The Pharma Innovation Journal 2022; SP-11(11): 1926-1933

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(11): 1926-1933

www.thepharmajournal.com
Received: 16-09-2022
Accepted: 21-10-2022

AP Bowlekar
Ph.D. Research Scholar, Department of Soil and Water Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur, Kerala Agricultural University, Kerala, India

KK Sathian
Professor and Head, Department of Soil and Water Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur, Kerala Agricultural University, Kerala, India

Corresponding Author:
AP Bowlekar
Ph.D. Research Scholar, Department of Soil and Water Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur, Kerala Agricultural University, Kerala, India

A review on water balance models

AP Bowlekar and KK Sathian

Abstract

Originally, water balance models were introduced to evaluate the importance of different hydrological elements under different hydrological conditions, but their current applications are mostly connected to water resources management. Since many factors affect hydrologic processes, the water balance equation can introduce enormous errors or complexities. The water balance models were computed based on different inputs like precipitation, precipitation and temperature, precipitation and potential evaporation and daily input data. Recently, lot of studies have been carried to assess the climate change and the impacts of human activities using water balance models. This paper provides a critical review on water balance model with special reference to humid tropics.

Keywords: Climate change, models, precipitation, water balance, watershed

1. Introduction

Water balance analysis is the basis of management and policy making in some critical matters related to water resources such as design of water supply systems, flood estimation, water allocation and use, management of and wastewater in urban areas, aquatic ecosystems management, water trading and virtual water. Based on the results of water balance computations a great number of important water projects can be planned (Quinn *et al.*, 2000) [57].

We can define two separate boundaries and scales for water balance equation: spatial boundaries for the region (spatial scstormwater ale) and temporal boundary for water balance period (time scale). Selecting different spatial or time scales in a specific region changes the accuracy, equation elements and methodology according to the reliability of data, financial conditions and facilities. Major classifications of water balance computation methods have performed to look at groundwater interactions with surface waters and water use in atmosphere-water-soil system.

Practical strategies for calculation of dynamic components of water balance equations depend on the targets, accuracy and the time period in which the equations are assessed. In this regard, a lot of internal processes and events are usually neglected and only the response of the region at the end of the period is considered. The calculations for monthly totals had been made at daily time steps; for this reason daily runoff values quickly have become a motive of calculation. The interest in calculation of day by day flows has step by step multiplied up to the present. However, the use of sub-daily water balance modeling for flood studies is necessary. The modeling purposes, target area, calculation method, temporal and spatial boundaries, available data and facilities drive the accuracy of water balance results; generally the degree of accuracy is determined before any computations.

Water balance models have been developed at various time scales (e.g. hourly, daily, monthly and yearly) and to varying degrees of complexity. Monthly water balance models were first developed in the 1940s by Thornthwaite (1948) [66] and later revised by Thornthwaite and Mather (1955, 1957) [67, 68]. These models have since been adopted, modified and applied to a wide spectrum of hydrological problems (e.g. Bellot and Chirino, 2013; Arnell, 1999) [7, 4]. Lately, they have been hired to explore the impact of climatic trade e.g. Global Climate Model (GCM) (Ndhlovu and Woyessa, 2020) [53], Canadian Centre for Climate Modelling and Analysis (CCCMA) (Nyatuame *et al.*, 2020) [55]. However, these models are more data intensive and have more parameters than do the corresponding monthly models.

A number of water balance models and parameter estimation algorithms have been considered, ranging from relatively complex conceptual models with 10 to 15 parameters (e.g. Dhote *et al.*, 2021; Corbari *et al.*, 2022) [20, 18] to very simple models with 2 to 5 parameters models (e.g. Arnell, 1999; Jayatilaka *et al.*, 2003; Liu *et al.*, 2021) [4, 35, 43].

There is a need that the model users must be familiar with the sensitivity, strengths and weaknesses of the model. Thus, there is a need to take stock of such models and review them. Recently, numerous models with different assumptions and affecting parameters have been introduced for water balance computations such as: WASIM (Singh *et al.*, 1999) [60]; WAVES (Mingan *et al.*, 2002) [46]; WetSpass (Batelaan and Woldeamlak, 2007) [6] and these models are specialized for modeling of water balance in a farm. NAM module from MIK-11 is applied to investigate the statistical importance of various parameters in water balance equations (Celleri *et al.*, 2000) [16]. There are hundreds of models based on explicit catchment water balance modeling and many new models are still being added.

A good review of monthly water balance models was presented by Xu and Singh (1998) [74] according their applications and kinds of input parameters. Similar, major review of water balance models was presented by Boughton (2004) [10]. Ghandhari and Moghaddam (2011) [31] also reviewed water balance principles for five watersheds in Iran. The dominant interests in water balance modeling vary in different regions like estimation of water yield, flood estimation and budget allocation and putting new constrains on groundwater exploitation. The wide application of water balance results and decisions which can be made, especially in India, show the importance of water balance applications. This study is an attempt to shed more light on the water balance computation process and its accuracy and also is to present some key points for improving the reliability of water balance results. The study focuses on the different models used for water balance analysis and its applications.

