

Estimation of Water Balance Components of Watersheds in the Manjira River Basin using SWAT Model and GIS



Akshata Mestry, Raju Narwade, Karthik Nagarajan

Abstract: This study mainly focus on hydrological behavior of watersheds in The Manjira River basin using soil and water assessment tool (SWAT) and Geographical information system (GIS). The water balance components for watersheds in the Manjira River were determined by using SWAT model and GIS. Determination of these water balance components helps to study direct and indirect factors affecting characteristics of selected watersheds. Manjira River contains total 28 watersheds among them 2 were selected having watershed code as MNJR008 and MNJR011 specified by the Central Ground Water Board. The SWAT input data such as Digital elevation model (DEM), land use and land cover (LU/LC), Soil classification, slope and weather data was collected. Using these inputs in SWAT the different water balancing components such as rainfall, baseflow, surface runoff, evapotranspiration (ET), potential evapotranspiration (PET) and water yield for each watershed were determined. The evaluated data is then validated by Regression analysis, in which two datasets were compared. Simulated rain data from SWAT simulation and observed rain data from Global Weather Data for SWAT was selected for comparison for each watershed.

Keywords — Water balance components, soil and water assessment tool (SWAT), Digital elevation model (DEM).

I. INTRODUCTION

Water resource management has proven important factor from several aspects, such as irrigation, development of water-bodies for future needs, protection of water resources from pollution and also controlling quality as well as quantity of water. The different climatic conditions and human activities are changing water resource characteristics such as land cover, land use, soil condition, surface runoff and rainfall [1]. For effective water resource management first of all various hydrological components and water cycle must be studied and taken into consideration, which includes evapotranspiration, transpiration, condensation, precipitation and runoff. Water scarcity is most common problem in many countries throughout the world and so in India. To overcome this problem proper water resource management is essential.

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The Marathwada region in Maharashtra, India faces water crisis every year due to depletion of water level. To find out the solution on such problems detailed study of water resources on smaller scale must be done [11]. The study area includes two watersheds from Manar stream (watershed code-MNJR008 and MNJR011) [19]. These watersheds come under Manjira river which is the tributary of India's second largest river Godavari and flows through some parts of Marathwada region. The various GIS data such as soil data, LU/LC, DEM used as inputs in SWAT to determine water balance components of study area. The water balancing components helps in water budgeting, gives brief idea about watershed characteristics, this further can be used to predict the availability of water and so can help in water resource management.[14]

II. LITERATURE REVIEW

In this detailed literature survey was done to study and understand the different uses of SWAT, GIS and similar softwares in water management. With the help of SWAT model and geospatial techniques assessment of water balance of watershed in kurumali sub basin and Karuvannur river basin was done by Sandra George, Sathian and K.K. (2016) [13]. Frederick Ayivi and Manoj K Jha (2018) Estimated Water yield and water balance in Reedy Fork-Buffalo creek watershed in North Carolina, they also assessed the performance of SWAT for future prediction of water balance and water yield in other watersheds of North Carolina [5]. Hayal Desta and Brook lemma (2017) quantified and compared water balance components, discharge of feeder river and evapotranspiration in Lake ziwaw watershed, Ethiopia using SWAT model[6]. O.M.M. Abdelwahab et al. (2018) compared simulation of soil erosion in Mediterranean watershed generated by two most widely used models, SWAT Soil and water assessment tool and Annualised agricultural Non-point source (AnnAGNPS) [10]. Muhammad adnan et al.(2019) quantified water budget of Nam Co lake by using SWAT (soil and water assessment tool coupled with DDM (Degree day model) over period of 2007 to 2013 [8]. David rivas-tabares(2019) assessed the water balance of cega-eresma-adaja watershed, they assessed land use in detail, water demand for period 2004-2014 of agricultural land using SWAT [4]. Natalja cerkasova et al.(2018) developed hydrology and water quality model for Nemunas large transboundaries watershed using SWAT, they used customized MATLAB scripts for HRU (hydrologic response unit) production also assessed SWAT model setup approaches for HRU definitions [9].



Aditya Nilawar and Milind Waikar (2019) quantified effects of climate change on sediment concentration and streamflow of Purna river basin in India by using SWAT [2]. Abeyou W. Worqlul et al. (2018) used SWAT model to evaluate hydrologic responses such as surface runoff response, water balance to soil characteristics for paired watershed in upper Blue Nile basin, the study demonstrated sensitivity of watershed hydrology to soil [1]. Cesar Perez-validivia et al. (2017) investigated potential impact wetland drainage on hydrology i.e peak flow, annual volume of Pipestone creek watershed in cannada using SWAT [3]. Tao Can et al. (2015) used SWAT to simulate various land use scenarios and assessed the impact of it on water budgeting. They calibrated 12 model parameters and validated for 7 years for baseline conditions [15].

III. OBJECTIVE

The main aim of this study is to determine the water balance components of watersheds such as rain, runoff, water yield and evapotranspiration in the Manjira River basin by using SWAT and GIS.

IV. STUDY AREA

The Manjira River is a tributary of Godavari River which is second largest river in India. Its origin is in balaghat range of hills near Ahmednagar district. This 724 km long river starts from Beed district then flows across Latur in Maharashtra state, Bidar in Karnataka state and finally in Telangana state. The Manjira River covers area about 30,844 Sqkm. The river has total six tributaries which are Terna, Tawarja, Gharni, Lendi, Manyad, Teru. There are total 28 watersheds in the Manjira river basin out of which two were selected. According to Central ground water board these watersheds are under Manar stream and coded as MNJR008 and MNJR011 respectively. Each of them is having area about 1550 and 957 Sqkm respectively. The watershed selected comes under Nanded district in Marathwada region. Fig 1 shows a map of watersheds selected for study

