Groundwater Quality Assessment Of Hebbal Valley, K-C Valley And Vrishabhavathi Valley For Drinking And Irrigation Suitability

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Abstract.
Groundwater is the main source of water in the Valley systems of Hebbal, K-C and Vrishabhavathi apart from River Kaveri water. It is used for drinking, domestic, agriculture and industrial purposes. The objective of the study was to check the Groundwater quality along the valley zones and check its suitability for drinking and agricultural purposes. Groundwater quality index was calculated using weighted arithmetic index method. and its irrigation suitability was checked by using Ayers and Westcot method in terms of salinity hazard, permeability hazard and specific ion toxicity. The results showed that few Groundwater quality parameters exceeded BIS drinking water quality standards. The Groundwater quality indicated that few borewell samples had excellent water quality and suitable for drinking, while few more needed minimum treatments before usage and many unfit for drinking purposes. Borewell water samples also had issues of salinity, permeability and specific ion hazard, which required specific treatment before usage for irrigation. Since few crops are sensitive to certain ions, based on the Groundwater characteristics, salt or specific ion resistant crops can be cultivated for better yield.

Key words: Groundwater Quality, Hebbal Valley, K-C Valley, Vrishabhavathi Valley, Irrigation suitability

1 Introduction

The Groundwater is an important natural resource and a component of hydrological cycle. It plays a key role in maintaining the water flow in rivers. It contributes nearly 80% of drinking water requirements in rural areas and 50% of the urban requirements. It is the main source of water for irrigation. (CGWB, 2013) It helps to maintain a fragile ecosystem. In the three major Valley systems i.e Hebbal Valley, K-C valley and Vrishabhavathi Valley, water dependency on the Groundwater has increased due to the absence of perennial water source, increased population density, industrialization, urbanization etc. The people are extracting Groundwater for domestic, industrial and agricultural purposes. The Groundwater quality in many areas of Bengaluru is deteriorated due to antropogenic activities (Shahid Gulgundi et.al., 2017). Groundwater is overexploited leading to depletion in Groundwater depth in the study area.

2 Materials and methods

Study area

The study area (Fig.1) is located in the Bengaluru Urban and Ramanagara Districts in the Deccan Plateau region of Karnataka at an elevation of 920m above MSL. Hebbal valley is located in Bengaluru Urban District between $12^{0}58^{1}30^{11}$ N to $13^{0}12^{1}00^{11}$N Parallels and between $77^{0}31^{1}30^{11}$E to $77^{0}46^{1}30^{11}$E Medians. Hebbal valley has an area of 311.26 Sq Kms and houses 74 lakes approximately. Kormangala-Challaghatta Valley (K-C Valley) is located in Bengaluru Urban District between $12^{0}50^{1}00^{11}$ N to $13^{0}01^{1}00^{11}$N Parallels and between $77^{0}34^{1}00^{11}$E to $77^{0}47^{1}00^{11}$E Meridians. It has a catchment area equal to 289.68 Sq Kms and has nearly 85 lakes. Vrishabhavathi Valley is part of Arkavathi River basin, which is the tributary of River Kaveri. Vrishabhavathi Valley (till Byramangala reservoir) is located in Bengaluru Urban and Ramanagara Districts between $12^{0}44^{1}30^{11}$ N to $13^{0}02^{1}30^{11}$N Parallels and between $77^{0}23^{1}30^{11}$E to $77^{0}35^{1}30^{11}$E Medians. It has a catchment area of 382.5 Sq Kms and house 88 lakes approximately. Study area gets rainfall from both South-west and North-east monsoons. The average rainfall in the study is around 900mm. Hebbal and K-C valley streams join Dakshina Pinakini River whereas Vrishabhavathi joins River Kaveri.

The soil in the study area is mainly laterite, loamy soil and clayey soil. The geology of the study area is characterized by Peninsular Gneissic Complex and includes gneisses, migmatites and granites.

