DEVELOPMENT OF WATER ACCOUNTS FOR THE SELECTED SUB-BASINS OF BRAHMAPUTRA, BARAK AND IRRAWADY-CHINDWIN BASINS IN THE STATE OF NAGALAND USING WATER ACCOUNTING PLUS (WA+) FRAMEWORK

(PDS-31)

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PREFACE

Increasing competition for land and water resources is expected in the future due to rising demands for food and bioenergy production, biodiversity conservation, and changing production conditions due to climate change. Growing competition for water in many sectors reduces its availability for irrigation. Thus, efficient approaches are required to manage water effectively in every sector, particularly in agriculture. There is an urgent need for efficient agricultural water management practices to bring more area under irrigation and diverting the excess water for other needs such as domestic, industrial, and environment. With advanced technological developments like satellite-based Remote Sensing and Geographical Information System, tools are becoming useful to account the water resources of a region. Water Accounting Plus (WA+) is a python-based tool designed to provide explicit spatial information on water depletion and the net withdrawal process of a region using globally available open-access datasets. In regions with data unavailability or scarcity, using such freely available open-access data is quite handy in performing water resources accounting.

For the hilly states such as Nagaland, with large-scale forest coverage and trans-boundaries basins, WA+ is useful in assessing the water resources. In hilly region, the rainfed agriculture is most crucial as it plays an important role in food security and livelihood. At the same time, rainfed agriculture is most vulnerable to changes in precipitation and increasing variability due to several reasons, including climate change. Nowadays, increasing the water and land productivity is becoming paramount importance to feed the increasing population. Identifying areas with low (high) water and land productivity is essential to plan and manage the water resources. WA+ tool provides information related to productivity (pixel-wise). WA+ also tracks water depletions rather than withdrawals, and it goes past flow and runoff accounting. Water is depleted by ET, flows to sinks, incorporates into products, or becomes non-recoverable due to quality degradation.

I congratulate the study team to come-up with the report on water accounting plus for the Nagaland state. NIH would also like to thank the officials of WRD, Nagaland for their constant interaction and involvement during the course of the study. I understand that it is a two-way learning process and I hope that officials of both the organizations would have gained during the project period. This may help them in their pursuits.

Place: NIH, Roorkee
Date: 31/05/2024

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ABSTRACT

Increasing competition for land and water resources is expected in the future due to rising demands for food and bioenergy production, biodiversity conservation, and changing production conditions due to climate change. Growing competition for water in many sectors reduces its availability for irrigation. Thus, efficient approaches are required for effective management of water in every sector particularly in agriculture. With advanced technological development like satellite-based Remote Sensing and Geographical Information System, tools are becoming useful to account the water resources of a region. Water Accounting Plus (WA+) is a python-based tool designed to provide explicit spatial information on water depletion and the net withdrawal process of a region using globally available open access data. In regions such as Nagaland with data unavailability or scarcity, use of freely available open access data is quite handy in accounting the water resources. The major objective of this study is to apply the newly developed WA+ framework for the selected sub-basins of Brahmaputra, Barak and Irrawady-Chindwin (Tizu) basins in the state of Nagaland for estimating the status of the water resources. Few major findings from the study are:

From the CHIRPS rainfall data analysis for the period 2001-02 to 2019-20, it was found that a considerable amount of rainfall is falling in the northern and north-eastern parts of Nagaland draining into the Brahmaputra basin. Sub-basins falling in the Brahmaputra basin generates maximum yield for the state of Nagaland. The water accounting-based land use (WALU) suggested that forest cover dominates in the state followed by shrub land, fallow land, agriculture, and built-up area. The area of four land use management classes viz. protected land use (PLU), utilized land use (ULU), Modified land use (MLU) and managed water use (MWU), were 134.42 Km^2, 12425.58 Km^2, 3651.25 Km^2 and 373.10 Km^2 respectively. WA+ tool was set-up for the period 2001-02 to 2019-20. Six factsheets viz. Sheet 2 (evapotranspiration), Sheet 3 (part 1: agricultural water consumption; part 2: land and water productivity), Sheet 4 (part 1: man-made utilization; part 2: natural utilization), Sheet 5 (surface water), Sheet 6 (groundwater) and Sheet 1 (Resource base) were generated. Sheet 2 revealed that an average water loss of 14.91 BCM (~ 900 mm) is occurring in the form of evapotranspiration from different basins and sub-basins annually. 37% of the ET loss is beneficially contributing to the intended purpose. The remaining loss of 63% is non-beneficial, and can be suitably converted to beneficial component by adopting suitable agronomical and mechanical measures. Sheet 3 estimated a total agricultural water consumption of 2.50 BCM and 2.55 BCM, predominantly met from the rainfall, during a dry and wet year respectively. Overall, the average land productivity was found to vary from 2564.2 to 4028.3 kg/ha/year and 6149.6 to 7818.9 kg/ha/year during the period 2001-02 to 2019-20, respectively for rainfed and irrigated cereals. The WP was found to vary from 0.66 to 1.02 kg/m^3 (with an overall average of 0.83 kg/m^3) and 1.90 to 2.56 kg/m^3 (with an overall average of 2.2 kg/m^3) for rainfed and irrigated cereals respectively. Spatial maps of land and water productivity provide the areas performing well (progressive farmers with high productivity) and poor (farmers with low productivity) in a large basin. These rich information enables the water managers to understand the interventions undertaken at local level by both progressive and less progressive farmers. This helps in planning different interventions for a particular area for higher productivity. The annual average gross withdrawal for man-made and natural land uses are 0.8 BCM and 1.94 BCM respectively. It can be seen that water utilized for natural purposes is almost double than the man-made utilization. Out of the total man-made utilizations, almost 63% of withdrawal was from the surface water. Whereas, surface water utilization was 23% for the natural land uses. The total outflow from the seven sub-basins viz. Dhansiri, Chathe-Dzuza, Doyang, Dikhu, Tizit, Tsurang and Milak to the river Brahmaputra were about 14051 MCM. The estimated outflow from the catchment within the Nagaland to the Barak and Tizu (Irrawady-Chindwin) basins were about 572 MCM and 4435 MCM respectively (Sheet 5). As per the estimates in Sheet 6, an annual vertical recharge of 15.68 BCM was estimated, out of which 87% was contributing to the baseflow. Groundwater withdrawal was about 1.77 BCM. An average annual gross inflow of 29 BCM of water was estimated in the study. A net inflow of 28.5 BCM was estimated with a net storage contribution of -0.5 BCM (a negative sign indicates net recharge). The committed flow, as provisioned in the WA+ framework, was estimated to the tune of 3.1 BCM. An annual average of 15.3 BCM of water is available for utilizations in the state, of which about 22% (3.4 BCM) is utilized, and the remaining 11.7 BCM of water was available for utilization (utilizable flow), but yet to be harnessed. Out of the total net inflow into the basin (28.5 BCM), 48% of water is consumed to meet mainly the ET requirements (ET green and ET blue). The study estimated an annual average outflow of 16.2 BCM (Sheet 1). Although all the estimates from WA+ was not validated, but the rich information available from the study provides a preliminary accounting of the water resources for the state of Nagaland entirely based on the satellite-based open access datasets. This will help the planners, policy makers and others associated in the water sector for undertaking appropriate actionable measures.

Originating unit	National Institute of Hydrology, Roorkee
Keywords	Water Accounting Plus, Water productivity, Land productivity, Budyko curve, Blue ET, Green ET, Utilized flow, WALU
Security classification	Unrestricted
Distribution	General

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AET	Actual ET
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
ASCAT	Advanced Scatterometer
ALEXI	Atmosphere-Land Exchange Inverse Model
BOM	Australian Bureau of Meteorology
AWAS	Australian Water Accounting Standard
BCM	Billion Cubic Meter
CFSR	Climate Forecast System Reanalysis
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CPC	Climate Prediction Center
CV	Coefficient of Variation
CMRSET	CSIRO MODIS Reflectance-based Evapotranspiration
ESMs	Earth System Models
ETensV1.0	Ensemble ET
E	Evaporation
ET	Evapotranspiration
FAO	Food and Agricultural Organisation
GLDAS	Global Land Data Assimilation System
GLEAM	Global Land Evaporation Amsterdam Model
GMIA	Global Map of Irrigated Areas
GPCC	Global Precipitation Climatology Center
GRAND	Global Reservoir and Dam Database JRC
GRACE	Gravity Recovery and Climate Experiment
GPP	Gross Primary Production
IMD	India Meteorological Department
ICRIER	Indian Council for Research on International Economic Relations
ISM	Indian summer monsoon
IHE-Delft	Institute for Water Education
I	Interception
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
JRC	Joint Research Centre Data Catalogue
LP	Land Productivity
LULC	Land Use Land Cover
LAI	Leaf Area Index
MWU	Managed Water Use
MCM	Million Cubic Meter
MODIS	Moderate Resolution Imaging Spectroradiometer

MERRA-2	Modern-Era Retrospective Analysis for Res. and Applications-2
MLU	Modified Land Use
MOD16	Modis Global Terrestrial Evapotranspiration Algorithm
MIRCA	Monthly Irrigated and Rainfed Crop Areas
mm	Millimeter
NABARD	National Bank for Agriculture and Rural Development
NWI	National Water Initiative
NDM	Net Dry Matter
NPP	Net Primary Production
NDVI	Normalized Difference Vegetation Index
SSEBop	Operational Simplified Surface Energy Balance
PEARSON	Pearson Correlation Coefficient
PBIAS	Percent Bias
PAR	Photo-synthetically Active Radiation
P	Precipitation
PLU	Protected Land Use
PET	Reference Evapotranspiration
SWAT	Soil and Water Assessment Tool
SMAP	Soil Moisture Active Passive
SMOS	Soil Moisture and Ocean Salinity
SM2RAIN	Soil Moisture to Rain
SEBS	Surface Energy Balance System
SEEAW	System of Environmental Economic Accounting for Water
T	Transpiration
TRMM	Tropical Rainfall Measuring Mission
UNEP	United Nations Environment Programme
UNO	United Nations Organization
UNSD	United Nations Statistics Division
ULU	Utilized Land Use
WA	Water Accounting
WA+	Water Accounting Plus
WASB	Water Accounting Standards Board
WALU	Water Accounting+ based Land Use
WC	Water Consumption
WP	Water Productivity
WUE	Water Use Efficiency
WDPA	World Database on Protected Areas
WEF	World Economic Forum
World POP	World Population

CHAPTER 1
INTRODUCTION

1.1 Background

1.1.1. Water resources accounting: need and methods

About 80% of the global population is impacted by water security (Vörösmarty et al., 2010). Highlighting the importance of water resources, the UNEP (2022) stated: "*For two-plus generations, now, humanity has lived in a relative time of plenty, but we are undermining the freshwater resources that make it possible for us to grow crops. And if we keep doing that, the consequences could be severe*". While wealthy nations are coping with the related challenges by investing in water-related technologies, the less-developed and developing nations remain vulnerable due to economic and technical constraints. Note that we cannot manage that which we cannot measure. Hence, only temporary solutions to the water scarcity problem can be achieved without remedying the underlying causes, which demands scientific accounting of the availability and use of water. Contextually, the concept of water accounting was first floated by Molden and Sakthivadivel (1999). Water accounting is the systematic (scientific) study of the current status and trends in water supply, demand, accessibility, and use by the different stakeholders (FAO, 2024). The stakeholders could be agriculture, domestic (city or rural water supply), energy sector, industry, and the riparian ecosystem. With increased mobility and globalisation, the relationship between these stakeholders is getting more complex. Under such a complex and stressed scenario, water management policies should be framed based on detailed technical analysis. Hence, an appropriate knowhow is required on the following: i) how much water is available, ii) at which location is it available, iii) how long is it available, iv) what is the source of the available water, and v) what cost is to be invested to get water. The above discussion stresses the importance of water accounting.

The different water accounting methods traditionally available are broadly based on the water balance approach, wherein the different input and output fluxes into and out of the system are measured or estimated. Based on the interest, the system can be a small population, a city or municipality, an industry, a watershed, or a canal command. However, for practical purposes, river basin-scale studies are preferred as water balance is closed at this scale. Moreover, from the water management perspective, the different methods of water accounting in different sectors are: water footprint (e.g., Long et al., 2022), cycle evaluation (Ma et al., 2018), and water pinch analysis (Liu et al., 2019). Similarly, considering the components of the hydrologic cycle, it can be classified as virtual water accounting, irrigation accounting, groundwater accounting, and basin water accounting (Delavar et al., 2022). Conversely, for operational purposes, the need of the hour is a holistic accounting framework that considers the different components of the hydrologic cycle, the complex supply-demand relationship at different stakeholder levels and spatiotemporal scales, the concept of blue, green, and grey water, the different productive and non-productive water uses. The water accounting framework would aid in drawing appropriate scientific inferences in simpler forms for aiding policymakers.

1.1.2. Increased competition for resources

Over the last two decades, the per capita freshwater availability has decreased by 20% (UN, 2020). Consequently, the water supply-demand relationships are changing. An expert committee of the World Economic Forum (WEF, 2015) reported on the highest-ever societal impact of water stress on food and energy production. Apart from population growth and consequent water stress to meet the food demand, a consumerism-based economy, higher energy needs, and increased lifestyle would increase the water demand. For example, in a business-as-usual scenario, the water demand by the agriculture sector is projected to double in the next four decades (IWMI, 2007). As an example of escalated future water demand for feeding the growing population, food processing industries demand huge amounts of water for food processing in addition to the agriculture sector for growing food. Further, for financial benefits, water-demanding crops are grown and exported from underdeveloped to developed regions – a case of virtual water transfer.

Similarly, new industries, such as tourism and information technology, have established new infrastructure and cities. These new establishments have increased the competition for natural resources. Moreover, several hydroelectric projects are being established to fulfil the increased energy demand. This alters the downstream discharge pattern and affects water availability for the riparian biota. Similarly, in the case of delayed monsoons, there is conflict among the industries withdrawing water from reservoirs and the agriculture sector to meet the irrigation demand. From the above discussion, it is evident that water accounting is also essential for conflict resolution among competing stakeholders.

1.1.3. Climate change: impact on water availability?

Climate change can disturb the probability distribution of hydrologic events and alter its shape, influencing the spatio-temporal distribution of available water (Cosgrove and Loucks, 2015). Indian summer monsoon (ISM) brings in nearly 80% of annual rainfall over Nagaland from June to September (Nagaland Water Policy 2016). The ISM largely dictates agriculture, economy, and water availability. However, disturbed ISM has resulted in sporadic rainfall in recent decades (Kishore et al., 2022). Several studies (e.g., Tsarouchi and Buytaert (2018)), including the Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC) have reported climate change as the cause of the extremes. Further, it has been reported that a decrease in the frequency of light and moderate storms and an increase in heavy storms (Scoccimarro et al., 2013) could worsen the hydrological extremes, such as floods. The decline in snowfall, low-intensity rainfall, and increased evapotranspiration caused by heat waves could result in water scarcity. Hence, to study the impact of climate change on the water resources of this region, it is essential to conduct water accounting under the current scenario by setting appropriate hydrological models that can be forced with future climate data to get an idea of the region's future water security.

1.1.4. Use of technologies such as RS & GIS; Open data, etc.

As most of the areas of the state of Nagaland belong to hilly topography and are inaccessible, using data products that are alternative to station-based data would be beneficial. The promising alternate data sources are: remote sensing-based reanalysis products, the output of land surface models or earth system models (ESMs), and globally available gridded products derived from global observation networks (Lodge et al., 2023). Remote sensing involves the collection of desired information remotely with the help of sensors that could be optical, microwave, or radar-based. Similarly, reanalysis datasets are obtained by constraining the ESMs with observed data and taking output at desired grids. To name a few dataset/satellite missions, the Climate Prediction Center (CPC) and Global Precipitation Climatology Center (GPCC) provide gridded precipitation datasets; ERA-5 and MERRA-2 provide global reanalysis precipitation datasets; MOD16A2 and GLEAM provide evapotranspiration datasets; AMSR-E, ASCAT, SMAP and SMOS provide remote sensing-based soil moisture estimates; and Landsat, MODIS and Sentinel-2 provide water surface area information.

1.1.5 Hilly region – in the context of remote areas like Nagaland state

Due to its location in the northeastern Himalayas and hilly terrain, Nagaland primarily depends on the sources of surface water, viz., rivers, streams, natural springs, and ponds to some extent. The aquifer in the hilly region is shallow. Further, due to sloping topography, precipitation has less opportunity to infiltrate and recharge the aquifers. The rivers of the region, such as Doyang, Dhansiri, and Dhiku are shared with Assam, and Tizu River joins the Irrawaddy River in Myanmar. The area is mainly inhabited by native tribals on the hilltops, lacking the development of organized water infrastructure. The challenges for the policymakers and water managers in this region are immense due to: i) mountainous and rugged terrain; ii) the highly variable nature of rainfall; iii) remote location hindering instrumentation and maintenance of gauging sites; iv) fewer number of gauging sites; and most importantly, v) occurrence of transboundary water bodies (including the international ones). The current geo-political scenario could escalate the hydro-political scenario involving transboundary rivers and aquifers during the water-sharing conflict. Hence, before such dispute arises, the countries/states or groups of countries/states need to come to an agreement on 'how to share water during stress', which demands water accounting (Nagaland Water Policy – 2016).

In this backdrop, this study is a timely attempt to account the water resources for the state of Nagaland with the help of available new technologies such as water accounting plus (WA+) framework.

1.2 Water accounting plus framework

1.2.1 What is water accounting plus (WA+)?

Water Accounting is systematic acquisition, analysis and communication of information relating to ***stocks, flows and fluxes*** of water (from sources to sinks) in natural, disturbed or heavily engineered ***environment*****s** (FAO, 2017).

Water Accounting Frameworks

System of Environmental Economic Accounting for Water (SEEAW)	United Nations Statistics Division (UNSD) in collaboration with the London Group on Environmental Accounting.
Aquastat	FAO
Water Accounting Standard of Australia	Water Accounting Standards Board, Bureau of meteorology, Govt of Australia
Water Accounting Plus	UNESCO-IHE, IWMI and FAO

While the former three are mostly flow accounting frameworks, WA+ is a comprehensive depletion accounting framework, used for assessing, reporting, communicating, and analysing the water resources status based on open-access datasets, and with standard terminology.

For communicating water resources-related information and services obtained from consumptive use in a geographical domain to users, water accounting (WA) is the best process. WA is a tool to take a sound water management decision. The IWMI WA framework was originally designed for irrigation schemes within a basin but was later used for basin analysis. For instance, water depletion at the irrigation service scale represents only crop evapotranspiration, while at the basin-scale, it also includes municipalities, industries, fisheries, forestry, dedicated wetlands, and all other uses. As a result, parts of the information that are important in a basin context are not covered in the original IWMI WA framework.

Thus, WA+ is a modified and upgraded version of water accounting which IWMI has developed (Karimi et al., 2013a-b) based on original initiatives taken by the Delft University of Technology (Bastiaanssen, 2009; Bastiaanssen and Ali, 2003). Water accounting plus (WA+) is a framework designed to provide explicit spatial information on water depletion and the net withdrawal process from river basins. It provides the link between water balance, land use, water use, and management options to modify it by grouping land use classes with common management characteristics. WA+ goes past flow and runoff accounting and tracks water depletions rather than withdrawals. Water is depleted by ET, flows to sinks, incorporates into products, or becomes non-recoverable due to quality degradation. Water depletions are divided into beneficial and non-beneficial categories according to the type of use and intended purpose. WA+

has eight fact sheets (Figure 1.1). Sheet 2 and Sheet 3 represent the evapotranspiration and agricultural services (land productivity and water productivity) assessment, respectively. Sheet 4, Sheet 5, and Sheet 6 represent the utilized flow (both natural and man-made), surface water, and groundwater, respectively. The final Sheet 1 provides the total water balance of the basin, and is termed as 'Resource base' (Wardlow and Egbert, 2008; Zhao et al., 2019). Sheet 7 and Sheet 8 are under development, and provides information related to ecosystem services and sustainability. WA+ framework has been developed using python codes and is available at https://github.com/wateraccounting.

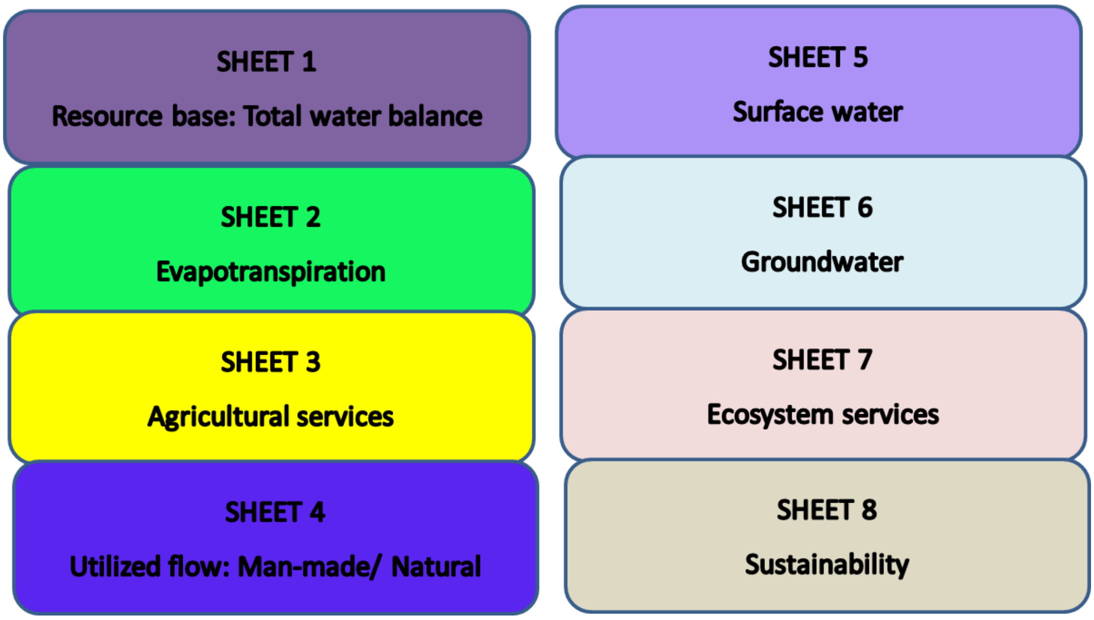


Figure 1.1. Eight factsheets considered in WA+ Framework.

1.2.2 Application of WA+ in other basins/ sub-basins

The WA+ Framework is an entirely new technique and has been applied in a few other basins of India and the world. Initially, the WA+ Framework was applied to selected river basins in Cambodia (IHE, 2017). More recently, WA+ Framework has been also applied to some Indian river basins such as Cauvery (CWC & IHE, 2018), Krishna basin (Salvadore et al.,2020), Subarnarekha (Singh et al., 2022), Mahi (Patle et al., 2023), Ghaghara (Kumar et al., 2023), Betwa basin (Singh et al., 2022), Central Godavari (Chatterjee et al., 2024). Karimi et al. (2013) applied WA+ to the Indus River basin. They demonstrated how the satellite-derived estimates of land use, rainfall, evaporation(E), transpiration (T), interception (I), and biomass production (NPP and GPP) can be used in addition to measured basin outflow for water accounting with WA+. Dembele et al. (2023) used WA+ framework to assess the climate change impacts on the transboundary Volta River basin (VRB). Karimi and Bastiaanssen (2015a) evaluated the reliability of satellite data used for WA+, and they found that the absolute values of evapotranspiration can be estimated with an overall accuracy of 95% (SD 5%) and rainfall with an overall absolute accuracy of 82% (SD 15%). Land use can be identified with an overall accuracy of 85% (SD 7%). Further, Karimi et al. (2015b) applied the WA+ Framework to the Awash River basin. They found that the majority of WA+ parameters and performance indicators have a coefficient of variation (CV) of less than 20%, which implies that they are reliable and provide consistent information on the functioning of the basin. More recently, Delavar et al. (2020) coupled the SWAT model with WA+ framework to develop water accounts and formulate water management strategies for Tashk-Bakhtegan basin (Iran). Recently, WA+ Framework was applied by Salvadore et al. (2020) for developing water accounts and productivity estimates for Tonle Sap and Kamping Puoy, Cambodia. Further, Salvadore et al. (2020) developed the water accounts for three sub-basins of the Krishna basin. A recent study conducted by National Bank for Agriculture and Rural Development (NABARD) (Sharma et al., 2018) highlights that although 78% of the water resources available are diverted towards agriculture, however, till now, only 48 per cent of the gross cropped area is irrigated in India. This indicates that there is a need for efficient agricultural water management practices to bring more area under irrigation and divert the excess water for other needs, such as domestic and industrial, which demands for assessment of the water and land productivity in the basin at different scales, i.e., state level, district level, and farm level.

1.3 Water use efficiency vis-à-vis land and water productivity?

Sheet 3 (agricultural services) in WA+ accounts the agricultural water consumption w.r.t the crop yield. Understanding the land and water productivity is essential to manage the agricultural water consumption. Water use efficiency has been in common use since long, and provides how best the supplied water is utilized. However, productivity in terms of land- and water- productivity gives information on the yield by consumption of a certain amount of supplied water. The actual nexus of food and water is explained by assessing land and water productivity.

Efficiency, in general, is defined as the ratio of the effective or useful output to the total input in any system. Water use efficiency is defined as the production (of crops) per unit of water applied. It is defined as the weight of crop produce per unit depth of water over a unit area i.e. kg/cm per hectare. There are other explanations of water use efficiency such as (i) more yield (or equivalent income) over unit depth of water consumed per unit area of application, (ii) more yield with less water, (iii) eliminating waste of water, (iv) BC ratio>1 i.e. more return (benefit) with less water, (v) optimizing water use, etc. Several other measures of efficiency were also considered in the past, such as 'duty of water (1920), permissible waste (1928), irrigation efficiency (1932), uniformity coefficient (1942), water storage efficiency (1960), seasonal application efficiency (1960), adequate irrigation (1965), application efficiency and distribution efficiency (1978), irrigation sagacity: beneficial and non-beneficial water (1997), water productivity (1997), allocative efficiency (1998) and the present day water use efficiency (WUE) and water productivity (WP).

Productivity is the ratio between a unit of output and a unit of input. Here, water productivity is used exclusively to denote the product's amount or value over the volume or value of water depleted or diverted. The value of the product might be expressed in different terms (biomass, grain, money). For example, the so-called ‘crop per drop’ approach focuses on the amount of product per unit of water. However, water productivity, defined as kilogram per drop (kg/m^3), is a useful concept when comparing the productivity in different parts of the same system or river basin and comparing the productivity of water in agriculture with other possible water uses. Again, land productivity also indicates the amount of production per unit of land (kg/ha). The purpose of defining these terms is to measure these resources' existing performance (Molden et al., 2004; 2010).

WUE and WP are two different terms, both have different definitions and applications. WUE is the ratio between Output and Input, but both have the same units. Whereas, WP is also the ratio between Output to Input, but both with different units as shown below in Figure 1.2.

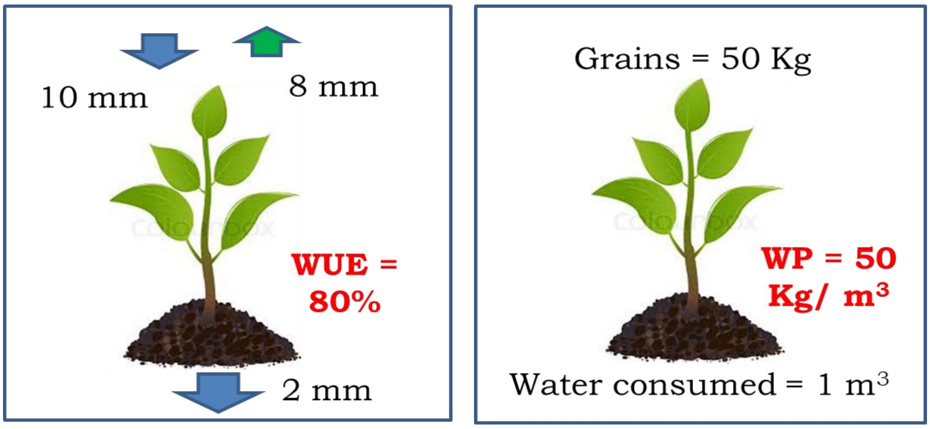


Figure 1.2. Pictorial representation of WUE and WP.

1.3.1 The need for land and water productivity assessment

Increasing competition for land and water resources is expected in the future due to rising demands for food and bioenergy production, biodiversity conservation, and changing production conditions due to climate change. Growing competition for water in many sectors reduces its availability for irrigation. Thus, efficient approaches are required to effectively manage water in every sector, particularly in agriculture. To achieve efficient and effective use of water, it requires to increase the crop water productivity (WP) and crop yield through the use of improved crop varieties. Only a high water productivity values carry little importance if they are not associated with high or acceptable yields. Such association of high (or moderate) water productivity values with high (or moderate) yields has considerable implications on the effective use of water. Land productivity and water productivity increment are the most efficient solutions for increasing food demand and climate variation. It is worth noting that water consumption (evapotranspiration (ET)) influences productivity estimation across a command area.

1.4 Study objectives

WA+ is an evolving tool, developed in the recent past. Recent studies suggest that WA+ performs well in plain areas with limited undulation. This is because of the dependency on freely available open-access data with different spatial resolutions. The data could be, of course-resolution in nature, e.g. the crop data (10 km x 10 km). In the case of hilly terrain, often, the performance of WA+ is compromised while accounting for the resources. However, given data inadequacy and unavailability, and large tracts of inaccessible areas, WA+ is otherwise handy for coming up with information pertaining to water resources. Nagaland is a state in northeastern India, known for its rich cultural heritage and beautiful landscapes. It is characterized by its hilly terrain, with mountain ranges and valleys. Also, the basin(s) are transboundary in nature and spread in Indian states like Manipur, Assam and Arunachal Pradesh, and countries like Myanmar (Burma). As per the existing Nagaland Water Policy (2016), Dept. of Soil and Water Conservation, Govt. of Nagaland, the few of the emerging concerns and challenges enumerated that need urgent attention are: (i) Due to a wide temporal and spatial variation in the availability of water, likely to exacerbate due to a number of variable factors including climate change impacts resulting in incidences of water-related disasters such as loss of soil fertility, flash floods and river meandering, the water crisis in the state is likely to deepen, (ii) Development of irrigation infrastructure is critical to ensuring food sustainability in the state, (iii) Access to water for drinking and other domestic needs is an emerging challenge in many urban areas, towns and villages in the state, and (iv) Scientific capacity building of institutions for the integrated water resource management.

Thus, in the present study, the water accounting plus (WA+) Framework has been utilized to assess the total water consumptions, agricultural water consumption (using green water and blue water), and estimation of land and water productivity, estimation of utilized water, and total water balance in different basins/sub-basins situated in the state of Nagaland. The capacity building of the officials on the various components of water accounting plus is also a key aspect of the study. The major objective of this study is to apply the newly developed WA+ framework for the selected sub-basins of Brahmaputra, Barak, and Irrawady-Chindwin (Tizu) basins in the state of Nagaland for estimating the status of the water resources. This will generate useful base data to help the development of proper water management strategies and decision processes.

The specific objectives include:

- To set-up WA+ Framework for the selected study basins/sub-basins.
- To estimate ET consumption patterns for the selected basins/sub-basins.
- To estimate land and water productivity for the selected basins/sub-basins.
- To develop a Resource Base (Surface water & Groundwater) for the selected basins/sub-basins.
- To develop capacity of the State Govt. officials from WRD, Nagaland, through training programmes on WA+

CHAPTER 2
STUDY AREA AND DATASETS USED

2.1 Study area

The state of Nagaland is a northeastern state of India and is surrounded by the states of Assam, Manipur, Arunachal Pradesh, and also by Myanmar in the East. The state covers a geographical area of approximately 16580 km^2. The major part of the State is drained by the Brahmaputra basin (~10881 km^2, 65.6%), followed by the Barak basin (~814 km^2, 4.9%) and by the Irrawady-Chindwin basin (~4884 km^2, 29.5%) as given in Figure 2.1. The state of Nagaland is divided into three river basins viz, rivers flowing to Brahmaputra, rivers flowing to Barak and the rivers flowing to the Irrawady-Chindwin basin. Figure 2.1, reveals that out of 9 sub-basins of Brahmaputra, Barak, and Irrawady-Chindwin basins in Nagaland, only three sub-basins, i.e., Doyang (catchment area = 3558 km^2), Dikhu (catchment area = 3028 km^2), and Tizu (catchment area = 4884 km^2)) are medium river basin and rest six are minor river basins having catchment area ranging from 495 km^2 to 1466 km^2.

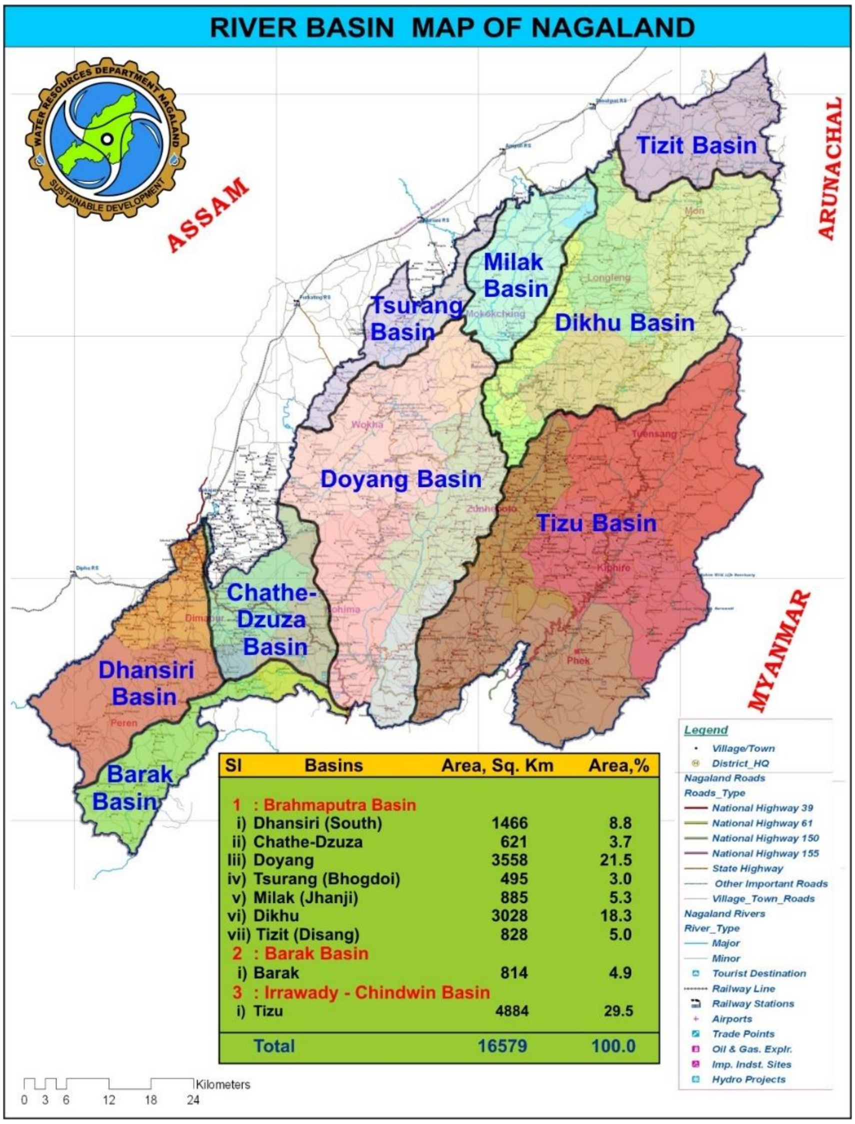


Figure 2.1. River basin map of the Nagaland (Source: WRD, Nagaland).

The state receives an average annual rainfall of 1715 mm. About eighty percent of the rainfall is received during the pre-monsoons and monsoons. The heavy rains during the monsoons, coupled with the hilly topography of the state leads to high surface runoff. The predominant sources of water in Nagaland are surface water in rivers, streams, ponds, and natural springs and subsurface water occurring as groundwater. Nagaland has four main rivers, namely, Doyang, Dhansiri, Dhiku and Tizu. Of these, the first three flow towards the west through the Assam plains to join the mighty Brahmaputra, while the Tizu river system flows towards the east and southeast and pours into the Irrawaddy in Myanmar. The Barak River also drains a small area in the Peren district of Nagaland. The catchment area of Brahmaputra Basin in the state is 10,881 sq. km, which is 65.6% of the total geographical area, leading to a total water yield of 14282 MCM. The catchment area of Barak Basin is 814 sq. km, which is around 4.9% of the total area, and has a water yield of 738 MCM. The catchment area of Tizu Basin covers 4884 sq. km, which is 29.5% of the total area, and has a water yield of 4463 MCM. For domestic utilisation, most of the populations depend upon spring water. The groundwater draft for domestic use is very less. The water level varies from 1.4 meters to 16.4 meters bgl in valley areas and 2.2 meters to 54.5 meters bgl in hilly terrain (Nagaland Water Policy (2016), Dept. of Soil and Water Conservation, Govt. of Nagaland).

The basin, sub-basin, elevation, aspect, slope, drainage network, and district map of the Nagaland state are shown in Figures 2.2 to 2.7. The basins and sub-basins area statistics are given in Table 2.1.

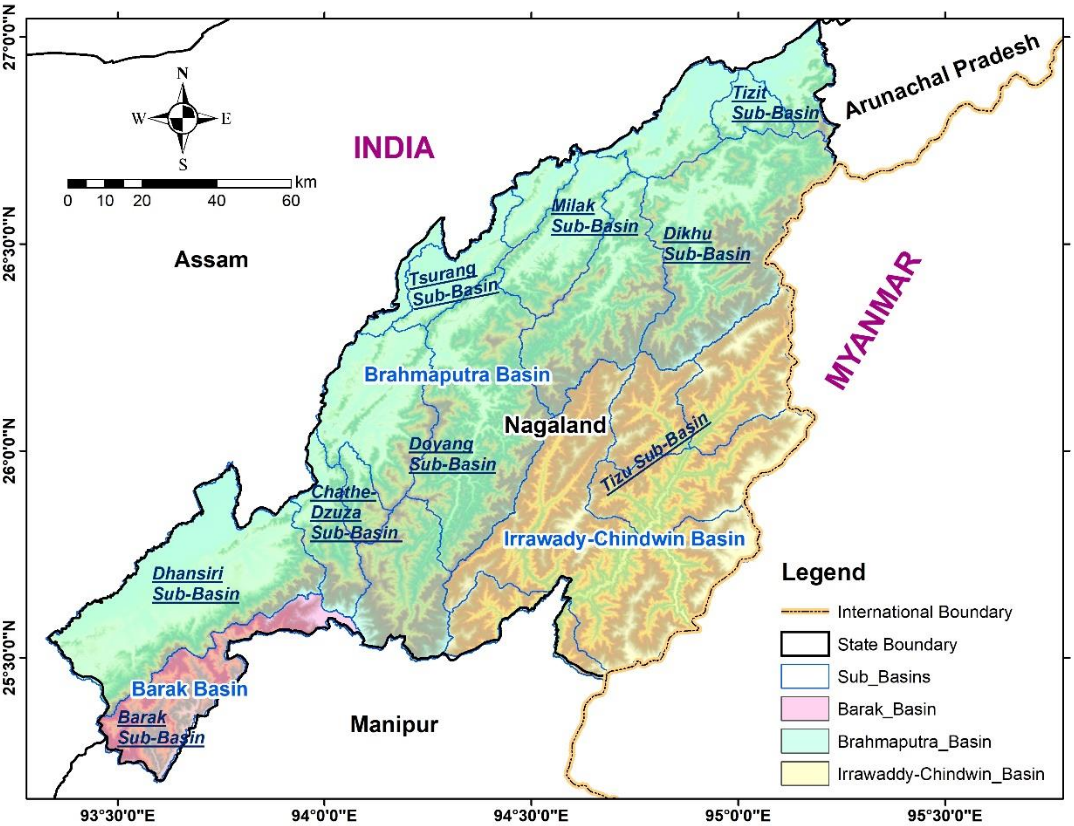


Figure 2.2. Map showing different Basins & Sub-basins of the Nagaland state.

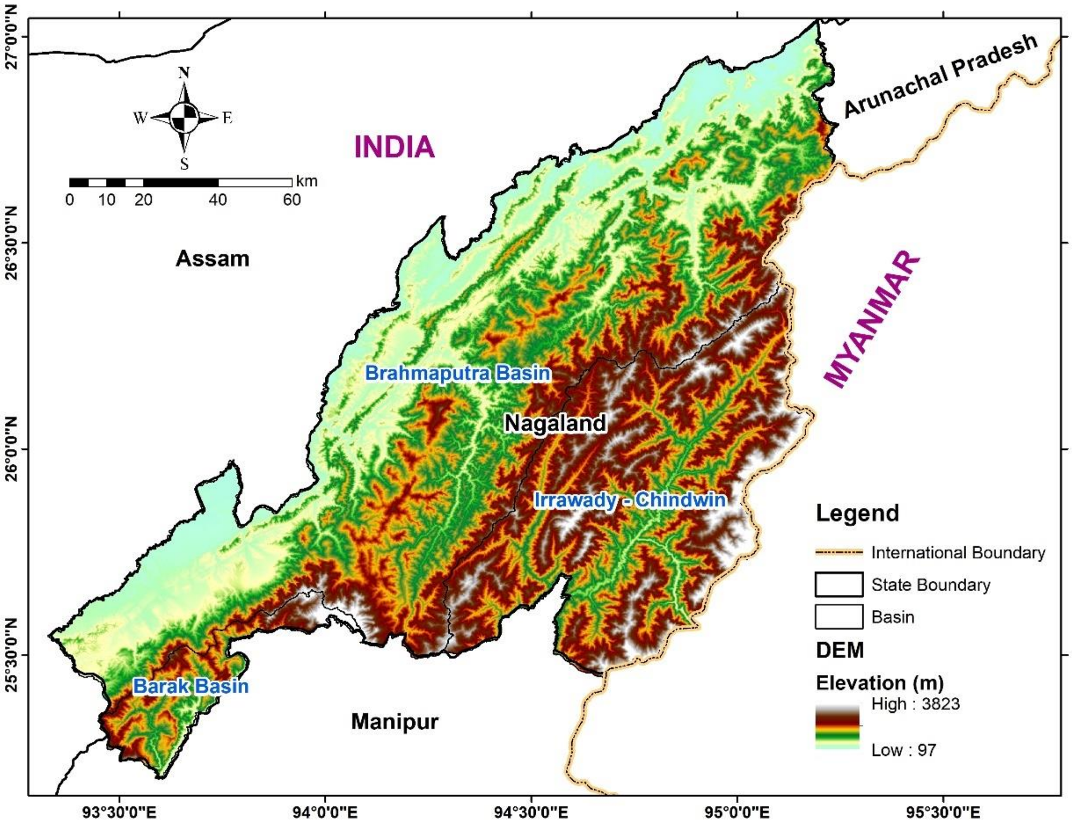


Figure 2.3. DEM showing the Elevation ranges of the Nagaland state.

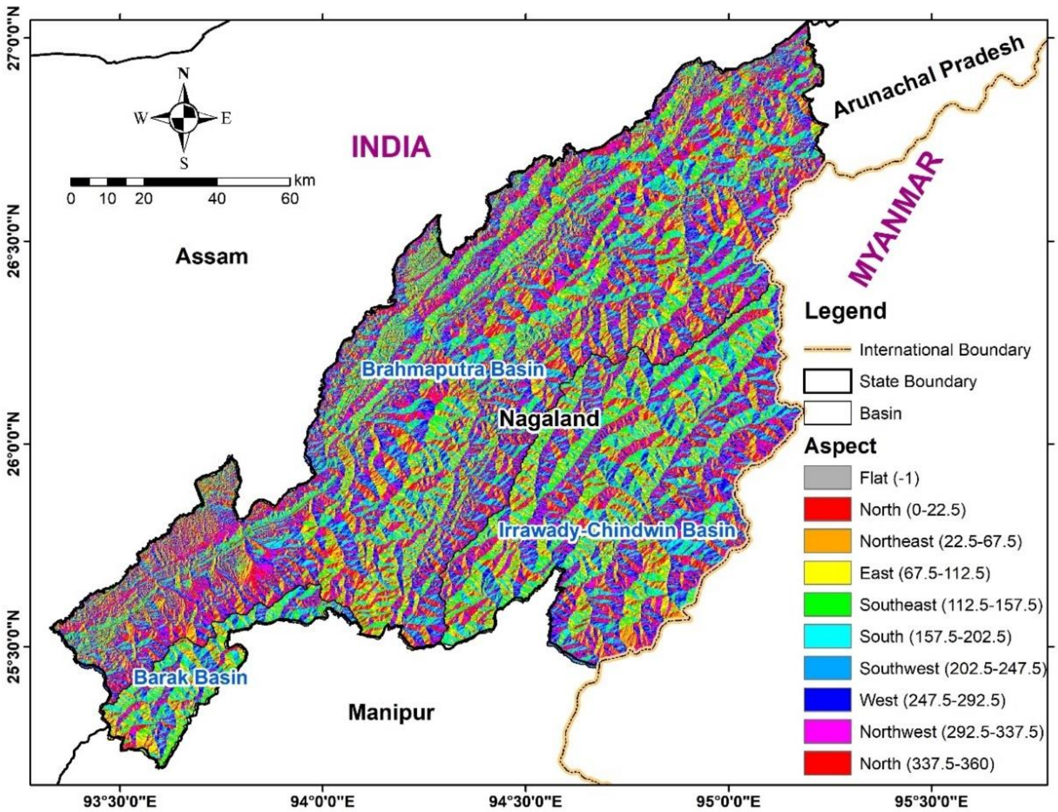


Figure 2.4. Map showing the Aspect of the Nagaland state.

