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ORIGINAL ARTICLE

Long-term trend analysis of water-level response to rainfall of Gulbarga watershed, Karnataka, India, in basaltic terrain: hydrogeological environmental appraisal in arid region

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Abstract
Hydrogeological environment of an area includes surface and subsurface water resources. Groundwater is continuously getting recharged by surface water sources and rainfall. Recharge and discharge of an area can be reflected by water-table rise and drawdown. Water table of an area represents the groundwater strategy in the formation and majorly depends on the amount of precipitation. An attempt is carried out to analyze the correlation between rainfall and water table in arid climatic condition within the Gulbarga watershed, Karnataka, India. Rainfall and water-table data were collected from Department of Mines and Geology, Government of Karnataka, which consists of information from 2001 to 2011. Month-wise data are processed into distinctive four seasonal data, namely winter, summer, monsoon and post-monsoon. The rainfall data are analyzed, and accordingly they have been classified as good year and bad year depending upon the amount of precipitation. The study focuses on the need of rainwater harvesting and artificial recharge structures to improve groundwater resource sustainability for future generation.

Keywords Rainfall analysis · Good/bad year · Water-table analysis · Correlation

Introduction

Watershed is an area of land enclosed within ridges from which water drains to a particular point along a stream. Each watershed can be classified into three regions, (1) runoff, (2) recharge and (3) storage, depends on rainfall infiltration. Usually, the watershed with large runoff region has low groundwater levels, where a watershed with large storage region will have good groundwater levels (Bharathkumar and Mohammed-Aslam 2015). Karnataka State in India ranks second, next to Rajasthan in drought condition (Jayasree and Venkatesh 2015). Rainwater gained its importance with the emerging need and to meet the demands of water resources. Overexploitation of groundwater resource collectively results in declining water levels in most part of the country (Dhakate et al. 2013). Aquifer characterization will be the starting point for groundwater management and decision-making (Ahmed 2009; Mohammed-Aslam and Balasubramanian 2010; Mohammed-Aslam et al. 2010). Groundwater is affected by climate change through various hydrological processes. The trends in climate variables were seen reflected in groundwater trends (Okkonen and Kløve 2010). Groundwater resource of a region is one of the building blocks for balanced economic development of the area (Raghavendra 2013). The availability of groundwater in the terrain is based on the presence and pervasiveness of secondary permeability in the forms of fractures and/or weathered zones and the degree of connectivity of these structures (Yidana et al. 2014). The water table represents the groundwater reservoir, and changes in its level represent the changes in groundwater storage (Raghavendra 2013). The rise in the water table indicates the condition when the recharge exceeds discharge, whereas fall in water table indicates the situation when the discharge exceeds recharge (Seeyan et al. 2014). Water resources are extremely limited but renewable, exhibiting diversity in their quality and quantity (Moon et al. 2004). One of the major solutions to meet ever-increasing water demands would be storing the

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available rainwater through rainwater harvesting techniques (Jothiprakash and Sathe 2009). The studies of seasonal groundwater table fluctuations are important in understanding the development and management of existing sub-watershed system. Variations of rainfall and groundwater table depth are closely related as rainfall is the primary source of recharge to aquifers. The timing and quantity of recharge reaching the water table has significant consequences for water resources and for the movement of pollutants into groundwater (Lee et al. 2006). Direct surface recharge is very important in recent decades to manage water resource effectively (Rahimi et al. 2014). However, the correlation may sometimes be imperfect because of the differences in rainfall intensity and distribution that produce different amounts of recharge for the same amount of rainfall (Jasmin et al. 2010). The aim of the research is to analyze groundwater level data of past 11 years to correlate with rainfall distribution. An attempt is carried here to analyze the long-term fluctuation in water-level response to rainfall, for understanding the hydrogeological setup of an arid environment.

