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Physico-Chemical and Spatial Analysis of Ground Water Quality in and Around the Industrial Hubs of Vijayawada City, A.P., India Using GIS

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Abstract:

Spatial variations of ground water quality were studied in and around the industrial estates of Vijayawada using Geographical Information System. Geographical information system is an efficient tool in finding out the spatial distribution of various physico-chemical and heavy metal parameters in ground water. Many studies on ground water quality have indicated that the industrial hubs throughout the world are partially responsible for the degradation of its quality causing long term consequences on the health and well being of the people living in the vicinity of these industries. The present paper is an attempt to identify any such consequences on the quality of ground water due to the industries surrounding in and around the Vijayawada city. Various Physico-chemical and heavy metal parameters were selected to analyse the ground water quality at twelve sampling stations for the three consecutive years. Water Quality Index was also calculated for all the sampling stations which were also indicated using GIS maps. The ground water quality maps for the parameters exceeding the BIS prescribed standards for drinking water were prepared using spatial distribution technique using GIS software (ArcGIS 10). As there is lack of ground water quality monitoring data in Vijayawada which is growing industrial hub and a new capital city of Andhra Pradesh with a population of 1034358 (census 2011), this study would meet the requirement as a baseline data for the future planning and development of the city.

Keywords: Ground water, Physico-chemical parameters, GIS etc.,

Introduction:

Ground water is the major source of drinking water supply for rural and urban areas around the world (Rawat and Singh 2018). The ground water resources become a major source of water to meet agricultural, commercial and industrial needs. Risk assessment of groundwater involves identifying and understanding the hazard associated with a particular occurrence, action or circumstance and determination of the probability for the occurrence of such hazards (Smith, 2001). Geographical Information System has emerged as an efficient and powerful tool in different fields of science over the last two decades (Konkey et al., 2014). The GIS has the ability to store, arrange, retrieve, classify, manipulate, analyze and present huge spatial data and information in a simple manner (Latha and Rao, 2010). The present study was carried out to monitory the ground water quality in the vicinity of industrial, agricultural, commercial and

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residential areas in and around Vijayawada city on a monthly basis for two seasonal cycles i.e., 24 months. The compliance criteria with Bureau of Indian Standards (BIS) was also evaluated and the parameters exceeding the BIS standards were represented using GIS maps of the study area.

Study Area:

The present study has been carried out at various industrial estates falling under the Vijayawada city limits in Krishna district.

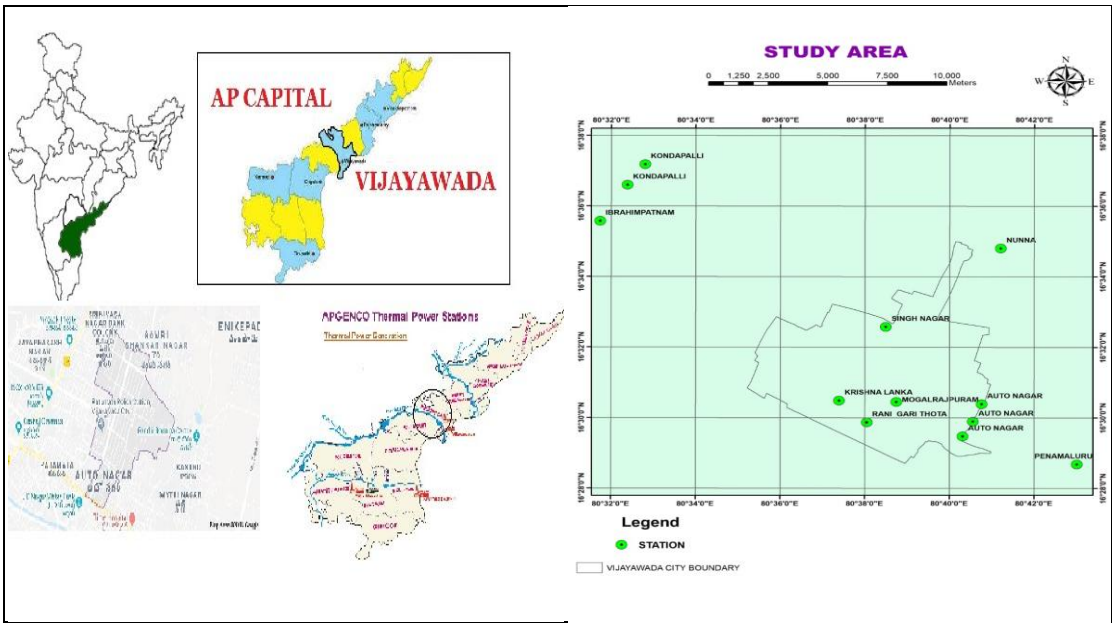

Figure 1: Location map of the Study area with all the twelve stations

Table 1: Sampling Stations

Sample No	Period Three Years	Location	Latitudes	Longitudes	Industry type
Station-I	June 2016-17 June 2017-18 June 2018-19	Autonagar	80.672375	16.4955067	Electroplating Alloys
Station-II		Autonagar	80.675945	16.4981883	Automobiles and Electrical work shops
Station-III		Autonagar	80.6783115	16.5044418	Automobile Body building works
Station-IV		Ibrahimpatnam	80.5264517	16.5935433	Chemical Industries

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Station-V		Kondapalli	80.53971	16.6127283	Power Plant
Station-VI		Kondapalli	80.543107	16.6252569	Power Plant
Station-VII		Mogalrajpuram	80.6457833	16.50744	Residential
Station-VIII		Nunna	80.6868116	16.5800622	Residential
Station-IX		Singhnagar	80.6415842	16.5800622	Residential
Station-X		Krishnalanka	80.6415842	16.5429339	Residential
Station-XI		Ranigarithota	80.7208067	16.473405	Residential
Station-XII		Penamaluru	80.6341267	16.4978067	Residential

Physicochemical analysis of ground water

The samples were analyzed various water quality parameters such as Temperature (^oC), pH, Total dissolved solids (TDS), Electrical conductivity (EC), Total hardness (TH), Calcium hardness (CH), Magnesium hardness (MH), Total alkalinity (TH), Fluorides (F^-), Sodium (Na^+), Potassium (K^+), Chlorides (Cl^-), Nitrates (NO_3^-), Phosphates (PO_4^-), Dissolved oxygen (DO), Biological oxygen demand (COD), Chemical oxygen demand (BOD), Cadmium, Copper, Ferrum, Lead, Nickel, Zinc using standards procedures described in NEERI Manual (1984).