2. Water Balance in Watersheds

Water balance is an efficient means for programming and evaluating in the scale of watersheds especially in the case of ungauged basins (Boughton and Chiew, 2007 [11]; Boughton, 2004) [10]. Long-term water storage changes in watersheds, including surface water and ground water, are expressed in the form of residual water balance equation (Berezovskaya *et al.*, 2005) [8].

$$Ds/DT = P-Q-ET \quad (1)$$

Where,
Ds/DT is total water change in watershed
P is average precipitation
ET is evapotranspiration
Q is the surface water discharge at the main drain of basin

This simple expression of water balance is valid where the groundwater output and its withdrawals are negligible. Correct definition of water balance period or hydrological year is a very important factor in the simplification of computations and can be evaluated as a basis for judgment about the hydrological regime of watershed (Najjar, 1999) [51]. In arid and semi-arid zones, all sub-basins contribute to final discharge that means infiltration, evaporation and evapotranspiration are influenced significantly because of expanded floodplains and vegetation cover development. Dividing a watershed into smaller sub-hydrological systems can improve the results in these basins (Cohen *et al.*, 2001) [17].

A lacking element in the present day water balance models is transmission loss in flow channels among the regions wherein runoff is generated and the catchment outlet in which runoff is measured. The significance of transmission loss is growing because the importance of low flows for both water allocation and aquatic ecosystems will increase.

Flerchinger and Cooley (2000) [23] computed a ten-year water balance of a mountainous semi-arid watershed at Upper Sheep Creek watershed, which was a 26-ha semi-arid mountainous sub-basin within the Reynolds Creek Experimental watershed in southwest Idaho, USA. Oroud (2015) [56] assessed water budget for semi-arid watershed in the eastern Mediterranean. It was observed that the significant runoff occurred over steep terrains where vegetation cover was limited and this adversely affected the water quality and life span of dams constructed over these catchments.

Lv *et al.* (2017) [44] studied the water budget closure based on Gravity Recovery and Climate Experiment (GRACE) measurements and reconstructed ET and water use data for two large densely-populated mid-latitude basin, Yellow River Basin (YRB) and Changjiang River Basin (CJB). They recommended the proposed reconstruction method to be relevant to other human-managed river basins to provide an alternative estimation. Noviadi *et al.* (2019) [54] analysed water balance in Bera watershed of 164.6 km2 in the Sumbawa River basin, Indonesia using excel by comparing the demand and supply of water.

3. Methods for Computation of Water Balance Components

3.1 Precipitation

In general, precipitation is the principal input for water stability models. The accuracy of dimension and computation of precipitation from a network of stations determines to a vast quantity the reliability of water stability computations. No reliable water stability computation is viable with insufficient know-how of the spatial rainfall patterns. Areal rainfall may be incorrect both randomly and systematically. A variety of general interpolation methods is available for areal estimation (Fung *et al.*, 2022) [26]. Remote sensing and satellite data can be used for catchment modeling. Radars are employed for rainfall measurement (Caseri *et al.*, 2022; Ghimire *et al.*, 2022) [15, 32]. Satellite data can be used for estimation of area and intensity of rainfall. Recently, remote-sensing techniques based on satellite imagery and ground-based radar with a network of recording raingauges has proved to be promising for estimation of precipitation (Mtibaa and Asano, 2022; Sukanya and Kalapureddy, 2022) [50, 64].

3.2 Evapotranspiration

In most cases, evapotranspiration is the second largest quantity in the hydrological water balance. Accurate spatial and temporal predictions of ET are required for water balance models. Complex models have been developed to determine evapotranspiration (Traore *et al.*, 2010) [70]. In water balance models, most researchers have found it necessary to derive "true" evapotranspiration as a function of potential evapotranspiration and soil dryness. In fact, this has been the most popular method of calculating evapotranspiration for most conceptual hydrological models (Casado-Rodriguez and Jesus, 2022; Dile *et al.*, 2020) [14, 21]. Interpolation and aggregation methods are used to present weather and land cover data at appropriate spatial and temporal scales for catchment hydrology. Remote sensing methods will play an increasing role in water balance assessment, which use models of varying complexity to estimate evaporation from the surface (Soltani *et al.*, 2021; Fu *et al.*, 2022) [62, 25].

3.3 Runoff

Streamflow records provide a measure of watershed response to time-varying input and internal hydrologic processes. For water balance studies, it is important to know the different components of runoff and their regimes. The number of runoff components to be analyzed depends on the watershed characteristics and separation objective, including the time base to be considered (Wang *et al.*, 2014; Knoll *et al.*, 2020) [72, 37].

4. Monthly Water Balance Models

Monthly water balance models are not only used to investigate the importance of various hydrological variables in different watersheds, but also monthly water balance models are used to assess the impact of climate change, predict river flow, design and operate water projects, etc. (Desai *et al.*, 2021; Ahmad *et al.*, 2022; Guo *et al.*, 2022; Motschmann *et al.*, 2022) [19, 3, 33, 48].

