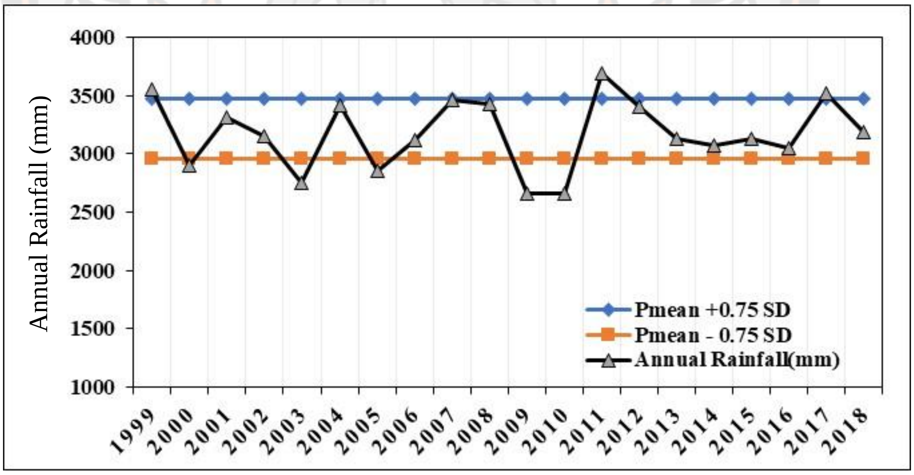


Figure 15 Normal, wet, and dry years of the study area from 1999 to 2018

3.4.4 Supply and Resources

Supply and resources section in WEAP determines the total water amounts, the available amounts, and the allocation of supply sources, and then simulates monthly river flows, surface water/groundwater interactions, instream flow requirements, hydropower generation, reservoir storage, and groundwater storage based on the definitions of the system demand sites and catchments, and its hydrology (SEI, 2015).

1) Rivers and Diversion

Head flow data of the river and the maximum inflow of the diversion are necessary to insert for the simulation of the rivers and diversion system. Head flow denotes the mean inflow to the first node on a river. In this model, the head flow data was the released flow of the Zaung Tu Hydropower dam because it is located in the upstream part of the Bago River. Diversion nodes are withdrawn water from a river, and this diverted flow becomes the headflow for a diversion. The study area had considered Zaung Tu weir which was located outside of the BRB as a diversion node and its beneficiary area for the agriculture is 115km^2 (IWUID, Bago).

2) Groundwater

Surface water and groundwater are hydraulically connected, for example, groundwater recharge will gain water from a stream or groundwater aquifer will lose water to a stream depending on the level of groundwater in the aquifer (SEI, 2015). The required input data for groundwater nodes are Storage Capacity, Initial Storage, Maximum withdrawal, and Natural Recharge.

In this study, there are 21 tube wells to supply water in agricultural areas and in rural areas. Unfortunately, there was no proper record, report or reliable paper to get the ground water data in this study. Thus, some realistic data were assumed to simulate the groundwater system. By assuming unlimited storage capacity, storage capacity for the aquifers was left blank. Initial Storage of the aquifers was estimated by using FAO groundwater potential data of Sittaung River and the corresponding township areas where groundwater projects were located, were used to represent the storage amount of the aquifers. Sittaung River has about **48100 km^2** of the catchment area and **28.402 km^3** of potential groundwater (Ti, 2004). Actual maximum withdrawal data were used exclusively from BRB owned tube wells were used to represent Maximum Withdrawal data, and Natural Recharge data was determined based on the Ayeyarwady SOBA Synthesis Report that Delta region (Ayeyarwady river), with 38323km^2 of the catchment area and 6093Mm^3 of groundwater natural recharge (Viossanges et al., 2017). The data used in groundwater simulation in this study were reported in the following **Table 3**.

Table 3 Data of groundwater sources of the Study Basin

Groundwater Source	
Storage Capacity (Mm^3)	unlimited
Initial storage (Mm^3)	190
Total Area (km^2)	321
Maximum Withdrawal (m3/year)	751255
Natural Recharge (Mm^3)	51

Source: DRD (Bago Township)

3) Local Reservoirs

Local reservoirs in WEAP are managed independently on river streamflow and are needed to enter monthly Inflows. Besides, the Physical data and operating data for local reservoirs are necessary to input for the simulation in WEAP model. The physical data, volume elevation curves, and the input operation data of the dams in this study model were summarized in the following **Table 4**, **Figure 16**, and **Table 5**.

Table 4 Physical Data of Local Reservoirs in the Study Basin (IWUMD, Bago)

Reservoir	Kodukwe	Shwelaung	Salu	Mazin
Inflow	Received simulated runoff			
Storage Capacity (Mm^3)	183.0	123.4	111.0	32.3
Initial Storage (Mm^3)	102.9	48.7	66.1	31.6
Net Evaporation	Calculated monthly data using monthly evaporation and precipitation data (1991-2018)			

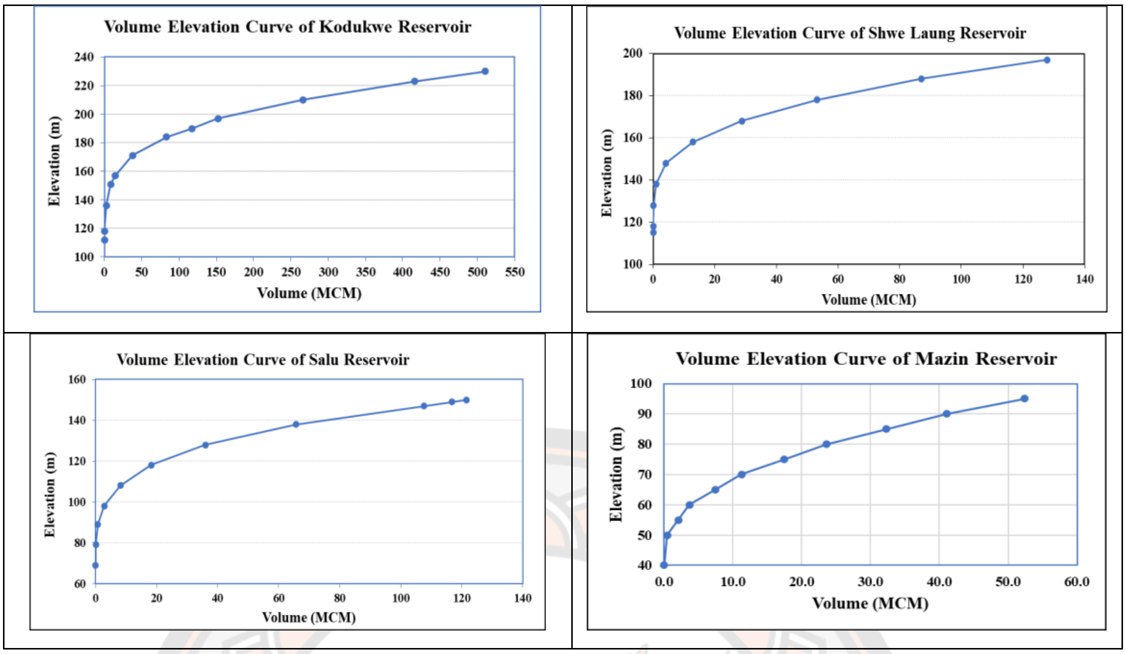


Figure 16 Volume elevation curve of reservoirs of the study basin model (IWUMD, Bago)

Table 5 Operation Data of Reservoirs in the Study Basin model (IWUMD, Bago)

Reservoir	Kodukwe	Shwelaung	Salu	Mazin
Top of Conservation (Mm^3)	183.0	123.4	111.0	32.3
Top of Buffer (Mm^3)	90.39	43.23	50.11	20.19
Top of Inactive	12.56	5.47	4.99	2.41
Buffer Coefficient	0.33	0.33	0.33	0.33
Priority	99	99	99	99

4) Transmission links

Transmission links represent water transmission from dams, rivers, groundwater, and other water supplies to satisfy the required demand at demand sites. The supply preference for each transmission link needs to be define for the water allocation (SEI, 2015). In this study model, there were 7 transmission links and the maximum capacities of the sources were used as maximum flows of the transmission links in this model, and there was no constraint in every link and the supply preferences for all nodes were taken as 1 referring as first priority. Losses from the system in transmission links to surface water sources were used as 66% to represent the amount of losses of demand sites (EDWS, 2018), however, that of groundwater sources was taken as 10% because the groundwater transmission pipeline system is shorter and leakage from this system is also smaller compared to the surface water system. Losses from the system of the link from the reservoirs to all demand sites were assumed as 10% to represent the open channel transmission links and evaporation losses from it. Losses to Groundwater of all links were assumed as zero because of the requirement of less data. The detail input data are summarized in **Table 6**.

Table 6 Data of Transmission links in the Study Basin (EDWS, Bago Township)

Transmission link		Maximum Flow (Volume) (cumecs)	Maximum Flow (% of demand)	Supply Preference	Loss from System	Loss to ground water
From	**To**					
Kodukwe R	Agriculture demand site 1	15	No constraint	1	10	0
Bago River		No constraint	No constraint	1	66	0
Shwelaung R	Agriculture demand site 1	4	No constraint	1	10	0
Salu R		5.7	No constraint	1	10	0
Bago River		No constraint	No constraint	1	66	0
Mazin R	Bago Town Demand site	1.5	No constraint	1	10	0
Groundwater		0.29	No constraint	1	33	0

5) Runoff/infiltration and Return flow links

Runoff/infiltration links represented the runoff and infiltration from the catchments to reservoirs, rivers, and groundwater nodes. The runoff fraction values for branches needed to be defined. In this model, two runoff links from upstream catchment and downstream catchment were connected to the downstream gauging station of each catchment and runoff fraction values for all links are taken as 100%.

3.5 Model Performance

The present situation of this study can be evaluated according to the results of the Current Accounts and Reference Scenario for the period of 1999-2018. Before the simulation of the scenarios, it is necessary to do the calibration and validation in WEAP, but WEAP has no automatic calibration operation and the changes implemented were tested manually by comparing the simulated and observed time series (SEI, 2015). In this study, the catchment parameters controlling the generation of runoff from data inputs were calibrated and validated using the historical measurement of streamflow obtained from the Zaung Tu gauging station for the upstream catchment and Bago Gauging station for the downstream catchment located on the Bago River during 1999-2018.

The period of 2011-2018 in the model performance, as the first 5 years (2011-2015) were dedicated for calibration while the following 3 years (2016-2018) were dedicated for validation. The adjustable parameters of the WEAP model were calibrated by trial and error. The quantitative statistics (coefficient of determination, R^2; Nash-Sutcliffe efficiency, NSE and Root Mean Square Error, RMSR) were computed for each set of simulated and historical streamflow over the period of 2011-2018. Moreover, Error in Volume (VE in %) statistics was used for the simulation of four reservoir storage volumes.

3.5.1 Coefficient of determination (R^2)

The coefficient of determination (R^2) outlines the degree of collinearity between simulated and observed data. R^2 defines the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, given higher values indicating less error variance. Values, which are greater than 0.5 are considered acceptable (Santhi et al., 2001). The computation of R^2 is shown below:

$$R^2 = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{sim} - \overline{Y}^{sim}\right)\left(Y_i^{obs} - \overline{Y}^{obs}\right)}{\sqrt{\sum_{i=1}^{n}\left(Y_i^{sim} - \overline{Y}^{sim}\right)^2 \sum_{i=1}^{n}\left(Y_i^{obs} - \overline{Y}^{obs}\right)^2}} \right] \tag{1}$$

3.5.2 Nash-Sutcliffe efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) means a standardized statistic which controls the relative magnitude of the remaining adjustment (“noise”) compared to the measured data adjustment (“information”) (Nash et al., 1970). NSE specifies how well the plot of observed versus simulated data fits the 1:1 line. NSE arrays between $-\infty$ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. The values of NSE between 0.0 and 1.0 are generally regarded as acceptable levels of performance, whereas values <0.0 indicates unacceptable performance. NSE is computed as shown below:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - \overline{Y}^{obs}\right)^2} \right] \tag{2}$$

3.5.3 Root Mean Square Error (RMSE)

The root mean square error (RMSE) has been used as a standard statistical metric to measure, model prediction error in meteorology, air quality, and climate research studies; a smaller RMSE value indicates better model performance (Addis et al., 2016). The computation of RMSE is shown below:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(Y_i^{sim} - Y_i^{obs}\right)}{n}} \tag{3}$$

where,

Y_i^{sim} : the ith simulated streamflow

Y_i^{obs} : the ith observed streamflow

$\overline{Y}^{obs}$: the mean of observed streamflow.

$\overline{Y}^{sim}$: the mean of simulated streamflow

3.5.4 Error in Volume (VE in %)

In hydrological studies used for management purposes, total volume errors below 10% are very good, between 10% and 20%is good and between 20% and 30% is fair (Ingol-Blanco, 2009). VE is computed as shown below:

$$\mathrm{VE}=\frac{\mathrm{V_{obs}}-\mathrm{V_{sim}}}{\mathrm{V_{obs}}}\times 100$$

where,

V_{obs}: Observed storage volume of reservoir

V_{sim}: Simulated storage volume of reservoir.

3.6 Creation Scenarios of the Study Basin in WEAP model

In the model development, the real processes must be clearly comprehended to mimic these in the model, however the most relevant processes should be concentrated to simplify the model.

In order to assess the capability of water supply in meeting the demand for water resources in the study area, five types of future projections were investigated: Reference Scenario, High Population Growth Rate Scenario, Higher living Standard Scenario, Climate Change Scenario and Water Supply Management Scenario. Scenario analysis could answer the ‘what if’ questions in a water supply system, by comparing the reference or business-as-usual scenario and other scenarios. This section described different scenarios based on the feasible changes in the study basin extending the current situation of the Current Accounts Year (2018) to the future until the Last Year of Scenarios (2040) with monthly time steps. At first, reference scenario was built to represent the current situation of the system. Then, the other scenarios, which represented the possible changes in the system supply sources and demand sites, were constructed to study the impacts of these changes by comparing with the reference scenario.

3.6.1 Reference scenario

Reference scenario brings forward the current data into the entire time horizon in which no major changes were executed and serves as a point of comparison for the other scenarios in the system data. In this study, Reference Scenario was applied to analyses the future situation of the study model without any development in the existing situation of the system except the population growth rate of 1.85 %. To set up this Reference Scenario (2019-2040), the data for population growth was needed. The average population growth rate of 1.85% was used to project the population until the end of the study period.

3.6.2 High Population Growth Rate Scenario (HPG)

To draw this study area's master plan and that of urban development projects, population growth predictions of RAPID URBAN DIAGNOSTIC REPORT of Myanmar (2018) was used. By using the population growth rate of 2014, this report predicted that the population will reach 20.4 Million in 2030. On par with this projection of BRB, a population growth rate of 2.74% was used for this study area because the existing population of the study basin in 2018 was 353,816 people. "How much of the demand water could be met, if the population growth rate is higher in the future?"

3.6.3 Higher Living Standard Scenario (HLS)

Parallel with urbanization and economic development in the study area, the water consumption rate will increase in order to achieve higher living standards. The water usage rate will suggestively increase due to rapid economic growth, urbanization, lifestyle changes and other social evolutions in Asian Countries (Hubacek et al., 2009). For the improvement of water supply service in the BRB as other Asian cities, Municipal council of Bago Township put forth a plan to serve higher water consumption amounts year-by-year leading to higher living standard in the future. In this study, the situation related to increased water consumption rate was analysed using the future target value of the Bago River Sub-Basin Management Plan, NIVA (2018), which is a plan aimed at improving the water supply service with good water quality, rapid economic development, lifestyle changes for an increased consumption rate compared to the present.

For this scenario, the annual water use rate for the study basin is changed from 41.45 m^3 per person or 0.114 m^3/day in 2018, to 48.36 m^3 per person or 0.132 m^3/day in 2030, and 55.27 m^3 per person or 0.151 m^3/day in 2040. Therefore, increasing water use rate will be interpolated from 0.114 m^3/day to 0.151 m^3/day rates as shown in **Figure 17**. "If the water consumption rate will be increased, how much of the water demand could be met by the water supply source in the future?"

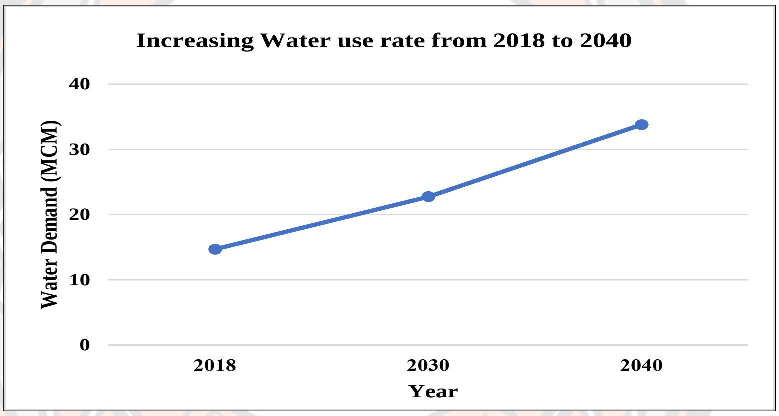


Figure 17 The increasing water demand for HLS (2018-2040) (MIP, Bago)

3.6.4 Climate Change Scenario (CC)

Climate change is important for the water supply system because it can change the existing water management situations and increase the requirement for new management options (Mounir et al., 2011). The study by Shrestha (2014, 2016, and 2017) showed projected climate change scenario and streamflow of BRB of Myanmar with the future periods as 2021-2050 by using three GCMs. The results of that paper showed: all the GCMs amounts were in agreement and predicted that the average temperature of the basin will increase in the future compared with the baseline period (1991– 2005). In the near future, the rainfall will decrease, while it will increase during 2040s. The analysis shows that, the relative annual mean discharge in the river will decline during 2020s and 2030s under both the RCP scenarios, but will incline during 2040s.

For the analysis of climate change effects in this study area, Climate Change (CC) scenario was constructed by using the rainfall data with water year method based on the results of Shrestha et al.,'s studies (2014, 2016, and 2017). For this scenario, the annual mean precipitation amount for the study area will be changed from 2018 to 2025 with the rate of -5%, from 2025 to 2030 with the rate of -5%, from 2030 to 2035 with the rate of +5%, and from 2035 to 2040 with the rate of +10%. Moreover, the annual mean precipitation amount will be changed from 3184 mm in 2018 to 3025 mm in 2025, 2866mm in 2030, 3343 mm in 2035 and 3502 mm in 2040. "If an annual mean rainfall amount will be changed the different form, how much of the water demand could be met by the supply with current design capacity?"

3.6.5 Water Supply Management Scenario (WSM)

As urban water utilities are facing increasing water scarcity problems due to population growth, climate change and environmental issues, city water planners are trying to find management strategies not only to advance the water supply but also to reduce the water demand (Baerenklau, Schwabe, & Dinar, 2013). To solve the encountering problems of the study area, and the indirect effects of external changes, local authorities and water managers also need to find out the strategies for management options. In this study, the water supply management scenario has been generated and analysed to help the decision makers for management options, and future development plans.

The losses from the transmission link in surface water sources were 66% and EDWS has responsible to reduce losses as improve the quality and quantity of supply water. Therefore, the future target for water loss control in the Bago River Sub-Basin Management Plan, NIVA (2018) and in YCDC-JICA master plan (2014) is to reduce the current water loss amount of 66% to 15% in 2040 by using different improvement plans. This scenario will analyse the situation with establishment of a loss control management plan in the study area to decrease the amount of water loss from 66% to 35% in 2030 and 15% in 2040. "If the amount of water loss transmission links were reduced, how much of the water demand could be met by the supply with current design capacity?"

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Overview of the Existing Water Availability

This chapter presents an overview of the existing availability of water resources, reference scenario results (1999-2018), WEAP model performance results, and future scenario results (2019-2040).

