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Groundwater Recharge Estimation Using Empirical Methods and Water Table Fluctuation: A Case Study of Chanal and Hirehalla Watershed, Gadag District, Karnataka, India

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Abstract:
One of the most precious natural resources is groundwater, which promotes ecological diversity, human health, and economic growth. For the sustainable management of groundwater resources, knowledge about groundwater recharge is crucial. Natural ground water recharge is the total volume of water that will eventually reach the water table. The rate and length of the rainfall, the conditions at the upper boundary afterward, the antecedent soil moisture conditions, the depth of the water table, and the type of soil all affect how much recharge occurs. In hydrology and hydrogeology, evaluating groundwater recharge from precipitation is a key component. Using empirical methods and the water table fluctuation method, an attempt was made in this paper to estimate groundwater recharge in the Chanal and Hirehalla watershed, Gadag District, Karnataka. Data on rainfall were gathered for the years 2000 to 2020. The findings demonstrated that, for the study area, the average groundwater recharge of six empirical methods and the water table fluctuation method varied by 5.22 to 196.33 mm annually and 4.62 to 103.07 mcm/yr, respectively. It is discovered that comparing different approaches is helpful in identifying the range of conceivable recharge rates as well as highlighting the estimates' uncertainty.

Introduction:
Because of the current rate of urbanisation, economic development, and climatic variability, surface water resources are not able to keep up with the increasing demand for water. Approximately 22% of the estimated 37 Mkm3 of freshwater on Earth is groundwater, making up approximately 97% of all liquid freshwater that is potentially suitable for human use (Foster, 1998). As a result, groundwater is utilised as a substitute source of food production, water supply, and economic growth. Because groundwater is so inexpensive and of such high quality, it is favoured for many applications. The rate of overuse and depletion of groundwater, in conjunction with the effects of climate change and growing population pressure, will make it difficult to use the resource sustainably for future generations The rate of natural replenishment has not kept up with the water withdrawals. One explanation for this might be land degradation. By 2050, 95% of Earth's land areas could be degraded if the current trend of degradation continues (GEF 2022). As a result, the groundwater levels drop. The sustainability of groundwater

extraction depends on groundwater recharge. Still, some of the rainfall that helps replenish the reservoir is insufficient. Water is a limited and delicate resource that needs to be used wisely and sustainably for the benefit of current and future generations. This is a well-known fact.

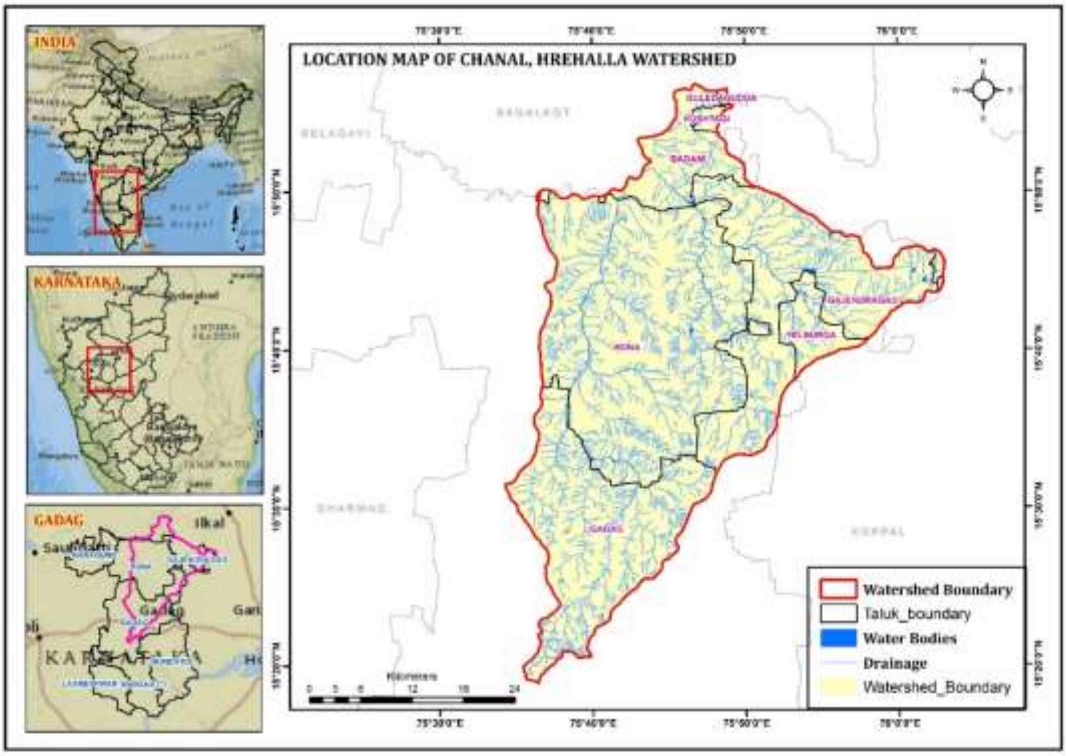
It is said correctly that groundwater will serve as a long-term barometer of the water and land management acumen of this generation. There are temporal and spatial variations in the recharge rate. The topography, land use, vegetation cover, soil moisture content, and the recharge beds' and aquifer's capacity to store and transfer water are some of the factors that affect groundwater recharge (Bureau of Rural Science, 2007). Concerns that changes in land use may decrease recharge and that certain areas' ground water resources might not be sustainable during drought periods have led to an increase in interest in quantifying recharge rate (Risser et al., 2005). The plants' evapotranspirative demand dictates recharge for a specific rainfall regime and soil moisture capacity. While there are variances in the water requirements of various crops, the main distinction is between crops and pasture and trees and woody shrubs.