Table 2: Physico-Chemical parameters and metals analysed

S.No	Parameter	Units	BIS STANDARDS
1	Temperature	^oC	26
2	pH	-	8.5
3	Total dissolved solids (TDS)	mg/L	500
4	Electrical conductivity (EC)	µmhos/cm	750
5	Total hardness (TH)	mg/L	300
6	Calcium hardness (CH)	mg/L	75
7	Magnesium hardness (MH)	mg/L	30
8	Total alkalinity (TH)	mg/L	200
9	Chlorides (Cl^-)	mg/L	250
10	Nitrates (NO_3^-)	mg/L	45
11	Phosphates (PO_4^-)	mg/L	0.5
12	Sodium (Na^+)	mg/L	200
13	Potassium (K^+)	mg/L	10

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14	Dissolved oxygen (DO)	mg/L	3
15	Biological oxygen demand (COD)	mg/L	5
16	Chemical oxygen demand (BOD)	mg/L	10
17	Cadmium	mg/L	0.003
18	Copper	mg/L	0.05
19	Ferrum	mg/L	0.3
20	Lead	mg/L	0.01
21	Nickel	mg/L	0.02
22	Zinc	mg/L	5

Results:

Any appropriate water quality management measures need reliable quantitative information on water quality parameter behavior (Hucche and Bandela, 2016). The ground water quality was analysed for the selected physico-chemical and heavy metal parameters for three consecutive years (i.e., from June 2016 to June 2019) at twelve sampling stations. The annual means were calculated using with standard deviation which is presented in the table below:

GROUND WATER ANNUAL MEANS ± SD

Table : Annual Mean±SD for ground water for the year 2016-17

S.No	Parameters	GROUND WATER Mean±SD of 2016-17											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Temperature (°C)	27.942 ±2.326	29.25± 0.934	28.817 ±1.039	28.317 ±1.104	28.817 ±0.86	29.392 ±1.152	26.942 ±2.1	26.742 ±1.923	27.05± 1.996	27.225 ±1.769	27.458 ±1.747	28.317 ±2.849
2	pH	6.817± 0.147	7.033± 0.29	7.542± 0.323	7.525± 0.201	7.725± 0.148	7.192± 0.3	7.525± 0.201	7.542± 0.323	7.925± 0.148	7.567± 0.242	7.642± 0.207	7.908± 0.138
3	Total Dissolved Solids	2964.167±295.051	4483.333±345.292	2902.917±714.793	4429.333±606.144	4308.5 ±646.176	4437.833±728.887	3500± 893.41	735.333±119.381	1027.5 ±359.422	775.5± 98.44	1926.5 ±202.955	1905± 274.64
4	Electrical Conductivity (µmhos/cm)	4424.129±440.375	6691.542±515.36	4332.711±1066.856	6610.945±904.692	6430.597±964.442	6623.632±1087.891	5384.615±1374.477	1131.282±183.663	1580.769±552.957	1193.077±151.446	2963.846±312.238	2930.769±422.523
5	Total Hardness	2896.167±1385.863	2396.167±881.648	2482.167±672.906	1912.333±128.164	2396.167±881.648	1571.25±1066.694	2011.417±554.95	506.5± 32.475	1628.333±206.607	227.417±65.915	1477.167±125.673	2364.583±277.243
6	Calcium Hardness	59.333 ±14.926	57.417 ±11.658	53±14.161	38.833 ±10.098	33.333 ±7.82	55.5±8.174	50.25± 14.833	249.333±14.048	36.75± 10.393	132.417±9.977	49.167 ±15.59	32.75± 12.352
7	Magnesium Hardness	2836.833±1395.189	2338.75±878.916	2429.167±684.01	1873.5 ±133.623	2362.833±877.048	1515.75±1066.256	1961.167±557.722	257.167±37.416	1591.583±205.427	95±66.923	1428± 112.999	2331.833±282.653
8	Total Alkalinity	560.083±153.181	509.167±103.251	456.833±141.599	456.833±141.599	635.5± 120.894	596.667±126.055	462.833±80.693	482.417±102.89	498.917±104.297	151.167±28.47	670.833±122.422	637±129.374
9	Chlorides	1188.963±138.149	902.448±100.843	720.963±138.149	515.448±100.843	680.539±433.539	546.481±194.118	176.417±88.511	1670.522±2831.799	761.297±137.516	74.667 ±14.189	643.814±222.294	490.066±170.709
10	Nitrates	0.416± 0.515	1.883± 3.046	1.921± 0.79	1.514± 0.825	30.45± 7.564	22.45± 7.564	0.493± 0.577	1.852± 3.069	1.725± 0.704	1.518± 0.821	32.208 ±8.384	5.015± 6.738
11	Phosphates	0.292± 0.183	0.386± 0.083	0.262± 0.094	0.282± 0.094	0.543± 0.187	0.413± 0.187	0.457± 0.208	0.348± 0.068	0.256± 0.047	0.341± 0.238	0.455± 0.079	0.209± 0.159
12	Sodium	576.225±104.002	558.108±80.066	388.125±91.852	530.817±110.508	888.525±182.298	673.793±82.117	577.575±124.67	609.075±72.33	368.483±110.421	64.583 ±19.024	85.667 ±13.753	68.167 ±4.97

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13	Potassium	91.25±5.32	73.483±8.251	57.658±12.296	47.892±12.46	55.05±13.715	58.275±13.329	71.225±20.696	76.325±6.835	51.658±7.518	9.25±3.467	51.442±18.877	55.967±18.836
14	DO	0.983±0.493	0.767±0.396	4.917±0.484	3.9±0.497	4.458±0.472	4.683±0.471	1.367±1.092	2.542±2.055	4.358±0.739	4.008±0.637	4.392±0.558	5.525±1.353
15	BOD	0.508±0.657	0.367±0.403	0.792±0.825	1.683±0.677	1.767±0.996	2.167±0.996	0.975±0.349	1.658±1.232	0.458±0.438	1.05±0.579	1.433±0.74	1.833±0.74
16	COD	10.735±5.813	9.891±4.845	7.865±3.186	6.6±5.953	8.503±5.48	8.903±5.48	8.741±6.608	5.141±3.4	6.748±1.761	7.057±2.813	6.285±3.022	6.685±3.022
17	Cadmium	0.003±0.001	0.002±0.001	0.003±0.001	0.002±0.001	0.008±0.005	0.008±0.003	0.003±0.001	0.008±0.006	0.002±0.001	0.013±0.005	0.014±0.008	0.002±0.001
18	Copper	0.023±0.007	0.037±0.008	0.026±0.009	0.018±0.011	0.003±0.001	0.025±0.004	0.036±0.007	0.026±0.007	ND	ND	ND	ND
19	Ferrum	0.337±0.16	0.015±0.009	0.015±0.009	0.102±0.09	0.031±0.017	0.152±0.109	0.015±0.013	0.026±0.011	0.153±0.094	0.056±0.014	0.216±0.117	0.115±0.073
20	Lead	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21	Nickel	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22	Zinc	0.054±0.01	0.337±0.291	0.02±0.031	0.013±0.006	0.015±0.005	0.025±0.01	0.182±0.256	0.069±0.083	0.014±0.006	0.047±0.012	0.012±0.007	0.013±0.006

(All the values are expressed in mg/L except where specifically mentioned)

