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Rainfall – Runoff Simulation and Assessment of Groundwater Recharge for Upper Narmada River Basin

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Abstract
One of the most important natural resources is a Groundwater in earth, which supports the human health, development of economy. For Developing and developed countries of urban and rural areas, it has an important role for water supply sources and agriculture irrigation sources in each and every climatic regions. Due to the increasing the population, excessive use of water and mismanagement of water resources, the groundwater level is randomly decreases. There are many factors influencing the groundwater recharge, like bed recharge characteristics, topography, soil characteristics, LULC, existing soil moisture, aquifer materials. Considering the above facts, the specific objectives setup for the present study. So for serenity of the objectives, Hydrological Model is modeled to simulate runoff process in Upper Narmada Basin using HEC-HMS version 4.2.1. In this Model, the variable parameters considered in this study are runoff volume, peak runoff rate and flow routing methods, SCS curve number, SCS unit hydrograph and Muskingum routing methods are chosen. Two events are selected randomly for three gauging stations are Dindori, Mohgaon and Manot stations was simulated and calibrated, one more event was selected for the validation. For Calibration and Verfication, the data of Streamflow at three gauging stations along the river were used. At three gauging Stations, observed hydrographs based on flood peaks and the Nash Sutcliffe coefficient were compared. Hence it shows that, the modeling of the Upper Narmada River basin can be suitable in HEC-HMS software.After calibration of the model, to extract the hydrograph from the HEC-HMS, from these hydrographs, initially find out the recession index K based upon the each segment of the assumptions and the varies logarithm of stream flow data log$Q$. Critical time Tc, Pre-Event and Post-Event discharges Q2 and Q1 respectively groundwater recharge obtained by Displacement of Recession Curve method and some empirical formulas. The recession curve displacement method results shows that, average recharge of the Dindori, Mohgaon and Manot stations are 15.54, 20.035 and 28.755 mm respectively. And also for estimation of groundwater recharge, Water Table Fluctuation method and empirical methods are used. During 2000 – 2013, collected the rainfall data and groundwater level data collected from the gauging stations. Keeping in view of the two dominated Water Table Fluctuation and six empirical methods, the Study area results about average groundwater recharge (calculated in mm /year) varies with 64.638 to 624.834 and 46.704 to 277.505 respectively. However, all empirical methods are compared with the Water Table Fluctuation method, from these Bhattacharjee formula shows the closure recharge values with Water Table Recharge method. The NSE and R^2 values are obtained 0.832 and 0.7186 respectively for Bhattacharjee and Water Table Fluctuation method, this is good among all the comparisons.

Key Words: Gauging Stations**,** Groundwater Recharge, HEC-HMS, Hydrograph, Recession Curve Method, SCS, Digital Elevation Model (DEM), Water Table Fluctuation.

Introduction

One of the most important natural resources is a groundwater in earth, which supports the human health, development of economic. Developing and developed countries of urban and rural areas it has important water supplies sources and agriculture irrigation sources in every climatic region. Due to the increasing the population, excessive use of water and mismanagement of water resources the groundwater level is randomly decreases. There are many factors influencing the groundwater recharge, like bed recharge characteristics, topography, soil characteristics, LULC, existing soil moisture, aquifer materials. Estimating groundwater recharge based on the analysis of the equilibrium between groundwater recharge and streamflow hydrograph discharge. Estimating groundwater recharge in hydrogeological research is a significant problem.

With the discrepancy of natural environment because of human intrusions together with the possessions of worldwide climate change, current years have seen floods to happen more regularly and randomly through the world. Urbanization and variation of demographic landscapes in the river flood plain has resulted in enhanced exposure to flood risk by populations. Specifically, developing nations face the wrath of such a catastrophe as the amount of susceptibility across these areas is very large owing to bad socio-economic circumstances and haphazard settlements. On the other side, if flood is not correctly managed, advanced nations with considerably more built-up regions and infrastructure in location will suffer enormous financial losses. Consequently, predicting floods and adequate design of control and mitigation measures remain a significant challenge everywhere, suitable and coherent.

1.1 DESCRIPTION OF THE STUDY AREA:

The study area Narmada River (Rewa) covers entire region in central India i.e., Mostly Madhya Pradesh, Gujarat and small areas in Maharashtra and Chhattisgarh. It covers an area of 92,672.42 Sq.km wirh location extends from longitudes 72° 38‘to 81°43’ ESAT and latitudes 21° 27’ to 23° 37’ NORTH. So 3% of the total geographical area of the country is under Narmada basin. After Godavari and the Krishna Rivers, Narmada River will takes third place when compared west flowing river. It originates from Maikala range near Amarkantak Plateau near Anuppur district at the elevation of about 1057m. Due to its huge contribution, it is also known as “Life line of Madhya Pradesh”.

