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Assessment of Water Balance Components of Bhadar River Basin Using SWAT Model

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Abstract

Knowledge of water balance and water yield of a river basin is an indispensable prerequisite in the sustainable management of water resources at basin level. Components of water balance are influenced by climate & physical characteristics of the catchment such as morphology, land use and soil. Therefore, understanding the relationship between these physical parameters and hydrological components is necessary to access the hydrologic response to climate and land cover variability in determining the water availability. The SWAT model is the tool to assess the water balance components of the hydrological cycle like rainfall, runoff, evapotranspiration and groundwater recharge under given land use, management and climate. The runoff and groundwater recharge assessment are very useful for the water resources development and planning. This study was undertaken for the Bhadar River basin divided into 16 watersheds and total drainage area of 7330.40 km^{2}with the help of remote sensing and GIS techniques. The climatic, discharge and sediment yield data were divided into calibration period (1981-2000) and validation period (2001-2010). The climatic and discharge data, sediment data, SRTM-DEM imagery, soil maps and land use/cover classification from LISS IV imagery are used as primary inputs for SWAT model. SWAT model provides a better description of water balance of the watershed. The average annual rainfall, runoff, evapotranspiration, percolation to shallow aquifer and recharge to deep aquifer in the basin is 670, 243.67, 252.9, 150.14, and 7.51 mm, respectively. The annual average runoff is 36.37% of the average annual rainfall.

Keywords: Arc GIS, Bhadar, water balance, SWAT, groundwater

1. Introduction

Water is indispensable for life, but its availability at a sustainable quality and quantity is threatened by many factors, in which climate plays a leading role. Groundwater is the major source of water across the world for life particularly in rural areas of arid and semi-arid regions (Lal et al., 2018). Within river basins, water resources competition often exists between agricultural, municipal and industrial sectors, particularly in semi-arid regions where surface water and groundwater are managed conjunctively to sustain urban areas and food production(Aliyari et al., 2019). The SWAT is a semi-physically distributed hydrological model, operated on daily time step to simulate runoff and sediment at watershed scale (Arnold et al., 1996; Arnold and Fohrer, 2005; Neitsch et al., 2001;

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Gassman et al., 2007). Primarily SWAT was developed to assess the effects of land use and management changes on long-term runoff, sediment and non-point source pollution loads to surface water bodies on daily basis which has been subsequently modified to study expected changes in weather-climate processes. The SWAT model requires meteorological input mainly precipitation, temperature, solar radiation, relative humidity, wind speed and information on topography, soil and land use over the region. Model divides the entire catchment into number of watersheds and then into hydrological response units (HRUs) based on unique combination of land cover and soils to simulate the hydrologic processes. Then aggregation is done across watersheds to determine the overall watershed hydrologic balance including stream flow at the outlet of the entire watershed using a stream routing process. Model simulates processes like plant growth and root depth cycle; delay in groundwater and lateral flow; and also simulates the detachment of sediments from the watersheds and their transportthrough stream channels.

Spatial and temporal analysis of a basin provides useful information for sustainable water resource planning and management. (Kumar et al., 2016)

The present study can be helpful to make conservation structures in watersheds of the basin for the soil and water management, assess the surface and groundwater resources and plan the water harvesting-cum-groundwater recharge structures. The knowledge of runoff will give an outlook of water that is available to replenish water bodies in the watersheds of the basin.

2. Materials and Methods

This chapter deals with the description of the study area, details of data collected and generated, SWAT model and the procedure involved in model that help to understand the hydrologic process of the basin and methodology adopted to find water balance components.

2.1. Study area description

Saurashtra is the western peninsular region of Gujarat, which covers an area of about 58,743 square km lying on Arabian Sea Coast, with the coastline of about 925 km length. All the rivers in Saurashtra region are short in length with low flows except in rainy season which are flowing in all directions. The average annual rainfall varies from 400 mm in North Saurashtra to 800 mm in South Saurashtra (Patel, 2007).

Bhadar is one of the major rivers of Saurashtra and it drains about 1/7[th] of the area of Saurashtra. The Bhadar basin is the South Western basin and situated between 21° 25' to 22° 10' North latitude and69° 45' to 71° 20' East longitude. The river Bhadar originates at an elevation of 261 m above m.s.l. in Vaddi about 26 km North–West of Jasdan in Rajkot district and flows towards South uptoJasdan village and then turns towards South – West up to village Jetpur and finally changes its direction towards West till its confluence with Arabian sea at Navibandar (Porbandar). Thus from Jetpur to Porbandar the River Bhadarfertiles Rajkot, Jamnagar, Amreli and Junagarh districts of Saurashtra (Figure 1). The river Bhadar drains an area of 7330.40 sq km out of which 706 sq km in hilly and the rest in plain regions of Saurashtra. The river Bhadar receives several tributaries on both the banks. There are 9 major tributaries having a length more than 25 km out of which 6 tributaries namely Gondali, Chapparwadi, Phopal, Utawali, Moj and Venu are feeding from right and the remaining 3 tributaries namely Vasavadi, Surwaand Galolia from left. The drainage system on the right bank of river Bhadar is more extensive as compared to the left bank. Gondali, Chapperwadi, Phopal and Venu, these 4 important right bank tributaries together account for nearly 35% of total catchment area of Bhadar. Venu, which is the principal tributary of Bhadar also passes in Jamnagar district in hilly range and drains Jamnagar and Rajkot districts. Phopal, another tributary rises at high level range about 5 km north of the town Lodhika.