Table : Annual Mean±SD for ground water for the year 2017-18

S.No	Parameters	GROUND WATER Mean±SD of 2017-18											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Temperature (°C)	27.292±1.462	28.608±0.909	28.717±0.877	28.467±0.935	29.692±0.643	30.192±1.024	27.25±1.664	27.858±2.43	28.167±1.265	28.183±1.313	29.075±0.897	28.992±1.8
2	pH	7.042±0.323	7.067±0.242	7.525±0.201	7.542±0.323	7.642±0.207	7.3±0.2	7.375±0.336	7.367±0.239	7.85±0.207	7.483±0.237	7.542±0.294	7.542±0.323
3	Total Dissolved Solids	2891.083±432.155	4580.25±224.905	4516.167±577.844	4514.167±577.844	4467.167±577.844	4537.167±577.844	3391.667±832.803	753.083±104.786	951.583±132.045	845.667±87.904	1422.167±168.981	1945±455.774
4	Electrical Conductivity (µmhos/cm)	4315.05±645.008	6836.194±335.68	6740.547±862.454	6737.562±862.454	6667.413±862.454	6771.891±862.454	5217.949±1281.235	1158.59±161.209	1463.974±203.146	1301.026±135.237	2187.949±259.971	2992.308±701.19
5	Total Hardness	3738.333±1352.182	1779±724.309	2684.167±672.906	2794.75±691.053	2478.917±729.863	2031.25±1066.694	1871.5±454.173	508.25±55.163	1564.75±167.158	213.667±46.736	1501.833±159.865	2298.25±224.355
6	Calcium Hardness	46.333±14.926	49.417±13.534	40.583±9.977	34.25±6.917	55.5±8.174	31.5±10.579	53.917±11.164	250.917±16.082	42.917±10.9	142.583±8.67	40±12.577	51.333±10.03
7	Magnesium Hardness	3692±1357.638	1729.583±718.133	2643.583±668.01	2760.5±689.023	1723.5±723.197	1999.75±1063.475	1817.583±454.676	257.333±50.766	1521.833±165.427	71.083±47.027	1461.833±161.805	2246.917±219.298
8	Total Alkalinity	449.5±141.909	478.333±99.852	494.167±103.251	494.167±103.251	675.833±132.095	637±129.374	560.083±153.181	509.167±103.251	456.833±141.599	148.5±24.284	635.5±120.894	596.667±126.055
9	Chlorides	1176.263±138.149	1670.522±2831.799	761.297±137.516	1283.522±2831.799	738.206±433.926	490.066±170.709	277.583±97.388	1696.829±2822.867	731.38±140.935	71.5±12.34	703.789±443.185	546.443±198.692
10	Nitrates	0.592±0.5	1.783±3.046	1.821±0.79	1.414±0.825	33.017±9.251	25.017±9.251	0.706±0.488	1.883±3.046	1.863±0.792	1.456±0.814	33.283±7.548	1.353±0.602
11	Phosphates	0.775±0.181	0.348±0.089	0.293±0.04	0.272±0.043	0.565±0.08	0.435±0.08	0.623±0.262	0.391±0.043	0.231±0.065	0.23±0.053	0.461±0.116	0.331±0.116
12	Sodium	665.133±92.387	633.533±23.173	462.733±98.028	620.517±89.07	843.35±185.164	638.712±75.022	679.9±81.45	618.075±29.524	486.508±69.361	69.167±18.235	78.167±16.574	67.583±10.104
13	Potassium	54.475±6.521	78.65±7.374	48.183±6.46	38.967±6.532	43.2±16.968	51±17.537	66.025±16.505	72.625±13.76	51.075±12.786	10.083±4.699	43.192±11.346	47.267±14.958
14	DO	1.325±1.491	1.033±1.136	5.067±0.491	4.092±0.466	4.7±0.475	4.883±0.484	0.658±0.574	0.592±0.368	4.725±0.439	3.725±0.449	4.267±0.41	4.525±0.433
15	BOD	0.975±0.349	1.658±1.232	0.458±0.438	1.05±0.579	1.433±0.74	1.833±0.74	0.917±0.451	0.992±0.994	0.875±0.785	1.583±0.791	2.283±0.656	2.175±1.09

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16	COD	8.257±5.968	4.563±2.257	6.882±1.764	8.839±2.819	7.361±3.887	7.761±3.887	10.822±6.273	8.233±5.009	6.604±2.444	6.435±3.499	6.749±3.665	7.149±3.665
17	Cadmium	0.003±0.002	0.003±0.001	0.008±0.006	0.002±0.001	0.011±0.007	0.014±0.008	0.003±0.001	0.008±0.007	0.002±0.001	0.008±0.007	0.01±0.008	0.004±0.003
18	Copper	0.025±0.004	0.036±0.007	0.026±0.007	0.019±0.011	0.008±0.008	0.023±0.007	0.037±0.008	0.026±0.009	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
19	Ferrum	0.365±0.098	0.015±0.013	0.015±0.004	0.072±0.044	0.031±0.017	0.108±0.082	0.015±0.009	0.031±0.017	0.159±0.079	0.055±0.016	0.271±0.109	0.156±0.076
20	Lead	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21	Nickel	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22	Zinc	0.054±0.013	0.082±0.09	0.019±0.01	0.012±0.003	0.02±0.007	0.021±0.01	0.196±0.261	0.022±0.023	0.013±0.006	0.041±0.014	0.022±0.035	0.019±0.01

(All the values are expressed in mg/L except where specifically mentioned)

Table : Annual Mean±SD for ground water for the year 2018-19

S.No	Parameters	GROUND WATER Mean±SD of 2018-19											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Temperature (°C)	28.175±1.884	28.633±1.403	29.45±0.605	28.633±0.734	28.85±1.102	29.433±1.064	27.292±1.462	28.608±0.909	28.717±0.877	28.467±0.935	29.692±0.643	30.192±1.024
2	pH	6.933±0.352	7.025±0.29	7.442±0.168	7.55±0.318	7.633±0.15	7.042±0.247	7.067±0.277	7.325±0.28	7.692±0.239	7.55±0.294	7.375±0.249	7.658±0.235
3	Total Dissolved Solids	1471.667±214.299	1905±274.64	18029.167±1395.157	12720.833±5091.323	6675±301.888	2147.5±483.061	3391.667±832.803	796±158.41	1014.917±387.469	757.833±67.881	2147.5±483.061	2892.417±419.996
4	Electrical Conductivity (µmhos/cm)	2264.103±329.691	2930.769±422.523	27737.179±2146.395	19570.513±7832.805	10269.231±464.443	3303.846±743.17	5217.949±1281.235	1224.615±243.708	1561.41±596.106	1165.897±104.432	3303.846±743.17	4449.872±646.147
5	Total Hardness	3448.333±829.522	1838.667±621.001	2600±606.793	2256.25±642.21	2245.833±404.611	1839.583±985.175	2794.75±691.053	522.917±96.187	1838.667±621.001	231±77.265	1779±724.309	2684.167±672.906
6	Calcium Hardness	51.75±11.561	47.833±16.32	37.917±10.22	37.25±10.446	48±13.578	40.333±14.393	50.417±12.258	231.167±58.896	39.667±12.565	141.25±27.297	49.75±13.666	40.667±14.531
7	Magnesium Hardness	3396.583±833.312	1790.833±612.893	2562.083±609.543	2219±643.15	2197.833±407.051	1799.25±980.824	2744.333±685.25	291.75±120.548	1799±616.019	89.75±81.75	1729.25±725.066	2643.5±665.368
8	Total Alkalinity	508±194.883	507.083±102.114	469.167±66.48	469.167±66.48	665.417±137.236	624.75±136.204	506.25±146.976	497.583±34.836	480.5±119.823	163.167±27.008	696.583±110.931	659.083±108.168
9	Chlorides	1679.733±178.508	785.208±204.964	731.233±165.587	426.008±206.086	772.498±397.499	629.029±394.084	490±130.155	451.976±211.231	755.023±172.769	71.333±10.378	825.558±506.251	618.962±379.758
10	Nitrates	0.868±0.475	1.841±3.06	1.879±0.792	1.473±0.839	30.183±9.175	22.183±9.175	0.65±0.505	1.781±3.064	4.608±4.047	1.402±0.854	23.15±13.45	1.821±0.79
11	Phosphates	0.478±0.36	0.379±0.097	0.318±0.055	0.313±0.069	0.632±0.122	0.502±0.122	0.619±0.302	0.353±0.11	0.301±0.067	0.243±0.146	0.568±0.177	0.508±0.122
12	Sodium	408.817±231.806	659.742±55.831	523.658±143.196	532.742±113.757	797.408±152.3	764.98±143.264	215.417±33.727	77.583±16.234	426.417±120.032	60±23.246	75.5±17.064	66.583±9.671
13	Potassium	74.883±19.043	70.483±11.795	50.475±10.232	47.442±14.365	50.308±15.511	47.842±14.967	60.75±14.137	67.467±17.09	42.85±5.881	7.917±2.275	37.425±3.329	37.3±8.664
14	DO	0.942±1.057	0.658±0.46	4.675±0.475	3.7±0.471	4.233±0.446	4.483±0.49	0.758±0.36	4.792±0.478	3.775±0.475	4.3±0.435	4.533±0.444	5.992±1.2
15	BOD	1.083±0.262	1.75±1.368	0.6±0.439	1.175±0.654	1.642±0.761	1.667±0.733	1.6±1.212	1.942±0.938	1.283±0.912	1.708±0.713	2.158±0.537	1.883±0.687
1	COD	10.608	7.026±	5.718±	6.667±	7.344±	8.322±	13.433	10.703	6.343±	7.395±	9.676	9.593±

