Chapter 14
Application of Water Accounting Plus Framework for the Assessment of the Water Consumption Pattern and Food Security

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Abstract India's major issue is water scarcity and security. To deal with these issues, proper management plans and strategies are required. To diminish the adverse impacts and improve the benefits of water depletion for citizens, a strong knowledge of hydrological processes at basin level is required. Water professionals currently lack a mutual framework that connects reduction to water user groups and their profits. The lack of ground-based data drives the application of remotely sensed data in the WA+ framework. The water accounting framework assists decision-makers in understanding and implementing policies to address water scarcity and security. Water accounting requires precise input data to provide accurate explanations of water allocation and depletion in river basins. This framework improves understanding of the basin's complex hydrological processes by separating non-manageable, manageable, reserved, and committed flow for downstream demands and environmental flows with the interaction of land use on the basis of the water management classes. The WA+ evapotranspiration sheet depicts the basin's consumption pattern by categorizing evaporation, transpiration, and interception. The set of indicators applied to assess the basin's overall water resource condition. The Water Accounting Plus (WA+) framework provides an agricultural services sheet that connects the productivity of land and water of rainfed and irrigated areas using the green and blue water concepts of the Budyko framework. To understand the applicability of the framework, we discussed a recent study of the

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Krishna basin, which is used to investigate the conditions of water resources applying the WA+ framework formed by IHE Delft, FAO, and IWMI.

Keywords Water accounting plus · Evapotranspiration · Budyko framework · Water productivity · Land productivity · Krishna basin

14.1 Introduction

The goal of water accounting plus is to track inflows and outflows and assess liabilities, stocks, and resources for a specific area over a period of time (Karimi et al. 2013). Water accounting plus framework has been developed with the collaboration of IHE DELFT, FAO, IWMI, CGIAR and UNESCO. Recently, many organizations developed their water accounting frameworks, which had some sort of limitations. The water accounting framework of the International Water Management Institute (IWMI) (Molden and Sakthivadivel 1999), System of Environmental and Economic Accounting (SEEA) UN Statistics Division' Accounting for Water (SEEAW) (Vardon et al. 2012), Australian Water Accounting Conceptual Framework (Merz et al. 2006), and UNEP' Water Footprint are samples of existing water accounting systems. However, none of those programs of water accounting frameworks was taken as a broad normal (Dost et al. 2013). The water accounting system developed by AQUASTAT does not give detailed information regarding the interface between the use of land and water. The system emphases on water withdrawals only and will not differentiate between consumptive and non-consumptive use. The United Nations Statistics Division proposed a WA framework called System of Environmental Economic Accounting for Water (SEEA-WATER); however, important necessary data are not likely to be accessible (Perry 2012). The vital change in green and blue water resources of Australian Water Accounting Standard (AWAS) formed by the Water Accounting Standards Board (WASB). The framework accounts for water withdrawals instead of consumptive use (refer to Table 14.1), and it consists of irrigated agriculture, industrial, and domestic users. However, it will not offer any information on rainfed systems and natural evapotranspiration (ET) processes. A WA procedure was developed by the International Water Management Institute (Molden 1997) with the purpose of stalking water depletion instead of withdrawals to prevent errors when ignoring recycling and to account for ET. Agriculture is the world's largest water user, and India is even more so. According to recent research by the National Bank for Agriculture and Rural Development (Sharma et al. 2021), agriculture consumes 78% of available water resources. The idea of WP (linking engineering, agronomical, and economic factors) can be one of the most effective tools for addressing India's current water scarcity and food security issues. Molden (1997), for example, coined the term WP for the first time to emphasize the advantages of water use in terms of productivity. As a result, the agricultural WP can be used to improve agricultural water management in India (Zwart and Bastiaanssen 2004; Brauman et al. 2013; Mekonnen and Hoekstra 2014). A greater WP signifies either a higher crop yield from the same water supply

