

Groundwater Quality Assessment Using Active Monitoring and GIS Technologies: A Case Study of Zirabad Reservoir Area, Madhya Pradesh, India.

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Abstract:

Across rural India, daily life and the local economy depend entirely on groundwater—whether it is needed for household chores, farming, industry, or keeping local ecosystems alive. But around the Zirabad Reservoir, the landscape is shifting. Because farming practices are intensifying and land usage is transforming so fast, the actual quality of this subsurface water is now a major concern.

To see what is really happening chemically, our approach combined physical field tracking with lab tests and GIS mapping. We didn't just look at one source type. Right before the monsoons hit in 2021–2022, fifty water samples were collected directly from a mix of borewells and traditional dug wells spread across the entire study area.

While doing this fieldwork, logging the fluctuating water quality parameters became our primary focus. We dropped sensors into key observation wells scattered around Zirabad to keep a close eye on everything from pH and electrical conductivity (EC) to TDS. We also tracked the specific ion concentrations Ca^{2+} , K^+ , Na^+ , Mg^{2+} , and Cl^- , SO_4^{2-} , CO_3^{2-} , Fe , NO_3^- .

Once we pulled all that raw chemical data, we brought it straight into a GIS platform. Doing this we could easily spot exactly where the pollution hotspots were hiding. From there, we put together a Groundwater Quality Index. The point of this index is straightforward. It tells us exactly which zones contain safe drinking water, and which zones are only good enough to water crops or supply industrial sites.

What the maps exposed was pretty clear. We found distinct pockets of localized contamination tying directly back to heavy fertilizer runoff and poor waste management right next to the farming zones. Mapping things out visually made interpreting these results much easier, which helps a lot when planning targeted interventions.

The bottom line is that merging spatial maps with active tracking actually works. If applied correctly, this exact setup could become the standard framework for managing groundwater sustainably in other rural pockets of Madhya Pradesh.

Keywords: Groundwater quality, assessment, reservoir, active monitoring, GIS.

Introduction:

Water doesn't just sit there—it actively shapes the earth's surface. When rain falls or snow melts, it doesn't all wash away. A huge chunk of it infiltrates the soil, moving downward under the pull of gravity to accumulate as groundwater. In central India, where surface water routinely falls short, this hidden reserve is an absolute lifeline. People need it to drink, to wash, and to keep local development moving forward.

If someone look beneath the crust, groundwater isn't an underground river. It's the water locked deeply inside rock fractures, sedimentary pore spaces, and geological cracks. It makes up the largest pool of accessible freshwater we actually have, acting as an indispensable piece of the hydrological cycle. Without it, the domestic, industrial, and farming sectors across central India would simply collapse. And obviously, just having water isn't enough; the physical quality of that water dictates both human health and crop survival.

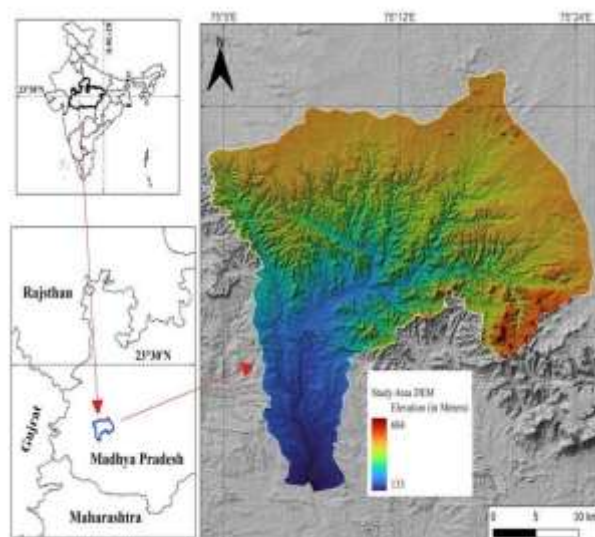
But things are changing fast in the 21st century. Right now, aggressive shifts in how we use the land, heavy-handed cultivation techniques, and sheer over-pumping are actively wrecking that subsurface water quality.

That brings us to the Zirabad Reservoir. Both the upper and lower streams of this area are feeling the squeeze from intense farming and shifting land-use patterns. Because of this mounting pressure, figuring out exactly what is happening to the groundwater is critical. So, we set up a detailed assessment to map out the spatial variability of the contaminants.

To figure out the real conditions, we didn't just rely on guesswork. Our approach leaned heavily on active sensor monitoring paired with GIS spatial analysis. We tracked the physical, chemical, and biological makeup of the water—keeping tabs on pH, EC, TDS, nitrates, along with various cations and anions. These readings came straight from sensors dropped into key observation wells all over the Zirabad area. To get a complete picture, we pinned down 50 different groundwater sample locations using exact GPS coordinates, ensuring we covered a wide spread of local sites.

Once the test center finished processing those samples, we threw the raw data directly into a geospatial environment. Doing this let us build spatial distribution maps so we could physically point out the pollution hotspots. Finally, we built a Groundwater Quality Index. It does one specific job—it categorizes exactly which zones are actually safe for human consumption and hydration, cutting through the complex data to give practical answers.

Research Area:



Map 1. Location map

The location map of current research area lies and covers 22°15' N to 22°37' N latitude and 75°06' E to 75°24' E longitude. The toposheet numbers of the present study area are as 46N/2, 46N/3, 46N/6, and 46J/14 on the Scale of 1:50,000.

Methodology:

In this investigation, a physio-chemical assessment was undertaken through the standard methodology which integrated with remote sensing and GIS. This study is based on the raw material or primary data of water Sample collected from the wells, dug wells, boreholes and streams also.

The total 50 Groundwater Samples were self-contained (collected) from the different sites to marked wells into polyethylene bottles with well-labeled in the study area. All the polyethylene bottles were suitably washed out with dug-well or borehole, stream water for avoid the contamination before collecting the main water samples in the whole study area of the Zirabad reservoir.

