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# Groundwater Resources as Influenced by Climatic Change in Shetrunji basin of Gujarat State, India

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## ABSTRACT

The estimation of climatic alteration influencing on groundwater recharge will help to prepare a future plan for groundwater development and management planning for the basin. It will also be helpful for agriculture as well as other resource planning. The required shift in cropping pattern can also be judged. The study was undertaken for Shetrunji river basin having an area of 5646.98 km$^2$. The entire area was found consisting of 17 watersheds. The climate change impact on Rainfall, Runoff and estimated groundwater recharge by 3 different methods were assessed. The groundwater recharge varied from 3.11% to 49.28%, 0% to 15.34% and 0.72% to 14.62% of rainfall by water balance, Krishna Rao (1970) and water table variation respectively. The climate change impacts favors to increase the rainfall significantly in 6 out of 17 watersheds while the runoff is found increasing in 5 out of 17 watersheds of the basin. The rainfall and runoff was influenced by the climate change in Northern part of upper reach and southernmost part of middle reach of basin. The area weighted rainfall of the Shetrunji river basin was found increasing significantly. The areal mean depth of monsoon runoff for entire Shetrunji basin was increasing significantly at the rate of 17.7 mm per decade. The groundwater recharge assessed by water balance method was found higher as compared to Krishna Rao (1970) and water level fluctuation method. The groundwater recharge expected by water balance, Krishna Rao (1970) and water level fluctuation methods is found to be enlarged in 13, 9 and 6 watersheds out of 17 watershed of the basin. The areal mean depth of groundwater recharge in Shetrunji basin during monsoon season in water level fluctuation method was found increasing significantly at the rate of 13.01 mm per decade due to climate change impacts.

**Key words:** Basin; Watershed; Rainfall; Runoff; Groundwater recharge; Climate.

## INTRODUCTION

About sixty-seven percent of irrigation water applied to crop through runoff and evaporation. Though, the evaporation is significant component of irrigation efficiency, not much attention has been given to it. Generally, irrigation water applied in agriculture is based on experience of farmer. So, evaporation component should be incorporated in development of any irrigation project or plan. The plant losses their water through the process of evaporation and transpiration. Evapotranspiration (ET) the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants Potential evapotranspiration is the rate at which the amount of evaporation that would occur if a sufficient water source were available[1].

Groundwater as influenced by climatic change is an issue of discussion since long in our country. Though, earlier and preliminary research showed substantial scope for reduction in carbon footprint of India's groundwater optimization. For the region like Haryana and Andhra Pradesh, quantitative models have been developed to assess the marginal influence on greenhouse gas emission from pumping[2].Some of the major findings of the studies were (a) increases in emission of greenhouse gas is 4.37 percent per meter decline in pumping water level in Haryana and the same is 6 percent in Andhra Pradesh.(b) Greenhouse gas emission elasticity percent of the area under irrigation by use of groundwater is 2.2 and through 1990s, the area irrigated through groundwater in these two states increased at 3 percent annual growth rate, resulted in an increase of greenhouse gas emission of 6.6 percent per year.(c) When the share of diesel pumps increased by 1 percent, it reduced GHG emission by 0.3 percent. (d) GHG emissions elasticity concern with irrigation efficiency is maximum at 2.1.Hence; the major determinant of carbon footprint of our country through irrigation economy of pump is due to variation or fluctuation in head over which the farmers had to lift the water for irrigation. The more the head, the more the consumption of energy and it is more likely that deep tube well electrified pump use for groundwater exploitation, multiplies the Carbon footprint. Previously, our country was using surface storage of water and irrigated crops through gravity flow during last four decades. It has declined and rise of energy consumed irrigation through member of small and private tube wells.

Pumping through groundwater with electricity and diesel, accounted 16-25 million tons of carbon emission and it is 4-6 percent of country's total. For climatic change point of view, India's groundwater hot spots are western and peninsular regions. These are more critical for mitigation and adaptation to climate change. To attain both, it is needed to make a transition from surface storage to "managed groundwater storage" as a indicator of water use strategies with productive demand and supply management. For that, learning of countries like Australia and the USA, who had a long experience of managing groundwater recharge must be taken into account[3].

The above discussion leads to conclude that groundwater resources management have a great impact on emission of GHG reduction climate change mitigation. If the groundwater in an aquifer is available at shallow depth, it can be utilized at lower cost and so ultimately less will be the GHG emission.

