

Assessment of Water Pollution in an Industrial Area by Using Multi-Variant Analysis—A Case Study from Bollaram Area, Hyderabad, India

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Abstract: A number of chemical and pharmaceutical industries have been established since past three decades. Effluents from these industries are being directly discharged into surrounding land, irrigation fields and surface water bodies thereby contaminating the groundwater table.

Application of different multivariate statistical approaches is used to interpret the relationship between the specific process that control the quality of water in surface and ground water in Bollaram industrial town near Hyderabad (India). Thirteen parameters have been monitored on thirty eight sampling points from a survey conducted in surface and ground water. This data was analysed using statistical analysis (CA). Sr, Ba, Co, Ni and Cr were associated and controlled by mixed origin with similar contribution from anthropogenic and geogenic sources whereas Fe, Mn, As, Pb, Zn, B and Co were derived from anthropogenic activities. Statistical analysis showed good results rendering the three different groups for surface water and two groups for ground water of similarity between the sampling sites reflecting the different water quality parameters of the study area. This correlation identified with the processes of salinity, alkalinity and pollution which are considered as lithologically and non-lithologically controlled factors.

Key words: Water pollution, heavy metals, statistical analysis of regression and pearson correlation, Bollaram, India.

Introduction

Anthropogenic influences as well as natural processes degrades surface and ground water, and impair their use for drinking, industrial, agricultural, recreation or other purposes (Carpenter et al., 1998; Fergusson, 1990). Due to spatial and temporal variations in water chemistry a monitoring programme that will provide a representative and reliable estimation is necessary (Aswathanarayana, 1995). With the rapid growth in the industrialization and urbanization in developing countries like India, industrial wastewater, sewage sludge and solid waste materials are currently being discharged into the environment indiscriminately. These materials enter the surface water and subsurface aquifers resulting in pollution of irrigation and drinking water (Forstner and Wittman, 1981). Toxic

metals in these effluents are concentrated in biota, depending on accumulation factors of individual metals, thus constituting a potential source of direct intake to man (Zayed et al., 1992).

In the present paper, the data subjected to different multivariate statistical approaches (i) to define geogenic and anthropogenic origin, (ii) to identify possible non-point sources of contamination and (iii) to estimate the contributions of possible sources on concentration of determined parameters.

Materials and Methods

Study Area

Bollaram industrial development area, covering about 100 km², has been established during mid eighties on

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Hyderabad-Mumbai national highway (NH9) about 28 km from Hyderabad city in Medak district, Andhra Pradesh, India (Figure 1). It is also identified as one of the most polluted area by Central Pollution Control Board, New Delhi, and referred to as an area of ecological disaster. The study area forms part of the catchment of Nakkavagu stream, which in turn is a tributary of the Manjira River, one of the main sources of drinking water to Hyderabad city. The industrial effluents contain appreciable amounts of inorganic and organic chemicals and their by-products. Most of the industries are small to medium scale sector and are not having any sewer lines. Many of them don't have proper waste water treatment plants and they discharge industrial effluents in unlined channels/streams, thereby causing contamination of water and soil. As a result the highly coloured and toxic chemical effluents join Nakkavagu, polluting surface water and ground water (Gurunadha Rao, 2001; Govil et al., 2001).

The contaminants from Nakkavagu seep through stream bed into the groundwater region, contaminating it and results in substantial degradation of groundwater

quality (Govil et al., 2001). Dipankar Saha (2008) studied the chemical quality of ground water using Principal Component Analysis (PCA).

Geology and Drainage

The study area forms a part of Precambrian peninsular shield and is referred to as basement complex or peninsular gneissic complex. The area is a granitic terrain comprising both grey and pink granites. Granites are traversed by pegmatite and quartz veins in some pockets. Alluvium of recent formation is deposited by the stream action along flood plain of Nakkavagu. Alluvium comprises sand and gravel with small amount of silt and clay. Thickness of alluvium varies from 10 to 15 m and is covered with 2-4 m of soil. Precipitation is the main source of groundwater recharge and takes place during south-west monsoon, mostly between June and September. The groundwater recharge varies from 110 to 115 mm/year for an annual rainfall of 800 mm. Pamalavagu, Peddavagu and Nakkavagu streams while carrying effluents contribute as diffuse source of contamination all along their courses upto the confluence

