Application of Remote Sensing for Water Accounting in Data Scarce Areas: The Case of Wabi Shebelle River Basin

Redeat Daneil Ayele

A Thesis Submitted to

The department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Hydrology and Water Resources Management

Office of Graduate Studies

Adama Science and Technology University

June, 2022

Adama, Ethiopia

Application of Remote Sensing for Water Accounting in Data Scarce Areas: The Case of Wabi Shebelle River Basin

Redeat Daneil Ayele

Advisor: Mesfen Benti (PhD)

A Thesis Submitted to

The department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Hydrology and Water Resources Management

Office of Graduate Studies

Adama Science and Technology University

June, 2022

Adama, Ethiopia

Declaration

I hereby declare that this Master Thesis entitled "Application of Remote Sensing for Water Accounting in Data Scarce Areas: The Case of Wabi Shebelle River Basin" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

______________ ______________ ______________

Name of the student Signature Date

Approval Page of M.Sc. Thesis

I/we, the advisors of the thesis entitled “Application of Remote Sensing for Water Accounting in Data Scarce Areas: The Case of Wabi Shebelle River Basin” and developed by Redeat Daneil, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

______________________	______________________	______________
Major Advisor	Signature	Date
______________________	______________________	______________
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Redeat Daneil have read and evaluated the thesis entitled “Application of Remote Sensing Products for Water Accounting in Data Scarce Areas: The Case of Wabi Shebelle River Basin” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Hydrology and Water Resources Management.

______________________	______________________	______________
Chairperson	Signature	Date
______________________	______________________	______________
Internal Examiner	Signature	Date
______________________	______________________	______________
External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

______________________	______________________	______________
Department Head	Signature	Date
______________________	______________________	______________
School Dean	Signature	Date
______________________	______________________	______________
Office of Postgraduate Studies, Dean	Signature	Date

Recommendation

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Application of Remote Sensing for Water Accounting in Data Scarce Areas: The Case of Wabi Shebelle River Basin" prepared under my/our guidance by Redeat Daneil submitted in partial fulfillment of the requirements for the degree of Masters of Science in Hydrology and Water Resources Management.

Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

________________________	________________________	________________
Major Advisor	Signature	Date
________________________	________________________	________________
Co-advisor	Signature	Date

Acknowledgement

First of all, I would like to thank God Almighty for giving me the opportunity and guidance to achieving my goal and to be successful in completion of this thesis work.

I would like to thank my family for supporting me in every aspect of the thesis. This thesis would not have been accomplished without their outstanding supervision, scientific knowledge and experience. This thesis work would not have been possible without the support of many people. I would like to express my gratitude to my advisor, Mesfen Benti (PhD) and Derje Birhanu (PHD) who guided me throughout this project. He has been an ideal teacher, mentor, and thesis supervisor, offering advice and encouragement with a perfect blend of insight and humor. I'm proud of, and grateful for, my time working with him.

I would also like to thank Million Teshome Head of the department and my external and internal examiners of Water Resource Engineering for their valuable comment and support, with respect, honor and appreciation. With respect, honor and appreciation I dually acknowledge all my friends at the water resource department. I wish to extend my warm thanks to all of my friends.

Table of Contents

List of figures

List of Tables

List of Acronyms and Abbreviations

AETI	Actual evapotranspiration, Interception
AWA	Agricultural Water Accounting
CFSR	Climate Forecast System Reanalysis
CHIRPS	Climate hazards group infrared precipitation
DSS	Decision-Support-Systems
ET	Evapotranspiration
Et_a	Actual evapotranspiration
ET_{inc}	Incremental of evapotranspiration
FAO	Food and Agriculture organization
GRACE	Gravity Recovery and Climate Experiment
GW	Ground water
METRIC	Mapping ET with internalized calibration
MLU	Modified land use
MoWE	Ministry of Water and Energy of Ethiopia
MWU	Managed Water use
NASA	National seronautics and space administration
NMA	National Meteorological Agency (NMA)
I	Interception
IWMI	International Water Management Institute
LULC	land use land cover
P	Precipitation
PLU	Protected Land Use
Q_{sro}	Surface runoff
Q_{sup}	Supply
RS	Remote sensing
S	Soil moisture
SDG	Sustainable development goal
SW	Surface water
SEEA	System of environment economic accounting for water

SWAT	Soil and Water Assessment Tool
T	Transpiration
TWSA	Total Water Storage Anomalies
UN	United nations
WaPOR	Water Productivity through Open access of Remotely sensed derived data
WA+	Water accounting plus
WDPA	World Database on Protected Areas
WMC	Water management class
WRM	Water resource management
WSRB	Wabi Shebelle River basin
WP	Water Productivity
WWAP	World water assessment program

Abstract

Water is a basic necessity for sustaining life and development of society an output of this study is readily available to assist planners and managers to make decision on water resource availability in a catchment and also is to assess and forecast water demand in the basin. The WaterPix model and Remote sensing data were used for the design of surface water potential of WSRB. The research objective is to apply remote sensing products for data scarce areas using water accounting plus (WA+). To assess the water resources situation in WSRB using remotely sensed derived data for the period 2012 to 2021. To explore this methodology water accounting plus (WA+) was done with WaterPix model using WaPOR with 5km resolution data for precipitation, 100m resolution ET_a *, LULC with 10m resolution from sentinel-2 and* ΔS *was assessed from GRACE. Precipitation data from WaPOR, on the other hand, significant correlations were observed between these data and rainfall records. In addition, the Sentinel-2 LULC map was reclassified to WA+ classes using World database on protected areas. Application of WA+ to WSRB result for a 10-year analysis shows the net inflow into the basin is 1327.4*Mm^3*/year with depleted water from evapotranspiration of about 1276* Mm^3 */year. The basin has a considerable outflow of 51*Mm^3 */year and the available exploitable water is 585.9*Mm^3*/year. The majority of Evapotranspiration incremental (*ET_{inc}*) total volume of 534.9* Mm^3 */year originates from natural withdrawals (429* Mm^3*/year) and less from human-made withdrawals (105.9*Mm^3*/year) the majority of the available water resources go to Utilized Land Use (ULU) and protected Land Use (MLU). Evapotranspiration sheet and Withdrawal sheet was quantified. In this study lack of data, has been overcome by relying on remotely sensed data like WaPOR and other data for water accounting analysis. The results of this study highlights that the satellite datasets can provide a spatial overview of where in the basin water is generated and consumed via ET.WA+ shows the value of hydrological, manageable, utilizable flows, sustainability of water in the resource base sheet, Beneficial & non-beneficial flows in the Evapotranspiration sheet and quantification of the gross and net withdrawals via the withdrawals sheet. To improve understanding of the basin water resources and conditions, and water management achievements in WRSB.*

Key words: *GRACE, WA+, WaPOR, WaterPix,Resorse basesheet ,Evapotranspiration sheet,Withdrwal sheet,ULU,MLU,*

1. INTRODUCTION

1.1 Background

Water resources occupy a special place among other natural resources. Water is the most widely distributed substance on our planet it is available everywhere and plays a vital role in both the environment and human life. Human life itself is impossible without it because it can be substituted by nothing else. Human beings have always consumed fresh water and used the various natural surface water bodies for a whole range of purposes(Figuères et al., 2012). In most parts of the world, dealing with water scarcity necessitates a change in the way water is managed. The basic information on the availability and usage of water resources is at the heart of water management (Karimi et al., 2013). Water problems around the world are increasing Water resources accessible to human use also change over time. The accessibility, quantity, and quality of water resources are the basic requirements for guaranteeing water resource security. however, information useful for decision-makers within the water sector and related to the water sector seems to be decreasing. Solving water problems requires information from many disciplines

Water resource information useful for regional and national assessments of water availability and use requires a continuing process of coordination and collaboration with water demand scenarios. Assessing water resource potential and demand will improve water facts today and in the future, what variables or indicators would be useful, what spatial and temporal scales would be appropriate, how to build on existing efforts, and where to expand collaborative opportunities (kindie,.2015).

Like many other developing countries across the globe, significant water problems in Ethiopia on water resources are difficult to obtain for a variety of reasons, one of which is data availability. Because of the hydrologic complexities of water consumption, even when data is available, determining who uses how much water remains challenging. Making greater use of water-related data is one way to solve these difficulties. In most parts of the world, dealing with water scarcity necessitates a change in the way water is managed (Delavar et al., 2020).

The Wabi Shebelle river basin is one of Ethiopia's twelve major river basins, located in the country's south-eastern region. It is one of the country's most water-scarce basins. Despite having the largest geographical coverage, it has one of the lowest annual runoff and water availability among the major river basins. Rainfall is the most significant data in hydrological models, thus obtaining it with sufficient temporal and spatial precision is critical. The regional and temporal distribution of hydrological variables is influenced by the spatial and temporal variability of rainfall (Berhanu B. et al., 2016).

Despite this, due to the significant spatial variability of rainfall, only a dense network of rain gauge stations can reliably collect it. However, unlike most developing countries, the WSRB lacks a dense network (Worqlul et al., 2015).There is a scarcity of hydrological data in the basin. The meteorological and hydrological gauging station distribution is not effectively integrated, there is insufficient and low-accuracy precipitation, and rainfall data are incoherent (R. Basin et al., 2022). To give an integrated picture suitable for problem assessment, the information must be cohesive and harmonized. This thesis aims to serve as a foundation for future scenarios of water resource management in the Wabi Shebelle River Basin, as well as to assess WA+'s potential to deliver complete, consistent, and comparable policy-relevant water information.

1.4 Problem of Statement

The Wabi Shebelle River Basin in Ethiopia is the fourth largest river basin covering 202,220km^2. however, its water resource potential is limited. The basin is among the most vulnerable areas due to uncertain water availability, climate change and the frequency of extreme conditions which result in a more frequent hydrologic disasters, such as floods and droughts (Getachew,2019).

Its surface water potential is consistently ranked as the lowest of the river basins. Climate and hydrological data shortage still plagues the assessment and management of water resources in WSRB, as it does in many other developing and arid parts of the world. According to (Elias Nkiaka et al, 2017) the WSRB is one of the water scarce basins in the country. While having the largest area coverage, its annual runoff and water availability are one of the lowest among the major river basin. The annual water yield of a basin is primarily dependent on the amount of annual rainfall the basin receives relatively low mean annual rainfall of about 425 mm as compared to most of Ethiopian basins. The annual runoff coefficient is also very low (0.04) as compared to the Abbay basin (0.19). The basin water yield is only 0.53 l/s/km^2 while in the

Abbay basin annual the yield is 8.63 l/s/km^2 (Awass, 2009).Obtaining historical river records is difficult in the WSRB. Some of the gauging stations in the upper basin show inconsistencies in their data (Wudineh et al., 2021a). Hydrological data collection and sharing is challenging due to the remote area data distribution, cost of maintaining the stations and collecting data lack of information on how the data is collected or validated lacking the use of extra data extension. Therefore, remote sensing data provides important information for sustainable water allocation and conflict management also has the advantage that it is applicable without the need of extensive field monitoring and data collection.

1.5 Objectives

1.5.1 General Objective

The main objective of this study is to apply remote sensing products for water accounting, to assess the water resources situation and the extent to which water is consumed by different land use classes, in data scarce areas of Wabi Shebelle river basin (WSRB).

1.5.2 Specific Objectives

- To assess the current water resource availability in the WSRB.
- To identify the water required by different land use classes in the WSRB
- To quantify the water balance (resource base sheet), Evapotranspiration sheet, and Withdrawal sheets of the WSRB.

1.6 Research Questions

- What is the current water resource availability in the WSRB?
- How to identify the water required by different land use classes in the WSRB?
- How to quantify the water balance situation in the WSRB?

1.7 Significance of the study

The WSRB is the largest river basin among the twelve river basins in Ethiopia. The population is divided into highland and lowland populations with the highlanders relying heavily on agriculture and the lowlanders, in general, being pastoralists. There is an increasing demand of irrigation development, hydropower generation. This study is advantageous to have information about what is going on in the basin and to complement the lack of routine water resources data collection and integrates spatially distributed water consumption. Determining the basin's surface water potential of the basin is subject to change in the future water needs and is critical for long-term water allocation in the development of irrigation schemes, drought mitigation measures and power generation techniques and dispute resolution.

1.8 Scope of the study

The scope of this research is arranged to assess water availability, consumptive use and non-consumptive use in different land classes and the water withdrawals in WSRB of using remote sensing derived data from different dataset. Since there is increasing demand of irrigation development by evaluating the reliability of the satellite data from 2012 to 2021 with observed data for better estimation of the research. The study was achieved by WaterPix hydrologic model through the combined use of QGIS and RS to investigate different maps to covers the present concepts and definition to account for water use. The accounting procedures developed to design universally applicable for evaluating water management among all water use sectors

2.LITERATURE REVIEW

2.1 Water Resource Management

WRM (water resources management) is a major global issue. Water is necessary for life in the form of clean water and sanitation, as well as for the provision of food, energy, and health. Water cycle extremes (floods and droughts) can have a significant impact on all human activities, particularly on vulnerable people. As a result, water is a critical component of development, and one of the United Nations' Sustainable Development Goals (SDGs; UN, 2015) has been established: SDG6 Sanitation and clean water are essential. Water shortage is a persistent issue due to insufficient water supply and low availability of water, which combine to produce water scarcity (Veldkamp et al., 2015). The ability to store and sustainably manage basins and aquifers, as well as the mean and variability of precipitation, and its translation into usable water through surface water supply and aquifer recharge, are the primary determinants of water supply.

Dependency of communities and nations on single sources of water (e.g., from aquifers) and upstream rivers (with or without Trans boundary agreements) can easily lead to short-term crises and long-term unsustainable use although conflict is rare (AT,1998). Demand for water is also poorly understood and managed in many regions, in part because of lack of effective governance and institutional structures capable to equitably and sustainably balance competing needs with limited resources. This is set in the context of ongoing and future projected changes in supply and demand that make addressing these challenges imperative. On the supply side, climate change is expected to lead to regional changes in water resources, including declines through decreased precipitation and increased evapotranspiration (ET), especially in the subtropics, increases mainly from more precipitation, particularly in the tropics and high latitudes, and changes in seasonality, such as via earlier snowmelt linked to warming. At the same time, there is potential for greater climate variability leading to more droughts.

A river basin or watershed is an area over which various hydrologic processes such as precipitation, snowmelt, interception, evapotranspiration, infiltration, surface runoff, and sub - surface flows are integrated. The water resources of Ethiopia are governed strongly by the amount and distribution of rainfall. The distribution of rainfall over the country is highly variable. Variations in rainfall throughout the country are highly influenced by differences in elevation and seasonal changes in the atmospheric pressure systems that control the prevailing winds. These factors are the drivers of spatial and temporal variability of rainfall distribution and water availability in Ethiopia (Woldeamlak B. et al, 2015). Surface water resources are available although their spatial and temporal distribution and settlement pattern of the population limits their utilization. The mean annual specific runoff varies from zero to 35 l/s per km2. Minimum flows occur in the period from December to March. Apart from the big rivers and their major tributaries, there is hardly any perennial flow in areas below 1500m. In general, perennial streams and springs exist only in the vicinity of mountains with an annual rainfall of more than 1000mm (UN-Water, 2014).

According to Ho (2020) Water accessibility is closely related to a series of natural and human factors. These natural factors mainly include the water source, distance, relative height difference, slope, and land use type, whereas human factors mainly include funds(income, water fee),infrastructure(water supply pipelines, waterworks), and technology (irrigation technology, water treatment technology). In this study, rivers, lakes, and reservoirs were selected as the main water sources. We assumed that water users collect water from the nearest water source, and the water resource accessibility is mainly affected by natural factors such as runoff, water intake distance, relative height difference, slope, and land use type, and ignoring human factors.

Availability is a broadly accepted concept in various scientific fields such as urban planning, transportation planning, and geography. Less attention has been paid to water resource accessibility. Water resource accessibility refers to the difficulty of obtaining water resources from water sources. which is the fundamental factor determining the quantity, quality, and the efficiency of the water supply. Water resource accessibility is essential for human well-being, economic development, and ecological maintenance and includes both spatial accessibility and time accessibility (wang et al, 2019). The quantity, quality, and accessibility of water resources are the basic requirements for ensuring water resource security and were initially used to measure potential interaction opportunities in transportation networks as research progressed, accessibility was defined as the difficulty in reaching a destination from a given location. There are two main manifestations of accessibility: The number of opportunities or benefits that can be obtained within a given time or distance, and the mount of spatial resistance that needs to be overcome to reach a destination, the measurement of accessibility depends primarily on the spatial distribution of potential destinations and the spatial resistance that needs to be overcome to reach each destination. The former is mainly measured by quantity or quality, reflecting the attractiveness of the destination, and the latter is mainly measured by indicators such as time, distance, or cumulative cost, reflecting the convenience of reaching the destination. (Loucks & van Beek, 2017a) Water resources accessible to human use also change over time. The accessibility, quantity, and quality of water resources are the basic requirements for guaranteeing water resource security.

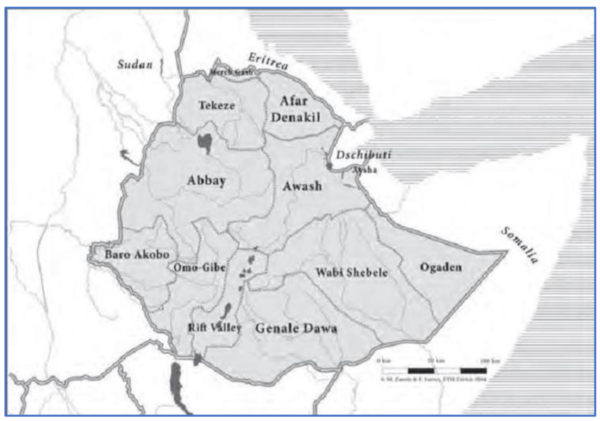


Figure 2.1: River Basins of Ethiopia Separated by Broken Lines (source: woldeamlak b, 2015)

The majority of Ethiopia's rivers begins in the highlands and flow in various directions to lowlands, including neighboring nations. Ethiopia has long been known as the water tower of Northeast Africa for this reason. Surface drainage from the twelve river basins totals around 124 billion cubic meters per year (Awulachew et al, 2007). Despite the fact that this is a huge sum, its distribution in terms of time and space is irregular. Eight river basins, namely Abbay, Baro Akobo, Tekeze, Mereb, WabiShebele, GenaleDawa, Omo Gibe, and Awash, can be termed wet basins since they create significant amounts of flow.Several lakes are fed by various rivers and streams in the Lakes Basin (Worku Ayalew, 2018).

2.1.1 Water Accounting Plus

WA+ (Water Accounting Plus) is a standard paradigm for estimating controllable and unmanageable water flows, stocks, user consumption, and interactions with land use. Remotely sensed data from online open access databases is used to predict the water balance terms. A measuring reporting monitoring system is required for the long-term planning of water and environmental resources in river basins. The Water accounting Plus (WA+) paradigm is based on Molden's early WA work on agriculture and irrigation systems (Molden, 1997). (Karimi et al, 2013) further improved WA+ for river basin assessments and encompassing all water use sectors. More hydrological and water management methods, as well as a focus on specific land uses, will be developed in the future. IHE Delft's water accounting group.

Water accounting is a systematic examination of the hydrological cycle, as well as the current state and future developments in both supply and demand for water. It goes beyond conventional volume and flow accounting to include factors such as water accessibility, uncertainty, and governance. As a result, water accounting is a crucial tool for any campaign attempting to reduce water consumption (Bhattarai et al.,2016). Various attempts have been launched over the last two decades to build a water accounting system to assist water managers and decision makers. Despite the fact that a variety of frameworks have been presented, a widely approved norm extensively used by water managers and policymakers has yet to emerge. Bastiaanssen (Bastiaanssen, 2000).The art of water accounting is to classify water balance components into water use categories that reflect the consequences of human interventions in the hydrologic cycle to integrate water balance information.

A key element of WA+ is that it includes the hydrology of natural watersheds that provide the main source of water in streams and aquifers, as well as the quantification of water consumption. WA+ separates evapotranspiration (ET) into green (ET_{green}, also called rainfall ET) and blue ET (ET_{blue}, sometimes called incremental ET), thereby clearly identifying managed water flows.

The water accounting framework distinguishes between a vertical and horizontal water balance.
A vertical water balance is made for the unsaturated root zone of every pixel and describes the exchanges between land and atmosphere (i.e. precipitation and evapotranspiration) as well as the

partitioning into infiltration and surface runoff. Percolation and water supply are also computed for every pixel, to facilitate attributing water supply and consumption to each land use class. As the study was focused on rapid water accounting, only the separation of ET green and ET blue is of interest (Sulser et al, 2010).

Karimi et al (2013)Water withdrawals, or water abstractions, are defined as freshwater taken from ground or surface water sources, either permanently or temporarily, and conveyed to a place of use.Water Use Intensity (WUI) generally refers to the rate at which water is used in a given area. It is an indicator of how much water your building requires during its occupation. WUI informs sustainable water allocation. The level of water stress freshwater withdrawal as a proportion of available freshwater resources is the ratio between total freshwater withdrawn by all major sectors and total renewable freshwater resources, after taking into account environmental water requirements.

Evapotranspiration (ET) is a term used to describe the water consumed by plants over a period of time. Evapotranspiration is the water loss occurring from the processes of evaporation and transpiration. Evaporation occurs when water changes to vapor on either soil or plant surfaces. Water Accounting Plus (WA+) is a new framework that uses the IWMI WA principles of tracking water depletions rather than withdrawals. WA+ adopts the same definition for water depletion as the IWMI WA, but considers more details in the processes and essential mechanisms. In line with IWMI WA, we use the term depletion hereafter because water consumption in non-agricultural sectors is often associated with withdrawals. FAO (2012) and the International Commission on Irrigation and Drainage, ICID (Perry, 2007) are using consumptive use for crop ET. Depletion in WA+ includes ET and flow to sinks. Datasets on withdrawals and return flows are scarce and incomplete both at the river basin scale, as well as locally by certain water use sectors. Advances in earth observations have, however, demonstrated that ET can be acquired from satellite measurements (Anderson et al., 2012). By exploring the spatial data on ET, WA+ provides explicit information on water depletion processes for every land use class. WA+ is based on a mass water balance approach. 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 process. Therefore, the advantage is that withdrawals and return flows are no longer necessary to be measured because the depletion can be obtained directly from satellite measurements.

WA+ provides four sheets to summarize a basin's water resources situation (i) a resource base sheet, (ii) an evapotranspiration sheet, (iii) a productivity sheet, and (iv) a withdrawal sheet. Remote sensing (RS) data can be used to gather the essential data for each sheet, which makes it particularly relevant and feasible for data-scarce areas and large-scale applications like the Indus Basin (1,160,000 km^2) and Helmand Basin (262,342 km^2) (Karimi et al., 2013b). However, using RS data limits the WA+ framework's applicability to historical and current events, and it may not be applicable for tiny sub basins due to existing uncertainties that would be magnified as the spatial scale of the basin increased (Delavar et al., 2020) .

Limitations WA+ are a reporting system that contains strategic information. WA+ does not provide daily data on water demands and water supply. So the tool cannot be used to operate reservoirs and irrigation canals. The latter requires continuously updated real time information on the water demand from the irrigation systems, domestic sector, industry, hydropower and wetlands vs. the water availability from reservoirs, lakes and rivers. Decision-Support-Systems (DSS) are designed for this purpose. While WA+ can compute the monthly biomass production and carbon assimilation in agro (Bastiaanssen et al., 2015).

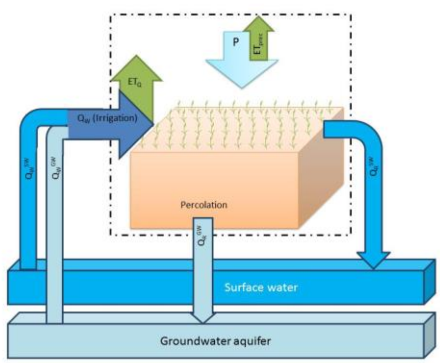


Figure 2. 1 Basic Diagram Explaining Fundamental Differences Between Gross And Net Withdrawals in Relation To Incremental Et .(Sources Of Image Adopted (P. Karimi,2013)

2.2 Water Accounting plus (WA+) Analytical Frame work

The IWMI developed WA procedure (Molden., 1997) which considers depletion rather than the withdrawals to account for measurable ET process. This framework has been applied to the Bhakra system in India (Molden, 1997); Zhanghe Irrigation System in China (Dong et al., 2014) and for developing water accounts at the national scale in India (Amarasinghe et al., 2007) in Sri Lanka (Bastiaanssen and Chandrapala, 2003). However, only a few countries have applied these WA+ mechanisms, commonly due to the lack of data needed to implement these approaches. The Water Accounting Plus (WA+) framework developed by IHE-Delft in partnership with IWMI, FAO, and the World Water Assessment Program (WWAP) specifically utilizes open access satellite datasets in conjunction with open access various hydrological model outputs to develop the water accounts.

FAO (2012) describes water accounting as the systematic acquisition, analysis and communication of information relating to stocks, flows and fluxes of water in natural, disturbed or heavily engineered environments. The somewhat sharper definition of water accounting is the systematic study of the current status and trends in water supply, demand, accessibility and use in domains that have been specified recognizes that water accounting centers on analysis of trends in water supply, demand, accessibility and use in time and space within specified domains.

Water Accounting Plus (WA+), which is a new framework designed to provide explicit spatial information on water depletion and net withdrawal processes in complex river basins. The influence of land use and landscape evapotranspiration on the water cycle is described explicitly by defining land use groups with common characteristics. The reporting style of WA+ is thematic and by means of easy to understand sheets. The sheets include only a small set of numbers. WA+ estimates the withdrawals, consumptive use and return flows of each water use sector. Results of WA+ will be presented in four so-called accounting sheets: (i) Resource Base Sheet, (ii) Evapotranspiration Sheet, (iii) Productivity Sheet and (iv) Withdrawal sheet . Moreover, some key summarizing indicators will be calculated to support water managers, policy makers and donors in their task to ensure accountable water resources management.

