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GROUNDWATER RECHARGE ESTIMATION OF DHATARWADI RIVER BASIN

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ABSTRACT

Groundwater recharge for the study area *i.e.,* Dhatarwadi river basin of Amreli district of Gujarat state was estimated using Water Table Fluctuation method, Krishna Rao (1970), Athavale (2003), Maheta & Rank (2017), Kumar & Seetapathi (2002), developed linear models; Model I, Model II and non-linear; Model III during year 2002 to 2017. The linear empirical model II (R^2 = 0.828) for ground water recharge estimation performed well than empirical model I and III during calibration period (year 2003 – 2011). During validation period (year 2013 – 2017) the non-linear empirical model III performed well with 0.848 R^2 value. The lowest groundwater recharge obtained was 52.29 mm in the year 2017. While the highest groundwater recharge was found as 249.48 mm in the year 2013. Data shown that the overall mean groundwater recharge in the Dhatarwadi river basin was estimated to be 15.09 % (87.61 MCM) of the mean annual rainfall. The highest groundwater recharge was found as 179.81 mm, 183.96 mm, 294.89 mm, 205.65 mm, 125.21 mm, 135.00 mm and 133.46 mm for the year 2007 by Krishna Rao (1970), Athavale (2003), Maheta & Rank (2017), Kumar & Seetapathi (2002), developed Model I, Model II and Model III, respectively and 249.48 mm in the year 2013 by Water Table Fluctuation method. Groundwater recharge estimation formulae *i.e*. Athavle (2003), Maheta and Rank (2017), developed Model I and Model II are found perfectly positively correlated to each other. The non-linear empirical model for the ground water recharge in the Dhatarwadi river basin is proposed as; $R= 0.037(P-20)^{1.17}$.

***Key words*:** Dhatarwadi, groundwater recharge, watertable fluctuation, modelling

Introduction

Groundwater is a major source for all purposes of water requirements in India. More than 90% of rural and nearly 30% of urban population depend on it for drinking water. To irrigate about 32.5 million hectares area accounts for nearly 60% of the total irrigation potential in the country groundwater is utilized. Due to increase in population the dependency on the ground water is expected to increase in future (Anonymous, 2015).

According to National Water Policy (1987), the dynamic ground water resource, i.e. utilizable ground water resource which is meant for meeting the water requirements is about 43.2 M ha m as per the estimation of Central Ground Water Board. The static ground water resource also known as fossil water available in the aquifer zones below the zone of water level fluctuation is about 1081.2 M ha m. The dynamic resource gets replenished every year through natural recharge, so that the balance is maintained (Anonymous, 2015).

Farmers of many regions are using groundwater more than it gets replenish by nature, causing continuous decline in water levels. In India, as in other developing countries, agriculture accounts for most water use, as much as 85% of total annual draft. In the Indo-Gangetic Basin region about 15–20% of seasonal rainfall is the contributed to groundwater recharge, which drops to 5–10% in the peninsular hard-rock region, these results are outcome of natural recharge measurements carried out in about

Table 1: Data used and source.

Data	Description	Source
Hydrological and Meteorological Data	• Daily rainfall of 5 raingauge stations • Daily streamflow data of river basin at runoff gauging site *i.e.* Hindorana • Daily temperature (max and min) • Daily relative humidity • Daily average wind speed • Daily sunshine hours	State Water Data Center, Gandhinagar.
	• Monthly water table fluctuation data	Central Ground Water Board, Ahmedabad
Remote Sensing Data	• 30 m resolution SRTM DEM • Landuse/Landcover map • Soil map • Drainage map • Lineament map • River basin boundary	Bhaskaracharya Institute for Space Application and Geo-informatics (BISAG), Gandhinagar

20 river basins across India (Athavale *et al.,* 1992). Shivanna *et al.,* (2004) estimated that about 6% *i.e.* 33 mm of groundwater was recharged from an annual rainfall of 550 mm during 1992 in the semi-arid regions of Karnataka. The complexes of gneissic and weathered granitic of Southern India have neither hydro-meteorological nor hydro-geological factors in their favor results in their small recharge rates. Consolidated aquifers consist of the basaltic and granitic–gneissic complexes have natural recharge rate of only 3–15% (20–100 mm) (Adhikari *et al.,* 2013).