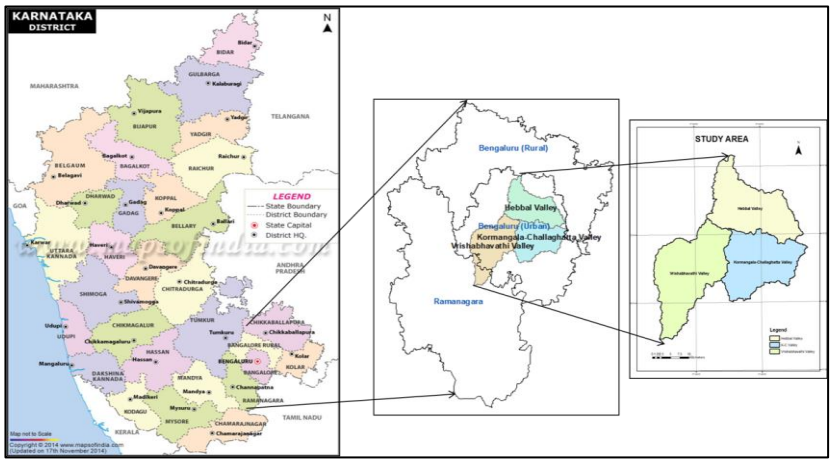

Fig. 1 Study area: Hebbal Valley, K-C Valley and Vrishabhavathi Valley

Sample collection and analysis

In the study area, Groundwater samples were collected from seventeen borewells within the Valley systems during the year 2021 and 2022 pre-monsoon season (April) using clean bottles polyethylene plastic. The collection, storage and transportation were done as per International Organization for Standardization (ISO) procedures. The borewells were allowed to flow more than ten minutes before collection of samples. Careful standardization, blank preparation, and measurements were done to ensure analytical data quality and analysis was done in triplicates. The samples were analysed for physico-chemical parameters such as pH, Electrical conductivity(EC), Total Alkalinity (TA), Total Dissolved Solids (TDS), Total Hardness(TH), Calcium Harness, Magnesium Hardness, Turbidity, Calcium(Ca), Magnesium(Mg), Chlorides(Cl), Fluoride(F), Nitrates(NO_3), Boron(B), Sodium(Na), Potassium(K), Carbonates, bicarbonates, Aluminium(Al), Sulphates(SO_4), Manganese(Mn), Magnesium(Mg), Copper(Cu), Nickel(Ni), Lead(Pb), Total Chromium(Cr), Zinc(Zn), Iron(Fe), Cadmium(Cd), Chromium(Cr), Arsenic(As) and each parameter was compared with the BIS drinking water quality standards (2012) to check its suitability for drinking purpose. Onsite measurement of pH, EC and Turbidity was done. Groundwater quality index was calculated using Brown et. al. methodology and grades were assigned (fig.3 and table 1) to compare the Groundwater quality of three valley systems. Irrigation suitability of waster was checked by using Ayres and Westcot, 1985 (table 2) in terms of Salinity hazard, Permeability hazard and Specific toxicity hazard.

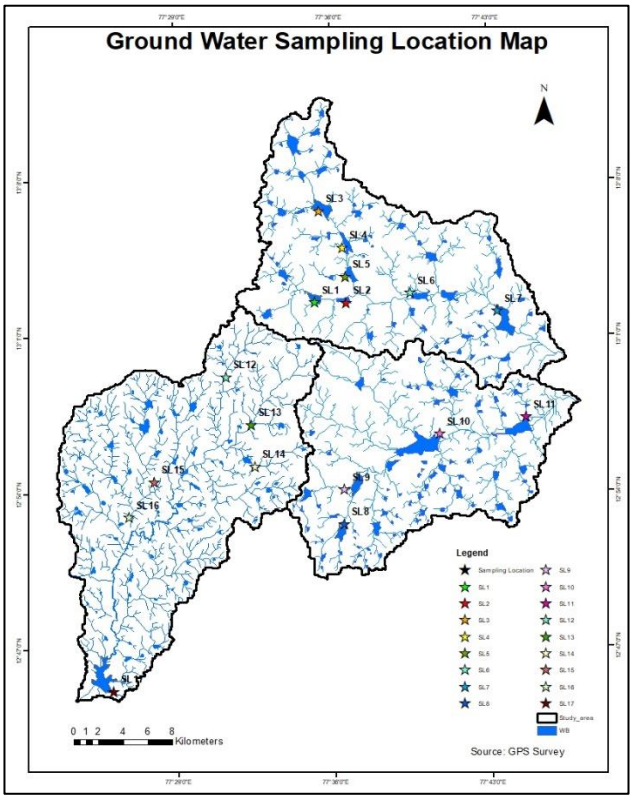

Fig. 2 Groundwater quality sampling stations

*SL1 –Near Hebbal Lake, SL2- Nagawara Lake, SL3- Near Yelahanka Lake, SL4- Near Jakkur Lake, SL5- Near Rachenahalli Lake, SL6- Near Kalkere Lake, SL7-Near Yelemallappashetty Lake, SL8- Near Hulimavu lake, SL9-Madiwala lake, SL10-Bellandur Lake, SL11-Varthuelake, SL12-Near Sumanahalli bridge, SL13-Near Gali Anganeya Temple, SL14-Near Ittamadu, SL15-Near Mylasandra, Kengeri, SL16- Near Kumbalagodu, SL17-Near Byramangala Lake, Bannigiri.

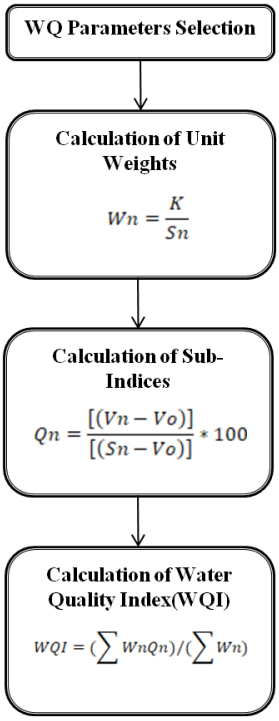

Fig. 3 WQI Calculation (Brown et. al, 1972)

Table 1: Groundwater quality grading as per Weighted Arithmetic Index method (Brown et. al, 1972)

QI Range	Water quality	Grades
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very Poor water quality	D
>100	Not suitable for drinking purpose	E

