Chapter 15
Groundwater Contamination in Parts of Northwestern Hyderabad: A Hydrogeochemical and Geospatial Approach

Pothuri Ramesh Chandra Phani and Kanchi Rajendra Prasad

Abstract The northwestern part of Hyderabad is known to have its groundwater contaminated due to the influence of several industries. The area is a focal point for many educational institutes and residential gated communities; the required water quantum is increasing yearly. The groundwater is polluted due to the existence of industries for decades together. The present work focuses on groundwater contamination during the pandemic in Patancheru and its northern part covering 282 km^2 area in view of increasing urbanization which is 3 times more than that in 1985. The Patancheru area has been declared a "groundwater problem area" by the Central Pollution Control Board. Pre- and post-monsoon samples ($n = 30$), from the bore and dug wells, were collected adapting standard procedures and analyzed for major constituents such as cations like Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and CO_3^{-}; anions like HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, and F^{-}; and metallic trace elements such as Bi, Co, Cr, Fe, Pb, Mn, and Ni. The Piper diagrams revealed highly mixed type groundwater. Geospatial plotting of trace metal concentrations reveals that a high concentration regime of heavy metals occurs around Patancheru and Pashamylaram areas. The physicochemical parameters show no correlation, which is attributed to erratically high heavy industrial contamination, lack of complete effluent treatment, insufficient recharge, poor sanitation, increasing civil constructions, and other anthropogenic activities than geogenic factors. From this investigation, it is opined that either recent COVID-19 lockdowns or excess precipitation have no influence on remediating the problem.

Keywords Groundwater · Contamination · Industrial effluents · Urbanisation

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1 Introduction

The chemical quality of groundwater depends on several aspects such as (i) the amount and composition of recharging water, (ii) lithological assemblage, (iii) anthropogenic activity, and (iv) environmental conditions. These factors affect the geochemical mobility of certain constituents of the groundwater (Kumar et al., 2006; Palanisamy & Kavitha, 2010). Hydrogeochemical data plays a major role in the assessment of groundwater quality. The data is plotted in several geochemical diagrams to assess the quality and character (Rao, 2006; Raju, 2007; Rashid & Izrar, 2007; Niranjan Kumar et al., 2009; Venkateswara Rao et al., 2016; Rama Mohan et al., 2021). Groundwater is the prime resource as surface water sources have become scarce, and some water bodies are no longer potable due to brackishness or contamination. The increasing urbanization demands more quantum of water for drinking and domestic purposes. The ever-increasing population and, in turn, the spread of residential colonies and the conversion of agricultural lands to gated residential communities are making the situation worse. Groundwater is contaminated either by geogenic or anthropogenic factors or both. In some cases, geogenic factors significantly impact groundwater quality, especially in igneous terrains where lithology is homogenous. Still, in such cases, anthropogenic activities may contaminate the groundwater, where the industries exist, and their effluents are let out to the open environment, the imminence of groundwater contamination is high. Therefore, a periodical assessment of groundwater is inevitable in the areas where industrial effluents are released into the environment and in upcoming urban regions.

Hyderabad city is growing rapidly in all directions in terms of infrastructure and urbanization. The industrial zones, a few tens of kilometers away from the city in the past, are now merging into the growing city. One such area is the northwestern part of Hyderabad, engulfing the Patancheru Industrial Area (PIA). In this area, several industries are actively producing their products. The industries include aquaculture, automobile, batteries, bio-products, cement and concrete products, chemicals, cold storages, dairy, electrical and electronics, fly ash, food products, metal fabrication, machinery and mechanical equipment, mineral-based products, paints and pigments, pharmaceuticals, plaster of Paris, petroleum-polymer-plastic products, paper products, poultry, rubber, seed processing, stone polishing, tannery, textiles, wood products, etc. Due to the continuous release of industrial wastes and effluents for decades, the area has been exposed to pollutants that spread into surface waters as well as percolate into groundwater. In addition, the increased urbanization in this area due to manifold increase in population and the necessity for new livable areas has drastically disturbed the drainage system. PIA was established in 1962, with 56 acres containing 67 plots and 34 units. In due course of time, it grew rapidly since 1973 with the initiative of Andhra Pradesh Industrial Infrastructural Corporation (APIICC) in the united Andhra Pradesh. Currently, 500+ industrial units of small-medium- and large-scale groups are operating. The PIA has seen flamboyant development in the mid-1980s. As per the latest information, about 323 industries are currently actively running after the COVID-19 pandemic. The PIA covering Patancheru, Pashamylaram, Indrakaran, Isnapur, Rudraram, etc. areas is the prime location where the focal point of industrial waste generation occurs. The groundwater of Patancheru and adjoining areas have been reported to contain toxic elements such as arsenic (As), bismuth (Bi), chromium (Cr), copper (Cu), iron (Fe), selenium (Se), and zinc (Zn) (Kumar et al., 1997). Although preventive measures are implemented, massive urbanization and industrialization severely damage natural resources such as soil, vegetation, surface, and groundwater. The two main streams in the area are Peddavagu and Nakkavagu, along with the other two, Chinnavagu and Pamlavagu, which remain dry whole through the year. However, they flow sometimes, with effluent water in seasons of increased precipitation than usual.

The government has implemented several remedial measures to control groundwater contamination in this area. However, the projects halted abruptly due to several reasons. The Central Industrial Effluent Treatment Plant (CETP) is located in the PIA, is not fully equipped or upgraded to the day-to-day technology, and is not efficient in treating different types of effluents. The final effluents not completely treated are openly released into the streams, causing toxic pollutants to the open environment and subsurface by percolation through fracture systems, contaminating the groundwater. Water is vital for the livelihood of human, animal, and plant life, its contamination will raise environmental imbalance. In areas of industrial contamination, the extent of damage will be more pronounced and have immediate percussions on the natural resources, especially the groundwater resources, as they have limited movement and flushing capacity. In India, groundwater contamination will be intense in regions of industrial contamination, as industrial waste material is often released into drainages, abandoned open wells, and lakes, which is point contamination and, in many cases, to open river systems.