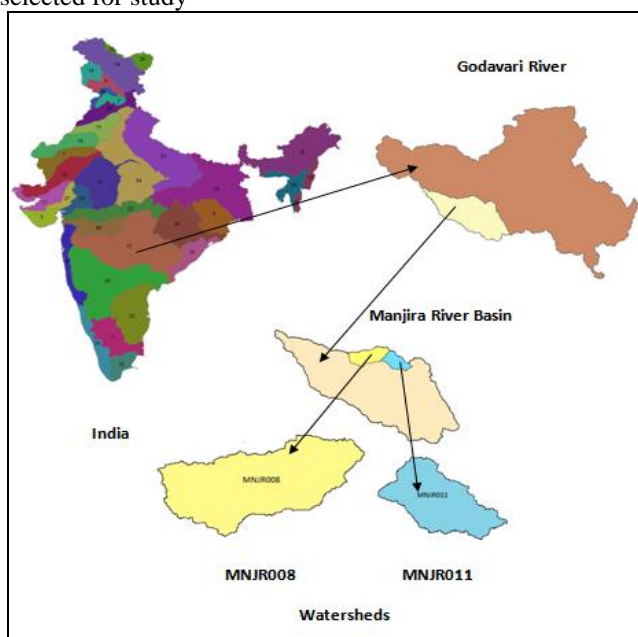


Fig 1. Study area (watershed MNJR008 and MNJR011)

V.METHODOLOGY

The flowchart showing methodology adopted for this study is given in Fig 2. The flowchart gives detail idea about method followed, input data and output received. Initially all the required input data was collected and prepared. The data was downloaded from USGS earth explorer to prepare DEM which is used as base map. The data downloaded for watersheds was of SRTM 1 Arc-Second Global Data. Also the shape files of respective watersheds were made further used to prepare DEM of respective watershed. The data required to prepared shape file was collected from HydroSHEDS. The information regarding soil map was procured from official SWAT website in which Indian dataset is provided by Dr.Balaji Narasimhan .From Oak Ridge National Laboratory (ORNL) Distributed Active Archieve Centre (DAAC) the decadal landuse/landcover data at 100m resolution for India at intervals 1985,1995 and 2005 was gathered. This data was procured from Indian Remote Sensing Satellites (IRS) Resourcesat Linear Imaging Self-Scanning Sensor-I or III (LISS-I, LISS-III) data, Landsat 4 and 5 Thematic Mapper (TM), Enhance Thematic Mapper Plus (ETM+), Multispectral (MSS) Data and visual interpretation and ground truth survey [16].

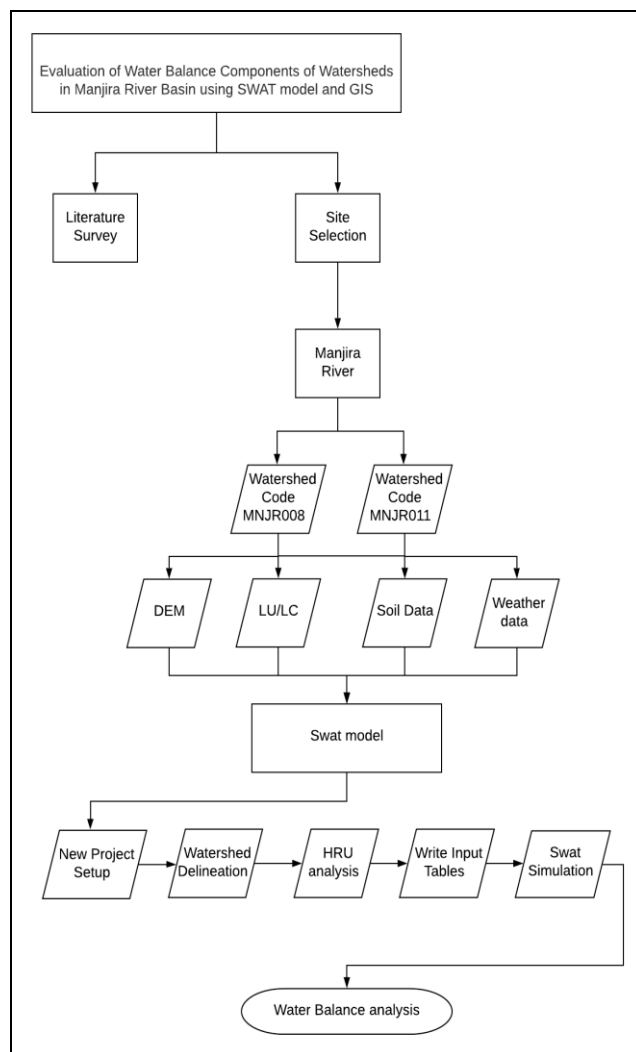


Fig 2. Flowchart of Methodology

VI. SWAT MODEL

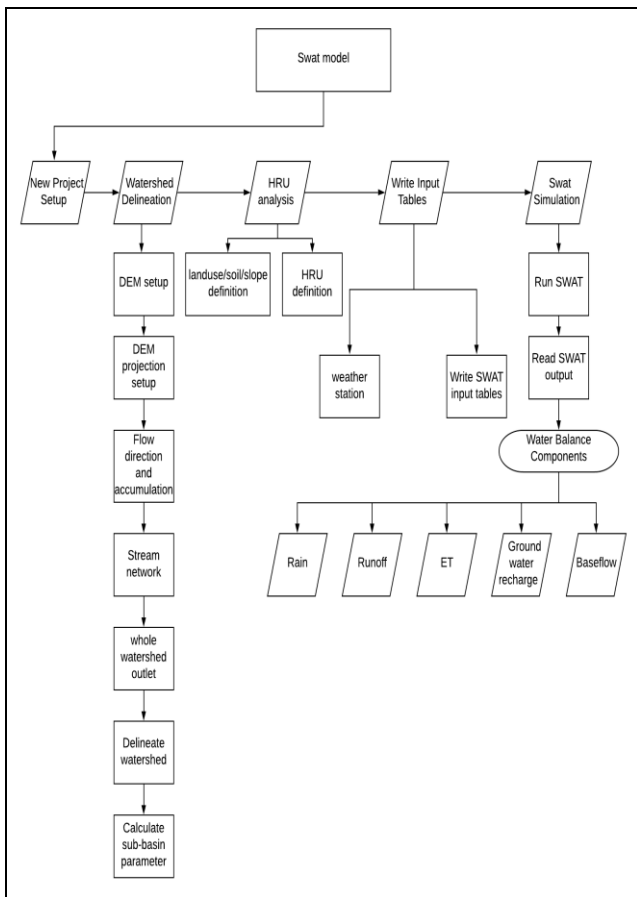


Fig 3. Flowchart of SWAT model

The SWAT means Soil and Water Assessment Tool, which is basin scale model extensively used to quantify water balance components. The steps involved in SWAT model setup has been given in flowchart shown in Fig 3. The input for SWAT model i.e SRTM DEM is corrected if any error, the DEM used was projected and corrected for watershed delineation. The topographic parameters of watershed were calculated.