4.1 Purpose

The main purposes of monthly water balance models can be summarized as follows:

- Synthesis of long-term watershed records
- Generation of runoff records for uncelebrated watersheds
- Providing hydrological data as inputs for validating deterministic general circulation models
- Forecasting yield within one or two months for real-time control of water resource systems
- Derivation of climatic and hydrological regional classifications
- Predicting the possible hydrological effects of changes in land use and climate change.

Although these targets can be derived from hourly or daily models, the use of monthly water balance models is preferred because short-term models are more data intensive and in many cases these data are not available and short-term models are usually more complex.

4.2 Concepts and Structure

Hydrological models are often classified into three types, empirical models (black box models), conceptual models (grey box models) and theoretical models (white box models). Empirical models relate outputs to inputs through a structure that may be entirely statistical or partly mathematical and does not aid physical understanding, as in the application of linear and nonlinear systems theory. Hydrologic models are considered conceptual here if the form of the model equations is designed with respect to the physical processes acting on the inputs and outputs in a highly simplified form. Theoretical models have a logical structure similar to a real-world system and can be useful under changed circumstances. Each user of an individual model is thus faced with the choice of using either a sophisticated model with less perfect input data, or a less complex model based on a simpler conceptualization of "known reality" for which the data requirements are less stringent.

4.3 Model evaluation and parameters estimation

When a model has been developed or selected for use in predicting hydrologic outputs for a particular practical problem, it is then necessary to assess its applicability and potential accuracy for that problem and determine the values of the model parameters or constants for that problematic watershed. In general, several levels of evaluation are required before a model can be used to estimate watershed output. These are: rational examination of model structure, estimation of parameter values, testing of the fitted model to verify its accuracy, and estimation of its range of applicability.

Many types of techniques are used to estimate the parameters of various hydrological models. Of these, automatic optimization using search techniques was the most common method in calibrating monthly water balance models. It is believed that when model time steps are chosen large enough, the mode will be a balance model in which the ratio of watershed response time to time step is negligible (Mouelhi *et al.*, 2006) [47]. Sometimes it can be defined from a simple bucket model to really complex hydrological models according to their resolution (Zhang *et al.*, 2002) [75]. In this case, the water balance is a set of equations in which each process or part of the process is simulated by an equation. In general, the dominant view of the water budget calculates all volume components to/from three-dimensional space that lead to storage changes (Burt, 1999) [12].

Sinha *et al.* (2019) [61] studied the effects of watershed characteristics on long-term annual and interannual water balances over India. They developed a model using multiple linear regression and machine learning techniques (ANN: Artificial Neural Network and RVM: Relevance Vector Machine).

5. Models using Different Inputs

5.1 Models using precipitation as inputs

Precipitation generally forms the largest component of the water balance equation. Deriving the relationship between rainfall over a catchment and the resulting discharge in a river is a fundamental problem in hydrology. Precipitation records are usually abundant in most countries, but stream flow data are often limited and rarely available for a particular river under study. The need to evaluate river flows from rainfall has therefore arisen. A number of monthly water balance models using only precipitation as input have been developed.

5.1.1 The model divides runoff into three components

- Instantaneous runoff, calculated as a certain fraction of precipitation during the current month;
- Delayed outflow, calculated using the linear reservoir concept
- A time function that is assumed to have no interaction with other components.

A common feature of these models is that evapotranspiration is calculated as a fraction of precipitation, and the remainder of precipitation is empirically treated as either infiltration and/or direct runoff.

5.2 Models using precipitation and temperature as input

Temperature is used as the driver for estimating potential evapotranspiration using Thornthwaite's approach, which together with monthly precipitation can be used as input data for the models. These models differ in their treatment of the relationship between actual and potential evapotranspiration and accounting for soil moisture and aquifer recharge.

5.3 Models using precipitation and potential evaporation as input

Monthly areal precipitation and potential evapotranspiration were used as the only inputs to most of the monthly rainfall-runoff models. These models have been developed in a wide variety of climates for a wide variety of applications and vary greatly in complexity.

Fowler (2002) [28] evaluated the validity of using mean potential evaporation in long-term soil water balance calculations in Auckland, New Zealand. Modeling experiments were conducted over 13 years at a selected site comparing model performance during wet and dry years and achieved the best results where PE reduction was applied to account for PE suppression on rainy days. Campos *et al.* (2016) [13] estimated the total available water in the soil layer by integrating actual evapotranspiration data into a remotely sensed soil water balance. Wang *et al.* (2021) [73] modeled ET coupling processes and soil water balance in agroforestry systems.

5.4 Monthly models using daily input data

The use of daily precipitation as an input is believed to improve the estimation of such processes as infiltration, evapotranspiration, interception, and depression storage. On the other hand, using daily data increases the amount of work and may limit research to fewer watersheds instead of water balance calculations on large geographic units.