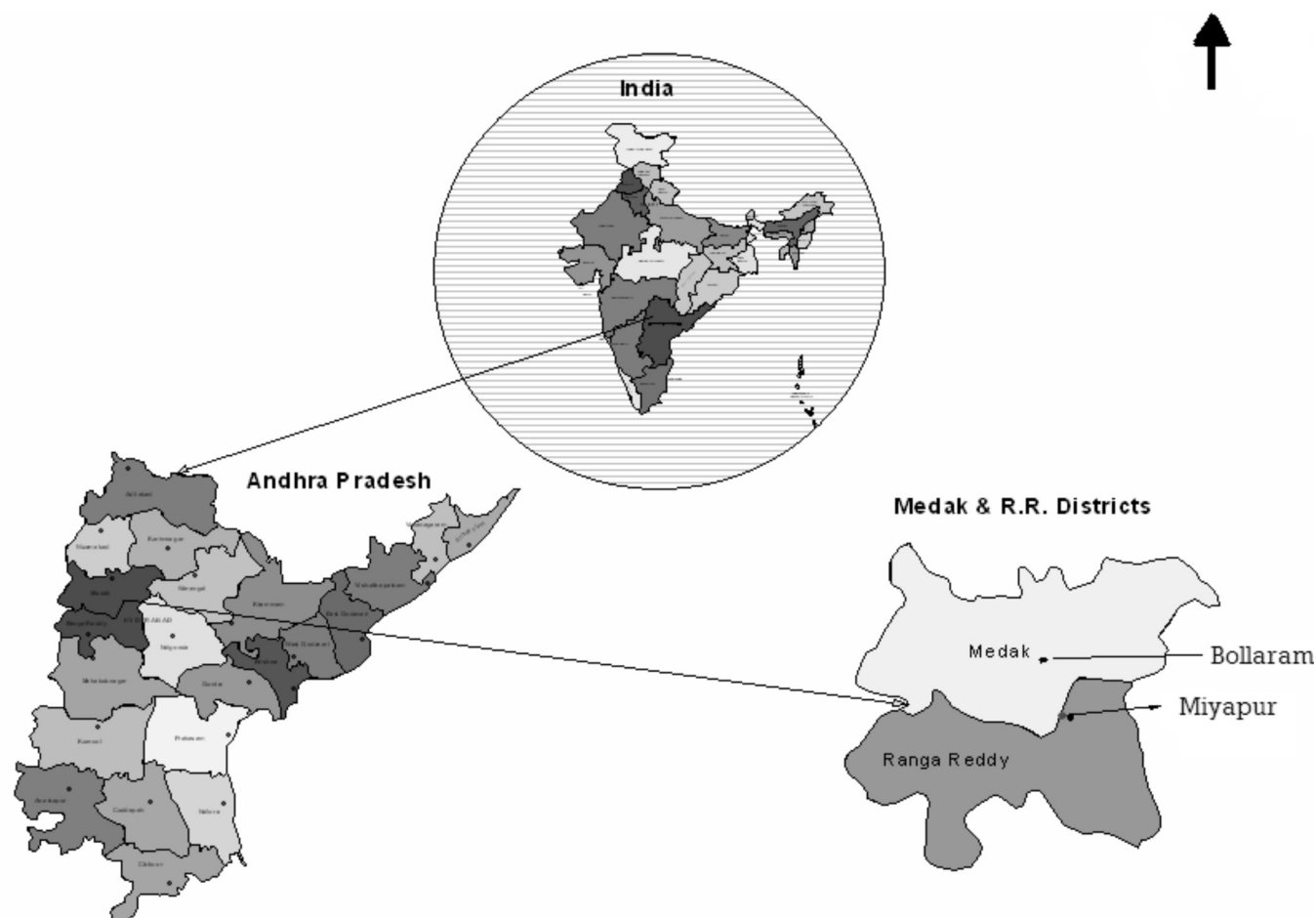


Figure 1: Location map of the study area.

with Manjira River. The pollution enters into subsurface water through fractures and joints. The rate of moment and consequent spread of pollutants depends upon the hydraulic gradient and groundwater velocity (Gurunadha Rao et al., 2001).

Methodology

Forty water samples (surface and ground water) were collected, covering entire Bollaram, Peddavagu, Pamalavagu basin. They include: effluent discharges from industries, water samples along the course of Nakkavagu, water samples from open streams and groundwater samples from borewells, handpumps and dugwells.