During the last five decades, the northwestern part of Hyderabad witnessed a prominent growth in industries and urbanization. Many residential colonies, educational institutes of national importance, shopping centers, etc. have emerged in the recent past, engulfing and amidst the industrial area. The Patancheru area has been declared problematic for groundwater contamination. Owing to the presence of a variety of industries, the northwestern part of Hyderabad has been impacted by the industrial effluents contaminating the groundwater (Saibaba, 2005; Saibaba et al., 2007; Hussain & Prasad Rao, 2014; Johnson, 2016; Venkateswara Rao et al., 2016). The state and central governments have taken up several measures to attenuate the pollution. However, there has been no improvement in the quality of groundwater. This is because of several factors, such as inefficient or incomplete effluent treatment, negligence of industries in effluent disposal, reduced rainfall and recharge, excess groundwater drawdown due to an increase in an urban area, and so on. The groundwater of the northwestern part of Hyderabad is observed to contain very high concentrations of many ions and heavy metals such as arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), molybdenum (Mo), selenium (Se), strontium (Sr), vanadium (V), and zinc (Zn) (Rao et al., 2001; Govil et al., 2001). A plethora of diseases is developed by the people living in the PIA and its proximity (Reddy et al., 2011). A substantial amount of land in the peripheries of major water bodies is subjected to encroachments by rampant constructions. The emergence of industries and other residential encroachments in the lake beds in the buffer zones has defeated the primary purpose of irrigation and the general ecosystem due to the release of industrial and domestic sewerage pollutants. The PIA is well-equipped for infrastructural development and urbanisation, but the sewerage system is poorly built, which is a vital basic means for properly channeling the effluents.

Considerable research has been published on the groundwater quality of other localities during the pandemic period (Patel et al., 2020; Selvam et al., 2020; Venkatcharyulu et al., 2020; Krishan et al., 2021; Rahimi et al., 2021; Shanmugamoorthy et al., 2021). However, the northwestern part of Hyderabad, although known as a groundwater pollution hot spot, has not been touched upon. This work focuses on account of chemical assessment of groundwater involving physicochemical parameters and some trace elements in the northwestern part of Hyderabad graphically and geospatially, along with a briefing on the pace of urbanization in this area. This investigation showed that no significant impact of pandemic and/or lockdowns occurred in the study area; the groundwater contamination continued to persist.

2 Location and Study Area

The study area lies between geographic coordinates 17°36′6.10″N; 78° 6′56.05″E and 17°29′43.05″N; 78°20′25.65″E (Fig. 15.1). The area falls in the Medak district of Telangana, which is geographically merged with the Hyderabad city. The study area falls within the Manjira river basin. The area has national institutes like the Indian Institute of Technology Hyderabad (IITH) at Kandi, GITAM University at Rudraram, Ordnance Factory at Edulamailaram, Toshiba Transmission &

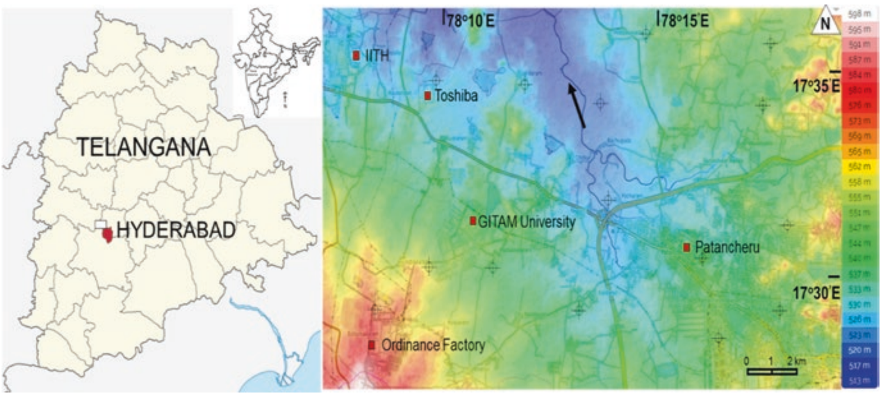

Fig. 15.1 Map showing study area and sampled well locations on elevation map (www.topographic-map.com). Arrow indicates stream course flow to meet Manjira river in the north

Distribution Systems (India) Private Limited at Degloor, and so on. In connection to the proposed regional ring road (RRR), the area is rapidly developing with many satellite townships and is soon expected to become a busy extended urban component of Hyderabad. At many locations in the selected area, the ground is being leveled for the purpose of civilian constructions such as private educational institutes, new industrial units, residential colonies, etc. As the area is leveled down, the individual watersheds are getting disturbed and disappearing, causing geomorphological imbalance. Many surface streams ranging from first order to fifth order exist in the area, which was leveled and used for agriculture, many of which are now being converted as real estate plots. Hence, the study area was chosen in such a way that it covers the span of urbanization.

3 Geology and Hydrogeomorphology

The study area is endowed with granites and granite gneisses of the Archaean age. The granites are massive, coarse to medium-grained, and occasionally display gneissosity. The granites are traversed by quartz and pegmatite veins ranging from a few cm to a few feet in width and extend for a few tens of meters. The quartz and pegmatite are rich in quartz and feldspar; however, non-mineralized. The granites are medium to coarse-grained, mesocratic studded with mafic enclaves. The granites are cut across by dolerite dykes in NE-SW, NE-SW, NNE-SSW, and EW trends. Occasionally, small laterite patches occur in the study area's western part. The granites are weathered and moderately fractured. The thickness of the weathered zone ranges from 6 to 20 m. More than two sets of joints trending in NNE-SSW and NNW-SSE are present. The streams are filled with assorted valley fill gravel and boulders. The streams are filled with densely grown acacia. The stream banks are filled with Quaternary alluvium comprising boulder to sand sized material. As observed in the stream sections and well inventory, the thickness of alluvium ranges from 5 to 60 m. The highest elevation in the study area is 598 m in the SW and western part, and the lowest is 510 m in the northern part towards the Manjira basin. Geomorphologically, the area comprises undulated terrain, including subtle mounds, hillocks, pediplain, forming a pediment-inselberg-pediplain complex. In the pediplain areas, the groundwater potential is more when compared to the pediment areas. The soil thickness ranges from 0.5 to 1.5 m. The dug wells (depth 8–22 m) are of low capacity, and tap water from shallow aquifers is controlled by weathered and fractured zones. In dug wells in weathered granitic and alluvial zones, the full recuperation is attained in 5–10 h, while it is 12–16 h and 15–45 h in laterite zones and hard rock terrains, respectively. The depth of groundwater in May 2020 ranged from 20 to 40 m, while it was raised to 10–20 m depth by November 2020 (CGWB, 2021). The area forms part of the Godavari main valley, having the Manjira River as the main tributary on the northern side of the study area. Several streams and tanks exist in the area. The total area under tank command is approximately 75,000 ha, land irrigated by canals, and life irrigation is 3400 ha. The area belongs to the tropical savannah type. The average temperature ranges from 22 °C in winter and more than 45 °C in peak summer. The average annual rainfall is 800–900 mm. The humidity ranges from 55 to 75%, with an annual mean of 65%. The potential annual evaporation is 1940 mm.