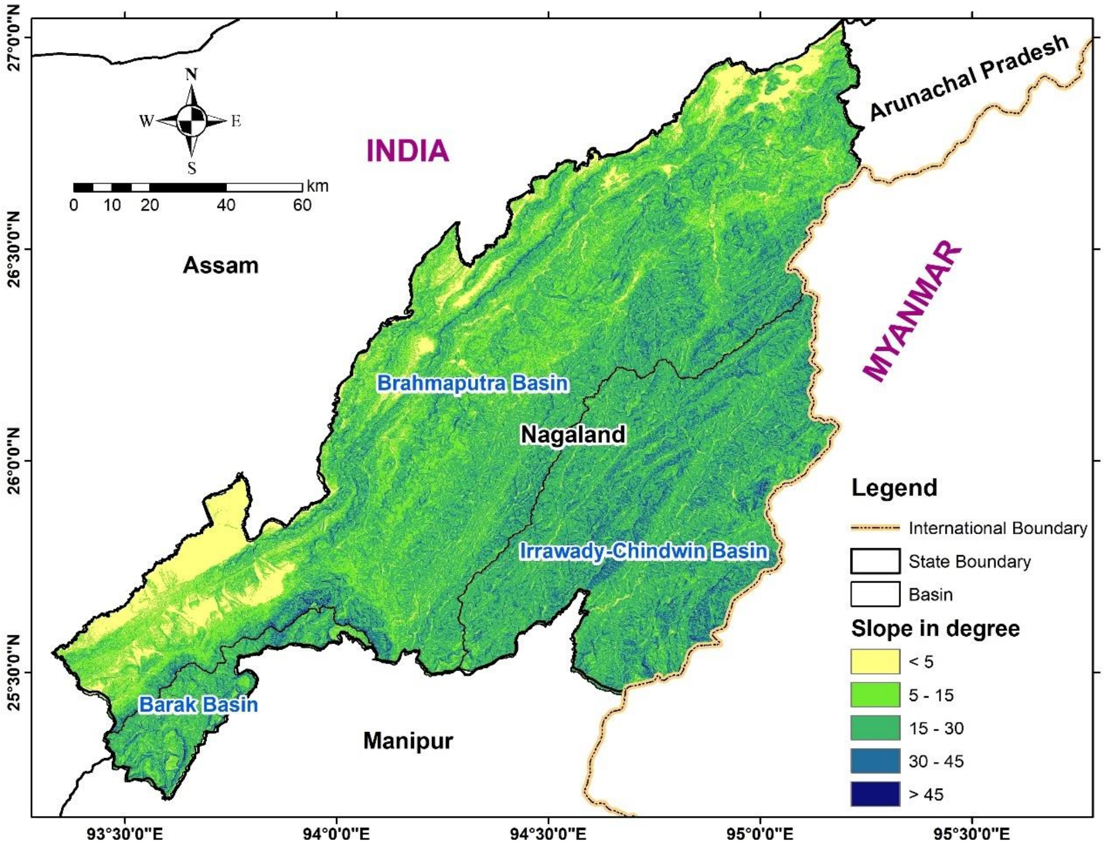


Figure 2.5. Map showing the Slope of the Nagaland state.

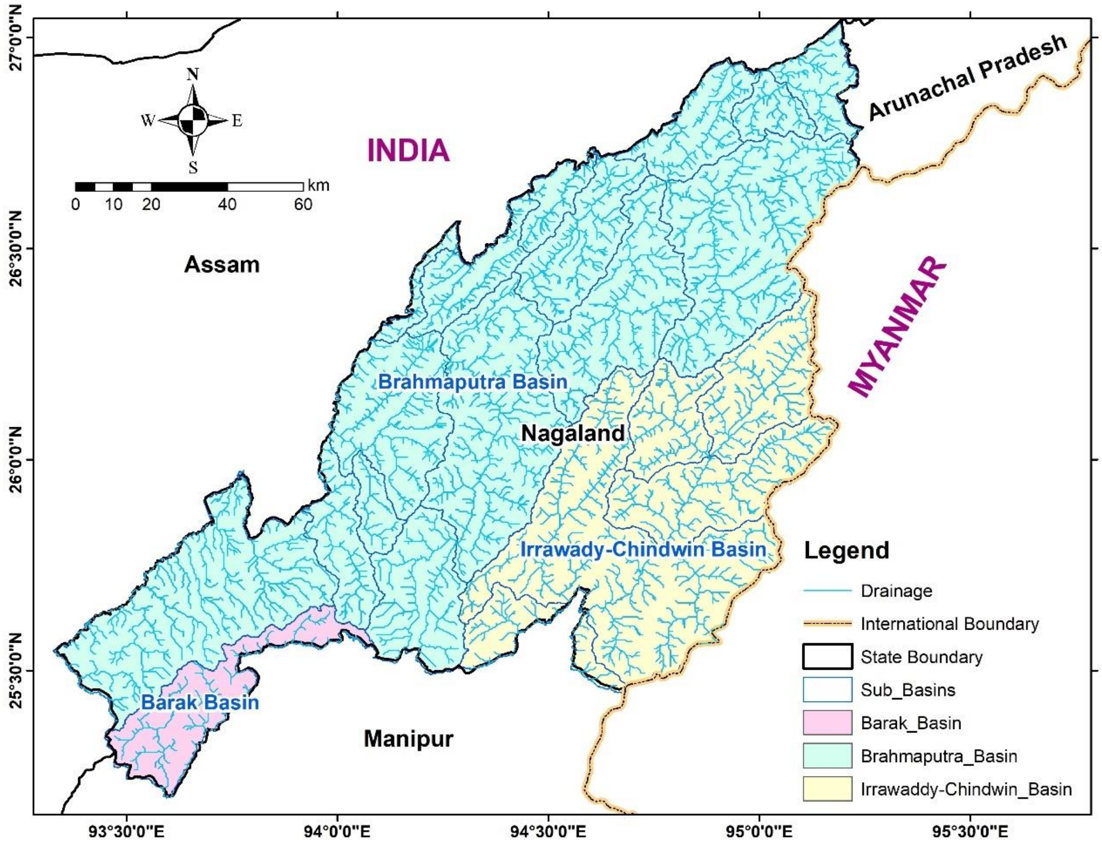


Figure 2.6. Map showing Drainage Network of the Nagaland state.

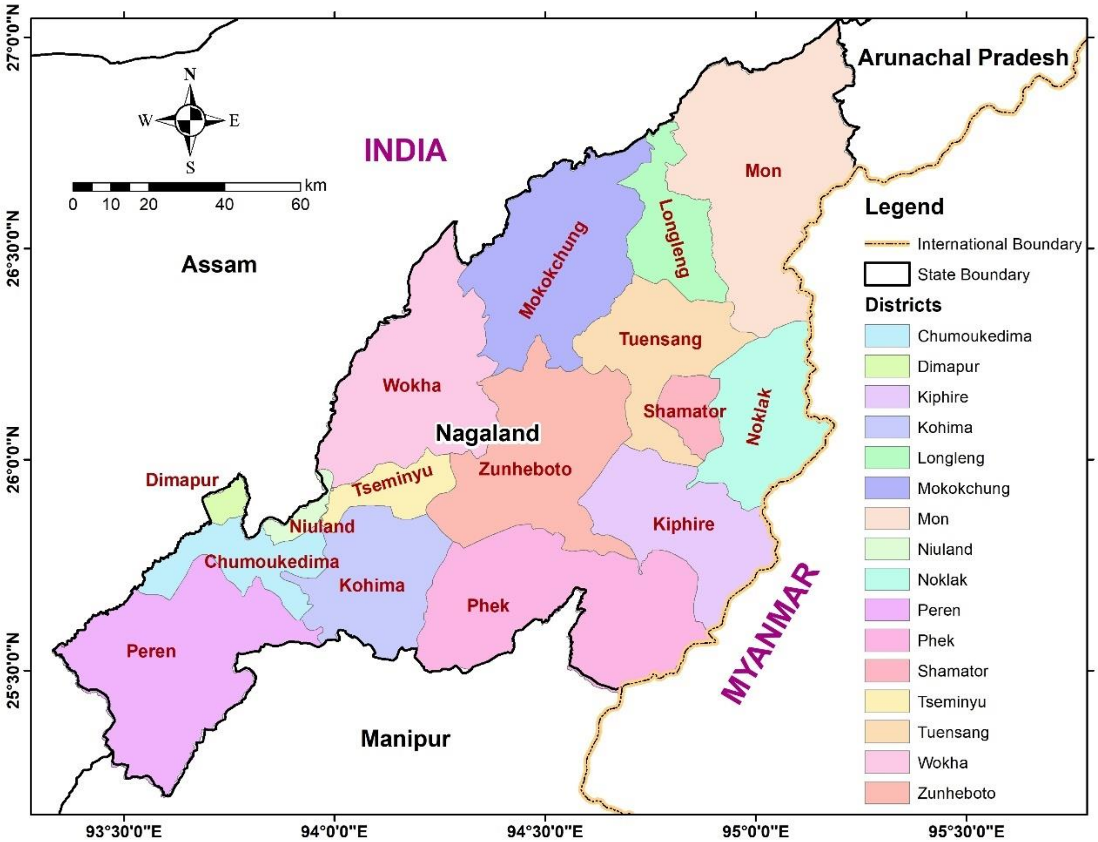


Figure 2.7. Map showing different districts of the state of Nagaland.

Table 2.1
Area statistics of Basins & Sub-basins as per administrative boundary

Sl. No.	Basins/Sub-basins	Area (km^2)	Area (%)
1	**Brahmaputra basin**		
i.	Dhansiri (South)	1466	8.8
ii.	Chathe-Dzuza	621	3.7
iii.	Doyang	3558	21.5
iv.	Tsurang (Bhogdoi)	495	3.0
v.	Milak (Jhanji)	885	5.3
vi.	Dikhu	3028	18.3
vii.	Tizit (Disang)	828	5.0
Sub-total		10881	65.6
2	**Barak basin**		
i.	Barak	814	4.9
3	**Irrawady-Chindwin basin**		
ii.	Tizu	4884	29.5
Total		**16579**	**100.0**

The WA+ tool is a depletion-based accounting tool, and provides information at different spatial scale viz. administrative, basins/sub-basins. Sheet 2 and Sheet 3 pertaining to evapotranspiration and agricultural services (land productivity and water productivity) can be generated at administrative scale (districts/sub-districts). But, the remaining sheets viz. Sheet 4 (Utilized flow), Sheet 5 (Surface water), Sheet 6 (Groundwater) and Sheet 1 (Resource base) can only be achieved at basins/sub-basins scale with proper hydrological units delineated from the available digital elevation models. Further, the setting up of the 'WaterPix' model also requires inputs at basins/sub-basins scale whose outputs are necessary to generate the above sheets. Accordingly, restricting the model to run within the Nagaland state boundary is not possible. Therefore, suitable outlets are chosen beyond the administrative boundary (Nagaland state) to delineate hydrological boundaries to accommodate the nine sub-basins from three major basins viz. Brahmaputra, Barak and Irrawady-Chindwin. These result in additional areas falling beyond the administrative boundary. Table 2.2 presents the basin area as per the administrative boundary and the area actually considered in setting up the WA+ tool. The additional and delineated area considered in setting up the WA+ tool is shown in Figures 2.8 to 2.10.

Table 2.2

Comparison of delineated area statistics of Basins & Sub-basins w.r.t administrative boundary in the Nagaland state

Sl. No.	Basins/Sub-basins	Area as per administrative boundary (km^2)	Area as per administrative boundary (%)	Area as per delineated basins/sub-basins boundary (km^2)	Area as per delineated basins/sub-basins boundary (%)	Additional area considered (km^2)
1	**Brahmaputra basin**					
i.	Dhansiri (South)	1466	8.8	3194.7	14.9	1107.7
ii.	Chathe-Dzuza	621	3.7			
iii.	Doyang	3558	21.5	3773.4	17.6	215.4
iv.	Tsurang (Bhogdoi)	495	3.0	1299.5	6.0	(-) 80.5
v.	Milak (Jhanji)	885	5.3			
vi.	Dikhu	3028	18.3	3002.5	14.0	25.5
vii.	Tizit (Disang)	828	5.0	1164.6	5.4	336.6
Sub-total		10881	65.6	12434.7	58.1	1553.7
2	**Barak basin**					
i.	Barak	814	4.9	2559.5	11.9	1745.5
3	**Irrawady-Chindwin basin**					
i.	Tizu	4884	29.5	6387.2	29.8	1503.2
Total		**16579**	**100.0**	**21381.1**	**100.0**	**4802.1**

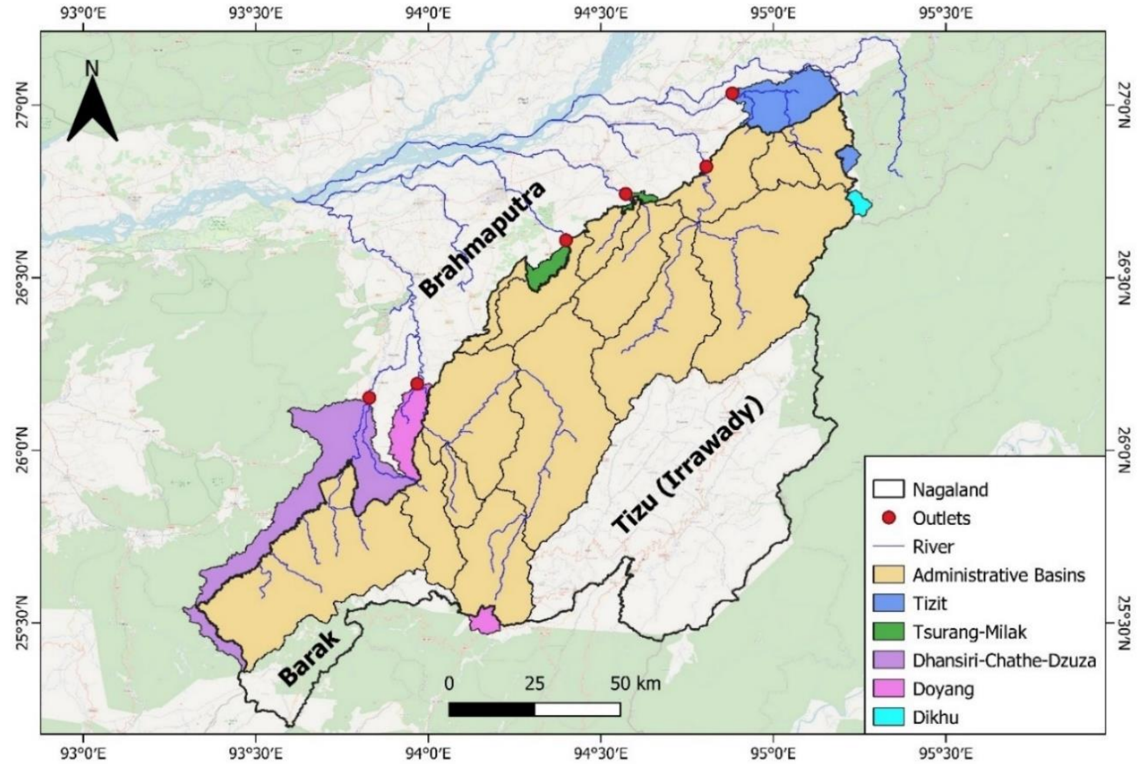


Figure 2.8. Map showing additional area w.r.t the administrative area for the Brahmaputra basin.

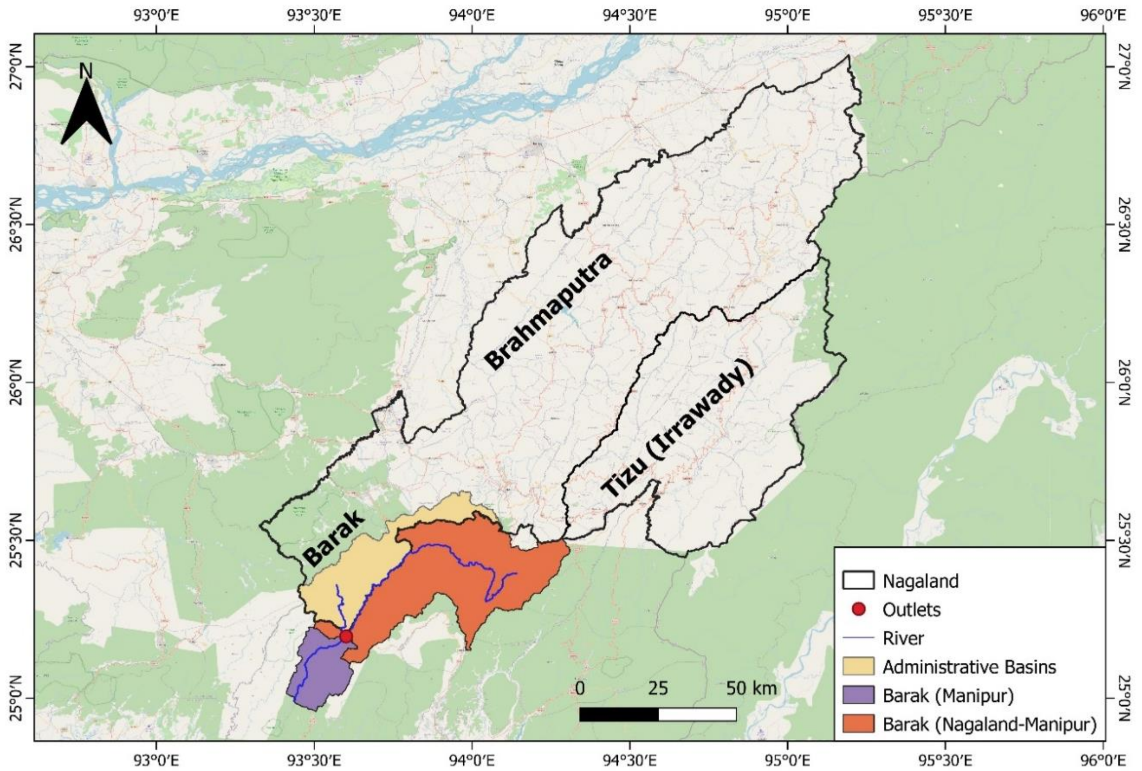


Figure 2.9. Map showing additional area w.r.t the administrative area for the Barak basin.

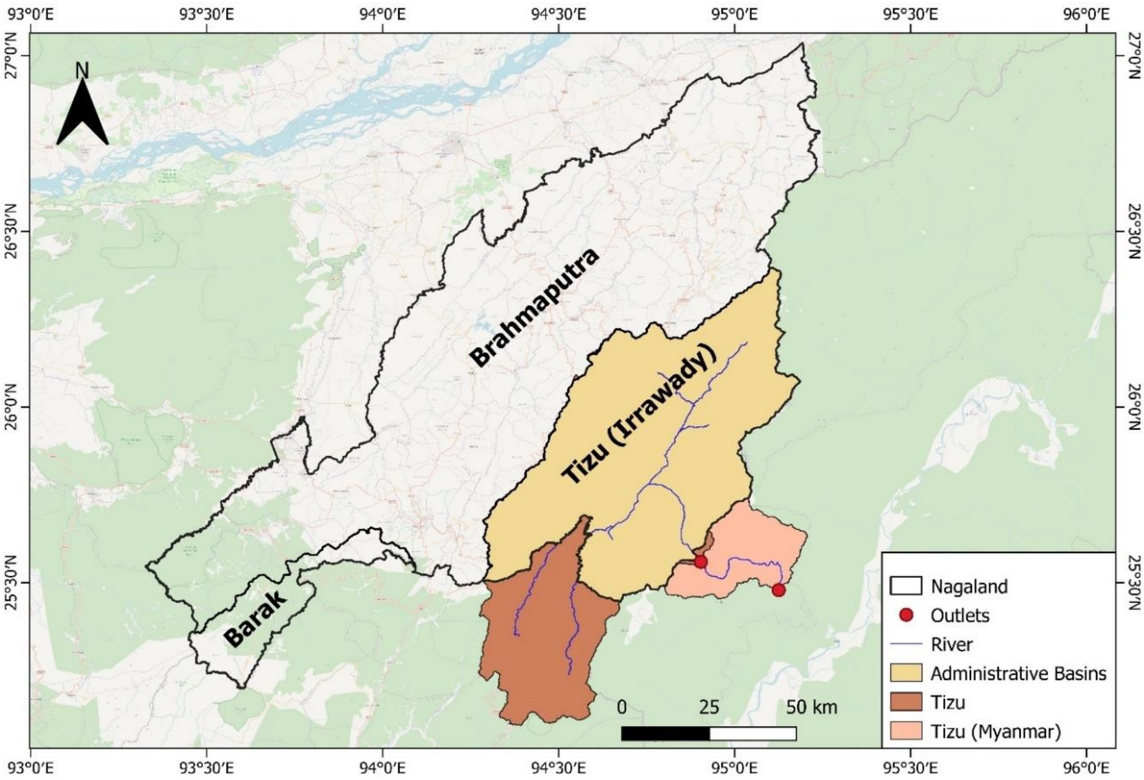


Figure 2.10. Map showing additional area w.r.t the administrative area for the Irrawady basin.

2.2 Data used

Different types of data are needed for effective water management planning. However, the staggered and poor availability of in-situ data is the primary cause of ineffective water management of a basin. Generally, the interpretation and communication of water-related data to researchers, planners, and policymakers are inadequate. Application of various satellite data products leads to timely, cost-effective, and nearly accurate basin evaluation. Datasets used for this study are freely available and openly accessible. However, it is advisable to be cautious and careful while using global open access data. The open-access datasets useful for water accounting can be referred in Annexure – I.

In the context of Global data w.r.t WA+, it has both strengths as well as weaknesses.

Strengths:

- ✓ Satellite-based indirect measurement
- ✓ Transparent – never lies
- ✓ Scale neutrality
- ✓ Easy to access, no bureaucracy hurdles

Weaknesses:

- ✓ Limited in period
- ✓ Different resolutions, different sources with large memory (bytes)
- ✓ A small mistake during analysis may spoil entire efforts

2.2.1 WA+ based land use (WALU)

Land use and land cover (LULC) is the main parameter, which affects the hydrological cycle and the services and benefits for society and the environment. Thus, spatially distributed information on LULC is necessary for running WA+. Based on remotely sensed data and different algorithms, several regional and global land cover databases are available (Arino et al., 2010). There are different data products like Globcover, global map of irrigation area (GMIA), moderate resolution imaging spectroradiometer (MODIS), international water management institute (IWMI) crop maps, monthly irrigated and rainfed crop area (MIRCA), world database on the protected area (WDPA), world population data were used to prepare WA+ based LULC (WALU), see Table 2.2. The WA+ framework has 80 classes globally covering both land cover and land use. The classes include crop classification type as per FAO classification. WA+ recognizes the influence of land use on the water cycle and provides the link between water balance, land use and water use, and management options to modify it by grouping the land use classes with common management characteristics. In terms of water management, the WALU classes have been categorized into four major clusters: protected land use (PLU), utilized land use (ULU), modified land use (MLU), and managed water use (MWU).

2.2.2 Precipitation

Precipitation data is a primary input for WA+. Climate hazards group infrared precipitation with station data (CHIRPS), tropical rainfall measurement mission (TRMM) remote sensing rainfall products are available for this accounting procedure (Mitra et al., 2009). In the study, CHIRPS precipitation data with a spatial resolution of 5 km x 5 km has been used.

2.2.3 Evapotranspiration (ET)

Over the past decades, various methods and algorithms have been used to calculate actual evapotranspiration (ET). ET ensemble product is an accurate product that was created by linear averaging of seven individual ET products: (1) Modis Global Terrestrial Evapotranspiration Algorithm (MOD16), (2) Atmosphere-Land Exchange Inverse Model (MOD16), (3) Global Land Evaporation Amsterdam Model (GLEAM), (4) Operational Simplified Surface Energy Balance (SSEBop), (5) CSIRO MODIS Reflectance-based Evapotranspiration (CMRSET), and (6) Surface Energy Balance System (SEBS), (7) ETmonitor and subsequently downscaled to 0.0025° using the MODIS-based, normalized difference vegetation index (NDVI) data. Potential evapotranspiration (ET Ref) is also available from the climate forecast system reanalysis (CFSR) dataset.

2.2.4 Leaf area index (LAI), Net dry matter (Biomass production) (NDM)

Leaf area index (LAI) and net dry matter (NDM), which give information on leaf area per unit ground surface area and mass of carbon per unit area, were used for Sheet 3 (Agricultural services) preparation to determine vegetation coverage and amount of production from agriculture, respectively. Net Dry Matter (NDM) was obtained from gross primary production (GPP) and net primary production (NPP), which are MODIS datasets. The details of data integrated to generate the water accounting plus based land use (WALU) and other data considered in the study are presented below in Tables 2.3 & 2.4, respectively.

Table 2.3

Details of data used to generate WA+ based land use (WALU)

Sl. No.	Data product	Period of availability	Spatial resolution	Temporal resolution	File type	Remarks
1	Globcover	Dec'04-June'06; Jan-Dec'2009	300 m	annual	tiff	Based on ENVISAT MERIS, 22 style classes
2	GMIA (Global Map of Irrigated Areas)	Since 01-10-2013	10 km	annual	shp	gives information about % irrigated areas or hectare per pixel
3	MIRCA (Monthly Irrigated and Rainfed Crop Areas)	1998-2002	10 km	monthly	shp	% of each cell monthly covered by each of 26 nos. Irrigated or rainfed crops
4	WDPA (World Database on Protected Areas by United Nations Environmental Programme)	2010-2016	-	-	shp	29 descriptors, referred to as data attributes; global spatial dataset on terrestrial and marine protected areas
5	JRC (Joint Research Centre Data Catalogue)	2000-2016	1 km	-	tiff	Flood hazard maps- Total 13 datasets available with different return period frequency
6	GRAND (Global Reservoir and Dam Database)	2000-2010	230 m	-	tiff	Contains 6862 reservoirs/ dams of a capacity > 0.1 km^3
7	MODIS (Moderate Resolution Imaging Spectroradiometer) -MCD12Q1	2001-2013	500 m (0.05 deg)	monthly, Annual	tiff	17 classes
8	World POP	2010; 2015; 2020	100 m (0.000833deg)	annual	tiff	people per hectare' (pph) datasets
9	NRSC	2012	30 m	annual	tiff	

Table 2.4

Details of precipitation, evapotranspiration, and other meteorological data products

SL.No.	Data Product	Period of Availability	Spatial Resolution	Temporal Resolution	File Type	Remarks
A.	RAINFALL					
1	Climate Hazards Group Infrared Precipitation with Station data (CHIRPS)	1981 onwards	5 km	daily, monthly	tiff	Funded by USGS and USAID
B.	EVAPOTRANSPIRATION					
1	MOD 16	2000 onwards	1 km	8 daily, monthly, annual	tiff	MODIS Product
2	Global Land Evaporation Amsterdam Model (GLEAM)	2003-2012	27 km (0.25deg)	daily, monthly	tiff	Global
3	ETensemble (ETensV1.0)	January 2003 until December 2014	250 m (0.0025 deg)	monthly	tiff	Global
C.	OTHER DATASETS					
1	Global Land Data Assimilation System (GLDAS)	1948 onwards	110 km (1 deg)	3-hourly, monthly	tiff	Measures meteorological parameters such as atmospheric pressure, radiation, temperature, etc.
2	Climate Forecast System Reanalysis (CFSR)	1979 -2009	0.5 deg	hourly	tiff	Provides the output at atmospheric, oceanic, and land surface (10 data products)
3	MOD 15-17 Vegetation	2000 onwards	1 km	8-daily, monthly	tiff	NDVI, LAI, FPAR, GPP, NPP
4	Gravity Recovery and Climate Experiment (GRACE)	2003-2022	300 KM	daily	csv	-

CHAPTER 3
APPROACH AND METHODOLOGY

This chapter briefly discusses the methodology adopted in the study. This section briefly discusses the WA+ framework, its basic concepts, Budyko theory, WA+ based LULC map, ET separation, and generation of different Fact-sheets.

3.1 Water Accounting Plus (WA+)

Using public public-domain remote sensing datasets, WA+ provides independent estimates of water flows, fluxes, stocks, consumption, and services. Large basins with transboundary reach, involving multiple stakeholders need an independent, scientifically sound, standardized water accounting system. WA+, since satellite-data based, is an unbiased accounting tool, and is recommended for the regions with data scarcity or unavailability and are conflict-prone. It serves as a tool to evaluate and plan water resources management, monitor water resource changes, and assess the impacts of future interventions in a basin. It also provides explicit spatial and temporal information on water yield, depletion, and net withdrawal processes. WA+ reports on water resources conditions of a basin by means of eight fact sheets, spatial maps and tables. It presents information on water supply, water depletion processes, beneficial and non-beneficial depletion, biomass production, water and land productivity, and water withdrawals and reuse. The flowchart showing the basic steps involved in the WA+ Framework is illustrated in Figure 3.1.

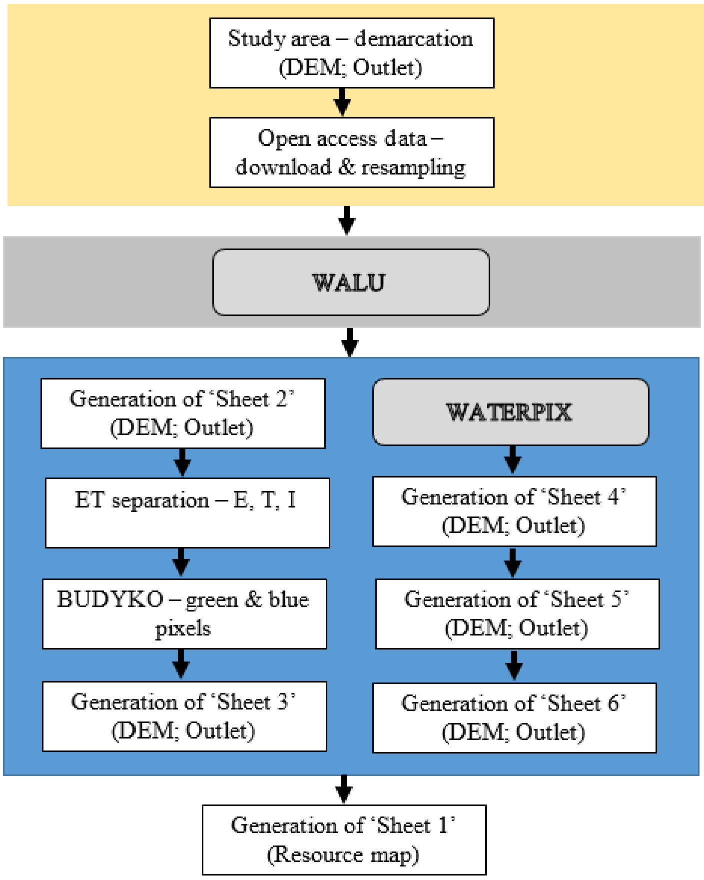


Figure 3.1. Flowchart illustrating basic steps involved in WA+ Framework.

3.1.1 WA+ based land use and land cover (WALU)

In any modelling exercises for water resources management, the generation of land use and land cover (LULC) is an important component. Generally, LULC is generated to identify different classes such as agriculture, forest, built-up area, wasteland, waterbodies, etc. However, if someone needs to know the benefits and services of a specific use of land or to plan different interventions for rainfed or irrigated agriculture, the traditional approach of generating LULC is inadequate. In this situation, the existing LULC is value-added with the help of global public domain datasets. For example, based on the population density, rural and urban areas can be segregated. Similarly, based on WDPA, reserve forests and protected (virgin) areas can be identified. The WALU is basically a land use generated utilizing different sources of open data. WA+ framework has 80 classes and covers both land cover and land use. In terms of water management, the LULC classes have been classified into four major clusters: protected land use (PLU), utilized land use (ULU), modified land use (MLU), and managed water use (MWU), as shown in Figure 3.2.

Protected land use represents areas set aside for no/ minimal human disturbance. It includes natural ecosystems or biomes earmarked for conservation and coastal protection. Examples are national parks, coastal dunes, game reserves, and glaciers. The group "utilized land use" represents land use that offers a range of ecosystem services and has had little interference from man. However, people often use such land for the services it provides, like food production or fuelwood, and nomads on natural pastures. Examples include grassland or savanna (for grazing or wood) and forest land (for timber). The group "modified land use" refers to land that is significantly modified by human activity for the sake of food, feed, fibre, (bio-)fuels, and fish production. It also includes improved road networks to connect growing populations, dump sites and increasing space for leisure and for socio-economic growth in the most general terms. Water diversions and withdrawals do not take place in the "modified land use" group, but by modifying vegetation density, hydrological processes such as ET, drainage, percolation, and recharge are affected. Changes in ET in the "modified land use" class can have a significant impact on groundwater levels, streamflow, and downstream water availability. Rainfed cropping systems, deforestation, creation of plantation forests, the establishment of lanes and parks, home gardens, and wind shelters typically fall in the "modified land use" class. The group "managed water use" represents the land use classes in which the natural water cycle is manipulated by physical infrastructure. Herein, water is intentionally retained, withdrawn, pumped, diverted, and spilled by pumping stations, valves, pipes, dams, weirs, gates, canals, sluices, culverts, and drains for specific objectives. Examples are drinking water supply schemes, irrigation systems, storage for hydropower, maintaining water levels for navigation, flood storage in wetlands, etc. Managed water use includes domestic water use in urban areas and villages, irrigated agriculture, expanding industries for economic development, and golf courses. The following datasets were used for the preparation of the WA+ based LULC map:

- NRC-250k LULC; GLOBCOVER
- IWMI; GMIA; MICRA
- WDPA’ JRC
- GRAND; MODIS
- WORLD POP; GLOBAL SURFACE WATER

All the datasets were clipped and resampled to 250 m x 250 m resolution, and were used for LULC map generation using automated script written in Python.

Figure 3.2. Representation of 4 major LULC management classes in WALU.

3.1.2 Generation of Sheet 2 (Evapotranspiration)

3.1.2.1 What is evapotranspiration?

The second major parameter in the water cycle is evapotranspiration (ET). A small error in the ET analysis can result in different conclusions. Evapotranspiration is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces, and by transpiration from plants. It is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere (Figure 3.3). The fact sheet i.e., ‘Sheet 2’, provides the evapotranspiration component. As per WA+ standards, it is also named as Sheet 2 (ET sheet), which informs details about beneficial and non-beneficial ET as per the prevailing LULC.

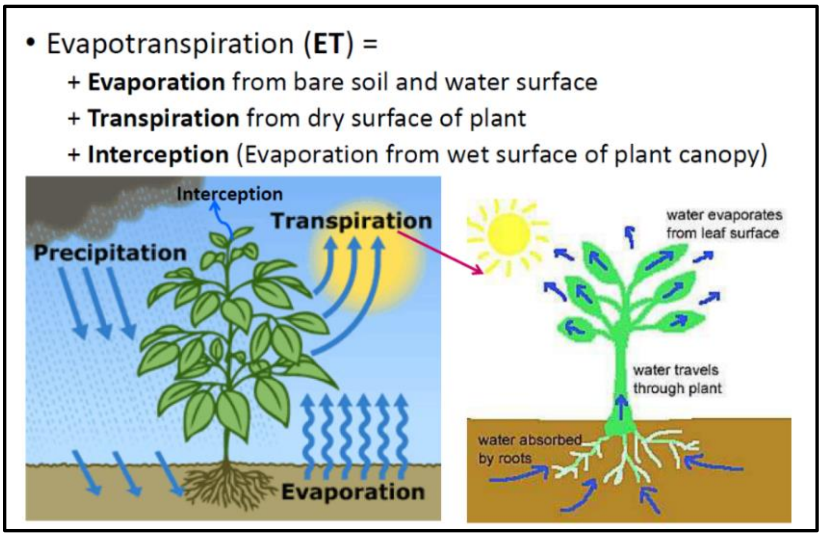


Figure 3.3. Schematic showing the evapotranspiration (ET) process.

3.1.2.2 Purpose of Sheet 2

- Quantify water consumption of all land use classes
- Describing the anthropogenic impact on ET and concepts of ET management to reduce incremental ET from withdrawals and inundations
- Understand the impact of land use planning on consumptive use (and indirectly stream flow)
- Relate water consumption to intended processes (beneficial vs. non-beneficial ET & agriculture/ environment/ economy/ energy/ leisure)

3.1.2.3 Outputs from Sheet 2

- Total evapotranspiration (ET)
    - *Non-manageable – Protected LU*
    - *Manageable – Utilized LU*
    - *Managed – Modified LU + Managed LU*
        - Conventional ET
        - Non-conventional ET
    - ✓ Total Beneficial ET
        - Agriculture
        - Environment
        - Economy
        - Energy
        - Leisure
    - ✓ Total Non-beneficial ET
- Total transpiration (T)
    - Non-manageable – Protected LU
    - Manageable – Utilized LU
    - Managed – Modified LU + Managed LU
- Total evaporation (E)
  = Total ET – Total T
    - Water
    - Soil
    - Interception

Important glossary:

- Conventional ET which is the ET that occurs through natural processes
- Non–conventional ET which is the ET that occurs by non–natural processes such as steam from cooling towers, green houses, respiration by humans and animals, sweating and turbine spray, among others
- Beneficial ET which is the water consumed for its intended purpose
- Non-Beneficial ET which is the water consumed for purposes

3.1.2.4 How to generate Sheet 2

Sheet 2 (Evapotranspiration, km^3/ year) presents information regarding water consumption in a basin as a total value per water sector (land use type). The major inputs for the generation of Sheet 2 are RS-based evapotranspiration maps (ET), Leaf area index (LAI), Net primary production (NPP), Gross primary production (GPP), daily precipitation, and a LULC map (WALU). The procedure involves the separation of evapotranspiration into evaporation, transpiration and interception, and then, splitting evapotranspiration into beneficial and non-beneficial components.

3.1.2.5 Inputs for Sheet 2

i. Evapotranspiration, ET
ii. Precipitation, P
iii. NPP
iv. GPP
v. Land use map (WALU)

<u>Note:</u> *The downloaded dataset has different spatial and temporal resolutions, and hence, we needed to resample to make all data with the same resolutions. Here, the spatial resolution is kept similar to LULC, and the temporal resolution is kept monthly.*

3.1.2.6 ET separation

By knowing the quantity of ET from different land use, the next step is to estimate the benefits obtained from various water use. This means that every land use land cover needs a value to describe both aspects of ET, i.e., the beneficial and non-beneficial fractions. In general, evaporation (E) is counted as non-beneficial, as a considerable quantity of E is generated from wet soils (fallow or partially filled land) (Choudhury et al., 1998). However, evaporation from water bodies, meant for fishing, leisure, and water sports, is considered beneficial. In this manner, each LULC class assigned a percentage of beneficial and non-beneficial use of water based on its ***intended purpose***. For example, evaporation from wetlands, rivers, and natural lakes was assumed beneficial. Conversely, evaporation from other sources was assumed to be 100% non-beneficial. Transpiration from all the sources was assumed to be 100% beneficial, except for transpiration from wastelands and floating vegetation in the reservoir. Although interception has certain benefits for crops, all interceptions from different sources were considered non-beneficial. This percentage can be modified by users according to their study area. Again, the beneficial evapotranspiration (ET) is expressed in agriculture, environment, economic, energy, and leisure. In addition to that, independent assessment of transpiration (T), interception (I), and evaporation (E) from soil and water helps to prepare effective water management policies and strategies. A schematic showing steps of ET separation is shown in Figure 3.4.

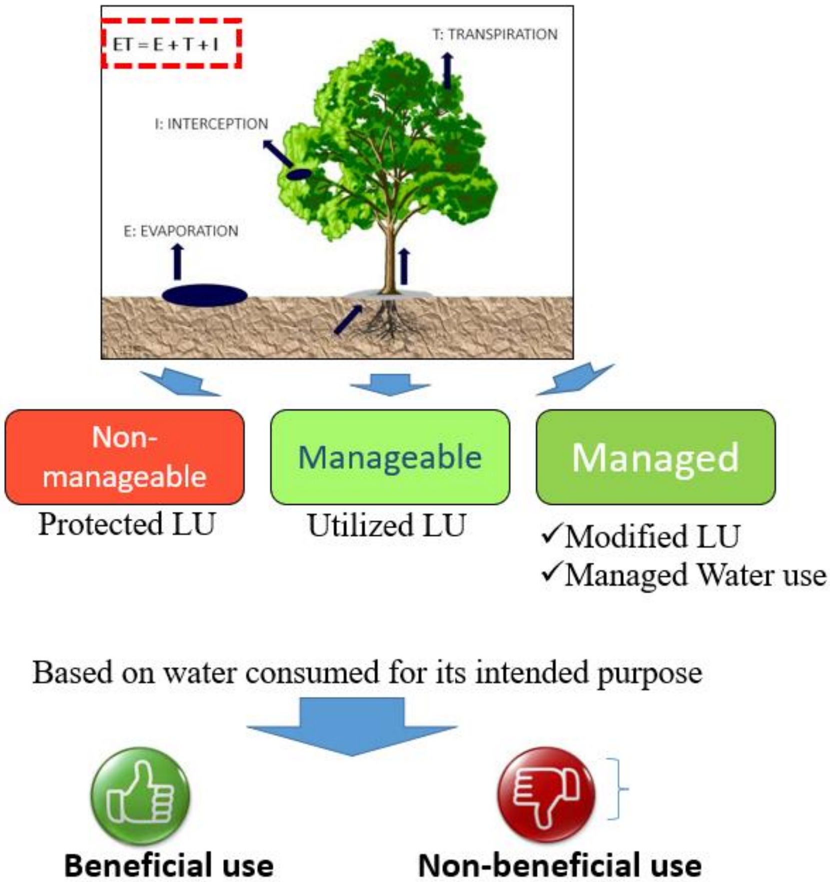


Figure 3.4. Schematic showing ET separation.

A generalized flow chart followed for generation of Sheet 2 is shown in Figure 3.5.

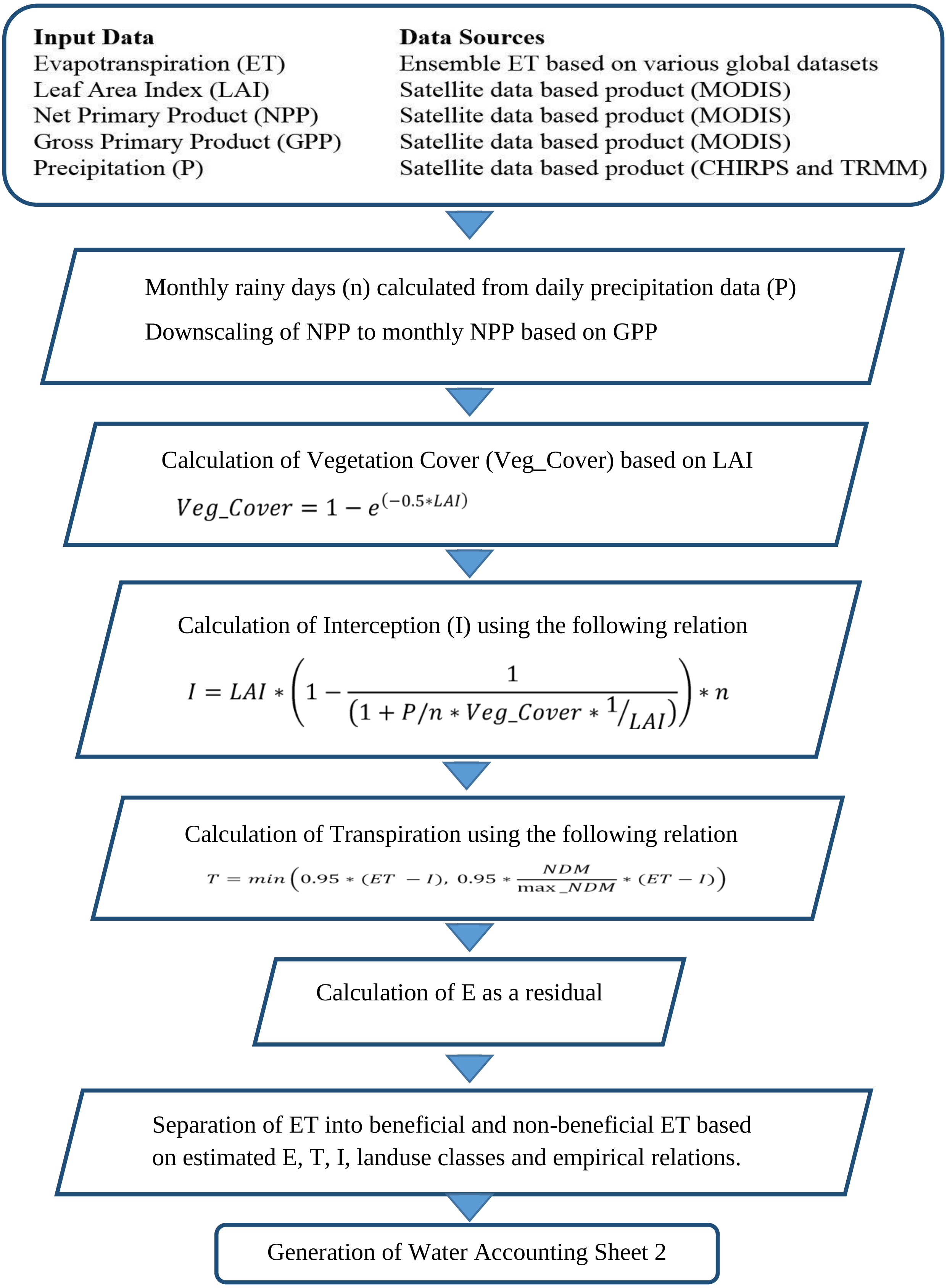


Figure 3.5: A generalized flow chart for generation of Sheet 2.