Study area

Detailed study has been conducted in Gulbarga watershed that lies in Gulbarga Taluk of Karnataka as shown in Fig. 1. The study area covers an area of about 225.54 sq kms and covers major part of Gulbarga City and southern part of adjoining villages up to Saradagi Dam. The major lithology comprises Deccan trap basaltic formation. Surface water and groundwater conditions are in safe zone, and the area needs proper management to sustainably utilize the resource. The climatic condition is arid zone, and the major source of groundwater is from rainfall recharge. The southwestern monsoon occurs from June to September and constitutes about 70% of the rainfall. The normal rainfall is about 777 mm. The streams originate from north of the study area and reaches Saradagi Dam. The water table varies from 4.7 to 11.54 meters below ground level. The study area is drained by the fifth-order stream, which is connected to Saradagi Dam.

Methodology

Groundwater recharge is an important and required necessary activity in managing and developing water resource of a watershed. Rainfall is the major source of groundwater recharge. The infiltration of water is mainly governed by lithology, land use practice and elevation of the terrain. Spatial maps were prepared using ArcGIS 10.1 and Erdas Imagine 9.3 to analyze the factors controlling infiltration rate and surface runoff phenomenon.

Month-wise data of water table and rainfall were collected from Department of Mines and Geology, Government of Karnataka. Excel spreadsheets were used for the data analysis. The seasonal water-level fluctuations in Gulbarga watershed have been analyzed. Rainfall data are one of the important dataset in spatial domain, controlling the water resources budget of the region. Rainfall data of last 11 years were collected from Department of Mines and Geology. Good year and bad year analysis was conducted to analyze the effect of groundwater recharge. Good year and bad year were calculated based on the above and below values of average rainfall (Peiris 1989). The methodology for discriminating the good year and bad year is illustrated in Eq. 1.

The formula for good year and bad year analysis is as follows:

$$A = (\text{Maximum rainfall} - \text{Minimum rainfall}) / 2. \quad (1)$$

If yearly average rainfall $> A$, the year is good year
If yearly average rainfall $< A$, the year is bad year

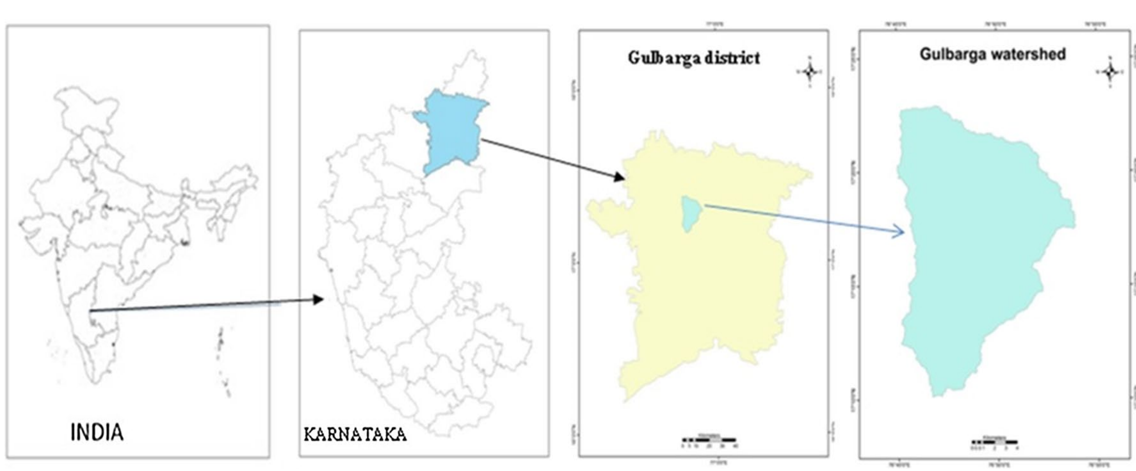

Fig. 1 Study area map

Water-level data were collected from Department of Mines and Geology. The data consist of groundwater levels of observatory wells from Gulbarga watershed for 11 years from 2001 to 2011. The observatory well characteristics are mentioned in Table 1. The data are processed to seasonal fluctuation by considering winter (January to February), summer (March, April and May), monsoon (June, July, August and September) and post-monsoon (October, November and December) seasons.