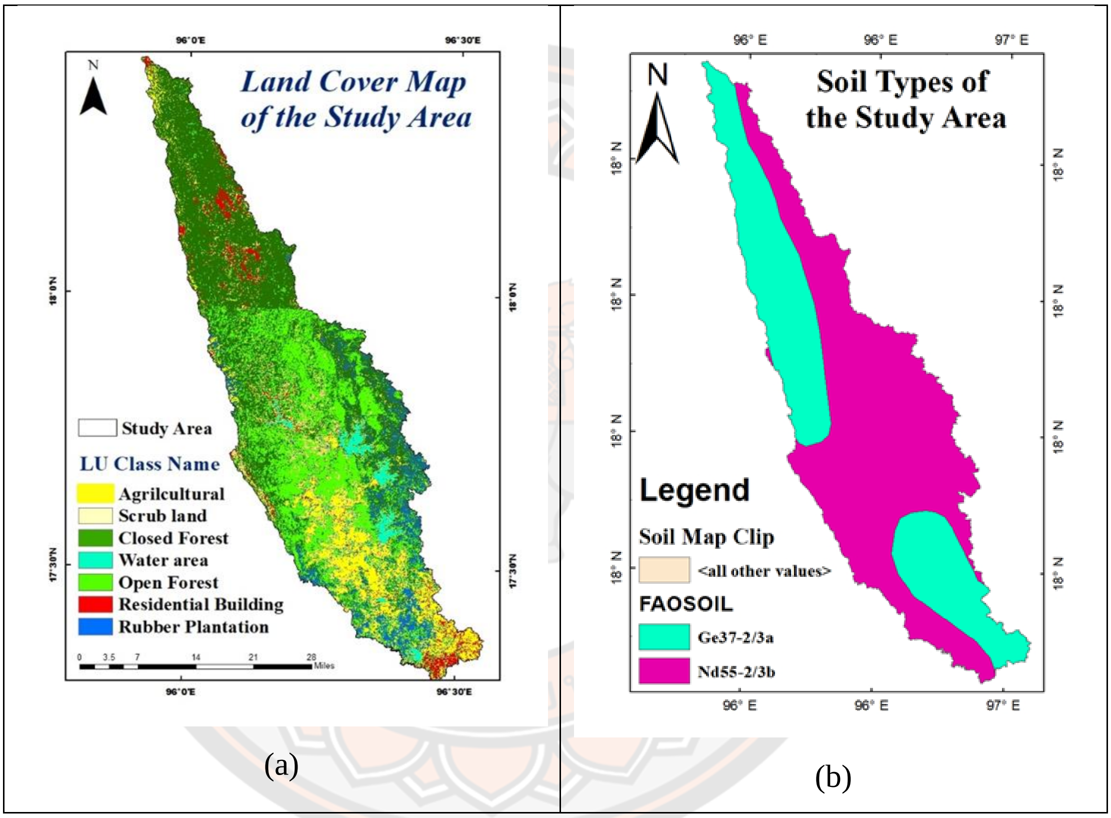
4.1.1 Study Organization Description

Several organizations are responsible for water management and monitoring in the Bago River Basin. A delegation of the TU Delft found the following information regarding government actors in IWRM. The Irrigation Department (ID) and Irrigation and Water Utilization Department (IWUMD) under- the Ministry of Agriculture and Irrigation (MOAI) is responsible for the monitoring of reservoirs and weir water levels, river water levels, water supply utilization and rainfall at the reservoirs, and flood protection works. Most of the reservoir in the Bago basin fall under the responsibility of MOAI, the remaining under the Ministry of Hydropower.

Improvement of rivers, their health, relevant protection and maintenance of flow in the rivers are under the mandate of the Ministry of Transport (MOT). In addition, MOT is responsible for conservation of water resources and accordingly, issued the ‘Rivers Law and Regulations’. Recently MOT has carried out a study on Bago River and plans are underway for Flood Control and Development Projects. The Department of Meteorology and Hydrology (DMH) under MOT is responsible for river water levels, rating curves and flood warnings. Monitoring of land use is a shared responsibility of MOAI and the Ministry of Forestry and Environmental Conservation (MOECAF).

4.1.2 Landcover and Soil Maps

Highlighted landsat satellite imagery (2018) from EarthExplorer-USGS (https://earthexplorer.usgs.gov/) was used to get landuse on BRB and this was analysed by using GIS to classify land use in the study area. There were seven ‘landuse’ types: closed forest, open forest, scrub land, rubber plantation, agricultural land, water area, and residential buildings as shown in **Figure 18(a)** and the areas are 43, 25, 5, 7, 14, 3, and 3 (percent) respectively in **Table 7**. The Soil data were collected from soil types and characteristics of Myanmar (MOAI, 2014) and analyzed with a soil map of Myanmar (Open Development Mekong, 2017). There were two types of soil in the study area as shown in **Figure 18(b)**: Nitosols (**Ne**) covering 62% of the area and Eutric Gleysols (**Ge**) covering 38% of the total area.



(a)

(b)

Figure 18 (a) Land cover map of the study area (Earthexplorer-USGS, 2018) and **(b) Soil map of the study basin (MOAI, 2014)**

Table 7 Area and Percentage of the different landuses in 2018

Class name		AREA (km^2)	Percentage (%)
1.	Agricultural area	362	14
2.	Rubber Plantation	195	7
3.	Closed Forest	1137	43
4.	Open Forest	662	25
5.	Scrub Land	141	5
6.	Residential Building	88	3
7.	Water Area	75	3
	Total	2,660	100

4.1.3 Existing Water Resources Development in the BRB

1) Rainfall and Streamflow at Gauging Stations

The existing rainfall runoff was observed through an initial glance of the annual rainfall and streamflow at two gauging stations of BRB (**Figure 19**). The monthly rainfall data of Bago station was higher than Zaung Tu station, but the pattern of both stations have similarities. The long-term average annual rainfall of Bago and Zaung Tu stations were 3365 mm and 3022 mm, respectively. The monthly streamflow data of both stations have similar trends. Moreover, Bago streamflow was higher than that of Zaung Tu expect during mid-analysis. Zaung Tu gauging station records streamflow data on the Bago river which includes the release flow from two larger dams and Bago gauging station records include one diversion weir and the release flow from dams. According to the gauging stations results, the streamflow of Zaung Tu gauging station causes abnormal condition from 2008 to 2012 because the station receives much release flow from dams due to the heavy rainfall during the late of the wet season to the end of the summer season (DMH, Myanmar). And then the amount of discharge might be occurred some errors in the dry season within 2008 to 2012 due to the effects of Cyclone Nargis in 2008 and heavy flood in 2011 in the study area. The average monthly discharge of Bago and Zaung Tu stations from 1999 to 2018 were 278 m^3/s, and 251 m^3/s, respectively.

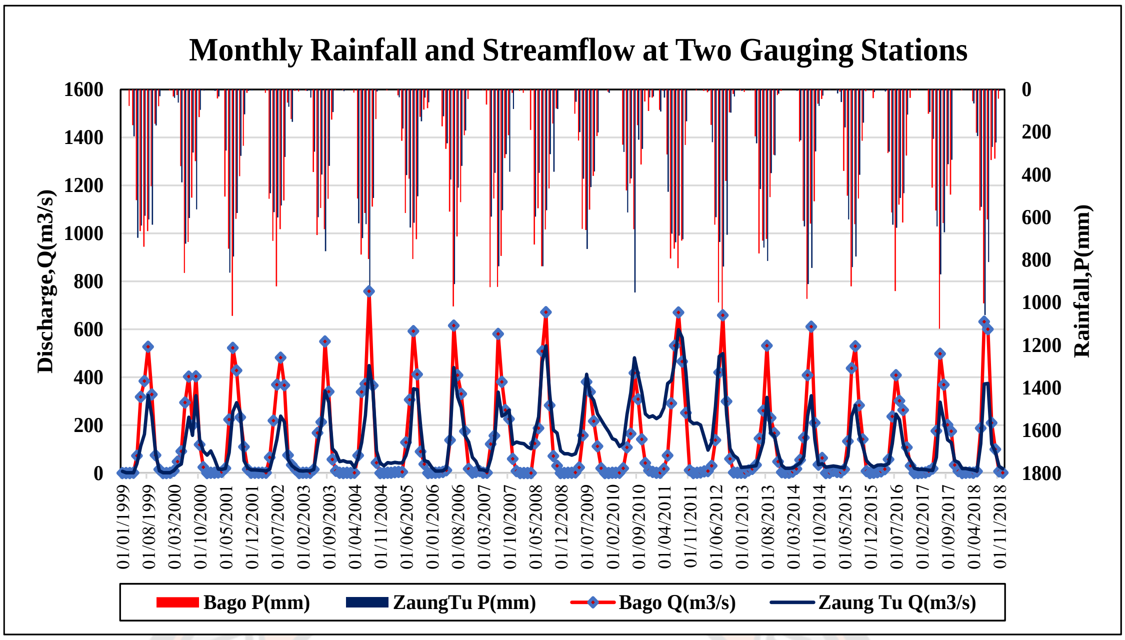


Figure 19 Monthly rainfall and streamflow at 2 gauging stations of BRB.

Source: DMH, Myanmar, 1999-2018

Since Cyclone Nargis in 2008, through transition to civilian rule and the Bago River flood in 2011, the disaster management system of the Myanmar government has changed and improved drastically (Kawasaki et al., 2017). The Bago river basin, a flood-prone basin in Myanmar where two severe floods occurred in 2011. Before and during 2011, there was no proper dam and channel operation within the basin. After the 2011 flood, three new dams and water released from the Zaungtu dam was properly controlled by the Department of Hydropower. Moreover, the flood diversion channel from Zaung Tu weir to Moeyongyi lake was also completed in 2012. The intake of Zaung Tu irrigation canal lies between Zaung Tu and Bago stations (Zin et al., 2015). As shown in **Figure 20**, these connections link Zaung Tu Weir with Moe Yin Gyi Lake and Bago-Sittaung Canal and water can be taken from the Bago River at the Zaung Tu Weir and conveyed through these irrigation canals to Bago Sittaung Canal and to Moe Yin Gyi Regarding Basin. Thus, the flow volume of Bago River can be kept at lower levels, which helps to reduce the risk of floods in Bago City and freshwater may be provided to the farmlands during the summer season. So, the rural people of the eastern bank of the Bago Region get more income and better living standard. (ID, 2014).

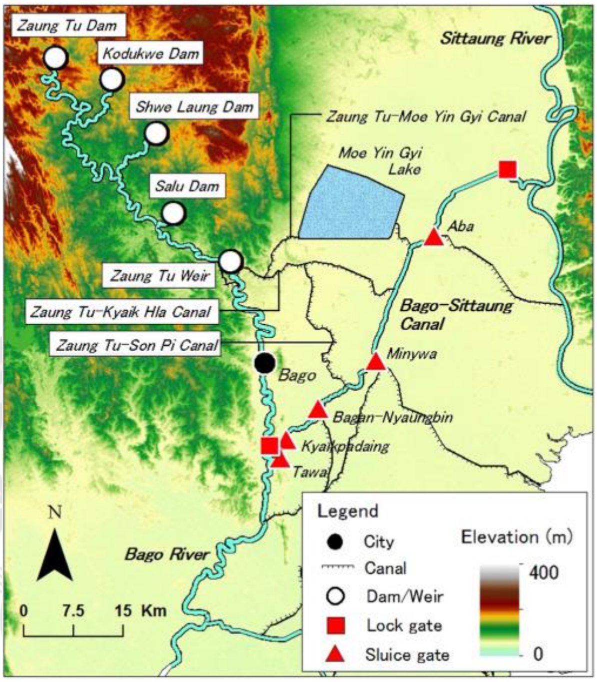


Figure 20 Overview of the river and canal systems in the middle Bago River Basin

Source: Kawasaki et al., 2017

2) Annual Runoff

The average annual runoff was estimated at 1,058 MCM and the average annual rainfall of the two gauging stations was 3,058 mm within the study area. The trend lines of annual rainfall and runoff were stated at the same direction from 1999 to 2018. The result of average rainfall and runoff records over a 20-year period (1999-2018) shows that there was inter-annual variability in annual discharge with peak flow registered in 2011, while the smallest flow is registered in 2010 (see **Figure 21**). About 50% of the results of the observation period show runoff discharge levels that are below average. Moreover, it is clear that the river channel capacity varies from location to location.

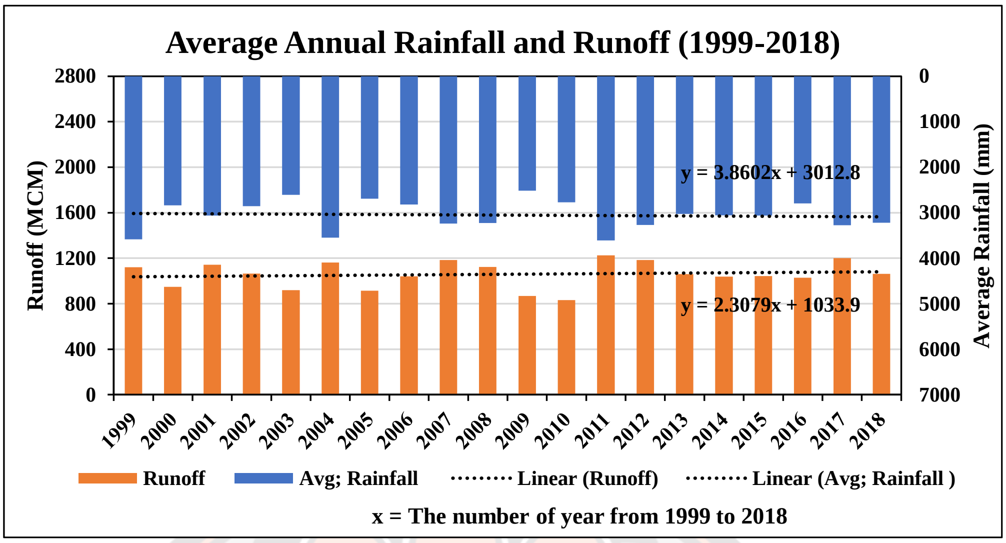


Figure 21 Annual flows of Bago River Basin (1999-2018)

3) Existing Demand for Water uses

The water demand means the requirement at each demand site, before the demand site losses, reuse and demand-side management savings are taken into account (SEI, 2015). The result of water demand simulation in 1999-2018 is shown in **Figure 22.** The water demand for the domestic site trended to increase from 1999 to 2018. However, the water demand for the agricultural sites, increased and decreased alternatively over the years (see in Appendix B). This is due to the altering levels of remaining water at the end of the wet season, which is irrigated to grow dry season crops. The average annual gross water demand for the agriculture demand sites were 1,212 MCM but only 13 MCM for the domestic demand site. The highest annual water demand was in 2004 and the lowest annual gross water demand was in 2011.

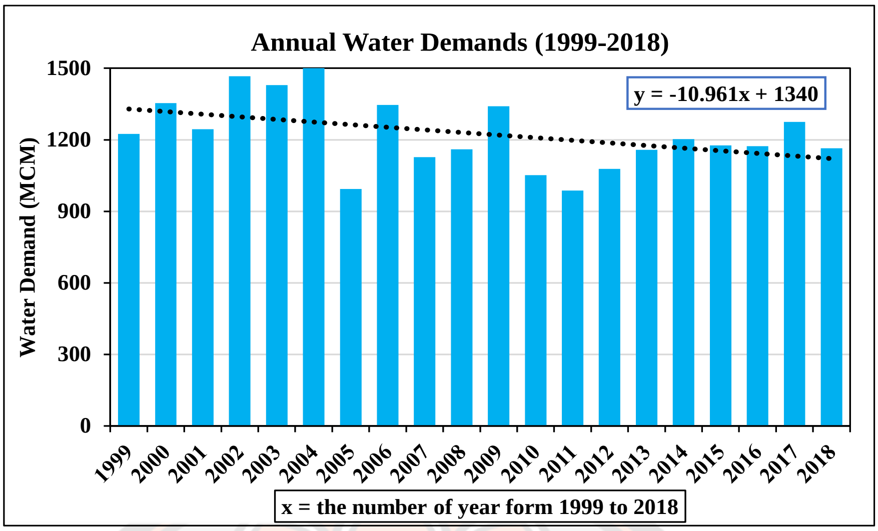


Figure 22 Annual gross water demands of the study area (1999 to 2018)

The rice cultivation in the dry season in the study area had a major effect on the agricultural demand for water. The average area of wet season rice was 352 km^2 from 310 to 370 km^2, the dry season rice was 61 km^2 from 40 to 70 km^2, the upland crop was 115 km^2 from 100 to 140 km^2, and orchard was 50 km^2 from 45 to 55 km^2, respectively. **Figure 23** shows average monthly rainfall and water demand of crops from 1999 to 2018.

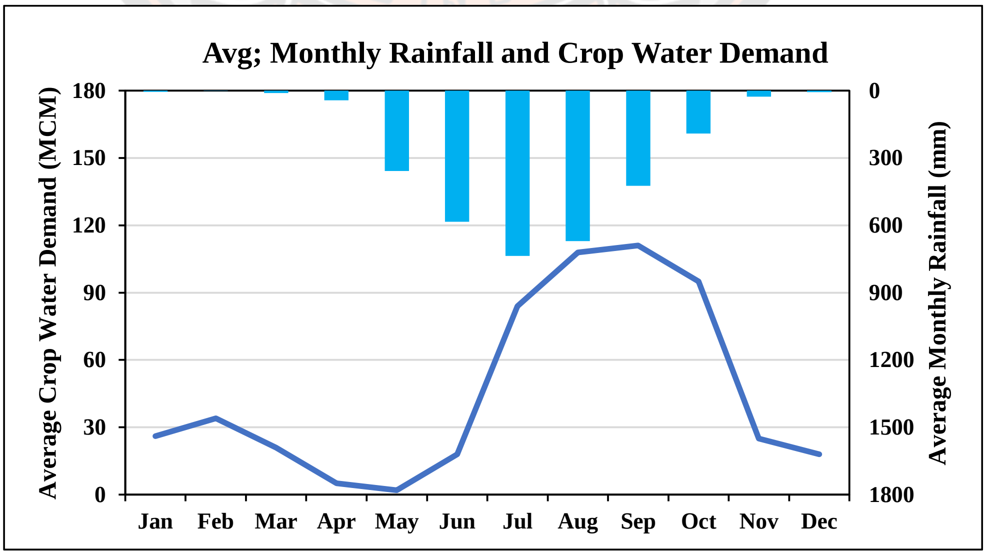


Figure 23 Average monthly rainfall and crop water demand (1999-2018)

The monthly average water demands for all kinds of demand sites are shown in Table 8 and the monthly average gross water-demand is shown in **Figure 24**. The high demand was in the dry season from November to March, in particular, the peak demand was in March. In contrast the wet season from May to October, there was sufficient flow, which was supplied to the all kinds of demand sites.