The WA+ resource base sheet provides information on water volumes. Inflows are shown on the left of the resource base sheet diagram, the middle part provides information on how and through what processes the water is depleted within a domain, and information on exploitable water and reports on outflows are summarized on the right.

Precipitation plus any surface or groundwater that flows to the domain from outside its boundaries is Gross inflow.Net inflow includes water storage changes over the period of accounting. The fresh water storage changes are (i) surface water, (ii) groundwater including soil moisture storage change in the vadose zone and (iii) snow and glacier melt. The net inflow is partitioned into landscape ET and exploitable water present in streams, soils and aquifers. The landscape ET is a consequence of a certain rainfall distribution across a composite terrain with mixed land use, geological formations, soil types, slopes, elevations and natural drainage to streams. (Falkenmark &Rockstrom.,2006) defined this as green water. This evaporated ¨ water is accounted as being consumed and not available for downstream withdrawals and water resources development, unless moisture recycling through the atmosphere occurs (Savenije.,1995; Van der Ent & Savenije., 2011).

2.3 Water Accounting through Remote Sensing (RS data for WA+)

Remote-sensing data provides important information for water resources management, particularly in Mediterranean countries where water resources are scarce. The progressive improvements in spatial, temporal, and spectral resolution of remote-sensing data made them invaluable sources of information for managing water resources at different scales (Al-Bakri, 2016). The integration of remote sensing and geographic information systems (GIS), as geospatial techniques, with ground data has become widely adopted in new tools for water-use assessment and reporting. A good example of these new reporting and full water budgeting tools is the water accounting, which provides detailed information on water inflows and outflows with proportions of beneficially used and recoverable water. The rationale behind water accounting is the improvement of water-related sectoral and inters sectoral decision-making methods at local, regional, and national levels. Improvements can often be initiated by basing decisions on ‘best-available’ information, evidence and analysis rather than intuition, assumptions, and guesswork.

Water accounting based on remote sensing for water accounting has the advantage that it is applicable without the need for extensive field monitoring and data collection. The approach developed by (Bastiaanssen., 2009) focuses on the water consumption of four different types of land use: protected areas, pastures, rain fed and irrigated agriculture. The approach makes a distinction between beneficial and non-beneficial parts of evaporation, transpiration and interception, expressed in productivity per unit of land and productivity per unit of water consumed. Since the approach is based on remotely sensed information, it has the advantage that a study can be implemented in a short time and that the source of information is neutral and does not depend on field data that might or might not have been collected already. Since it focuses on water consumption of different types of land use, it is less amenable to taking into consideration water use sectors with large return flows that are not area bound, such as industry and the domestic sector return flows that are not area bound, such as industry and the domestic sector (Steduto et al., 2012).

WA+ is largely based on remote sensing data and integrates hydrological processes with land use, managed water flows and the services that result from water consumption in river basins. In this way, it aims to provide the information needed to achieve equitable and transparent water governance for all users. Explicit spatial information is provided through this framework on water consumption and withdrawal processes, going beyond flow and runoff accounting. Software tools are being prepared that link open-access input data to reporting sheets. WA+ can be used to evaluate and plan water resources management, to monitor changes in water resources and to assess the impacts of future interventions, ensuring a sustainable water balance.(Ghassemi &White.,2017).

Hoogeveen.J (2017) apply water accounting for agricultural areas requires an accurate information on water use, flows and fluxes. This can be achieved by integrating geospatial techniques of both remote sensing and GIS within water accounting systems. The use of remote sensing (RS) in agricultural water accounting (AWA), specifically in the irrigation sector, includes mapping of irrigated crops and their evapotranspiration (ET). Analysis of remotely sensed data is carried out within GIS environment that integrates different spatial, climatic and management data to derive information and indicators used in AWA. In AWA, ET is the most important water flux for assessing water balance, water-use efficiency, and fractions of beneficially used water (Garrido et al., 2020).

According (R. Basin et al, 2022) studies have been undertaken to evaluate the performance of global precipitation estimates, which were concentrated in the Blue Nile Basin and central parts of the country with a coarser resolution and limited time period. The performance of the global precipitation product is highly affected by spatial resolution, which is largely uncertain because of the scale discrepancy with point measurements. The authors validated 10 satellite precipitation estimates across 120 relatively dense gauge network highlands of Ethiopia. TAMSAT, CMORPH, and TRMM-3B 42 from the first (high-resolution) group had a strong performance. The authors of [40] evaluated CHIRPSv2, TRMM 3B43v7, CMORPH, ARC2, and TAMSAT across various rainfall regimes (eastern, central, western, and southern) of Ethiopia. The CHIRPSv2 precipitation products at a monthly timescale performed comparatively better across all rainfall regimes.

Depending on the context, it is important to identify and quantify other components of water balance and outflows. In addition, detailed maps of land use, including water-related infrastructure and urban areas, are needed. The influence of land use and landscape ET on the water cycle is obtained by recoding LU maps, derived from RS data, to water-use groups.

The integration of remotely sensed evaporation estimates and hydrological applications seems to be more common in distributed hydrological modeling. However, remotely sensed actual evaporation has been used successfully as soft data to decide on a model structure (Franks & Beven,1997; klees et al., 2008) and for updating parameter probability distributions of parameters that relate transpiration to soil moisture states (Winsemius et al., 2008)used the evaporation signal for parameter calibration in a distributed model. Depending on the temporal and spatial resolution of the remotely sensed evaporation products.

(Allen et al.,2007) Among the remote-sensing based ET models are METRIC (mapping evapotranspiration with internalized calibration) and SEBAL (surface energy balance algorithm for land). Both models, which are widely used for irrigation and hydrological applications using the medium resolution data of Landsat, require ground data to reduce biasness in ET estimates. In the context of water accounting, the RS-based FAO56PM is preferred over other methods as it has the ability to separate ET components into evaporation and transpiration, and therefore it provides data needed for evaluating the beneficially used fraction of irrigation water. A good example of these models is the ET Look, which uses the FAO56PM method separately to estimate evaporation and transpiration with a daily time step. The method was developed to provide free data of ET and water productivity through an open access portal supported through the Food and Agricultural Organization of the United Nations (FAO). The FAO portal, known as WaPOR, provides the 10-day, monthly, and annual ET data for Africa and the Near East at 100–250m spatial resolution (FAO.,2022).

Karimi, P.& Bastiaanssen (2013) The major components of water accounting systems are the water inflows and outflows data that must be filled into the resource base and the ET sheets of the water accounting system. Performance indicators can be then calculated based on the data outputs from the water accounting sheets. In the study, the open-source sheets of the Water Accounting Plus (WA+) system were used to assess the water fluxes and the proportions of recoverable and beneficially used water and to perform the AWA for the NJV. The data of inflows and outflows were based on integration of remote-sensing and ground data. Bearing in mind that the intended outcome from the work of water accounting, within the context of FAO-RNE project, was the institutionalizing of this water reporting and analysis system at the MWI, so it was important to assess the level of accuracy of remotely sensed data, as these would control the outputs and results of water accounting (FAO,2020).

2.4 Role of Land Use Land Cover Categories in WA+

According to (Singh et al., 2021) WA+ Framework classifies land use land cover (LULC) into 80 classes. These 80 LULC classes are grouped under four main Water Management Classes (WMC), i.e., Protected Land Use (PLU), Utilized Land Use (ULU), Modified Land Use (MLU), and Managed Water Use (MWU). These four WMC classes have been developed on the basis of the degree of the anthropogenic disturbances that tend to alter the natural ‘hydrologic cycle’ with varying extent. This classification explicitly helps understand the impacts of anthropogenic activities on consumptive uses as per LULC classes with enough details on the interaction between land use and water use. The class ‘PLU’ represents areas with no anthropogenic activities and includes natural ecosystems like reserved forest areas, rainforests, glaciers, etc. The class ‘ULU’ represents areas like grasslands or savannah, or forest lands which provide ecosystem services to humans with minimal interventions. The ‘MLU’ includes here only the rain-fed agriculture and only the land use has been changed for food, feed, fiber, etc. The areas under ‘MWU’ are highly intervened with physical infrastructures such as dams, weirs, canals, etc. to manage the water resources. Irrigated agriculture typically comes under this class only.

The entire basin water resources consist of rainfall, inflow across water divides and storage changes in surface water, ground water (including soil moisture) and snow water. Only a fraction of the total basin water resources can be controlled and regulated by means of barrier dams, infiltration dams, diversion weirs, inlet points and water harvesting facilities, to create ET that otherwise would not occur. Land use change (e.g., urban expansion, land reclamation, deforestation) and land cultivation practices (land preparation, crop sowing date, and zero tillage) have a regulating effect on ETQ. Hence land use, cultivation practices and water resources development are controlling factors of ET at the basin scale. Regulation of ET in areas with a high degree of natural land cover such as savannah and mountains is very limited and largely dependent on natural ecosystem processes (e.g., grazing). Consequently, not all land use classes and their associated water flows can be controlled. Water management practices are commonly focused on those water resources that can be controlled. Influencing the disposition of water through changes in managing land use is less common, but essential to address the growing water scarcity of the future. The WA+ framework encompasses four accounting sheets that each reveals specific insights into how water is used. For the sake of simplicity, the hydrological summary can be portrayed on a single page “resource base sheet”. The second component is to describe the water depletion (presented on an “Evapotranspiration sheet”), and the third component is to estimate the biomass services.

2.5 Related Review

There are many studies conducted in the watersheds of Ethiopia using satellite data set for its applicability for hydrological predications and water accounting plus. 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 recover able 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.

Karimi et al (2013) conducted study on Basin-wide water accounting based on remote sensing data an application for the Indus Basin. The paper demonstrates the application of a new water accounting plus (WA+) framework to produce information on depletion of water resources, storage change, and land and water productivity in the Indus basin. It shows how satellite-derived estimates of land use, rainfall, evaporation (E), transpiration (T), interception (I) and biomass production can be used in addition to measured basin outflow, for water accounting with WA+ It is demonstrated how the accounting results can be interpreted to identify existing issues and examine solutions for the future. Their results indicate for one selected year (2007) showed that total annual water depletion in the basin (501 km^3) plus outflows (21 km) exceeded total precipitation (482km^3). The water storage systems that were affected are groundwater storage (30 km), surface water storage (9 km^3), and glaciers and snow storage (2 km^3).

Tatek (2014) and Worglul (2015) suggested that the use of satellite data set without model calibration showed reasonable performance at Gilgel Abay and Gumera River gauging stations at a monthly time step. He used two performance indicators, Nash–Sutcliffe Efficiency (NSE) and Percentage Bias (PBIAS) coefficients. His research found an NSE value of more than 0.75 showed the very good performance of the model in these gauging stations. The PBIAS value for Gilgel Abay also indicated very good performance, while the PBIAS value for the Gumera showed good model performance.

Tatek Abate (2014) in his study he concluded that the quality of data in the case of CFSR data is higher than conventional data which sometimes hard to find in the required quality and proper allocation especially in developing countries. In addition, when the conventional data exist, it may be unreliable because of gaps and random errors.

Vinayak S. et al (2009) in their study found that there is high underestimation of rainfall amounts in tipping bucket rain gauges under different rainfall intensities. In addition, the use of CFSR data set in areas where there is data scarcity has an advantage over conventional data set in that it provides complete sets of climatic data. This allows the flexibility to apply different functions pertaining to hydrological models.

Tatek Abate (2015) conducted a study for comparison of different gridded data sets with ground observed data as an input for hydrological models in data scarce watershed at Upper Blue Nile Basin, Ethiopia. The study also indicated that 75% gauged areal rainfall occurred during the period from June through September and CFSR data hold about 80 % of the data within this period interval. Simulating the stream discharge of the two basins using PED model resulted a good fit between CFSR and observed flow data with very good NSE Values. The CFSR data captured 73% of the flow variation in the daily flow analysis of the observed flow and it is nearly similar with the gauged data which captured 82% of the flow variation.

Tewodros W. et al (2017) studied on the evaluation of different precipitation reanalysis datasets over Ethiopia using observed gauged data for a period of 33 years. He pointed out that water resources management and hydrologic modeling studies are limited in Ethiopia mainly because of the unavailability of long term observed data for hydrologic variables. He then, indicated the use of reanalysis data set as a replacement of observed data. He selected 16 representative administrative regions of Ethiopia to collect gauged precipitation data for the analysis. On his evaluation, CFSR data showed a more closed behavior to the observed rainfall distribution in all station in annual rainfall characteristics.

However, the study found a poor performance of reanalysis data sets in general in replicating the observed trends in annual rainfalls. The study indicated that observed daily rainfall shown a high correlation value with CFSR rainfall data in most of the stations taken for the investigation (Ibid).

According to the study conducted by (Daniel R. 2013) in simplifying watershed modeling using CFSR data, he found a better simulation result than conventional weather data in Gumera watershed in Ethiopia. He indicted a very good performance of a stream simulation with NSE result of 0.71using CFSR data and 0.68 applying the conventional weather data. The paper concluded the reason for the good performance of CFSR data as the weather data are effectively averaged over spatial scales that are more similar to many watershed extents; or, at least more similar than a typical point measurement of a weather station is to a watershed. He further indicated that although most hydrology textbooks note that the magnitude of point rainfall needs to be adjusted when considering the rainfall over a larger surrounding area (Dingman, 2002) few modelers do this explicitly, and often account for these differences during model calibration. Using the spatial CSFR data, such adjustments are not needed. As a result of the difference in spatial scales between CFSR data and weather station data direct comparisons between the two give little correlation.

Assayew (2016) tries to summarize the causes of magnitude differences between satellites sourced data and meteorological measured rain gauge data. As his summary the causes are 1) satellite rainfall estimates are indirect estimates of rainfall from cloud properties observed space in case of Geo-stationary satellites and derived from microwave emissions from raindrops and scattering from ice in orbiting Satellites 2) assumptions like the surface emissivity, neglecting evaporation below clouds, and empirical relationships are the driving factors of error 3) satellite rainfall estimates errors are caused by various factors like sampling frequency, field of view of the sensors, and uncertainties in the rainfall retrieval algorithms.

Habib et al (2014) cited in Assayew N.(2016) identify errors can be random or systematic. It is the systematic error that is commonly referred to as bias and reflects errors which are systematically distributed over time and space. Bias in satellite rainfall products can cause large uncertainties in hydrological modeling. (Margaret Wambui., 2018) suggested to reduce the errors these satellite products hold to make them more representative with the local rainfall variability as they often exhibit large discrepancies with ground measurements. Although rain gauge data have low spatial distributions, their direct way of measuring rainfall are still vital as a reference to the local rainfall variability. For better representations of local rainfall processes, the inclusion of all available quality-controlled rain gauge data merged with satellite products can enhance the products' future applications (Ibid).

Berhanu B. et al (2016) indicated that many studies tried to evaluate CFSR by comparing its accuracy to ground observed precipitation with different spatial and temporal scale.
Different methods have been proposed to reduce satellite rainfall estimates errors. A study by (Margaret Wambui, 2018) applied bias correction using empirical cumulative distribution (CDF) maps on a seasonal basis for hydrological applications in the upper Blue Nile in Ethiopia. To reduce temporal rainfall variability, a seasonal timescale was utilized. However, the study indicated that in high elevated areas, areas near inland water bodies and those with maritime influences high rainfall variability are experienced. Hence the study identified the choice of temporal scale which may differ from place to place. It is worth noting that the effectiveness of bias correction on rainfall products may also differ from location to location and consideration of spatial scale is of great importance.

Berhanu B. et al (2016) showed that CFSR data set is a good alternative dataset for large scale hydrological modeling. Hence, his study indicated that a bias correction method which focuses mainly on the magnitude of the data is only important rejecting the pattern and trend of the dataset based on the research finding of Worqlul et al (2014) which reported CFSR precipitation can reproduce the observed rainfall pattern in the Blue Nile, Ethiopia, but it overestimated or underestimated the observed values.

2.6 Hydrological models

According to Devia et al., (2015) a model is a simplified representation of real world system. The best model is the one which give results close to reality with the use of least parameters and model complexity. Models are mainly used for predicting system behavior and understanding various hydrological processes. A model consists of various parameters that define the characteristics of the model. A runoff model can be defined as a set of equations that helps in the estimation of runoff as a function of various parameters used for describing watershed characteristics. The two important inputs required for all models are rainfall data and drainage area. Along with these, water shed characteristics like soil properties, vegetation cover, watershed topography, soil moisture content, characteristics of ground water aquifer are also considered. Hydrological models are now a day considered as an important and necessary tool for water and environment resource management.

2.6.1 Classification of Hydrological Models

Hydrological models vary in many ways: time step, spatial scale, whether the model simulates single events or on a continuous basis, and how different hydrological components are computed. Depending upon the way the hydrological processes are described, the models can be also classified as deterministic, stochastic, or mixed. In a deterministic model outcome are precisely determined through known relationships among states and events, without any room for random variation. In such models, two equal sets of input always yield the same output if run through the model under identical conditions. On the other hand, if a model has at least one component of random character which is not explicit in the model input, but only implicit or hidden 'it is called stochastic model. If the model components are described by a mix of deterministic and stochastic components, the model is called stochastic-deterministic or hybrid model. A vast majority of the models are deterministic, and virtually no model is fully stochastic. On the basis of process description, the hydrological models can be classified into three main categories: lumped models, semi-distributed models and distributed models (Kassa, 2009).

2.6.2 Guidelines for model selection

There are various criteria that can be utilized to select the best hydrologic model. Because each project has its own unique requirements and needs, these criteria are always project-specific. Some models require a lot of data, which is either lacking or unavailable in its whole (Kassa, 2009). There are four general, essential questions that must always be answered among the different project-specific selection criteria:

- Model output that is critical to the project and must be estimated by the model (Does the model predict the variables required by the project, such as peak flow, event volume and hydrograph, and long-term flow sequence?)
- Hydrologic processes that had to be described in order to accurately predict the intended outputs (Can the model simulate the needed reservoir operation, as well as single-event or continuous processes?)

- Availability of input data (Can all of the model's inputs be supplied within the project's schedule and budget constraints?)
- Price (Does it appear that the investment is justified in light of the project's goals?)

WaterPix hydrological model is chosen for this investigation based on the criteria given above.

2.7 WaterPix model

WaterPix model was developed by Espinoza & Bastiaanssen (2007). WaterPix model is a hydrologic data-based model used to perform water balance at a pixel scale. A vertical water balance is made for the unsaturated root zone of every pixel and describes the exchanges between land and atmosphere (i.e. rainfall and evapotranspiration) as well as the partitioning into infiltration and surface runoff. Percolation and water supply are also computed for every pixel, to facilitate attributing water supply and consumption to each land use class. The WaterPix model calculates for each pixel the vertical soil water Rainfall ET (ET_{rain}) and incremental ET (ET_{inc}) are separated by keeping track of the soil moisture balance and determining if ET is satisfied only from rainfall or stored in the soil moisture or additional source (supply) is required (FAO; IHE Delft, 2019).

WaterPix model used in some countries all over the world for the analysis, evaluation and estimation of stream flow and management measures in the river basin. Several research studies are conducted using WaterPix model to calculate the water balance and best management practice for a different river basins. The WaterPix model was applied in the Jordan River basin applied to gain full insights into the state of the water resources in the basin for the period 2010 to 2018(Sensing & Water, 2020a);WaterPix also used for litani and Niger river basin to estimate the base flow, recharge ,runoff and to distinguish the green and blue water for the water accounting resource reporting sheets(FAO and IHE Delft, 2020).

WaterPix also has been successfully applied in some part of Ethiopian river basins. It was used in the Awash river basin (FAO and IHE Delft, 2020) and Blue Nile Basin (Sensing & Water, 2020a) to separate between vertical and horizontal water balance using the main inputs precipitation, actual ET, interception and land use land cover for the water balance for calculating.

3.MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Wabi Shebelle river basin, located in Ethiopia's south-eastern region, is one of the country's twelve major river basins (figure2.1). It is located between latitudes 40 45' N and 90 45' N, and longitudes 380 45' E and 450 30' E. It starts about 4000 meters above sea level in the Galama and Ahmar mountain ranges and drains into the Indian Ocean via Somalia. Ethiopia accounts for 72 percent of the catchment area (202, 220 km^2) making it the fourth longest river in Ethopia. The basin occupies around 19% of the country's surface area. It is bordered on the west by the Rift Valley, on the north by the Awash Basin, on the east by the Ogaden, and on the south by Somalia. Oromiya, Somalia, and Ethiopia comprise the basin (figure3.1).

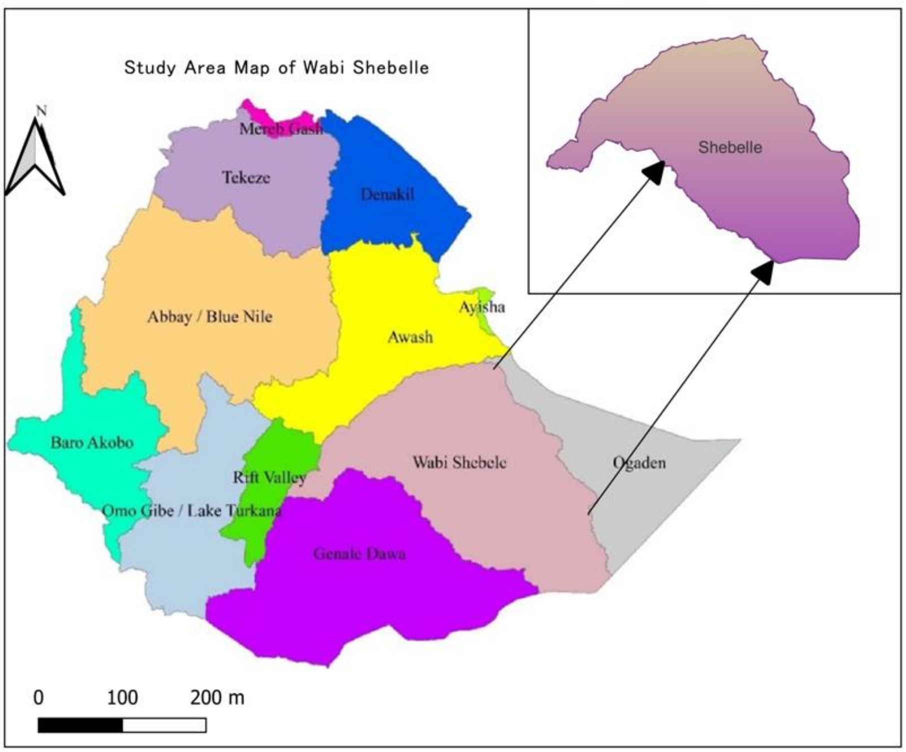


Figure3.1: Study Area Map of Wabi Shebelle Basin

3.1.2 Topographic feature

The altitude varies from 166 m above mean sea level (MSL) north of Mustahil in Somali region to about 4216m on the highlands of Bale. The Wabi Shebelle River flows eastward until it meets with another major component of the main river joining from Hareri region where most of the left bank tributaries originated, and then it changes its course to flow southwards. The lower valley is a vast alluvial plain stretching up to Somalia border with a very gentle slope of 0.25 to 0.35m/km, most of the tributaries after this portion do not add a significant flow to the main water.

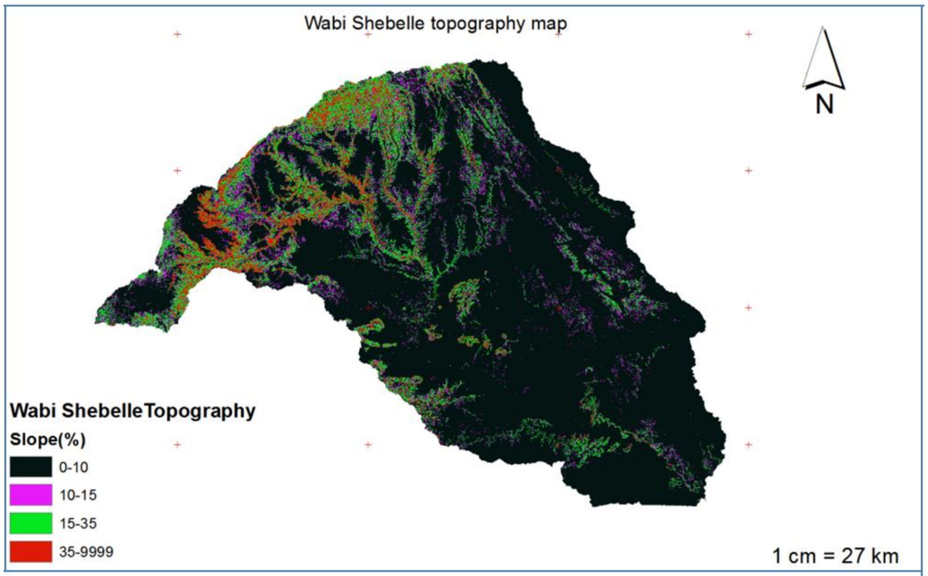


Figure3.2: Wabi Shebelle Topography Map

3.1.3 Climate and Hydrology

The climate of Wabi-Shebelle River Basin is dependent on the basin altitude. The highland areas are cool and suitable for people settlement while the lowland areas are arid and not suitable for settlement (Adane, 2009). There are some meteorological stations placed Assessment of Surface Water Potential in Data Scarce River Basin in 'Ethiopia: Case Of Wabi Shebelle River Basin 42 around the basin very few of them are located within the basin and most are located around the cities of the basin. The rainfall amount within the Wabi Shebelle river basin ranges from 200 mm on the arid part of the basin to 1250 mm towards the upper part of the basin (Ibid). The major reason for the variability of the rainfall amount is the difference in altitude which ranges from 73 m at the lower part to 4216 m to the highlands of bale. Wabi Shebelle River Basin is one of the water scarce basins in the country. While having the largest area coverage, its annual runoff and water availability are one of the lowest among the major river basins. The available hydrological data in the basin are very sparse. There are some stream gauging stations in the basin and fewer are operational at present. A significant portion of which have operated intermittently, the distribution of the meteorological and hydrological gauging stations is not well integrated reducing the plausibility of such data(Wudineh et al., 2021b).