The evaluation in influence of climatic change on groundwater recharge will help to prepare a future plan for groundwater development and management plan for the basin. It will also be helpful for agriculture as well as other resource planning. The required shift in cropping pattern can also be judged. The quantity predictions can be achieved to aid managerial and policy action directed towards natural resources management. Keeping above in analysis, the current find out be undertaken with objectives to estimate groundwater recharge and evaluate the Groundwater recharge as influenced by climatic change.

## MATERIALS AND METHODS

### Analysis region

The Shetrunji river basin is situated between 21° 00' to 21° 47' North latitude and 70° 50' to 72° 10' East longitude in Saurashtra region of Gujarat state. Groundwater is main source of irrigation for the agriculture. The position map of analysis region is shown in Figure 1.

### Data collection

Maps of India, Gujarat and watershed along with cadastral map of Shetrunji basin and Satellite images of IRS P6 of sensor LISS IV and Awifs digital data were collected from BISAG, Gandhinagar. The daily rainfall data records (1961-2010) were collected from State Water Data Centre, Gandhinagar and the daily runoff data from Irrigation Department, Junagadh. The climatic data records (1965-2010) required for the estimation of daily reference evapo- transpiration by Penman-Monteinth method as per FAO-56 was collected from the JAU Agro meteorological Observatory, JAU, Junagadh[4]. The water table data records (1985-2010) before and after monsoon for the different gauge stations of the study area with aquifer properties were collected from the Central Groundwater Board, Ahmadabad.

An empirical approach suggested by Krishna Rao (1970) for hard rock area was adopted for the groundwater estimation[5].

Rainfall recharge ($R_g$, mm) = Recharge coefficient (K) (Precipitation (P, mm) – Imperial coefficient (X)) ...(1)

$R_g$ = 0.25(P-400); Where annual rainfall is 60-100cm.

$R_g$ = 0.35(P-600); Where annual rainfall is greater than 200cm.

Where, $R_g$ = Rainfall Recharge (mm), P = Precipitation (mm), K = Recharge coefficient and X = Imperial coefficient. Following relation holds good for different part of hard rock region in Karnataka.

**Water table fluctuation method**

The hypothesis of this method is that a rise in water-level height measured in wells is due to the adding of recharge transversely the water level. Recharge by Water level variation method has been estimated for the following relation,

$$R_g = S_y \times \Delta L \times A \qquad ...(2)$$

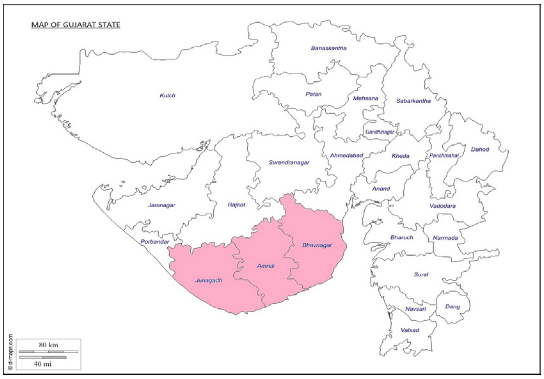
Where, $R_g$ = Rainfall Recharge (mm), $S_Y$ = Specific yield, dimensionless, “L = Water table difference (m) and A = Net geographical area of river basin (m²).

**Water balance method**

These estimates is substituted in the water balance equation to obtain rainfall recharge,

$$V_{rrf} = (V_{sms1} - V_{sms2}) + V_{rf} - V_{ro} - V_{cwc} - V_{se} - V_{gwd} + V_{rc} + V_{rfi} + V_{rt} + V_{rr} + (V_{ig} - V_{og}) \qquad ...(3)$$

Where, $V_{rr}$ = Volume of recharge from rainfall (ha-m), $V_{rf}$ = Volume of rainfall (ha-m), $V_{sms1}$