Amreli district has an area of 0.7397 M ha located near the Gulf of Khambhat in the Arabian Sea, in the western part of Saurastra region of Gujarat, India. The district has 11 Taluka viz., Amreli, Bagasara, Babra, Jafrabad, Dhari, Lathi, Khambha, Liliya, Savarkundla, Rajula and Vadiya). Amreli comes under North Saurashtra Agro Climatic zone and have semi-arid climate having average annual rainfall of 585 mm.

Dhatarwadi is a river in Amreli district contributing for Agricultural water requirement. Dhatarwadi River flows from Savarkundla, Jafrabad, Khambha and Rajula talukas of Amreli district. Dhatarwadi river basin has semi-arid climate. The average annual rainfall in the basin is 660 mm. In the basin there are two major dams Dhatarwadi Dam-1 and Dhatarwadi Dam-2 constructed over the Dhatarwadi river, the water stored is used for agriculture and drinking water supply. Due to limited rain water harvesting and low rainfall amount, population has to depend upon groundwater resource. So it is required to estimate the groundwater recharge incurring in the Dhatarwadi watershed to properly manage the water resource.

Material and Methods

Materials

The materials used for this study include hydrological and meteorological data (from year 2002 to 2017) and remote sensing data, which are enlisted as in Table 1 along with their source of collection.

Data set used

The data used for the study are as given in Table 1.

Software Used

The remote sensing and GIS software used for the study are ArcGIS-ArcMap 10.6 and ArcSWAT. ArcGIS was used for working with geographic information and maps. It was used for generate maps, integration of geographic data, analyzing map information, discovering also sharing geographic information and managing geographic information in a database. ArcSWAT is an interface of SWAT to work directly into ArcMap of ArcGIS software. SWAT model is also a GIS based model to simulated runoff of various geographical areas. SWAT-CUP enables users to analyze output of SWAT model. For sensitivity analysis, calibration, validation and uncertainty analysis, of developed SWAT models it is being used.

Methodology

The methodology of the study includes study of the working area, demarcation of the watersheds, use of remote sensing and GIS techniques for the preparation of thematic maps, geomorphologic analysis of watersheds including the calculation of linear, areal and relief aspects and assigning the priority to the watersheds by estimating the compound parameters, estimation of runoff potential using curve number technique, runoff water harvesting site selection using AHP method and estimation of groundwater potential.

Study Area

The Dhatarwadi river basin is situated in Amreli

Map of India **Map of Gujarat** **Location Map of Study Area**

Fig. 1: Location map of study area (Dhatarwadi river basin)

district of Saurastra region of Gujarat, India. The basin is located between 20° 50' to 21° 20' North latitude and 71° 05' to 71° 35' East longitude. Dhatarwadi river flows through Savarkundla, Khambha, Rajula and Jafrabad talukas of Amreli district encompassing tributaries namely Likhala, Sonardi and Surajwadi. The river basin covers an area of 85899 ha.

Groundwater Recharge Estimation

Various formulae for natural groundwater recharge estimation were developed for specific area, climate and aquifer properties. In this section, groundwater recharge estimation by water table fluctuation method and other empirical approach and also development of new empirical approach is described.

Empirical approach

The amount of rainfall recharge depends on various hydro meteorological and topographic factors, soil characteristics and depth to water table. While in the study area rainfall is the most significant source of groundwater recharge, the accuracy of currently attainable techniques for measuring recharge is not completely acceptable. Also, there isn't any known method to measure recharge directly. Therefore, the empirical approach was used because they can be transposed in time and space and renders themselves practically useful for preliminary recharge estimates.