4 Materials and Methods

Groundwater samples (n = 30) were collected in the second year of the COVID-19 pandemic during the 2021 lockdowns, and fieldwork has been carried out. The samples for pre- and post-monsoon from 15 locations were collected in March 2021 and December 2021, respectively. The area covered is about 282 km^2, with a sample interval is about 3 km. The sampling is carried out in areas where urbanization is spreading. The groundwater samples have been collected from dug wells, bore wells fitted with hand pumps, and submersible pumps. The sampling, preservation, and chemical analyses of samples have been carried out following the Central Pollution Control Board (n.d., 2007), and APHA (2012).

The physical parameters such as temperature and pH of water were measured using a normal mercury thermometer and digital pH meter (EI make, 1997 model). The EC and TDS were determined by the EC/TDS analyzer (CM183, Elico). The chemical methods were conducted at Lucid Laboratories Pvt. Limited, Hyderabad, accredited by the National Accreditation Board for Testing and Calibration Laboratories (NABL). For determining the total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), carbonate (CO_3^-), bicarbonate (HCO_3^-), and chloride (Cl^-). Sodium (Na^+), and potassium (K^+) were analyzed by the flame photometry method (CL345, ELICO). Sulfate was estimated by the turbidity method with the aid of Nephelo Turbidity meter (Model 132, Systronics). Nitrate was estimated by using the UV-VIS screen technique using a UV-VIS spectrophotometer (UV1201, Shimadzu). Fluoride is determined by the ion-selective electrode technique (Orion 290A+, Thermoelectron Corp.). The TDS was determined by calculating EC (Hem, 1991). The trace elements such as bismuth (Bi), iron (Fe), lead (Pb) and manganese (Mn) are determined by Atomic Absorption Spectrophotometer (AA6500, Shimadzu) while cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), nickel (Ni), and zinc (Zn) were estimated using inductively coupled plasma (ICP) (1000IV, Shimadzu). The normalized inorganic charge balance method was adopted to obtain accurate results (Huh et al., 1998). For the majority of the samples, the ion exchange balance was <15% confirming the precision of analysis. The accuracy of analyses was controlled by including certified reference NIST1640a (National Institute of Standards and Technology, USA). The precision of analyses was checked by including blank and duplicate samples. Trace element distribution maps were constructed using ArcGIS (v10.3) software. Land use mapping, specific to built-up areas, was carried out using Google Earth imagery of the years 1985 and 2020. The built-up area polygons were digitized, and their area was measured from the latest imagery using ArcGIS (v10.3) and compared with the past imagery.

5 Results and Discussion

5.1 Increased Urbanization

A temporal-spatial assessment using a satellite (Google Earth) indicates there has been a drastic increase in urbanization in the northwestern part of Hyderabad. The satellite image of 1985 shows that there were certain very distant and sporadic habitations, especially the native villages, in this area. In 1985, there were no constructions north of Patancheru, and however, by the year 2020, the area had become like a concrete jungle (Fig. 15.2a, b). Ever since the Telangana state was separated from Andhra Pradesh in 2014, urbanization has taken a greater pace. Since the year 2015, there has been a plethora of urban development in northwestern Hyderabad, interfusing the adjacent rural areas. It is believed that industrialization causes pollution of the natural environment; however, domestic sewage alone can also remarkably increase pollution despite industrial effluents (Patel et al., 2020). The fast-growing residential colonies are also contaminating the study area groundwater due to incipient sewerage systems.

Several high-rise towers for residential purposes are coming up in the area, increasing the spatial spread of concrete jungles (Fig. 15.3a). Several granite quarries have also been opened up in the area to meet the requirement of construction material (Fig. 15.3b). Spatial analysis of study area (282 km^2) reveals that, in the year 1985, the urban area was about 68.78 km^2 (24.39%) which has been increased to 156.67 km^2 (55.55%) in 2021 with approximately an additional area of 78.9 km^2 (27.97%) with upcoming real estate plots in 2022. In other words, including upcoming residential plots, there has been a three-fold increase in urbanization. Prominent educational institutes have been developed in recent times. The residential colonies encroach into the borders of water bodies, thereby blocking the drainage system. The disused and/or abandoned metal and solid waste are dumped openly on the ground allowing certain toxic metals into the soil and therefrom to the subsurface aqueous systems (Fig. 15.3c, image source: Google Earth Photos). Due to the effluents released to the surface water bodies, the water has become unpotable irrespective of the amount of precipitation to dilute it. The effluents are released to first-order streams, making them severely contaminated (Fig. 15.3d). The mainstream of Nakkavagu, which had a valley of approximately 1 km width, now has been reduced to a few meters at a few locations and shortened as a sewerage pond at Rudraram village. The partially treated industrial effluents are directly released to the streams causing visibly severe contamination (Fig. 15.3e, f). The contamination of surface waters is being carried down to the groundwater, thereby causing heavy pollution in the groundwater. There is an increasing demand for drinking water in the study area. The available groundwater is not potable even at deeper depths (>400 m). As groundwater is not easily available, people depend on canned water. Recently, the number of mineral water plants has tremendously increased in the study area.