After that the collected water samples were subjected to analyzed in the research laboratory for the examination of both cations and anions concentration as well as the variability of different types of physio-chemical parameters in current study area. The present research work considered with cations involves Ca^{2+} , Na^+ , Mg^{2+} and K^+ .

The considered anions included Carbonate (CO_3), Sulphate (SO_4^{2-}), Cl^- , NO_3^- , HCO_3^- are analyzed in the laboratory.

A Cartosat Digital Elevation Model of the current study area is created in GIS environment which represents the surface topography of the research area derived from the Cartosat-1 stereo satellite data of 10m resolution.

The thematic base map of the current research work was generated using Sentinel-2 multispectral Satellite imagery providing a natural appearance similar to observed by the human eye in the field observation.



Map 2. Sample location map showing sampling sites.

Results:

The physio-chemical properties of the sub-surface water samples which are collected to the various sites of the present study area are summarized below (shown in Table 1).

Table 1: physico-Chemical characteristics of Groundwater samples

Parameters	Range	Mean values	WHO (2022) Standard
pH	7.3-8.3	7.6	6.5-8.5
Tem (°C)	24.5-26.8	25.8	not stated
EC (μS/cm)	1.0-951	517	<1500μS/cm
Total Dissolved Solids	127-993	551	≤1000(desirable)
Chloride (Cl ⁻)(mg/l)	20-453	77.66	250
Sulfate(SO ₄ ²⁻)(mg/l)	1.4-133	40.45	250-500
Nitrite(NO ₂ ⁻)(mg/l)	0.32-6.68	2.62	0.2
Bicarbonate(HCO ₃ ⁻)	0.08-0.31	0.18	not stated
Ca ²⁺	11.2-172	49.25	≤ 200
Na ⁺	0.12-0.8	0.58	200
Mg ²⁺	14.3-123	60.54	<100
K ⁺	0.01-0.06	0.03	not stated

In this study the different parameters have shows different values like temperature shows varying values between 24.5℃ to 26.8℃with the calculated average value of 25.8℃. The mean pH was 7.6, which shows the basic nature and the concentration of pH in the current research area remaining within the permissible limits of WHO standard. However, among the cations, Ca²⁺ has dominated mean value of 49.2 mg/l while among the anions Chloride (Cl⁻) shows the dominant concentration in that study area

Generally, most of the groundwater physio-chemical parameters have lower mean values with compared to WHO standard(2022), besides of NO₂⁻ has higher mean value with compared to the WHO standard guidelines 2022.

The relatively, order of abundance of cations and anions in the study area are in the following given sequence which shows the concentration ratios of the ions in the study area:

Ca≥Mg≥Na≥K = Cl≥SO₄≥NO₂≥HCO₃.