For the HRU analysis land use/land cover, soil and slope data was collected from Indian dataset. The landuse/landcover,soil and slope map were prepared and Hydrological Response Unit was generated (HRU Unit).The model required weather data which was taken from Indian dataset. All the input tables for SWAT run are prepared by model. Then SWAT model is ready to run, by performing SWAT check and then read SWAT all the water balance components are determined.

VII. THEMATIC MAPS

A. Landuse/ Landcover

Landuse and Landcover map showing distribution of land in watershed MNJR008 and MNJR011 in Manjira river basin have shown in Fig 4 and Fig 5,where WATR stands for Water, RNGB is for Rangeland brush, AGRL stands for Agricultural Land- Generic ,AGRR denotes Agricultural Land- Row Crops, AGRC is for Agricultural Land- close grown and FRST stands for Forest.

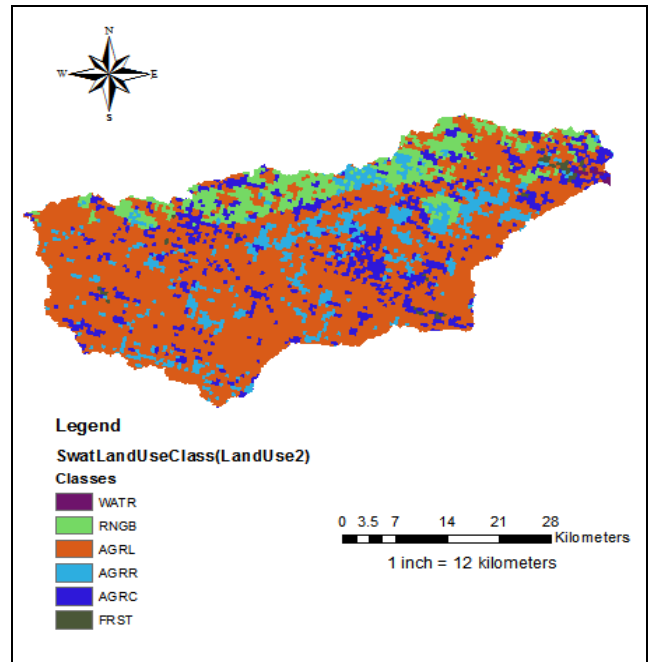


Fig 4: Landuse/landcover map of Manjira River Watershed (MNJR008)

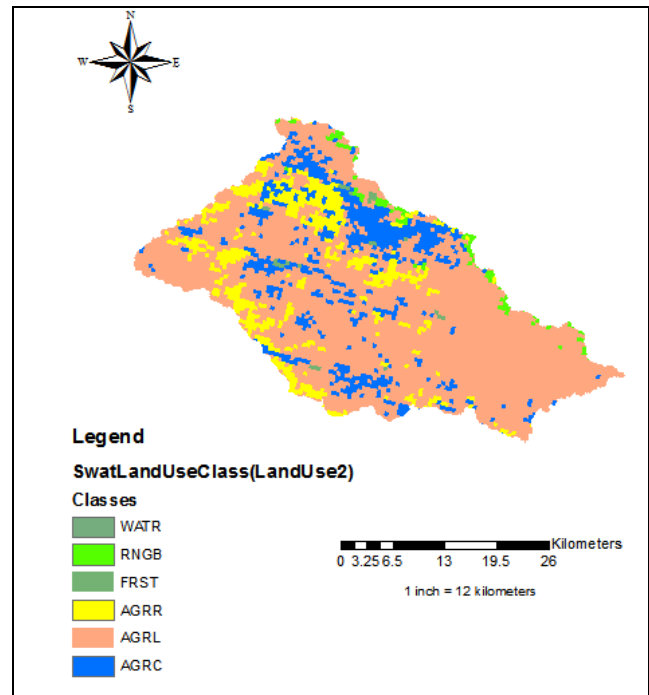


Fig 5. Landuse/landcover map of Manjira River Watershed (MNJR011)

B. Soil map

Soil Map of watershed MNJR008 and watershed MNJR011 in the Manjira river basin have shown in Fig 6 and Fig 7 respectively. In watershed MNJR008 there are three types of soils which are Clay-Loam, Clay and Clay and in Watershed MNJR011 there are two types of soils which are Clay-Loam and Clay shown in Table I.