Narmada basin covers (1079KM) maximum at the upper of the Madhya Pradesh as hilly region and at Middle and lower regions covers broad and fertile which is known for good cultivation purpose.

It crosses Madhya Pradesh and Maharashtra over a length of 35 km and Runs over 39 KM between the common boundary between Maharashtra and Gujarat. It covers an extent of 159 km around Gujarat. It gets the Hiran on the right bank as Narmada joins the lower fertile plains. The river then gets several tributaries from the left, the Sher, the Shakkar, the Dudhi, the Tawa, the Ganjal and the Tendoni, from the right, the Barna, the Kolar. The study area is small subBasins of Upper Narmada i.e. Dindori (latitude 22°57' ; longitude 81°05'), Mohgaon (latitude 22°45' ; longitude 80°37') and Manot (latitude 22°44' ; longitude 80°31') catchment. The catchment consists of fertile land and thus agriculture is the back bone of its economy. So it can be concluded that there is very good scope for the development of ground water resource in the district and these sub basin are falling in the category.

1.2 DATA SOURCE

The Data Source is considered as the most important and for any models input data plays a crucial role. Topographic Data collected from the *https://earthexplorer.usgs.gov/* in the present study, Shuttle Radar Topography Mission (SRTM) with 30 m resolution helps us to obtain Digital elevation model (DEM). Present study 0.25°×0.25° spatial resolution of daily gridded rainfall data is used. For Land Use Land Cover, Landsat IV images are used; Ground water levels are taken from Central Ground Water Board (CGWB).

1.3 Land use / Land cover and Soil map

Arc GIS is used for preparing Land use, land cover and Soil map for the present study area, in which indicates that about 24.1% of the land is deciduous forest, 13.6% is water body, and 19.2% agricultural and 17.2% is built-up area. The soil map (1: 5000000 scale) and associated characteristic obtained from FAO – Unesco soil map of the world.

1.4 SCOPE AND OBJECTIVE OF THE STUDY:

Groundwater recharge estimation by using three different methods is the main objective of the present study for Upper Narmada Basin. The input data considered are precipitation, streamflow and groundwater levels.

- ✓ Development of rainfall-runoff model of the Upper Narmada Basin by using HEC-HMS.
- ✓ Three methods Recession Curve Displacement method, empirical formulas and Water Table Fluctuation method used to calculate the Groundwater Recharge of the Study Area
- ✓ Compare the similarities between the three groundwater recharges for the area considered for the study.

2 Literature Review

Romali et al. (2018) They created hydrologic modeling for flood risk assessment in Segamat Town, Malaysia, using HEC - HMS. The model capability was calculated by combining observed historical data with simulated results from specific flood episodes. The efficacy of model calibration and validation was validated using Nash-Sutcliffe modeling. The findings of a hydrological model for assessing flood danger when the predicted peak flow is combined with historical data. Model efficacy for calibrated and validated exercises is 0.90 and 0.76 respectively. **Rao, D. (2017)** The Brahmani-Baitarani River Basin in India has a continuous hydrological model for stream flow forecasts and flood simulation. The hydrological modeling technique includes rainfall-runoff modeling, stream routing, model calibration, and validation using field discharge data. The hydrological model was calibrated and validated with data from 2008 and 2011 using field-observed discharge data from 2006 and 2009. The estimated discharges are found to closely match the observed discharges based on the results. The advanced model can anticipate stream flow with more than 30 hours of lead time. **Ibrahim B.K and Ahmed S.A (2016)** The hydrological simulation model HEC-HMS is employed, together with embedded remote sensing and GIS. In this experiment, 3 hourly data from the Tropical Rainfall Measuring Mission and IMD rainfall data were used. SCS-CN loss model and SCS unit hydrograph were employed as transformation techniques to simulate surplus storm water to direct runoff in the watershed. The Muskingum-Cunge model is used for channel routing. They validated the model using field observation data and discharge data from the neighboring Hoovin a hole watershed. Observed and simulated stream flow findings show increased confidence and model accuracy. Similar techniques and calibration parameters were employed in the Doddahalla watershed to estimate rainfall runoff.