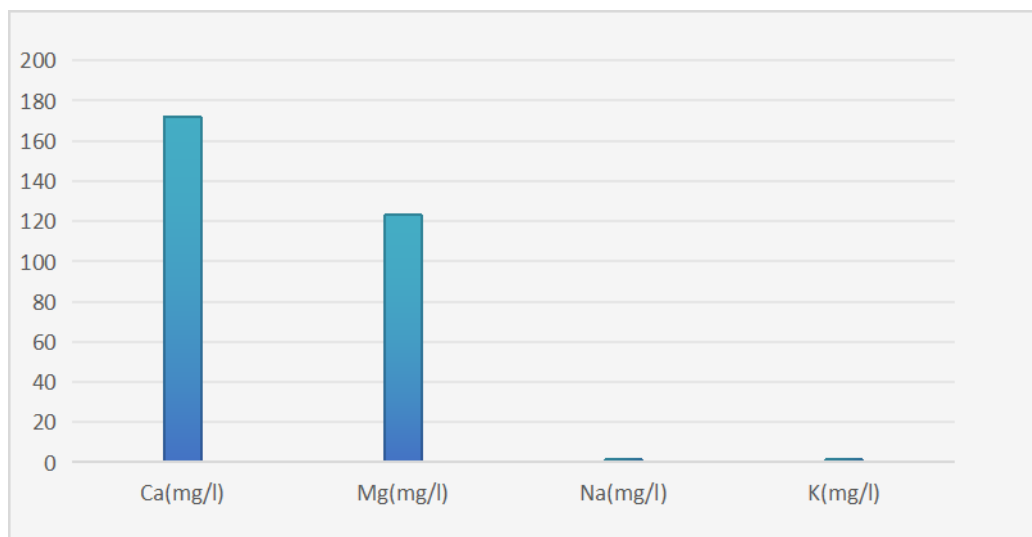


Figure 1: cations distribution

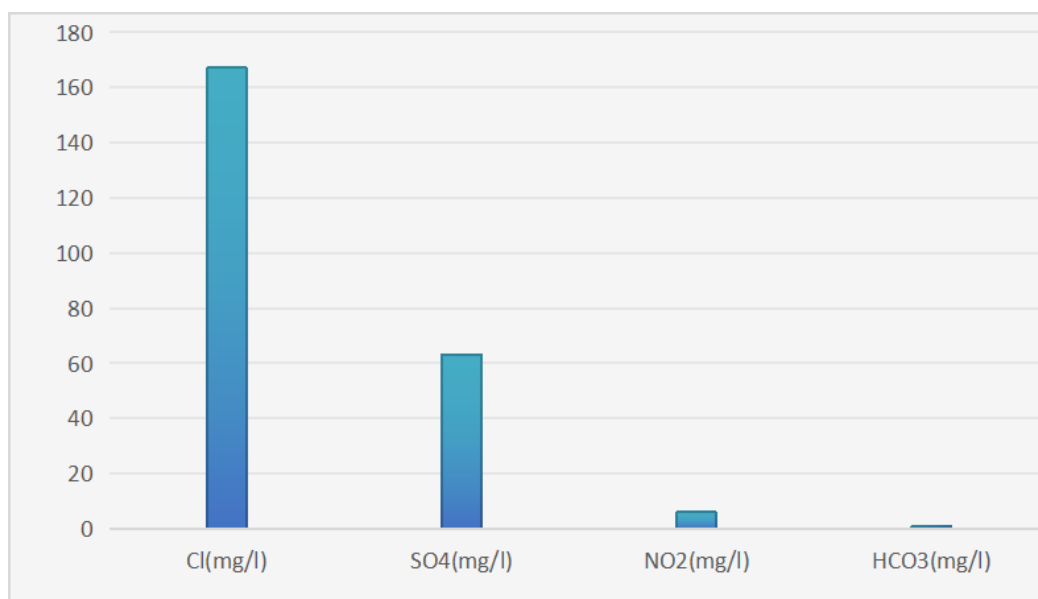


Figure 2: anions distribution

In the above figure 1 and 2 , the concentration of ions are showing with their ascending order from right to left in the given bar-diagrams. Among the concentration of cations the Calcium has highest concentration with compared to other parameters while, among the anions the highest concentration has Chloride(Cl^-) compared with the other anions in the current study.

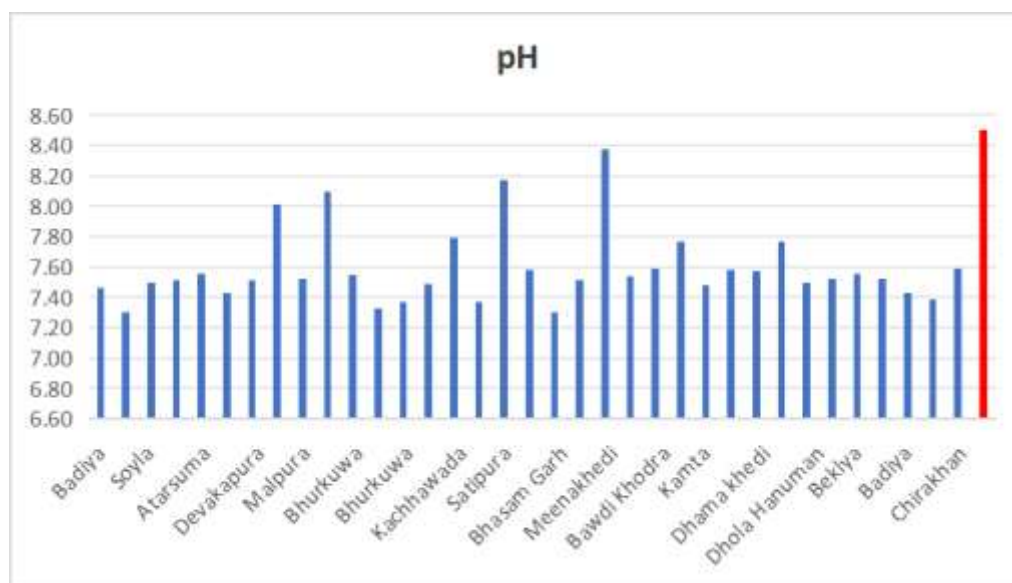


Figure 3: pH Concentration in research area.

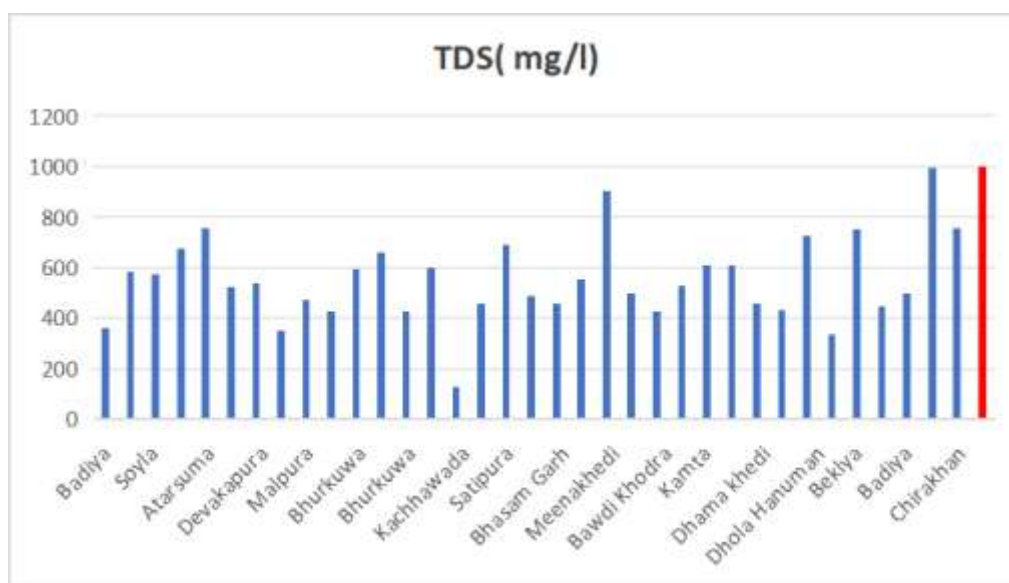


Figure 4: TDS distribution in study area.

The above fig. 3 and 4 showing the concentration of pH, TDS with the WHO standard guideline of the year 2022, indicating in the red colour values in the bar-diagrams. All the values of pH, TDS were calculated below the standard values of WHO standard guideline 2022 of this chemical parameters in the current Zirabad reservoir area.

The minimum value of pH is 7.3 in the village Karondiya patelpura and the maximum pH value analyzed in the Meenakhedi is 8.3 which is acceptable for the WHO standard guideline of year 2022.

The concentration of TDS was examined highest in the Borlai with an average value of 993mg/l while least in Kachhawada with an value of 127mg/l.

Electric conductivity(EC), significantly showing the variation across the entire study area. Electric Conductivity to be found highest at Soyla (951 μ S/cm) and lowest value at Devakapura (1.03 μ S/cm) in the Zirabad reservoir study area.