Table 14.1 WA+ sheets and their description

S No.	WA+ sheets	Purposes
1.	Resource-based sheet	Represent overexploitation, unmanageable, manageable, exploitable, reserved, utilized, and utilizable flows at river basin scale that are discussed in general. Examine the many water sources that influence net inflow. Determine the difference between landscape ET (due to rain) and incremental ET (due to natural and artificial withdrawals)
2.	Evapotranspiration sheet	Assess water consumption patterns (in terms of volume of water) by land use classes and water user groups, explaining the human influence on ET, beneficial and non-beneficial consumption, and breaking down beneficial consumption in agricultural, ecological, economic, energy, and leisure
3.	Agricultural sheet	Assess productivity of agricultural (kg/ha) and water (kg/m^3) and water consumption in terms of crops, timber, and fish product. Assess the productivity of land and water from the rain-fed and irrigated regions
4.	Utilized flow sheet	Report water shortage based on water needs and supplies, as well as an overview of all man-made withdrawals. Make strategies for water allocation. Make volumetric water entitlements, and assess non-authorized use and monitor compliance with water withdrawals. Calculate natural withdrawals (e.g., seasonal floods, shallow groundwater tables, and groundwater dependent ecosystems)
5.	Surface water sheet	Provide a summary of the basin's surface water and estimate the flow of the river in different reaches (even ungauged). Govern the availability of surface water and the amount of water that can be withdrawn. Calculate the amount of surface water that can be stored
6.	Ground water sheet	Assess the role of groundwater in renewable water resources, specifically for dry season base flow, making reliable groundwater withdrawal strategies (i.e., avoid decreasing groundwater tables) and map groundwater withdrawals for irrigation

or the same crop productivity from a low water supply (Goyal et al. 2018; Das et al. 2020; Poonia et al. 2021).

P. Karimi and Bastiaanssen (2015) had presented only four sheets, which were (1) resource-based sheet (2) evapotranspiration sheet, (3) productivity sheet, and (4) withdrawal sheet. The resource-based sheet gives a broad summary on overexploitation, unmanageable, manageable, exploitable, reserved, utilized, and utilizable flows at river basin scale, whereas the total ET sheet provides a thorough understanding on how, where, and when water is consumed in river basins and designs ET management principles to define a cap on consumptive use from withdrawals and inundations and classify beneficial and non-beneficial water consumptions. The productivity sheet presents relations between water depletion and biomass production, production of crop and water, and the withdrawal sheet delivers information on water withdrawals and reuse. With the passage of time, due to increasing demands, these sheets have been updated, the withdrawal sheet has been replaced with utilized flow sheet, and more sheets has been included to understand the hydrological processes (Table 14.1). Each sheet is associated with the set of indicators used to describe the situation of water resources of the basin.

14.2 Land Use in the WA+ Framework

Land use land cover is an essential component in water accounting since, it establishes whether water is manageable or non-manageable. Land use in water accounting plus has been classified centered on the water management classes, which are as follows: (1) protected land use (PLU), (2) utilized land use (ULU), (3) modified land use (MLU), and (4) managed water use (MWU). Protected land uses are the areas where no interferences are allowed; these are secured by the government and international NGOs, including national parks, RAMSAR sites, tropical rainforests, wetlands, etc. (Karimi et al. 2013; Dembele 2020; Food and Agriculture Organization of the United Nations and IHE Delft Institute for Water Education 2019). Utilized land use (ULU) is the land where vegetation is not managed on a regular basis and human influences are limited. It includes forests, woodlands, shrublands, pastures, savannas, etc. Modified land uses are the regions where vegetation and soils are managed, but water supply is not disturbed (rainfall). It includes rainfed agriculture, biofuel crops, forest plantations, etc. Managed water uses are the classes where human interventions are present and water supply is also not natural and withdraws from surface and groundwater resources, for instance, irrigation canals, hydropower schemes, urban water supply, treatment plants, etc. Figure 14.1 represents the water accounting land use pattern of Meghalaya.