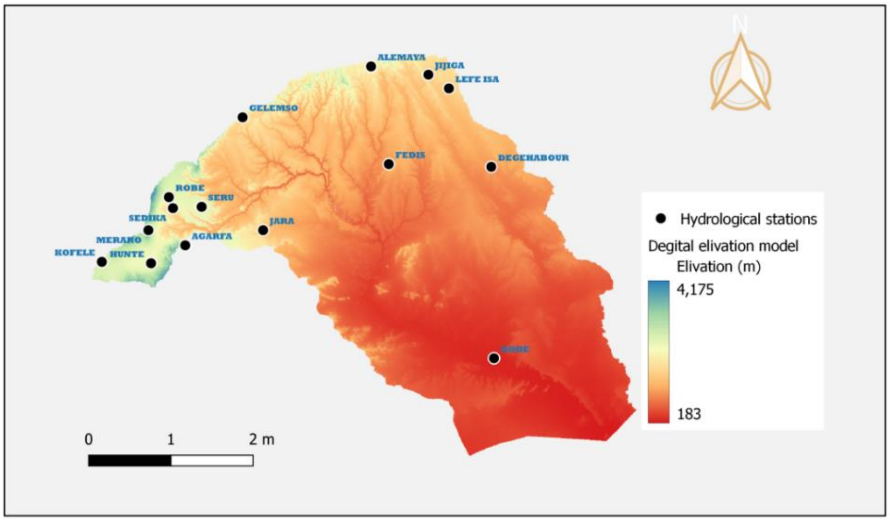


Figure3.3: Digital Elevation Model for Wabi Shebelle Basin

3.1.4 Land use and Land cover

In WSRB, only a small percentage of the north western area is intensively and moderately cultivated land. Large parts of the area are bush, wooded or open grasslands. The northeastern part of the lowlands is covered by shrubs and bush and is used mainly for pasture; crop cultivation is not common in this area (Getachew, 2019). The basin's northwestern section contains a small dense forest. The most common land cover in the basin is dense shrub land (range land) (74%), forest (14%) and crop (9%) . The shrub land is found mostly in semi-arid areas and is made up of patches of shrubs interspersed with grasslands and a few low trees. In areas of the Bale and Hararghe plains in the southeast, exposed rock or sand surfaces can be found. Afro-alpine and sub-afro-alpine vegetation cover parts of central Arsi and northern Bale.

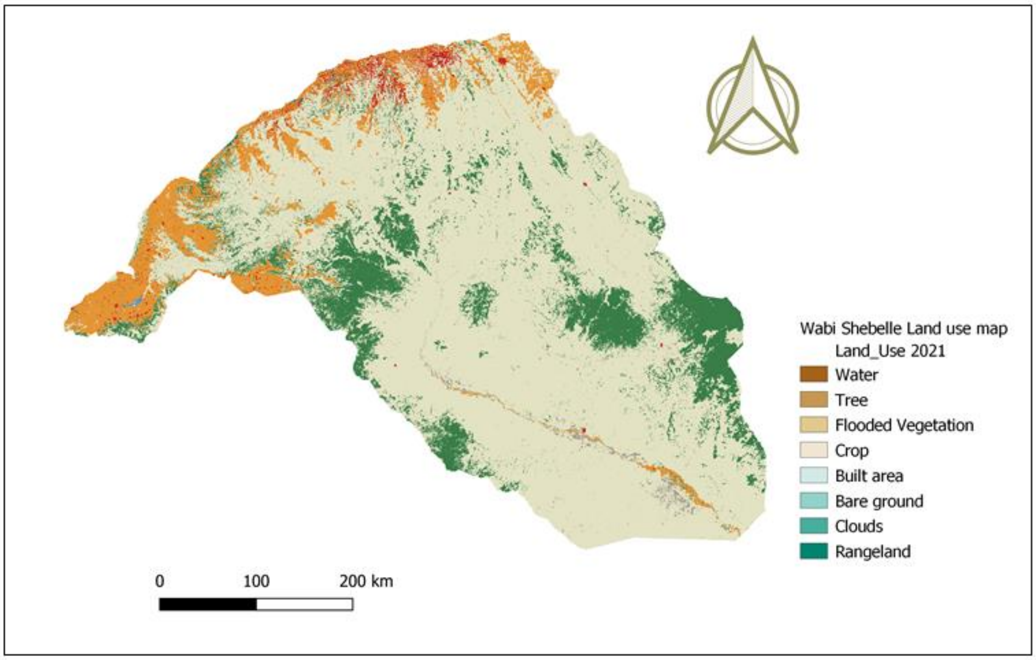


Figure3.4: Land Use/Land Cover Map of The Study Area

3.15 Soil

The study area is dominated by the presence of the distal portion of the main perennial rivers of the Wabi Shebelle river, Because of the high proportion of alluvium, many soils comprise layers of deposited materials because of the semi-arid climate, have been little-affected by normal soil-forming processes. Despite their variability most soils share the characteristics of heavy texture and low permeability with a tendency to poor drainage. The soil map and soil data of the study area was obtained from the Ministry of Water and Energy (MoWE) and Food and Agriculture Organization (FAO) Harmonized World Soil Database (HSWD) of soil classification to determine the soil type of the study area (FAO, 2002). The FAO soil classification method was used and eleven different soil types were classified in Wabi Shebelle watershed. The major soils of the basin are Cambisols (34.7%), Phaeozems (19.7%).Leptosols(12%),Regosols (11,6%),Luvisols (11.2%),Vertisols (4.53%),and Nitsol (3.5%) .Cambisols are distributed in the upper most parts of the watershed, especially areas on hills where the land is too steep.

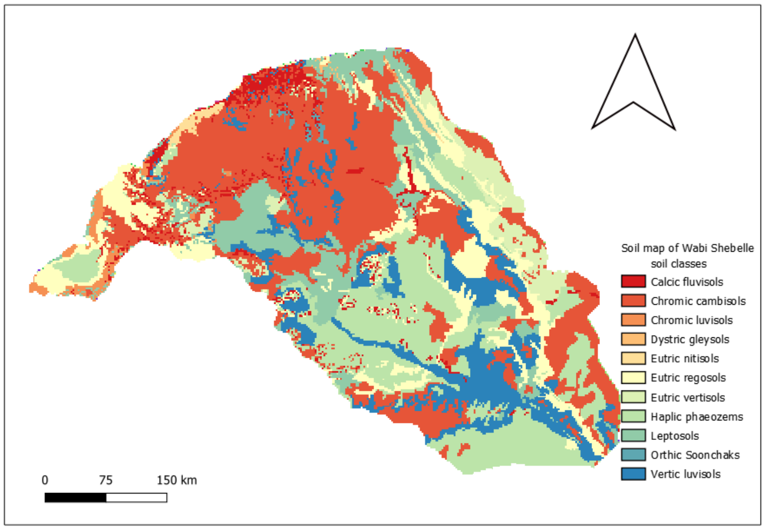


Figure3.5: Soil Map of The Study Area

3.16 Data Collection

3.2.1Precipitation

Rainfall data is the main component of the hydrologic model accordingly there are different data base for rainfall daily data. As shown in the table below (Table3.1)

Table 3.1: Alternative Precipitation data sources and its resolution

Name	**Spatial Resolution**	**Temporal Coverage**	**Spatial Coverage**
TRMM: Tropical Rainfall Measurement Mission	0.25 (~25 km)	1997 - 2015	50°S - 50°N
GPM: Global Precipitation Measurement Mission	0.1° (~10 km)	2014 - present	90°S - 90°N
CHIRPS: Climate Hazards Group InfraRed Precipitation with Station data	0.05° (~5 km)	1981 - present	50°S - 50°N

WaPOR version2.1 database was selected for this study WaPOR rainfall data is based on the CHIRPS database which contain information at three different spatial resolutions. As a result, the

WaPOR database having 5km resolution which is best from TRMM and GPM data's was considered as precipitation data source. The annual precipitation over the Wabi Shebelle river basin varied between 547.7 to 920.2mm/year. During the period of 2012-2021.It can be seen clearly in the map (figure 3.6) maps for the individual years are provided in Appendix A. Most of the precipitation falls in the (high lands) of the WSRB and the biggest land area receives less than 200mm/year. The data collected from National Meteorological Agency (NMA) of Ethiopia for 17 stations located around the watershed and within the watershed for the available period of records have a missing data for some times using normal ratio method the data was filled. However, out of the 17 stations 6 of them found to have relatively better recorded data during the recent years of record. The stations are Gelemso, Gode,Fedis,Jara,Jijiga and Robe. These stations have relatively good quality data for calculating bias.

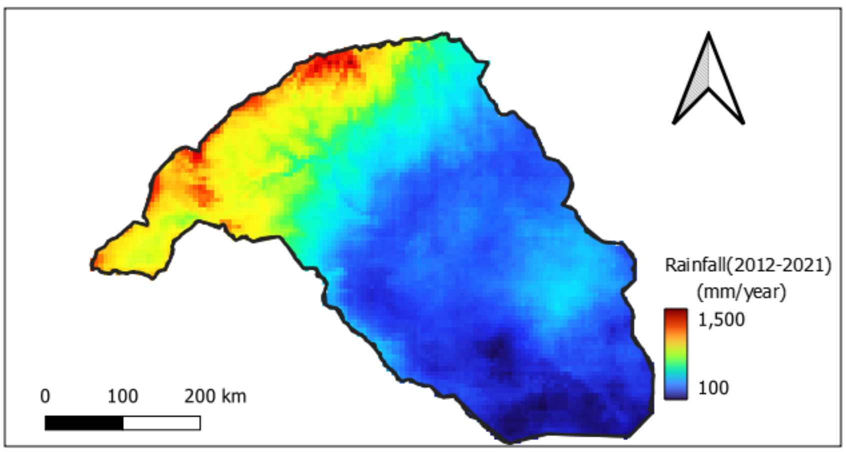


Figure 3.6: Precipitation Map Based on Wapor Average Annual Data of Hydrological Year from (2012 To 2021)

3.2.2 Actual Evapotranspiration and Interception

The sum of evaporation and transpiration from the Earth's land surface to the atmosphere is referred to as evapotranspiration. Evaporation is the conversion of water vapor from rivers, lakes, reservoirs, the sea and oceans, and water tables at or near the land surface to atmospheric water vapor, whereas transpiration is the conversion of water vapor from vegetated surfaces, forests and woodlands, and other plants through leaf stomata to atmospheric water vapor. (Yadeta et al., 2020).

The actual evapotranspiration (ET_a) value for this study observed from the WaPOR (ET_a) level 2 layer estimate the total evapotranspiration including interception with 100m resolution from 2012 to 2021. The precipitation, actual evapotranspiration and interception use to detect areas of the basin which generate and consume water. According to Bastiaanssen (2014).If the precipitation is greater than the actual evapotranspiration and interception it is considered as water generating areas and for those with precipitation less than the actual evapotranspiration and interception are considered as net consumers.

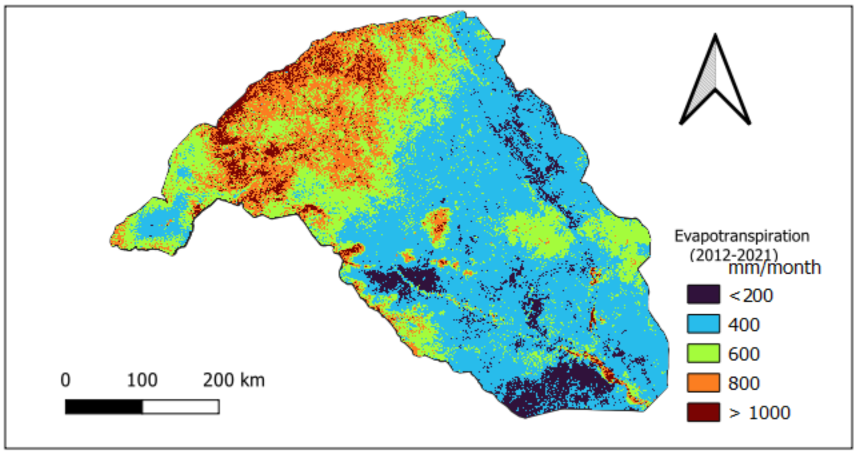


Figure3.7: Et Map Based on WaPOR Average Annual Data of Hydrological Year From (2012 To 2021)

3.2.3 Land cover Classes

Land conservation, sustainable development, and water resource management all benefit from information produced from land use and land cover data (LULC). The amount of evapotranspiration, groundwater infiltration, and overland runoff are all affected by LULC (Tewabe & Fentahun, 2020). A yearly land cover maps for the Wabi Shebelle river basin, which is based on 10-meter resolution of the Sentinel-2 LULC map produced by Esri, Microsoft, and Impact Observatory. The map is derived from ESA Sentinel-2 imagery and is a compound of LULC predictions for 9 classes for each year from 2017-2021.The land cover map provides 9 classes with different land cover classes. The map shows that land cover varies mostly along crop and flooded vegetation at high altitude and shrub land, water and tree in the lower basin trough out the study period 2012-2021 there is no significant change in the area of natural LULC based on Sentinel-2 imaginary.

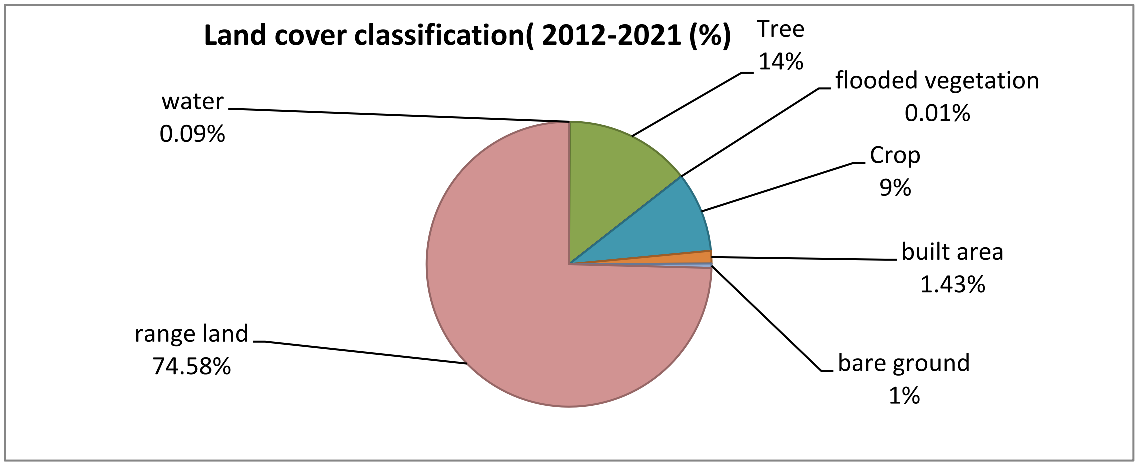


Figure3.8: Land Cover Classes of the Study Area

3.2.4 Saturated water content

The saturated water content (SWC) which are defined as the maximum water content and water in the soil retained against gravity are two important soil hydraulic parameters an alternative, indirect estimation of soil hydraulic properties from widely available or more easily measured. Basic soil properties attracted considerable attention of researchers in a variety of fields such as soil scientists, hydrologists, and agricultural and environmental engineer (Yi et al.,2013).For this study the saturated water content was downloaded from Hihydrosoil (θ_{SAT})$V_{2.0}$ with 250m resolution for the calculation of water balance(Simons et al.,2020).

3.2.5 Protected Areas

A protected area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values. (IUCN,2008).IUCN management categories for protected areas are classified (figure3.9) (Damnjanovic et al, 2016). In Wabi Shebelle 698,200ha Babile Elephant Sanctuary is located 560km east of Addis Ababa and 25km south of the city of Harar and it covers an area of 698,200ha. The area covers a highland, as well as the lowlands of the valleys of the Erer, Daketa, Fafen, Gobele and Borale Rivers; all being tributaries of the WSRB.

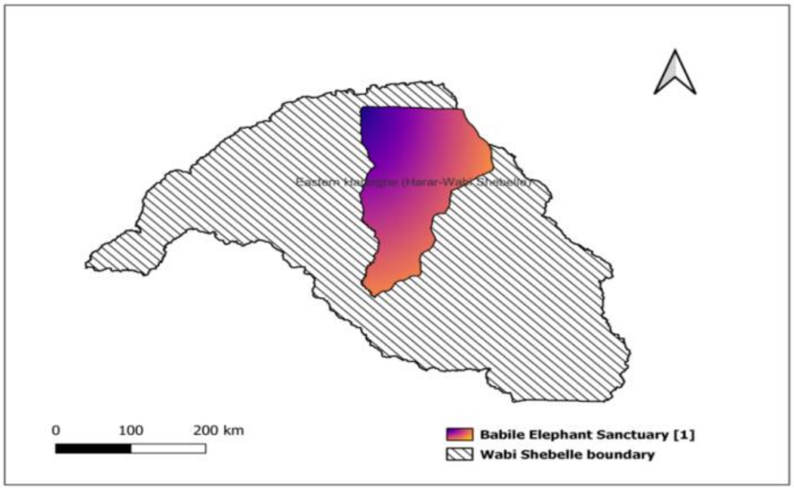


Figure 3.9: Protected Area of the Study Area

3.2.6 Change in Storage

To evaluate how much of the difference between P and ET_a is due to groundwater outflow and change in storage the study used the Gravity Recovery and Climate Experiment (GRACE), a dual-satellite mission continuously monitoring and mapping Earth’s changing gravity field to estimate the total water storage anomalies (TWSA). The GSFC-v02.4-ICE6G solution (Luthcke et al., 2013) was used to validate the assumption that storage change over a longer time scale such as hydrological year should be zero or close to zero. Though, GRACE solution provides mean monthly TWSA, the number of days may not exactly match the days of the months and as such the change in storage ($\Delta S/\Delta t$) in a time period was approximated. After that, $P - ET_a$ should be equal to the total outflow Q_{out}, after correction in change of storage ($\Delta S/\Delta t$) following the water balance equation:

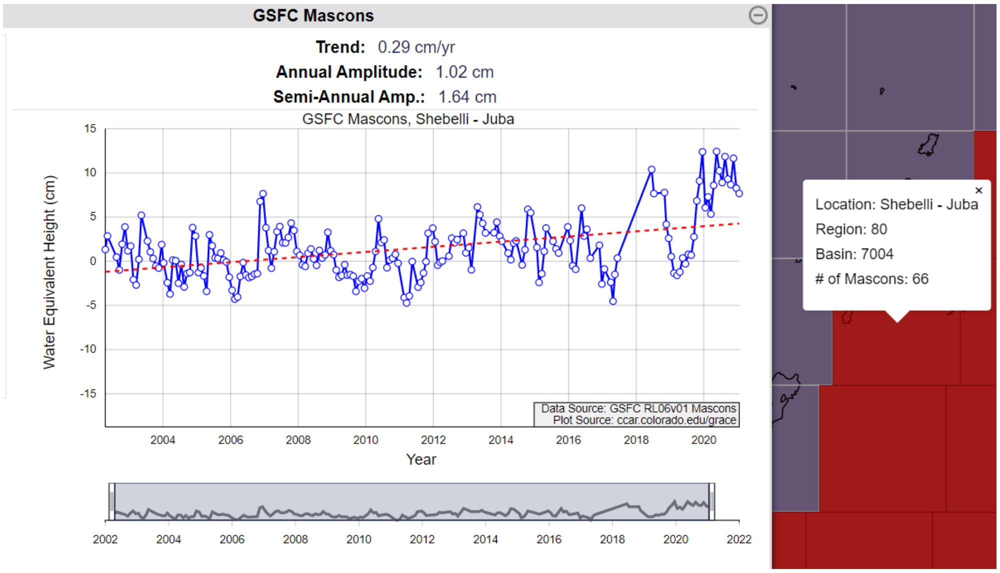


Figure3.10: Longer Term Change In Storage Of Wabi Shebelle Based On Grace Gravity Measurements (Source:Mascon Visualization Tool (Colorado.Edu)

3.3 Preliminary Assessment

Reliability of the collected meteorological and hydrological data significantly affects quality of the model input data. Before using the data for the water accounting plus, several checks must be performed before using the data for Water accounting plus such as

1) Comparing the rainfall data from ground (observed) rainfall data
2) Water generation and consumption analysis
3) Assessment of errors in water balance

3.3.2 Compare Remote sensing products with Ground data precipitation

Long term observed rainfall data for fourteen stations source was taken from Ethiopian National metrological Agency. For the assessment 6 stations was used for comparing namely Fedis, Gode, Gelemso, Jara ,Jijiga and Robe from the period of(2009-2018). The monthly rainfall values were computed from 2008 to 2017 which is for 10-year period. The results showed that CHIRPS data has the finest correlation. Since WaPOR Precipitation data is based on CHIRPS v2.1, it can be considered the best available precipitation product in the Wabi Shebelle River Basin.

Table3.2: Station Name, Location of the Rainfall, Observation Used for Comparison from(2009-2021)

Station Name	Latitude	Longitude	Elevation
Gode	5.9	43.6	295
Jijiga	9.3	42.8	1775
Fedis	8.6	42.3	1700
Gelmso	8.8	40.5	1940
Robe	7.9	39.6	2480
Jara	7.5	40.7	1960