However, all the chemical concentration values do not exceed the WHO guideline 2022, also values are considered or acceptable below the values of WHO standard guideline(2022), based on the physio-chemical examinations of the groundwater samples in the Zirabad reservoir study region, suggested that no health issues were observed related to the groundwater in the present research area.

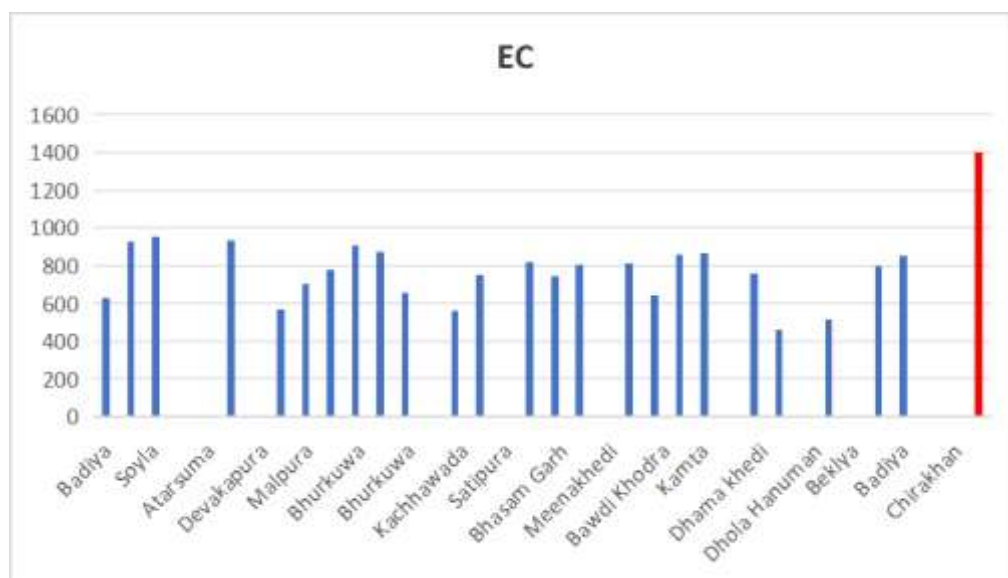


Fig. 5: Electric Conductivity

The Concentration of calcium(Ca^{2+}) and Chloride(Cl^-) were shows in the figure 5 & 6 which given below. The Concentration of Calcium(Ca^{2+}) was vary high in the village Anjnai with a value of 172mg/l and minimum value at the Satipura village with an average value of 11.22mg/l. The varied values of Calcium(Ca^{2+}) cation were acceptable because of all these are below the standard guideline values of WHO. In the Zirabad reservoir study area the resultant values of Chloride(Cl^-) was maximum at Satipura with a value of 453mg/l and minimum at the village Bawdi khodra with a minimum of 20mg/l.

In the present study area the three localities are Meenakhedi, Dhola Hanuman and Satipura which have values respectively 267,322 and 453mg/l, behave abnormal i.e. the values of Chloride(Cl^-) were higher than the value of WHO (250mg/l) standard. These abnormal values of Chloride (Cl^-) indicating the salinity in the Meenakhedi, Dhola Hanuman and Satipura villages due to leaching, anthropogenic pollution and less groundwater quality in these three villages.

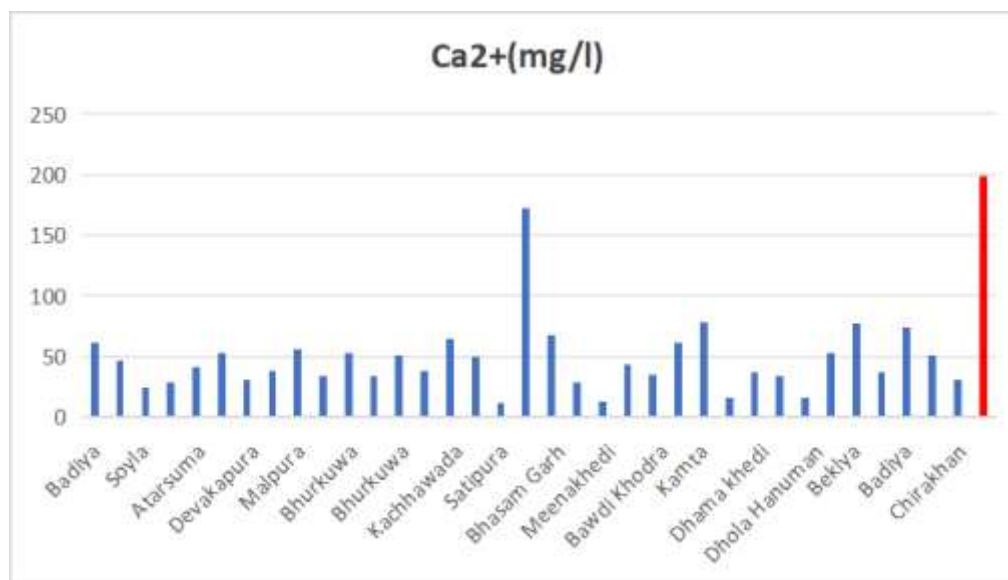


Fig. 6: Calcium distribution.