Spruill *et al.* (2000) [63] simulated daily and monthly streamflow for a small watershed in central Kentucky using the Soil and Water Assessment Tool (SWAT) model. They observed that the model adequately predicted daily stream flow trends during this period. Muttiah and Wurbs (2002) [49] studied the effects of scale-dependent soil and climate variability on the water balance of the SWAT model basin for large watersheds in Texas, USA. Tripathi *et al.* (2006) [71] studied the effect of watershed subdivision on the simulation of water balance components using the SWAT model for the Nagwan watershed in eastern India. They collected and used meteorological and hydrological data (daily precipitation, temperature, relative humidity and runoff) for the years 1995 to 1998. The water balance was found to be perfect under all decomposition schemes.

Schilling *et al.* (2008) [59] studied the impacts of Land Use and Land Cover (LULC) change on the water balance of a large agricultural watershed in the Raccoon River in the west-central Lowa, United States, to analyze historical effects and future directions using the SWAT model. They stated that future LULC change will affect the water balance of the basin, with consequences largely dependent on the future LULC trajectory. Bonuma *et al.* (2013) [9] evaluated hydrological processes using the SWAT model with respect to measurement uncertainty for the Arrio Lino watershed in southern Brazil. They used measured flow from the catchment outlet to evaluate the flow sensitivity of selected parameters for calibration and validation between 2001 and 2005.

George and Sathian (2016) [30] assessed the water balance of the basin using the SWAT model for water resource management for the Kurumali sub-basin of the Karuvannur river basin. It was suggested that the SWAT model could be effectively used in river flow simulation and water balance prediction of watersheds in the humid tropics. Ayivi and Jha (2018) [5] estimated water balance and water yield in the Reedy Fork-Buffalo Creek watershed in North Carolina using SWAT. From the graphical results, they found that the SWAT model accurately tracked monthly flow trends during both the calibration and validation periods.

Li *et al.* (2018) [42] studied an improved approach for ET estimation using the water balance equation for the Yangtze River Basin (YRB). They developed an improved regional approach to ET estimation, based on the Gravity Recovery and Climate Experiment (GRACE) water balance equation, daily precipitation and streamflow data. Rohtash *et al.* (2019) [58] used the SWAT model to model rainfall runoff in the Chaliyar catchment, Kerala. They used DEM, LULC map, soil map, precipitation data, discharge and temperature data, RH, solar radiation and wind speed. They studied rainfall trend analysis for the period 1991 to 2011. Abdulla and Al-Shurafat (2020) [1] conducted rainfall-runoff modeling for semi-arid and transboundary conditions for the Yarmouk River Basin (YRB) using the SWAT model. They used available daily precipitation, ET, and runoff data coupled with an optimization technique for SWAT calibration.

Eini *et al.* (2020) [22] developed alternative SWAT-based models to simulate water budget and stream flow components for a karst-influenced watershed in southwestern Iran. Fousiya and Varughese (2020) [27] modeled streamflow using the SWAT model for the Thuthapuzha river basin in Kerala. They confirmed that the flow simulations were successful for the model based on statistical results. Gebru and Tesfahunegn (2020) [29] estimated water balance components using GIS for the Dura sub-basin in northern Ethiopia. They estimated the components of the hydrological water balance using the flexible, physical and GIS water balance model WetSpass. They used descriptive and inverse weighted distance to analyze various data and calculated current ET, surface runoff, and groundwater recharge. Krishnan *et al.* (2018) [38] applied a SWAT model to estimate runoff from the Nethravathi river basin in Dakshina Kannada district of Karnataka, India. Mestry *et al.* (2020) [45] estimated the basin water balance components in the Manjira River Basin using a SWAT model and GIS. Using SWAT input data such as DEM, LULC, soil classification, slope and weather data, they determined various water balance components such as precipitation, base flow, surface runoff, ET, PET and water yield for each catchment. Nasiri *et al.* (2020) [52] simulated water balance components in the Samalqan basin in Iran. They used the SWAT model and water balance components such as surface runoff, lateral flow, base flow and evapotranspiration were simulated. Nyatuame *et al.* (2020) [55] assessed the impacts of LULC on the water balance of the Tordzie basin. They used SWAT embedded in ArcGIS to assess water availability after calibration (2000–2003) and validation (2004–2006) using the Tordzin discharge.

6. Flow Record Generation in Ungauged Catchments

One of the main goals in developing a conceptual water balance model is to provide a model that can be used on ungauged catchments to generate a runoff record for planning and design purposes. Monthly water balance models usually have a simple structure and a small number of parameters, which has led to some successful studies in the field. Regression equations can be used to calculate model parameters from watershed characteristics.

Tejaswini and Sathian (2018) [65] assessed the hydrological processes in a small watershed in Valancheri, a sub-basin of the Bharathapuzha river basin in Kerala using the SWAT model. They used a regionalization technique and a calibrated model to predict hydrological features at the micro-basin level. They claimed that these simulation results were very useful for planning the development of water resources in the locality.