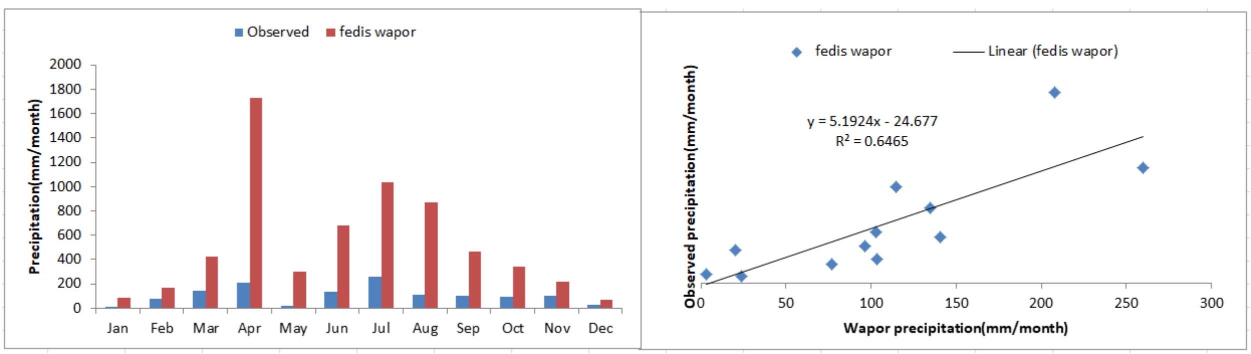


Figure3.11: Monthly Mean Precipitation for Fedis Station

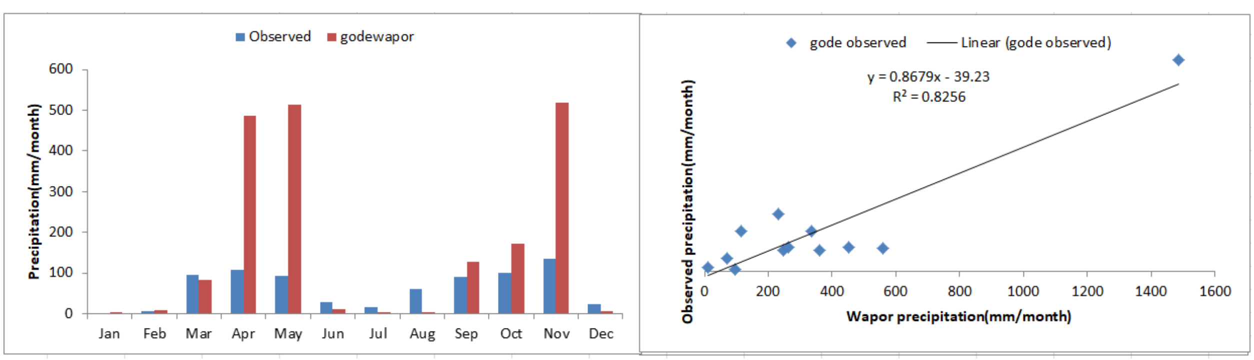


Figure3.12: Monthly Mean Precipitation for Gode Station

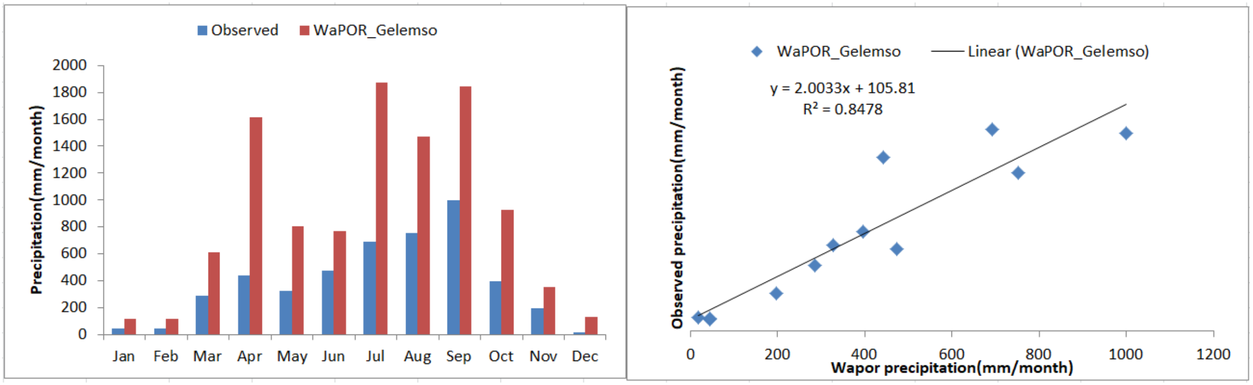


Figure3.13: Monthly Mean Precipitation for Gelemso Station

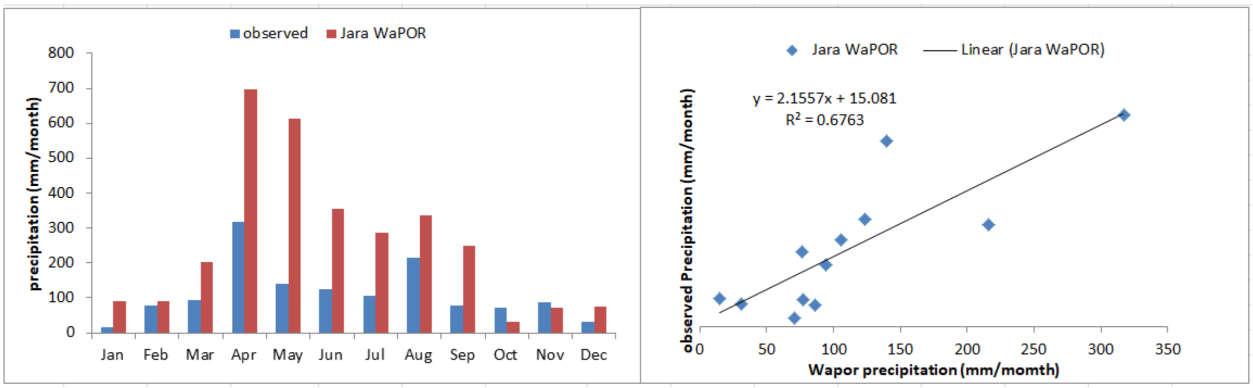


Figure3.14: Monthly Mean Precipitation for Jara Station

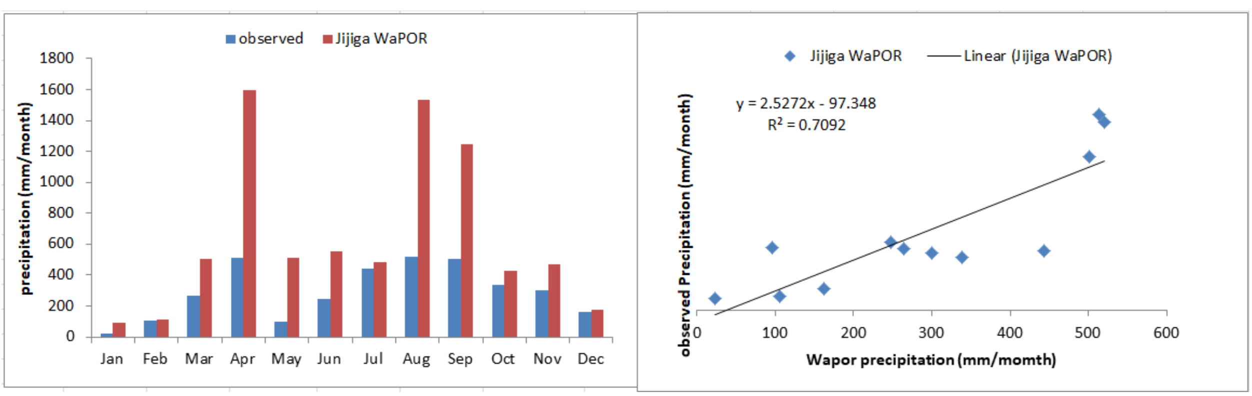


Figure3.15: Monthly Mean Precipitation for Jijiga Station

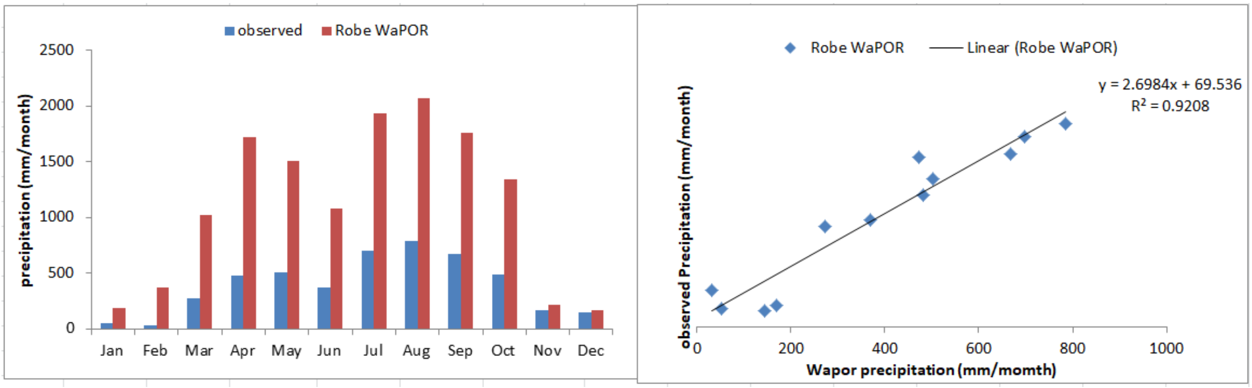


Figure3.16: Monthly Mean Precipitation of Robe Station

3.3.3 Water Generation and Consumption Analysis

The Wabi Shebelle water balance value for each year is compared to have a better sense of the basin. The WaPOR datasets for precipitation, actual evapotranspiration and interception, and land cover class were used to describe rainfall excess (water generation), and lateral transport of water from water surplus to net water consumption per land cover class. Land cover classes that satisfy $P > ET_a$ are considered water generating areas while those fulfill $ET_a > P$ are net consumers of water (Bastiaanssen et al., 2014). The mean annual rainfall excess or deficit ($P - ET_a$) for the years from 2012 to 2021 is mapped in (Figure3.17). The basin wide long term rainfall excess is 198.35 mm/year. As shown in the (table 3.3) difference between precipitation and evapotranspiration showed 40% negative and 60% positive results. The preliminary data quality assessments show that WaPOR 2.1 data can be useful to map the spatial patterns and identify hotspots of net water generation and water consumption in the basin. In general, spatial variation of P and ET_a are reliable with the characteristics of the basin. However, when using these values as absolute in water balance, the excess rainfall $P – ET_a$ is often over-estimated, both at local and basin scales. As can be seen in this map (Figure3.17), the net water consumers are Shrub land and croplands. Specific parts of the WSRB are net water generating areas yielding between 0 and 200 mm/year. However, the total area of these parts is large so even a small excess can accumulate into a large amount of water.

Table3.3: The total annual precipitation (P) and actual evapotranspiration and interception (ET_a) from WaPOR data for the WSRB for hydrological years from 2012 to 2021.

Year	P (mm/year)	P (Mmm^3/year)	ET_a (mm/year)	ET_a (Mmm^3/year)	P-ET_a (mm/year)	P-ET_a (Mmm^3/year)
2012	721.05	1359.31	686.85	1294.82	34.21	64.51
2013	834.51	1573.19	722.11	1361.3	112.4	211.89
2014	713.18	1344.46	653.91	1232.73	59.27	111.73
2015	547.7	1032.5	592.98	1117.86	**-45.28**	**-85.36**
2016	732.21	1380.34	619.48	1167.82	112.73	212.52
2017	626.58	1181.12	629.36	1186.45	**-2.77**	**-5.33**
2018	795.11	1498.92	702.3	1323.94	92.81	174.98
2019	920.2	1734.72	721.85	1360.8	198.35	373.92
2020	767.15	1446.2	818.53	1543.06	**-51.38**	**-96.86**
2021	659.65	1243.54	710.7	1339.7	**-51.05**	**-96.16**
Average	**724.89**	**1366.54**	**685.81**	**1292.8**	**39.08**	**73.682**

The Esri land cover database provides annual map of (2017-2021).Which is based on ESA sentinel-2 imagery at 10m resolution. The land cover map provides 10 land use classes with two different land classes for tree. The major land cover classes in the WSRB is range lands which count 74.58%.Throughout the study period, there were no significant changes in the area of natural land cover classes based on Sentinel-2 data except a very small increase on the crops between (2017-2021).The same calculation was done for each land cover class to identify net water generating and consuming land cover classes (Figure 3.17). It can be seen here that 74% of the WSRB area is made up of the shrub land class. The same calculation was done for each land cover class to identify net water generating and consuming land cover classes (Table 3.5). The biggest net water consumers are shrub lands (-55 Mm^3/year), followed by the croplands class (-6.68 Mm3/year). Though all tree cover classes are net water generators, they account 14.64% of the WSRB. The water balance per land use class (Table3.5) shows, as expected the range land consumed water followed by crops and forest.

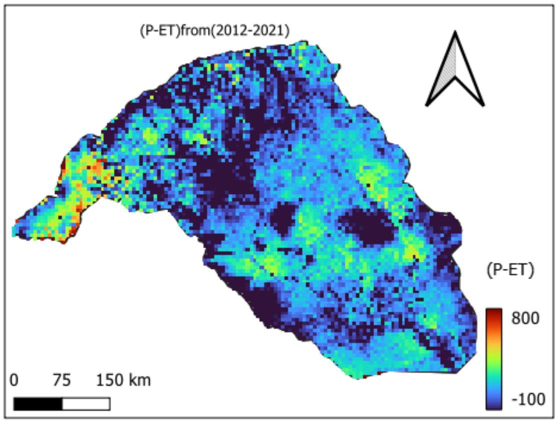


Figure 3.17: Yearly Average of Difference Between Total Precipitation and Total Actual Evapotranspiration and Interception (P – Et_a) from Hydrological Years 2012 To 2021

Table 3.5: Contribution of the land cover classes to mean annual precipitation (P) and actual evapotranspiration (ET_a) of the WSRB for the hydrological years from 2012 to 2021. The land cover classes that contribute less than 0.1% are not presented in the table.

code	**Land cover classification**	**Area (km^2)**	**Area (%)**	**P (Mmm^3/ year)**	**ET_a (Mmm^3/year)**	**P-ET_a (Mmm^3/ year)**	**P-ET_a (%)**
2	Tree	27038.04	14.34	195.96	185.38	10.58	13.33
5	Crop	17061.19	9.05	123.67	116.99	6.68	8.42
7	Built Area	27.01071	1.43	19.54	12.92	6.62	8.34
11	Range land	140586.09	74.58	1019.16	964.17	54.99	69.32
	Total	**188515.302**	**99.4**	**1366.54**	**1292.8**	**79.32**	**99.97**

The water balance per land use class (Table3.5) shows, as expected the range land generate water followed by crops and forest. Range land cover is the largest type with 74.58% of the total area.

The preliminary data quality assessments show that WaPOR 2.1 data can be useful to map the spatial patterns and identify hotspots of net water generation and water consumption in the basin. In general, spatial variation of P and ET_a are consistent with the characteristics of the basin.

However, when using these values as absolute in water balance, the excess rainfall P – ET_a is often over-estimated, both at local and basin scales. Land cover maps from sentinel-2 imagery include some essential Land cover classes (tree, crop and flooded vegetation) but lack many Land and Water use classes in the current WA+ methodology. For example, WaPOR does not differentiate between natural and dammed water bodies and built-up areas of different sectors (residential, industry, greenhouses, etc.). Therefore in sentinel-2 imagery for this rapid assessment, land use maps with only four categories were derived and used in WA+ Sheet 1. For full WA+ sheets.

3.3.4 Assessment of Errors in water balance

The conservation of mass should be fulfilled at basin level, therefore, P – ET_a should be identical after storage corrections ΔS. Since GRACE solution provides mean monthly TWSA not the exact TWSA of the first and last day of the month, change of storage (ΔS/Δt) in a time period was approximated using a second order central difference as proposed by (Biancamaria ,2019; FAO,2020). After that, P – ET_a should be equal to the total outflow Q_{out}, after correction in change of storage (ΔS/Δt) following the water balance equation.

$$\frac{\Delta s}{\Delta t} = P - ETa - Qout \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (3.1)$$

The longer-term trend in storage change (ΔS) as observed by GRACE is almost positive (see Figure 3.10). The trend of water storage for a number of GRACE pixels that cover WSRB from 2012 to 2018 is 39.78 mm/year. This can be considered as a quality check of the WaPOR ET_a. Data for the total river basin from 21012 to 2018 observed data for quality check for the change in storage. On average the mean difference between GRACE TWSA change and WaPOR based water balance is -14.28%. (Table3.4) shows the result of water balance compared WaPOR data.

Error in Water balance for the WaPOR-based Water Accounts of 2012-2018, the total storage change estimated from water balance will be used as GRACE data available for the whole period. However, the error estimated for years is (-14%) at Gode station. For periods and locations without GRACE data and/or observed flow data the error may be larger. For this study it's safe to use the GRACE change in storage since the error is considerable (table3.4). Table 3.4 shows Estimation of Error in Water Balance of WSRB based on GRACE Total Water Storage from2012 to 2018. ΔS from GRACE was calculated from the GRACE TWSA solution and ΔS from Water Balance was calculated as $P - ET_a - Q_{gode}$, where P and ET_a were gathered from WaPOR data and Q_{gode} was the outflow from Ministry of Water and Energy of Ethiopia (MoWE).

Table 3.6: Difference between Storage Change Computed from WaPOR water balance ($P-ET_a$

Year	**$P-ET_a$ (mm/year)**	**Q_{gode} (mm/year)**	**∆s Grace (mm/year)**	**Error (mm/year)**	**Error as %of (mm/year)**
2012	-34.21	21.4	1.3	-56.91	40
2013	112.4	15.3	80.5	16.6	11.9
2014	59.27	14.5	48.3	-3.53	2.5
2015	-45.28	14.19	0.1	-59.57	42.7
2016	112.73	14.21	129.6	-31.08	22.3
2017	-2.77	14.19	-9.4	-7.56	5.4
2018	92.81	14.18	75.9	2.73	1.9
Average	**39.08**	**15.42**	**39.78**	**-19.9**	**-14.28**

3.4 WA+ Methodology

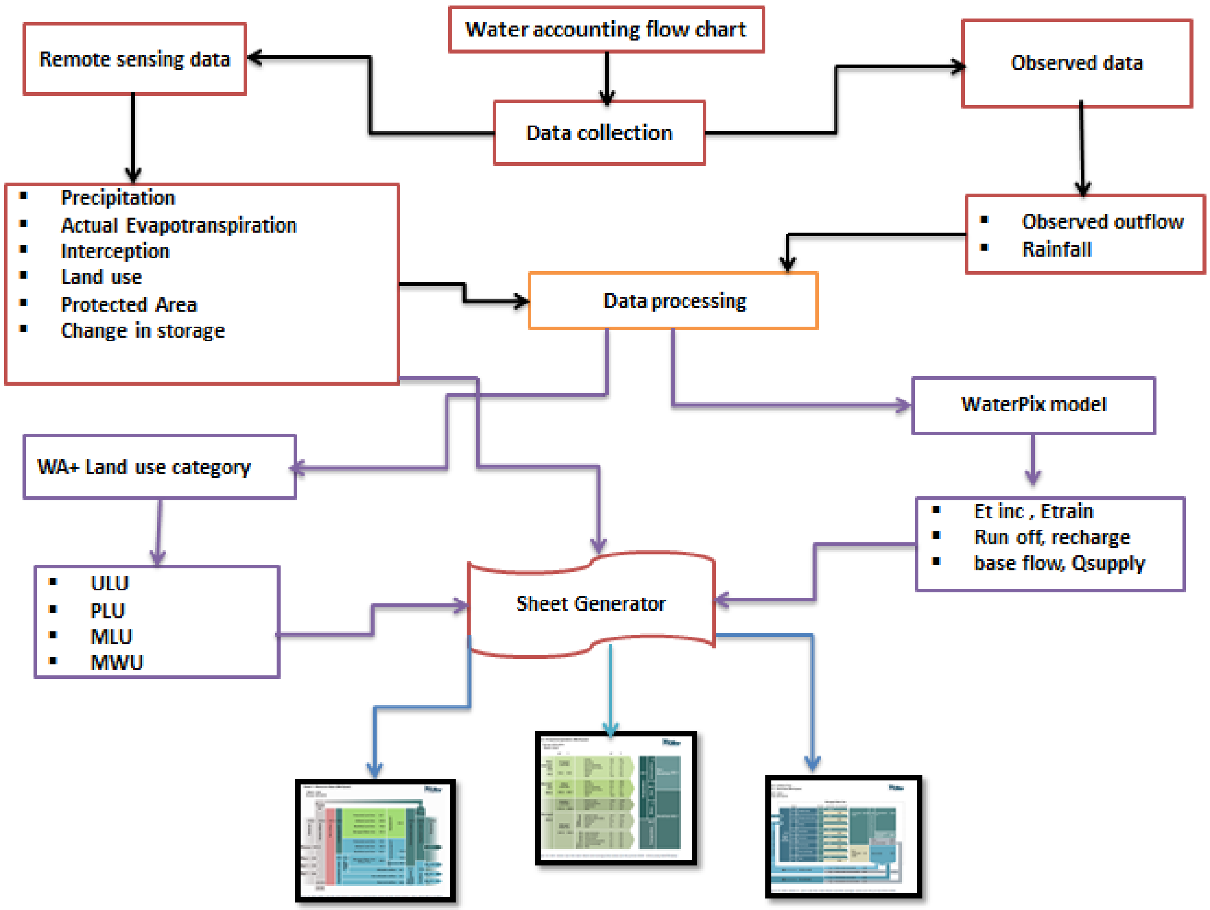


Figure 3.18: Flow Chart Step for WA+ Process

The Water accounting Plus (WA+) framework uses open access remote sensing and GIS data and hydrological model output (Singh et al., 2021). A possible solution to the aforementioned problem is to build on the fact that input data for WA+ can also be obtained from hydrological simulation and water allocation models (Karimi et al., 2013a). In this manner, it would be possible to capitalize on various hydrological simulation models such as HSPF, VIC, Mike Basin, WEAP, WaterPix and the Soil Water Assessment Tool (SWAT). A measurement reporting monitoring system is required for the longer-term planning process of water and environmental resources in river basins. The WA+ framework is developed WA+ for river basin studies to include all water use sectors. More hydrological and water management methods, as well as a focus on specific land uses, will be conducted in the future. WA+ distinguishes between rainfall (ET rain) and incremental ET (ET incremental), due to easy identification of managed water flows. WA+ incorporates the hydrology of natural watersheds, which generate the amount of water in streams and aquifers, as well as water consumption quantification. (Bastiaanssen, 2014).

The output of WA+ is presented a number of sheets and supporting spatial maps. Remote sensing, GIS and spatial models form the core methodology, so all data has a spatial context. The accounts are reported on an annual basis, as WA+ is meant for longer term planning. The rapid WA+ mainly uses satellite data such as precipitation and annual time series of land cover classification, interception and actual evapotranspiration and interception. Additional data sources used include GRACE satellite data for estimating the change in storage in the basin, the World Database on Protected Areas to identify the protected land uses, and the map of top soil saturated water content (de Boer, 2016).

3.5 WA+ Land Use Categorization

According to (Karimi et al., 2013) WA+ divide the landscape into four primary types of land and water utilization (ULU,MLU,MWU,PLU). The goal of classifying is to differentiate their management options from keeping them clean.

- Utilized Land Use (ULU); areas that have a light utilization with a minimum anthropogenic influence. The water flow is essentially natural
- Modified Land Use (MLU); areas where the land use has been modified. Water is not diverted but land use affects all unsaturated zone physical process such as infiltration, storage, percolation and water uptake by roots.
- Managed Water Use (MWU); areas where water flows are regulated by humans via irrigation canals, pumps, hydraulic structures, utilities, drainage systems, ponds etc.
- Protected Land Use (PLU); areas that have a special nature status and are protected by National Governments or Internationals NGO's.

The land use category map is based on the land cover layer from Sentinel-2 database, but needed to be reclassified into the water accounting classes. Protected Land Use (PLU) class was updated using the protected area profile from the World Database on Protected Areas (UNEP-WCMC, 2019). The Managed Water Use class was reclassified from the 'Cropland,

and 'Built-up' classes in Sentinel-2 LCC layer. Water bodies' class except for natural lakes was also reclassified as Managed Water Use class. The Modified Land Use was reclassified from the class 'Cropland, fallow' and 'Cropland' in the Sentinel-2 LCC layer. Thereafter, the rest of the area was reclassified as Utilized Land Use class.

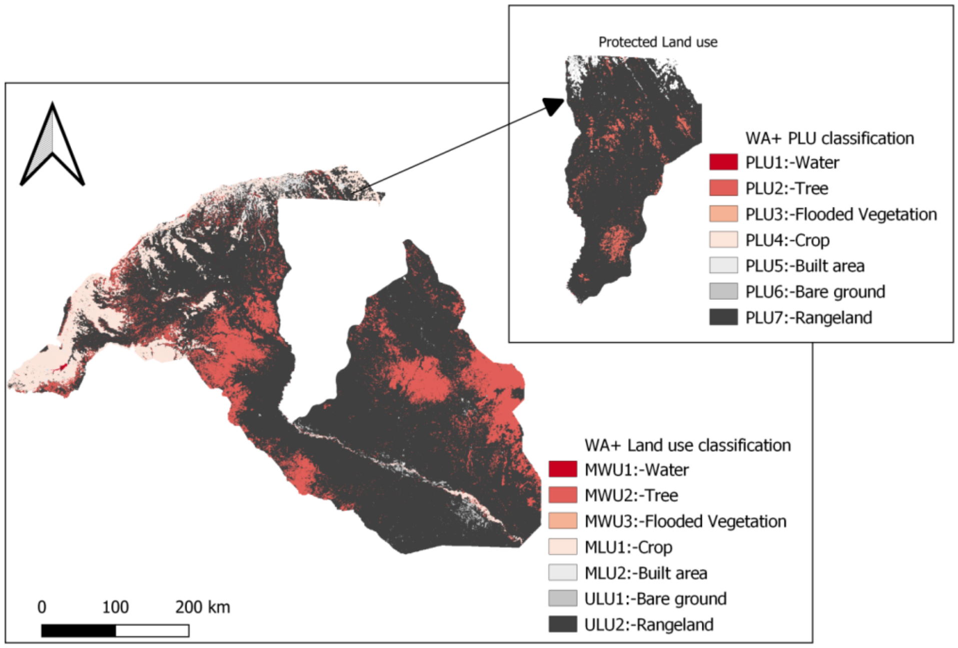


Figure3.19: WA+ Land Use Category Map of Wabi Shebelle in 2021 Based on Sentinel-2 Land Cover (Lcc) Layers and Global Dataset of Protected Area.

3.5.1 Water Accounting sheets

(WA+ sheet 1) the water accounts provide an overview of the water resources and its current utilization per different land use classes. In addition to withdrawals and consumptive use, the return flow must be assessed for quantifying reuse and recycling. As part of the return flow is polluted and contaminated, therefore non-recoverable flow must be addressed explicitly in water accounting. For MWU class. The total consumed water is the sum of water depleted by evapotranspiration and the non-recoverable flow.

(WA+ sheet 2) Identifying the Beneficial and non-beneficial flows, water consumption by land use classes, manmade impact on water consumption.

(WA+ sheet 3) summarizes the utilized flow from groundwater and surface water (Q_{sup}) as well as the return flows to groundwater and surface water per land use class respectively.

3.5.2 Performance Indicators for Water Accounting sheets

The water accounting offers a range of standard indicators. Every sheet comes with its own indicators that derived from information in the sheets.

The WA+ resource base sheet indicator includes Exploitable water fraction is that part of the net inflow that is not lost to the landscape ET processes. The fraction relates to total run-off generated in a river basin and also exploited water from fresh water storage.
Storage change fraction defines the degree of dependency on fresh storage change (1Sfw). The fresh water resources are surface water storage, groundwater storage and total water storage. The negative values indicate storage depletion while positive values indicate that in the accounting period water storage has been increased in the domain.
Available water fraction relates available water to exploitable water. It describes the portion of exploitable water that is actually available for withdrawals within a basin.
Basin closure fraction describes to what extent available water is already depleted in a basin or domain. A closed basin is one where all available water is depleted. According to this definition a closed basin can still have substantial discharge in case all outflow is reserved (Molden et al., 2003). Reserved outflows fraction relates the reserved outflows to outflow via streams and aquifers. It indicates whether the committed outflows are being met. The reserved outflows are intended to surface and groundwater outflow.

Performance indicators for the WA+ evapotranspiration sheet provide key information on the magnitude of beneficial ET in a basin. Water used by key water users in a basin is expressed in terms of five indicators namely Transpiration fraction, a beneficial fraction, a managed fraction, an agricultural ET fraction and an irrigated ET fraction.

the WA+ withdrawal sheet can be essential for estimating the impact of some widely supported solutions in water scarce environments, including efficiency improvements, capturing recoverable flows and groundwater quota. Given the importance of these concepts the performance indicators defined for this sheet include the following:

The Groundwater withdrawal fraction indicator provides information related to the extent that a basin is reliant on groundwater resources for development.

Recoverable fraction indicates the proportion of water withdrawal that is not consumed and, thus, returns to surface and groundwater system. It relates to the definition of recoverable flows presented by ICID (Perry, 20011).