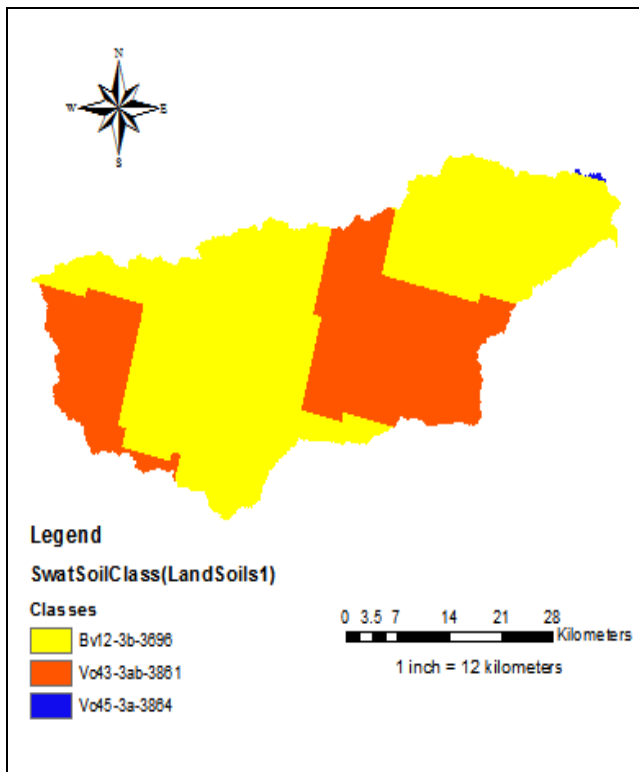


Fig 6: Soil map of Manjira River Watershed (MNJR008)

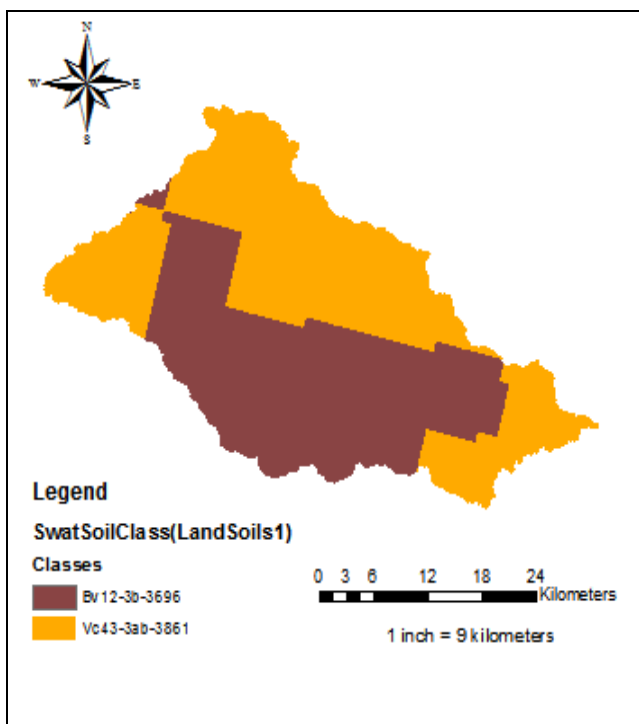


Fig 7. Soil map of Manjira River Watershed (MNJR011)

Table I: Soil Taxonomy

Bv12-3b-3696	CLAY_LOAM
Vo43-3ab-3861	CLAY
Vo45-3a-3864	CLAY

C. Digital Elevation Map

Digital Elevation Model (DEM) of watershed MNJR008 and MNJR011 in Manjira river basin have shown in Fig 8 and Fig 9 respectively.

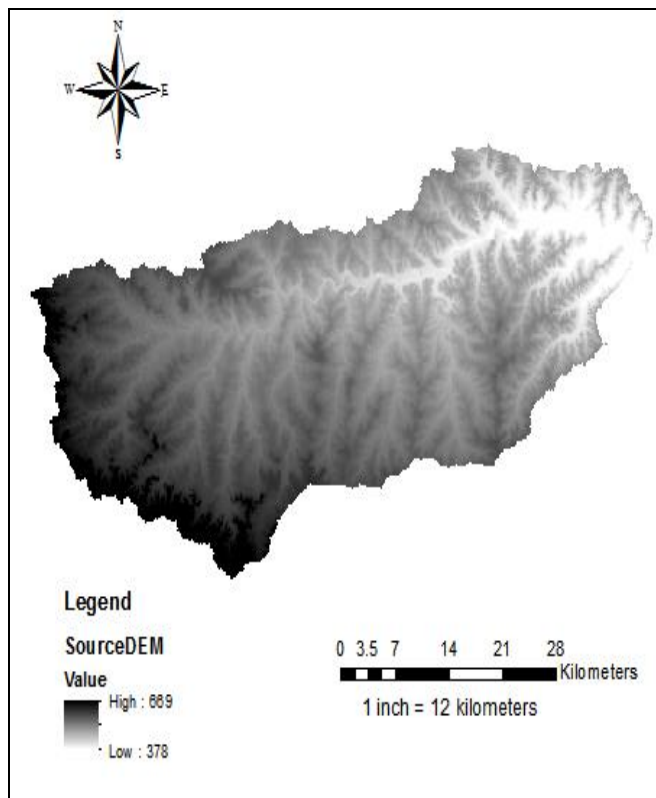


Fig 8: Digital Elevation of Manjira River Watershed (MNJR008)

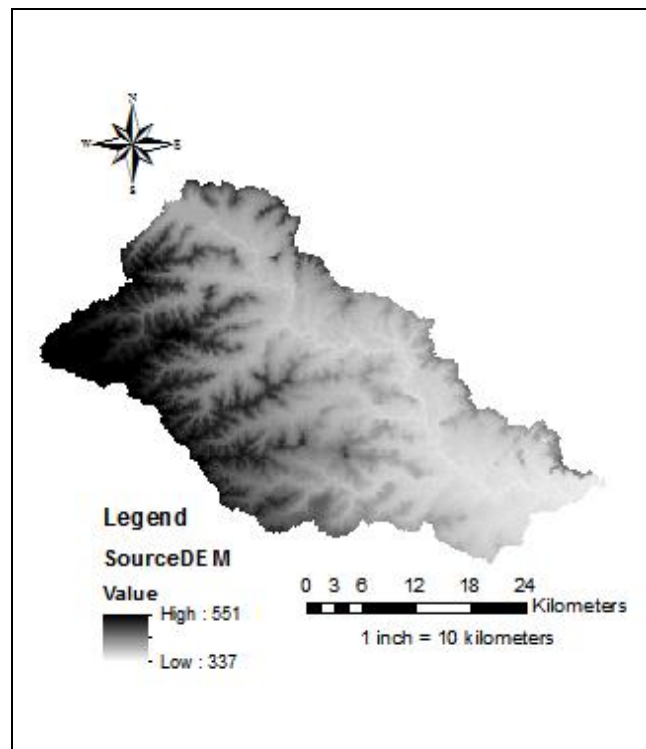


Fig 9: Digital Elevation of Manjira River Watershed (MNJR011)

