

ESTIMATION OF GROUNDWATER RECHARGE IN KARMAL WATERSHED OF BHADAR BASIN USING EMPIRICAL MODELS

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ABSTRACT

Estimation and forecast of groundwater recharge and capacity of aquifer are essential issues in water resources investigation especially in regions with large demands for groundwater supplies, where such resources are the key to economic development. In this paper, three empirical models are developed to derive groundwater recharge from rainfall in Karmal watershed of Bhadar basin. The non-linear empirical model III performs better than empirical model I and empirical model II during calibration and validation period. The seasonal rainfall and recharge relationship for Karmal watershed of the Bhadar can be described empirically as mathematical model: $R = 0.496(P - 90.898)^{0.921}$.

KEY WORDS: Bhadar basin, empirical model, groundwater recharge, watershed

INTRODUCTION

The growing world population has put a lot of strain on natural resources. Water as one of these resources is of absolute importance in regard to the health and economy of all countries. In arid and semi-arid regions, the search for water which are under increasing stress from the growing human population, poses a great challenge due to its scarcity (Kishan *et al.*, 2012). Ground water is located beneath the ground surface of the earth as a part of a dynamic system. It occurs and moves with the control of various parameters, which are studied in different fields of sciences such as hydrogeology, hydrology and climatology (Kumar, 1977). The amount of water that will ultimately arrive at the water table is defined as natural ground water recharge. The amount of this recharge depends upon

the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type. Recharge is taking place in little and significant quantity for spatially and temporally is subjective by parameters such as meteorology, soil characteristics, earth surface cover, slope and deepness of ground water level (Bouwer, 1978). Groundwater recharge estimation from precipitation is an integral part of hydrology and hydrogeology (Xi *et al.*, 2008) Although, precipitation is the most important source of groundwater recharge, the accuracy of currently attainable techniques for measuring recharge are not completely acceptable. In measuring groundwater recharge, indirect methods such as empirical formulae shows great potential as an easy means of estimating

recharge, which is often difficult if not impossible to obtain reliably by other methods (Adelana, *et al.*, 2006). Thus, this paper employed the empirical methods for estimating groundwater recharges from rainfall data obtained from State Water Data Center, Gandhinagar. Estimation of groundwater recharge was derived from rainfall data by developing three empirical formulae, which include the linear and non-linear empirical formula.

MATERIALS AND METHODS

Study area

The Karmal watershed of Bhadar river in Saurashtra region of Gujarat is selected. It is located between 21°50' to 22°10' North latitude and 70°55' to 71°20' East longitudes. The total area of the Karmal watershed is 1196.46 km². The study area has maximum elevation of 305 m and a minimum of 80 m above mean sea level. The average annual rainfall in the study area (Karmal watershed) is 660 mm. As the watershed being situated in tropical and sub-tropical region and dominated with agriculture land, water availability in the region is an important and critical issue. The Karmal watershed originates from Vaddi about 26 km North-West of Jasdan in Rajkot district and flows towards South up to Jasdan village and outlet located at Kamdhiya village. The location map of study area is shown in Figure 1.

Water table fluctuation method

The water-table fluctuation (WTF) method provides an estimate of groundwater recharge by analysis of water-level fluctuations in river basin. The method is based on the assumption that a rise in water-table elevation measured in shallow wells is caused by the addition of recharge across the water table. Thirty years (1981-2011) water table fluctuation data of the three sites under study area were used for groundwater recharge estimation using following formula;

$$R_g = S_y \times \Delta L \times A$$

Where, R_g is groundwater recharge, A is area of watershed (m²), S_y is specific yield and ΔL is water table difference (m) (Gaur, 2001; Ravi *et al.*, 2008). The groundwater recharge was then compared with total recharge estimated.

Empirical models

Empirical models were developed using the dataset of water table fluctuation for the period 1982-2011. The annual data of rainfall and recharge of the period 1982-2001 were used for the training/calibration of the model, whereas the annual data of years 2002 - 2011 were used for validation of the model. Natural groundwater recharge from rainfall was estimated using following empirical formulae.