Table 2 Guidelines for Groundwater quality analysis for Irrigation purpose

Sl No	**Irrigation problem**		**Degree of the problem**		
			No problem	**Slight to moderate**	**Severe problem**
1	Salinity EC (dS/m)		<0.75	0.75-3.0	>3.0
2	Permeability				
	Evaluate using ECW and SAR together	SAR	EC(dS/m)		
		0-3	>0.7	0.7-0.2	<0.2
		3-6	>1.2	1.2-0.3	<0.3
		6-12	>1.9	1.9-0.5	<0.5
		12-20	>2.9	2.9-1.3	<1.3
		20-40	>5.0	5.0-2.9	<2.9
3	Specific Ion Toxicity- Surface Irrigation				
	Sodium (SAR)		<3	3-9	>9
	Chloride (m. eq/l)		<4	4-10	>10
	Boron(mg/L)		<0.7	0.7-0.3	>3

(Source: Ayres and Westcot, 1985)

3. Results and Discussion

Water suitability for Irrigation purpose

The results of the Groundwater quality (WQ) assessment are presented in the tables below

Table 3 Groundwater quality (GWQ) analysis results of Hebbal Valley during 2021(April)

Sl. No	Test Parameter	SL1	SL2	SL3	SL4	SL4	SL5	SL6
1	pH @ 25˚C	7.4	7.2	7.1	7	7.42	6.8	7.27
2	EC, µS/cm	356	526	1320	456	1524	1125	1666
3	TA as $CaCO_3$, mg/L	135	263	132	84.5	65	154	196
4	TDS, mg/L	250	569	657	256	756	568	928
5	TH as $CaCO_3$, mg/L	352.5	263.5	350	242.62	220.14	332.6	456.41
6	Ca Hardness as $CaCO_3$, mg/L	235.7	154.2	215.2	10.32	112.6	210.2	388.34
7	Mg Hardness as $CaCO_3$, mg/L	116.8	109.3	134.8	112.3	107.54	122.4	68.07
8	Cl, mg/L	158.9	70	216.3	82.31	56.2	200	123.1
9	F, mg/L	0.6	0.33	0.41	0.28	0.6	0.5	0.55
10	NO_3, mg/L	1.2	0.44	3.2	1.2	0.05	1.3	0.65
11	B, mg/L	1.2	0.1	0.9	0.2	0.12	0.23	0
12	Na, mg/L	56	67.5	46	29	56	67	82
13	K, mg/L	4.2	12	8	4	12	6	10
14	Al, mg/L	0	0	0	0	0	0	0
15	SO_4, mg/L	0	64	71.3	68.71	25.6	2.6	13.23
16	Ca, mg/L	94.28	61.68	86.08	4.13	45.04	84.08	155.34
17	Mg, mg/L	28.36	26.54	32.73	27.26	26.11	29.72	16.53
18	Mn, mg/L	0	0	0	0	0	0	0
19	Cu, mg/L	0.0114	0	0	0	0.0001	0	0
20	Ni, mg/L	0.0623	0	0.014	0.011	0.01	0.001	0.0308
21	Pb, mg/L	0.0017	0	0.0021	0	0	0.0023	0
22	Zn, mg/L	0.61	0.02	0.012	0.01	0.01	0.021	0
23	Fe, mg/L	0.18	0.031	0.03	0.03	0.0213	0.032	0.32
24	Cd, mg/L	0	0	0	0	0	0	0
25	Total Chromium as Cr, mg/L	0	0	0	0	0	0	0
26	As, mg/L	0	0	0	0	0	0	0
27	Carbonates, mg/L	0	0	0	0	0	0	0
28	Bicarbonates, mg /L	125	212	100	62	89	123	186

*Electrical conductivity-EC, TA- Total Alkalinity, TDS- Total Dissolved Solids, TH-Total Hardness, Ca-Calcium, Mg-Magnesium, Cl-Chloride, F-Fluorine, NO_3-Nitrates, B-Boron, Na-Sodium, K-Potassium, Al-Aluminium, SO_4-Sulphates, Mn-Manganese, Mg-Magnesium, Cu-Copper, Ni-Nickel, Pb-Lead, Zn-Zinc, Fe-Iron, Cd-Cadmium, Cr-Chromium, As-Arsenic.

Table 4 Groundwater quality analysis results of Hebbal Valley during 2022(April)

Sl. No	Test Parameter	SL1	SL2	SL3	SL4	SL4	SL5	SL6
1	pH @ 25˚C	7.41	7.07	6.54	6.86	7.54	6.78	7.28
2	EC, µS/cm	407	1564	1452	516	1648	1220	1678
3	TA as $CaCO_3$, mg/L	136	296	124	84	72	152	288
4	TDS, mg/L	218	928	762	262	850	630	868
5	TH as $CaCO_3$, mg/L	376.33	284.25	364.32	248.22	168.15	368.33	272.24
6	Ca Hardness as $CaCO_3$, mg/L	264.23	164.14	208.18	136.12	80.072	204.18	140.12
7	Mg Hardness as $CaCO_3$, mg/L	112.1	120.11	156.14	112.1	88.078	164.15	132.12
8	Cl, mg/L	271.91	85.97	249.92	73.97	65.97	263.91	313.9
9	F, mg/L	0.55	0.25	0.4	0.3	0.75	0.45	0.75
10	NO_3, mg/L	1.4	0.62	2.35	1.15	0.096	2.4	2.05
11	B, mg/L	1.45	0.13	1.924	0.621	0.858	1.924	1.095
12	Na, mg/L	55	76	91	36	88	68	84
13	K, mg/L	5	11	9	5	13	7	7
14	Al, mg/L	0	0	0	0	0	0	0