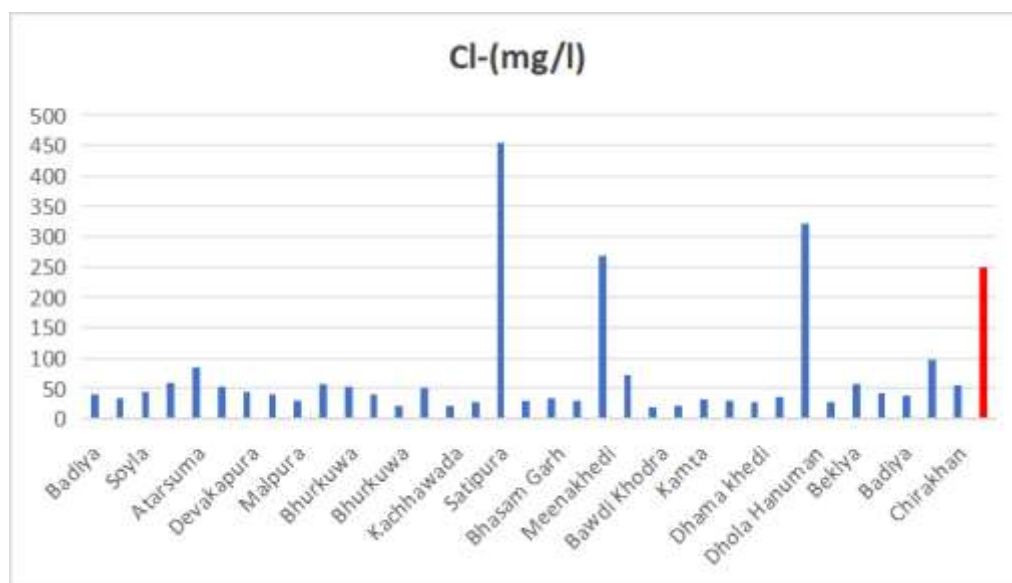


Fig. 7 Chloride distribution.

Table 2: physio- Chemical analysis of Groundwater Samples

Lat	Long	Tem(°C)	pH	EC	TDS	Cl	SO ₄ ²⁻	NO ₂
22°22'15.49	75°04'12.75	24.6	7.46	632.4	363	40	34.41	3.29
22°22'59.57	75°04'04.88	25.8	7.3	930.3	585	34	26.07	2.52
22°23'03.93	75°04'4.88	26.5	7.5	951.1	571	44	28.64	2.01
22°22'59.64	75°04'12.11	25.5	7.51	1.124	675	60	29.21	3.42
22°23'39.39	75°04.28.06	26.4	7.56	1.375	757	84	30.01	1.68
22°24'22.51	75°04'45.42	26.7	7.43	936.3	524	54	57.06	3.43
22°24'12.92	75°04'55.19	25.7	7.51	1.039	540	44	45.10	2.47
22°24'03.11	75°06'39.11	25.8	8.01	567	348	40	59.37	2.53
22°23'47.35	75°07'17.96	26.6	7.52	707.2	474	30	31.56	2.66
22°24'26.29	75°07'27.30	25.5	8.10	777.6	426	58	40.71	1.63
22°24'56.85	75°07'28.83	26.1	7.55	908.8	594	52	60.63	2.23
22°24'44.13	75°07;30.42	25.3	7.33	876.2	662	40	53.86	3.00
22°25'01.67	75°07'46.62	26.4	7.37	653.9	428	22	30.75	1.80
22°25'26.23	75°07'25.66	25.1	7.49	1.04	600	50	42.67	3.19
22°25'51.29	75°08'15.82	25.8	7.79	564.9	127	22	21.04	1.90
22°26'11.04	75°09'09.24	25.4	7.37	750.3	457	28	32.07	3.78
22°26'37.89	75°10'16.33	25.7	8.17	1.999	690	453.85	0.27	0.33
22°26'32.59	75°10'55.66	25.8	7.58	822	488	30	17.21	1.80
22°25'30.15	75°11'45.08	24.9	7.30	746.7	456	34	19.39	2.78
22°26'50.92	75°11'40.51	26	7.51	808.3	553	30	20.37	2.32
22°26'53.74	75°08'55.24	25.7	8.38	1.537	903	267.91	10.95	1.13
22°29'24.89	75°07'13.82	25.9	7.54	812.8	497	72	66.93	2.01
22°30'05.93	75°07'14.16	24.5	7.59	642.7	427	20	10.13	2.77
22°26'13.46	75°04'25.70	25.8	7.77	860.1	526	22	13.68	0.62
22°27'14.38	75°03'46.33	26.3	7.48	866.3	610	32	54.78	5.83
22°27'39.25	75°02'58.34	26.1	7.58	1.092	610	30	24.98	2.02
22°29'26.18	75°02'04.05	25.7	7.57	760.1	456	28	28.05	1.72
22°30'52.57	75°01'03.78	26.1	7.77	457.5	429	36	27.04	1.67
22°30'59.84	75°00'59.87	26.3	7.50	1.561	726	322	-1.41	0.80

22°26'44.94	75°02'40.39	26.7	7.52	513.2	334	28	63.58	1.24
22°25'24.85	75°02'40.87	26.8	7.56	1.225	751	58	113.32	4.70
22°24'23.17	75°02'51.26	25.5	7.52	796.1	449	42	69.72	0.79
22°21'31.97	75°04'50.84	26.5	7.43	849.7	498	38	36.32	5.30
22°21'56.84	75°07'01.55	26.6	7.39	1.437	993	98	107.11	6.69
22°22'29.73	75°07'19.82	25.7	7.59	1.2	755	56	79.40	3.28
22°30'56.09	75°04'18.39	25.3	7.1	451.3	610	44	32.4	2.53
22°29'40.63	75°04'48.45	26	7.5	1.08	523	62	26.04	2.05
22°32'31.04	75°06'15.51	26.1	7.7	615.4	467	37	29.24	3.44
22°30'58.86	75°05'13.76	25.8	7.43	743.1	423	84	28.54	1.62
22°31'26.40	75°04'58.42	24.6	8.2	517.4	136	52	57.04	2.44
22°30'36.87	75°06'0.89	24.4	7.3	623.7	298	30	45.12	2.67
22°31'13.22	75°06'6.47	25.2	7.5	527	156	56	0.29	1.69
22°31'59.68	75°06'6.61	25.4	8.1	623.4	411	23	59.22	2.25
22°30'51.97	75°08'25.31	26.8	8.5	951.4	600	67	30.64	3.26
22°30'16.37	75°09'13.07	26.3	7.0	831.6	671	20	42.76	0.35
22°28'21.50	75°11'15.86	25.5	7.2	756.1	954	28	21.05	1.92
22°31'23.66	75°11'29.27	24.7	8.12	1.05	816	33	29.30	2.77
22°28'12.69	75°14'18.40	24.4	8.3	474.5	876	22	19.26	2.30
22°29'37.69	75°14'52.78	25.3	7.6	1.68	322	50	10.88	3.24
22°27'13.96	75°17'12.81	26.3	7.4	467.4	654	54	61.93	2.74
WHO(2022)		NS	6.5-8.5	<1500	<_1000	250	250-500	0.2