The simplest empirical formula takes recharge R as a proportion (a) of precipitation (P);

$$\text{Model -I} \quad R = a P$$

$$\text{Model -II} \quad R = a (P - b)$$

Non-linear empirical formula to estimate recharge R ;

$$\text{Model -III} \quad R = a (P - b)^c$$

Where, R is ground water recharge from rainfall (mm), P is total annual rainfall (mm) and a , b , c are constant. Two performance indices i.e. coefficient of determination (R^2) and Nash-sutcliffe efficiency (NSE) is used to evaluate performance of the developed empirical models (Tiwari and Chatterjee, 2010)

RESULTS AND DISCUSSION

The groundwater recharge through rainfall in the Karmal watershed was estimated by developing three empirical equations and Soil and Water Assessment Tool (SWAT). Groundwater recharge was also estimated using water table fluctuation method to compare with total recharge estimated using empirical equations.

Water table fluctuation method

The recharge for the 1982-2011 has been estimated from water table fluctuations

data. The recharge has been estimated from three well observation sites i.e. Kotadapitha, Viraragar and Untvad. Manual gauge data has been used to estimate the annual recharge of three locations. The dynamics of recharge and its relationship with rainfall as determined by the water table fluctuation method were investigated at different time's steps from year to year. The groundwater recharge estimated was compared to validate with three empirical models and to further investigate the rainfall-recharge relationships. The groundwater recharge for each of the observed wells was calculated by multiplying the water level rise with the specific yield values of the aquifer material in which the wells are situated. The groundwater recharge of the entire watershed was estimated by area weighted method. Annual recharge estimated using water table fluctuation method is given in Figure 2. The lowest groundwater recharge was observed as 2.0 mm in 1982, while the highest groundwater recharge was found as 248.1 mm in 2006. The overall mean groundwater recharge in the Karmal watershed was estimated to be 24.55 per cent of the mean annual rainfall. Sandwidi (2007) applied this method to the Kompienga Dam Basin, Burkuna Faso, in 2005 and estimated the recharge to be from 5.3 to 29.4 per cent of the annual rainfall. It was observed that as the rainfall increases the amount of recharge also increases, but the increase is not linearly proportional.

Development of empirical models

The water balance model simulates the catchment hydrology but does not offer a directly predictive formula for estimating the recharge. The central question in groundwater resources management is the estimation of groundwater recharge - can recharge be predicted from rainfall at a specified time step? In answering this question, it is important to develop some models that can predict the recharge at

different time steps. The annual relationships can give an idea of the gross annual recharge. Often they give an indication of a threshold annual rainfall below which rainfall is not expected to result in significant recharge. To overcome this difficulties and considering the phenomena of above discussion, an attempt was taken to develop a relation between groundwater recharge and precipitation. Simple linear and non-linear regression using SPSS was used to estimate the parameter of empirical equation. The following empirical relationship was derived by best fitting the estimated values of rainfall recharge;

Model-I $R = 0.198$

Model-II $R = 0.291(P - 69.031)$

Model-III $R = 0.496(P - 90.898)^{0.921}$

Performance of empirical models

Performances of groundwater recharge estimation models during calibration and validation are presented in Table 1. The scatter plot between observed and simulated groundwater recharge during calibration year 1982 – 2001 and validation year 2002-2011 are shown in Figure 3 and Figure 4, respectively