7. Farm Water Balance

In the water balance of the farm, field measurements are not effective by themselves. They are time consuming and do not capture ongoing data. On the farm, we usually need to determine the proportion of leached water and evapotranspiration as a percentage of total irrigation water. Therefore, farm water balance models need to develop some modules and codes to evaluate transport budget, root zone moisture, etc. (Zhang, 2002) [75]. Water scarcity, water rights, project development, irrigation system efficiency, common water resources around the farm and reclaimed water from neighboring farms are arguments that lead to serious legal problems in many watersheds and plains (Burt, 1999) [12].

8. Climatic Change Impact Assessment

The use of monthly water balance models appears to offer significant advantages over other methods in accuracy, flexibility and ease of use. Several case studies have been reported. Abdulla *et al.* (2009) [2] assessed the impact of potential climate change on the water balance of a semi-arid catchment located in the Zarqa River Basin (ZRW), Jordan. They used the U.S. The Environmental Protection Agency (EPA) developed the BASINS-HSPF modeling environment, which was designed to simulate the major hydrologic processes that affected the spatiotemporal distribution of water.

Kavvas *et al.* (2011) [36] evaluated water balances over the Tigris-Euphrates basin using the regional hydro-climatic model RegHCM-TE to reconstruct historical precipitation data, perform terrestrial hydrologic water balance calculations for infiltration, soil water storage, actual evapotranspiration, and direct runoff as input to streamflow calculations, and for estimating irrigation water requirements. Touhami *et al.* (2015) [69] assessed the impacts of climate change on soil water balance and aquifer recharge in a semi-arid region in southeastern Spain. They used the HYDROBAL hydrological model to determine the water balance of the soil. The required input data were soil data, climate and vegetation data, and reference evapotranspiration. Model outputs were interception, net precipitation, surface runoff, soil water storage, actual evapotranspiration, direct percolation, infiltration and potential recharge.

Kumar and Srinivasan (2020) [21] studied the climatic water balance and drought assessment in the Kallar Watershed of Tamil Nadu, India. They used data on rainfall, temperature and water holding capacity as the three primary parameters. They proposed sustainable water management practices for such areas. Leta *et al.* (2016) [41] assessed the impacts of climate change on the water balance components of the Heeia watershed in Hawaii, USA, using SWAT. They used a calibrated model to assess the impact of changes in precipitation, temperature and CO2 concentration on the water balance of the basin. Kundu *et al.* (2017) [40] studied the individual and combined impacts of future climate and land use changes on the water balance for a portion of the Narmada river basin in Madhya Pradesh.

9. The Impacts of Human Activities and Climate Change on Water Balance

The development of water balance formulations, especially when targets include future programming based on forecasts, is highly dependent on human activities and climate change; however, many models have an inability to incorporate these effects. Human activity has the potential to directly and indirectly influence the amount of water and the natural flow regime of the river system. Indirect impacts on the hydrological cycle may result from changes in land use.

Urban and rural development in part of the catchment can have significant quantitative and qualitative impacts on flows. All kinds of constructions, such as roads, fences, asphalt surfaces, etc., can change the natural river regime and increase the occurrence of random hydrological phenomena. Changes to the landscape caused by the development of urban structures can affect hydrological systems. There are some models, such as the macaque model, TOPOG, ANTHROPOG, MM5 and SWAT, which have been effectively used to investigate some of the effects of human activations on components of the local water cycle (Fohrer *et al.*, 2001) [24].

10. Conclusions

Many models and software are developed and widely used to analyze water storage and movement within a watershed based on water balance equations. In countries like India, most of the models used in water resource planning have been extracted from other countries with different climatic and topographic conditions. Hence, it is very important to focus on the structure and adoptability of these models before it is put in use. Determination of minimum standards, required number of parameters and estimation methods in individual local zones, required reliability, new techniques and tools for cost reduction, field measurements, etc. can help achieve more efficient water management.

11. Acknowledgments

The authors are thankful to KCAET, Tavanur and Kerala Agricultural University, Kerala, India.

12. References

1. Abdulla F, Al-Shurafat AW. Rainfall-Runoff modeling for semi-arid and trans-boundary Yarmouk river basin. Procedia Manufacturing. 2020;44:180-188.
2. Abdulla F, Eshtawi T, Assaf H. Assessment of the impact of potential climate change on the water balance of a semi-arid watershed. Water Resource Management. 2009;23:2051-2068.
3. Ahmad MJ, Cho G, Choi KS. Historical climate change impacts on the water balance and storage capacity of agricultural reservoirs in small ungauged watersheds. Journal of Hydrology: Regional Studies. 2022;41:1-20.
4. Arnell NW. A simple water balance model for the simulation of stream flow over a large geographic domain. Journal of Hydrology. 1999;217(3):314-335.
5. Ayivi F, Jha MK. Estimation of water balance and water yield in the Reedy Fork-Buffalo Creek watershed in North Carolina using SWAT. International Soil and Water Conservation Research. 2018;6:203-213.
6. Batelaan O, Woldeamlak ST. User guide of WetSpass. Available in the website; c2007. http://www.vub.ac.be/WetSpa/introduction_wetspass.htm
7. Bellot J, Chirino E. Hydrobal: An eco-hydrological modelling approach for assessing water balances in different vegetation types in semi-arid areas. Ecological Modelling. 2013;266(1):30-41.
8. Berezovskaya S, Yang D, Hinzman L. Long term annual water balance analysis of the Lena River. Global Planetary Change. 2005;48:84-95.
9. Bonuma NB, Rossi CG, Arnold JG, Reichert JM, Paiva