Table 8 Monthly Average Water Demand (MCM)of the Study Area (1999-2018)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Monthly Avg:WD	195	256	365	13.3	1.04	1.04	1.04	1.04	1.04	1.04	183	207	1225

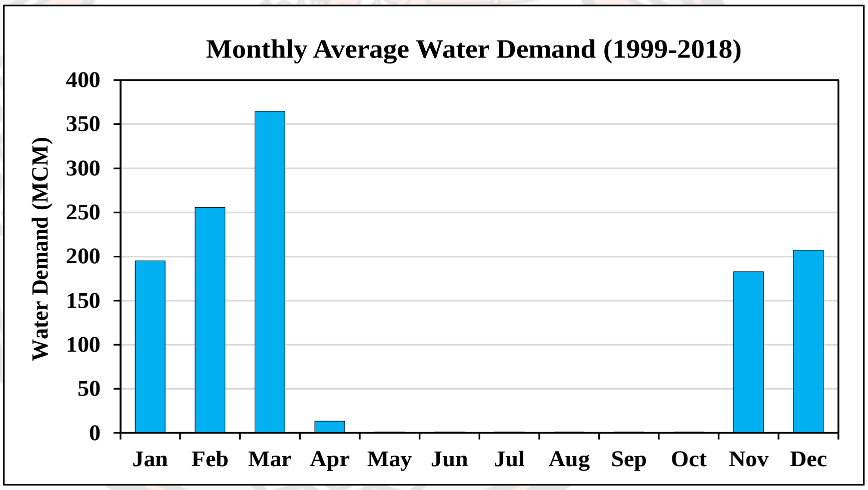


Figure 24 Monthly average gross water demand of the study area (1999-2018)

4) The Existing Water Supply Delivered and Coverage

The water supply delivered means the amount of water supplied to demand sites, listed either by source (supplies) or by destination (demand sites). Those are including rainfall-runoff over the study area and released flow from five existing dams, which are considered as the streamflow of BRB. According to the results of the water supply delivered amount in this study area, which is shown in **Figure 25**, the water supply delivered amount was less than the amount of water demands and the same variable. The delivered water supply decreased from 1999 to 2018. The average annual water supply delivered amount for the demand sites was approximately 1,208 MCM and the average monthly amount of water supply delivered was 92 MCM. They were 195.07, 247.30, 364.72, 13.30, 1.05, 1.05, 1.05, 1.05, 1.05, 1.05, 182.82, and 199.06 (MCM) from January to December, respectively.

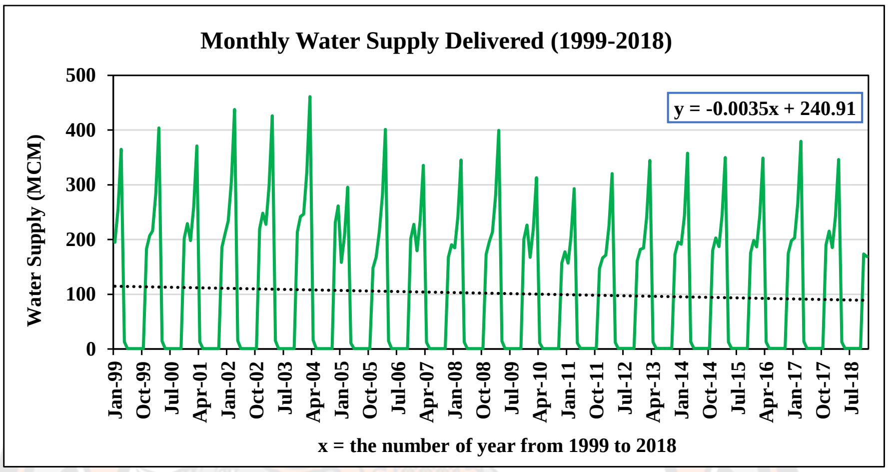


Figure 25 Monthly water supply delivered amount of the study area (1999-2018)

5) Unmet Demand in Reference Scenario (1999-2018)

Current account was used as the starting year of the simulation period and the basic definition for all scenarios reported of the existing water system in WEAP. The year 1999 was selected as the current account for the studying in WEAP model. After current account, the reference scenario, also called “Business as-usual” was established to evaluate the existing water situation in the study area based on current hydrological, social, and technological trends. The reference scenario was developed for the period of 1999-2018 and the unmet demands obtained from WEAP are shown in **Figure 26**. It shows that the demand for water supply in all demand sites was fully met in all years except in 2014 and 2018. The unmet demand of 8.34 MCM in February 2014 and 7.99 in December 2018 for the agricultural demand sites, can also be seen in the figure below.

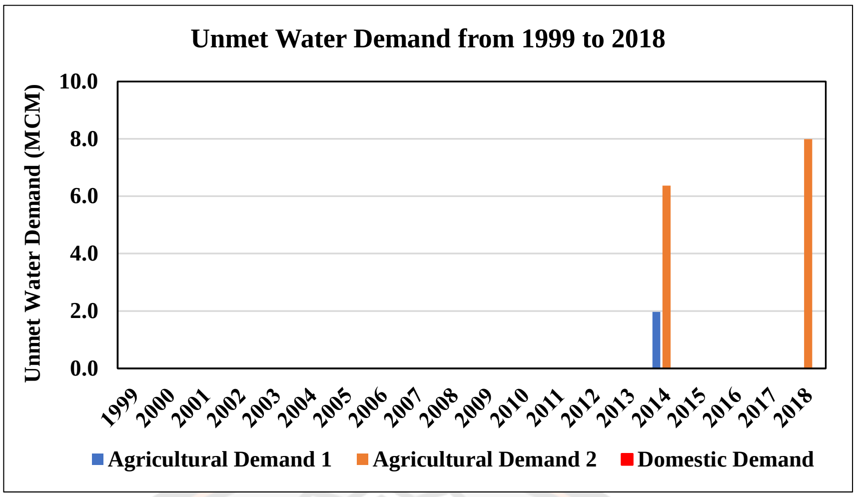


Figure 26 Unmet demand in the reference scenario (1999-2018)

4.2 WEAP Model Performance

The hydrologic calibration and validation of the reference model were carried out to analyze the WEAP Model Performance. The results of streamflow from simulation at the Bago and Zaung Tu gauging stations were compared to the observed data of 2011-2015 as calibration and the data of 2016-2018 as validation. The simulated streamflow of both stations show that the model replicates the observed flows reasonably well.

4.2.1 Calibration of Streamflow

The simulated results fitted to the observation data in 2011-2015 of both stations were shown in **Figure 27 and Figure 28**. As was clear from **Table 9**, all the statistical parameters were within the desirable range indicating that the model simulations reasonably agree well with the observed data.

Table 9 Performance statistics for calibration results (2011-2015)

Gauging Station	Statistics		
	R^2	NSE	RMSE
ZAUNG TU	0.97	0.81	9 m^3/s
BAGO	0.98	0.88	8 m^3/s

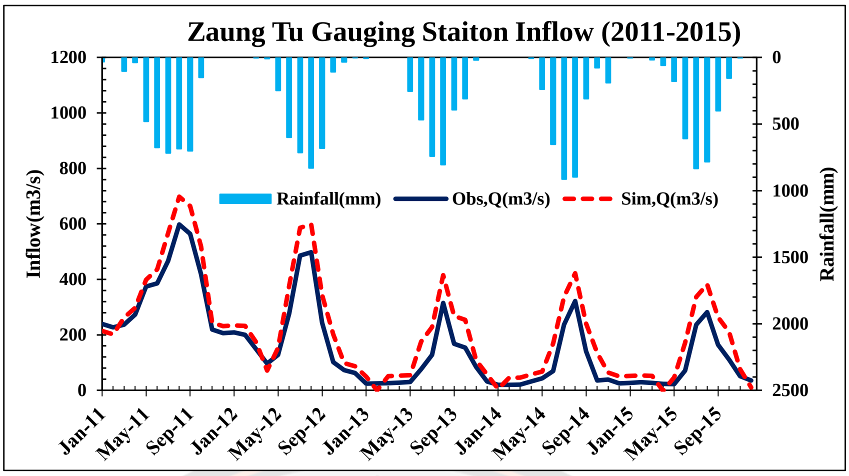


Figure 27 Comparison between the observed and simulated monthly streamflow at Zaung Tu gauging station

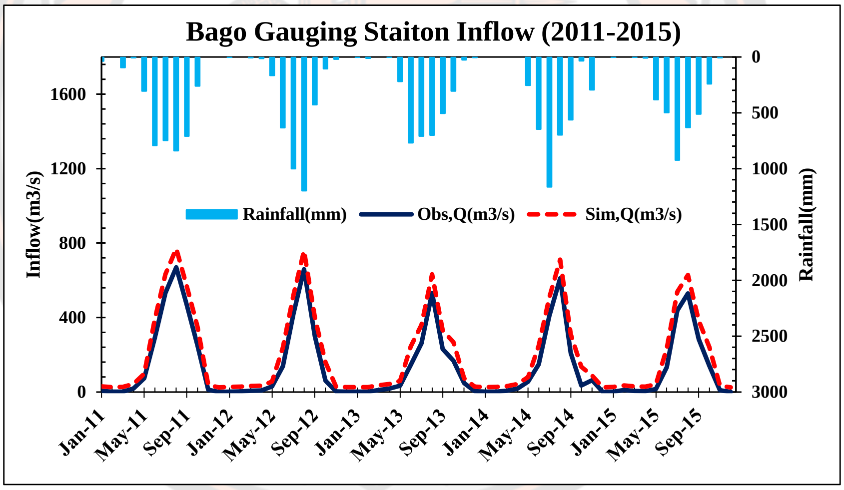


Figure 28 Comparison between the observed and simulated monthly streamflow at Bago gauging station

4.2.2 Validation of Streamflow

Validation results for the period 2016–2018 of both stations were shown in **Figure 29 and 30**. The simulated results for the validation period reasonably agree with the observed data. Performance statistics of the validation results were shown in Table 10.

Table 10 Performance statistics for validation results (2016-2018)

Gauging Station	Statistics		
	R^2	NSE	RMSE
ZAUNG TU	0.98	0.9	4 m^3/s
BAGO	0.99	0.94	3 m^3/s

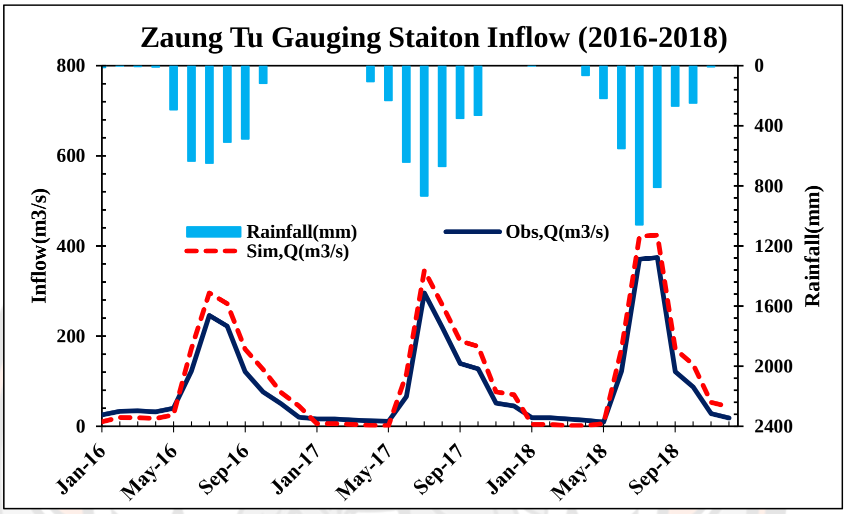


Figure 29 Comparison between the observed and simulated monthly streamflow at Zaung Tu gauging Station

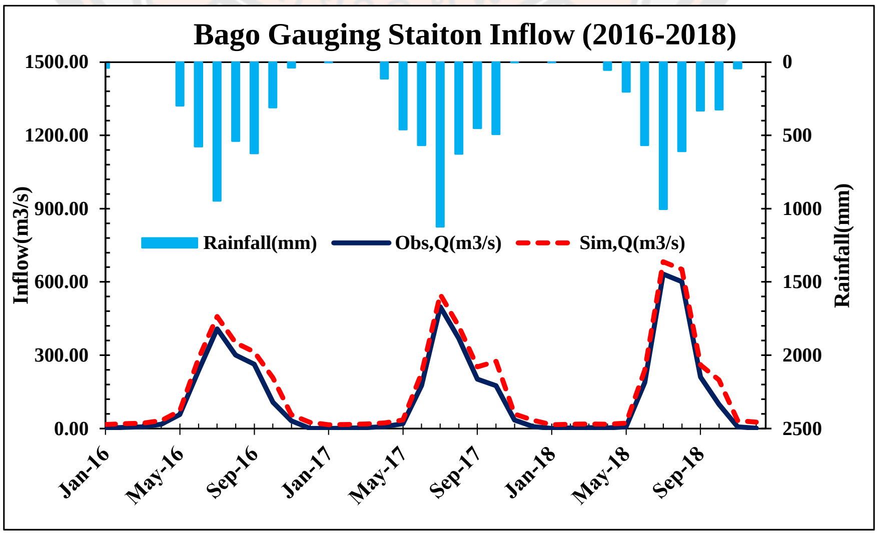


Figure 30 Comparison between the observed and simulated monthly streamflow at Bago gauging station.

4.2.3 Validation of WEAP for Reservoir Storages

In WEAP models, flow data are mostly used for calibration of the models. On the other hand, the models' performance was checked by using observed storage volume data of four reservoirs of this study from 2013 to 2018**. Figure 31** shows the graphs of the simulated volume and the observed volume for four reservoirs of the study basin for the period from 2013 to 2018. In this study, the differences between observed volume of 6 years and model simulated volume in Kodukwe, Shwelaung, Salu and Mazin reservoirs are -8.86%, -12.21%, -7.41%, and 1.89%, respectively, and the coefficient of determination (R^2) for these reservoirs are 0.62, 0.57, 0.19 and 0.87, respectively. This means that the model is over predicted and good to use for study according to the results of total volume errors, while this model has medium error variance according to the results of R^2 (Ingol-Blanco, 2009).

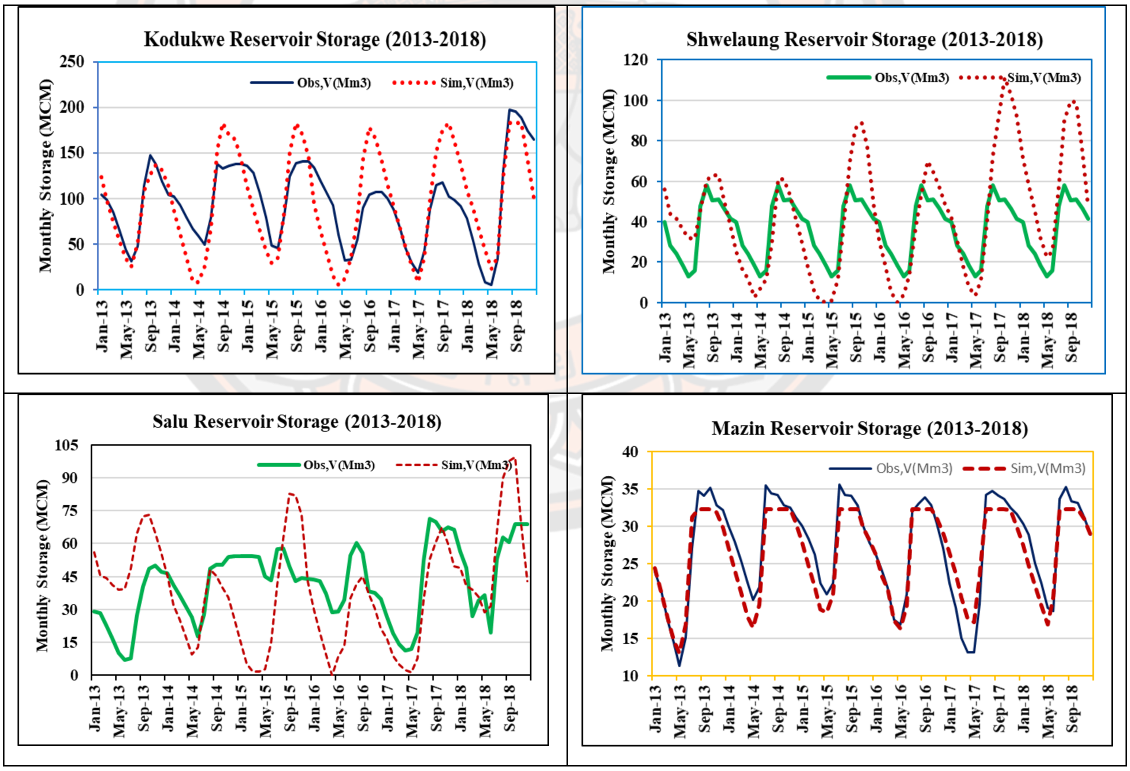


Figure 31 Comparison of the simulated reservoir storages with observed storages

4.3 Projected Reference Scenario (2019-2040)

The projected reference scenario (2019-2040) analyses the situation using normal population growth rate of 1.85% with no changes for all the situations as the reference scenario (1999-2018). **Figure 32** describes the trend of projected population growth with a normal growth rate of 1.85%.

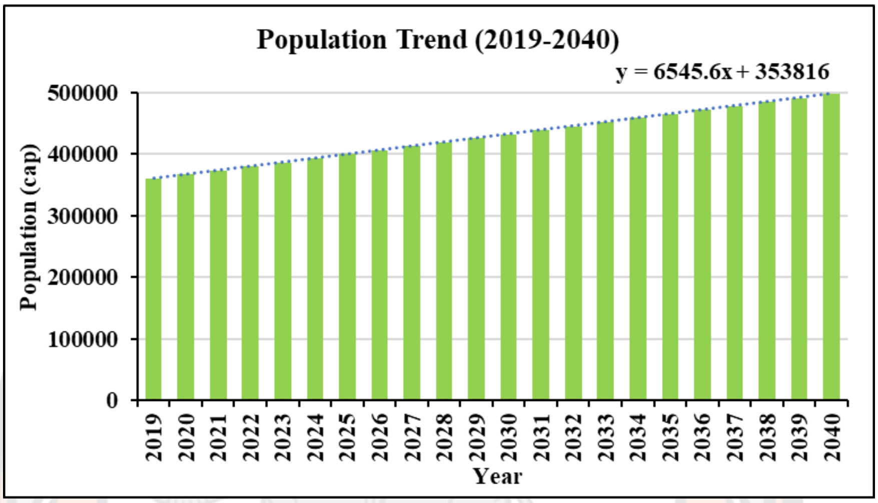


Figure 32 Population trend from 2019 to 2040 with a growth rate of 1.85%

4.3.1 Water Demand of Reference Scenario (2019-2040)

The simulation results annual water demand of Reference scenario are shown in **Figure 33.** The average annual gross water demand for the agriculture demand sites were 1,219 MCM but only 18 MCM for the domestic demand site. The highest annual water demand was in 2023 and the lowest annual gross water demand was in 2030. There was a major effect on the agricultural demand by rice cultivation in the dry season of the study area. **Figure 34** shows the average rainfall and water demand crops for the period 2019-2040. The monthly average water demands and gross water demand for all kinds of demand sites were shown in **Table 9** and **Figure 35**. The high demand will be in the dry season from November to March, in particular, the peak demand will be in March. In contrast to this, during the wet season from May to October, there will be sufficient flow, which can be supplied to all kinds of demand sites.