Materials and Methodology:

Study Area:

Chanal and Hirehalla are the principal feeders of the Malaprabha river, which originates in the districts of Gadag, Koppala, and Bagalkot and joins the Malaprabha in the Badami Taluk of the Bagalkot Region. About 89% of the Chanal and Hirehalla watershed region is contained in the Gadag region, with the remaining 4% and 7% of the watershed being in the areas of Bagalkote and Koppala. Between latitudes 15°18'51.96"N and 15°56'40.44"N and longitudes 75°35'51.66"E and 76° 3'13.58"E, the Chanal and Hirehalla watershed is located. The watershed's catchment area is 1518 square kilometres. While Chanal Halla flows east-west and joins the Malaprabha river in Badami Taluk, Bagalkot District, Karnataka, Hirehalla flows south-north. **Figure 1** shows the area of the Hirehalla and Chanal watershed.

Figure 1: Location Map of the Study area.



Methods of recharge estimation:

Groundwater recharge of the study area was estimated using two methods viz., (1) Empirical methods and (2) Water table fluctuation method.

Groundwater Recharge Estimation using Empirical Methods:

Rainfall has a major impact on groundwater recharge. The most widely used techniques for estimating natural groundwater recharge are empirical ones that were created for Indian scenarios. Groundwater balance and fluctuation methods are two additional techniques. Using the rainfall-recharge relationship, which has been studied for 20 years, empirical relationships have been developed for estimating natural recharge from rainfall. **Table 1** displays some of these empirical relationships for various hydrogeological scenarios under Indian conditions, and **Tables 2 and 3** display the results.