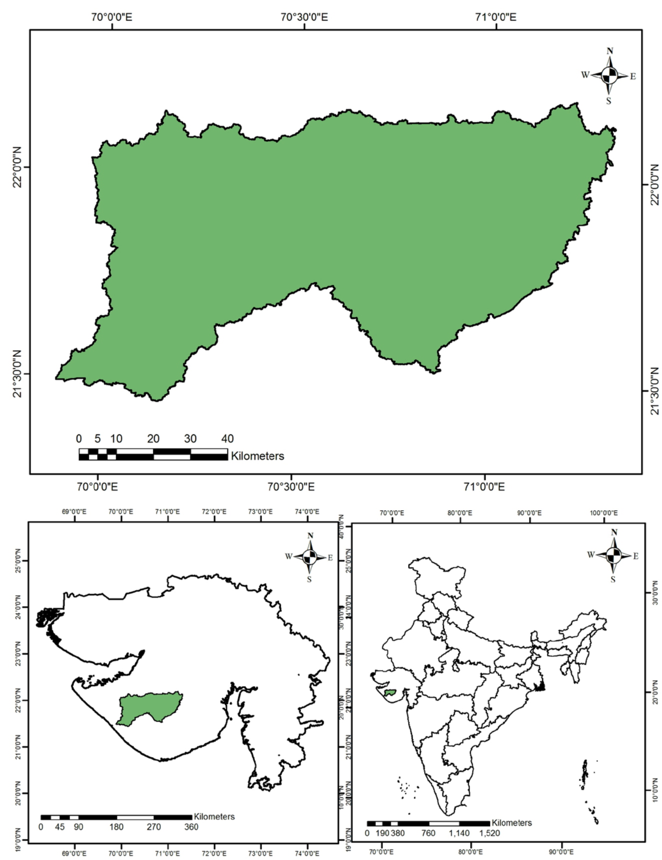

Figure 1: Bhadar river basin location map

The average rainfall in Bhadar basin is 625 mm. The South West monsoon sets in by the middle of June and withdraws by the first week of October. About 90% of total rainfall is received during July and August. Owing to the topographical characteristics, the climate is variable. In winter the temperature varies between 4 °C and 15 °C. May is the hottest month. Maximum temperature varies between 40 °C and 46 °C (Table 1).

Table 1: Data Used for the Experiment		
Data	Description	Source
Hydrological and meteorological data	• Daily rainfall of 37 raingauge stations • Daily streamflow data at outlet of watershed i.e. Bhadar runoff gauging site • Daily temperature (max and min) • Daily relative humidity • Daily average wind speed • Daily sunsine hours	State water data center, Gandhinagar, Gujarat
Remote Sensing Data	• Digital Elevation Model	earthexplorer.usgs.gov
	• Landuse/Landcover map • Soil map	Bhaskaracharya Institute for Space Application and Geo-informatics (BISAG), Gandhinagar, Gujarat

2.2. Water balance components

The hydrological components in the SWAT model simulation is calculated in the order of precipitation, interception, surface runoff and infiltration, lateral flow and percolation, evaporation and transpiration, groundwater recharge and groundwater flow, based on the water balance equation as below

$SW_t=SW_o+\sum^{t}_{i=1}R_{day}-Q_{surf}-E_a-w_{seep}-Q_{gw}$……………………(1)

Where, SW_o is initial soil water content and SW_t is the final soil water content on day i. All other measurements are taken in millimetres and time (t) is in days. The equation subtracts all forms of water loss on day i from precipitation on day i (R_{day}) including surface runoff (Q_{surf}), evapotranspiration (E_a), loss to vadose zone (w_{seep}) and return flow (Q_{gw}) (Neitsch, 2001, Arnold *et al.* 2012). By manipulating this equation the model can predict changes in variables of interest like runoff and return flow.

2.3. Surface runoff

Surface runoff is predicted for the daily rainfall by using SCS curve number equation as below:

$Q_{Surf}=(R_{day}-I_a)2/(R_{day}-I_a+S)$……………………(2)

Where, Q_{surf} is the accumulated surface runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstraction which includes surface storage, interception and infiltration prior to surface runoff (mm), and S is the retention parameter (mm). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. Retention parameter is calculated by equation as below where CN is the curve number of the area.

