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Evaluation of Groundwater Quality Index in Greater Visakhapatnam Municipal Corporation, Andhra Pradesh using GIS and Laboratory Methods

P. Swarna Latha* **and K. Nageswara Rao[1]**

Department of Geography, Andhra University, Visakhapatnam-530 003, India

[1]Geography Discipline, Indira Gandhi National Open University, New Delhi-110 068

✉ dr.swarnapisupati@gmail.com

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Abstract: An integrated approach of geographical information system (GIS), global positioning system (GPS) and water quality index (WQI) studies has been effectively used for identifying the spatial distribution for quality of groundwater zones in Greater Visakhapatnam Municipal Corporation (GVMC), a coastal city of Andhra Pradesh state. Physico-chemical analysis was carried out for various selected parameters such as pH, alkalinity, electrical conductivity (EC), total hardness (TH), calcium hardness (CaH), sodium (Na), potassium (K), chlorides (Cl), sulphates (SO_4), fluorides (F) and indirectly estimated parameters like total dissolved solids (TDS), magnesium hardness (MgH), carbonates plus bicarbonates (CO_3+HCO_3) by adopting standard methods and compared with the Bureau of Indian Standards (BIS). The analytical results revealed that most of the groundwater was found to be in polluted category. The GIS analysis of spatial distribution map of the overall water quality index revealed that only nine percent of groundwater during pre-monsoon and around sixteen percent in post-monsoon is suitable for drinking purpose.

Key words: Physico-chemical analysis, groundwater, water quality index, GIS, GVMC, Andhra Pradesh.

Introduction

Water is essential for sustenance of life. The knowledge of the occurrence, replenishment and recovery of potable groundwater assumes special significance in quality-deteriorated regions, because of scarce presence of surface water. Groundwater plays a significant role in daily lives especially in arid and semi-arid regions. It is now widely used for domestic drinking, irrigation and industrial supplies. Assessing quality of groundwater becomes one of the most important links in water resources utilization, development and management. The quality of groundwater is equally important as that of quantity and it depends upon the rock formation, physiography, soils and environmental conditions of the area. Development of industrial activity causes deterioration of groundwater quality because of industrial effluents disposal without pre-treatment on to the ground. Groundwater is worst affected in urban regions by sewage, chemical pollutants and agricultural effluents with the activity of heavy concentration of urban and industrial growth (CGWB, 1999; Swarna Latha and Nageswara Rao, 2007). Water quality index (WQI) is one of the most effective ways to communicate information on water quality trends to policy makers (Tiwari and Ali, 1988). GIS is a powerful tool for

*Corresponding Author

determining water availability, understanding the natural environment, assessing water quality and managing water resources on a local or regional scale.

In the present study, physico-chemical analysis of groundwater samples was carried out from selected bore wells in Greater Visakhapatnam Municipal Corporation (GVMC) area. The groundwater quality index was calculated from obtained analytical results and thematic spatial distribution maps were generated for selected parameters using GIS software.

Study Area

Geographically the area under investigation, covering 535 sq.km, lies between 17° 32′ N to 17° 51' N latitudes and 83° 05′ E to 83° 24′ E longitudes (Figure 1). In the year 2005, the Andhra Pradesh state government has upgraded the Visakhapatnam Municipal Corporation (VMC) to Greater Visakhapatnam Municipal Corporation (GVMC) merged along with Gajuwaka municipality and 32 gram-panchayats. Its area of jurisdiction has expanded merely from 111 sq.km to 535 sq.km encompassing sprawling suburbs. The total population is increased from approximately 0.9 million to around 1.5 million. The industrial city, GVMC is an important urban and commercial centre on the East Coast. It is well connected by land, sea and air transportation. Geologically the study area is a part of Eastern Ghat Mobile Belt (EGMB) region. Topographically the area is undulating terrain with eroded rocky hills. The relief of the study area ranges from 51 to 510 m above mean sea level. The area enjoys tropical climate of semi-arid in nature with an average monthly temperature variations of 21ºC to 34ºC and an average annual rainfall 940 mm with maximum contribution from south-west monsoon.

Methodology

Sampling was carried out using GPS survey during pre-monsoon season in the month of May and post-monsoon season in the month of December for the year 2006 from 71 selected bore wells in the study area (Figure 2 and Table 1). Proper care was taken in collecting the samples throughout the area. The samples were preserved by adding appropriate reagents in laboratory for the report of water quality analysis. The water samples were analyzed for various physico-chemical parameters by adopting standard methods (APHA, 1998). Electrical conductivity (EC) and pH were measured using digital meters immediately after sampling. Calcium hardness

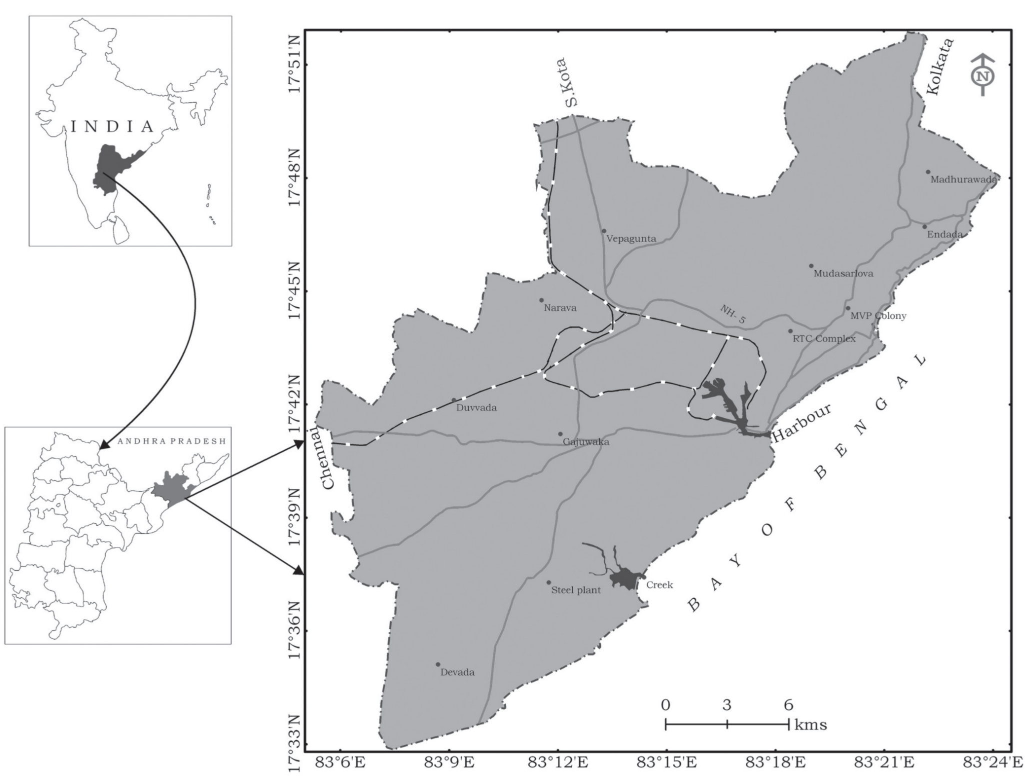

Figure 1: Location map of the study area.

(CaH), total hardness (TH), alkalinity and chlorides (Cl) were analyzed by volumetric titrations. Flame photometer was used to measure sodium (Na) and potassium (K) ions. Sulphates (SO_4) and fluorides (F) were determined by spectrophotometric techniques. Total dissolved solids (TDS), magnesium hardness (MgH), carbonates plus bicarbonates (CO_3+HCO_3) were measured indirectly using formulas 0.64 × EC µs/cm (Raghunath, 2003), [TH-(2.5×CaH)]/4.1 (Todd, 2001), 1.31×alkalinity (Hem, 1985) respectively. All the parameters were compared with the guidelines suggested by Bureau of Indian Standards (BIS, 2003). The analysis of quality of groundwater data (Table 2) forms the attribute database for the present study to generate spatial distribution maps in GIS environment.

Water Quality Index (WQI)

Water quality index is computed to reduce the large amount of water quality data to a single numerical value. WQI reflects the composite influence of different water quality parameters on the overall quality of water. WQI is calculated to determine the suitability of the groundwater for drinking purposes.

$$\mathrm{WQI} = \mathrm{Antilog}\left[\sum_{\mathrm{i}=1}^{\mathrm{n}} w_{\mathrm{i}} \log_{10} q_{\mathrm{i}}\right]$$

where w_{i} = weightage factor of i^{th} parameter, q_{i} = quality rating of i^{th} parameter.