Empirical model I, II and III is calibrated using the annual dataset for the duration 1982-2001 and validated for the year 2002-2011. The NSE and R^2 values for the calibration and validation phase are given in Table 1. During calibration phase, the best NSE for the empirical model III is as much as 82.89 per cent compared to 76.82 per cent and 82.88 per cent for empirical model I and II, respectively. This is true for R^2 values too, where the best R^2 for the empirical model III is 0.884 compared to 0.881 and 0.882 for empirical model I and II, respectively. During validation phase, also the empirical model III (NSE = 75.49%) outperformed than empirical model I (NSE = -4.8%) and II (NSE = 74.99%). The groundwater recharge

as per cent of rainfall was found 20 per cent by empirical model I, 12 per cent to 26 per cent by empirical model II approach and 9 per cent to 26 per cent by empirical model III during calibration, while during validation period, groundwater recharge as per cent of rainfall was found 20 per cent by empirical model I, 24 per cent to 27 per cent by empirical model II and 24 per cent to 26 per cent by empirical model III. The overall mean groundwater recharge in the Karmal watershed was estimated during validation period by empirical model III to be 25.67 per cent of the mean annual rainfall, which is slightly higher than recharge of water table fluctuation method. Kumar and Seethapathi, 2002 and Saghravani *et al.*, 2013 reported the same results.

CONCLUSION

In this paper, three empirical models are developed to estimate recharge in the Karmal watershed of Bhadar basin. The high amount of rainfall both in temporal and spatial strongly affects recharge in this area. The non-linear empirical model III for ground water recharge estimation outperformed than empirical model I and II. The overall mean groundwater recharge in the Karmal watershed during validation period for empirical model III is found 25.67 per cent of the mean annual rainfall, which is slightly higher than recharge by water table fluctuation method. It can be concluded that the non-linear empirical model III is preferred to estimate groundwater recharge in Karmal watershed of Bhadar basin.