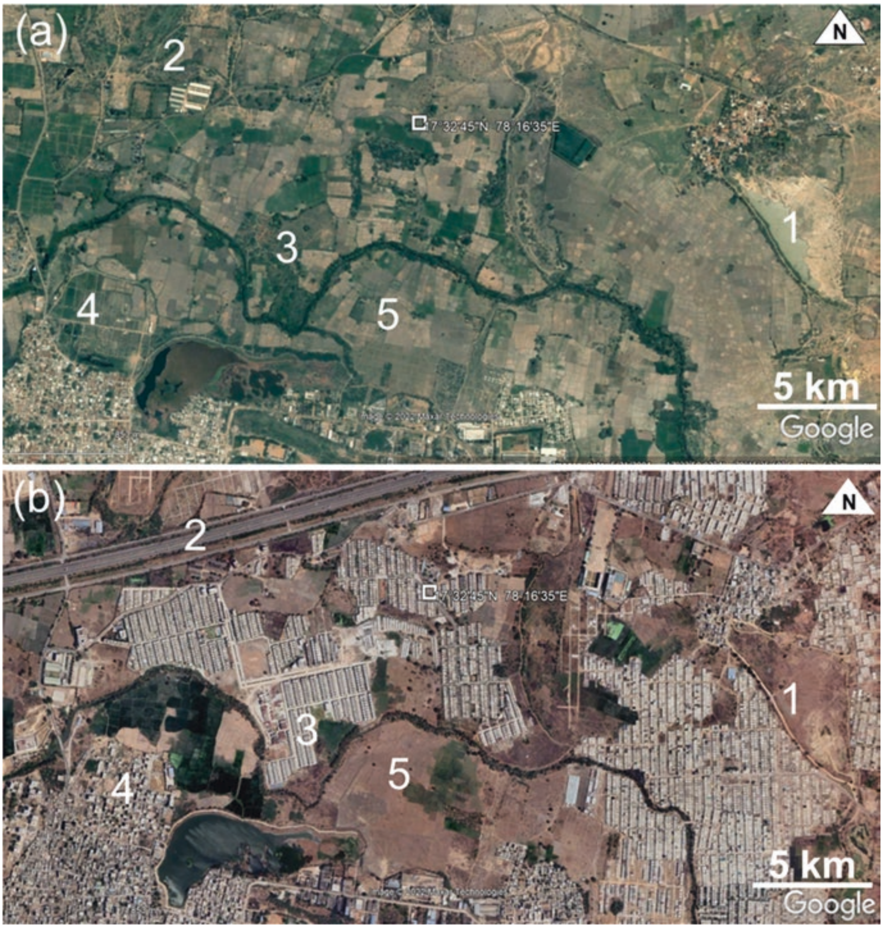

Fig. 15.2 Google Earth imagery showing the density of urbanization through time. (image source: Google Earth). (**a**) No constructions, with much of the area under cultivation in 1985, (**b**) highly dense constructions came up by 2020. 1. Water body in 1985, now dried up completely. 2. Development of outer ring roads. 3 and 4 Agricultural land replaced by residential colonies. 5 agriculture land turned to barren land. The imagery shows a part of study area reflecting intensity and increase in the built-up area

5.2 Physicochemical Characteristics

The anions in pre-monsoon and post-monsoon groundwater samples are shown in Tables 15.1 and 15.2, respectively. The pH is high, ranging from 7.42 to 8.9 in pre-monsoon samples and 73 to 8.88 in post-monsoon samples. The turbidity ranges from 4 to 8 in both pre- and post-monsoon samples. TDS ranges from 500 to 1700 mg/l and 820 to 1500 mg/l in pre- and post-monsoon samples. Total alkalinity ranges from 340 to 610 and 340 to 560 in pre- and post-monsoon samples,

Fig. 15.3 Field photographs of the study area showing various sources of groundwater contamination. (**a**) Growing urbanization in Patancheru near the outer ring road and solid waste dump in open land in the background and front ground, respectively. (**b**) An abandoned granite quarry with stagnant water at Mantrikunta (**c**) dumping of solid metal waste in open land. (**d**) Surface water contamination at Muthangi turned green and brackish due to influx of industrial effluents. (**e**) A higher order stream converted to a sewerage canal contaminated by industrial effluents at Rudraram. (**f**) Industrial effluents draining into a higher order stream at Patancheru

respectively. The total waste from animal farms, nitrogenous fertilizers, etc. are sources of nitrate in groundwater. Cations such as Ca and Mg are also in a higher range with a median of 110 and 44 mg/l in pre-monsoon samples and 140 and 48 mg/l in post-monsoon samples, respectively. Sulfate ranges from 15 to 230 mg/l for pre-monsoon samples and 70 to 230 mg/l for post-monsoon samples. The fluoride ranges from 0.86 to 5 in pre-monsoon samples, while in post-monsoon samples, it ranges from 0.9 to 1.2 mg/l. The samples show an affinity of anthropogenic influence rather than geogenic character when plotted NO_3 with conductivity