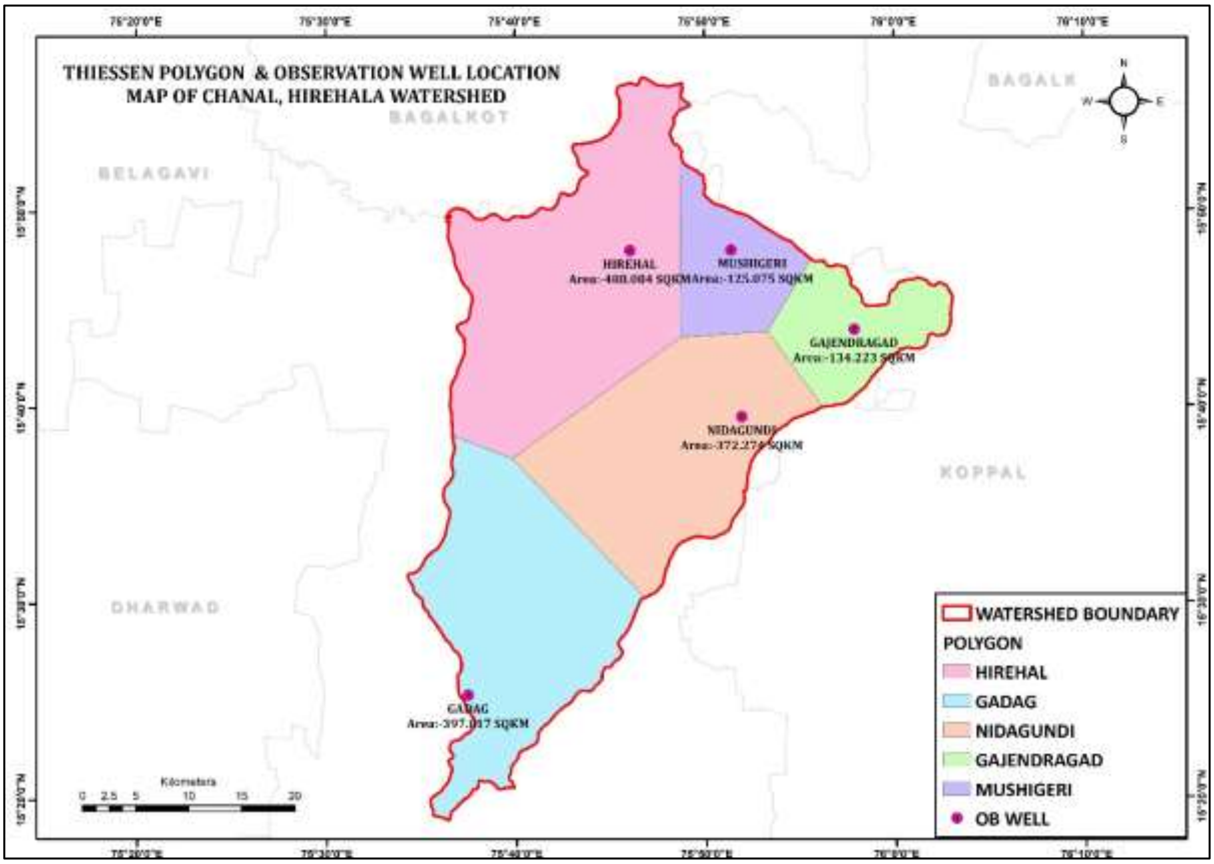
Table 1: Various Empirical methods for Indian scenarios

Sr. No	Empirical methods	Equations	Definition of Parameter, and coefficient value range
1	Chaturvedhi formula(1936)	$R_g = 2(P-15)^{0.4}$	Where R_g-GroundwaterRecharge P- Annual precipitation in Inches
2	UP Irrigation Research Institute Formula (UPRI) (1954)	$R_g = 1.35(P-14)^{0.5}$	Where R_g-GroundwaterRecharge P- Annual precipitation in Inches
3	Bhattacharjee Formula(1954)	$R_g = 3.47(P-38)^{0.4}$	Where R_g-GroundwaterRecharge P- Annual precipitation in cm
4	Krishna Rao Formula (1970)	$R_g = K(P-X)$	Where, K is constant P is the annual precipitation in mm X is number of point rainfall
		The following formulae is applied to different climaticconditions of Karnataka	
		$R_g = 0.20(P-400)$	Areas with annual rainfall between 400-600mm
		$R_g = 0.25(P-400)$	Areas with annual rainfall between 600-1000mm
		$R_g = 0.35(P-600)$	Areas with annual rainfall above 2000mm
5	Sehgal Formula (1973)	$R_g = 2.5(P-16)^{0.5}$	Where R_g-Groundwater Recharge P- Annual precipitation in Inches
6	Kumar & Seethapathi Formula (2002)	$R_g=0.63(P-15.28)^{0.76}$	Where R_g-GroundwaterRecharge P- Annual precipitation in Inches

Estimation of recharge by water table fluctuation method:

The water table fluctuation method was used to estimate groundwater recharge. The most popular technique for estimating recharge is water level fluctuation. A thorough method for calculating groundwater recharge using changes in groundwater levels was provided by Healy and Cook (2002). The groundwater fluctuation approach was suggested by the Groundwater Estimation Committee in 2002 for estimating groundwater recharge. Unlike other approaches where assumptions must be made for most of the components, the method is more scientific and considers the response of groundwater level fluctuation and specific yield, which are more realistic and directly measurable. Monthly groundwater levels (BGL) of observation wells in the study area were obtained from the District Ground Water Office for five open wells between 2000 and 2020 in order to compute recharge using the water table fluctuation method, as illustrated in **Figure 2**. The formula for estimating groundwater recharge was Rg = Aw*΄AL*Sy (7). Where ΄L is the water table difference (m), Sy is the specific yield, Aw is the watershed area (m2), and Rg is the groundwater recharge. Based on data from the literature, a constant specific yield (Sy) of 3.0% was determined.