The w_{i} is calculated from the following equation,

$$w_{\mathrm{i}} = \left(\frac{k}{s_{\mathrm{n}}}\right),$$

$$\text{where } k = \text{constant} = \frac{1}{1/v_{s1} + 1/v_{s2} \ldots\ldots\ldots + 1/v_{sn}},$$

s_{n} = standard value of i^{th} parameter

The q_{i} is calculated from the following equation,

$$q_{\mathrm{i}} = \left(\frac{v_a - v_i}{v_s - v_i}\right) \times 100$$

where v_{a} = actual value obtained from laboratory analysis of i^{th} parameter, v_{s} = standard value of i^{th} parameter, and v_{i} = ideal value (pH = 7 and 0 for all parameters).

The water quality standard values corresponding to weightage factor and ideal values are presented in Table 3. Based on the water quality index, the analyzed samples were grouped into three classes namely suitable for drinking (below 50), moderately polluted (51 to 80) and severely polluted (above 80).

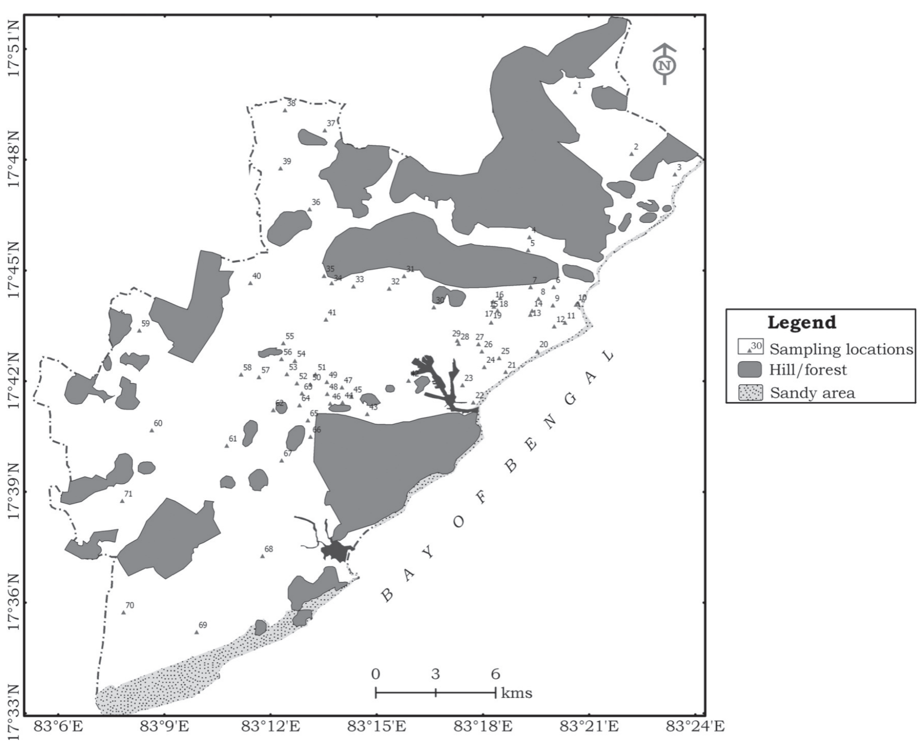

Figure 2: Sampling locations for the evaluation of groundwater quality in the study area.

Table 1: Details of sampling locations of the study area

Sl. no	Sampling station	Latitude dd-mm-sss	Longitude dd-mm-sss	Sl. no	Sampling station	Latitude dd-mm-sss	Longitude dd-mm-sss
1	Kommadi	17 49 50.7	83 20 34.8	37	Pulagalipalem	17 48 47.8	83 13 31.4
2	Madhurawada	17 48 08.1	83 22 11.8	38	Pendurthi	17 48 47.8	83 13 31.4
3	Rushikonda	17 47 25.4	83 23 16.2	39	Gollavllivanipalem	17 47 00.4	83 12 14.9
4	Arilova	17 45 53.5	83 19 19.4	40	Narava	17 44 40.4	83 11 25.9
5	China Gadili	17 45 32.6	83 19 17.4	41	Airport	17 43 40.6	83 13 33.3
6	M.V.P	17 44 33.7	83 19 17.4	42	Harbour	17 42 01.5	83 15 53.9
7	Venkojipalem	17 44 32.5	83 19 20.3	43	Malkapuram	17 41 07.4	83 14 43.1
8	Maddilapalem	17 44 13.8	83 19 33.2	44	Sriharipuram	17 41 25.6	83 14 02.1
9	Pedawaltair	17 44 03.7	83 19 58.9	45	Gollalapalem	17 41 35.4	83 14 16.5
10	Lawsons Bay	17 44 05.4	83 20 38.5	46	Ganeshnagar	17 41 24.6	83 13 40.5
11	East Point Colony	17 43 34.9	83 20 07.7	47	Coromandel Gate	17 41 50.1	83 14 01.1
12	China Waltair	17 43 29.2	83 20 00.9	48	Pilakavanipalem	17 41 40.3	83 13 34.9
13	T.B. Hospital	17 43 50.1	83 19 20.3	49	Mulagada	17 41 59.0	83 13 35.4
14	Respuvanipalem	1743 54.8	83 19 22.3	50	Chukkavanipalem	17 41 55.1	83 13 06.7
15	Sitammadhara	17 44 15.7	83 18 29.8	51	Mindi	17 42 11.8	83 13 05.9
16	Akkayyapalem	17 44 09.5	83 18 17.2	52	Appanna Colony	17 41 56.5	83 12 44.6
17	Sitampeta	17 44 02.2	83 18 18.7	53	BHPV Gate	17 42 11.8	83 12 27.2
18	RTC Complex	17 43 55.9	83 18 25.1	54	Akkireddypalem	17 42 33.9	83 12 40.5
19	Dwaraka Nagar	17 43 35.8	83 18 13.9	55	Sheelanagar	17 43 01.9	83 12 21.0
20	R.K. Beach	17 42 48.8	83 19 32.9	56	Natayyapalem	17 42 36.8	83 12 17.9
21	Jalaripeta	17 42 15.5	83 18 38.4	57	Autonagar	17 42 07.3	83 11 40.0
22	I Town	17 41 25.9	83 17 43.6	58	Tungalam	17 42 10.8	83 11 10.2
23	Port Area	17 41 53.8	83 17 25.5	59	Vedurlanarava	17 43 23.0	83 08 10.6
24	Poorna Market	17 42 23.9	83 18 02.1	60	Shaniwada	17 40 40.7	83 08 30.7
25	Maharanipeta	17 42 38.4	83 18 27.2	61	Rajupalem	17 40 15.9	83 10 45.8
26	Dabagardens	17 42 49.2	83 17 57.8	62	Old Gajuwaka	17 41 13.3	83 12 03.9
27	Allipuram	17 42 59.0	83 17 52.4	63	Zinc gate	17 41 40.7	83 12 52.8
28	Chavulamadam	17 43 01.6	83 17 18.8	64	Maruthinagar	17 41 21.7	83 12 48.4
29	Gnanpuram	17 43 07.1	83 17 16.1	65	New Gajuwaka	17 40 57.0	83 13 02.3
30	Kancharapalem	17 44 01.3	83 16 36.9	66	Yarada	17 40 30.4	83 13 07.1
31	Madhawadhara	17 44 52.1	83 15 46.5	67	Pedagantyada	17 39 51.9	83 12 18.3
32	Marripalem	17 44 31.7	83 15 21.5	68	Steel Plant	17 37 17.4	83 11 44.4
33	NAD	17 44 31.7	83 14 19.9	69	Velampeta	17 35 12.3	83 09 52.9
34	Buchirajupalem	17 44 40.5	83 13 42.9	70	Pittavanipalem	17 35 44.7	83 07 48.7
35	Goplapatnam	17 44 52.0	83 13 30.4	71	Desapatrunipalem	17 38 45.1	83 07 47.4
36	Vepagunta	17 46 40.2	83 13 05.4				

Database Creation-GIS Integration

Inverse distance weighted (IDW) raster interpolation technique of spatial analyst module in ArcGIS 9.0 software was used for this present study to delineate the locational distribution of water pollutants of constituents. The different locations of the sampling stations were imported into GIS software through point layer. Each sample point was assigned by a unique code and stored in the point attribute table. The data base file contains values of all chemical parameters in separate columns along with a sample code for each sampling station. Spatial and attribute data were integrated for the generation of spatial distribution maps of selected water quality parameters namely TDS, TH, Cl and WQI (Figures 3 to 10). The water quality data (attribute data) was linked to the sampling stations (spatial data) and maps showing spatial distribution were prepared to model the variation in concentrations of the above parameters.