15	SO_4, mg/L	0	72.26	78.15	87.6	30.67	1.68	10.9
16	Ca, mg/L	105.69	65.66	83.27	54.45	32.03	81.67	56.05
17	Mg, mg/L	27.22	29.16	37.91	27.22	21.38	39.85	32.08
18	Mn, mg/L	0	0	0	0	0	0	0
19	Cu, mg/L	0.0126	0	0	0	0.0016	0	0
20	Ni, mg/L	0.0196	0	0.0203	0.0185	0.0283	0.0026	0.045
21	Pb, mg/L	0.024	0	0.0162	0	0	0.0059	0
22	Zn, mg/L	0.7518	0.0465	0.097	0.0385	0.0713	0.0524	0.0391
23	Fe, mg/L	0.1838	0.0348	0.0389	0.0213	0.02	0.0458	0.0128
24	Cd, mg/L	0	0	0	0	0	0	0
25	Total Chromium as Cr, mg/L	0	0	0	0	0	0	0
26	As, mg/L	0	0	0	0	0	0	0
27	Carbonates, mg/L	0	0	0	0	0	0	0
28	Bicarbonates, mg /L	136	296	124	84	72	152	288

The pH value of all the Borewell samples in Hebbal Valley was well within the limits of the BIS drinking water quality standards. The Conductivity of Rachenahalli, Yelahanka, Kalkere and Yelemallappashetty borewell samples were greater than 1000 micro-mhos/cm in the year 2021, while the Conductivity of Nagawara, Rachenahalli, Yelahanka, Kalkere and Yelemallappashetty borewell samples were greater than 1000 micro-mhos/cm in the year 2022. High EC indicates more dissolved solids. Total Alkalinity of Nagarwa (both during 2021 and 2022) and Yelemallappashetty borewell (2022) samples exceeded acceptable BIS drinking WQ standards of 200mg/L. TDS values of Nagawara, Yelahanka, Rachenahalli, Kalkere, Yelemallappashetty borewell samples exceeded the acceptable BIS drinking WQ standards of 500 mg/L during both year 2021 and 2022. TDS indicates dissolved organic as well as inorganic matter in water. Highest TDS was found in Yelemallappashetty borewell (2021) and Nagawara borewell (2022) samples. All the borewell samples analysed for Total Hardness exceeded acceptable BIS drinking WQ standards (200mg/L) during 2021. The Total Hardness was greater than acceptable BIS drinking WQ standards except in Rachenahalli borewell (2022) sample. All the borewell samples analyzed for Chlorides were well within the BIS drinking WQ standards during 2021. The borewell samples near Hebbal, Yelahanka, Kalkere and Yelemallappashetty Lakes exceeded BIS drinking water WQ standards for Chlorides (250mg/L) during 2022. Nitrates and Fluorides are within the drinking WQ limits as prescribed by BIS. Hebbal and Yelahanka borewell samples exceeded the acceptable Boron values (0.5mg/L) prescribed by BIS drinking WQ standards during 2021. All the borewell samples except Nagawara exceeded Boron values of acceptable BIS drinking WQ standards during 2022. Ten heavy metals were tested during the study. Aluminium, Manganese, Arsenic, Total chromium and cadmium was not detected in any of the samples analysed. Nickel was found above the BIS drinking WQ standards in Hebbal and Yelemallappashetty borewell samples during 2021. Nickel was found above the BIS drinking WQ standards in Rachenahalli borewell sample and also lead was found above BIS drinking WQ standards in Hebbal borewell sample during 2022.

Table 5 Groundwater quality analysis results of K-C Valley during 2021 and 2022(April)

Sl. No.	Test Parameter	SL8	SL8	SL9	SL9	SL10	SL10	SL11	SL11
	Year	2021	2022	2021	2022	2021	2022	2021	2022
1	pH @ 25˚C	9	6.8	7.05	7.2	7.3	7.15	7.2	7.4
2	EC, µS/cm	912	932	908	958	1423	1524	1256	1318
3	TA as $CaCO_3$, mg/L	278	312	296	312	134.2	140	156	144
4	TDS, mg/L	359	488	472	452	687	780	652	680
5	TH as $CaCO_3$, mg/L	238.6	244.21	236.21	254.2	253.6	104.093	356.5	404
6	Ca Hardness as $CaCO_3$, mg/L	126.7	166.104	124.11	141.7	139.5	48.043	212.6	124.11
7	Mg Hardness as $CaCO_3$, mg/L	111.9	128.106	112.11	112.5	114.1	56.05	143.9	124.11
8	Cl, mg/L	271.91	85.97	249.92	73.97	65.97	263.91	313.9	8
9	F, mg/L	0.55	0.25	0.4	0.3	0.75	0.45	0.75	9
10	NO_3, mg/L	1.4	0.62	2.35	1.15	0.096	2.4	2.05	10
11	B, mg/L	1.45	0.13	1.924	0.621	0.858	1.924	1.095	11
12	Na, mg/L	55	76	91	36	88	68	84	12
13	K, mg/L	5	11	9	5	13	7	7	13
14	Al, mg/L	0	0	0	0	0	0	0	14
15	SO_4, mg/L	0	72.26	78.15	87.6	30.67	1.68	10.9	15
16	Ca, mg/L	105.69	65.66	83.27	54.45	32.03	81.67	56.05	16
17	Mg, mg/L	27.22	29.16	37.91	27.22	21.38	39.85	32.08	17
18	Mn, mg/L	0	0	0	0	0	0	0	18
19	Cu, mg/L	0.0126	0	0	0	0.0016	0	0	19
20	Ni, mg/L	0.0196	0	0.0203	0.0185	0.0283	0.0026	0.045	20
21	Pb, mg/L	0.024	0	0.0162	0	0	0.0059	0	21