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

$$R = a\,P \qquad (1)$$

$$R = a\,(P - b) \qquad (2)$$

Non-linear empirical formula to estimate recharge (R),

$$R = a\,(P\text{-}b)^c \qquad (3)$$

Where, R is ground water recharge from rainfall in mm, P is total annual rainfall in mm and a, b, c are constants.

Krishna Rao (1970) formula

Krishna Rao (1970) gave the following empirical relationship to determine the groundwater recharge in limited climatologically homogeneous areas (Kumar, 1996).

$$R = K\,(P\text{-}X) \qquad (4)$$

Where, R is rainfall recharge in mm, P is precipitation in mm, K is recharge coefficient and X is imperial coefficient.

Following relation holds good for different part of hard rock region in Karnataka.

R = 0.20 (P-400), where annual rainfall between 400-600 mm

R = 0.25 (P-400), where annual rainfall between 600-1000 mm

R = 0.35 (P-600), where annual rainfall greater than 2000 mm

Water table fluctuation method (WTF)

The water table fluctuation method provides an estimate of groundwater recharge by analysis of water level fluctuation in river basin. The method is dependent on the postulation that an ascent in water-table elevation measured in shallow wells is brought about by the addition of recharge across the water table. Recharge using the WTF method is estimated by below given formula,

$$R = S_y \times \Delta L \times A \qquad (5)$$

Where, R is groundwater recharge in m^3, S_y is specific yield, dimensionless, ΔL is water table difference in m and A is net geographical area of river basin in m^2.

Maheta and Rank (2017) formula

Maheta and Rank (2017) developed empirical model to derive groundwater recharge from rainfall in Karmal watershed of Bhadar basin of Gujarat state.

$$R = 0.496\,(P - 90.898)^{0.921} \qquad (6)$$

Where, R is ground water recharge from rainfall in mm and P is total annual rainfall in mm.

NGRI / Athavale (2003) formula

The National Geophysical Research Institute conducted a field work of measurement of a natural recharge on large scale for four rock types, namely, sedimentary, granites, alluvium and basalts across 36 basins of India (Athavale, 2003). A regression equation developed by Athavale (2003) is given below.

$$R = 0.174\,(P - 62) \qquad (7)$$

Where, R is ground water recharge in mm and P is total annual rainfall in mm.

Kumar and Seethapathi (2000) formula

The following empirical relationship was derived for Upper Ganga Canal command by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the monsoon season through the non-linear regression technique.

$$R = 0.63\,(P - 15.28)^{0.76} \qquad (8)$$

Where, R is ground water recharge in monsoon season in inch and P is mean rainfall in monsoon season in inch.

Results and Discussion

Groundwater recharge is the water which enters the saturated zone of soil until it reaches the water table surface (Freeze and Cherry, 1979). The precious resources of groundwater need to have significant management and safeguarding in order to obtain an accurate assessment of groundwater recharge rates. For decades numerous methods have been used to estimate recharge. However, it has been very difficult to evaluate the accuracy of any of the methods available. As a result, applying multiple methods is found useful to estimate groundwater recharge (Healy and Cook, 2002). Therefore, to assess groundwater recharge of the Dhatarwadi river basin four equations given by Krishna Rao (1970), Athavale (2003), Maheta and Rank (2017) and Kumar and Seethapathi (2002) from the year 2002 to the year 2017 were used together and the same was compared by groundwater recharge estimated using Water Table Fluctuation (WTF) method.

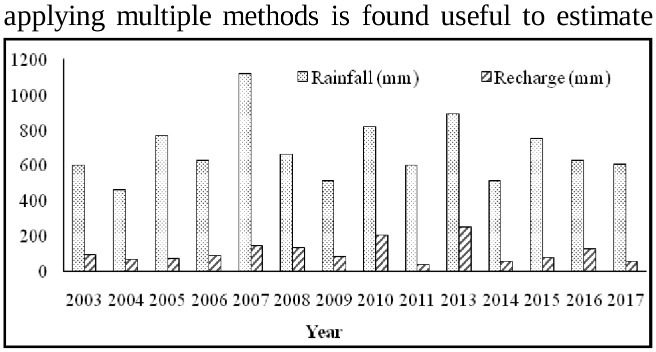

Fig. 2: Annual rainfall-recharge relationship.