3 Methodology

The input data for the HEC-HMS model is being processed using ArcGIS 10.2.2 software and the HEC - GeoHMS 10.2 (Geospatial Hydrologic Modelling). ArcGIS and the HEC-GeoHMS tools were used to prepare the HEC-HMS input parameters. SRTM (Shutter Radar Topography Mission) DEMs (Digital Elevation Model) of 30m 30m resolution are utilized for delineating sub-basins, and a LULC (Land Use Land Cover) map was created using Landsat pictures of the current research region. FAO world soil map is used to generate the soil map in ARC GIS 10.2. In ArcGIS, a curve number grid was created using these DEMs, LULC, and soil maps. HEC-GeoHMS tools in ArcGIS generate HMS input files, a stream network, sub-basin boundaries, and different hydrologic element connections in ArcView GIS tools, as well as a sequence of phases known as terrain pre-processing and basin processing. After all of these steps were completed, an HMS input model was created, which was then imported into HEC-HMS for simulation. The metrological data, time series specifications, and control specifications were then added to the HEC-HMS model of the research region. The model was calibrated using observed discharge from gauging stations, and validation was performed using the optimal parameters acquired from the calibration. These results were used to evaluate the model's performance. Figure 1 depicts a flow diagram of the methods used.

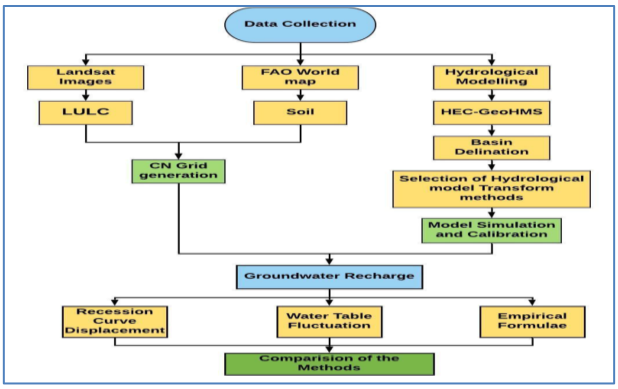

Figure 1 Flow chart of Methodology for Hydrological Modelling and Estimating GWR

3.1 Thiessen polygon

This method is one of the best method for estimation of average rainfall of any area. Grid of size 15′×15′ is laid down in the study area and gridded rainfall data which has been extracted from the Matlab is superimposed in it. Superimposed Thiessen polygon, gridded rainfall points and sub-basin which has been used to calculate the gage weight. Then Thiessen polygon is created in ARC GIS 10.2. Each sub basin, gage weight is obtained.

Calculation of basin CN

Hydrological measures, such as the Curve Number (CN), are used to calculate the watershed surface runoff. CN is affected by LULC, soil type, and previous watershed moisture conditions. The dimensionless number CN ranges from 1 to 100. By superimposing the area's land use and soil maps, the CN values were computed using ArcMap's HEC - GeoHMS tools. The CN grid created in ArcMap was then used to determine the CN of various sub-basins in the research area. The lag time for distinct reaches is also estimated from the sub-basin file generated following watershed delineation using the Kirpich formula.

Initial values of muskingum K (Wave travel time) and X were computed using the equations provided by Tewolde and Smithers (2006) for the routing.

3.2 HEC-HMS MODEL DEVELOPMENT:

Following pre-processing in HEC-GeoHMS, the model is loaded as a basin file, background maps, and river profile into the HEC-HMS software for simulation and optimization. The basins and reaches are then manually updated with hydrological characteristics such as CN, Initial Abstraction, Lag time, and Routing parameters such as K and X values. Each sub-basin is given a gauge weight. Precipitation and discharge data are entered as time series data by utilizing the time series data manager; this data is useful for model simulation and optimization. When input from the metrological model is provided, the basin model estimates the precipitation runoff response. The control requirements determine the simulation run's time period and time step.

The control specifications govern the model simulation. To run any model, the control specification must specify the starting date and time, the end date and time, and the time interval. The model will only run for the time period specified in the control specification. Control criteria are required to compare observed and simulated discharges. By integrating the basin model, met model, and control specification, a simulation may be run. The model is simulated for the current study for the year 2011.

3.3 CALIBRATION OF HEC-HMS MODEL:

The calibration of chosen events compared the observed hydrographs to the model's computed hydrographs. Table 1 compares the peak discharges of the simulated and observed discharges (before and after optimization) for individual events.

