

WATER ACCOUNTING PLUS

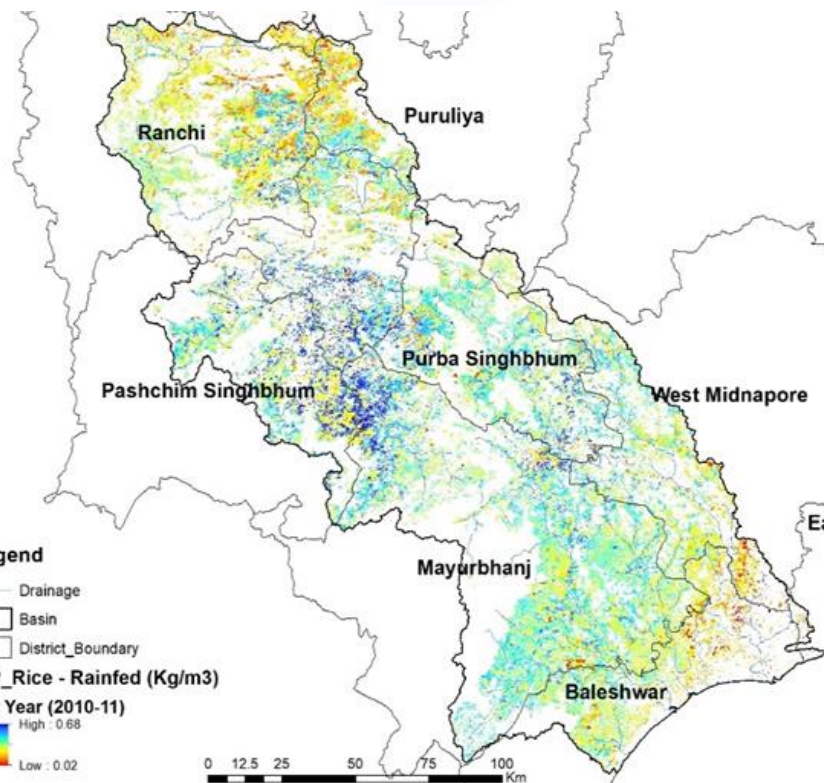
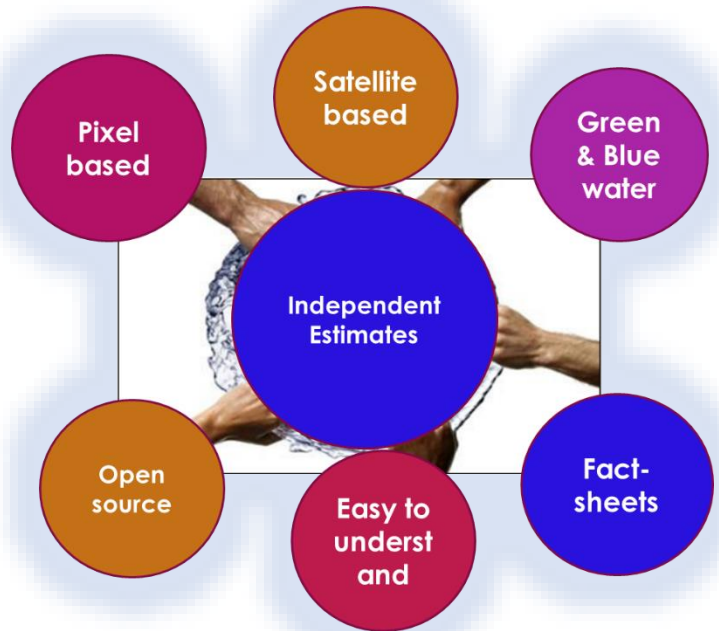
SUBERNAREKHA RIVER BASIN



NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE



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Developments of Water Accounts for Subarnarekha Basin Using Water Accounting Plus (WA+) Framework

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LIST OF ABBREVIATIONS

Actual ET	AET
Atmosphere-Land Exchange Inverse Model	ALEXI
Australian Bureau of Meteorology	BOM
Australian Water Accounting Standard	AWAS
Billion Cubic Meter	BCM
Climate Forecast System Reanalysis	CFSR
Climate Hazards Group Infrared Precipitation with Station data	CHIRPS
Coefficient of variation	CV
CSIRO MODIS Reflectance-based Evapotranspiration	CMRSET
Ensemble ET	ETensV1.0
Evaporation	E
Evapo-transpiration	ET
Food and Agricultural Organization	FAO
Global Land Data Assimilation System	GLDAS
Global Land Evaporation Amsterdam Model	GLEAM
Global Map of Irrigated Areas	GMIA
Global Reservoir and Dam Database JRC	GRAND
Gross Primary Production	GPP
Indian Council for Research on International Economic Relations	ICRIER
Institute for Water Education	IHE-Delft
India Meteorological Department	IMD
Interception	I
International Water Management Institute	IWMI
Joint Research Centre Data Catalogue	JRC
LAND USE LAND COVER	LULC
Leaf Area Index	LAI
Managed Water Use	MWU
Moderate Resolution Imaging Spectroradiometer	MODIS
Modified Land Use	MLU
Monthly Irrigated and Rainfed Crop Areas	MIRCA
Nash Sutcliffe Efficiency	NSE
National Bank for Agriculture and Rural Development	NABARD

National Water Initiative	NWI
Net Primary Production	NPP),
Operational Simplified Surface Energy Balance	SSEBop
Pearson Correlation Coefficient	PEARSON
Percent Bias	PBIAS
Precipitation	P)
Protected Land Use	PLU
Reference Evapotranspiration	PET
Root Mean Square Error	RMSE
SOIL AND Water Assessment Tool	SWAT
Soil Moisture to Rain Advanced Scatterometer	SM2RAIN-ASCAT
Standard Deviation	SD
Surface Energy Balance System	SEBS)
System of Environmental Economic Accounting for Water	SEEA-WATER
Transpiration	T
Tropical Rainfall Measuring Mission	TRMM
United Nations Organization	UNO
Utilized Land Use	ULU
Water accounting	WA
Water Accounting Plus system	WA+
Water Accounting Standards Board	WASB
World Database on Protected Areas by United Nations Environmental Programme	WDPA
World Population	World POP
World Water Assessment Program	WWAP

EXECUTIVE SUMMARY

WA+ Framework was applied to the Subernarekha river basin, India to develop water accounts to understand the water consumption patterns as per the different LULC (WALU) classes, land and water productivity, supply and withdrawals estimates (natural and manmade), stocks and flows in the basin. The basic data required for WA+ includes Precipitation (P), Evapotranspiration (ET), Reference Evapotranspiration (ET_{ref}), Net Primary Production (NPP), Gross Primary Production (GPP), Leaf Area Index (LAI), and many other open source datasets.

The CHIRPS dataset is found to have higher correlation with the station dataset as compared to the TRMM dataset. The lower parts, including the delta of the Subernarekha basin receive higher rainfall as compared to the rest part of the basin. The rainfall in the basin is found to gradually increase from upper to lower part of the basin with a monthly average of 105 mm/month to 145 mm/month (with an annual rainfall varying from 1200 mm to 2000 mm for the years 2010 and 2013, respectively). ET is found to vary from 45 mm/month to 130 mm/month (with an annual ET varying from 750 mm to 1100 mm for the years 2008 and 2013, respectively). The Water Yield (P-ET) is found to be higher for the wet year. i.e., 2013 and lowest for the dry year, i.e., 2010. On seasonal scale, the water yield is found to be negative for JAN to MAY and NOV-DEC, with the highest value of 235 mm/month in the month of August.

Sheet 2 presented the information regarding water consumption in a basin as a total value and per water sector (land use type). The total water consumptions of the basin for the wet year are found to be 27.1 km³/year with further partitioning of ET into evaporation (E) from soil and Transpiration from different LULC. Sheet 2 also showed that the non-beneficial consumptions in the basin are 14.1 km³/year much greater than the beneficial consumptions, i.e., 12.9 km³/year. This indicates that there is a large scope for water conservation practices to be adopted in the basin to minimize non-beneficial consumptions. For dry year, the total water consumptions are found to be 23.1 km³/year with the non-beneficial and beneficial consumptions as 13.9 BCM/year and 9.2 BCM/year, respectively. Overall, these results indicate that there is a large scope to adopt water conservation practices in the basin to minimize non-beneficial consumptions such as soil evaporation and increase the beneficial consumption along with improved water application practices.

Sheet 3 presented the agricultural water consumptions along with the land productivity and water productivity of the different crops in the basin for sustaining land and water resources

and food security in the basin using green water and blue water concept. Sheet 3 has two parts. Sheet 3 (part I) shows the agricultural water consumptions in the basin and Sheet 3 (part II) shows the Land Productivity (kg/ha/year) and Water Productivity (kg/m³). During the wet year, the basin has the land productivity of 2141 kg/ha/year and 2325 kg/ha/year, respectively for rainfed and irrigated cereals. During the dry year, the land productivity is found to be 1575 kg/ha/year and 1876 kg/ha/year, respectively for rainfed and irrigated cereals. Overall, the average land productivity is found to vary from 1575 to 2141 kg/ha/year and 1315 to 2325 kg/ha/year during the period of 2003-04 to 2013-14, respectively for rainfed and irrigated cereals. Interestingly, similar results were also reported in the Water Productivity Mapping of Major Indian Crops by NABARD and ICRIER in the publication entitled “Water Productivity Mapping of Major Indian Crops” and the “Agricultural Statistics” published by the Government of India. .

Sheet 4 deals mainly with blue water consumptions. It provides an overview of all man-made and natural withdrawals. For dry year, the surface water and groundwater withdrawals approximately equal in manmade land use classes. The total water withdrawals for manmade class are found to be 1.88 km³/year. The withdrawal for irrigated crops consists of maximum of total withdrawals, i.e., about 75%. In the natural landuse class, the gross water withdrawals are found to be 4.01 km³/year, in which the major portion is from groundwater withdrawals only, i.e., 3.60 km³/year. This is true as approximately 25% of the basin area is under the forest land use land cover, whereas, in case of natural land use, all the water withdrawals is taken as the consumed water, i.e., 4.01 km³/year. For wet year, the total water withdrawals for manmade class are found to be 4.39 km³/year. The withdrawal for irrigated crops consists of maximum of total withdrawals, i.e., about 80%. In the natural landuse class, the gross water withdrawals are found to be 6.69 km³/year, in which the major portion is from groundwater withdrawals only, i.e., 5.95 km³/year. In case of natural land use, all the water withdrawals are taken as the consumed water, i.e., 6.69 km³/year.

Sheet 6 describes the groundwater flow and storage within a river basin. For dry year, the total vertical groundwater withdrawals from natural and manmade landuse are found to be 3.70 km³/year and 0.90 km³/year, respectively. It is found that 13.10 km³/year is the total vertical recharge in the basin and out of which the rainfed crops and forest contribute to the tune of 4.90 km³/year and 3.10 km³/year, respectively. The irrigated crops also contribute to the groundwater recharge to the tune of 1.2 km³/year. For wet year, the total vertical groundwater withdrawals from natural and manmade landuse are 6.0 km³/year and 2.2 km³/year, respectively. It is found that 30.20 km³/year is the total vertical recharge in the basin

and out of which the rainfed crops and forest contribute to the tune of 7.4 km³/year and 11.0 km³/year, respectively. The irrigated crops also contribute to the groundwater recharge to the tune of 3.0 km³/year.

Sheet 5 quantifies the surface water availability (natural) at the point of the interest, i.e., at the sub-basin or basin scale or any intermediate point as per the four water management classes, i.e., PLU, ULU, MLU and MWU. It is found that the overall basin outflow to the sea is 13.5 BCM and 28.9 BCM, respectively during the dry and wet years. Further, the Sheet 5 categorizes the outflow in terms of (i) Committed outflow, (ii) Non-recoverable outflow, (iii) Non-utilizable flow, and (iv) Utilizable flow. Based on this classification of the outflow, it is found that 13.0 BCM is the utilizable flow out of 28.9 BCM for wet year, and similarly, for dry year the utilizable flow is found to be 4.1 BCM only out of 13.5 BCM. The storage change of most of the sub-basins during the deficit year is either zero negative meaning that more water was taken from storage in the dry months than water stored during the monsoon months.

Sheet 1 presented an overall overview of the over-exploitation, unmanageable, manageable, exploitable, reserved, utilized and utilizable flows at river basin scale. The results show that the most of the water utilized within the basin is coming from rainfall and only a small portion from storage (surface/groundwater) with changed proportions during the deficit and wet years. External outflows (fluxes) are composed of evapotranspiration (61.17% of the net inflow during the dry year and 46.56% during the wet year). During the dry and wet year, the utilizable flow is 4.4 km³/year and 13.3 km³/yr, which could be utilized or stored to prevent water shortages during particularly dry years. However, the scenario could be entirely different, if we analyze on the monthly/seasonal scale. Sheet 1 also computed the landscape ET (ETgreen: green water consumptions) and utilized flow (ETblue: blue water consumptions). During the wet year, the ETgreen accounts for 52.95% of the total ET (ETgreen + ETblue) and ETblue is 47.60% of the total ET. However, this proportion changes during the dry year where less rainfall occurs. ETgreen consumption increases to 65.92% and ETblue is 33.33% of the total ET.

CHAPTER-1

INTRODUCTION

1.0 Water Accounting (WA) Framework

Water accounting is the systematic quantitative assessment of the status and trends in water supply, demand, distribution, accessibility and use in specified domains, producing information that informs water science, management and governance to support sustainable development outcomes for society and the environment (FAO, 2012, 2016).

Water accounting (WA) has emerged in recent years as a key approach to understanding water scarcity and identifying gaps and in-efficiencies in water resources management. Efforts have been made by United Nations Organization (UNO), Food and Agricultural Organisation (FAO), International Water Management Institute (IWMI) and the Australian government to develop standard water accounting (WA) frameworks.

FAO's global information system on water and agriculture (AQUASTAT) is an important source of data, and has the advantage of consistency and standard terminology. However, AQUASTAT falls short of giving enough detail about the interaction between land use and water use. One major point pertinent to water scarce basins is that AQUASTAT focuses on water withdrawals, and does not distinguish between consumptive use and non-consumptive use. The United Nations Statistics Division has proposed a WA framework called System of Environmental Economic Accounting for Water (SEEA-WATER). However, its applicability for water stock accounting is in question mainly because key required data are unlikely to be available (Perry, 2012). The essential difference in green and blue water resources (Falkenmark and Rockstrom, 2006; Rockstrom and Gordon, 2001) is not recognised in the SEEA-W framework.

The Australian Water Accounting Standard (AWAS) developed by the Water Accounting Standards Board (WASB) of the Australian Bureau of Meteorology (BOM) as part of the National Water Initiative (NWI) is based on several aspects of the SEEA-W. The framework accounts for water withdrawals rather than consumptive use. The AWAS considers irrigated agriculture, industrial and domestic users and does not provide any information on rainfed systems and natural evapotranspiration (ET) processes.

The International Water Management Institute (IWMI) developed a WA procedure (Molden, 1997) with the aim of tracking water depletion rather than withdrawals to avoid errors when neglecting recycling, and to account for ET. The IWMI WA framework has been applied

by IWMI in many irrigation system studies (e.g., Bhakra system in India (Molden, 1997); Zhanghe Irrigation System in China (Dong et al., 2004)) and at the national scale (e.g., India: Amarasinghe et al., 2007; SriLanka: Bastiaanssen and Chandrapala, 2003). However, only a few countries have adopted these WA mechanisms usually due to the lack of data needed to implement these approaches.

1.1. Water Accounting Plus (WA+) Framework

The Water Accounting Plus system (WA+) is based on open access remote sensing data -in conjunction with open access GIS data and hydrological model output. WA+ communicates information on water storage, flows and fluxes for a variety of land use systems using eight intuitive fact sheets, tables and maps that are designed to be understood by people with technical and non-technical backgrounds alike. A schematic of WA+ Framework is shown in Figure 1, which shows how the satellite and open access data has evolved in helping WA in to WA+ Framework.

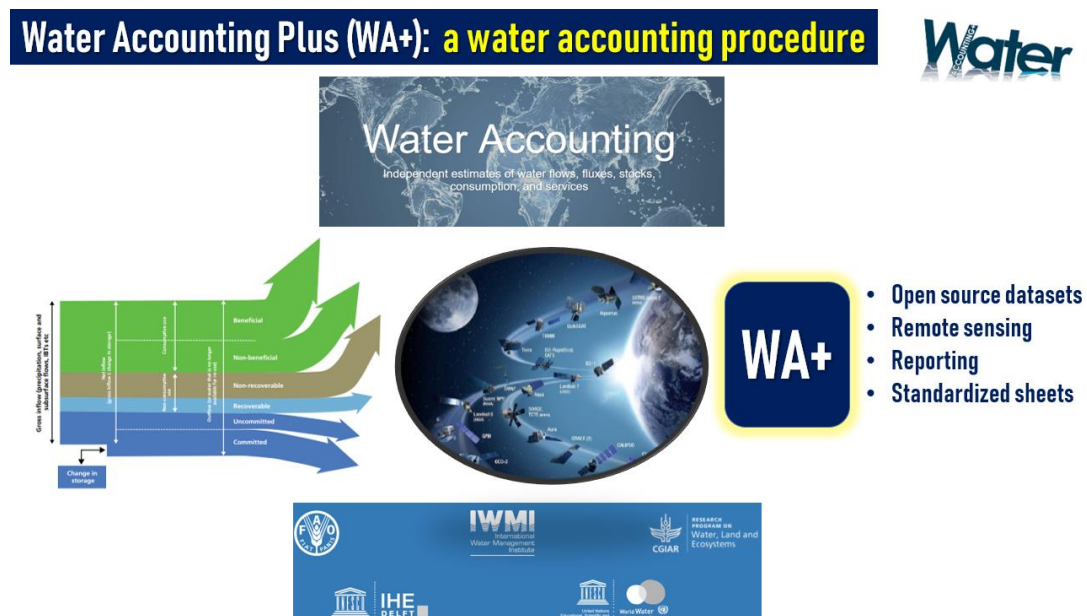


Figure 1.1: Schematic representation of WA+ Framework.

As shown in Figure 1.1, WA+ framework is developed by IHE-Delft in partnership with IWMI, FAO, and the World Water Assessment Program (WWAP). WA+ is based on a mass water balance approach (at the pixel level) and uses Budyko theory (Budyko, 1974) and WATERPIX

model (IHE, 2016) for this purpose. The basis of this water balance approach is that outflow from a certain area of interest (e.g., river basin) are explicitly related to the net inflow and depletion through a measurable ET processes.

1.2. Research Objectives

The major objective of this study is to apply newly developed WA+ framework for Subarnarekha river basin in India. The objectives of this study includes assessment of:

1. Agricultural water consumptions using green water and blue water concept
2. Total water withdrawals and their partitioning in to surface and groundwater withdrawals
3. Land productivity and water productivity for food security
4. Consumed and non-consumed water along with beneficial and non-beneficial consumptions
5. Water scarcity and develop water allocation plans from water demand and water supply statistics
6. Available, exploitable, utilized and utilizable water resources

CHAPTER-2

REVIEW OF LITERATURE

2.0 Why Do We Need Water Accounting?

Water accounting is about quantifying water resources and uses of water, much like financial accounts provide information on income and expenditure. Interest in water accounting is based on the premise that ‘*We cannot plan and manage what we do not measure*’ – a statement that few would disagree with. Water accounting helps to make sense of how much water is available and how it is allocated to make sure the taps do not run dry. This, in its simplest form is what water accounting is about (FAO, 2018).

There is a significant lack of hydrometric infrastructure (e.g. gauges) at field and basin levels to gather hydrological basic data, such as rainfall, evaporation, groundwater levels, and river flows. Data is also missing on water demands from agricultural, urban, industrial, and environmental sectors.

Water accounting can help us to cross the barrier of data in-adequacy and at the same time it can improve transparency over water allocations and enable stakeholders to challenge policy-makers to adopt sustainable solutions that may be at odds with short term voter, legal, fiscal interests.

2.1 Water Accounting Approaches

As mentioned above, various international and national organizations such as UN, FAO, IWMI and the Australian government have developed standard WA frameworks. Some of the popular approaches are being discussed here as follows.

2.1.1 AQUASTAT

FAO’s global information system on water and agriculture, AQUASTAT, remains an important source of data, and has the advantage of consistency and standard terminology. However, AQUASTAT falls short of giving enough detail about the interaction between land use and water use. One major point pertinent to water scarce basins is that AQUASTAT focuses on water withdrawals, and does not distinguish between consumptive use (i.e., ET) and non-consumptive use (i.e., return flows).

2.1.2 System of Environmental Economic Accounting for Water (SEEAW)

The United Nations Statistics Division has proposed a water accounting framework called System of Environmental Economic Accounting for Water (SEEAW). The SEEAW describes hydrological and economic information through a set of standard tables and has also some supplementary tables to cover social aspects (UN, 2007). The SEEAW accounting includes precipitation, soil water and refers to natural evapotranspiration as one cause of decreasing water stocks. The SEEAW separates consumptive use from non-consumptive use, thus, allows for a wider range of water resources and uses to be included. The SEEAW approach provides comprehensive flow accounting and a well-documented way of presenting links to non-agricultural elements of the economy. However, its applicability for water stock accounting is in question mainly because key required data are unlikely to be available (Perry, 2012).

The SEEAW, for example, describes water input from precipitation, and total evapotranspiration, but does not describe rainfall partitioning through the different water uses and evapotranspiration pathways characterised by different land use classes and the benefits that result from that. The essential difference in green and blue water resources (Falkenmark and Rockstrom, 2006; Rockstrom and Gordon, 2001) is not recognised in the SEEAW framework.

2.1.3 Australian Water Accounting System (ABS)

The Anderson with run-off as the first descriptor. Compared to rainfall and evapotranspiration, flow in streams and rivers represent only a small fraction of the total water movement in semi-arid basins (Molle and Wester, 2009; Sivapalan et al., 2003). The framework accounts for water withdrawals rather than consumptive use. It ignores the essence of consumed water being a sink of the water in the land hydrological system. The Australian method considers irrigated agriculture, industrial and domestic users and does not provide any information on rainfed systems. Thus, the impact of rainfed ecosystems on volumes of water available for irrigation is not addressed. The new Australian water accounting standard (Water accounting standard, 2010) provides a more comprehensive flow accounting and discloses information about the total water resource, the volume of water available for withdrawal, the rights to abstract water, and the actual withdrawals of water for economic, social, cultural and environmental benefit, for geographic regions of national significance. However, similar to the earlier Australian water accounting method, neither rain nor natural ET processes are covered in the accounting.

Perry (2007) proposed a framework for water accounting which divides withdrawals into consumed and non-consumed fractions of water. The consumed fraction is ET and like in the IWMI water accounting framework published by Molden (1997), it is divided into beneficial and non-beneficial consumption. The non-consumed fraction is considered as return flows which could be recoverable or non-recoverable. The latter being the water that is not available for further use like flows to saline groundwater aquifers. Foster and Perry (2010) suggested refinement of soil-water accounting into recoverable and non-recoverable water pathways in order to account for the effects of changes in irrigation practices on groundwater recharge. Perry and Bucknall (2009) proposed that basin water balances can be structured on the same approach by including rainfall and inflows as sources and classify uses as beneficial/non-beneficial, recoverable/non-recoverable flows and by dividing water accounts into different end-use classes.

2.1.4 International Water Management Institute (IWMI) (WA)

The International Water Management Institute (IWMI) developed Water Accounting (WA) procedure with the aim of tracking water depletion rather than withdrawals to avoid errors when neglecting recycling, and to account for evapotranspiration. The method provides a means to determine the output per unit of water effectively depleted (Molden, 1997; Molden and Sakthivadivel, 1999; Molden et al., 2003) without a need to account for all the flows related to these processes. The depletion of water resources renders water unavailable for further use. Water depletions are divided into beneficial and non-beneficial water according to the type of use. The IWMI WA framework has been applied by IWMI in many irrigation system studies (e.g., Bhakra system in India: Molden, 1997; Zhanghe Irrigation System in China: Dong et al., 2004; Loeve et al., 2004; Nile Delta: Molden et al., 1998). It has also been used to produce water accounts at river basin scale (e.g., Krishna: Biggs et al., 2007; Karkheh: Karimi et al., 2012; Indrawatti: Bhattarai et al., 2002) and at the national scale (e.g., India: Amarasinghe et al., 2007; SriLanka: Bastiaanssen and Chandrapala, 2003).

The IWMI WA framework was originally designed for irrigation schemes within a basin, but was later used for basin analysis. Some of the components of the IWMI WA are, therefore, too generic for basin level studies. For instance, water depletion at irrigation service scale represents only crop evapotranspiration while at basin scale it includes also 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 framework

2.2 Specific WA+ Applications

More recently, WA+ Framework has been applied to Cauvery river basin in India by IHE (2018). WA+ Framework was also applied to selected river basins in Cambodia (IHE, 2017). Karimi et al. (2013) applied WA+ to the Indus river basin and demonstrated that 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+. It was demonstrated how the accounting results can be interpreted to identify existing issues and examine solutions for the future.

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 Awash river basin and 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. The WA+ Framework is entirely new technique and has been applied in few other basins of the India and world as a whole.

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 diverting the excess water for other needs such as domestic and industrial.

CHAPTER-3

STUDY AREA AND DATA USED

3.0 Subarnarekha Basin

The Subarnarekha river originates from Nagri village near Ranchi, Jharkhand and flows through the states of Odisha and parts of West Bengal and traverses approximately 448.36 km. before draining to the Bay of Bengal. The total catchment area of Subarnarekha basin is approximately 25792.15 km², out of which 48.84% falls in the state of Jharkhand, 37.96% in Odisha and 13.2% in the state of West Bengal (<http://www.india-wris.nrsc.gov.in/wris.html>). The location map and digital elevation model (DEM) of the Subarnarekha river basin and its major tributaries is shown in Figs. 3.1a&b. Jamira, Panchpara, Burhabalang, and Mandagan are the major tributaries of the Subarnarekha river basin. Agriculture is the dominated landuse (53.76%) in the basin followed by forests (28.75%), settlements and water bodies.

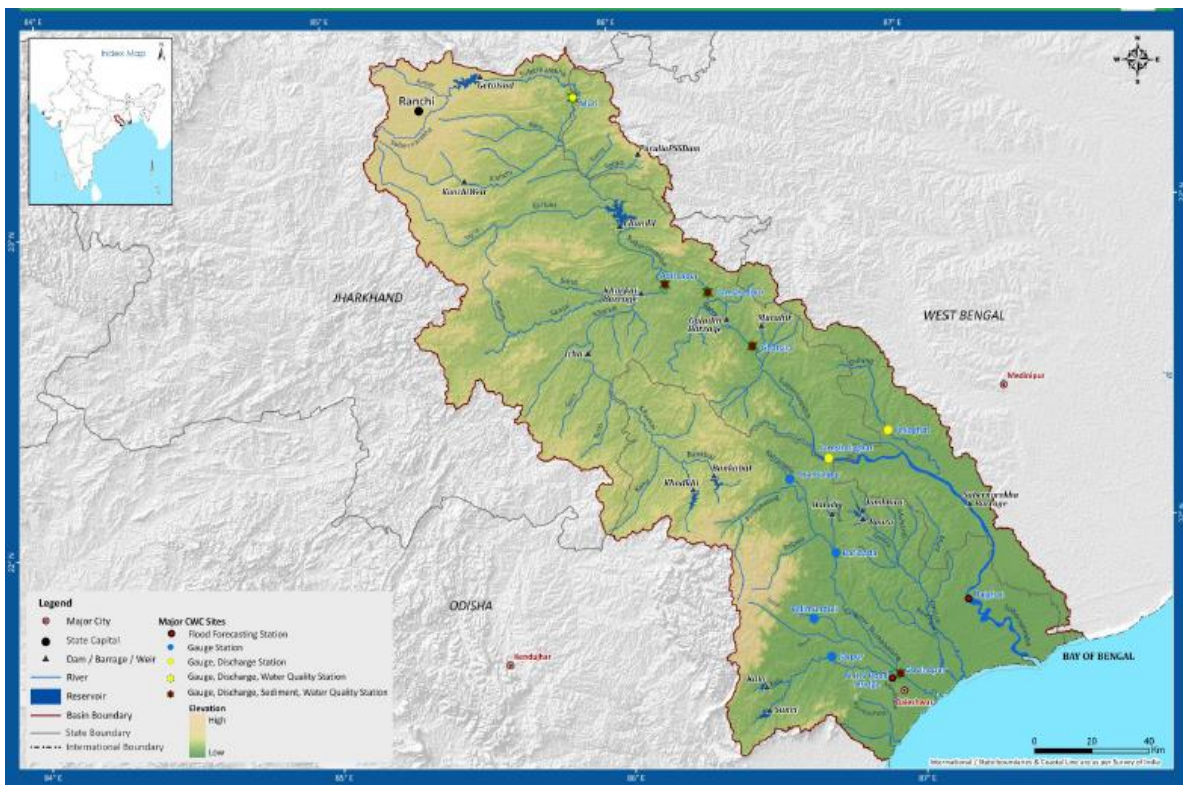


Figure 3.1a: Location map of Subarnarekha River Basin

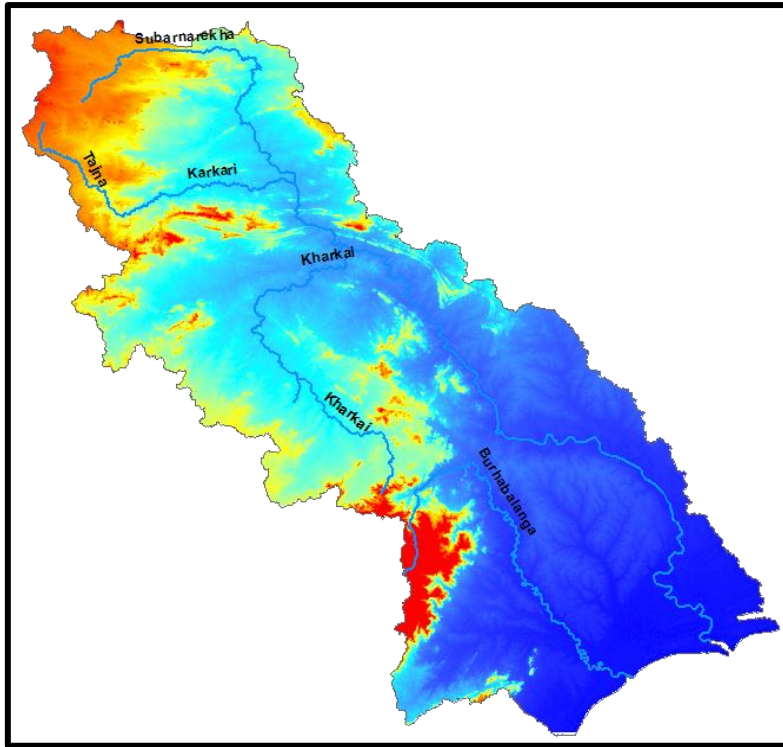


Figure 3.1b: Digital elevation model (DEM) of Subarnarekha River Basin

The aspect map, slope map, command and drainage map and elevation map of the Subarnarekha basin were also prepared as shown in Figures 3.2c-f.

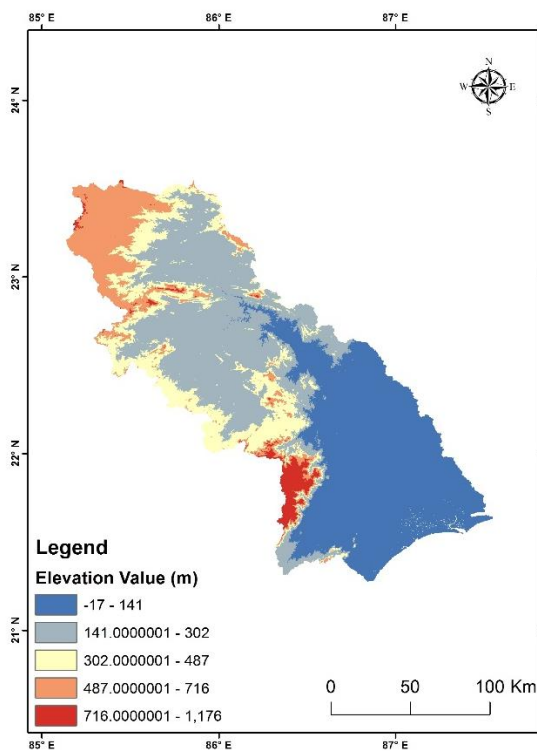


Figure 3.1c: Elevation map

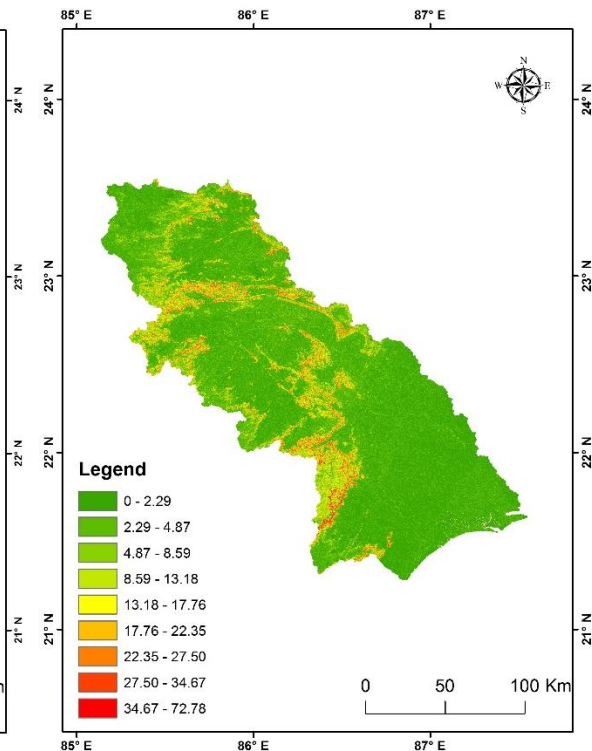


Figure 3.1d: Slope map

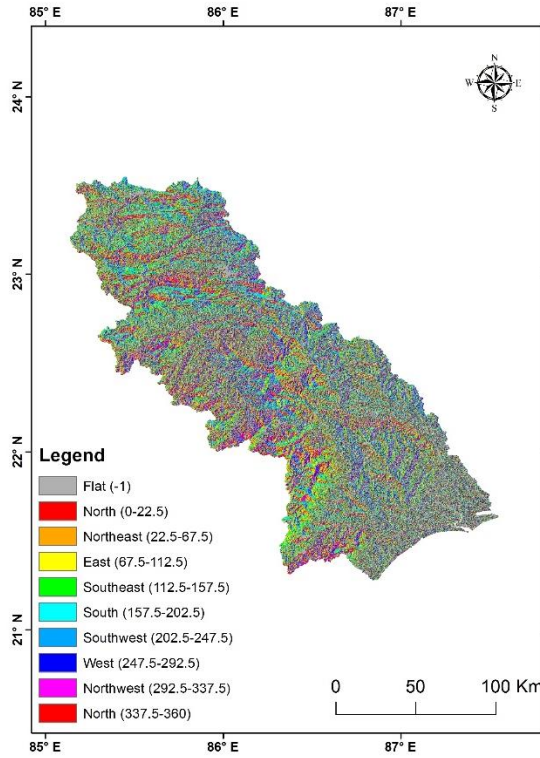


Figure 3.1e: Aspect map

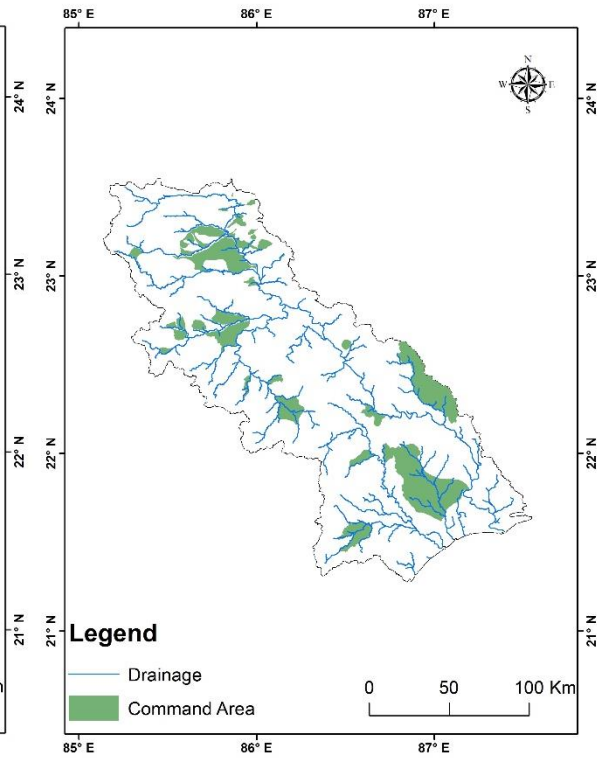


Figure 3.1f: Command and Drainage map

3.1 Satellite Data and Open Access Data Used in WA+ Framework

As discussed above, the WA+ Framework is entirely based on Satellite data and open access global hydrological model outputs. The basic data required for WA+ includes Precipitation (P), Evapotranspiration (ET), Net Primary Production (NPP), Gross Primary Production (GPP), Leaf Area Index (LAI), and many other datasets. Figure 3.2 shows the schematic of the data required in WA+. Table 3.1 the details of the satellite datasets used in WA+ Framework.