Results and Discussion

Quality of Groundwater

The pH of a solution is the negative logarithm of hydrogen ion concentration in moles per litre. From the

Table 2: Physico-chemical analysis of groundwater during pre- and post-monsoon season in the study area

Sl.	pH		Alkalinity		EC		TDS		TH		CaH		MgH		Na		K		HCO_3		Cl		SO_4		F	
No	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
1	7.1	6.9	196	184	928	910	594	582	412	402	152	144	7.9	10.3	28.6	26.6	14.8	11.5	256.8	241	127.6	124.8	34.2	30.6	1.0	0.8
2	7.1	7.0	192	190	916	910	586	582	358	350	110	110	20.2	18.3	32.6	32.6	20.3	20.3	251.5	248.9	92.2	90.2	40.2	40.2	0.9	0.9
3	7.0	7.0	190	190	1300	1300	832	832	464	444	158	158	16.9	12	60.2	58.8	18.1	14.2	248.9	248.9	290.6	290.6	60.6	58.2	0.7	0.7
4	7.2	7.2	202	196	1398	1376	895	881	432	424	94	82	47.9	53.3	68.9	66.1	8.2	6.6	264.6	256.8	140.2	144.2	60.4	62.5	0.8	0.7
5	7.9	7.6	212	220	1342	1336	859	855	426	400	132	128	23.4	19.5	52.5	48.9	22.6	17.4	277.7	288.2	144.5	140.8	72.2	62.8	1.0	0.7
6	7.6	7.2	218	212	1456	150	932	96	528	510	158	144	32.4	36.5	58.4	58.4	28.4	26.8	285.6	277.7	268.4	252.6	46.8	53.6	0.8	0.8
7	7.5	7.1	200	194	1348	1348	863	863	582	582	174	160	35.8	44.3	58.7	56.8	16.5	14.3	262	254.1	250.2	248.8	80.8	60.8	0.8	0.7
8	7.4	7.1	222	210	1512	1512	968	968	526	526	172	172	23.4	23.4	52.2	53.6	14.1	10.2	290.8	275.1	204.5	192.8	70.6	70.6	0.6	0.6
9	7.0	7.2	306	302	1448	1500	927	960	576	516	192	172	23.5	21	54.2	44.2	12.2	8.6	400.9	395.6	144.6	144.6	72.4	70.4	0.7	0.6
10	7.3	7.3	248	248	1552	1536	993	983	588	536	212	212	14.2	1.6	54.6	54.6	20.1	20.1	324.9	324.9	340.5	338.2	58.2	60.2	0.9	0.9
11	7.4	7.0	278	278	1584	1566	1014	1002	698	688	264	264	9.4	7	54.4	54.4	16.5	16.5	364.2	364.2	290.9	286.4	64.4	64.4	1.0	0.9
12	7.4	7.1	242	240	1410	1400	902	896	438	438	170	164	3.3	6.9	58.7	58.7	14.4	12.8	317	314.4	198.4	182.6	78.6	80.2	0.8	0.6
13	8.3	7.9	300	284	1242	1234	795	790	538	538	182	182	20.3	20.3	52.3	51.2	16.5	14.7	393	372	136.4	136.7	56.2	54.2	0.6	0.6
14	7.6	7.5	334	334	1312	1300	840	832	538	530	178	166	22.7	28.1	60.3	57.8	20.5	16.8	437.5	437.5	142.5	142.5	90.4	88.2	0.7	1.0
15	7.5	7.4	228	240	1222	1220	782	781	532	512	158	158	33.4	28.5	34.3	30.3	13.9	7.9	298.7	314.4	170.6	162.8	44.6	40.6	0.9	0.9
16	7.9	7.6	172	172	686	680	439	435	266	256	88	88	11.2	8.8	42.1	42.1	8.1	8	225.3	225.3	72.4	72.4	50.2	48.2	1.0	1.1
17	7.6	7.3	372	368	1412	1412	904	904	500	496	164	164	22	21	70.6	66	14.2	12.2	487.3	482.1	128.7	128.7	90.8	88.8	1.0	1.0
18	8.3	8.1	312	306	1464	1460	937	934	476	430	160	160	18.6	7.4	52.4	51.4	8.7	8.7	408.7	400.9	106.1	108.9	52.2	48.8	0.7	0.7
19	7.6	7.4	288	276	1338	1322	856	846	432	432	148	140	15.2	20	64.1	70.8	12.8	12.8	377.3	361.6	148.3	138.9	64.4	70	0.6	0.7
20	7.2	7.0	202	202	1264	1270	809	813	398	392	132	122	16.6	21.2	66.2	58.7	18.7	18.7	264.6	264.6	204.2	204.2	62.2	62.2	0.7	0.7
21	7.7	7.2	222	190	2816	2812	1802	1800	584	512	144	116	54.5	54	154.7	154.7	22.6	20.5	290.8	248.9	520.4	502.2	130.4	130.4	1.2	1.0
22	7.3	7.3	282	276	2822	2300	1806	1472	788	762	178	172	83.4	80.8	76.9	76.8	28.6	22.2	369.4	361.6	296.8	290.2	88.8	88.8	0.9	0.9
23	7.4	7.1	262	266	1978	1908	1266	1221	890	890	216	204	85.2	92.4	64.5	60.4	24.8	24.8	343.2	348.5	354.2	350.8	138.4	136.8	0.8	0.7
24	7.0	7.0	320	320	3552	3600	2273	2304	1152	1118	332	312	78.5	82.3	174.2	170.2	32.4	30.4	419.2	419.2	580.4	560.2	150.2	148.6	1.2	1.0
25	7.4	7.4	290	288	1410	1410	902	902	440	436	166	160	6.2	8.9	58.1	56.2	8.1	8	379.9	377.3	150.3	150.3	51.2	50.2	0.7	0.7
26	7.7	7.5	342	340	1540	1534	986	982	450	454	130	126	30.5	33.9	62.3	60.1	18.1	18.1	448	445.4	136.4	144.9	70.4	68.8	0.7	0.6
27	7.7	7.5	296	292	1432	1430	916	915	520	510	120	120	53.5	51.1	54.2	50.6	10.8	10.8	387.8	382.5	150.5	148.9	82.4	80.4	0.6	0.6
28	7.7	7.4	310	304	1752	1748	1121	1119	668	642	142	142	76.1	69.8	64.3	60.1	16.2	16.2	406.1	398.2	222.2	200.8	80.4	80.4	0.9	0.8
29	8.2	7.6	532	512	4772	4772	3054	3054	1658	1638	640	622	14.6	20.6	74.5	71.5	45.6	42.2	696.9	670.7	572.8	568.9	222.6	222.6	0.7	0.7
30	7.2	7.2	254	254	1188	1188	760	760	310	300	114	112	6.2	4.9	80.2	78.3	16.8	16.8	332.7	332.7	86.5	80.8	72.6	70.8	0.9	0.9
31	7.2	7.2	210	210	760	880	486	563	298	298	116	116	2	2	33.3	33.3	14.2	10.7	275.1	275.1	118.3	110	66.2	60.4	0.8	0.7
32	7.2	7.1	288	288	1565	1560	1002	998	462	450	134	134	30.9	28	68.9	68.9	24.6	24.6	377.3	377.3	134.2	134.2	72.4	72.4	0.8	0.9
33	7.1	7.1	200	208	1432	1444	916	924	292	284	110	110	4.2	2.3	28.4	28.4	7.5	7.5	262	272.5	80.6	76.3	44.4	44.4	0.8	0.7
34	7.3	7.2	240	240	1210	1102	774	705	400	400	152	152	5	5	22.5	20.2	20.3	18.2	314.4	314.4	100.6	98.4	36.2	36.2	0.8	0.8
35	7.4	7.1	222	200	1178	1177	754	753	488	464	172	172	14.2	8.4	36.6	33.9	10.5	10.5	290.8	262	132.6	132.6	34.6	32.6	0.9	0.9
36	8.4	7.9	248	248	1996	1996	1277	1277	580	570	192	188	24.4	24.4	64.5	62.2	28.4	28.8	324.9	324.9	327.8	300.8	38.6	30.4	0.6	1.0
37	8.3	8.3	326	326	1526	1526	977	977	580	580	200	220	19.6	7.4	70.2	68.9	26.4	26.4	427.1	427.1	78.6	72.1	176.2	162.2	0.7	0.8