Figure 2: Thiessen polygon & observation well location map of the study area.



Results and Discussion:

Groundwater recharge by using empirical formula:

Using six empirical methods, the long-term monthly rainfall data of the study area spanning 21 years, from 2000 to 2020, is used to estimate the groundwater recharge. Rainfall has a major impact on groundwater recharge. The most widely used techniques for estimating natural groundwater recharge are empirical ones that were created for Indian scenarios **(Table 1).** Groundwater balance and fluctuation methods are two more techniques. Using rainfall-recharge relationships that have been studied for many years, empirical relationships have been developed for estimating natural recharge from rainfall. This

section addresses some of these empirical relationships for various hydrogeological scenarios under Indian conditions; the results are shown in **Tables 2, 3, and Figure 3.**
While Chaturvedi and Bhattacharjee methods showed good matches to the average value of all six estimations, UPIRI and Kumar & Seethapathi methods showed minor variations from Chaturvedi and Bhattacharjee methods, the Krishna Rao method estimates the smallest values of the six empirical approaches, and the Sehagal method overestimates the recharge value in the study area. When interpreting the recharge estimates, this is taken into account: high recharge occurs during periods of high rainfall, and low recharge occurs during periods of low rainfall. Figure 4 shows the compression of annual rainfall with the average recharge value.

Table 2: Annual recharge calculation by using empirical methods (in mm).

Year	Average Annual Rainfall in mm	Chaturvedi	UPIRI	Bhattacharjee	Krishna Rao	Sehgal	Kumar & Seethapathi	Average of all
2000	808.75	157.18	144.83	156.03	102.19	252.73	135.10	158.01
2001	561.85	111.39	97.71	110.72	32.37	157.09	69.00	96.38
2002	483.85	88.88	77.05	88.49	16.77	110.88	43.87	70.99
2003	396.1	41.26	43.30	41.98	-0.78	0.00	6.64	22.07
2004	593.6	118.84	104.96	118.08	38.72	172.39	78.38	105.23
2005	727.25	144.44	131.16	143.41	81.81	225.69	114.71	140.20
2006	518.6	99.86	86.86	99.32	23.72	133.46	55.51	83.12
2007	902.75	170.18	159.15	168.91	125.69	280.71	157.49	177.02
2008	845	162.38	150.52	161.18	111.25	263.87	143.87	165.51
2009	1005.1	182.82	173.40	181.43	151.28	308.29	180.76	196.33
2010	987.5	180.74	171.03	179.37	146.88	303.73	176.83	193.10
2011	518.42	99.80	86.82	99.27	23.68	133.35	55.45	83.06
2012	492	91.63	79.46	91.20	18.40	116.57	46.68	73.99

2013	658.98	132.29	118.51	131.39	64.75	200.24	96.69	123.98
2014	743.3	147.08	133.97	146.03	85.83	231.26	118.81	143.83
2015	478.34	86.95	75.38	86.58	15.67	106.87	41.93	68.90
2016	376.76	0.00	31.30	0.00	0.00	0.00	0.00	5.22
2017	519.2	100.03	87.02	99.49	23.84	133.82	55.70	83.32
2018	449.98	75.76	66.10	75.56	10.00	83.18	31.48	57.01
2019	690.52	138.10	124.51	137.14	72.63	212.38	105.14	131.65
2020	783.5	153.40	140.74	152.29	95.88	244.67	128.90	152.65

Table 3: Annual recharge calculation by using empirical methods (in %).