Table 15.1 Major ion composition of groundwater in pre-monsoon

Sample	Location	Easting	Northing	pH	C (μs/Cm)	T (NTU)	TDS (mg/l)	Total Alkalinity as CaCO3 (mg/l)	TH	Ca^{2+} (mg/l)	Mg^{2+}(mg/l)	Cl-(mg/l)	SO_4^{2-} (mg/l)	NO3 (As N) (mg/l)	TOC (mg/l)
W1	Patancheru	78°17′4.89″E	17°31′46.39″N	7.8	2340	5	1600	360	1010	290	110	110	230	8	11
W2	Lakdaram	78° 9′49.08″E	17°34′44.57″N	7.9	1180	4	800	480	980	205	54	55	115	8.7	9
W3	Patancheru	78°18′35.89″E	17°30′31.66″N	8.23	870	6	1560	390	165	49	21	450	15	11.9	8
W4	Patancheru	78°18′56.43″E	17°32′15.84″N	7.9	2870	5	1630	610	980	110	98	130	210	10	10
W5	Patancheru	78°17′22.22″E	17°29′52.51″N	7.6	1880	7	1500	570	700	155	148	250	130	8	6
W6	Janakampet	78°18′40.58″E	17°34′16.55″N	7.19	1580	8	1700	420	750	90	136	130	66	10	9
W7	IDA Pashamylaram	78° 9′33.71″E	17°31′49.35″N	7.42	1100	5	1400	500	450	75	80	200	77	18.1	7
W8	Inole	78°15′53.63″E	17°35′29.09″N	7.53	890	6	1100	400	330	230	38	60	50	11	5
W9	Pashamylaram	78°11′41.10″E	17°31′42.60″N	8.1	910	5	700	340	220	110	44	50	30	10	4
W10	Muthangi	78°14′35.99″E	17°32′40.00″N	7.9	879	4	500	440	230	230	50	50	25	11	4
W11	Indresamdarga	78°14′5.85″E	17°34′26.53″N	7.9	710	5	600	450	140	120	30	45	40	8	5
W12	Madaram	78°18′40.67″E	17°35′24.51″N	7.4	650	6	530	350	130	110	29	120	45	10	6
W13	Patighanpur	78°13′35.85″E	17°30′34.64″N	7.5	610	5	670	480	120	50	29	90	30	16	4
W14	Ordinance factory	78° 8′37.65″E	17°31′16.89″N	8.2	580	5	540	380	115	60	44	80	25	8	4
W15	Nandigama	78°14′5.85″E	17°34′26.53″N	7.8	720	4	510	380	130	130	30	80	60	8	4

Table 15.2 Major ion compositions in groundwater, post-monsoon

Sample	Location	Easting	Northing	$_{P}H$	Conductivity (μs/Cm)	Turbidity (NTU)	TDS mg/l	Total Alkalinity (as CaCO3)	TH	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^{-}mg/l	SO_4^{2-}mg/l	Nitrates (As N)	TOC
W1	Patancheru	78°17′4.89″E	17°31′46.39″N	7.81	2240	5	1400	550	950	270	120	387	180	11	11
W2	Lakdaram	78° 9′49.08″E	17°34′44.57″N	7.68	2180	7	1100	500	700	140	89	210	139	23	10
W3	Patancheru	78°18′35.89″E	17°30′31.66″N	7.88	1100	7	1200	400	750	250	25	110	140	22	7
W4	Patancheru	78°18′56.43″E	17°32′15.84″N	7.76	2450	8	1100	450	780	220	130	389	210	7	13
W5	Patancheru	78°17′22.22″E	17°29′52.51″N	7.75	1280	6	1500	550	730	185	90	240	230	18	8
W6	Janakampet	78°18′40.58″E	17°34′16.55″N	7.81	2560	6	1350	400	820	210	45	160	130	18.7	14
W7	IDA Pashamylaram	78° 9′33.71″E	17°31′49.35″N	7.84	1370	7	1270	550	740	280	63	180	140	4.8	7
W8	Inole	78°15′53.63″E	17°35′29.09″N	7.77	2450	7	1300	530	770	170	42	230	150	8.9	8
W9	Pashamylaram	78°11′41.10″E	17°31′42.60″N	8.1	1100	5	1100	450	670	130	34	130	110	7	9
W10	Muthangi	78°14′35.99″E	17°32′40.00″N	7.3	560	5	980	560	780	120	35	120	130	8	10
W11	Indresamdarga	78°14′5.85″E	17°34′26.53″N	8.2	710	6	1020	390	700	90	40	110	80	11	8
W12	Madaram	78°18′40.67″E	17°35′24.51″N	7.5	440	5	990	420	600	110	65	50	85	17	8
W13	Patighanpur	78°13′35.85″E	17°30′34.64″N	7.3	570	4	820	510	580	140	50	90	90	9	12
W14	Ordnance factory	78° 8′37.65″E	17°31′16.89″N	7.6	820	7	930	340	710	110	40	110	110	10	13
W15	Nandigama	78°14′5.85″E	17°34′26.53″N	7.65+	650	7	1100	430	550	130	48	120	70	15	`4

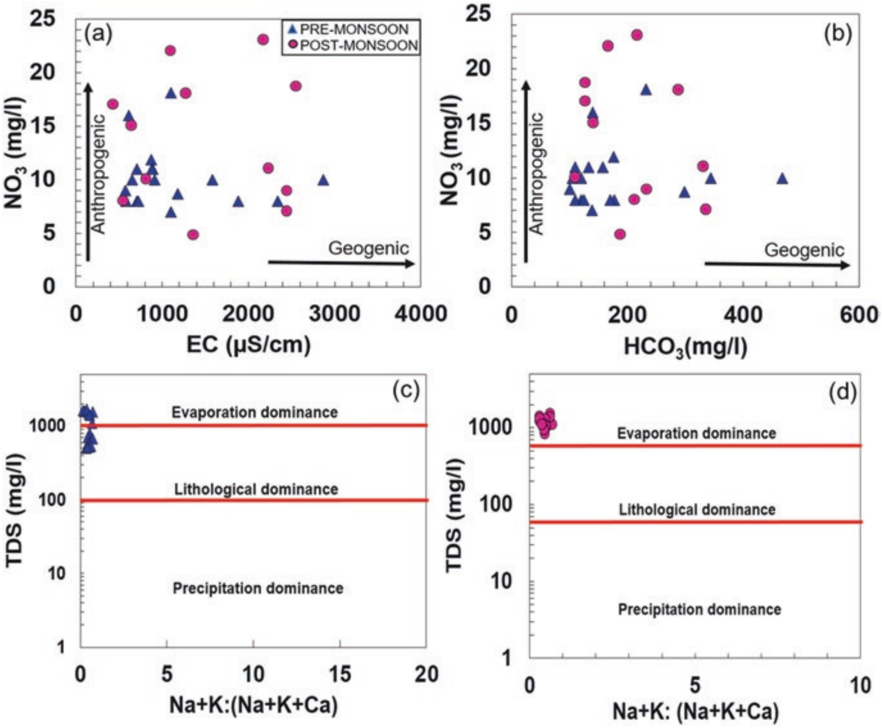

Fig. 15.4 Hydrogeochemical plots depicting anthropogenic sources of pollution and dominant character, (**a**) electrical conductivity versus nitrate, (**b**) bicarbonate (HCO_3^-) versus nitrate (NO_3^-). (**c**) Gibb's plot showing cations versus TDS in pre-monsoon samples. (**d**) Gibb's plot showing cations versus TDS in post-monsoon samples

(Fig. 15.4a) and with HCO_3 (Fig. 15.4b). Also, the major cations with TDS display a conspicuous non-geogenic character of groundwater contamination. The lithological dominance is negligible (Fig. 15.4c, d) (adopted from Brindha et al., 2020).