22	Zn, mg/L	0.01	0.0362	0.0364	0.0397	0.0519	0.0544	0.0512	0.055
23	Fe, mg/L	0.3	0.4986	0.109	0.1185	0.0311	0.0309	0.0564	0.0718
24	Cd, mg/L	0	0	0	0	0	0	0	0
25	Total Chromium as Cr, mg/L	0	0	0	0	0	0	0	0
26	As, mg/L	0	0	0	0	0	0	0	0
27	Carbonates, mg/L	200	312	214	296	132	140	214	300
28	Bicarbonates, mg /L	21	18	56	62	36	40	23	36

The pH value of all the Borewell samples in K-C Valley was well within the limits of the BIS drinking WQ standards. The Conductivity of Bellandur and Varthur borewell samples were greater than 1000 micro-mhos/cm during both year 2021 and 2022, while the Conductivity of Hulimavu and Madiwala borewell samples were greater than 500 micro-mhos/cm during both year 2021 and 2022. High EC (EC) indicates more dissolved solids. Total Alkalinity of Hulimavu and Madiwala borewell samples (both in 2021 and 2022) exceeded acceptable BIS drinking WQ standards of 200mg/L. The Total Dissolved Solids (TDS) values of Bellandur and Varthur borewell samples were greater than BIS drinking WQ standards (500mg/L) during both 2021 and 2022, while the TDS of Hulimavu and Madiwala borewell samples were within the BIS standards of 500 mg/L during both years. The Total Hardness of all the borewell samples except Bellandur (2022) borewell sample was greater than acceptable BIS drinking WQ standards. Chlorides, Nitrates and Fluorides are within the drinking WQ limits as prescribed by BIS. Hulimavu and Bellandur borewell samples exceeded the acceptable Boron values (0.5mg/L) prescribed by BIS drinking WQ standards during both years. Boron values in Madiwala and Varthur borewell samples were within the BIS drinking WQ standards during both years. Ten heavy metals were tested during the studies. Aluminium, Manganese, Lead, Arsenic, Total chromium and cadmium was not detected in any of the samples analysed. Only Iron was found above BIS drinking WQ standards of 0.3mg/L in the Hulimavu borewell sample and all other metals including iron was well within the BIS drinking standards.

Table 6 Groundwater quality analysis results of Vrishabhavathi Valley during 2021 (April)

Sl. No.	Test Parameter	SL12	SL13	SL14	SL15	SL16	SL17
1	pH @ 25˚C	7	6.8	7.1	7.7	7.3	7.2
2	EC, µS/cm	1021	695	958	325	1896	1208
3	TA as $CaCO_3$, mg/L	152	296	256	256	312	156
4	TDS, mg/L	526	357	429	156	856	562
5	TH as $CaCO_3$, mg/L	392.1	333.61	246	277.9	248.6	356.8
6	Ca Hardness as $CaCO_3$, mg/L	210.31	177.41	126.9	129	146.21	212.65
7	Mg Hardness as $CaCO_3$, mg/L	18.79	156.2	119.1	98	102.39	144.15
8	Cl, mg/L	86	69.2	66	68	45.61	215.6
9	F, mg/L	0.3	0.72	0.55	0.6	0.66	0.3
10	NO3, mg/L	1.1	1.8	0.61	0.7	0.5	2.1
11	B, mg/L	0.9	0.221	0.88	0.02	0.76	0.52
12	Na, mg/L	56	52	56	18	86	65
13	K, mg/L	6	6	11	4	15	9
14	Al, mg/L	0	0	0	0	0	0
15	SO_4, mg/L	115.2	166.3	241.3	46.2	256	125.8
16	Ca, mg/L	84.12	70.96	50.76	51.60	58.48	85.06
17	Mg, mg/L	4.56	37.92	28.91	23.79	24.86	35.00
18	Mn, mg/L	0	0	0	0	0	0
19	Cu, mg/L	0	0	0	0	0.025	0
20	Ni, mg/L	0.021	0.012	0.011	0.012	0.081	0
21	Pb, mg/L	0.015	0	0.002	0.0211	0.082	0
22	Zn, mg/L	0.05	0.021	0.055	0.0146	0.033	0.0581
23	Fe, mg/L	0.0351	0.0231	0.009	0.056	0.069	0.0326
24	Cd, mg/L	0	0	0	0	0	0
25	Total Chromium as Cr, mg/L	0	0	0	0	0	0
26	As, mg/L	0	0	0	0	0	0
27	Carbonates, mg/L	116	213	156	126	256	256
28	Bicarbonates, mg /L	33	23	32	16	12	12