14.3 Total Evapotranspiration Sheet

The WA+ total evapotranspiration sheet illustrates water depletion and recognizes components of water use that can be managed, manageable, and non-manageable on the basis of the LULC classifications. Total evapotranspiration (ET) is divided into soil and water evaporation (E) and vegetation transpiration (T) and interception (I), and then helpful and non-beneficial water consumption is distinguished (Karimi et al. 2013; Dembele 2020; Food and Agriculture Organization of the United Nations and IHE Delft Institute for Water Education 2019) (Fig. 14.2). ET is classified as beneficial or non-beneficial based on a value judgment based on case studies that must be up-to-date (Dembele 2020). For example, soil evaporation is seen as non-beneficial, but transpiration is regarded as a helpful ET contributing to food production and the economy. The formula developed by Von Hoyningen-Hüne (1983) and Braden (1985) is used to estimate interception losses.

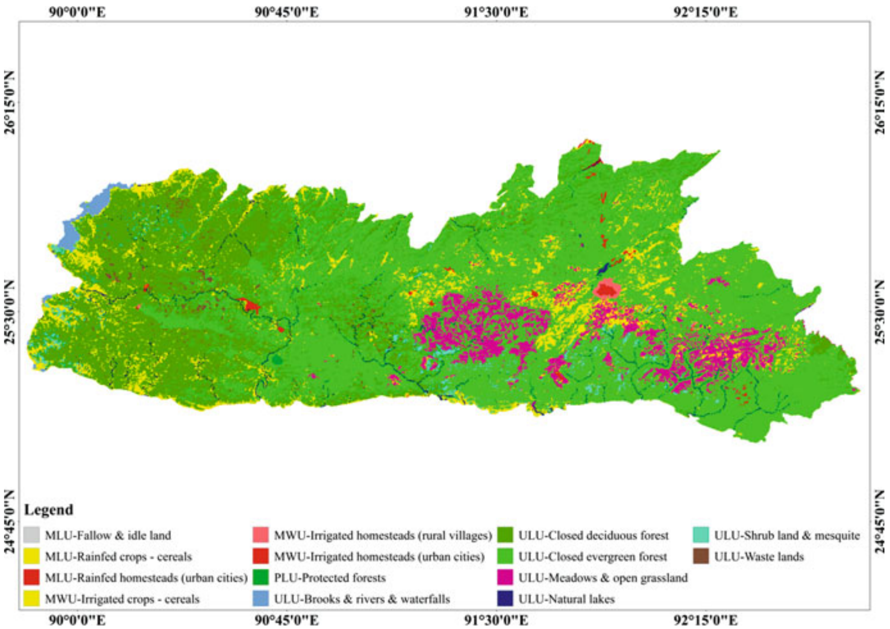

Fig. 14.1 WA+ land use classes of Meghalaya state, India

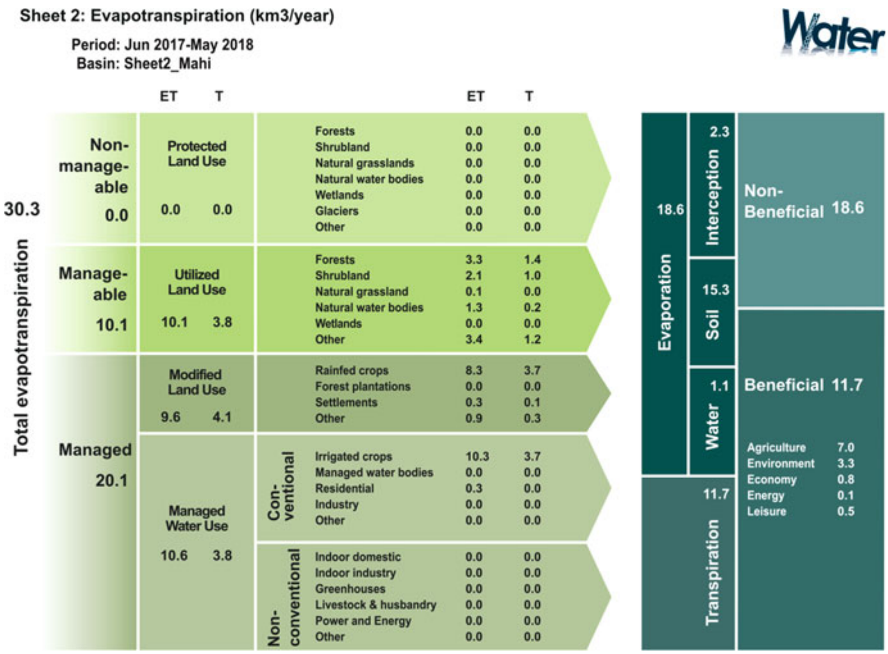

Fig. 14.2 Total ET sheet showing water consumption from different water management classes

$$\mathrm{Im} = \left(1 - \frac{1}{1 + \frac{\mathrm{Pm}}{\mathrm{Nm}} \times \left(1 - e^{(-0.5 \times \mathrm{LAIm})}\right) \times \frac{1}{\mathrm{LAIm}}}\right) \times \mathrm{LAIm} \times \mathrm{Nm} \tag{14.1}$$

Here, LAI represents leaf area index (m^2/m^2), Nm denotes the no. of rainy days in a month, and Pm denotes monthly precipitation.

14.4 Budyko Hypothesis for Estimation of Green and Blue Water ET