Table 1 Peak Flow Values for calibration event 1 (25 June 2011 to 03 July 2011)

Sub Basin	Peak Flow Values (m^3/s)	
	Observed	**Computed Q**
Dindori	567.8	448.6
Mohgaon	428.4	460.4
Manot	972.4	886.5

The model was simulated for the initial parameters values and attaining the values of optimized parameters for the optimization parameter trail. After getting the optimized parameter values are added to the model for the simulation.

3.3.1 Graphs obtained after simulation of individual calibration events

For the calibration of the model event 1 (25-June-2011 to 03-July-2011) is used. Computed and Observed hydrographs of the selected event of Dindori, Mohgaon and Manot stations are shown in Figure 2 to 4.

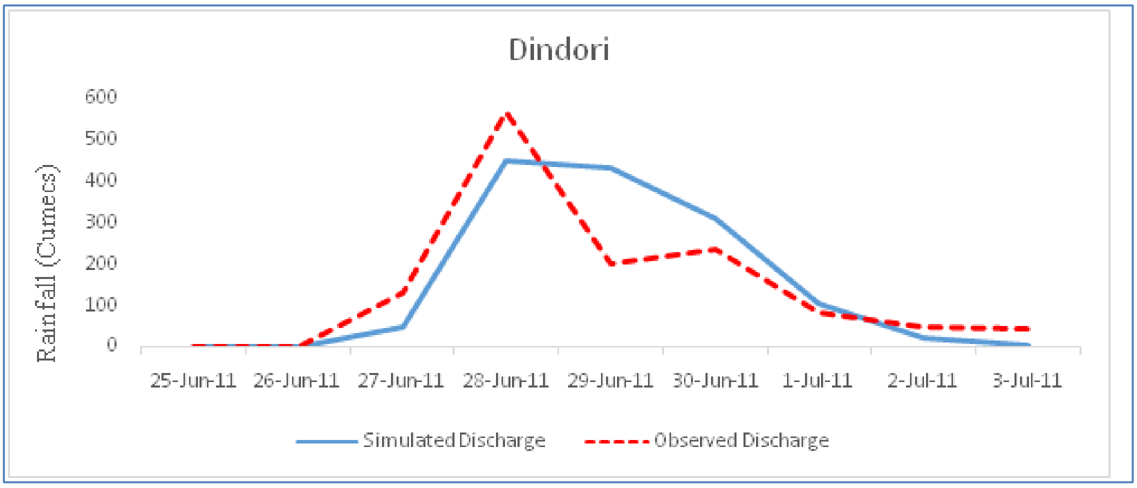

Figure 2: Observed and simulated discharge for the Subbasin - Dindori

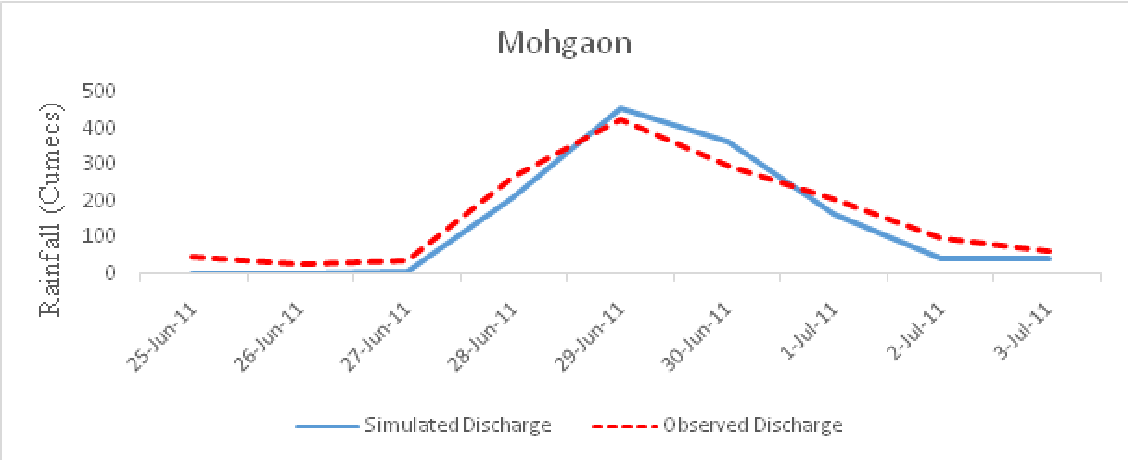

Figure 3: Observed and simulated discharge for the Subbasin - Mohgaon

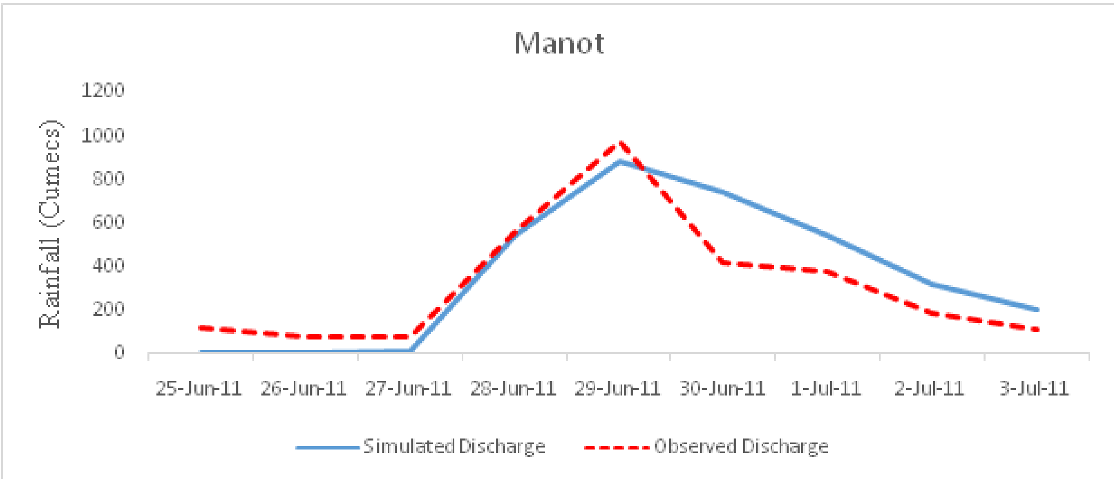

Figure 4: Observed and simulated discharge for the Subbasin - Manot

4 Results Analysis

4.1 Comparison of Groundwater Recharge for Selected Events:

The HEC-HMS is used to simulate and calibrate an event-based hydrological model of the selected events. The peak flow of the simulated and observed discharges does not differ significantly. The resultant hydrographs were compared to the observed hydrographs at these stations using the Nash Sutcliffe Coefficient (NSE), Normalized Objected Function (NOF), and R^2 values presented in the Table 2. The calibrated model with improved parameters is used for model validation.

Model validation with low statistical error functions was determined to be adequate.

Table 2: NSE, NOF and R^2 Values for the different sub-basins

Sub Basin	Nash-Sutcliffe efficiency (NSE)	Normalized Objective Function (NOF)	R^2
Dindori	0.685	0.650	0.7286
Mohgaon	0.889	0.307	0.960
Manot	0.731	0.440	0.801

The Recession Curve Displacement method and empirical formulas are utilized in this work to estimate groundwater recharge. The recession curve displacement approach revealed that the average recharge of the Dindori, Mohgaon, and Manot stations is 15.54, 20.035, and 28.755 mm, respectively. Table 3 also shows how groundwater recharge was approximated using the water table fluctuation approach.

Table 3 Comparison of Groundwater Recharge for Selected Events

	Station	Groundwater Recharge (mm)	
		Recession Curve Method	Water Table Fluctuation
Event 1	Dindori	0.75	1.89
	Mohgaon	3.562	8.63
	Manot	13.44	9.21
Event 2	Dindori	30	23
	Mohgaon	35	39
	Manot	43	32