Table 7 Groundwater quality analysis results of Vrishabhavathi Valley during 2022 (April)

Sl. No.	Test Parameter	SL12	SL13	SL14	SL15	SL16	SL17
1	pH @ 25˚C	7.09	6.92	7.2	7.65	7.3	7.4
2	EC, µS/cm	1216	762	1082	368	1896	1318
3	TA as $CaCO_3$, mg/L	168	304	300	288	312	144
4	TDS, mg/L	628	392	560	190	856	680
5	TH as $CaCO_3$, mg/L	388.34	364.23	248.22	256.23	248.6	404.36
6	Ca Hardness as $CaCO_3$, mg/L	208.18	136.12	124.11	124.11	146.21	232.2
7	Mg Hardness as $CaCO_3$, mg/L	18.016	128.11	124.11	132.13	102.39	172.16
8	Cl, mg/L	149.95	77.97	73.97	71.97	45.61	231.2
9	F, mg/L	0.45	0.85	0.6	0.75	0.66	0.3
10	NO_3, mg/L	2.425	1.925	0.675	0.9	0.5	2.325
11	B, mg/L	1.332	0.355	1.302	0.017	0.76	0.76
12	Na, mg/L	70	58	66	23	86	79
13	K, mg/L	7	5	12	3	15	12
14	Al, mg/L	0	0	0	0	0	0
15	SO_4, mg/L	376.99	184.87	377.31	98.31	256	136.13
16	Ca, mg/L	83.27	54.45	49.64	49.64	58.48	92.88
17	Mg, mg/L	4.37	31.10	30.13	32.08	24.86	41.80
18	Mn, mg/L	0	0	0	0	0	0
19	Cu, mg/L	0	0	0	0	0.025	0
20	Ni, mg/L	0.0409	0.0155	0.0185	0.1115	0.081	0
21	Pb, mg/L	0.0406	0	0.0121	0.0238	0.082	0
22	Zn, mg/L	0.2926	0.0341	0.0731	0.0279	0.033	0.0633
23	Fe, mg/L	0.0926	0.0417	0.0833	0.0838	0.069	0.0488
24	Cd, mg/L	0	0	0	0	0	0
25	Total Chromium as Cr, mg/L	0	0	0	0	0	0
26	As, mg/L	0	0	0	0	0	0
27	Carbonates, mg/L	168	304	169	288	256	296
28	Bicarbonates, mg /L	42	38	25	29	12	32

The pH value of all the Borewell samples in Vrishabhavathi Valley was well within the limits of the BIS drinking WQ standards. The Conductivity was greater than 1000 micro-mhos/cm near the borewell samples collected at Sumanahalli, Ittamadu, Kumbalgodu and Byramangala locations. The Kumbalgodu Borewell water sample had highest conductivity followed by Byramangala and Sumanahalli Bridge borewell samples. High Conductivity (EC) indicates more dissolved solids. Total Alkalinity of the River was found above the BIS WQ standards near Gali Anjaneya Temple, Mylasandra, Ittamadu and Kumabalgodu regions (during both 2021 and 2022). The Total Dissolved Solids (TDS) values of borewell samples near Sumanahalli, Ittamadu, Kumbalgodu and Byramangala was above the BIS drinking WQ standards (500mg/L). Kumbalgodu borewell sample has the highest TDS compared to all other borewell samples within the Valley system. The Total Hardness of all the samples exceeded the acceptable BIS drinking WQ standards (200mg/L) during both years analysed. Chlorides, Nitrates and Fluorides were within the drinking water quality limits as prescribed by BIS. The Boron values of Sumanahalli, Ittamadu, Kumbalgodu and Byramangala exceeded acceptable Boron values (0.5mg/L) prescribed by BIS drinking WQ standards during both years. Ten heavy metals were tested during the studies. Aluminium, Manganese, Arsenic, Total chromium and cadmium was not detected in any of the samples analysed. In Sumanahalli and Kumbalagodu borewell samples Nickel was found above BIS drinking WQ standards during 2021. In Sumanahalli, Mylasandra and Kumbalagodu borewell samples Lead was found above BIS drinking WQ standards during 2021. In Sumanahalli, and Kumbalagodu borewell samples Nickel was found above BIS drinking WQ standards during 2022. In Sumanahalli, Mylasandra, Ittamadu and Kumbalagodu borewell samples Lead was found above BIS drinking WQ standards during 2022.