Forty samples were collected from different places of Bollaram. The samples were collected in moderate climatic conditions in one litre poly propylene cans and acidified by 1 ml of ArHNO_3 in field at each station. The samples were immediately sealed and labelled along with relevant details. The samples were analyzed for trace elements by Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES). All the samples were analyzed following standard procedures (APHA, 1992). All the samples were collected at considerable distances from the outlets of the industries after effluents

had mixed with contaminated or less contaminated surface water. In order to understand the migration of pollutants and toxic heavy elements into groundwater system, subsurface water samples were collected from bore wells.

Results and Discussion

The analytical results of trace metal concentration in surface and ground water are given in Tables 1 and 2 respectively. Main descriptive statistics for both surface and ground water are shown in Tables 3 and 4. Statistical treatment of these data indicates their association and grouping in surface water (Table 3) and ground water (Table 4). pH of surface water varies from 6.3 to 8.5 with an average of 7.2, while on groundwater it varies from 6.3 to 9.1 (average = 7.2). All the water samples show neutral to basic and alkaline values. pH does not show significant positive correlation with any trace element in surface and ground water, while it shows negative correlation with As, B, Fe, Pb and Zn in surface water, and Ba, Co, Mn and Sr in ground water. This indicates that influence of pH on trace element is different in surface and ground water of the study area, and is not a major controlling factor. It was observed that there are

Table 1: Analytical analysis of surface water samples

Sample Id	pH	TDS (mg/l)	As	B	Ba	Co	Cr	Fe	Mn	Ni	Pb	Sr	Zn
WHO	6.5-8.5	550	0.01	<1	0.7	-	50	0.5-50	0.5	<0.02	0.05	-	3
BIS	7 - 8.5	500	0.05	5	2	0.1	0.05	1	0.5	0.04	0.1	350	10
S-1	8.5	4501	18.3	426.8	75.0	2.0	12	74.5	130.5	10.2	0.8	357.8	78.3
S-2	8.1	4300	14.8	120.0	68.3	1.9	21.6	67.7	180.6	12.0	1.1	232.2	44.0
S-3	8.2	1200	39.1	307.6	56.2	2.0	5.60	78.7	226.4	15.6	1.1	243.1	57.6
S-4	7.3	1435	21.0	186.5	174.3	4.2	3.5	95.5	12.80	14.9	1.4	678.3	64.5
S-5	6.9	1654	20.8	543.0	86.7	2.2	32.8	79.5	178.5	11.6	0.5	432.7	32.1
S-6	6.3	2435	113.3	291.3	76.3	3.1	13	81.0	190.4	5.7	1.5	543.7	363.1
S-7	6.6	4231	115.4	752.1	126.8	5.2	22.5	90.5	137.3	53.4	3.7	2305.1	234.5
S-8	7.1	2134	107.4	304.5	20.3	12.0	5.7	1865.3	83.2	8.5	11.8	675.5	153.4
S-9	6.6	1564	19.3	361.0	112.1	2.1	6.3	79.2	29.2	43.6	12.8	241.5	67.8
S-10	6.7	1875	22.9	453.3	160.1	3.2	21.9	114.5	15.1	42.1	10.6	1342	82.5
S-11	6.8	2431	6.4	452.1	69.8	1.4	23.1	488.2	8.3	32.5	13.9	2534	30.2
S-12	7.3	3247	11.3	1723.1	69.2	2.4	5.7	89.8	90	4.7	2.6	508.2	34.8
S-13	7.1	3704	5.3	432.9	24.9	0.4	11.5	157.7	19.5	15.2	3.5	175.8	56.9
S-14	6.9	2341	17.4	132.0	86.1	2.1	14.6	54.4	6.8	16.4	3.7	564.5	75.9
S-15	7.2	4511	106.2	456.7	177.8	3.2	7.32	57.8	11.2	39.0	8.7	632.3	67.9
S-16	7.3	3421	43.9	543.2	125.0	2.0	4.7	64.6	51.9	50.7	3.5	432.5	65.8
S-17	6.9	1573	20.8	987.5	47.0	1.7	5.8	40.0	3.1	43.0	0.2	115.4	55.9
S-18	8.5	3421	31.4	321.4	102.8	0.6	16.4	67.7	178.9	12.1	6.8	432.1	65.7
S-19	7.6	2564	108	456.3	110.6	8.8	15.3	40.2	5.2	6.9	3.2	1342	123.3
S-20	6.5	3241	23.8	243.0	43.7	1.1	45.8	87.2	8.6	4.3	8.5	654.8	111.5