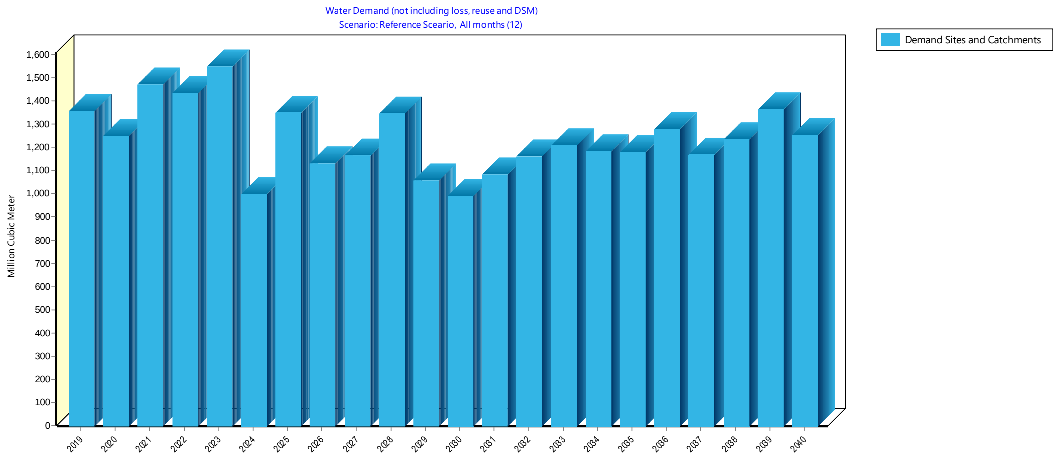


Figure 33 Future annual water demand for reference scenario (2019-2040)

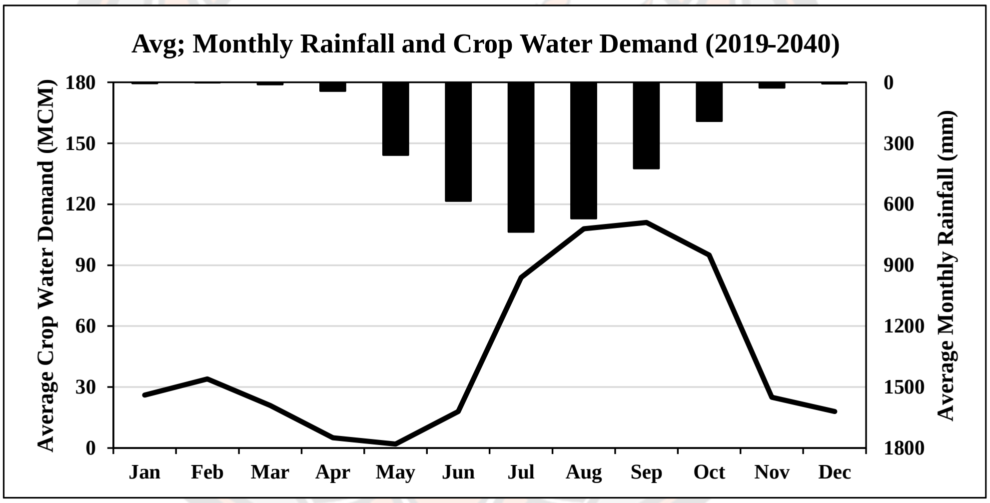


Figure 34 Average Monthly Rainfall and Crop Water Demand (2019-2040)

Table 9 Average Monthly Water Demand (2019-2040)

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Monthly Avg:WD	197	258	367	14	1.4	1.4	1.4	1.4	1.4	1.4	184	209	1237

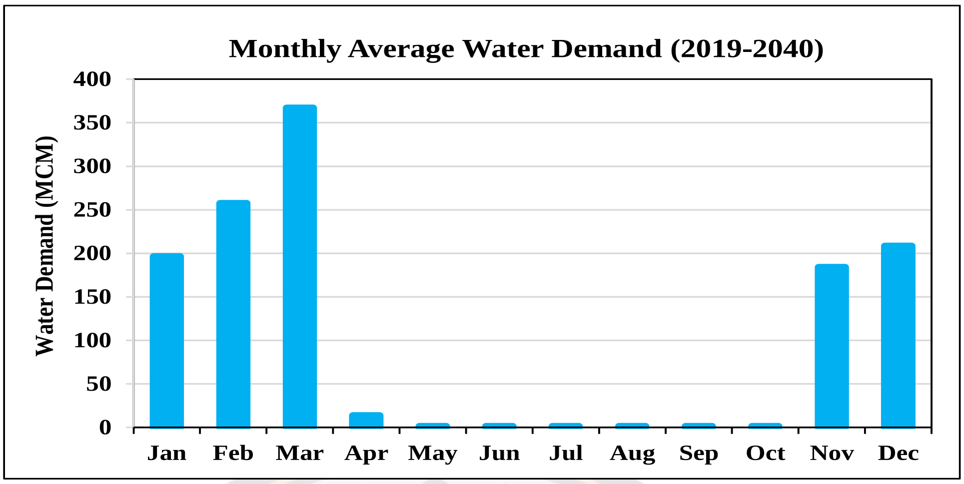
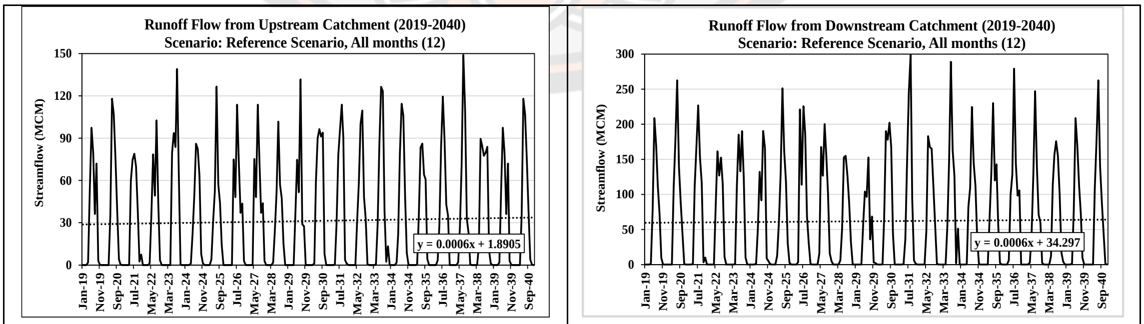


Figure 35 Monthly average gross water demand (2019-2040)

4.3.2 Streamflow of Reference Scenario (2019-2040)

In this Reference Scenario, the situations of catchment streamflow of supply sources in the study, which are surface water sources and ground water sources, can be evaluated by using rainfall-runoff (simplified coefficient method) in WEAP. **Figure36 (a) and (b)** describes that the graphs of the runoff flow from the two sub-catchments (Upstream and Downstream) for the study time horizon (2019-2040). According to these graphs, runoff from the catchment will decline remarkably in some dry years such as 2028 and 2035.

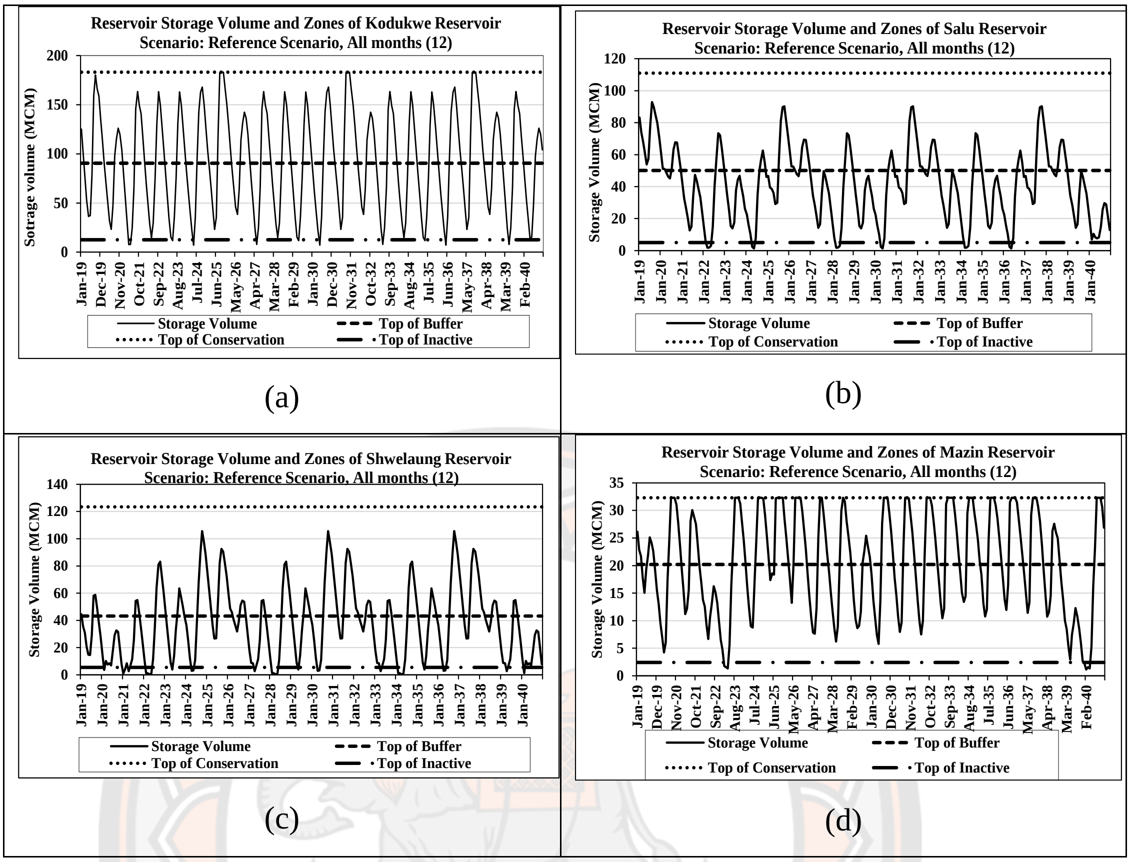


(a) (b)

Figure 36. (a) Runoff from upstream catchment (2019-2040) and (b) Runoff from downstream catchment (2019-2040)

4.3.3 Reservoir Storage Volume and Zones in the Reference Scenario (2019-2040)

According to the simulated results of the reservoir storage volumes and zones of reservoirs, WEAP forecasts that storage volumes of all reservoirs in this study will fluctuate in comparison to the top of buffer zone, because reservoirs are used for irrigation purposes of agricultural areas in the dry season and flood control purposes in the rainy season. Storage volume results of all reservoirs are predicted to be slightly lower than the top of inactive zone of reservoirs. This means the release flow will not be carried out in some months of these years. **Figure 37** lists the graphs for four reservoirs of the study throughout the study projection period starting from 2019 to the end of this study, 2040. However, according to the monthly average of reservoirs' storage volume and zones' results, their process will be satisfied for all months as shown in **Figure 38**. Therefore, it is noticeable that all reservoirs of this study are reliable for their operation until 2040 to supply their designated water capacity of the study basin via transmission links.



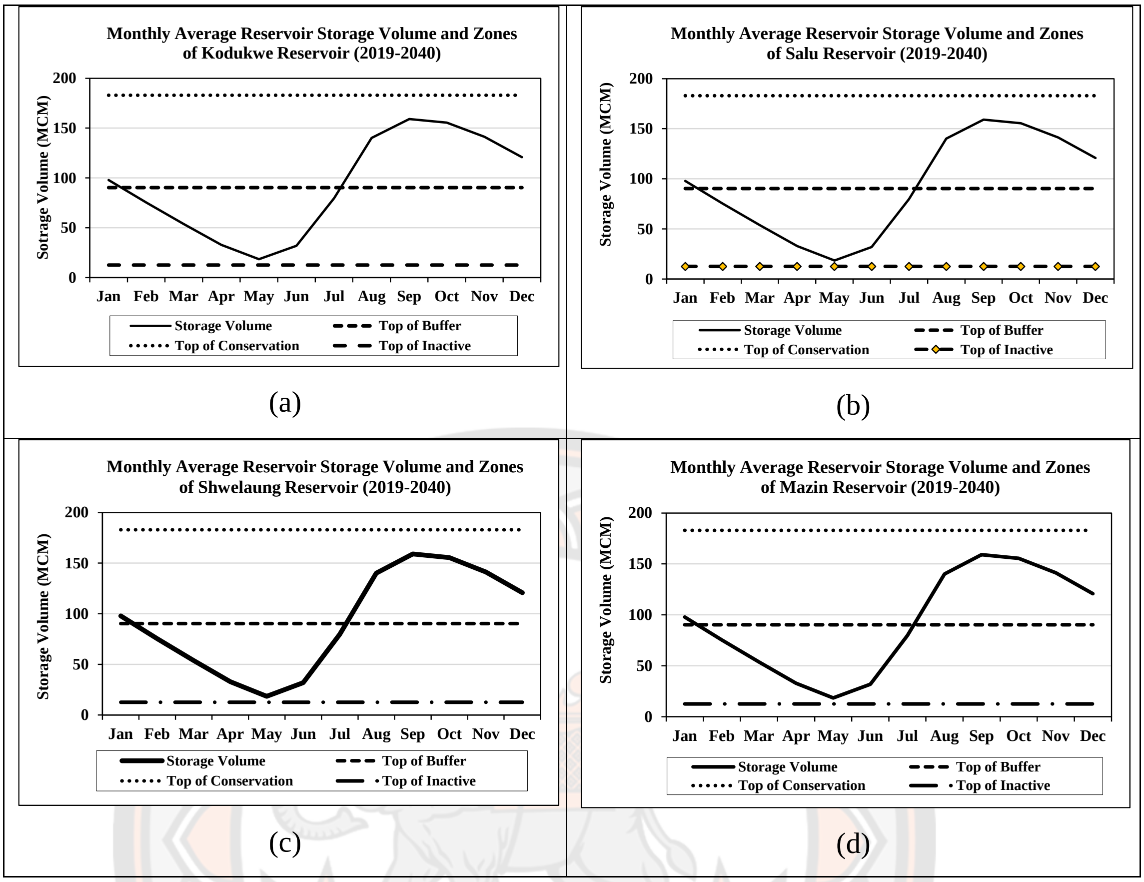
(a)

(b)

(c)

(d)

Figure 37 Simulated reservoir storage volumes and zones of (a) Kodukwe (b) Salu (c) Shwelaung (d) Mazin reservoirs of the study basin (2019-2040)



(a) (b) (c) (d)

Figure 38. Simulated monthly average reservoir storage volumes and zones of (a) Kodukwe (b) Salu (c) Shwelaung (d) Mazin reservoirs of the study area (2019-2040) in the Reference Scenario.

4.3.4 Water Supply Delivered and Demand Sites Coverage

In the Reference Scenario, the result of the water supply delivered amount in the study basin is shown in **Figure 39.** According to this graph**,** there will be a decrease from 112 MCM per month in 2019 to 111 MCM per month in 2025, and 103 MCM per month in 2040. During the scenario period, the highest water supply delivered amount will be in 2021 and 2039 and the lowest amount will be in 2031. According to the **Figure 40**, the demand site coverage of the study basin will be steadily stated in 2019, 2020, 2024, 2025, 2039 and 2040 at 100% and the coverage of the water demand site will gradually decrease in the remaining years with various percentages of coverage, because of the different water supply sites. The lowest decreased water demand site coverage percentage will be predicted to be in 2038 at 41%.

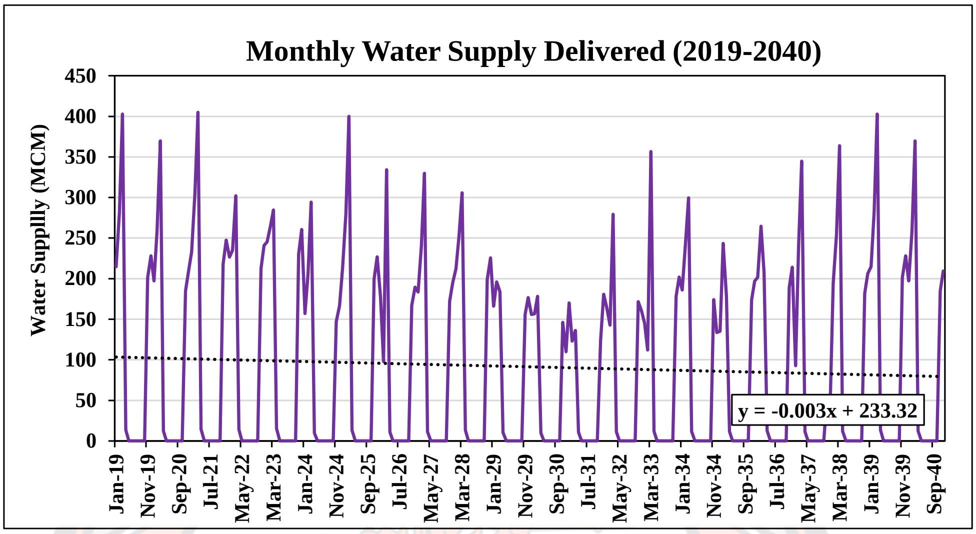


Figure 39 Reference Scenario results of water supply delivered (2019-2040)

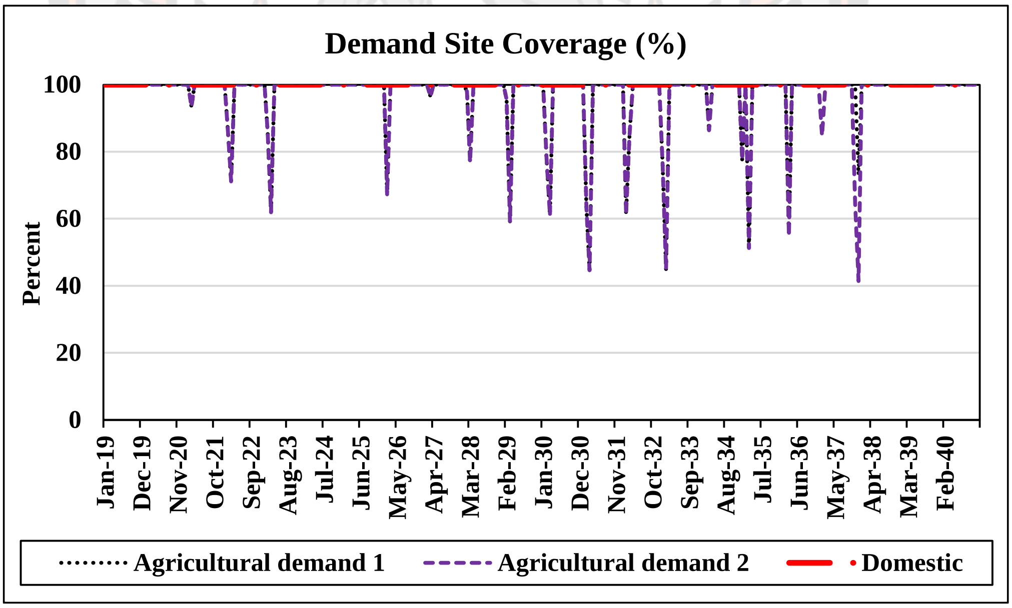


Figure 40 Reference Scenario results of demand site coverage (%) (2019-2040)

4.3.5 Unmet Demand of Reference Scenario (RS) (2019-2040)

Figure 41 and **Figure 42** illustrate the unmet demand of the study basin for the whole future study period from 2019 to 2040. The average annual unmet demand of reference scenario will be about 94.6 MCM per year for the period (2019-2040) and the demand for water will be fully met in 2019, 2020, 2024, 2025, 2038, 2039 and 2040. However, the unmet demand in 2021 is about 2.39 MCM per month, and the unmet demand will increase to 18.3 MCM per month in 2023. Afterwards it will steadily decrease year by year and it will reach a rate around 11.46 MCM per month in 2029. This will increase sharply to 21.6 MCM per month in 2031 and then fluctuations will be predicted with an amount of 12.1 MCM per month in 2032 and 14.06 MCM per month in 2037. Generally, the average monthly unmet demand will be the highest in March with 58.59 MCM and the lowest in November with 2.14 MCM, and it will fully be met in the wet season particularly from May to October month. These results showed that water shortages in the near future can be managed through effective water resource planning in the study basin.