Table 8 Groundwater Quality Index

	Hebbal Valley							**K-C Valley**				**Vrishabhavathi Valley**					
Sampling Locations	SL 1	SL2	SL 3	SL4	SL5	SL6	SL7	SL8	SL9	SL10	SL11	SL 12	SL13	SL14	SL 15	SL 16	SL17
2021 GWQI	31.06	0.62	85.91	15.51	32.35	14.64	43.47	4.76	1.86	26.57	1.65	110.76	17.10	27.70	129.78	555.33	1.51
2022 GWQI	162.06	0.66	118.54	26.41	40.61	14.64	63.11	7.21	1.32	35.06	2.56	275.85	22.25	93.21	277.69	164.36	2.13

Table 9 Groundwater quality grading as per Weighted Arithmetic Index method

WQI Value	Water quality rating	Grading	Year 2021	Year 2022
0-25	Excellent water quality	A	Nagawara Borewell, Jakkur Borewell, Kalkere Borewell, Hulimavu Borewell, Madiwala Borewell, Varthur Borewell, Near Gali Anjaneya Temple, Mysore Road Borewell and Byramangala Borewell	Nagawara Borewell, Kalkere Borewell, Hulimavu Borewell, Madiwala Borewell, Varthur Borewell, Near Gali Anjaneya Temple, Mysore Road Borewell and Byramangala Borewell
26-50	Good water quality	B	Hebbal Borewell, Rachenahalli Borewell, Yelemallappashetty Borewell, Bellandur Borewell and Ittamadu Borewell	Jakkur Borewell, Rachenahalli Borewell and Bellandur Borewell
51-75	Poor water quality	C	-	Yelemallappashetty Borewell
76-100	Very Poor water quality	D	Yelahanka Borewell	Ittamadu Borewell
> 100	Unsuitable for drinking	E	Mylasandra Borewell, Sumanahalli Borewell and Kumbalgodu Borewell	Hebbal Borewell, Yelahanka Borewell, Mylasandra Borewell, Sumanahalli Borewell and Kumbalgodu Borewell

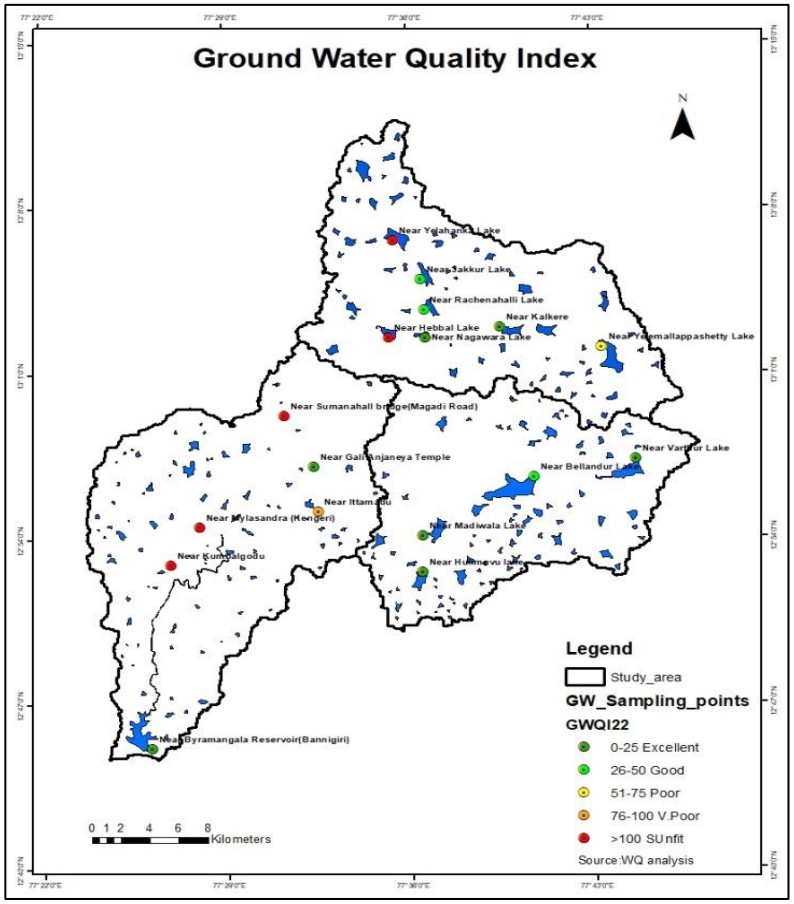

Fig.4 Groundwater quality index

As per Groundwater quality indices, the groundwater of Hebbal, Yelahanka and Yelemallappashetty Lakes are more polluted than the other borewell samples in Hebbal Valley. In K-C valley, Groundwater near Bellandur Lake is more contaminated compared to other borewell samples. In Vrishabhavathi Valley, Groundwater near Kumbalgodu industrial area, Sumanahalli bridge, Mylasandra STP, Ittamadu are more polluted. The results indicate that the contamination is mainly due to anthropogenic activities like percolation of polluted surface water, industrial discharges, sewage etc. Hebbal and K-C valleys have Migmatites and Granodiorite lithology, whereas Migmatites, Granodiorite and Granite (quartz, biotite, K-feldspar, opaque, plagioclase and hornblende) are found in Vrishabhavathi valley. The rocks indicate that the heavy metal Ni. Pb, Zn, Cu etc contamination is purely due to anthropogenic activities like industrial discharges, percolation of polluted surface water etc.