In order to find the controlling factors with respect to the water-table behavior and pattern, correlation has been attempted with the seasonal changes of rainfall. Correlation is the relation between dependence of one variable with respect to another. The correlation value ranges from + 1 to − 1, where + 1 is indicative of high positive correlation and − 1 is indicative of the low negative correlation. Zero values are indicative of the non-dependency of the parameters. Rainfall and water-table correlation were analyzed to show the dependency between two parameters.

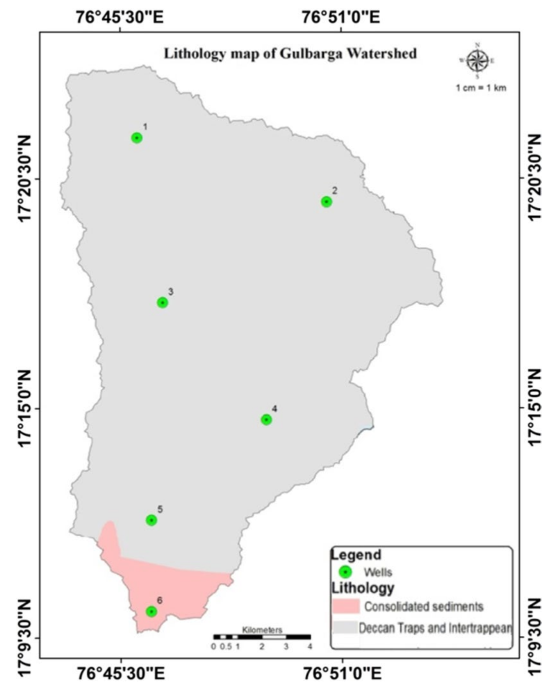

Fig. 2 Lithology map of Gulbarga watershed

Results and discussion

The lithology of this area comprises basalt and limestone formations as shown in Fig. 2. Basalt usually has low-to-medium permeability that depends on the presence of primary and secondary porosity. Fractured basalt serves as good groundwater storage in Deccan trap formations. Limestone is another variety of rock present in the study area, which is sedimentary formation with high groundwater yielding property. Since limestone is having solution cavities, significant changes in permeability for short distances are expected in this terrain.

Remote sensing and GIS applications provide an excellent platform to analyze watershed management and development through prioritization studies (Bharathkumar and Mohammed-Aslam 2016). Land use–land cover map was prepared by supervised classification in ERDAS Imagine 9.3 as shown in Fig. 3. Landsat 8, acquired on December 6, 2015, was used to prepare land use–land cover map.

Land use–land cover diversity directly influences the recharge condition and surface runoff processes. The map and statistics of the LULC classes are shown in Fig. 3 and Table 2, respectively. Land cover allows greater infiltration to groundwater; conversely, land use restricts the infiltration of groundwater to subsurface. The greater part is covered by 12,929.29 hectares of fallow land, and least part is covered by 69.66 hectares of surface waterbody.

Cartosat DEM data are used for terrain elevation analysis as shown in Fig. 4. The elevation of the watershed ranges from 300 meters to 470 meters above mean sea level. Water level follows the elevation of the terrain. Lower elevation is toward southern part of watershed which acts as catchment zone, and higher elevation is toward northern part of watershed which acts as runoff zone.