The cations and anion concentrations are plotted in Piper's trilinear diagram (Fig. 15.5). The samples showed the mixing nature of calcium chloride, magnesium bicarbonate, and sodium chloride type. While the cations are mixed, some samples show the dominance of Na, Mg, and Ca. The anions are also of similar behavior, showing no specific type. However, in some samples, bicarbonate and chloride are dominant. The mixed nature of groundwater in the area is attributed to the heavy influx of industrial wastewater, lack of recharge due to hard rock, and urbanization in the study area. The pre-monsoon samples are calcium chloride, magnesium bicarbonate, sodium chloride and mixed type, Mg, Ca, Na, and K type, bicarbonate, chloride, and some belong to no dominant type. The post-monsoon samples belong to the no dominant to chloride type.

The industries were dumping solid waste on their premises until the year 2002. The then Andhra Pradesh Pollution Control Board (APPCB) decided to mobilize the solid waste at a common hazardous waste treatment, storage, and disposal

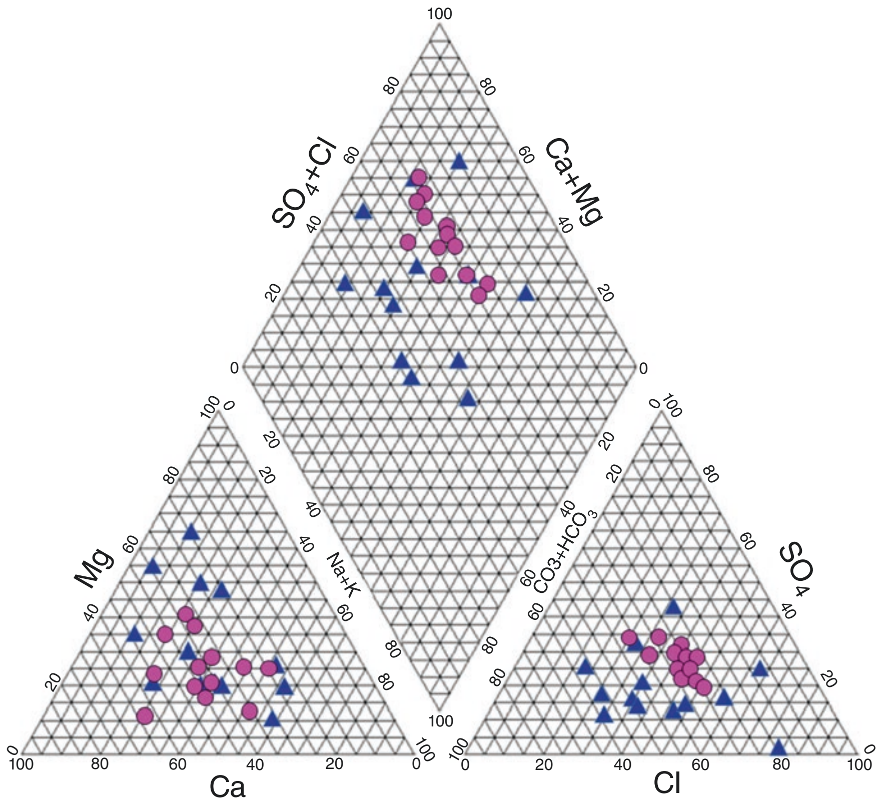

Fig. 15.5 Piper's trilinear diagrams for pre-monsoon and post-monsoon samples. Symbols as in Fig. 15.4

facility (TSDF) at Dundigal, RR district (APPCB, 2010). However, industries are still dumping the waste in open lands, causing pollution to the ground topsoil and allowing the toxic material to infiltrate into the subsurface waters. As a general phenomenon, nitrate is often naturally present in groundwater in feeble concentrations. Nitrate is sourced from anthropogenic factors such as domestic sewerage, industrial disposals, or agriculture. The correlation coefficients of various physicochemical parameters were determined to understand their interrelations. It is observed that nitrate shows a negative relationship with calcium (Ca^{2+}) and sodium (Na^{+}) while it shows positive correlation with magnesium (Mg^{2+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), total alkalinity, sulfate (SO_4^{-}), chloride (Cl^{-}), and conductivity (EC) (Table 15.2). The pre-monsoon samples show a positive correlation between conductivity, TDS, and total hardness, while the rest of the physicochemical parameters show a negative correlation (Table 15.3). The correlation matrix for post-monsoon samples shows distinct positive correlations between conductivity and the majority of other parameters. The majority of physicochemical parameters are in a negative correlation with turbidity. The positive correlation decreases with parameters TDS,

Table 15.3 Correlation matrix of major cations and anions in groundwater, pre-monsoon (green, positive; red, negative)

	pH	EC	T	TDS	TA	TH	Ca	Mg	Cl	SO_4	NO_3	TOC	*F*
pH	1												
EC	0.26	1											
T	0.26	0.21	1										
TDS	0.20	0.75	0.58	1									
TA	0.33	0.54	0.05	0.38	1								
TH	0.05	0.87	0.14	0.67	0.47	1							
Ca	-0.31	0.33	-0.23	0.04	-0.09	0.46	1						
Mg	0.14	0.78	0.53	0.72	0.47	0.75	0.22	1					
Cl	0.33	0.14	0.42	0.59	0.15	0.01	-0.37	0.15	1				
SO_4	0.08	0.92	-0.01	0.59	0.44	0.88	0.48	0.66	-0.01	1			
NO_3	-0.43	-0.21	-0.02	0.12	0.20	-0.21	-0.39	-0.15	0.24	-0.26	1		
TOC	0.14	0.77	0.24	0.78	0.26	0.85	0.25	0.56	0.32	0.77	-0.09	1	
F	0.40	0.65	-0.08	0.30	0.58	0.39	-0.10	0.21	-0.04	0.53	-0.06	0.37	