Table 2 Chemical Composition of Groundwater Samples

HCO ₃	Ca	Na	Mg	K	F	Fe	CO ₃
0.16	60.92	0.34	45.46	0.011	0.01	0.13	0.082
0.19	46.49	0.67	33.75	0.042	0.01	0.089	0.074
0.23	24.048	0.12	92.32	0.034	BDL	0.094	0.088
0.25	28.857	0.22	95.04	0.031	BDL	0.12	0.071
0.09	41.68	0.32	62.77	0.028	0.009	0.11	0.067
0.24	52.9	0.29	56.15	0.037	0.008	0.104	0.082
0.27	30.9	0.54	62.58	0.040	0.011	0.23	0.055
0.20	38.47	0.72	49.94	0.042	BDL	0.11	0.057
0.22	56.11	0.33	55.37	0.044	0.009	0.118	0.049
0.26	33.66	0.72	67.63	0.048	0.013	0.093	0.063
0.26	52.9	0.64	75.59	0.039	0.008	0.172	0.059
0.14	33.66	0.69	79.3	0.032	0.009	0.203	0.066
0.18	51.3	0.72	55.57	0.044	BDL	0.099	0.044
0.11	38.47	0.66	80.07	0.042	BDL	0.095	0.063
0.08	64.12	0.61	40.07	0.027	0.01	0.16	0.053
0.22	49.69	0.58	62.76	0.025	0.001	0.107	0.021
0.26	11.22	0.69	14.76	0.036	0.009	0.109	0.047
0.31	172	0.58	40.82	0.039	0.001	0.076	0.033
0.15	67.3	0.73	55.57	0.031	BDL	0.103	0.072
0.16	28.8	0.55	69.78	0.042	0.008	0.111	0.046
0.19	12.82	0.7	14.38	0.046	0.009	0.168	0.081
0.17	43.28	0.72	62.38	0.039	0.009	0.094	0.027
0.18	35.27	0.68	62.38	0.045	0.011	0.106	0.049

0.11	60.92	0.64	67.81	0.063	BDL	0.183	0.063
0.13	78.55	0.49	53.81	0.034	BDL	0.165	0.028
0.11	16.03	0.77	103.02	0.041	0.012	0.157	0.019
0.17	36.87	0.8	50.33	0.033	0.01	0.136	0.057
0.15	33.66	0.47	36.53	0.01	BDL	0.095	0.073
0.22	16.032	0.59	15.54	0.023	BDL	0.094	0.052
0.15	52.9	0.63	41.57	0.01	0.009	0.091	0.061
0.19	36.87	0.74	63.94	0.025	BDL	0.135	0.052
0.23	73.74	0.68	53.03	0.031	0.008	0.138	0.039
0.21	51.3	0.77	123.61	0.038	BDL	0.127	0.054
0.19	30.46	0.78	66.47	0.037	BDL	0.116	0.060
0.18	60.92	0.24	55.54	0.041	0.01	0.16	0.062
0.09	46.3	0.7	80.05	0.032	0.009	0.091	0.084
0.21	28.91	0.56	44.5	0.018	BDL	0.014	0.071
0.26	152	0.78	34.7	0.043	0.01	0.19	0.067
0.20	30.9	0.8	52.8	0.026	0.008	0.16	0.049
0.14	56.12	0.52	51.7	0.036	0.011	0.123	0.053
0.28	133.6	0.32	38.51	0.044	BDL	0.23	0.046
0.17	51.4	0.46	55.67	0.023	0.01	0.105	0.068
0.08	162.5	0.88	51.24	0.046	0.012	0.109	0.078
0.22	48.88	0.76	69.7	0.039	0.008	0.084	0.033
0.15	53.74	0.52	14.67	0.027	0.01	0.121	0.048
0.12	49.72	0.67	79.5	0.061	BDL	0.157	0.064
0.19	24.8	0.72	75.42	0.057	0.008	0.097	0.037
0.23	53.6	0.82	54.97	0.033	0.004	0.065	0.067
0.23	26.82	0.44	92.04	0.028	0.01	0.156	0.024
0.18	28.56	0.56	33.57	0.067	0.012	0.126	0.087
NS	<200	200	<100	NS	1.5	0.3	NS

Conclusion:

In the current study active monitoring techniques and GIS were used to analyzed the groundwater physio-chemical properties in the Zirabad reservoir area have been visualized in Arc GIS environment. The 3D representation of groundwater parameters like pH,TDS, EC,Chloride, calcium etc were mapped using interpolation methods to find out the special alterations of all the groundwater variables in the Zirabad reservoir study area. It is analyzed that Dugwells and Borewells were varied with depth in different localities of the Zirabad reservoir study area.