Year	Average Annual Rainfall in mm	Chaturvedi	UPIRI	Bhattacharjee	Krishna Rao	Sehgal	Kumar & Seethapathi	Average of all
2000	808.75	19.44	17.91	19.29	12.64	31.25	16.71	19.54
2001	561.85	19.83	17.39	19.71	5.76	27.96	12.28	17.15
2002	483.85	18.37	15.92	18.29	3.47	22.92	9.07	14.67
2003	396.1	10.42	10.93	10.60	-0.20	0.00	1.68	5.57
2004	593.6	20.02	17.68	19.89	6.52	29.04	13.20	17.73
2005	727.25	19.86	18.04	19.72	11.25	31.03	15.77	19.28
2006	518.6	19.26	16.75	19.15	4.57	25.73	10.70	16.03
2007	902.75	18.85	17.63	18.71	13.92	31.09	17.45	19.61
2008	845	19.22	17.81	19.07	13.17	31.23	17.03	19.59
2009	1005.1	18.19	17.25	18.05	15.05	30.67	17.98	19.53
2010	987.5	18.30	17.32	18.16	14.87	30.76	17.91	19.55
2011	518.42	19.25	16.75	19.15	4.57	25.72	10.70	16.02
2012	492	18.62	16.15	18.54	3.74	23.69	9.49	15.04
2013	658.98	20.08	17.98	19.94	9.83	30.39	14.67	18.81
2014	743.3	19.79	18.02	19.65	11.55	31.11	15.98	19.35
2015	478.34	18.18	15.76	18.10	3.28	22.34	8.77	14.40
2016	376.76	0.00	8.31	0.00	0.00	0.00	0.00	1.38
2017	519.2	19.27	16.76	19.16	4.59	25.77	10.73	16.05
2018	449.98	16.84	14.69	16.79	2.22	18.48	7.00	12.67

2019	690.52	20.00	18.03	19.86	10.52	30.76	15.23	19.07
2020	783.5	19.58	17.96	19.44	12.24	31.23	16.45	19.48

Figure 3: Plot showing comparison of Groundwater recharge estimated by various empirical methods (in mm)

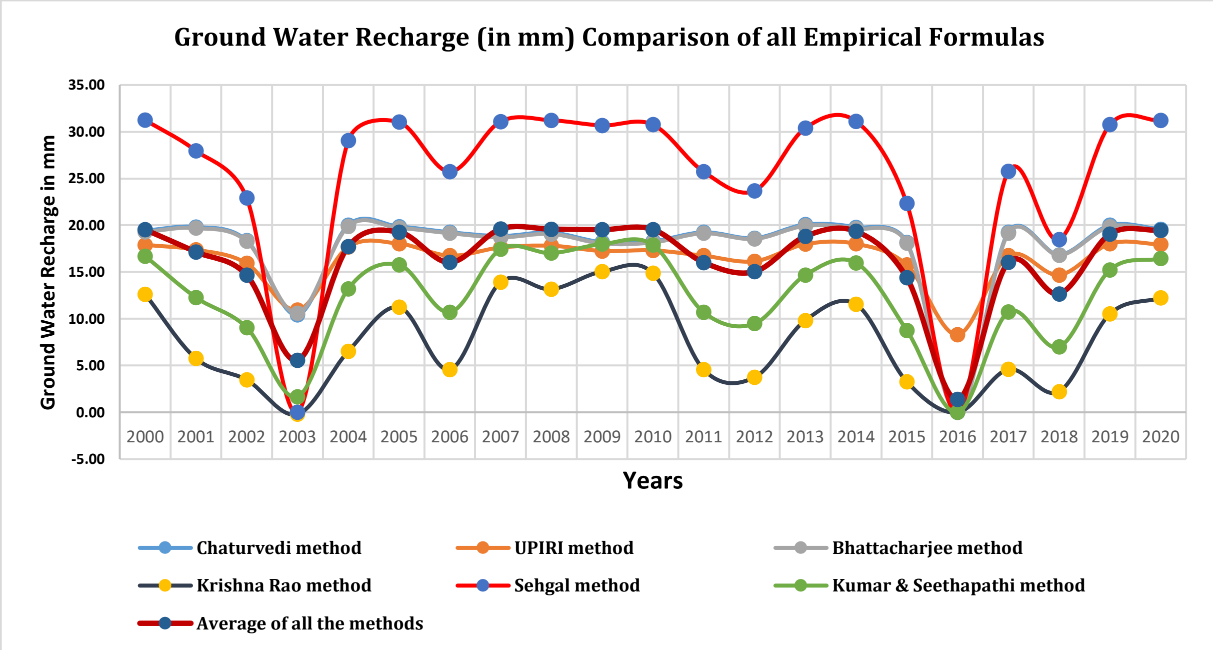
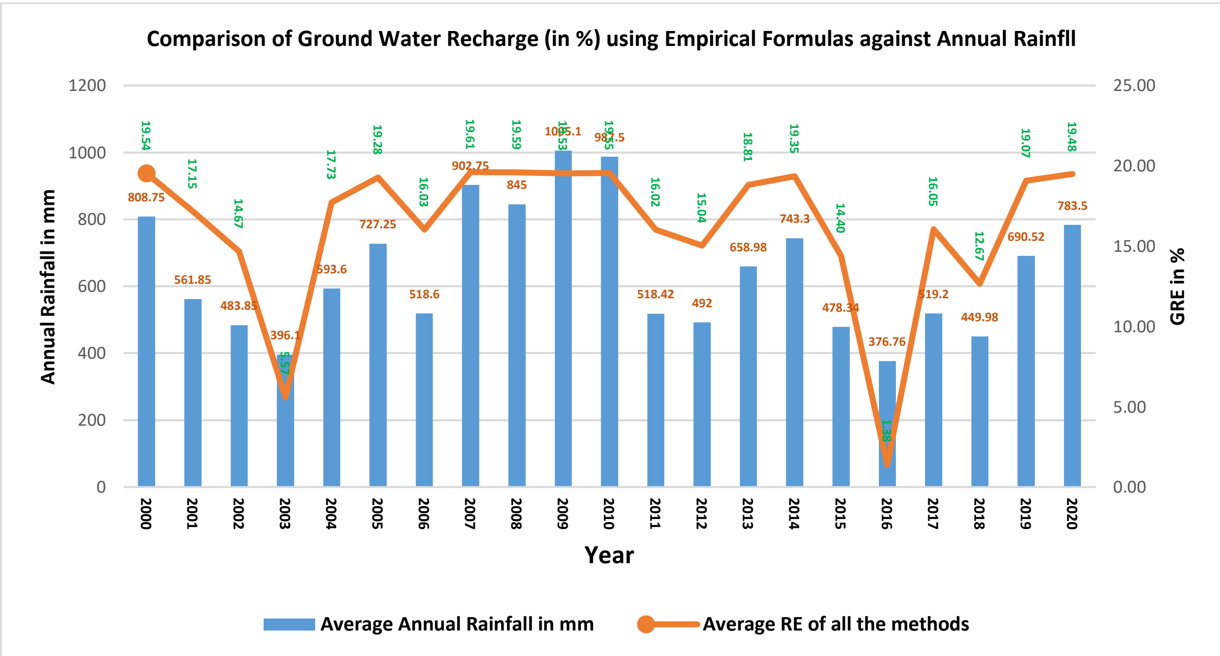