VIII. RESULTS

The various Water Balancing Components have been generated using SWAT model. The components which determined are Rainfall, ET, Runoff, Baseflow, Ground water recharge. The landuse and landcover distribution in study area was also given by SWAT model. It has also provided landuse/lancover and soil maps. soil maps show the soil classification across the study region. The SWAT simulation was used separately for each watershed, so we have two water balancing equation for each watershed. The water balance equation is as follows:

$$P - Q - ET - \text{Base flow} \pm \Delta TWS - (\text{other components}) = 0$$

.....(equation 1)

Where;

P= Precipitation

Q= Runoff

E = Evapotranspiration

ΔTWS = change in terrestrial water storage

And other components consist soil moisture, shallow and deep ground water storage, glacier and soil moisture. [12]

A. Watershed MNJR008:

The SWAT output for Watershed MNJR008 is shown in Fig 10. The Fig shows water balancing components in watershed and its values.

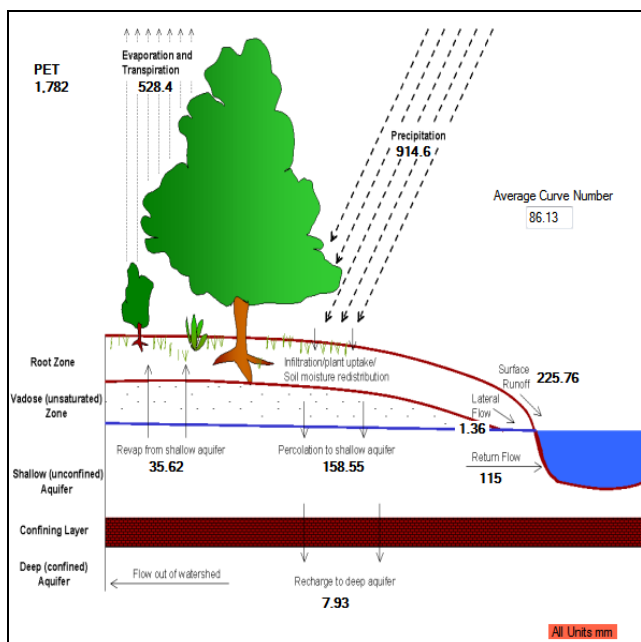


Fig 10: Water balance Components of the Manjira Watershed MNJR008

According to output the Average precipitation = 914.6 mm,
Average total Runoff (surface+lateral+return) = 342.12 mm,
Average ground water recharge = 7.93 mm and
Average Evapotranspiration = 528.4 mm.
So from equation 1;

$$914.6 - 342.12 - 528.4 - 7.93 = 36.15$$

The value 36.15 includes other components such as interception, shallow and deep ground water storage also soil moisture and snow, glaciers.

Therefore,

$$914.6 - 342.12 - 528.4 - 7.93 - 36.15 = 0$$

This equation shows water balance is equal to zero which means the incoming water in the MNJR008 watershed region is equal to the outgoing water in same region. Table 2 shows value of water entering and leaving watershed MNJR008 region which is equal.

Table II: Water Balance Components of watershed MNJR008

Water Balance Component	Incoming (mm)	Outgoing (mm)
Precipitation	914.6	-
ET	-	528.4
Runoff	-	342.12
Other components	-	36.15
Groundwater recharge	-	7.93
Total	914.6	914.6

The monthly Basin values for watershed MNJR008 of Manjira River was derived by SWAT simulation, which is shown in Table III.

Table III: Monthly basin value of the Manjira Watershed MNJR008

Month	Rain (mm)	Runoff (mm)	Water yield(mm)	ET (mm)
1	0.1	0.12	2.27	12.76
2	1.67	0.38	1.04	8.21
3	11.03	1.41	1.92	43.41
4	9.21	0.11	0.5	48.66
5	25.93	0.23	0.52	25.09
6	145.97	7.94	7.53	64.21
7	199.1	45.33	45.98	71.08
8	197.45	67.45	78.3	73.23
9	182.44	64.77	91.1	69.45
10	109.08	31.07	70.2	59.83
11	24.9	5.34	34.84	32.51
12	7.93	3.03	15.94	20.26

Table III gives average monthly values of precipitation, runoff, water yield and ET for watershed MNJR008 of Manjira River. The graphical representation of these components is shown in Fig 11, 12, 13, 14 respectively.