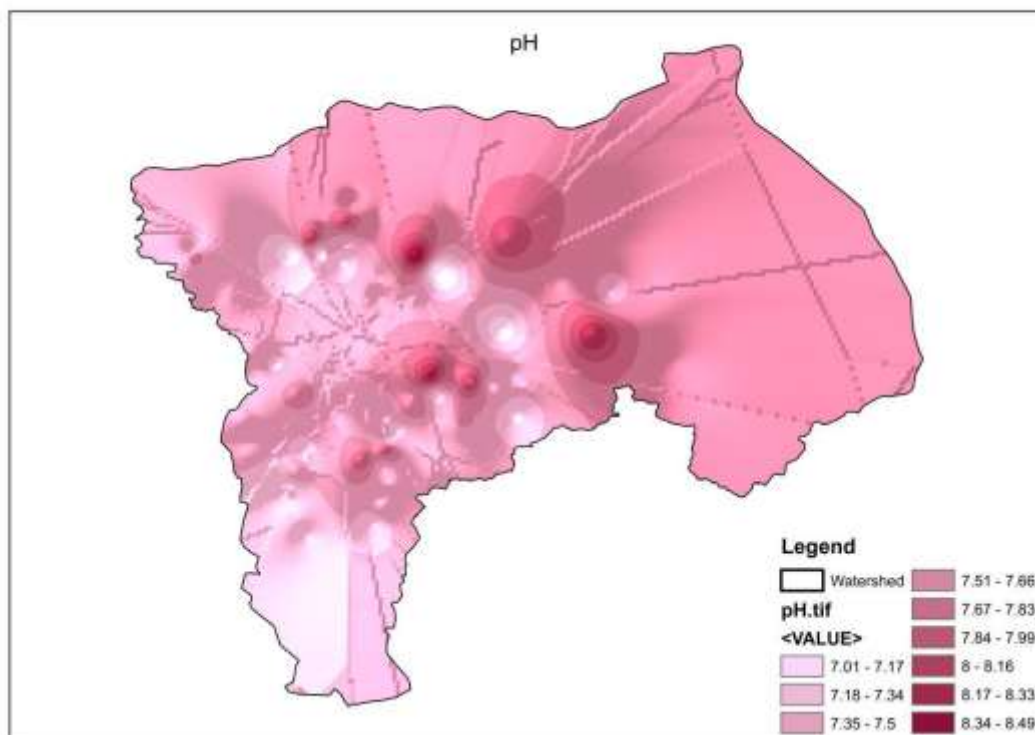
These different variables shows variations in their concentration in groundwater, shown which observed in maps are given below; The 3D map of pH shows the spatial distribution of its variation across the Zirabad reservoir watershed which illustrated different hydro-geochemical variations associated with the depth of dugwell. The lower pH values 7.0-7.5 found in the southern and southwestern parts indicates shallow depth dugwells which are effected by surface recharge while, in the central and eastern parts the higher values pH zones have highest enriched values which instance the attenuated water-rock interactions as well as deepest effects of aquifer in the study area. However, the range 7.0-8.5 demonstrate the overall alkaline conditions in the watershed area.

The TDS 3D map demonstrates varied qualities in the groundwater across all over the watershed area. In the Zirabad reservoir study area, TDS values ranging from 130-990mg/l, classified it into seven zones. The values ranging between 130-417mg/l has light shaded which indicate good quality of the groundwater, while Central and southeastern areas shows elevated TDS, which reflecting intense rock-water interaction i.e. contamination of the watershed area.

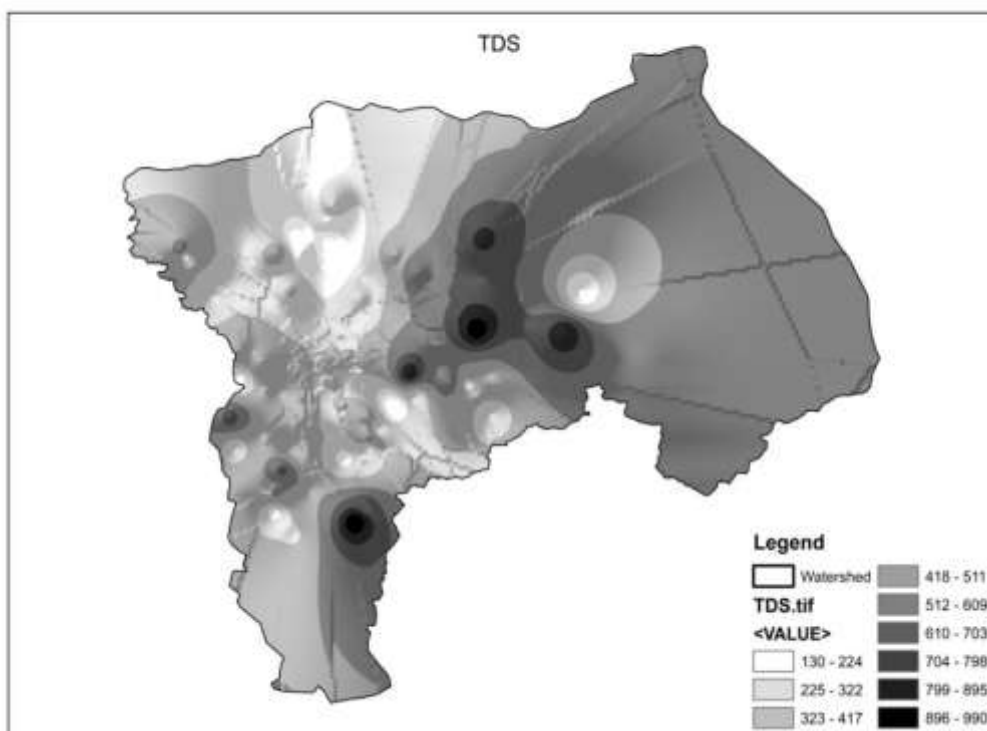
The thematic Chloride concentration variability map illustrates variation of its concentration across the watershed area. On the based of raster-interpolation techniques the Cl⁻ is classified into multiple ranges from 20.3-441 mg/l, characterized among low(green) to high(pink). In the central,southern, northwestern parts Chloride has low concentration values which is 20.3-114mg/l, suggest minimum human-induced effects with natural rechargeable circumstances.