3.1.3 Generation of Sheet 3 (Agricultural services)

Water is utilized for agricultural services. Sheet 3 generates crop-wise agricultural water consumption (km^3/year), land productivity (kg/ha/year), and water productivity (kg/m^3) on a monthly and yearly basis.

3.1.3.1 Purpose of Sheet 3

- Assess agricultural production (kg/ha) and food security (kg) in terms of food, feed, timber and fish products
- Showing crop water productivity (kg/m^3) and its gap by crop type
- Plan future rainfed and irrigated cropping systems using rainfall, exploitable, and available water
- Indicate possibilities for saving water in agriculture and making agricultural water management more efficient

3.1.3.2 Input data for Sheet 3

i. Actual evapotranspiration
ii. Reference evapotranspiration (ET green and ET blue)
iii. Precipitation
iv. Land use (WALU)
v. Crop-wise growing season (.csv)
vi. NDM
vii. Harvesting Index (HI) and efficiency

3.1.3.3 Output from Sheet 3

i. Part-1: Agricultural water consumption (km^3/year)
ii. Part-2: Land productivity (kg/ha/year) and Water productivity (kg/m^3)
iii. Split Yield (contribution from green and blue components)

3.1.3.4 Segregation of ET into ETgreen and ETblue

WA+ recognizes the essential difference between blue and green water. Accordingly, ET is also separated into ET blue and ET green based on Budyko analysis. Green water is the soil moisture from precipitation, used by plants via transpiration. Whereas, Blue water is the freshwater stored in lakes, streams groundwater, glaciers and snow. Blue water is, otherwise, also known as 'delayed rainfall'. The Budyko analysis helps identify rainfed and irrigated agriculture. In the rainfed agricultural system, water is provided as rainfall to meet the atmospheric demand i.e., green evapotranspiration. However, in an irrigated system, along with the rainfall, water is separately supplied during the deficit period as irrigation (additional supply), resulting in incremental yield and incremental evapotranspiration i.e., blue evapotranspiration (Figure 3.6). The concept behind blue water and green water, and its representation as 'green pixels' and 'blue pixels' is shown below in Figure 3.6.

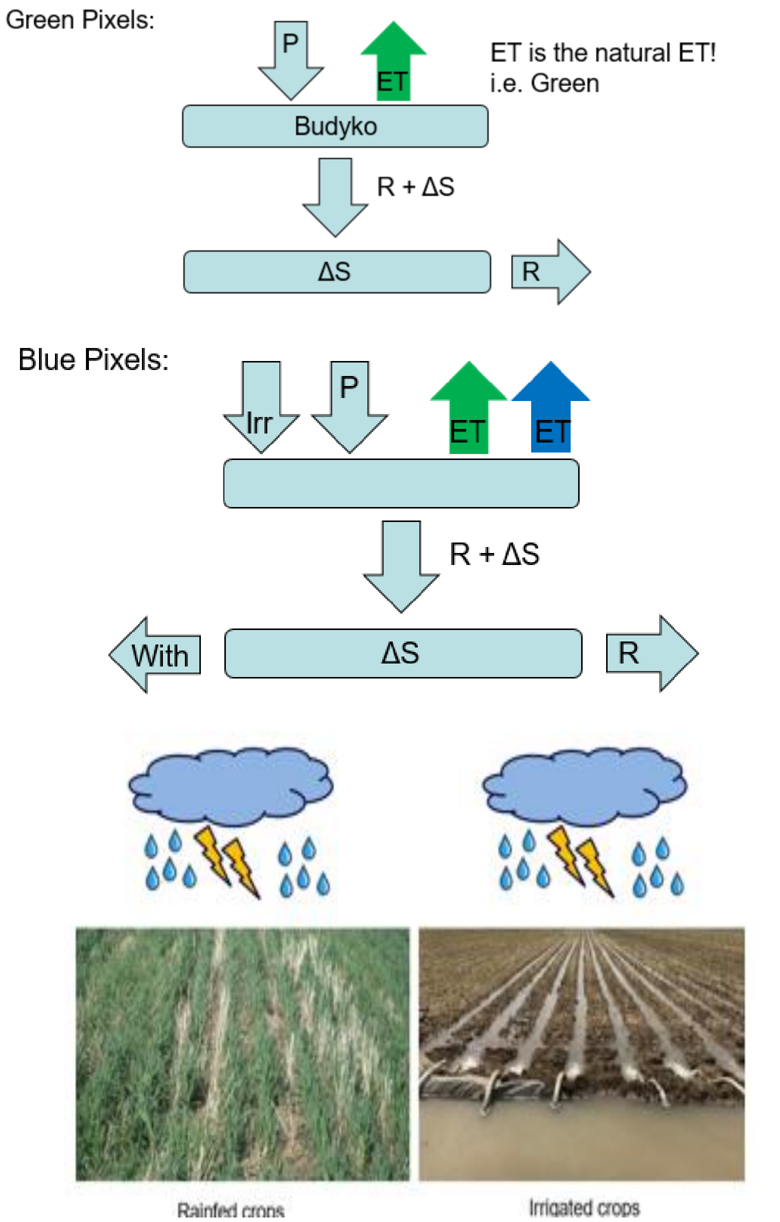


Figure 3.6: Concept behind Green and Blue pixels.

Calculating the fraction of ET, whether green or blue, is based on climate conditions using the Budyko curve (Budyko, 1974). The Budyko curve is explained through two indices viz. dryness index (PET/P) and evaporative index (ET/P) as shown in Figure 3.7. As the dryness index reaches maximum (x-axis), rainfall (P) will gradually decrease, and the climatic demand (PET) increases, indicating a dry catchment. The reverse is valid for a humid catchment where the climatic demand is much lesser than the rainfall received in the catchment. However, as the evaporative index reaches maximum, the actual climatic demand (AET) will touch maximum with diminishing rainfall.

The AET and PET increase linearly (1:1) until AET is in equilibrium with the PET. Beyond that, AET remains constant with the increase in PET. This method segregates the catchments geographically as water-limited (PET/P >1) or energy-limited (PET/P<1). PET is basically the reference evapotranspiration (ET_0), and can be estimated using several empirical equations, such as Hargreaves method, Blaney-Criddle method, FAO Penmann Monteith method, etc.

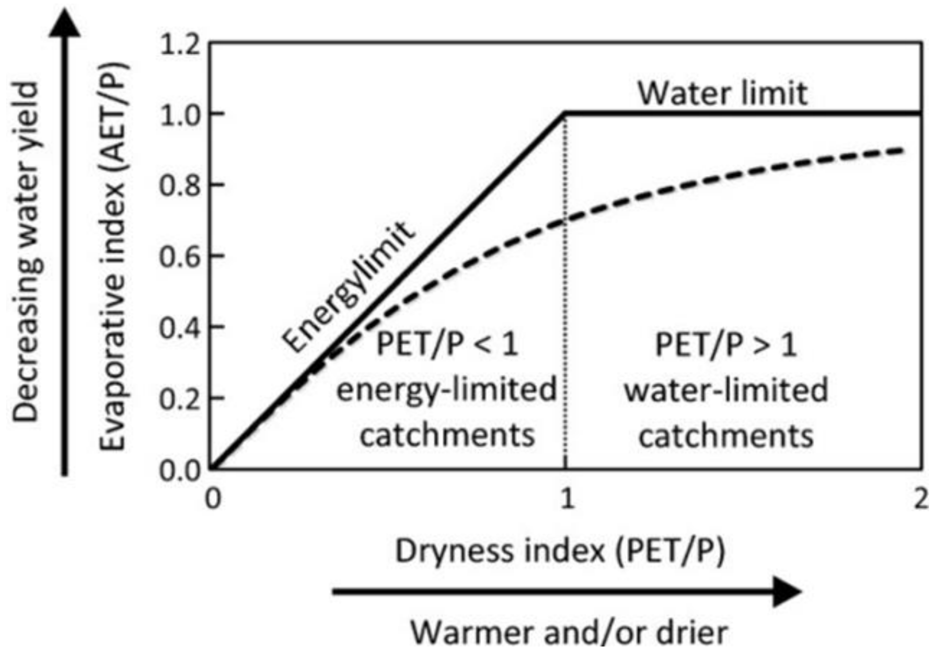


Figure 3.7: Budyko curve.

The dotted line is described as the ‘Budyko Curve’, and is represented through the following empirical equation:

$$\frac{ETgreen}{P} = \left[\emptyset \tanh\left(\frac{1}{\emptyset}\right)\left(exp^{-\emptyset}\right)\right]^{0.5} \qquad \text{…3.1}$$

Where, Ø = PET/P i.e. dryness index

The pixels falling within the dotted line are nothing but the green pixels since the entire climatic demand is met through rainfall. What happens when a pixel falls beyond the dotted line? This implies that the AET is much greater than the rainfall received. Otherwise, one can say that apart from the rainfall, there is an additional supply of water (withdrawal from GW or SW) in that particular pixel. The evapotranspiration generated due to this additional supply is the incremental evapotranspiration or the blue evapotranspiration. The increased yield due to surplus (irrigated) water is the incremental yield, as explained in Figure 3.8. Now, the blue evapotranspiration is calculated as:

ETblue = ET actual (AET) – ETgreen …3.2

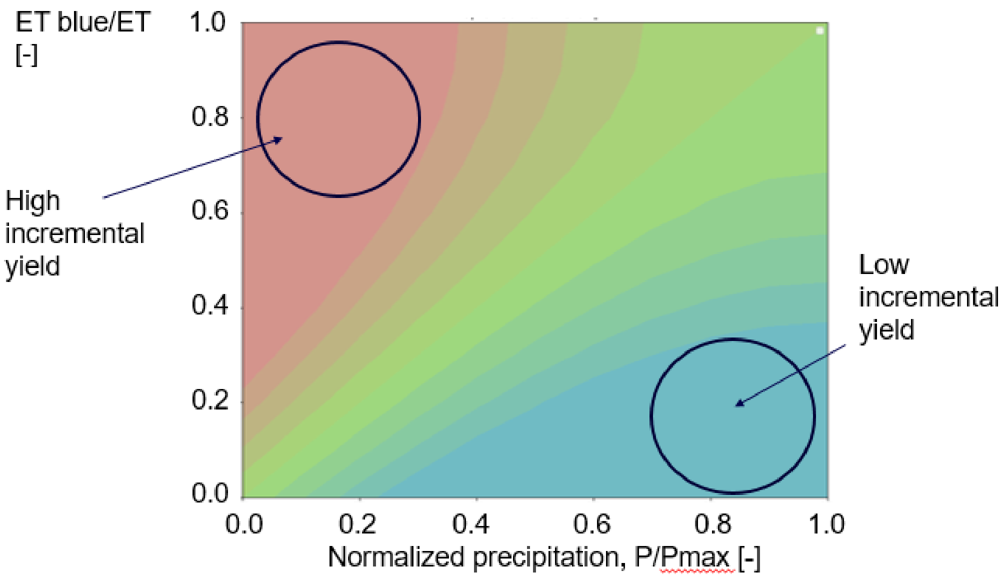


Figure 3.8: Incremental yield.

ETblue/ET = 1 indicates a considerable supply, resulting in higher incremental yield. However, when P/Pmax = 1, this indicates a pixel without supply; otherwise, it can be said that the yield is due to rainfall only. Hence, the incremental yield is zero since there is no supply. After splitting the yield in every pixel, one can compute the average per basin.

3.1.3.5 Estimation of yield (biomass)

Remote sensing quantifies the key crop production (yield) processes, as shown below in Figure 3.9. Plant photosynthesizes light energy into glucose as Gross Primary Product (GPP). It also consumes certain amount of energy for its own growth through respiration producing the Net Primary Product (NPP). The NPP and GPP products only account for energy used to produce Carbon; the most important molecule in crops is CH2O. This molecule is 30/12 times heavier than C. So, the NDM is derived by multiplying the NPP by 2.5 (= 30 / 12). The rate of photosynthesis depends on several factors, as shown in Figure 3.10.

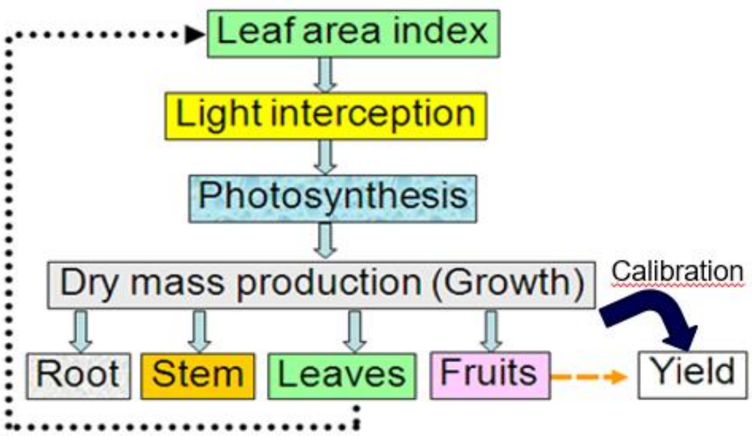


Figure 3.9: Crop production (Yield) processes.

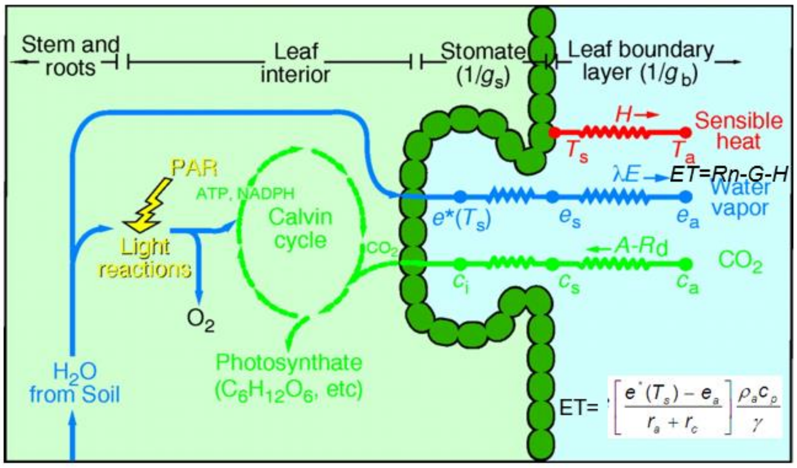
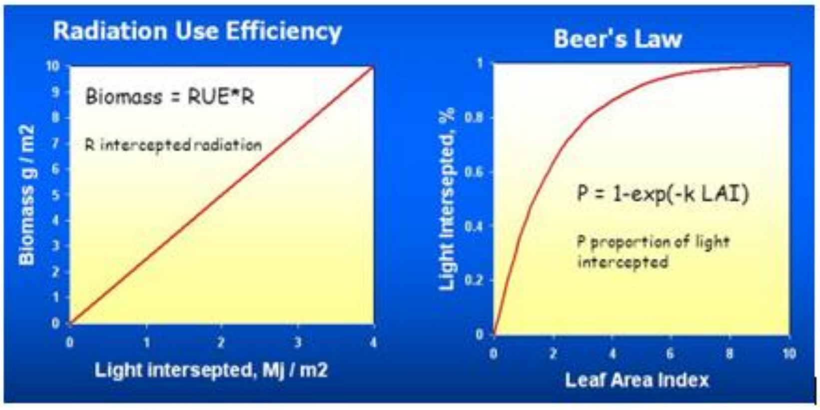


Figure 3.10: Bio-physical processes in a plant.

The higher the evapotranspiration through the plants, the higher the biomass production. A fraction (fPAR) of Photosynthetically active radiation (PAR) is converted into glucose, as demonstrated below in Figure 3.11:



$$\text{PAR} = 0.48 K_{24}^{\downarrow} \ (\text{W m}^{-2})$$

$$\text{APAR} = f \times \text{PAR} \ (\text{W m}^{-2})$$

Figure 3.11: Schematic showing relationship between biomass, LAI and light intercepted.

$$GPP = fPAR \times PAR \times \varepsilon_{max} \times Min(T_s, W_s)$$

$$fPAR = 1.24 \times NDVI - 0.168$$

$$Ts = \frac{(T_a - T_{min}) \times (T_a - T_{max})}{(T_a - T_{min}) \times (T_a - T_{max}) - (T_a - T_{opt}) \times (T_a - T_{opt})} \qquad \ldots 3.3$$

$$Ws = \frac{LE}{LE + H}$$

Once the net dry matter (biomass dry weight) is estimated, the fresh yield is calculated as below.

$$\text{Fresh yield [kg]} = \frac{\text{Harvest index * Biomass dry weight [kg]}}{1 - \text{moisture content product } \theta} \qquad \ldots 3.4$$

Note: Here, Biomass dry weight is NDM, and NDM is estimated using GPP and NPP data from MODIS. Since Sugarcane is a C4 plant with higher efficiency, a factor of 4.5/2.5 is multiplied by NDM.

To split yield into 'Yield due to Precipitation' and 'Yield due to Irrigation (Incremental Yield)', the following Yield Fraction is used.

$$Yield\ fraction = \left(\left(\left(\frac{ET_b}{ET} - 1\right) * a\right)^2 - \left(\left(\frac{P}{P_{max}} - 1\right) * b\right)^2\right) + 0.5 \quad \ldots 3.5$$

Where, a & b are parameters. Now, the yield due to irrigation i.e., incremental yield and the yield due to precipitation are estimated as given below.

Incremental yield = Total Yield * Yield fraction …3.6

Yield precipitation = Total Yield – Incremental yield …3.7

Water productivity (WP) = Yield/ ((ETblue + ETgreen) …3.8

WP blue = Incremental yield/ ETblue …3.9

WP green = Yield due to precipitation/ ETgreen …3.10

Land productivity (LP) = Yield/ Irrigated area …3.11

A flowchart describing the steps followed in generating Sheet 3 is presented below in Figure 3.12:

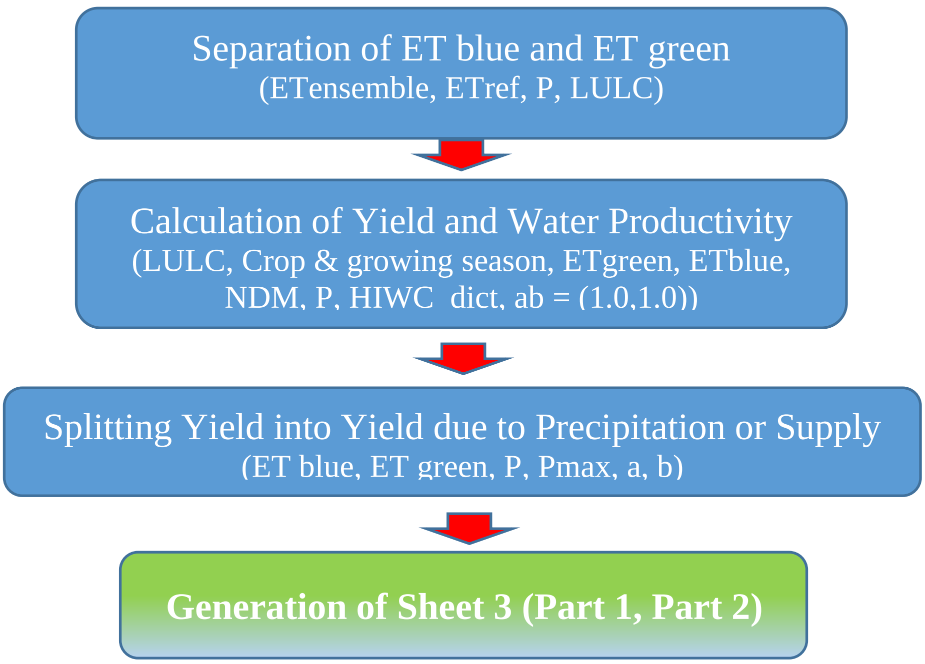


Figure 3.12: Flowchart showing Steps in generating Sheet 3.

3.1.3.6 Land and water productivity mapping

To find productivity separately from the rainfall and irrigation water, water consumption (ET) from rainfed and irrigated water was calculated as ET green and ET blue, respectively. Notably, the concept of green water was given by Falkenmark (1995) to address the issues of water scarcity and food security in the era of population growth and climate change. The assessment of WP and LP also involves the application of green water (rainfed) and blue water (irrigated) concepts using the Budyko framework (Figure 3.7). Spatial maps of land and water productivity provide the areas performing well (progressive farmers with high productivity) and poor (farmers with low productivity) in a large basin. These rich information enables the water managers to understand the interventions undertaken at the local level by both progressive and less progressive farmers. This helps in planning different interventions for a particular area for higher productivity. The calculation of yield and water productivity is done as given below.

$$\text{Fresh yield} = \frac{Harvest\ index \times Biomass\ dry\ weight}{1 - Moisture\ content}\ \text{(kg/ha)} \qquad \dots(3.12)$$

$$\text{Water productivity} = \frac{Yield}{Water\ consumption}\ (\text{kg/m}^3) \qquad \dots(3.13)$$

3.1.4 Generation of Sheet 4 (Utilized flow)

Sheet 4 provides the utilized flow for both manmade and natural sources of the basin. Sheet 4 can also be called the 'Withdrawal' sheet, which provides the surface water and groundwater withdrawal. A separate sheet for the withdrawal is important from the management point of view. Surface water can be used for hydropower generation. In contrast, groundwater is a preferred choice for farmers for irrigation and drinking water because of its instantaneous availability without passing through a larger conveyance network. The aim of Sheet 4 is to provide an explicit picture of flows for the Managed Water Use category. It reports water scarcity from water demands and water supply. The sheet also distinguishes between consumed and non-consumed water and recognizes the recoverable and non-recoverable flow. The outputs from Sheet 4 are shown in Figure 3.13.

<table>
<tr><td colspan="3">GW Supply</td><td colspan="2">SW Supply</td></tr>
<tr><td colspan="5">Total Supply</td></tr>
<tr><td colspan="2">Consumed</td><td colspan="3">Non Consumed</td></tr>
<tr><td>ET</td><td>Other</td><td colspan="3">Recoverable</td></tr>
<tr><td></td><td></td><td colspan="2">Recoverable GW</td><td>Recoverable SW</td></tr>
</table>

Figure 3.13: Outputs from Sheet 4.

3.1.5 Generation of Sheet 5 (Surface water)

Sheet 5 explicitly describes about the surface water availability of different sub-basins and basins. It distinguishes between fast/slow runoff and determines the surface water availability and utilizable withdrawals.

3.1.6 Generation of Sheet 6 (Groundwater)

Sheet 6 gives the groundwater resources of the basin. It estimates the vertical recharge of both natural and man-made along with the vertical groundwater withdrawal and return flow due to groundwater. It assesses aquifers as storage reservoirs for droughts and their role as the buffering mechanism. It also maps the groundwater withdrawal for irrigation.

3.1.7 Generation of Sheet 1 (Resource base)

Sheet 1, otherwise known as 'Resource Base' summarizes water resources scenarios of the basin. It provides the gross inflow, net inflow, availability of water, utilizable and non-utilizable flow, and finally, the surplus flow going out of the basin. It evaluates different sources of water that control the net inflow.

*Note: To compute Sheet 4, Sheet 5, Sheet 6, and Sheet 1, surface runoff, storage change, supply, and percolation are required, which is derived by using the **WaterPix model**. WA+ also comprises two other Sheets, viz. Sheet 7 (Ecosystem services), and Sheet 8 (Sustainability), which are beyond the scope of this study.*

3.1.8 WaterPix Model

The classical approach of hydrological water balance estimates runoff from rainfall after meeting the initial losses (infiltration, depression storage, etc.). The major limitations of this approach include the estimation of initial soil saturation, human-induced runoff, and spatial dimension. WaterPix is a depletion-based (conservation of mass) vertical approach used to perform water balances at a pixel scale (https://github.com/gespinoza/waterpix) (Espinoza-Dávalos and Bastiaanssen, 2017) as shown in Figures 3.14.

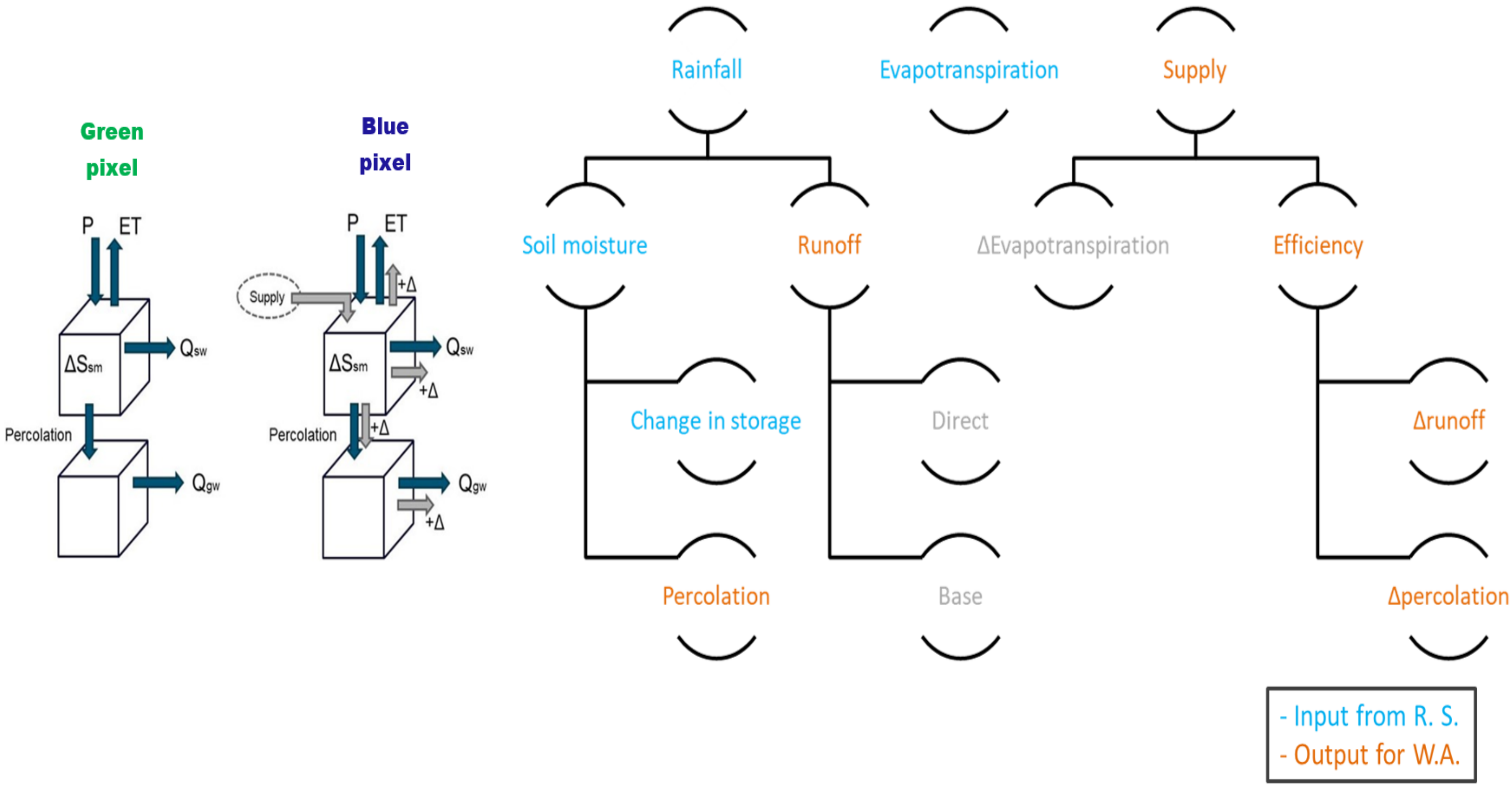


Figure 3.14: Approach adopted in the WaterPix model.

3.1.8.1 Steps followed in WaterPix Model

Step 1: Identify the Green pixel

The model identifies the 'green pixels' and 'blue pixels' using the Budyko theory already discussed in Section 3.1.3.4.

Step 2: Water balance at pixel scale – 1st round (Green pixel)

The model computes the water balance first for green pixels with 'no supply'.

i. Precipitation and evapotranspiration values are already known.

ii. Calculate the change in soil moisture storage as given below.

$$\Delta S_{sm} = R_d \times \left(\theta_{x_{rz}} - \theta_{o_{rz}}\right)$$

Where, R_d is the root depth; $\theta_{x_{rz}}$ is the root depth soil moisture at the end of the month; $\theta_{o_{rz}}$ is the root depth soil moisture at the start of the month.

Note: Remember that the root-depth soil moisture values (θ_{rz}) were calculated from the topsoil soil moisture (θ), for the first and last day with the following equation:

$$\theta_{rz} = \theta_{sat} \times (0.1 \times LAI + (1 - 0.1 \times LAI\ ) \times (1 - exp\left(\left(\frac{\theta}{\theta_{sat}}\right)(-0.5 \times LAI - 1)\right)$$

Where, LAI is the leaf area index (MODIS); θ_{sat} is the saturated water content (GLDAS)

iii. Calculate the vegetation cover

$$vc = 1 - \exp\left(-0.55\ \times LAI\right)$$

iv. Calculate the interception

$$I = LAI \times N_{rain}\left(1 - \frac{1}{1 + \frac{P \times vc}{N_{rain} \times LAI}}\right)$$

Where, P is the mean precipitation in the month (CHIRPS); $N_{rain}$is the number of rainy days in the month (CHIRPS)

v. Calculate the direct runoff (Modified SCS equation)

$$Q_{sw} = \frac{(P - I)^2}{P - I + (\theta_{sat} - \theta) \times Inf_z}$$

Where, θ_{sat} is the saturated water content; θ is the mean root depth soil moisture for the month; Inf_z is the infiltration depth

Note: The infiltration depth is a calibration parameter. Set an initial value of 200 mm and change this value later to adjust the water balance.

vi. Calculate the slow runoff using the runoff ratio (r) as defined below:

$$r = \frac{Q_{sw}}{Q_{sw} + Q_{gw}}$$

Where, Q_{sw} is the runoff (fast); Q_{gw} is the runoff (slow)

vii. Change the values of the infiltration depth (Inf_z) until the following is true:

$$\sum_{i=1}^{12} P^i - ET^i - \Delta S_{sm}^i = \sum_{i=1}^{12} Q_{sw}^i + Q_{gw}^i$$

Step 3: Percolation calculation

i. Calculate the remainder of the water balance on a monthly basis as:

$$Rest\ Term = \begin{cases} P - ET - \Delta SM - Qsw & if > 0 \\ 0 & if < 0 \end{cases}$$

ii. Calculate the monthly percolation as:

$$Perc = \max(Rest\ Term, 0)$$

Where, $Perc$ is the monthly percolation in mm

iii. Use the values of θ_{rz} and $Perc$ to fit the following function:

$$Perc = a \times (\theta_{rz})^b$$

Where, a and b are fitting parameters

Step 4: Estimation of the calibration depth (Kriging approach)

$$Z^*(\mathbf{u}) - m(\mathbf{u}) = \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_\alpha [Z(\mathbf{u}_\alpha) - m(\mathbf{u}_\alpha)]\ ."$$

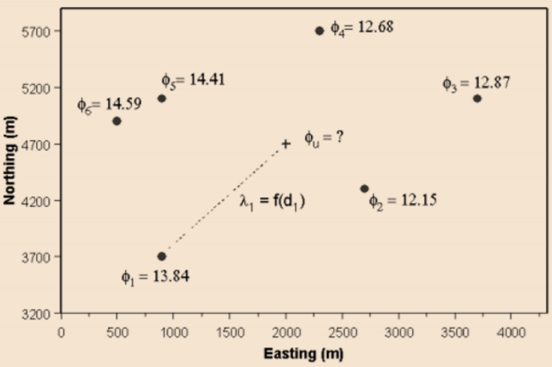
with

$\mathbf{u}, \mathbf{u}_\alpha$: location vectors for estimation point and one of the neighboring data points, indexed by α

$n(\mathbf{u})$: number of data points in local neighborhood used for estimation of $Z^*(\mathbf{u})$

$m(\mathbf{u}), m(\mathbf{u}_\alpha)$: expected values (means) of $Z(\mathbf{u})$ and $Z(\mathbf{u}_\alpha)$

$\lambda_\alpha(\mathbf{u})$: kriging weight assigned to datum $z(\mathbf{u}_\alpha)$ for estimation location $\mathbf{u}$; same datum will receive different weight for different estimation location



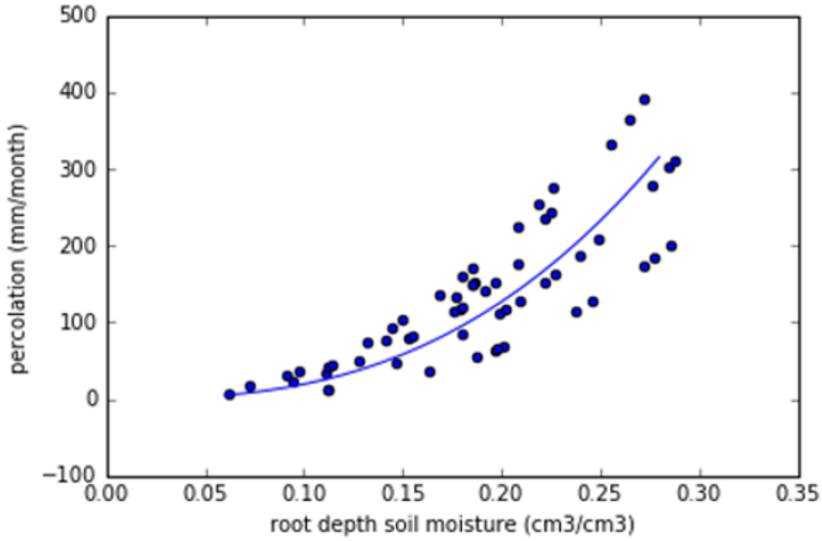
The goal is to determine weights, λ_α, that minimize the variance of the estimator

$$\sigma_E^2(\mathbf{u}) = \mathrm{Var}\{Z^*(\mathbf{u}) - Z(\mathbf{u})\}$$

under the unbiasedness constraint $\mathrm{E}\{Z^*(\mathbf{u}) - Z(\mathbf{u})\} = 0$.

Step 5: Fit Percolation and Soil moisture

For blue water pixels, the local fit was performed with increasing the search distance.



Step 6: Water balance at pixel scale – 2nd round (Blue pixel)

Here, the net supply is calculated following the above steps for blue pixels (with additional supply)

$$Q_{swgreen} = \frac{(P - I)^2}{P - I + (\theta_{sat} - \theta) \times Inf_z}$$

$$Perc_{green} = P - ET_{green} - Q_{swgreen} - \Delta S_{sm}$$

$$\Delta perc = perc - Perc_{green}$$

$$Supply = \Delta ET + \Delta Q_{sw} + \Delta perc$$

$$\Delta Q_{sw} = \frac{(supply)^2}{supply + (\theta_{sat} - \theta) \times Inf_z}$$

$$P + Supply = ET + \Delta ET + Q_{sw} + \Delta Q_{sw} + perc + \Delta perc + \Delta S_{sm}$$

$$\sum_{i=1}^{12} P^i + Supply^i - ET^i - \Delta S_{sm}^i = \sum_{i=1}^{12} Q_{sw}^i + Q_{gw}^i$$

Note: Python script is available to run the WaterPix model, including scripts for the preparation of Inputs compatible with the model as shown below:

```python
import os
from waterpix_etb import wp_gdal
#from waterpix import wp_gdal
data_folder_1 = r"D:\WA_DATA_DOWNLOAD\0_Data_Nagaland\0_Data_Waterpix_Nagaland" ##data folder is created while reprojected (
#data_folder_2 = r"F:\WA_PKM\2_Data_waterpix"
data_folder_3 = r"D:\WA_DATA_DOWNLOAD\0_Data_Nagaland\0_Data_Waterpix_Nagaland\SMoisture"
#data_folder_4 = r"F:\WA_PKM\2_Data_waterpix\SMoisture\gldas"
#data_folder_4 = r"D:\WA_DATA_DOWNLOAD\Cauvery_etb_etg_bb\data"
data_folder_output = r"D:\WA_DATA_DOWNLOAD\0_Data_Nagaland\0_Data_Waterpix_Nagaland"

##to run waterpix_etb, etg_path and etb_path has been inserted...comment if other modules are run..
#%%
### Install R packages before running Waterpix######
# Create input files
wp_gdal.create_input_nc(start_date='2007-06-01', years=7,
                        cellsize =  0.0026949459 * 4 * 5, #5k;0026949459
                        basin_shp = os.path.join(data_folder_1, 'BND_Naga_WGS.shp'),
                        p_path = os.path.join(data_folder_1, 'p', 'p_{yyyy}{mm}.tif'),
                        et_path = os.path.join(data_folder_1, 'et', 'ET_{yyyy}{mm}.tif'),
                        etb_path = os.path.join(data_folder_1, 'etb', 'ETblue_{yyyy}{mm}.tif'),
                        etg_path = os.path.join(data_folder_1, 'etg', 'ETgreen_{yyyy}{mm}.tif'),
                        eto_path = os.path.join(data_folder_1, 'etref', 'ETref_{yyyy}{mm}.tif'),
                        lai_path = os.path.join(data_folder_1, 'lai', 'LAI_{yyyy}{mm}.tif'),
                        swi_path = os.path.join(data_folder_3, 'SWI', 'SM_{yyyy}{mm}.tif'),
                        swio_path = os.path.join(data_folder_3, 'SWIo', 'SM_{yyyy}{mm}.tif'),
                        swix_path = os.path.join(data_folder_3, 'SWIx', 'SM_{yyyy}{mm}.tif'),
                        qratio_path = os.path.join(data_folder_1, 'Qratio', 'QR_{yyyy}.tif'),
                        rainydays_path = os.path.join(data_folder_1, 'n', 'Rainy_Days_{yyyy}{mm}.tif'),
                        thetasat_ras = os.path.join(data_folder_1, 'ThetaSat', 'thetasat_topsoil.tif'),
#                        rootdepth_ras = os.path.join(data_folder_2, 'RootDepth' , 'RootDepth_Cauvery.tif'),
                        rootdepth_ras = os.path.join(data_folder_1, 'RootDepth', 'RootDepth_Nagaland.tif'),
                        input_nc = os.path.join(data_folder_output, 'Nagaland_input_5k_2007_7_24032022.nc')
                        )

#%%
# Run
input_nc = os.path.join(data_folder_output, 'Nagaland_input_5k_2007_7_24032022.nc')
output_nc = os.path.join(data_folder_output, 'Nagaland_output_5k_2007_7_24032022.nc')
#wp_gdal.run(input_nc, output_nc)
wp_gdal.run(input_nc, output_nc, WY_Start_Month = 6, search_width = 2, perc_fit_method = 'smart')

#%%%
# Output nc to tiffs
output_nc = os.path.join(data_folder_output, 'Nagaland_output_5k_2007_7_24032022.nc')
output_folder = os.path.join(data_folder_output, 'output')
wp_gdal.output_nc_to_tiffs(output_nc, output_folder)
```

Figure 3.15: Screenshot showing Python-based WaterPix model.

CHAPTER 4
RESULTS AND DISCUSSION

This chapter deals with the results from the analysis of the WA+ framework w.r.t different basins and sub-basins falling in the state of Nagaland.

4.1 CHIRPS and SSEBop based Yield analysis

Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data is a 30+ year quasi-global rainfall dataset. Spanning 50°S-50°N (and all longitudes), starting in 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series. In the present study, CHIRPS precipitation data from January 01, 2001 to December, 31, 2020 has been used for analysis. Similarly, evapotranspiration data (SSEBop) for the same period was downloaded, and analysed for annual yield, as shown below in Figures 4.1 - 4.3.

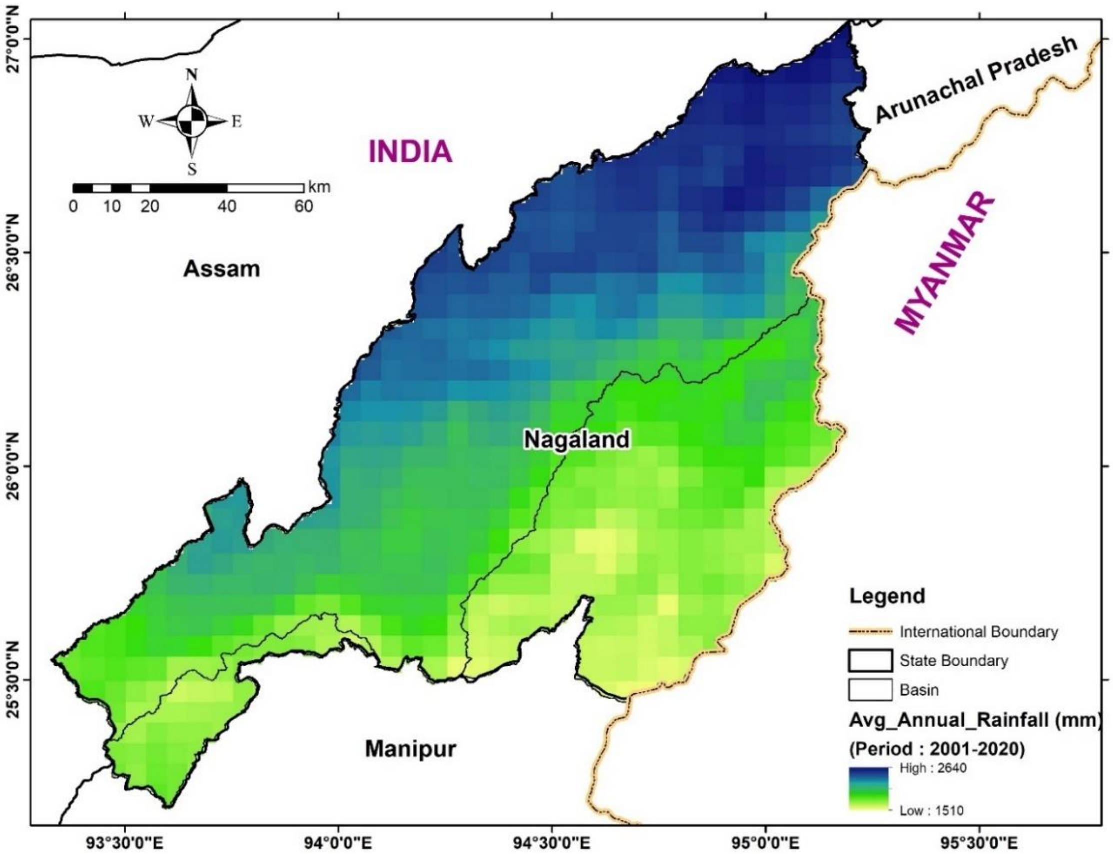


Figure 4.1: Spatial maps showing annual rainfall across Nagaland.