3.6 WaterPix Model

The WaterPix model is a hydrologic data-based model developed by (Espinoz & Bastiaanssen ,2017) to perform water balances at a pixel scale. Water accounting framework distinguishes between a vertical and horizontal water balance. A vertical water balance is made for the unsaturated root zone of every pixel and describes the exchanges between land and atmosphere (i.e. precipitation and evapotranspiration) as well as the partitioning into infiltration and surface runoff. Percolation and water supply are also computed for every pixel to facilitate attributing water supply and consumption to each land use class (Singh et al, 2021). The vertical water balance model used calculates the vertical soil water balance for each pixel (See Figure3.20 and described below). ET green and ET blue are separated by keeping track of the soil moisture balance and determining whether ET can be satisfied through direct precipitation and precipitation stored as soil moisture alone or if an additional water source supply is required. The main inputs into WaterPix are provided in (table3.7). Each parameter is calculated at the model resolution of 100m and available for monthly and annual time steps.

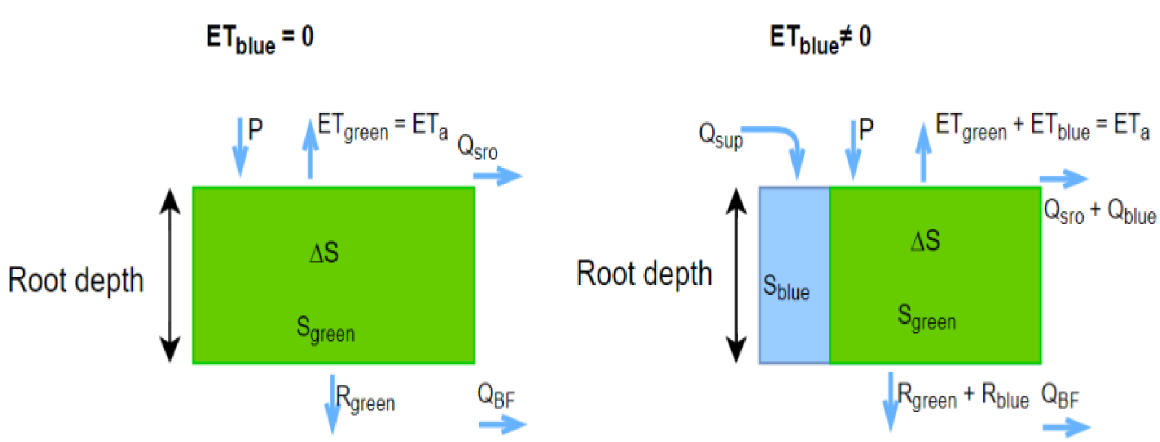


Figure3.20: Main Schematization of the Flows and Fluxes in Water Pix Model (Source:- Sensing&Water,2020a,B)

Table 3.7: Inputs Data for Waterpix Model

Variable	Parameter	Source	Temporal resolution
Precipitation	P	WaPOR	Daily
Actual Evapotranspiration	Eta	WaPOR	Monthly
Interception	I	WaPOR	Monthly
Land cover map	LULC	Sentinel-2	Yearly
Saturated Water content	θ_{SAT}	Hihydrosoil	Stationary

i. Soil Moisture

The soil moisture available for evaporative use (S_{green}) is computed as the soil moisture storage at the end of the previous time step (St-1) plus the effective precipitation (P-I) minus recharge (R_{green}) and surface runoff (Qs). Surface runoff flow is a flow that occurs along a sloping surface and it occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration (Neitsch et al., 2011).

$$S_{rain,\,t} = S_{rain,\,t-1} + (P - I) - R_{rain} - Q_{sro} \quad \text{Eqn(3.2)}$$

Where the surface runoff (Q_{sro},) is calculated using an adjusted version of the Soil Conservation Service runoff method. The adjusted version replaces the classical Curve Numbers by a dynamic soil moisture deficit term that better reflects the dry and wet season infiltration versus runoff behavior (FAO 2019). As the Curve Number method is developed for event based runoff, we calculated $Q_{sro,rain}$ on daily basis, dividing the effective rainfall by the number of rainy days (n) and a calibration parameter to account for the soil moisture variation due to drying up and filling with in a month. The total surface runoff for a month is then multiplied by n:

$$Q_{sro} = \frac{\left(\frac{P-I}{n}\right)2}{\frac{P-I}{n}+f(Ssat-Srain,t-1)} \;*n \quad if\ p\neq 0 \quad \text{Eqn (3.3)}$$

Where the saturated soil moisture (S_{sat}) is calculated by multiplying the Saturated Water Content (θ_{sat}) by the effective root depth (RD) for each land cover class estimated based on the effective root depth by Yang et al (2016).

ii. Separate ET_a into ET_{rain} and ET_{incr}

To compute the green and blue components of ET, ET_a is subtracted from $S_{rain,\ t}$. When S_{green}, t is insufficient for ET_a, the difference will be supplied by surface or groundwater uptake. The rainfall ET becomes the amount which can be supplied by the soil moisture, whereas the difference will become incremental ET.

ET_{rain} = if ($S_{rain,\ t} > ET_a$, ET_a , S_{rain},)……………………………..……………………………...(3.4)

$ET_{incr} = ET_a – Et_{rain}$………………………………………………………………………. ….. (3.5)

After calculating the rainfall ET the new soil moisture storage then becomes Eqn (3.6)

S_{rain}, t = S_{rain}, t – Et_{rain}……………………………………………………………………………..…..(3.6)

iii. Water Supply and Incremental soil moisture

There is still the need to estimate water supply and return flows in order to update the total soil moisture to insert into Eqn(3.2) at the following time step. The amount of water supplied to each pixel is estimated as a function of ET_{inc} and the so-called consumed fraction (fc).

$Q_{sup} = f\ (ET_{incr}, LU) = \frac{ETincr}{f\,c}$……………………………………………………………...(3.7)

Whereas fc is dependent on the land use class and was suggested to replace the classical irrigation efficiencies (Molden, 1997 ; Simons et al., 2016). The consumed fractions (f_c) applied in this study are specified Natural land use classes 1.00 and Irrigated crops 0.80.

A separate soil moisture storage is added to store Q_{sup} and calculate incremental recharge and runoff as follows:

$S_{incr,\ t} = S_{incr,\ t-1} + Q_{sup} - ET_{incr} - R_{incr} - Q_{sro,\ incr}$…………………………………….………….(3.8)

And total soil moisture storage (S_t) becomes:

$$S_t = S_{rain,\,t} + S_{incr,\,t} \quad (3.9)$$

Then total recharge (Rt) is calculated as exponential function of the soil moisture. If the soil moisture is above a certain percentage (calibration parameter) of the saturated content, the percolation will be computed using the following simple exponential function:

$$Rt = St * \exp(-\frac{1}{st}) \quad (3.10)$$

And the incremental recharge (R_{inc}) becomes:

$$R_{inc} = R_t - R_g \quad (3.11)$$

iv. Base Flow

Base flow is the volume of stream flow emerging from the groundwater estimated based on the basin level total outflow (Q_b) using the following basin scale formula (assuming surface storage change is negligible at annual timescale):

$$Q_b = P - ET - \Delta S = Q_{sro} + Q_{bf} - Q_{sup} \quad (3.12)$$

Where

$$Q_{sup}, = (Q_{sup}, LU) = Q_{sup} * f_x \quad (3.13)$$

Where fx is the ratio of surface water withdrawal to total withdrawal. It is assumed that for non-irrigated and non-water body land uses, the supply is only from groundwater, fx then becomes 0, and for water bodies, the supply is completely from surface water, fx becomes 0.95. For irrigated area, the ratio of $Q_{sup,sw}$ and Q_{sup}, is based on the percentage of area prepared with irrigation from surface water (FAO, 2016). The ratio of base flow and surface runoff at annual scale at basin level is calculated as follows:

$$r = \frac{Qsup,sw - Qsro}{Qsro} \quad (3.14)$$

4 RESULTS AND DISCUSSIONS

4.1 sResource Base Sheet

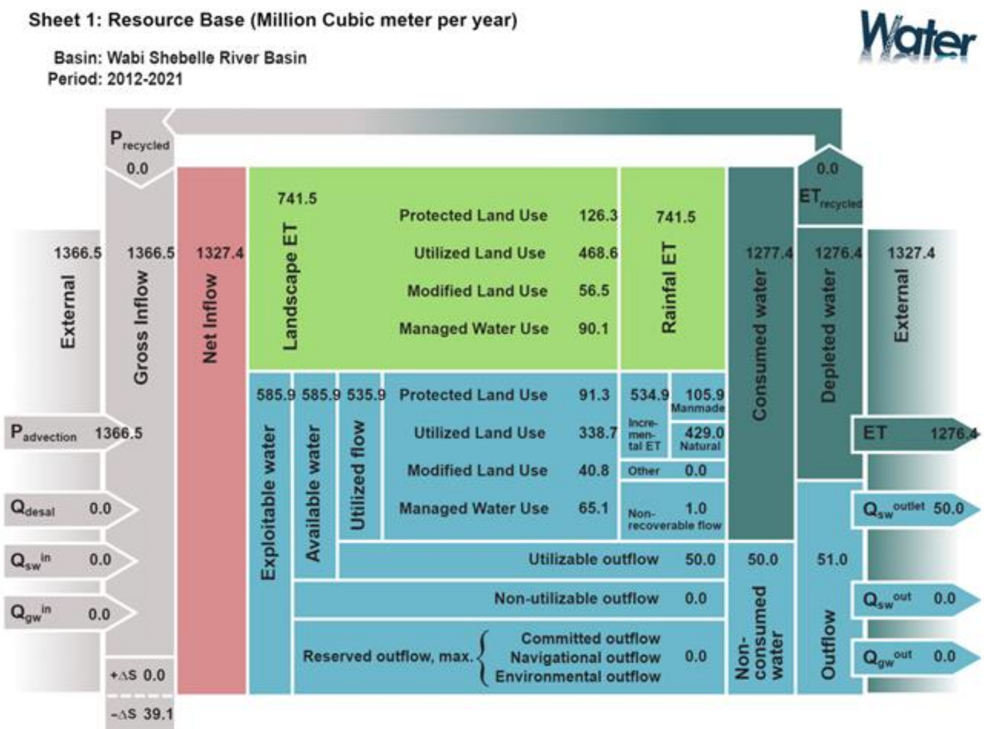


FIGURE 4.1: WA+ Sheet 1 for Wabi Shebelle Basin Containing Average flow Value for the Period of (2012-2021) Resource Base Sheet.

The Resource Base Sheet provides a quick overview of all incoming and outgoing flows for the entire basin and the four Water User Groups identified. The summary of average situation of the water resources in the WSRB for the period from 2012 to 2021 is given in the WA+ sheet 1 as shown in (Figure4.1). The WA+ sheet 1 for individual years is provided in Annex D. The year 2011 is considered as a 'warm-up' period for the WaterPix model and therefore it is not included in the analysis.

The Resource Base Sheet shows the available water for 10 years in WSRB is 585Mmm^3/ year. According to pervious study (Adane.,2009) estimate 578Mmm^3/year it shows reasonable estimate with the water accounting.Utilized Land Use controls the water balance of the basin.

The ten-year average gross inflow is 1366.5 Mm^3 /year while the total outflow from the basin is 1327.4 Mm3 /year with the difference 39.1 Mm^3 /year is supplied by depleting the storage. The exploitable water resources in the River Basin are 585.9 Mm^3 /year.

The highest water consumption is from the Utilized Land Use (468.6 Mm^3 /year from ET_{rain} and 338.7 Mm^3/year from ET_{incr}). The Modified Land Use consumes the least water (56.5 Mm^3 /year from ET_{rain} and 40.8Mm^3 /year from ET_{incr}). The Managed Water Use consumption is 155.2 Mm^3 /year (90.1Mm^3 / year from ET_{rain} and 65.1 Mm^3 /year from ET_{incr}). The Protected Land Use category consumes about 217.6 Mm^3 /year with about 41.9% from $ET_{rain.}$ The total ET_{incr} of the basin is about 42% of the gross inflow where about 54% of it is supplied from storage.

The available exploitable water resources in the Wabi Shebelle basin are 585.9 Mm^3 /year out of which 535.9Mm^3/year is utilized within the basin and 50Mm^3/year is transferred out. The renewable water resources are higher (625 Mm^3 /year), due to an increase of the basin storage by 39.1 Mm^3 /year. Not all utilized flow contributes to the economy. The majority of ET_{inc} (total volume 534.9Mm^3 /year) originates from natural withdrawals (429.01Mm^3 /year) and less from human-made withdrawals (105.9Mm^3 /year) meaning that the majority of the available water resources goes to Utilized Land Use (ULU). Rarely this usage of blue water appears in water allocation plans, because this consumption occurs naturally and is out of sight from water managers.

The water resources situation described above shows the average condition over the decade from 2012 to 2021, however the situation varies greatly from year to year depending on the amount of rainfall the basin receives, as described in the following section.

The graph (figure 4.2) shows the estimated annual ET_{rain} and ET_{incr} averaged over the study period .In the WA+ framework a distinction is made between two types of evapotranspiration .Evaporated water originating directly from precipitation is termed green evapotranspiration (ET_{rain}), while evaporated water coming from groundwater aquifers,lakes or streams is called blue evapotranspiration (ET_{incr}). Water flowing in rivers and water stored in surface and groundwater reservoirs is defined as blue water. Water in the root-zone on the other hand can consist of both green and blue water. This is either replenished through precipitation or therefore defined as green water, or water is replenished through human actions (e.g. irrigation) or through flooding, which then is defined as blue water. Figure 4.2 describes the partition of ET rain and ET incr of each hydrologic year and the ratio of each component relative to total rainfall. ET incr is increasing over the years. ET rain is greater than the ET_{inc} except 2013 and 2019.

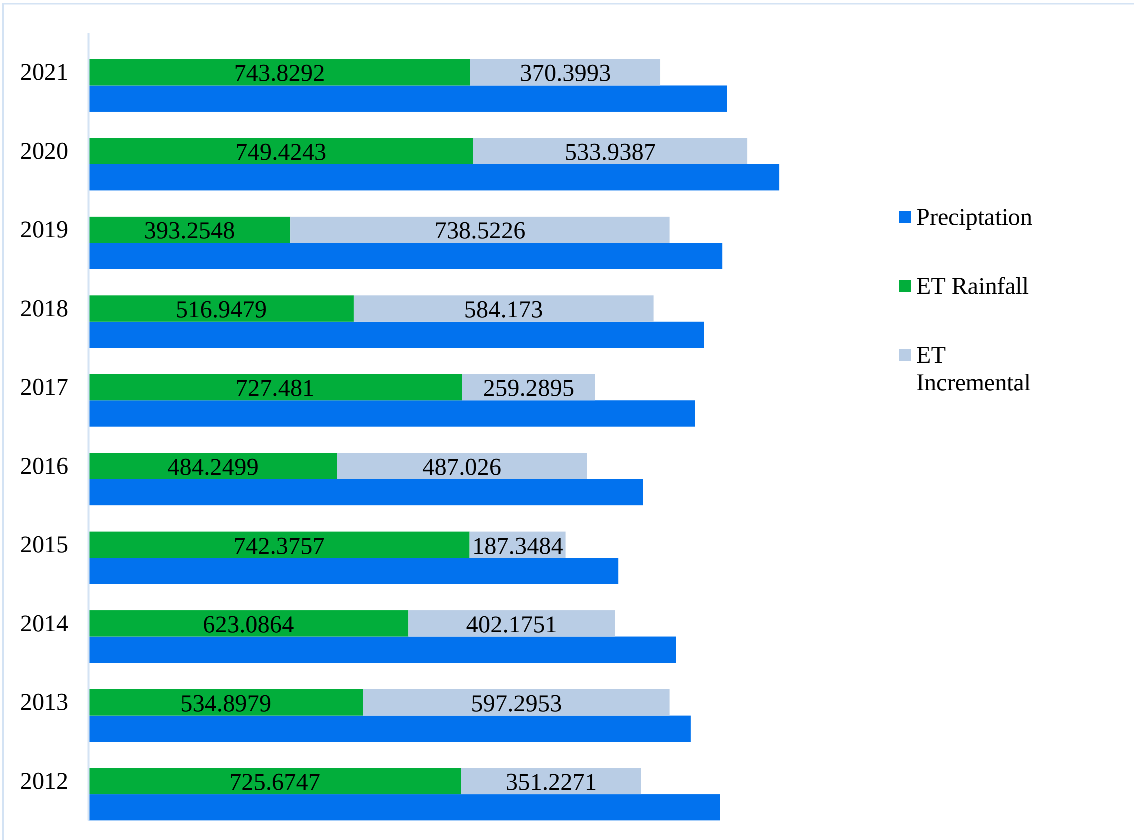


Figure 4.2: Yearly Average Precipitation, Et_{rain} and Et_{inc} of for The Hydrological Years 2012-2021

4.1.1 Performance Indicators for Resource Base Sheet

The key performance indicators are presented in Table 4.1. Since there were differences between the storage change computed from WaPOR data, GRACE gravity measurements, and change in storage computed from yearly water balance (Table 3), the later was used for computation of the key indicators as shown in (Table 4.1). The average ET fraction of the basin is 95.01 indicating consumption less than the average precipitation by about 5%. This difference is supplied from depletion of storage. However, GRACE total storage change estimates an increase in storage. Because of this discrepancy, the state of total water storage change from 2012-2021 cannot be reliably estimated.

Table 4.1: WA+ Resource Base Sheet Performance Indicator for the WSRB

Year	ET Fraction (%)	Stationary Index	Basin closure	Available Water (Mm^3/year)	Managed Water (Mm^3/year)
2012	103.9	-2.6	98.78	367.9	12.59
2013	85.51	8.3	92.66	937.7	10.44
2014	90.59	4.8	94.45	604.3	10.66
2015	106.9	-4.1	79.77	150.5	13.84
2016	83.59	9.7	91.76	805	10.15
2017	102.82	-0.02	97.4	317	3.16
2018	87.2	7.09	93.44	885	5.62
2019	77.51	14.74	88.94	1267.5	6.14
2020	105.42	-3.3	98.13	556.3	5.33
2021	106.44	-3.8	97.57	359.8	13.02
Average	**95.01**	**3.08**	**93.29**	**625.1**	**9.09**

The key performance parameters presented in Table 4.1 describes the river basin system by a few indicators. The ET fraction is highest in 2015 with about 106.9% indicating more than the precipitation amount was consumed in that year. The additional amount consumed (9%) comes from storages in the basin. The ET fraction is lowest for the year 2019 with 77.51% indicating that not all rainfall is consumed so that surplus of rainfall is used to increase storage in the basin. The representative value for ET fraction across the study period (2012 to 2021) is 95.01%. The Stationary Index indicator describes what percentage of the consumption is originating from storage changes. An average negative indicator of 3.08% means that wither groundwater or storage in the reservoirs were being depleted and there was net recharge in the period studied. The average basin closure index is 93.29 %, which shows that all water resources is consumed and/or stored in the basin.

The second set of indicators in Table 4.1 focuses on the actual amount of water that is currently managed, or is available to be managed. The total amount of Available Water is 625.1Mm^3 /year depicting a situation where more water than the available is already managed. 55.9 Mm^3 /year is being managed in addition to the average 78.7 Mm^3 /year.

4.2 Evapotranspiration Sheet

WA+ Evapotranspiration sheet divide the total ET in to evaporation, transpiration and interception and also quantifies the consumption of water per land use class and summarizes the relationship between beneficial and non-beneficial ET (Figure 4.2). Any WA+ user can insert a judgment value to estimate to what extent water is consumed beneficially. In Wabi Shebelle the transpiration is assumed to be beneficial and the interception is assumed to be non-beneficial according to (Karimi et al., 2013).

WA+ sheet 2 quantifies the consumption of water per land use class and summarizes the relationship between beneficial and non-beneficial ET (Figure 4.3). rainfed crops evaporates (48.3 Mm^3 /year) and this exceeds the ET volume rainfed crops (18.1 Mm^3 /year). The extensive Wabi Shebelle manageable natural areas in the mountains of the basin can be hold responsible for the large ET of (808.8 Mm^3 /year). One short-term conclusion is that the ET volume from all cropland (48.3 Mm^3 /year) is similar to the ET of ULU land use (808.9 Mm^3 /year). The ET components (T, E, I) presented in WA+ Evapotranspiration sheet are based on WaPOR dataset. E is with 838.1 Mm^3 /year (74.4 %) far more than T (441.3 Mm^3 /year with 14.6%) and I (122.6 Mm^3 /year with 10.9 %). As a consequence, the vast majority of the water resources is used beneficially (58.5%) and this is a very positive observation.

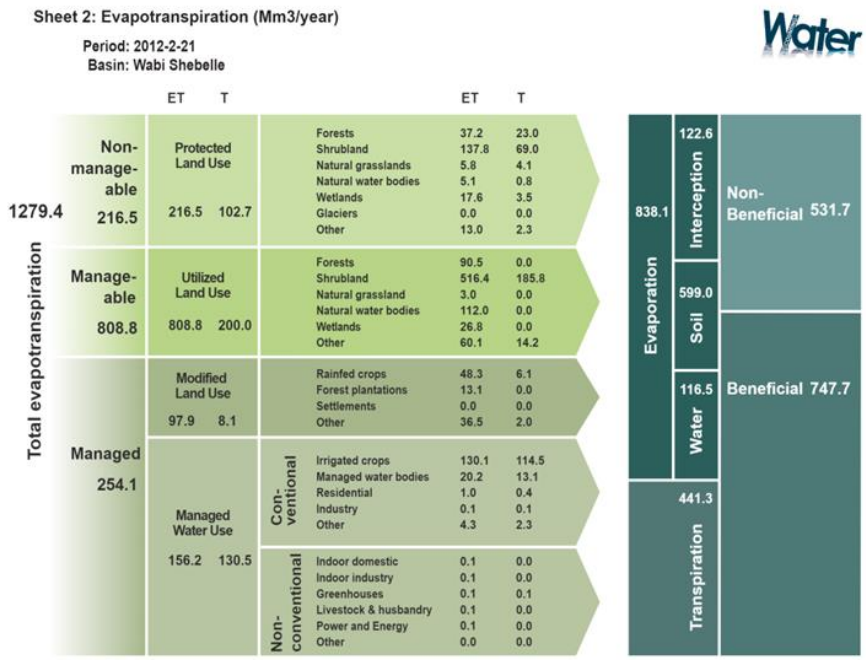


Figure 4.3: WA+ Sheet 2 for Wabi Shebelle Basin Containing Average Flow Value for the Period of (2012-2021) Evapotranspiration Sheet.

The amounts of water consumption for different land uses are presented on the left. The figure (4.3) shows 38% increase of ET_a of 'Managed land use' as the most significant component to show the role of human activities on water consumption. The right side of the report shows 'Beneficial' and 'Non-beneficial' water consumptions. In this part, beneficial evapotranspiration is considered as transpiration of crops and natural plants. While non-beneficial evapotranspiration occurs through evaporation from soil, reservoirs ,etc. The comparison between the WaPOR and WA+ ET split is provided in Figure(4.4). It shows the proportion of ET_a components following both methods. There is a considerable difference between T and E components generated by WaPOR at the one hand and the WA+ algorithm at the other hand. WA+ generally estimates substantially high T compared to the WaPOR algorithm (63% for WA+ compared to 59% for WaPOR) (Figure 4.4). This affects the estimation of beneficial and non-beneficial water consumption.

Figure 4.4:- Comparison of E, T,I Components from Input Wapor Data and Wa+ Output

4.2.1 Performance Indicators for Evapotranspiration Sheet

The Evapotranspiration Sheet provides an overview of what happens with the total amount of water consumed. Performance indicators for water accounting plus evapotranspiration sheet provide key information on the magnitude of beneficial ET in a basin and benefits of water consumption are determined per land cover. Water used by key water users in a basin is expressed in terms of fraction shown in the (table 4.2). A substantial amount of water (67 %) is used non-beneficially by vast volumes of soil evaporation. Soil evaporation in the Awash basin

The WA+ evapotranspiration sheet has five indicators namely a transpiration fraction, beneficial fraction, managed fraction, Agricultural ET fraction and an integrated ET fraction .The transpiration fraction gives an indication of which part of the ET evaporated by plant leaves for WSRB the ratio was 0.34 meaning the majority water depleted in the basin through soil and water evaporation and interception of canopies and other wet surfaces.

The managed fraction represent the portion of ET that is related to any kind of human intervention or the modified land use and managed water use used help to save water. It is the ET process in a basin manipulated by land use, cultivation practices and water withdrawal.

The agricultural ET fraction is the part of ET that is from agricultural activity and the irrigated ET fraction which indicate the portion of agricultural ET that is related to irrigated agriculture.