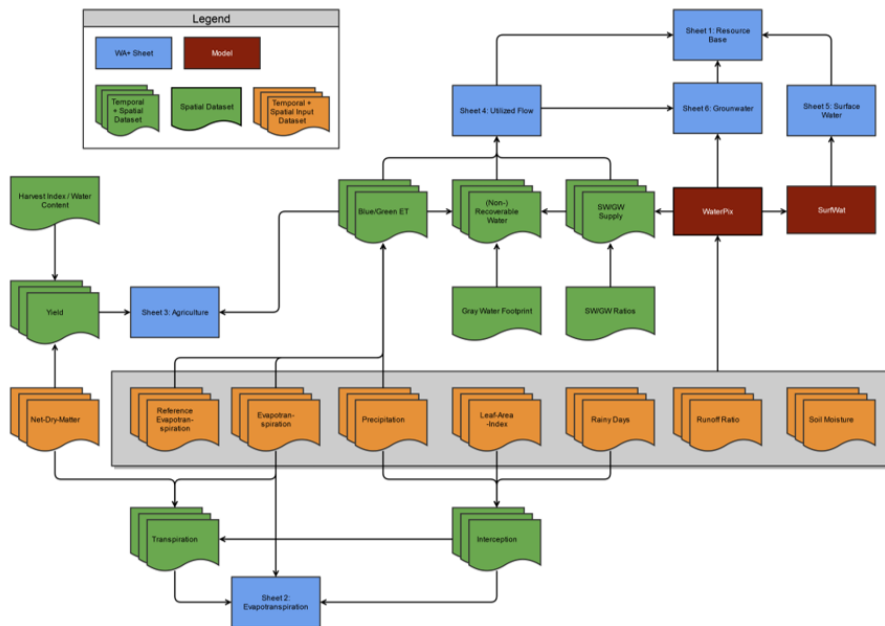


Figure 3.2: Data required in WA+ Framework

Table 3.1: Brief Information about WA+ datasets

Sl.No.	Data Product Name	Period of Availability	Spatial Resolution	Temporal Resolution	File Type	Remarks
A.	Land use/ Land cover					
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	10km	Annual	flt, gz	% 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)	-			shp	29 descriptors, referred to as data attributes; global spatial dataset on terrestrial and marine protected areas
5	JRC (Joint Research Centre Data Catalogue)		1 km		geotiff	Flood hazard maps- Total 13 datasets available with different return period frequency
6	GRAND (Global Reservoir and Dam Database)				shp	Contains 6862 records of reservoirs/ dams of a capacity > 0.1 km ³
7	MODIS (Moderate Resolution Imaging Spectroradiometer) - MCD12Q1	2001-2013	500m (0.05deg)	annual	tiff	17 classes
8	World POP	2010; 2015; 2020	100m			people per hectare' (pph) datasets

			(0.000833deg)			
9	Global Surface Water Explorer		30 m	16day		Surface Water maps based on 30-years of Landsat imagery.
B.	Rainfall					
1	Tropical Rainfall Measuring Mission (TRMM)	1998 to April 2015	27 km (0.25deg)	3-hourly, daily, monthly	tiff	NASA & JAXA mission
2	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	1981 onwards	5 km	daily, monthly	tiff	Funded by USGS and USAID
C.	EVAPOTRANSPIRATION					
3	Evapotranspiration - MOD 16 Data	2000 onwards	1 km	8 daily, monthly, annual	tiff	
4	Global Land Evaporation Amsterdam Model (GLEAM)	2003-2012	27 km (0.25deg)	daily, monthly	tiff	
5	Evapotranspiration: ETensV1.0	January 2003 until December 2014	250 m (0.0025 deg)	monthly	tiff	Global
D.	METEOROLOGICAL					
1	Global Land Data Assimilation System (GLDAS)	1948 onwards	110 km (1 deg)	3-hourly, monthly	tiff	Measures Meteorological parameters such as atm.pressure, radiation, temp, 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 -Vegetation	2000 onwards	1 km	8 daily, monthly		NDVI, LAI, FPAR

3.2 Development of WA+ Based Land Use Land Cover (LULC) Map (WALU)

WA+ recognizes the influence of land use on water cycle and provides the link between water balance, land use and water use as well as management options to modify it, by grouping land use classes with common management characteristics. WA+ classifies LULC in to four major LULC classes as:

- 1. Protected Lan Use**
- 2. Utilized Land Use**
- 3. Modified Land Use**
- 4. Managed Water Use**

A brief description of all the four LULC classes is being given here as follows and shown in Figure 3.3.

3.2.1 Protected Land Use:

It represents areas set aside for minimal disturbance by humans e.g. National Parks & Wildlife Sanctuaries, Ramsar wetlands of global importance etc.

3.2.2 Utilized Land Use

It represents a land use that provides a range of ecosystem services and which has had little interference by man. However, people often use such land for the services it provides, like food, fodder and firewood, e.g., Grasslands, forest land, natural pastures.

3.2.3 Modified Land Use

It refers to land that is significantly modified by human activity. It also includes improved road networks, dump sites and increasing space for leisure and for socioeconomic growth. By modifying land use and vegetation density, hydrological processes such as ET, drainage, percolation, and recharge are affected, e.g., Rainfed cropping systems, creation of plantation forests, parks, home gardens etc.

3.2.4 Managed Water Use

It represents the land use classes in which the natural water cycle is manipulated by physical infrastructure for certain objectives, e.g. Irrigation systems, Drinking water supply systems in urban areas and villages. All these four LULC classes are further classified in to 80 LULC classes. The details of these 80 LULC classes are given in Appendix A.

The following data set was used for preparation of WA+ based LULC map.

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

All the dataset was clipped and resampled to 250 m * 250 m resolution and were used for LULC map generation using automated script written in Python. The generated map of Subarnarekha river basin is shown in Figure 3.4.



Figure 3.3: Four major WA+ water management classes (WMC)

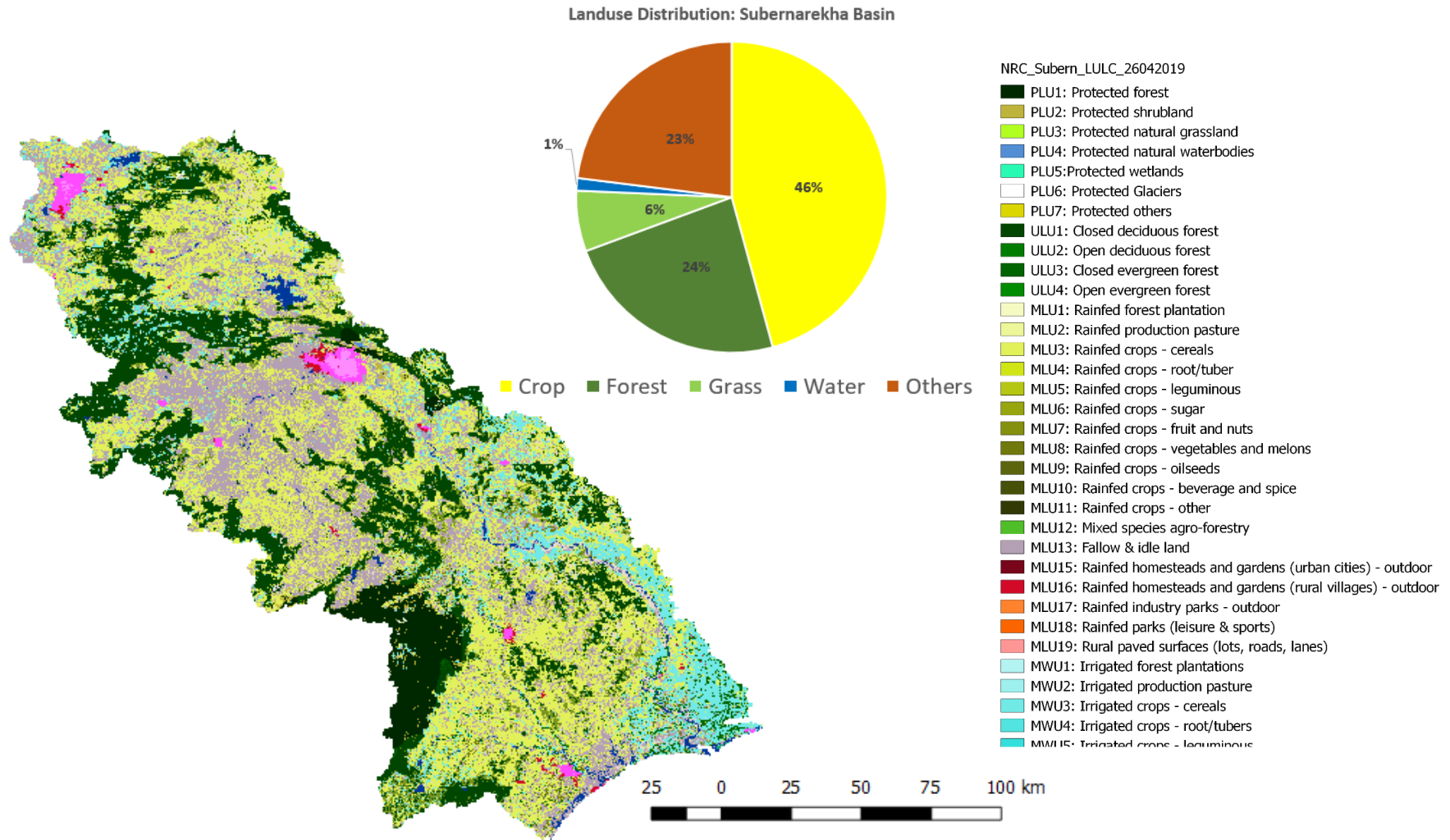


Figure 3.4: LULC map of Subarnarekha basin generated using WALU.

Figure 3.4 also shows the % distribution under different LULC classes. Under agricultural LULC class, the area under rainfed agriculture was found to be much higher than the irrigated agriculture, which is very true for Subarnarekha river basin.

3.3 WA+ Methodology

As discussed above, WA+ Framework is developed by IHE-Delft in partnership with IWMI, FAO, and the World Water Assessment Program (WWAP). WA+ is based on a mass water balance approach (at the pixel level) and uses Budyko theory (Budyko, 1974) and WATERPIX model (IHE, 2016) for this purpose. The basis of this water balance approach is that outflow from a certain area of interest (e.g., river basin) are explicitly related to the net inflow and depletion through a measurable ET processes. WA+ framework recognizes the essential difference between Blue and Green water.

Green water is the soil moisture from precipitation, used by plants via transpiration. It is part of the evapotranspiration flux in the hydrologic cycle. Bluewater is the freshwater: surface and groundwater. It is stored in lakes, streams groundwater, glaciers and snow. A pictorial representation of separation of green water and blue water is shown in Figure 3.5.

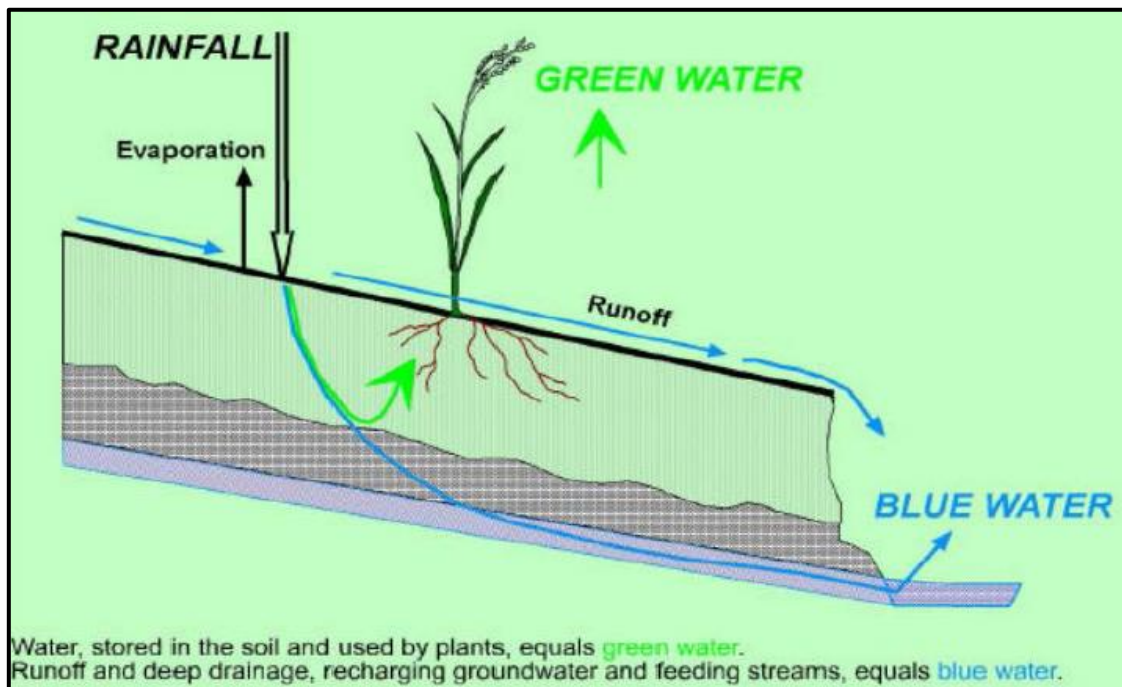


Figure 3.5. Separation of Green Water and Blue Water (Rockstrom, 1997).

3.3.1 Budyko Hypothesis

WA+ framework uses the Budyko hypothesis (Budyko, 1974) (Figure 3.6.) for ET separation into ET_{green} and ET_{blue} . The water stored in the soil is known as the green water and the water stored in rivers, lakes, ponds, other surface-water bodies and aquifers is known as the blue water. Water consumed by vegetation for ET that comes from green water is termed as ET_{green} and that coming from blue water sources is termed as ET_{blue} . Of course, if the crops face moisture deficit, the water is withdrawn from blue sources and applied to the soil from where the crops draw it. Hence, the actual ET (AET) can be partitioned as:

$$AET = ET_{green} + ET_{blue} \quad (1)$$

This partitioning of AET using Eq. (1) helps in knowing source-wise use of water for crop production and this information is useful in better management of water use for agriculture (Velpuri and Senay, 2017).

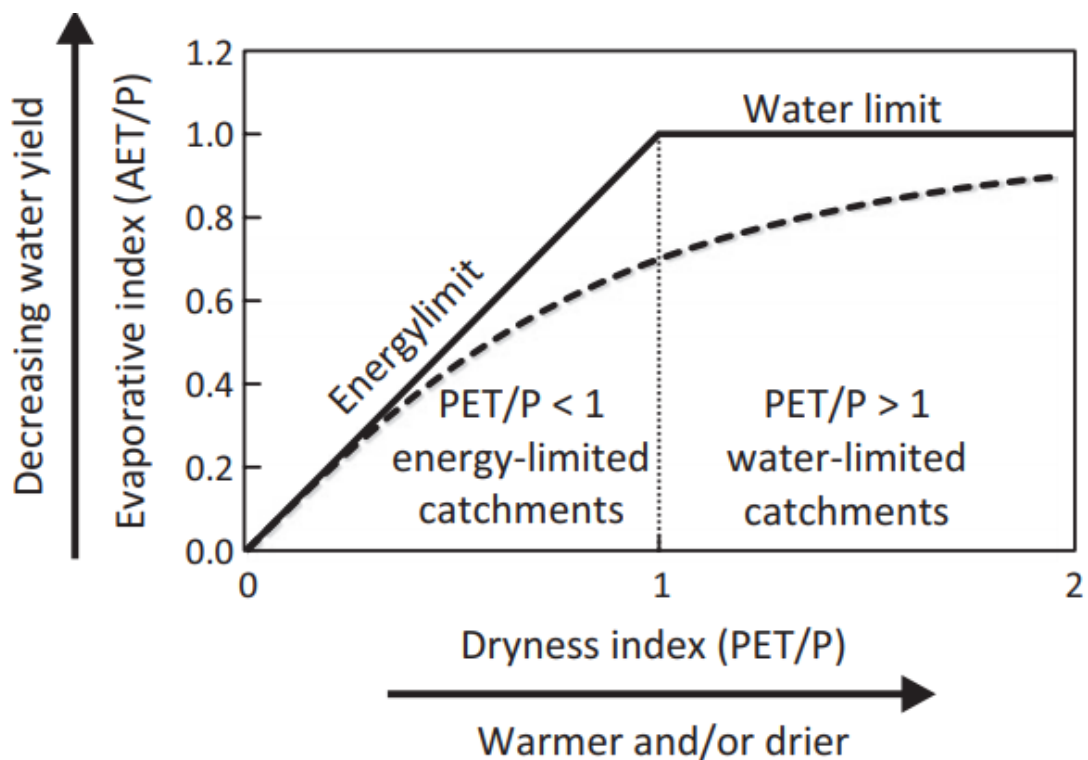


Figure 3.6: A Budyko diagram. The solid lines represent energy and water limits to the evaporative index, while the dashed line represents the original theoretical Budyko curve (after Budyko, 1974; Creed et al., 2014; Abera et al., 2019).

The term ET_{blue} is also known as the incremental evapotranspiration or secondary evaporation (Hoogeveen et al., 2015; Van Dijk et al., 2018; Simons et al., 2020). The term ET_{green} is referred to as net precipitation in classical formulations of irrigation water requirements (Jensen and Allen, 2016). Note that such information is not commonly available and the ability of WA+ to provide it by following a scientific procedure is a useful strength.

The Budyko hypothesis establishes an empirical relation between AET, reference evapotranspiration (PET) and P for areas in dynamic equilibrium and with negligible storage changes (Sposito, 2017) and thus provides the first order estimates of evaporation by using P and PET only (Mianabadi et al., 2019). It is based on the coupling of (a) Water balance approach and (b) Energy balance approach. The water balance is performed individually for green and blue pixels, respectively. The Budyko curve is explained through two indices viz. dryness index (PET/P) and evaporative index (AET/P) as shown in Fig.2. As the dryness index increases (x-axis), rainfall (P) gradually decreases and the climatic demand (PET) increases indicating a dry catchment. The reverse is true for a humid catchment where the climatic demand is much lesser than the rainfall received in the catchment. However, as the evaporative index increases, the AET increases with a diminishing rainfall. In the limiting cases, the AET and PET increase linearly (1:1) up to a point where AET will be in equilibrium with the PET. Beyond that, AET remains constant with increase in PET. This concept geographically segregates the catchments into water-limited catchments (PET/P >1) and energy-limited catchments (PET/P <1). The dotted curved line is described as ‘Budyko Curve’ and is represented through the following empirical equation (Budyko, 1974):

$$\frac{ET_{green}}{P} = \left[\phi \tanh(1/\phi)(1 - \exp^{-\phi}) \right]^{0.5} \quad (2)$$

where, $\phi = PET/P$.

The pixels falling below the dotted curve are nothing but the green pixels since the entire climatic demand is met through rainfall. When a pixel falls above the dotted curve, AET is much greater than the rainfall received. Otherwise, we can say that apart from the rainfall, there is an additional supply of water (withdrawal from groundwater or surface water) in that particular pixels. The ET generated due to this additional supply is the incremental ET or the ET_{blue} (Eq. 2) and the increased crop yield due to surplus (irrigated) water is termed as the incremental yield, which will be discussed in subsequent sections of this report.

3.3.2 WATERPIX Model

WaterPix is a hydrologic data-based model used to perform water balances at a pixel scale (<https://github.com/gespinoza/waterpix>). The model identifies very first the ‘green pixels’ and ‘blue pixels’ using the Budyko theory as discussed in Section 3.3.1. The model computes the water balance first for green pixels and then for blue pixels as shown in Figure 3.7. Major input for WATERPIX model are precipitation, LAI, no. of rainy days, reference ET, actual ET, soil moisture, root zone depth, degree of saturation of the top layer of the soil, etc. (Figure 3.8) are used for pixel level water balance to estimate total water supply, percolation, runoff, change in storage, and many other outputs as shown in Figure 3.8. These outputs are used as input for generation of Sheet 1-6, which will be discussed in the forthcoming sections of this report.

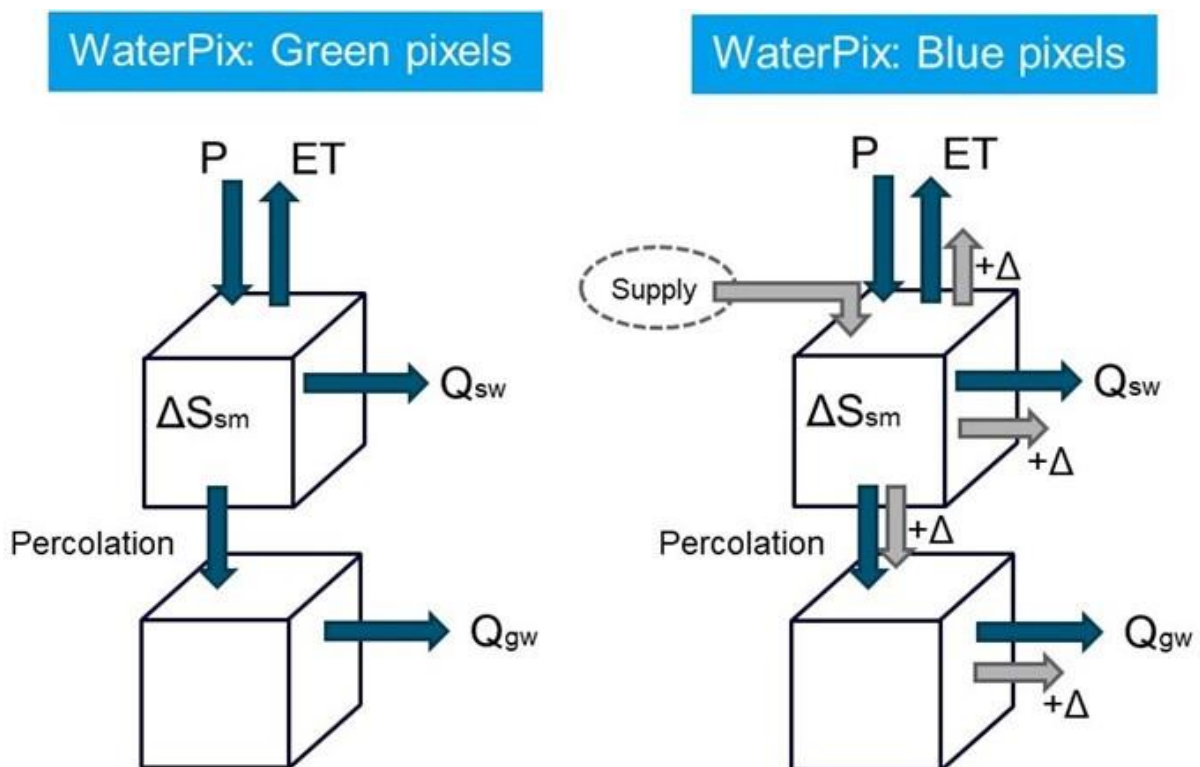


Figure 3.7: Schematic representation of computational flow of WaterPix model.

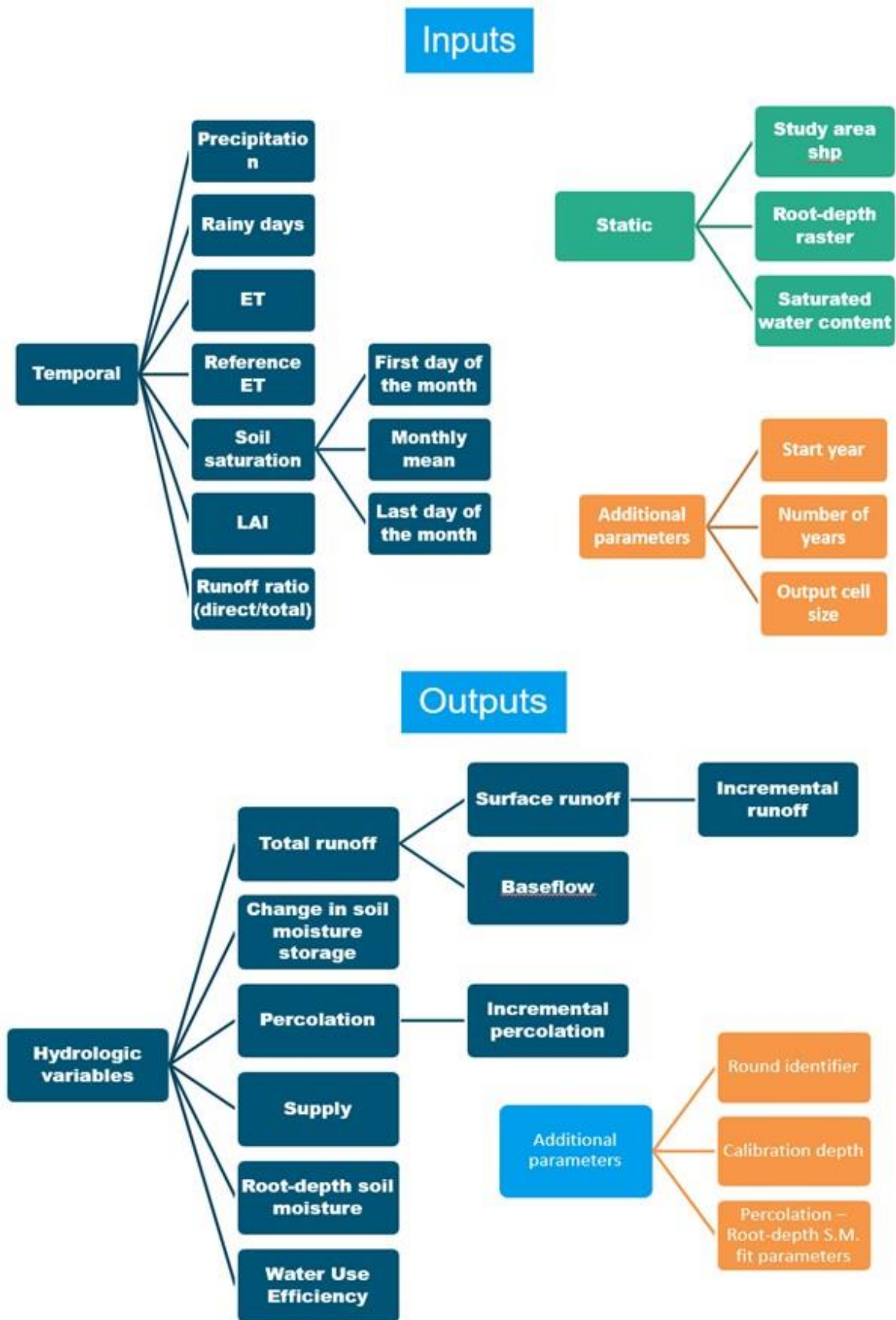


Figure 3.8: Inputs for and outputs from WaterPix model.

CHAPTER-4

RESULTS AND DISCUSSION: DEVELOPMENT OF SHEET

4.0 Precipitation and Evapotranspiration Variability

Attempts were made to analyze and understand rainfall patterns in Subernarekha basin. Figures 4.1a and Figure 4.1b show spatial variation of precipitation obtained from two different remote sensing satellite datasets viz. CHIRPS and TRMM for the period of 2003-2014. Python code was written for analysis and validation of data. It can be observed from these Figures (Fig. 4.1a and Fig. 4.1b), that the western parts of the Subernarekha basin receives higher rainfall as compared to the rest part of the basin. The mean monthly rainfall varies from 300 mm to 100 mm in the basin.

To achieve the objectives of the research project, Long-term (2003-2014) satellite data of rainfall products (P) of Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) and Tropical Rainfall Measuring Mission (TRMM) were analyzed to understand the spatial and temporal variability of the rainfall. The rainfall in the basin is found to gradually increase from upper to lower part of the basin with a monthly average of 105 mm/month to 145 mm/month (with an annual rainfall varying from 1200 mm to 2000 mm for the years 2010 and 2013, respectively). The spatial variability of TRMM and CHIRPS data for the period of 2003-2014 is shown in Figures 4.1 a&b.

It can be observed from Figs. 4.1a & b that the lower part of the basin has more monthly precipitation as compared to the other parts of the basin. Figure 4.2 also shows the spatial variability and identification of dry, average and wet year using CHIRPS data. In this analysis, year 2013 and 2010 are found to be wet and dry years, respectively. Figure 4.3a and Figure 4.3b also show the variation of mean annual rainfall using CHIRPS and TRMM datasets. The CHIRPS dataset has higher mean annual rainfall than the TRMM dataset. A comparison between the annual rainfall predicted by the CHIRPS and TRMM datasets was also conducted and the results are shown in Figure 4.3.