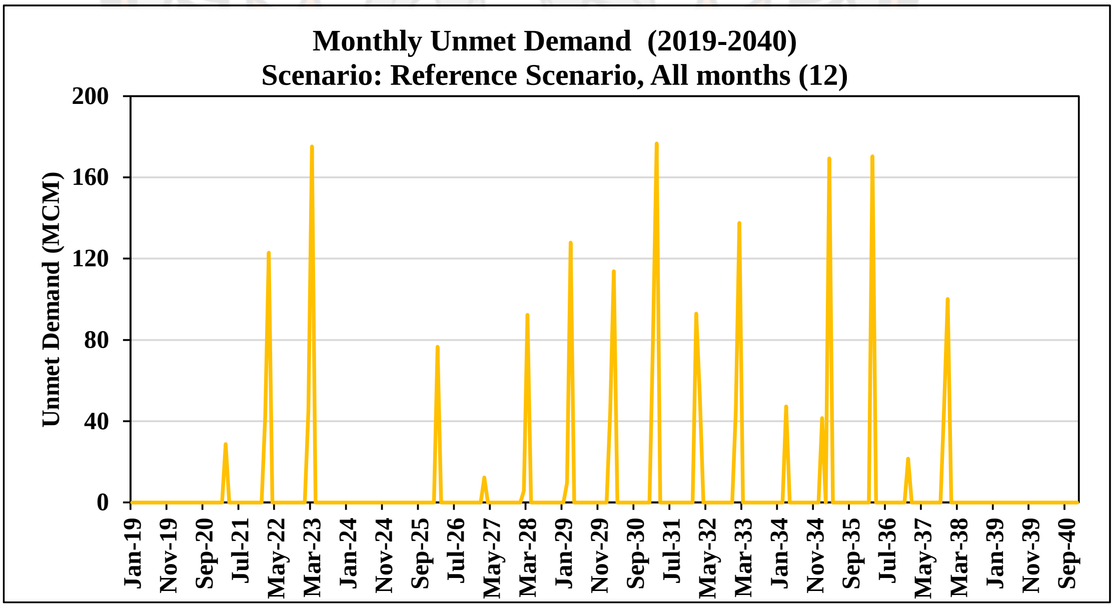


Figure 41 Unmet demand of the study basin in Reference Scenario (2019-2040)

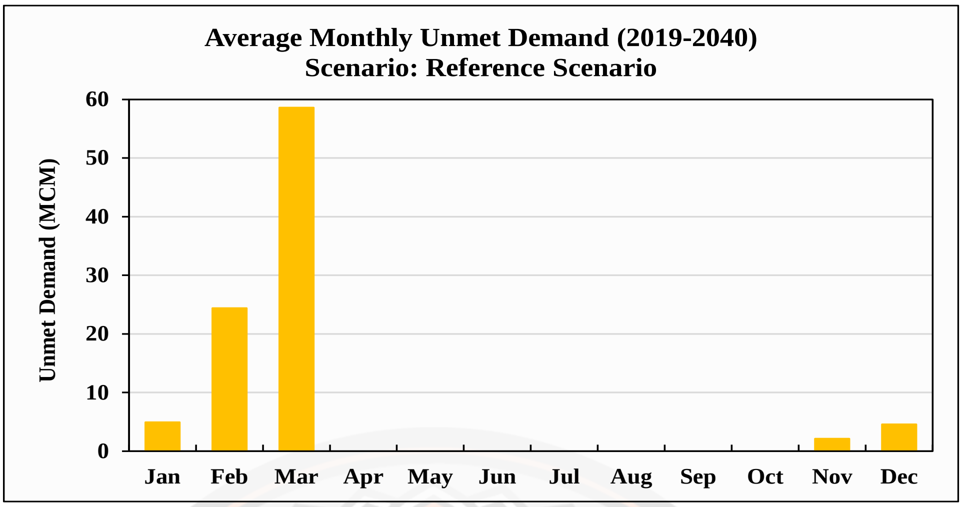


Figure 42 The Mean monthly unmet demand in Reference Scenario (2019-2040)

Therefore, the reference scenario of (2019-2040), based on the current situation of the study basin, it can be predicted that there will be a shortage in demand coverage and the average unmet demand of the agriculture and domestic demand sites will be 0.26 MCM per day. The current study area mainly depends on the surface water from rivers and reservoirs, which seem to be secure for the future, whereas groundwater sources in the study will have problems in the future because of its limited amount and other environmental impacts. By reducing water demand in the summer season crops, it can be solved the unmet demand problems in the study area can be solved. Moreover, other scenarios such as population growth and economic development of the city, and climate change, can have an effect on the situation of the study basin, and these impacts will be discussed in the next section by simulating the different scenarios.

4.4 Evaluation of Future Scenarios (2019-2040)

4.4.1 Impacts of Different Scenarios

Figure 43 and **Figure 44** show the demand site coverage and the unmet demand of the study under four different scenarios, such as Climate Change, High Population Growth Rate, Higher Living Standard and Water Supply Site scenarios. These were used in comparison to the Reference Scenario for the simulation period 2019-2040. In general, there will be significant negative impacts on water demand coverage of the study basin under CC scenario and a great positive influence under WSM scenario, whereas there was no effect under the HPG and HLS scenario. Likewise, the unmet demand amount in CC scenario will gradually become higher than that in the Reference Scenario, but this, in WSM Scenario was noticeably lower. However, there were no difference between the results of HPG and HLS Scenario and Reference Scenario. The detailed discussion of the results data of these scenarios is presented in the sub-sections that follow.

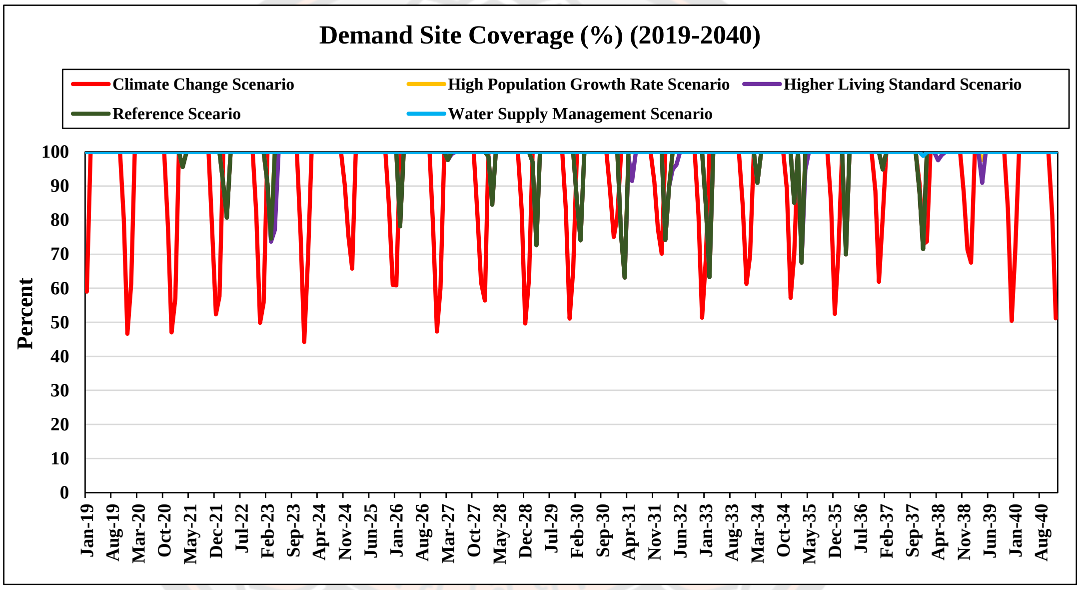


Figure 43 Demand site coverage of the study under different scenarios (2019-2040)

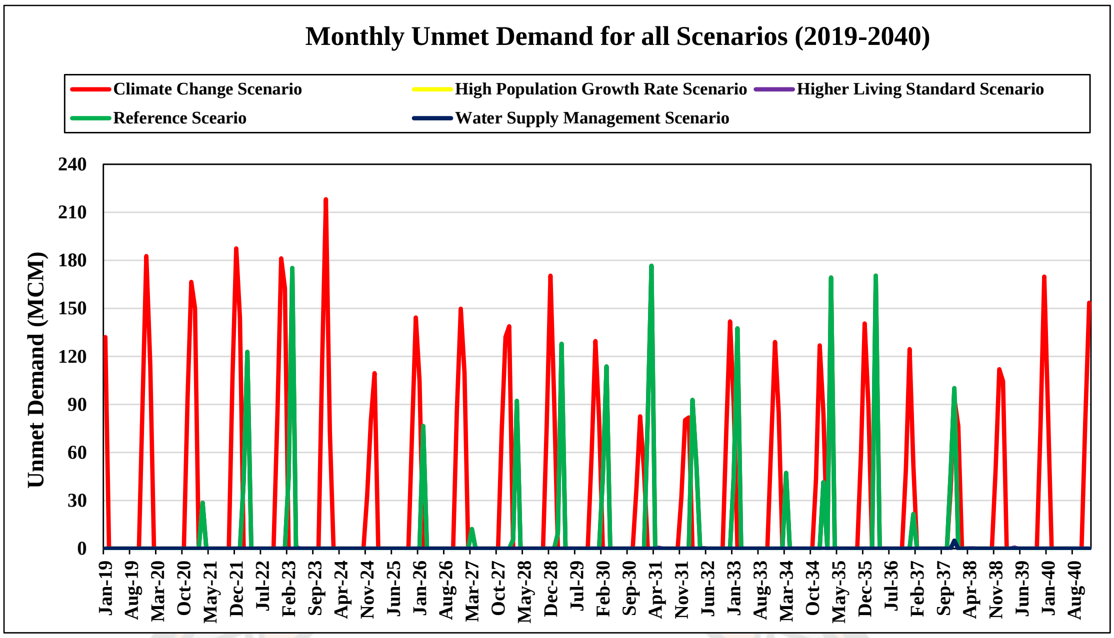
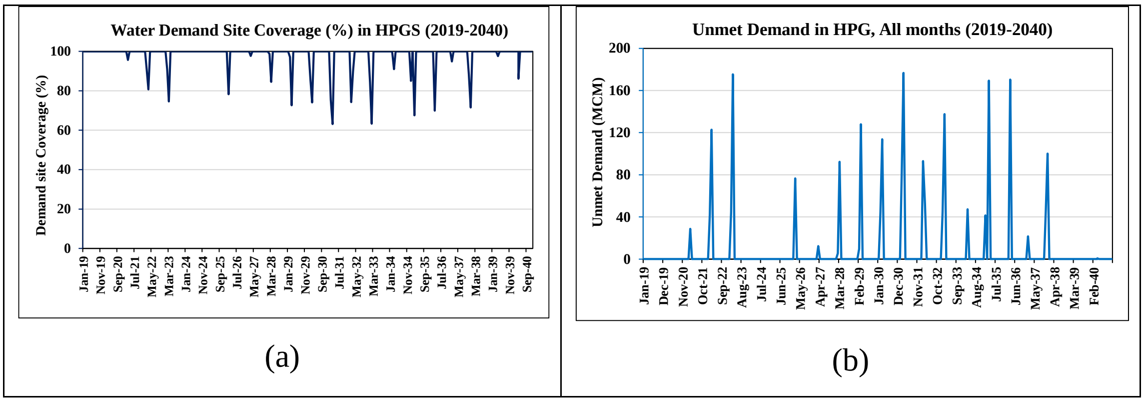


Figure 44 Unmet demand of the study under different scenarios (2019-2040)

4.4.2 High Population Growth Rate (HPG) Scenario

In this HPG Scenario, the population growth rate was used as 2.74 % instead of the normal growth rate of 1.85 % as in the Reference Scenario. The simulated results for both demand site coverage and unmet demand of the study under this scenario show exactly the same trends as in the Reference Scenario (see in **Figure 45 (a) and (b)**). Hence, these results demonstrated that there was no impact of HPG scenario on this study model and these results also highlighted the inflow data used in Reference Scenario. **Figure 46** also shows the projection of the annual water demand and unmet demand based on both scenarios: high population growth rate and the reference. The accompanying projected average annual water demand raises to a maximum of 1,239 MCM per year instead of 1,237 MCM per year under the reference scenario. However, the simulation results under high population growth rate scenario were similar for all coverage and unmet demand as the reference scenario.



(a)

(b)

Figure 45 Water demand site coverage (%) and Unmet demand of HPG scenario

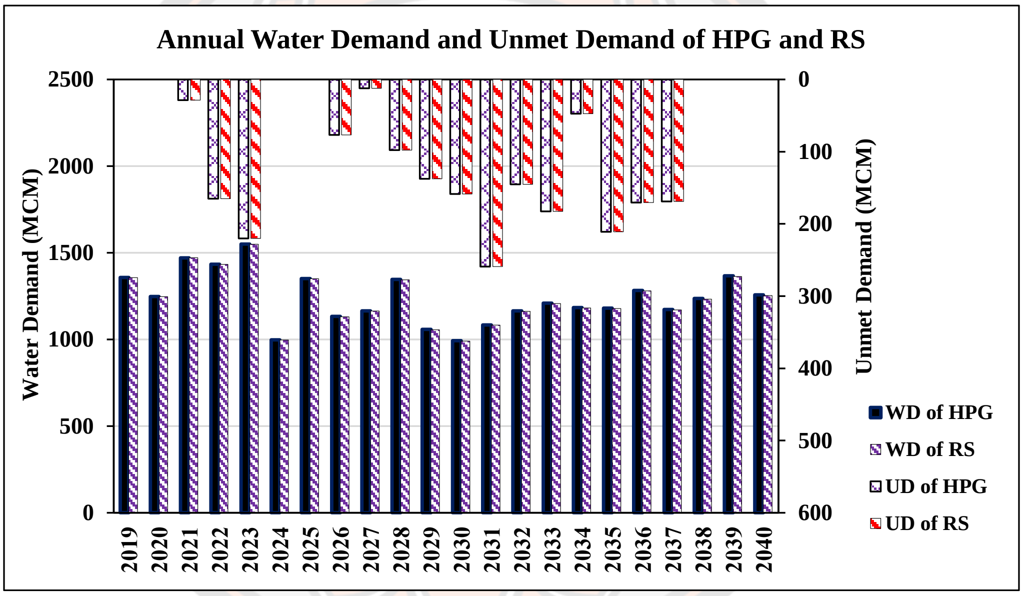
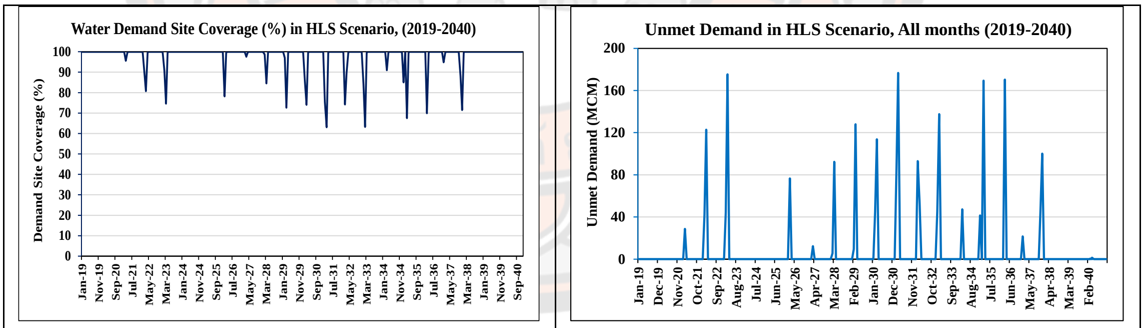


Figure 46 Annual water demand and unmet demand of RS and HPG Scenario

4.4.3 Higher Living Standard (HLS) Scenario

In HLS Scenario, it was assumed that the water use rate would increase together with the economic growth of the city because of higher living standards. There was a higher water consumption rate in this study area because of their oriental living style, for example, wet sanitation. Future service target of the study for water consumption rate, 0.114 m^3/day in 2018 to 0.132 m^3/day in 2030 and 0.151 m^3/day in 2040, were used to analyse the impact of these changes. The simulation results for demand site coverage of the study basin show that both scenarios have similar patterns but the results of HLS Scenario in the domestic demand site coverage was slightly lower than that of Reference Scenario (**see Figure 47(a)**). The lowest demand site coverage amount in HLS scenario will be 63 % in 2033 as that of the same coverage in Reference Scenario. As a result of this low demand coverage problem, the unmet demand under this scenario will reach 6.08 MCM per month in 2033 as the maximum amount under this scenario (**see Figure 47(b)**).

Figure 48 also shows the projection of annual unmet water demand based on both scenarios: higher living standard and the reference. The accompanying projected annual water demand raises to a maximum of 1,241 MCM per year instead of 1,237 MCM per year under the reference scenario. The simulation results demonstrate that with higher living standard scenario, Bago river basin area will start water deficits in 2020, which is similar as the reference scenario. Thus, there was no significant impact for all kinds of demand sites under higher living standard scenarios. In long-term perspective reflects the need to develop new technologies, new cooperation mechanisms, or better water management plans to offset this anticipated shortfall.



(a) (b)

Figure 47 Water demand site coverage (%) and unmet demand of HLS scenario

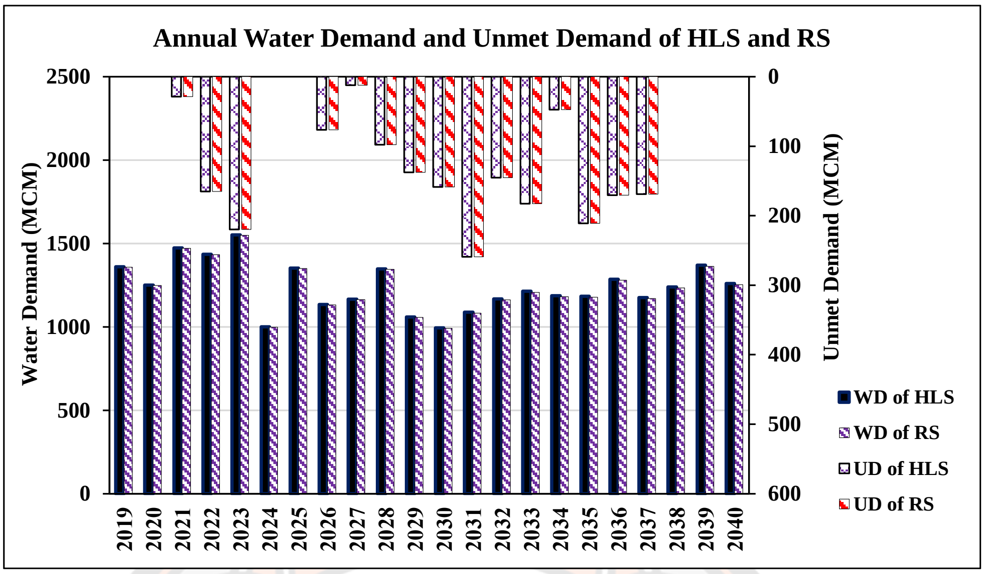


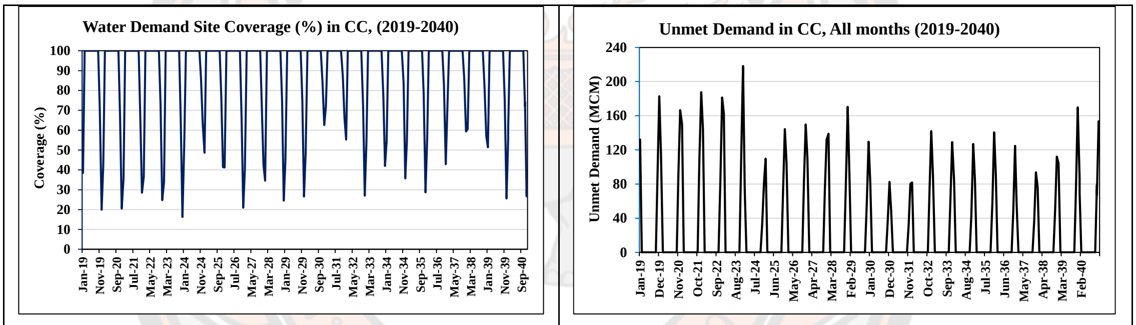
Figure 48 Annual water demand and unmet demand of RS and HLS Scenario

4.4.4 Climate Change (CC) Scenario

In this CC Scenario, water year method was used to study the impacts of climate change in the BRB based on the hydrological method in WEAP. The simulation results for demand site coverage of the study basin show that both scenarios have similar trends but the results of CC Scenario are much lower than that of Reference Scenario **(see Figure 49 (a)**). The lowest demand coverage amount in CC scenario will be 16 % in December 2023, whereas the same in Reference Scenario will be about 100 % in December 2023. As a result of this low demand coverage problem, the unmet demand in this scenario will reach 218 MCM per month in December 2023 as the maximum amount under this scenario (**see Figure 49 (b)**).

The accompanying projected water demand shows a similar trend as well as a similar amount of 1,237 MCM per year under the reference scenario (**see Figure 50**). This is because there was no change in the amount of water demand sites in this scenario, while there was a change in the water supply sites. **Figure 50** also shows the projection of annual unmet water demand based on both scenarios: climate change and the reference. The simulation results demonstrate that with climate change, the BRB area has started to show water deficits in 2019, however the water shortage will start in 2021 under reference scenario. The average annual unmet demand for climate change indicated a maximum of 310 MCM, which is nearly three times the amount of the mean annual unmet demand of reference scenario (94.6 MCM).