The rainfall data are analyzed to get seasonal rainfall fluctuations. Based on the precipitated amount of rainfall, good year or bad year classification was carried out to analyze the hydrological environment of successive years (Khadeeja 2015; Peiris 1989). Hydrogeologically, the greater intensity

Table 1 Observatory well characteristics

Serial number	Well number	Latitude	Longitude	Well type	Geology	Well use
1	OW1	17°26′45″	76°53′45″	Dug well	Basalt	Public supply
2	OW2	17°10′45″	76°47′45″	Dug well	Limestone	Public supply
3	OW3	17°07′24″	76°38′00″	Dug well	Basalt	Public supply
4	OW4	17°24′09″	76°43′30″	Bore well	Basalt	Monitoring
5	OW5	17°21′00″	76°44′00″	Bore well	Basalt	Monitoring
6	OW6	17°18′10″	76°54′48″	Bore well	Basalt	Public supply

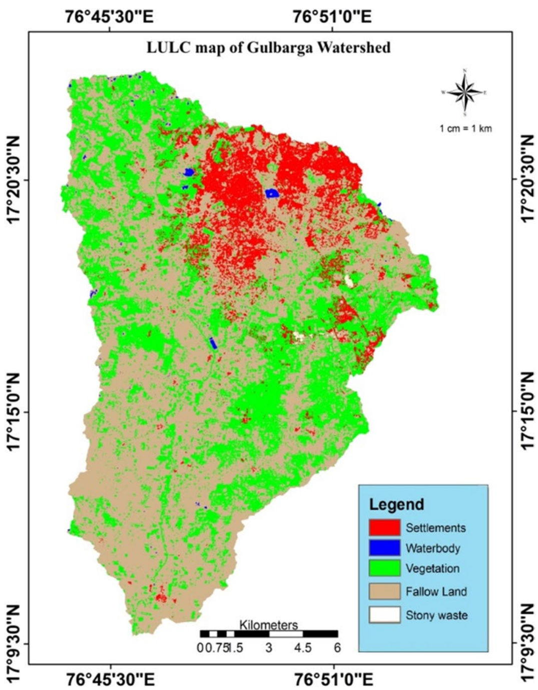

Fig. 3 Land use–land cover map

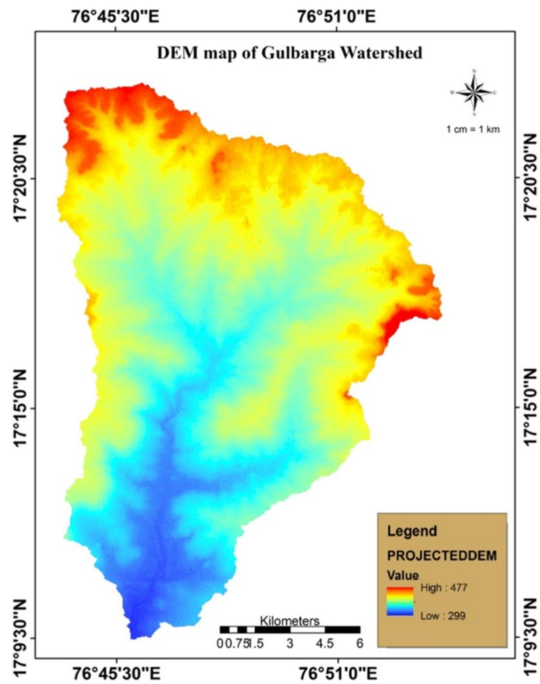

Fig. 4 Digital elevation model map

Table 2 Area of LULC classes

Class	Area in hectares	Area in percentage
Settlements	2455.329	10.85
Water	69.66	0.30
Vegetation	6916.84	30.59
Stony waste	238.95	1.05
Fallow land	12,929.29	57.18

of infiltration due to higher amounts of rainfall is expected in good year, whereas such conditions do not prevail during the bad year causing the poor infiltration. Therefore, the occurrence of water table bears a direct relation with respect to the depth from ground level. During the good year, since the rainfall amount is high, water table is confined to shallow depth. Bad year is a year with poor rainfall and deeper groundwater level. The water-level monitoring data were found to match clearly with the data of season-wise average rainfall of good year and bad year as shown in Table 3 and Fig. 5.