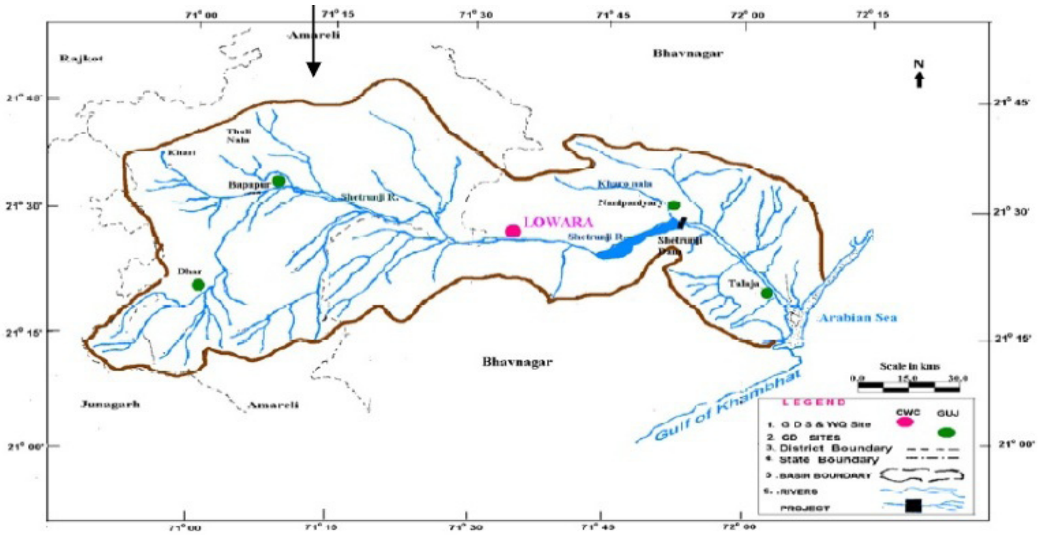




**Fig.1: Location map of Shetrunji river basin**

= Volume of soil moisture storage at starting of period (ha-m), $V_{rc}$ = Volume of recharge from canal (ha-m), $V_{rfi}$ = Volume of recharge from field irrigation (ha-m), $V_{rt}$ = Volume of recharge from tank (ha-m), $V_{rr}$ = Volume of recharge from rivers (ha-m), $V_{ig}$ = Volume of inflow from other basins (ha-m), $V_{ro}$ = Volume of runoff (ha-m), $V_{cwc}$ = Volume of crop water consumption (ha-m), $V_{se}$ = Amount of soil water disappearance from uncropped area (ha-m), $V_{og}$ = Volume of outflow to other basins (ha-m), $V_{gwd}$ = Volume of groundwater draft (ha-m), $V_{sms2}$ = Volume of soul moisture storage at ending of period (ha-m). The water balance components were estimated separately for each watershed of the shetrunji river basin.

## Climate change impact assessment

The climate change impact on the Rainfall, Runoff and groundwater recharge estimated by different methods were assesses in analyzing the respective time series data for each watershed and river basin as a whole adopting the approaches