Table 4.2**:** WA+ Evapotranspiration Sheet Performance Indicator for the WSRB

Indicators	**Calculation methods**	**Values**	**Description**
T fraction	$\frac{Transpiration}{ET}$	0.34	Low canopy water depletion
Beneficial fraction	$\frac{ETbeneficial}{ET}$	0.58	Low benefits from water depletion
Managed fraction	$\frac{ET\ managed}{ET}$	0.19	Low ET process can be regulated
Agricultural ET fraction	$\frac{AgriculturalET}{ET}$	0.16	Agriculture is not major water consumer
Irrigational ET fraction	$\frac{IrrigatedET}{AgriET}$	0.57	Agriculture relies on irrigation water

4.3 Withdrawal sheet

The WA+ withdrawal sheet delivers information on total withdrawal (surface water and ground water abstractions). Withdrawal data for WSRB used from WaterPix model results to complete the WA+ withdrawal sheet. The average exploitable water is 585.9 Mm^3 /year, out of which an amount of 535.9 Mm^3 /year is utilized (Figure4.4). WA+ sheet 3 describes in more detail how this water resources are currently utilized. A distinction between human-made (Figure 4.4) and natural land-use withdrawals (Figure 4.5) is made. The Utilized Flow Sheet provides a summary of consumptive and non-consumptive water uses in the basin within the category of Managed Water Use, including the amount recovered through return flow. This sheet reflects the manmade decisions on allocating and re-distributing surface and groundwater

The WaterPix modeling result after integrating the remote sensing data showed that an amount of 37.1Mm^3/year of water was diverted of this 390Mm^3/year originated from ground water and surface water contributed 156.35Mm3/year .The gross human induced withdrawal is the sum of supplied water computed by WaterPix, which is 91.71 Mm^3 /yr. This is the total amount from all the pixels that are identified to have a certain minimum period of time during which extra water is supplied (in addition to rainfall). A fraction of 68% is assumed to originate from groundwater, as groundwater is the major source of water management applications. The groundwater withdrawals in WA+ sheet are 72.65 Mm^3 /year and the incremental ET the depleted due to water supply is 66.6 Mm^3 /year and that 56.8 Mm^3 /year goes to irrigated crops land-use. The non-depleted part of the utilized water return to groundwater and surface water as the incremental surface runoff (5.62Mm^3 /year) and incremental percolation (19.43 Mm3 /year). In WA+ sheet 3, the non-recoverable flow is estimated based on return flow from supplied water (i.e. through irrigation), which is 19.43 Mm^3 /year in addition to the 5.62 Mm^3 /year recoverable return flow.

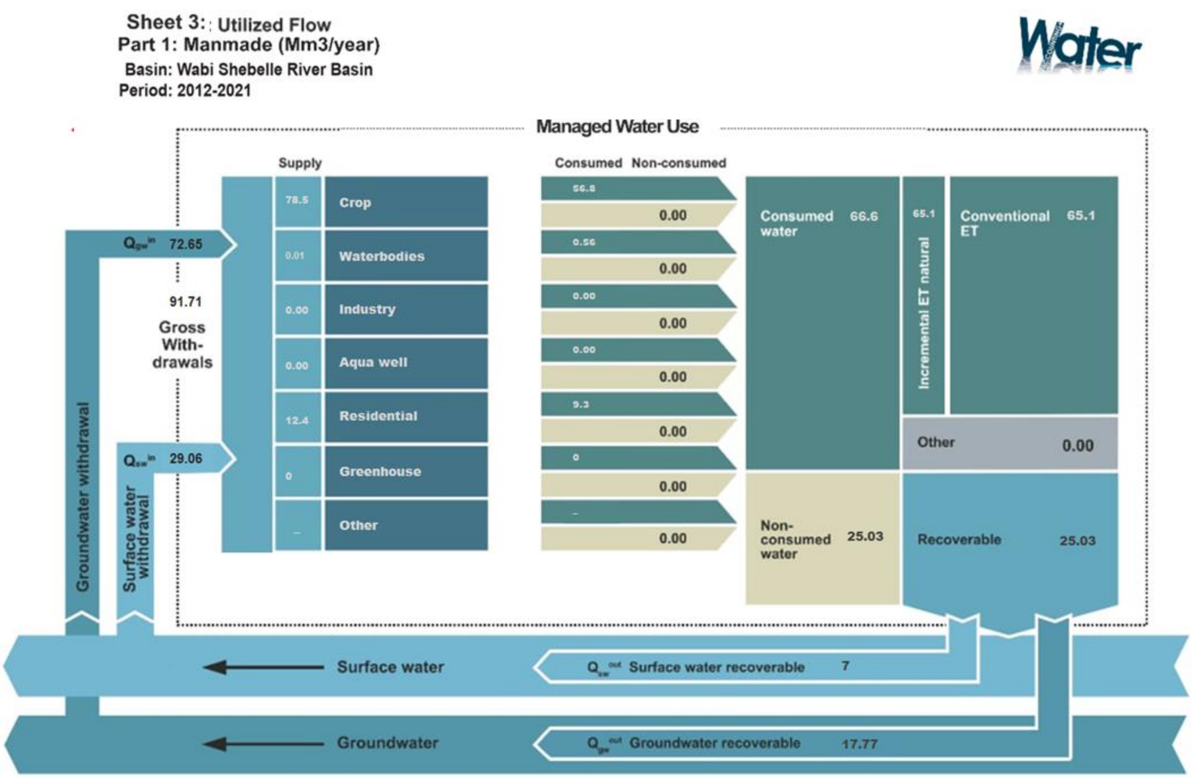


Figure 4.6: wa+ sheet 3-Part One for WSRB and the Average Values for the Period (2012-2021)

For a more explicit recognition, inter-basin transfer is kept out of the Utilized Flow. The large areas of Utilized Land Use and their interception of exploitable water in a natural manner due to various mechanisms for longer or shorter periods is expressed in a total natural gross withdrawal of 445.1 Mm^3 /year (Figure 4.5). In other words, the ET of forests cannot be explained by rainfall only and their ET in summer and fall relies on underground water availability. Because of the character of natural withdrawals, which is that vegetation withdraw only the amount of water it requires, all supplied water is consumed.

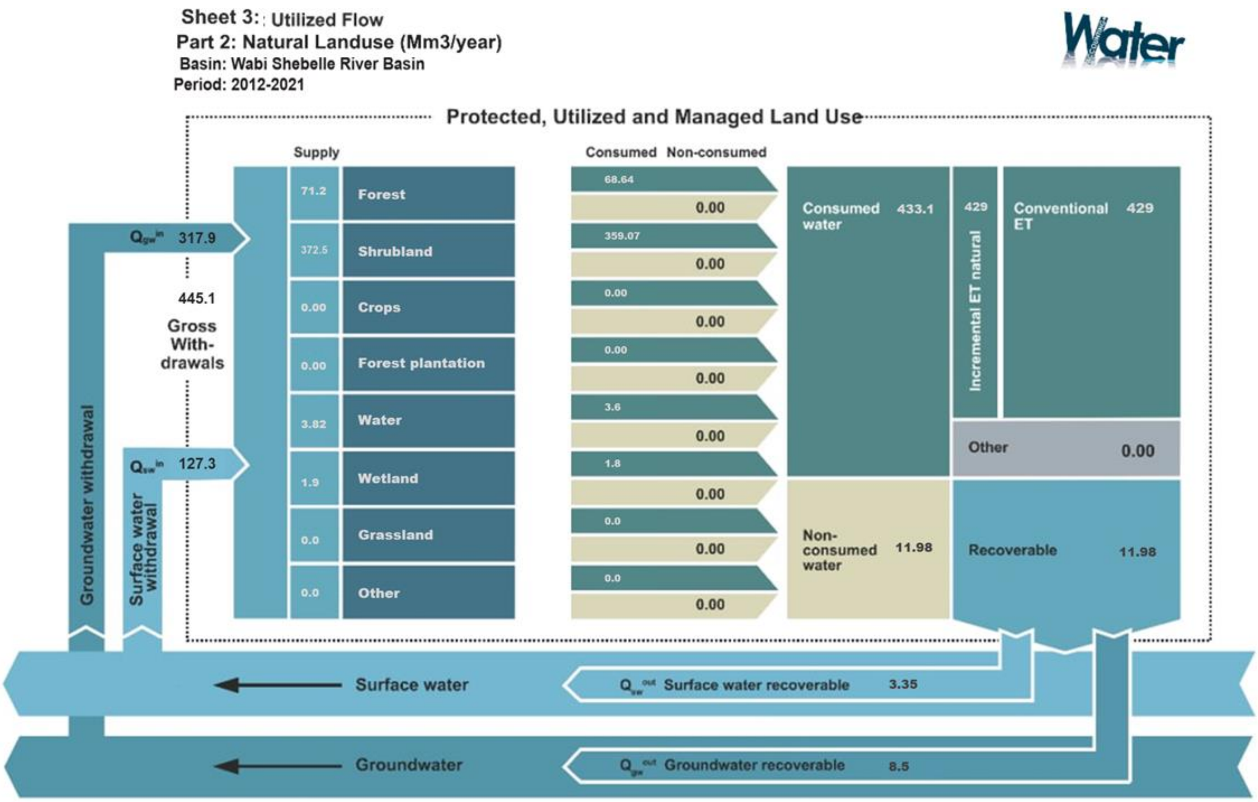


Figure 4.7: WA+ Sheet 3-Part 2 for WSRB and the Average Value from 2012-2021

(Table 4.3) given the importance of these concepts the performance indicators defined for this sheet include the following

Table 4.3: WA+ Withdrawal Sheet Performance Indicator for the WSRB

Withdrawal sheet	**Calculation methods**	**Values**	**Description**
GW withdrawal fraction	$\frac{Qgw}{Qsw + Qgw}$	0.71	Reliance on groundwater is significant
Basin Efficiency	$\frac{IncriET}{QW}$	0.9	Basin as a whole is an efficient system
Recoverable fraction	$\frac{Qr}{Qw}$	0.06	Recycling situation is very low

The result show the basin relishes a high classical basin efficiency of 0.9 at basin level the WA+ performance indicator reveals that the irrigation efficiency for the basin is excellent and will be difficult to improve. The recoverable fraction for the basin is 0.06 which indicate than 6% of the gross water withdrawal were recovered into the hydrological system and reused through surface and groundwater systems. Information presented in the WA+ withdrawal sheet can be essential for estimating the impact of some widely supported solutions in water scarce environments, including efficiency improvements, capturing recoverable flows and groundwater measure.

5 CONCLUSION AND RECOMANDATION

5.1 Conclusion

The WSRB faces a huge challenge in terms of water security. Water accounting plus (WA+) provides an analytical framework that summarizes water resources condition and management in River basin. The framework uses state of the art satellite based measurement of land and water to quantify hydrological variables. This makes WA+ application to a large amount independent from conservative hydrological measurements. This makes it feasible to apply WA+ on any river basin including poorly gauged and ungagged basins.

Water supply in the basin will further be depleted as demands for agriculture, domestic and industry continues to grow. Water resources of the basin are already being limitedly utilized. Hence, considering the state of water resources in the basin provide helpful information for stakeholders and decision maker for collaborative and sustainable development of the basin and beyond. A simple and rapid water accounting of the WSRB has been performed using remote sensing data for the period 2012 to 2021.

WA+ uses satellite data measurements as input data, instead of detailed hydro-metrological measurements with consideration of data uncertainty and errors in water balance, it is still safe to use the data. This independence makes it feasible to apply WA+ basically everywhere to get clear understanding of the water resource situation. The study shown that for the period 2012 to 2021 the evapotranspiration (ET_a) is receiving greater precipitation (P). Even with a very small proportion (0.23%) of outflow from the average gross inflow to the basin, part of the consumption is supplied by depleting water from the storage in the basin. The spatial patterns of the difference between P and ET_a revealed that ET_a far exceeds P in shrub lands and wetlands. The WaPOR 2.1 Level 2 data quality assessments showed reasonable estimates of P and ET_a at basin scale and as such can be useful to map the general spatial distribution and identify areas of net water generation and water consumption in the basin.

However, the water consumption in bare and sparse land use is unrealistic and could be due to uncertainties in P and/or ET_a . Irrigated croplands consume far greater amount of water than precipitation but these are not the only consumer land use cover types. Natural land covers also consumed water though in a reduced amount. Land cover in the basin remains largely unchanged though out the decade, except small percentage change of irrigated cropland to rainfed cropland and vice versa, and as such the water consumption pattern remained the same. The average gross inflow (1366.5Mm^3 /year) is less than the total outflow (51 Mm^3 /year) with the difference being (1315.5 Mm^3 /year) indicating there is more outflow from the basin. There is huge uncertainty associated with the values of P and ETa , the gap between inflow and outflow would be in the right order of magnitude compared to observed outflow. It is clear from the analysis that even if the WaPOR P and ETa have some errors especially for low values in the low lands and thus the water balance is not accurate, the basin is a closed basin in a way that the outflow is a very small fraction of the inflow and all the remaining water is consumed together with storage depletion. Therefore, the largest proportion of the water in the basin is consumed by natural land covers. The largest net water consumption is from range or shrub lands. The beneficial water consumption contribution to ET_a is low compared to non-beneficial consumptions. Agricultural expansion in the basin can be applied if non-consumptive use of water by natural land covers is minimized through improvement of landscape strategies. However, such expansion should take into account the impacts of land uses changes and its impact on hydrological response of the basin. The input data for the other WA+ sheets may generally be calculated by satellite observations, with the exception of the withdrawal sheet, which is more tied to traditional water accounting techniques. Basin outflow and inter-basin transfer flows must be monitored at all times. Remote sensing techniques provide access to spatial data and allow the framework to be used to any basin that is not gauged or is poorly gauged. Another advantage of adopting remote sensing is the low cost of data acquisition and quick data availability. Ground data collection and survey data collection often necessitate a large amount of labor to collect and analyze the data. Remote sensing analysis may be completed fast and inexpensively.

5.2 Recommendation

This research doesn’t provide the productivity sheet and recommendations for the management of the WSRB. The intention is merely to assess the current water resource availability in the WSRB and to identify the water consumed by different land use classes in the WSRB. The WA+ results for the Wabi Shebelle demonstrate that there is limited scope for allocating water for agriculture in the WA+ productivity to describe the agricultural production per unit of water and information on the bio-physical land productivity and water productivity in the WA+'s four land categories. By connection of a conceptual model having high simulation capabilities with a significant water accounting framework perform a useful integrated tool to support: more realistic policy and decision making, better understand of the current state of water resources and predict future challenges and opportunities that is strongly recommended for other regions suffering water scarcity.

REFERENCE

Abdollahi, K., Bazargan, A., & McKay, G. (2019). Water Balance Models in Environmental Modeling. Handbook of Environmental Materials Management, July 2018, 1961–1976. https://doi.org/10.1007/978-3-319-73645-7_119

Adane Abebe, 2009. Hydrological Drought Analysis-occurrence, severity, risks: the case of Wabi Shebele River Basin, Ethiopia. A dissertation vom Fachbereich Bauingenieurwesen der University at Siegen genehmigte.

Al-Bakri, J. T., Shawash, S., Ghanim, A., & Abdelkhaleq, R. (2016). Geospatial techniques for improved water management in Jordan. Water (Switzerland), 8(4), 1–22. https://doi.org/10.3390/w8040132

Amarasinghe, U. A., Shah, T., Turral, H., and Anand, B. K.: India's Water Future to 2025–2050: Business-as-Usual Scenario and Deviations, IWMI Research Report 123, International Water Management Institute, Colombo, Sri Lanka, 2007.

Anderson, M. C., Allen, R. G., Morse, A., & Kustas, W. P. (2012). Use of Landsat thermal imagery in monitoring evapotranspiration and managing water resources. Remote Sensing of Environment, 122, 50–65. https://doi.org/10.1016/j.rse.2011.08.025

Awass, A. A. (2009). Hydrological Drought_thesis.

Awulachew, S. B., Yilma, A. D., Loulseged, M., Loiskandl, W., Ayana, M., & Tena, A. (2007). Water Resources and Irrigation Development in Ethiopia. In Iwmi: Vol. Working Pa (Issue January).

AT, W. (1998). Conflict and cooperation along international waterways. Water Policy, 1(June), 251.

Basin, C., Plus, W. A., International, W., Basin, C., Basin, C., Wa, U., & Plus, W. A. (2013). Synthesis WA+ facts. January 2003. www.wateraccounting.org

Basin, R., Tadesse, K. E., Melesse, A. M., Abebe, A., Lakew, H. B., & Paron, P. (2022). Evaluation of Global Precipitation Products over Wabi Shebelle. 1–17.

Bastiaanssen, W., Ha, L. T., & Fenn, M. (2015). Water Accounting Plus (WA+) for Reporting Water Resources Conditions and Management: A Case Study in the Ca River Basin, Vietnam. 35pp. www.wateraccounting.org.

Bastiaanssen, W.G.M. and P. Droogers, 2001. Interactive hydrology and remote sensing models for irrigation performance assessment and water accounting studies. nalysis no. 23: 91-106.

Batchelor, C.; Hoogeveen, J.; Faurès, J.M.; Peiser, L. (2016). Water accounting and Auditing: A sourcebook. http://www.fao.org/publications/card/en/c/d43dad58-d587-48dd-ad0e-7c4a7397a175/

Berhanu B., Yilma Seleshi, Solomon S. Demisse and Assefa M. Melesse, 2016. Bias correction and characterization of climate forecast system re-analysis daily precipitation in Ethiopia using fuzzy overlay. Meteorological Applications, Meteorol. Appl. (2016).

Bhattarai, N., Shaw, S. B., Quackenbush, L. J., Im, J., & Niraula, R. (2016). Evaluating five remote sensing based 49, 75–86. https://doi.org/10.1016/j.jag.2016.01.010.

De Boer,F.,2016.Hihydrosoil:A high resolution soil map of hydraulic properties version 1.2,FutureWater report 134,Wageningen.

Biancamaria, S., Mballo, M., Le Moigne, P., Sánchez Pérez, J. M., Espitalier-Noël, G., Grusson, Y., Cakir, R., Häfliger, V., Barathieu, F., Trasmonte, M., Boone, A., Martin, E. and Sauvage, S.: Total water storage variability from GRACE mission and hydrological models for a 50,000 km2 temperate watershed: the Garonne River basin (France), J. Hydrol. Reg. Stud., 24, 100609, doi:10.1016/j.ejrh.2019.100609, 2019.

Damnjanovic, I., Đokovic, F., & Petrovic, L. P. (2016). Protected Areas: ManagementObjectives As an Aspect of Sustainable Tourism - a Regional Perspective. Quaestus, 8, 235–248. 2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%3Aabiglobal&atitle=PROTECTED+AREAS%3A+MANAGEMENT+OBJE

Delavar, M., Morid, S., Morid, R., Farokhnia, A., Babaeian, F., Srinivasan, R., & Karimi, P. (2020). Basin-wide water accounting based on modified SWAT model and WA+ framework for better policy making. Journal of Hydrology, 585, 124762. https://doi.org/10.1016/j.jhydrol.2020.124762

Devia, G. K., Ganasri, B. P., & Dwarakish, G. S. (2015). A Review on Hydrological Models. Aquatic Procedia, 4(Icwrcoe), 1001–1007. https://doi.org/10.1016/j.aqpro.2015.02.126

Dong, B., Molden, D., Loeve, R., Li, Y. H., Chen, C. D., and Wang, J. Z.: Farm level practices and water productivity in Zhanghe Irrigation System, Paddy Water Environment, 2, 217–226, 2004.

Dost, R., Obando, E. B., & Bastiaanssen &jippe Hoogeveen, W. (2013). Water Accounting Plus (WA+) in the Awash River Basin Coping with Water Scarcity-Developing National Water Audits Africa Client: FAO, Land and Water Division.

Elias Nikaka,Nawaz N . R. and Jon C. Lovett, 2017. Evaluating Global Reanalysis Datasets as Input for Hydrological Modelling in the Sudano-Sahel Region. Hydrology 2017, 4(1), 13; doi:10.3390/hydrology4010013

Espinoza-Dávalos, G. E., & Bastiaanssen, W. G. M. (2017). WaterPix: A Data Based Water Balance Model for Water Accounting. http://doi.org/10.5281/zenodo.1045574

FAO; IHE Delft. (2019). Water Accounting in the Litani River Basin. 62. http://www.fao.org/documents/card/en/c/CA6679EN/

FAO and IHE Delft. (2020). Water accounting in the Awash River Basin. FAO WaPOR water accounting reports. www. fao.org/contact-us/licence-request.

FAO: Coping with water scarcity; an action framework for agriculture and food security, FAO water reports 38, FAO, Rome,2012

Falkenmark, M. and Rockstrom, J.: The new blue and green wa- ¨ ter paradigm: Breaking new ground for water resources planning and management, J. Water Resour. Plann. Manage., 132, 129– 133, 2006

Franks, S. W., Beven, K. J., Quinn, P. F., & Wright, I. R. (1997). On the sensitivity of soil-vegetation-atmosphere transfer (SVAT) schemes: equifinality and the problem of robust calibration. Agricultural and Forest Meteorology, 86(1-2), 63-75.

Garrido-Rubio, J., Gonzalez-Piqueras, J., Campos, I., Osann, A., Gonzalez-Gomez, L., & Calera, A. (2020). Remote sensing–based soil water balance for irrigation water accounting at plot and water user association management scale. Agricultur

Gashaw, T., Dile, Y. T., Worqlul, A. W., Bantider, A., Zeleke, G., Bewket, W., & Alamirew, T. (2021). Evaluating the Effectiveness of Best Management Practices On Soil Erosion Reduction Using the SWAT Model: for the Case of Gumara Watershed, Abbay (Upper Blue Nile) Basin. Environmental Management, 68(2), 240–261. https://doi.org/10.1007/s00267-021-01492-9

Ghassemi, F., & White, I. (2007). Inter-basin water transfer: Case studies from Australia, United States, Canada, China and India. Cambridge university press.

Karimi, P., & Bastiaanssen, W. G. M. (2015). Spatial evapotranspiration, rainfall and land use data in water accounting - Part 1: Review of the accuracy of the remote sensing data. Hydrology and Earth System Sciences, 19(1), 507–532. https://doi.org/10.5194/hess-19-507-2015

Karimi, P., Bastiaanssen, W. G. M., Molden, D., & Cheema, M. J. M. (2013). Basin-wide water accounting based on remote sensing data: An application for the Indus Basin. Hydrology and Earth System Sciences, 17(7), 2473–2486. https://doi.org/10.5194/hess-17-2473-2013

Klees, R., Revtova, E. A., Gunter, B. C., Ditmar, P., Oudman, E., Winsemius, H. C., & Savenije, H. H. G. (2008). The design of an optimal filter for monthly GRACE gravity models. Geophysical Journal International, 175(2), 417-432.

Kindie. (2016). ASSESSMENT OF SURFACE WATER POTENTIAL AND Addis Ababa Institute of Technology School of Graduate Studies School of civil and environmental engineering Assessment on Surface Water Potential and Demands of Wabishebele Basin in Ethiopia. July.

Loucks, D.P. and van Beek, E. (2017) Water Resources Planning and Management An Overview. In Water Resource Systems Planning and Management, Springer, Berlin, 1-49. -

References—Scientific Research Publishing. (n.d.). Retrieved November 25, 2021, from https://www.scirp.org/reference/referencespapers.aspx?referenceid=2941726

Luthcke, S.B., Sabaka, T.J., Loomis, B.D., Arendt, A.A., McCarthy, J.J., Camp, J. 2013. Antarctica, Greenland and Gulf of Alaska land-ice evolution from an iterated GRACE global mascon solution. Journal of Glaciology. 59, 613–631. https://doi.org/10.3189/2013JoG12J147

Molden, D. (1997). Accounting for Water Use and Productivity. Swim, February 2014, 26. https://doi.org/10.1080/07900629948934

Musyoka, F. K., Strauss, P., Zhao, G., Srinivasan, R., & Klik, A. (2021). Multi-step calibration approach for SWAT model using soil moisture and crop yields in a small agricultural catchment. Water (Switzerland), 13(16). https://doi.org/10.3390/w13162238

Perera, K. A. R. S., & Amarasinghe, M. D. (2021). Vegetation structure, biomass and carbon retention capacity of mangroves at Northeast coast of Sri Lanka. Ceylon Journal of Science, 50(2), 183. https://doi.org/10.4038/cjs.v50i2.7881

Perry, C. J., & Bucknall, J. (2009). Water resource assessment in the Arab world: new analytical tools for new challenges. Water in the Arab World, 97.

Perry, C. (2007). Efficient irrigation; Inefficient communication; flawed recommendations. Irrigation and Drainage, 56(4), 367–378. https://doi.org/10.1002/ird.323

Sensing, R., & Water, F. O. R. (2020a). Water accounting in the Jordan River Basin. In Water accounting in the Jordan River Basin. https://doi.org/10.4060/ca9181en.

Sensing, R., & Water, F. O. R. (2020b). Water accounting in the Nile River Basin. In Water accounting in the Nile River Basin. https://doi.org/10.4060/ca9895en.

Savenije, H. H. G.: New definitions for moisture recycling and the relationship with land-use changes in the Sahel, J. Hydrol., 167, 57–78, 1995.

Savenije, H. H. G.: The importance of interception and why we should delete the term evapotranspiration from our vocabulary, Hydrolog. Process., 18, 1507–1511, 2004

Simons, G., Koster, R., & Droogers, P. (2020). HiHydroSoil v2.0-High Resolution Soil Maps of Global Hydraulic Properties, FutureWater Report 213. October, 1–18. www.futurewater.eu/hihydrosoil

Singh, P. K., Jain, S. K., Mishra, P. K., & Goel, M. K. (2021). An assessment of water consumption patterns and land productivity and water productivity using WA+ framework and satellite data inputs. Physics and Chemistry of the Earth, July, 103053. https://doi.org/10.1016/j.pce.2021.103053

Steduto, P., Faurès, J.-M., Hoogeveen, J., Winpenny, J. T., & Burke, J. J. (Eds.). (2012). Coping with water scarcity: An action framework for agriculture and food security. Food and Agriculture Organization of the United Nations.

Tatek Abate, M. D. (2015). Proportion of Maternal Near Misses and Associated Factors in Referral Hospitals of Amhara Regional State, Northwest Ethiopia: Institution Based Cross Sectional Study. Gynecology & Obstetrics, 05(08). https://doi.org/10.4172/2161-0932.1000308

Teixeira, A. H. de C., Bastiaanssen, W. G. M., Ahmad, M. D., & Bos, M. G. (2009). Reviewing SEBAL input parameters for assessing evapotranspiration and water productivity for the Low-Middle São Francisco River basin, Brazil: Part A: Calibration and validation. Agricultural and UN-WATER, 2014. United Nations Educational, Scientific, and Cultural Organization World Water Assessment Program. National Water Development Report for Ethiopia (Final) Addis Ababa December 2004.