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6		±6.243	3.833	1.987	3.2	3.667	4.126	±6.795	±6.314	1.838	3.249	±3.806	3.877
17	Cadmium	0.003±0.001	0.002±0.001	0.003±0.001	0.002±0.001	0.005±0.005	0.008±0.003	0.002±0.001	0.006±0.006	0.003±0.001	0.007±0.007	0.012±0.007	0.006±0.005
18	Copper	0.013±0.012	0.012±0.017	0.034±0.01	0.011±0.012	0.016±0.006	0.024±0.007	0.037±0.008	0.024±0.01	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
19	Ferrum	0.361±0.125	0.015±0.004	0.144±0.1	0.144±0.087	0.026±0.011	0.043±0.014	0.015±0.004	0.043±0.014	0.21±0.066	0.058±0.012	0.236±0.155	0.184±0.123
20	Lead	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21	Nickel	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22	Zinc	0.057±0.056	0.035±0.031	0.018±0.01	0.017±0.01	0.061±0.092	0.027±0.021	0.112±0.123	0.015±0.022	0.015±0.007	0.021±0.014	0.019±0.007	0.012±0.003

(All the values are expressed in mg/L except where specifically mentioned)

WATER QUALITY INDEX FOR GROUND WATER

Water Quality Index being a very useful tool for assessment and management of water resources around the world, the Water Quality Index was calculated using Indian Standards for the surface and ground water in the present study. WQI reflects the composite influence of different water quality parameters and is being used to provide comparisons of water quality status for different locations and at different time and acts as a water quality status prediction tool (Singh *et al*, 2013a, 2016, Tiwari *et al.*, 2014)

Table: Weighted Arithmetic Index (Wi) calculation to calculate Water Quality Index

S.No	Parameters	BIS STANDARD (Si)	1/Si	∑1/Si	K=1/∑1/Si	wi	Wi
1	pH	8.5	0.117647	509.8092	0.001962	0.000231	0.000231
2	Total Dissolved Solids	500	0.002	509.8092	0.001962	3.92E-06	3.92E-06
3	Electrical Conductivity(μmhos/cm)	300	0.003333	509.8092	0.001962	6.54E-06	2.62E-06
4	Total Hardness	300	0.003333	509.8092	0.001962	6.54E-06	6.54E-06
5	Calcium Hardness	75	0.013333	509.8092	0.001962	2.62E-05	2.62E-05
6	Magnesium Hardness	30	0.033333	509.8092	0.001962	6.54E-05	6.54E-05
7	Total Alkalinity	200	0.005	509.8092	0.001962	9.81E-06	9.81E-06
8	Chlorides	250	0.004	509.8092	0.001962	7.85E-06	7.85E-06
9	Nitrates	45	0.022222	509.8092	0.001962	4.36E-05	4.36E-05
10	Phosphates	0.5	2	509.8092	0.001962	0.003923	0.003923
11	Sodium	200	0.005	509.8092	0.001962	9.81E-06	9.81E-06
12	Potassium	10	0.1	509.8092	0.001962	0.000196	0.000196
13	DO	3	0.333333	509.8092	0.001962	0.000654	0.000654
14	BOD	5	0.2	509.8092	0.001962	0.000392	0.000392
15	COD	10	0.1	509.8092	0.001962	0.000196	0.000196
16	Cadmium	0.003	333.3333	509.8092	0.001962	0.653839	0.653842
17	Copper	0.05	20	509.8092	0.001962	0.03923	0.039231
18	Ferrum	0.3	3.333333	509.8092	0.001962	0.006538	0.006538

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19	Lead	0.01	100	509.8092	0.001962	0.196152	0.196153
20	Nickel	0.02	50	509.8092	0.001962	0.098076	0.098076
21	Zinc	5	0.2	509.8092	0.001962	0.000392	0.000392

- **Si = BIS 10500 (2012) STANDARDS For Drinking Water Were Considered**

Table: WQI ranking according to the range of values

WQI RANKING	CLASSIFICATION
0-25	Excellent
25-50	Slightly Polluted(Good)
50-75	Moderately Polluted (Poor)
75-100	Polluted(Very Poor)
>100	Excessively Polluted(Unsuitable For Drinking)

WATER QUALITY INDEX FOR GROUND WATER

Table: WQI for ground water for all the stations during the three consecutive years

WQI	2016-17	2017-18	2018-19	WQI Ranking
I	69.03664834	69.75583447	68.5434	Moderately polluted
II	47.56399584	69.13250924	45.46737	Slightly to Moderately polluted
III	68.4720474	177.4996188	69.44894	Moderate to excessively polluted
IV	46.09718627	46.28677574	45.74163	Slightly polluted
V	175.8831584	241.5161284	111.5279	Excessively polluted
VI	177.5968875	308.2210884	177.3801	Excessively polluted
VII	69.26010169	69.41618799	47.82113	Slightly to Moderately polluted
VIII	177.0543693	177.0496228	133.3934	Excessively polluted
IX	45.10471728	44.82088593	66.78385	Slightly to Moderately polluted
X	283.8978854	174.8283074	153.0655	Excessively polluted
XI	306.5226037	219.4632596	263.119	Excessively polluted
XII	44.80585974	88.52586122	132.4191	Slightly to Excessively polluted

Temperature (^{o}C)

The temperature of ground water ranged between 22.6^{o}C at Station-VIII and 32.5^{o}C at Station-XII during the study period. The maximum temperature was recorded in summer season and the minimum temperature was recorded in winter season. The Temperature was observed to be nearly same during the three seasons with slight increase during the summer season followed by rainy and winter seasons

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pH

The pH of ground water ranged between 6.5 and 8.3 during the study period. The pH was observed to be near neutral to alkaline at all the stations during the study period and did not exceed the BIS standard for drinking water. The lowest pH (6.5) was observed during the months of February, 2016 and May, 2017 and the highest pH (i.e., 8.3) was in the month of December, 2016. The pH was more or less consistent and the seasonal variations were negligible at all the stations during the study period.

Total dissolved solids

The mean of Total Dissolved Solids (TDS) in the ground water samples at the study area was in the range of 478 mg/L at Station-VIII in winter season and 19320 mg/L at Station-III in the summer season. The TDS values were exceeding the BIS permissible limit of 500 mg/L for the drinking water at all the stations during the study period.

Electrical Conductivity

The Electrical Conductivity (EC) is the measurement of the dissolved ions present in water and increases or decreases based on the ion concentrations in water (Venkataraman and Manikumari, 2019). The Electrical Conductivity (EC) in the ground water samples at the study area was in the range of 735.38 μmhos/cm at Station-VIII in winter season and 29723.07 μmhos/cm at Station-III in the summer season. The EC values were exceeding the BIS permissible limit of 750 μmhos/cm mg/L for the drinking water at all the stations during the study period.