The lowest average rainfall recorded in the year 2002 was 29.08 mm. The highest average of rainfall recorded in the year 2001 was 56.49 mm. The yearly average rainfall is found to be 42.78 mm/year. The rainfall values above average were considered as good year, and those of below average were considered as bad year. The analysis clearly showed that the 2002, 2003 and 2011 years having less rainfall were considered as bad years. There was an acute shortage of water resource and faced severe drought during those years. The remaining years were good years and have a rainfall greater than the mean value during the assessment period in this study.

Seasonal rainfall and water-table analysis

The obtained monthly rainfall and water-table data were scaled down to seasonal datasets and analyzed with correlation coefficients to determine the dependency between the parameters. The analyzed seasonal statistics of rainfall and water table are represented in Tables 4, 5, 6 and 7 and Figs. 6, 7, 8 and 9.

Correlation analysis

The analysis clearly illustrated that both negative and positive correlations exist between rainfall and water table as shown in Table 8. The highest positive correlation was recorded up to 0.552, and the highest negative correlation was recorded up to −0.677. Lower value of water level represents shallow water-table condition. Hence, negative correlation indicates shallow water level with respect to higher amount of rainfall and positive correlation indicates deeper water level with respect to lower amount of rainfall.

Table 3 Season-wise average rainfall and good year/bad year categories

Year	Winter rainfall (mm)	Summer rainfall (mm)	Monsoon rainfall (mm)	Post-monsoon rainfall (mm)	Yearly average (mm)	Good/bad year
2001	0.344	0.324	201	24.33	56.49	Good year
2002	0.305	0.433	113.275	2.329	29.08	Bad year
2003	0.068	1.382	119.625	13	33.51	Bad year
2004	0.48	41.33	117.025	34.833	48.41	Good year
2005	0.52	14.666	141.2	30.333	46.67	Good year
2006	0.3	52.333	112.625	14.233	44.87	Good year
2007	0.28	45.215	149.4	27.5333	55.60	Good year
2008	0.25	31.3	115.975	29.166	44.17	Good year
2009	0.65	16.466	132	32.966	45.52	Good year
2010	0.5	6.3	128.122	42.458	44.34	Good year
2011	0.45	10.45	112.547	29.365	38.20	Bad year

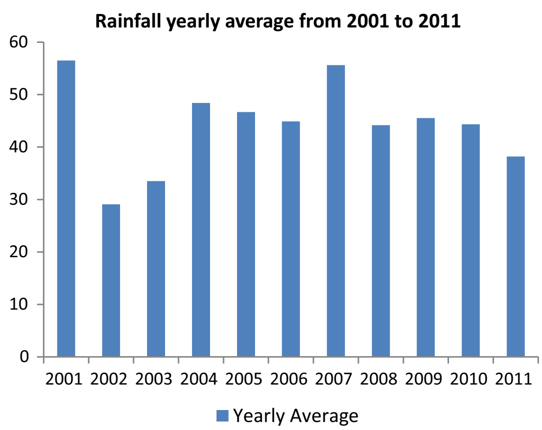

Fig. 5 Column chart representing average rainfall from 2001 to 2011

Negative correlation indicates higher dependency and positive relationships between the parameters.

Hence, locations which are having higher negative correlations are good in respect of water resources management. Higher correlation is recorded during the monsoon season as the rainfall plays an important role in groundwater recharge during the season. Post-monsoon season is the next dependency season followed by monsoon. The results clearly illustrate the dependency of water table on rainfall recharge. It states that proper rainwater harvesting is the only solution to manage water resource in an effective manner.

Conclusion

The economy of an area depends mainly on the available water resources. Recently, it has been found that much emphasis has been given on conserving water resources. Water table of an area is an important available identity to study aquifer and groundwater changes in the formation. Consequently, deeper water table results in reducing soil moisture and hence reduces the crop yield which affects the economy of the nation. The drawdown of water table is indicative of the discharge of water from the aquifer, whereas raise in water table is indicative of the recharge of water to