UNEP-WCMC (2019). User manual for the world Database on protected Areas and world database on other effective area-based conservation measures ;- 1.6. UNEP-WCMC: Forest Meteorology, 149(3–4), 462–476. Cambridge,UK,Available at: http://wcmc.io/WDPA Manual

Woldeamlak Bewket et al, 2015. Climate Change Impact, Vulnerability, Adaptation and Mitigation, IV, Water and Energy. Ethpiopian Acedamy of Science.

Worqlul A. W., Collick A. S., Tilahun S. A., Langan S., Rientjes T. H. M., and Steenhuis T. S., 2015. Comparing TRMM 3B42, CFSR and ground-based rainfall estimates as input for hydrological models, in data scarce regions: the Upper Blue Nile Basin, Ethiopia. Journal of Hydrology and Earth System Science. HESSD 12, 2081–2112, 2015.

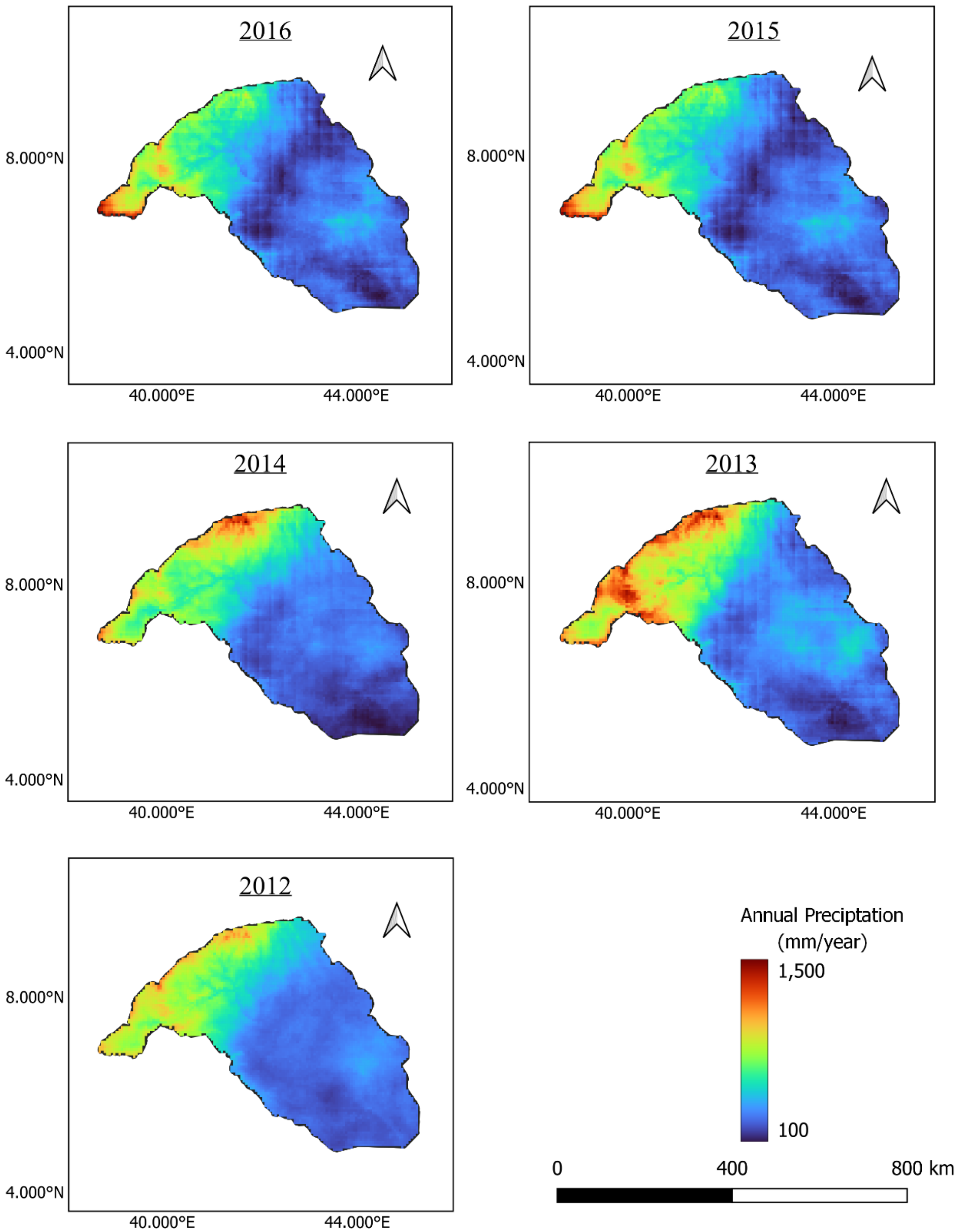
Wudineh, F. A., Moges, S. A., & Kidanewold, B. B. (2021). Flood Change Detection and Attribution Using Simulation Approach in Data-Scarce Watersheds: A Case of Wabi Shebele River Basin, Ethiopia. Journal of Water Resource and Protection, 13(05), 362–393. https://doi.org/10.4236/jwarp.2021.135023

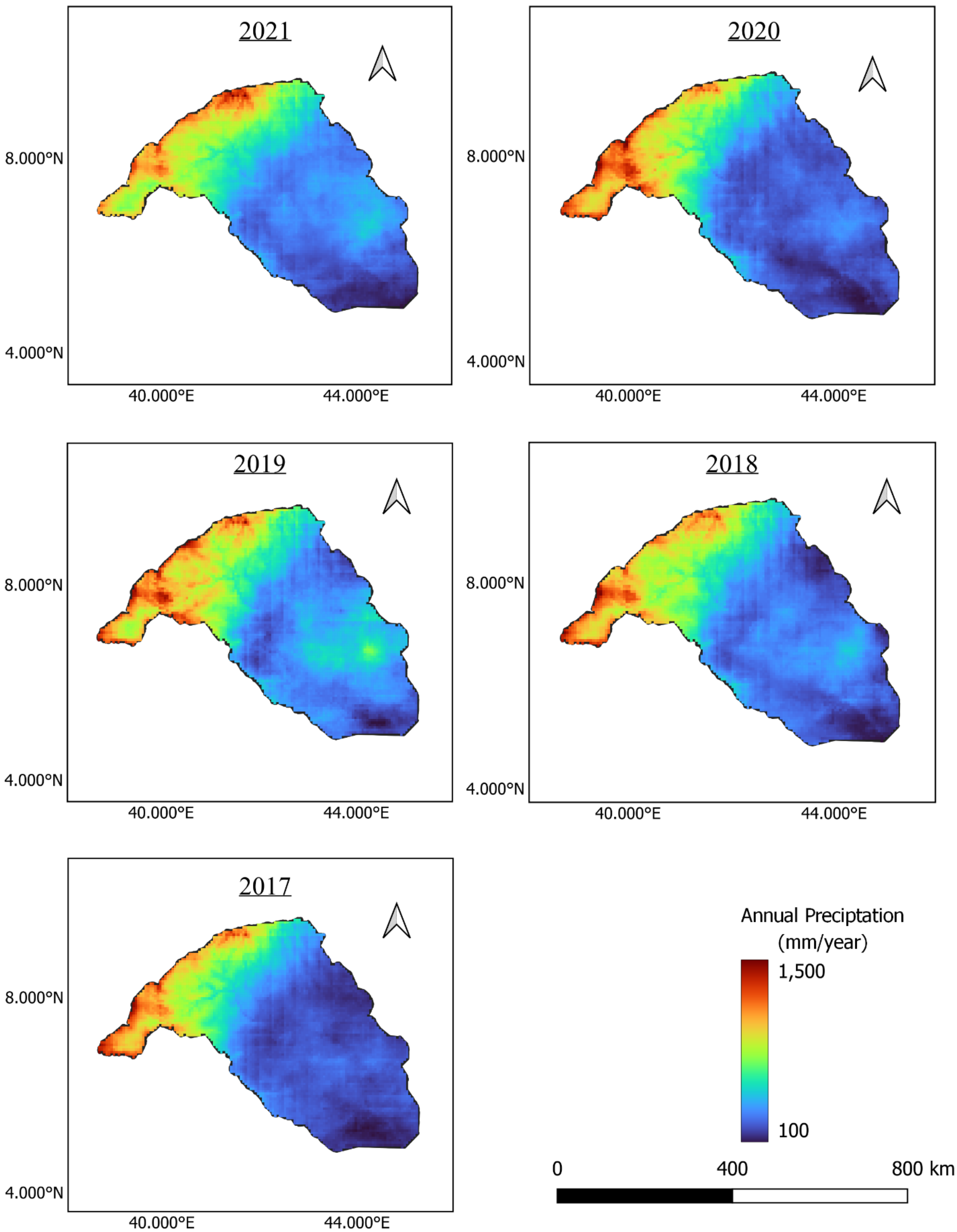
Van der Ent, R. J. and Savenije, H. H. G.: Length and time scales of atmospheric moisture recycling, Atmos. Chem. Phys., 11, 1853– 1863, doi:10.5194/acp-11-1853-2011, 2011.

Yi, X., Li, G., & Yin, Y. (2013). Comparison of three methods to develop pedotransfer functions for the saturated water content and field water capacity in permafrost region. Cold Regions Science and Technology, 88, 10–16. https://doi.org/10.1016/j.coldregions.2012.12.005

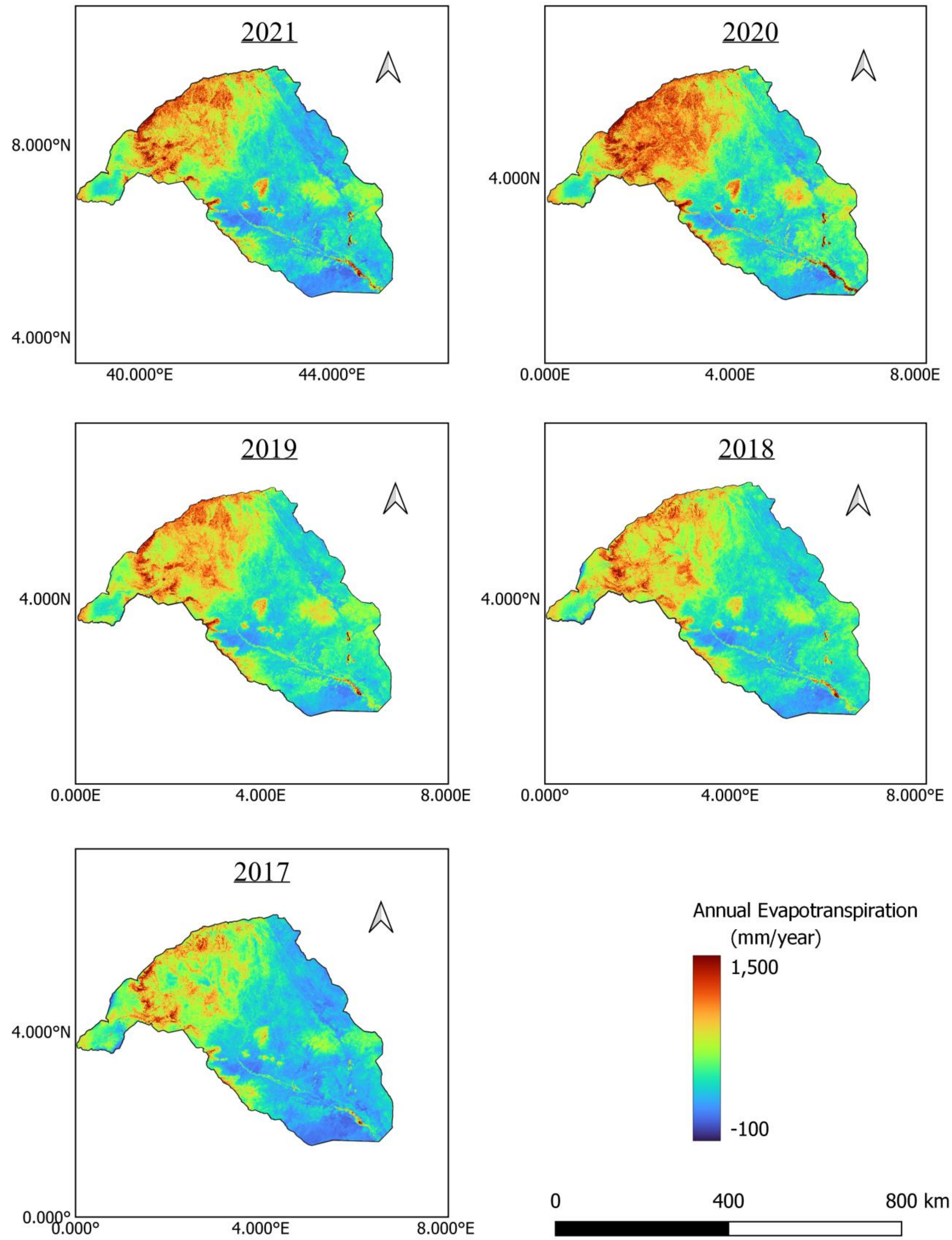
APPENDIXES

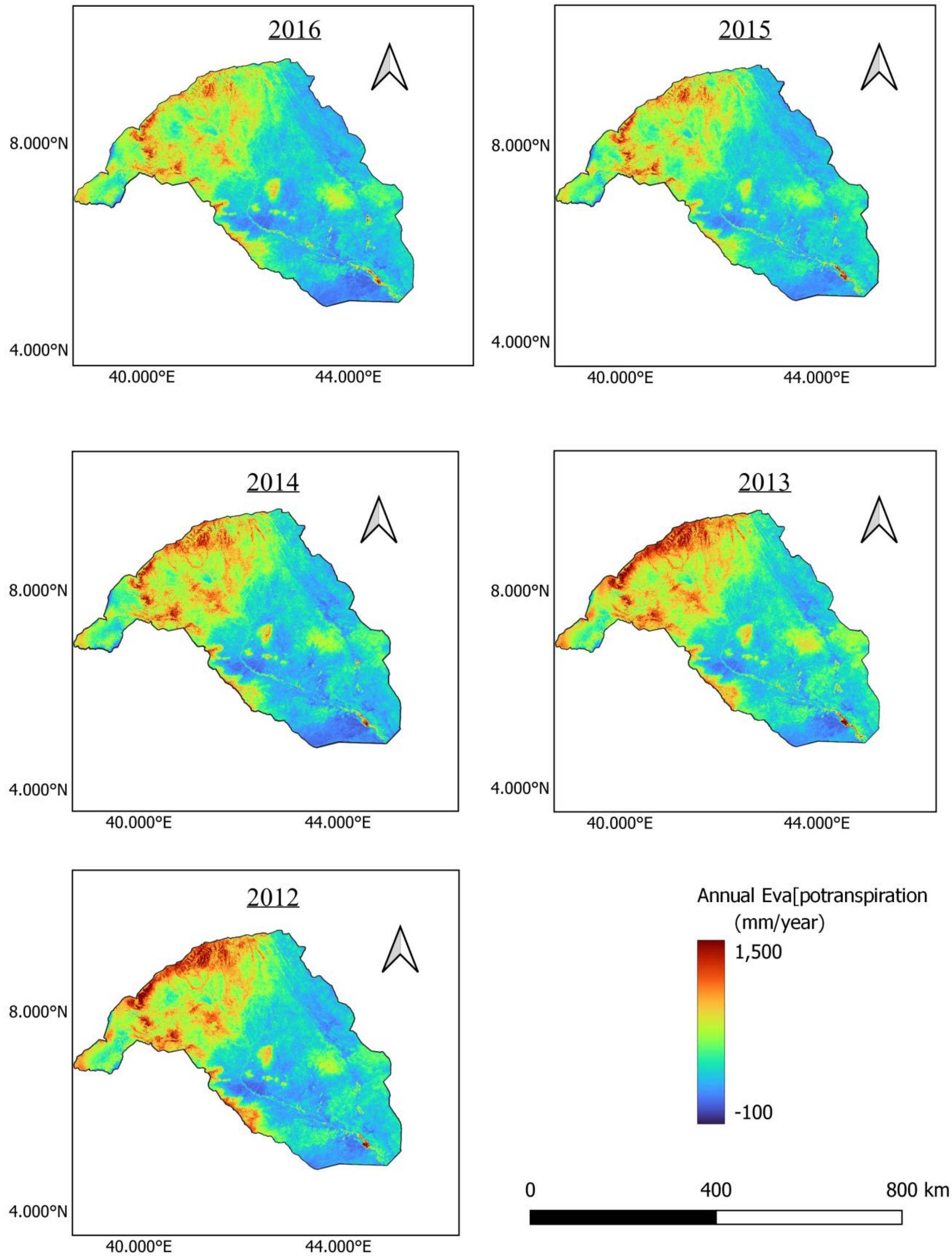
Appendix A. Total annual Precipitation (p) of hydrological years

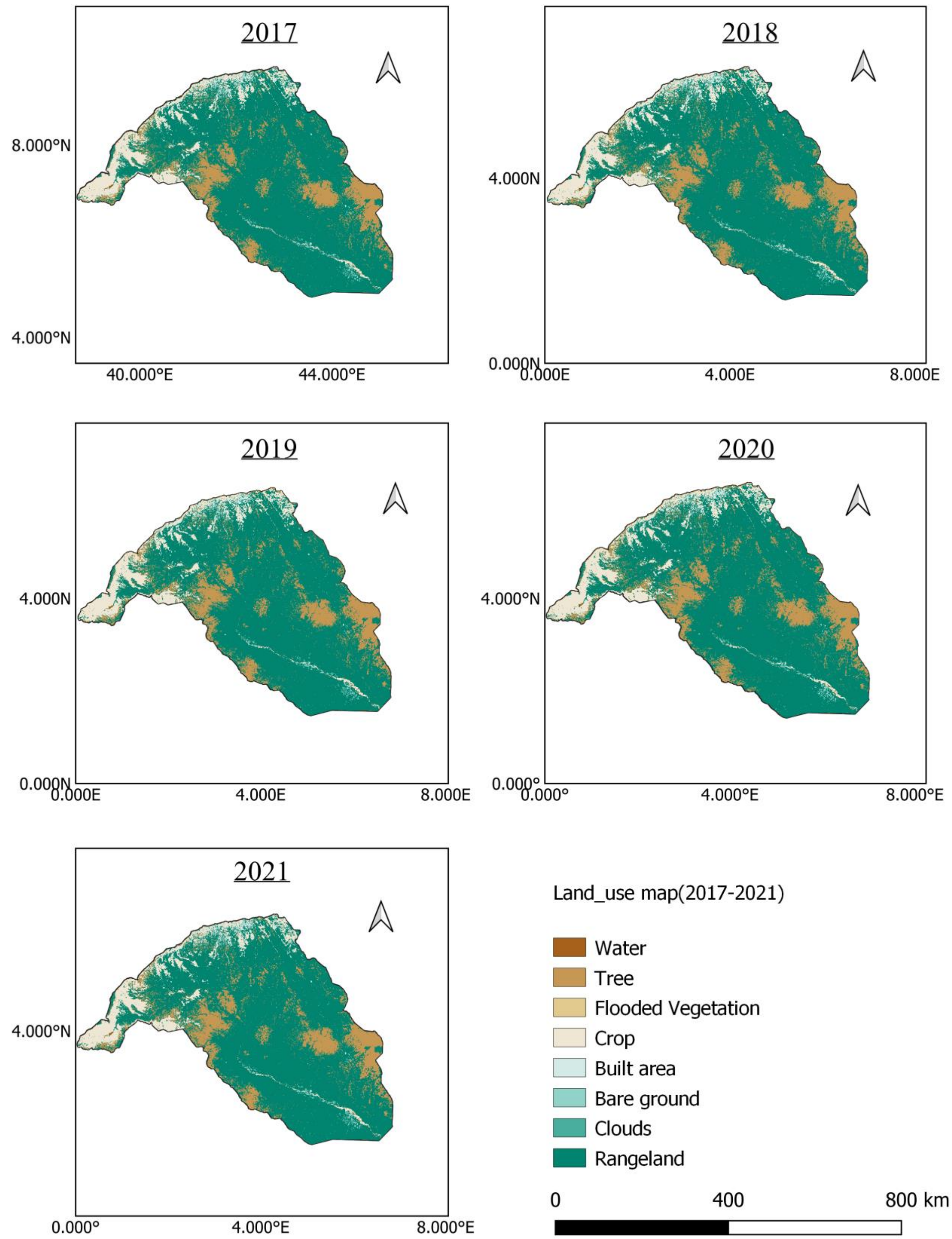



2021
2020
2019
2018
2017
8.000°N
4.000°N
40.000°E
44.000°E
Annual Preciptation
(mm/year)
1,500
100
0
400
800 km

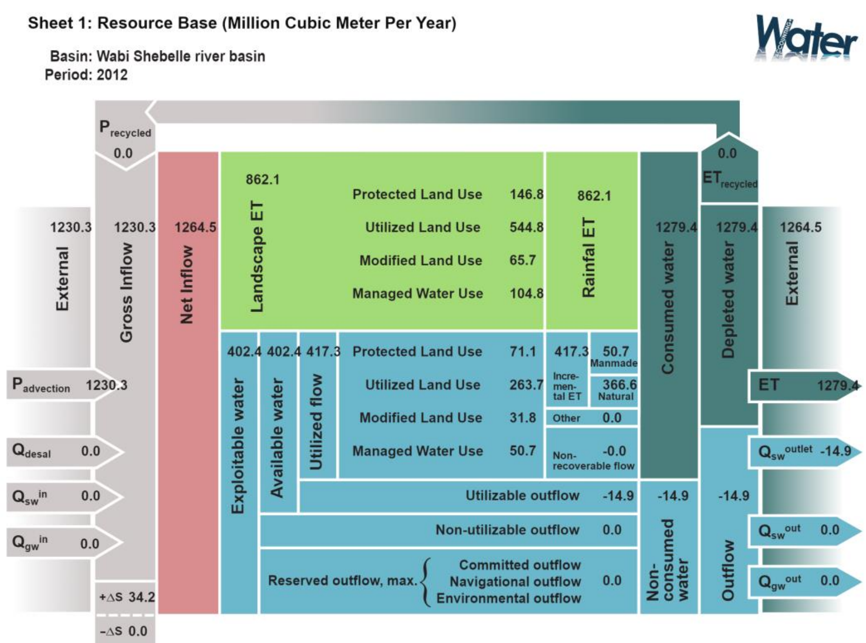
Appendix B. Total annual Evapotranspiration (ET) of hydrological years

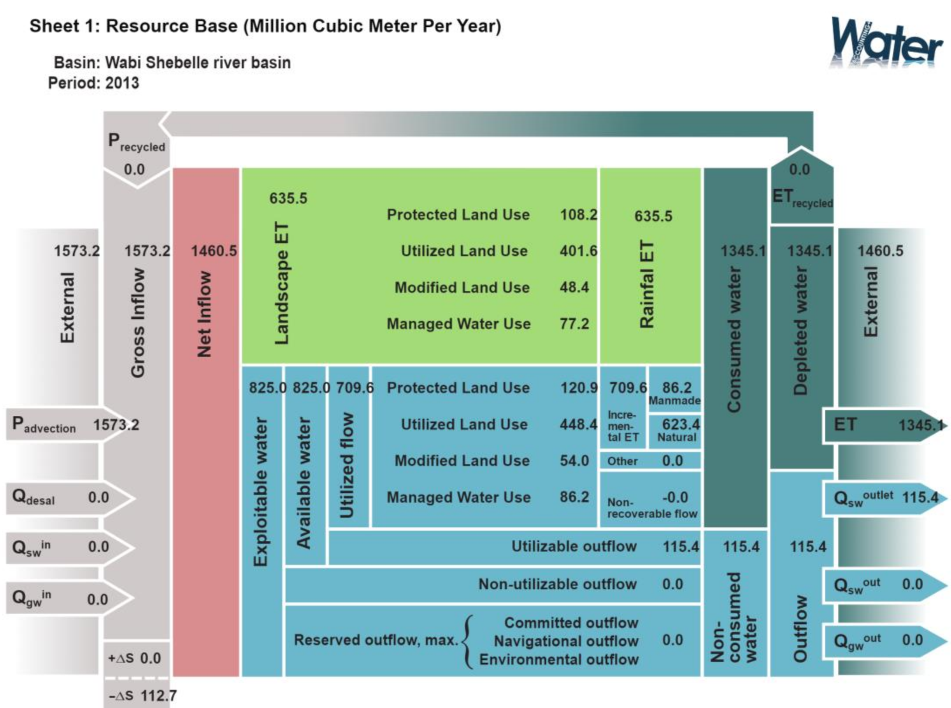


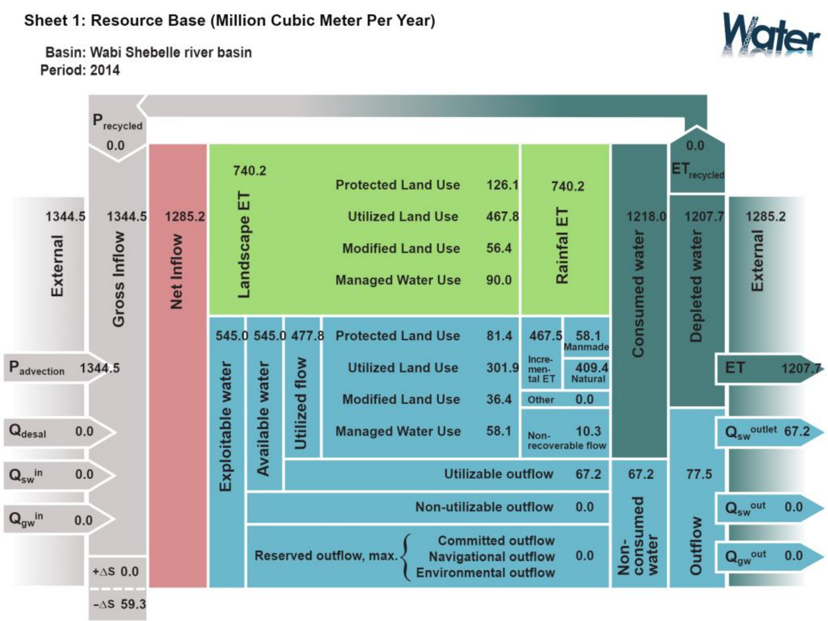

2016
8.000°N
4.000°N
40.000°E
44.000°E
2015
8.000°N
4.000°N
40.000°E
44.000°E
2014
8.000°N
4.000°N
40.000°E
44.000°E
2013
8.000°N
4.000°N
40.000°E
44.000°E
2012
8.000°N
4.000°N
40.000°E
44.000°E
Annual Eva[potranspiration
(mm/year)
1,500
-100
0
400
800 km