(*Contd.*)

Table 2 (*Contd.*)

Sl.	pH		Alkalinity		EC		TDS		TH		CaH		MgH		Na		K		HCO_3		Cl		SO_4		F	
No	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
38	8.5	8.4	266	266	1985	1985	1270	1270	688	678	186	192	54.3	48.2	34.5	28.7	16.4	10.8	348.5	348.5	392.5	388.7	22.2	22.8	0.7	0.9
39	8.4	8.2	246	246	1846	1834	1181	1174	644	630	198	220	36.3	19.6	28.7	19.9	14.4	12.2	322.3	322.3	300.5	298.7	18.6	16.6	0.9	0.6
40	7.3	7.1	308	302	1986	1980	1271	1267	422	410	88	74	49.1	54.7	222.9	200	25.5	21.9	403.5	395.6	272.6	267.5	92.4	92.4	1.0	0.9
41	7.4	7.2	328	318	1262	1260	808	806	398	384	142	138	10.5	9.6	25.4	20.7	8.8	7.3	429.7	416.6	92.4	90.2	46.8	42	1.2	1.1
42	7.4	7.4	324	308	4762	4752	3048	3041	1120	1100	288	302	97.4	84	220.9	220.9	28.4	26.4	424.4	403.5	1064	1020	182.8	168.4	0.9	1.0
43	7.3	7.3	436	436	2460	2340	1574	1498	564	540	128	120	59.4	58.4	158.4	158.4	30.5	28.8	571.2	571.2	354.6	318.9	128.6	128.6	1.5	1.4
44	8.2	7.3	398	388	2236	2236	1431	1431	520	520	158	144	30.5	39	118.4	100	30.9	28.8	521.4	508.3	316.8	300.2	96.2	90.2	0.6	0.8
45	8.2	8.2	422	416	2600	2312	1664	1480	666	664	92	92	106	105.5	144.7	140.2	22.6	18.8	552.8	545	348.4	346.7	126.4	118.2	1.2	1.0
46	8.1	7.6	332	330	2376	2356	1521	1508	688	678	96	92	108.9	108.9	68.9	68.9	12.2	10.2	434.9	432.3	270.6	272.8	224.6	224.6	1.0	0.9
47	7.9	7.9	448	448	2398	2240	1535	1434	626	600	164	142	52.6	59.6	118.1	118.1	32.1	22.8	586.9	586.9	136.2	130.7	178.4	178.4	0.7	0.8
48	8.1	8.1	382	356	2384	2231	1526	1428	658	616	248	238	9.4	5.3	62.1	62.1	12.2	10	500.4	466.4	254.6	250.8	208.4	208.4	0.9	0.9
49	8.3	8.1	420	420	2212	2212	1416	1416	498	472	120	128	48.2	37	220.6	210.7	28.2	28.2	550.2	550.2	210.3	210.3	250.2	250.2	0.7	0.7
50	7.7	7.2	452	450	4986	4966	3191	3178	1680	1636	520	444	92.7	128.1	188.4	180	40.4	40.4	592.1	589.5	678.1	700.5	333.2	32.8	0.6	0.8
51	7.3	7.2	398	398	5123	5102	3279	3265	1786	1720	672	614	26.2	45.4	94.3	94.3	50.5	44.7	521.4	521.4	666.5	660.1	320.2	316	1.5	1.2
52	7.2	7.2	278	266	1978	1978	1266	1266	454	410	118	118	38.7	28	188	179.9	24.4	24.4	364.2	348.5	150.5	148.4	228.4	216.8	0.6	0.6
53	7.9	7.9	298	298	1462	1462	936	936	512	532	188	162	10.3	31	34.2	30.2	12.6	8	390.4	390.4	140.6	138.7	56.2	54.2	0.9	0.9
54	6.9	6.9	220	220	2413	2340	1544	1498	894	832	352	330	3.7	1.9	32.2	32.2	14.6	12.1	288.2	288.2	348.2	327.7	84.6	84.6	0.7	0.8
55	7.9	7.8	322	322	1280	1280	819	819	288	222	98	86	10.5	1.8	70.1	70.1	24.7	20.8	421.8	421.8	126.5	120.2	32.4	33.4	1.1	0.9
56	7.6	7.3	220	198	1157	1152	740	737	358	354	126	118	10.5	14.4	28.4	20	14.2	13.8	288.2	259.4	118.6	116.2	48.2	44.8	0.7	0.6
57	7.0	7.0	192	190	1442	1442	923	923	480	480	172	178	12.3	8.6	40.1	38.7	10.3	9.8	251.5	248.9	158.6	154.3	44.6	44.6	0.7	0.7
58	8.3	7.4	268	258	1680	1649	1075	1055	478	478	158	142	20.3	30	36.2	32.9	20.6	17.4	351.1	338	126.4	124	70.4	74.4	0.7	0.7
59	8.2	8.2	322	322	1505	1505	963	963	464	444	172	168	8.4	6	48.6	40.9	26.6	20.4	421.8	421.8	126.3	126.3	62.4	60.6	1.1	0.8
60	8.1	8.1	292	290	1488	1480	952	947	498	452	186	176	8.2	3	32.4	30.8	18.5	16.9	382.5	379.9	134.4	134.4	66.8	66.8	1.2	1.2
61	8.2	7.9	288	288	1398	1388	895	888	342	342	130	130	4.2	4.2	90.3	90.3	28.3	24.4	377.3	377.3	96.6	92.1	114.8	110.6	1.0	1.0
62	8.1	8.1	248	248	2013	2000	1288	1280	682	682	150	132	74.7	85.6	52.5	52.5	18.2	13	324.9	324.9	276.2	260.4	94.6	90.4	0.9	0.7
63	8.2	8.2	346	330	2896	2900	1853	1856	1024	988	352	342	35.2	32.6	62.4	62.4	16.8	15.4	453.3	432.3	292.3	300.1	124.2	120.4	1.0	0.8
64	8.2	7.6	308	312	1998	1888	1279	1208	578	578	222	222	5.7	5.7	44.6	40.1	12.2	10.2	403.5	408.7	238.6	236.9	150.6	148.8	1.0	1.0
65	8.0	8.0	266	258	1232	1232	788	788	322	310	118	108	6.6	9.8	68.4	61.8	18.1	16.1	348.5	338	70.6	64.2	30.2	30.2	0.9	0.9
66	7.4	7.4	300	300	1994	1988	1276	1272	558	552	168	152	33.6	41.9	130.2	120	26.6	20.7	393	393	226.5	220.7	104.6	98.8	1.1	1.1
67	7.2	7.0	252	244	1520	1520	973	973	498	478	180	176	11.8	9.4	42.4	38.4	11.8	8.6	330.1	319.6	210.1	208.9	66.4	60.6	0.6	0.9
68	7.4	7.0	268	256	1522	1544	974	988	424	422	164	164	3.5	3	86.2	81.9	12.2	8.9	351.1	335.4	176.6	174.2	62.4	58	0.7	0.7
69	7.5	7.4	252	252	1328	1321	850	845	402	398	152	138	5.5	13	72.1	62.3	16.3	11.5	330.1	330.1	172.1	172.1	60.4	58.6	1.0	0.9
70	7.1	6.9	164	152	1638	1630	1048	1043	420	384	128	114	24.4	24.1	114.5	112.8	22.6	20.7	214.8	199.1	240.6	238	90.6	88.2	0.9	1.0
71	7.7	7.2	280	272	1552	1532	993	980	432	410	126	120	28.5	26.8	98.4	91.7	10.2	7.5	366.8	356.3	146.3	140.9	190.8	168.8	1.0	0.9

All parameters expressed in mg/l except pH and EC; where EC is expressed in µS/cm, pH has no units.
Sl.No. Sampling location number, P1: Pre-monsoon season, P2: Post-monsoon season.