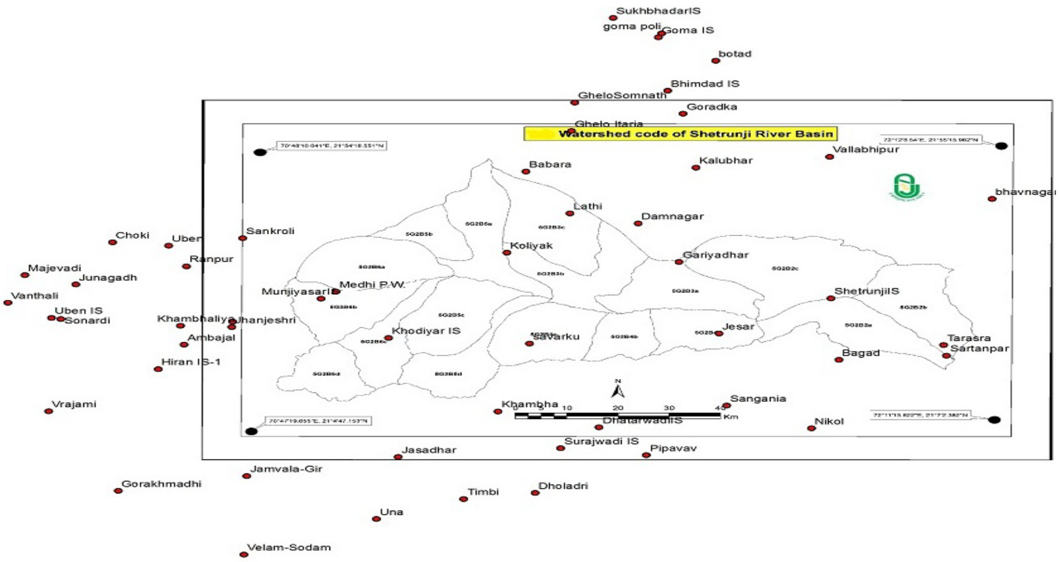



**Fig.2: Location map of Rain gauge station of Shetrunji basin**

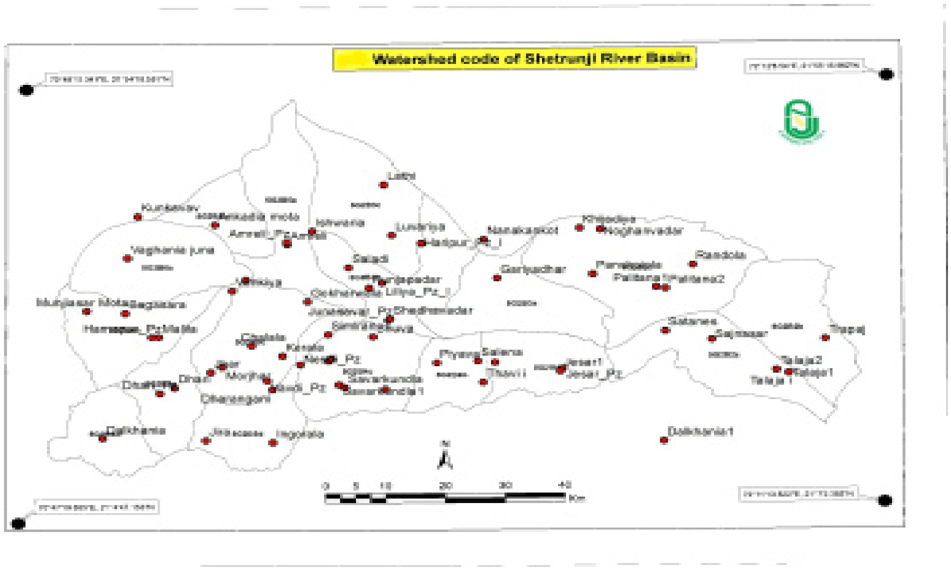



**Fig.3: Location map of groundwater level gauging station of shetrunji basin**

suggested by Mann-Kendall (1975) and Sen's (1968) and compared with the best fit trend line [6,7].

## RESULTS AND DISCUSSION

The drainage and watershed map of the Shetrunji river basin were prepared by remote sensing and GIS having maximum stream order of basin is 7. Area of each watershed was determined using GIS software. The entire basin was found consisting of 17 watershed which were named as 5G2B2a, 5G2B2b, 5G2B2c, 5G2B3a, 5G2B3b, 5G2B3c, 5G2B4a, 5G2B4b, 5G2B4c, 5G2B5a, 5G2B5b, 5G2B5c, 5G2B5d, 5G2B6a, 5G2B6b, 5G2B6c and 5G2B6d. The location of the rain gauge stations and groundwater level gauging stations were marked on the basin map (Fig. 2 and Fig. 3).

### Comparison of groundwater recharge by different methods

The lowest groundwater recharge caused by water balance, Krishna Rao approach[5] and water level fluctuation methods was observed as 5.9 mm in 1987, 0 mm in 1987 and 4.6 mm in 2002 respectively. Similarly, the highest groundwater recharge was found as 473.2 mm in 2005, 151.7 mm in 2007 and 85.8 mm in 2007 respectively by water balance, Krishna Rao approach[5] and water level