REFERENCES

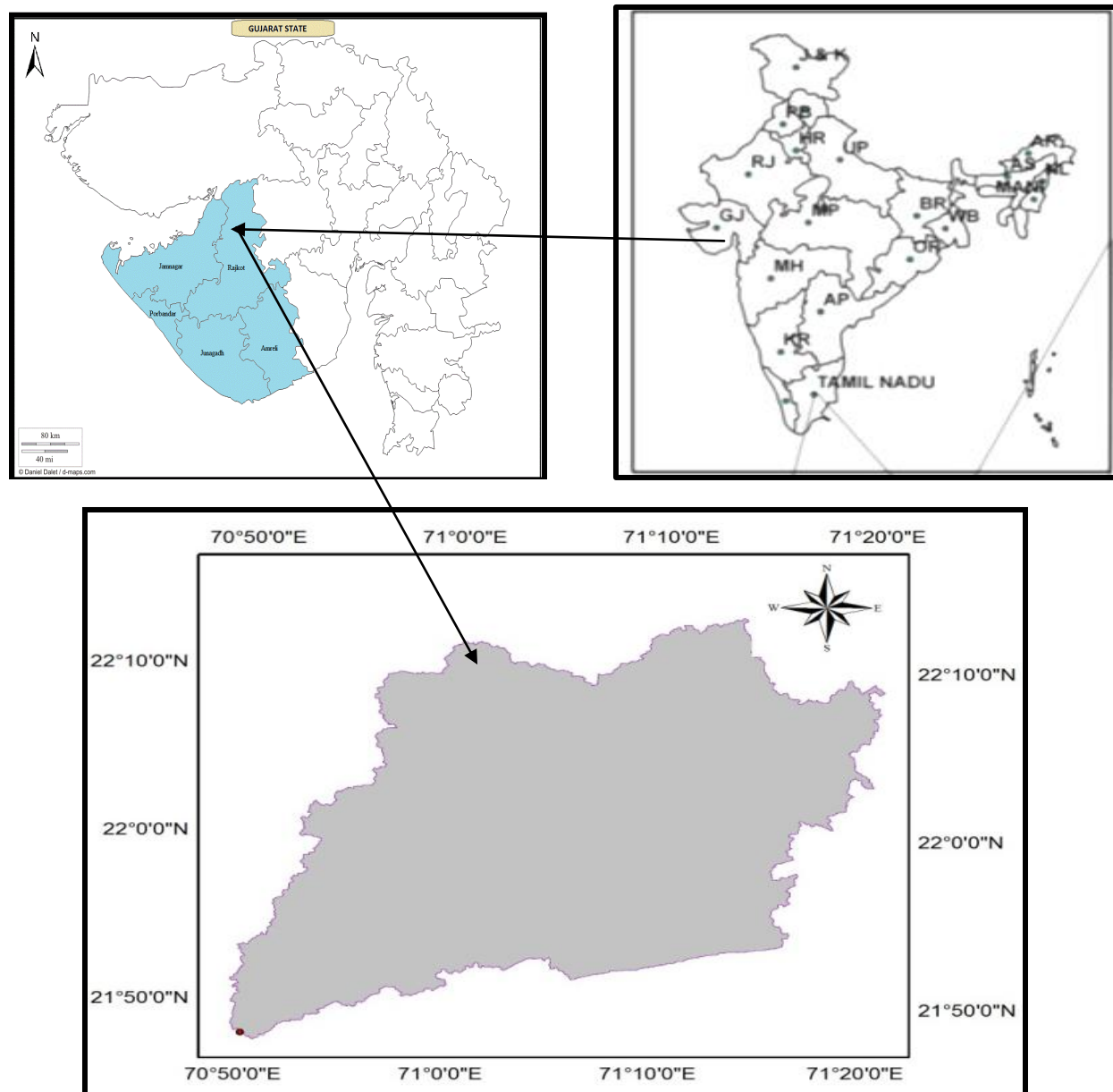
- Adelana, S. M. A.; Olasehinde, P. I. and Vrbka, P. (2006). A quantitative estimation of groundwater recharge in part of the Sokoto basin, Nigeria. *J. Environl. Hydro.*, **14**(5): 1-16.
- Bouwer, H. (1978). Groundwater hydrology. McGrawhill Book Publication, New York.
- Gaur, M. L. (2001). Groundwater recharge estimates of a small watershed. *Indian J. Soil Cons.*, **29**(2): 126-132.
- Kishan, S. R.; Anil, K. M.; George, P. and Rakesh, K. (2012). Estimation of ground water recharge in Shankargarh block of Allahabad (India) using remote sensing and statistical approach. *Glob. J. Sci. Eng. Technol.*, **1**: 34-48.
- Kumar, C. P. (1977). Estimation of natural groundwater recharge. *ISH J. Hydraulic Engg.*, **3**(1): 61-74.
- Kumar, C. P. and Seethapathi, P. V. (2002). Assessment of natural ground water recharge in upper Ganga canal command area. *J. Appl. Hydro.*, **15**(4):13-20.
- Ravi, E.; Mayilswami, C.; Raviraj, A.; Thiyagarajan, G. and Ranghaswami, M. V. (2008). Groundwater recharge estimation in Noyil river basin. In M. V. Ranghaswami, K. Palanisami & C. Mayilswami (Eds.), Groundwater resources assessment, recharge and modeling. Macmillan India Ltd., New Delhi, pp. 229-237.
- Saghravani, S. R.; Yusoff, I.; Mustapha, S. and Saghravani, S. F. (2013). Estimating groundwater recharge using empirical method: A case study in the tropical zone. *Sains Malaysiana*, **42**(5): 553–560.
- Sandwidi, W. J. P. (2007). Groundwater potential to supply population demand within the Kompienga dam basin in Burkina Faso. Ph.D. Thesis (Unpublished), Bonn University, Germany.
- Tiwari, M. K. and Chatterjee, C. (2010). Development of an accurate and reliable hourly flood forecasting model using Wavelet-Bootstrap-ANN hybrid approach. *J. Hydro.*, **394**(3-4): 458-470.

Xi, C.; Zhang, Z.; Zhang, X.; Chen, Y.;
Qian, M. and Peng, S. (2008).
Estimation of groundwater recharge
from precipitation and

evapotranspiration by lysimeter
measurement and soil moisture
model. *J. Hydrol. Engg.*, **13**: 333-
340.