EMCD. Hydrology evaluation of the Soil and Water Assessment Tool considering measurement uncertainty for a small watershed in Southern Brazil. Applied Engineering in Agriculture. 2013;29(2):189-200.
10. Boughton W. Catchment water balance modelling in Australia 1960-2004. Agricultural Water Management. 2004;71:91-116.
11. Boughton W, Chiew F. Estimating runoff in ungauged catchments from rainfall, PET and the AWBM model. Environmental Modelling Software. 2007 22:476-487.
12. Burt CM. Irrigation water balance fundamentals. Proceeding of the Conference on Benchmarking Irrigation System Performance using Water Measurement and Water Balance. San Luis Obispo, CA, USCID, Denver, Colony; c1999. p. 1-13.
13. Campos I, Gonzalez-Piqueras J, Carrara A, Villodre J, Calera A. Estimation of total available water in the soil layer by integrating actual evapotranspiration data in a remote sensing-driven soil water balance. Journal of hydrology. 2016;534:427–439.
14. Casado-Rodriguez J, Jesus M. Hydrograph separation for tackling equifinality in conceptual hydrological models. Journal of Hydrology. 2022;610:1-12.
15. Caseri AN, Santos LBL, Stephany S. A convolutional recurrent neural network for strong convective rainfall nowcasting using weather radar data in Southeastern Brazil. Artificial Intelligence in Geosciences. 2022;3:8-13.
16. Celleri R, Timbe L, Vazquez RF, Feyen J. Assessment of the relation between the NAM rainfall-runoff model parameters and the physical catchment properties. Proceedings of the Conference on Monitoring and Modeling Catchment Water Quantity and Quality, Ghent, Belgium; c2000. p. 9-16.
17. Cohen M, Henges-Jeck C, Castillo-Moreno G. A preliminary water balance for the Colorado River delta. Journal of Arid Environment. 2001;49:35-48.
18. Corbari C, Charfi B, Bita BB, Skokovic D, Sobrino JA, Perelli C, *et al.* Fully coupled crop-water-energy balance model based on satellite data for maize and tomato crops yield estimates: The Fest-Ewb-Safy model. Agricultural Water Management. 2022;272:1-15.
19. Desai S, Singh DK, Islam A, Sarangi A. Multi-site calibration of hydrological model and assessment of water balance in a semi-arid river basin of India. Quaternary International. 2021;571:136-149.
20. Dhote PR, Thakur PK, Shevnina E, Kaushik S, Verma A, Ray Y, *et al.* Meteorological parameters and water balance components of Priyadarshini Lake at the Schirmacher Oasis, East Antarctica. Polar Science. 2021;3:1-10.
21. Dile YT, Ayana EK, Worqlul AW, Xie H, Srinivasan R, Lefore N, *et al.* Evaluating satellite-based evapotranspiration estimates for hydrological applications in data-scarce regions: A case in Ethiopia. Science of the Total Environment. 2020;743:1-22.
22. Eini MR, Javadi S, Delavar M, Gassman PW, Jarihani B. Development of alternative SWAT based models for simulating water budget components and streamflow for a Karstic-influenced watershed. Catena. 2020;195:1-13.
23. Flerchinger GN, Cooley KR. A ten-year water balance of a mountainous semi-arid watershed. Journal of Hydrology. 2000;237:86-99.
24. Fohrer N, Haverkamp S, Eckhardt K, Fredo HG. Hydrologic response to land use changes on the catchment scale. Physics and Chemistry of the Earth: Hydrology, Oceans and Atmosphere. 2001;26:577-582.
25. Fu J, Wang W, Shao Q, Xing W, Cao M, *et al.* Improved global evapotranspiration estimates using proportionality hypothesis-based water balance constraints. Remote Sensing of Environment. 2022;279:1-18.
26. Fung KF, Chew KS, Huang YF, Ahmed AN, Teo FY, Ng JL *et al.* Evaluation of spatial interpolation methods and spatiotemporal modeling of rainfall distribution in Peninsular Malaysia. Ain Shams Engineering Journal. 2022;13:1-20.
27. Fousiya, Varughese A. Modelling stream flow using SWAT model: A case study of Thuthapuzha River basin, Kerala. International Journal of Farm Sciences. 2020;10(2):86-95.
28. Fowler A. Assessment of the validity of using mean potential evaporation in computations of the long-term soil water balance. Journal of Hydrology. 2002;256:248–263.
29. Gebru TA, Tesfahunegn GB. GIS based water balance components estimation in Northern Ethiopia catchment. Soil and Tillage Research. 2020;197:1-17.
30. George S, Sathian KK. Assessment of water balance of a watershed using SWAT model for water resources management. International Journal of Engineering Sciences and Research Technology. 2016;5(4):177-184.
31. Ghandhari A, Moghaddam SA. Water balance principles: A review of studies on five watersheds. Journal of Environmental Science and Technology. 2011;4(5):465-479.
32. Ghimire GR, Krajewski WF, Ayalew TB, Goska R. Hydrologic investigations of radar-rainfall error propagation to rainfall-runoff model hydrographs. Advances in Water Resources. 2022;161:1-18.
33. Guo S, Wang J, Xiong L, Ying A, Li D. A macro-scale and semi-distributed monthly water balance model to predict climate change impacts in China. Journal of Hydrology. 2022;268:1-15.
34. He F, Tan S, Liu H. Mechanism of rainfall induced landslides in Yunnan Province using multi-scale spatiotemporal analysis and remote sensing interpretation. Microprocessors and Microsystems. 2022;90:1-10.
35. Jayatilaka CJ, Sakthivadivel R, Shinogi Y, Makin IW, Witharana P. A simple water balance modelling approach for determining water availability in an irrigation tank cascade system. Journal of Hydrology. 2003;237(1):81-102.
36. Kavvas ML, Chen ZQ, Anderson ML, Ohara N, Yoon JY, Xiang F. A study of water balances over the Tigris–Euphrates watershed. Physics and Chemistry of the Earth. 2011;36:197-203.
37. Knoll P, Zirlewagen J, Scheytt T. Using radar-based quantitative precipitation data with coupled soil- and groundwater balance models for stream flow simulation in a karst area. Journal of Hydrology. 2020;586:1-9.
38. Krishnan G, Kumar KS, Rejani R. Application of SWAT model for estimating runoff of Nethravathi River basin using sequential uncertainty fitting technique. International Journal of Science and Research. 2018;9(3):893-902.
39. Kumar G, Srinivasn D. Climatic water balance study and drought assessment in Kallar watershed, Tamil Nadu, India. International Journal of Earth Sciences and