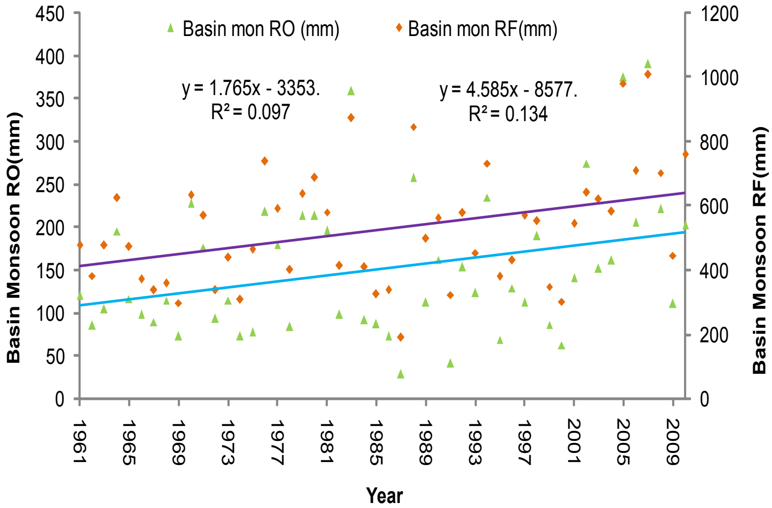



**Fig.4: Effect of climate change on monsoon rainfall and runoff in Shetrunji basin**

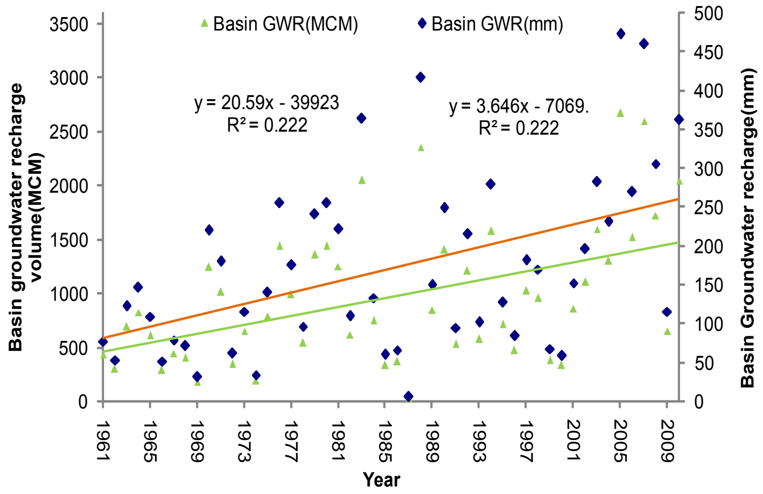



**Fig.5: Influence of climatic change on groundwater recharge through water balance method in Shetrunji basin**

fluctuation methods. It could be seen that there was large variation among the groundwater recharge by water balance and rest of the methods. However, the close similarity was found in groundwater recharge by Krishna Rao approach[5] and water level fluctuation methods.

The local inquiry of the farmers of the basin showed that about 50% of the geographical area could be brought under irrigation during winter season and 10 to 20% area during summer season using groundwater during last 5 years. The depth of water application was 45-50 cm and 50-60 cm during winter and summer season respectively. The groundwater recharge estimated by the groundwater balance seems more reliable taking into account of irrigated crop acreage and irrigation depth during winter and summer season. The groundwater recharge by water table fluctuation may be under estimated. The reason was lack of data of spatial aquifer properties for the entire basin. Based on groundwater level fluctuation method for estimating groundwater recharge are prone to large uncertainties due to the uncertainty in values for specific yield ($S_y$)[8].