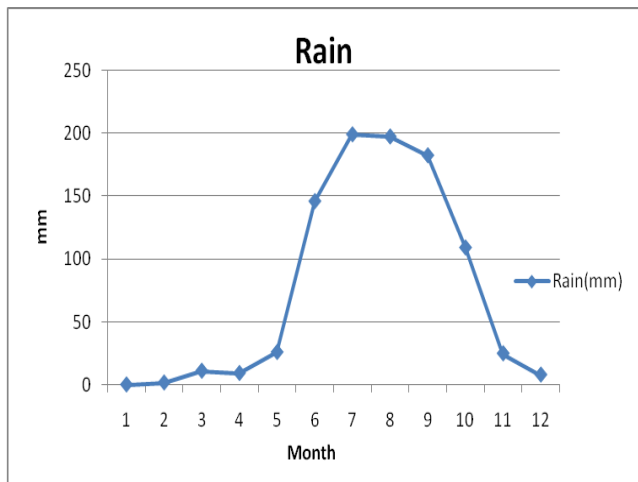


Fig 11: Average monthly rainfall for the Manjira River watershed MNJR008

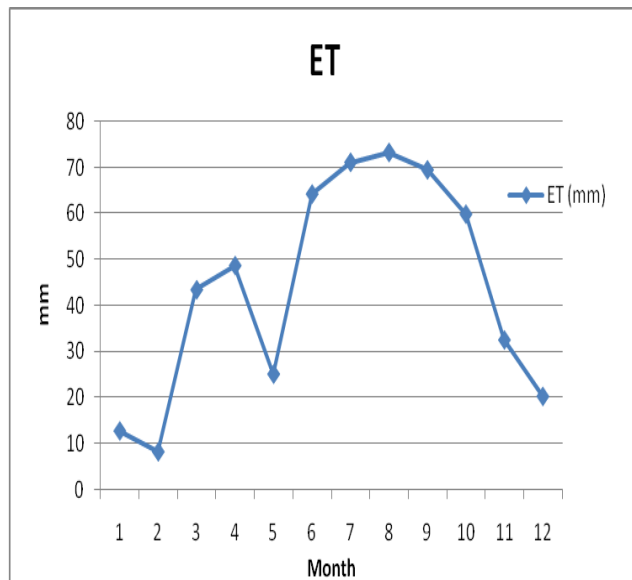


Fig 14: Average monthly evapotranspiration for the Manjira the River watershed MNJR008

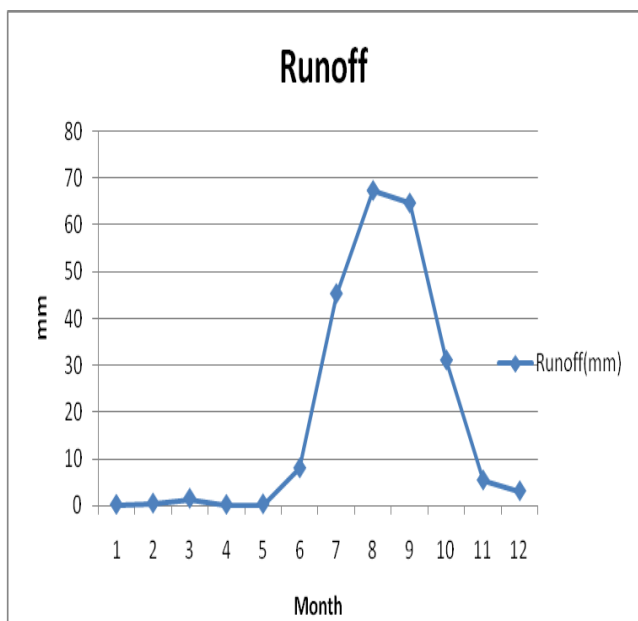


Fig 12: Average monthly runoff for Manjira River watershed MNJR008

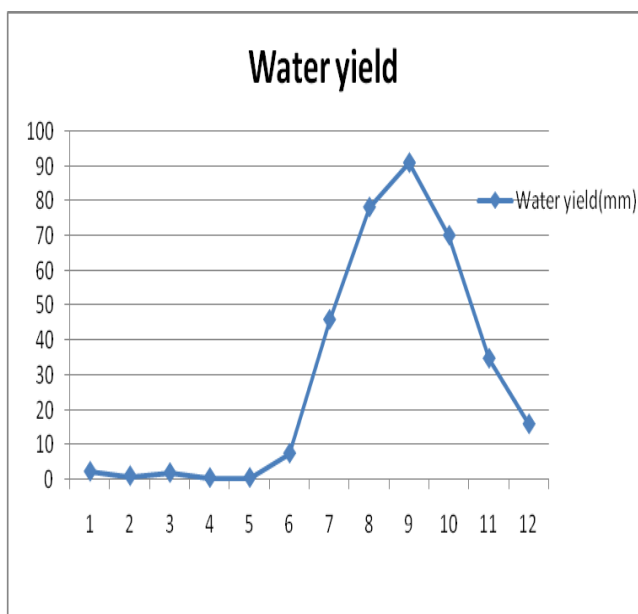


Fig 13: Average monthly water yield for the Manjira River watershed MNJR008

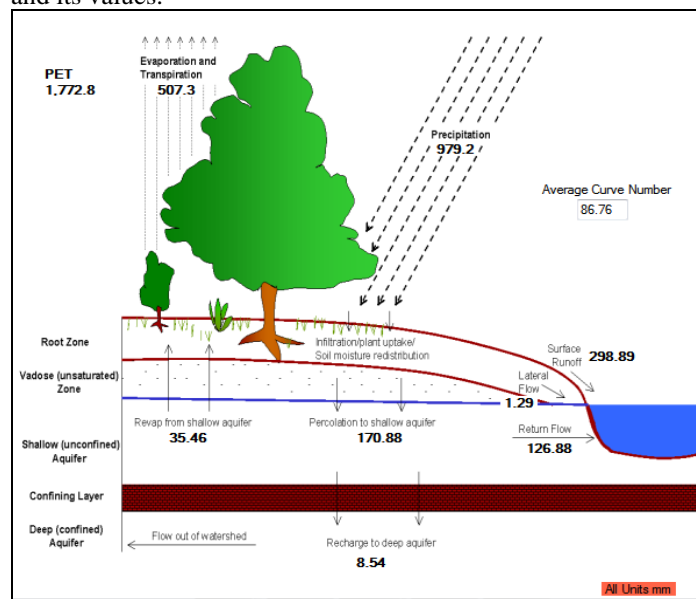


Fig 15: Water balance Components of the Manjira Watershed MNJR011

According to output the Average precipitation = 979.2mm, Average total Runoff (surface+lateral+return) = 427.06 mm, Average ground water recharge =8.54mm and Average Evapotranspiration = 507.3 mm. From equation 1;

$$979.2 - 427.06 - 507.3 - 8.54 = 36.3$$

The value 36.3 includes other components such as interception, shallow and deep ground water storage also soil moisture and snow, glaciers. Therefore,

$$979.2 - 427.06 - 507.3 - 8.54 - 36.3 = 0$$

This equation shows water balance is equal to zero which means the incoming water in the MNJR011 watershed region is equal to the outgoing water in same region. Table IV shows value of water entering and leaving watershed MNJR011 region which is equal.