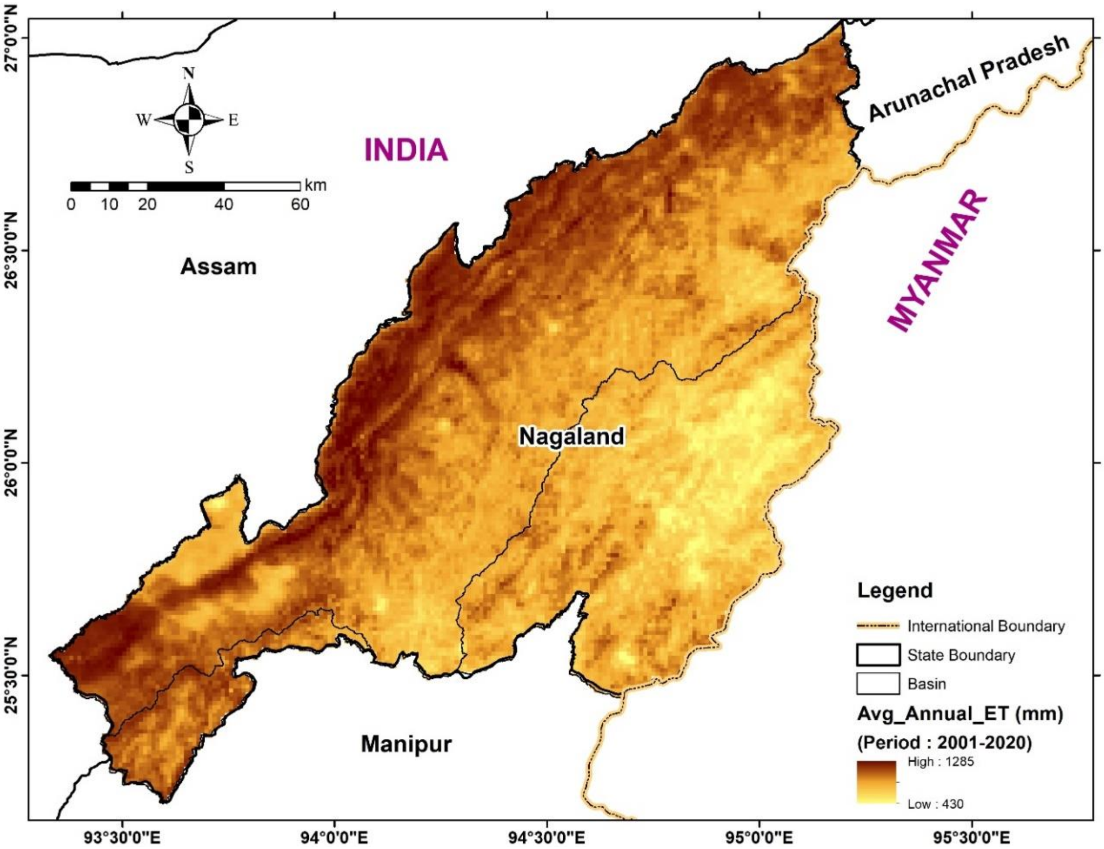


Figure 4.2: Spatial maps showing annual ET across Nagaland.

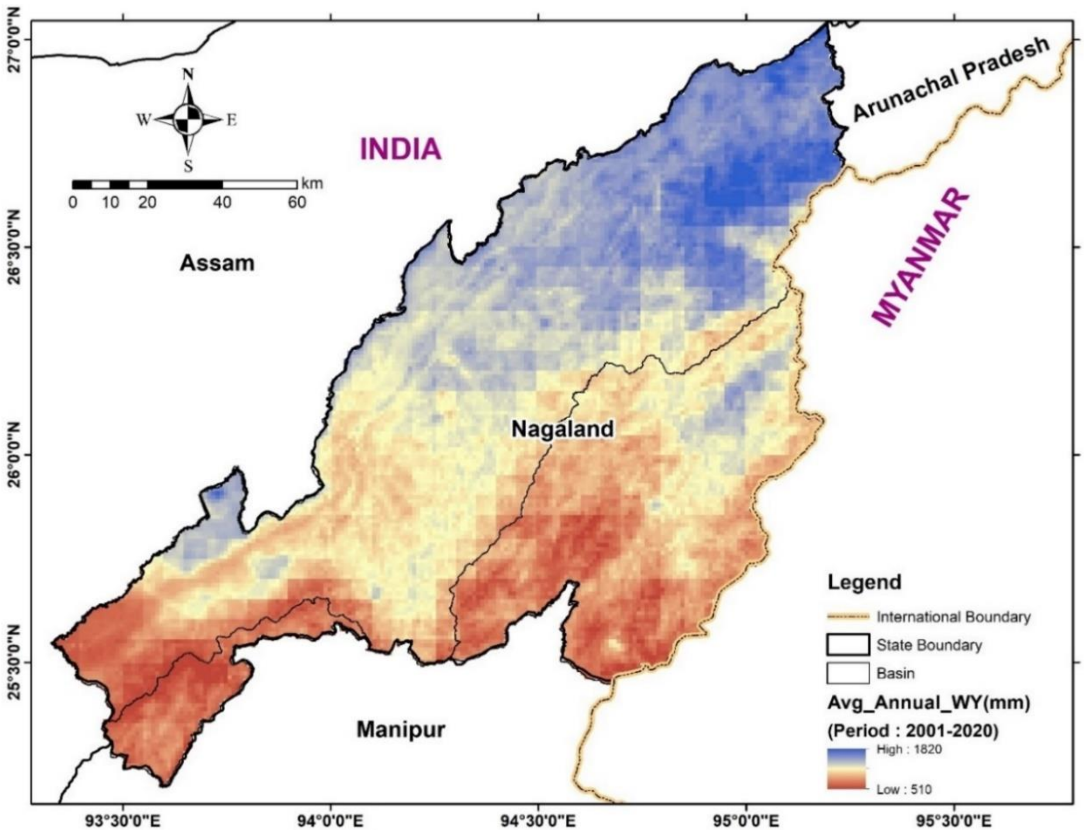


Figure 4.3: Spatial maps showing annual yield across Nagaland.

It can be seen that a considerable amount of rainfall falls in the north and north-eastern parts of Nagaland. This region basically drains into the Brahmaputra basin. Analyses were also carried out to estimate the yield for dry, wet, and mean year and monthly basis as per the CHIRPS data, as shown in Figure 4.4. It was seen that the monsoon season (June-September) dominates the rainfall in Nagaland. Considerable rainfall is also witnessed in the month of April and May just before the monsoon. Rainfall during winter is not significant. Years 2008-09, 2011-12, and 2003-04 were identified as dry year, mean year, and wet year, respectively. Sub-basins falling in the Brahmaputra basin generate maximum yield for the state of Nagaland.

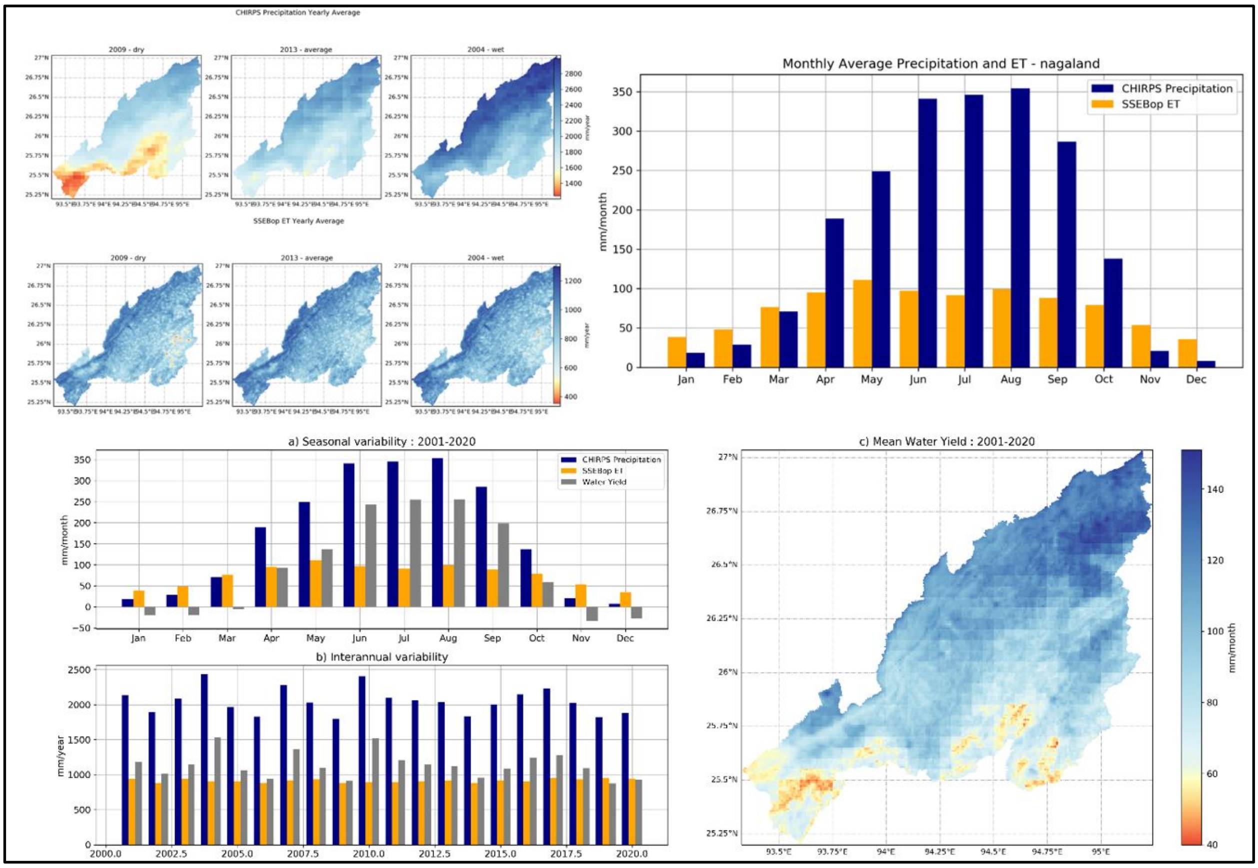


Figure 4.4: Mean water yield using rainfall (CHIRPS) and ET (SSEBop) data.

4.2 WA+ based land use (WALU)

WALU is basically a land use land cover map generated using multi-source data. It is one of the essential inputs before setting up the WA+ model. Globally, WALU has 80 classes (refer Annexure - II), which are further categorized into four classes viz. (i) protected land use, (ii) utilized land use, (iii) modified land use, and (iv) managed water use. These classes are otherwise known as management classes, and all the outputs from the WA+ pertain mostly to these four management classes. The generation of WALU was based on data from eight sources viz. DEM from Hydroshed, LULC from Globcover and NRSC, Population density, MIRCA irrigated, MIRCA rainfed, WDPA, and crop data from IWMI as shown in Figures 4.5 and 4.6. Figure 4.7 shows the WALU map, which is generated using the above datasets.

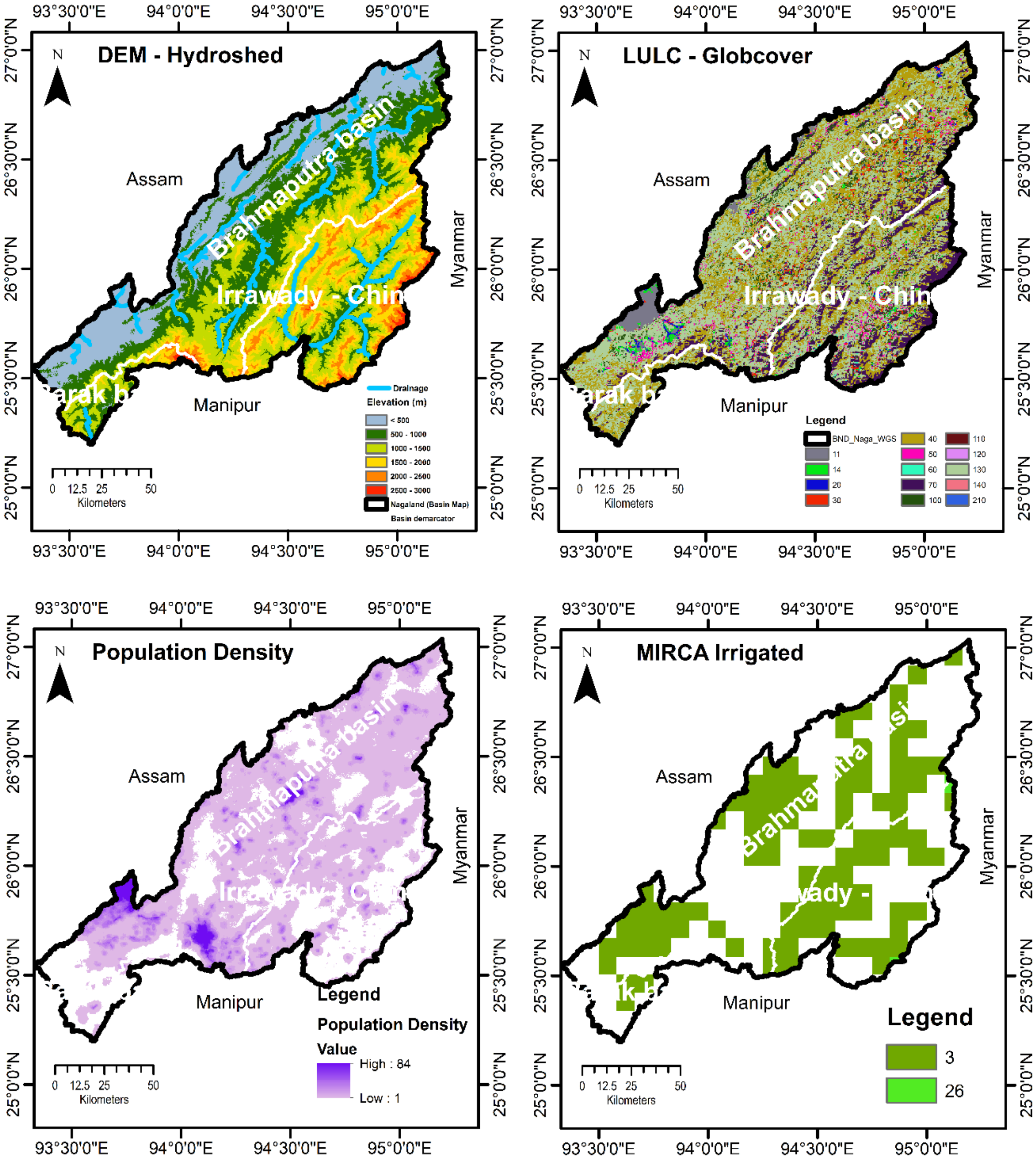


Figure 4.5: Datasets - I used for generation of WA+ based land use (WALU).

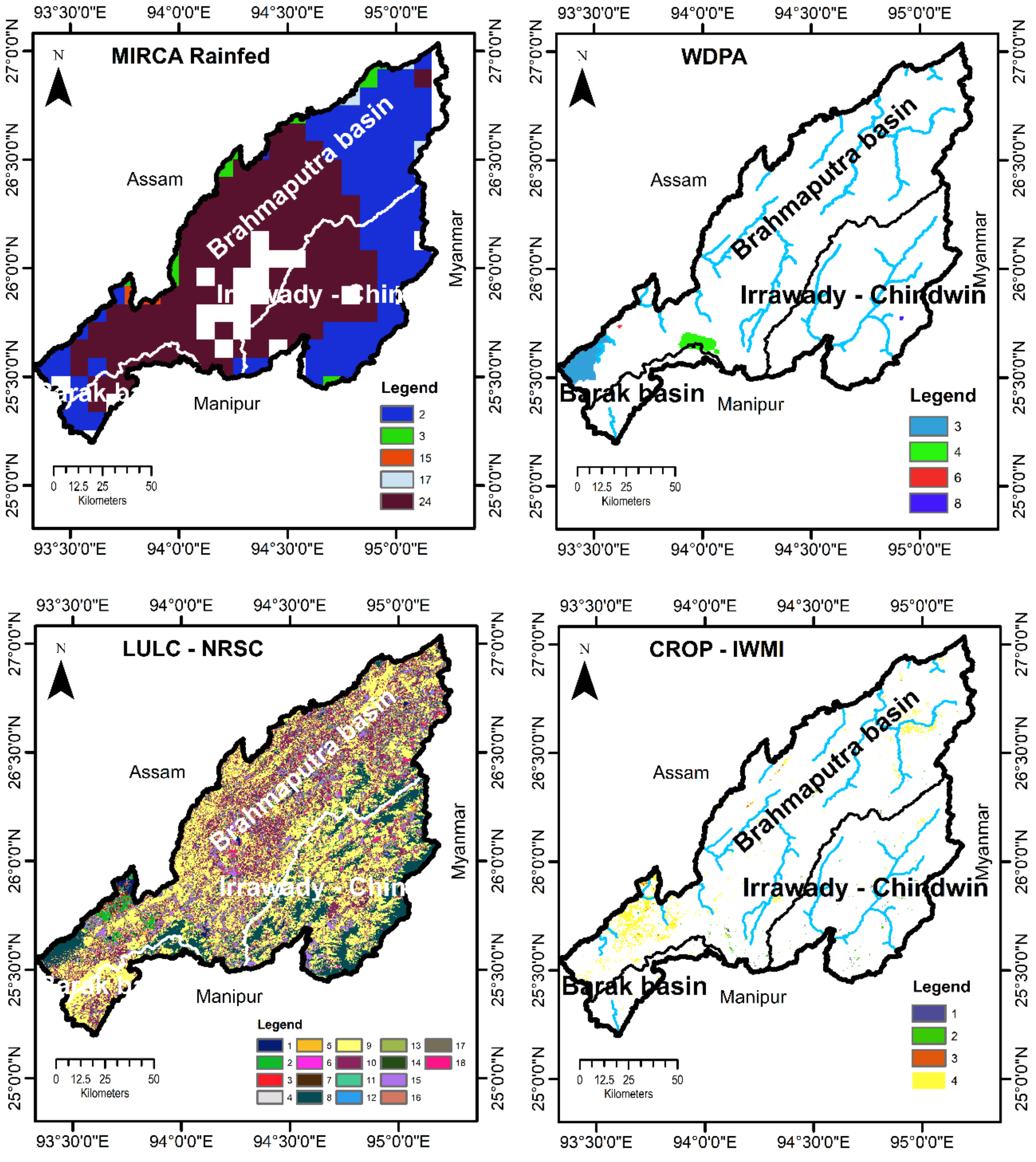


Figure 4.6: Datasets - II used for generation of WA+ based land use (WALU).

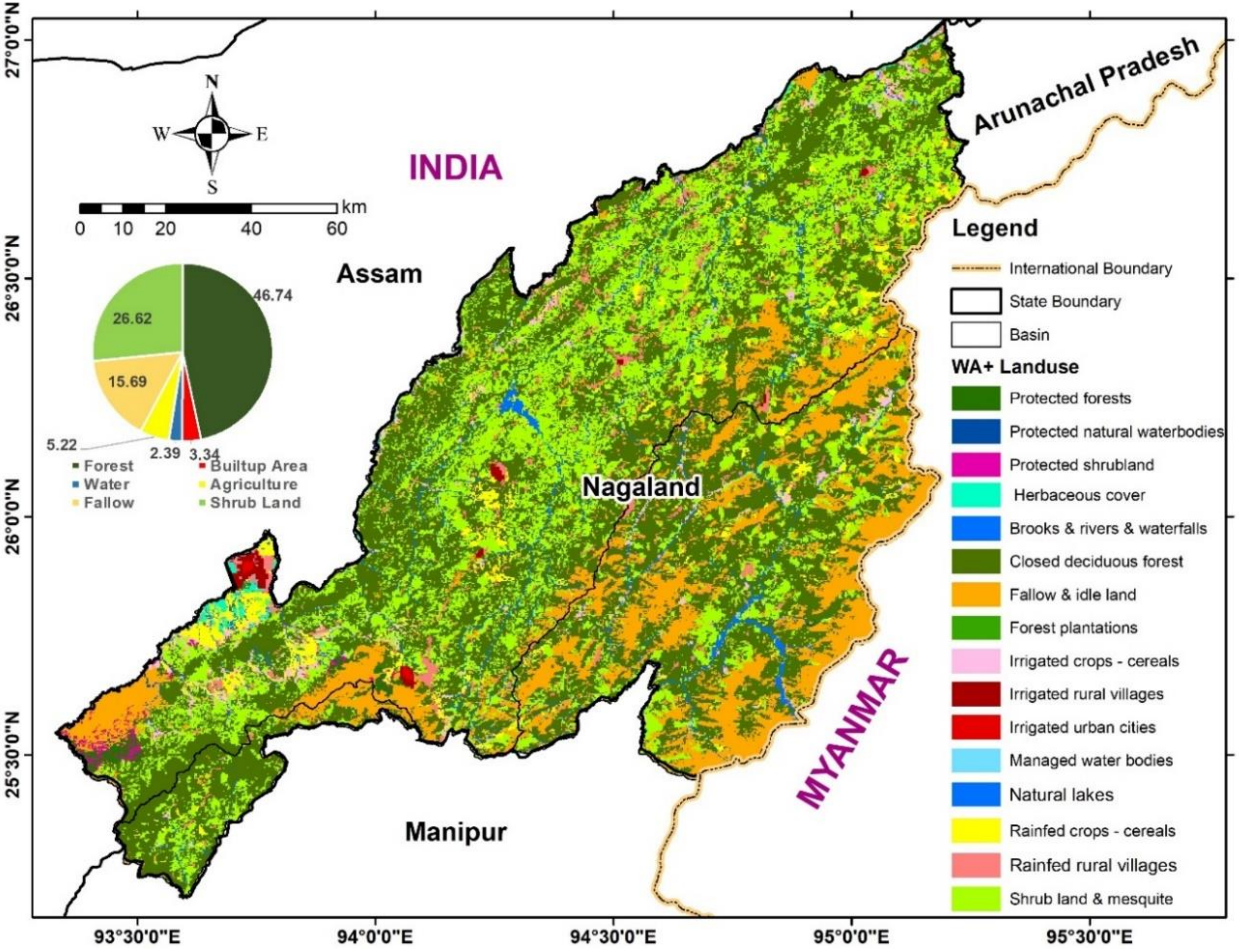


Figure 4.7: Map showing WA+ based land use (WALU).

The generated WALU was analysed for the distribution of areas under each class. It was seen that forest cover dominates in the state, followed by shrubland, fallow land, agriculture, and built-up area. The distribution of the major land use classes is shown in Figure 4.8 below.

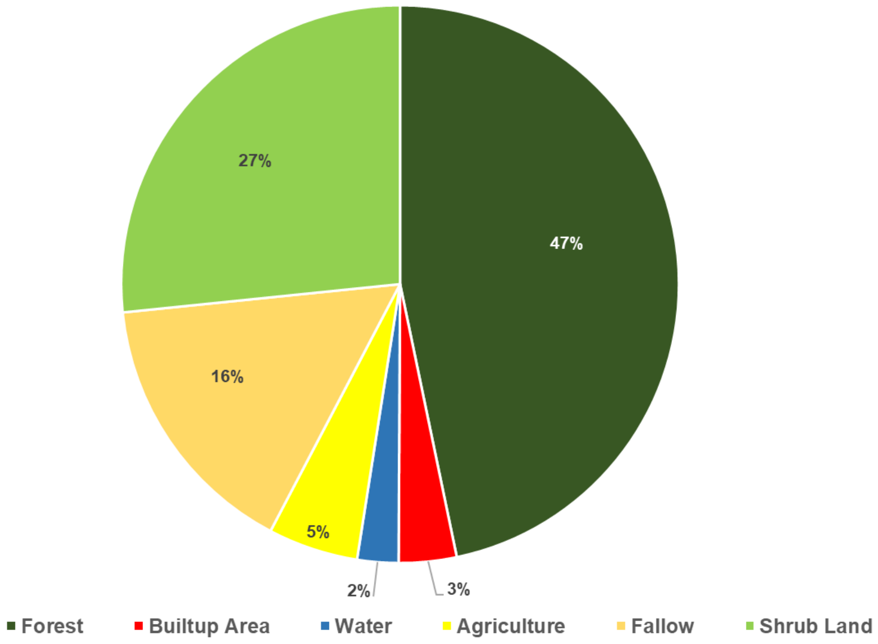


Figure 4.8: Major land use classes as per WALU for Nagaland.

4.3 Development of Sheet 2 (Evapotranspiration)

Sheet 2 quantifies water consumption (evapotranspiration) in a basin. It separates evapotranspiration (ET) into evaporation (E), transpiration (T), and interception loss (I). It also quantifies water consumption w.r.t different management classes and categorizes it into beneficial and non-beneficial losses from the basin. The major outputs from Sheet 2 are:

- Total Evapotranspiration (ET)
- Evaporation loss
- Transpiration loss
- Interception loss
- Non–conventional ET is the ET that occurs by non–natural processes such as steam from cooling towers, greenhouses, respiration by humans and animals, sweating, and turbine spray, among others
- Conventional ET which is the ET that occurs through natural processes
- Beneficial ET is the water consumed as per the intended purpose
- Non-beneficial ET is the water consumed for purposes other than the intended purpose

Major inputs for the generation of Sheet 2 are RS-based evapotranspiration (ET) data, leaf area index (LAI), net primary production (NPP), gross primary production (GPP), daily precipitation, and WALU map. The procedure in generating Sheet 2 has already been discussed in Chapter 3 (Section 3.1.2). The analysis was carried out from 2001-02 to 2019-20. The analysis revealed that an average water loss of 14.91 BCM (~ 900 mm) occurs as evapotranspiration from different basins and sub-basins annually. Tables 4.1 and 4.2 present the annual status of ET consumption in BCM and mm units, respectively. The average monthly ET is presented in Table 4.3. Figures 4.9 and 4.10 show the annual E, T, and I fractions and monthly average ET for the period 2001-2020, respectively.

Table 4.1
Status of annual ET consumption (BCM)

Units: BCM

Year	Total T	Evaporation E				Total ET
		Total I	ET water	ET soil	Total E	
2001-2002	7.15	3.86	0.01	3.98	7.84	14.99
2002-2003	7.80	3.20	0.01	4.20	7.41	15.21
2003-2004	6.58	3.67	0.01	4.74	8.41	14.99
2004-2005	6.41	4.06	0.01	4.41	8.48	14.88
2005-2006	6.67	3.53	0.01	4.18	7.73	14.39
2006-2007	6.89	4.07	0.01	3.91	7.99	14.88
2007-2008	7.74	3.62	0.01	3.99	7.62	15.36
2008-2009	6.87	3.08	0.01	4.48	7.56	14.44
2009-2010	6.62	3.68	0.01	4.05	7.74	14.36
2010-2011	6.49	3.22	0.01	4.91	8.14	14.63
2011-2012	6.50	3.85	0.01	4.38	8.24	14.74
2012-2013	5.98	3.68	0.01	5.25	8.94	14.92
2013-2014	5.27	3.83	0.01	5.56	9.40	14.67
2014-2015	5.46	3.30	0.01	5.87	9.18	14.64
2015-2016	5.70	3.97	0.01	5.07	9.05	14.75
2016-2017	6.27	3.77	0.01	5.22	9.00	15.27
2017-2018	5.85	4.01	0.01	5.55	9.57	15.42
2018-2019	6.81	3.31	0.01	5.19	8.52	15.33
2019-2020	7.59	3.78	0.01	4.06	7.85	15.44
Average	**6.56**	**3.66**	**0.01**	**4.68**	**8.35**	**14.91**

T: Transpiration, I: Interception loss, E: Evaporation, ET: Evapotranspiration, BCM: Billion Cubic Meter (or Km^3)

Table 4.2
Status of annual ET consumption (mm/ year)

Units: mm/ year

Year	Total T	Evaporation E				Total ET
		Total I	ET water	ET soil	Total E	
2001-2002	431.07	232.54	0.63	239.83	473.00	904.07
2002-2003	470.30	192.71	0.63	253.36	446.70	917.00

2003-2004	396.71	221.12	0.67	285.56	507.36	904.07
2004-2005	386.27	244.75	0.63	265.84	511.22	897.50
2005-2006	401.94	213.10	0.62	252.34	466.06	868.00
2006-2007	415.41	245.55	0.58	235.69	481.82	897.23
2007-2008	466.61	218.05	0.64	240.64	459.33	925.95
2008-2009	414.50	185.47	0.62	269.91	456.00	870.50
2009-2010	399.26	221.86	0.60	244.32	466.77	866.03
2010-2011	391.59	193.87	0.70	296.17	490.73	882.32
2011-2012	392.07	232.14	0.65	263.90	496.70	888.76
2012-2013	360.37	222.01	0.69	316.45	539.15	899.52
2013-2014	317.80	230.69	0.73	335.38	566.80	884.60
2014-2015	329.20	198.73	0.67	354.21	553.61	882.81
2015-2016	343.73	239.45	0.62	305.66	545.73	889.46
2016-2017	377.81	227.11	0.64	315.02	542.78	920.59
2017-2018	352.53	241.86	0.67	334.68	577.21	929.74
2018-2019	410.84	199.87	0.73	312.95	513.54	924.39
2019-2020	457.72	227.84	0.60	244.93	473.37	931.09
Average	**395.56**	**220.46**	**0.65**	**282.47**	**503.57**	**899.14**

T: Transpiration, I: Interception loss, E: Evaporation, ET: Evapotranspiration

Table 4.3

Status of average monthly ET consumption

Units: mm/ month

Month	Total T	Evaporation E				Total ET
		Total I	ET water	ET soil	Total E	
Jan	20.92	4.90	0.04	12.10	17.04	37.96
Feb	25.47	6.86	0.04	15.28	22.18	47.65
Mar	39.71	9.18	0.06	26.11	35.35	75.06
Apr	43.44	20.47	0.07	29.81	50.36	93.80
May	52.81	20.32	0.08	36.68	57.08	109.89
Jun	34.43	28.03	0.06	33.30	61.40	95.83
Jul	29.92	29.97	0.05	29.97	59.99	89.91
Aug	30.96	39.91	0.05	26.66	66.61	97.58
Sep	31.00	33.44	0.05	22.42	55.91	86.91
Oct	38.05	17.43	0.06	22.39	39.87	77.92
Nov	29.56	6.83	0.05	16.43	23.31	52.87
Dec	20.31	3.24	0.04	11.45	14.73	35.04
Average	**33.05**	**18.38**	**0.05**	**23.55**	**41.99**	**75.03**

T: Transpiration, I: Interception loss, E: Evaporation, ET: Evapotranspiration

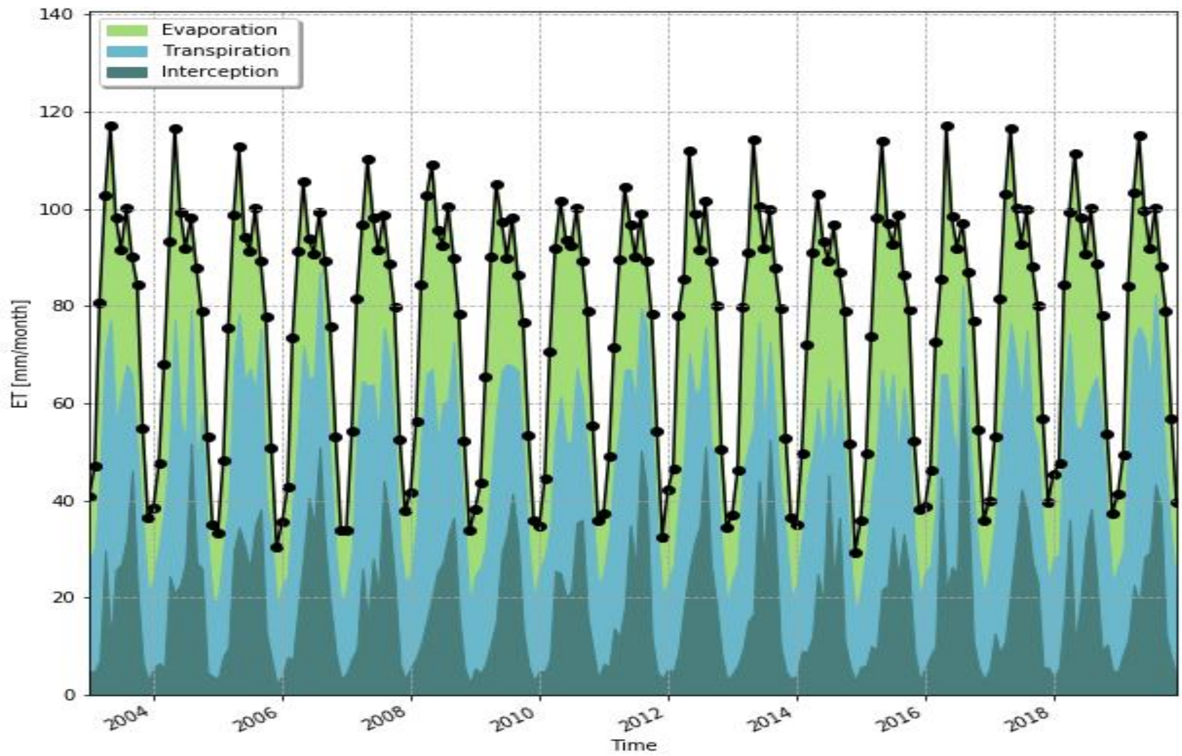


Figure 4.9: E, T and I fractions for the period 2001-2020.

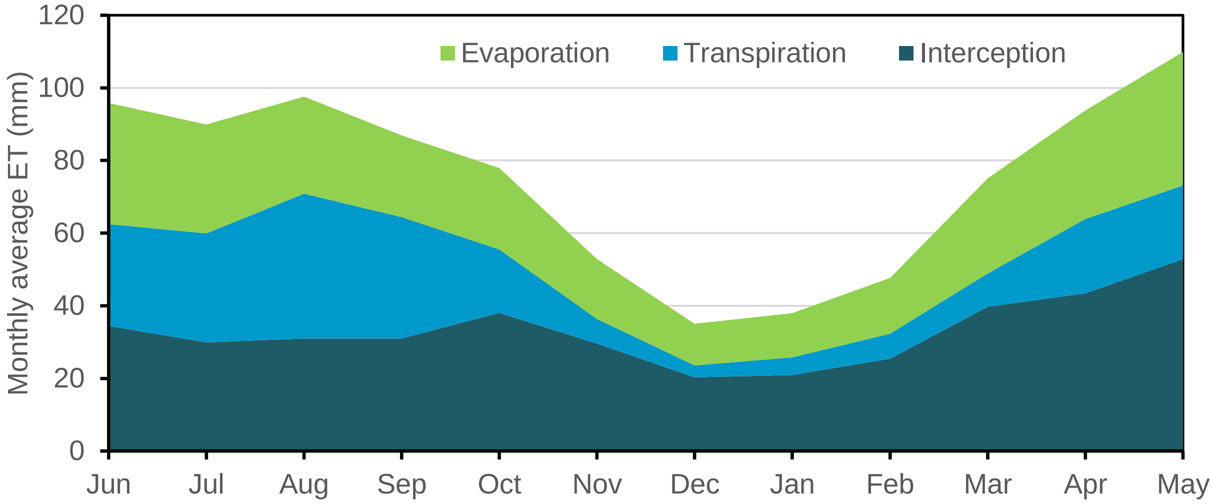


Figure 4.10: Monthly average E, T, and I fractions for the period 2001-2020.

For demand-side water management, knowing the water consumption w.r.t different land use classes helps the water manager to undertake appropriate measures to optimize the water use. Tables 4.4 and 4.5 present the ET consumption pattern for the four management classes for the dry year and wet year, respectively. The screenshots of Sheet 2 for the dry and wet years is shown in Figures 4.11 and 4.12, respectively. The total ET in a wet year is higher than in dry year because of the greater ETgreen contribution from the increased rainfall.

WA+ also segregates the total evapotranspiration into three more classes viz. non-manageable (ET from Protected land use), manageable (ET from Utilized land use), and managed (ET from Modified land use and Managed water use). It can be seen that a considerable chunk of ET (75.88%) is manageable. This implies that this portion of ET, which is a significant loss from the system, has the potential to be managed through scientific measures. Almost 23% of ET loss is managed through rainfed and irrigated agriculture. Figure 4.13 shows the distribution of ET into non-manageable, manageable, and managed for the state. Based on the intended purpose of use, ET can also be categorized into beneficial and non-beneficial components. A higher beneficial percentage indicates a well-performing basin, wherein water loss from the system is meeting the intended purpose for which it was meant. Equally, a higher value of non-beneficial components signals basin managers to adopt better conservation and management steps. The distribution of ET into beneficial and non-beneficial components is shown in Figure 4.14. It can be seen that there is ample scope for managing the water resources in the state beneficially. The beneficial ET loss mainly contributes to the environment, followed by agriculture, leisure, energy, and the economy. Figure 4.15 indicates the sectors that contributed beneficially to the ET loss. ET and its different fractions for the period 2001-2020 is shown in Figure 4.16.

Table 4.4

Status of ET consumption w.r.t WALU-based Management classes (Dry year)

Units: BCM

WALU class	Class	Area (sq.km.)	ET (BCM)	Transpiration (BCM)	Evaporation		
					Water	Soil	Interception
Utilized land use (ULU)	Natural grasslands	92.90	0.08	0.03	0.00	0.03	0.01
	Shrubland	4366.82	3.88	1.84	0.00	1.14	0.90
	Natural water bodies	391.00	0.33	0.15	0.10	0.00	0.08
	Forest	7574.86	6.66	3.20	0.00	2.00	1.46
	Sub-total	**12425.58**	**10.94**	**5.22**	**0.10**	**3.16**	**2.45**
Protected land use (PLU)	Shrubland	47.72	0.05	0.02	0.00	0.01	0.01
	Nat. water bodies	4.31	0.00	0.00	0.00	0.00	0.00
	Forest	82.39	0.08	0.04	0.00	0.03	0.02
	Sub-total	**134.42**	**0.14**	**0.06**	**0.00**	**0.04**	**0.03**
Modified land use (MLU)	Others	2601.70	2.22	0.99	0.00	0.85	0.38
	Settlements	467.70	0.39	0.19	0.00	0.13	0.07
	Forest plantations	1.27	0.00	0.00	0.00	0.00	0.00
	Rainfed crops	580.58	0.45	0.21	0.00	0.15	0.09
	Sub-total	**3651.25**	**3.06**	**1.38**	**0.00**	**1.14**	**0.54**
Managed water use (MWU)	Residential	86.55	0.07	0.02	0.00	0.03	0.01
	Managed water bodies	0.85	0.00	0.00	0.00	0.00	0.00
	Irrigated crops	285.70	0.24	0.11	0.00	0.08	0.05
	Sub-total	**373.10**	**0.31**	**0.14**	**0.00**	**0.11**	**0.06**
	Grand Total	**16584.35**	**14.44**	**6.81**	**0.10**	**4.45**	**3.08**

Table 4.5

Status of ET consumption w.r.t WALU-based Management classes (Wet year)

Units: BCM

WALU class	Class	Area (sq.km.)	ET (BCM)	Transpiration (BCM)	Evaporation		
					Water	Soil	Interception
Utilized land use (ULU)	Natural grasslands	92.90	0.08	0.04	0.00	0.03	0.02
	Shrubland	4366.82	4.03	1.78	0.00	1.16	1.09
	Nat. water bodies	391.00	0.34	0.14	0.11	0.00	0.09
	Forest	7574.86	6.93	3.06	0.00	2.12	1.75
	Sub-total	**12425.58**	**11.38**	**5.03**	**0.11**	**3.31**	**2.94**
Protected land use (PLU)	Shrubland	47.72	0.05	0.02	0.00	0.01	0.02
	Natural water bodies	4.31	0.00	0.00	0.00	0.00	0.00
	Forest	82.39	0.08	0.04	0.00	0.03	0.02
	Sub-total	**134.42**	**0.14**	**0.06**	**0.00**	**0.04**	**0.04**
Modified land use (MLU)	Others	2601.70	2.26	0.88	0.00	0.95	0.42
	Settlements	467.70	0.41	0.18	0.00	0.14	0.09
	Forest plantations	1.27	0.00	0.00	0.00	0.00	0.00
	Rainfed crops	580.58	0.48	0.21	0.00	0.17	0.11
	Sub-total	**3651.25**	**3.15**	**1.28**	**0.00**	**1.26**	**0.61**
Managed water use (MWU)	Residential	86.55	0.07	0.02	0.00	0.03	0.01
	Managed water bodies	0.85	0.00	0.00	0.00	0.00	0.00
	Irrigated crops	285.70	0.26	0.12	0.00	0.08	0.06
	Sub-total	**373.10**	**0.33**	**0.14**	**0.00**	**0.11**	**0.07**
	Grand Total	**16584.35**	**15.00**	**6.51**	**0.11**	**4.72**	**3.67**

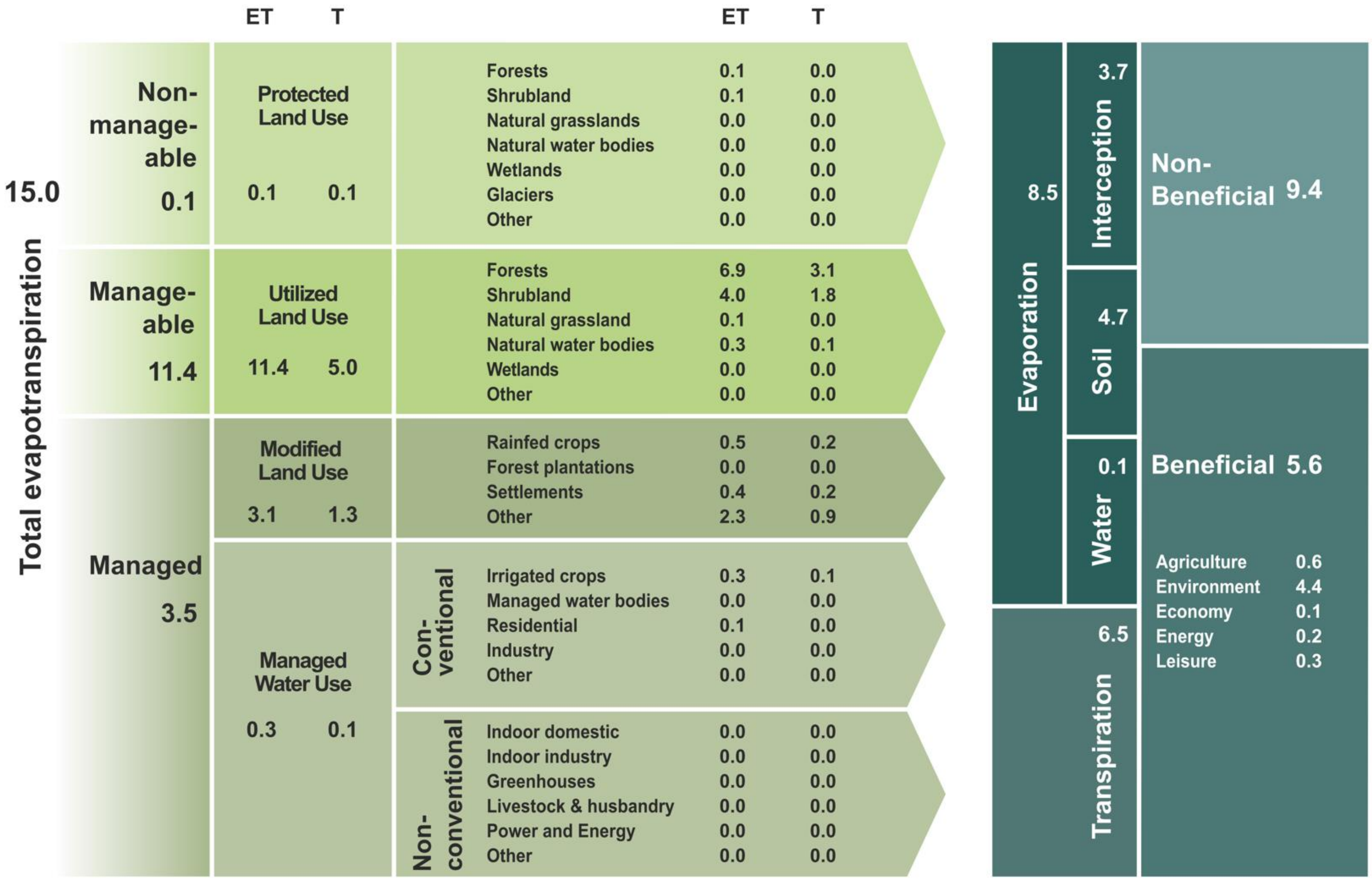


Figure 4.11: Sheet 2 generated for the wet year (2003-04).

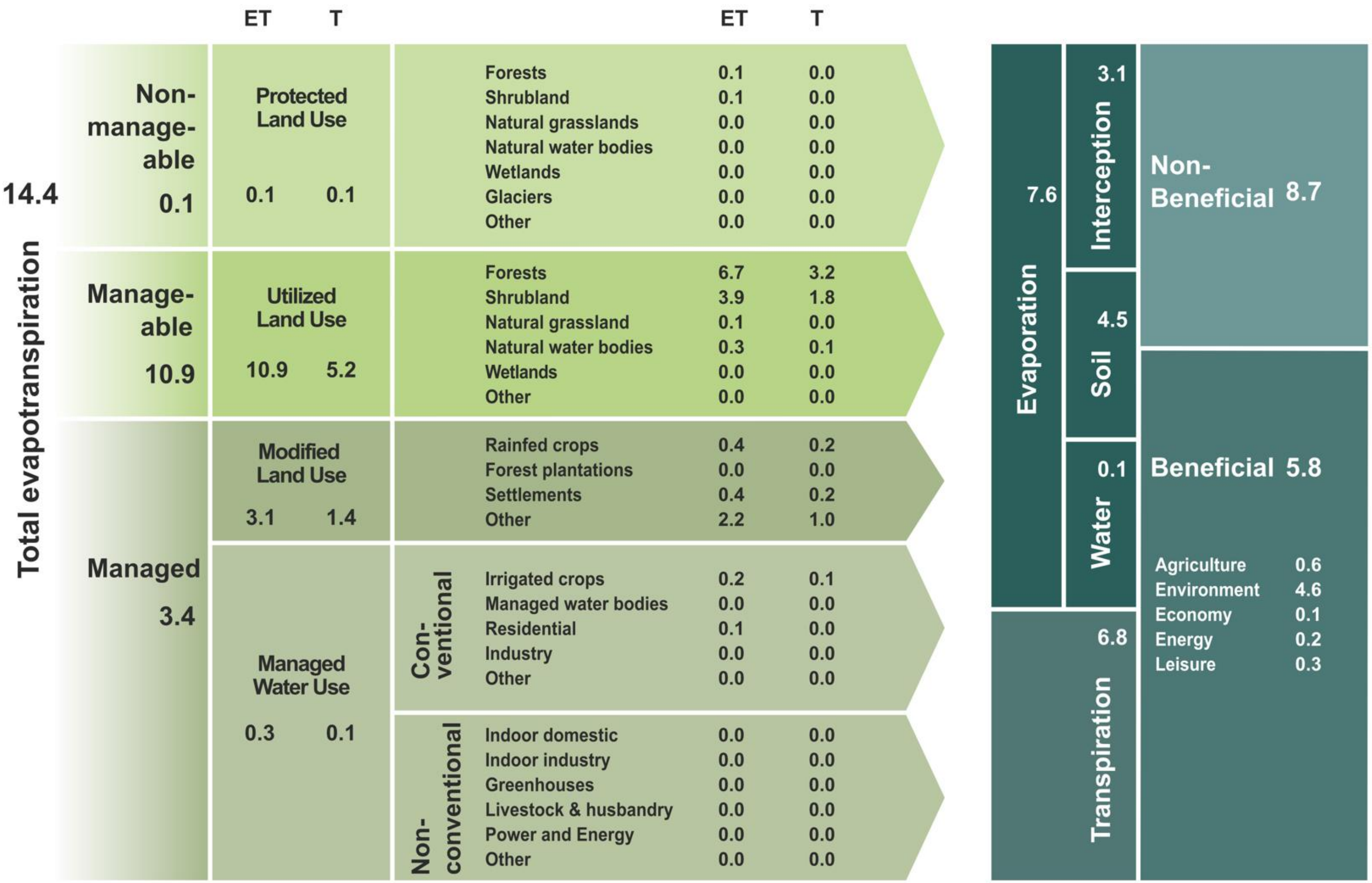


Figure 4.12: Sheet 2 generated for the dry year (2008-09).