The value above 302mg/l considered as high concentration showing the noticeable hot-spots in central and northwestern regions, the peak level 396-441mg/l indicating the contamination from agriculture, domestic lithological characteristics.

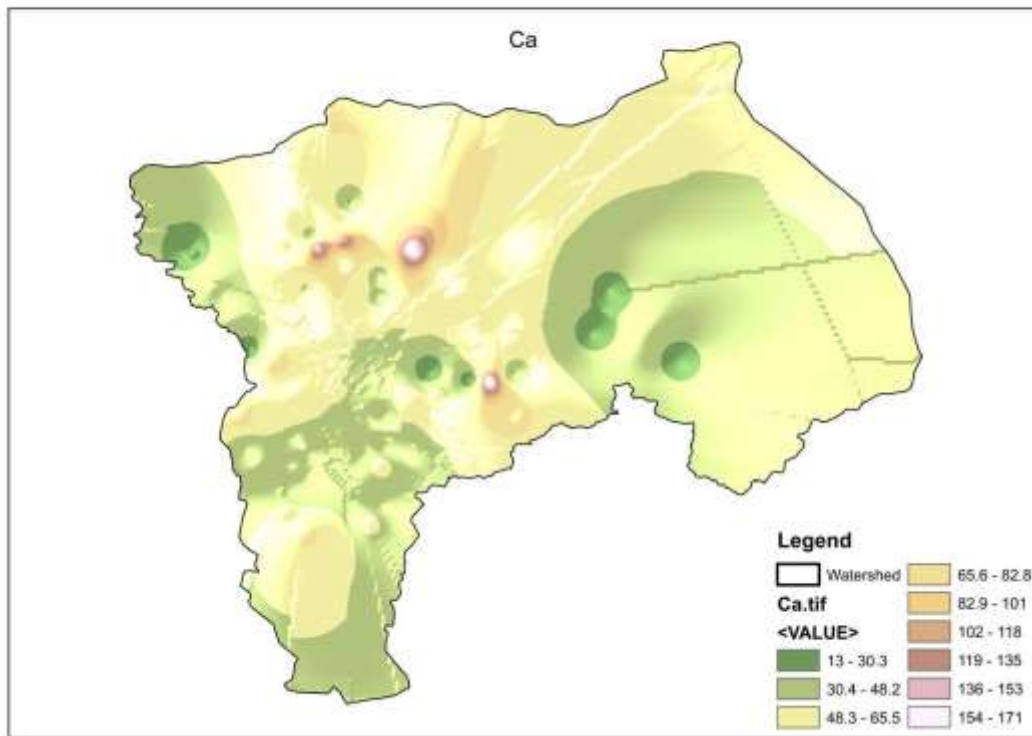
The spatial separation map of Calcium(Ca^{2+}) exemplify the variability of groundwater hardness across the watershed. The concentration values are ranging from 13-171mg/l, classified into seven zones with a colour gradients from low(green) to high(pink). In the western and southern regions the value range between 13-48.3mg/l, signifying defeated dominated recharge areas with limited mineral partition. The embellishment is distributed unequally with elevated areas which is coincidence for discharge region and water-rock interaction zones. The presence of highly concentrated values includes potential assistance of limestone, dolomite with filtering procedure.



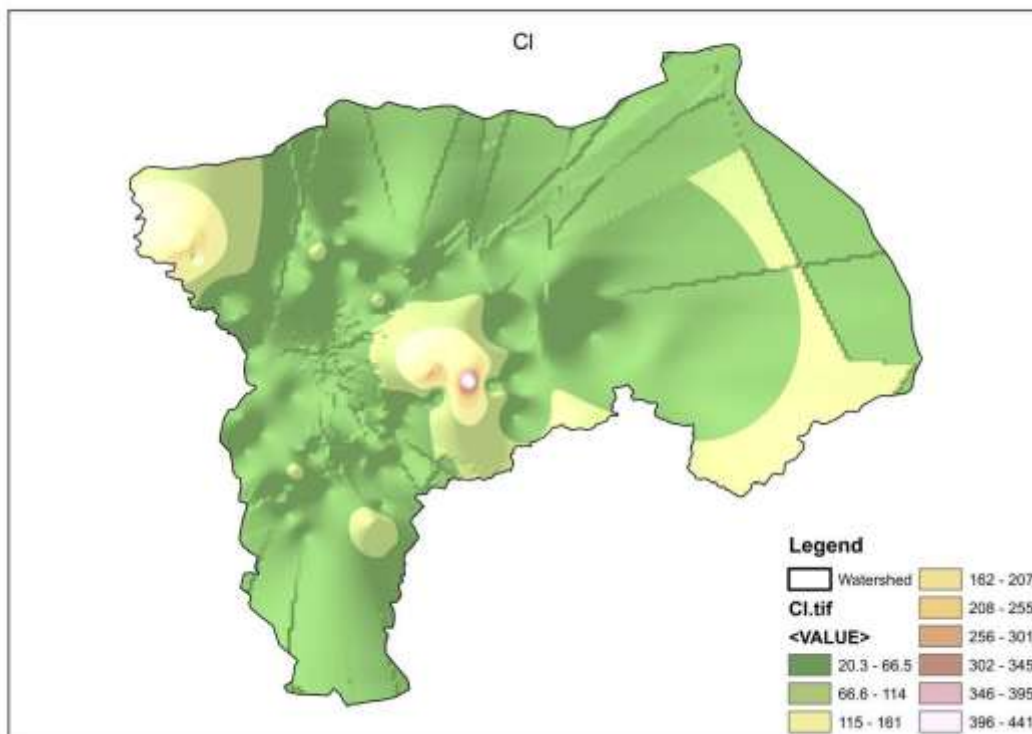
pH Variability in Zirabad reservoir area.



TDS variation in Zirabad reservoir area.



Calcium Variability of groundwater in Zirabad reservoir area



Chloride Variability in Zirabad reservoir area

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