Table 15.4 Correlation matrix of major cations and anions in groundwater, post-monsoon (green, positive; red, negative)

	pH	EC	T	TDS	TA	TH	Ca	Mg	Cl	SO_4	NO_3	TOC	F
pH	1												
EC	0.34	1											
T	0.06	0.42	1										
TDS	0.42	0.61	0.24	1									
TA	-0.06	0.21	-0.26	0.37	1								
TH	0.27	0.67	0.11	0.61	0.29	1							
Ca	0.60	0.56	0.28	0.67	0.35	0.63	1						
Mg	0.19	0.52	0.18	0.34	0.36	0.39	0.42	1					
Cl	0.12	0.77	0.33	0.56	0.42	0.69	0.60	0.84	1				
SO_4	0.06	0.61	0.30	0.68	0.48	0.65	0.61	0.67	0.81	1			
NO_3	0.46	0.09	0.12	0.24	-0.26	-0.08	-0.01	-0.01	-0.17	0.02	1		
TOC	-0.07	0.40	-0.14	-0.14	-0.13	0.41	0.06	0.27	0.29	0.25	-0.14	1	
F	-0.34	0.13	-0.08	-0.05	0.11	-0.11	-0.11	0.40	0.34	0.32	-0.44	0.27	1

TA, and TH prevail between the physicochemical parameters in both pre- and post-monsoon samples. This is attributed to the severe influx of effluents to the aquifers and a lack of adequate recharge (Table 15.4).

5.3 Trace Elements

The trace element distribution is a vital aspect to be noted in the study area (Table 15.5). As the industrial effluents are being let out into the open ground, the heavy metals are absorbed into the ground and interact with the aquifer, contaminating the groundwater. While Bi and Cd are not detected in the analysis, the other elements, namely, Cr, Fe, Ni, Pb, Mn, and Ni, are of higher range. Cr concentration ranges from 0.01 to 0.08 and 0.02 to 0.04 mg/l in pre- and post-monsoon samples, respectively. Fe content ranges from 1.12 to 1.61 and 1 to 1.84 in pre- and post-monsoon samples. Pb concentration ranges from 0.03 to 0.7 and 0.02 to 0.45 mg/l in pre- and post-monsoon samples. Mn content ranges from 0.24 to 0.68 and 0.23 to 0.5 in pre- and post-monsoon samples. Ni content is of negligible amounts in very few samples. The geospatial analysis gives a glimpse of the dispersion of heavy

Table 15.5 *Trace* element concentrations in pre-and post-monsoon groundwater samples

Sample	Location	Trace element concentration (mg/l)					
		Cr	Cr	Fe	Pb	Mn	Ni
Pre-monsoon							
W1	Patancheru	61	0.05	1589	0.08	0.54	0.005
W2	Lakdaram	12	0.02	1610	0.05	0.24	0.004
W3	Patancheru	32	0.01	1340	0.05	0.3	0.004
W4	Patancheru	60	0.08	1450	0.06	0.45	0.004
W5	Patancheru	58	0.04	1200	0.055	0.42	0.005
W6	Janakampet	59	0.03	1120	0.065	0.63	0.004
W7	IDA Pashamylaram	48	0.03	1578	0.035	0.68	0.004
W8	Inole	61	0.02	1330	0.056	0.32	0.004
W9	Pashamylaram	18	0.04	1290	0.08	0.33	0.003
W10	Muthangi	16	0.02	1120	0.04	0.44	0.003
W11	Indresamdarga	15	0.03	1340	0.03	0.3	0.002
W12	Madaram	21	0.04	1540	0.06	0.34	0.002
W13	Patighanpur	20	0.05	1490	0.7	0.33	0.003
W14	Ordnance factory	27	0.06	1340	0.07	0.45	0.002
W15	Nandigama	22	0.05	1440	0.06	0.54	0.002
Post-monsoon							
W1	Patancheru	62	0.03	1625	0.078	0.4	0.004
W2	Lakdaram	15	0.03	1298	0.045	0.5	0.004
W3	Patancheru	16	0.04	1190	0.047	0.23	0.004
W4	Patancheru	72	0.04	1745	0.066	0.32	0.004
W5	Patancheru	58	0.04	1840	0.07	0.34	0.004
W6	Janakampet	56	0.03	1745	0.06	0.45	0.004
W7	IDA Pashamylaram	12	0.03	1200	0.45	0.34	0.004
W8	Inole	11	0.03	1500	0.06	0.29	0.004
W9	Pashamylaram	23	0.02	1600	0.07	0.3	0.003
W10	Muthangi	20	0.03	1560	0.04	0.4	0.004
W11	Indresamdarga	21	0.04	1340	0.02	0.5	0.003
W12	Madaram	18	0.02	1700	0.04	0.4	0.003
W13	Patighanpur	18	0.04	1450	0.05	0.3	0.004
W14	Ordnance factory	16	0.04	1480	0.03	0.4	0.03
W15	Nandigama	14	0.02	1300	0.04	0.4	0.03

elements in groundwater in the study area. In the pre-monsoon samples, chromium, the chromium (Cr) content is higher on the western side of Patancheru and lower towards the northern part of the study area, i.e., the downstream side (Fig. 15.6a). In the post-monsoon samples, it shows the highest concentration in addition to Patancheru area, and the downstream portion is also enriched in Cr (Fig. 15.6b). The iron (Fe) content in pre-monsoon groundwater samples is higher in the NW part of the study area (Fig. 15.6c), and it shows higher concentrations on the western side of Patancheru in post-monsoon samples (Fig. 15.6d). The manganese (Mn) is higher