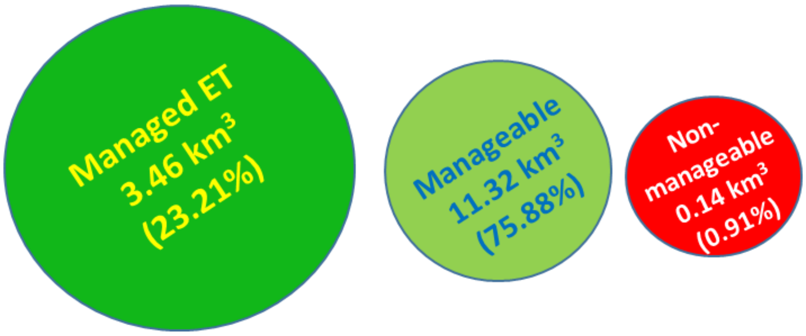


Figure 4.13: Distribution of ET into non-manageable, manageable, and managed class.

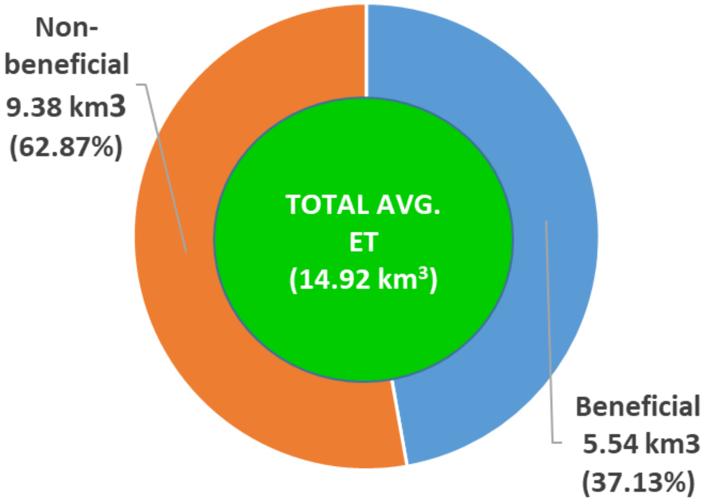
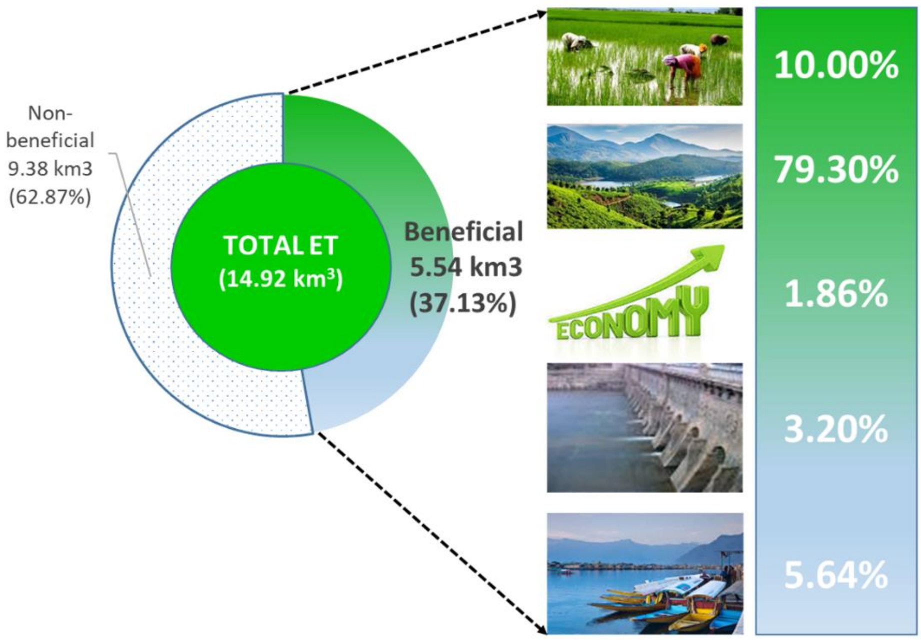


Figure 4.14: Distribution of ET into beneficial and non-beneficial classes.



Note: Agriculture; Environment; Economy; Energy; Leisure

Figure 4.15: Beneficial ET contribution to different sectors.

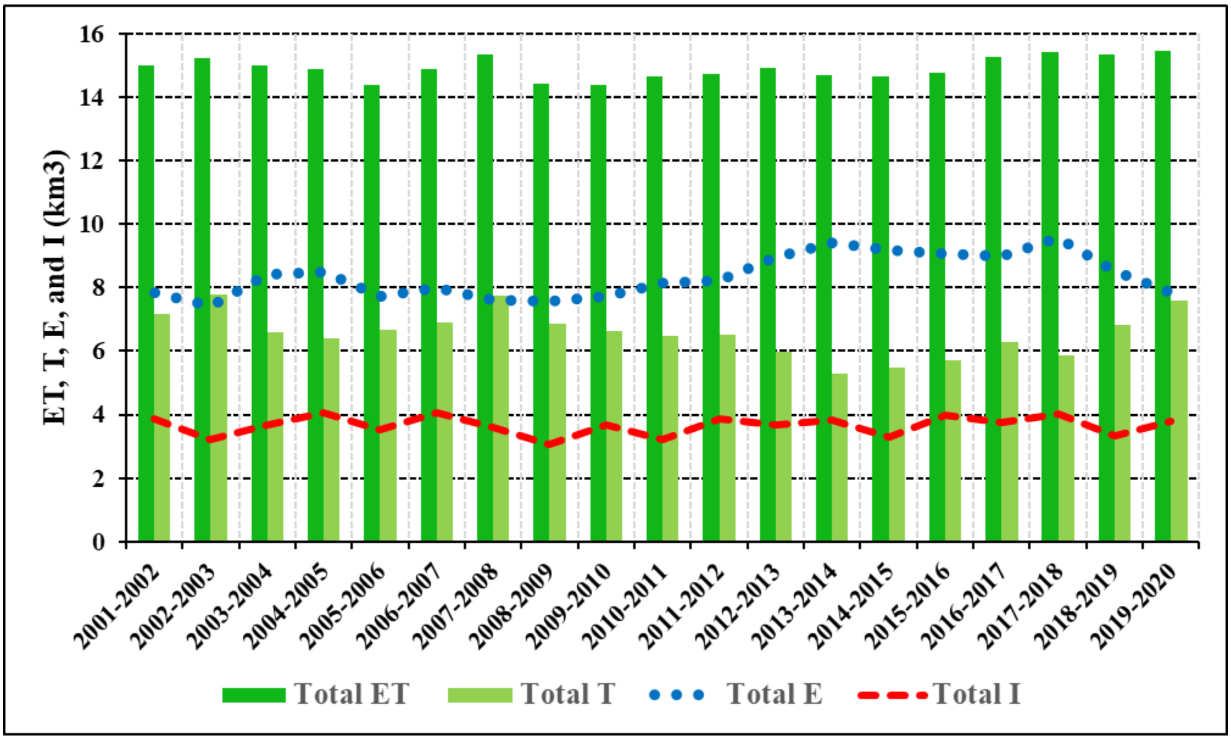


Figure 4.16: ET and its different fractions for the period 2001-2020.

4.4 Development of Sheet 3 (Agricultural services)

Sheet 3 provides crop-wise agricultural water consumption (km^3/year), LP (kg/ha/year), and WP (kg/m^3) on monthly and yearly basis. Agriculture is one of the major consumers of water in most of the basins or states. Therefore, knowing the agricultural water consumption and its productivity is important for planning and management. The procedure in generating Sheet 3 has already been discussed in Ch. 3 (Sec. 3.1.3). The analysis was carried out from 2001-02 to 2019-20. The concept of green and blue water has been introduced in developing Sheet 3. Accordingly, rainfed areas (green water) and irrigated areas (green and blue water) have been segregated. Irrigation consumes the largest proportion of blue water. Therefore, assessing agricultural water consumption (ET Green and ET Blue) is essential for managing water resources in agriculture and food security of the basin. Equally important is to know the corresponding yield from the consumed water. Yield from the blue water consumed is also known as 'incremental yield'. Sheet 3 provides the estimate of WP and LP. This helps in identifying areas with low or high productivity, which guides us in knowing the cause and suggesting measures for improvement. In the study, cereals, feed crops, and other crops were considered for analysis. The agricultural water consumptions along with the land productivity and water productivity of the different crops were assessed. Sheet 3 has two parts. Sheet 3 (part I) shows the agricultural water consumption in the basin, and Sheet 3 (part II) shows the land productivity (kg/ha/year) and water productivity (kg/m^3). Fig. 4.17 and Fig. 4.18 show the land and water productivity in the basin for dry and wet years, respectively. It can be observed from Figs. 4.17a and 4.18a that the basin has a total agricultural water consumption of 2.50 BCM and 2.55 BCM, predominantly met from the rainfall during a dry and wet year, respectively. The LP and WP during a dry year for rainfed rice are 3707.95 kg/ha/year and 0.93 kg/$m^{3,}$ respectively. However, the land and water productivity reduced during a wet year to 3097.48 kg/ha/year and 0.76 kg/m^3, respectively. A higher productivity was seen in the case of irrigated rice. The LP and WP during a dry year for irrigated rice are 7273.31 kg/ha/year and 2.32 kg/m^3, respectively. However, during a wet year, the LP and WP become 7152.46 kg/ha/year and 2.56 kg/m^3, respectively. Overall, the average land productivity is found to vary from 2564.2 to 4028.3 kg/ha/year and 6149.6 to 7818.9 kg/ha/year during the period of 2001-02 to 2019-20, respectively, for rainfed and irrigated cereals. The region has an average WP of 0.83 kg/m^3 and 2.2 kg/m^3, respectively for rainfed and irrigated cereals. Overall, the WP is found to vary from 0.66 to 1.02 kg/m^3 (with an overall avg. of 0.83 kg/m^3) and 1.90 to 2.56 kg/m^3 (with an overall avg. of 2.2 kg/m^3) during the period of 2001-02 to 2019-20, respectively for rainfed and irrigated cereals (Table 5.4b). District-wise average LP and WP of the irrigated and rainfed cereals for the period 2001-2020 is shown in Fig. 4.19. The area and production statistics as per Nagaland Statistical Handbook, 2021 is shown in Fig. 4.20. The details on productivity for cereal crops can be seen in Tables 4.6 – 4.9. Figs. 4.21 and 4.22 show the spatial maps LP and WP of rainfed and irrigated rice for the dry and wet years, respectively.

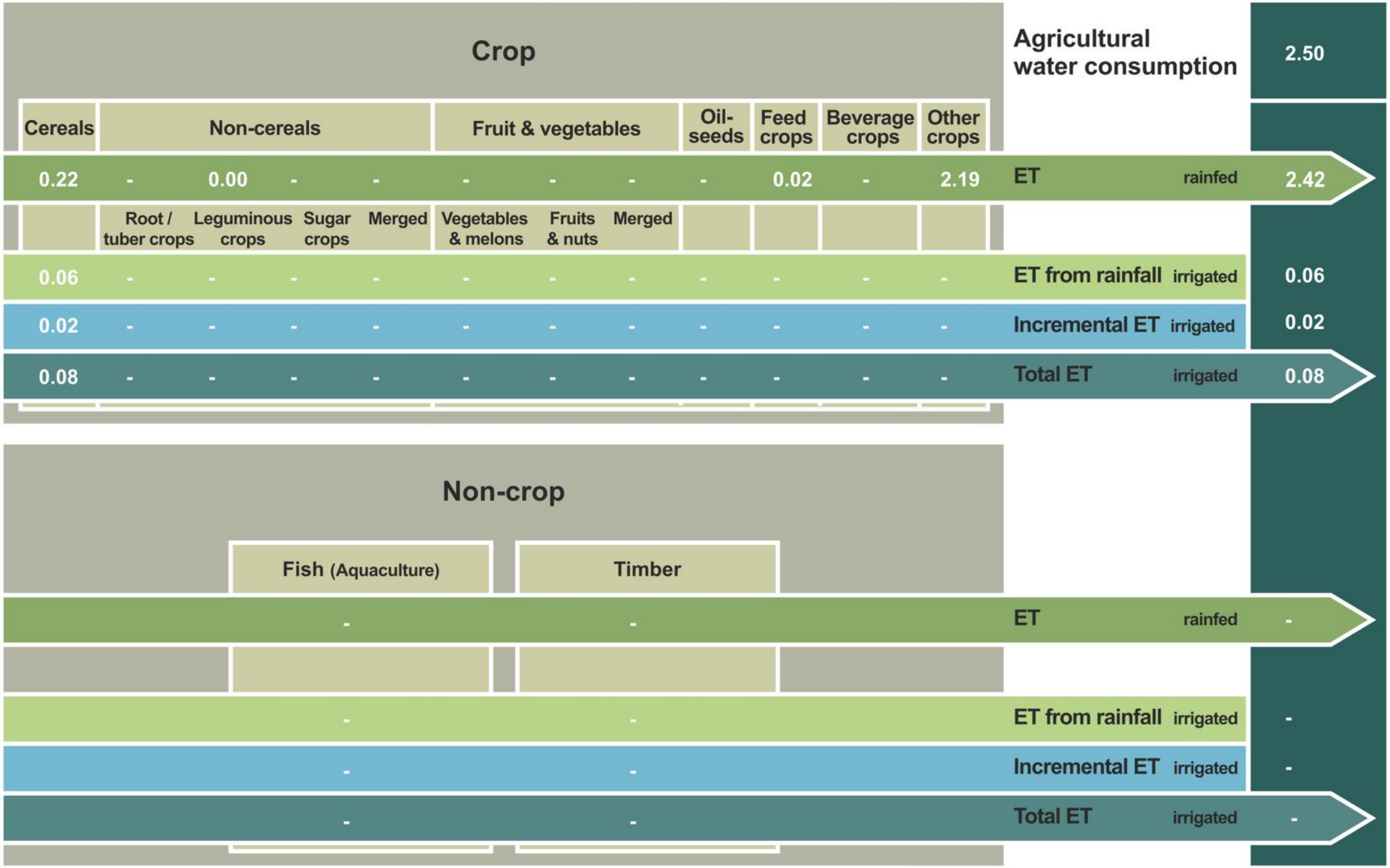


Figure 4.17a: Sheet 3 (Part 1) – agricultural water consumption during a dry year.

		Crop												
		Cereals	Non-cereals				Fruit & vegetables			Oil-seeds	Feed crops	Beverage crops	Other crops	
			Root / tuber crops	Leguminous crops	Sugar crops	Merged	Vegetables & melons	Fruits & nuts	Merged					
Land productivity	Yield	3708	-	2557	-	-	-	-	-	-	9371	-	34705	rainfed
	Yield from rainfall	6000	-	-	-	-	-	-	-	-	-	-	-	irrigated
	Incremental yield	1152	-	-	-	-	-	-	-	-	-	-	-	irrigated
	Total yield	7152	-	-	-	-	-	-	-	-	-	-	-	irrigated
Water productivity	WP	0.93	-	0.78	-	-	-	-	-	-	1.20	-	4.02	rainfed
	WP from rainfall	2.98	-	-	-	-	-	-	-	-	-	-	-	irrigated
	Incremental WP	1.48	-	-	-	-	-	-	-	-	-	-	-	irrigated
	Total WP	2.56	-	-	-	-	-	-	-	-	-	-	-	irrigated

		Non-crop				
		Livestock		Fish (Aquaculture)	Timber	
		Meat	Milk			
Land productivity	Yield	-	-	-	-	rainfed
	Yield from rainfall	-	-	-	-	irrigated
	Incremental yield	-	-	-	-	irrigated
	Total yield	-	-	-	-	irrigated
Water productivity	WP	-	-	-	-	rainfed
	WP from rainfall	-	-	-	-	irrigated
	Incremental WP	-	-	-	-	irrigated
	Total WP	-	-	-	-	irrigated

Figure 4.17b: Sheet 3 (Part 2) – land and water productivity during a dry year.

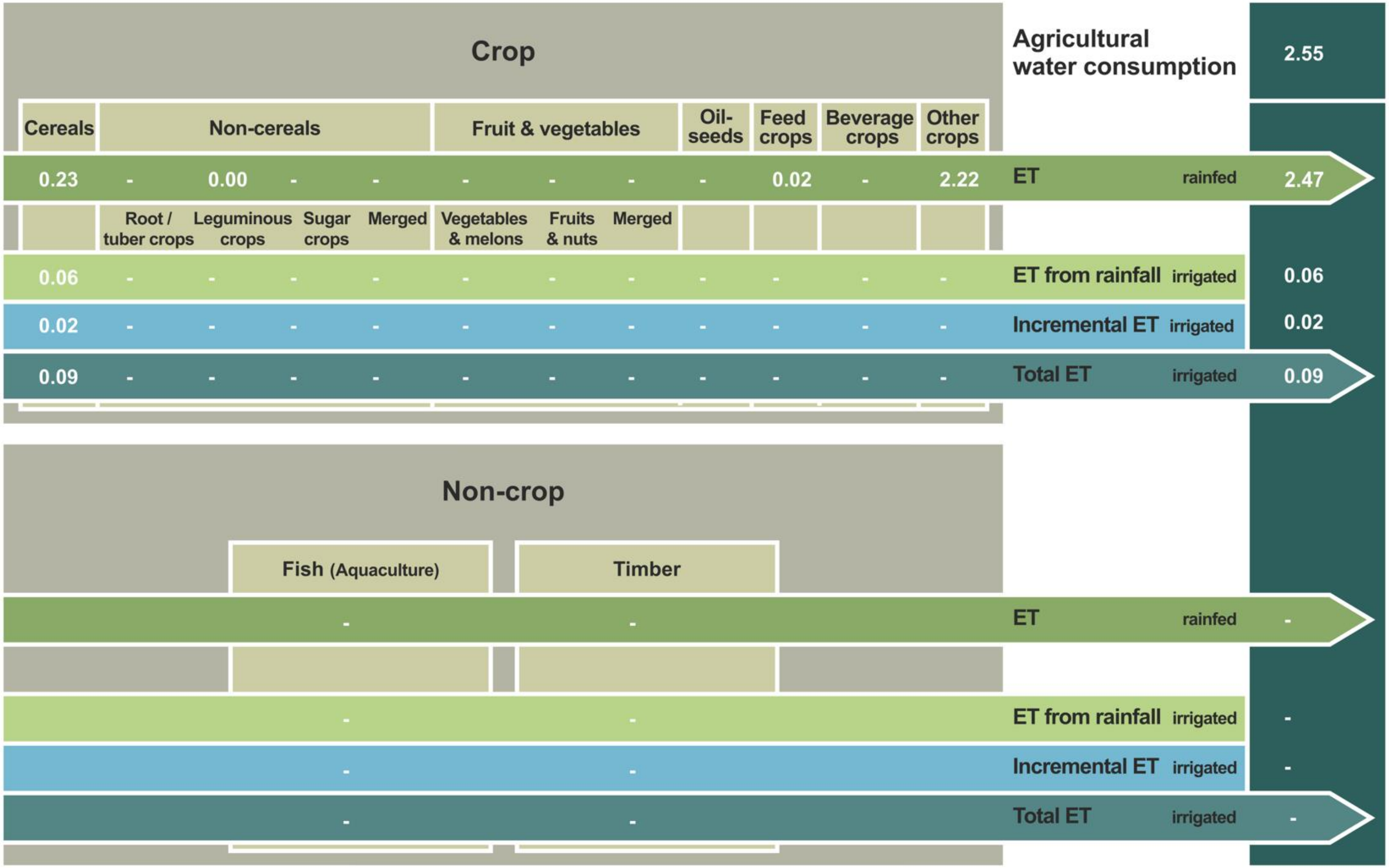


Figure 4.18a: Sheet 3 (Part 1) – agricultural water consumption during a wet year.

Crop

		Cereals	Non-cereals				Fruit & vegetables			Oil-seeds	Feed crops	Beverage crops	Other crops		
			Root / tuber crops	Leguminous crops	Sugar crops	Merged	Vegetables & melons	Fruits & nuts	Merged						
Land productivity		3097	-	2354	-	-	-	-	-	-	9710	-	30585	Yield	rainfed
		6689	-	-	-	-	-	-	-	-	-	-	-	Yield from rainfall	irrigated
		585	-	-	-	-	-	-	-	-	-	-	-	Incremental yield	irrigated
		7273	-	-	-	-	-	-	-	-	-	-	-	Total yield	irrigated
Water productivity		0.76	-	0.66	-	-	-	-	-	-	1.13	-	3.49	WP	rainfed
		2.87	-	-	-	-	-	-	-	-	-	-	-	WP from rainfall	irrigated
		0.72	-	-	-	-	-	-	-	-	-	-	-	Incremental WP	irrigated
		2.32	-	-	-	-	-	-	-	-	-	-	-	Total WP	irrigated

Non-crop

	Livestock		Fish (Aquaculture)	Timber		
	Meat	Milk				
Land productivity	-	-	-	-	Yield	rainfed
	-	-	-	-	Yield from rainfall	irrigated
	-	-	-	-	Incremental yield	irrigated
	-	-	-	-	Total yield	irrigated
Water productivity	-	-	-	-	WP	rainfed
	-	-	-	-	WP from rainfall	irrigated
	-	-	-	-	Incremental WP	irrigated
	-	-	-	-	Total WP	irrigated

Figure 4.18b: Sheet 3 (Part 2) – land and water productivity during a wet year.

Table 4.6

Cereal (Rice rainfed) productivity across Nagaland (552.21 km^2)

Year	Yield	Yield due to rainfall	Incremental yield	WP	WP from rainfall	Incremental WP	WC	WC_Blue water	WC_Green water
2001-2002	3623.10	3622.43	0.66	0.89	0.00	0.96	0.23	0.02	0.21
2002-2003	3678.72	3678.72	0.00	0.93	0.00	0.95	0.22	0.01	0.21
2003-2004	3097.48	3095.73	1.75	0.76	0.01	0.81	0.23	0.01	0.21
2004-2005	3097.22	3094.46	2.76	0.78	0.01	0.82	0.22	0.01	0.21
2005-2006	3491.73	3491.73	0.00	0.88	0.00	0.90	0.22	0.00	0.21
2006-2007	4028.30	4025.18	3.12	1.02	0.02	1.07	0.22	0.01	0.21
2007-2008	3661.55	3630.12	31.42	0.91	0.11	0.98	0.22	0.02	0.21
2008-2009	3707.95	3682.59	25.36	0.93	0.10	0.99	0.22	0.01	0.21
2009-2010	3650.33	3642.80	7.52	0.92	0.04	0.97	0.22	0.01	0.21
2010-2011	3236.33	3095.79	140.54	0.80	0.33	0.86	0.22	0.02	0.20
2011-2012	3547.10	3524.01	23.09	0.88	0.08	0.95	0.22	0.02	0.21
2012-2013	3298.74	3266.20	32.55	0.81	0.11	0.87	0.22	0.02	0.21
2013-2014	2867.56	2813.86	53.70	0.70	0.15	0.76	0.23	0.02	0.21
2014-2015	2564.20	2538.89	25.31	0.66	0.09	0.70	0.21	0.02	0.20
2015-2016	3099.52	3099.52	0.00	0.78	0.00	0.78	0.22	0.00	0.22
2016-2017	2927.56	2927.46	0.11	0.74	0.00	0.75	0.22	0.00	0.22
2017-2018	3176.88	3176.88	0.00	0.78	0.00	0.80	0.22	0.00	0.22
2018-2019	2720.39	2720.31	0.08	0.68	0.00	0.70	0.22	0.01	0.22
2019-2020	3574.79	3574.79	0.00	0.89	0.00	0.90	0.22	0.00	0.22
Average	**3317.10**	**3299.70**	**17.40**	**0.83**	**0.05**	**0.87**	**0.22**	**0.01**	**0.21**

Yield in kg/ha; WP in kg/ m^3; WC (Water consumption) in km^3;

Table 4.7
Cereal (Rice irrigated) productivity across Nagaland (275.8 km^2)

Year	Yield	Yield due to rainfall	Incremental yield	WP	WP from rainfall	Incremental WP	WC	WC_Blue water	WC_Green water
2001-2002	7445.87	6219.36	1226.51	2.37	1.24	2.89	0.09	0.03	0.06
2002-2003	7277.18	6175.34	1101.84	2.13	0.96	2.71	0.09	0.03	0.06
2003-2004	7273.31	6688.66	584.65	2.32	0.72	2.87	0.09	0.02	0.06
2004-2005	7179.55	6397.54	782.02	2.31	0.97	2.79	0.09	0.02	0.06
2005-2006	6842.77	5361.66	1481.11	2.37	1.53	2.79	0.08	0.03	0.05
2006-2007	6978.99	6364.95	614.05	2.20	0.70	2.78	0.09	0.02	0.06
2007-2008	7818.97	6673.22	1145.75	2.24	1.04	2.80	0.10	0.03	0.07
2008-2009	7152.46	6000.28	1152.18	2.56	1.48	2.98	0.08	0.02	0.06
2009-2010	6691.24	6074.36	616.88	2.33	0.87	2.81	0.08	0.02	0.06
2010-2011	6971.47	5915.49	1055.97	2.31	1.25	2.72	0.08	0.02	0.06
2011-2012	6460.23	5295.87	1164.36	2.17	1.13	2.72	0.08	0.03	0.05
2012-2013	6665.30	5340.38	1324.92	2.21	1.40	2.58	0.08	0.03	0.06
2013-2014	6358.93	5015.37	1343.56	2.18	1.27	2.70	0.08	0.03	0.05
2014-2015	6149.64	4814.91	1334.73	2.08	1.27	2.53	0.08	0.03	0.05
2015-2016	6607.47	6271.39	336.08	2.16	0.54	2.58	0.08	0.02	0.07
2016-2017	6926.45	6072.54	853.91	2.07	0.94	2.48	0.09	0.02	0.07
2017-2018	6516.37	5275.50	1240.87	1.90	1.27	2.14	0.09	0.03	0.07
2018-2019	6637.39	4800.83	1836.56	1.95	1.37	2.32	0.09	0.04	0.06
2019-2020	6487.07	5669.26	817.81	1.93	0.79	2.44	0.09	0.03	0.06
Average	**6865.30**	**5811.94**	**1053.35**	**2.20**	**1.09**	**2.66**	**0.09**	**0.03**	**0.06**

Yield in kg/ha; WP in kg/ m^3; WC (Water consumption) in km^3;

Table 4.8
Cereal (Maize) productivity across Nagaland (74.2 km^2)

Year	Yield	Yield due to rainfall	Incremental yield	WP	WP from rainfall	Incremental WP	WC	WC_Blue water	WC_Green water
2001-2002	2919.66	2662.90	256.77	1.25	1.38	0.62	0.02	0.003	0.014
2002-2003	3377.89	3144.19	233.70	1.21	1.37	0.47	0.02	0.004	0.017
2003-2004	2750.44	2643.99	106.45	1.17	1.30	0.34	0.02	0.002	0.015
2004-2005	2866.15	2830.98	35.17	1.16	1.24	0.19	0.02	0.001	0.017
2005-2006	3147.11	2928.25	218.86	1.39	1.54	0.59	0.02	0.003	0.014
2006-2007	3523.96	3393.77	130.19	1.34	1.51	0.33	0.02	0.003	0.017
2007-2008	3722.38	3360.24	362.14	1.37	1.49	0.80	0.02	0.003	0.017
2008-2009	2365.38	2142.60	222.78	1.10	1.14	0.84	0.02	0.002	0.014
2009-2010	2871.16	2727.50	143.65	1.30	1.36	0.72	0.02	0.001	0.015
2010-2011	3123.03	2926.77	196.26	1.40	1.52	0.65	0.02	0.002	0.014
2011-2012	3048.38	2829.42	218.97	1.30	1.44	0.58	0.02	0.003	0.015
2012-2013	2694.36	2544.91	149.45	1.12	1.22	0.45	0.02	0.002	0.015
2013-2014	2431.98	2223.86	208.12	1.11	1.27	0.46	0.02	0.003	0.013
2014-2015	2773.35	2576.51	196.84	1.15	1.25	0.57	0.02	0.003	0.015
2015-2016	2559.75	2537.68	22.07	1.06	1.13	0.13	0.02	0.001	0.017
2016-2017	2735.98	2711.10	24.88	1.09	1.13	0.22	0.02	0.001	0.018
2017-2018	2571.51	2400.59	170.92	1.05	1.11	0.56	0.02	0.002	0.016
2018-2019	3189.06	2909.71	279.34	1.22	1.39	0.53	0.02	0.004	0.016
2019-2020	3212.23	2984.29	227.94	1.30	1.44	0.57	0.02	0.003	0.015
Average	**2941.25**	**2762.07**	**179.18**	**1.21**	**0.51**	**1.33**	**0.02**	**0.00**	**0.02**

Yield in Kg/ha; WP in kg/ m^3; WC (Water consumption) in km^3;

Table 4.9
Cereal (Ragi) productivity across Nagaland (19.7 km^2)

Year	Yield	Yield due to rainfall	Incremental yield	WP	WP from rainfall	Incremental WP	WC	WC_Blue water	WC_Green water
2001-2002	9284.09	9283.01	1.09	1.08	0.00	1.26	0.02	0.00	0.01
2002-2003	9959.67	9959.21	0.46	1.11	0.00	1.31	0.02	0.00	0.02
2003-2004	9710.11	9710.11	0.00	1.13	0.00	1.25	0.02	0.00	0.02
2004-2005	8863.02	8863.02	0.00	1.09	0.00	1.16	0.02	0.00	0.02
2005-2006	8719.50	8719.50	0.00	1.09	0.00	1.20	0.02	0.00	0.01
2006-2007	10509.86	10509.86	0.00	1.21	0.00	1.30	0.02	0.00	0.02
2007-2008	10920.25	10920.25	0.00	1.23	0.00	1.38	0.02	0.00	0.02
2008-2009	9371.11	9371.11	0.00	1.20	0.00	1.29	0.02	0.00	0.01
2009-2010	9223.58	9223.58	0.00	1.19	0.00	1.25	0.02	0.00	0.01
2010-2011	9981.82	9981.82	0.00	1.21	0.00	1.31	0.02	0.00	0.02
2011-2012	9439.04	9439.04	0.00	1.15	0.00	1.29	0.02	0.00	0.01
2012-2013	9686.27	9686.27	0.00	1.19	0.00	1.30	0.02	0.00	0.01
2013-2014	8897.74	8897.74	0.00	1.08	0.00	1.20	0.02	0.00	0.01
2014-2015	9403.86	9403.86	0.00	1.15	0.00	1.29	0.02	0.00	0.01
2015-2016	10293.76	10293.76	0.00	1.23	0.00	1.31	0.02	0.00	0.02
2016-2017	10522.27	10522.27	0.00	1.21	0.00	1.31	0.02	0.00	0.02
2017-2018	10053.04	10053.04	0.00	1.18	0.00	1.30	0.02	0.00	0.02
2018-2019	9245.49	9245.49	0.00	1.05	0.00	1.24	0.02	0.00	0.01
2019-2020	8015.61	8015.61	0.00	0.93	0.00	1.04	0.02	0.00	0.02
Average	**9584.21**	**9584.13**	**0.08**	**1.14**	**0.00**	**1.26**	**0.02**	**0.00**	**0.02**

Yield in Kg/ha; WP in kg/ m^3; WC (Water consumption) in km^3;

District-wise analysis was also carried out to estimate the average land and water productivity as presented in Table 4.10. The graph showing district-wise land and water productivity for rainfed and irrigated rice is shown in Figure 4.18.

Table 4.10
District-wise status of LP and WP

Units: LP: Kg/ha; WP: kg/m^3

District	Average productivity			
	Rice rainfed		Rice irrigated	
	LP	WP	LP	WP
Wokha	3607.58	0.85	7520.99	2.11
Peren	3550.42	0.84	6535.20	2.08
Phek	2816.51	0.77	6855.66	2.26
Chumoukedima	3429.57	0.80	5463.14	1.96
Mokokchung	3685.74	0.82	7199.51	2.01
Mon	3289.37	0.81	6903.87	2.25
Noklak	2986.21	0.97	6996.68	3.32
Zunheboto	3536.91	0.88	7979.76	2.73
Kohima	3028.96	0.78	7216.82	2.30
Kiphire	2726.34	0.82	7147.56	2.72
Longleng	3517.46	0.79	7450.40	2.41
Dimapur	3931.75	0.93	4208.84	1.78
Niuland	2398.28	0.56	6091.53	2.00
Tseminyu	3755.90	0.90	8276.44	2.30
Tuensang	3328.94	0.87	7471.86	2.83
Shamator	2719.24	0.80	6215.98	3.46
Average	**3269.33**	**0.83**	**6845.89**	**2.41**

LP: Land productivity, WP: Water productivity

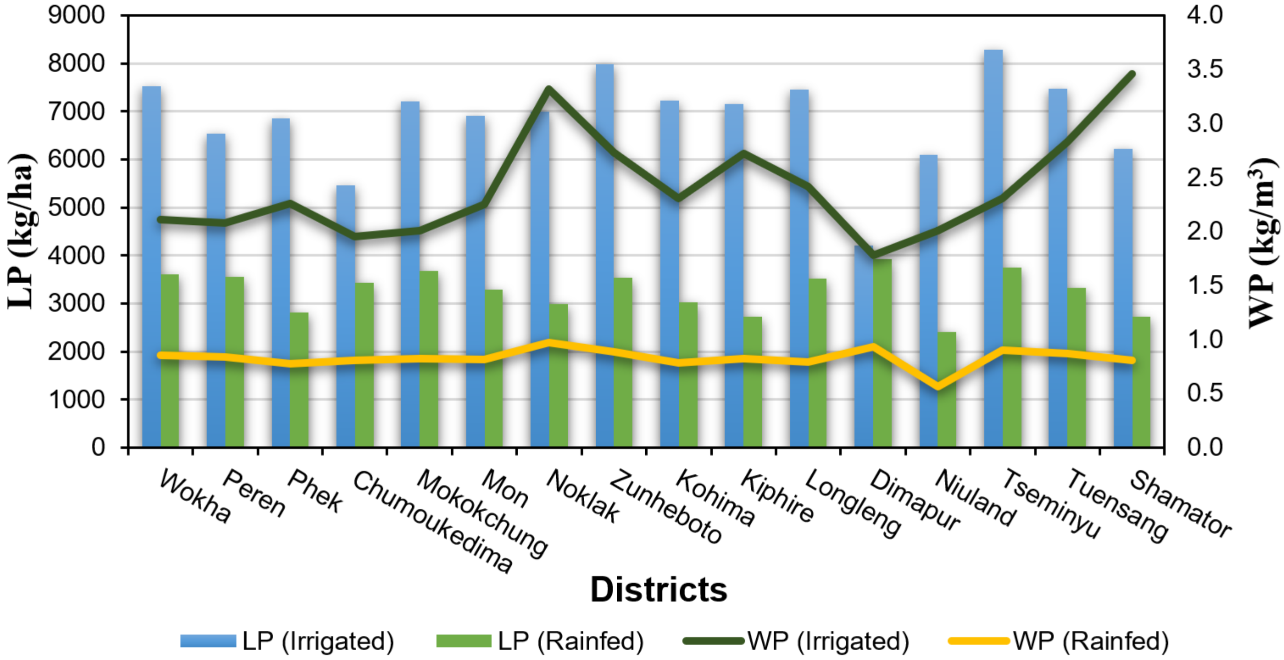


Figure 4.19: District-wise average LP and WP of the irrigated and rainfed cereals for the period 2001-2020.

Similar results of the land productivity were also reported in the Nagaland Statistical Handbook 2021 published by the Directorate of Economics & Statistics – Table No. 4.2: Area & Production of Principal crops (Figure 4.19):

SN	Crops	Area & Productio	Kohima	Phek	Mokokchung	Tuensang	Mon	Dimapur	Wokha	Zunheboto	Peren	Kiphire	Longleng	Nagaland
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A. CEREALS														
1	Jhum Paddy	A	5130	1620	9290	10010	15880	9040	10040	9200	6300	8430	5800	**90740**
		P	10205	3234	18500	19928	31626	17991	20000	18321	12511	16763	11491	**180570**
2	WTRC Paddy	A	11680	15970	7820	7620	7420	41950	10580	5850	12390	3780	3010	**128070**
		P	33760	46250	22680	22080	21386	121269	30629	16910	35766	10930	8720	**370380**
3	Maize	A	4614	8865	3972	10159	5646	6780	5284	10115	3102	7600	3053	**69190**
		P	9176	17631	7906	20200	11201	13514	10518	20080	6164	15076	6064	**137530**

Figure 4.20: Reported area and production statistics as per Nagaland Statistical Handbook, 2021.

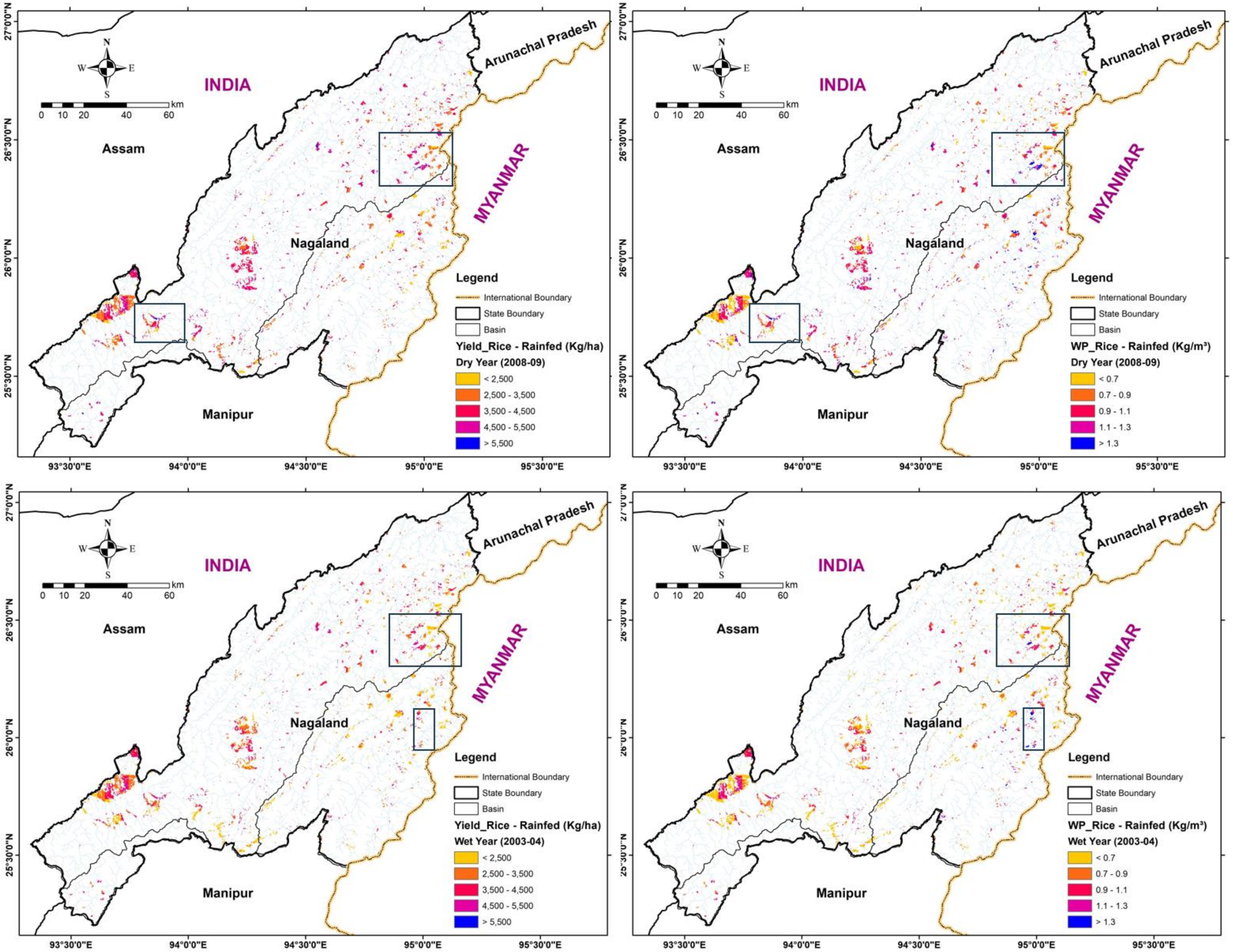


Figure 4.21: Land and water productivity for Rainfed rice for dry and wet years.

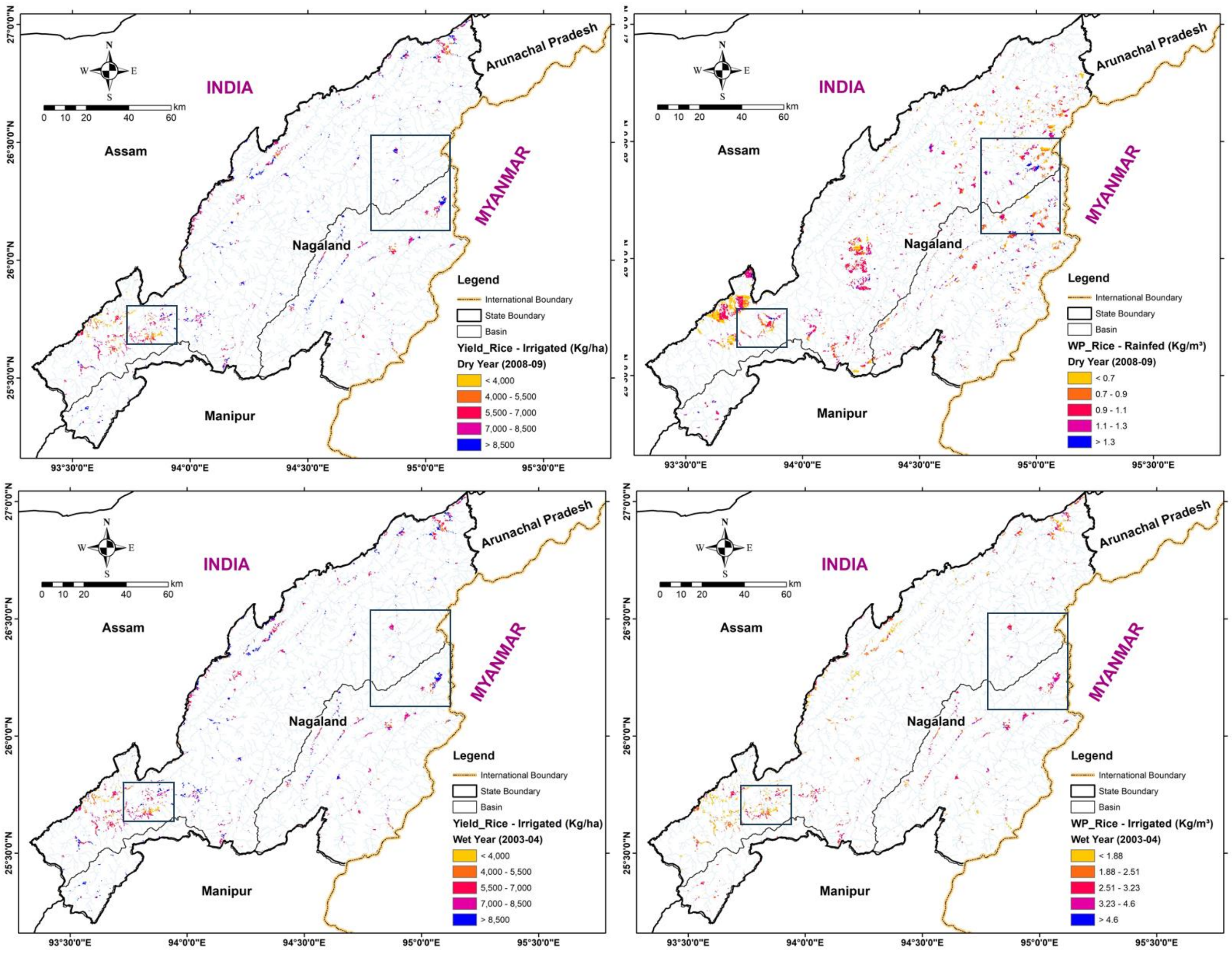


Figure 4.22: Land and water productivity for Irrigated rice for dry and wet years.