Table 3: The water quality standards, ideal value and weightage factors for calculating water quality index

Parameter	*Standard* S_n *and* V_s	*Ideal value* V_i	*Weightage factor* W_i
pH	8.5	7	0.1384
Alkalinity	200	0	0.0059
TDS	500	0	0.0024
TH	300	0	0.0039
CaH	75	0	0.0157
MgH	30	0	0.0392
Cl	250	0	0.0047
SO_4	200	0	0.0059
F	1.5	0	0.7840

Figure 3: Spatial distribution of TDS concentration during pre-monsoon season.

results (Table 2), it was observed that the pH varies from 6.8 to 8.5 in pre-monsoon water samples, while in the post-monsoon season it ranges from 6.9 to 8.4 indicating well permissible limits. Alkalinity varies from 164 to 532 mg/l during the pre-monsoon season and ranges from 152 to 512 mg/l during post-monsoon season in the study area. Dissolved carbon dioxide, bicarbonate and carbonates produce alkalinity in water. Carbonates and bicarbonates are being estimated from the alkalinity values (Hem, 1985). Bicarbonates vary in the study area from 214 to 696 mg/l during pre-monsoon season while in post-monsoon water samples it ranges between 199 and 670 mg/l. More than 87% of the water samples in the study area contains alkalinity values higher than the desirable limit during pre-monsoon season, while in post-monsoon season it was observed that 86% of samples indicating above the limits. The high alkalinity values in the study area are raised due to the action of carbonates on the basic materials in the soil which gives an unpleasant taste to water.

Electrical conductivity (EC) indicates the capacity of electrical current that passed through the water, which in

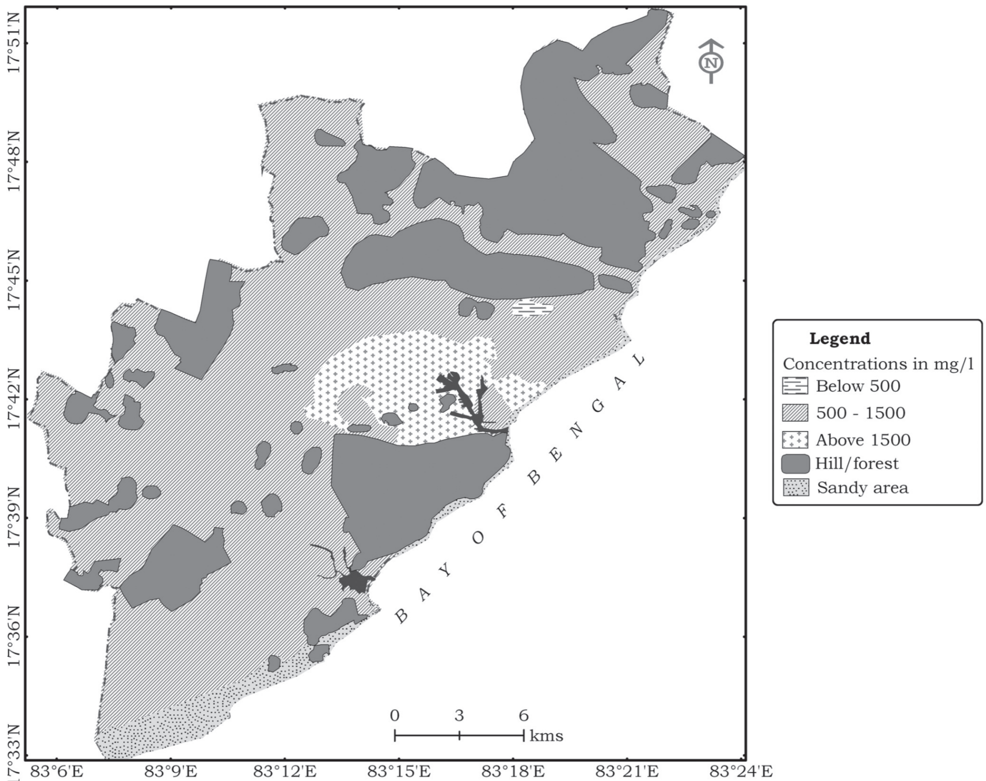

Figure 4: Spatial distribution of TDS concentration during post-monsoon season.

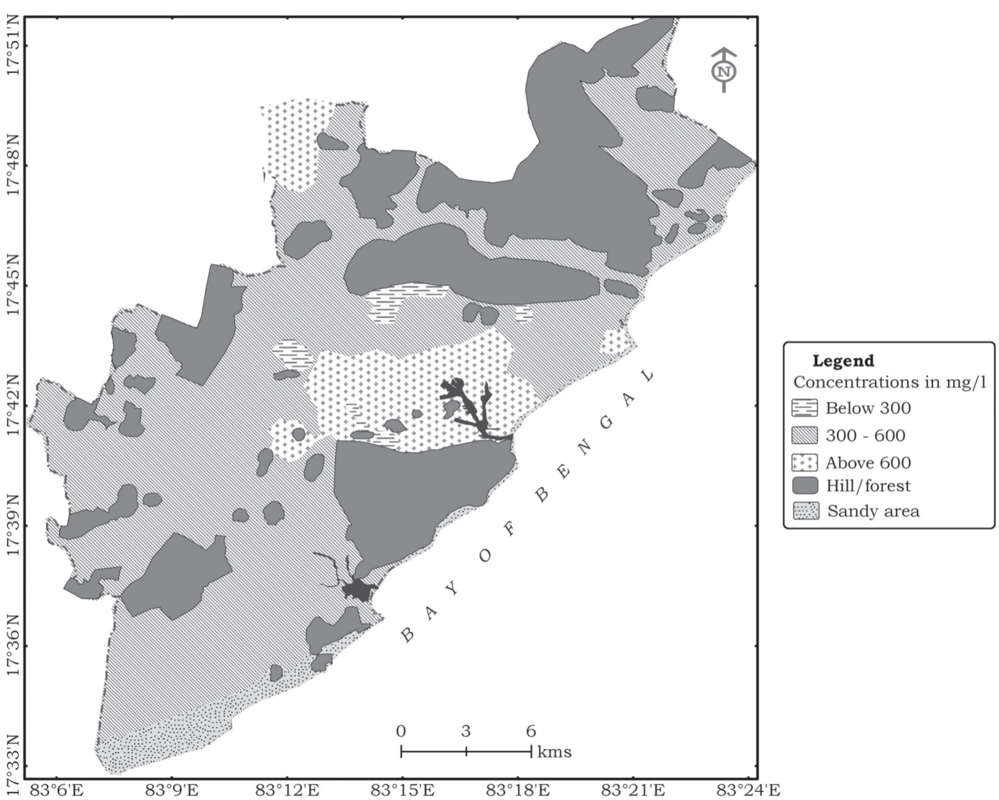

Figure 5: Spatial distribution of TH concentration during pre-monsoon season.

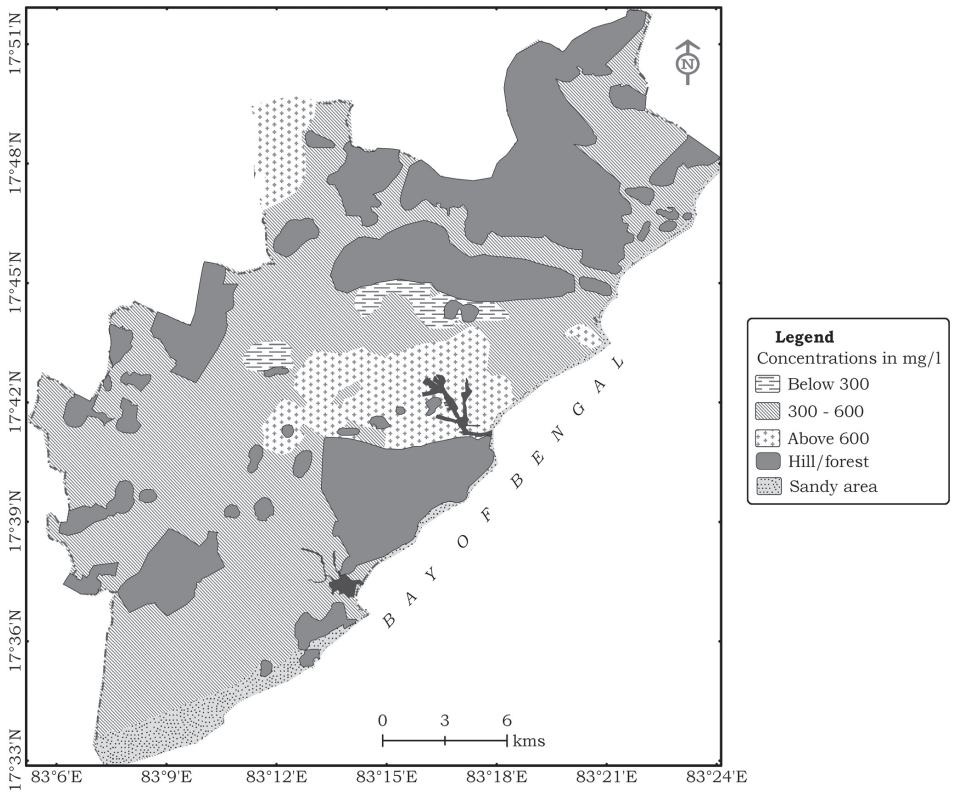

Figure 6: Spatial distribution of TH concentration during post-monsoon season.