Hence, these results demonstrated that there was a significant impact of climate change on this study model using water year method based on the results of Shrestha (2014, 2016 & 2017), and these results also highlighted the inflow data used in Reference Scenario. The other climate change data for different scenarios from different climate change models should be used for further studies about the climate change impact on this study. It is advisable to look at the long-term perception and reflect the requirements to develop new technologies, new cooperation mechanisms, or well water management plans to offset this anticipated shortfall.



(a) (b)

Figure 49 Water demand site coverage (%) and unmet demand of CC Scenario

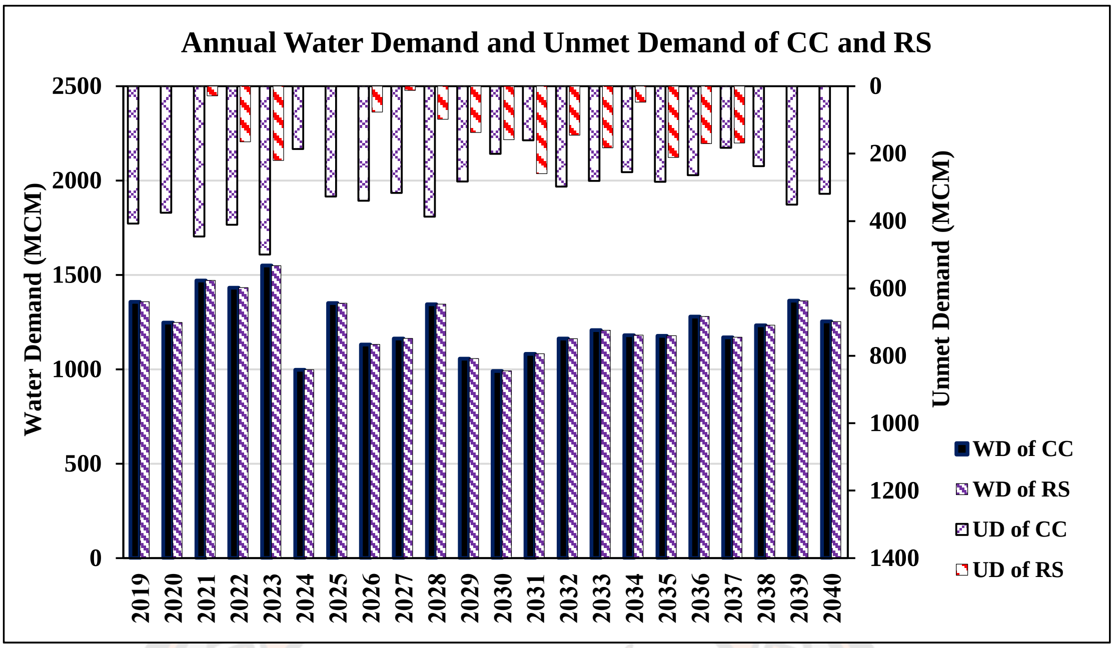


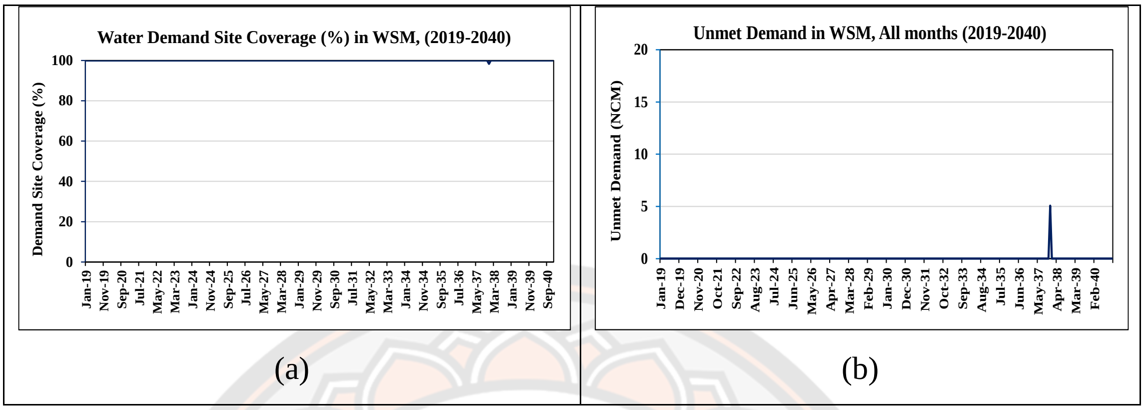
Figure 50 Annual water demand and unmet demand of RS and CC Scenario

4.5 Improvement of Future Scenario

4.5.1 Water Supply Management (WSM) Scenario

For this WSM scenario, EDWS will reduce the water losses in the system by implementing different strategies, such as leakage control plan, pipeline rehabilitation plan, connection control plan, and water-meter re-installation plan and so forth, in order to reach the future target of 15 % in 2040. For this scenario, future target data of Bago River Sub-Basin Management Plan, NIVA (2018) were used to study the effect of loss control. According to the results, this scenario can raise the water supply service enormously, for example, the average demand site coverage in this scenario will be 100 %, and 45% in Reference Scenario for the simulation period (**see Figure 51**).

The average unmet demand in this scenario will be 0.02 MCM per month, whereas 7.88 MCM per month in Reference Scenario (**see Figure 52**). Simulation of this WSM-loss water control in the transmission links showed that the water supply service in this study area could be improved fully by controlling losses with low investment and energy. Moreover, transmission losses control not only improve the quantity of the water supply, but also it may upgrade the quality of the supplied water without disturbing the environment. Therefore, WSM was the best strategy for the improvement of the study.



(a) (b)

Figure 51 Water demand site coverage (%) and unmet demand of WSM scenario

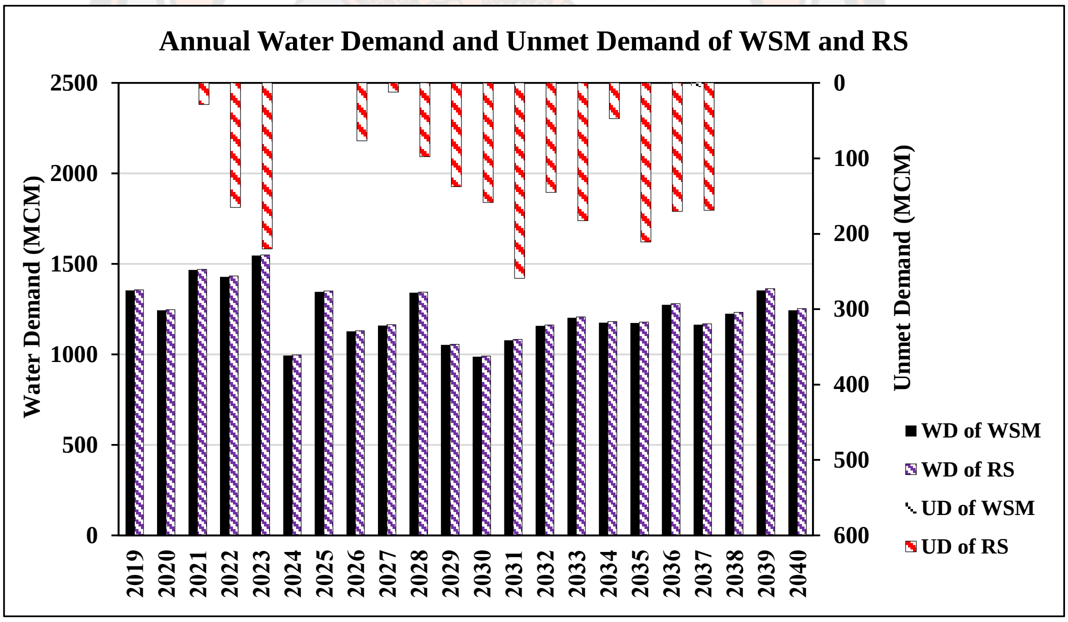
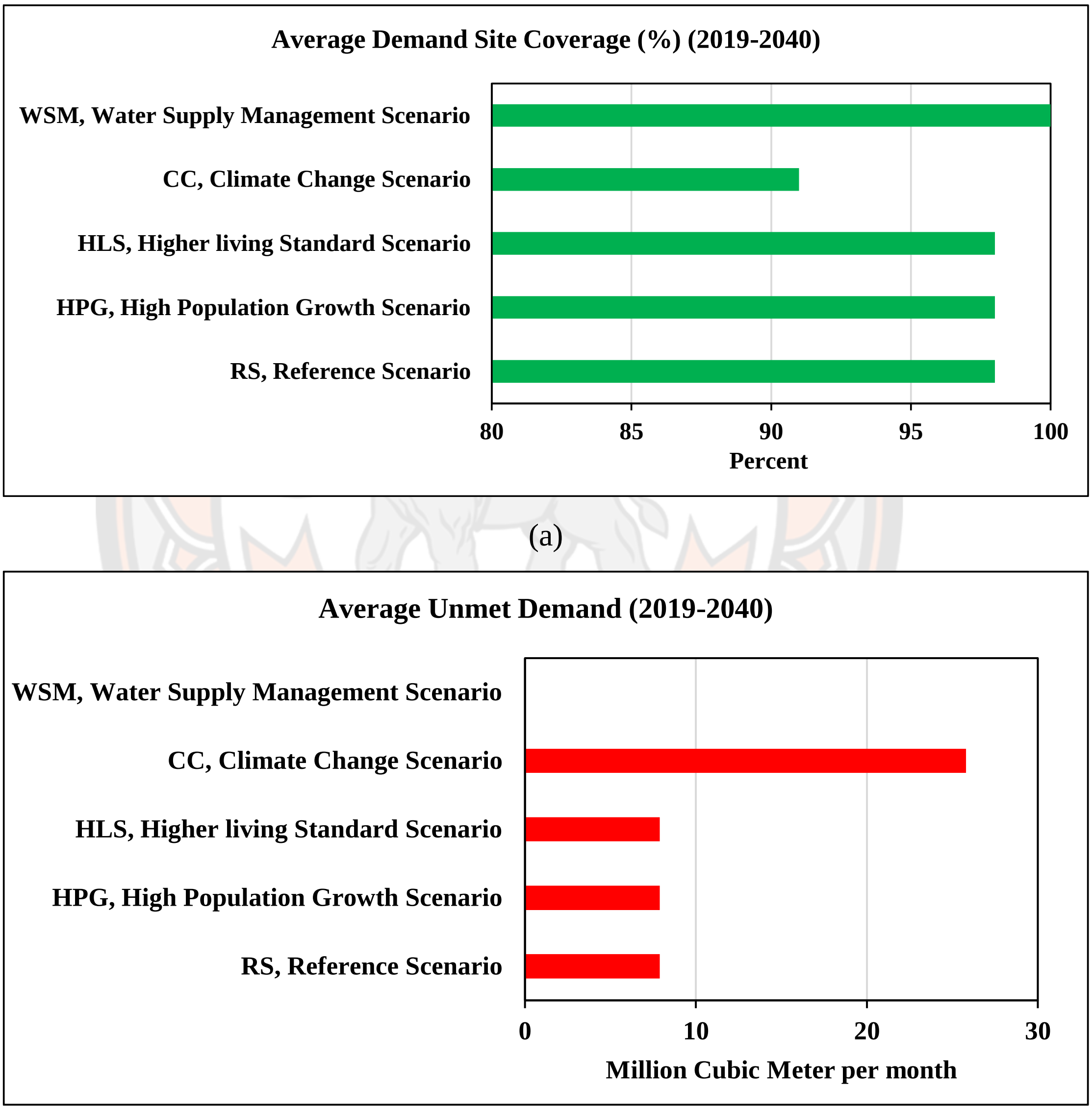


Figure 52 Annual water demand and unmet demand of RS and WSM scenario

4.5.2 Development Options for Future Study

Figure 53 illustrates the demand coverage percentage and unmet demand in this study that will be encountered as an average under different scenarios. The average unmet demand of RS, HPG and HLS scenario will be 7.88 MCM per month, CC scenario will be 25.8 MCM per month and WSM scenario will show a low amount of 0.02 MCM per month, respectively. According to these figures, CC scenarios can have a negative impact on the system, and WSM option is the best option to gain 100 % system reliability. Furthermore, HPG and HLS option can give a moderate advantage to the system in comparison to the reference scenario.



(a)

(b)

Figure 53 Average demand site coverage (%) and unmet demand from 2019 to 2040

CHAPTER V

CONCLUSIONS

5.1 Conclusions

This study applied the Water Evaluation and Planning (WEAP) model for the BRB, Myanmar, to evaluate the existing situation of water resources and projected changes in water status in the future. The existing results indicated that currently the basin has sufficient water to meet the water demands except in 2014 and 2018. The average unmet demand for all kinds of demand sites in the BRB was 0.82 MCM per year. The calibrated results fitted the observed data during 2011-2015 with $R^2 = 0.97$, NSE = 0.84, and RMSE = 9 m^3/s, and the validated in 2016-2018 with $R^2 = 0.98$, NSE = 0.92, and RMSE = 4 m^3/s, respectively. The model developed through WEAP was highly proficient and exhibited great performance to manage available water resources with water demand.

Five scenarios were developed keeping within the future plans for the basin, to evaluate the impact of increasing water demands on the water resources available in the basin. Reference Scenario was created using current accounts data to evaluate the future trends in both supply sources and demand sites. According to the analysis of Reference Scenario, the results showed the average demand coverage of 100% in 2019, 2020, 2024, 2025, 2039 and 2040. However, the results pointed out the average demand coverage of the study basin in 2038 will reduce gradually reaching a low of 41%. The average unmet demand of the study basin from 2019-2040 will be 7.88 MCM per month.

In the Climate Change (CC) Scenario when using water year method in WEAP model, the demand site coverage of the study basin declines considerably compared with the results of Reference Scenario of 91% and the average unmet demand of 25.8 MCM per month. The High Population Growth (HPG) and Higher Living Standard (HLS) Scenario, showed no effect in the water demand coverage of the study basin getting nearly the same results as Reference Scenario of 98%, and the unmet demand of 7.88 MCM per month. The water supply management (WSM)

Scenario, showed good improvement in demand coverage of the study area of 100% of the average coverage (2019-2040) and only 0.03 MCM per month of the average unmet demand.

Water shortages occurred in all scenarios and improvement of water efficiency needs to be adopted in the basin for long-term sustainability of water resources. The development of WEAP model as a water balance tool could assist water planners and policy makers in the process of decision-making regarding water demand system in order to tackle the current water-related problems and prepare for the future water management of the Bago River Basin, Myanmar.

5.2 Recommendations

Since the objectives of this study were to evaluate existing and future water balance with the different scenarios, water managers and decision maker of Bago River Basin should formulate a development plan for water demand and supply system in order to contribute to socioeconomic development of the study area. Therefore, Bago River Basin water supply system should be developed not only for the business-as-usual case, but also for the worst-case scenario by using the best management strategies. WEAP can be highly recommended as a powerful tool in evaluating the current situation and future options in water supply systems to meet all demands. Climate change scenario should also be taken into consideration among different future scenarios. It would be ideal to put in motion scenario result analysis and productive discussions among water planners, and local authorities to develop management plans for the improvement of BRBWSS.

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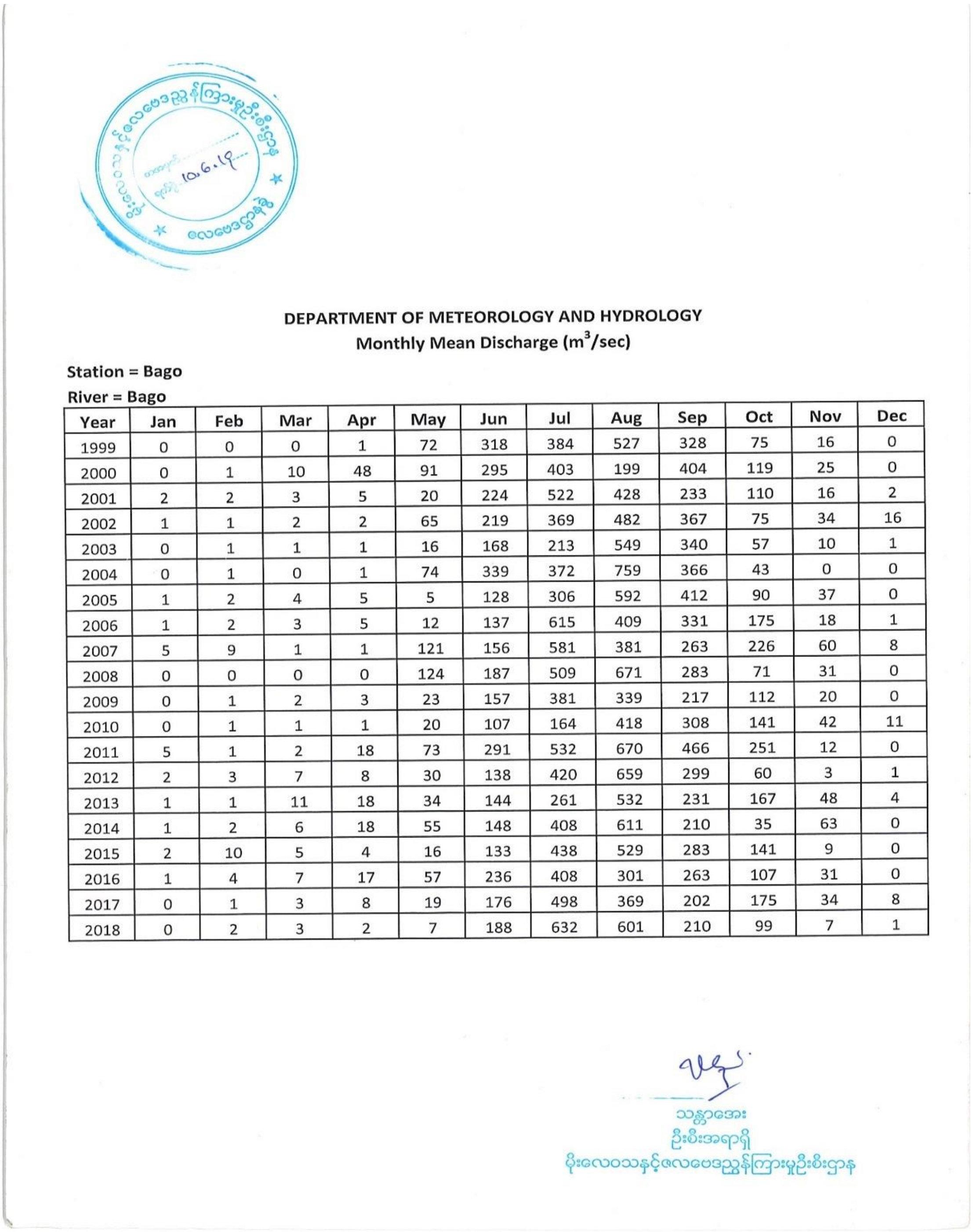
APPENDIX