Engineering. 2016;9(3):958-962.
40. Kundu S, Khare D, Mondal A. Individual and combined impacts of future climate and land use changes on the water balance. Ecological Engineering. 2017;105:42-57.
41. Leta OT, El-Kadi AI, Dulai H, Ghazal KA. Water assessment of climate change impacts on water balance components of Heeia watershed in Hawaii. Journal of Hydrology: Regional Studies. 2016;8:182-197.
42. Li Q, Zhicai L, Zhong B, Zhou H. An improved approach for evapotranspiration estimation using water balance equation: case study of Yangtze River basin. Water. 2018;10(812):1-21.
43. Liu W, Engel BA, Feng Q. Modelling the hydrological responses of green roofs under different substrate designs and rainfall characteristics using a simple water balance model. Journal of Hydrology. 2021;602:1-12.
44. Lv M, Ma Z, Yuan X, Lv M, Li M, Zheng Z. Water budget closure based on GRACE measurements and reconstructed evapotranspiration using GLDAS and water use data for two large densely-populated mid-latitude basins. Journal of Hydrology. 2017;547:585-599.
45. Mestry A, Narwade R, Nagarajan K. Estimation of water balance components of watersheds in the Manjira River basin using SWAT model and GIS. International Journal of Engineering and Advanced Technology. 2020;9(3):3898-3907.
46. Mingan S, Huang M, Zhang L, La Y. Simulation of field-scale water balance on the Loess Plateau using the WAVES model. Proceedings of the Assessment for Managing Sustainable Agriculture in China and Australia (AMSACA02), ACIAR, Australia; c2002. p. 48-56.
47. Mouelhi S, Michel C, Perrin C, Andreassian V. Stepwise development of a two-parameter monthly water balance model. Journal of Hydrology. 2006;20:1-15.
48. Motschmann A, Teutsch C, Huggel C, Seidel J, Leon CD, Munoz R, *et al.* Current and future water balance for coupled human-natural systems - Insights from a glacier zed catchment in Peru. Journal of Hydrology: Regional Studies. 2022;41:1-23.
49. Muttiah RS, Wurbs RA. Scale-dependent soil and climate variability effects on watershed water balance of the SWAT model. Journal of Hydrology. 2002;256:264-285.
50. Mtibaa S, Asano S. Hydrological evaluation of radar and satellite gauge-merged precipitation datasets using the SWAT model: Case of the Terauchi catchment in Japan. Journal of Hydrology: Regional Studies. 2022;42:1-10.
51. Najjar RG. The water balance of the Susquehanna River basin and its response to climate change. Journal of Hydrology. 1999;219:7-19.
52. Nasiri S, Ansari A, Ziaei AN. Simulation of water balance equation components using SWAT model in Samalqan watershed (Iran). Arabian Journal of Geosciences. 2020;421:1-15.
53. Ndhlovu GZ, Woyessa YE. Modelling impact of climate change on catchment water balance, Kabompo River in Zambezi River Basin. Journal of Hydrology: Regional Studies. 2020;27:1-15.
54. Noviadi SC, Sukarno S, Setiawan E, Wardani K. Water balance analysis in Bera watershed Sumbawa River basin. Satia Cahya Noviadi Journal of Engineering Research and Application. 2019;9(7):33-39.
55. Nyatuame M, Amekudzi LK, Agodzo SK. Assessing the land use/land cover and climate change impact on water balance on Tordzie watershed. Remote Sensing Applications: Society and Environment. 2020;20:1-10.
56. Oroud IM. Water budget assessment within a typical semiarid watershed in the Eastern Mediterranean. Environmental Processes. 2015;2:395-409.
57. Quinn PF, Connell PE, Kilsby CG, Parkin G, Riley MS. Catchment water hydrology and sustainable management (CHASM): generic experimental design. Proceedings of the Conference on Monitoring and Modeling Catchment Water Quantity and Quality, (MMCWQQ00), Ghent (Belgium); c2000. p. 77-81.