Table 4 Winter rainfall and water-table records

Year	Rainfall	Average water levels (mbgl) from observatory wells (maintained by DMG)					
		OW1	OW2	OW3	OW4	OW5	OW6
2001	0.344	3.2	5.6	6.65	1.93	9.05	3.28
2002	0.305	2.78	5.88	4.96	1.63	9.14	2.83
2003	0.068	3.6	10.28	9.39	3.2	10.63	5.18
2004	0.48	4.85	9.95	13.38	3.58	11.88	5.1
2005	0.52	4.9	13	12.33	2.88	11.58	6.15
2006	0.3	3.03	6.55	7.5	2.73	11.2	5.8
2007	0.28	3.38	13.05	6.23	1.83	11.35	6.78
2008	0.25	3.23	7	6.95	3.7	8.98	5.45
2009	0.65	3.7	6.23	6.25	1.9	7.2	6.8
2010	0.5	3.58	6.88	6.63	2.23	6.51	7.2
2011	0.45	3.45	8.05	4.13	4.4	9.63	9.2

Table 5 Summer rainfall and water-table records

Year	Rainfall	Water levels (mbgl) of observatory wells (maintained by DMG)					
		OW1	OW2	OW3	OW4	OW5	OW6
2001	0.324	4.15	9.3	8.1	3.2	10.63	3.63
2002	0.433	4.03	10.63	9.72	3.45	11.37	4.58
2003	1.382	5.35	12.35	10.95	3.83	11.05	6.32
2004	41.33	6.22	13.43	14.52	4.27	13.57	6.35
2005	14.666	5.25	14.32	13.35	4.53	12.93	6.78
2006	52.333	3.92	10.12	7.82	5.83	12.57	7.2
2007	45.215	4.18	13.85	6.83	2.4	12.2	5.9
2008	31.3	3.22	7.32	7.05	1.4	10.85	7.98
2009	16.466	4.15	7	7.07	2.37	7.82	8.4
2010	6.3	4.28	7.35	7.22	2.489	6.9	7.6
2011	10.45	4.15	11.93	5.88	4.73	9.58	8.6

Table 6 Monsoon rainfall and water-table records

Year	Rainfall	Water levels (mbgl) of observatory wells (maintained by DMG)					
		OW1	OW2	OW3	OW4	OW5	OW6
2001	201	4.58	11.83	8.74	2.46	10.53	3.39
2002	113.275	4.62	10.23	11.76	2.41	10.31	5.1
2003	119.625	5.41	10.45	13.25	3.88	10.71	6.54
2004	117.025	6.45	14.82	14.98	4.5	14.3	6.75
2005	141.2	4.3	10	11.73	4.73	13.7	5.4
2006	112.625	3.26	12.45	6.7	2.75	10.4	6.4
2007	149.4	3.06	6.79	6.54	2.08	10.3	6.48
2008	115.975	4.45	7.18	6.95	2	11.05	5.897
2009	132	4.34	7.61	7.79	2.69	7.8	7.54
2010	128.122	3.6	6.54	6.43	3.05	6.49	5.98
2011	112.547	4.3	12.4	7.4	4.7	10.54	6.45

Table 7 Post-monsoon rainfall and water-table records

Year	Rainfall	Water levels (mbgl) of observatory wells (maintained by DMG)					
		OW1	OW2	OW3	OW4	OW5	OW6
2001	24.33	2.43	4.5	4.69	1.02	8.93	1.39
2002	2.329	3.1	8.37	9.03	0.93	9.47	4.28
2003	13	4.13	9.03	11.62	1.97	10.03	4.67
2004	34.833	4.72	12.38	11.7	1.73	10.33	5.65
2005	30.333	2.42	5.7	11.04	1.18	6.6	5.64
2006	14.233	2.86	9.8	5.52	1.3	10.08	6.45
2007	27.5333	2.4	6.13	6.3	1.6	7.72	7.65
2008	29.166	4.13	5.32	5.8	1.48	10.5	7.58
2009	32.966	3.15	6.3	5.98	1.68	5.23	8.45
2010	42.458	3.2	5.6	4.32	2.07	8.02	9.45
2011	29.365	4.5	11.3	6.9	2.57	11.25	8.45

the aquifer. The depth of occurrence of water table mainly depends on precipitation, whereas precipitation in turn to some extent is controlled by the vegetation (Raghavendra and Mohammed Aslam 2016). The correlation analysis showed that the maximum probability of positive correlation was found between rainfall and water table. This analysis is helpful in focusing the research for better groundwater resource management by proper way of recharging methods in hard rock terrain. The hydrological environment should be preserved safely by recharge awareness and recharge