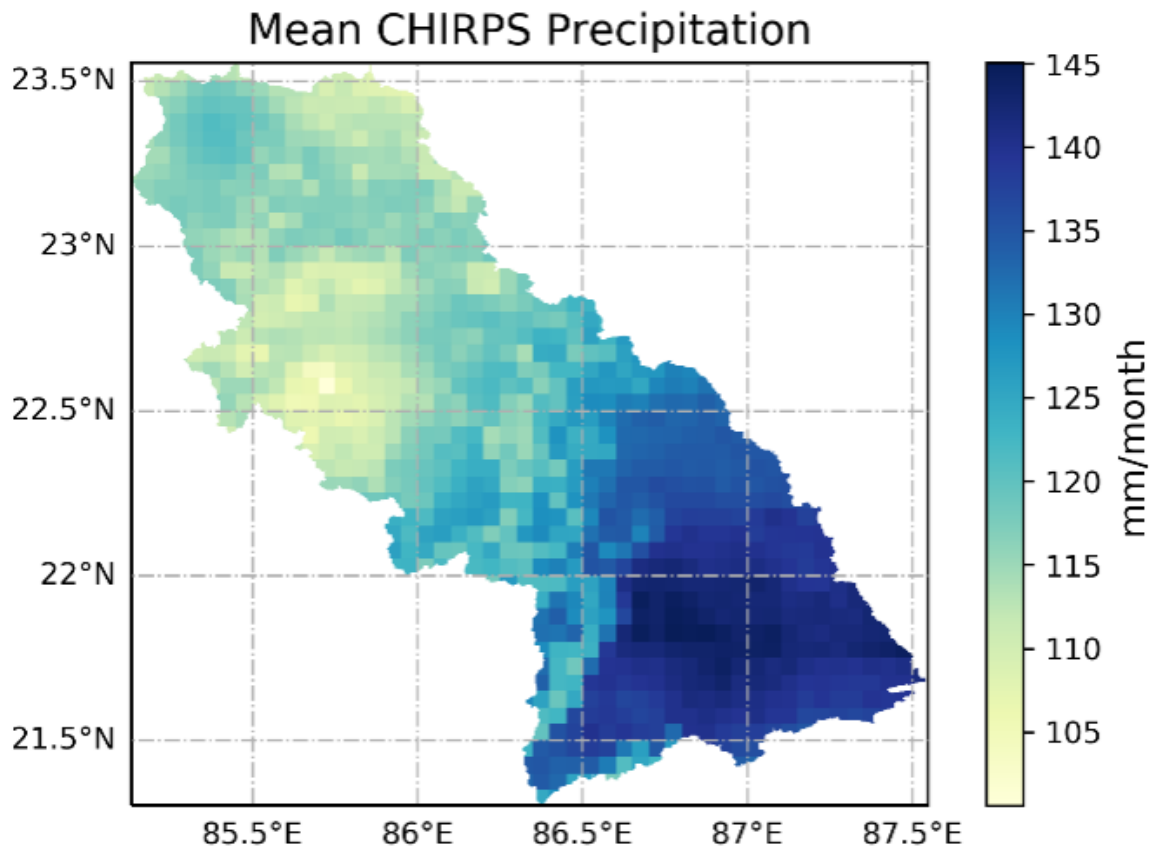


Figure 4.1a: Spatial variation of mean monthly CHIRPS precipitation

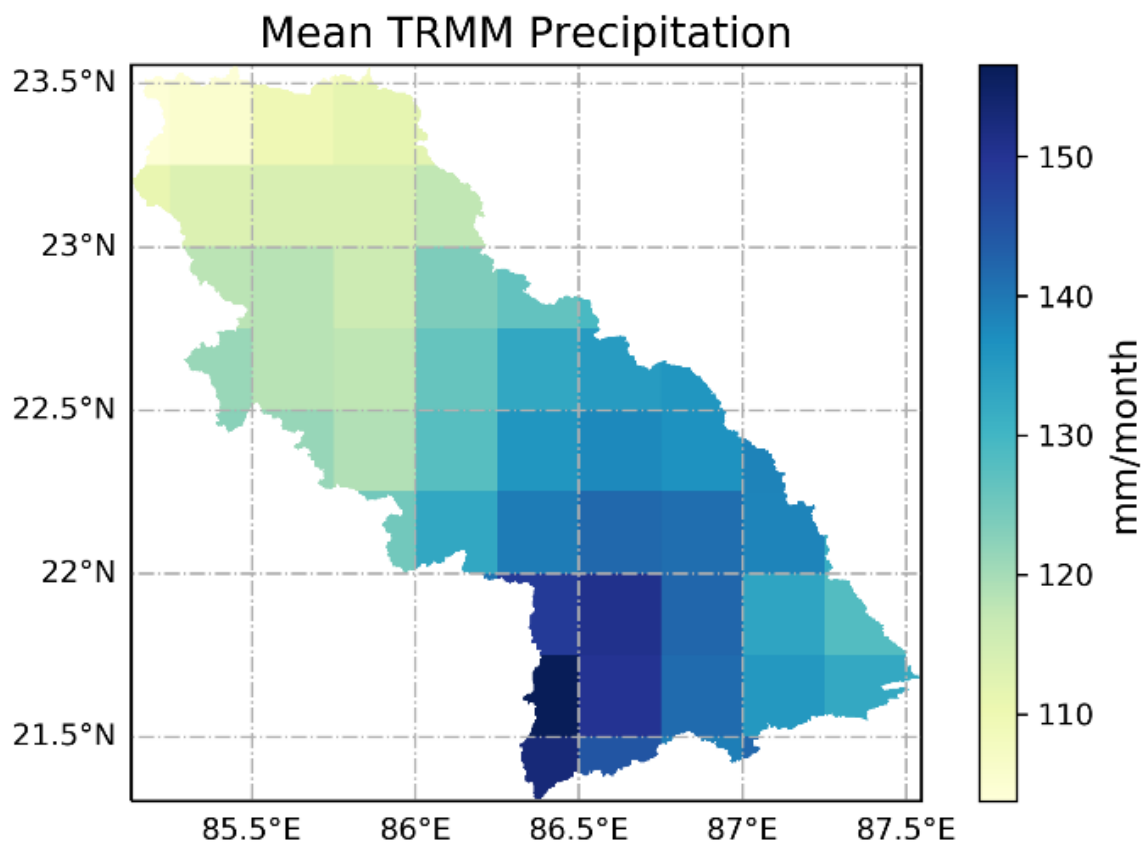


Figure 4.1b: Spatial variation of mean monthly precipitation TRMM datasets

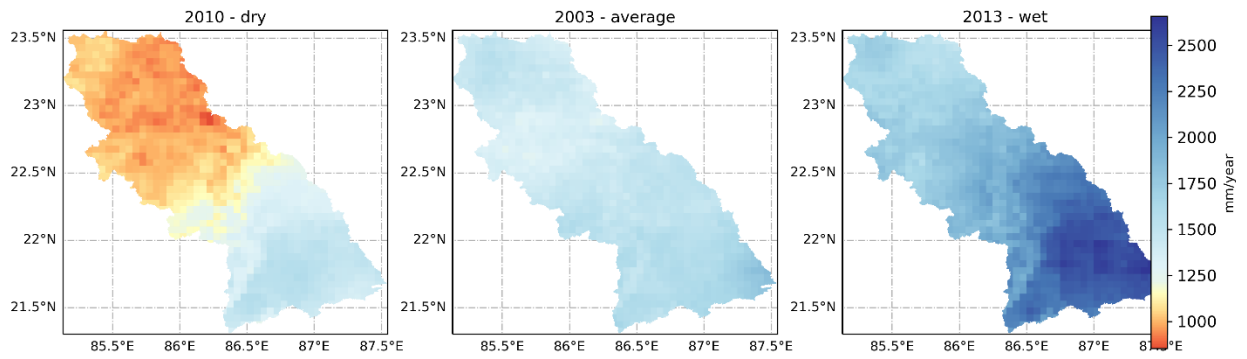


Figure 4.2: Identification of Dry, Average and Wet year using CHIRPS data

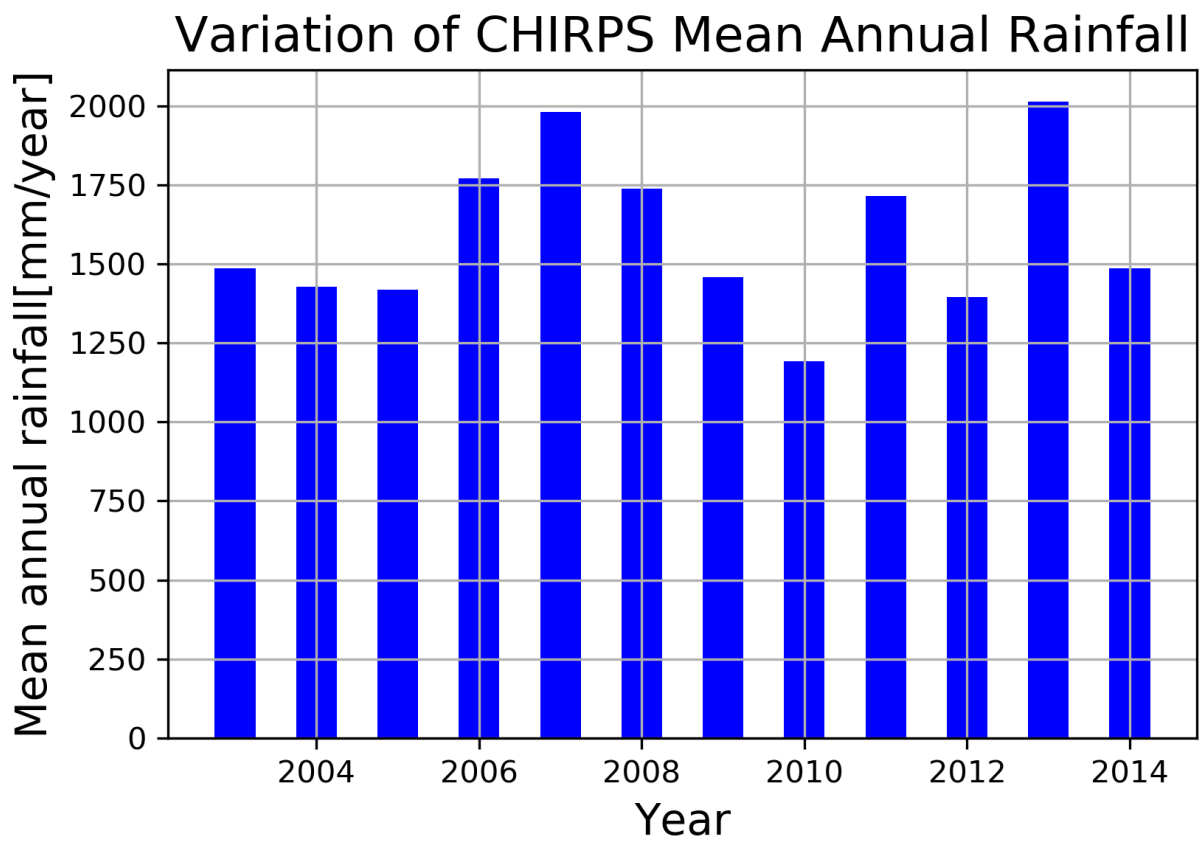


Figure 4.3a: Variation of Mean Annual Rainfall Using CHIRPS Datasets

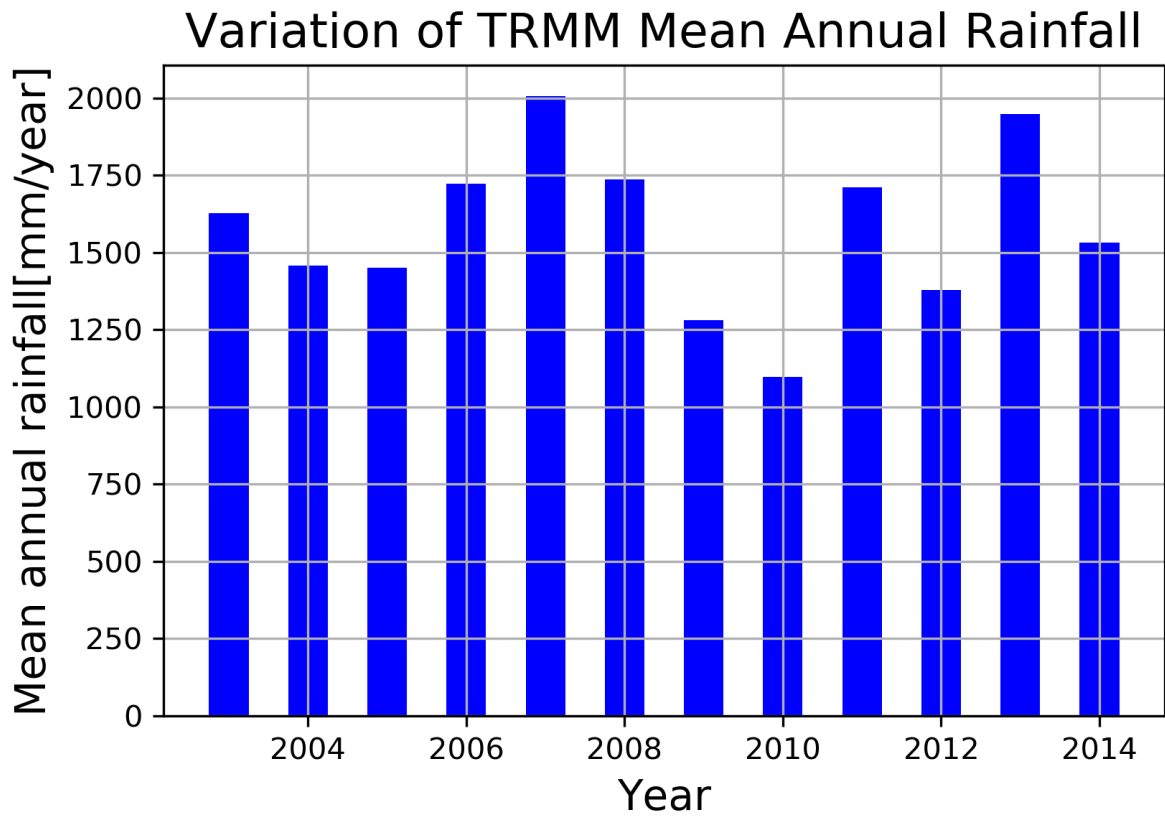


Figure 4.3b: Variation of Mean Annual Rainfall Using TRMM Datasets

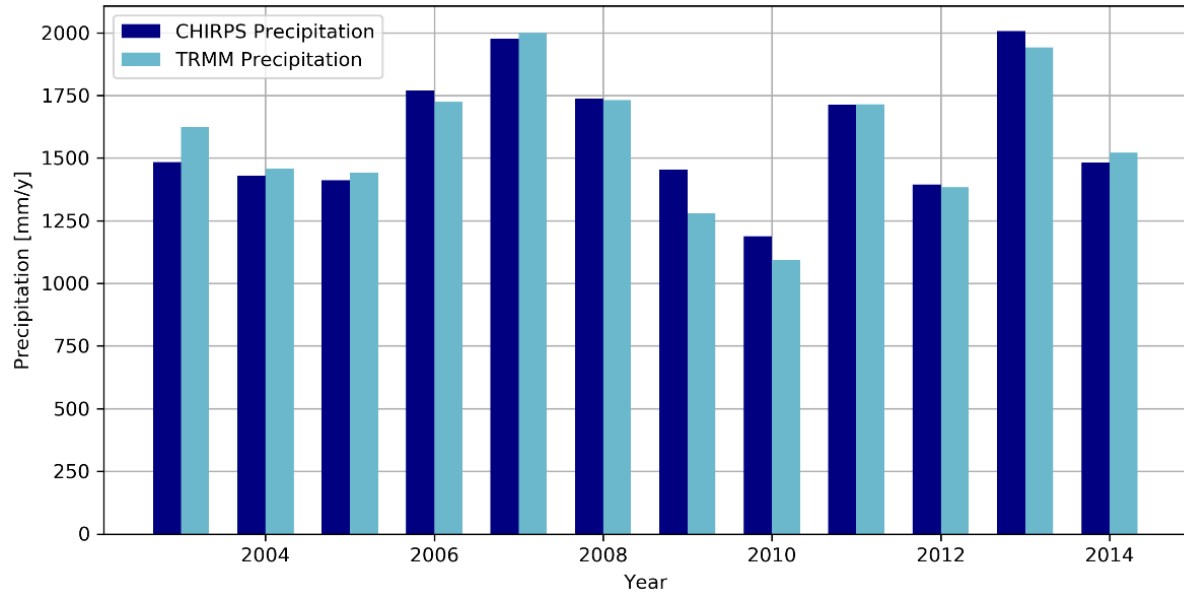


Figure 4.4: Comparison between the annual precipitation using CHIRPS and TRMM Dataset.

4.1 Validation of CHIRPS and TRMM Datasets with Observed Station Rainfall

The validity of the CHIRPS and TRMM rainfall data was adjudged using the station rainfall data of the various station falling in the Subarnarekha river basin. The station rainfall data of the following seven stations namely Basahi, Betnati, Bijatala, Bisoi was used for this purpose. The validation was conducted using the Pearson correlation coefficient, root mean square error (rmse), and bias. First, we are showing the results for CHIRPS datasets in Figures 4.5a-h for the period of 2003-2014.

4.1.1 Comparison of CHIRPS and Station Data

Using Scattered Plots:

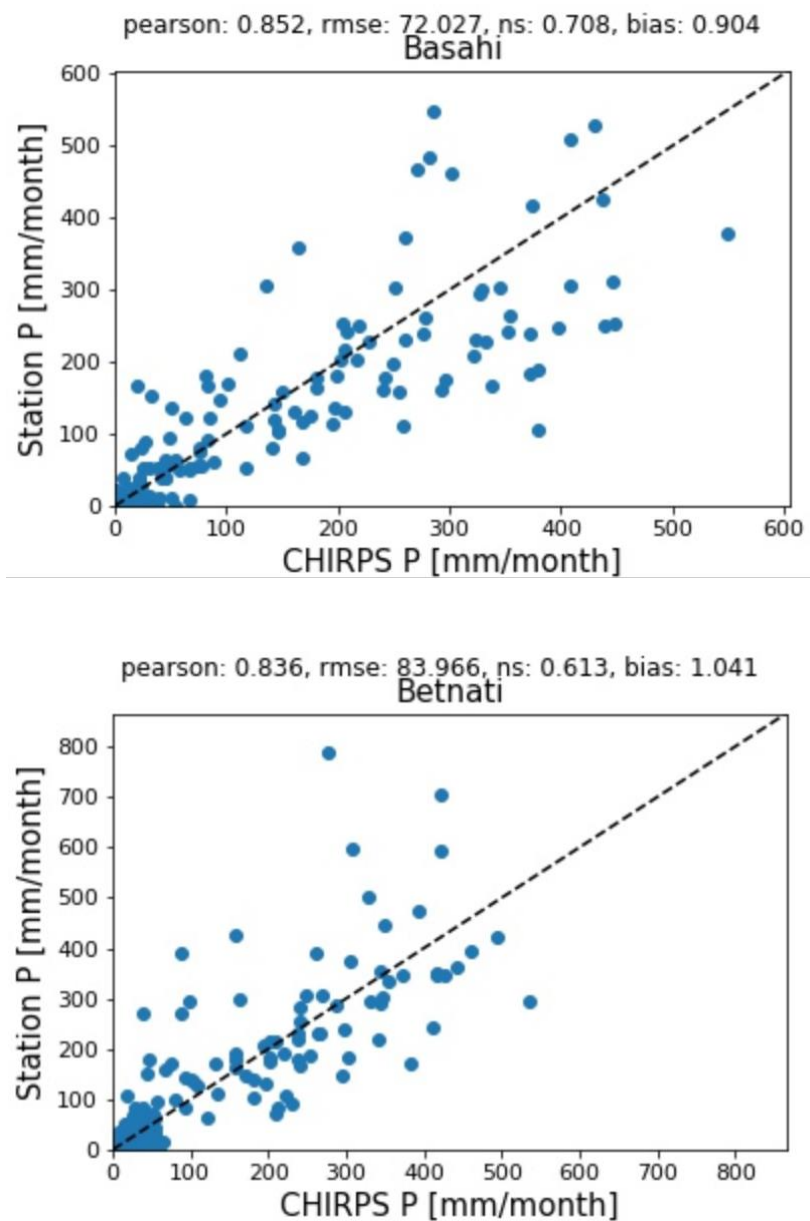


Figure 4.5a-b: Comparison between the observed station rainfall and CHIRPS data

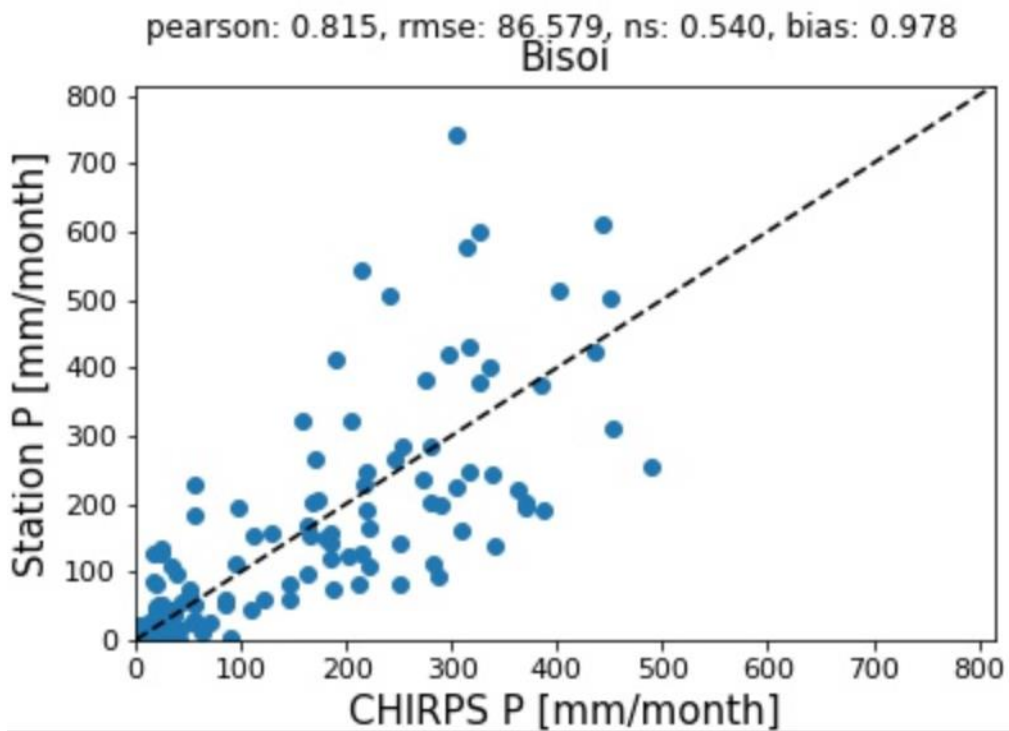
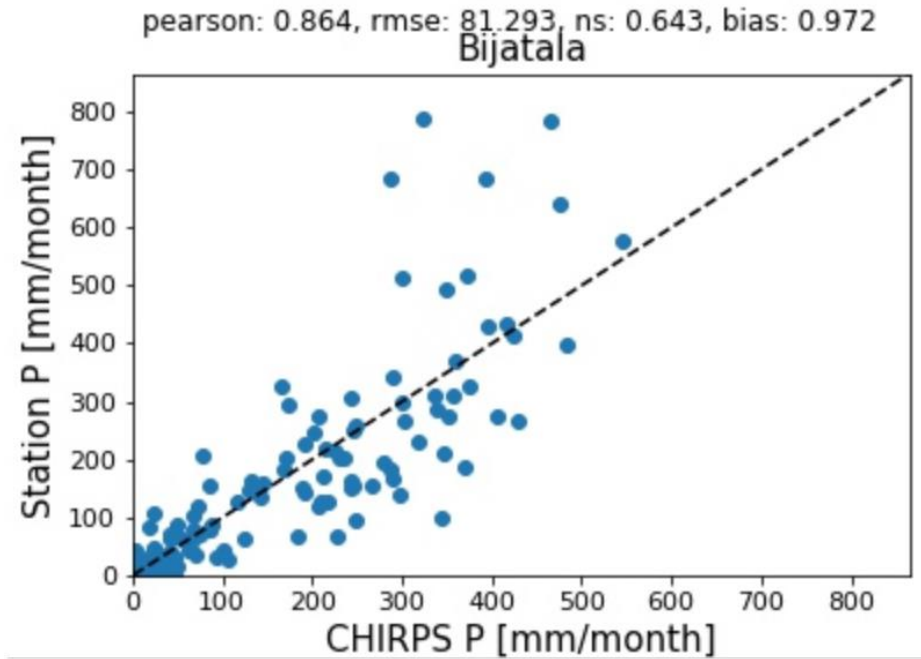
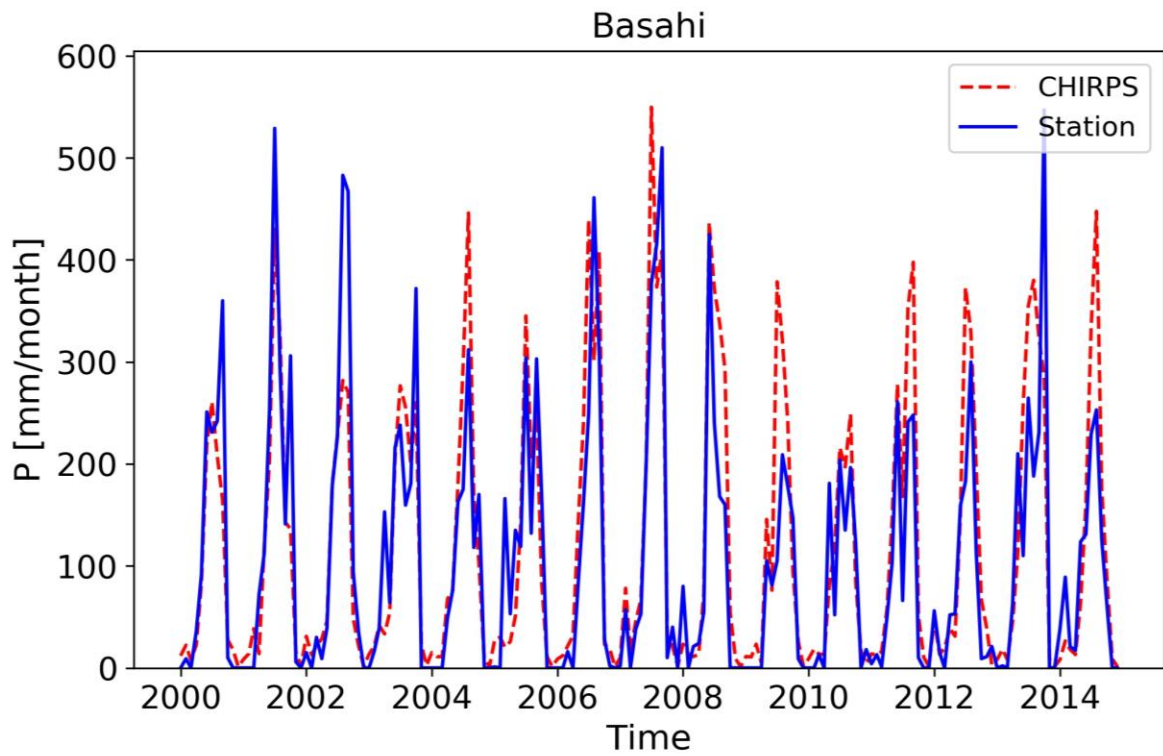


Figure 4.5c-d: Comparison between the observed station rainfall and CHIRPS data

Using Time Series:

The long-term comparison (time-series) is also given in Figure 4.5e-h. These Figures shows that there is good comparison between the station rainfall data and CHIRPS data.

pearson: 0.852, rmse: 72.027, ns: 0.708, bias: 0.904



pearson: 0.836, rmse: 83.966, ns: 0.613, bias: 1.041

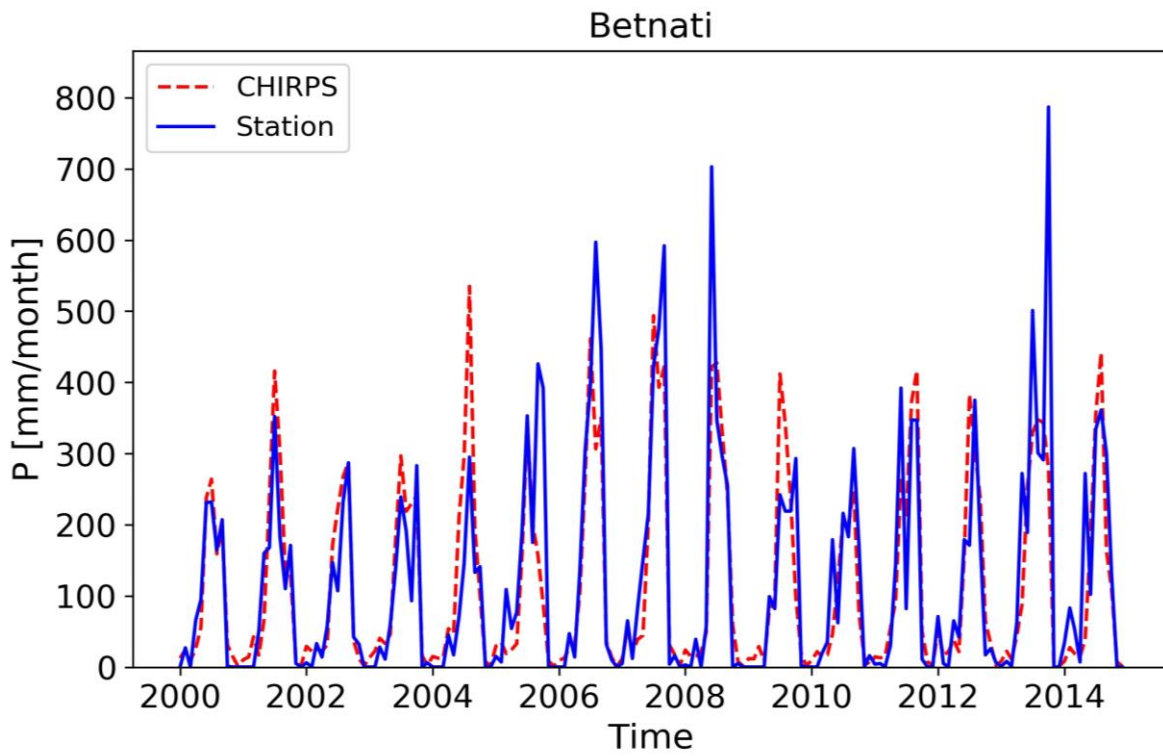
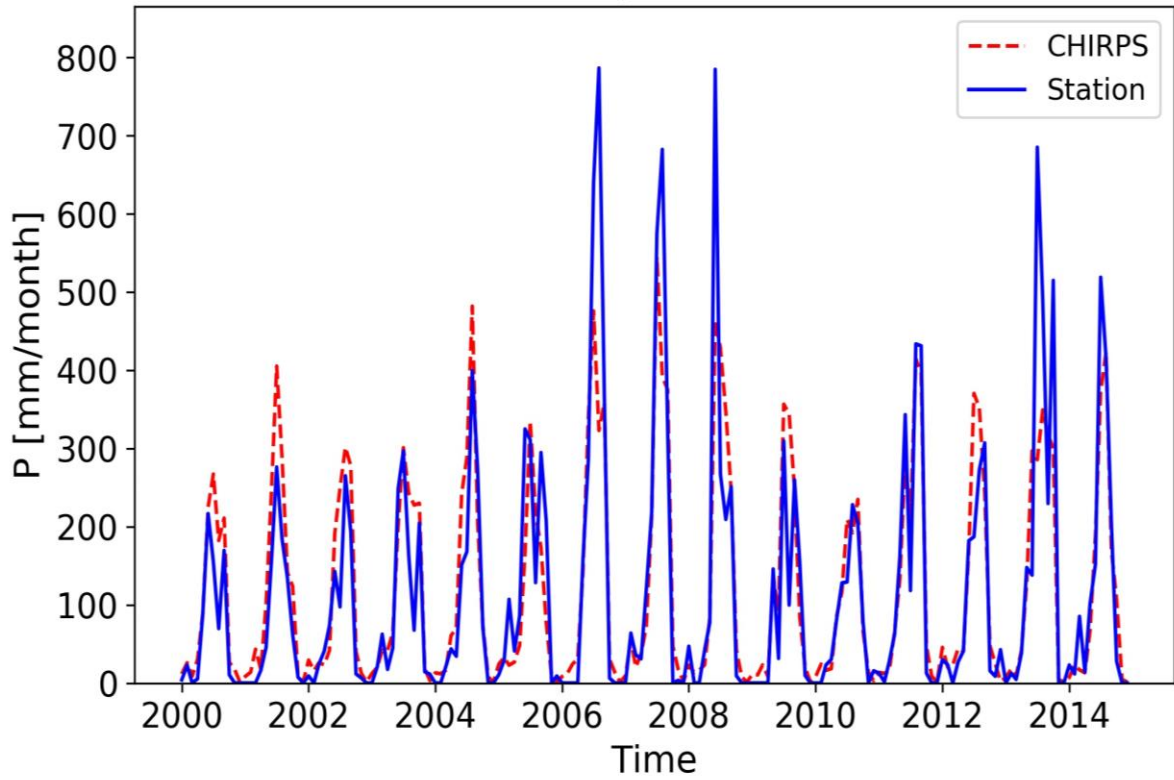


Figure 4.5e-f: Comparison between the observed station rainfall and CHIRPS data

pearson: 0.864, rmse: 81.293, ns: 0.643, bias: 0.972

Bijatala



pearson: 0.815, rmse: 86.579, ns: 0.540, bias: 0.978

Bisoi

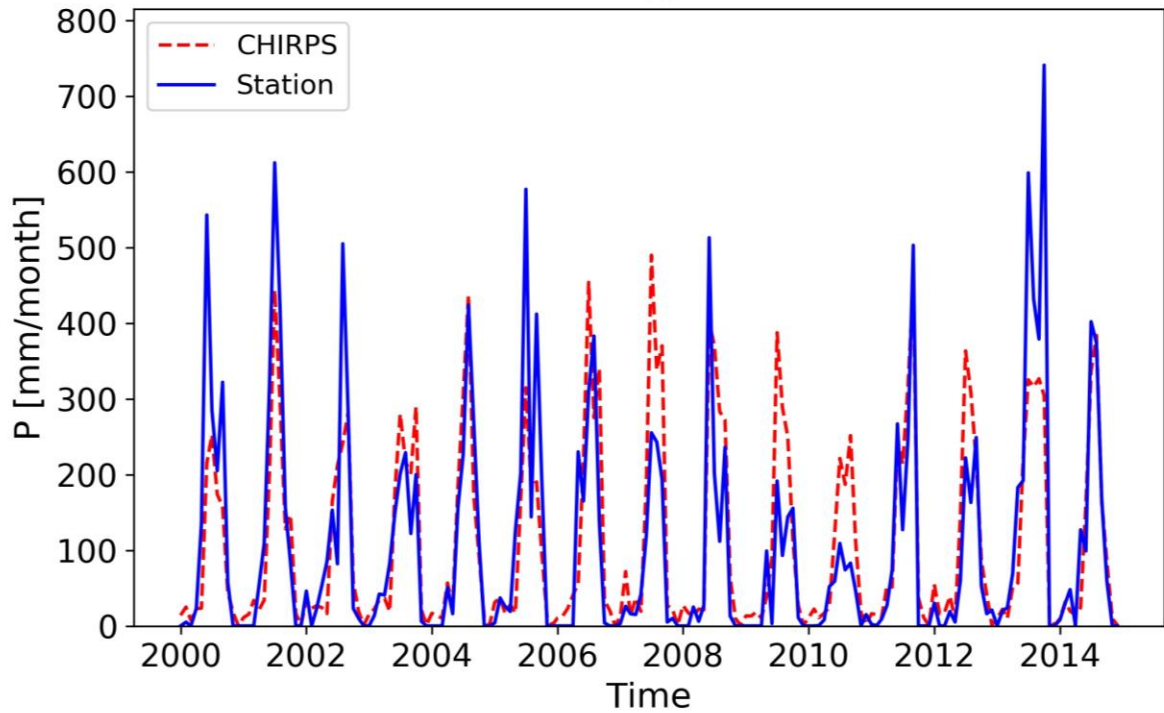


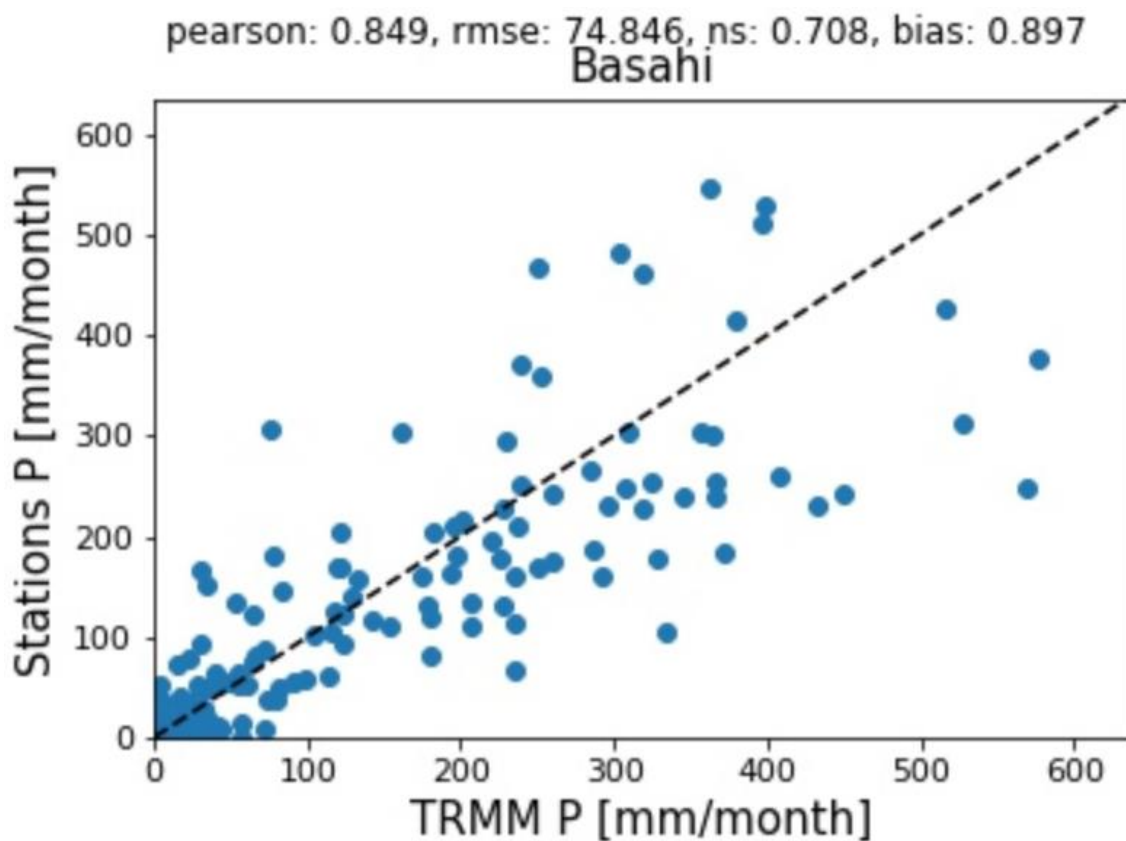
Figure 4.5g-h: Comparison between the observed station rainfall and CHIRPS data

4.1.2. Comparison of TRMM and Station Data

The validity of the TRMM rainfall data was also adjudged using the station rainfall data of the various station falling in the Subarnarekha river basin. The station rainfall data of the following seven stations namely Basahi, Betnati, Bijatala, Bisoi was used for this purpose. The results are given in Figures 4.6a-h for the period of 2003-2014. The validation was conducted using the Pearson correlation coefficient, root mean square error (rmse), and bias.