4.5 Development of Sheet 4 (Utilized flow)

Sheet 4 provides the utilized flow for both manmade and natural sources of the basin. Sheet 4 is also known as the 'Withdrawal' sheet, which provides information on surface water and groundwater withdrawal. A separate sheet for the withdrawal is important from the management point of view. Surface water can be used for hydropower generation, whereas groundwater is a preferred choice for farmers for irrigation and drinking water because of its instantaneous availability without passing through a larger conveyance network. The aim of the Sheet 4 is to provide an explicit picture of flows for the Managed Water Use category (mainly irrigated area). Sheet 4 has two parts. Sheet 4 (Part I) shows the utilized flow for the man-made land uses, e.g., irrigated crops, managed water bodies, industry, aquaculture, residential area, greenhouses, power, and energy, etc., and Sheet 4 (Part II) shows the utilized flow for natural land use, eg. Forests, shrubland, rainfed crops, forest plantations, natural water bodies, wetlands, natural grasslands, etc. The basic difference from the supply and withdrawal point of view in the case of man-made and natural land uses is that man-made land uses met its water requirement from both surface and groundwater. However, natural land uses mostly depend on groundwater except for natural water bodies, wetlands, and natural grasslands, which draw water from the surface as well as groundwater. Take the case of forests, shrublands, rainfed crops, and forest plantations. These natural land uses withdraw only groundwater. Again, water consumed by the natural land uses cannot be recovered, and assumed to be left from the system. Whereas, in the case of man-made water uses, part of the utilized water is returned back to the system (return flow), and treated as recoverable water. With these assumptions, Sheet 4 also distinguishes between consumed and non-consumed water and recognizes the recoverable and non-recoverable flow. The status of utilized flow, withdrawal, and supply from groundwater and surface water, recoverable and non-recoverable flow is presented in Table 4.11. The status of man-made and natural withdrawal is shown in Figures 23 & 24, respectively. Figures 4.25a & 4.25b and 4.26a & 4.26b show the screenshots of the Sheet 4 generated for dry and wet years, respectively.

Table 4.11

Sheet 4: Status of Utilized flow

Units: BCM

Year	Man-made						Natural					
	Gross withdrawal		Consumption		Recoverable		Gross withdrawal		Consumption		Recoverable	
	GW	SW	CW	NCW	Recov	Non-Recov	GW	SW	CW	NCW	Recov	Non-Recov
2002-03	0.24	0.42	0.37	0.30	0.30	0.18	1.63	0.45	2.09	0.00	0.00	0.00
2003-04	0.31	0.49	0.35	0.44	0.44	0.19	1.40	0.41	1.81	0.00	0.00	0.00
2004-05	0.25	0.43	0.34	0.33	0.33	0.18	1.37	0.41	1.78	0.00	0.00	0.00
2005-06	0.25	0.42	0.35	0.32	0.32	0.18	1.40	0.42	1.81	0.00	0.00	0.00
2006-07	0.22	0.41	0.32	0.31	0.31	0.18	1.44	0.44	1.88	0.00	0.00	0.00
2007-08	0.25	0.47	0.35	0.37	0.37	0.18	1.72	0.56	2.28	0.00	0.00	0.00
2008-09	0.25	0.45	0.34	0.36	0.36	0.18	1.53	0.50	2.04	0.00	0.00	0.00
2009-10	0.22	0.41	0.36	0.27	0.27	0.17	1.33	0.45	1.77	0.00	0.00	0.00
2010-11	0.29	0.49	0.35	0.43	0.43	0.19	1.60	0.52	2.12	0.00	0.00	0.00
2011-12	0.41	0.61	0.39	0.64	0.64	0.21	1.64	0.49	2.13	0.00	0.00	0.00
2012-13	0.28	0.48	0.33	0.43	0.43	0.19	1.49	0.46	1.96	0.00	0.00	0.00
2013-14	0.39	0.57	0.36	0.59	0.59	0.20	1.71	0.53	2.24	0.00	0.00	0.00
2014-15	0.31	0.54	0.35	0.50	0.50	0.19	1.67	0.51	2.18	0.00	0.00	0.00
2015-16	0.23	0.44	0.33	0.34	0.34	0.18	1.02	0.32	1.33	0.00	0.00	0.00
2016-17	0.26	0.46	0.33	0.39	0.39	0.19	1.32	0.39	1.72	0.00	0.00	0.00
2017-18	0.38	0.58	0.36	0.60	0.60	0.20	1.31	0.39	1.71	0.00	0.00	0.00
2018-19	0.54	0.75	0.44	0.85	0.85	0.24	1.71	0.47	2.19	0.00	0.00	0.00
2019-20	0.32	0.53	0.36	0.50	0.50	0.19	1.45	0.43	1.88	0.00	0.00	0.00
Average	**0.30**	**0.50**	**0.35**	**0.44**	**0.44**	**0.19**	**1.49**	**0.45**	**1.94**	**0.00**	**0.00**	**0.00**

GW: Groundwater, SW: Surface water; CW: Consumed water; NCW: Non-consumed water

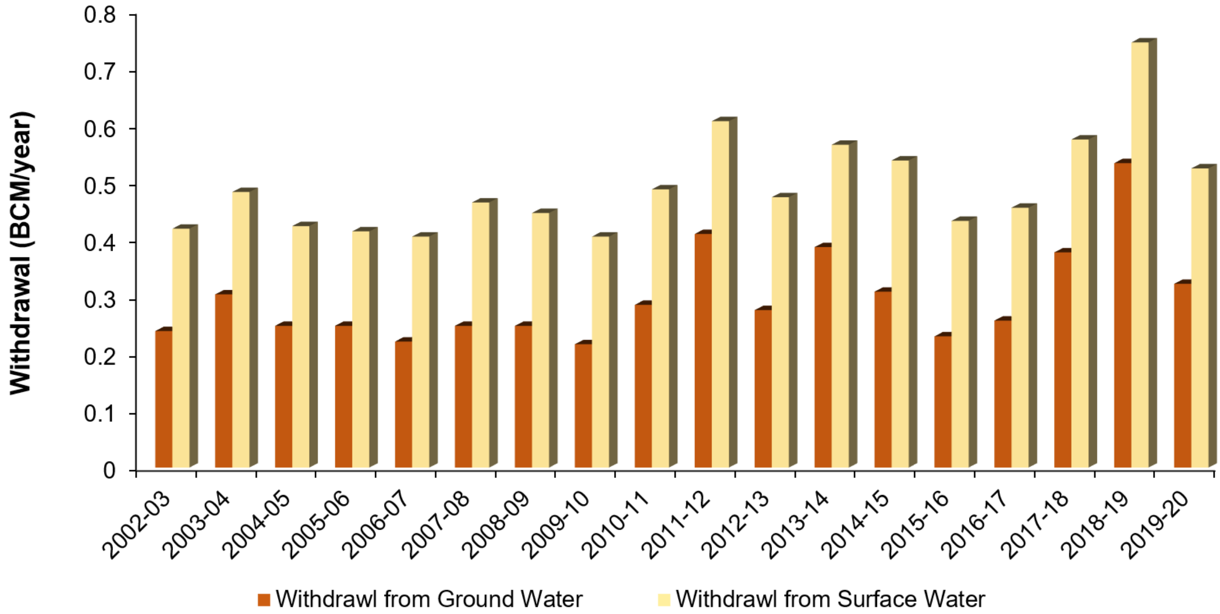


Figure 4.23: Status of man-made withdrawal.

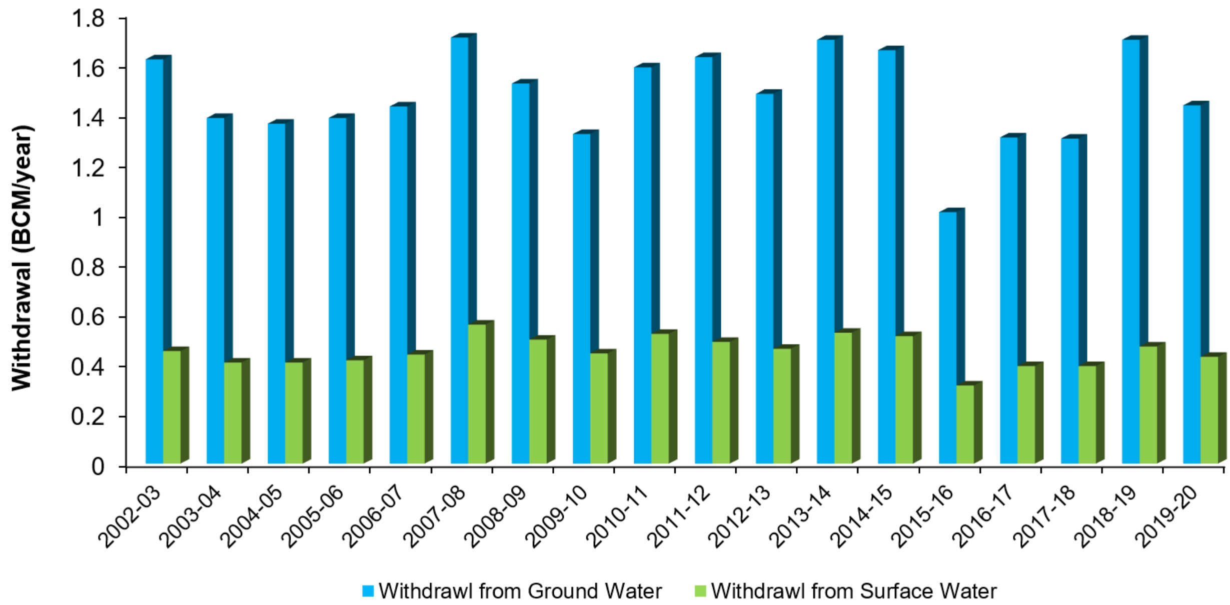


Figure 4.24: Status of natural withdrawal.

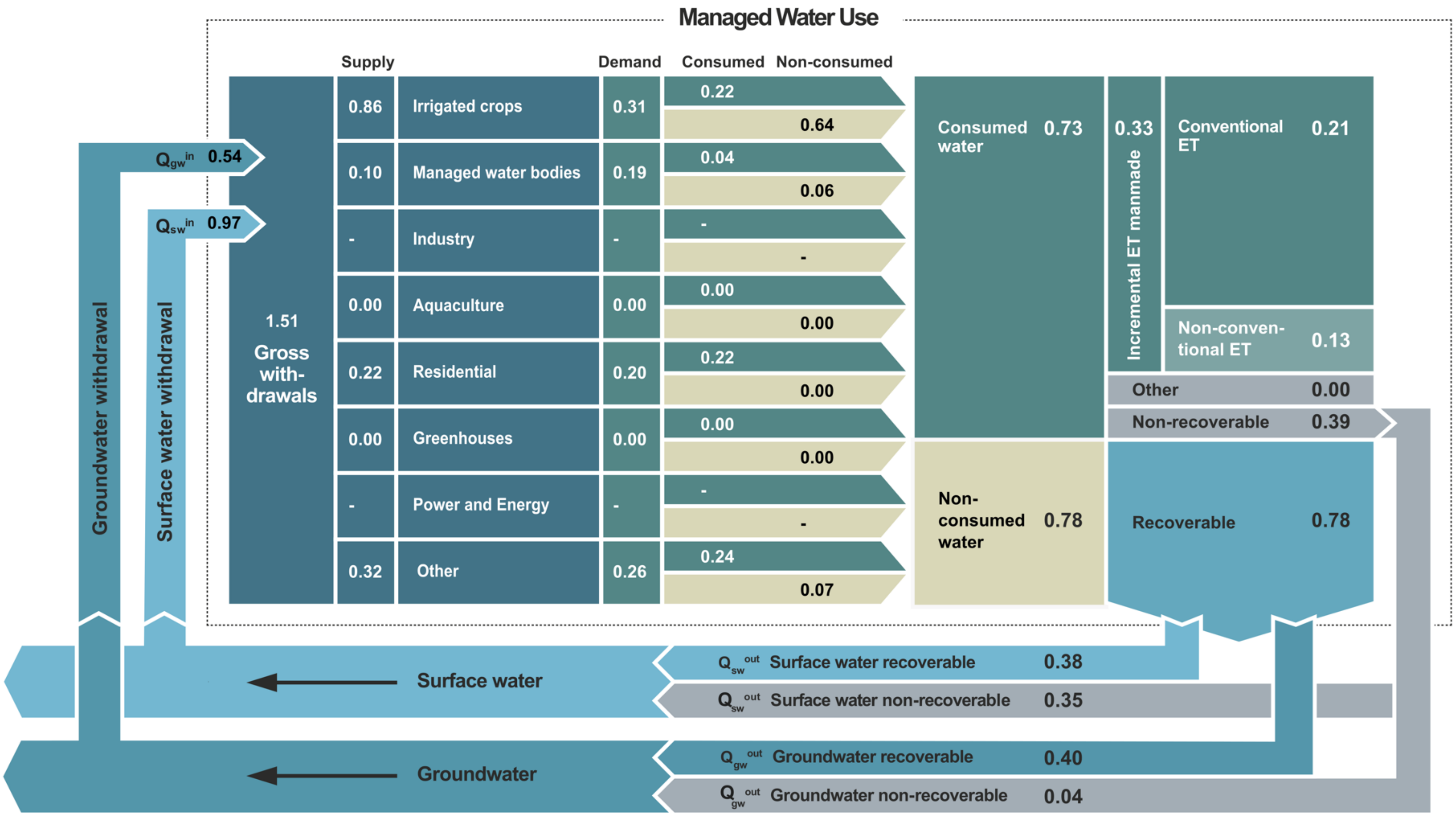


Figure 4.25a: Sheet 4 (Part 1) - Man-made withdrawal and supply in a dry year.

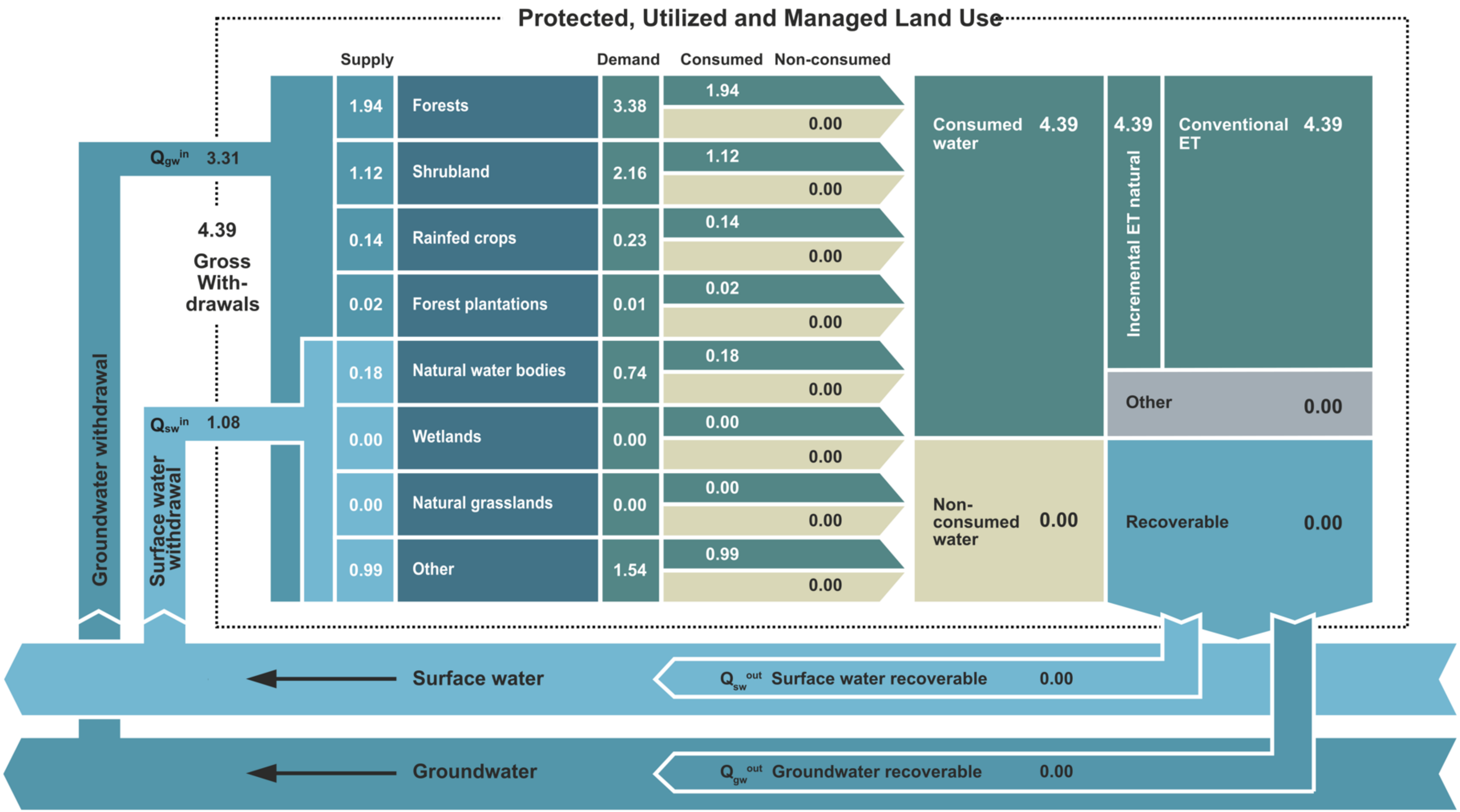


Figure 4.25b: Sheet 4 (Part 2) - Natural withdrawal and supply in a dry year.

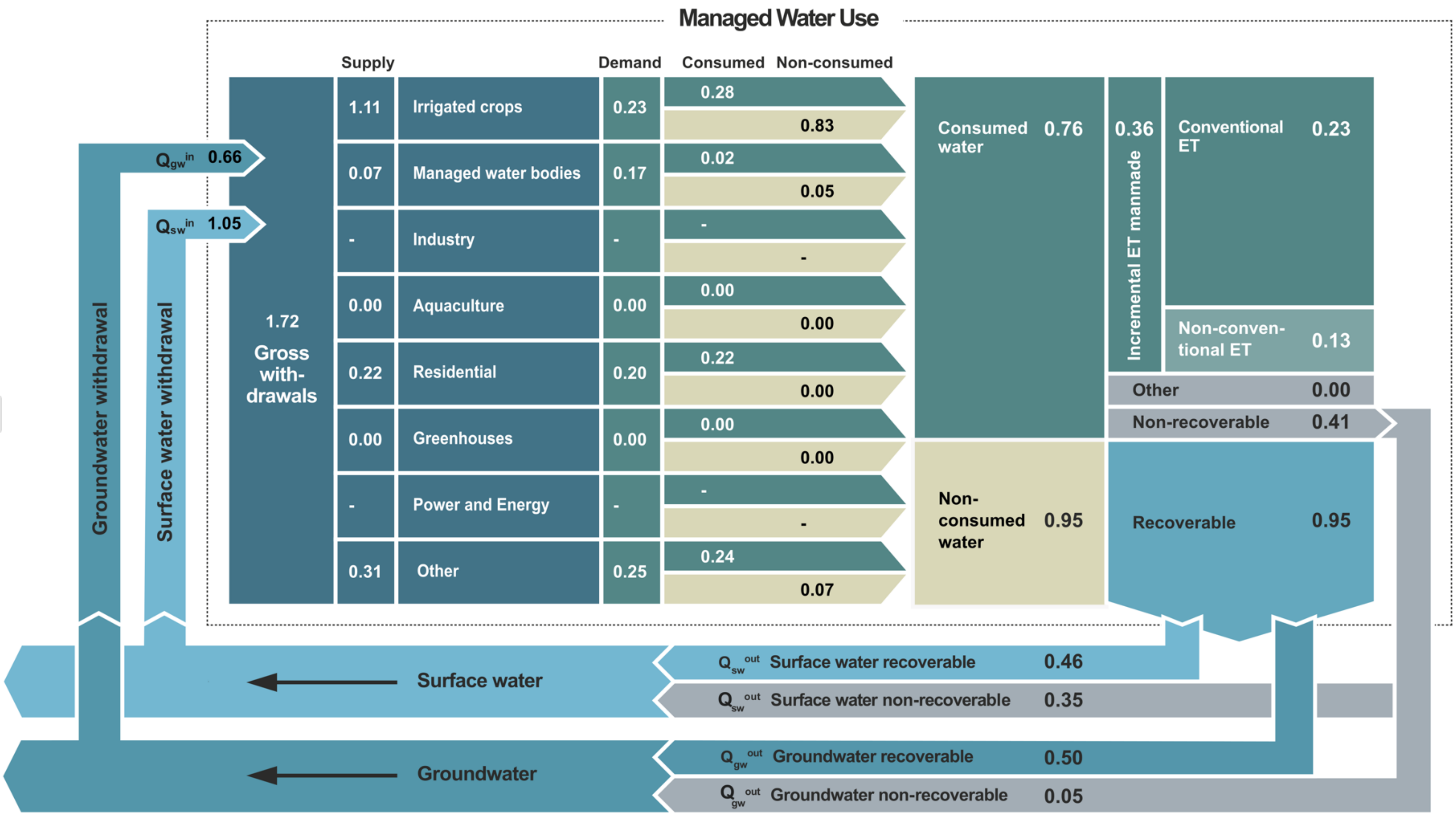


Figure 4.26a: Sheet 4 (Part 1) - Man-made withdrawal and supply in a wet year.

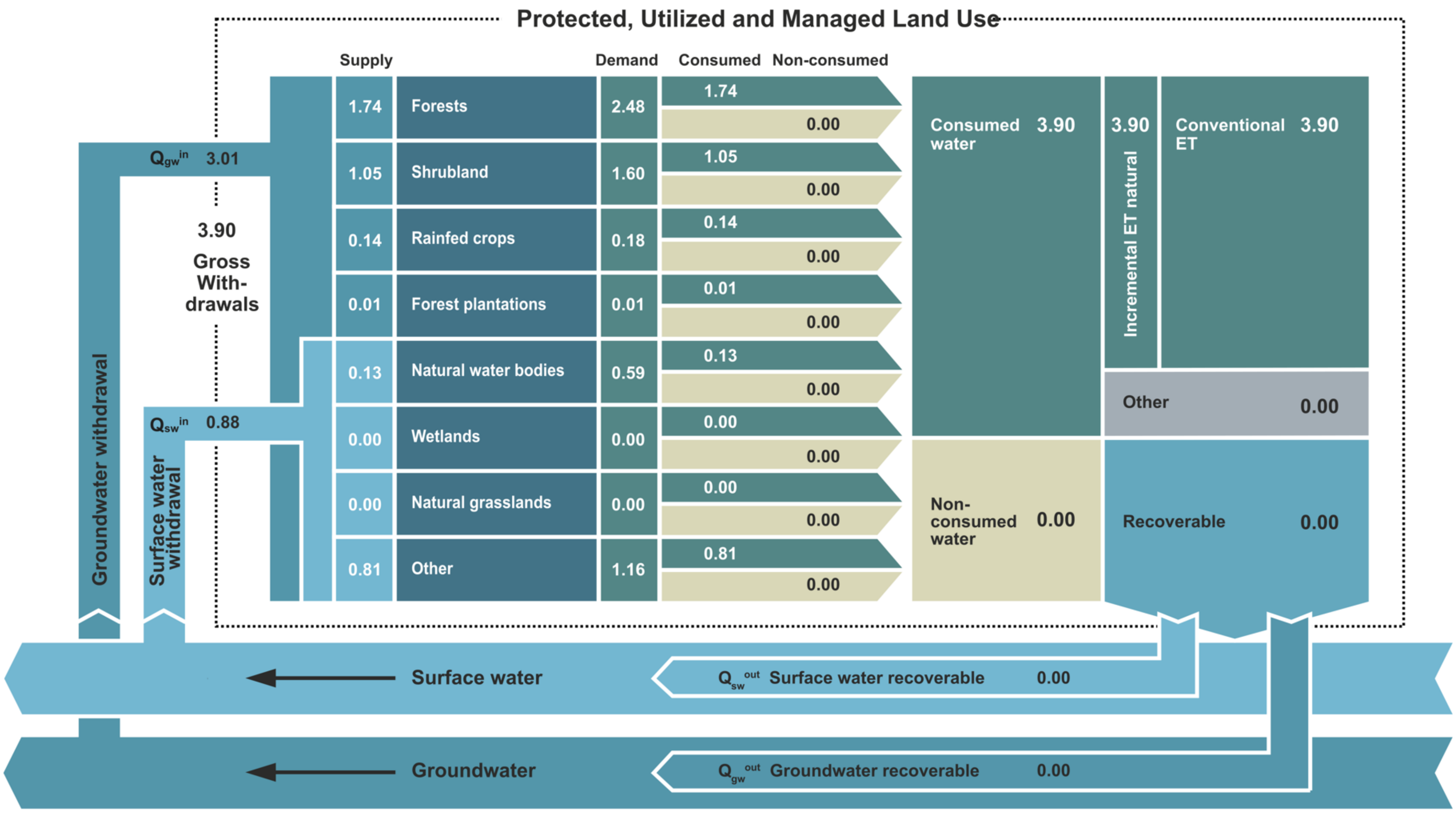


Figure 4.26b: Sheet 4 (Part 2) - Natural withdrawal and supply in a wet year.

4.6 Development of Sheet 5 (Surface water)

Sheet 5 describes about the surface water availability of different sub-basins and basins. It distinguishes between fast/slow runoff and determines the surface water availability and utilizable withdrawals. Nagaland is a hilly and rugged terrain state. Hydrometeorological measurement, including establishing G&D sites is difficult. In a situation like this, a first-hand information on the surface water availability and utilizable withdrawal of the sub-basins and basins is crucial for management.

The state of Nagaland is divided into three important basins viz. Brahmaputra, Barak and Tizu (Irrawady-Chindwin). Unlike basins like Mahanadi and Krishna in the mainland, a basin with a single outlet is next to impossible. Sheet 5 and the WaterPix model run based on the hydro-geological units rather than the administrative boundaries. To accommodate the sub-basins within the administrative boundaries, dummy (secondary) basin has been delineated. This has already been discussed elaborately in Chapter 2 (Section 2.1). As shown in Figure 4.27, a total of nine sub-basins were delineated. The nine sub-basins with their administrative area are given below in Table 4.12. An area proportionate approach was adopted to convert the outputs from Sheet 5 w.r.t the sub-basins as per the administrative area of Nagaland. The status of sub-basin-wise surface water availability is presented below in Table 4.13. The screenshots of Sheet 5 for the dry and wet years are shown in Figures 4.28 and 4.29, respectively. As shown in the screenshots, the estimates are for the extended delineated area and require revision based on the area proportionate method already discussed earlier.

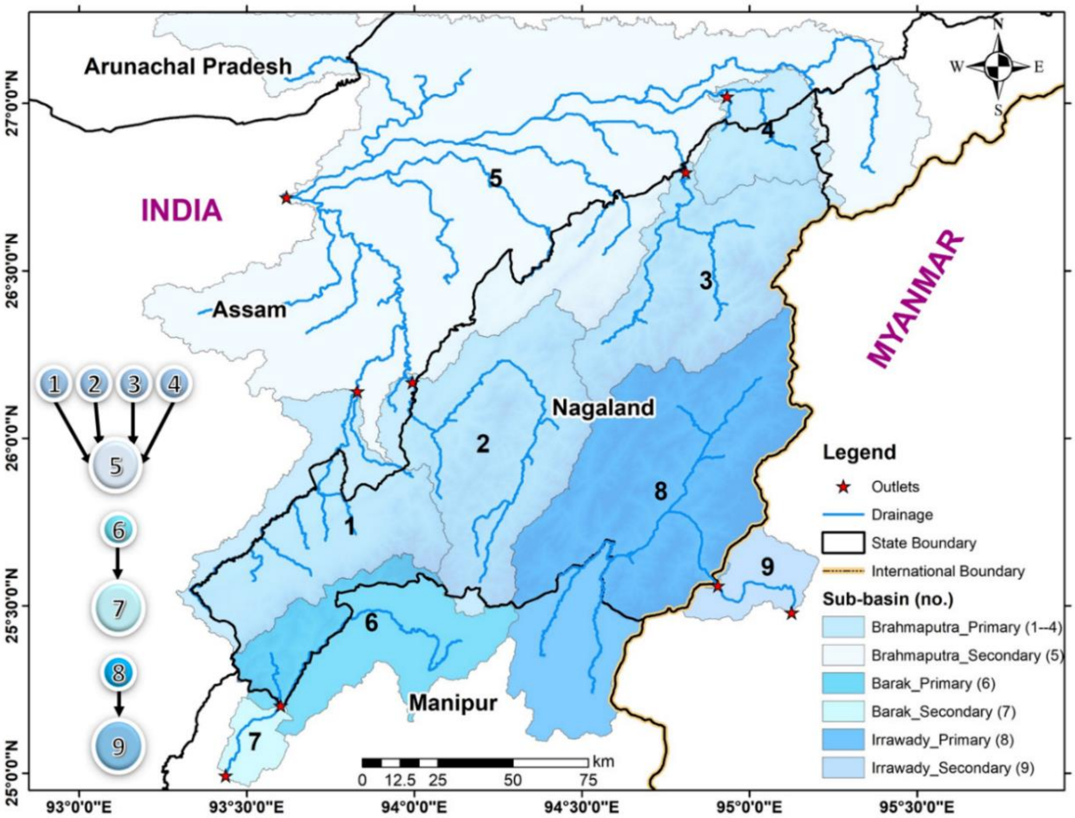


Figure 4.27: Delineated sub-basins and flow-network considered in Sheet 5.

Table 4.12

Administrative area of nine sub-basins

Sub-basin Scheme	Name of Sub-basin	Area (km^2)
1	Dhansiri-Chathe-Dzuza	3194.7
2	Doyang	3773.4
3	Dikhu	3002.5
4	Tizit	1164.6
5	Brahmaputra (Dummy) including Tsurang-Milak	37061.5
6	Barak (includes Manipur)	2559.5
7	Barak (Dummy)	402.5
8	Tizu (includes Manipur)	6387.3
9	Tizu (Dummy)	699.4

The study revealed that the total outflow from the seven sub-basins viz. Dhansiri, Chathe-Dzuza, Doyang, Dikhu, Tizit, Tsurang, and Milak to the river Brahmaputra is about 14051 MCM. The estimated outflow from the catchment within the Nagaland to the Barak and Tizu (Irrawady-Chindwin) basins are about 572 MCM and 4435 MCM, respectively. Similar results were also reported as per the Nagaland Water Policy (2016), Dept. of Soil and Water Conservation, Govt. of Nagaland as given below.

Government of Nagaland
Department of Soil and Water Conservation

NAGALAND WATER POLICY (2016)

2. OVERVIEW OF WATER RESOURCES OF THE STATE

2.1 Rainfall

The state receives an average annual rainfall of 1715 mm. Eighty percent of the rainfall is received during the pre-monsoons and monsoons. The heavy rains during the monsoons, coupled with the hilly topography of the state leads to high surface runoff.

2.2 Surface Water

The predominant sources of water in Nagaland are surface water in rivers, streams, ponds and natural springs and subsurface water occurring as ground water. Nagaland has four main rivers, namely, Doyang, Dhansiri, Dhiku and Tizu. Of these, the first three flows towards west through Assam plains to join the mighty Brahmaputra, while Tizu river system flows towards the east and southeast and pours into the Irrawaddy in Myanmar. The Barak River also drains a small area, in Peren district, of Nagaland. The catchment area of Brahmaputra Basin in the state is 10,881 sq. km, which is 65.6% of the total geographical area leading to a total water yield of 14282 MCM. The catchment area of Barak Basin is 814 sq. km, which is around 4.9 % of the total area and has water yield of 738 MCM. The catchment area of Tizu Basin covers 4884 sq.km, which is 29.5% of the total area and has water yield of 4463 MCM.

Table 4.13

Sheet 5: Status of Surface water

Units: MCM

Sub-basin Scheme	Name of Sub-basin	Area (km^2)	Inflow	Total Runoff	Total SW withdrawal	Total Return Flow	Total Outflow
1	Dhansiri-Chathe-Dzuza	3194.7	0.0	3656.9	469.6	238.2	3187.4
2	Doyang	3773.4	0.0	4519.5	103.9	37.3	4415.6
3	Dikhu	3002.5	0.0	4253.2	126.5	23.6	4126.8
4	Tizit	1164.6	0.0	1862.0	23.1	10.3	1839.0
5	Brahmaputra (Dummy) including Tsurang-Milak	37061.5	13568.7	22097.7	557.4	328.1	35109.0
6	Barak	2559.5	0.0	1944.4	145.1	10.1	1799.5
7	Barak (Dummy)	402.5	1799.5	362.6	1.2	0.1	2161.0
8	Tizu	6387.3	0.0	6206.3	406.3	26.0	5800.2
9	Tizu (Dummy)	699.4	5800.2	1089.7	6.6	0.2	6883.3
Sub-basin Scheme	**Name of Sub-basin**	**Area (km^2)**	**Inflow**	**Total Runoff**	**Total SW withdrawal**	**Total Return Flow**	**Total Outflow**
1	Dhansiri	1466	0.0	2559.8	328.7	166.8	2231.2
2	Chathe-Dzuza	621	0.0	1097.1	140.9	71.5	956.2
3	Doyang	3558	0.0	4261.5	98.0	35.2	4163.5
4	Dikhu	3028	0.0	4289.3	127.5	23.8	4161.8
5	Tizit	828	0.0	1323.8	16.4	7.3	1307.5
6	Tsurang	495	170.7	277.9	7.0	4.1	441.6
7	Milak	885	305.1	496.9	12.5	7.4	789.5
8	Barak	814	0.0	618.4	46.1	3.2	572.3
9	Tizu	4884	0.0	4745.6	310.7	19.9	4435.1

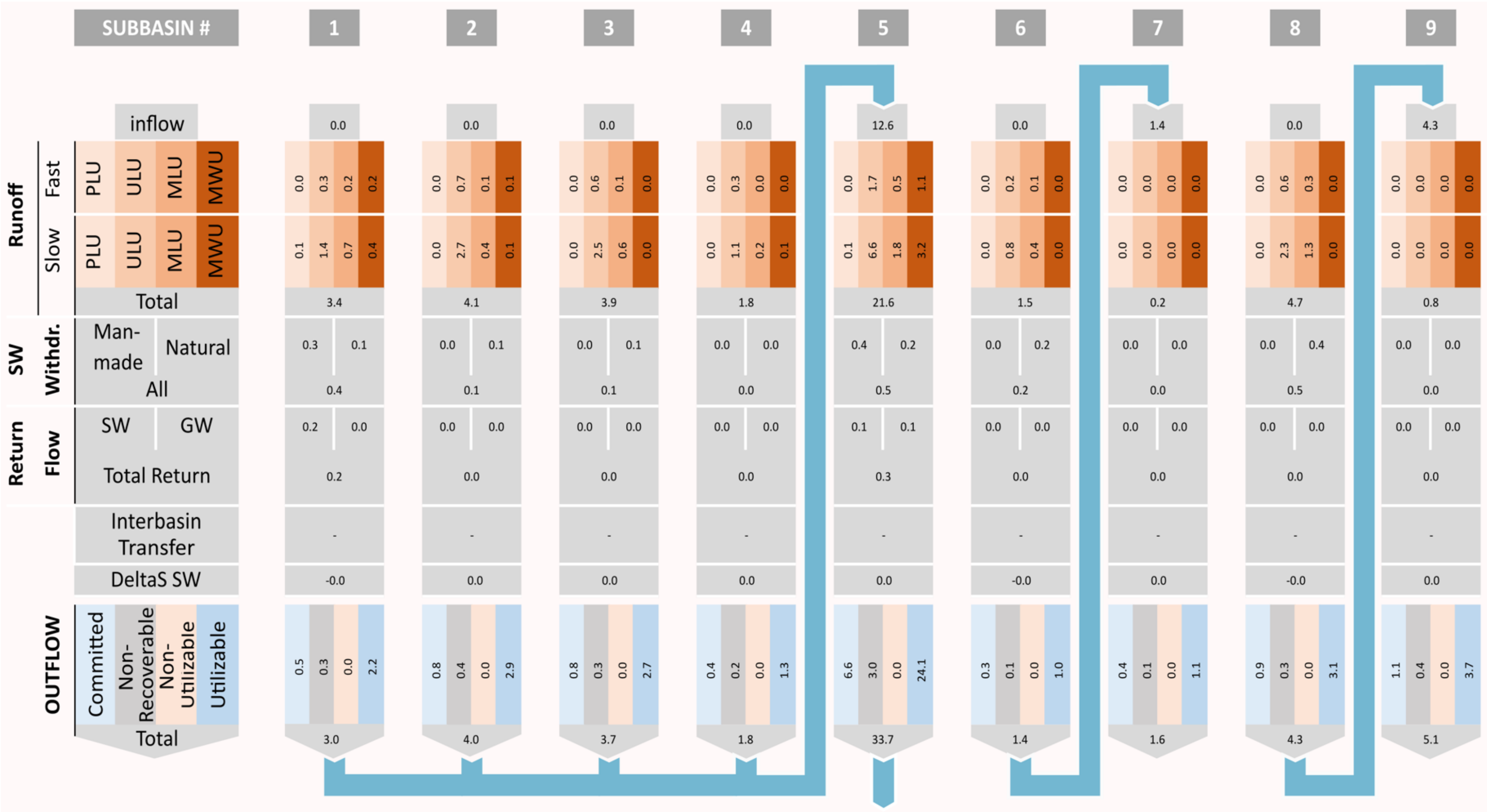


Figure 4.28: Sheet 5: Status of surface water in a dry year.

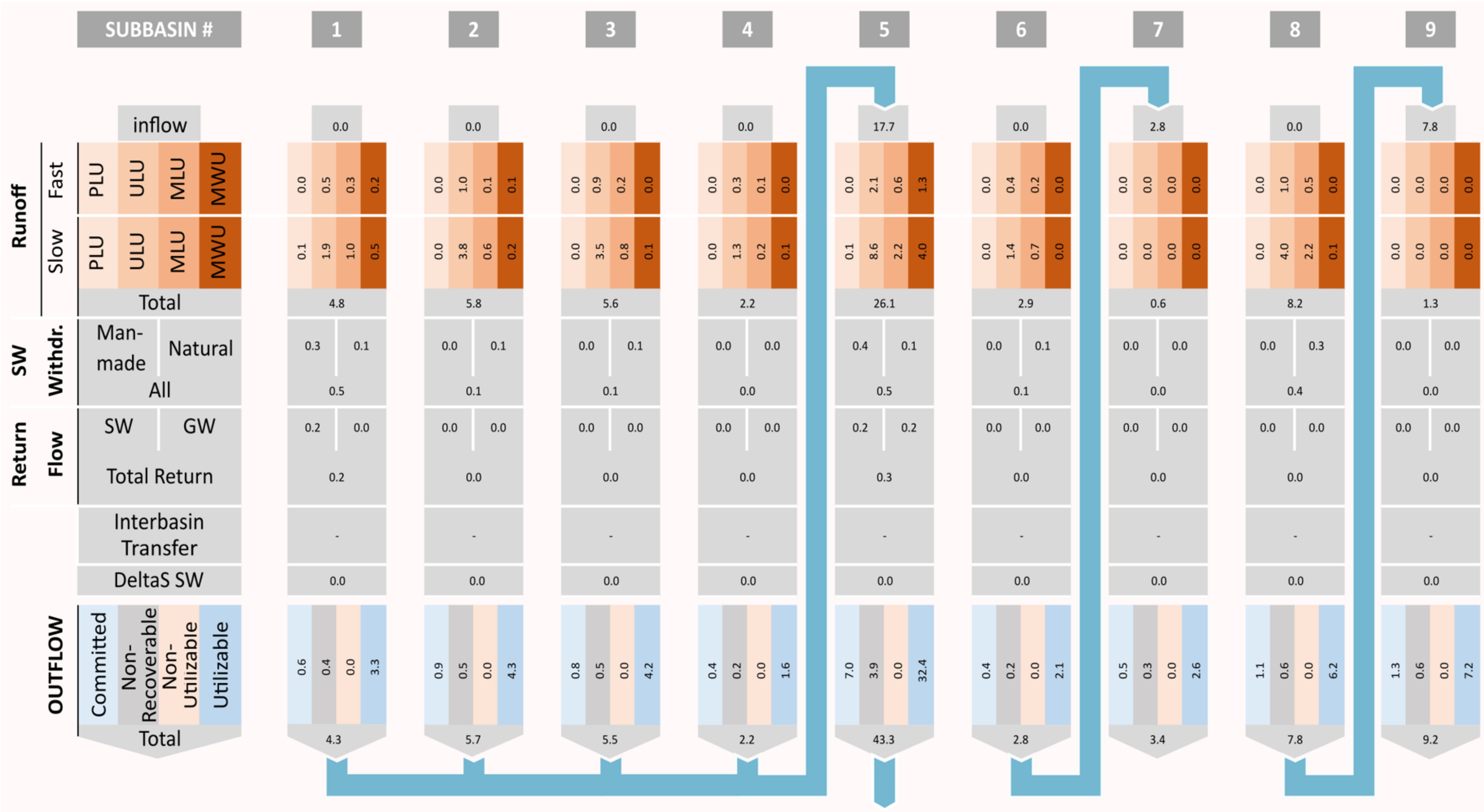


Figure 4.29: Sheet 5: Status of surface water in a wet year.

4.7 Development of Sheet 6 (Groundwater)

Sheet 6 gives the groundwater resources of the basin. It estimates the vertical recharge of both natural and man-made along with the vertical groundwater withdrawal and return flow due to groundwater. It assesses aquifers as storage reservoirs for droughts and their role as the buffering mechanism. It also maps the groundwater withdrawal for irrigation. Nagaland being a hilly state, estimating the groundwater condition is very challenging. However, Sheet 6 has been developed entirely to provide the groundwater-related scenario in WA+. The status of year-wise groundwater is presented below in Table 4.14. The screenshots of Sheet 6 for the dry and wet years are shown in Figures 4.30 and 4.31, respectively. The estimates, as shown in the screenshots, are for the extended delineated area and require revision based on the area proportionate method already discussed earlier.