Water table fluctuation method

In this section, the recharge for 16 years (year 2002 to 2017) has been estimated from water table fluctuations data. The recharge has been estimated from three well observation sites *i.e.* Lotpur, Goradka, Badhda, Khambha, Vankiya and Chok. Groundwater table level data of observation sites were downloaded from Central Ground Water Board (CGWB) website. 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 as suggested by Bhanja *et al.,* (2016) who has studied groundwater storage for the whole country India. Groundwater recharge of the entire watershed was estimated by area weighted method. Annual rainfall and annual recharge estimated using water table fluctuation method are given in Fig. 2. The lowest groundwater recharge obtained was observed as 52.29 mm in the year 2017. While the highest groundwater recharge was found as 249.48 mm in 2013. Data shows that the overall mean groundwater recharge in the Dhatarwadi river basin was estimated to be 15.09% of the mean annual rainfall. Rathod (2010) estimated groundwater recharge using this method for the Meghal river basin of Gujarat, was varying from 13 to 16 % of annual rainfall. The study result is similar to the findings by Kuruppath *et al.,* (2018) for the Aravakurichi and K. Paramathi block of Tamil Nadu. It was observed that the amount of recharge increases as the rainfall increase but the increase is not linearly proportional.

Empirical formula development of groundwater recharges estimation

The principal source for rejuvenation of moisture in the soil water system and recharge to groundwater is the Rainfall. Moisture movement in the unsaturated zone is monitored by suction pressure, moisture content and hydraulic conductivity relationships. Natural groundwater recharge can be referred as the quantity of moisture that join water table. The proportion of this recharge relies upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the former soil moisture conditions, the water table depth and the soil type.

Table 2: Developed Models.

Sr. No.	Model Number	Model
1	Model I	R = 0.112P
2	Model II	R = 0.134 (P–112.18)
3	Model III	R= 0.037(P-20)$^{1.17}$
Where, R is recharge in mm and P is rainfall in mm.		

The response of aquifer possibly in the form of amount of water, may be used for groundwater recharge estimation, e.g. by using specific yield concept converting groundwater level changes in to amounts of water or by using inverse modeling (the recharge amount determination needed to maintain the groundwater levels). In the evaluation of groundwater resources, estimation of the rate of aquifer replenishment is probably the most exhausting of all the measures used. These estimates are ordinarily and almost undeniably subject to large errors. No single comprehensive estimation technique can yet be identified from the spectrum of those available, which gives reliable results (Kumar, 1996).

To develop an empirical formula for groundwater recharge estimation particularly for the Dhatarwadi river basin, groundwater recharge was calculated by using the water table fluctuation method with mean rainfall. For Linear and Non-linear relationship Regression analysis, SPSS was used. The following empirical relationship was derived by applying the estimated values of recharge and the corresponding values of rainfall through trial and error.

Evaluation of developed formula

The performance of groundwater recharge estimation models during calibration and validation are presented in Table 3.

During the calibration phase, all the three models are showing good result, R^2 is more than 0.7 and NSE is more than 50.0 %. The calibrated model performed even better during the validation period as all models given higher R^2 than during calibration. It can be concluded from this result that all three formulas can fairly represent groundwater recharge in the Dhatarwadi river basin. Maheta (2017) developed 2 liner and 1 nonlinear model to estimate groundwater recharge for the Karmal watershed, Gujarat, which show similar performance for calibration and validation duration having R^2 ranging between 0.816 and 0.881. Estimation of groundwater recharge using any method is normally subject to large uncertainties and errors (Kumar and Seethapathi, 2002). Oke *et al.*, (2013) also stated that the aquifer recharge is one of the most difficult factors to measure in the evaluation of groundwater resources.