Table 2: Statistical analysis of surface water samples

<i>Elements</i>	<i>Min</i>	<i>Max</i>	<i>Std Dev</i>	<i>Average</i>	<i>Median</i>
pH	6.3	8.5	0.652	7.22	7.5
TDS	1200	4511	1093.13	2789.15	2499.5
As	5.3	115.4	40.6	43.34	21.95
B	120	1723.1	356.15	474.715	429.85
Ba	20.3	177.8	45.513	90.65	81.2
Co	0.4	12	2.79	3.08	2.1
Cr	3.5	45.8	10.81	14.756	12.5
Fe	40	1865.3	405.893	188.7	79.35
Mn	3.1	226.4	78.376	78.375	40.55
Ni	4.3	53.4	16.894	22.12	15.05
Pb	0.2	13.9	4.473	4.995	3.5
Sr	115.4	2534	666.01	722.15	525.95
Zn	30.2	363.1	79.285	993.185	66.8

Table 3: Analytical analysis of ground water samples

<i>Sample Id</i>	<i>pH</i>	<i>TDS (mg/l)</i>	<i>As</i>	<i>B</i>	<i>Ba</i>	<i>Co</i>	<i>Cr</i>	<i>Fe</i>	<i>Mn</i>	<i>Ni</i>	<i>Pb</i>	<i>Sr</i>	<i>Zn</i>
WHO	6.5-8.5	550	0.01	<1	0.7	-	50	0.5-50	0.5	<0.02	0.05	-	3
BIS	7 - 8.5	500	0.05	5	2	0.1	0.05	1	0.5	0.04	0.1	350	10
G-1	7.1	4201	18.3	426.8	75.0	2.0	1.2	67.7	130.5	10.2	0.8	357.8	78.3
G-2	8.3	4400	418	120.0	68.3	0.9	21.6	40.2	1800.6	12.0	1.1	232.2	44.0
G-3	7.8	2200	39.1	307.6	2356.2	2.0	5.60	87.2	2126.4	15.6	1.1	243.1	57.6
G-4	6.7	1435	12.0	186.5	474.3	4.2	3.5	79.2	12.80	14.9	1.4	678.3	64.5
G-5	6.8	5023	34.9	543.0	686.7	2.2	32.8	114.5	178.5	111.6	0.5	432.7	32.1
G-6	7.3	2435	113.3	291.3	776.3	3.1	2.3	488.2	1390.4	5.7	1.5	543.7	323.1
G-7	7.1	4231	115.4	752.1	2326.8	5.2	22.5	89.8	137.3	153.4	3.7	2305.1	234.5
G-8	6.9	2134	1177.4	304.5	20.3	12.0	5.7	95.5	83.2	18.5	8.8	675.5	153.4
G-9	9.1	800	19.3	361.0	2112.1	2.1	16.3	49.5	29.2	43.6	2.8	2741.5	65.8
G-10	6.4	600	22.9	453.3	160.1	43.2	26.9	81.0	15.1	42.1	10.6	1342	72.5
G-11	7.5	200	6.4	452.1	69.8	1.4	23.1	90.5	6.3	32.5	13.9	22534	30.2
G-12	7.2	1200	11.3	3723.1	69.2	22.4	5.7	665.3	90	4.7	2.6	508.2	28.8
G-13	6.8	1400	35.5	442.9	24.9	0.4	11.5	157.7	19.5	15.2	3.5	175.8	56.9
G-14	6.3	1500	447.4	432.0	86.1	2.1	14.6	54.4	6.8	16.4	3.7	561.5	75.9
G-15	7.2	1000	106.2	556.7	1077.8	3.2	74.32	57.8	11.2	239.0	8.7	432.3	67.9
G-16	7.3	1600	243.9	643.2	1215.0	2.0	4.7	64.6	51.9	50.7	3.5	332.5	65.8
G-17	6.9	1873	240.8	787.5	467.0	0.7	8.8	40.0	3.1	43.0	0.3	115.4	55.9
G-18	8.5	3221	301.4	3221.4	1021.8	0.6	14.4	74.5	178.9	12.1	6.8	432.1	65.7
G-19	7.6	2664	1108	4156.3	110.6	8.8	18.3	67.7	3.2	60.9	3.2	1342	103.3
G-20	6.5	3441	233.8	4243.0	43.7	1.1	35.8	78.7	9.6	14.3	8.5	1654.8	121.5

BIS – Bureau of Indian Standards; WHO – World Health Organisation

some high values of Fe, Mn, As, Pb, Zn, B and Co due to point and non-point sources. Some standard deviation values in accordance with variance levels are found in the study. This situation suggests a strong variability due to presence of anthropogenic sources from surface water affecting ground water.