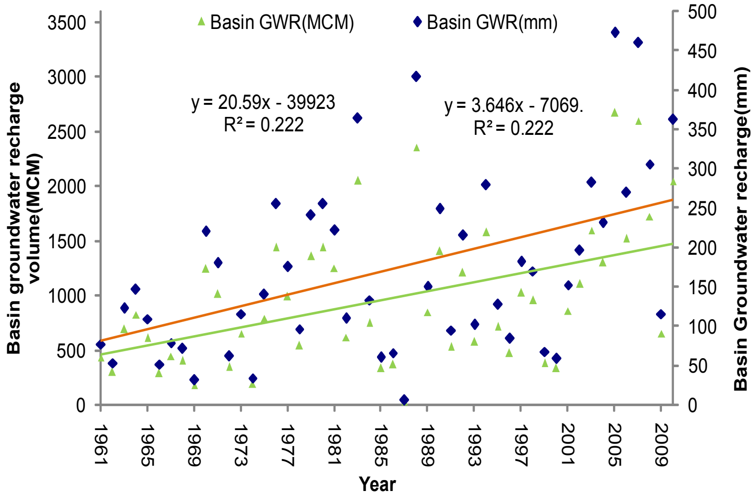



**Fig.6: Effect of climatic change on groundwater recharge by Krishna Rao (1970) approach in Shetrunji basin**

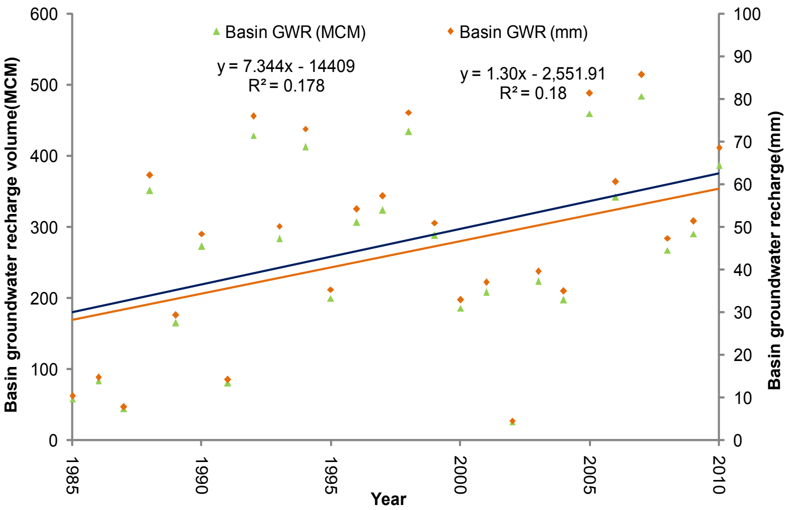



**Fig.7: Effect of climatic change on groundwater recharge by water level fluctuation method in Shetrunji basin**

The groundwater recharge was found varies as 3.11 % to 49.28 % by water balance method, 0 % to 15.34 % by Krishna Rao approach[5] and 0.72 % to 14.62 % by water level fluctuation method. The Groundwater renew was found 8 to 15 per cent of rainfall by using pre-monsoon and post-monsoon water level fluctuation data of years 1998-2005 which was not sufficient for sustainability of groundwater resources in the basin[9]. Using water table fluctuation method, it was found that the recharge contribution to groundwater from the rainfall and irrigated fields was at the rate of 0.502 mm $d^{-1}$ [10]. The recharge to the groundwater from rainfall alone was about 20 percent of total rainfall, which was 0.225 mm $d^{-1}$. The predicted net annual groundwater recharge as 2.058 MCM quantify the groundwater budget of a 1381 ha watershed in Uttar Pradesh, India using water table fluctuation method[11]. It was also reported that the ground water recharge in 267 ha watershed area of Shivar watershed in Akola district, Maharashtra was 11.70 percent of the rainfall using water balance model[12]. The groundwater renew approximated through water level variation method has been approximated at 13,520 ha-m with yearly rainfall of 40 years for the Meghal river basin of Saurashtra region[13]. However, in all the above studies, the different methods of the groundwater recharge were not compared.

## Climate change impact assessment

The rainfall and runoff are the two most influencing water balance components on the groundwater recharge. Therefore, the climate change impacts on Rainfall, Runoff and Groundwater recharge were assessed. The daily runoff for each watershed of the basin was estimated using SCS-CN technique for the period (1961-2010). The CN of the basin was obtained as 74. Monsoon runoff was obtained by summing up the daily runoff values during the monsoon period (June-September).