Total Hardness

Hardness is the measure of dissolved calcium and magnesium ions present in the water (Venkataraman and Manikumari, 2019)**.** The mean of Total Hardness concentration in ground water was in range of 140 mg/L at Station-X and 6600 mg/L at Station-I. The lowest value (i.e., 140 mg/L) was observed in winter season whereas the highest value (i.e., 6600 mg/L) was recorded in summer season at majority of the stations. The concentrations of Total hardness were exceeding the BIS specified limit of 300 mg/L during the three seasons.

Calcium Hardness

The mean values of Calcium Hardness were observed to be exceeding the BIS standard limit of 75 mg/L at all the stations during the study period. The lowest value (i.e., 12 mg/L) of Calcium Hardness was recorded at Station-XII during winter season whereas the highest value (i.e., 271 mg/L) was recorded at Station-VIII during winter season. The prolonged agricultural activities prevailing in some areas may also directly or indirectly affect the mineral dissolution in ground water (moorthy et al., 2014).

Magnesium Hardness

The Magnesium Hardness was observed to be high (i.e., 6563 mg/L) at Station-I and low (i.e., 0 mg/L) at Station-X during the study period. The Magnesium Hardness values were observed to be high during summer season and lowest during winter season. The concentration of Magnesium Hardness was also increasing the BIS specified limit of 30 mg/L during the three seasons at majority of the stations during the study period. Ca^{2+} and Mg^{2+} are both essential minerals for living organisms and both of them occur in all kind of natural water with Mg^{2+} concentration generally lower than Ca^{2+} (Shov, 2014).

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Total Alkalinity

The alkalinity of ground water is primarily due to the carbonate, bicarbonate and hydroxide content and is often interpreted in terms of the concentration of these constituents (Zidi *et al.*, 2017). The mean values of Alkalinity were observed to range between 109 mg/L at Station-X and 940 mg/L at Station-I during the period of study. The mean values of Total Alkalinity recorded to exceed the BIS standard limit of 200 mg/L at majority of the stations (i.e., I, II, III, VIII, IX, X, XI) in ground water during the study period.

Chlorides

Chlorides in groundwater may occur naturally and from human sources such as road salt, agricultural runoff containing fertilizers and effluents from septic tanks, sea water intrusion and industrial waste water (Venkataraman and Manikumari, 2019). The Chlorides in the samples ranged between 58 mg/L at Station-X and 10650.37 mg/L at Station-VIII in winter season. The annual mean concentrations of Chlorides were exceeding the BIS standard of 200 mg/L at all the stations except Station-X during the study period. The concentrations of Chlorides did not follow any specific common seasonal trend during the study period at all the stations.

Nitrates

The Nitrates concentration was absent at Station-I and VII whereas the highest concentration of Nitrates (i.e., 45.6 mg/L) was observed at Stations V and XI during the study period. But the concentrations were far below the BIS desirable limit of 45 mg/L during the three seasons in the ground water at all the stations.

Phosphates

The Phosphate concentration in the samples ranged between 0 and 0.96 mg/L at all the Stations during the study period. The phosphate concentration did not follow any common seasonal trend during the study. The concentrations of Phosphate were observed to be slightly high at Station-V when compared with the BIS specified limit of 0.5 mg/L.

Sodium

A least value of Sodium (i.e., 28 mg/L) was recorded at Station-X during summer season and the highest (i.e., 1000mg/L) was recorded at Station-V during all the seasons (i.e., winter, rainy and summer). Except Stations X, XI and XII at all the stations the mean Sodium concentrations exceeded the BIS specified limit of 200 mg/L during the period of study.

Potassium

The lowest value of Potassium (i.e., 3 mg/L) was recorded at Station-X during April, 2017 (i.e., summer season) and the highest (i.e., 101.6 mg/L) was recorded at Station-VI during rainy season. Except Station-X all the mean concentrations of Potassium exceeded the BIS specified limit of 10 mg/L during the study period.

Dissolved oxygen

The Dissolved oxygen refers to the level of free, non-compound oxygen present in water and is one of the important parameter to judge the water quality (Chalise *et al.*, 2019). DO values were observed to be in the range of 0 to 7.6 mg/L at all the stations during the study period. At some of the sampling stations (i.e., I, II, VII, VIII) the mean DO values were observed to be below 3 mg/L which is the BIS

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specified limit for water. The DO was also identified to be high during rainy season followed by winter and summer seasons at majority of the stations during the study period.

Biological oxygen demand

The Biological oxygen demand (BOD) values ranged between 0 to 3.9 mg/L at all the stations during the study period. But the mean BOD values did not exceed the BIS standard limit of 5 mg/L at any station during the study.

Chemical oxygen demand

The Chemical Oxygen Demand (COD) was observed to be in the range of 0.53 mg/L (at Stations-IV, V, X, XI) to 21.86 mg/L at Station-IV and the mean concentrations of COD were observed to be slightly more than the BIS specified limit of 10 mg/L only at Station-I in the initial two years during the period of study.

Cadmium

The concentrations of Cadmium were recorded to be in the range of 0.001 mg/L at most of the stations (I, II, IV, VII, IX and XII) during winter season and 0.025 mg/L at Station-XI during the summer season. The mean concentrations of Cadmium were observed to be exceeding the BIS specified standard of 0.003 mg/L at some of the stations (i.e., V, VI, VIII and X) during the study period.

Copper

The concentrations of Copper were recorded to be in the range of 0.001 mg/L at Stations I, II and V in winter season and 0.045 mg/L at stations II and VIII in summer season. But at all the stations the mean concentrations of Copper were observed to be within the BIS specified limit of 0.05 mg/L during the study period.

Ferrum

The concentrations of Ferrum were recorded to be in the range of 0.001 mg/L Stations-VII during winter and summer seasons and 0.572 mg/L at Station-I during the winter and rainy seasons. The mean concentrations of Ferrum were observed to be slightly exceeding the BIS specified standard of 0.3 mg/L at Station-I during the study period.

Zinc

The concentrations of Zinc were observed to be far below the BIS specified standard of 5 mg/L at all the stations during the study period. The concentrations of Zinc ranged between 0.004 mg/L at stations (III, VIII and XI) to 0.942 mg/L at stations (II and VII) in ground water during the period of study.

GIS MAPING FOR THE PARAMETERS EXCEEDING BIS STANDARDS IN GROUND WATER

Monitoring of water quality spatially and at a continuous trend will help to identify the local causes of water pollution such as products from farms or industries etc (Boubakri and Rhinane,

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2017). The spatial distribution for the parameters having poor Water Quality Index value in ground water was analyzed using GIS maps. The GIS maps were shown for the three consecutive years, especially for the parameters exceeding the BIS prescribed standards in ground water.

WQI for ground water was observed to be having higher values during the year 2017-18 followed by 2016-17 and 2018-19. This indicated that the water quality was observed to be poor during the year 2017-18 when compared to the rest of the two years during the study. The sampling stations Kondapalli, Krishnalanka and Nunna (i.e., Stations V, VIII & X) were identified as the stations with poor water quality during the study period.