Water suitability for Irrigation purpose

Table 10 Groundwater quality comparison with Irrigation Water requirement during 2021 (Source: Ayres and Westcot, 1985)

		HEBBAL VALLEY							K-C VALLEY				Vrishabhavathi Valley					
Sl. No.	**SAR Values**	**SL1**	**SL2**	**SL3**	**SL4**	**SL5**	**SL6**	**SL7**	**SL8**	**SL9**	**SL10**	**SL11**	**SL12**	**SL13**	**SL14**	**SL15**	**SL16**	**SL17**
1	Salinity Hazard	No problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem
2	Permeability Hazard	Severe problem	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Severe problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem)	Slight to moderate problem	Severe problem
3	Sodium Hazard	Slight to moderate problem	Severe problem	Slight to moderate problem	No problem	Severe problem	No problem	Slight to moderate problem	Severe problem	Severe problem	Severe problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	No problem	Severe problem	Slight to moderate problem
4	Chloride Hazard	Slight to moderate problem)	No problem	Slight to moderate problem	Slight to moderate problem	No problem	Slight to moderate problem	No problem	No problem	No problem	No problem	No problem	No problem	No problem	No problem	No problem	No problem	Slight to moderate problem
5	Boron Hazard	Slight to moderate problem	No problem	Slight to moderate problem	No problem	No problem	No problem	Slight to moderate problem	No problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	No problem

Table 11 Groundwater quality comparison with Irrigation Water requirement during 2022 (Source: Ayres and Westcot, 1985)

		HEBBAL VALLEY							K-C VALLEY				Vrishabhavathi Valley					
Sl. No.	**SAR Values**	**SL1**	**SL2**	**SL3**	**SL4**	**SL5**	**SL6**	**SL7**	**SL8**	**SL9**	**SL10**	**SL11**	**SL12**	**SL13**	**SL14**	**SL15**	**SL16**	**SL17**
1	Salinity Hazard	No problem	Slight to moderate problem	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem
2	Permeability Hazard	Severe problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Severe problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Severe problem	Slight to moderate problem	Slight to moderate problem	Severe problem
3	Sodium Hazard	Slight to moderate problem	Severe problem)	Severe problem	No problem	Severe problem	No problem)	Severe problem	Severe problem	Severe problem	Severe problem	Severe problem	Severe problem	Slight to moderate problem	Severe problem	Slight to moderate problem	Severe problem	Severe problem
4	Chloride Hazard	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem	No problem	No problem	No problem	No problem	No problem	No problem	No problem	No problem	No problem	Slight to moderate problem
5	Boron Hazard	Slight to moderate problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	Slight to moderate problem	No problem	Severe problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	No problem	Slight to moderate problem	Slight to moderate problem

In Hebbal Valley, Salinity Hazard is found in Groundwater sample near Yelahanka, Kalkere, Rachenahalli, Yelemallappashetty Lakes. Permeability Hazard is noticed in all the Groundwater samples. Sodium Hazard is found in all places except near Groundwater of Jakkur and Kalkere Lakes. Chloride Hazard is in all places except Nagawara and Rachenahalli borewells. Boron Hazard is in all places except near Groundwater of Nagawara and Jakkur Lakes. In K-C Valley, Salinity Hazard is found near Groundwater of Hulimavu, Madiwala, Bellandur and Varthur Lakes. Permeability Hazard is noticed in all the Groundwater samples. Sodium Hazard is noticed in all the Groundwater samples. No chloride Hazard is noticed in any samples. Boron Hazard is found in Hulimavu and Bellandur samples of Groundwater. In Vrishabhavathi Valley, Salinity Hazard is found near Groundwater of Sumanahalli, Ittamadu, Kumbalgodu areas and also Byramangala Lake. Permeability Hazard is noticed in all the Groundwater samples. Sodium Hazard is noticed in all the Groundwater samples. Boron Hazard is found in Sumanahalli, Ittamadu, Kumbalagodu and Byramangala Samples. As per the results, Groundwater has issues even when used for irrgation purposes. High salinity might affect the crop's growth, productivity and reduce water intake in plants. It also causes soil pollution. Permeability hazard leads affects hydraulic properties of soil like hydraulic conductivity and infiltration rate leading to crusting, erosion, runoff and poor erosion. Few plants are sensitive to certain ions like Sodium, Boron, Chloride. When such ions are found in excess quantity in irrigation water, it leads to damage of plant tissues, stunted growth, affects crops yield etc.

4. Conclusion

The present study showed that the borewell samples of Nagawara, Jakkur, Kalkere, Hulimavu, Madiwala, Varthur, Near Gali Anjaneya Temple and Byramangala had excellent water quality and suitable for drinking purposes. Mylasandra, Sumanahalli, Kumbalagodu, Hebbal, Yelahanka Borewell samples were unfit for drinking as per the calculated Groundwater quality index. The other borewell samples tested requires minimum amount of treatment before using it for drinking purpose. Many borewells samples within the valley systems also had issues of salinity, permeability and specific ion hazard. Since few crops are sensitive to salts and specific ions, based on the Groundwater and soil characteristics, the agricultural crop has to be chosen for cultivation. Necessary treatment has to be provided before using such Groundwater.

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