Table 1: Performances of groundwater recharge estimation models during calibration and validation

Sr. No.	Model	Calibration (1982-2001)		Validation (2002-2011)	
		R^2	NSE	R^2	NSE
1	Empirical model I	0.881	76.82%	0.819	-4.80%
2	Empirical model II	0.882	82.88%	0.820	74.99%
3	Empirical model III	0.884	82.89%	0.822	75.49%

**Figure 1: Location map of Karmal watershed of Bhadar basin**

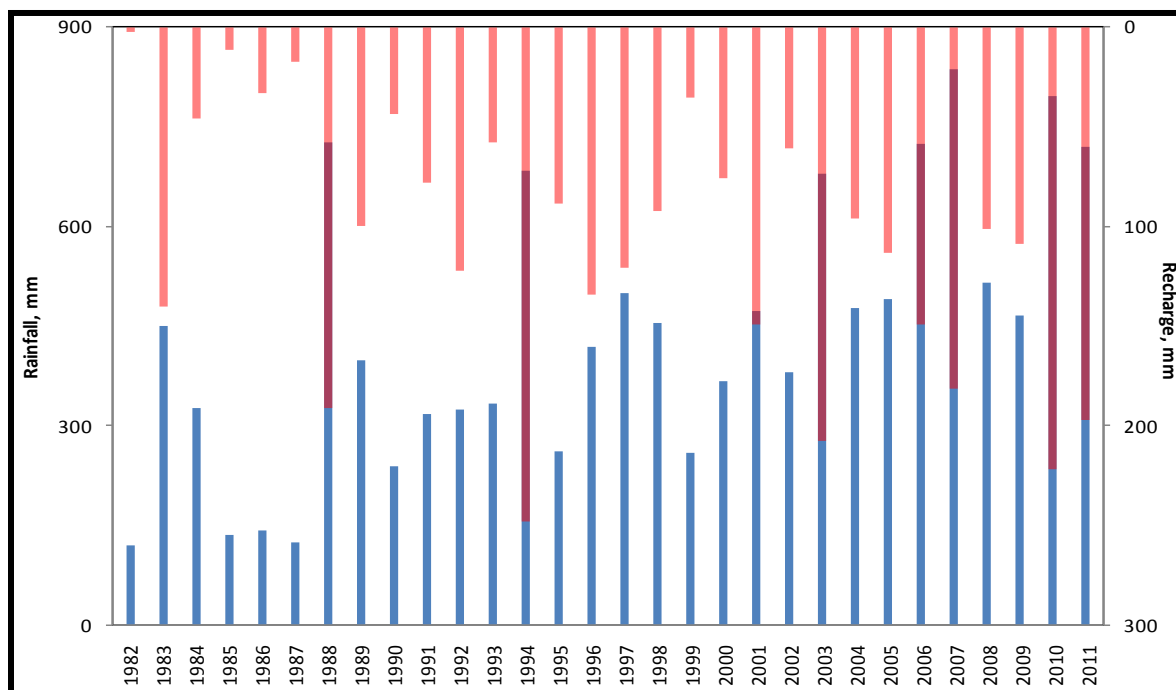


Figure 2: Annual rainfall-recharge relationship determined by water table fluctuation method