For ET separation into ETgreen and ETblue, the WA+ framework employs the Budyko hypothesis (Budyko 1974). The water held in the soil is referred to as green water, whereas the water accumulated in rivers, ponds, lakes, other bodies of surface water, and aquifers is referred to as blue water (Singh et al. 2021; Goyal and Ojha 2010, 2012; Falkenmark and Rockström 2006). The Budyko hypothesis determines an experiential relationship between AET, reference evapotranspiration (PET), and P (Sposito 2017; Singh et al. 2021) and hence offers first-order estimations of evaporation employing only P and PET (Mianabadi et al. 2019). The Budyko hypothesis is based on the combination of two approaches: (a) water balance and (b) energy balance (Singh et al. 2021) For each green and blue pixel, the water balancing is performed separately. The aridity index (PET/P) and the evaporative index (AET/P) are used to explain the Budyko curve. A pixel-based analysis has been adopted in this framework to identify the rainfed and irrigated pixels. Pixels falling over the water limit are considered blue water pixels, and those falling below are considered green water pixels (Fig. 14.3). Since the original Budyko equation is on basis of the long-term water balance method to identify arid or humid areas, in this framework, the equation is modified, and total ET is considered the sum of green and blue water consumption. ·

$$\frac{\mathrm{ETg}*}{\mathrm{P}} = \mathrm{f}(\phi) = \sqrt{\phi \cdot \tanh\left(\frac{1}{\phi}\right) \cdot \left(1 - e^{-\phi}\right)} \tag{14.2}$$

$$\mathrm{ETg} = \min(\mathrm{ETa}, f(\phi) \cdot \mathrm{P}) \tag{14.3}$$

$$\phi = \frac{\mathrm{PET}}{\mathrm{P}} \tag{14.4}$$

PET and AET represent potential and actual ET (mm/month), and ETg and ETb represent green and blue water evapotranspiration.