## Monsoon rainfall and runoff

The time series of seasonal depth of rainfall and runoff for the entire Shetrunji basin was computed using area weighted value of rainfall and runoff respectively from each watershed of basin. The coefficient of variation in time series data of rainfall was found as 34.6% while that of for the time series of runoff was found as 54.2%. The coefficient of variation in runoff was found higher as compare to that of rainfall indicating that runoff is influenced by uncertainty in rainfall magnitude as well as its temporal distribution during the monsoon period. The Mann-Kendall statistics showed that the rainfall is increasing significantly in the Shetrunji river basin. The close agreement was found between the slopes of the best fit trend line (Fig.4) and estimated by Sen's method. The Mann-Kendall statistics for the runoff data series showed that runoff is significantly increasing at 5% level. The climate change impact will increases the runoff at the rate of 17.7 mm per decade for the entire river basin. This result was supported by the findings reported stating that an increasing linear trend was observed in the rainfall for the Luni river basin of north-west arid India[14]. It was also found increasing trend in 5 years moving average data series of annual rainfall at Junagadh station[15]. It has expected thirteen percent rise in monsoon period rainfall in India by means of ECHAM4 model[16]. Particularly the Western Ghats are likely to occurrence a 5–10% increase in total precipitation due to climatic change[17]. The seasonal rainfall of West Coast, North Andhra Pradesh and Northwest India have been found increasing trend while decreasing trend have been found over East Madhya Pradesh, Orissa and Northeast India during recent years predicted an intensification of the rainfall in the Indian region during the monsoon season as a results of the increase in the greenhouse gases absorptions[18, 19]. It was examined a daily precipitation dataset and establish a increasing trend in the occurrence of heavy precipitation events and a significant fall in the frequency of moderate events over central India from 1951 to 2000[20]. Rising occurrence of very wet rainy seasons is also liable to mean rising of runoff [21]. As contrast to 1900–1970, most of India is likely to familiarity five to twenty percent rise in yearly runoff during 2041–60[22]. However, based on precipitation data over the 1872–2005 periods, rainfall in North India barring Punjab, Haryana, West Rajasthan and Saurashtra has been found decreasing trend and increasing trend has been found in southern India[23]. However, no significant trend was found in rainfall data series of 125 stations for the period 1901-80 for major river basin in India[24]. The results of rainfall trend analysis in Iran showed that there was no evidence of climate change in the study area[25]. In country, investigation through a number of investigators revealed that during last century, rainfall is insignificant on all

India basis[26,27,28,29,30] and significant in regional basis[31,18,32,33]. It seems that the climate change impact on rainfall may not be same for different regions of India during different seasons.

### Groundwater recharge

#### Groundwater recharge through water balance method

The groundwater gaining in the basin was evaluated by the area weightage method using groundwater recharge data of each of 17 watersheds of the basin. The mean and median of the groundwater recharge for the entire river basin was observed as 170.5 mm and 143.3 mm respectively. The Mann-Kendall statistics showed that the groundwater recharge was significantly increasing for the entire basin. However, the Sen's slope statistics showed that the groundwater recharge is increasing significantly for the basin. The best fitted trend line (Fig. 5) also showed increasing trend. So, there may be much impact on groundwater recharge by water balance method due to climate change.

#### Groundwater recharge by Krishna Rao (1970) approach

The mean and median of the groundwater recharge for the entire river basin was observed as 41.5 mm, and 29 mm respectively. The Mann-Kendall and Sen's slope statistics showed that the groundwater recharge was significantly increasing for the entire basin. The best fitted trend line (Fig. 6) also showed increasing trend. Due to climate change, the groundwater recharge will increase by the tune of 8.86 mm per decade in the basin.

#### Groundwater recharge by Water level fluctuation method

The mean and median of the groundwater recharge for the entire river basin was observed as 46.4 mm, and 49.3 mm respectively. The Mann-Kendall statistics showed that the groundwater recharge was significantly increasing at 5% level. Also, the Sen's slope statistics showed that it is increasing significantly at 5% level. The best fitted trend line (Fig. 7) also showed increasing trend. Due to climate change the groundwater recharge will increase by the tune of 13.01 mm per decade for entire river basin.

However, the ground water level was estimated to decrease up to four meter for an aquifer close to Grenoble (France), creation of unfeasible practice of irrigated agriculture in the future[34].

Falls in groundwater level of up to seven meter were analyzed of the future climatic circumstances a chalk aquifer in Belgium [35,36]. For the UK, particularly in the Southern part a reduction in groundwater recharge is expected, in spite of the increased winter rainfall[37]. In the exceptional hot and arid summer of 2003, declining more than five meter groundwater levels were observed during nine months in Switzerland[38].

## CONCLUSION

The monsoon seasonal recharge was found nil or negligible up to the seasonal rainfall of less than four hundred millimeter. The climate change impacts on rainfall favors to increase the rainfall significantly in six watersheds while the runoff is increasing significantly in five out of seventeen watersheds of the basin. The areal mean depth of monsoon runoff is significantly increasing for entire Shetrunji river basin due to influence of climatic change. The groundwater recharge expected by water balance method differed widely from that of by rest of the two methods. The reason was computation of water balance component on daily basis. Also, the observed data on recharge from harvesting structures / reservoirs and rivers are not available. The data on aquifer properties as well as water table fluctuation are not adequate for each sub watershed of the basin for estimation of groundwater recharge by the water level variation method. Therefore, it is suggested to estimate the groundwater balance components using models like SWAT and MODFLOW for such studies.

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