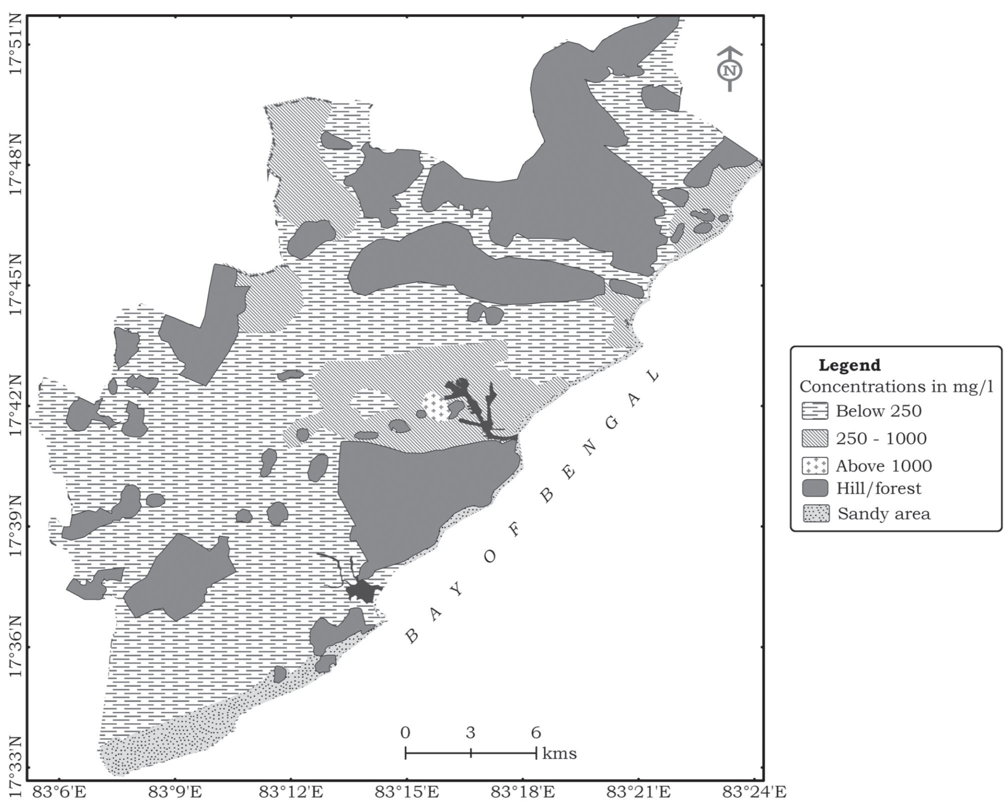

Figure 7: Spatial distribution of Cl concentration during pre-monsoon season.

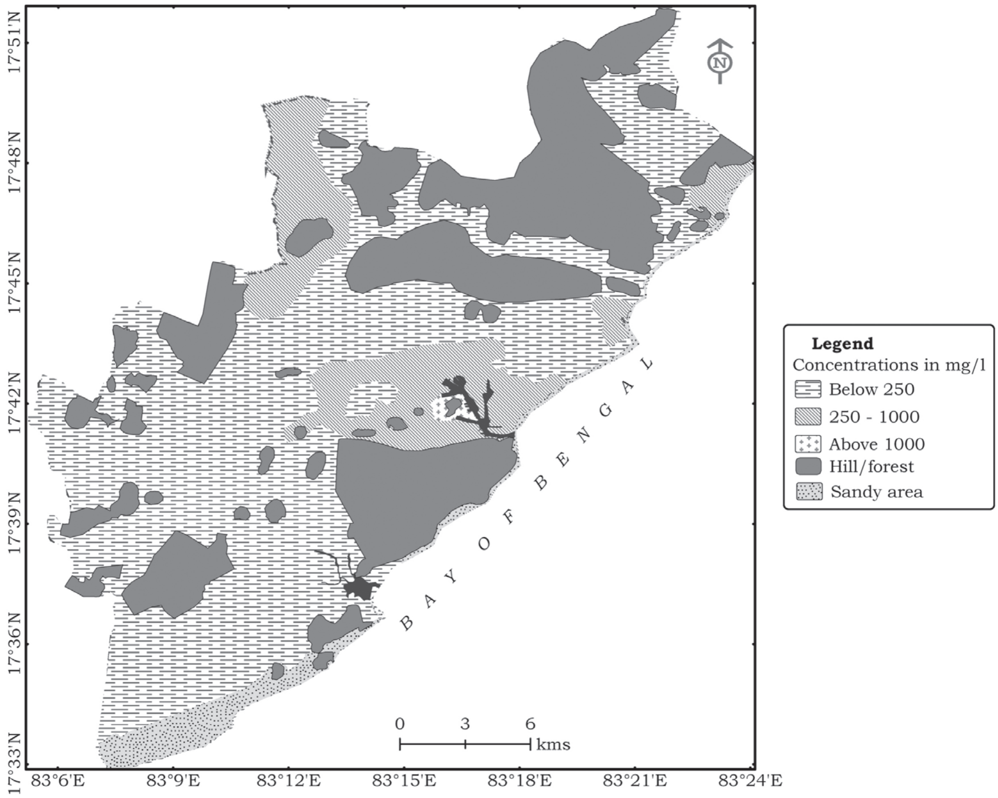

Figure 8: Spatial distribution of Cl concentration during post-monsoon season.

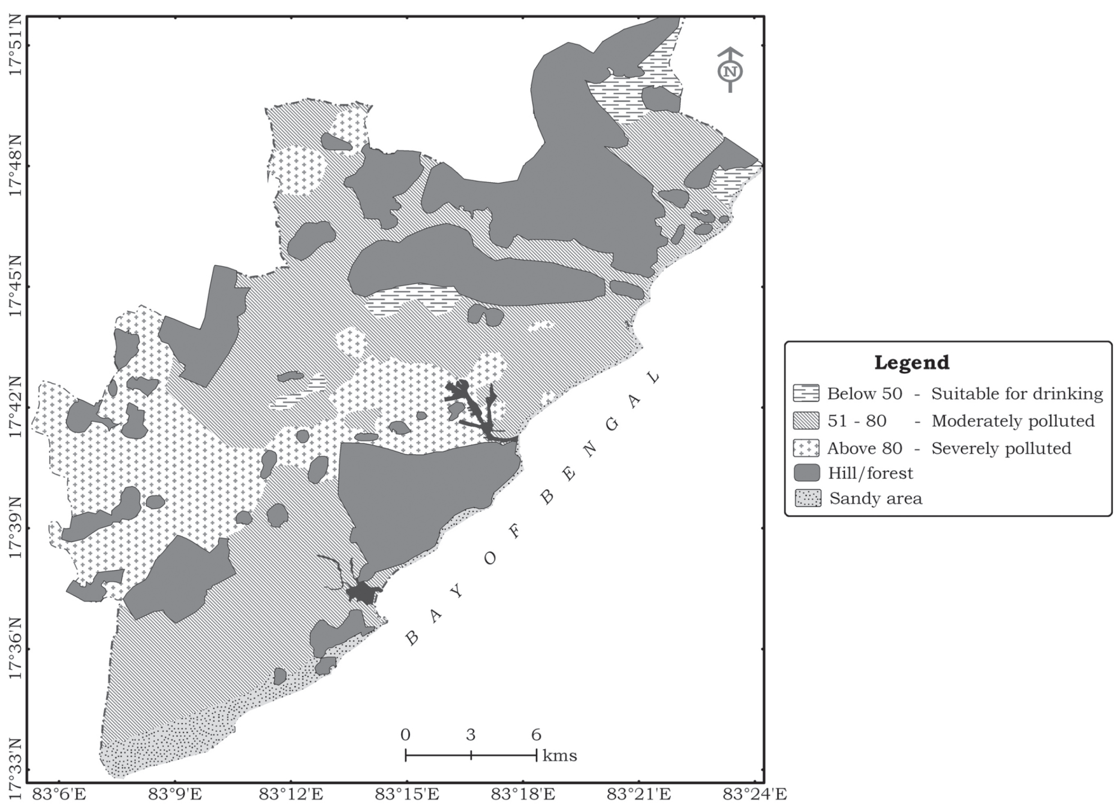

Figure 9: Spatial distribution of WQI during pre-monsoon season.