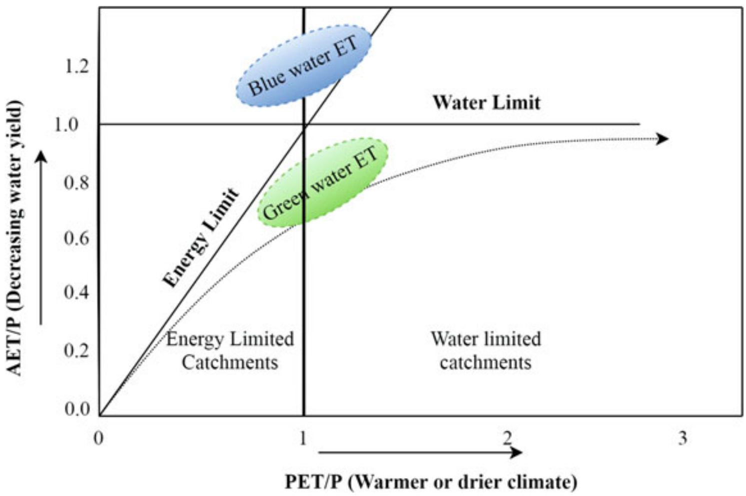

Fig. 14.3 Budyko curve for assessing blue water ET and green water ET

14.5 Agricultural Services Sheet

Water scarcity and food security are the two major threats due to changing climatic conditions, inefficient water usage, and improper management plans; hence, it's important to focus on them. The agricultural services sheet distinguishes between the productivity of land (Kg/ha) and water (Kg/m^3) (Fig. 14.4). Productivity measurement in WA+ is on biomass production base (Karimi et al. 2013). This sheet indicates the possibilities for saving water in agriculture and making agricultural water management more efficient. Water productivity (WP) is a basic indicator in the performance evaluation of river basins, and it has huge food and water security consequences (Molden 2007; Sharma et al. 2021). Land and water productivity are calculated on the basis of green and blue water ET calculations. The water productivity concept mainly focuses on the *More Crop Per Drop*, which represents how much volume of water is consumed to generate per *Kg* of crop. The agricultural sheet reflects light on the type of crop grown in the area and whether it is suitable for that area to produce it (in terms of water consumption). The main purpose of this sheet is to plan future rainfed and irrigated cropping methods using rainfall, exploitable, and available water and show potentials for conserving water in agriculture and making agricultural water management more efficient.

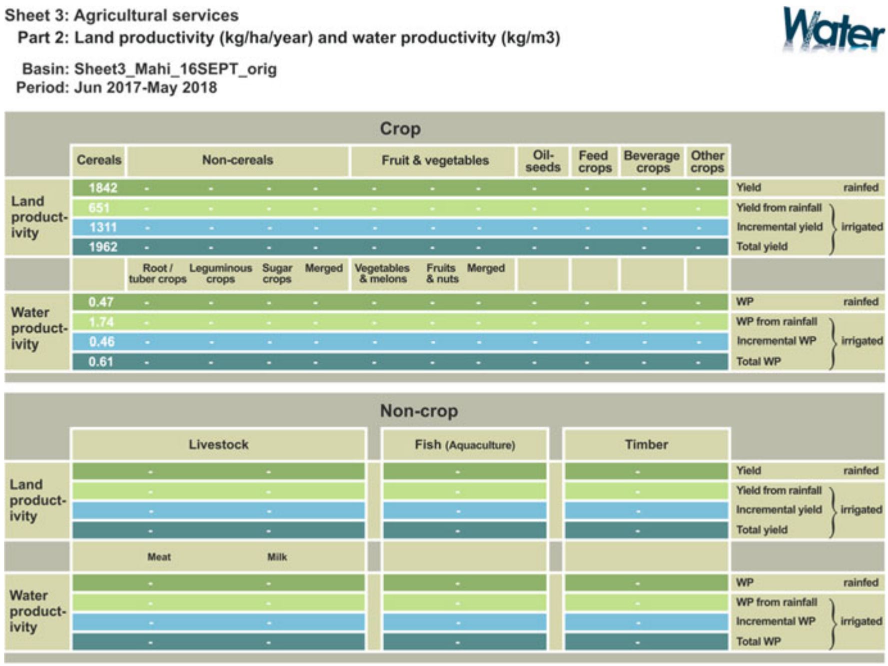

Fig. 14.4 Agricultural services sheet showing land and water productivity of irrigated and rainfed areas

14.6 Key Indicators

WA+ summarizes the overall water resources and their consumption with the help of some indicators associated with each sheet, enabling the understanding of a common man. These indicators are summarized in Table 14.2.