Table 4.14

Sheet 6: Status of Groundwater

Units: BCM

Year	Vertical recharge	Capillary rise	Vertical GW withdrawals	Return Flow from GW	Return Flow from SW	Baseflow
2002-2003	13.42	0.02	1.86	0.08	0.08	11.25
2003-2004	17.94	0.02	1.69	0.12	0.13	17.40
2004-2005	18.61	0.02	1.61	0.09	0.09	15.38
2005-2006	13.08	0.02	1.63	0.08	0.08	10.99
2006-2007	14.18	0.02	1.65	0.08	0.09	12.59
2007-2008	16.57	0.02	1.96	0.09	0.11	14.54
2008-2009	15.17	0.02	1.77	0.09	0.11	12.36
2009-2010	15.42	0.02	1.53	0.07	0.08	15.23
2010-2011	18.10	0.02	1.87	0.12	0.13	14.68
2011-2012	16.11	0.02	2.04	0.17	0.19	13.37
2012-2013	16.83	0.02	1.76	0.11	0.13	14.44
2013-2014	15.23	0.02	2.08	0.16	0.17	11.74
2014-2015	14.30	0.02	1.96	0.13	0.16	12.25
2015-2016	15.47	0.01	1.24	0.09	0.10	15.11
2016-2017	15.85	0.02	1.56	0.10	0.12	14.09
2017-2018	16.84	0.02	1.68	0.15	0.17	14.55
2018-2019	15.49	0.02	2.23	0.23	0.25	13.16
2019-2020	13.60	0.02	1.76	0.13	0.15	11.80
Average	**15.68**	**0.02**	**1.77**	**0.12**	**0.13**	**13.61**

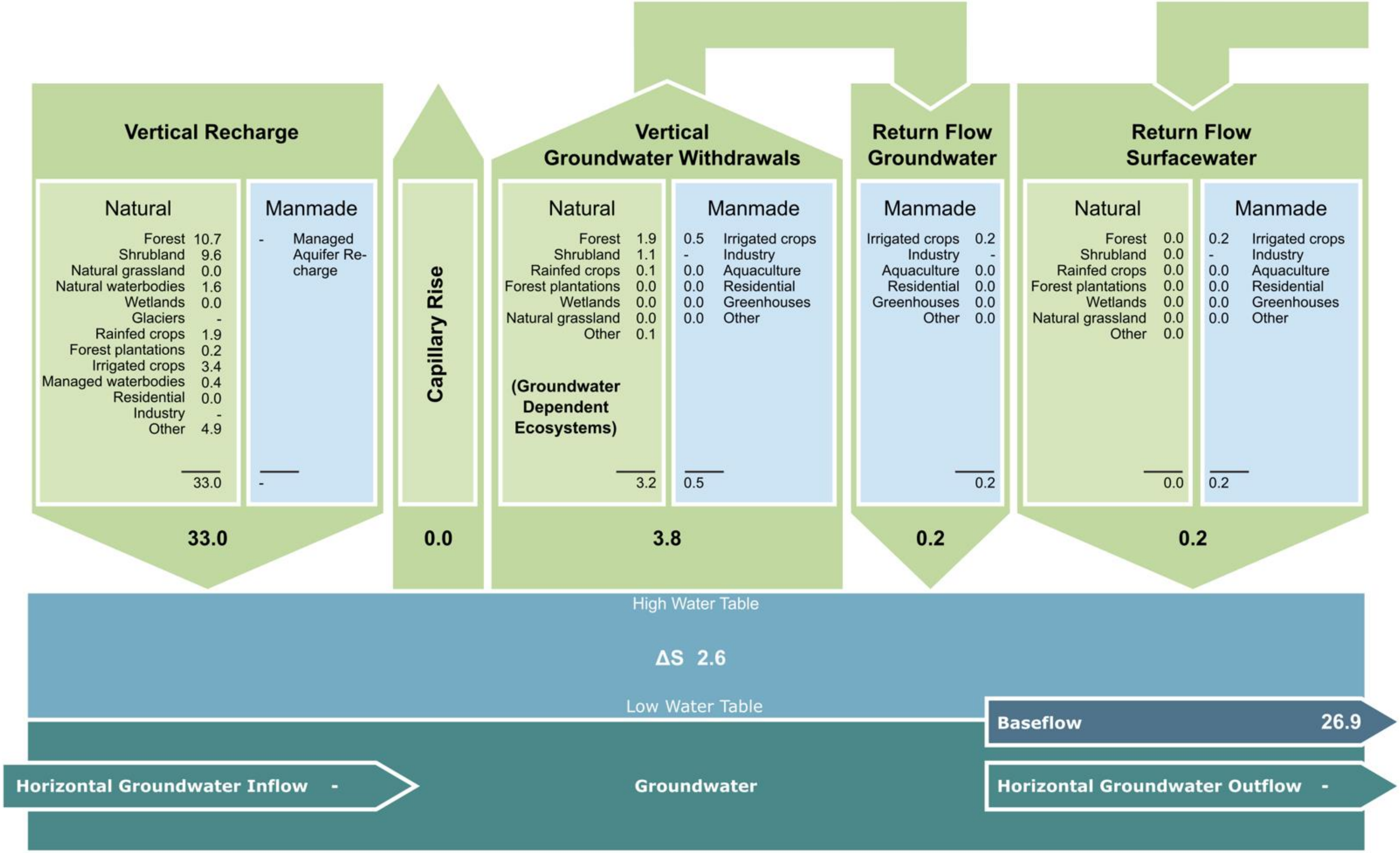


Figure 4.30: Sheet 6: Status of groundwater in a dry year.

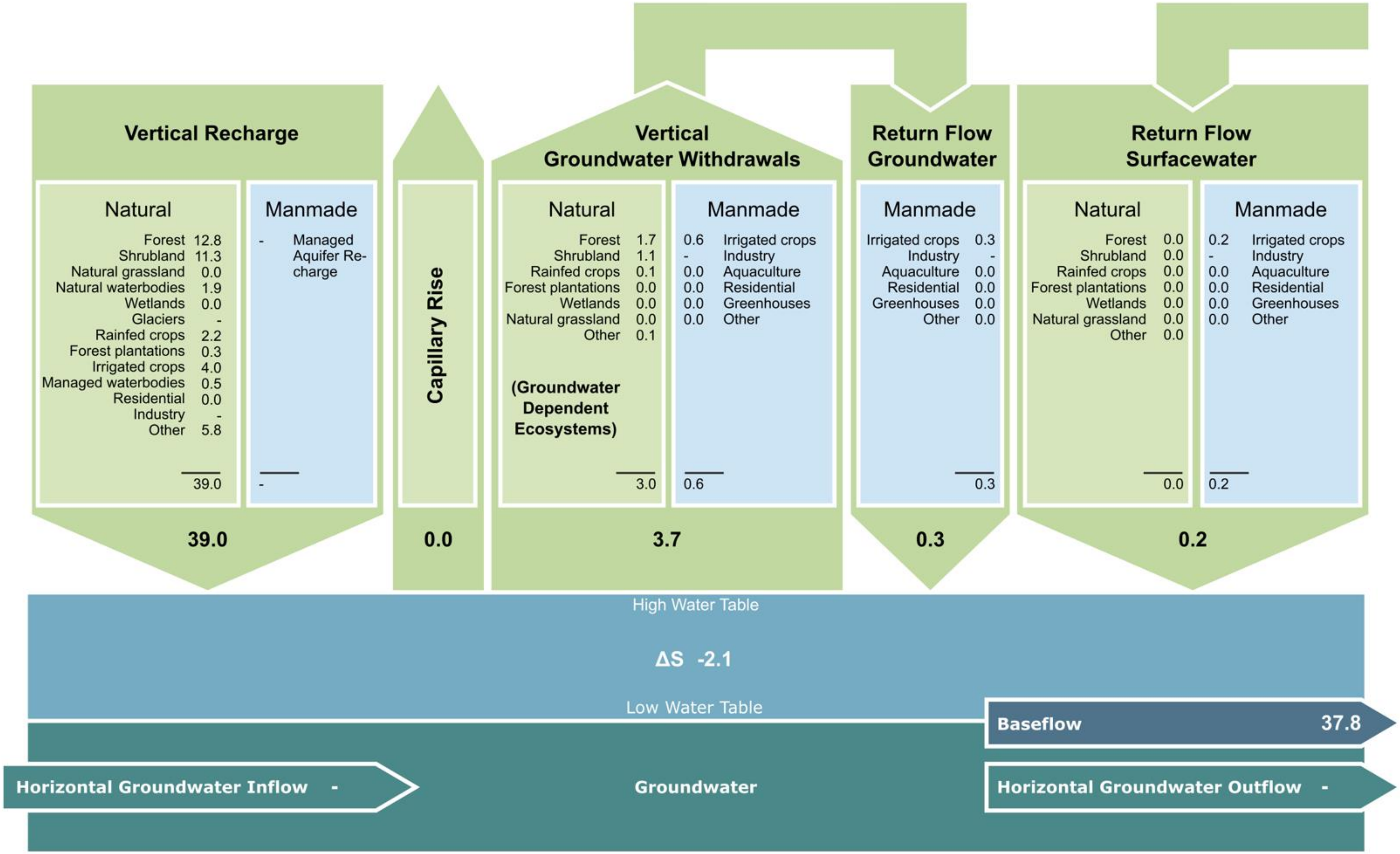


Figure 4.31: Sheet 6: Status of groundwater in a wet year.

4.8 Development of Sheet 1 (Resource base)

Sheet 1, otherwise known as 'Resource Base' summarizes water resources scenarios of the basin. It provides the gross inflow, net inflow, availability of water, utilizable and non-utilizable flow, and finally, the surplus flow going out of the basin. It evaluates different sources of water that control the net inflow. It has already been explained that dummy basins were delineated to formulate the flow network so as to include sub-basins within the administrative boundaries of Nagaland. WaterPix model and sheets depending on the inputs from WaterPix models (Sheet 4, Sheet 5, Sheet 6 and Sheet 1) give estimates of a larger area beyond the administrative boundaries. Therefore, an area proportionate approach was adopted to convert the outputs from Sheet 1 w.r.t the sub-basins/basins as per the administrative area of Nagaland. The gross inflow and the net storage for the period 2002-03 to 2019-20 is shown in Figure 4.32. The annual average gross inflow is about 29 BCM. Table 4.15 presents the 'exploitable water' (net inflow into the basin minus landscape ET). Exploitable water is basically the maximum amount of water that can be exploited (used) after meeting the mandatory landscape ET. The 'available water' estimated after deducting the 'committed flow' if any. This is the amount of water which can either 'utilized' or 'utilizable' (yet to be utilized) as given in Table 4.16.

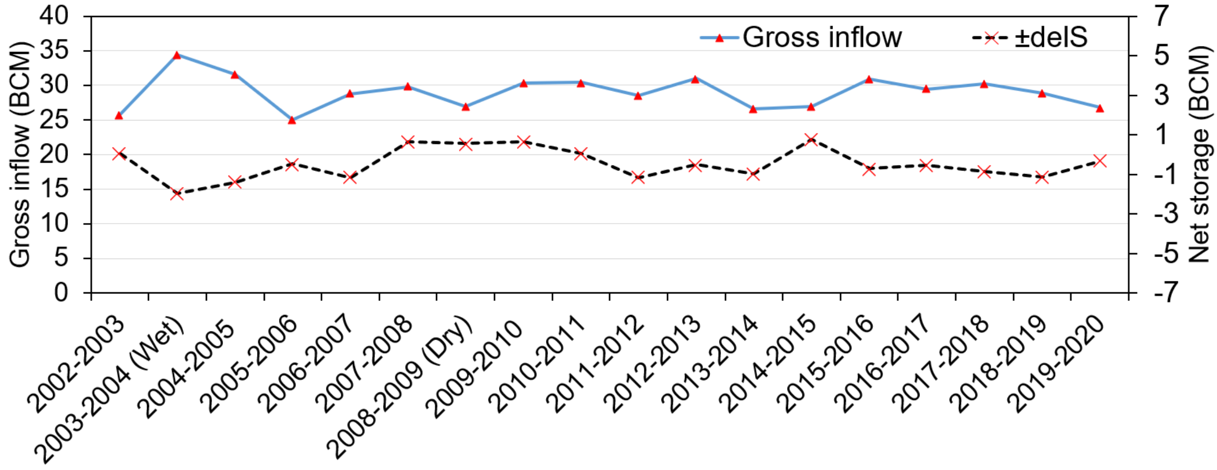
Table 4.15

Sheet 1: Status of gross inflow, net inflow and exploitable water

Units: BCM

Year	Gross inflow	Storage contribution (±delS)	Net inflow	Landscape ET	Exploitable water
2002-2003	25.8	0.0	25.9	10.2	15.6
2003-2004 (Wet)	34.4	-1.9	32.5	10.6	22.0
2004-2005	31.6	-1.4	30.2	10.5	19.7
2005-2006	25.0	-0.5	24.6	10.1	14.5
2006-2007	28.8	-1.2	27.6	10.3	17.2
2007-2008	29.8	0.6	30.5	10.3	20.3
2008-2009 (Dry)	27.0	0.6	27.5	9.8	17.8
2009-2010	30.4	0.6	31.0	10.1	21.0
2010-2011	30.4	0.0	30.5	9.9	20.5
2011-2012	28.6	-1.2	27.4	9.9	17.5
2012-2013	31.0	-0.5	30.5	10.2	20.2
2013-2014	26.7	-1.0	25.7	9.6	16.0
2014-2015	26.9	0.8	27.7	9.6	18.0
2015-2016	30.9	-0.7	30.2	11.0	19.2
2016-2017	29.5	-0.6	28.9	10.7	18.3
2017-2018	30.3	-0.8	29.4	10.8	18.6
2018-2019	28.9	-1.1	27.8	10.3	17.5
2019-2020	26.8	-0.3	26.5	10.6	15.9
Average	**29.0**	**-0.5**	**28.5**	**10.3**	**18.3**

Gross inflow = Inflows due to Padvection (i.e. precipitation) + Precycled + others (desalinization, basin transfer, etc.); Net inflow = Gross inflow + Storage contribution (±delS)



Note: A negative value in net storage indicates storage build-up/ recharge.

Figure 4.32: Gross inflow and net storage during the period 2002-2020.

It was found that there was a reduction of ≈ 22% in the gross inflow between wet and dry years. During a wet year, there was a considerable recharge of ≈ 2 BCM to groundwater (contribution to storage). However, about ≈ 1 BCM of water was withdrawn (contribution from storage) during a dry year. Exploitable water (Blue water) is the amount of water available for utilization after meeting the demand due to landscape evapotranspiration. An increase/ reduction in exploitable water depends on (i) rainfall received in a year, (ii) atmospheric demand, and (iii) recharge/ extraction from storage. A wet year significantly contributes towards the storage (SW + GW). However, in a dry year the storage (SW + GW) is exploited to meet the demand. About 18 BCM of exploitable water is available to meet different needs. The study also explored to know the available water, utilized water, and utilizable water. Available water is the amount of water available to meet the basin demand excluding the committed flow and non-utilizable flow. It is also the combined amount of utilized flow and utilizable flow in a basin. Utilized flow is the amount of blue water already utilized or consumed to meet different needs of four management classes viz. protected land use, utilized land use, modified land use, and managed water use. Utilizable water is the portion of non-consumed blue water that goes unutilized from the basin. This amount of water can be better utilized through different interventions for preservation and conservation. The time-series plot of the available water, utilized flow and utilizable flow is shown in Figure 4.33.

Table 4.16

Sheet 1: Status of available water and utilizations in Nagaland

Units: BCM

Year	Exploitable water	Committed flow	Available water	Utilized flow	Utilizable flow
2002-2003	15.6	3.1	12.5	3.4	9.1
2003-2004 (Wet)	22.0	3.2	18.7	3.6	15.1
2004-2005	19.7	3.5	16.2	3.4	12.8
2005-2006	14.5	3.0	11.5	3.0	8.5

2006-2007	17.2	3.1	14.1	3.3	10.8
2007-2008	20.3	3.3	16.9	3.9	13.0
2008-2009 (Dry)	17.8	3.1	14.7	3.5	11.2
2009-2010	21.0	3.3	17.6	3.5	14.1
2010-2011	20.5	3.2	17.3	3.8	13.5
2011-2012	17.5	3.1	14.5	3.6	10.9
2012-2013	20.2	3.2	17.0	3.6	13.4
2013-2014	16.0	2.8	13.3	3.5	9.7
2014-2015	18.0	3.2	14.9	3.6	11.3
2015-2016	19.2	3.2	16.0	2.9	13.0
2016-2017	18.3	3.2	15.0	3.2	11.8
2017-2018	18.6	3.2	15.4	3.2	12.2
2018-2019	17.5	2.8	14.7	3.6	11.1
2019-2020	15.9	3.0	12.9	3.2	9.7
Average	**18.3**	**3.1**	**15.2**	**3.4**	**11.7**

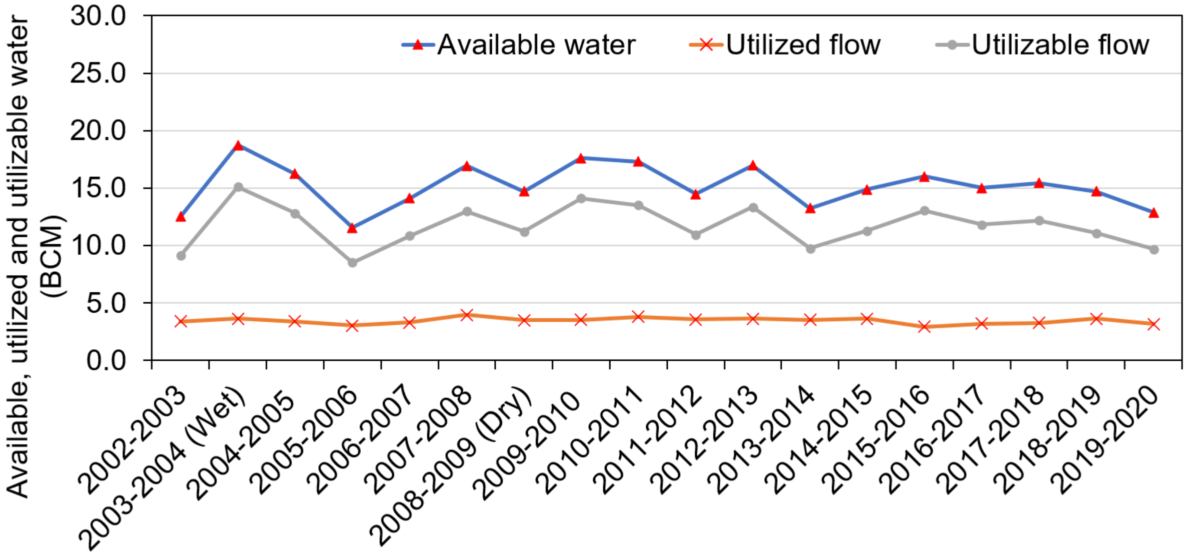


Figure 4.33: Available, utilized and utilizable flow during the period 2002-2020.

The average available water in the basin is about 15 BCM. The available water varies from 19 BCM to 14.7 BCM between a wet and dry year. It can be seen that there is a considerable amount of utilizable flow (12 BCM) which can be judiciously used in the state of Nagaland. About 3.4 BCM of blue water is being utilized in the state. Now, the question arises how the utilized flow is used. Figure 4.34 provides the distribution of blue water utilized by different WA+ based land use management classes.

Almost 87% of the Utilized flow (Blue water) is utilized for the Utilized land use (insignificant exploitation) and Managed water use (irrigated) in the basin. Remaining amount of Utilized flow is used to sustain Protected and Managed land use. 60% of the utilized flow meets the evaporative demand of different land uses (incremental ET), remaining 40% flow is the non-recoverable flow. Any flow into the basin (Net inflow) either it can be consumed or it is moving out of the basin as non-consumed. Table 4.17 presents the distribution of consumed and non-consumed water in the basin.

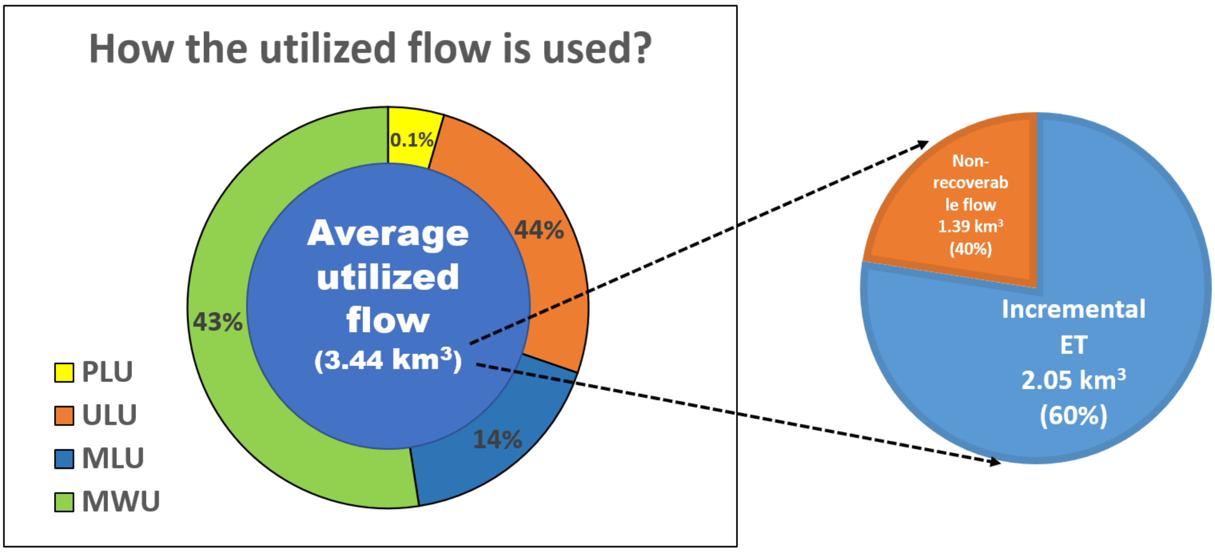


Figure 4.34: Distribution of utilized flow by different land use management classes.

Table 4.17

Sheet 1: Status of consumed and non-consumed water

Units: BCM

Year	Net inflow	Net inflow	
		Consumed flow	Non-consumed flow
2002-2003	25.9	13.6	12.2
2003-2004 (Wet)	32.5	14.2	18.4
2004-2005	30.2	13.9	16.3
2005-2006	24.6	13.1	11.5
2006-2007	27.6	13.5	13.9
2007-2008	30.5	14.2	16.3
2008-2009 (Dry)	27.5	13.3	14.3
2009-2010	31.0	13.6	17.4
2010-2011	30.5	13.7	16.7
2011-2012	27.4	13.4	14.0
2012-2013	30.5	13.8	16.6
2013-2014	25.7	13.1	12.6
2014-2015	27.7	13.3	14.4
2015-2016	30.2	14.0	16.3
2016-2017	28.9	13.9	15.1
2017-2018	29.4	14.1	15.4
2018-2019	27.8	14.0	13.9
2019-2020	26.5	13.8	12.7
Average	**28.6** (100%)	**13.69** (48%)	**14.88** (52%)

Out of the total net inflow into the basin, 48% of water is consumed to meet mainly the ET requirements (ET green and ET blue). The remaining amount of water is non-consumed (52%), and can be considered as an asset which is utilizable, but yet to be explored. It can be seen that a major chunk of water consumed in the basin is moving out of the basin as landscape ET (75%) followed by incremental ET (15%) and non-recoverable (10%) water as given in Table 4.18. The overall water balance for the state of Nagaland is shown in Figure 4.35.

Table 4.18

Sheet 1: Status of utilizations of consumed water

Units: BCM

Consumed	**Consumed flow**		
	Landscape ET (Green ET)	**Utilized flow**	
		Incremental ET (Blue ET)	**Non-Recoverable**
13.6	10.2	2.2	1.2
14.2	10.6	1.9	1.7
13.9	10.5	1.9	1.5
13.1	10.1	1.9	1.1
13.5	10.3	2.0	1.3
14.2	10.3	2.4	1.5
13.3	9.8	2.1	1.3
13.6	10.1	1.9	1.6
13.7	9.9	2.2	1.6
13.4	9.9	2.2	1.3
13.8	10.2	2.0	1.5
13.1	9.6	2.3	1.2
13.3	9.6	2.3	1.3
14.0	11.0	1.4	1.5
13.9	10.7	1.8	1.4
14.1	10.8	1.8	1.4
14.0	10.3	2.3	1.3
13.8	10.6	2.0	1.2
13.69 (100%)	**10.26** (74.9%)	**2.05** (15.0%)	**1.39** (10.1%)

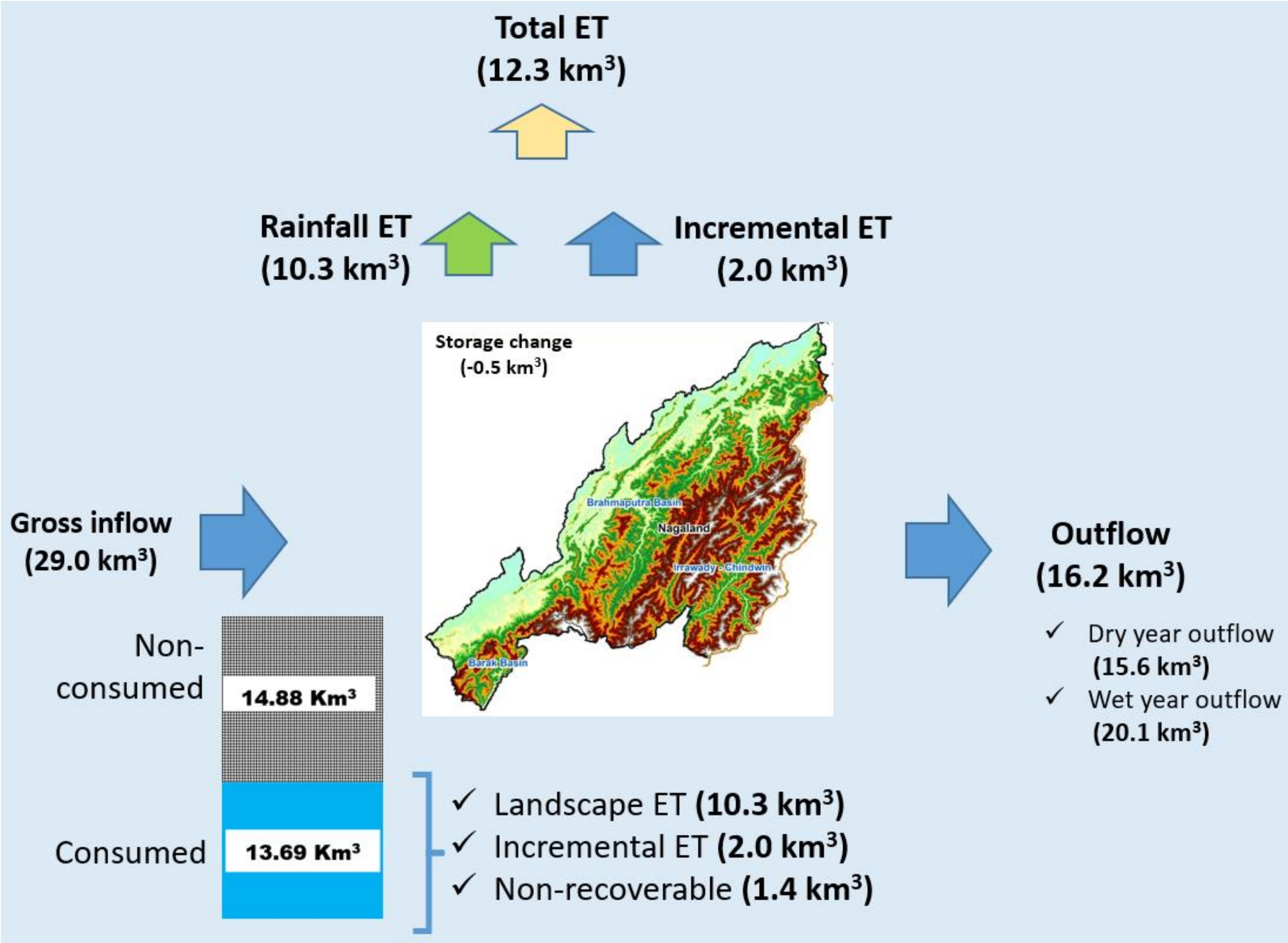


Figure 4.35: Overall water balance in the Nagaland state.

CHAPTER 5
SUMMARY AND CONCLUSIONS

5.1 Summary & Conclusions

Increasing competition for land and water resources is expected in the future due to rising demands for food and bioenergy production, biodiversity conservation, and changing production conditions due to climate change. Growing competition for water in many sectors reduces its availability for irrigation. Thus, efficient approaches are required for the effective management of water in every sector, particularly in agriculture. With advanced technological developments like satellite-based Remote Sensing and Geographical Information System, tools are becoming useful to account the water resources of a region. Water Accounting Plus (WA+) is a python-based tool designed to provide explicit spatial information on water depletion and the net withdrawal process of a region using globally available open-access data. In regions with data unavailability or scarcity, use of freely available open access data is quite handy in accounting the water resources. Further, Nagaland is hilly terrain, and mainly depends on the sources of surface water, viz., rivers, streams, and natural springs. The highly variable nature of rainfall, fewer number of gauging sites due to remote locations hindering instrumentation and maintenance, and most importantly, the occurrence of transboundary water bodies are key challenges to improve the water infrastructure. There is an urgent need for efficient water management practices which requires adoption of new tools for accurate measurement of resources.

In this backdrop, this study is a timely attempt to account the water resources for the state of Nagaland with the help of available new technologies such as water accounting plus (WA+) framework. In this study, WA+ Framework has been utilized to assess the total water consumptions, agricultural water consumptions (using green water and blue water), and estimation of land and water productivity, estimation of utilized water, and total water balance in different basins/sub-basins situated in the state of Nagaland. The capacity building of the officials on the different components of water accounting plus is also a key aspect of the study. The major objective of this study is to apply the newly developed WA+ framework for the selected sub-basins of Brahmaputra, Barak and Irrawady-Chindwin (Tizu) basins in the state of Nagaland for estimating the status of the water resources.

The following conclusions are drawn from this study as given below:

1. From the CHIRPS rainfall data analysis for the period 2001-02 to 2019-20, it was found that a considerable amount of rainfall is falling in the northern and north-eastern parts of Nagaland. This region is basically draining into the Brahmaputra basin. It was seen that monsoon season (June-September) dominates the rainfall in the state of Nagaland. Considerable rainfall is also witnessed in the month of April and May, just before the monsoon. Rainfall during winter is not significant. Sub-basins falling in the Brahmaputra basin generates maximum yield for the state of Nagaland.

2. The water accounting-based land use (WALU), developed using nine open datasets, suggested that forest cover dominates in the state followed by shrub land, fallow land, agriculture, and built-up area. The area of four land use management classes viz. protected land use (PLU), utilized land use (ULU), Modified land use (MLU) and managed water use (MWU), as per WA+ framework, is 134.42 Km^2, 12425.58 Km^2, 3651.25 Km^2 and 373.10 Km^2 respectively.
3. WA+ tool was set-up for the period 2001-02 to 2019-20. Six factsheets viz. Sheet 2 (evapotranspiration), Sheet 3 (part 1: agricultural water consumption; part 2: land and water productivity), Sheet 4 (part 1: man-made utilization; part 2: natural utilization), Sheet 5 (surface water), Sheet 6 (groundwater) and Sheet 1 (Resource base) were generated.
4. Sheet 2 revealed that an average water loss of 14.91 BCM (~ 900 mm) is occurring in the form of evapotranspiration from different basins and sub-basins annually. 56% of the evapotranspiration loss was contributed from evaporation; the remaining 44% of loss was due to transpiration. Out of the total evaporation loss, about 44% is due to interception loss, and the remaining is from the soil surface and water bodies. Utilized land use contributes maximum to the evapotranspiration loss, followed by modified land use, managed water use and protected land use. The study also revealed that a considerable chunk of ET (75.88%) is manageable. This implies that this portion of ET, which is a significant loss from the system, has the potential to be managed through scientific measures. Presently, almost 23% of ET loss is being managed through rainfed and irrigated agriculture. 37% of the ET loss is beneficially contributing to the intended purpose. The remaining loss of 63% is non-beneficial, and can be suitably converted to beneficial component by adopting the agronomical and mechanical measures.
5. Sheet 3 estimates the crop-wise agricultural water consumption (km^3/year), land productivity (kg/ha/year), and water productivity (kg/m^3) on monthly and yearly basis. The study estimated total agricultural water consumption of 2.50 BCM and 2.55 BCM, predominantly met from the rainfall during a dry and wet year respectively. The land productivity and water productivity during a dry year for rainfed rice were 3707.95 kg/ha/year and 0.93 kg/m^3 respectively. However, the land and water productivity reduced during a wet year to 3097.48 kg/ha/year and 0.76 kg/m^3 respectively. A higher productivity was seen in case of irrigated rice. The land productivity and water productivity during a dry year for irrigated rice are 7273.31 kg/ha/year and 2.32 kg/m^3 respectively. However, the land and water productivity during a wet year becomes 7152.46 kg/ha/year and 2.56 kg/m^3 respectively. Overall, the average land productivity was found to vary from 2564.2 to 4028.3 kg/ha/year and 6149.6 to 7818.9 kg/ha/year during the period 2001-02 to 2019-20, respectively for rainfed and irrigated cereals respectively. The region has an average WP of 0.83 kg/m^3 and 2.2 kg/m^3, respectively for rainfed and irrigated cereals. Overall, the WP was found to vary from 0.66 to 1.02 kg/m^3 (with an overall average of 0.83 kg/m^3) and 1.90 to 2.56

kg/m^3 (with an overall average of 2.2 kg/m^3) during the period 2001-02 to 2019-20, respectively for rainfed and irrigated cereals.

6. Spatial maps of land and water productivity provide the areas performing well (progressive farmers with high productivity) and poor (farmers with low productivity) in a large basin. These rich information enables the water managers to understand the interventions undertaken at local level by both progressive and less progressive farmers. This helps in planning different interventions for a particular area for higher productivity. The water productivity and the land productivity data can also be coupled with the prevalent crop price to estimate the income of farmers. Such information will be helpful in preparing poverty alleviation programs and in improving the livelihoods of farmers.
7. Sheet 4 provides the utilized flow for both manmade and natural sources of the basin. Sheet 4 is also known as the 'Withdrawal' sheet which provides the surface water and groundwater withdrawal. The annual average gross withdrawal for man-made and natural land uses are 0.8 BCM and 1.94 BCM respectively. It can be seen that water utilized for natural purposes is almost double than the man-made utilization. Out of the total man-made utilizations, almost 63% of withdrawal was from the surface water. Whereas, surface water utilization was 23% for the natural land uses. 45% of the total withdrawal (SW+GW) for man-made utilizations was consumed to meet incremental ET requirement, and the remaining water was non-recoverable. 55% of total man-made withdrawal was non-consumed, and can be recovered back to the system. The entire 1.94 BCM of natural utilizations was consumed.
8. Sheet 5 describes about the surface water availability of different sub-basins and basins. The state of Nagaland is divided into three important basins viz. Brahmaputra, Barak and Tizu (Irrawady-Chindwin). The study revealed that the total outflow from the seven sub-basins viz. Dhansiri, Chathe-Dzuza, Doyang, Dikhu, Tizit, Tsurang and Milak to the river Brahmaputra were about 14051 MCM. The estimated outflow from the catchment within the Nagaland to the Barak and Tizu (Irrawady-Chindwin) basins were about 572 MCM and 4435 MCM respectively. The outflow from Dhansiri, Chathe-Dzuza, Doyang, Dikhu, Tizit and Milak sub-basins were 2231.2 MCM, 956.2 MCM, 4163.5 MCM, 4161.8 MCM, 1307.5 MCM, 441.6 MCM and 789.5 MCM respectively.
9. Nagaland being a hilly state, estimating the groundwater conditions is very challenging. As per the estimates in Sheet 6, an annual vertical recharge of 15.68 BCM was estimated, out of which 87% was contributing to the baseflow. Groundwater withdrawal was about 1.77 BCM.
10. Sheet 1 provides the overall water balance of the basin. An average annual gross inflow of 29 BCM of water was estimated. A net inflow of 28.5 BCM was estimated with a net storage contribution of -0.5 BCM (a negative sign indicates net recharge). The landscape ET was estimated to the tune of 10.3 BCM (36% of net inflow). This implies that 64% of the net inflow (18.3 BCM) is available as 'exploitable water' in the state. The committed flow, as provisioned in the WA+ framework, was estimated to the tune of 3.1 BCM (17% of exploitable water).

An annual average of 15.3 BCM of water is available for utilizations in the state, of which about 22% (3.4 BCM) is utilized, and the remaining 11.7 BCM of water was available for utilization (utilizable flow), but yet to be harnessed. The available water varies from 19 BCM to 14.7 BCM between a wet and dry year. Almost 87% of the utilized flow (Blue water) was used for the utilized land use (ULU, indicating less exploitation) and Managed water use (MWU, irrigated) in the basin. Remaining amount of utilized flow was used to sustain Protected land use (PLU) and Managed land use (MLU, rainfed).

11. Out of the total net inflow into the basin (28.5 BCM), 48% of water is consumed to meet mainly the ET requirements (ET green and ET blue). The remaining amount of water is non-consumed (52%), and can be considered as an asset which is utilizable, but yet to be explored. It can be seen that a major chunk of water consumed in the basin is moving out of the basin as landscape ET (75%) followed by incremental ET (15%) and non-recoverable (10%) water. The study estimated an annual average outflow of 16.2 BCM.
12. Although all the estimates from WA+ was not validated, but the rich information available from the study provides a preliminary accounting of the water resources for the state of Nagaland entirely based on the satellite-based open access datasets. This will help the planners, policy makers and others associated in the water sector for undertaking appropriate actionable measures.

5.2 Limitations of WA+ Framework

1. All satellite data parameters have some level of uncertainty and error because of the indirect way of measurement especially for the hydro-meteorological parameters and processes. The mean absolute error for satellite-based estimates of ET, Rainfall and LU classification are 5.4%, 18.5% and 14.6% respectively as per the Poolad Karimi's thesis on WA+ for WR Reporting and River Basin Planning**.** Water accounting plus framework is still evolving in nature. Increasing availability of high-quality data from earth observation satellites will further increase the ability to quantify water resources at different scales.
2. LULC map (WALU), is one of the key inputs to the WA+, needs to be accurate for reliable water accounting at basin scale. It is prepared using multi-sources, multi-resolutions spatial and static data. From the available global data, it is resampled to the local conditions increasing the chances of errors. Crop data considered is also courser in nature.
3. The WA+ framework is more suited for near-real time and long-term analysis based on the data availability. Future prediction is difficult because of high dependency on data mostly of satellite-based.

5.3 Future Scope of Research

1. Land use map (WALU) can be improved with fine-resolution data, especially the crop data.
2. Setting-up the WA+ framework for different scenarios through altering the precipitation and ET.
3. Integrating the WA+ framework with Google Earth Engine (GEE) and other platforms with open data.
4. Development of a user-friendly Dashboard to visualize the rich outputs of WA+.

CHAPTER 6
KNOWLEDGE DISSEMINATION AND TRAINING

Knowledge dissemination and outreach in the form of training is an important component of any project. Further, WA+ is a newly developed tool relying heavily on the satellite-based open datasets. A prior knowledge of the new tools and techniques such as remote sensing and GIS, utility of computer programming (here Python language) in hydrology, although not compulsory, but essential to begin with the WA+ tool. Apart from this, both the inputs and outputs datasets in WA+ tool is huge, and requires an appropriate computing facility with considerable storage space. Data are auto-downloadable from different sources. Hence, an optimum internet speed is also recommended. During the study period, a five-day training programme was conducted during 28th Nov. to 02nd Dec., 2022 at the Conference Hall of State Data Centre of Chief Engineer's Office, WRD, Kohima, Nagaland. A total of 17 participants participated in the training programme (Table 6.1). The participants were sensitized on the WA+ tool and its different components during the training. A five-day training only makes the participants acquainted with the tools; however, more long-term trainings are recommended to equip them with the necessary skill in this framework. Few photographs of the training programme are provided in Figures 6.1. The local Newspaper highlighted the importance of WA+ in the state of Nagaland as shown in Figure 6.2.

Table 6.1
List of participants

SN	Name	Designation	Department	State
1	Er. K. Hutoi Sema	SE	WRD, Nagaland	Nagaland
2	Er. Chubasashi Chang	SE	WRD, Nagaland	Nagaland
3	Er. Sobu Agami	EE	WRD, Nagaland	Nagaland
4	Er. Wapangnaro Imchen	EE	WRD, Nagaland	Nagaland
5	Er. Obed Natso	SDO	WRD, Nagaland	Nagaland
6	Er. Khriebeituo Kulnu	SDO	WRD, Nagaland	Nagaland
7	Er. Neizevono Mor	SDO	WRD, Nagaland	Nagaland
8	Er. Ngakuchingmak	EE	WRD, Nagaland	Nagaland
9	Er. Keduvizo Sophie	EE	WRD, Nagaland	Nagaland
10	Er. Zhato Yhoshu	SDO	WRD, Nagaland	Nagaland
11	Er. Khitangpila	SDO	WRD, Nagaland	Nagaland
12	Er. Karipong Walling	SDO	WRD, Nagaland	Nagaland
13	Er. Rulin T	SDO	WRD, Nagaland	Nagaland
14	Er. Phutheguo Khawakhrie	SDO	WRD, Nagaland	Nagaland
15	Er. Yhunkolo Kath	SDO	WRD, Nagaland	Nagaland
16	Er. Sademkaba Ozukum	SDO	WRD, Nagaland	Nagaland
17	Er. Puloka	JE	WRD, Nagaland	Nagaland

Figure 6.1: Photographs showing glimpses of a training programme organized at Kohima, Nagaland.

Training on application of WA+ underway in Kohima

DIMAPUR: A five-day training on "Application of Water Accounting Plus (WA+) Tool for Water Resources Management" under the National Hydrology Project (NHP) got underway on November 28 at the Conference Hall of State Data Centre, Chief Engineer Office, Water Resources Department, Kohima. The training is being held from November 28 to December 2.

According to DIPR report, chief engineer-cum-nodal officer (NHP) Water Resources Department, Er. Hotovi Ayemi, informed that the training on application of water accounting plus (WA+) is the first of its kind to be conducted in the state and it is of utmost importance so that people can evaluate, manage and asses the water resources in the State.

Executive engineer, Water Resources Department, Er. Wapangnaro, in her introductory speech said that lack of water information and consensus hinders water reform. She said that Water Accounting Plus (WA+) serves as a tool to evaluate and plan water resources management, monitor changes in water resources, and assess the impacts of future interventions. She pointed out that the training is useful for the planning and management of water resources in Nagaland as it gives an accurate estimate of water availability and it provides an informed decision for the water planners in a basin or state. She also said that in the absence of data or data scarcity particularly for regions like Nagaland state with hilly terrain, this tool becomes more important.

Scientist D from the Indian Institute of Technology Roorkee, Dr. P.K Singh, said that the WA+ system is a python-based tool and utilizes freely available, open-access data and satellite information to estimate the water resources. "It provides information on water withdrawal and utilization, water and land productivity, and agricultural water consumption in the form of standardized Factsheets", he added.

Participants attends a training at the Conference Hall of State Data Centre, Kohima. (DIPR)

National Hydrology Project (NHP) is being implemented in the state of Nagaland and the National Institute of Hydrology (NIH), Roorkee in association with Water Resources Department (WRD), Kohima is conducting a study on the "Application of Water Accounting Plus tool in the state of Nagaland".

This capacity-building programme is intended to improve the skills of officials from the water resources department, Nagaland and to make them acquainted with the WA+ tool and independently run its applications in the state. A total of 17 participants from the department are participating in the training programme

Scientist D, Dr. P. K. Mishra and scientist D from NIH, Roorkee, Dr. P. K. Singh, are the resource persons providing the training on WA+.

The Morung Express, Tuesday, 29-11-2022

Nagaland WRD introduces Water Accounting Plus (WA+) tool

KOHIMA, NOVEMBER 28 (MExN): The inaugural programme of a five-day training programme on 'Application of Water Accounting Plus (WA+) Tool for Water Resources Management' under National Hydrology Project (NHP) was held at the Conference Hall of State Data Centre, Chief Engineer Office, Water Resources Department (WRD), Kohima on November 28.

According to a DIPR report, the Chief Engineer-cum-Nodal Officer (NHP) WRD, Er Hotovi Ayemi said that the training on WA+ is the first-of-its-kind to be conducted in the State and it is of utmost importance so that people can evaluate, manage, and assess the water resources in the State.

Er Wapagnaro, Executive Engineer, WRD, Nagaland said that lack of water information and consensus hinders reforms. She said that WA+ serves as a tool to evaluate and plan Water Resources Management, monitor changes in water resources, and assess the impacts of future interventions.

"So, this training is useful for the planning and management of water resources in Nagaland as it gives an accurate estimate of water availability and it provides an informed decision for the water planners in a basin or state," she stated.

In the absence of data or data scarcity particularly for regions like Nagaland state with hilly terrain, this tool becomes more important, she added.

Dr PK Singh, Scientist D from the Indian Institute of Technology, Roorkee said that WA+ system is a python-based tool and utilises freely available, open-access data and satellite information to estimate the water resources. It provides information on water withdrawal and utilization, water and land productivity, and agricultural water consumption in the form of standardized Factsheets.

NHP is being implemented in the state of Nagaland and the National Institute of Hydrology (NIH), Roorkee in association with WRD, Kohima is conducting a study on the 'Application of Water Accounting Plus tool in the state of Nagaland,' the DIPR report stated.

This capacity-building programme is intended to improve the skills of Officials from the WRD, Nagaland, and to make them acquainted with the WA+ tool and independently run its applications in the state. Dr PK Mishra, Scientist D, and Dr PK Singh, Scientist D from NIH, Roorkee are the resource persons providing the training on WA+ to 17 participants from the department.

Figure 6.2: Local newspaper covering the training programme organized at Kohima, Nagaland.