$S=25.4(1000/CN-10)$……………………(3)

Where, CN is the curve number. The initial abstraction, I_a is commonly approximated as 0.2S and then equation (2) becomes equation (4) as follows. Runoff will occur when $R_{day}>Ia$.

$Q=(P-0.2S)^2/(P+0.8S)$ ……………………(4)

3. Results and Discussion

The average annual precipitation during calibration and validation are 511 mm and 670 mm respectively. In which the 172.15 mmand 243.67 mm runoff passed at outlet point for calibration and validation period, respectively.The average annual sediment yield during calibration and validation are 14.13 t ha^{-1} and 19.40 t ha^{-1}. Here, Runoff and sediment yield of validation is higher than calibration period due to high annual precipitation and number of peak event. According to the relationship between the annual runoff coefficient (annual runoff/annual precipitation) with precipitation, It was found that there was a relatively higher correlation between runoff coefficient and precipitation (Figure 2).

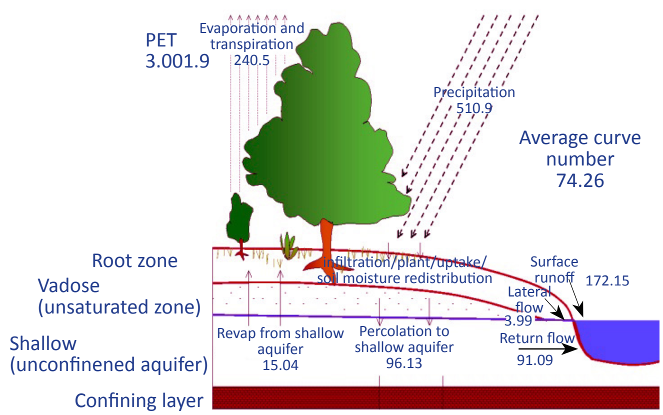

Figure 2: Water balance of the Bhadar basin during calibration period

In this study, evapotranspiration is measured using the Penman-Monteith method and it was found that the evapotranspiration were 240.5 mm and 252.9 mm for the calibration and validation period, respectively. The area under the agriculture land is more. So, evapotranspiration was high during calibration and validation period.Saxena and Gupta (2017) reported that PET ranges from 140 cm to 180 cm in most part of India, while highest value of 214.5 cm has been reported from Rajkot in Gujarat.Ground water parameters like percolation to shallow aquifer, return flow and recharge to deep aquifer for calibration were 96.13, 91.09 and 4.81 mm, for validation, it were 150.14, 136.95 and 7.51 mm, respectively. All the water balance components are shown in the Figure 4.20 and 4.21 during calibration and validation periods, respectively. From the results, we could fill in the multi-scale knowledge gap of water balance of the watershed in inland river basins. This information is very useful for developing an overview of where the water resources are coming from and what changes have been taken place.Performance of SWAT model is satisfactory in terms of different performance indices such as NSE=64.6%, R^2=0.762 during calibration and NSE=68.5%, R^2=0.798 during validation (Pfannerstill et al., 2017; Phomcha et al. 2011;Stratton et al., 2009; Visakh et al., 2019). Similarly Awotwi et al., 2015 alsofound that statistical test performance for calibration period R^2 of 0.88 and NSE of 0.84 and for validation from 2006 to 2008 also showed a close match with the observation R^2 of 0.82 and NSE of 0.79 for theWhite Volta Basin in West Africa (Figure 3).

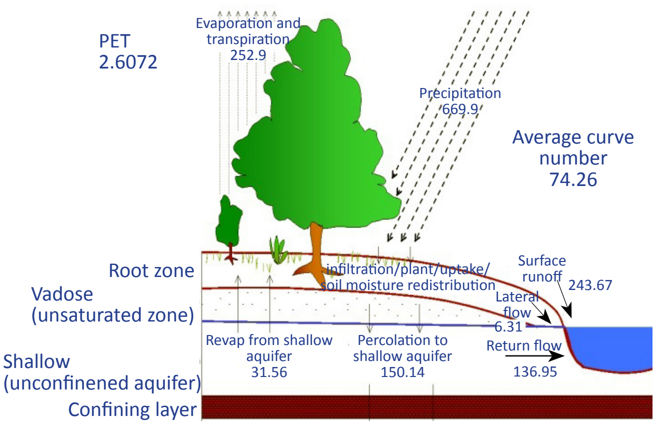

Figure 3: Water balance of the Bhadar basin during validation period

4. Conclusion

Overall, SWAT demonstrated good performance in in capturing the water balance scenario. Model was found to produce a reliable estimate of aggregated monthly runoff which was demonstrated by NSE and R^2 for both calibration and validation period. High value of NSE and R^2 of SWAT model during validation period indicate the predictive ability of the model and suggest its appropriateness for estimation of water balance components in the study basin. The study provide baseline understanding of the hydrologic processes to deal with water management issues in the basin. The study suggest that SWAT model could be promising tool to predict water balance to support policies and decision making for sustainable management at basin level.

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