Harvest index can vary crop to crop (Murray et al. 2021). For example, rice and wheat have the harvest index value of 0.44 and 0.37, respectively.

14.7 An Example of Water Accounting Study of Krishna Basin, India

One of the recent studies (ABD and IHE DELFT 2020) used water accounts to investigate the conditions of water resources in the Krishna basin, which consists of three subbasins, applying the water accounting plus (WA+) framework formed by IHE Delft, FAO, and IWMI. In this example of study, authors examined the Krishna basin in Karnataka state which consists of three subbasins, namely, Middle Krishna (K2), Ghatprabha (K3), and Malaprabha (K4; Fig. 14.5). This study considered

Table 14.2 Key indicators of total ET (sheet 2) and agricultural services sheet (sheet 3)

Sheet-2 Indicators		
1.	Transpiration ET fraction	$\frac{\text{Transpiration}}{\text{ET}}$
2.	Beneficial ET fraction	$\frac{\text{Ebeneficial} + \text{Tbeneficial}}{\text{ET}}$
3.	Managed ET fraction	$\frac{\text{ET managed}}{\text{ET}}$
4.	Agricultural ET fraction	$\frac{\text{Agricultural ET}}{\text{ET}}$
5.	Irrigated ET fraction	$\frac{\text{Irrigated ET}}{\text{Agricultural ET}}$
Sheet-3 Indicators		
1.	Land productivity (Kg/ha)	$\frac{\text{Biomass production} \times \text{Harvest index}}{\text{Crop area}}$
2.	Water productivity (Kg/m^3) (rainfed crops)	$\frac{\text{Rainfed crop production} \times \text{Harvest index}}{\text{Rainfed crops ET}}$
3.	Water productivity (Kg/m^3) (irrigated crops)	$\frac{\text{Irrigated crop production} \times \text{Harvest index}}{\text{Irrgated crop ET}}$
4.	Food-irrigation dependence	$\frac{\text{Irrigated agriculture ET}}{\text{Total agriculture ET}}$