Table IV: Water Balance Components of watershed MNJR011

Water Balance Component	Incoming (mm)	Outgoing (mm)
Precipitation	979.2	
ET	-	507.3
Runoff	-	427.06
Other components	-	36.3
Groundwater recharge	-	8.54
Total	979.2	979.2

The monthly Basin values for watershed MNJR011 of the Manjira River was derived by SWAT simulation which is given in Table V.

Table V: Monthly basin value of the Manjira Watershed MNJR011

Month	Rain (mm)	Runoff(mm)	Water yield (mm)	ET (mm)
1	0.10	0.11	1.89	11.29
2	0.17	0.10	0.78	6.71
3	12.83	1.94	2.50	41.50
4	9.26	0.15	0.55	48.37
5	20.17	0.26	0.57	19.83
6	157.66	14.82	13.97	61.37
7	224.25	68.00	68.58	70.72
8	228.08	89.53	105.49	73.62
9	165.90	59.72	92.91	68.44
10	125.38	53.23	93.82	54.38
11	31.82	10.08	39.74	31.81
12	3.74	2.28	14.97	19.53

The table gives average monthly values of precipitation, runoff, water yield and ET for Watershed MNJR011 in Manjira River.

The graphical representation of these components is shown in Fig 16, 17, 18, 19 respectively

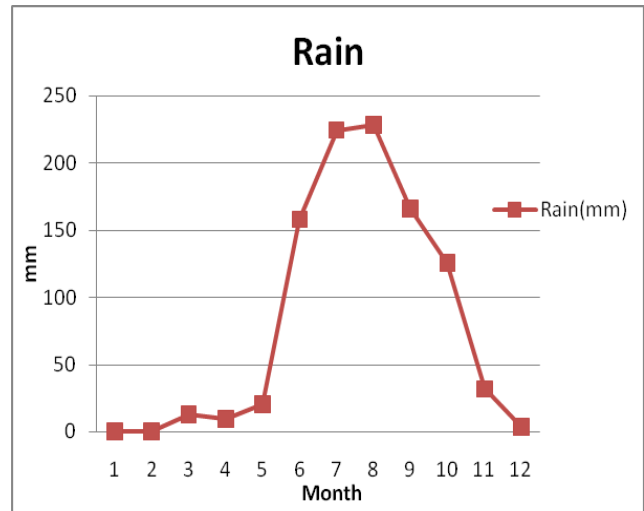


Fig 16. Average monthly Rainfall for the Manjira River watershed MNJR011

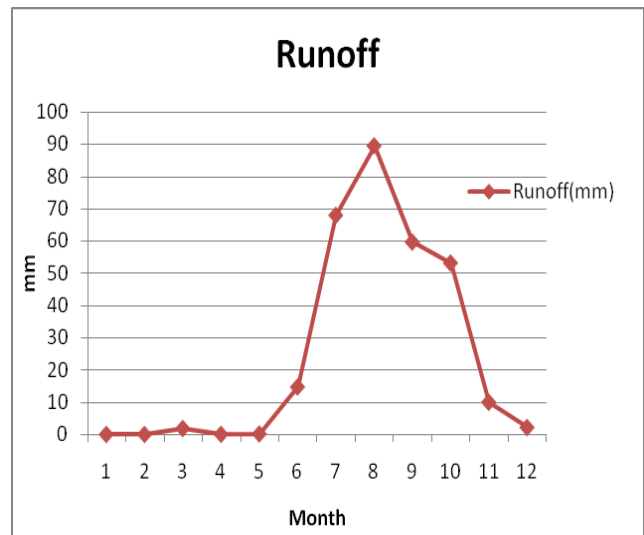


Fig 17. Average monthly Runoff for the Manjira River watershed MNJR011

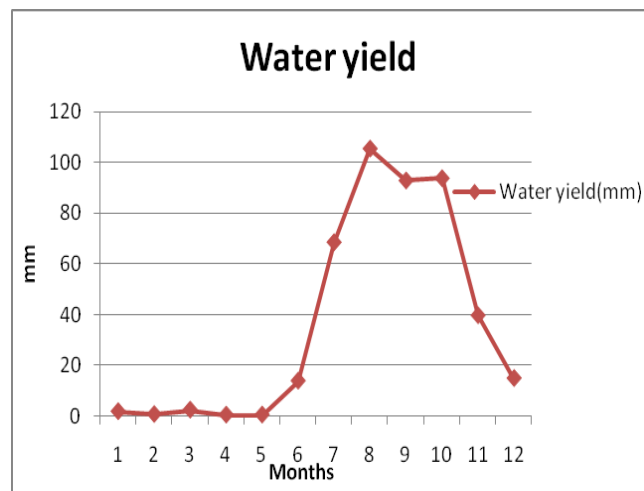


Fig 18. Average monthly water yield for the Manjira River watershed MNJR011

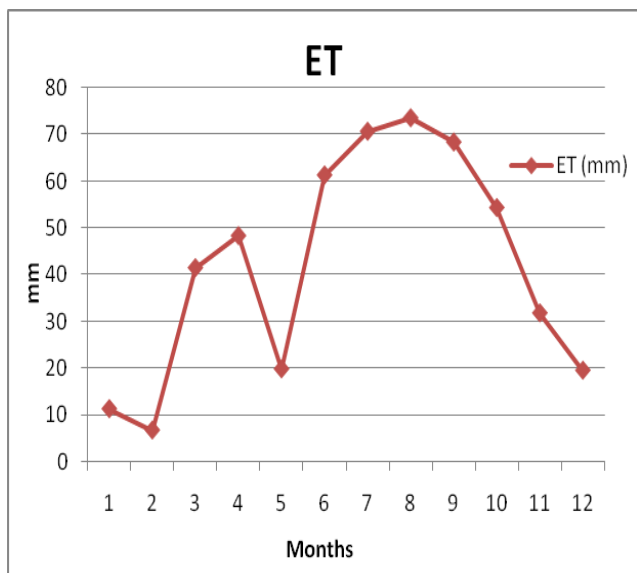


Fig 19. Average monthly evapotranspiration for the Manjira River watershed MNJR011

Modelling results gave us various Water balance components of the Manjira River Watersheds, which gives us brief idea about water availability for use hence which can be prove helpful in effective water resource management and allocation of water for different purposes in study region.