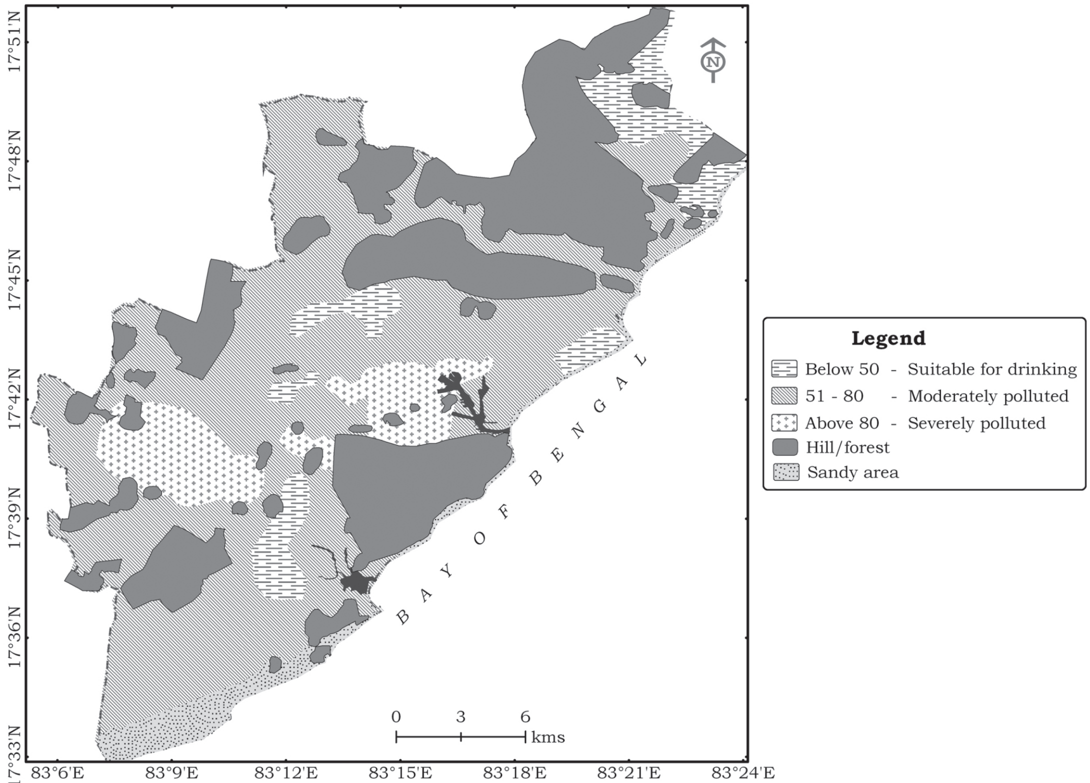

Figure 10: Spatial distribution of WQI during post-monsoon season.

turn is related to concentration of ionized substances present in it. Most dissolved inorganic substances present in the water are in ionized form and contribute to electrical conductivity. In the study area, EC varies from 686 to 5123 μS/cm for pre-monsoon water samples, while it ranges between 150 and 5102 μS/cm for post-monsoon samples. Electrical conductivity of water is considered to be an indication of the total dissolved salt content (Hem, 1985). A rapid estimation of total dissolved solids (TDS) content in water is obtained by EC. In the pre-monsoon season, the mean values of TDS are varied from 439 to 3279 mg/l whereas during the post-monsoon the values ranges between 96 and 3265 mg/l. Except two samples, remaining all water samples during pre-monsoon in the study shows above the limits of BIS, whereas in post-monsoon season one sample only falls under permissible limits. Water containing more than 500 mg/l of TDS is not considered potable. However, it is denoted that highly mineralized water is also used in the absence of good quality water. In this region, on the other hand 1500 mg/l is accepted as the maximum permissible limit for drinking water (BIS, 2003). The GIS analysis reveals that 83% (pre-monsoon) and 90% (post-monsoon) area under study contains TDS<1500 mg/l (Figures 3 and 4) and is safe for drinking. The remaining area is not found suitable owing to high TDS concentration, which is mainly due to seepage of surface water from open drains and their proximity to the industrial area and seacoast.

Total hardness (TH) is a measure of the capacity of water to the concentration of calcium and magnesium in water and is usually expressed as the equivalent of $CaCO_3$ concentration. In the present study, TH of the pre-monsoon waters ranges between 266 and 1786 mg/l, while it varies from 222 to 1720 mg/l in post-monsoon waters. Ninety four percent of area samples have more than 300 mg/l during pre-monsoon season and 83% of area samples during post-monsoon period, falling under hard water category (Figures 5 and 6). In the absence of alternative source of water, the maximum permissible limit is 600 mg/l (BIS, 2003). In all 25% of total samples with hardness more than 600 mg/l are recorded at north-west and surrounding Harbour regions, may be due to the natural accumulation of salts from contact with soil or it may enter from direct pollution by human activities. Most of the geological material aquifers are composed of calcium. It was present in groundwater as a material of suspension where calcium bicarbonate is the prime cause for the hardness in water. In groundwater the calcium content generally exceeds the magnesium content (CGWB, 2005). The values of both the seasons showed that calcium hardness (CaH) was high in concentration for all the samples. The maximum CaH value was observed at Mindi (sl.no. 51) and minimum value was at Narava (sl.no. 40) same for both the seasons. Excessive calcium in drinking water is linked to the formation of concretions in the body and may cause gastro intestinal diseases and stone formations. The magnesium hardness (MgH) of the pre-monsoon waters ranges between 2 and 109 mg/l while it varies from 2 to 128 mg/l in post-monsoon waters. From the analysis it is observed that 65% of the pre-monsoon water samples and 62% of the post-monsoon water samples are suitable for drinking purpose.

Higher values of sodium (Na) are found in the groundwater in the areas of saline water intrusion. Discharge of effluents such as domestic and industrial etc. onto the ground is another source of sodium in water. In general, sodium salts are not actually toxic substances to humans because of the efficiency with which mature kidneys excrete sodium. Excessive intake of sodium chloride causes vomiting and hypertension. In the pre-monsoon season, the values of Na are varied from 22.5 to 222.9 mg/l whereas during the post-monsoon season these values range between 19.9 and 220.9 mg/l. Potassium (K) is slightly less common than sodium in igneous rocks, but more abundant in all the sedimentary rocks. Potassium is an essential element for plants and animals. The elements present in plant material are lost from agricultural soil by crop harvesting and removal as well as leaching and runoff on organic residues. Potassium varies in the study area from 7.5 to 50.5 mg/l during pre-monsoon season while in post-monsoon water samples it ranges between 6.6 and 44.7 mg/l.