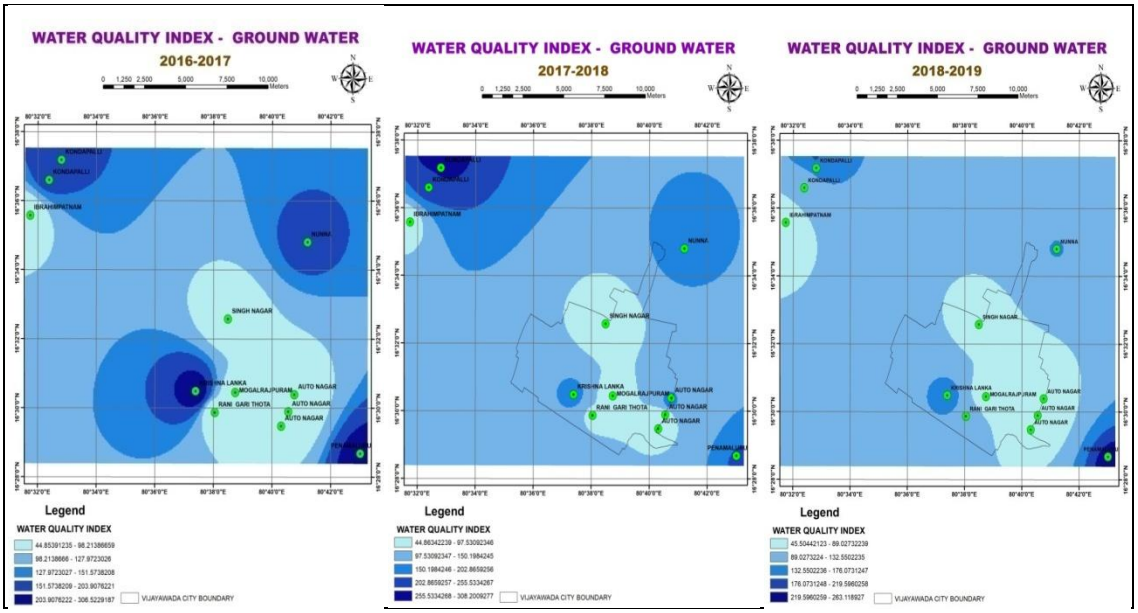

Figure : GIS maps for the WQI values in ground water

The spatial distribution for the parameters that were exceeding the BIS prescribed standard in ground water

The combination of WQI and GIS would help to provide detailed, quick and reliable information for decision making to adopt or implement strategies related to water pollution and scarcity (Singh *et al.*, 2013b). The spatial distribution for the parameters that were exceeding the BIS prescribed standard in ground water was analyzed using GIS maps. The GIS maps were shown for the three consecutive years, especially for the parameters exceeding the BIS prescribed standards in ground water.

Total Dissolved Solids:

Total Dissolved Solids were observed to be exceeding the BIS specified limit of 500 mg/L at all the sampling stations during the study period and especially at the stations Nunna, Singnagar and Krishnalanka (i.e., Stations VIII, IX & X) the TDS values were very high indicating the water was not suitable for drinking or domestic activities.

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Table: The annual mean values of Total Dissolved Solids exceeding the BIS standard limit at all the stations in ground water

Parameter	Stations	GROUND WATER			BIS
		2016-17	2017-18	2018-19	
Total Dissolved Solids	I	2964.167	2891.083	1471.667	500mg/L
	II	4483.333	4580.25	1905	
	III	2902.917	4516.167	18029.167	
	IV	4429.333	4514.167	12720.833	
	V	4308.5	4467.167	6675	
	VI	4437.833	4537.167	2147.5	
	VII	3500	3391.667	3391.667	
	VIII	735.333	753.083	796	
	IX	1027.5	951.583	1014.917	
	X	775.5	845.667	757.833	
	XI	1926.5	1422.167	2147.5	
	XII	1905	1945	2892.417	

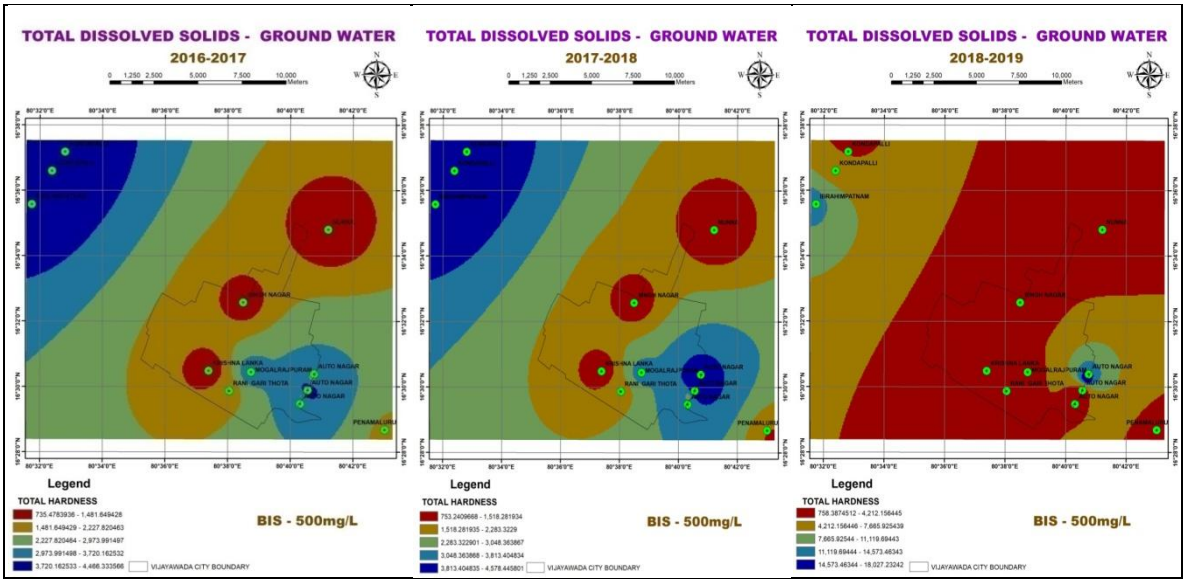

Figure : GIS maps for the TDS values in ground water at all the stations

Electrical Conductivity:

Electrical Conductivity was observed to be exceeding the BIS specified limit of 750 µmhos/ cm at all the sampling stations during the study period and especially at the stations Nunna, Singnagar and Krishnalanka (i.e., Stations VIII, IX & X) the EC values were very high indicating the water was not suitable for drinking or domestic activities.

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Table: The annual mean values of Electrical Conductivity exceeding the BIS standard limit at all the stations in ground water

Parameter	Stations	GROUND WATER			BIS
		2016-17	2017-18	2018-19	
Electrical Conductivity(µmhos/cm)	I	4424.129	4315.05	2264.103	750 µmhos/cm
	II	6691.542	6836.194	2930.769	
	III	4332.711	6740.547	27737.179	
	IV	6610.945	6737.562	19570.513	
	V	6430.597	6667.413	10269.231	
	VI	6623.632	6771.891	3303.846	
	VII	5384.615	5217.949	5217.949	
	VIII	1131.282	1158.59	1224.615	
	IX	1580.769	1463.974	1561.41	
	X	1193.077	1301.026	1165.897	
	XI	2963.846	2187.949	3303.846	
	XII	2930.769	2992.308	4449.872	