Surface Water

Anthropogenic addition of Fe in surface water varying

from 40 to 1865 µg/l with an average of 188.7 µg/l is low in the area; apparently effluent waters are only causing its increase in surface water. Fe does not show high concentrations in ground water suggesting that there is little percolation of Fe from surface to ground water. Ni concentration varies from 4.3 to 53.4 (average of 22.12 µg/l), Pb varies from 0.2 to 13.8 µg/l (average of 24.9 µg/l) and Zn varies from 30.2 to 363.1 ppm (average of 993.1 µg/l). Sample nos. S-8, S-11 and S-1 show high

Table 4: Statistical analysis of groundwater samples

<i>Elements</i>	<i>Min</i>	<i>Max</i>	<i>Std Dev</i>	<i>Average</i>	<i>Median</i>
pH	6.3	9.1	0.71692	7.265	7.15
TDS	200	5023	1392.0	2277.	2003.5
As	6.4	1177.4	339.33	235.2	109.7
B	120	4243	1415.14	1120.215	452.7
Ba	20.3	2356.2	792.28	662.1	313.5
Co	0.4	43.2	10.181	5.98	2.1
Cr	1.2	74.32	16.80	17.48	14.5
Fe	40	665.3	158.6	127.2	78.95
Mn	3.1	2126.4	642.4	314.2	40.55
Ni	4.7	239	58.90	45.82	17.45
Pb	0.3	13.9	3.85	4.35	3.35
Sr	115.4	22534	4914.2	1882.02	89.88
Zn	28.8	323.1	72.56	525.95	65.8

values of Fe, S-7, S-9, S-10 and S-11 show high concentrations of Ni, S-8, S-9 and S-11 show high concentration of Pb and S-6 and S-7 show high concentration of Zn, which are near the vicinity of industrial areas. Ba concentration varies from 20.3 to 177.8 $\mu\text{g/l}$ with an average of 90.65 $\mu\text{g/l}$, and Sr varies from 115.4 to 2534 $\mu\text{g/l}$ (average = 722.15 $\mu\text{g/l}$). Samples S-6, S-7, S-10, S-11, S-14, S-15, S-18 and S-20 show comparatively higher concentration.

High values of Sr upto 1000 $\mu\text{g/l}$ can be derived from the surrounding acidic rocks having Sr of about 400-500 ppm. Hence this factor can be attributed to mixed origin of Sr and Ba in the area from anthropogenic and geogenic source. Boron varies from 120 to 1723.4 $\mu\text{g/l}$ (average = 474.7 $\mu\text{g/l}$) and Mn varies from 3.4 to 226.1 $\mu\text{g/l}$ (average = 78.3 $\mu\text{g/l}$). High levels of B are mostly restricted to Bollaram industrial area where its concentration goes upto 1723.1 $\mu\text{g/l}$. This element does not show appreciable migration, but percolates down and is concentrated in the ground water without exhibiting much mobility. B is mainly of anthropogenic origin. Principal sources of B are due to agriculture. Sample nos. S-5, S-7, S-12 and S-16 show more than average concentration of B and S-1, S-2, S-3, S-4, S-6, S-8 and S-10 show more than average concentration of Mn, and are located all along Nakkavagu, indicating dispersion of these elements from the untreated effluents released from CETP. Co varies from 0.4 to 12 $\mu\text{g/l}$ with an average of 3.08 $\mu\text{g/l}$, and Cr from 4.5 to 45.8 $\mu\text{g/l}$ (average = 14.7 $\mu\text{g/l}$). There is no contamination due to Cr and Co in surface water and the values represent natural concentration in granite terrain. This factor is attributed to the geogenic processes representing background concentration of Cr and Co in surface water.

Ground Water

Groundwater contamination can originate above or below the surface of the earth. Infiltration of polluted surface water causes contamination below the surface of the earth. When compared to water in streams and rivers, the movement of ground water is very slow and hence once the contaminant reaches the ground water, there is little scope for dilution and dispersion. The substances that can contaminate ground water can be basically classified as natural and artificial.