APPENDIX A DMH CLIMATE DATA



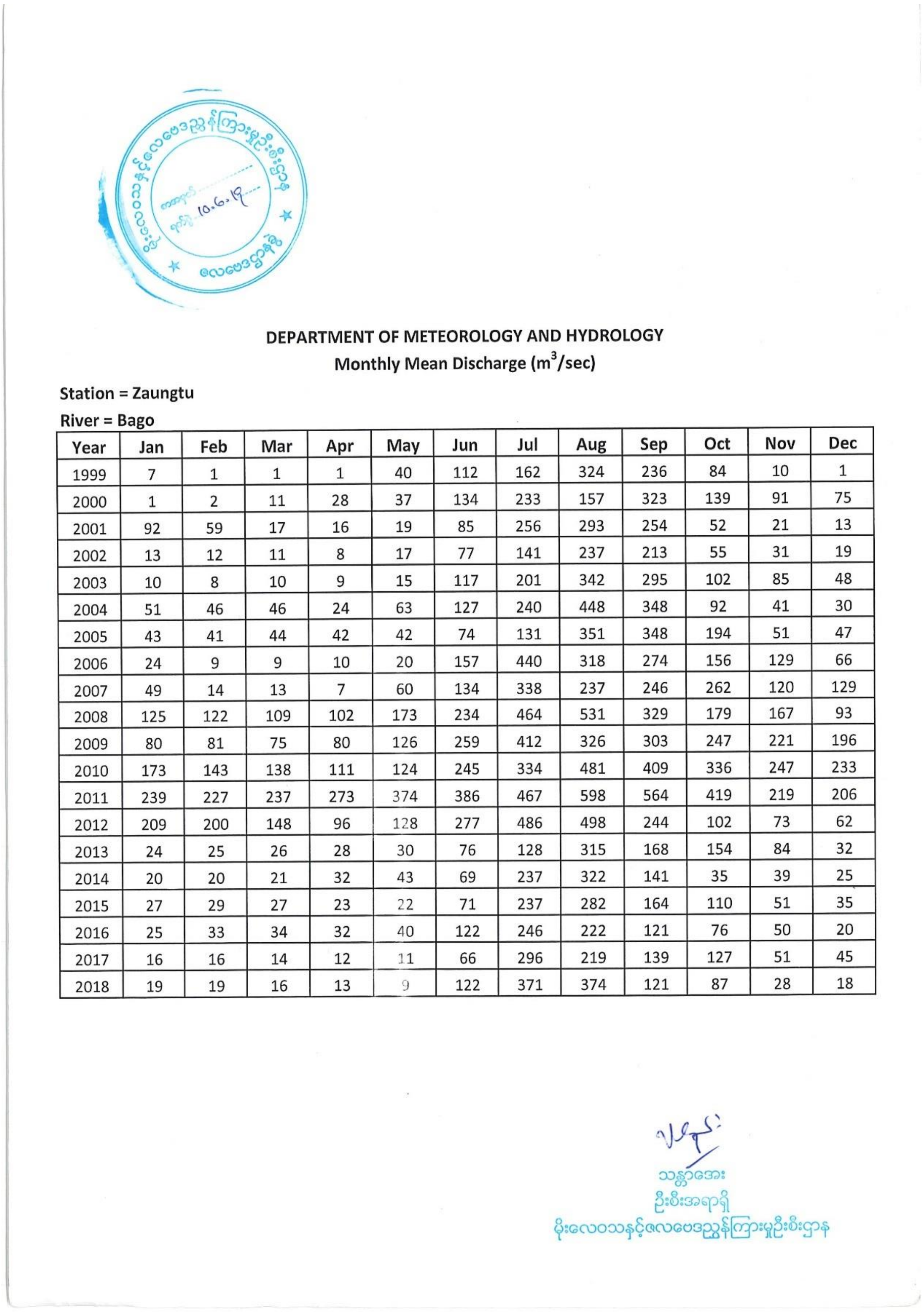
10.6.19

DEPARTMENT OF METEOROLOGY AND HYDROLOGY
Monthly Mean Discharge (m^3/sec)

Station = Bago
River = Bago

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	0	0	0	1	72	318	384	527	328	75	16	0
2000	0	1	10	48	91	295	403	199	404	119	25	0
2001	2	2	3	5	20	224	522	428	233	110	16	2
2002	1	1	2	2	65	219	369	482	367	75	34	16
2003	0	1	1	1	16	168	213	549	340	57	10	1
2004	0	1	0	1	74	339	372	759	366	43	0	0
2005	1	2	4	5	5	128	306	592	412	90	37	0
2006	1	2	3	5	12	137	615	409	331	175	18	1
2007	5	9	1	1	121	156	581	381	263	226	60	8
2008	0	0	0	0	124	187	509	671	283	71	31	0
2009	0	1	2	3	23	157	381	339	217	112	20	0
2010	0	1	1	1	20	107	164	418	308	141	42	11
2011	5	1	2	18	73	291	532	670	466	251	12	0
2012	2	3	7	8	30	138	420	659	299	60	3	1
2013	1	1	11	18	34	144	261	532	231	167	48	4
2014	1	2	6	18	55	148	408	611	210	35	63	0
2015	2	10	5	4	16	133	438	529	283	141	9	0
2016	1	4	7	17	57	236	408	301	263	107	31	0
2017	0	1	3	8	19	176	498	369	202	175	34	8
2018	0	2	3	2	7	188	632	601	210	99	7	1

သန္တာအေး
ဦးစီးအရာရှိ
မိုးလေဝသနှင့်ဇလဗေဒညွှန်ကြားမှုဦးစီးဌာန



10.6.19

DEPARTMENT OF METEOROLOGY AND HYDROLOGY

Monthly Mean Discharge (m^3/sec)

Station = Zaungtu

River = Bago

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	7	1	1	1	40	112	162	324	236	84	10	1
2000	1	2	11	28	37	134	233	157	323	139	91	75
2001	92	59	17	16	19	85	256	293	254	52	21	13
2002	13	12	11	8	17	77	141	237	213	55	31	19
2003	10	8	10	9	15	117	201	342	295	102	85	48
2004	51	46	46	24	63	127	240	448	348	92	41	30
2005	43	41	44	42	42	74	131	351	348	194	51	47
2006	24	9	9	10	20	157	440	318	274	156	129	66
2007	49	14	13	7	60	134	338	237	246	262	120	129
2008	125	122	109	102	173	234	464	531	329	179	167	93
2009	80	81	75	80	126	259	412	326	303	247	221	196
2010	173	143	138	111	124	245	334	481	409	336	247	233
2011	239	227	237	273	374	386	467	598	564	419	219	206
2012	209	200	148	96	128	277	486	498	244	102	73	62
2013	24	25	26	28	30	76	128	315	168	154	84	32
2014	20	20	21	32	43	69	237	322	141	35	39	25
2015	27	29	27	23	22	71	237	282	164	110	51	35
2016	25	33	34	32	40	122	246	222	121	76	50	20
2017	16	16	14	12	11	66	296	219	139	127	51	45
2018	19	19	16	13	9	122	371	374	121	87	28	18

သန္တာအေး
ဦးစီးအရာရှိ
မိုးလေဝသနှင့်ဇလဗေဒညွှန်ကြားမှုဦးစီးဌာန

Diversion Flow of Zaung Tu Weir (m^3/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	2.3	3.4	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
2000	2.4	3.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.2	1.6
2001	2.3	3.0	1.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.5
2002	2.4	3.4	2.9	0.4	0.0	0.0	0.0	0.0	0.0	3.5	0.0	1.5
2003	2.1	3.4	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.0	1.6
2004	2.1	3.4	2.9	0.5	0.0	0.0	0.0	0.0	0.0	0.8	3.2	1.6
2005	2.3	3.4	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	2.3	3.4	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.6
2007	4.8	5.9	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1
2008	3.1	4.4	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
2009	3.2	4.7	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.3
2010	3.6	6.5	5.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.3
2011	1.6	4.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.2
2012	3.2	4.7	3.8	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.4
2013	2.3	3.8	3.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
2014	2.4	3.6	3.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	2.7	1.8
2015	1.6	2.4	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	1.2
2016	1.3	2.3	2.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	2.3	1.2
2017	1.9	2.7	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	1.3
2018	1.9	2.7	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.4
Avg;	2.5	3.8	2.8	0.2	0.0	0.0	0.0	0.0	0.0	0.3	1.6	1.6
Max;	4.8	6.5	5.5	0.9	0.0	0.0	0.0	0.0	0.0	3.5	3.2	3.1
Min;	1.3	2.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SD	0.80	1.09	1.17	0.26	0.00	0.00	0.00	0.00	0.00	0.83	1.29	0.68

Bago Station: Rainfall(mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1999	0	0	77	168	519	664	738	665	454	161	79	0	3525
2000	0	4	33	26	360	861	715	507	336	130	1	0	2973
2001	0	0	42	0	502	747	1062	607	407	264	16	0	3647
2002	0	0	0	15	513	711	924	655	520	61	139	6	3544
2003	9	0	5	0	387	683	556	655	513	141	2	0	2951
2004	2	0	0	14	511	774	579	795	550	138	0	0	3363
2005	4	0	0	27	240	579	419	795	703	128	94	87	3076
2006	0	0	0	173	279	573	1018	689	529	214	45	0	3520
2007	0	0	2	70	928	512	926	781	322	214	16	0	3771
2008	6	16	1	190	727	557	830	657	464	160	89	0	3697
2009	0	0	0	114	239	654	660	564	405	218	0	0	2854
2010	10	0	0	0	259	473	441	655	167	352	56	100	2513
2011	38	0	95	7	305	793	747	839	709	260	0	0	3793
2012	4	0	7	13	166	634	1000	1199	429	107	21	0	3580
2013	4	12	0	3	220	769	709	701	505	306	26	6	3261
2014	0	0	0	0	245	616	983	629	524	67	45	0	3109
2015	1	0	1	10	382	498	924	632	512	241	8	0	3209
2016	41	0	0	0	298	577	946	540	624	310	39	0	3375
2017	2	0	0	114	461	568	1123	626	452	493	1	0	3840
2018	2	0	0	55	203	568	1004	609	331	324	43	0	3139
Avg	6	2	13	50	387	641	815	690	473	214	36	10	3337
Max	41	16	95	190	928	861	1123	1199	709	493	139	100	
Min	0	0	0	0	166	473	419	507	167	61	0	0	
SD	12	4	28	65	191	108	208	148	129	108	39	29	

Zaung Tu Station: Rainfall(mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1999	0	0	0	220	696	639	593	609	635	169	31	0	3592
2000	0	0	39	61	435	723	603	296	562	95	5	0	2819
2001	0	7	32	0	287	859	783	579	311	116	7	4	2985
2002	0	0	0	3	486	576	601	544	317	81	152	4	2764
2003	4	0	6	38	292	599	399	759	359	106	0	0	2561
2004	8	0	0	0	628	697	632	996	509	9	0	0	3479
2005	0	0	0	36	183	402	648	625	501	149	38	60	2643
2006	0	0	0	126	252	422	913	461	358	192	1	0	2725
2007	0	0	0	0	596	391	829	566	303	386	92	0	3163
2008	0	0	0	0	596	391	829	566	303	386	92	0	3163
2009	0	0	0	58	200	418	748	458	385	201	0	0	2468
2010	15	0	0	0	293	577	417	952	236	278	0	36	2804
2011	32	0	103	38	480	676	717	685	702	149	0	0	3582
2012	0	0	3	8	247	599	715	831	681	108	33	1	3226
2013	7	0	0	0	253	467	742	805	393	309	19	0	2995
2014	0	0	0	7	238	642	913	837	290	77	29	0	3033
2015	2	0	18	59	178	609	834	783	400	155	3	0	3041
2016	12	2	4	9	292	635	649	509	486	117	0	0	2715
2017	0	0	0	106	232	642	867	670	351	330	0	0	3198
2018	1	0	0	65	218	551	1059	810	269	249	7	0	3229
Avg	4	0	10	42	354	576	725	667	418	183	25	5	3009
Max	32	7	103	220	696	859	1059	996	702	386	152	60	
Min	0	0	0	0	178	391	399	296	236	9	0	0	
SD	8	2	25	56	167	127	164	178	140	107	41	15	

Bago,Maximum Temperature('C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	33	34	35	35	32	30	30	31	31	32	32	30
2000	33	34	34	36	32	30	30	30	31	32	31	30
2001	31	31	33	39	33	30	30	29	30	32	32	32
2002	32	35	37	40	35	30	29	29	30	33	32	31
2003	30	34	37	39	33	30	30	29	30	32	32	31
2004	32	34	37	39	33	31	30	30	32	34	34	31
2005	33	36	38	39	35	31	30	30	31	34	33	31
2006	31	35	38	37	33	31	29	30	31	33	33	31
2007	32	34	37	40	31	32	30	30	31	32	32	31
2008	31	33	37	36	31	30	30	30	31	33	32	30
2009	31	34	37	37	34	30	29	31	31	32	33	31
2010	32	35	37	40	37	31	31	30	31	31	32	30
2011	30	33	33	37	32	30	30	29	30	32	32	31
2012	31	34	36	37	35	31	29	29	31	33	33	32
2013	32	35	37	38	35	31	30	29	31	32	34	30
2014	31	34	37	38	35	31	30	30	31	33	32	33
2015	31	34	37	38	35	32	31	31	32	33	34	33
2016	31	34	37	38	37	31	32	31	32	32	33	33
2017	32	34	37	37	35	32	29	31	33	32	34	32
2018	32	35	37	38	35	31	29	30	32	33	34	33

Zaung Tu, Maximum Temperature ('C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	32	34	35	36	33	31	30	30	31	33	33	31
2000	33	34	36	39	34	31	31	33	32	34	33	33
2001	32	34	37	40	34	31	30	30	31	34	33	33
2002	32	34	37	40	35	32	30	30	31	34	33	32
2003	31	34	36	39	34	31	32	31	32	34	34	33
2004	33	34	36	39	33	31	31	29	31	33	33	31
2005	32	34	37	38	38	32	30	29	31	32	31	31
2006	30	32	36	37	33	32	29	30	31	33	33	32
2007	32	33	37	40	32	32	31	30	32	33	32	32
2008	32	33	37	38	32	32	31	31	32	33	32	31
2009	31	33	36	38	36	31	30	32	32	33	34	32
2010	33	35	37	41	37	32	32	32	32	32	33	31
2011	30	34	35	38	35	32	32	31	31	33	33	32
2012	32	35	37	39	36	31	30	30	32	33	34	33
2013	33	36	39	40	37	32	31	30	32	32	33	30
2014	32	34	37	39	36	32	30	30	31	32	33	33
2015	32	34	38	38	36	31	30	30	31	33	34	33
2016	32	35	37	40	37	31	30	30	31	32	33	33
2017	32	34	38	38	36	32	30	30	32	32	34	32
2018	32	34	37	37	35	30	29	29	31	32	33	33

Bago,Minimum Temperature('C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	16	19	19	22	21	21	21	21	21	21	19	14
2000	16	17	19	23	23	20	20	20	21	21	20	17
2001	16	18	22	23	23	23	23	23	23	23	19	17
2002	16	16	18	19	18	18	20	24	24	24	23	20
2003	17	18	18	24	20	18	24	23	23	24	20	18
2004	16	18	20	23	23	19	23	22	23	23	23	15
2005	14	15	19	21	22	21	20	19	20	23	19	18
2006	16	17	21	23	23	23	23	24	24	24	22	17
2007	17	18	20	24	25	25	24	25	25	25	22	18
2008	18	19	22	25	24	25	24	24	24	24	22	19
2009	17	19	23	24	25	23	23	23	23	23	20	16
2010	17	16	20	23	23	22	21	20	21	24	21	18
2011	17	17	20	22	24	23	22	22	21	22	19	18
2012	16	19	22	25	25	25	24	24	25	25	25	20
2013	18	22	23	25	25	25	24	24	25	25	24	19
2014	17	19	21	26	26	25	25	25	25	25	23	20
2015	19	19	23	25	26	25	25	25	25	25	24	20
2016	17	19	24	25	26	26	25	25	24	24	22	21
2017	19	18	20	23	23	24	24	24	25	24	24	20
2018	19	19	22	25	25	25	24	24	25	24	22	21

Zaung Tu, Minimum Temperature ('C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	18	18	18	24	24	23	23	23	23	23	22	16
2000	15	16	18	25	24	23	24	24	24	23	20	16
2001	15	15	21	23	24	24	23	24	23	23	19	15
2002	13	13	14	18	20	20	20	18	20	21	20	16
2003	13	13	15	22	22	20	20	20	21	22	18	16
2004	15	16	17	21	22	17	23	23	23	22	19	13
2005	14	12	18	23	24	23	23	22	22	23	22	21
2006	16	16	21	22	22	23	25	23	22	22	20	16
2007	13	13	18	23	23	22	22	23	23	23	21	15
2008	14	13	16	20	22	22	21	21	21	21	19	18
2009	15	15	20	23	23	22	21	23	23	23	20	16
2010	16	16	21	24	23	22	22	22	22	22	20	18
2011	15	15	20	23	23	22	21	21	21	21	20	18
2012	15	15	19	22	23	23	22	22	22	22	21	16
2013	15	20	22	24	24	24	23	23	22	22	21	17
2014	14	15	18	25	24	24	22	22	22	22	20	17
2015	15	14	18	21	23	23	23	23	23	22	21	17
2016	13	15	20	22	23	22	22	22	22	21	21	19
2017	17	15	18	24	25	25	24	25	25	25	24	19
2018	17	16	19	23	25	28	24	24	24	24	24	22

Bago,Wind Speed (miles per hour)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	2.1	2.1	1.7	2.5	2.8	1.3	1.1	1.4	1.6	1.7	2.2	2.0
2000	2.2	2.3	2.3	2.4	1.7	2.1	1.8	1.9	1.7	1.5	1.9	2.1
2001	2.0	2.3	2.3	2.5	2.1	2.0	1.9	1.9	1.6	1.5	1.9	2.1
2002	2.1	2.3	2.7	2.6	2.1	2.0	2.2	2.0	2.1	1.3	1.9	1.9
2003	1.7	2.0	2.3	2.3	2.3	2.1	2.0	1.8	1.6	1.5	2.0	2.0
2004	2.1	2.6	2.5	2.6	2.2	1.9	1.8	2.0	1.5	1.6	1.9	2.1
2005	2.2	2.5	2.5	2.4	2.1	2.1	1.8	1.9	1.9	1.6	1.6	2.1
2006	1.8	2.2	2.4	2.5	2.0	1.9	2.0	2.0	1.6	1.7	1.8	2.1
2007	2.2	2.4	2.6	2.4	2.4	1.8	1.7	1.8	1.6	1.8	1.9	2.2
2008	2.0	2.3	2.4	2.4	2.0	1.9	1.9	1.8	1.5	1.5	1.8	1.9
2009	2.0	2.2	2.5	2.2	1.9	2.2	2.1	1.7	1.6	1.5	1.7	1.7
2010	1.9	2.5	2.5	2.6	2.3	1.9	1.8	1.8	1.4	2.1	1.7	1.9
2011	1.9	2.1	2.4	2.2	1.8	2.3	2.0	1.9	1.7	1.4	2.2	2.4
2012	2.2	2.3	2.5	2.4	2.1	2.3	2.1	2.0	1.6	1.5	1.4	2.0
2013	1.8	2.2	2.7	2.7	2.4	2.1	2.3	2.0	1.6	1.5	1.9	1.9
2014	1.2	1.2	1.3	1.5	1.2	1.2	1.3	1.2	1.2	1.3	1.2	1.2
2015	1.3	1.2	1.3	1.4	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2
2016	1.3	1.2	1.2	1.4	1.5	1.8	1.6	1.7	1.4	1.5	1.2	1.2
2017	1	1	1.4	1.6	1.5	1.3	1.4	1.6	1.3	1.3	1.4	1.4
2018	1.1	1	1	1	1.1	1.1	0.9	1.1	1	1.1	1	1.1