Figure 4: Plot showing comparison of Groundwater recharge estimated by various empirical methods against average annual rainfall.



Estimation of recharge by water table fluctuation method:

Monthly groundwater levels (BGL) of observation wells in the study area were obtained from the District Ground Water Office for five open wells between 2000 and 2020. The area was then divided into five zones using the Thiessen polygon method, as illustrated in **Figure 2**, in order to compute recharge using the water table fluctuation method. Based on the recommendations of the GEC of GOI, 2002, a value of 3.0% was assumed for the specific yield of the aquifer in the study area (a hard rock area). **Table 4** displays the annual rise in groundwater level, which was calculated based on the rise of the water table for each rainfall event.

Using **Equation 7**, the average annual recharge for wells over the 2000–2020 period was calculated in order to estimate spatial variability in recharge using the water table fluctuation method. According to Table 4's results, recharge rates can range from **4.62 to 103.07 mcm/yr**, with some years having negative values. Recharge rates are typically higher in years with maximum rainfall and lower in years with minimum rainfall.

Table: 4: Estimation of groundwater recharge by water table fluctuation method for the period of 2000-2020

Year	Annual Rainfall in mm	Hirehalla		Gadag		Nidagundi		Gajendragad		Mushigeri		Average GWR in MCM
		Difference in Ground Water Level (in Mts)	GWR in MCM	Difference in Ground Water Level (in Mts)	GWR in MCM	Difference in Ground Water Level (in Mts)	GWR in MCM	Difference in Ground Water Level (in Mts)	GWR in MCM	Difference in Ground Water Level (in Mts)	GWR in MCM	
2000	808.75	0.37	5.37	-2.93	-34.92	-0.25	-2.79	-1.86	-7.48	-1.09	-4.07	**-8.78**
2001	561.85	0.83	12.20	2.10	25.02	-1.79	-19.99	3.45	13.89	2.56	9.61	**8.15**
2002	483.85	0.28	4.03	-1.76	-21.05	1.06	11.84	1.16	4.68	-0.07	-0.25	**-0.15**
2003	396.1	0.18	2.68	1.63	19.49	-1.25	-13.96	-2.43	-9.80	-2.17	-8.13	**-1.94**
2004	593.6	0.56	8.20	-1.02	-12.13	3.50	39.09	0.55	2.21	0.43	1.63	**7.80**
2005	727.25	2.95	43.20	4.86	58.00	4.05	45.23	2.85	11.48	1.37	5.13	**32.61**
2006	518.6	-2.98	-43.68	0.65	7.76	-3.48	-38.81	-2.35	-9.46	-4.82	-18.07	**-20.45**