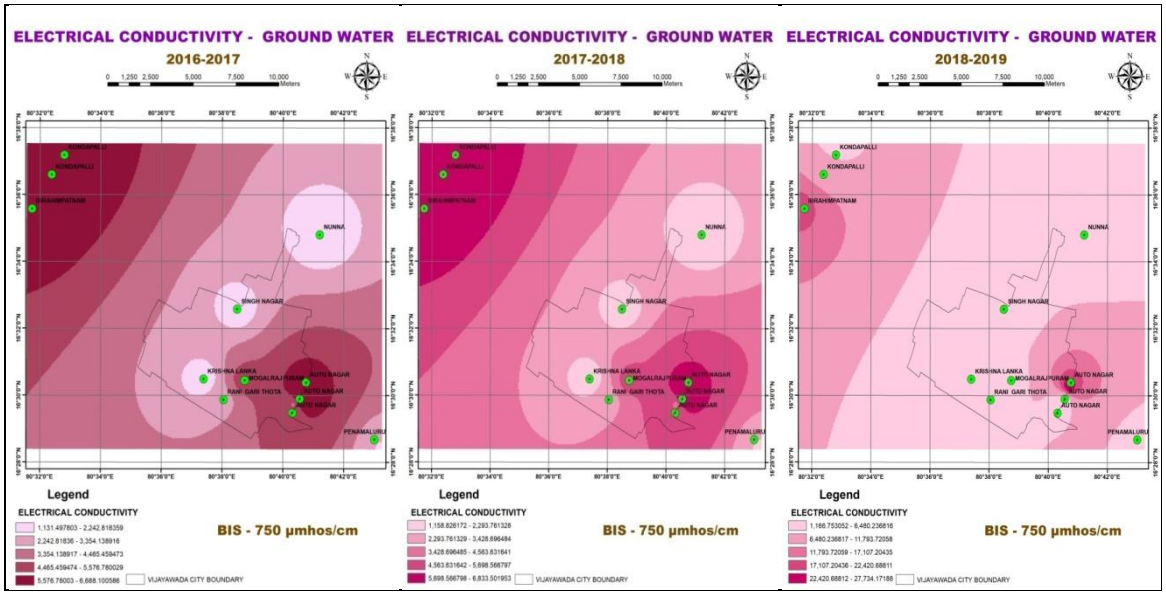

Figure : GIS maps for the EC values in ground water at all the stations

Total Hardness:

The Total Hardness was observed to be very high at all the stations in ground water during the study period exceeding the BIS specified limit of 300 mg/L except at Station-X i.e., Krishnalanka as shown the Table below. From the GIS maps it was observed that the values were exceptionally high at Autonagar (i.e., Stations I, II & III) during the study period. Various studies have quoted that good percentage of

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people lack access to safe water supplies, hence consume hard water which becomes a significant etiological factor around the globe causing many diseases such as cardiovascular problems, diabetes, reproductive failure, neural diseases and renal dysfunction and so on (UNICEF & WHO, 2008)

Table : The annual mean values of Total Hardness exceeding the BIS standard limit at all the stations in ground water

Parameter	Stations	GROUND WATER			BIS
		2016-17	2017-18	2018-19	
Total Hardness	I	2896.167	3738.333	3448.333	300mg/L
	II	2396.167	1779	1838.667	
	III	2482.167	2684.167	2600	
	IV	1912.333	2794.75	2256.25	
	V	2396.167	2478.917	2245.833	
	VI	1571.25	2031.25	1839.583	
	VII	2011.417	1871.5	2794.75	
	VIII	506.5	508.25	522.917	
	IX	1628.333	1564.75	1838.667	
	X	227.417	213.667	231	
	XI	1477.167	1501.833	1779	
	XII	2364.583	2298.25	2684.167	

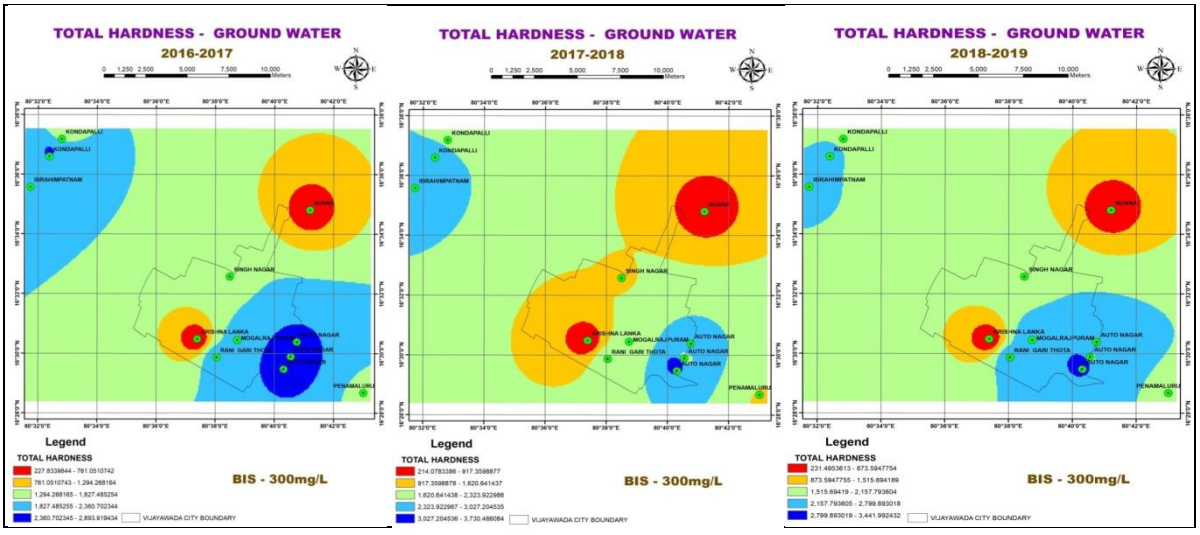

Figure : GIS maps for the TDS values in ground water at all the stations

Chlorides:

The Chlorides were observed to be very high at all the stations except exceeding the BIS specified limit of 250 mg/L except Station-X i.e., Krishnalanka which is shown in the Table below. The concentrations of Chlorides were comparatively very high at Autonagar area i.e., Stations I, II & III during the study period.

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Chloride is one the most important parameter in assessing the water quality and high concentration of chloride indicates higher degree of organic pollution (Huchhe and Bandela, 2016).

Table: The annual mean concentrations of Chloride exceeding the BIS standard limit at all the stations in ground water

Parameter	Stations	GROUND WATER			BIS
		2016-17	2017-18	2018-19	
Chlorides	I	1188.963	1176.263	1679.733	250mg/L
	II	902.448	1670.522	785.208	
	III	720.963	761.297	731.233	
	IV	515.448	1283.522	426.008	
	V	680.539	738.206	772.498	
	VI	546.481	490.066	629.029	
	VII	176.417	277.583	490	
	VIII	1670.522	1696.829	451.976	
	IX	761.297	731.38	755.023	
	X	74.667	71.5	71.333	
	XI	643.814	703.789	825.558	
	XII	490.066	546.443	618.962	

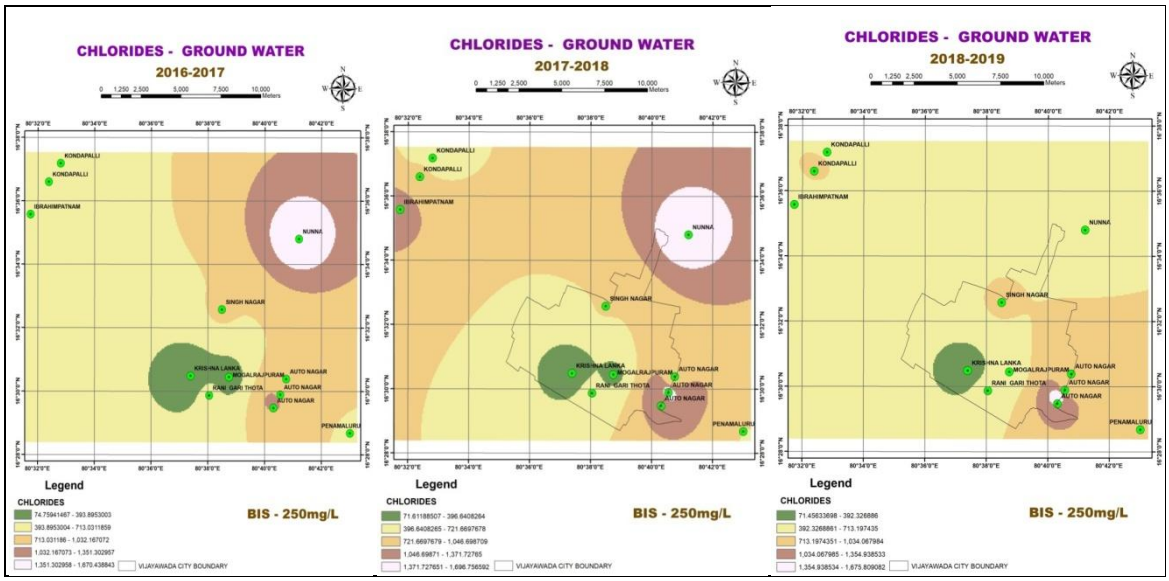

Figure : GIS maps for the Chlorides in ground water at all the stations

Sodium:

The concentrations of Sodium were observed to be high at all the stations exceeding the BIS specified limit of 200 mg/L except Stations X, XI & XII. The very high concentrations of Sodium were observed to be high at Stations V and VI (i.e., Kondapalli) compared to other stations.

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Table : The annual mean concentrations of Sodium exceeding the BIS standard limit at all the stations in ground water

Parameter	Stations	GROUND WATER			BIS
		2016-17	2017-18	2018-19	
Sodium	I	576.225	665.133	408.817	200mg/L
	II	558.108	633.533	659.742	
	III	388.125	462.733	523.658	
	IV	530.817	620.517	532.742	
	V	888.525	843.35	797.408	
	VI	673.793	638.712	764.98	
	VII	577.575	679.9	215.417	
	VIII	609.075	618.075	77.583	
	IX	368.483	486.508	426.417	
	X	64.583	69.167	60	
	XI	85.667	78.167	75.5	
	XII	68.167	67.583	66.583	

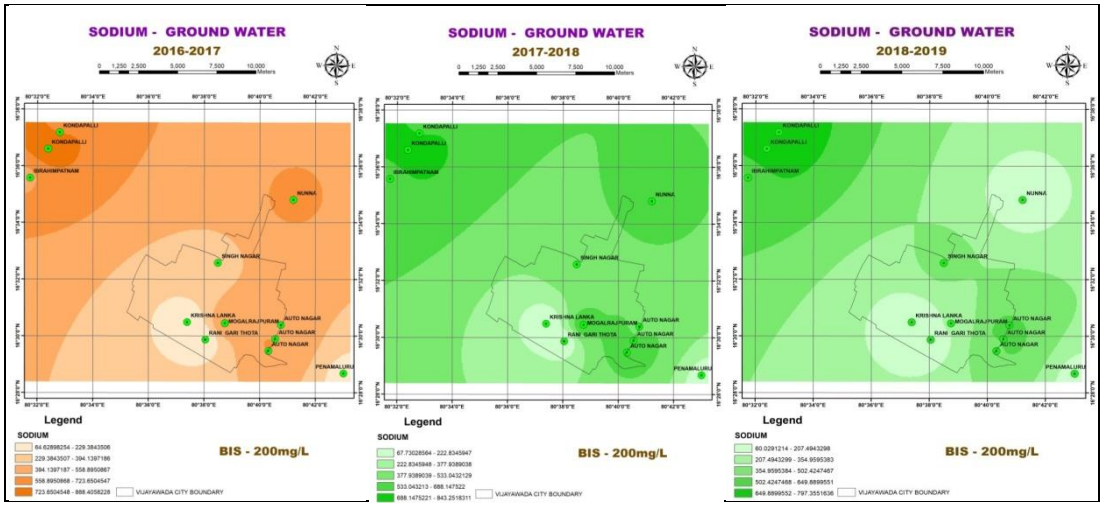

Figure : GIS maps for the Sodium concentrations in ground water at all the stations

Potassium:

The concentrations of potassium were observed to be high and exceeding the BIS standard limit of 10mg/L at all the stations except Station-X (i.e., Krishnalanka) during the study period. The concentrations of Potassium were comparatively high at Autonagar (i.e., Stations I & II) and Nunna (i.e., Station-VIII) as shown the Figure below.

Table : The annual mean concentrations of Potassium exceeding the BIS standard limit at all the stations in ground water

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Parameter	Stations	GROUND WATER			BIS
		2016-17	2017-18	2018-19	
Potassium	I	91.25	54.475	74.883	10mg/L
	II	73.483	78.65	70.483	
	III	57.658	48.183	50.475	
	IV	47.892	38.967	47.442	
	V	55.05	43.2	50.308	
	VI	58.275	51	47.842	
	VII	71.225	66.025	60.75	
	VIII	76.325	72.625	67.467	
	IX	51.658	51.075	42.85	
	X	9.25	10.083	7.917	
	XI	51.442	43.192	37.425	
	XII	55.967	47.267	37.3	

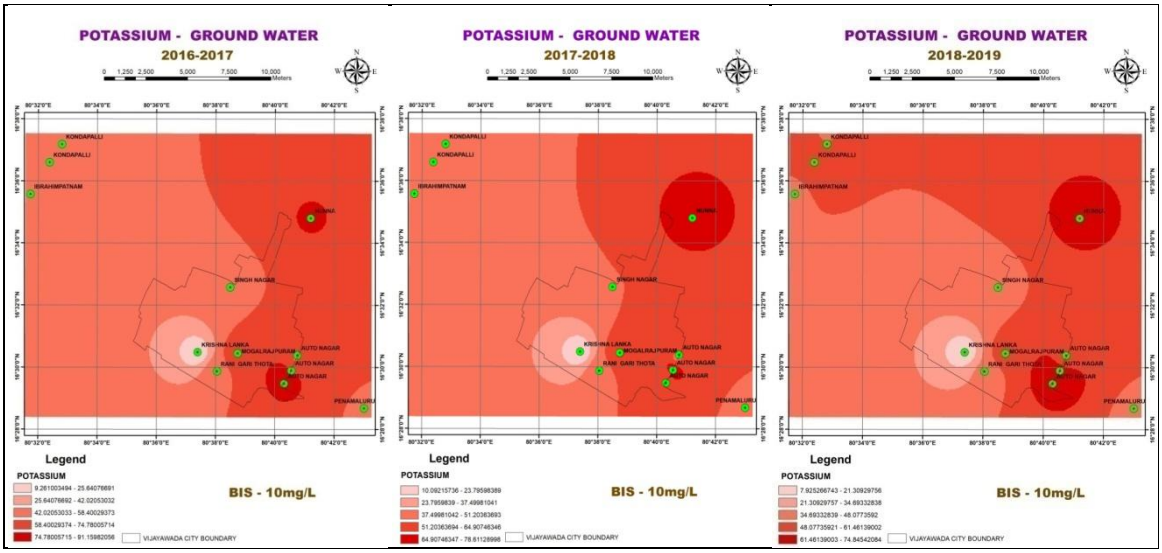

Figure : GIS maps for the Sodium concentrations in ground water at all the stations

Conclusion:

The water quality of industrial areas in and around Vijayawada city was studied using spatial analysis tools like ArcGIS software. The results indicated that the concentration of most of the parameters (TDS, EC, Sodium, Potassium, Total Hardness and Chlorides) were high in groundwater samples at the selected sampling stations which indicated that the impact of industrial waste water on the ground water.

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