Groundwater recharge estimation using various methods

Table 3: Performances of groundwater recharge estimation models.

Sr. No.	Model	Calibration (year 2003 – 2011)		Validation (year 2013-2017)	
		R^2	NSE	R^2	NSE
1	Empirical model I	0.821	51.37 %	0.835	50.28 %
2	Empirical model II	0.828	51.76 %	0.838	51.88 %
3	Empirical model III	0.731	51.67 %	0.848	55.94 %

Various methods were used to get an idea about groundwater recharge happening in the Dhatarwadi river basin. Equation given by Krishna Rao (1970), Athavale (2003), Maheta & Rank (2017), Water Table Fluctuation and Kumar & Seethapathi (2002) were used to estimate groundwater recharge.

Rainfall recharge relation by used formulas, Krishna Rao (1970), Athavale (2003), Maheta & Rank (2017), Kumar & Seethapathi (2002), Model I, Model II and Model III are showing that recharge is linearly related to rainfall. Fitted trend line to these formulas R^2 values were obtained as, 0.9887, 1.0, 0.9997, 0.9923, 1.0, 1.0 and 0.9853. This indicates that in the Dhatarwadi river basin, precipitation, in most cases, regulates groundwater recharge. Only Water Table Fluctuation method showed low R^2 0.5129 for the linear trend line. The high R^2 may be related to only temporal variability in recharge data because treating the basin as one unit in the recharge calculation. However, when spatial variability is also included, the R^2 can be much lower (Wu *et al.*, 2019). $R^2 < 0.3$ was observed for recharge data synthesized from around the globe and from Australia by Petheram*et al.*, (2002) and Kim & Jackson (2012), respectively. This is because other explanatory variables, such as soil texture (Pulido-Velazquez *et al.*, 2015; Martos-Rosillo *et al.*, 2014) and root depth (Li *et al.*, 2018) also contributed to the variability in the recharge.

The lowest groundwater recharge by all the methods was observed in the year 2012 when the mean annual rainfall was minimum during the study period, Krishna Rao (1970) and Kumar & Seethapathi (2002) shown no recharge; Athavale (2003) and Maheta & Rank (2017) given possible recharge as 48.97 mm and 80.92 mm, respectively; developed models of study area estimated recharge as 38.42 mm, 31.00 mm and 30.26 mm for Model I, Model II and Model III, respectively. Water table fluctuation depicted the lowest recharge of 52.30 mm in the year 2017.

The highest groundwater recharge was found as 179.81 mm, 183.96 mm, 294.89 mm, 205.65 mm, 125.21

Table 4: Correlation between various methods.

	Krishna Rao (1970)	Athavle (2003)	Maheta & Rank (2017)	Kumar & Seethapathi (2002)	Water Table Fluctuation Method	Model I	Model II	Model III
Krishna Rao (1970)	**1.000**	0.994	0.993	0.987	0.717	0.994	0.994	0.988
Athavle (2003)	0.994	**1.000**	1.000	0.996	0.716	1.000	1.000	0.993
Mehta & Rank (2017)	0.993	1.000	**1.000**	0.997	0.719	1.000	1.000	0.993
Kumar & Seethapathi (2002)	0.987	0.996	0.997	**1.000**	0.729	0.996	0.996	0.989
Water Table Fluctuation Method	0.717	0.716	0.719	0.729	**1.000**	0.716	0.716	0.697
Model I	0.994	1.000	1.000	0.996	0.716	**1.000**	1.000	0.993
Model II	0.994	1.000	1.000	0.996	0.716	1.000	**1.000**	0.993
Model III	0.988	0.993	0.993	0.989	0.697	0.993	0.993	**1.000**

mm, 135.00 mm and 133.46 mm for the year 2007 by Krishna Rao (1970), Athavale (2003), Maheta& Rank (2017), Kumar & Seethapathi (2002), developed Model I, Model II and Model III, respectively and 249.48 mm in the year 2013 by Water Table Fluctuation method. All the methods except Water table fluctuation are based on only rainfall, therefore they have given the highest recharge for the highest rainfall year 2007 and the lowest recharge for lowest rainfall during the year 2012.