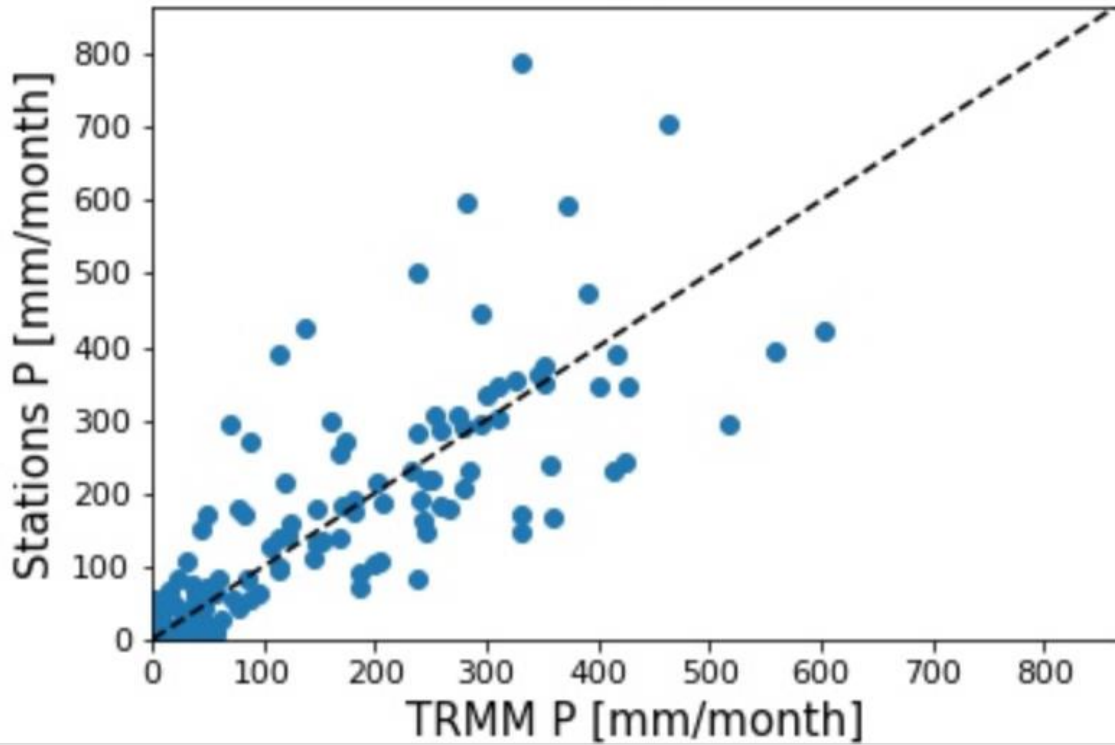
Using Scattered Plots:

The scatter plots between the station rainfall data and TRMM data are shown in Figures 4.6a-g. It can be observed from these plots the Pearson correlation coefficient and the NS values are comparatively lower as compared to the CHIRPS data and the rmse values are higher. Thus, it can be inferred that the CHIRPS data is better suited for analysis as compared to the TRMM data for Subarnarekha river basin.

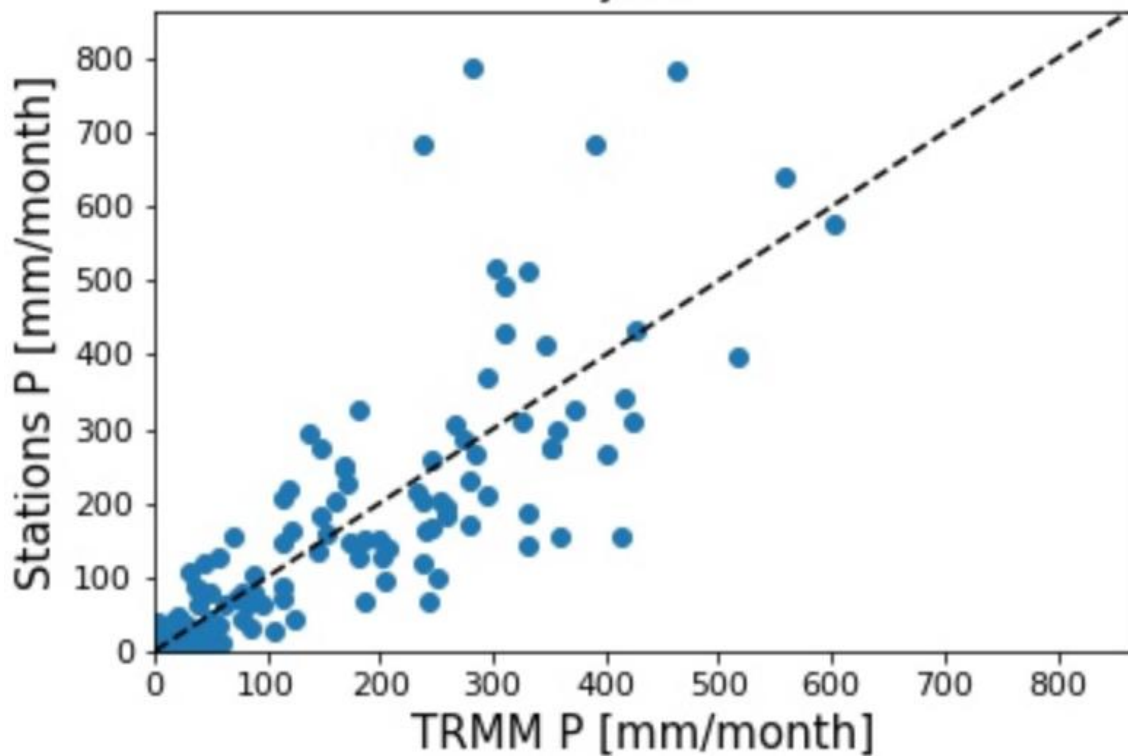


Figures 4.6a: Comparison between the Station Rainfall data and TRMM data

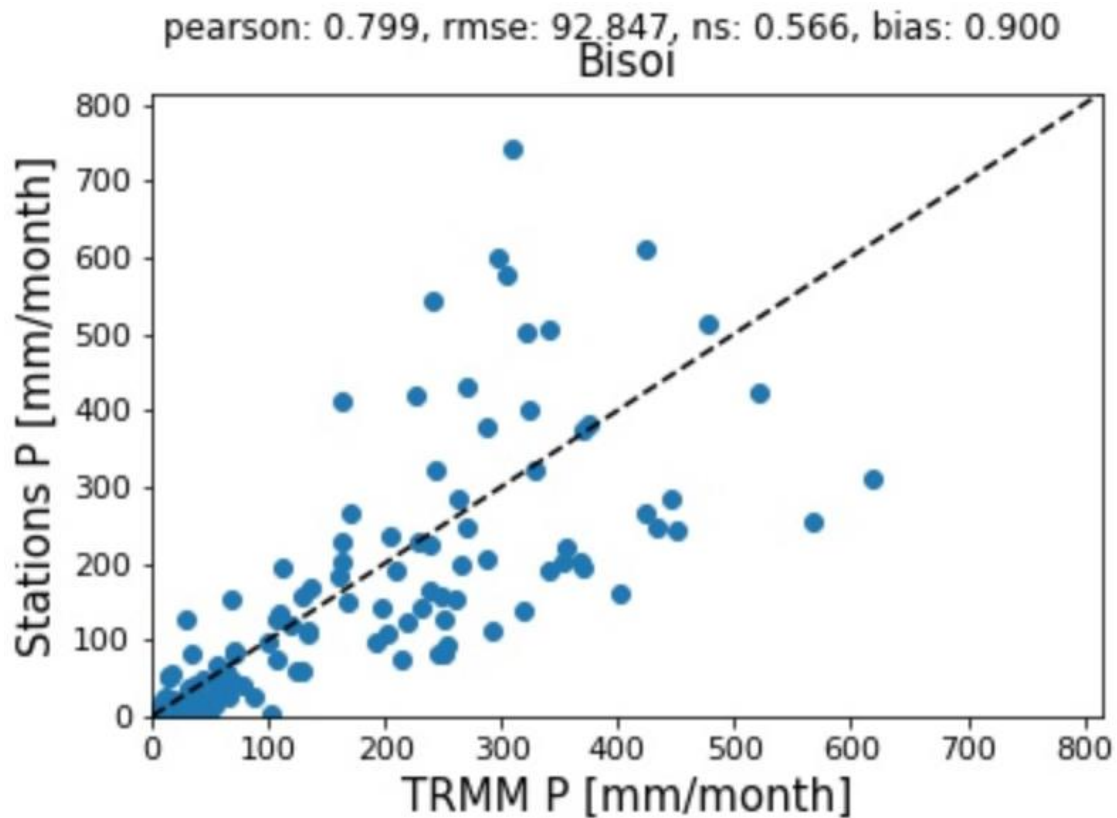
pearson: 0.830, rmse: 85.580, ns: 0.610, bias: 1.033
Betnati



pearson: 0.842, rmse: 86.979, ns: 0.597, bias: 0.999
Bijatala



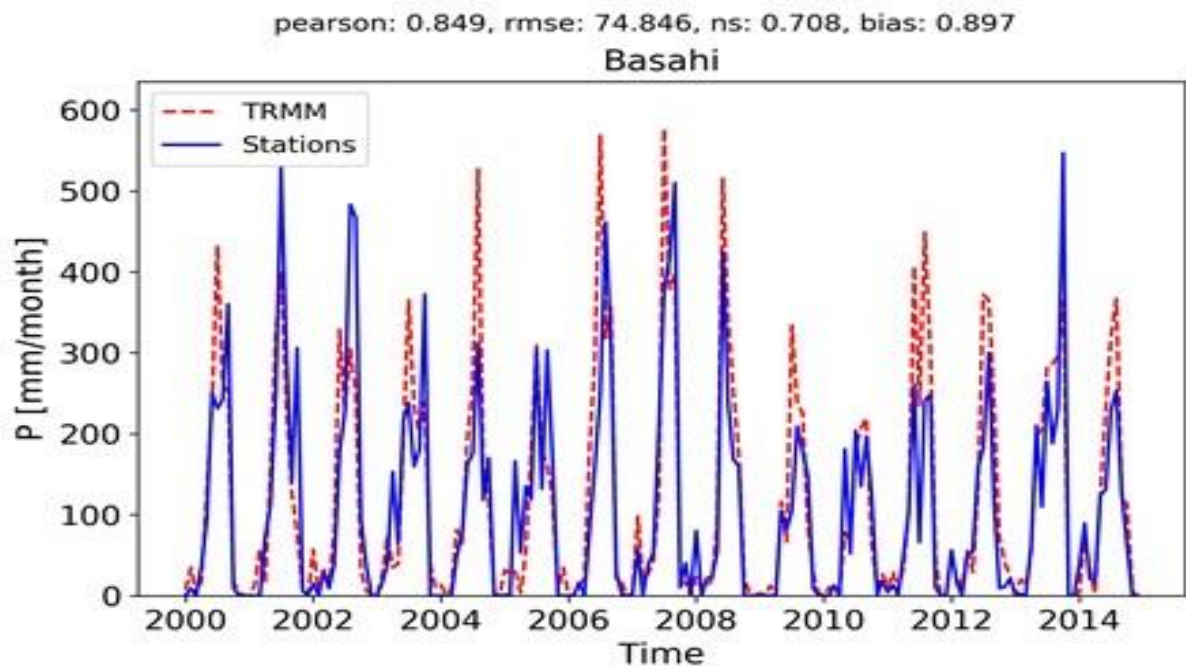
Figures 4.6b-c: Comparison between the Station Rainfall data and TRMM data



Figures 4.6d: Comparison between the Station Rainfall data and TRMM data

Using Time-Series Plots

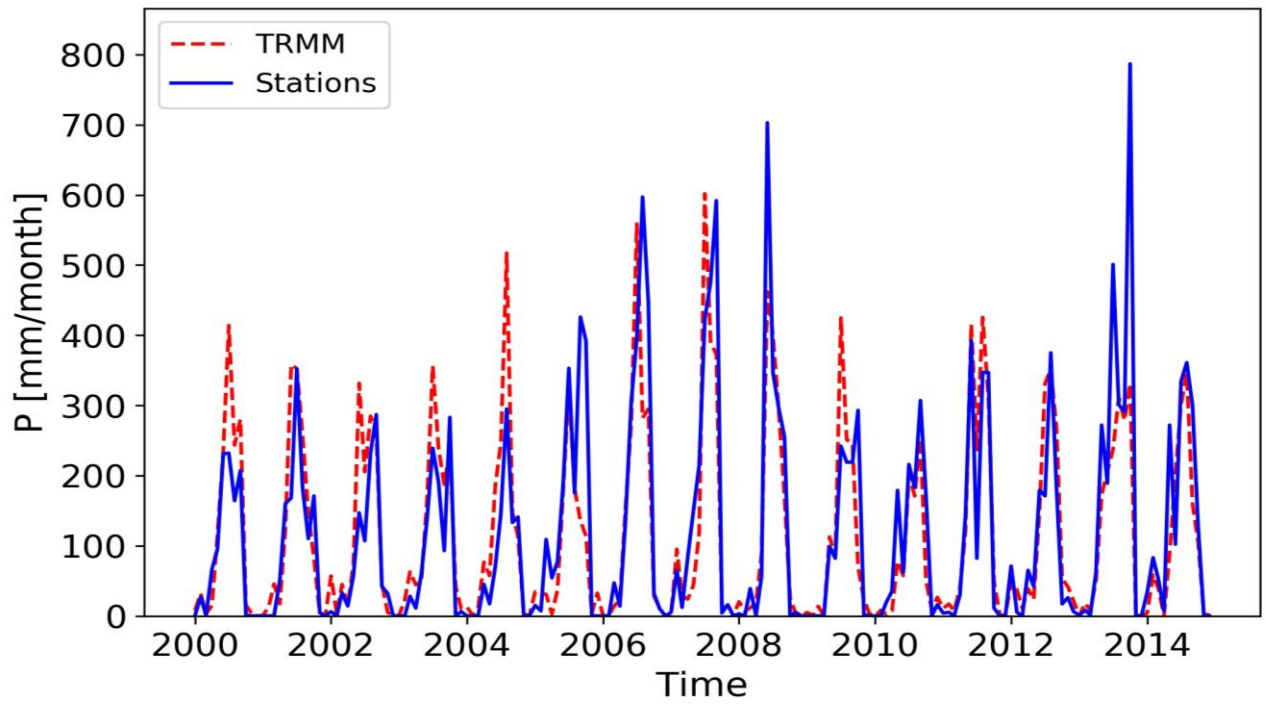
The time series plots between the station rainfall data and TRMM data are shown in Figures 4.6e-h.



Figures 4.6e: Comparison between the Station Rainfall data and TRMM data

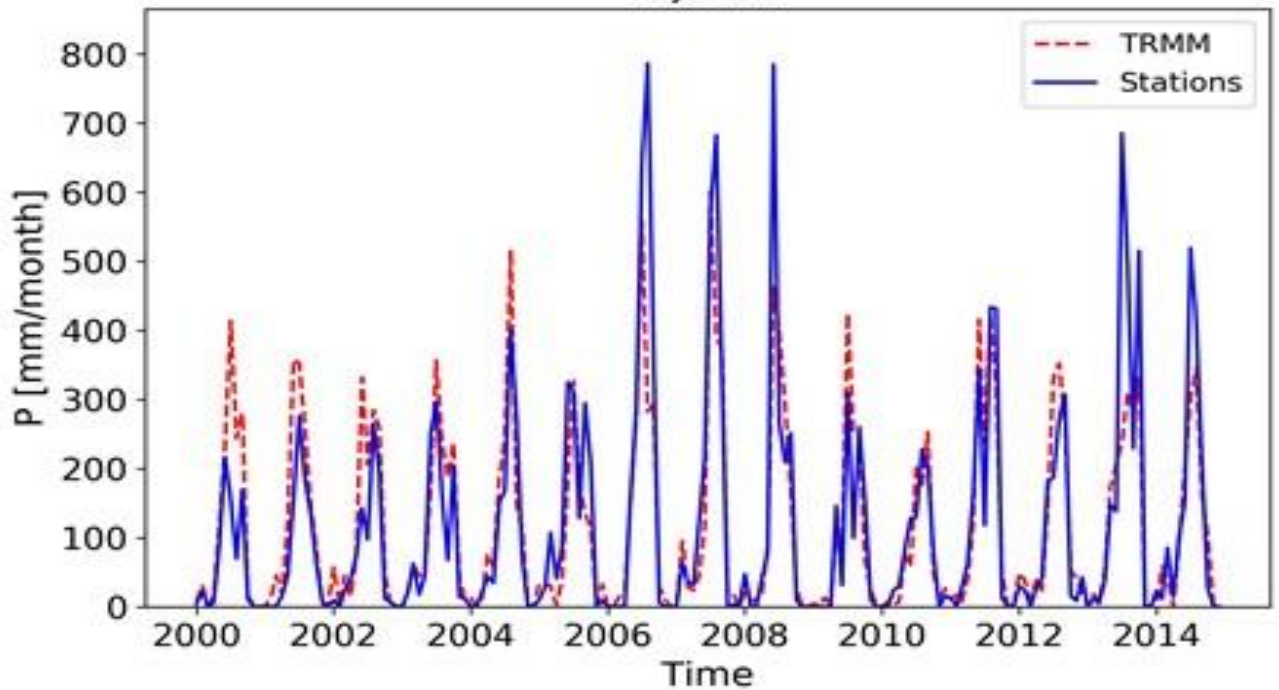
pearson: 0.830, rmse: 85.580, ns: 0.610, bias: 1.033

Betnati



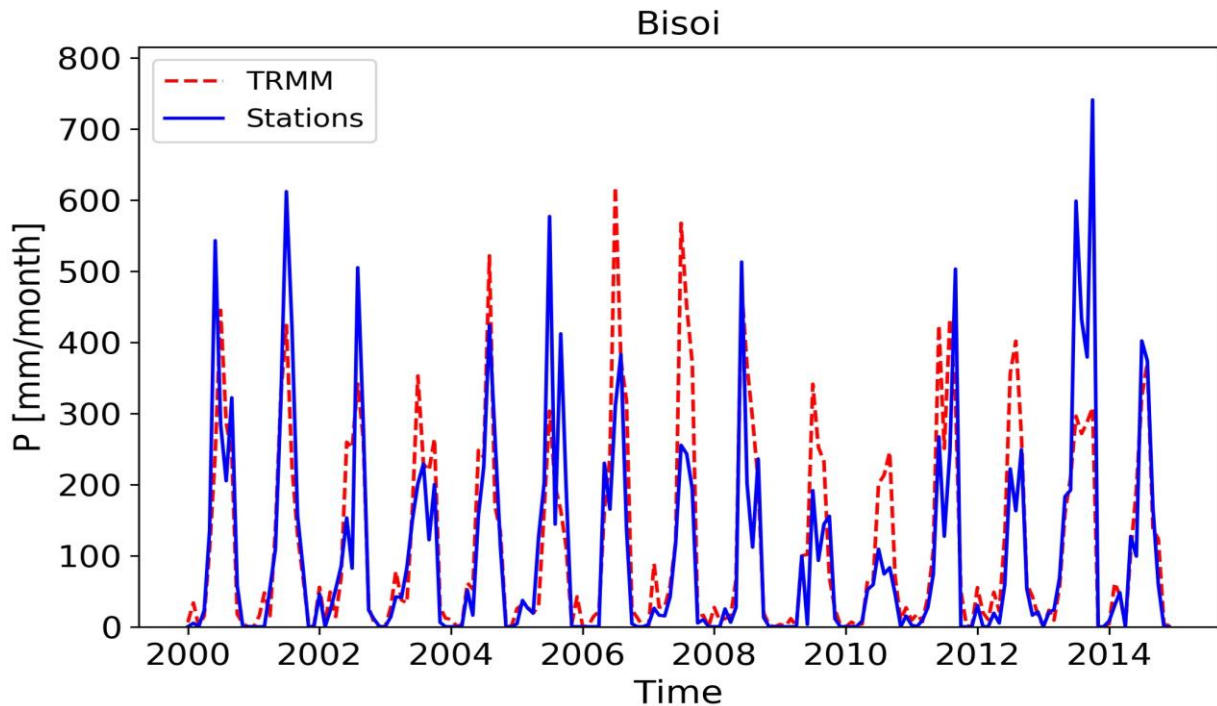
pearson: 0.842, rmse: 86.979, ns: 0.597, bias: 0.999

Bijatata



Figures 4.6f-g: Comparison between the Station Rainfall data and TRMM data

pearson: 0.799, rmse: 92.847, ns: 0.566, bias: 0.900



Figures 4.6h: Comparison between the Station Rainfall data and TRMM data

The goodness-of-fit (GOF) statistics in terms of pearson, rmse, ns, and bias shows that a high positive correlation (0.79-0.86) and higher efficiency (0.50-0.92) exists between the observed and satellite derived precipitation datasets, i.e. CHIRPS and TRMM (Figures 4.5 and 4.6). However, if we closely analyse these Figures then we find that the CHIRPS datasets have higher correlation with the station datasets as compared to the TRMM datasets. Similar results were also reported by various researchers in India and worldwide. Gupta et al. (2020) assessed the performance of global precipitation datasets such as CHIRPS, TRMM, Satellite Soil Moisture to Rain (SM2RAIN-ASCAT) and IMD datasets and found that both TRMM and CHIRPS performed well across India. Prakash (2019) found that CHIRPS dataset is comparable to station precipitation datasets at all-India and sub-regional scales. Gupta et al. (2019) also noted that the CHIRPS dataset performed well across most regions in India. Musie et al. (2019) also found that CHIRPS dataset is very useful in data-sparse regions (Musie et al., 2019). Ali and Mishra (2017) found that CHIRPS datasets has a higher correlation (>0.75) with wet season GPCP precipitation than the other satellite precipitation datasets. More recently, Dembele et al. (2020) also found that the CHIRPS dataset performs best as compared to the other precipitation datasets for streamflow modelling. Therefore, the CHIRPS data was further used in this study for estimation of water consumption patterns and estimates of land and water productivity in the basin.

4.3 ET Data Analysis and Potential Water Yield Estimates

ET is one of the most uncertain input in every water balance assessment. The measurements of actual ET are rare and the ET validation process is extremely challenging. No actual ET measurements were available for this study. In this study, the IHE developed ETensemble was used for further analysis.

The ETensemble is the output of the statistically combined six global actual ET products, i.e., (i) MODIS Global Terrestrial Evapotranspiration Algorithm (MOD16) (Mu et al., 2011), (ii) Atmosphere-Land Exchange Inverse Model (ALEXI) (Anderson et al., 2007), (iii) Global Land Evaporation Amsterdam Model (GLEAM) (Miralles et al., 2011), (iv) Surface Energy Balance System (SEBS) (Su, 2002), (v) Operational Simplified Surface Energy Balance (SSEBop) (Senay et al., 2013) and (vi) CSIRO MODIS Reflectance-based Evapotranspiration (CMRSET) (Guerschman et al., 2009)).

Temporal and spatial variability of ET was analyzed for Subarnarekha basin. The spatial variability of ET in Subarnarekha basin is shown in Figure 4.8. It shows that the ET variability is uniform in the most part of the basin, except in the Mayurbhanj district of Odisha, which has the highest ET. Figure 4.7 also shows the comparison between the monthly average precipitation and ET for the period of 2003-2014. ET is found to vary from 45 mm/month to 130 mm/month (with an annual ET varying from 750 mm to 1100 mm for the years 2008 and 2013, respectively).

Seasonal and inter-annual variability of CHIRPS, TRMM, and ET and Water Yield (P-ET) was also analyzed for the basin (Figure 4.9). The Water Yield (P-ET) was found to be higher for the wet year, i.e., 2013 and lowest for the dry year, i.e., 2010. On seasonal scale, the water yield was found to be negative for JAN to MAY and NOV-DEC, with the highest value of 235 mm/month in the month of August.

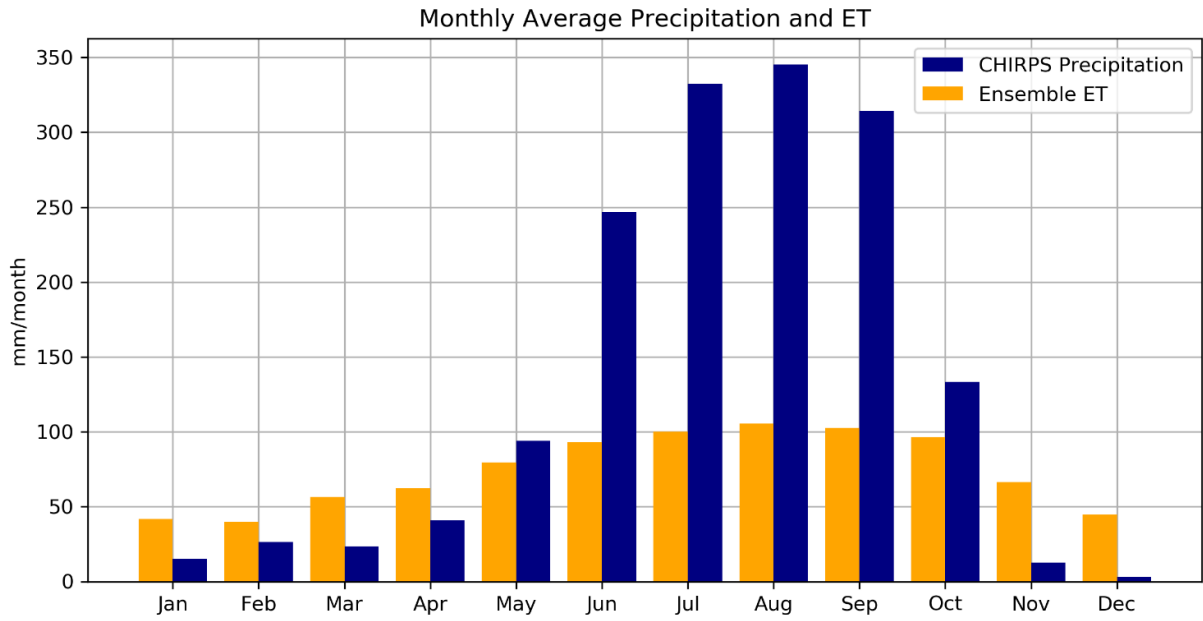


Figure 4.7: Comparison between Monthly average precipitation and ET for the period of 2003-2014.

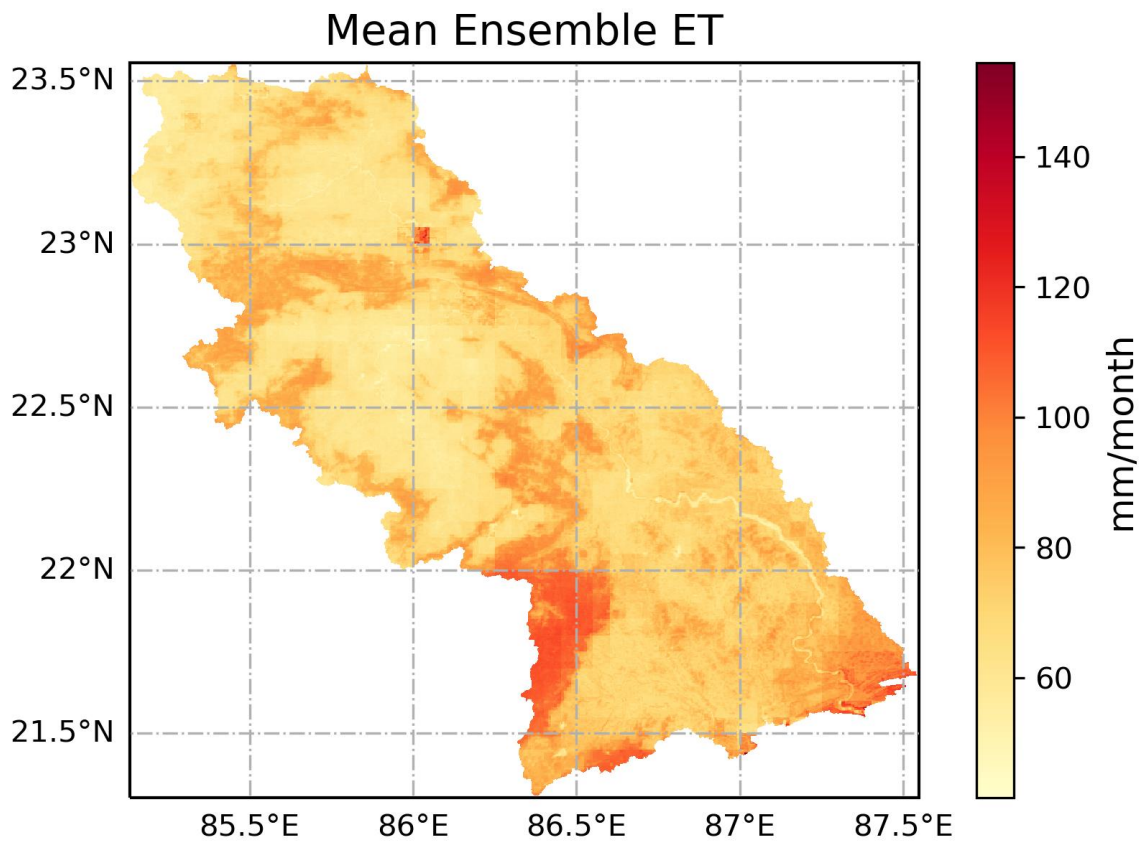


Figure 4.8: Spatial variability of the long-term mean monthly ET for Subernarekha basin.

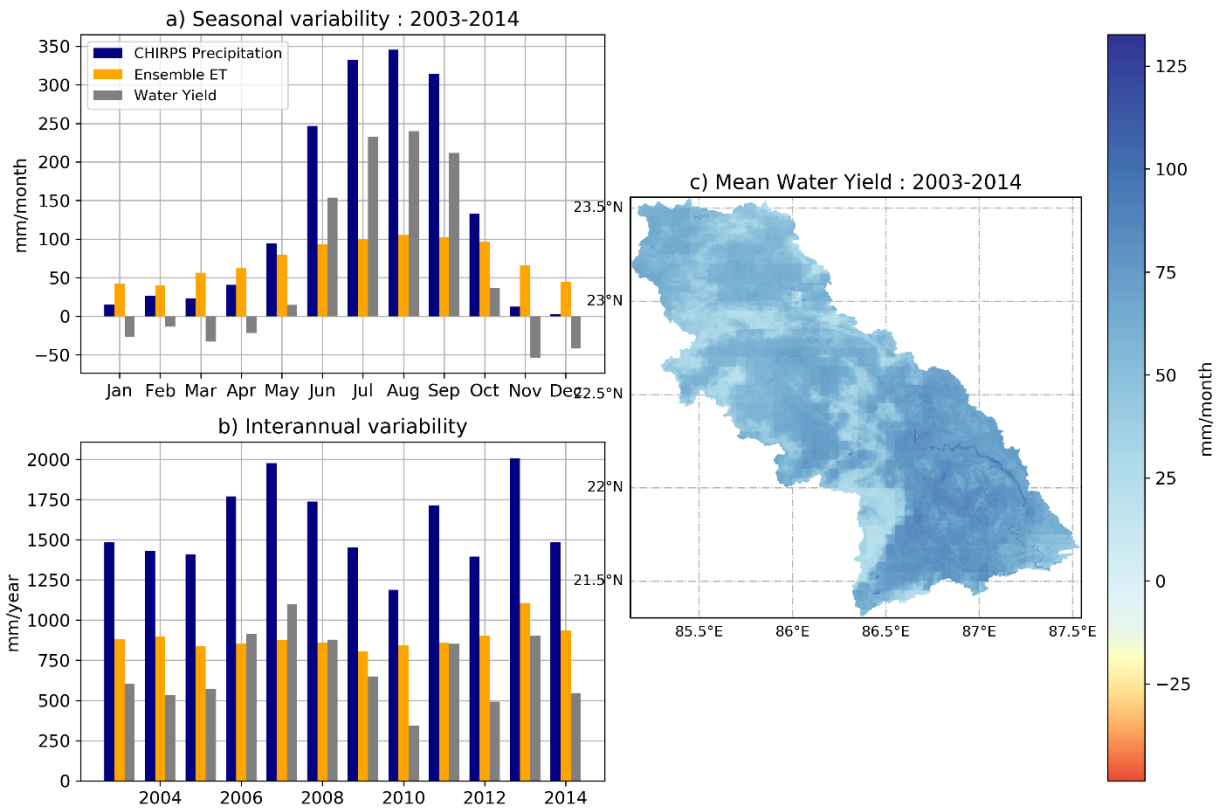


Figure 4.9: Seasonal and inter-annual variability of CHIRPS, Ensemble ET and Water Yield (P-ET) for the period of 2003-2014.