Chloride (Cl) concentrations vary widely in natural water and it is directly related to mineral content of the water. It is known that the sea water intrusion is showing abnormal concentration of chloride. In potable water, the salt taste is produced by chloride concentrations. At concentrations above 250 mg/l, water acquires salty taste which is objectionable to many people. BIS prescribes 250 mg/l as permissible limit and 1000 mg/l as desirable limit in the absence of alternate source. The Cl concentration in the study area is less than 250 mg/l in 66% water samples and the remaining samples have less than 1000 mg/l which are recorded in pre-monsoon season. Similarly, post-monsoon water samples indicating that all water samples are falling within the desirable limits (1000 mg/l) except one sample. The maximum Cl concentration was observed at Harbour (sl.no: 42) for both the seasons. Spatial distribution of Cl concentration during pre- and post-monsoon seasons is shown in Figures 7 and 8 respectively. The higher chloride content in groundwater may be attributed to the presence of soluble chloride from rocks, saline intrusion, connate and juvenile water. The sulphate concentrations are varied from 18.6 to 333.2 mg/l during pre-monsoon season whereas in the post-monsoon season it ranges between 16.6 and 316 mg/l. From the analysis it is observed that about 10% of samples having sulphates value above 200 mg/l for both the seasons. During the pre-monsoon season lowest value was observed at Gollavllivanipalem (sl.no. 39) and the highest concentration was recorded at Chukkavanipalem (sl.no. 50). Similarly, in the post-monsoon water samples recorded the lowest and highest values at Gollavllivanipalem (sl.no. 39) and Mindi (sl.no. 51) respectively.

Fluoride is essential for human beings as a trace element and higher concentration of this element causes toxic effects. Concentration of fluoride between 0.6 and 1.0 mg/l in potable water protects tooth decay and enhances bone development (Kundu et al., 2001). BIS suggested permissible limit of fluoride in drinking water at 1.0 mg/l and tolerance range is upto 1.5 mg/l. Ingestion of water with fluoride concentration above 1.5 mg/l results in fluorosis, dental mottling and bone diseases. In the study area, fluoride ranges between 0.6 and 1.5 mg/l of pre-monsoon samples and in post-monsoon water samples it varied from 0.6 to 1.4 mg/l. Seventy nine percent of the wells have fluoride within 1.0 mg/l and 21% of the wells have fluoride in the range of 1.0 to 1.4 mg/l i.e. all the pre-monsoon water samples fall within the desirable limit of BIS. All of water samples in post-monsoon season fall within the desirable limits (1.5 mg/l) of BIS.

Water Quality Index

Water quality index computations were done from the equations and obtained results are given in Tables 4 and 5. The spatial distribution of the WQI map generated for the study area during pre- and post-monsoon seasons is presented in Figures 9 and 10. The distribution of WQI in the present study reveals that 9% of groundwater during pre-monsoon and 15.5% in post-monsoon season of the area (WQI<50) is suitable for human consumption. The remaining area of samples are ranging between moderately polluted to severely polluted condition that may be due to the domestic sewage from open drains, sea water intrusion and industrial effluents from various industries.

Table 4: Status of groundwater quality based on WQI in pre-monsoon season

Status of groundwater	*Sl.No*	*Location*	*WQI value*	*Status of groundwater*	*Sl.No*	*Location*	*WQI value*
Suitable	1	Kommadi	43.2		47	Coromandel Gate	77.2
	3	Rushikonda	44.8		48	Pilakavanipalem	75.2
	31	Madhawadhara	47.3		50	Chukkavanipalem	77.9
	33	NAD	49.8		52	Appanna Colony	55.5
	54	Akkireddypalem	38.2		53	BHPV Gate	71.6
	57	Autonagar	47.1		55	Sheelanagar	77.6
					56	Natayyapalem	64.4
Moderately polluted	2	Madhurawada	63.2		58	Tungalam	79.4
	4	Arilova	66.2		67	Pedagantyada	55.3
	5	China Gadili	79.8		68	Steel Plant	59.2
	6	M V P	75.2		69	Velampeta	68.2
	7	Venkojipalem	64.8		70	Pittavanipalem	74
	8	Maddilapalem	61.6				
	9	Pedawaltair	62	Severely polluted	17	Sitampeta	82.7
	10	Lawsons Bay	71.3		21	Jalaripeta	87.2
	11	East Point	68.2		23	Port Area	80.9
	12	China Waltair	65		28	Chavulamadam	93.2
	13	T.B. Hospital	65		29	Gnanpuram	80.2
	14	Respuvanipalem	67.1		37	Pulagalipalem	82.4
	15	Sitammadhara	77.3		39	Gollavllivanipalem	84
	16	Akkayyapalem	76.4		41	Airport	89.3
	18	RTC complex	74.2		42	Harbour	96.3
	19	Dwaraka Nagar	62.8		43	Malkapuram	99.9
	20	R K Beach	56.8		45	Gollalapalem	125
	22	I Town	76.8		46	Ganeshnagar	90.4
	24	Poorna Market	71.9		49	Mulagada	87.6
	25	Maharanipeta	64.3		51	Mindi	108
	26	Dabagardens	64.3		59	Vedurlanarava	82.7
	27	Allipuram	68.6		60	Shaniwada	99.9
	30	Kancharapalem	64.8		61	Rajupalem	89.5
	32	Marripalem	66.7		62	Old Gajuwaka	98.1
	34	Buchirajupalem	64.5		63	Zinc Gate	82.8
	35	Goplapatnam	70.1		64	Maruthinagar	83.2
	36	Vepagunta	72.2		65	New Gajuwaka	80
	38	Pendurthi	77.8		66	Yarada	98.8
	40	Narava	79.5		71	Desapatrunipalem	91.4
	44	Sriharipuram	65.4				

Conclusions

The present study deals with an integrated approach for quality groundwater in the coastal city of GVMC, Andhra Pradesh. Most of the groundwater samples show that the area is under hard water category. GIS provides an ideal platform for identifying the sources of pollution and mapping of concentration of pollutants. The distribution of thematic maps generated through GIS software in the present study is very useful for the assessment of water quality and its management. It can be concluded that the use of GIS can improve not only the analytical capabilities for assessment of water quality and management but also provide information on environmental pollution from research findings to the decision makers and the public at large scale.

Table 5: Status of groundwater quality based on WQI in post-monsoon season

Status of groundwater	*Sl.No*	*Location*	*WQI value*
Suitable	1	Kommadi	39.5
	3	Rushikonda	39.8
	8	Maddilapalem	50.0
	11	East Point	46.9
	12	China Waltair	49.4
	20	R K Beach	40.7
	33	NAD	47.3
	54	Akkireddypalem	39.9
	57	Autonagar	42.7
	67	Pedagantyada	37.9
	68	Steel Plant	47.9
Moderately polluted	2	Madhurawada	51.1
	4	Arilova	57.5
	5	China Gadili	67.2
	6	M V P	67.0
	7	Venkojipalem	56.2
	9	Pedawaltair	54.9
	10	Lawsons Bay	68.8
	13	T.B. Hospital	61.8
	14	Respuvanipalem	76.1
	16	Akkayyapalem	77.7
	17	Sitampeta	75.0
	18	RTC complex	72.7
	19	Dwaraka Nagar	61.4
	21	Jalaripeta	65.6
	22	I Town	77.7
	23	Port area	54.4
	24	Poorna Market	68.2
	25	Maharanipeta	52.3
	26	Dabagardens	59.4
	27	Allipuram	65.0
	29	Gnanpuram	77.5
	30	Kancharapalem	67.4
	31	Madhawadhara	54.7
	32	Marripalem	68.2
	34	Buchirajupalem	62.4
	35	Goplapatnam	56.8
	36	Vepagunta	75.7
	37	Pulagalipalem	76.0
	39	Gollavllivanipalem	70.4
	40	Narava	66.2
	41	Airport	76.4
	44	Sriharipuram	59.7
	46	Ganeshnagar	78.9
	47	Coromandel Gate	76.1
	48	Pilakavanipalem	75.2
	50	Chukkavanipalem	69.9
	52	Appanna Colony	51.4
	53	BHPV Gate	72.3
	55	Sheelanagar	66.1
	56	Natayyapalem	51.4
	58	Tungalam	68.0
	59	Vedurlanarava	79.1
	63	Zinc Gate	74.4
	64	Maruthinagar	77.1
	69	Velampeta	57.5
	70	Pittavanipalem	72.0
	71	Desapatrunipalem	69.0
Severely polluted	15	Sitammadhara	80.1
	28	Chavulamadam	84.7
	38	Pendurthi	80.0
	42	Harbour	91.9
	43	Malkapuram	101.4
	45	Gollalapalem	110.9
	49	Mulagada	83.0
	51	Mindi	81.5
	60	Shaniwada	100.1
	61	Rajupalem	81.0
	62	Old Gajuwaka	81.6
	65	New Gajuwaka	82.3
	66	Yarada	84.8

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