Water table fluctuation does not depend only on rainfall, but also depend on other environmental parameters, soil properties, aquifer properties, etc. also contribute. Therefore, recharge estimated by WTF does not show a high low trend like other methods. Natarajan *et al.,* (2018) estimated groundwater recharge using six empirical formulae *i.e.* Chaturvedi Formula (1936), Krishna Rao Formula (1970), Amritsar Formula (1973), Bhattacharjee Formula (1954), U.P.I.R.I. Formula (1954), Kumar and Seethapathi Formula (2002) and Water Table Fluctuation method for the Sirumugai study area which is located in the Coimbatore district, Tamil Nadu. They concluded that high recharge coincides with a period of high rainfall and low recharge with low rainfall. A similar result also was obtained by Deshbhandari and Krishnaiah (2017) for the Venkatapura watershed of Karnataka State.

Groundwater recharge from annual rainfall shows the percent of rainfall contributes to recharge to the study zone. Formulae used in this study given the highest and lowest percentage annual recharge of annual rainfall for the year 2007 and the year 2012, except Water Table Fluctuation and developed Model I. According to Krishna Rao (1970) formula, estimated recharge varied from 0 % to 16.07 %. Athavle (2003) estimated recharge between 14.26 % and 16.44 %. Maheta and Rank (2017) estimated the highest recharge percent of 23.56 % to 26.35 %. According to Kumar and Seethapathi (2002), recharge ranged between 0 % and 18.37 %. Developed Model II and Model III estimated recharge from 9.03 % to 12.06 % and 8.81 % to 11.92 %, respectively. Water Table Fluctuation estimated the lowest recharge of 6.69 % in the year 2011 and highest recharge 28.04 % in year 2013. Developed Model I estimated 11.19% recharge constant for every year, as this model is 0.112 constant multiplicative to rainfall. Mean recharge for the study period was highest obtained as 25.63 % by Maheta and Rank (2017) and lowest obtained as 8.31 % by Krishna Rao (1970). The result shows that for the Dhatarwadi river basin Maheta and Rank (2017) estimate higher recharge and lowest recharge is estimated by Krishna Rao (1970) for the study period. Kelaiya (2013) reported 0 to 17.02 % ground water recharge of rainfall by Krishna Rao approach and 0 to 10.10 % groundwater recharge of rainfall by Water Table Fluctuation method in Bhadar Basin which supports the groundwater recharge found by Krishna Rao approach in present study for the Dhatarwadi river basin. Paradava & Rank (2015) used Krishna Rao (1970) and Water Table Fluctuation method to estimate groundwater recharge of the Shetrunji river basin, found that the groundwater recharge varies from 0-15.34% and 0.72-14.62% of rainfall by Krishna Rao (1970) and Water Table Fluctuation method respectively which also supports the groundwater recharge estimated by Krishna Rao (1970). Natarajan *et al.,* (2018) estimated groundwater recharge at various locations in the Sirumugai study are located in the Coimbatore district of Tamil Nadu state was found 67.5- 340 mm per year groundwater recharge of rainfall by water table fluctuation method which is similar in the range of the study area. Kuruppath *et al.,* (2018) also found that Krishna Rao (1970) formula has given the lowest recharge as compare to Amritsar formula, Chaturvedi formula, UPIRI formula and Kumar and Seethapathi formula for the Aravakurichi and K. Paramathi block of Karur district of Tamil Nadu state.

It is difficult to determine the accuracy of results from different methods as the true value of annual recharge is unknown. None of the available methods can be termed as the "best" at estimating the recharge. Out of the methods used in this study, the WTF method is based on actual observation and more reliable. Data requirements for the method are very few and computations are limited. However, the method's success depends on reliable estimates of specific yield, a parameter that may be transient and spatially variable (Natarajan *et al.,* 2018).