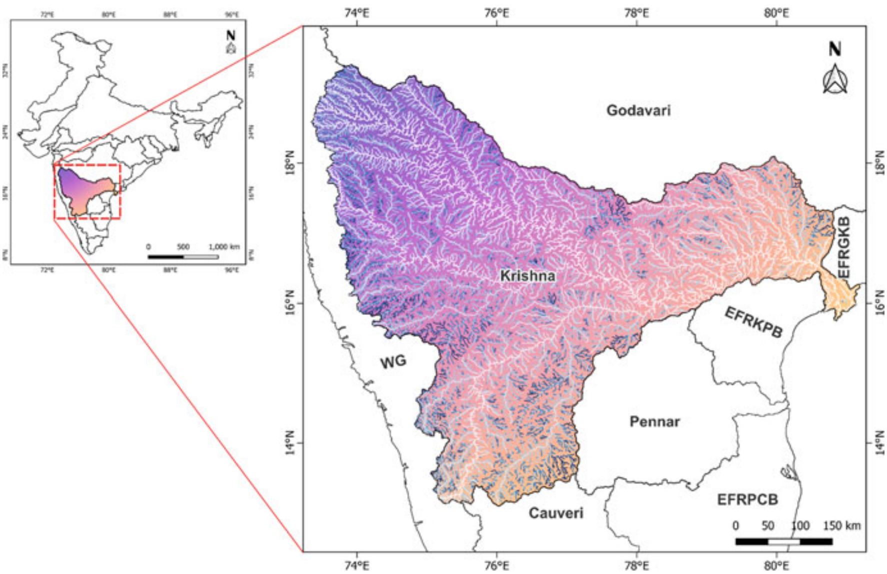

Fig. 14.5 Location of the Krishna basin boundary with stream network overlaid

subbasins of the Krishna basin in Karnataka state for the analysis, and inflows are assessed by means of available in situ measures. This study used the distinction between precipitation and evapotranspiration, which were derived from remote sensing data across the upstream region in locations where inflows are not calculated. The Krishna basin includes surface water reservoirs of over 40,000. Water resource development is ongoing, and currently, 76 large and 135 medium irrigation projects are proposed in the basin. The basin is under significant environmental strain due to a rising population (now above 66 million), increased need for agricultural production, and intensive water resource development.

The most appropriate datasets were chosen in this study based on the following: (a) inter-relationship of data products, (b) validation with making use of in situ measurement, (c) annual water balance measurement and evaluation with in situ discharge quantities, and (d) accessibility of data in recent times. The CHIRPS dataset was used for precipitation, while the SSEBop dataset was used for actual ET estimations. Remotely sensed ET data exhibits less marked month-to-month and seasonal variation than precipitation, with greater ET values during the monsoon season, when ample amounts of water and energy are available, and lower values throughout the winter season. The basic rationale for categorizing these four land use types is that their management options range from maintaining pristine conditions to managing hourly water flows. The PLU regions account for barely 1% of K3, whereas natural lands (ULU) account for 4–5% in all three subbasins. The MLU and MWU have comparable coverage (about 50%) in K2 and K3, while irrigated agriculture is less established in K4, and the MWU only reports 63%.

Figure 14.6 illustrates a flowchart of the central computational stages in the water accounting method, including input datasets and data type applied in the study.

Key findings of this study (Krishna basin) are:

- The quantity of consumption of non-beneficial water in agriculture is higher throughout the subbasins, accounting for 42% in rainfed and 48% in irrigated cultivations. The observed soil evaporation was high in all three subbasins, particularly in paddy crops; however, other crop varieties also have high evaporation values. This demonstrates that there is substantial potential to boost agricultural output without increasing overall water usage by reducing wasteful soil evaporation. Measures to reduce soil evaporation, such as advanced irrigation planning and effective management of farm field water, should also be explored in the agriculture sector.
- The pixel balancing model results show a cumulative storage loss of 0.2 km^3/year for all three subbasins, which is below 1% of precipitation. There are spatial changes, with K2 and K3 losing and K4 gaining. This shows that there is no evidence of overexploitation of water resources over the time period studied. The changes in interannual storage are substantially larger and are closely related to the monsoon climate. Changes in storage for both surface and groundwater must be closely observed on a regular/seasonal basis.
- The water accounting statistics are generated using an underlying pixel balance model, which is derived by remotely sensed datasets with constrained calibration settings. The present version excludes routing and dam operations. Furthermore, the development of the water accounts might be achieved by model improvement or the use of outputs of locally calibrated model.