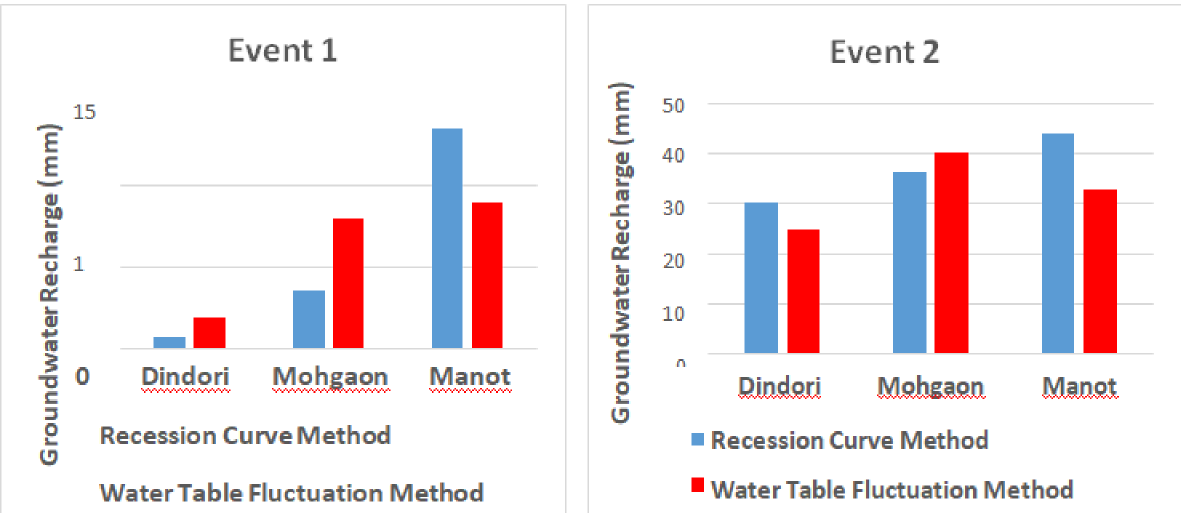

Figure 5 Plot between Groundwater Recharge for Recession Curve Method and WTF

4.2 Comparison among all the methods

The groundwater recharge was compared using the Water Table Fluctuation method and empirical calculations. Figure 6 depicts a comparison of recharging with respect to annual rainfall.

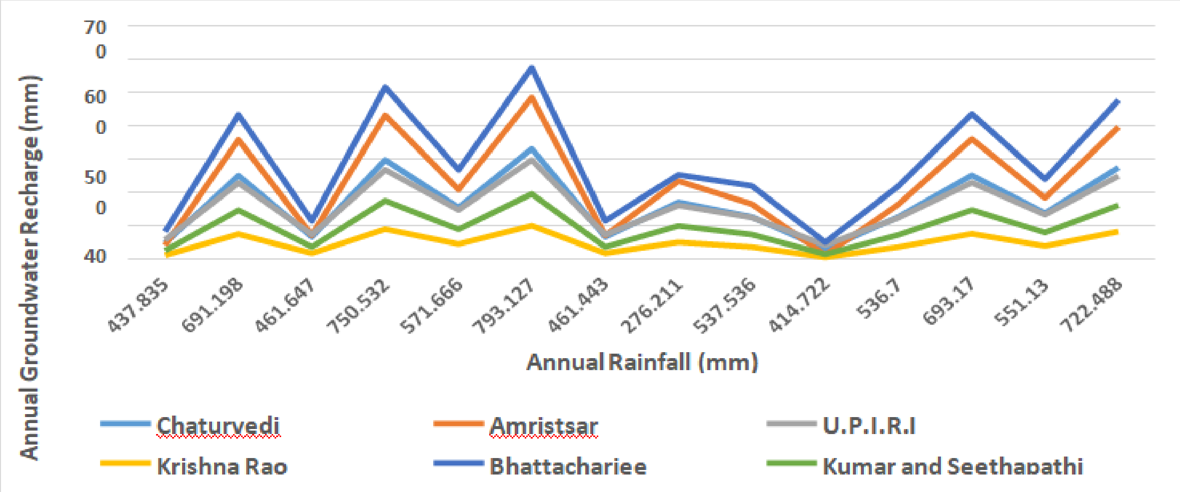

Figure 6 Plot between Annual Precipitation and Annual Groundwater Recharge

The empirical formulae were used to calculate groundwater recharge; among all techniques, the Krishna Rao formula provides the lowest recharge and the Bhattacharjee model provides the maximum recharge. Water Table Fluctuation method and Bhattacharjee formula exhibit the closure values among all approaches. Figure 7 depicts a comparison of the groundwater recharge of the Water Table Fluctuation method and the Bhattacharjee formula graph with respect to annual rainfall.