4.4 Development of Evapotranspiration Sheet [SHEET 2]

Sheet 2 presents information regarding water consumption in a basin as a total value and per water sector (land use type). Major parameters available from sheet 2 are:

- Total Evapotranspiration (ET)
- Total Evaporation
- Total Transpiration
- Interception
- 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
- Conventional ET which is the ET that occurs through natural processes
- Beneficial ET which is the water consumed for its intended purpose
- Non-Beneficial ET which is the water consumed for purposes other than the intended ones

Major inputs for the generation of Water Accounting 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. The procedure involves separation of evapotranspiration to evaporation, transpiration and interception (Fig.3) and then splitting evapotranspiration into beneficial and non-beneficial components. A generalized flow diagram is given in Figure 4.10, which was followed for generation of Water Accounting Sheet 2. Developed Sheets for wet and dry year are shown in Figure 4.11a and Figure 4.11b, respectively.

The total water consumptions of the basin for the wet year, i.e., 2013-14 is found to be 27.1 km³/year with further partitioning of ET into evaporation (E) from soil and Transpiration from different LULC. Sheet 2 indicates about ET management options as per LULC to reduce total water consumptions and hence withdrawals in the basin. Sheet 2 also shows that the non-beneficial consumptions in the Subarnarekha basin are 14.1 km³/year much greater than the beneficial consumptions (12.9 km³/year). This indicates that there is a large scope for water conservation practices to be adopted in the basin to minimize non-beneficial consumptions. Similarly, Figure 4.11b shows the Sheet 2 for dry year, i.e., 2010-11. The estimates of the total water consumptions (ET), transpiration (T), evaporation (E) and interception (I) from four

major land use classes are given in Table 4.1. A brief summary of these results is also given in Tables 4.2a and 4.2b for wet and dry years.

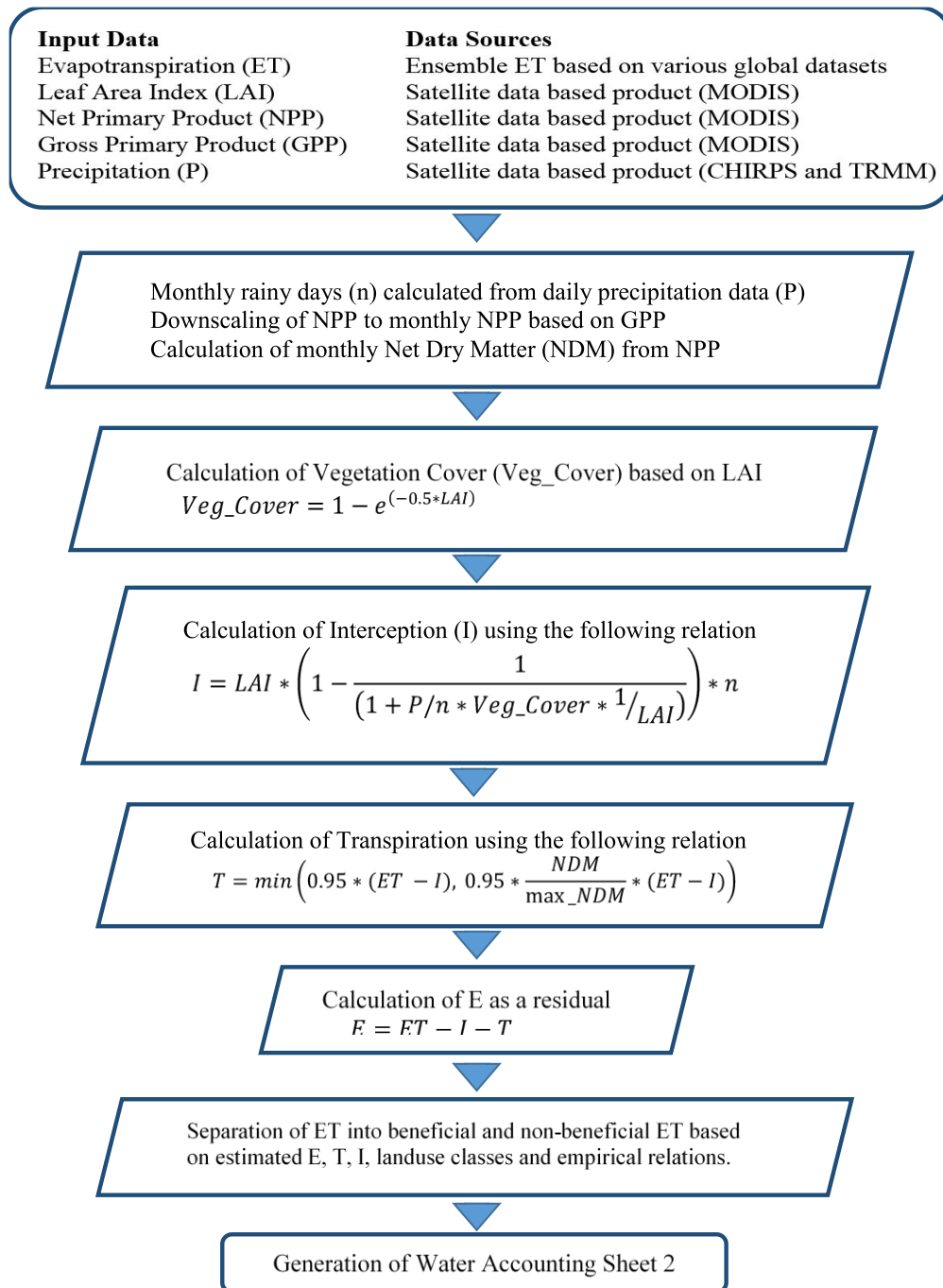


Figure 4.10: Flow chart for generation of Sheet 2

Sheet 2: Evapotranspiration (km3/year)

Period: Jun 2013-May 2014
 Basin: Subarnarekha_18012021

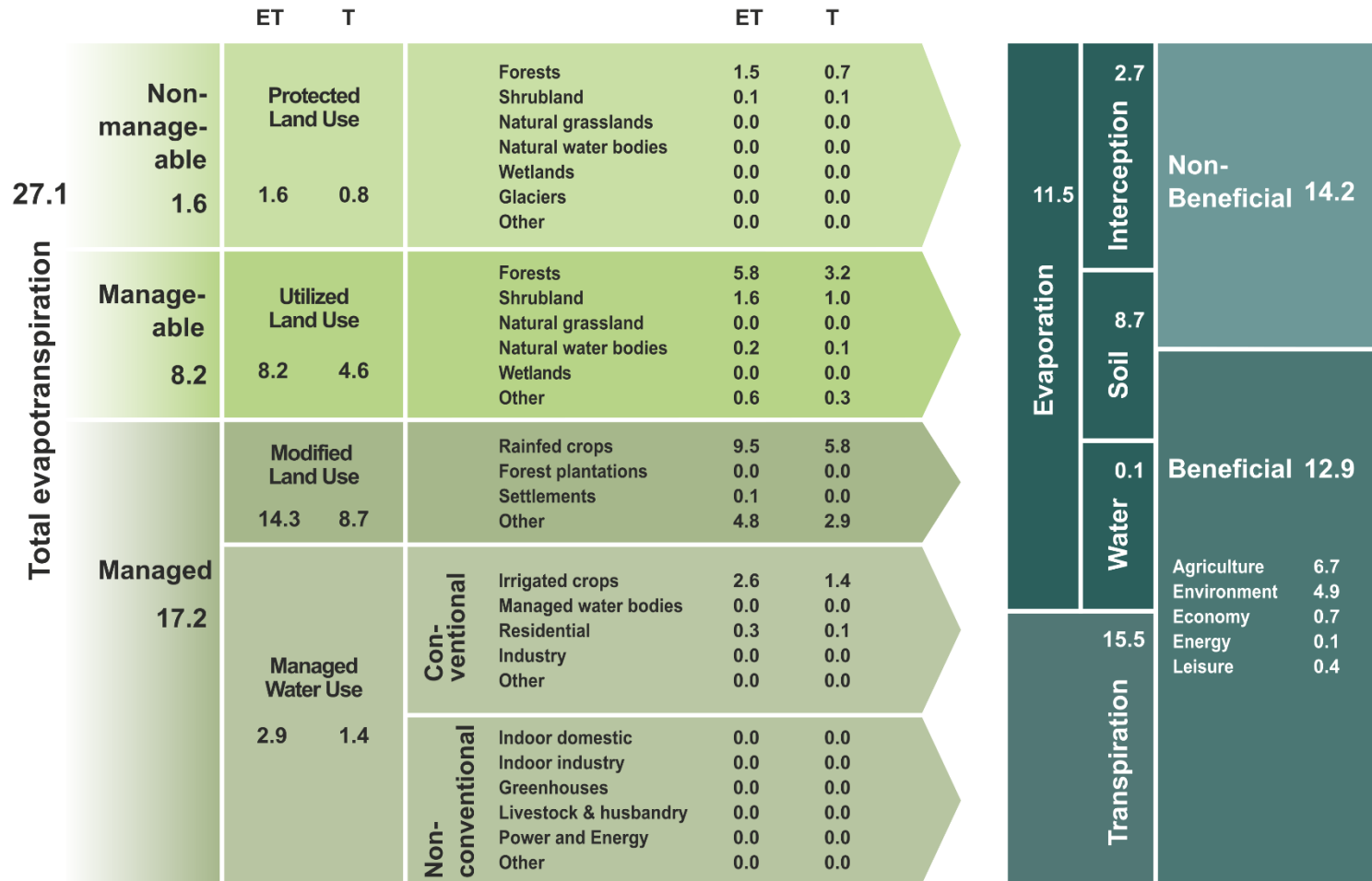


Figure 4.11a: Evapotranspiration Sheet: Sheet 2 for wet Year 2013-14.

Sheet 2: Evapotranspiration (km3/year)

Period: Jun 2010-May 2011

Basin: Subarnarekha_18012021

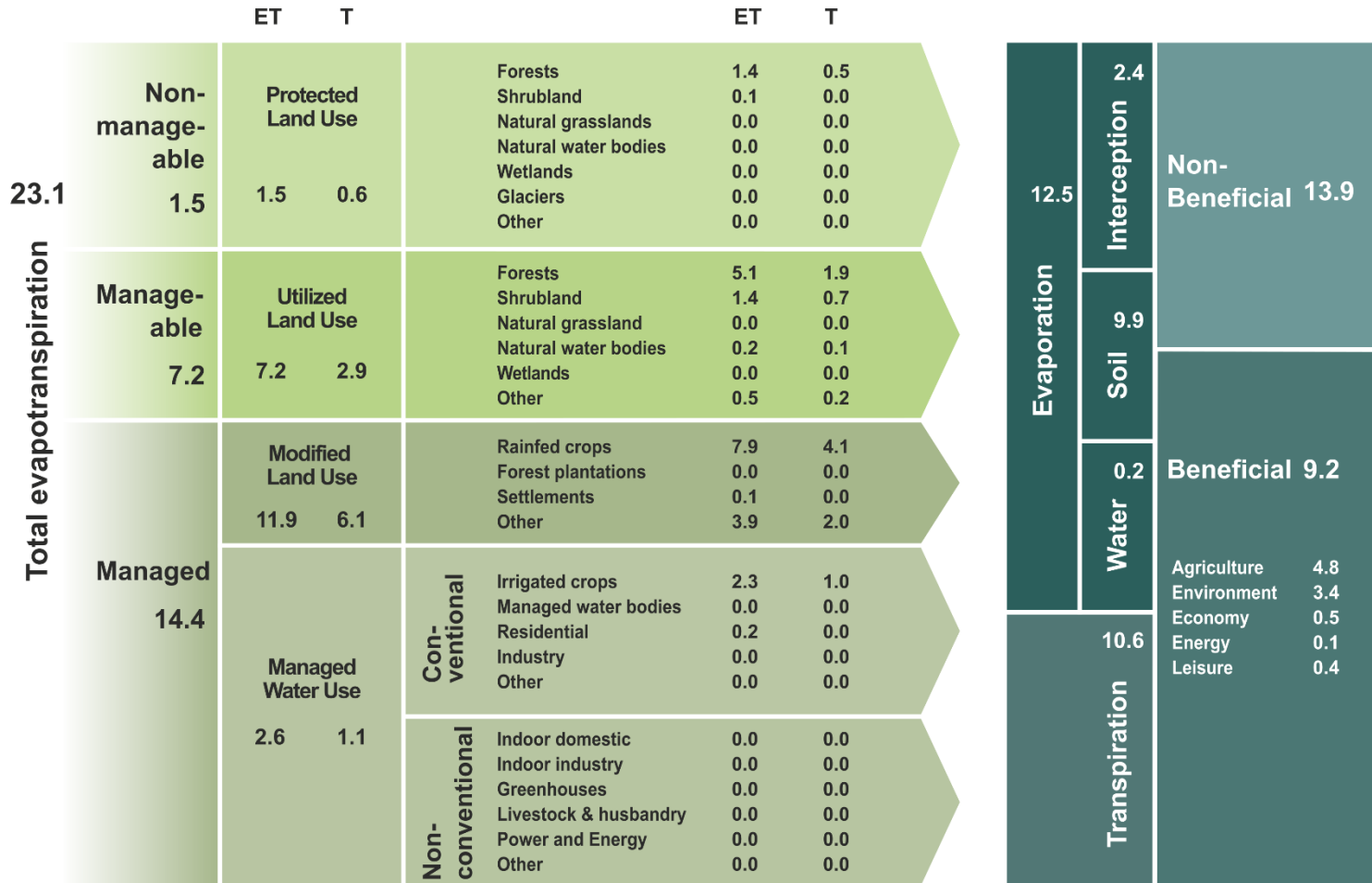


Figure 4.11b: Evapotranspiration Sheet: Sheet 2 for Dry Year 2010-11.

Table 4.1: Total water consumption (ET), transpiration (T), evaporation (E), and interception (I) from the four major landuse classes in the Subernarekha basin for the period of 2003-2014.

Year	LAND_USE	Area (km ²)	ET (BCM)	T (BCM)	E (BCM)		I (BCM)
					Water	Soil	
2003-04	Protected	1211.36	1.463	0.602	0.006	0.620	0.235
2004-05			1.465	0.517	0.001	0.740	0.208
2005-06			1.390	0.478	0.005	0.680	0.227
2006-07			1.480	0.690	0.005	0.542	0.243
2007-08			1.474	0.713	0.005	0.509	0.246
2008-09			1.356	0.526	0.005	0.627	0.197
2009-10			1.404	0.355	0.007	0.851	0.191
2010-11			1.497	0.556	0.006	0.690	0.245
2011-12			1.478	0.660	0.006	0.594	0.219
2012-13			1.577	0.624	0.008	0.751	0.194
2013-14			1.616	0.817	0.006	0.554	0.239
				Total	16.199	6.538	0.060
2003-04	Utilized	9556.89	7.439	3.569	0.133	2.923	0.814
2004-05			7.238	3.396	0.128	2.937	0.778
2005-06			6.741	2.929	0.128	2.980	0.704
2006-07			7.335	3.859	0.124	2.569	0.783
2007-08			7.073	3.675	0.131	2.426	0.841
2008-09			6.625	3.131	0.138	2.553	0.802
2009-10			6.830	2.356	0.151	3.613	0.710
2010-11			7.181	2.920	0.147	3.293	0.821
2011-12			7.315	3.677	0.129	2.745	0.764
2012-13			8.189	3.493	0.158	3.835	0.702
2013-14			8.228	4.586	0.120	2.610	0.912
				Total	80.194	37.592	1.487
2003-04	Modified	16630.3	12.260	6.637	0.000	4.556	1.067
2004-05			11.629	6.570	0.000	4.100	0.959
2005-06			10.863	5.554	0.000	4.380	0.929
2006-07			12.136	7.391	0.000	3.722	1.023
2007-08			11.586	6.748	0.000	3.732	1.106
2008-09			10.671	5.776	0.000	3.784	1.111
2009-10			11.147	5.005	0.000	5.208	0.934
2010-11			11.850	6.083	0.000	4.693	1.074
2011-12			11.946	6.898	0.000	4.032	1.016
2012-13			14.243	6.877	0.000	6.392	0.973
2013-14			14.337	8.680	0.000	4.333	1.324
				Total	132.667	72.220	0.000
2003-04	Managed	888.44	2.536	1.150	0.000	1.187	0.199
2004-05			2.437	1.133	0.000	1.123	0.181

2005-06			2.298	0.960	0.000	1.155	0.184
2006-07			2.513	1.261	0.000	1.063	0.190
2007-08			2.435	1.173	0.000	1.064	0.198
2008-09			2.273	1.006	0.000	1.069	0.197
2009-10			2.397	0.868	0.000	1.349	0.181
2010-11			2.554	1.069	0.000	1.267	0.218
2011-12			2.539	1.211	0.000	1.138	0.190
2012-13			2.994	1.241	0.000	1.562	0.191
2013-14			2.892	1.442	0.000	1.201	0.249
		Total	27.869	12.513	0.000	13.178	2.178

Table 4.2a: Summary of total water consumptions (ET), transpiration (T) and evaporation E as per land use class across the entire Subernarekha basin for wet year

LAND_USE	Class	Area (km ²)	ET (BCM)	T (BCM)	E (BCM)		I (BCM)
					Water	Soil	
Utilized	Wetlands	337.44	0.002	0.001	0.000	0.001	0.000
	Natural grasslands	1611.19	0.003	0.001	0.000	0.001	0.000
	Shrubland	1031.6	1.629	0.966	0.000	0.489	0.174
	Natural water bodies	685.62	0.226	0.092	0.120	0.000	0.013
	Forest	4543.63	5.793	3.216	0.000	1.899	0.677
	Others	1347.41	0.577	0.310	0.000	0.220	0.047
Protected	Wetlands	10.74	0.000	0.000	0.000	0.000	0.000
	Natural grasslands	32.97	0.000	0.000	0.000	0.000	0.000
	Shrubland	58.23	0.134	0.070	0.000	0.049	0.016
	Natural water bodies	10.81	0.013	0.006	0.006	0.000	0.001
	Forest	1039.09	1.469	0.742	0.000	0.505	0.223
	Glaciers	19.21	0.000	0.000	0.000	0.000	0.000
	Others	40.31	0.000	0.000	0.000	0.000	0.000
Modified	Others	2683.02	4.764	2.868	0.000	1.467	0.430
	Settlements	199.8	0.098	0.047	0.000	0.045	0.007
	Forest plantations	909.62	0.000	0.000	0.000	0.000	0.000
	Rainfed crops	12837.87	9.474	5.766	0.000	2.821	0.887
Managed Water use	Residential	256.82	0.297	0.062	0.000	0.225	0.010
	Managed water bodies	21.63	0.000	0.000	0.000	0.000	0.000
	Irrigated crops	276.82	2.594	1.380	0.000	0.976	0.239
	Industry	15.73	0.000	0.000	0.000	0.000	0.000
	Others	318.23	0.000	0.000	0.000	0.000	0.000

Table 4.2b: Summary of total water consumptions (ET), transpiration (T), evaporation (E), and interception (I) as per land use class across the entire Subernarekha basin for dry year

LAND_USE	Class	Area (km ²)	ET (BCM)	T (BCM)	E (BCM)		I (BCM)
					Water	Soil	
Utilized	Wetlands	337.44	0.002	0.000	0.000	0.002	0.000
	Natural grasslands	1611.19	0.002	0.001	0.000	0.001	0.000
	Shrubland	1031.6	1.393	0.672	0.000	0.570	0.151
	Natural water bodies	685.62	0.234	0.075	0.147	0.000	0.012
	Forest	4543.63	5.051	1.947	0.000	2.488	0.616
	Others	1347.41	0.498	0.225	0.000	0.232	0.041
Protected	Wetlands	10.74	0.000	0.000	0.000	0.000	0.000
	Natural grasslands	32.97	0.000	0.000	0.000	0.000	0.000
	Shrubland	58.23	0.115	0.049	0.000	0.052	0.014
	Natural water bodies	10.81	0.011	0.004	0.006	0.000	0.001
	Forest	1039.09	1.371	0.502	0.000	0.638	0.231
	Glaciers	19.21	0.000	0.000	0.000	0.000	0.000
	Others	40.31	0.000	0.000	0.000	0.000	0.000
Modified	Others	2683.02	3.859	1.956	0.000	1.562	0.341
	Settlements	199.8	0.086	0.035	0.000	0.045	0.006
	Forest plantations	909.62	0.000	0.000	0.000	0.000	0.000
	Rainfed crops	12837.87	7.906	4.093	0.000	3.086	0.727
Managed Water use	Residential	256.82	0.246	0.042	0.000	0.195	0.009
	Managed water bodies	21.63	0.000	0.000	0.000	0.000	0.000
	Irrigated crops	276.82	2.308	1.027	0.000	1.072	0.209
	Industry	15.73	0.000	0.000	0.000	0.000	0.000
	Others	318.23	0.000	0.000	0.000	0.000	0.000

4.5 Development of Agricultural Services Sheet [SHEET 3]

The agricultural water consumptions along with the land productivity and water productivity of the different crops in the Subarnarekha basin were also estimated as shown in Sheet 3 for sustaining land and water resources and food security in the basin. Sheet 3 has two parts. Sheet 3 (part I) shows the agricultural water consumptions in the basin and Sheet 3 (part II) shows the Land Productivity (kg/ha/year) and Water Productivity (kg/m³). Here, we are discussing the results for wet and dry years, i.e., 2010-11 and 2013-14 only. The agricultural water consumptions (Sheet 3-Part I) for both dry and wet years are shown in Figure 4.12a&b.

Sheet-3 (part II) also gives the estimates of the land and water productivity in the basin. Figure 4.13a and Figure 4.13b show the land and water productivity in the basin for wet and dry years. It can be observed from Figure 4.13a that during the wet year, the basin has the land productivity of 2141 kg/ha/year and 2325 kg/ha/year, respectively for rainfed and irrigated cereals. During the dry year, the land productivity is found to be 1575 kg/ha/year and 1876 kg/ha/year, respectively for rainfed and irrigated cereals (Figure 4.13b). Similar Sheets were also developed for the rest of the years. Overall, the average land productivity is found to vary from 1575 to 2141 kg/ha/year and 1315 to 2325 kg/ha/year during the period of 2003-04 to 2013-14, respectively for rainfed and irrigated cereals (Table 4.3a). Interestingly, similar results were also reported in the Water Productivity Mapping of Major Indian Crops by NABARD and ICRIER (Sharma et al., 2018), wherein the land productivity of the irrigated rice is reported as 3000 kg/ha/year, 2800 kg/ha/year, and 2200 kg/ha/year, respectively for the many parts of the states of Jharkhand, West Bengal and Odisha and also by the “Agricultural statistics of India” (Figure 4.14).

Figures 4.13a&b show that the basin has an average WP of 0.43 kg/m³ and 0.55 kg/m³, respectively for rainfed and irrigated cereals. Overall, the WP is found to vary from 0.34 to 0.49 kg/m³ (with an overall average of 0.42 kg/m³) and 0.38 to 0.69 kg/m³ (with an overall average of 0.59 kg/m³) during the period of 2003-04 to 2013-14, respectively for rainfed and irrigated cereals for all the 12 years (Table 4.3b). Similar results were also reported in the Water Productivity Mapping of Major Indian Crops by NABARD and ICRIER, wherein the irrigation WP of the rice has been reported as 0.75 kg/m³, 0.25 kg/m³, and 0.35 kg/m³, respectively for the states of Jharkhand, West Bengal and Odisha (Figure 4.14). Figures 4.15a-b and Figures 4.15c-d show the spatial variability of land productivity for dry and wet years, respectively for rainfed and irrigate cereals, mainly rice. Similarly, Figures 4.16a-b and Figures 4.16c-d show the spatial variability of WP for dry and wet years, respectively for rainfed and irrigate cereals, mainly rice.

Sheet 3: Agricultural services

Part 1: Agricultural water consumption (km³/year)

Basin: Subarnarekha_18012021

Period: Jun 2010-May 2011

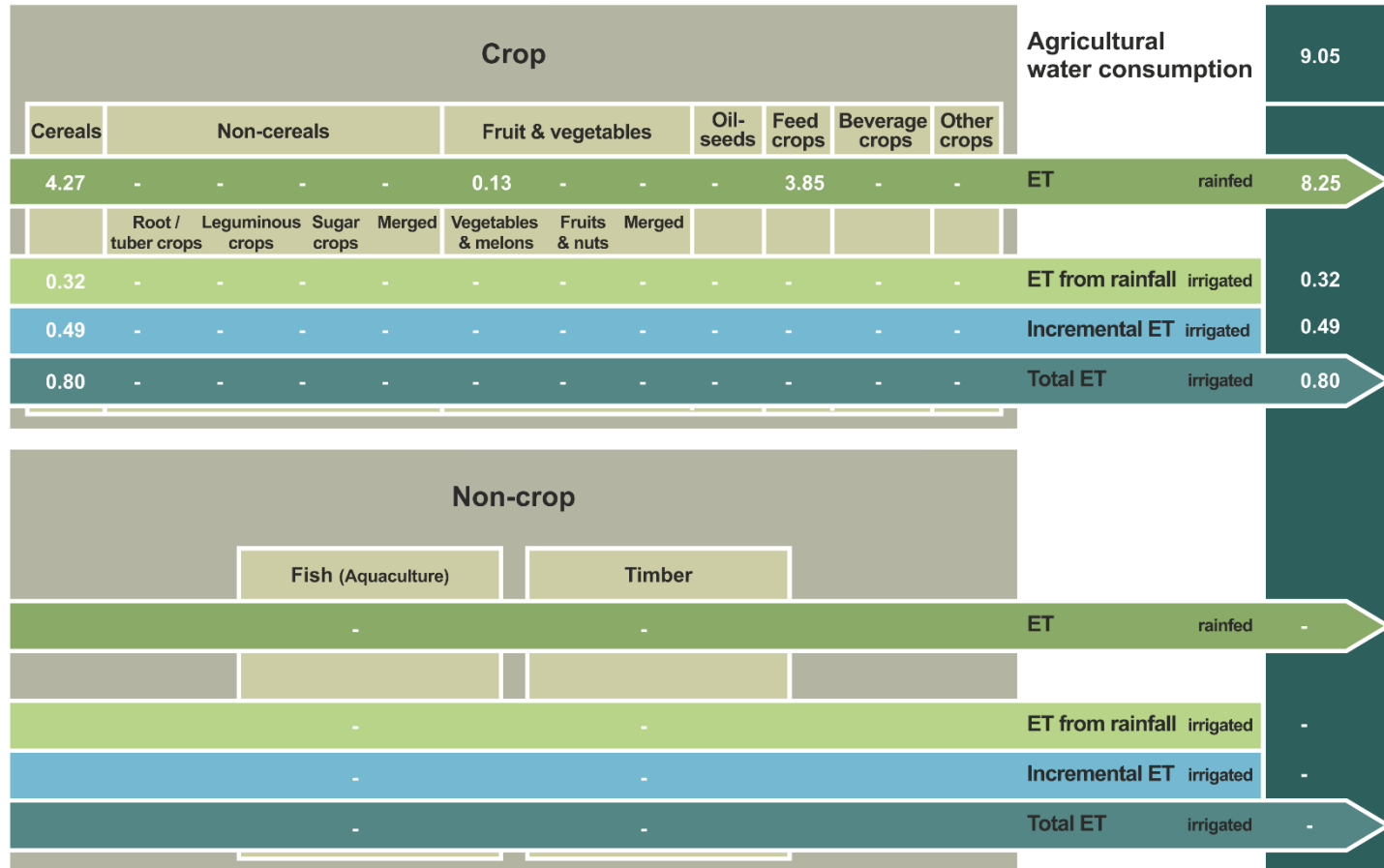


Figure 4.12a: Sheet3 (part I) shows the agricultural water consumptions in the basin for dry year

Sheet 3: Agricultural services
 Part 1: Agricultural water consumption (km³/year)



Basin: Subarnarekha_18012021
 Period: Jun 2013-May 2014

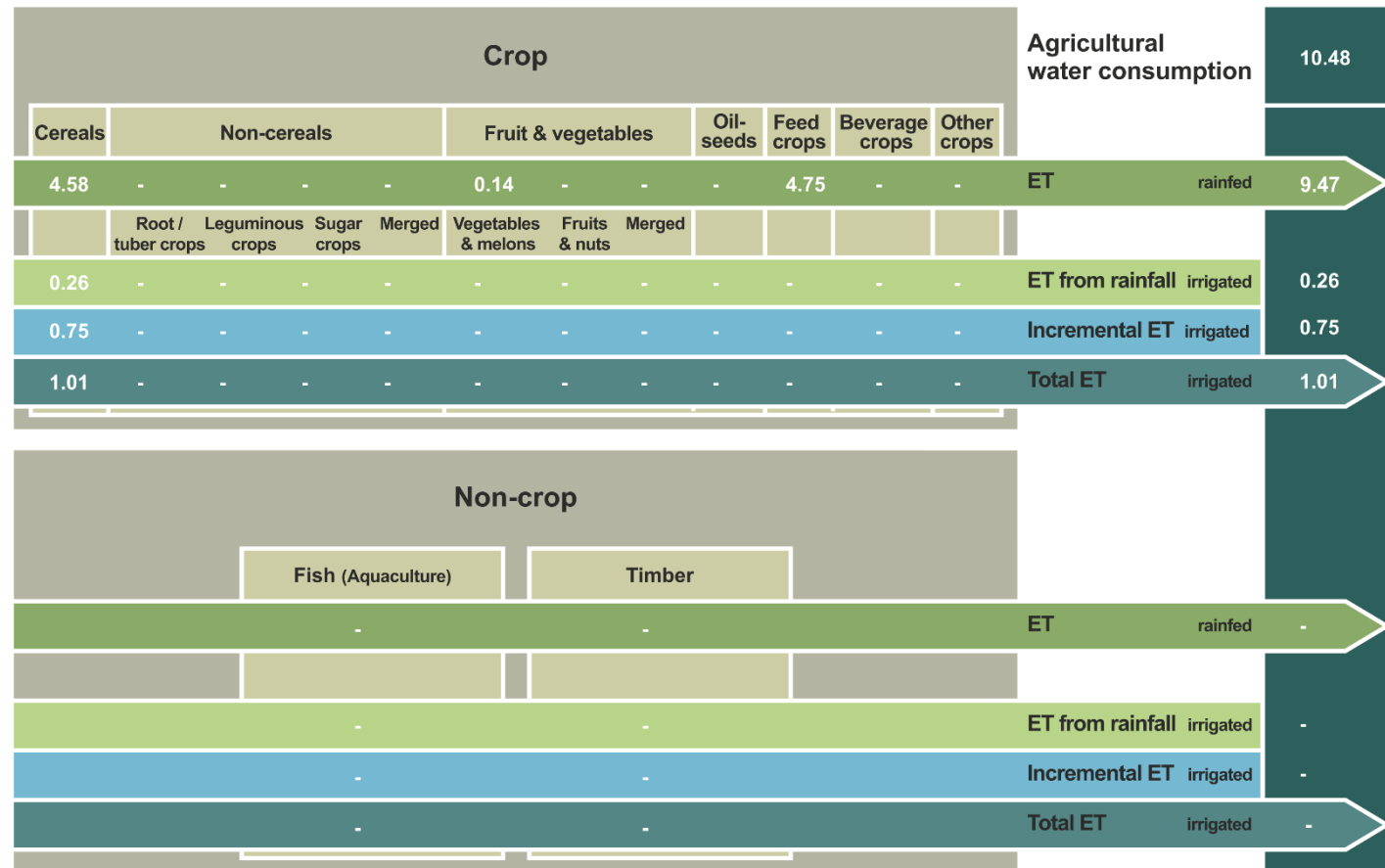


Figure 4.12b: Sheet3 (part I): the agricultural water consumptions in the basin for wet year

Sheet 3: Agricultural services

Part 2: Land productivity (kg/ha/year) and water productivity (kg/m3)



Basin: Subarnarekha_18012021

Period: Jun 2013-May 2014

		Crop															
		Cereals	Non-cereals				Fruit & vegetables			Oil-seeds	Feed crops	Beverage crops			Other crops		
Land productivity		2141	-	-	-	-	18568			-	-	-	10173	-	-	Yield	rainfed
		964	-	-	-	-	-	-	-	-	-	-	-	-	-	Yield from rainfall	} irrigated
		1361	-	-	-	-	-	-	-	-	-	-	-	-	-	Incremental yield	
		2325	-	-	-	-	-	-	-	-	-	-	-	-	-	Total yield	
			Root / tuber crops	Leguminous crops	Sugar crops	Merged	Vegetables & melons	Fruits & nuts	Merged								
Water productivity		0.43	-	-	-	-	3.25			-	-	-	1.08	-	-	WP	rainfed
		0.89	-	-	-	-	-	-	-	-	-	-	-	-	-	WP from rainfall	} irrigated
		0.44	-	-	-	-	-	-	-	-	-	-	-	-	-	Incremental WP	
		0.55	-	-	-	-	-	-	-	-	-	-	-	-	-	Total WP	

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

Figure 4.13a: Sheet3 (part II): Land and water productivity in the basin for wet year

Sheet 3: Agricultural services

Part 2: Land productivity (kg/ha/year) and water productivity (kg/m3)