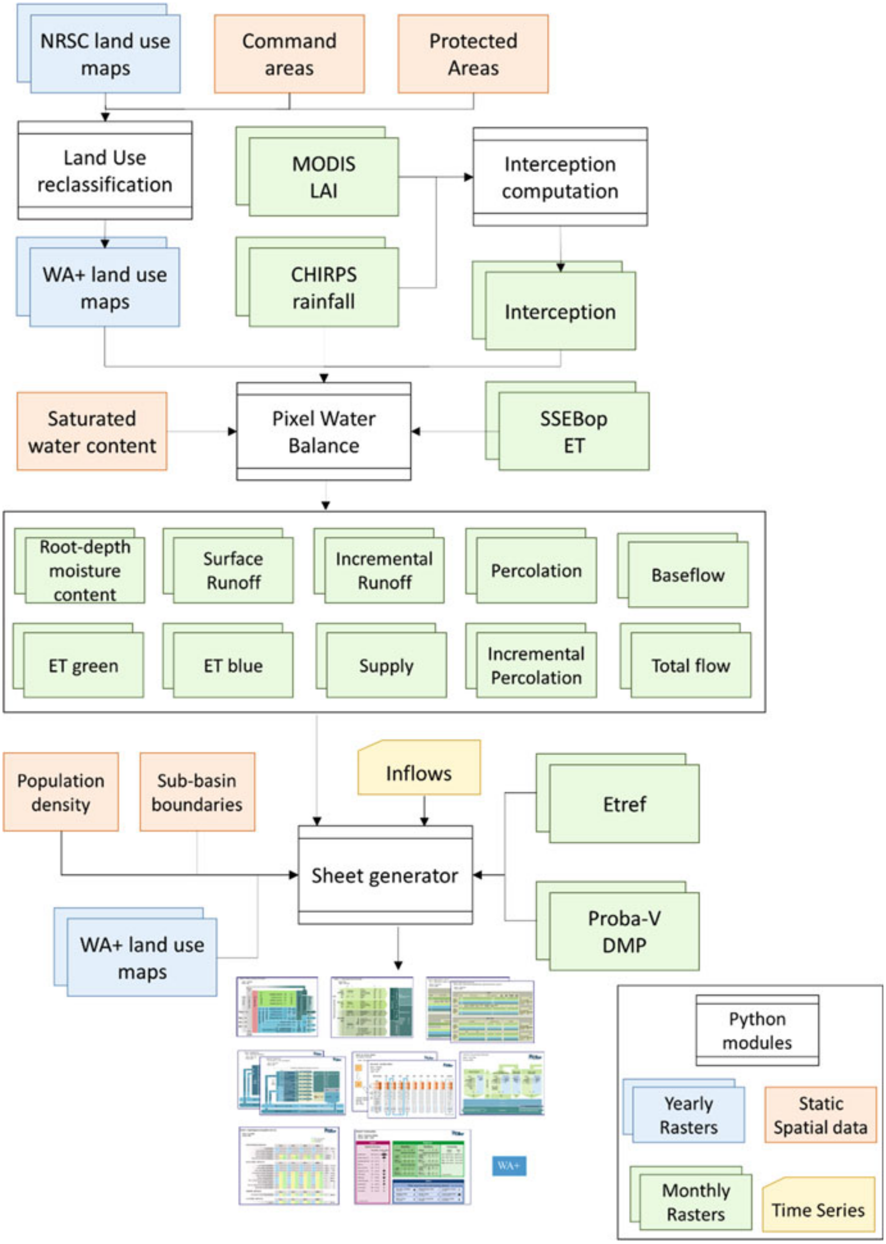

Fig. 14.6 Water accounting plus flow chart (Source: ABD and IHE DELFT 2020)

14.8 Conclusion

The use of the WA+ framework can be studied for the evaluation of water consumption patterns and land and water productivity, providing insights into developing adequate management plans and schemes for the optimal use of water resources for increased agricultural output. WA + 's water productivity approach promotes effective water utilization. This study also suggests the amount of water required by a specific crop. Budyko framework integration improves its ability to categorize rainfed and irrigated agricultural pixels on green and blue water use basis, which is a unique feature of it. According to the findings of this study, the role of land use is critical because consumption is entirely dependent on it, as it becomes feasible to check the water consumption from a particular land use class, and can be managed or not. The comprehension of hydrological processes will become more clear with the assistance of the other four sheets for the assessment of downstream water demand, surface and groundwater withdrawals, and available, utilizable, and exploitable water. Another advantage of utilizing WA+ is that it allows for the use of satellite-driven datasets (precipitation, actual ET, potential ET, LAI, NPP, and GPP), allowing the study to be conducted for an ungauged basin. Further research can be conducted by including climate change scenarios to determine a basin's existing and future water resource conditions.

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