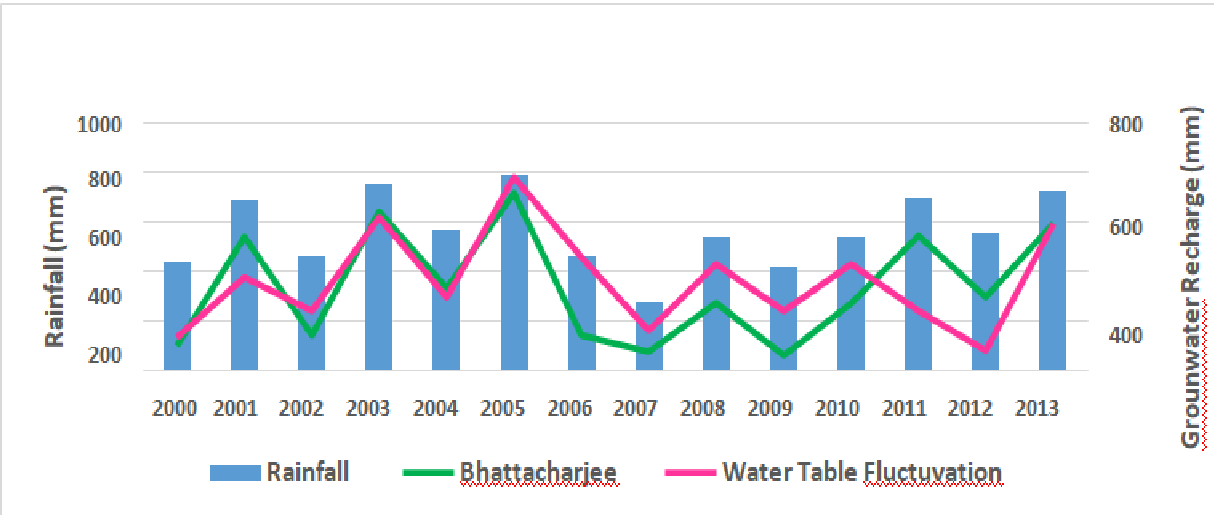

Figure 7 Comparison of annual Groundwater Recharge with respect to Annual Rainfallfor Upper Narmada Basin

4.3 Comparison of empirical formulas with respect to the Water Table Fluctuation method:

The Nash-Sutcliffe model efficiency coefficient (NSE) and R^2 values are shown in Table 4 with respect to empirical formulas and the Water Table Fluctuation technique. Figures 8–13 provide a comparison of groundwater recharge plots with respect to the Water Table Fluctuation technique plots. Among all approaches, the Bhattacharjee formula and the Water Table Fluctuation method produce the highest R^2 values when compared to others.

Table 4 Comparison of methods with NSE and R^2 values

Empirical Formula	Chaturvedi Formula	Amritsar Formula	U.P.I.R.I. Formula	Krishna Rao Formula	Bhattacharjee Formula	Kumarand SeethapathiFormula
NSE	0.811	0.608	0.724	0.363	0.832	0.598
R^2	0.5667	0.6048	0.514	0.4121	0.7156	0.4275

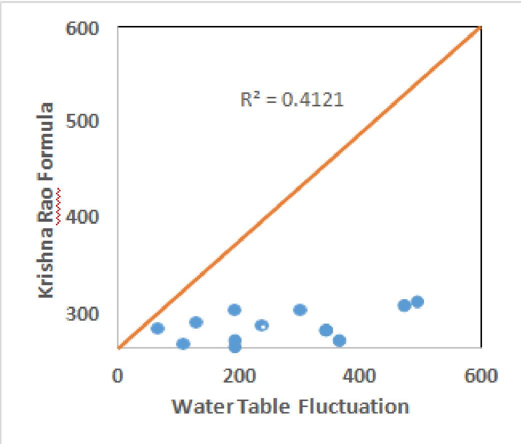

Figure 8 Comparison of Krishna Rao formula and Water Table Fluctuation method

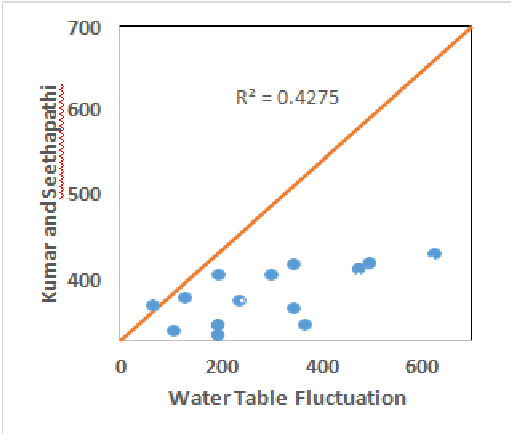

Figure 9 Comparison of Kumar and Seethapathi formula & Water Table Fluctuation method