2007	902.75	4.02	161.31	9.11	108.76	12.19	136.18	12.44	50.09	15.72	59.00	**103.07**
2008	845	-2.00	-29.28	-0.55	-6.56	-3.95	-44.08	-2.17	-8.75	-2.24	-8.39	**-19.41**
2009	1005.1	2.24	32.80	2.92	34.85	1.25	13.96	7.34	29.57	3.47	13.03	**24.84**
2010	987.5	0.74	10.80	2.05	24.47	0.60	6.70	3.72	14.97	2.75	10.32	**13.45**
2011	518.42	0.67	9.76	0.55	6.56	-3.62	-40.39	-1.48	-5.97	0.64	82.23	**10.44**
2012	492	-0.43	-6.35	-1.07	-12.73	1.00	11.17	0.05	0.20	-1.08	-139.13	**-29.37**
2013	658.98	-1.18	-17.33	-4.87	-58.08	1.43	16.01	-0.67	-2.68	-2.60	-9.76	**-14.37**
2014	743.3	0.86	12.59	1.95	23.23	0.17	1.86	3.28	13.22	2.70	10.14	**12.21**
2015	478.34	3.37	49.34	-0.69	-8.27	4.55	50.81	-1.02	-4.09	-6.00	-22.51	**13.06**
2016	376.76	0.20	2.93	2.04	24.39	1.23	13.70	-0.56	-2.25	-4.18	-15.67	**4.62**
2017	519.2	1.11	16.30	4.93	58.84	4.70	52.53	-0.61	-2.44	0.92	3.45	**25.73**
2018	449.98	-2.78	-40.75	2.59	30.87	-1.71	-19.06	-0.76	-3.07	-3.14	-11.79	**-8.76**
2019	690.52	2.53	37.09	3.72	44.36	1.37	15.26	-0.92	-3.69	7.40	27.77	**24.16**
2020	783.5	1.43	20.94	1.61	19.21	0.98	10.98	6.93	27.89	4.35	16.33	**19.07**

Conclusions

From the above study, it is noticed that the groundwater occurs in both phreatic and fractured zones. In the study area there are mainly two types of aquifers viz. (i) Weathered Granite Gneiss and, (ii). fractured Granite gneiss and, Gneiss. The main water bearing horizon is composed of fractured granite gneiss and gneisses. The depth of the bore wells is varying from 180 mbgl to 240 mbgl. Depth of weathered zone (Aquifer-I) ranges from 10 to 20 m bgl. The second layer occupies below 80 m. Groundwater recharge mainly depends on rainfall contribution, however in some of the locations, it is found that there is recharge from artificial recharge structures constructed for the conservation of surface water. Number of Check dams and percolation ponds are found in various parts of the study area. Water level fluctuation (water level difference between pre-monsoon and post-monsoon) varied from 0.18m and 4.02 m. It is also observed that apart from the lithological variation, structural features also showed significant control over the groundwater flow and availability. This could be attributed to its strong influence on the topography and on the surface water bodies including drainage patterns. The morphology of structural or residual hills are controlled by large-scale rock structures and lithology. Geomorphological conditions such as inselberg, pediment, buried sediment, and valley fill showed the complex nature of hydrogeological nature in the Gadag district. Joints, fractures, shear zones, faults and other contacts etc. However, structurally the area displays shears, joints, faults, lineaments which appear to be moderate in the intensity of development. Therefore, there are wide variations in the ground water level fluctuations. A set of infiltration experiments in the study based on soil, land use and hydrogeological conditions indicated significant variation in infiltration and soil hydrological characteristics which influenced the negative values in recharge. Such observations need to be further examined using various field and laboratory studies.

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