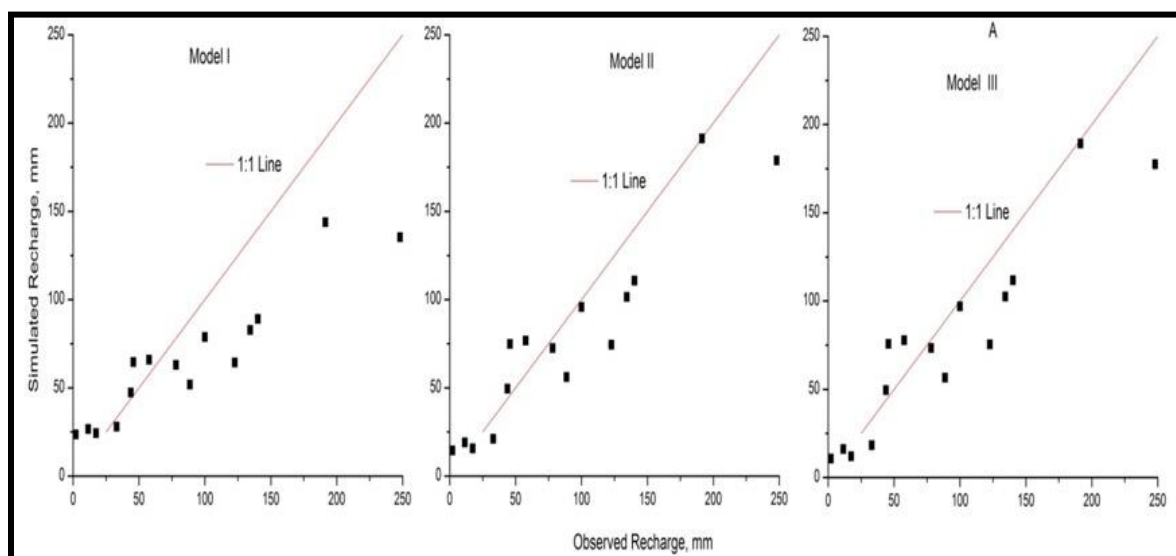


Figure 3: Scatter plot using empirical models I, II and III during calibration

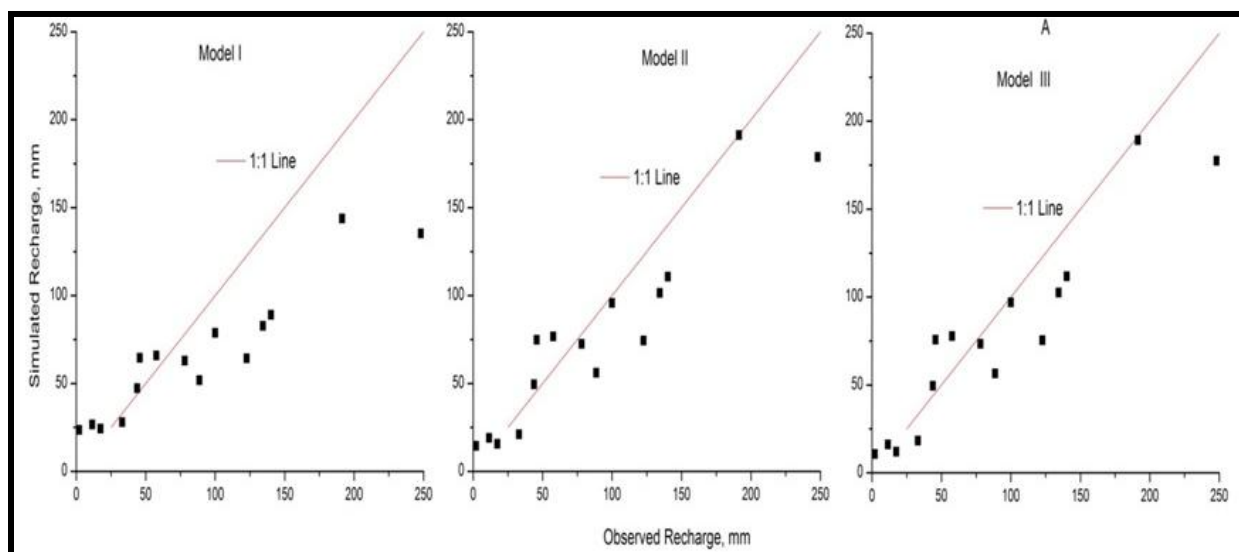


Figure 4: Scatter plot using empirical models I, II and III during validation

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