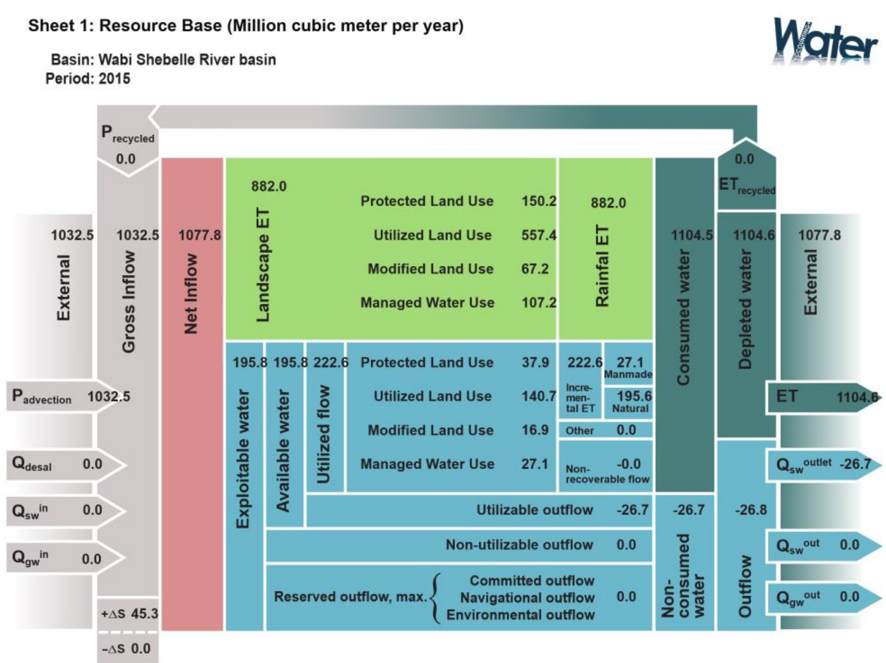

2017
8.000°N
4.000°N
40.000°E
44.000°E
2018
4.000N
0.000N
0.000E
4.000E
8.000E
2019
4.000N
0.000N
0.000E
4.000E
8.000E
2020
4.000°N
0.000°
0.000°
4.000°E
8.000°E
2021
4.000°N
0.000°
4.000°E
8.000°E
Land_use map(2017-2021)
Water
Tree
Flooded Vegetation
Crop
Built area
Bare ground
Clouds
Rangeland
0
400
800 km

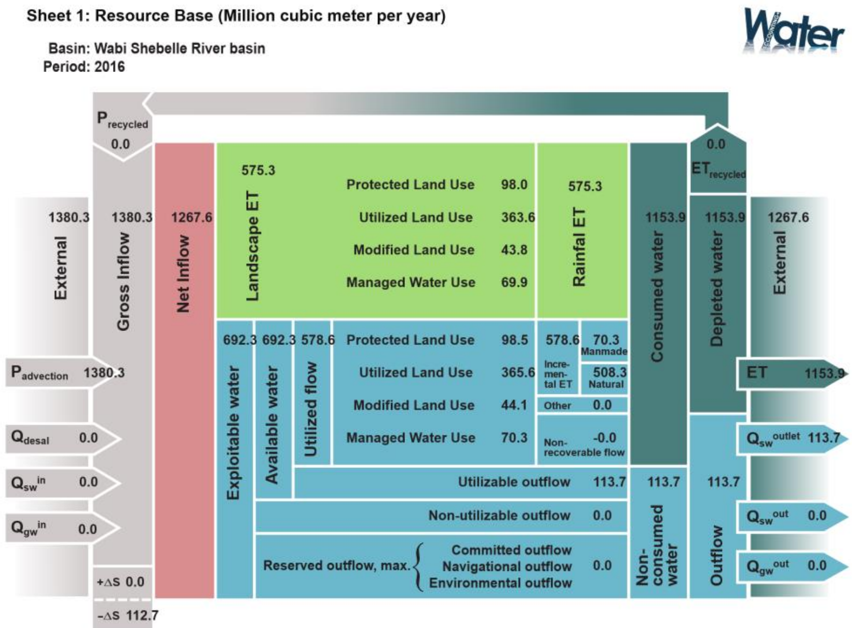
Appendix D. Yearly WA+ Sheet 1 Resource Base sheet

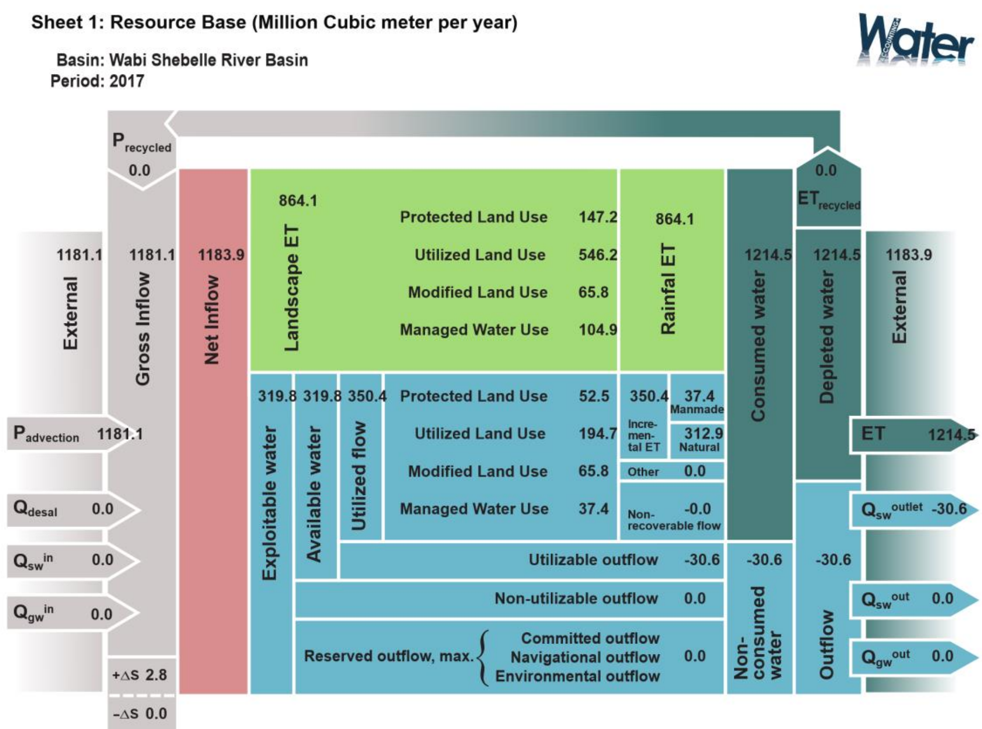


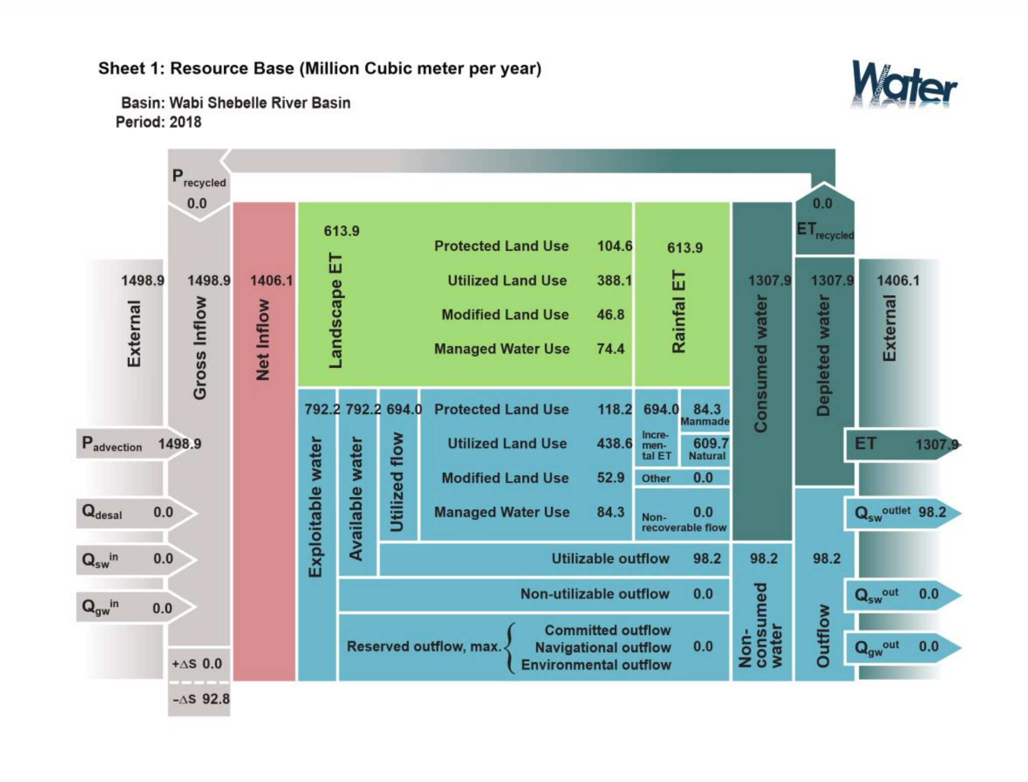


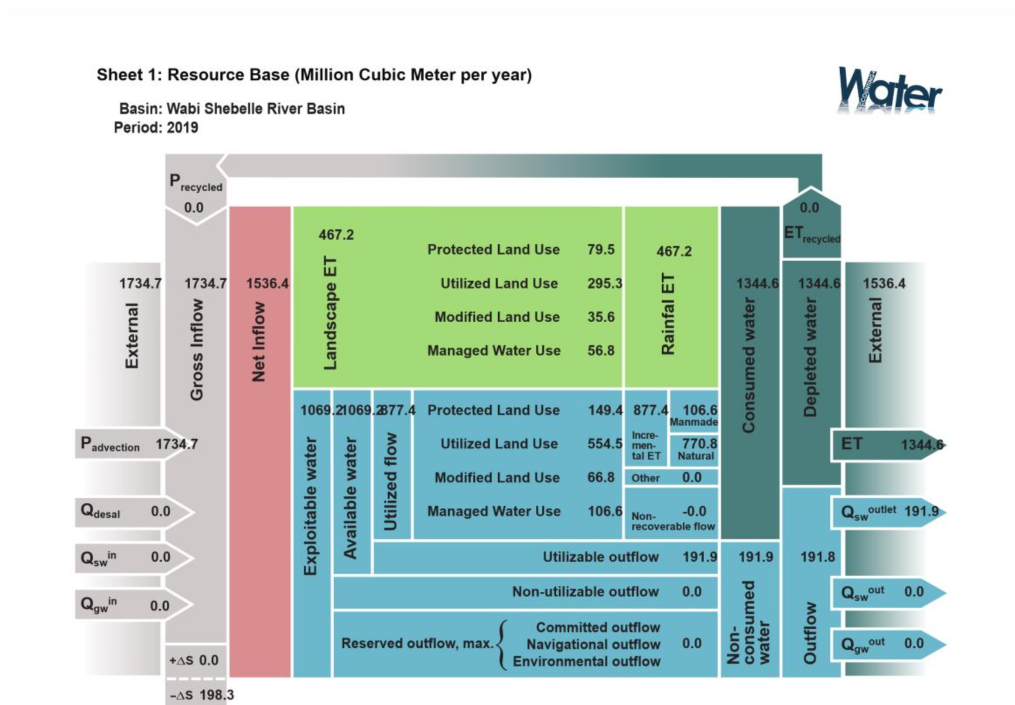

Sheet 1: Resource Base (Million Cubic Meter Per Year)
Basin: Wabi Shebelle river basin
Period: 2014
Water
P recycled 0.0
0.0
ET recycled
External 1344.5
Gross Inflow 1344.5
Net Inflow 1285.2
Landscape ET 740.2
Protected Land Use 126.1
Utilized Land Use 467.8
Modified Land Use 56.4
Managed Water Use 90.0
Rainfall ET 740.2
Consumed water 1218.0
Depleted water 1207.7
External 1285.2
P advection 1344.5
Exploitable water 545.0
Available water 545.0
Utilized flow 477.8
Protected Land Use 81.4
Utilized Land Use 301.9
Modified Land Use 36.4
Managed Water Use 58.1
Incremental ET 467.5
58.1 Manmade
409.4 Natural
Other 0.0
Non-recoverable flow 10.3
ET 1207.7
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
Utilizable outflow 67.2
Non-utilizable outflow 0.0
Reserved outflow, max. Committed outflow Navigational outflow Environmental outflow 0.0
Non-consumed water 67.2
Outflow 77.5
Q sw outlet 67.2
Q sw out 0.0
Q gw out 0.0
+ΔS 0.0
-ΔS 59.3

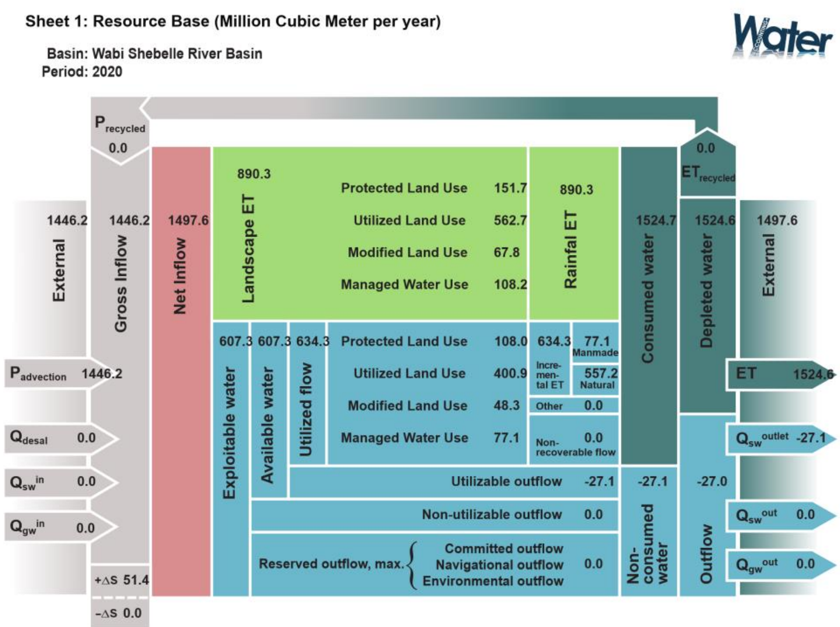

Sheet 1: Resource Base (Million cubic meter per year)
Basin: Wabi Shebelle River basin
Period: 2015
Water
P recycled 0.0
0.0
ET recycled
External 1032.5
Gross Inflow 1032.5
Net Inflow 1077.8
Landscape ET 882.0
Protected Land Use 150.2
Utilized Land Use 557.4
Modified Land Use 67.2
Managed Water Use 107.2
Rainfall ET 882.0
Consumed water 1104.5
Depleted water 1104.6
External 1077.8
P advection 1032.5
Exploitable water 195.8
Available water 195.8
Utilized flow 222.6
Protected Land Use 37.9
Utilized Land Use 140.7
Modified Land Use 16.9
Managed Water Use 27.1
Incremental ET 222.6
27.1 Manmade
195.6 Natural
Other 0.0
Non-recoverable flow -0.0
ET 1104.6
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
Utilizable outflow -26.7
Non-utilizable outflow 0.0
Reserved outflow, max. Committed outflow Navigational outflow Environmental outflow 0.0
Non-consumed water -26.7
Outflow -26.8
Q sw outlet -26.7
Q sw out 0.0
Q gw out 0.0
+ΔS 45.3
-ΔS 0.0

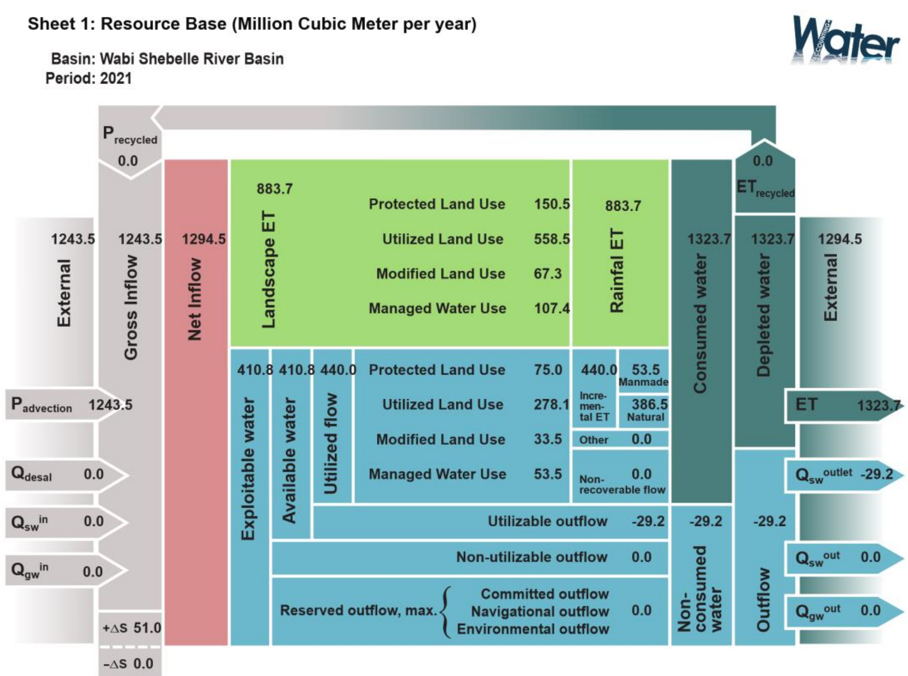

Sheet 1: Resource Base (Million cubic meter per year)
Water
Basin: Wabi Shebelle River basin
Period: 2016
P recycled 0.0
0.0 ET recycled
External 1380.3
Gross Inflow 1380.3
Net Inflow 1267.6
Landscape ET 575.3
Protected Land Use 98.0
Utilized Land Use 363.6
Modified Land Use 43.8
Managed Water Use 69.9
Rainfall ET 575.3
Consumed water 1153.9
Depleted water 1153.9
External 1267.6
P advection 1380.3
Exploitable water 692.3
Available water 692.3
Utilized flow 578.6
Protected Land Use 98.5
Utilized Land Use 365.6
Modified Land Use 44.1
Managed Water Use 70.3
578.6 Incremental ET
70.3 Manmade
508.3 Natural
Other 0.0
Non-recoverable flow -0.0
ET 1153.9
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
Utilizable outflow 113.7
113.7
113.7
Q sw outlet 113.7
Non-utilizable outflow 0.0
Q sw out 0.0
Reserved outflow, max.
Committed outflow
Navigational outflow
Environmental outflow
0.0
Non-consumed water
Outflow
Q gw out 0.0
+ΔS 0.0
-ΔS 112.7


Sheet 1: Resource Base (Million Cubic meter per year)
Water
Basin: Wabi Shebelle River Basin
Period: 2017
P recycled 0.0
0.0 ET recycled
External 1181.1
Gross Inflow 1181.1
Net Inflow 1183.9
Landscape ET 864.1
Protected Land Use 147.2
Utilized Land Use 546.2
Modified Land Use 65.8
Managed Water Use 104.9
Rainfall ET 864.1
Consumed water 1214.5
Depleted water 1214.5
External 1183.9
P advection 1181.1
Exploitable water 319.8
Available water 319.8
Utilized flow 350.4
Protected Land Use 52.5
Utilized Land Use 194.7
Modified Land Use 65.8
Managed Water Use 37.4
350.4 Incremental ET
37.4 Manmade
312.9 Natural
Other 0.0
Non-recoverable flow -0.0
ET 1214.5
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
Utilizable outflow -30.6
-30.6
-30.6
Q sw outlet -30.6
Non-utilizable outflow 0.0
Q sw out 0.0
Reserved outflow, max.
Committed outflow
Navigational outflow
Environmental outflow
0.0
Non-consumed water
Outflow
Q gw out 0.0
+ΔS 2.8
-ΔS 0.0


Sheet 1: Resource Base (Million Cubic meter per year)
Basin: Wabi Shebelle River Basin
Period: 2018
P recycled 0.0
0.0 ET recycled
External 1498.9
Gross Inflow 1498.9
Net Inflow 1406.1
Landscape ET 613.9
Protected Land Use 104.6
Utilized Land Use 388.1
Modified Land Use 46.8
Managed Water Use 74.4
Rainfal ET 613.9
Consumed water 1307.9
Depleted water 1307.9
External 1406.1
P advection 1498.9
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
Exploitable water 792.2
Available water 792.2
Utilized flow 694.0
Protected Land Use 118.2
Utilized Land Use 438.6
Modified Land Use 52.9
Managed Water Use 84.3
694.0 Incre-men-tal ET
84.3 Manmade
609.7 Natural
Other 0.0
Non-recoverable flow 0.0
ET 1307.9
Q sw outlet 98.2
Utilizable outflow 98.2
98.2
98.2
Non-utilizable outflow 0.0
Q sw out 0.0
Reserved outflow, max. Committed outflow Navigational outflow Environmental outflow 0.0
Non-consumed water
Outflow
Q gw out 0.0
+ΔS 0.0
-ΔS 92.8


Sheet 1: Resource Base (Million Cubic Meter per year)
Basin: Wabi Shebelle River Basin
Period: 2019
P recycled 0.0
0.0 ET recycled
External 1734.7
Gross Inflow 1734.7
Net Inflow 1536.4
Landscape ET 467.2
Protected Land Use 79.5
Utilized Land Use 295.3
Modified Land Use 35.6
Managed Water Use 56.8
Rainfal ET 467.2
Consumed water 1344.6
Depleted water 1344.6
External 1536.4
P advection 1734.7
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
Exploitable water 1069.2
Available water 1069.2
Utilized flow 877.4
Protected Land Use 149.4
Utilized Land Use 554.5
Modified Land Use 66.8
Managed Water Use 106.6
877.4 Incre-men-tal ET
106.6 Manmade
770.8 Natural
Other 0.0
Non-recoverable flow -0.0
ET 1344.6
Q sw outlet 191.9
Utilizable outflow 191.9
191.9
191.8
Non-utilizable outflow 0.0
Q sw out 0.0
Reserved outflow, max. Committed outflow Navigational outflow Environmental outflow 0.0
Non-consumed water
Outflow
Q gw out 0.0
+ΔS 0.0
-ΔS 198.3


Sheet 1: Resource Base (Million Cubic Meter per year)
Water
Basin: Wabi Shebelle River Basin
Period: 2020
P recycled 0.0
0.0 ET recycled
External 1446.2
Gross Inflow 1446.2
Net Inflow 1497.6
Landscape ET 890.3
Protected Land Use 151.7
Utilized Land Use 562.7
Modified Land Use 67.8
Managed Water Use 108.2
Rainfall ET 890.3
Consumed water 1524.7
Depleted water 1524.6
External 1497.6
Exploitable water 607.3
Available water 607.3
Utilized flow 634.3
Protected Land Use 108.0
Utilized Land Use 400.9
Modified Land Use 48.3
Managed Water Use 77.1
634.3 Incremental ET
77.1 Manmade
557.2 Natural
Other 0.0
Non-recoverable flow 0.0
P advection 1446.2
ET 1524.6
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
Q sw outlet -27.1
Utilizable outflow -27.1
-27.1
-27.0
Non-utilizable outflow 0.0
Q sw out 0.0
Reserved outflow, max. Committed outflow Navigational outflow Environmental outflow 0.0
Non-consumed water
Outflow
Q gw out 0.0
+ΔS 51.4
-ΔS 0.0


Sheet 1: Resource Base (Million Cubic Meter per year)
Water
Basin: Wabi Shebelle River Basin
Period: 2021
P recycled 0.0
0.0 ET recycled
External 1243.5
Gross Inflow 1243.5
Net Inflow 1294.5
Landscape ET 883.7
Protected Land Use 150.5
Utilized Land Use 558.5
Modified Land Use 67.3
Managed Water Use 107.4
Rainfall ET 883.7
Consumed water 1323.7
Depleted water 1323.7
External 1294.5
Exploitable water 410.8
Available water 410.8
Utilized flow 440.0
Protected Land Use 75.0
Utilized Land Use 278.1
Modified Land Use 33.5
Managed Water Use 53.5
440.0 Incremental ET
53.5 Manmade
386.5 Natural
Other 0.0
Non-recoverable flow 0.0
P advection 1243.5
ET 1323.7
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
Q sw outlet -29.2
Utilizable outflow -29.2
-29.2
-29.2
Non-utilizable outflow 0.0
Q sw out 0.0
Reserved outflow, max. Committed outflow Navigational outflow Environmental outflow 0.0
Non-consumed water
Outflow
Q gw out 0.0
+ΔS 51.0
-ΔS 0.0