IX. VALIDATION

The simulated water balance data from SWAT is compared with the observed data which was taken from Global weather Data for SWAT. The simulated and observed rain data was taken for comparison for both the watersheds. To validate the obtained result regression analysis was performed. The value for coefficient of determination i.e R^2 was found for both watersheds. The coefficient of determination R^2 ranges between 0 to 1. It is considered that if the value of R^2 is closer to 1 then the similitude between the two dataset is more.

A. Watershed MNJR008:

The regression analysis was performed for the simulated and observed rain data of the watershed MNJR008. Table VI shows monthly simulated and observed data for watershed MNJR008. Fig 20 shows the graphical representation between simulated and observed rain data for watershed MNJR008 of the Manjira River.

Table VI: Average monthly simulated and observed rain data for MNJR008 watershed

Month	Simulated	Observed
January	0.1	4.23
February	1.67	2.64
March	11.03	11.53
April	9.21	7.05
May	25.93	15.36
June	145.97	163.88
July	199.1	206.35
August	197.45	264.55
September	182.44	241.3
October	109.08	87.22
November	24.9	39.75
December	7.93	2.51

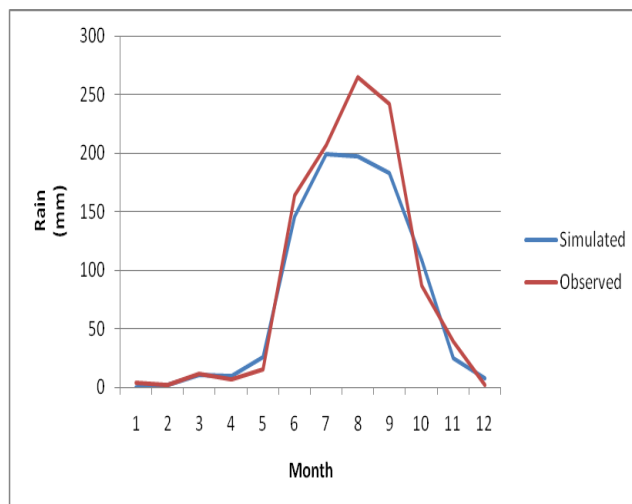


Fig 20. Comparison between Simulated and observed rain data for MNJR008 watershed

Table VII shows summary of regression analysis (R^2) between simulated and observed rain dataset. The value of R^2 was found to be 0.9566.

Table VII: Regression analysis for MNJR008 watershed

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.980119184
R Square	0.960633614
Adjusted R Square	0.956696975
Standard Error	17.40383048
Observations	12

B. Watershed MNJR011:

The regression analysis was performed for the simulated for and observed rain data of the watershed MNJR011. Table VIII shows monthly simulated and observed data for watershed MNJR011. Fig 21 shows the graphical representation between simulated and observed rain data for watershed MNJR011 of the Manjira River.

Table VIII: Average monthly simulated and observed rain data for MNJR011 watershed

Month	Simulated	Observed
January	0.1	13.27
February	0.17	10.16
March	12.83	12.26
April	9.26	7.37
May	20.17	14.62
June	157.66	163.92
July	224.25	206.4
August	228.08	255.49
September	165.9	238.76
October	125.38	85.64
November	31.82	31.19
December	3.74	2.17

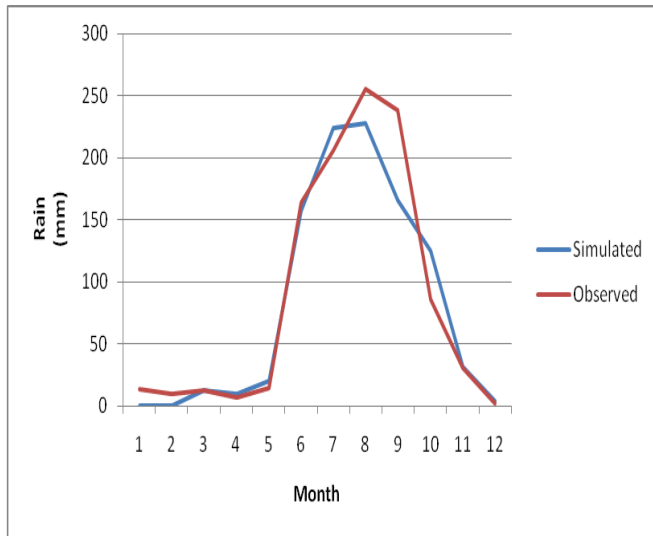


Fig 21. Comparison between Simulated and observed rain data for MNJR011 watershed

Table IX shows summary of regression analysis between simulated and observed rain dataset. The value of R² i.e Coefficient of was found to be 0.9232.

Table IX: Regression analysis for MNJR011 watershed

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.964486059
R Square	0.930233358
Adjusted R Square	0.923256694
Standard Error	25.35726296
Observations	12

X. CONCLUSION

In this study the different water balancing components of two watersheds in the Manjira River was evaluated with the help of SWAT and GIS. To validate the evaluated data regression analysis was performed between simulated data and observed data from Global weather Data for SWAT for each watershed. The value of R² was obtained for watershed MNJR008 and MNJR011 is 0.9566 and 0.9232 respectively, which shows the data evaluated from SWAT simulation is similar to observed data. This data can be used for various water resource management programs. This gives brief idea about different watershed characteristics. The water yield obtained tells us about the actual usable water available. Further research can be done to allocate and distribute this available water.

CONFLICT OF INTEREST STATEMENT

On behalf of all the authors, the corresponding author states that there is no conflict of interest.

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