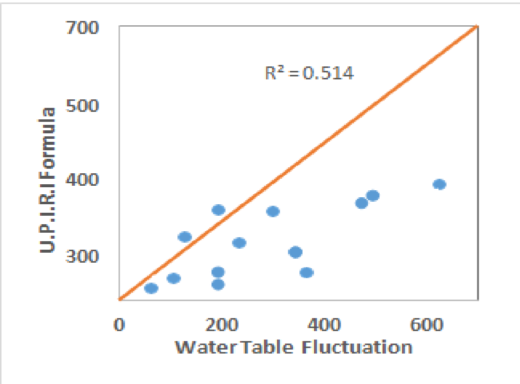

Figure 10 Comparison of U.P.I.R.I formula and Fluctuation method

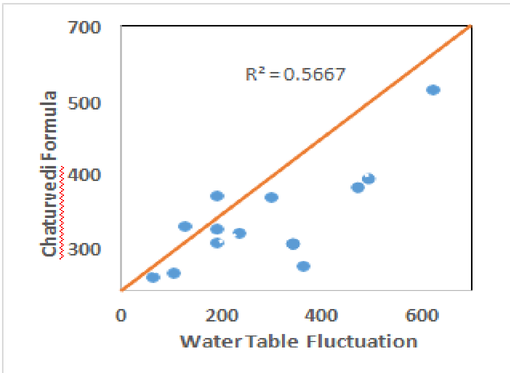

Figure 11 Comparison of Chaturvedi formulaWater Table and Water table Fluctuation Method

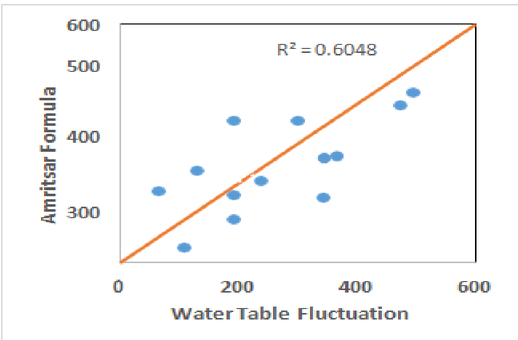

Figure 12 Comparison of Amritsar formula and Water Table Fluctuation method

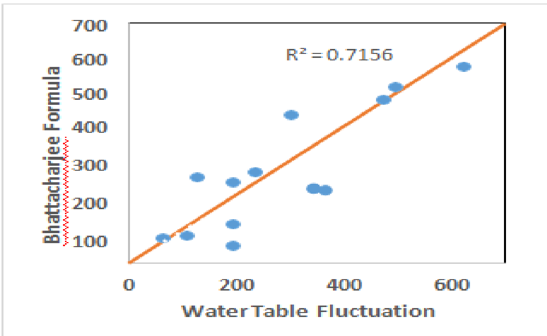

Figure 13 Comparison of Bhattacharjee formula and Water Table Fluctuation method

5 Conclusions

The hydrological model was developed and groundwater recharge for upper Narmada Basin resulted in the following conclusions.

1. The HEC-HMS model have been calibrated for the selected events of 2011 and the calibrated values are used for the validated purpose in 2012.
2. In the case of optimized parameters, the CN and K values have a greater influence on the estimated discharge value than the initial parameters. Mohgaon has a higher CN score than Dindori and Manot due to a higher proportion of imperviousness.
3. The calibration results reveal that the model worked well at the outlet location, as all performance indicators such as NSE and R^2 are more than 0.5.
4. The calibrated model values were validated and the results have been found reasonably satisfactory.
5. Groundwater Recharge is computed for Upper Narmada Basin by using the Recession Curve Displacement method, Water Table Fluctuation Method and empirical formulas.
6. The recession curve displacement approach revealed that the average recharge of the Dindori, Mohgaon, and Manot stations is 15.54, 20.035, and 28.755 mm, respectively.
7. Observed groundwater level data is taken and which is used in the Water Table Fluctuation method and precipitation data is used for the empirical formulas for estimation of groundwater recharge.
8. From all the empirical formulas Krishna Rao formula gives the low recharge and Bhattacharjee formula gives the highest recharge.
9. However, all the empirical methods are compared with the Water Table Fluctuation method, from this Bhattacharjee formula shows the closure recharge values with Water Table Recharge method
10. The NSE = 0.832 and R^2 = 0.7156 values are obtained for Bhattacharjee and Water Table Fluctuation method, this is good among all the comparisons.

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