Anthropogenic addition of Fe in ground water varying from 40 to 665.3 $\mu\text{g/l}$ with an average of 127.2 $\mu\text{g/l}$. Ni concentration varies from 4.7 to 239 (average of 45.82 $\mu\text{g/l}$), Pb varies from 0.3 to 13.9 $\mu\text{g/l}$ (average of 4.35 $\mu\text{g/l}$) and Zn varies from 28.8 to 323.1 ppm (average of 525.91 $\mu\text{g/l}$). Sample nos. G-4, G-5, G-12 and G-13 show high values of Fe. G-5, G-6, G-7 and G-15 show high concentrations of Ni, S-8, S-9 and S-11 show high concentration of Pb and G-10, G-11, G-15 and G-18 show high concentration of Zn, which are near the vicinity of industrial areas. Fe-oxyhydroxides are known to influence trace elements through their adsorbing characteristics. The geochemical nature of Fe has a bearing on the presence of Ni and B in ground water. While Fe and Ni exhibit natural background concentration in ground water, B shows migrative characteristics from surface water. However it seems that geochemical behaviour of Fe-oxyhydroxides have influenced the B and Ni concentration, and so has been grouped into this factor which can be attributed to geogenic processes.

Ba concentration varies from 20.3 to 2356.2 $\mu\text{g/l}$ with an average of 662.1 $\mu\text{g/l}$, and Sr varies from 115.4 to 2534 $\mu\text{g/l}$ (average = 1882.15 $\mu\text{g/l}$). Samples G-3, G-5,

G-7, G-9, G-14, G-15 and G-18 show comparatively higher concentration than the average in Ba. G-7, G-9, G-11 and G-20 show the higher concentration than the average values. B, Cr, Mn, Co, Sr and Ba are distributed over the study area with concentrations of most of the samples showing below average distribution, indicating these elements to be influenced by anthropogenic as well as geogenic source. Whereas, high pollution exhibit increase in concentrations of As, Fe, Ni, Pb and Zn indicative of external source of these metals in surface water, particularly from industries producing pharmaceutical, paint, fertilizer and pesticide. Boron varies from 120 to 4243 µg/l (average = 1120 µg/l) and Mn varies from 3.4 to 226.1 µg/l (average = 78.3 µg/l). High levels of B are mostly restricted to Bollaram industrial area where its concentration goes upto 4243 µg/l.

The minimum and maximum concentration of these trace elements along with their average values are listed in Tables 3 and 4. This factor is attributed to anthropogenic influence of these trace metals in ground water. The data reveals that these trace elements have migrated from surface water. Especially with reference to Sr and Ba values, very abnormal concentration of Sr (2741 µg/l) can be attributed to anthropogenic source as there are pharmaceutical industries in the close vicinity and Sr is used to manufacture skin ointment and toothpaste. Ba was present upto 2326.8 µg/l, except in two samples (G-13 and G-20), which also show high concentration of Sr and Ni indicating the source of the metals from industrial effluents. Sr and Ba are abnormally high due to surrounding industries. Migration of trace elements in granitic terrain is through fractures and joints, and is much faster than that in sedimentary formation. Even though some trace element concentrations are within permissible limits, the values are indicative of an increase in their rate in due course of time.

Conclusion

The case study of ground water/surface water pollution due to uncontrolled industrial effluent discharges and the results of factor analysis performed on 11 heavy metals confirmed by the statistical analysis identified four factors for surface water and two factors for ground water controlling their variability in waters of Bollaram. Pollution around the Bollaram industrial area increased during the past one and half decade due to discharge of industrial effluents in surface water bodies. Multivariate statistical approaches show that the polluted surface water is strongly influencing the quality of ground water in the

study area. Migration patterns of heavy metals released into the environment in the form of untreated effluents by CETP and industries of Bollaram indicate the point source of pollution. Central effluent treatment plant (CETP) was found to be increasing the concentration of toxic metals in surface and ground water which was confirmed by high concentration of all the heavy/toxic metals in Peddavagu, adjacent to CETP. Water streams Nakkavagu, Peddavagu should be lined in the bottom on both sides to prevent the spread of contaminants horizontally and vertically. Some remedial measures should be applied in agricultural fields by removing topsoil and applying bioremediation techniques. The present study suggests that regular monitoring of the quality of ground water should be undertaken temporally and spatially to identify the source of toxic pollutants and other inhibitory chemicals which affect the water around industries in Bollaram.

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