Basin: Subarnarekha_18012021

Period: Jun 2010-May 2011

Crop														
	Cereals	Non-cereals				Fruit & vegetables			Oil-seeds	Feed crops	Beverage crops	Other crops		
Land productivity	1575	-	-	-	-	13989	-	-	-	7975	-	-	Yield	rained
	1020	-	-	-	-	-	-	-	-	-	-	-	Yield from rainfall	} irrigated
	856	-	-	-	-	-	-	-	-	-	-	-	Incremental yield	
	1876	-	-	-	-	-	-	-	-	-	-	-	Total yield	
		Root / tuber crops	Leguminous crops	Sugar crops	Merged	Vegetables & melons	Fruits & nuts	Merged						
Water productivity	0.34	-	-	-	-	2.63	-	-	-	1.05	-	-	WP	rained
	0.78	-	-	-	-	-	-	-	-	-	-	-	WP from rainfall	} irrigated
	0.42	-	-	-	-	-	-	-	-	-	-	-	Incremental WP	
	0.56	-	-	-	-	-	-	-	-	-	-	-	Total WP	

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

Figure 4.13b: Sheet3 (part II): Land and water productivity in the basin for dry year

Table 4.3a: Temporal variations of land productivity of cereals across in the Subernarekha basin

		Land Productivity of Cereals (kg/ha)			
		Rainfed	Irrigated		
Sl. No.	Year		Rainfall	Irrigation	Total
1	2003-04	1871.72	1167.13	1113.27	2280.40
2	2004-05	1992.38	1249.02	697.66	1946.68
3	2005-06	1706.38	966.77	1046.01	2012.78
4	2006-07	1976.92	1284.56	875.82	2160.38
5	2007-08	2015.89	1231.91	978.76	2210.68
6	2008-09	2066.83	824.00	840.30	1664.30
7	2009-10	1722.69	779.70	535.47	1315.17
8	2010-11	1575.22	1020.28	855.73	1876.01
9	2011-12	2183.40	1161.69	692.65	1854.34
10	2012-13	1875.46	844.21	939.03	1783.24
11	2013-14	2140.56	963.90	1360.88	2324.69

Table 4.3b: Temporal variations of water productivity of cereals in the Subernarekha basin

		Water Productivity of Cereals (kg/m ³)			
		Rainfed	Irrigated		Total
Sl. No.	Year		due to rainfall	due to supplemental irrigation	
1	2003-04	0.41	0.86	0.55	0.67
2	2004-05	0.44	0.86	0.43	0.63
3	2005-06	0.39	0.99	0.54	0.69
4	2006-07	0.44	0.82	0.55	0.68
5	2007-08	0.45	0.93	0.48	0.66
6	2008-09	0.46	1.10	0.48	0.66
7	2009-10	0.38	0.68	0.29	0.44
8	2010-11	0.34	0.78	0.42	0.56
9	2011-12	0.49	0.72	0.36	0.52
10	2012-13	0.40	0.58	0.29	0.38
11	2013-14	0.43	0.89	0.44	0.55

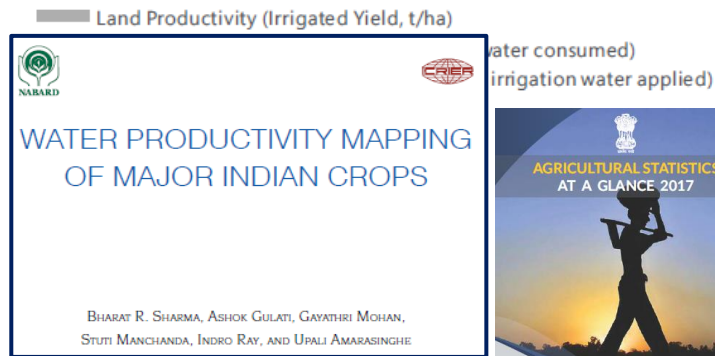
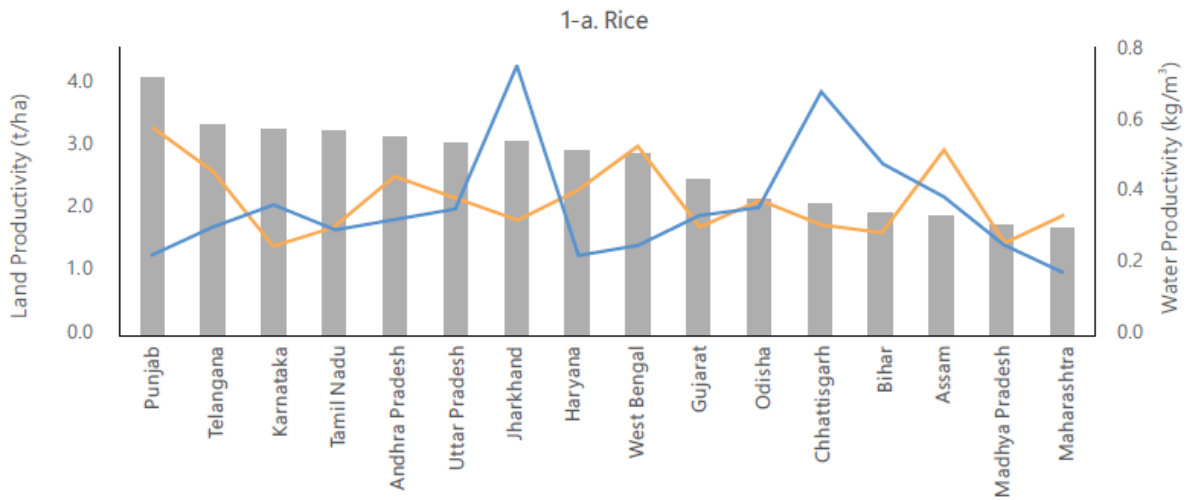


Table 4.6 (b): Rice: Area, Production and Yield during 2015-16 and 2016-17 in major F

State	2016-17#					2015-16					Area Under Irrigation (%) 2014-15*
	Area	% to All - India	Production	% to All - India	Yield	Area	% to All - India	Production	% to All - India	Yield	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
West Bengal	5.15	11.91	15.09	13.70	2933	5.52	12.70	15.95	15.28	2888	46.9
Uttar Pradesh	5.65	13.07	12.95	11.76	2295	5.86	13.48	12.50	11.97	2133	86.7
Punjab	2.76	6.39	11.03	10.02	3998	2.98	6.84	11.82	11.32	3974	99.7
Odisha	3.88	8.98	8.38	7.61	2162	3.94	9.06	5.88	5.63	1491	33.3
Chhattisgarh	3.83	8.87	8.05	7.31	2101	3.82	8.77	5.79	5.54	1517	35.7
Bihar	3.29	7.63	7.48	6.79	2270	3.23	7.43	6.80	6.52	2104	65.0
Andhra Pradesh	2.11	4.87	7.45	6.76	3539	2.16	4.97	7.49	7.17	3465	97.1
Assam	2.45	5.67	5.23	4.75	2134	2.49	5.71	5.13	4.91	2062	11.0
Telangana	1.68	3.89	5.17	4.70	3075	1.05	2.40	3.05	2.92	2913	98.1
Haryana	1.39	3.21	4.45	4.04	3213	1.35	3.11	4.15	3.97	3061	99.9
Madhya Pradesh	2.29	5.30	4.23	3.84	1847	2.02	4.65	3.55	3.40	1752	34.2
Tamil Nadu	1.44	3.34	4.04	3.67	2796	2.00	4.60	7.52	7.20	3758	94.4
Jharkhand	1.59	3.68	3.56	3.23	2238	1.59	3.65	2.88	2.76	1814	5.0
Maharashtra	1.63	3.76	3.35	3.04	2059	1.50	3.46	2.59	2.48	1725	26.1
Karnataka	1.01	2.33	2.54	2.30	2522	1.11	2.55	3.02	2.89	2722	76.0
Gujarat	0.84	1.94	1.93	1.75	2306	0.77	1.77	1.70	1.63	2205	61.5
Uttarakhand	0.26	0.60	0.63	0.57	2418	0.26	0.61	0.64	0.61	2420	70.0
Others	1.97	4.55	4.59	4.17	@	1.84	4.23	3.96	3.79	@	-
All India	43.19	100.00	110.15	100.00	2550	43.50	100.00	104.41	100.00	2400	60.1

Figure 4.14: Water Productivity Mapping of Major Indian Crops by NABARD and ICRIER and Agricultural Statistics, Government of India.

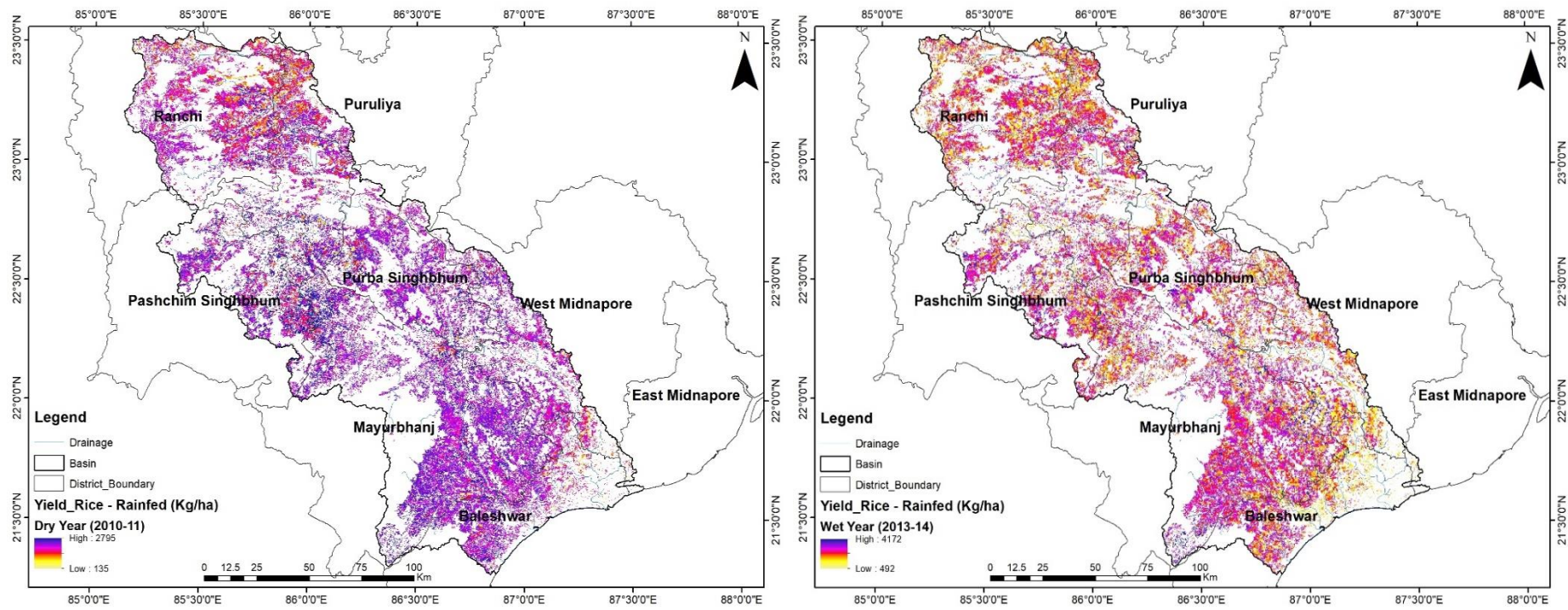


Figure 4.15a-b: Sheet3 (part II): Spatial variability of land productivity (rainfed Rice) for dry and wet years.

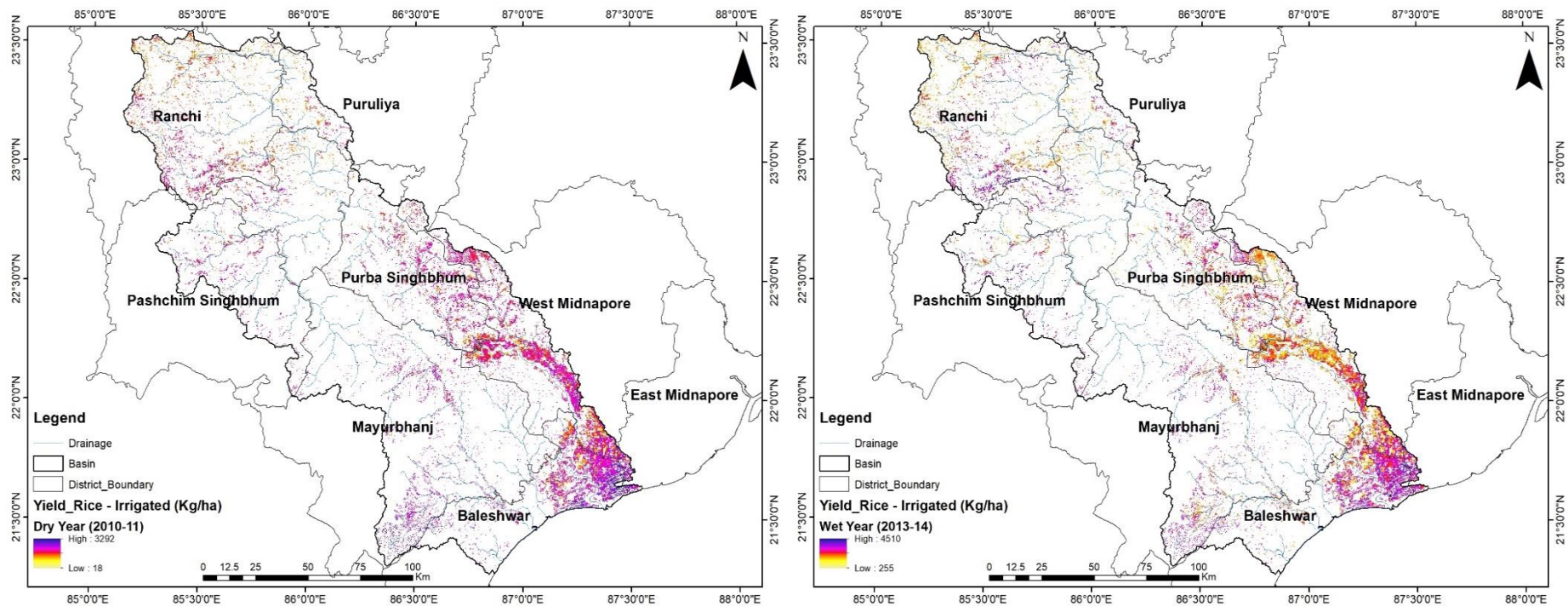


Figure 4.15c-d: Sheet3 (part II): Spatial variability of land productivity (irrigate Rice) for dry and wet years.

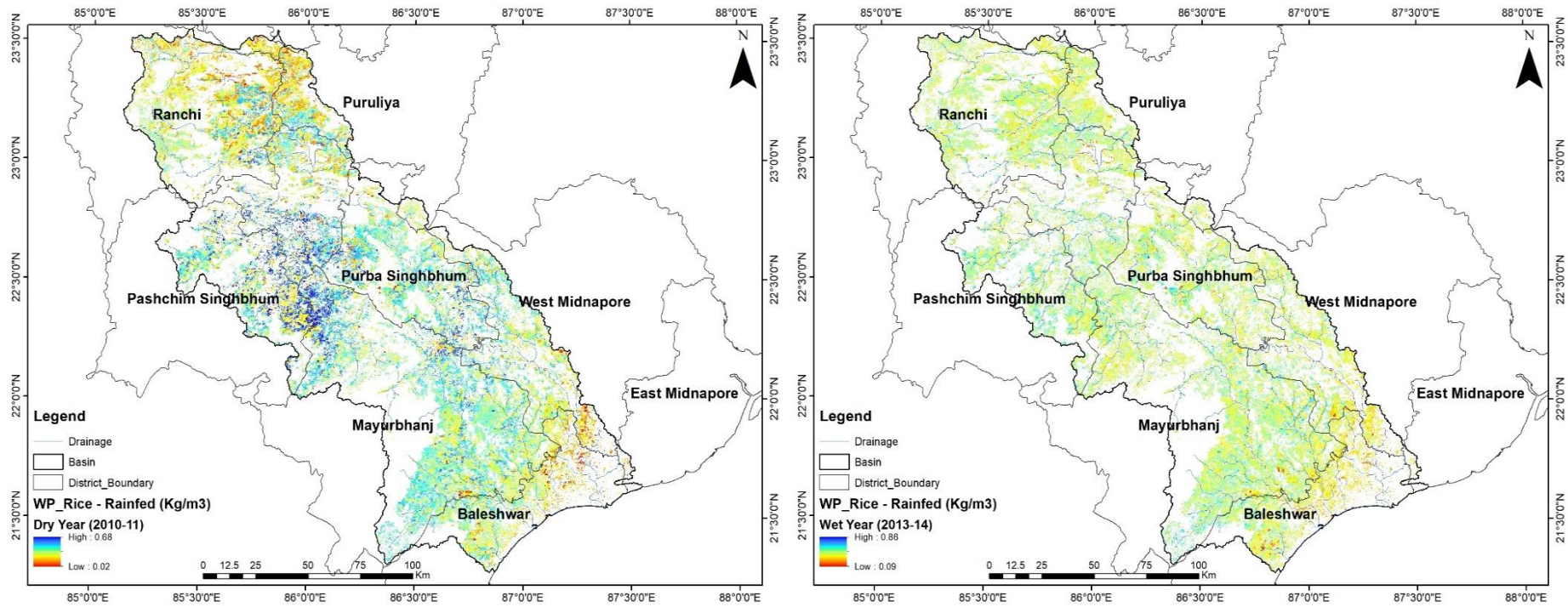


Figure 4.16a-b: Sheet3 (part II): Spatial variability of Water Productivity (rainfed Rice) for dry and wet years.

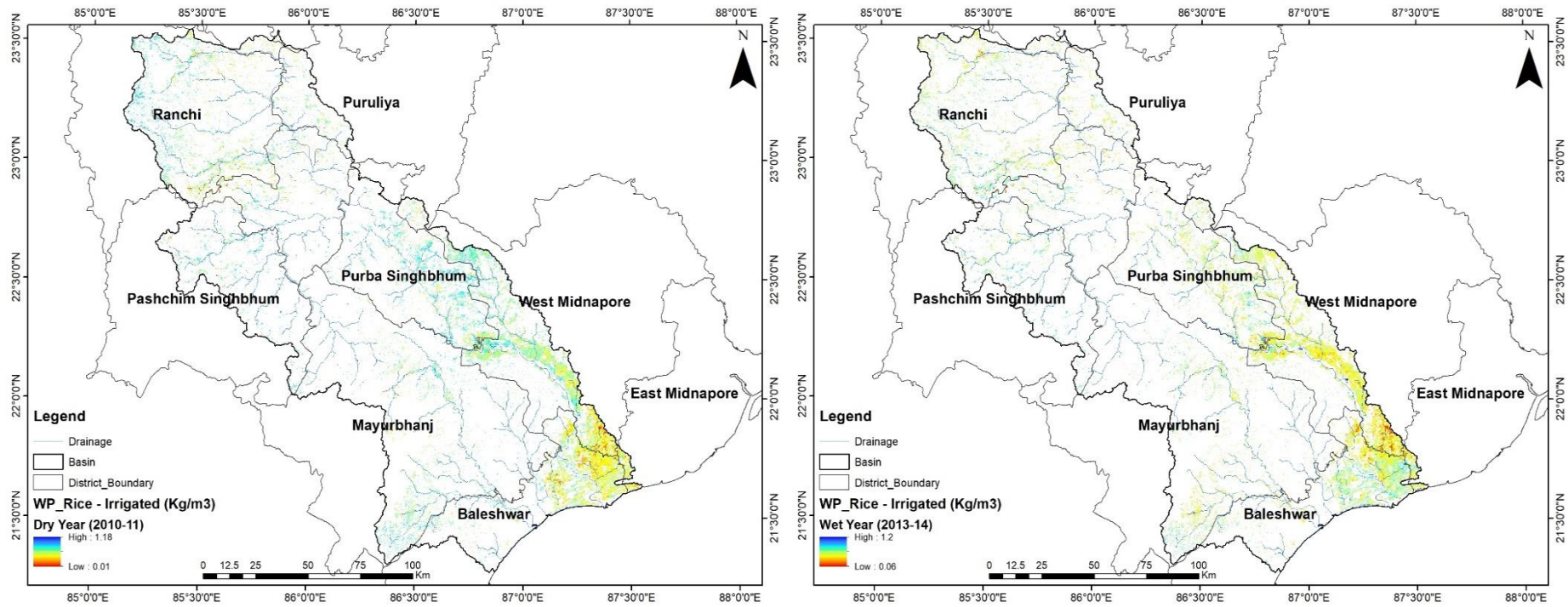


Figure 4.16c-d: Sheet3 (part II): Spatial variability of Water Productivity (irrigated Rice) for dry and wet years.

4.6 Development of Sheet 4 (UTILIZED FLOW)

Sheet 4 deals mainly with blue water consumption, relates it to the different sectors, and compares it with the demands of every sector. The main purpose of Sheet 4 is to provide an overview of all man-made withdrawals and to identify and quantify non-authorized use (Sheet 4 Part I). It also estimates natural withdrawals due to seasonal flows, shallow groundwater tables and groundwater dependent ecosystems such as wetlands and forests (Sheet-4 Part II). The sheet presents surface and groundwater contributions to the total withdrawal and it makes a distinction between consumed and non-consumed water, and recoverable and non-recoverable flows. The salient output characteristics of Sheet-4 are as follows.

- Reports water scarcity from water demands and water supply
- Introduces options to reduce sectoral water demands
- Provides an overview of all manmade withdrawals
- Prepares water allocation plans
- Estimates natural withdrawals (e.g. seasonal floods, shallow groundwater tables and groundwater dependent ecosystems)
- Estimates Surface water and groundwater withdrawals
- Distinguishes between consumed and non-consumed water
- Recognizes recoverable and non-recoverable flow

The output from the WATERPIX model is used in the development of Sheet 4 and Sheet 6. The main purpose of Sheet 4 is to provide an overview of all man-made withdrawals and to identify and quantify non-authorized use (Sheet 4 Part 1). It also estimates natural withdrawals (Sheet 4 Part II) due to seasonal flows, shallow groundwater tables and groundwater dependent ecosystems such as wetlands and forests. The sheet presents surface and groundwater contributions to the total withdrawal and it makes a distinction between consumed and non-consumed water, and recoverable and non-recoverable flows. The developed sheets for the Subarnarekha basin are given in Figure 4.17 a&b (manmade) and Figure 4.18 a&b (natural) withdrawals for dry year and wet year, respectively. Sheet 4 deals mainly with blue water consumption, relates it to the different sectors, and compares it with the demands of every sector.

Sheet 4: Utilized Flow
Part 1: Manmade (km³/year)

Basin: Subarn46_2
Period: Jun 2010-May 2011

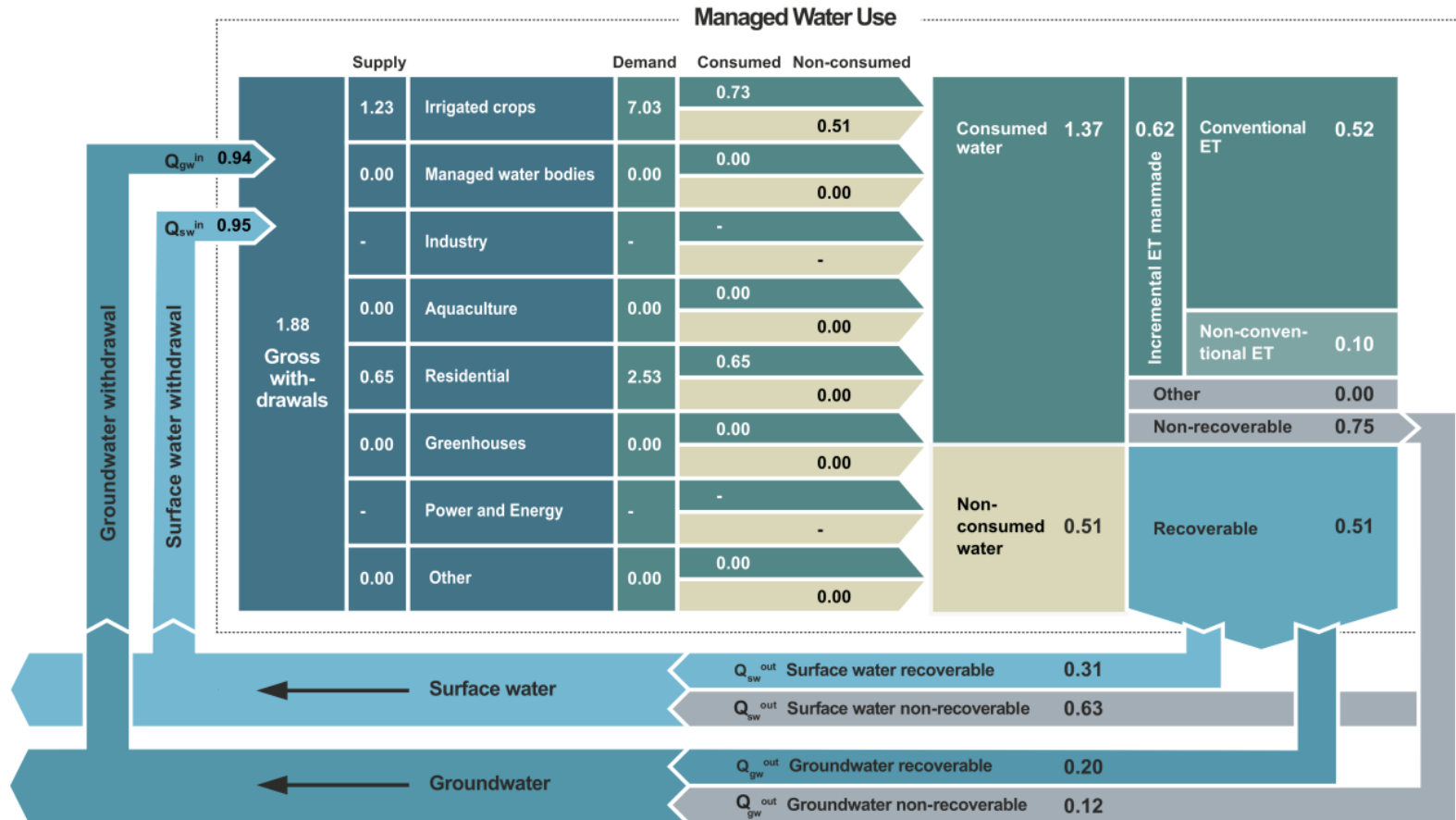


Figure 4.17 a: Utilized flow (manmade): Manmade withdrawals for Subarnarekha basin during dry year

Sheet 4: Utilized Flow
Part 1: Manmade (km³/year)

Basin: Subarn46_2
Period: Jun 2013-May 2014

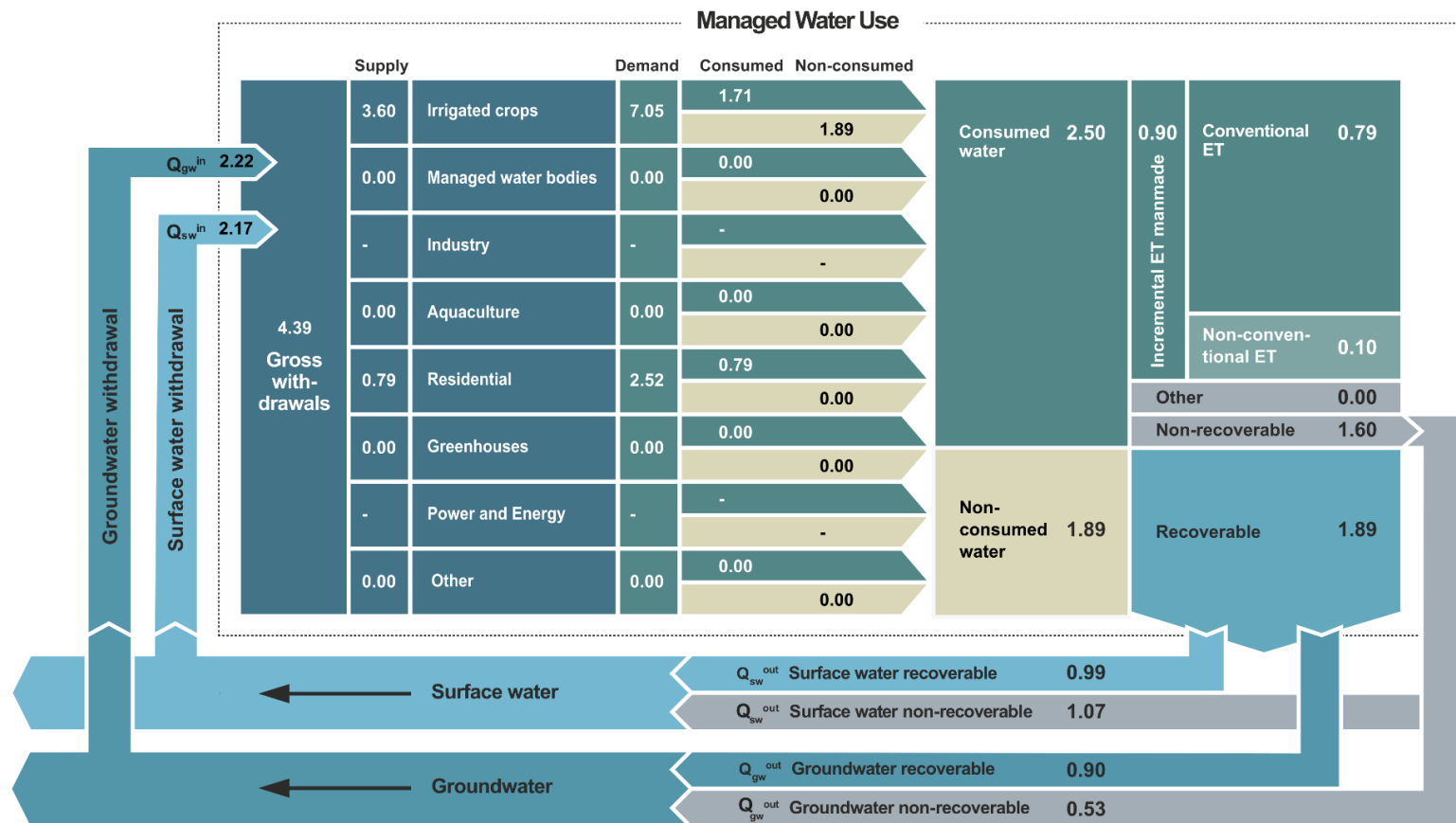


Figure 4.17 b: Utilized flow (manmade): Manmade withdrawals for Subarnarekha basin during wet year

Sheet 4: Utilized Flow

Part 2: Natural Landuse (km3/year)

Basin: Subarn46_2

Period: Jun 2010-May 2011

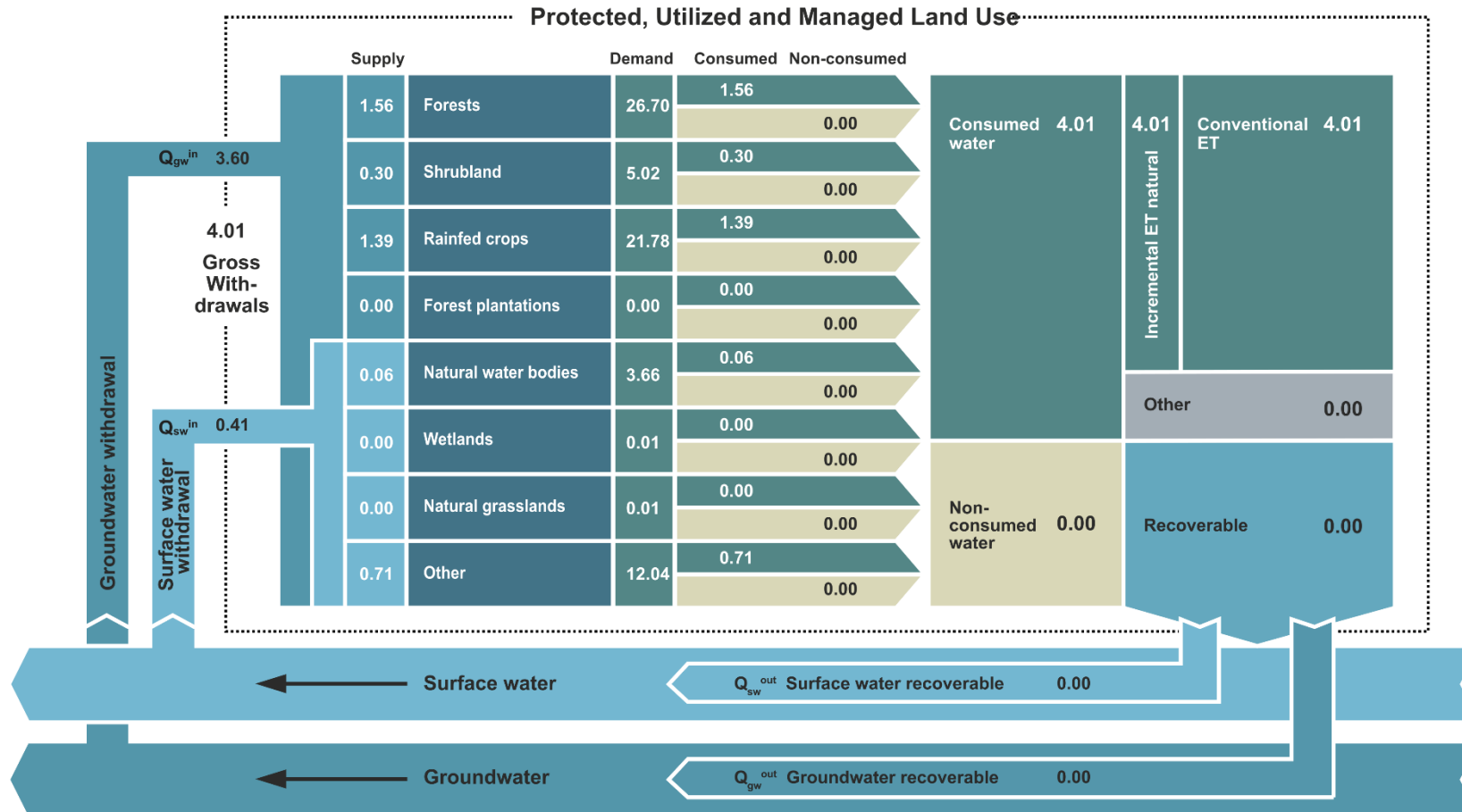


Figure 4.18a: Utilized flow (Natural): Natural withdrawals for Subarnarekha basin during dry year

Sheet 4: Utilized Flow

Part 2: Natural Landuse (km3/year)

Basin: Subarn46_2

Period: Jun 2013-May 2014

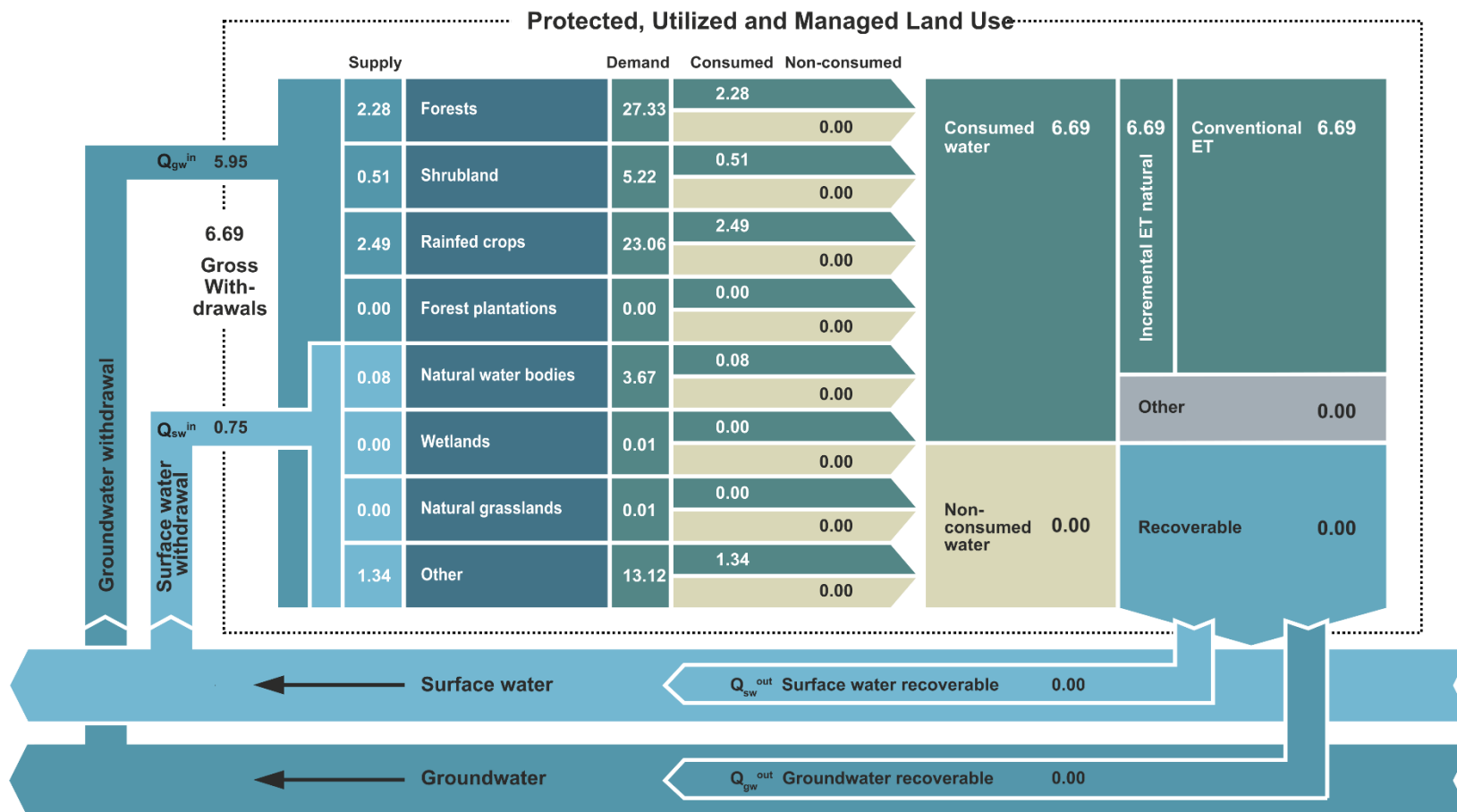


Figure 4.18b: Utilized flow (Natural): Natural withdrawals for Subernarekha basin during dry year

For the dry year, i.e., 2010-11, it can be seen that surface water withdrawals and groundwater withdrawals are approximately equal in manmade land use classes (Manage Water Use class). The total water withdrawals for manmade class are found to be 1.88 km³/year. The withdrawal for irrigated crops consists of maximum of total withdrawals, i.e., about 75%. In the natural landuse class, the gross water withdrawals are found to be 4.01 km³/year, in which the major portion is from groundwater withdrawals only, i.e., 3.60 km³/year. Which is true as approximately 25% of the basin area is under the forest land use land cover. The consumed and non-consumed water in the basin are found to be 1.37km³/year and 0.51 km³/year, respectively. Whereas, in case of natural land use, all the water withdrawals is taken as the consumed water, i.e., 4.01 km³/year.