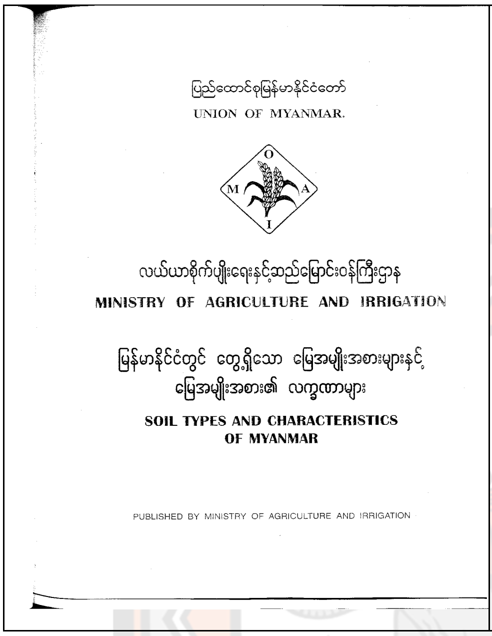
Zaung Tu, Wind Speed (miles per hour)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	2.3	2.0	2.3	2.1	2.1	2.3	2.3	2.3	1.8	1.9	1.6	2.3
2000	2.3	2.1	2.2	2.3	1.8	2.3	1.9	1.9	1.8	1.5	2.1	2.3
2001	2.2	2.2	2.2	2.2	2.2	2.1	2.0	2.0	1.6	1.5	1.9	2.3
2002	2.4	2.3	2.4	2.2	2.0	2.1	2.3	2.1	2.0	1.3	1.9	2.1
2003	1.8	1.9	2.1	2.1	2.2	2.3	2.1	1.8	1.6	1.4	2.2	2.0
2004	2.3	2.6	2.2	2.3	2.2	1.9	2.0	2.1	1.5	1.6	1.9	2.2
2005	2.2	2.5	2.3	2.2	1.9	2.2	1.9	2.0	1.9	1.5	1.7	2.1
2006	2.0	2.2	2.3	2.3	1.9	2.0	2.1	2.1	1.7	1.7	1.9	2.1
2007	2.3	2.5	2.4	2.3	2.5	2.0	1.8	1.9	1.6	1.7	1.9	2.4
2008	2.1	2.3	2.2	2.2	1.9	2.1	2.0	2.0	1.6	1.5	1.8	1.8
2009	1.8	2.1	2.3	2.0	1.9	2.2	2.3	1.8	1.7	1.4	1.5	1.7
2010	2.1	2.4	2.2	2.3	2.1	2.0	1.9	1.8	1.5	2.1	1.7	2.1
2011	1.9	2.0	2.1	2.0	1.9	2.5	2.2	2.1	1.9	1.4	2.6	2.8
2012	2.6	2.2	2.2	2.2	2.1	2.6	2.4	2.2	1.8	1.5	1.5	2.0
2013	1.7	2.0	2.4	2.5	2.4	2.3	2.5	2.2	1.7	1.4	2.1	2.2
2014	1.8	1.9	2	2.3	2.4	1.8	1.5	2	2.1	2.1	2	1.1
2015	1.5	1.7	1.7	2.3	2.4	2.4	2.4	2.4	2.5	2.6	2.6	2.5
2016	2.4	2.2	2.3	2.5	2.4	2.6	2.4	2.5	2.3	2.3	2.4	2.4
2017	2.4	2.4	1.2	1.6	1.7	1.8	1.4	1.5	1.5	1.5	1.2	1.5
2018	1.2	1.6	1.6	1.7	1.9	1.8	1.7	1.6	1.9	2.4	2.5	2.5

Bago,Relative Humidity (%)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	48	44	38	61	82	84	83	89	89	79	67	56
2000	40	42	36	53	85	91	90	91	91	89	75	59
2001	48	46	57	37	83	90	91	91	93	87	74	66
2002	47	39	39	39	73	91	91	91	92	87	83	78
2003	72	43	46	41	73	91	91	91	93	85	65	53
2004	45	41	39	39	80	63	91	92	91	79	62	49
2005	48	35	40	42	56	82	83	87	90	83	79	69
2006	51	37	41	51	80	88	91	91	93	84	64	48
2007	39	34	37	38	86	88	89	91	92	86	78	57
2008	50	44	38	56	89	90	91	91	91	86	77	62
2009	50	38	42	62	76	90	91	88	92	89	73	56
2010	51	42	43	39	58	89	89	90	91	89	72	65
2011	59	47	57	56	86	91	91	92	93	87	70	60
2012	42	36	41	47	70	91	91	92	93	84	80	63
2013	55	41	42	41	70	89	91	92	92	87	78	70
2014	72	73	73	74	77	89	91	90	88	81	85	78
2015	76	77	75	69	77	87	90	90	86	85	78	74
2016	71	66	71	63	71	86	90	88	87	86	81	78
2017	72	66	61	68	76	88	92	88	85	84	77	67
2018	70	66	72	69	76	93	95	93	88	83	76	72

Zaung Tu,Relative Humidity (%												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	54	43	37	59	84	86	85	90	90	80	66	56
2000	39	41	37	51	86	93	92	93	92	91	79	65
2001	52	45	54	36	84	92	92	93	94	89	79	72
2002	52	39	38	36	73	93	93	93	93	88	86	80
2003	76	48	44	40	74	93	93	93	94	88	70	60
2004	48	41	38	38	81	64	93	94	93	83	69	56
2005	49	36	38	42	56	84	85	88	91	86	81	75
2006	55	39	41	50	84	91	93	93	94	86	70	55
2007	43	34	36	39	88	91	91	93	93	88	83	65
2008	56	45	38	55	90	92	93	93	93	88	80	68
2009	56	37	40	63	78	92	93	91	93	90	77	63
2010	53	41	42	38	59	91	91	92	93	90	77	70
2011	64	47	57	55	87	93	93	93	94	88	71	63
2012	44	36	39	46	69	93	93	94	94	84	80	67
2013	58	40	41	40	71	91	93	93	93	89	79	73
2014	77	87	90	90	86	85	78	74	0	71	66	71
2015	71	86	90	88	87	86	81	78	0	72	66	61
2016	86	87	85	84	83	88	90	90	89	89	89	91
2017	89	90	80	81	79	88	93	91	89	86	87	91
2018	91	89	87	79	82	90	91	92	92	91	89	88

APPENDIX B SOIL TYPES, LANDUSE, POPULATION AND CROPPING PERIODS & AREA, SOIL TYPES AND CHARACTERISTICS OF BAGO DIVISION (MOAI, 2014)



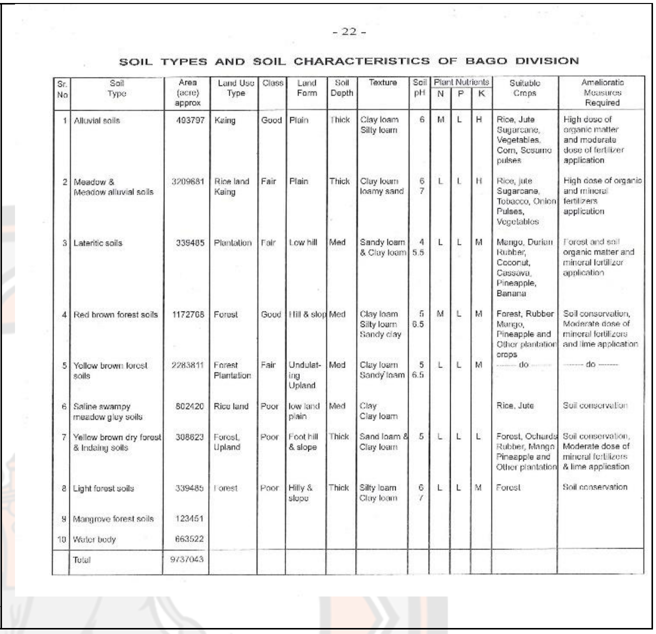
ပြည်ထောင်စုမြန်မာနိုင်ငံတော်
UNION OF MYANMAR.

လယ်ယာစိုက်ပျိုးရေးနှင့်ဆည်မြောင်းဝန်ကြီးဌာန
MINISTRY OF AGRICULTURE AND IRRIGATION

မြန်မာနိုင်ငံတွင် တွေ့ရှိသော မြေအမျိုးအစားများနှင့်
မြေအမျိုးအစား၏ လက္ခဏာများ

**SOIL TYPES AND CHARACTERISTICS
OF MYANMAR**

PUBLISHED BY MINISTRY OF AGRICULTURE AND IRRIGATION



SOIL TYPES AND SOIL CHARACTERISTICS OF BAGO DIVISION

Sr. No	Soil Type	Area (acre) approx	Land Use Type	Class	Land Form	Soil Depth	Texture	Soil pH	Plant Nutrients			Suitable Crops	Amelioratic Measures Required
									N	P	K		
1	Alluvial soils	493797	Kaing	Good	Plain	Thick	Clay loam Silty loam	6	M	L	H	Rice, Jute Sugarcane, Vegetables, Corn, Sesame pulses	High dose of organic matter and moderate dose of fertilizer application
2	Meadow & Meadow alluvial soils	3209681	Rice land Kaing	Fair	Plain	Thick	Clay loam loamy sand	6 7	L	L	H	Rice, jute Sugarcane, Tobacco, Onion Pulses, Vegetables	High dose of organic and mineral fertilizers application
3	Lateritic soils	339485	Plantation	Fair	Low hill	Med	Sandy loam & Clay loam	4 5.5	L	L	M	Mango, Durian Rubber, Coconut, Cassava, Pineapple, Banana	Forest and soil organic matter and mineral fertilizer application
4	Red brown forest soils	1172768	Forest	Good	Hill & slop	Med	Clay loam Silty loam Sandy clay	5 6.5	M	L	M	Forest, Rubber Mango, Pineapple and Other plantation crops	Soil conservation, Moderate dose of mineral fertilizers and lime application
5	Yellow brown forest soils	2283811	Forest Plantation	Fair	Undulating Upland	Med	Clay loam Sandy loam	5 6.5	L	L	M	------- do -------	------- do -------
6	Saline swampy meadow gley soils	802420	Rice land	Poor	low land plain	Med	Clay Clay loam					Rice, Jute	Soil conservation
7	Yellow brown dry forest & Indaing soils	308623	Forest, Upland	Poor	Foot hill & slope	Thick	Sand loam & Clay loam	5	L	L	L	Forest, Ochards Rubber, Mango Pineapple and Other plantation	Soil conservation, Moderate dose of mineral fertilizers & lime application
8	Light forest soils	339485	Forest	Poor	Hilly & slope	Thick	Silty loam Clay loam	6 7	L	L	M	Forest	Soil conservation
9	Mangrove forest soils	123451											
10	Water body	663522											
	Total	9737043											

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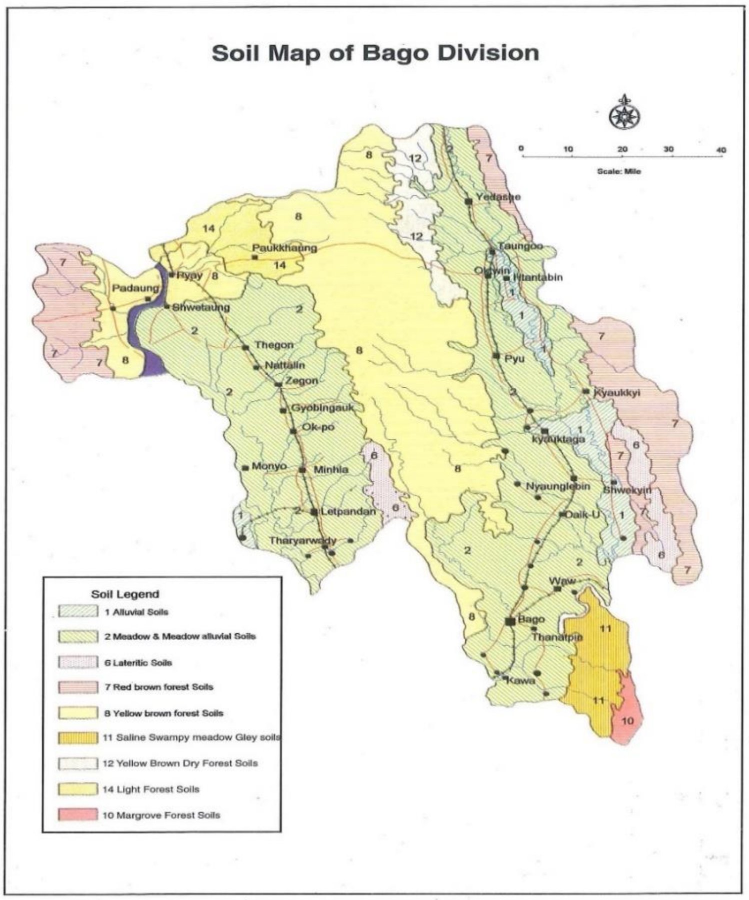
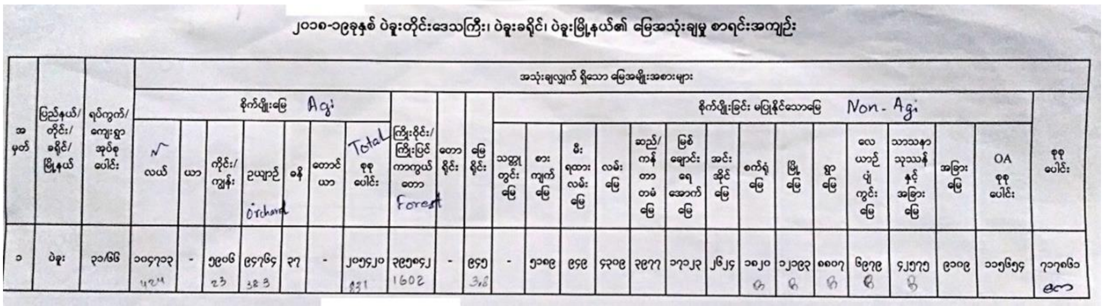


Landuse of Bago Township (2018-2019_

2018-2019 Land Management and Statistics of Bago Town, Bago District, Bago Region (DALMS, 2019)



၂၀၁၈-၁၉ခုနှစ် ပဲခူးတိုင်းဒေသကြီး၊ ပဲခူးခရိုင်၊ ပဲခူးမြို့နယ်၏ မြေအသုံးချမှု စာရင်းအကျဉ်း

အမှတ်	ပြည်နယ်/တိုင်း/ခရိုင်/မြို့နယ်	ရပ်ကွက်/ကျေးရွာအုပ်စုပေါင်း	အသုံးချလျက် ရှိသော မြေအမျိုးအစားများ																							
			စိုက်ပျိုးမြေ Agi							ကြိုးဝိုင်း/ကြိုးပြင်ကာကွယ်တော Forest	တောရိုင်း	မြေရိုင်း	စိုက်ပျိုးခြင်း မပြုနိုင်သောမြေ Non-Agi													စုစုပေါင်း
			√ လယ်	ယာ	ကိုင်း/ကျွန်း	ဥယျာဉ် Orchard	ဓနိ	တောင်ယာ	Total စုစုပေါင်း				သတ္တုတွင်းမြေ	စားကျက်မြေ	မီးရထားလမ်းမြေ	လမ်းမြေ	ဆည်/ကန်တာတမံမြေ	မြစ်ချောင်းရေအောက်မြေ	အင်းအိုင်မြေ	စက်ရုံမြေ	မြို့မြေ	ရွာမြေ	လေယာဉ်ပျံကွင်းမြေ	သာသနာ သုသာန်နှင့်အခြားမြေ	အခြားမြေ	OA စုစုပေါင်း	
၁	ပဲခူး	၃၁/၆၆	၁၀၄၇၁၃ 424	-	၅၉၀၆ 23	၉၄၇၆၄ 383	၃၇	-	၂၀၅၄၂၀ 831	၃၉၅၈၄၂ 1602	-	၉၄၅ 3.8	-	၅၁၈၉	၉၄၉	၄၃၀၉	၃၉၇၇	၁၇၁၂၃	၂၆၂၄	၁၈၂၀	၁၂၁၉၃	၈၈၀၇	၆၉၇၉	၄၂၅၇၅	၉၁၀၉	၁၁၅၆၅၄	၇၁၇၈၆၁ ဧက

The unit of land area is acre (ac) for Burmese language

2018-2019 Land Management and Statistics of Bago Town, Bago District, Bago Region

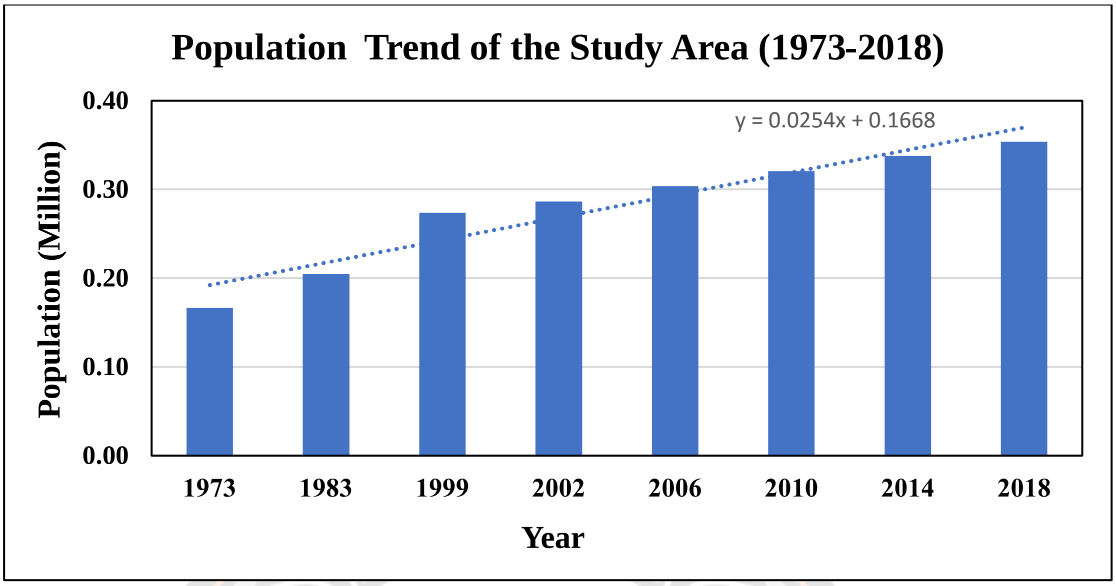
No.	Region/ District Township	Ward/ Village Tract	Different Types of Land Management Statistics																							
			Agriculture						Closed/ Open Forest	Wild Forest	Wild Land	Non-Agriculture														Total (km2)
			Farmland	Branch/Island	Orchard& Rubber	Nipa palm	Hill Farming	Total (km2)				Mining	Field	Railway	Road	Dams/Weir	River/Stream	Lake	Industry	Urban	Rural	Airport	Religious land	Other	Total (km2)	
1	Bago	31/66	423	23	383	0.15	-	831	1602	-	3.8	-	21	3.84	17.4	16	69	11	7.2	49.3	35.6	28	172	37	467	2904

The unit of land area is square kilometer (sq-km) for English language

Population Data (MIP (Bago Region), 2018)

Name and Population of Urban/Rural area of Bago Township in 2014

Urban	Population	Rural	Population	Rural	Population
Myo Twin	55544	Zaung Tu	10942	Me Khone	3390
Leik Pyar Kan	5358	Zee Taw	3772	Tat Ka Lay	5727
Pon Nar Su	12285	Ta Mar Pin	2277	Oke Hpo	1465
Pan Hlaing	1128	Kan Myint	2392	Shan Ywar Gyi	3030
Zay Paing	967	Ah Seik Taung	3804	Ka Mar Nat	7798
Nyaung Waing	2443	War Pyan Kone	2841	War Ma Yan	3051
Thun Hpa Yar	1641	Htan Taw Gyi	3468	**Total**	**83512**
Gyauk Gyi Su	7867	Tha Yet Kone	2841		
Zyaing Ga Naing	15980	Auk Ka Bar	1273		
Ma Zin	42424	Than Soet Pin	3452		
Hin Thar Kone	8148	Baw Net Gyi	4849		
Bo Kone	5566	Let Pan Khon	2975		
Han Thar Wa Di	5041	Htaw Kar	2711		
Ywa Thit	2517	Kyiak Dar Yon	3184		
Myo Thit	10537	Lay Ein Su	1938		
Oue Thar 1 to 9	60173	Sit Pin Seik	2361		
Phyar Gyi 1 to 3	16805	Ah Waing	3971		
	254424				



Cropping Pattern of the various crops (2018-2019) (MoALI, 2019)

No.	Crop Types	Growing Periods of Crops											
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	Beans							110 days					
							Mid of Nov to 1st week of March						
2	Rubber							365 days					
							June to May						
3	Ochard							365					
							June to May						

Area of the main crops in the study area (1999-2018) (MoALI, Bago)