Fig. 6 Line chart representing winter rainfall and water-table trends

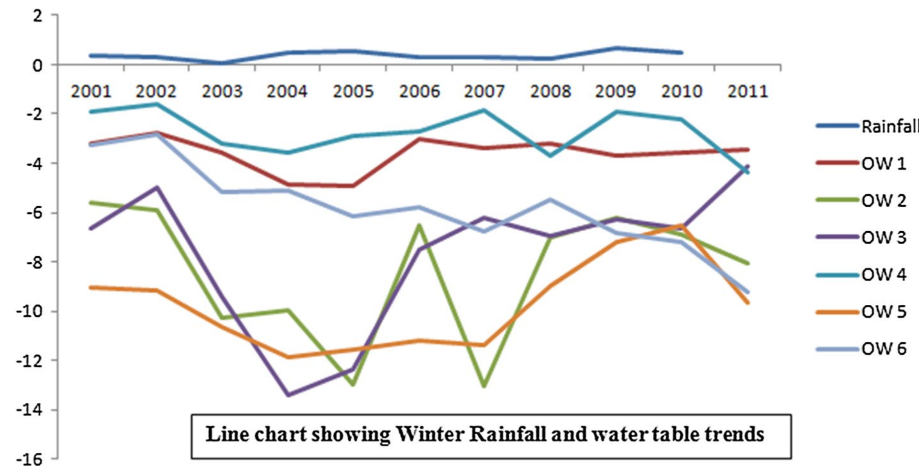

Fig. 7 Line chart representing summer rainfall and water-table trends

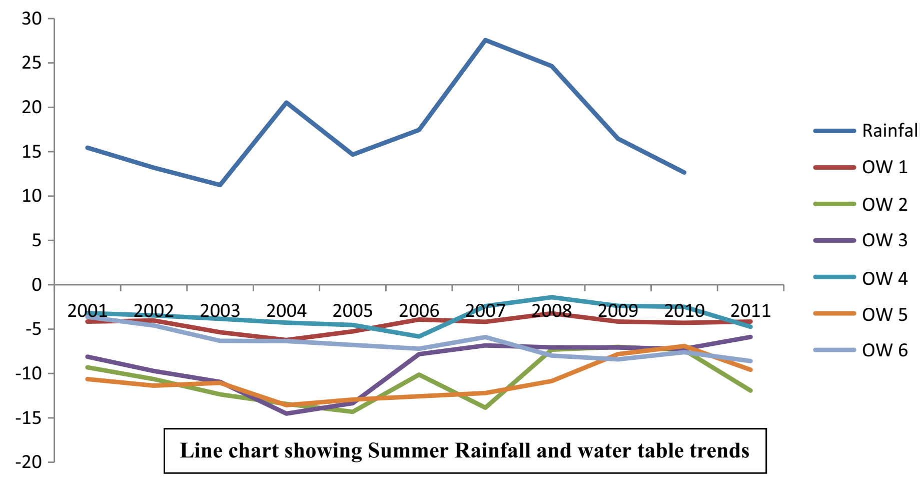

Fig. 8 Line chart representing monsoon rainfall and water-table trends

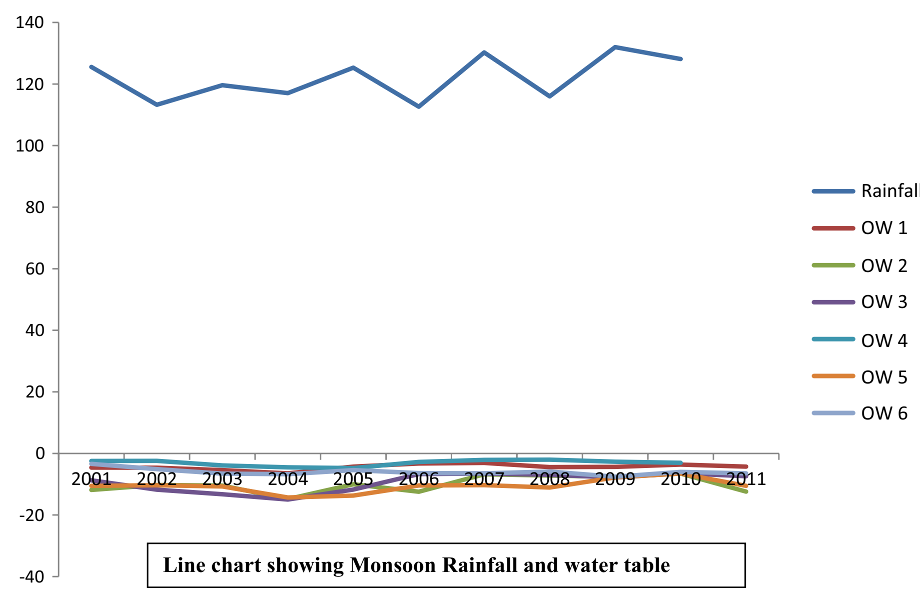

Fig. 9 Line chart representing post-monsoon rainfall and water-table trends

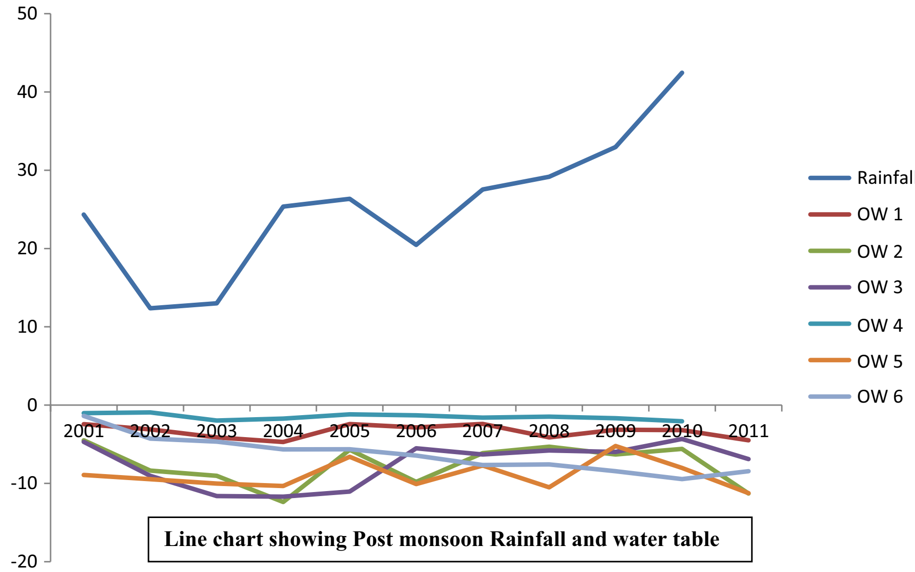

Table 8 Correlation between rainfall and water-table records

Seasonal rainfall (mm)	Water levels (mbgl) of observatory wells (maintained by DMG)					
	OW1	OW2	OW3	OW4	OW5	OW6
Winter	−0.096	0.090	−0.090	−0.347	0.387	0.468
Summer	0.205	0.015	0.167	0.510	0.252	−0.005
Monsoon	−0.065	−0.134	−0.254	−0.034	−0.677	−0.131
Post-monsoon	−0.205	−0.254	0.466	−0.323	0.552	0.125

structures. Proper utilization of water resource is an important step in conserving the water resource.

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