58. Rohtash, Thakural LN, Choudhary MK, Tiwari D. Rainfall runoff modelling using SWAT model for Chaliyar basin Kerala, India. International Journal of Science and Research. 2019;8(5):90-97.
59. Schilling KE, Jha MK, Zhang YK, Gassman PW, Wolter CF. Impact of land use and land cover change on the water balance of a large agricultural watershed: historical effects and future directions. Water Resources Research. 2008;44(9):1-12.
60. Singh P, Alagarswamy G, Pathak P, Wani SP, Hoogenboomb G, Virman SM. Soybean-chickpea rotation on Vertic Inceptisols 1. Effect of soil depth and landform on light interception, water balance and crop yields. Field Crops Research. 1999;63:225-236.
61. Sinha J, Jha S, Goyal MK. Influences of watershed characteristics on long-term annual and intra-annual water balances over India. Journal of Hydrology. 2019;577:1-16.
62. Soltani M, Bjerre E, Koch J, Stisen S. Integrating remote sensing data in optimization of a national water resources model to improve the spatial pattern performance of evapotranspiration. Journal of Hydrology. 2021;603:1-16.
63. Spruill CA, Workman SR, Taraba JL. Simulation of daily and monthly stream discharge from small watersheds using the SWAT model. Biosystems and Agricultural Engineering. 2000;43(6):1431-1439.
64. Sukanya P, Kalapureddy M.C.R. Cloud radar perspective on tropical warm clouds associated with summer monsoon rainfall and warm rain onset process. Atmospheric Research. 2022;278:1-10.
65. Tejaswini V, Sathian KK. Assessment of hydrological processes in a small watershed using SWAT. International Journal of Agricultural Engineering. 2018;11(1):41-48.
66. Thornthwaite CW. An approach toward a rational classification of climate. Geographical Review. 1948;38(1):55-94.
67. Thornthwaite CW, Mather JR. The water balance. Publications in Climatology, Laboratory of Climatology. Drexel Institute of Technology. 1955;8(8):1-104.
68. Thornthwaite CW, Mather JR. Instructions and tables for computing potential evapotranspiration and the water balance. Publications in Climatology, Laboratory of Climatology. Drexel Institute of Technology. 1957;10(3):185-311.
69. Touhami I, Chirino E, Andreu JM, Sanchez JR, Moutahir H, Bellot J. Assessment of climate change impacts on soil water balance and aquifer recharge in a semiarid region in South East Spain. Journal of Hydrology. 2015;527:619-629.
70. Traore S, Wang Y, Kerh T. Artificial neural network for modeling reference evapotranspiration complex process in Sudano-Sahelian zone. Agricultural Water Management. 2010;97:707-714.

71. Tripathi MP, Raghuwanshi NS, Rao GP. Effect of watershed subdivision on simulation of water balance components. Hydrological Processes. 2006;20:1137-1156.
72. Wang GQ, Zhang JY, Jin JL, Liu YL, He RM, Bao ZX, *et al.* Regional calibration of a water balance model for estimating stream flow in ungauged areas of the Yellow River Basin. Quaternary International. 2014;336:65-72.
73. Wang Z, Wu Y, Cao Q, Shen Y, Zhang B. Modeling the coupling processes of evapotranspiration and soil water balance in agroforestry systems. Agricultural Water Management. 2021;250:1-16.
74. Xu CY, Singh VP. A review on monthly water balance models for water resources investigations. Water Resources Management. 1998;12:20-50.
75. Zhang L, Walker GR, Dawes WR. Water balance modelling concepts and applications. In: regional water and soil assessment for managing sustainable agriculture in China and Australia, ACIAR Monograph Canberra, Australia; c2002. p. 31-47.