Similarly, for the wet year, i.e., 2013-14 also, it can be seen that surface water withdrawals and groundwater withdrawals are approximately equal in manmade land use classes (Manage Water Use class). The total water withdrawals for manmade class are found to be 4.39 km³/year. The withdrawal for irrigated crops consists of maximum of total withdrawals, i.e., about 80%. In the natural landuse class, the gross water withdrawals are found to be 6.69 km³/year, in which the major portion is from groundwater withdrawals only, i.e., 5.95 km³/year. Which is true as approximately 25% of the basin area is under the forest land use land cover. The consumed and non-consumed water in the basin are found to be 2.50 km³/year and 1.89 km³/year, respectively, whereas, in case of natural land use, all the water withdrawals are taken as the consumed water, i.e., 6.69 km³/year.

4.7 Development of Sheet 6 (Groundwater)

It describes groundwater flow and storage within a river basin. This WA+ fact sheet includes: vertical recharge, capillary rise, vertical groundwater abstraction (withdrawals), return flows to groundwater from groundwater and from surface water withdrawals, groundwater storage change, groundwater discharge (base flow), and groundwater flow. These fluxes and storages are expressed as total volumes within the basin but also subdivided per land use type. Negative values indicated a decrease in storage. The purpose of Sheet 6 is to increase the understanding of the role of groundwater in renewable water resources, monitor and sustainably manage its use. The groundwater sheet is useful in:

- Assessing the role of groundwater in renewable water resources, in particular for dry season base flow
- Preparing safe groundwater withdrawal plans (i.e. prevent declining groundwater tables)
- Map groundwater withdrawals for irrigation
- Describe role of shallow groundwater tables to maintain wetlands, riparian corridors, oases and the like, i.e. water allocation to groundwater dependent ecosystems

The groundwater sheets for the dry year for Subarnarekha basin is shown in Figure 4.19a. It can be observed from Figure 4.19a (for dry year), the total vertical groundwater withdrawals from natural and manmade landuse are $3.70 \text{ km}^3/\text{year}$ and $0.90 \text{ km}^3/\text{year}$, respectively. From the natural landuse, $1.60 \text{ km}^3/\text{year}$ is by forest and $1.4 \text{ km}^3/\text{year}$ by the rainfed crops and $0.6 \text{ km}^3/\text{year}$ for the irrigated crops. On the other side, if we closely look at Figure 4.19a, then it shows that $13.10 \text{ km}^3/\text{year}$ is the total vertical recharge in the basin and out of which the rainfed crops and forest contribute to the tune of $4.90 \text{ km}^3/\text{year}$ and $3.10 \text{ km}^3/\text{year}$, respectively. The irrigated crops also contribute to the groundwater recharge to the tune of $1.2 \text{ km}^3/\text{year}$. The return flow from the groundwater and surface water in the basin is found to be $0.1 \text{ km}^3/\text{year}$ and $0.2 \text{ km}^3/\text{year}$, respectively. Notably, a major portion of the groundwater is contributed to the base flow, i.e., $10.7 \text{ km}^3/\text{year}$. And overall, there is a decrease in the groundwater storage and in this case it is $1.9 \text{ km}^3/\text{year}$. Figure 4.19b also shows the annual groundwater balance of the Subarnarekha river basin.

Sheet 6: Groundwater (km³/year)

Basin: Subarn46_2

Period: Jun 2010-May 2011

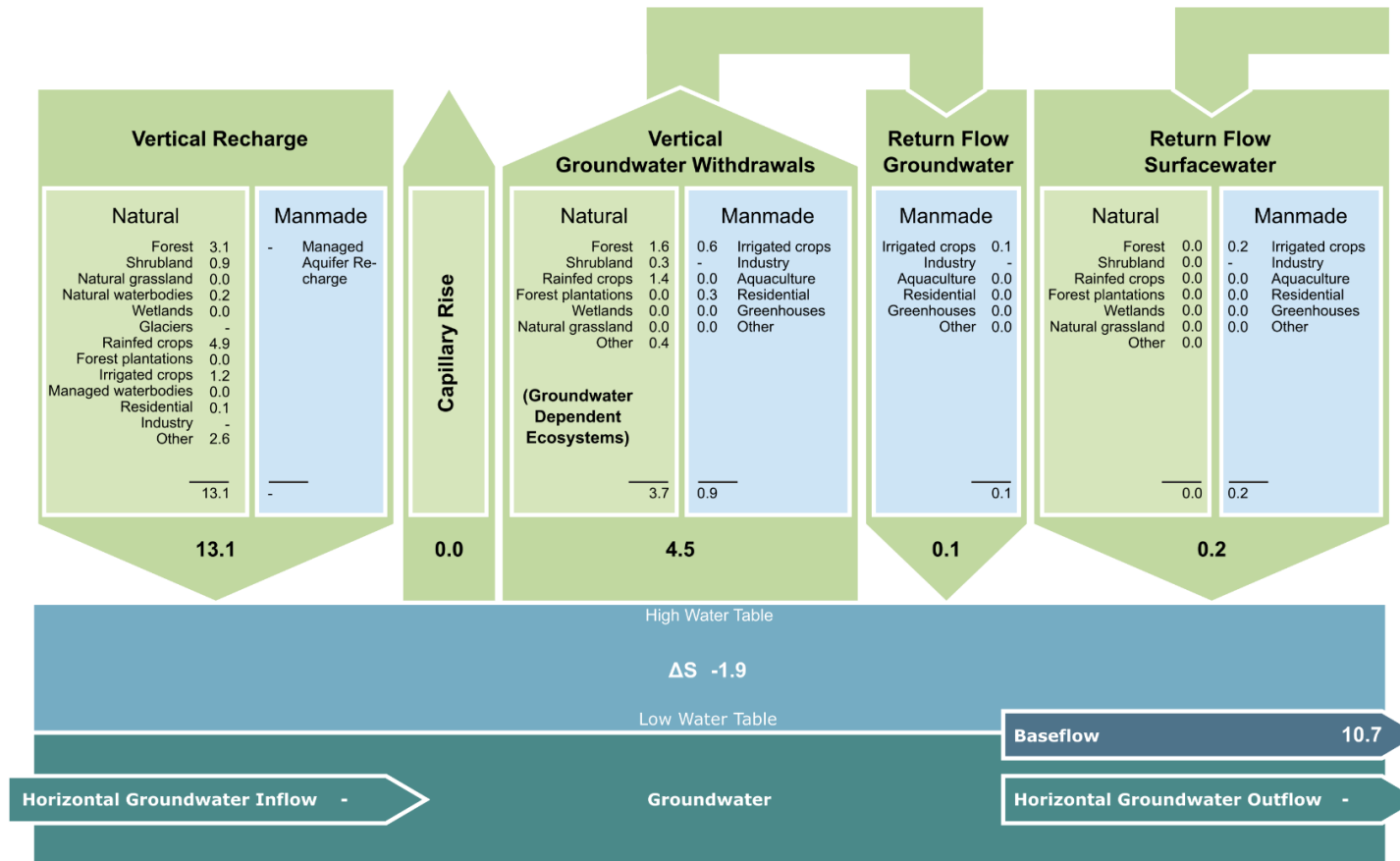


Figure 4.19a: Groundwater sheet for the Subarnarekha basin during the deficit year (2010-2011).

Annual Ground Water Balance

(2010-11)

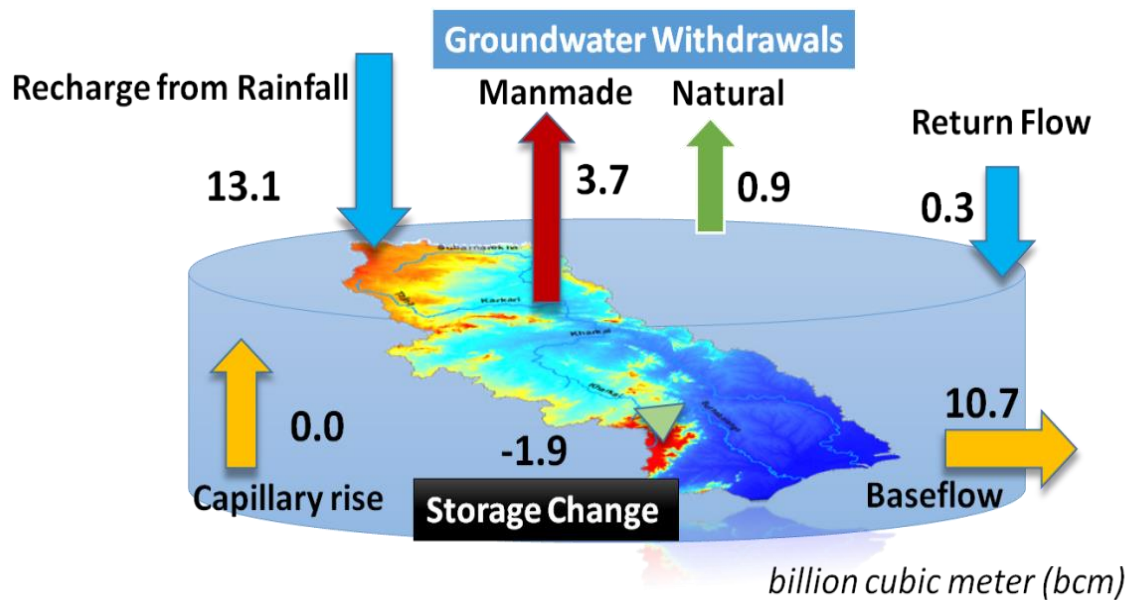


Figure 4.19b: Annual groundwater balance for the Subernarekha basin during dry year (2010-2011).

Similarly, for wet year, i.e., 2013-14, it can be observed from Figure 4.20a, the total vertical groundwater withdrawals from natural and manmade landuse are $6.0 \text{ km}^3/\text{year}$ and $2.2 \text{ km}^3/\text{year}$, respectively. From the natural landuse, $2.3 \text{ km}^3/\text{year}$ is by forest and $2.5 \text{ km}^3/\text{year}$ by the rainfed crops and $1.8 \text{ km}^3/\text{year}$ for the irrigated crops in manmade landuse. On the other side, if we closely look at Figure 4.20a, then it shows that $30.20 \text{ km}^3/\text{year}$ is the total vertical recharge in the basin and out of which the rainfed crops and forest contribute to the tune of $7.4 \text{ km}^3/\text{year}$ and $11.0 \text{ km}^3/\text{year}$, respectively. The irrigated crops also contribute to the groundwater recharge to the tune of $3.0 \text{ km}^3/\text{year}$. The return flow from the groundwater and surface water in the basin is found to be $0.7 \text{ km}^3/\text{year}$ and $0.7 \text{ km}^3/\text{year}$, respectively. Notably, a major portion of the groundwater is contributed to the base flow, i.e., $22.9 \text{ km}^3/\text{year}$. Overall, there is an increase in the groundwater storage and in this case it is $0.4 \text{ km}^3/\text{year}$. Figure 4.20b also shows the annual groundwater balance of the Subarnarekha river basin.

Annual Ground Water Balance

(2013-14)

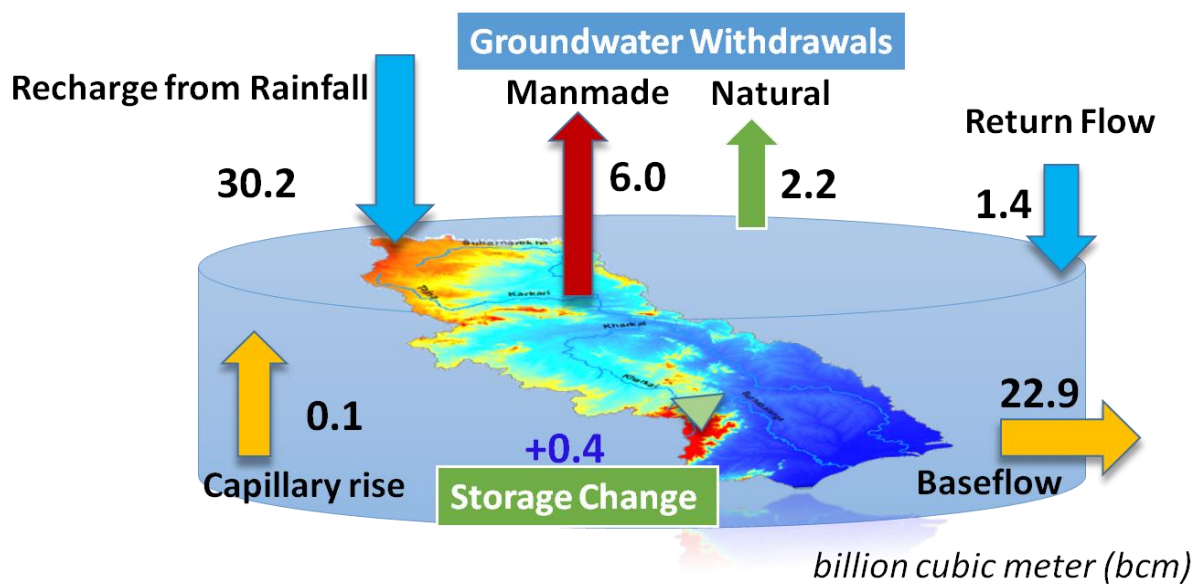


Figure 4.20b: Annual groundwater balance for the Subernarekha basin during wet year (2013-2014).

4.8 Development of Sheet 5 (SURFACE WATER)

Sheet 5 quantifies the surface water availability (natural) at the point of the interest, i.e., at the sub-basin or basin scale or any intermediate point as per the four water management classes, i.e., PLU, ULU, MLU and MWU. The sheet also details about the total surface water withdrawals (both from manmade and natural) along with the return flows. This sheet also details about the how much water is utilizable, non-utilizable, committed and non-committed flow at the sub-basin and basin scale.

The Subernarekha basin was divided into seven sub-catchments (six sub-basins and 1 delta) for developing the Sheet 5, i.e., surface water potential of the sub-basins and basin as a whole. For this purpose, very first the sub-basin masks were prepared as per the sub-basins given in India-WRIS system (Figure 4.21a). The sub-basin masks developed are shown in Figure in 4.21b. Once the datasets were ready, the WA+ Framework (which consists of a “WA_HYPERLOOP”) was executed to get the results. The Sheets were developed for different years (here for dry and wet years) are shown as Figure 4.22a and Figure 4.22b, respectively for dry and wet years. It can be observed from Figure 4.22a and Figure 4.22b that the overall basin outflow to the sea is 13.5 BCM and 28.9 BCM, respectively during the dry and wet years. However, if we critically examine these Sheets, then we can find here that (also as discussed above), these Sheets categorize the outflow in terms of (i) Committed outflow, (ii) Non-recoverable outflow, (iii) Non-utilizable flow, and (iv) Utilizable flow.

Based on this classification of the outflow, we can see that 13.0 BCM is the Utilizable flow out of 28.9 BCM for wet year, and similarly, for dry year the Utilizable flow is found to be 4.1 BCM only out of 13.5 BCM. The storage change of most of the sub-basins during the deficit year is either zero negative meaning that more water was taken from storage in the dry months than water stored during the monsoon months. If this situation persists also during average years, it might lead to unsustainable water use. Monthly Sheets of surface water availability were also developed for all the years. As an example, we are also showing here the monthly sheets of surface water availability for the month of March 2011 and March 2014 in Figure 4.23a and Figure 4.23b, respectively for Subernarekha basin.

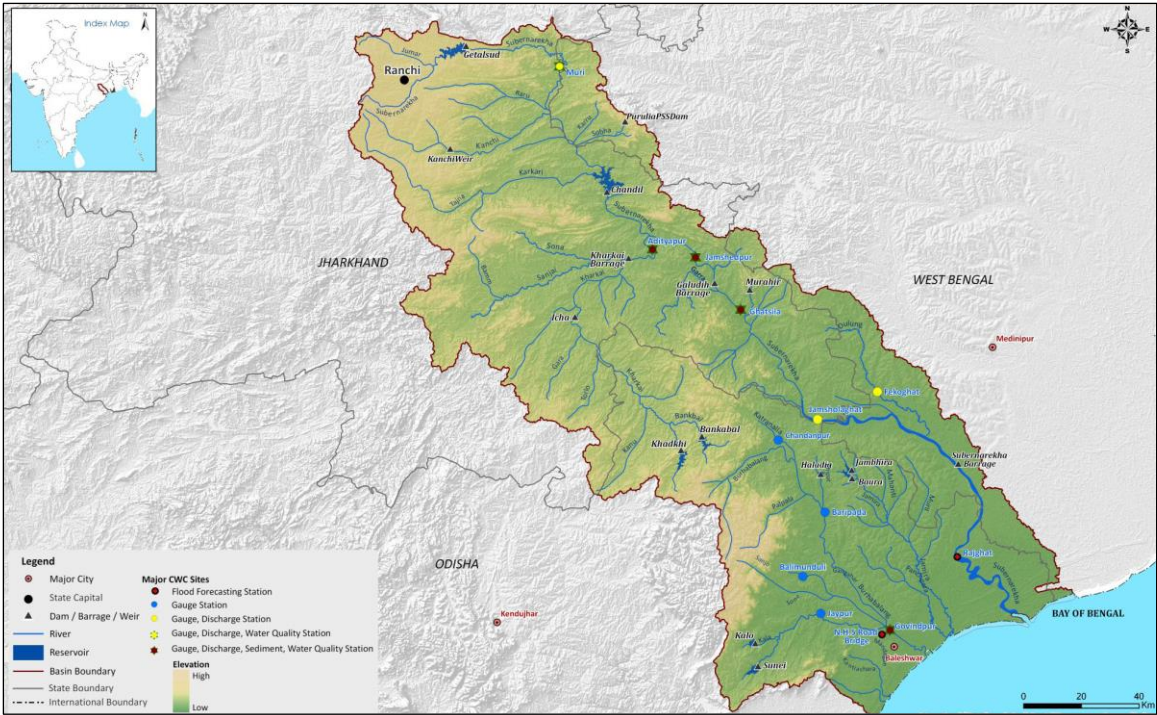


Figure 4.21a: Subernarekha Basin- Drainage & Sub-basin (www.india-wris.nrsc.gov.in)

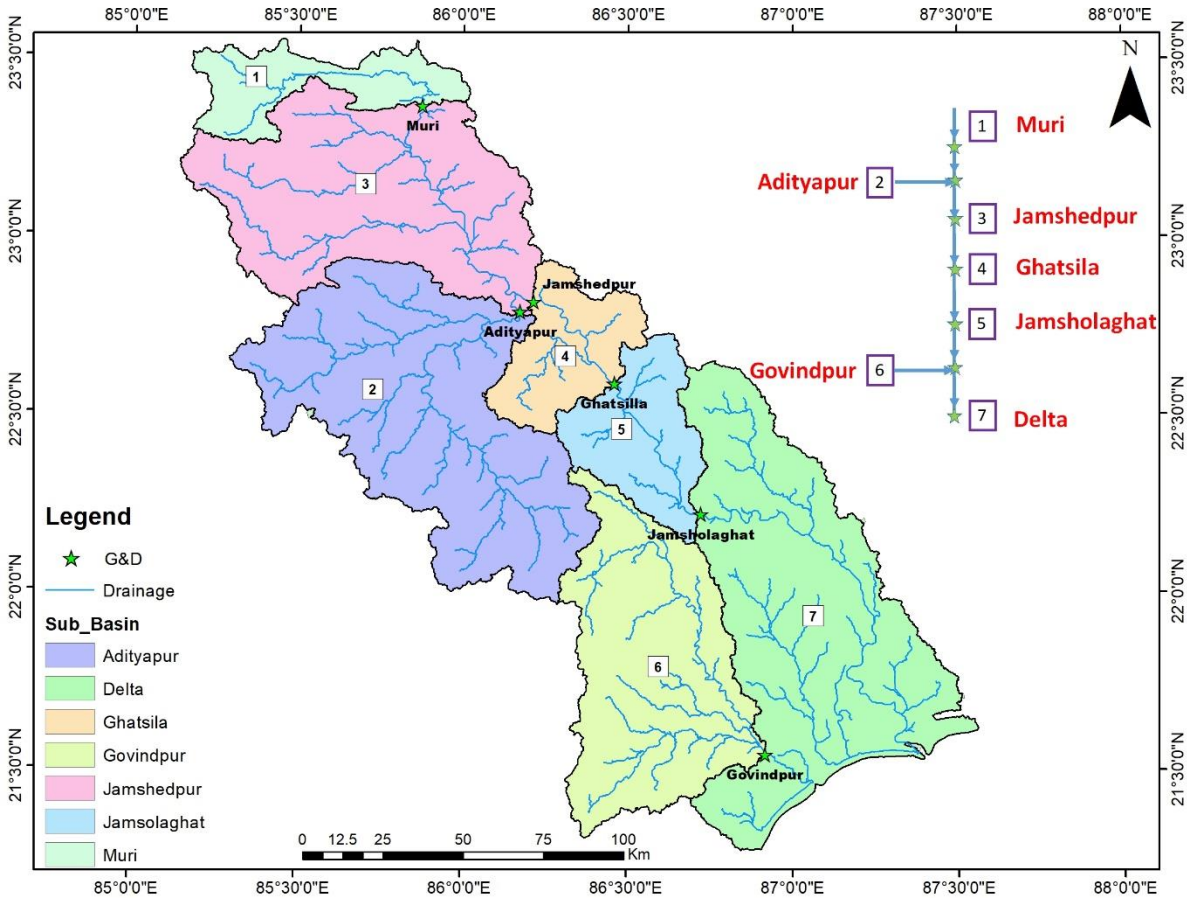


Figure 4.21b: Division of Subernarekha basin into seven sub-catchments.

Sheet 5b: Surface Water[km3/year]

Basin: Subarnarekha_19012021

Period: Jun 2010-May 2011

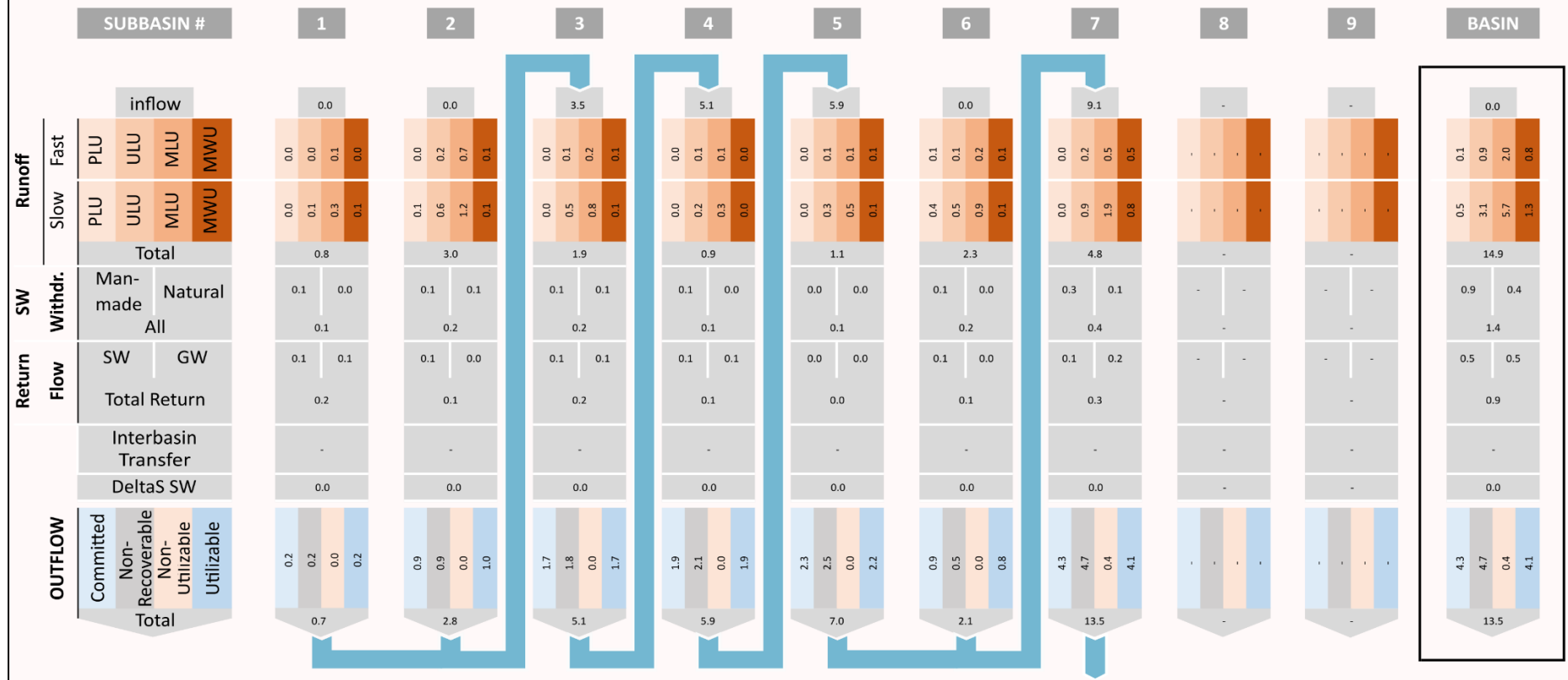


Figure 4.22a: Sheet: 5: Surface Water computations at the sub-basin and basin scale using WA+ Framework during the deficit year (2010-2011).

Sheet 5b: Surface Water[km3/year]

Basin: Subarnarekha_19012021

Period: Jun 2013-May 2014

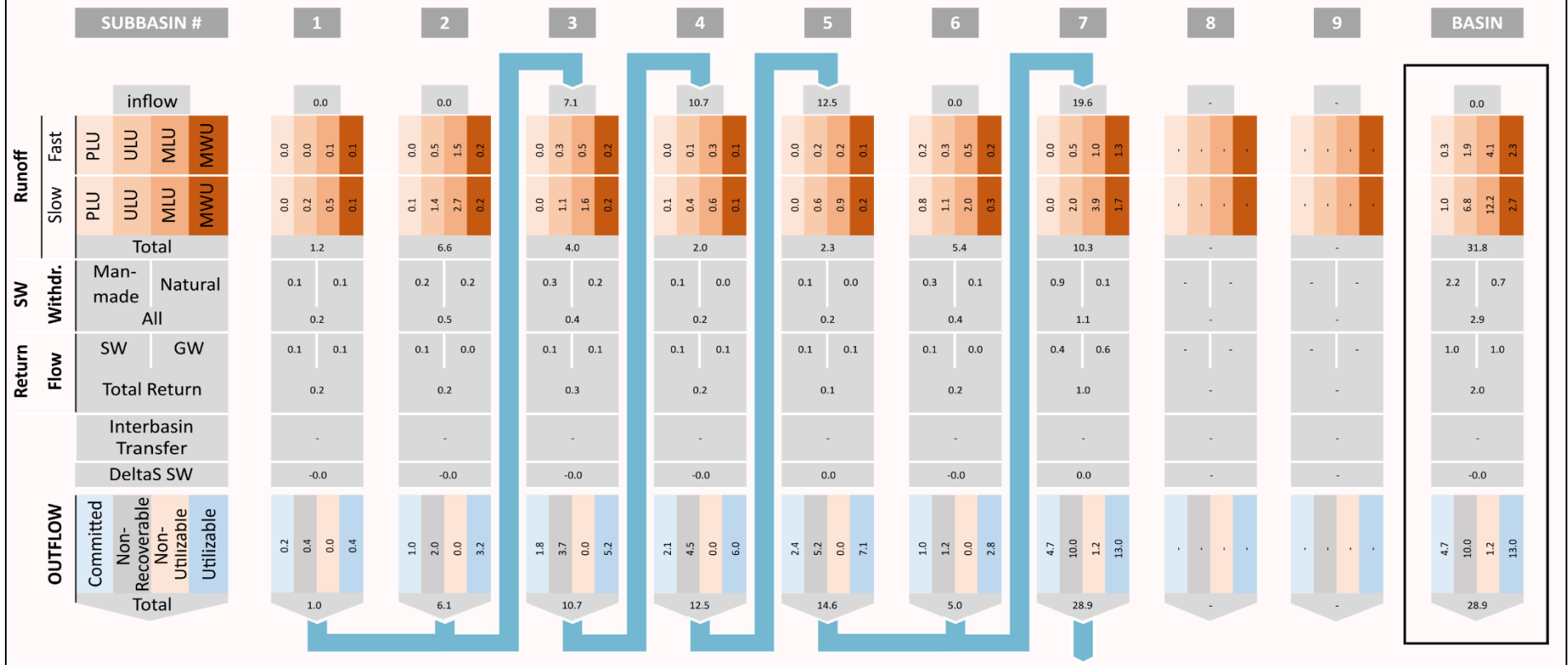


Figure 4.22b: Sheet: 5: Surface Water computations at the sub-basin and basin scale using WA+ Framework during the wet year (2013-2014).