None of the utilized methods always produce the highest or lowest estimate of annual recharge for all groundwater systems. A comparison of multiple methods is found to be valuable for determining the range of plausible recharge rates and for highlighting the uncertainty of the estimates (Natarajan *et al.,* 2018).

The correlation analysis

Comparing various recharge estimation equations is a very difficult task as they all are developed for the local area, but to get a possible recharge scenario they have been used. To know the relation between various methods correlation analysis was done and results are presented in Table 4.

Inter Correlation Matrix of annual recharge shows all the employed equations are positively correlated to each other. Krishna Rao (1970) is more positively correlated to Athavle (2003), developed Model I and Model II. The correlation between Athavle (2003) with Maheta and Rank (2017), developed Model I and Model II is 1.0, which shows a perfect positive correlation. Kuma (1984) has categorized correlation into three classes which are $\leq$ 0.35 are generally considered to represent low or weak correlations, 0.36 to 0.67 modest or moderate correlations and 0.68 to 1.0 high or strong correlations with r coefficients, $\geq$ 0.90 very high or very strong correlations. Based on this categorization Krishna Rao (1970), Athavale (2003), Maheta and Rank (2017), Kumar and Seethapathi (2002), developed Model I, Model II and Model III are lowest but strongly positively correlated with Water Table Fluctuation method as having correlation 0.717, 0.716, 0.719, 0.729, 0.716, 0.716 and 0.697, respectively. Kumar and Seethapathi (2002) show very high correlation with Maheta and Rank (2017). Water Table Fluctuation method has a strong correlation with Kumar and Seethapathi (2002). This indicates that Athavle (2003), Maheta and Rank (2017), developed Model I and Model II are working similarly for the Dhatarwadi river basin and with Krishna Rao (1970), Kumar and Seethapathi (2002) and developed Model III are nearly the same. Oke *et al.,* (2015) similarly found that Kumar and Seethapathi formula and Krishna Rao had a 1.0 correlation which forges them perfectly positively correlated to each other for the Ogun-Osun River basin, Nigeria. Therefore, it can be considered that any of the recharge formula can be used for recharge estimation in Dhatarwadi river basin, but Kumar and Seethapathi is most preferable.

Conclusion

Groundwater recharge for the study area were estimated using Water Table Fluctuation method, Krishna Rao (1970), Athavale (2003), Maheta & Rank (2017), Kumar & Seetapathi (2002), developed linear models; Model I, Model II and non-linear; Model III during year 2002 to 2017. The linear empirical model II (R^2 = 0.828) for ground water recharge estimation performed well than empirical model I and III during calibration period (year 2003 – 2011). During validation period (year 2013 – 2017) the non-linear empirical model III performed well with 0.848 R^2 value. The lowest groundwater recharge obtained was 52.29 mm in the year 2017. While the highest groundwater recharge was found as 249.48 mm in the year 2013. Data shown that the overall mean groundwater recharge in the Dhatarwadi river basin was estimated to be 15.09 % (87.61 MCM) of the mean annual rainfall. The highest groundwater recharge was found as 179.81 mm, 183.96 mm, 294.89 mm, 205.65 mm, 125.21 mm, 135.00 mm and 133.46 mm for the year 2007 by Krishna Rao (1970), Athavale (2003), Maheta & Rank (2017), Kumar & Seetapathi (2002), developed Model I, Model II and Model III, respectively and 249.48 mm in the year 2013 by Water Table Fluctuation method. Groundwater recharge estimation formulae *i.e.* Athavle (2003), Maheta and Rank (2017), developed Model I and Model II are found perfectly positively correlated to each other. The non-linear empirical model for the ground water recharge in the Dhatarwadi river basin is proposed as; $R = 0.037(P-20)^{1.17}$.

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