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APPENDIX - A Project summary

Table A.1: Summary

<table>
<tr><td colspan="5">Project objectives</td></tr>
<tr><td colspan="2">Objectives as per project document</td><td colspan="2">Revised objective</td><td>Reasons for revision</td></tr>
<tr><td colspan="2">1. To set-up WA+ Framework for the selected study basins/sub-basins.
2. To estimate ET consumption patterns for the selected basins/sub-basins.
3. To estimate land and water productivity for the selected basins/sub-basins.
4. To develop Resource Base (Surface water & Groundwater) for the selected basins/sub-basins.
5. To develop capacity of the State Govt. officials from WRD, Nagaland through training programmes on WA+</td><td colspan="2">None</td><td>None</td></tr>
<tr><td colspan="5">Manpower deployed (against sanctioned manpower)</td></tr>
<tr><td colspan="3">Sanctioned</td><td colspan="2">Deployed</td></tr>
<tr><td>Designation</td><td colspan="2">Person months</td><td>Designation</td><td>Person months</td></tr>
<tr><td>NA</td><td colspan="2">NA</td><td>NA</td><td>NA</td></tr>
<tr><td colspan="5">Infrastructure/ equipment</td></tr>
<tr><td colspan="2">Planned (as per project proposal)</td><td colspan="2">Developed/ procured</td><td>Reasons for deviation</td></tr>
<tr><td colspan="2">Work Station</td><td colspan="2">Procured</td><td>-</td></tr>
<tr><td colspan="5">Field work</td></tr>
<tr><td colspan="2">Planned (as per project proposal)</td><td colspan="2">Completed</td><td>Reasons for deviation</td></tr>
<tr><td colspan="2">NA</td><td colspan="2">NA</td><td>NA</td></tr>
<tr><td colspan="5">Workshop/ Capacity building/ technology transfer</td></tr>
<tr><td colspan="2">Planned (as per project proposal)</td><td colspan="2">Organized</td><td>Reasons for deviation</td></tr>
<tr><td colspan="2">Imparted trainings on WA+ to the state officials of WRD, Nagaland.</td><td colspan="2">01</td><td>NA</td></tr>
<tr><td colspan="5">Study area</td></tr>
<tr><td colspan="2">Planned</td><td colspan="3">Extended</td></tr>
<tr><td colspan="2">02 Years</td><td colspan="3">03 Years</td></tr>
<tr><td colspan="5">New data generated in the project</td></tr>
<tr><td colspan="2">Planned (as per project proposal)</td><td colspan="2">Achievement</td><td>Reasons for deviation</td></tr>
</table>

<table>
<tr><td>Precipitation (CHIRPS), AET (SSEBop), Water yield, ET-Green, ET-Blue, GPP, NPP, NDM, Soil Moisture, GRACE, Land and Water Productivity (Irrigated and rainfed), DEM, Soil map, Land use map and others</td><td colspan="2">100%</td><td>NA</td></tr>
<tr><td colspan="4">Envisaged contribution of the project</td></tr>
<tr><td>Planned (as per project proposal)</td><td colspan="2">Contribution made</td><td>Reasons for deviation</td></tr>
<tr><td>Beneficial and non-beneficial consumptions, ET-Green and ET-Blue, Agricultural accounts: Water Productivity and Land Productivity, Training of the stakeholders on WA+</td><td colspan="2">100%</td><td>NA</td></tr>
<tr><td colspan="4">How research outcome benefited the end user department and society</td></tr>
<tr><td>Planned (as per project proposal)</td><td colspan="2">Benefit derived</td><td>Reasons for deviation</td></tr>
<tr><td>All the outcomes (FactSheets) from WA+ provides insights on the water resources of the basins and sub-basins</td><td colspan="2">These maps can be used for formulating policy on actionable water management plans.</td><td>NA</td></tr>
<tr><td colspan="4">End-of-project deliverables</td></tr>
<tr><td>Planned (as per project proposal)</td><td colspan="2">Achieved</td><td>Reasons for deviation</td></tr>
<tr><td>• Water consumption patterns; Beneficial and non-beneficial use
• Accounts for land and water productivity
• Utilized flow, utilizable flow, gross inflow, net inflow, exploitable water, available water, Resource Base (Surface water & Groundwater; Overall water balance
• Capacity development of the State Govt. officials from WRD, Nagaland
• WALU and other thematic maps.
• WA+ Report and Recommendations</td><td colspan="2">100%</td><td>-</td></tr>
<tr><td colspan="4">Outsourcing (>1 lakh)/ consultancy (All)</td></tr>
<tr><td>Consultant (name and qualifications), organization / outsource agency</td><td>Work assigned</td><td>Estimated cost Rs</td><td>Actual cost Rs</td></tr>
<tr><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
</table>

Financial achievement					
Sl. No	Head	Approved budget	Approved revised budget	Final expenditure	Reasons for deviation
1	Remuneration/Emoluments for Manpower etc.	-	-	-	-
2	Travelling Expenditure	300000	-	108081	-
3	Infrastructure/Equipment	350000	-	324800	-
4	Experimental Charges/Field work/Consumables	200000	-	7970	-
5	Capacity building/Technology transfer	-	-	-	-
6	Contingency	-	-	-	-
7	Outsourcing/ consultancy	50000	-		-
	Total	9,00,000/-	-	4,40,851/-	-

Table A.2: Quantitative outcome

i. Research papers published/ submitted

S No	Research paper (National/ International Journal/ conferences/ symposium/ workshop/ seminar)	Impact factor for Journal
	02	Modelers Meet, NHP

Reports/Monographs/Internal publications brought out

S. No.	Reports/Monographs/Internal publications
	NA

ii. New techniques/models/ software/ knowledge developed, if any
WA+
Under development
https://solutions.esri.in/portal/apps/dashboards/c7a333bfe2164fe884961a011a3795a2

iii. Web site/ application developed

Name	Web address	Server location	Launch date	Details of information available
WA+ Dashboard	As above	ESRI and NIH Roorkee	To be launched	Spatial and temporal variability of water and land productivity, ET-Green and ET-Blue, Precipitation, and AET.

iv. Patents filed/awarded, if any

Workshop/ conferences/ seminars/capacity building programmes organised

Sl. No.	Topic	Dates, duration, No. of participants	Report published (Y/N)
1:	Application of Water Accounting Plus (WA+) Tool for Water Resources Management	16-20 Nov. 2020; 50	N
2:	Application of Water Accounting Plus (WA+) Tool for Water Resources Management for the WRD officials of the State of Nagaland state	28 Nov., 02 Dec., 2022, 2022	N

v. Stake holders feedback and action taken on constructive feed back

Sl. No.	Feedback received	Action taken

Stake holder meet (Topic and date)		
1:	National Hydrology Project Third Modelers Meet Development of Water Accounts for different Sub-basins of Brahmaputra and Barak River Basins in the state of Meghalaya Using Water Accounting Plus (WA+) Framework (NIH)	December 19, 2022 Time 1000 hrs to 1035 hrs [Appreciated]
2:	National Hydrology Project Agenda of 12th R&D Session on PDS Development of Water accounts for the different basins of Brahmaputra and Barak River Basins.	10th and 11th November 2021 [Appreciated]

vi. Field observations obtained, thematic maps generated (water quality and salinity, isotope, soil moisture, stage and discharge, sediment, water level, river cross sections, geophysical/ resistivity survey, hydrogeological investigations etc.)

Sl. No.	Parameter, frequency, period, groundwater/ river/ tank/ hand pump/ spring/ sea-water	Number (planned)	Numbers (measured)
	DEM, Slope map, Aspect map, WALU map, maps of ET-Green, ET-Blue, WP and LP (irrigated and rainfed), relationship maps of climatic and bio-physical parameters.	NA	NA

vii. Field installations (piezometers, river stage/ discharge, soil moisture etc.)

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
	NA	NA	NA	NA	NA

viii. Equipment/ software purchased

a. Equipment purchased

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
	NA	NA	NA	NA	NA

b. Software purchased

S. No	Name, version, license	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
	NA	NA	NA	NA	NA

ix. Plans for utilizing the equipment facilities in future

S. No.	Installation/ equipment	Planned future use

	NA	NA
x. Data dissemination policy for data generated in the project		
xi. Number of post-graduate/doctoral candidates completed their courses (Please give a list of such candidates)		
xii. Foreign deputation/visit of PI/Co-PIs/students, if any		

Table A.3: Activity chart

Include activity chart/ modified activity chart, reasons for modification of activity chart.

Project Year	**June 2021-May 2022**				**June 2022-May 2023**			
Project Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
a. Data downloading and processing, and generation of data bases and maps; data collection from CWC, and state govt. departments	↔	↔						
b. Data analysis in WA+ Framework, and testing		↔	↔					
c. Water Consumption Patterns and beneficial non-beneficial consumptions			↔	↔				
d. Accounts of Land Productivity and Water Productivity				↔	↔			
e. Catchment wise Water Accounts: Supply-Demand and Consumptions and Water Availability					↔	↔	↔	
f. WA+ Report and Recommendations of best practices suitable for the catchments							↔	↔
g. Training modules on WA+							↔	↔

Annexure - I

Open-Access Datasets Useful for Water Accounting

Rainfall	
CHIRPS rainfall	http://chg.geog.ucsb.edu/data/chirps/
TRMM rainfall	http://pmm.nasa.gov/data-access/downloads/trmm
GPM rainfall	http://pmm.nasa.gov/data-access/downloads/gpm
CMORPH	http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html ftp://ftp.cpc.ncep.noaa.gov/precip/CMORPH_V1.0/CRT/0.25deg-3HLY/
PERSIANN	http://chrs.web.uci.edu/research/satellite_precipitation/approach.html#training ftp://persiann.eng.uci.edu/pub/PERSIANN_daily/binary/
RFE	http://earlywarning.usgs.gov/fews/product/30 ftp://ftp.cpc.ncep.noaa.gov/fews/fewsdata/africa/rfe2/geotiff/
ARC	https://catalog.data.gov/dataset/climate-prediction-center-cpc-africa-rainfall-climatology-version-2- 0-arc2 ftp://ftp.cpc.ncep.noaa.gov/fews/fewsdata/africa/arc2/geotiff/
GPCC	http://www.esrl.noaa.gov/psd/data/gridded/data.gpcc.html https://www.dwd.de/EN/ourservices/gpcc/gpcc.html ftp://ftp-anon.dwd.de/pub/data/gpcc/html/download_gate.html
Evapotranspiration	
MOD16	http://www.ntsg.umt.edu/project/mod16
LandSAF	http://landsaf.meteo.pt/algorithms.jsp;jsessionid=BCD989669B8E1FF2B7ACCB034908F198?seltab=7 &starttab=7
METRIC / EEFLUX	http://eeflux-level1.appspot.com/
GLEAM	http://www.gleam.eu/
Meteorological data	
Climate Engine	http://clim-engine.appspot.com/
Land Data Assimilation System (LDAS)	http://ldas.gsfc.nasa.gov/index.php http://disc.sci.gsfc.nasa.gov/uui/datasets?keywords=GLDAS
ECMWF ERA-interim	http://www.ecmwf.int/en/research/climate-reanalysis/era-interim http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/
KNMI climate explorer	https://climexp.knmi.nl/start.cgi?id=someone@somewhere
LandSAF	http://landsaf.meteo.pt/algorithms.jsp;jsessionid=3A42D12B3CF3D87C2338736117FBE6F3?seltab=1 &starttab=1
ClimSAF	http://www.cmsaf.eu/EN/Home/home_node.html
CFSR	http://www.ngdc.noaa.gov/docucomp/page?xml=NOAA/NESDIS/NCDC/Geoportal/iso/xml/C00765.x ml&view=getDataView&header=none

WRF-Hydro	https://www.ral.ucar.edu/projects/wrf_hydro
Land use / land cover	
Globcover	High resolution (30 m) global land cover map http://data.ess.tsinghua.edu.cn/ Moderate resolution (300 m) GlobCover map http://due.esrin.esa.int/page_globcover.php
GFSAD30	https://croplands.org/
Global Cropland Extent	http://glad.geog.umd.edu/projects/croplands/globalindex.html
Fraction of agricultural land	http://www.iiasa.ac.at/web/home/about/news/150116-Cropland-Maps.html
Crop land	http://geography.wr.usgs.gov/science/croplands/index.html
IWMI	http://waterdata.iwmi.org/applications/irri_area/
IFPRI	http://mapspam.info/about/
FAO global irrigated area map GMIA	http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm
EcoClimap	https://opensource.cnrm-game-meteo.fr/projects/ecoclimap/wiki
Soil Moisture	
ESA - University of Vienna	http://www.esa-soilmoisture-cci.org/node/93
Jet Propulsion Laboratory - SMAP	http://smap.jpl.nasa.gov/data/
EumetSat - ASCAT	http://www.eumetsat.int/website/home/News/DAT_2633340.html
Vito Copernicus Portal	http://land.copernicus.vgt.vito.be/PDF/portal/Application.html#Home
River flow	
GRDC	http://www.bafg.de/GRDC/EN/Home/homepage_node.html
Water levels	
GRLM	http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=GCMD&MetadataType=0&MetadataView=Full&KeywordPath=&EntryId=%5BGCMD%5DUSDACROPLAKES Hydroweb http://www.legos.obs-mip.fr/en/soa/hydrologie/hydroweb/
ESA River and Lake project	ftp://ftp.space.dtu.dk/pub/Altimetry/BENEDEK/RIVERANDLAKE/website/jason_two.html
NASA IceSat	http://icesat.gsfc.nasa.gov/icesat2/index.php
Groundwater storage	
Grace satellite	http://www.csr.utexas.edu/grace/asdp.html http://grace.jpl.nasa.gov/data/get-data/monthly-mass-grids-land/
Vegetation	
Vegetation cover and Leaf Area Index (100 m pixels)	http://www.vito-eodata.be/PDF/portal/Application.html#Home
MOD15	http://modis.gsfc.nasa.gov/data/dataprod/dataproducts.php?MOD_NUMBER=15 http://e4ftl01.cr.usgs.gov/MOLT/MOD15A2H.006/

Digital Elevation Model	
SRTM	http://www2.jpl.nasa.gov/srtm/
HydrShed	http://hydrosheds.cr.usgs.gov/dataavail.php
Tools for land and water monitoring	http://aqua-monitor.appspot.com
Data Discovery Portals	https://earthdata.nasa.gov/ http://www.geoportal.org/web/guest/geo_home_stp https://www.hydroshare.org/

Annexure - II

WA+ Land class system				
		Water Management Classes (WMC)	**Water use - Land Use - Land Cover**	**Description**
1	PLU1	Protected land use	Protected forests	All forest classes that are within a protected site (source of the protected sites www.protecttheplanet.org)
2	PLU2	Protected land use	Protected shrubland	The savanna classes, shrubland and herbaceous cover that are within a protected site.
3	PLU3	Protected land use	Protected natural grasslands	The open grasslands and natural alpine pastures that are within a protected site
4	PLU4	Protected land use	Protected natural waterbodies	Natural lakes and rivers that are within a protected site
5	PLU5	Protected land use	Protected wetlands	Wetland & swamps, mangrove that are within a protected site
6	PLU6	Protected land use	Glaciers	All glaciers are considered protected sites
7	PLU7	Protected land use	Protected other	All other ULU classes that are within a protected site (excluding Alien invasives species)
8	ULU1	Utilized land use	Closed deciduous forest	Leaf losing forest with a coverage percentage of more than 40%
9	ULU2	Utilized land use	Open deciduous forest	Leaf losing forest with a coverage percentage of less than 40%
10	ULU3	Utilized land use	Closed evergreen forest	Evergreen forest with a coverage percentage of more than 40%
11	ULU4	Utilized land use	Open evergreen forest	Evergreen forest with a coverage percentage of less than 40%
12	ULU5	Utilized land use	Closed savanna	Savanna type land with a coverage percentage of more than XX%
13	ULU6	Utilized land use	Open savanna	Savanna type land with a coverage percentage of less than XX%
14	ULU7	Utilized land use	Shrub land & mesquite	Shrubland type of land
15	ULU8	Utilized land use	Herbaceous cover	Low cover
16	ULU9	Utilized land use	Meadows & open grassland	grasslands of different types
17	ULU10	Utilized land use	Riparian corridor	Vegetation along the banks of a river or stream
18	ULU11	Utilized land use	Deserts	Sand deserts areas
19	ULU12	Utilized land use	Wadis	Streams that are dry during part of the year
20	ULU13	Utilized land use	Natural alpine pastures	mountain pastures
21	ULU14	Utilized land use	Rocks & gravel & stones & boulders	Rocks including stones, boulders, gravel and other stony surfaces.
22	ULU15	Utilized land use	Permafrost	Permafrost

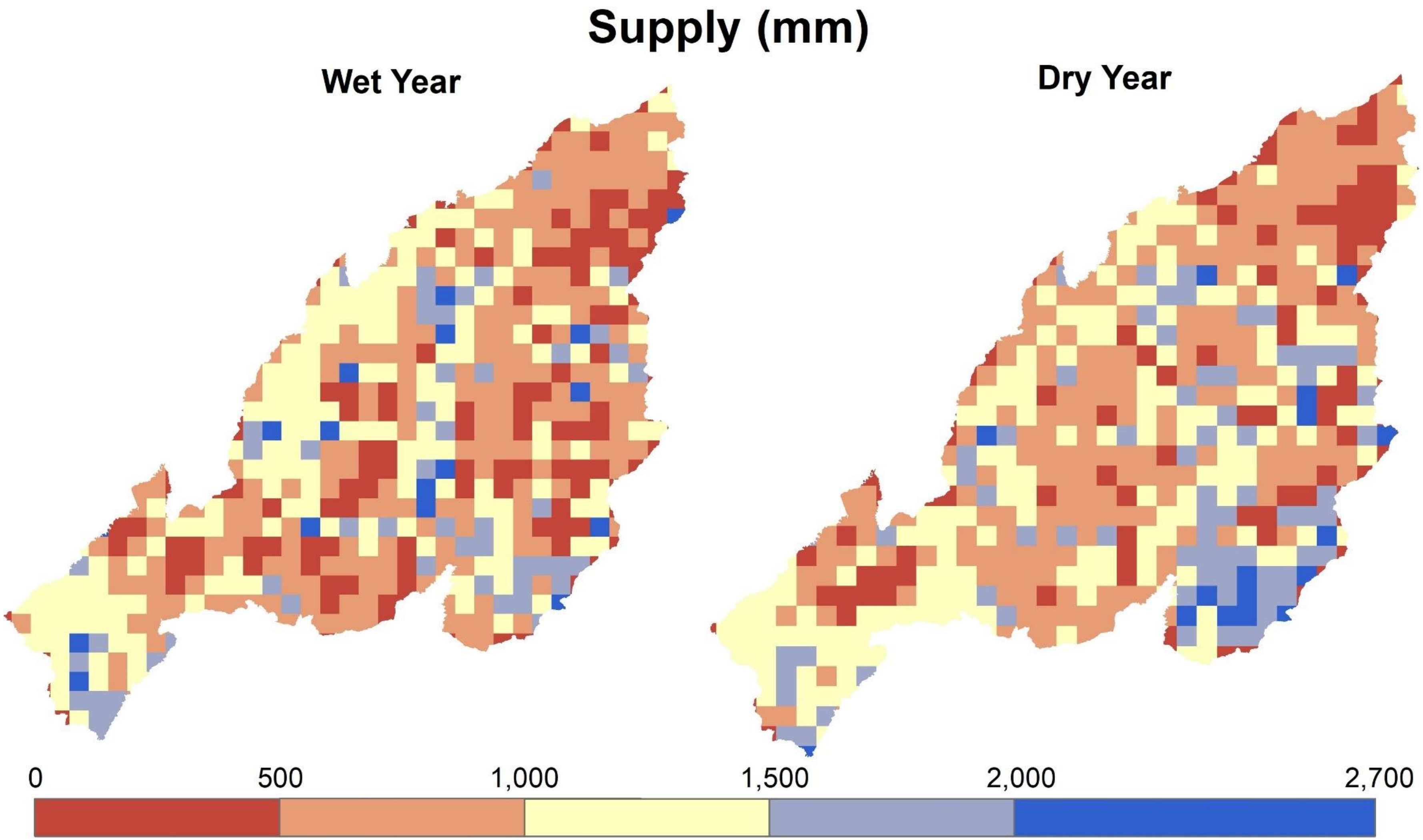
23	ULU16	Utilized land use	Brooks & rivers & waterfalls	Flowing water that is not a lake.
24	ULU17	Utilized land use	Natural lakes	Natural lakes
25	ULU18	Utilized land use	Flood plains & mudflats	Floodplains and mudflats that are temporally flooded.
26	ULU19	Utilized land use	Saline sinks & playas & salinized soil	Salinized soil, including salt lake beds and salinized sinks
27	ULU20	Utilized land use	Bare soil	Bare soil that is permanently bare, that does not consist of sand or rocks otherwise it would be ULU11 Deserts or ULU14 Rocks
28	ULU21	Utilized land use	Waste land	Land that has been abandoned and has no specific type of vegetation
29	ULU22	Utilized land use	Moorland	Moorlands
30	ULU23	Utilized land use	Wetland	Wetlands including swamp (wet all year-round)
31	ULU24	Utilized land use	Mangroves	Mangroves
32	ULU25	Utilized land use	Alien invasive species	Alien invasive species
33	MLU1	Modified land use	Forest plantations	Forest plantations that are rainfed
34	MLU2	Modified land use	Rainfed production pastures	Rainfed pastures for grazing
35	MLU3	Modified land use	Rainfed crops - cereals	Rainfed Cereals as defined by the FAO classification of crops
36	MLU4	Modified land use	Rainfed crops - root/tuber	Rainfed root/ tuber crops as defined by the FAO classification of crops
37	MLU5	Modified land use	Rainfed crops - leguminous	Rainfed leguminous crops as defined by the FAO classification of crops
38	MLU6	Modified land use	Rainfed crops - sugar	Rainfed sugar crops as defined by the FAO classification of crops
39	MLU7	Modified land use	Rainfed crops - fruit and nuts	Rainfed fruits and nut as defined by the FAO classification of crops
40	MLU8	Modified land use	Rainfed crops - vegetables and melons	Rainfed vegetables and melons as defined by the FAO classification of crops
41	MLU9	Modified land use	Rainfed crops - oilseed	Rainfed oilseed crops as defined by the FAO classification of crops
42	MLU10	Modified land use	Rainfed crops - beverage and spice	Rainfed beverage and spice crops as defined by the FAO classification of crops
43	MLU11	Modified land use	Rainfed crops - other	Rainfed other crops such as cotton or flax
44	MLU12	Modified land use	Mixed species agro-forestry	Agriculture mixed with forest (swidden cultivation)
45	MLU13	Modified land use	Fallow & idle land	Land that is not used and is thus idle or fallow
46	MLU14	Modified land use	Dump sites & deposits	XX
47	MLU15	Modified land use	Rainfed homesteads and gardens (urban cities) - outdoor	Rainfed houses and gardens in an urban environment

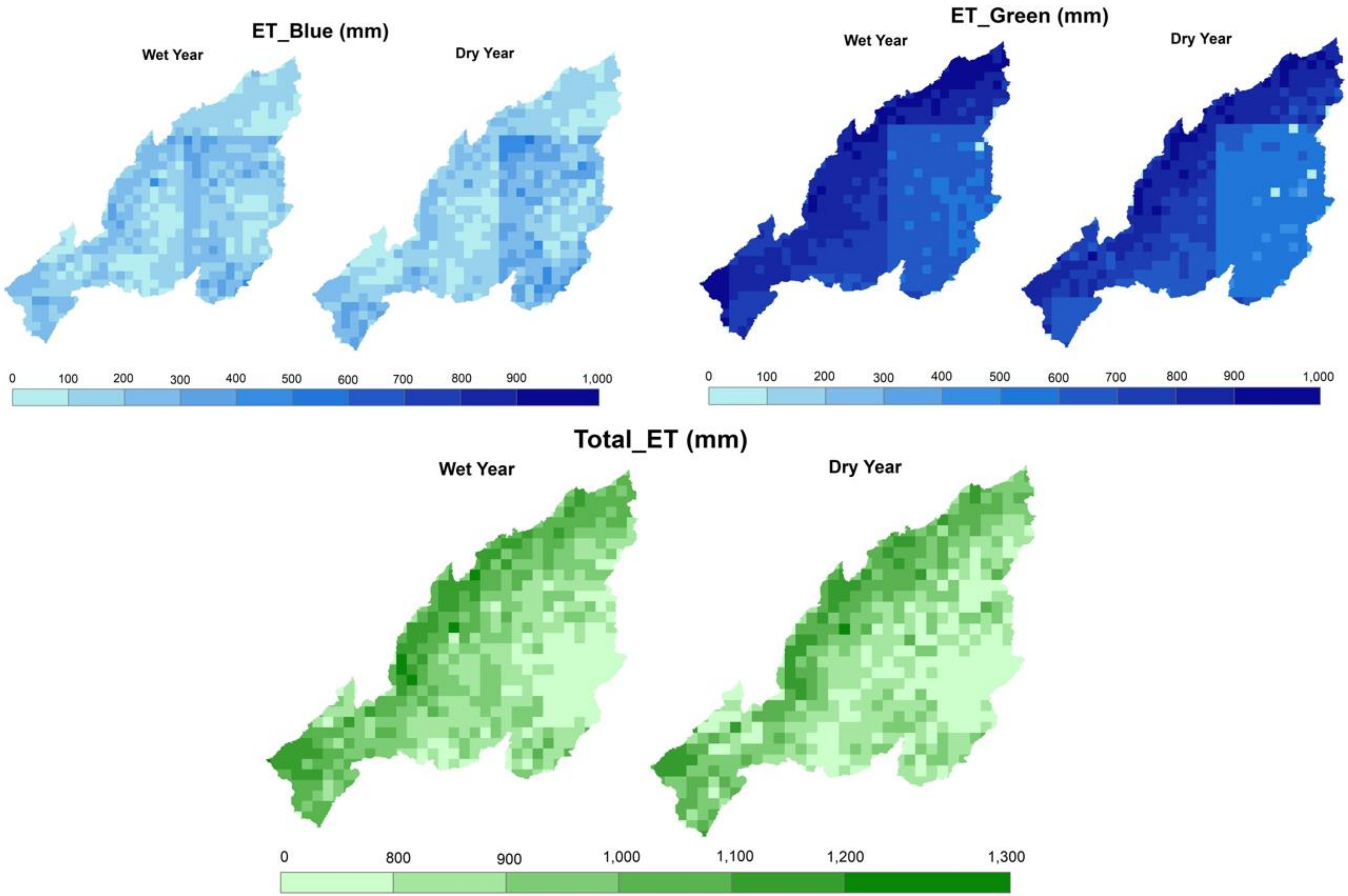
48	MLU16	Modified land use	Rainfed homesteads and gardens (rural villages) - outdoor	Rainfed houses and gardens in a rural environment
49	MLU17	Modified land use	Rainfed industry parks - outdoor	The greenery in an industrial zone
50	MLU18	Modified land use	Rainfed parks (leisure & sports)	Rainfed city parks that are for leisure and sports
51	MLU19	Modified land use	Rural paved surfaces (lots, roads, lanes)	Rural paved surfaces such as road lots and other hard surfaces
52	MWU1	Managed water use	Irrigated forest plantations	Forest plantations that are irrigated
53	MWU2	Managed water use	Irrigated production pastures	Irrigated pastures for grazing
54	MWU3	Managed water use	Irrigated crops - cereals	Irrigated Cereals as defined by the FAO classification of crops
55	MWU4	Managed water use	Irrigated crops - root/tubers	Irrigated root/ tuber crops as defined by the FAO classification of crops
56	MWU5	Managed water use	Irrigated crops - leguminous	Irrigated leguminous crops as defined by the FAO classification of crops
57	MWU6	Managed water use	Irrigated crops - sugar	Irrigated sugar crops as defined by the FAO classification of crops
58	MWU7	Managed water use	Irrigated crops - fruit and nuts	Irrigated fruits and nut as defined by the FAO classification of crops
59	MWU8	Managed water use	Irrigated crops - vegetables and melons	Irrigated vegetables and melons as defined by the FAO classification of crops
60	MWU9	Managed water use	Irrigated crops - Oilseed	Irrigated oilseed crops as defined by the FAO classification of crops
61	MWU10	Managed water use	Irrigated crops - beverage and spice	Irrigated beverage and spice crops as defined by the FAO classification of crops
62	MWU11	Managed water use	Irrigated crops - other	Irrigated other crops such as cotton or flax
63	MWU12	Managed water use	Managed water bodies (reservoirs, canals, harbours, tanks)	Waterbodies that are managed such as canals reservoirs and ponds
64	MWU13	Managed water use	Greenhouses - indoor	Greenhouses
65	MWU14	Managed water use	Aquaculture	Aquaculture
66	MWU15	Managed water use	Domestic households - indoor (sanitation)	The indoor water consumption of a household, the sanitation water

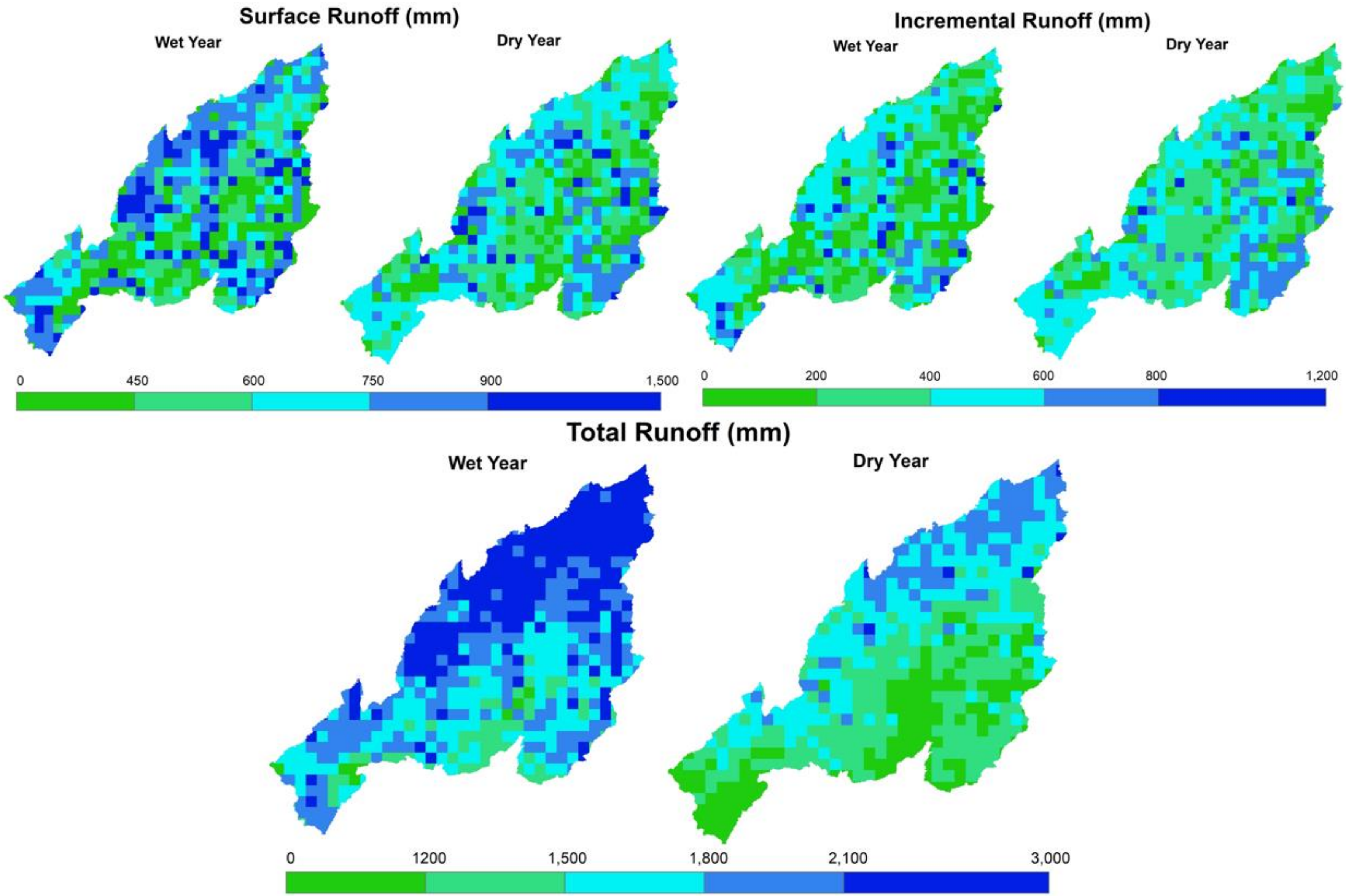
67	MWU16	Managed water use	Manufacturing & commercial industry - indoor	The indoor water consumption related to manufacturing and industry
68	MWU17	Managed water use	Irrigated homesteads and gardens (urban cities) - outdoor	Irrigated houses and gardens in an urban environment
69	MWU18	Managed water use	Irrigated homesteads and gardens (rural villages) - outdoor	Irrigated houses and gardens in a rural environment
70	MWU19	Managed water use	Irrigated industry parks - outdoor	The greenery in an industrial zone
71	MWU20	Managed water use	Irrigated parks (leisure, sports)	Irrigated city parks that are for leisure and sports
72	MWU21	Managed water use	Urban paved Surface (lots, roads, lanes)	
73	MWU22	Managed water use	Livestock and domestic husbandry	Water consumption by livestock and domestic husbandry
74	MWU23	Managed water use	Managed wetlands & swamps	Wetlands that are managed (wet the whole year)
75	MWU24	Managed water use	Managed other inundation areas	Managed areas that are flooded part of the year
76	MWU25	Managed water use	Mining/ quarry & shale exploration	Mining areas
77	MWU26	Managed water use	Evaporation ponds	Evaporation ponds
78	MWU27	Managed water use	Waste water treatment plants	Waste water treatment plants
79	MWU28	Managed water use	Hydropower plants	Hydropower plants
80	MWU29	Managed water use	Thermal power plants	Thermal power plants either gas, nuclear, or coal fired.

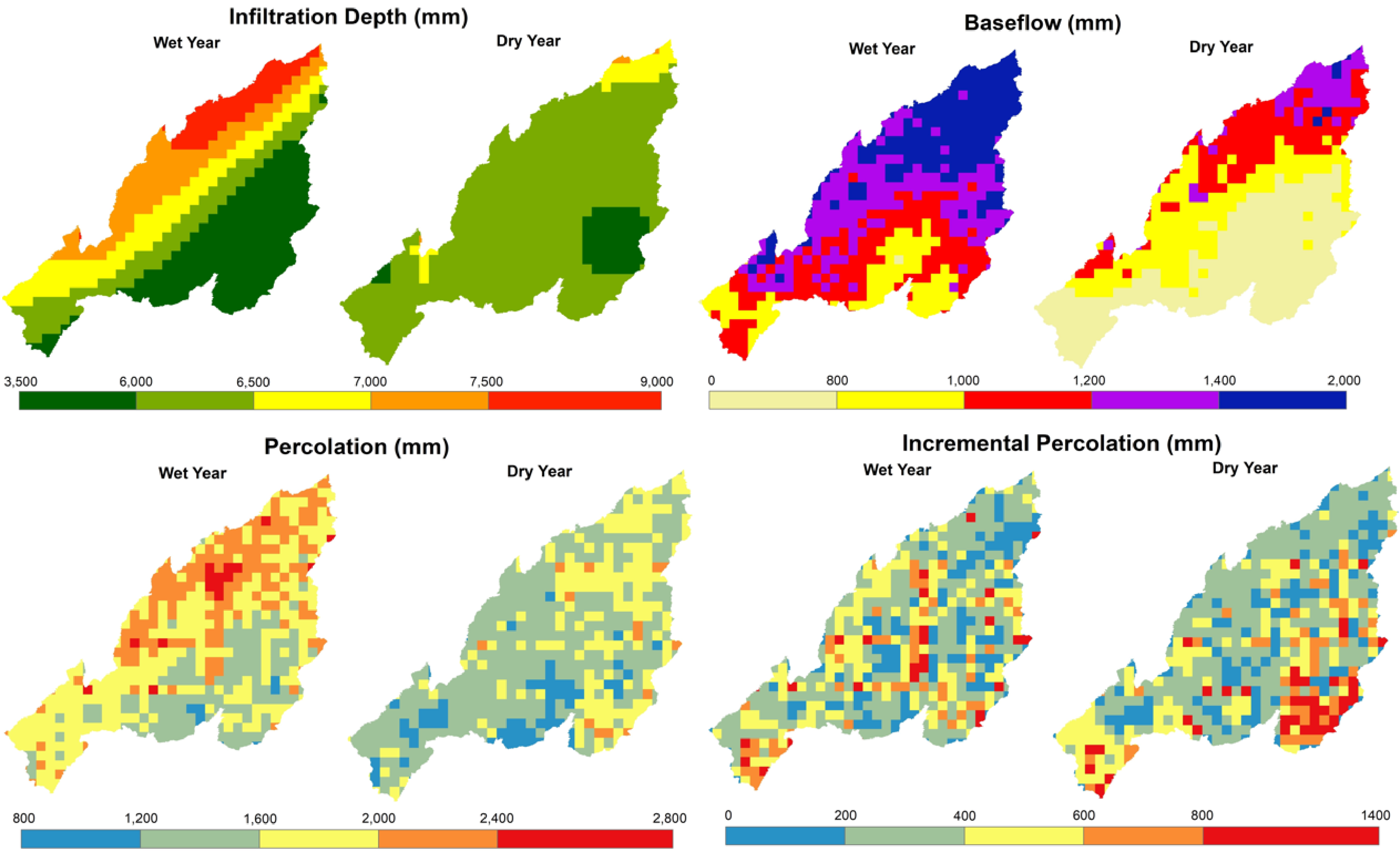
__Annexure - III__

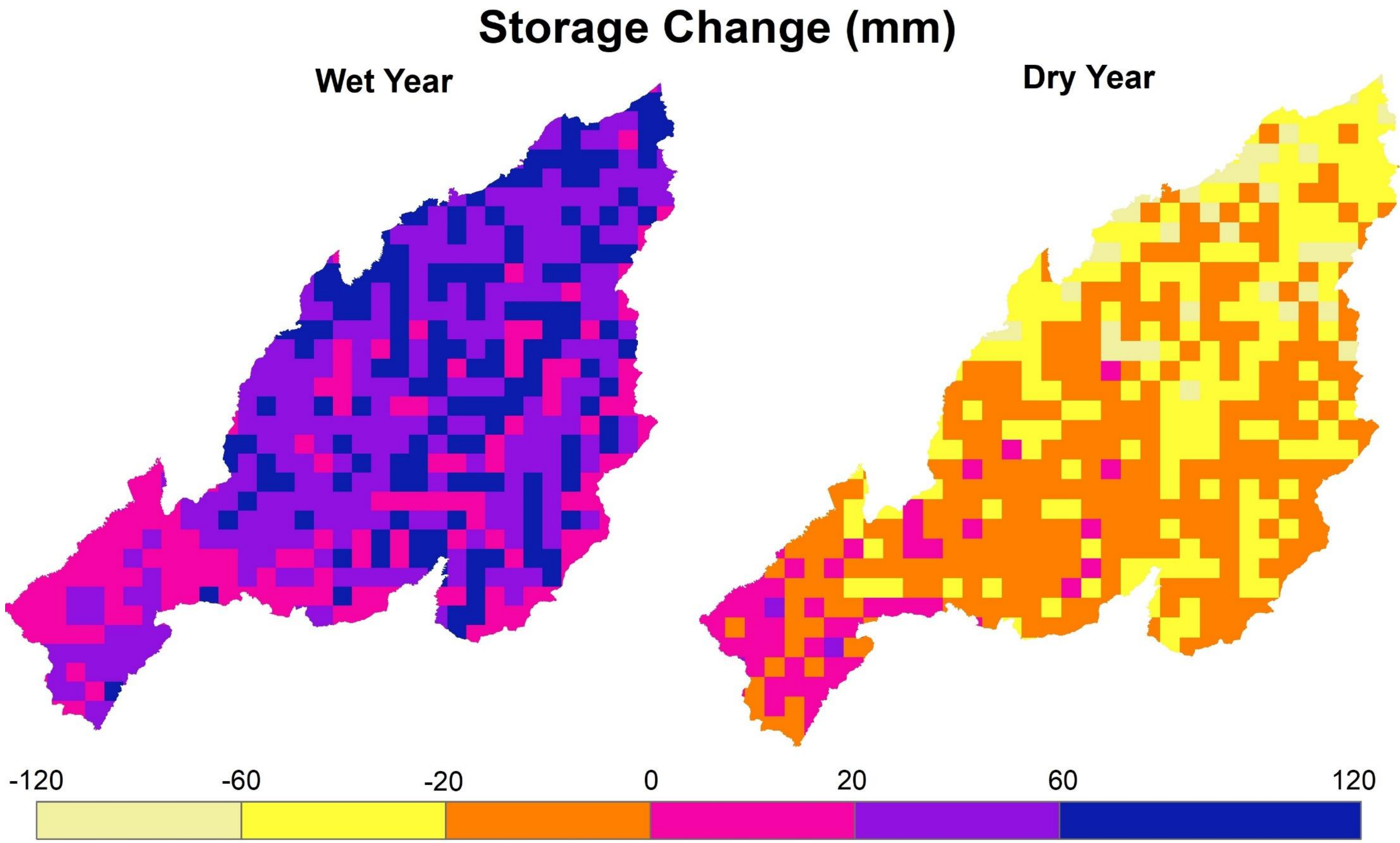
Sample outputs from WaterPix model



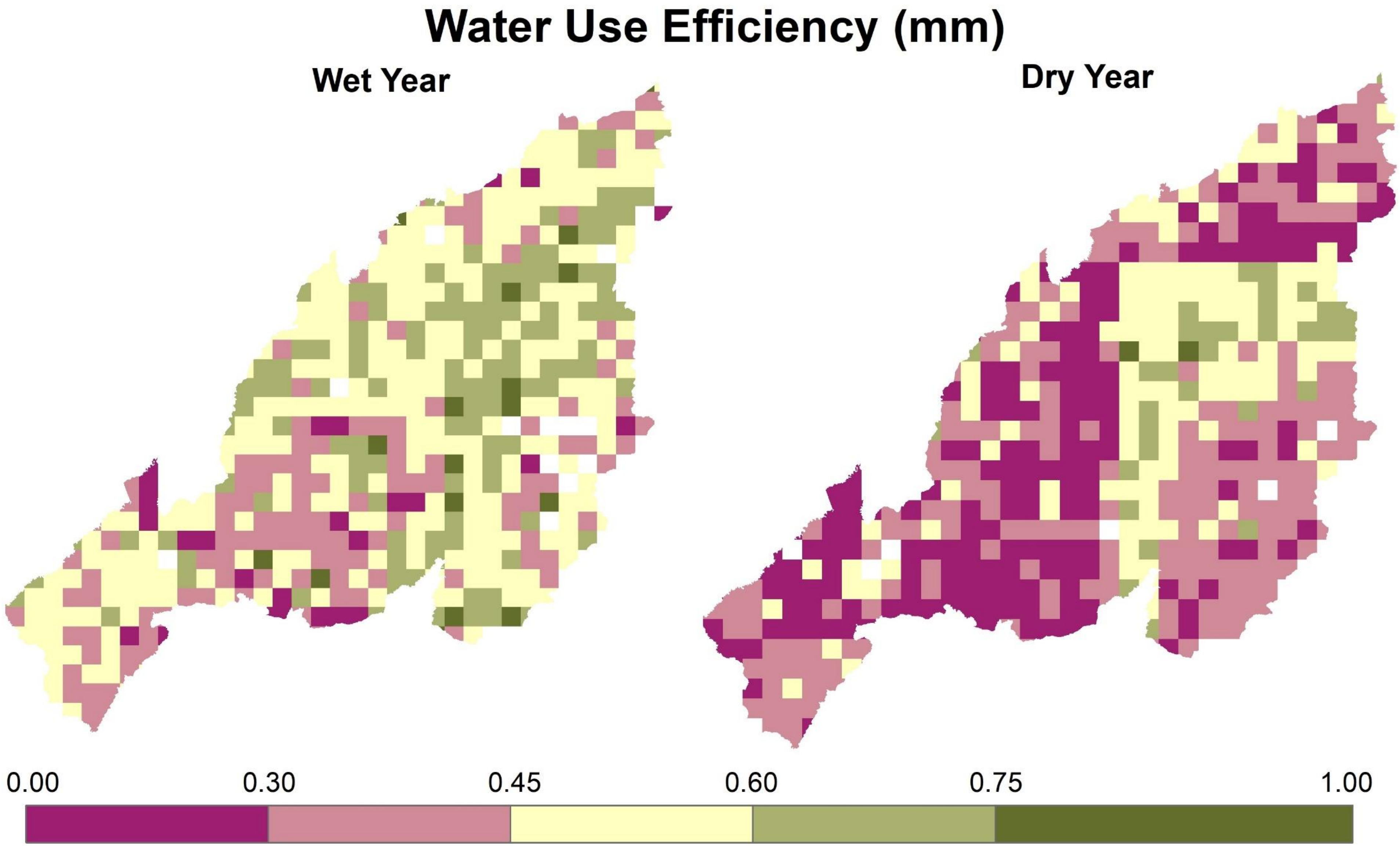

ET_Blue (mm)
Wet Year
Dry Year
0
100
200
300
400
500
600
700
800
900
1,000
ET_Green (mm)
Wet Year
Dry Year
0
100
200
300
400
500
600
700
800
900
1,000
Total_ET (mm)
Wet Year
Dry Year
0
800
900
1,000
1,100
1,200
1,300


Surface Runoff (mm)
Wet Year
Dry Year
0
450
600
750
900
1,500
Incremental Runoff (mm)
Wet Year
Dry Year
0
200
400
600
800
1,200
Total Runoff (mm)
Wet Year
Dry Year
0
1200
1,500
1,800
2,100
3,000


Infiltration Depth (mm)
Wet Year
Dry Year
3,500
6,000
6,500
7,000
7,500
9,000
Baseflow (mm)
Wet Year
Dry Year
0
800
1,000
1,200
1,400
2,000
Percolation (mm)
Wet Year
Dry Year
800
1,200
1,600
2,000
2,400
2,800
Incremental Percolation (mm)
Wet Year
Dry Year
0
200
400
600
800
1400



Storage Change (mm)
Wet Year
Dry Year
-120
-60
-20
0
20
60
120


Water Use Efficiency (mm)
Wet Year
Dry Year
0.00
0.30
0.45
0.60
0.75
1.00