Sheet 5b: Surface Water (0.01 km3)

Basin: Subarnarekha 19012021

Period: 201103

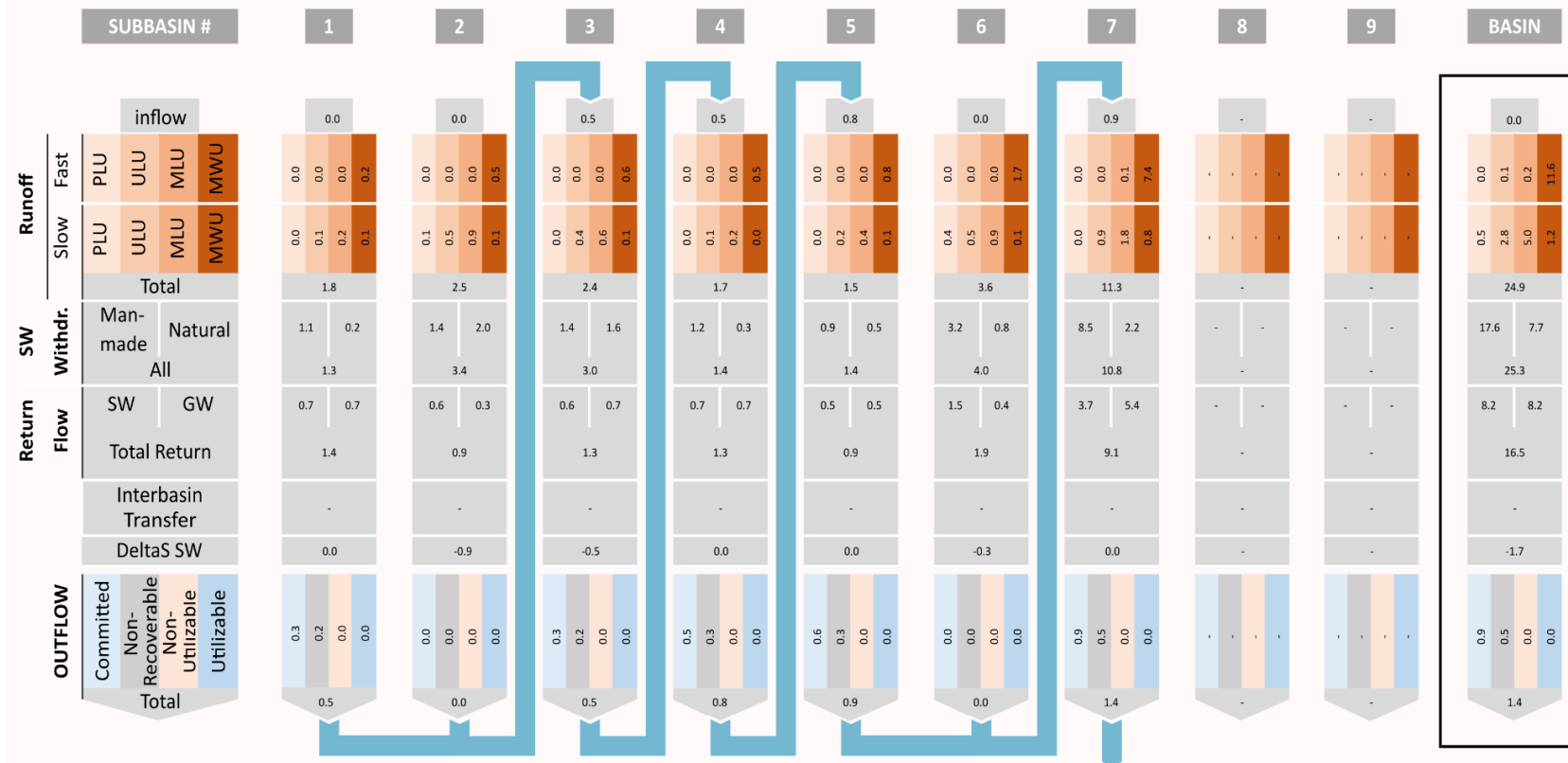


Figure 4.23a: Sheet 5: Monthly Surface Water computations at the sub-basin and basin scale using WA+ Framework during March 2011.

Sheet 5b: Surface Water (0.01 km3)

Basin: Subarnarekha 19012021

Period: 201403

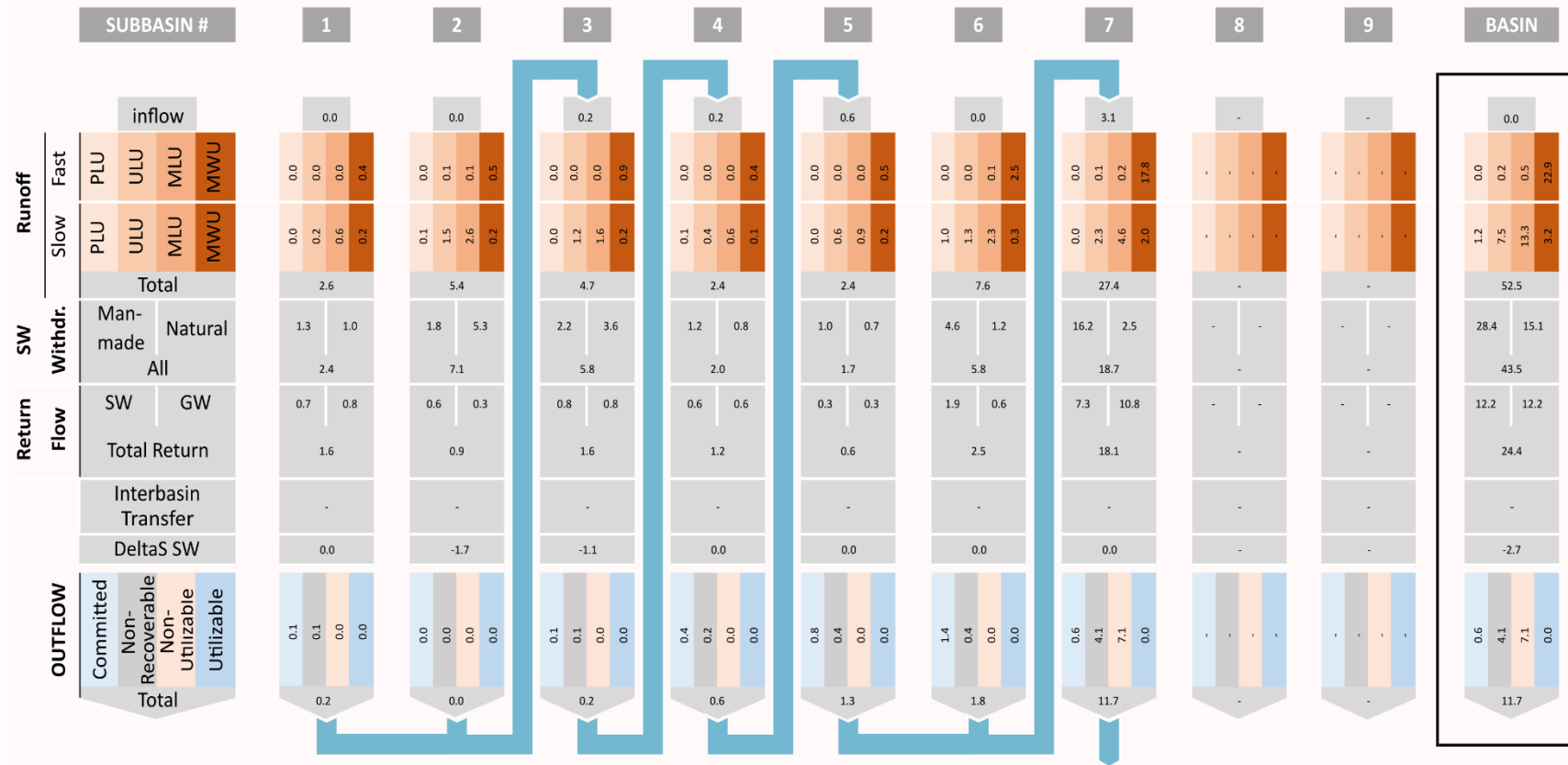


Figure 4.23b: Sheet:5: Monthly Surface Water computations at the sub-basin and basin scale using WA+ Framework during March 2014.

4.9 Development of Sheet 1 (RESOURCE BASE SHEET)

Sheet 1 presents an overall overview of the over-exploitation, unmanageable, manageable, exploitable, reserved, utilized and utilizable flows at river basin scale. Figure 4.24a and Figure 4.24b present the overview of the Resource Base sheets (at annual scale) for the years 2010-11 and 2013-14, respectively for dry and wet years. The gross inflow to the basin is the external inflow and withdrawals from or recharge to the system. In these Figures, ΔS represents the overall change in storage, i.e., water bodies + groundwater + soil moisture. A negative value of ΔS represents that the water is filling the reservoirs or recharging to the groundwater system, whereas, a positive value of ΔS means that water is taken from artificial storages or from the groundwater system. Therefore, the Net Inflow to the system depends on the negative and positive value of ΔS .

These Sheets show that the most of the water utilized within the basin is coming from rainfall and only a small portion from storage (surface/groundwater) (Figure 4.24a and Figure 4.24b). This proportion however changes during the deficit and wet years. External outflows (fluxes) are composed of evapotranspiration (61.17% of the net inflow during the dry year and 46.56% during the wet year). During the dry and wet year, the utilizable flow is 4.4 km³/year and 13.3 km³/yr, which could be utilized or stored to prevent water shortages during particularly dry years. However, the scenario could be entirely different, if we analyze on the monthly/seasonal scale.

Figure 4.24a and Figure 4.24b also show the landscape ET (ETgreen: green water consumptions) and utilized flow (ETblue: blue water consumptions) in the Subernarekha basin. During the wet year, the ETgreen accounts for 52.95% of the total ET (ETgreen + ETblue) and ETblue is 47.60% of the total ET. However, this proportion changes during the dry year where less rainfall occurs. ETgreen consumption increases to 65.92% and ETblue is 33.33% of the total ET. Land use types are grouped into four management categories: Protected Land Use (e.g. protected forest), Utilized Land Use (e.g. grassland), Modified Land Use (e.g. rainfed areas), and Managed Water Use (e.g. irrigated areas, urban/industrial).

On monthly scale, Figure 4.25a and Figure 4.25b show the resource base sheet for the months of June 2010 and June 2013. It can be inferred from these Figures that the ΔS (overall change in storage, i.e., water bodies + groundwater + soil moisture) is negative, which indicates that the water is being fed into the system, either from water storage structures or groundwater reservoirs.

Sheet 1: Resource Base (km³/year)

Basin: Subarnarekha_19012021
 Period: Jun 2010-May 2011

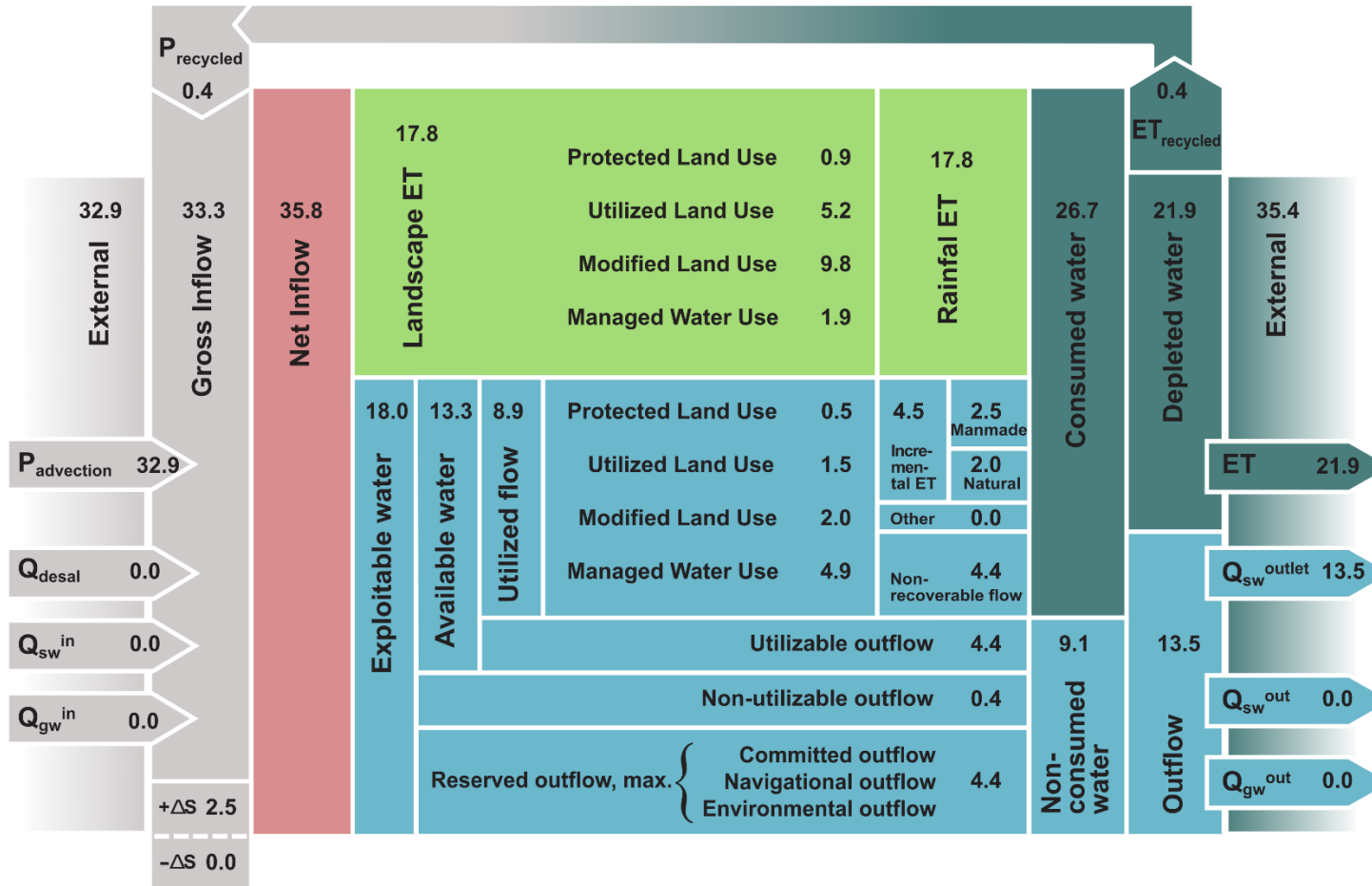


Figure 4.24a: Sheet 1 (Resource Base) of the Subarnarekha basin during the dry year (2010-2011).

Sheet 1: Resource Base (0.1 km³/month)

Basin: Subarnarekha_19012021
 Period: 2010-06

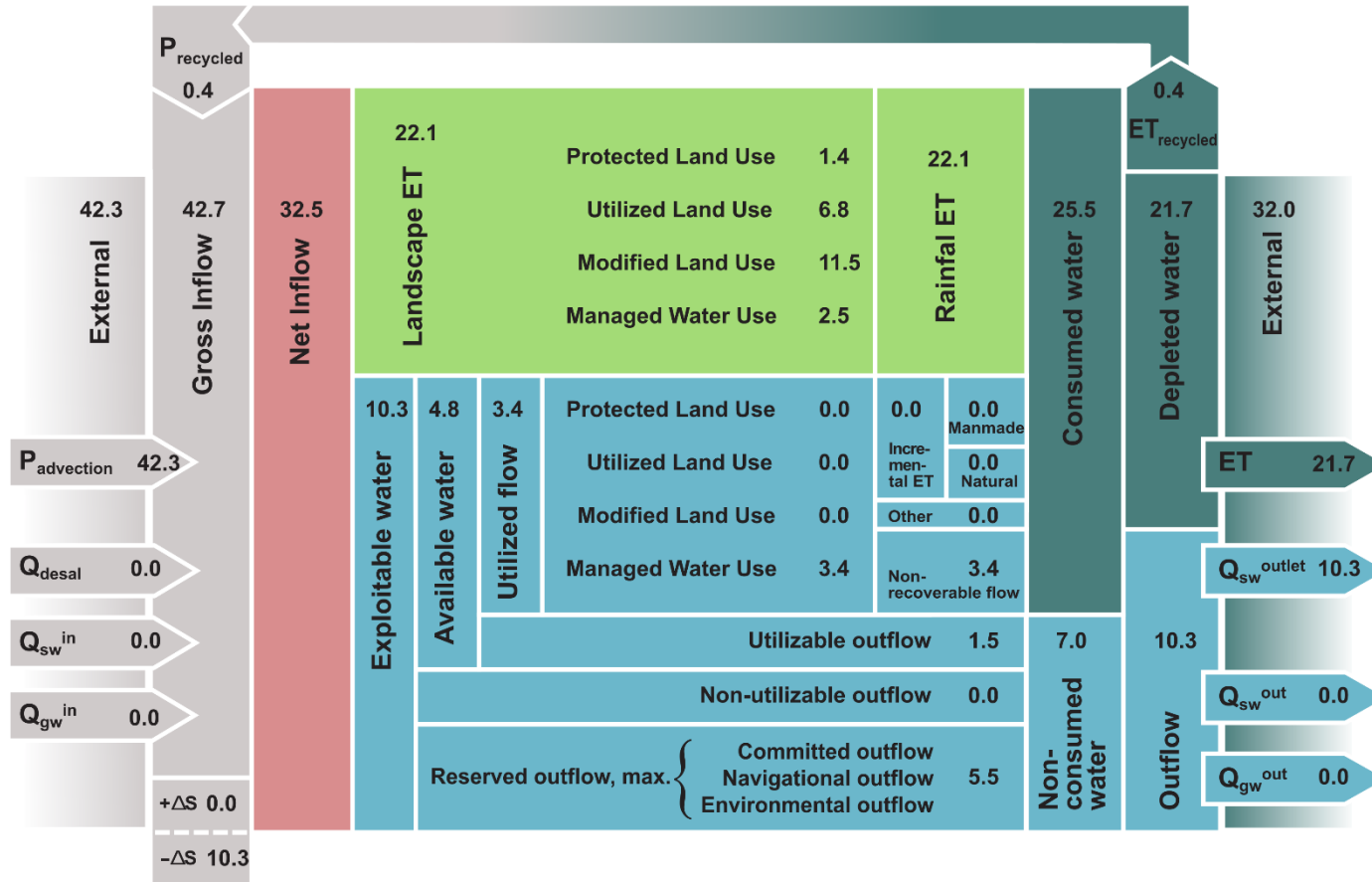


Figure 4.25a: Sheet 1 (Resource Base) of the Subarnarekha basin for June 2010.

Sheet 1: Resource Base (0.1 km³/month)

Basin: Subarnarekha_19012021
 Period: 2013-06

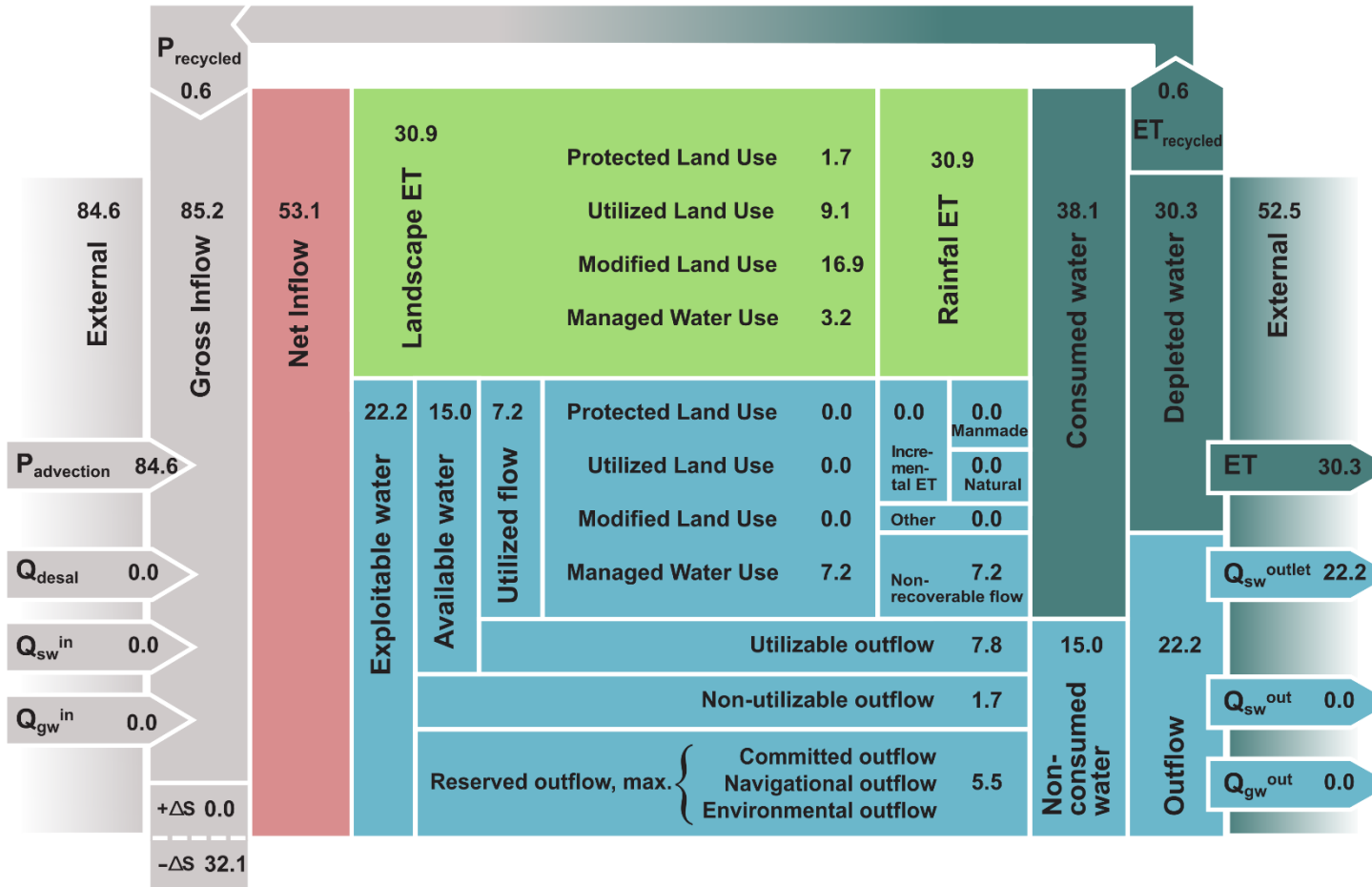


Figure 4.25b: Sheet 1 (Resource Base) of the Subarnarekha basin for June 2013.

5.0 Conclusions

In the present study newly developed WA+ Framework was applied to the Subarnarekha basin to develop water accounts. This study basin is covered in three states viz. Oddisha, Jharkhand and West Bengal. The following conclusions are drawn from this study.

The total water consumptions in the basin for the period of 2003-2014 are found to be 16.199, 80.194, 132.667 and 17.869 BCM, respectively for four major landuse classes (WMCs), i.e., PLU, ULU, MLU and MWU. For the wet and dry year, the total water consumptions are found to be 27.1 BCM/year and 23.1 BCM/year, respectively. For wet year, the non-beneficial consumptions in the basin are 14.1 BCM/year much greater than the beneficial consumptions, i.e., 12.9 BCM/year. Similarly, for dry year, the non-beneficial and beneficial consumptions are found to be 13.9 BCM/year and 9.2 BCM/year, respectively.

The land productivity is found to vary from 1575 to 2141 kg/ha/year and 1315 to 2325 kg/ha/year for rainfed and irrigated cereals with an average of 1920.67 and 1948.06 kg/ha/year, respectively during the period of 2003-2014.

The water productivity is found to vary from 0.34 to 0.49 kg/m³ and 0.38 to 0.69 kg/m³ for rainfed and irrigated cereals with an average of 0.42 kg/m³ and 0.59 kg/m³, respectively during the period of 2003-2014. A follow up analysis to identify the factors behind large differences in WP will guide the government in taking steps to improve WP in areas where it is low. Awareness programs for farmers can be organized in the districts where water and land productivity is low. The WP data can be merged with crop price to estimate the income of farmers. Such information will be helpful in preparing poverty alleviation programs and in improving village livelihoods. The spatial variability of the WP reflects that the WP for irrigated cereals is higher in parts of the West Bengal than the Jharkhand and Odisha, whereas, for rainfed cereals, the WP is higher in the state of Jharkhand and Odisha than the West Bengal. Therefore, to achieve the higher WPs in these regions, efforts may be made to reduce non-beneficial consumption through mulching, reduced tillage and improved irrigation methods such as drip irrigation, sprinkling irrigation, alternate furrow-irrigation.

Surface water withdrawals and groundwater withdrawals for dry year are approximately equal in manmade land use classes (Manage Water Use class). The total water withdrawals for manmade class are found to be 1.88 km³/year. The withdrawal for irrigated crops consists of maximum of total withdrawals, i.e., about 75%. While for wet year, the surface water withdrawals and groundwater withdrawals are approximately equal in manmade land use classes (Manage Water Use class). The total water withdrawals for manmade class are found

to be 4.39 km³/year. The withdrawal for irrigated crops consists of maximum of total withdrawals, i.e., about 80%.

In case of dry years, for natural landuse class, the gross water withdrawals are found to be 4.01 km³/year, in which the major portion is from groundwater withdrawals only, i.e., 3.60 km³/year. It is because of approximately 25% of the basin area is under the forest land use land cover. In case of natural land use, all the water withdrawals are taken as the consumed water, i.e., 4.01 km³/year. While for wet year, the gross water withdrawals are found to be 6.69 km³/year, in which the major portion is from groundwater withdrawals only, i.e., 5.95 km³/year. In case of natural land use, all the water withdrawals are taken as the consumed water, i.e., 6.69 km³/year.

For wet year, the total vertical groundwater withdrawals from natural and manmade landuse are 6.0 km³/year and 2.2 km³/year, respectively. For dry year, the total vertical groundwater withdrawals from natural and manmade landuse are 3.70 km³/year and 0.90 km³/year, respectively. Overall outflow from the basin is 13.5 BCM and 28.9 BCM, respectively during the dry and wet years. It is found that the 13.0 BCM is the utilizable flow out of 28.9 BCM for wet year, and for dry year, the utilizable flow is 4.1 BCM only of 13.5 BCM.

The storage changes of most of the sub-basins during the deficit year is either zero negative meaning that more water was taken from storage in the dry months than water stored during the monsoon months.

During the wet year, the ET_{green} accounts for 52.95% of the total ET (ET_{green} + ET_{blue}) and ET_{blue} is 47.60% of the total ET. However, this proportion changes during the dry year when less rainfall occurs. The ET_{green} consumption increases to 65.92% and ET_{blue} is 33.33% of the total ET.

External outflows (fluxes) are composed of evapotranspiration (61.17% of the net inflow during the dry year and 46.56% during the wet year). During the dry and wet year, the utilizable flow is 4.4 km³/year and 13.3 km³/yr, which could be utilized or stored to prevent water shortages during particularly dry years.

Sheet 2 indicates that there is a large scope to adopt water conservation practices in the basin to minimize non-beneficial consumptions such as soil evaporation and increase the beneficial consumption along with improved water application practices.

Overall, the results show that WA+ Framework may assist in achieving “More Crop Per Drop”, which is the ultimate aim of the Pradhan Mantri Krishi Sinchai Yojana (PMKSY).

6. 0 Future Scope of Research

1. As the WA+ Framework is based on the satellite data and hence better resolution of the satellite data, improved will be the estimates of the water consumptions, land and water productivity and green and blue waters and overall water resources estimations in the basin. The WALU classification is in the primitive stage and hence its customization for the country/basin basis will further improve the findings.
2. The WA+ Framework specifically does not consider the storages in the reservoirs and does not have any routing mechanism inbuilt and hence the introduction of the reservoir operation concept and routing concept will essentially improve the estimation efficacy of the WA+ Framework.
3. Finally, the coupling of the climate projections with the WA+ Framework may help projecting the consumption patterns and changes in land and water productivity.

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PUBLICATIONS:

Research Paper:	01 (Journal of Physics and Chemistry of Earth)
International conference:	01 (IGWC-2019)
5-Day On-line Training Course:	01
Work presented at:	NHP Modelers' Meet (2019-20)
On-Line Lectures:	03



ANNEXURE-I

WA+ Based Land class system				
Water Management Classes (WMC)			Water use - Land Use - Land Cover	Description
PLU				
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, mangroves 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)
ULU				
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	Permafrosts	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 temporary 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 swamps (wet all year round)
31	ULU24	Utilized land use	Mangroves	Mangroves
32	ULU25	Utilized land use	Alien invasive species	Alien invasive species
MLU				
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 - legumious	Rainfed legumious 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 a 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
MWU				
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 - legumious	Irrigated legumious 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, harbors, 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 a 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 exploitation	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.

WATER ACCOUNTING PLUS (WA+)

List of Indicators and Definitions

(Source: IHE Delft, The Netherlands and Perry, 2011*)

1.0 INFLOWS

1.1 Precipitation

It is the total amount of rainfall over the various land use types.

1.2 Advective (external) Precipitation

It is the total precipitation without atmospheric or recycled precipitation. This precipitation originates outside the basin eg. evaporated water from oceans that forms precipitation inside the basin.

1.3 Atmospheric (or Recycled) Precipitation

It is the portion of evaporated water that contributes to precipitation within the basin. This precipitation is produced by evaporated water within the basin boundary and forms precipitation within the basin.

1.4 Surface water inflow

It is the total inflow into the system including that from the main riverstem, tributaries, flood and utilized surfaces.

1.5 Groundwater inflow

It is the inter-basin groundwater inflow and utilized groundwater inflow

1.6 Desalinized inflow

It is the total amount of water that is desalinized in a basin.

1.7 Total Extra Inflow

It is the combination of the inflow from the groundwater, surface water and other sources into the basin.

1.8 Across boarder Inflows

It is the inflows from the groundwater, surface water, other sources and external (advective) precipitation.

1.9 Gross Inflows

It is the total inflow from surface water, groundwater, other inflow and precipitation.

1.10 Net Inflows

It is the gross inflow and the storage change.

2.0 OUTFLOWS

2.1 Surface water Outflow

It is the total outflow from the surface sources including the main riverstem, tributaries, flood and other utilized surface water outflow.

2.2 Groundwater Outflow

It is also called as the inter-basin groundwater outflow. It represents the total outflow from the groundwater sources including the main channel and other utilized groundwater outflow

2.3 ET Outflow

It is the difference between the actual ET and recycled ET

2.4 Net Outflow

It is the outflow from Evaporation, other sources, groundwater and surface water sources.

3.0 EVAPOTRANSPIRATION

3.1 Evapotranspiration (ET)

It is the energy process that converts water from liquid to gaseous phase. Evapotranspiration occurs as interception evaporation, soil evaporation, water evaporation, canopy transpiration. ET occurs outdoor. The Total Evapotranspiration is evapotranspiration from non-manageable, manageable and managed land uses.

3. 2 Incremental ET

It is the ET that occurs from any other sources except rainfall. For example evaporation of irrigation water, evaporation of groundwater through deep rooted plants/trees, water evaporated from a lake or other water bodies that exceeds the rainfall on the water body itself.

3.3 Landscape ET

It represents the water from rainfall that evaporates.

3.4 Total Evaporation is the evaporation from water, soil and that due to interception.

3.5 Interception

It represents the evaporation of a thin water film from wet leaves or other wet impermeable (artificial) surfaces.

3.6 Non-conventional ET

It 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.

3.7 Conventional ET

It is the ET that occurs by through natural processes.

3.8 Total Transpiration

It represents the conventional transpiration from all the land use classes.

3.9 Non-Beneficial ET

It represents the water consumed for purposes other than the intended use.

3.10 Beneficial ET

It represents the water consumed for its intended use.

4.0 AGRICULTURAL WATER CONSUMPTION

The total ET from agricultural crop and non-crop areas with rain-fed or irrigated water source

4.1 LAND PRODUCTIVITY

It represents the yield per unit area of land during the accounting period (kg/ha).

4.2 WATER PRODUCTIVITY

It represents the yield per unit volume of water (kg/m³; “Crop per drop”). This gives the economic value of production compared to the consumptive use of water.

5.0 UTILIZED FLOW

5.1 GROUNDWATER WITHDRAWAL

Water taken out from groundwater sources.

5.2 SURFACE WATER WITHDRAWAL

Water taken out from surface water sources.

5.3 GROSS WITHDRAWAL

Water taken out from both groundwater and surface water sources.

5.4 CONSUMED WATER

Water that is depleted by the system

5.5 NON CONSUMED WATER

Water that is not depleted up by the system

5.6 RECOVERABLE WATER

Non-consumed water that can be captured and reused in streams, rivers, lakes, reservoirs and aquifers.

5.7 NON-RECOVERABLE WATER

Non-consumed water that is lost to further use, by pollution that exceeds international standards, flows to saline groundwater sinks, deep aquifers that are not economically exploitable or flows to the sea.

6 SURFACE WATER

6.1 VIRGINAL FLOW

River flow without anthropogenic interference, i.e. no withdrawals and no return flows.

6.2 RETURN FLOW

The portion of water from the groundwater or surface water withdrawals which returns to the surface water.

6.3 RESERVED FLOW

Surface water that has been reserved to meet committed flows, navigational flows, and environmental flow conditions.

6.4 UTILIZABLE FLOW

Surface water flow that is available for additional resources development.

6.5 ENVIRONMENTAL FLOW

The minimum river flow required for maintaining the biodiversity of riverine ecosystem including endangered fish species and the riparian corridor.

7 OTHER IMPORTANT TERMS

7.1 CONSUMPTIVE USE

Water withdrawn for an intended process that does not return back into the basin, except from atmospheric recycling; It relates to evapotranspiration, water pollution and water incorporated in products.

7.2 AVAILABLE WATER

The total exploitable water minus the reserved flows.

7.3 WATER DEMAND

The amount of extra water needed to supplement naturally available water.

7.4 SCARCITY

The difference between supply and demand.

7.5 TOTAL WATER STOCK

Represents water present in reservoirs, rivers, lakes and groundwater that can be used for withdrawals.

7.6 SUPPLY

The provision of water that is withdrawn from a source to a user

7.7 TRIBUTARY

The section of a stream or river that flows into a main stem (or parent) river or lake. The tributary does not flow directly into the sea or ocean.

7.8 UTILIZED WATER

The part of available water that is depleted for uses.

7.9 UTILIZABLE WATER

The water that is available for additional resources development.

7.10 WATER GOVERNANCE

Political, social, economic and administrative systems that are in place, and which directly or indirectly affect the use, development and management of water resources and the delivery of water service delivery at different levels of society

8.1 WATER WITHDRAWALS

Water taken away from a water source, either natural (e.g. inundation, leakage) or artificial (i.e. pumping, diversions).

8.2 CHANGES IN STORAGE (positive or negative) – changes in storage include any flows to or from aquifers, in-system tanks, reservoirs, etc.

8.3. CONSUMED FRACTION (evaporation and transpiration)

It is divided into two parts as:

8.3.1. Beneficial consumption: The water evaporated or transpired for the intended purpose – for example evaporation from a cooling tower, transpiration from an irrigated crop.

8.3.2. Non-beneficial consumption: The water evaporated or transpired for purposes other than the intended use – for example evaporation from water surfaces, riparian vegetation, waterlogged land.

8.4 NON-CONSUMED FRACTION

It is divided into two parts as:

8.4.1. Recoverable fraction: Water that can be captured and reused – for example, flows to drains that return to the river system and percolation from irrigated fields to aquifers; return flows from sewage systems.

8.4.2. Non-recoverable fraction: Water that is lost to further use – for example, flows to saline groundwater sinks, deep aquifers that are not economically exploitable, or flows to the sea.

*Perry (2011). Accounting for water use: Terminology and implications for saving water and increasing production. *Agril. Water Manage.*, Vol. 98, pp. 1840– 1846