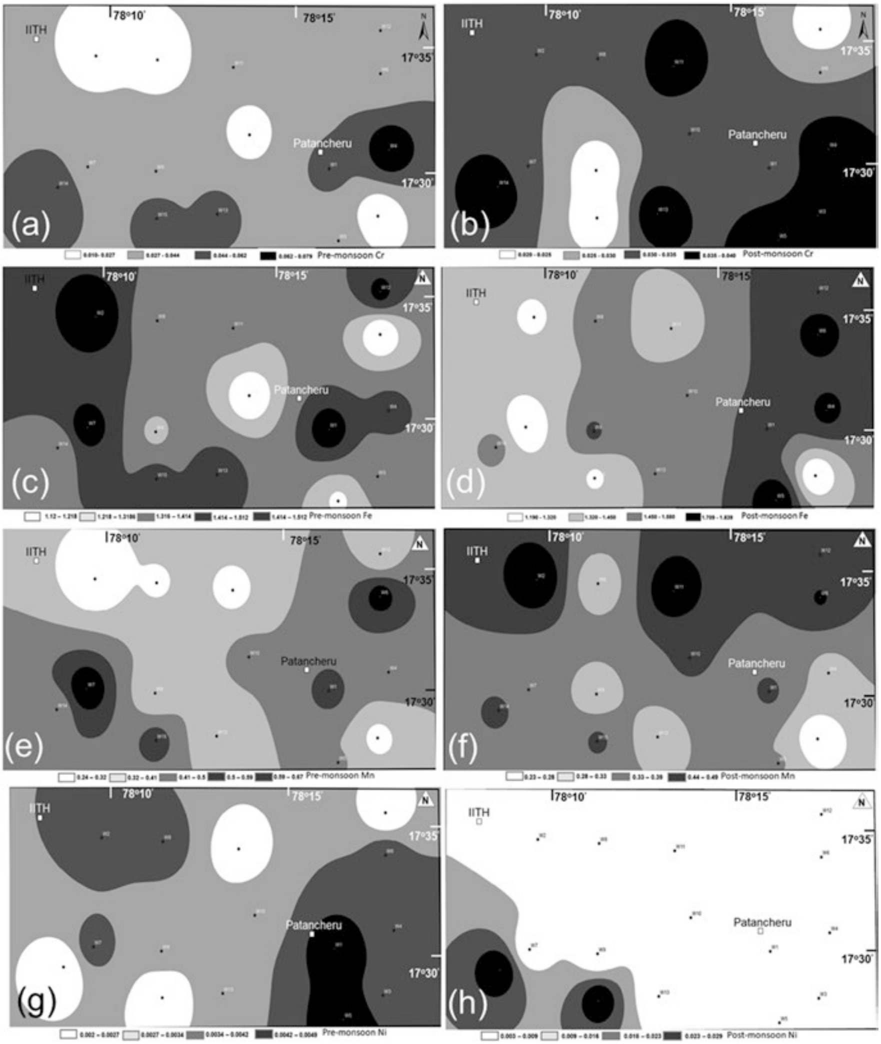

Fig. 15.6 Spatial distribution of trace elements. (**a**) Cr in pre-monsoon, (**b**) Cr in post-monsoon, (**c**) Fe in pre-monsoon, (**d**) Fe in post-monsoon, (**e**) Mn in pre-monsoon, (**f**) Mn in post-monsoon, (**g**) Ni in pre-monsoon, (**h**) Ni in post-monsoon. White and black zones represent the lowest and highest concentrations, respectively, with grey shades as intermediate ranges

in the SE and western part in pre-monsoon samples (Fig. 15.6e) while it is higher in the northern part (Fig. 15.6f).

The nickel (Ni) content is higher in the Patancheru area in pre-monsoon samples (Fig. 15.6g), while the post-monsoon samples show a higher concentration in the west of the Patancheru area (Fig. 15.6h). The Ni concentrations for most of the area are no signs in post-monsoon samples. The trace element distribution on overall shows that they are more concentrated in the Patancheru area, which is attributed to the disposal of heavily contaminated industrial effluents to the ground, which infiltrated to interact with the aquifer and contaminate the groundwater.

5.4 Impact on Health

The people living within a radius of 5 km of PIA are reported to suffer from genetic disorders. The wastewater released from the industries, both treated and untreated, is being discharged to the open ground or roads or outside the industry campuses and finally ends either as a pool of sewerage or joining streams that are tributaries of the Manjira River course. The elevated concentrations of toxic heavy metals in the groundwater of the study area are causing disorders in chromosomes with thread-like cells called organelle. These organelles carry DNA and form genes that enter the body of biota upon consumption of contaminated groundwater. The field inventory in the villages during this study reveals that genetic disorders are up to 8% in people living within the proximity of 2 km radius from the industrial zones of Patancheru, Pashamylaram, and Rudraram and 2–3% away from the industrial area. Consultations with senior medical professionals revealed that the causative factor for the genetic damages is the presence of heavy metals in the groundwater, which are sourced from industrial effluents in the area. A survey conducted by the National Environmental Engineering Research Institute (NEERI), Nagpur, revealed that a plethora of ailments such as epilepsy, skin and throat problems, respiratory diseases, cancer, and paraplegia (paralysis of both the legs), while pregnant women are giving birth to still-born children. There are two common effluent treatment plants (CETP) in the Patancheru and Bollarum industrial areas. The tankers will transport the effluents to the CETP, from where the treated or semi-treated effluent water will be released to the surface drainage system. The CETPs do not comply with the standard operating procedures (SOP) of pollution control measures for instance, such as physical properties TDS, colour or pH (Reddy et al., 2011).

5.5 Contamination Schema

A schematic diagram pertaining to the study area has been drawn. The industrial effluents are let out for open ground, and natural stream courses are getting percolated to the subsurface through riverbeds and fractures in hard rock areas. The toxic elements are also mobilized and mixed with the groundwater. Thus, the toxic elements are, in turn, drawn out through groundwater pumping, upon consumption of which the people and environment are impacted (Fig. 15.7).

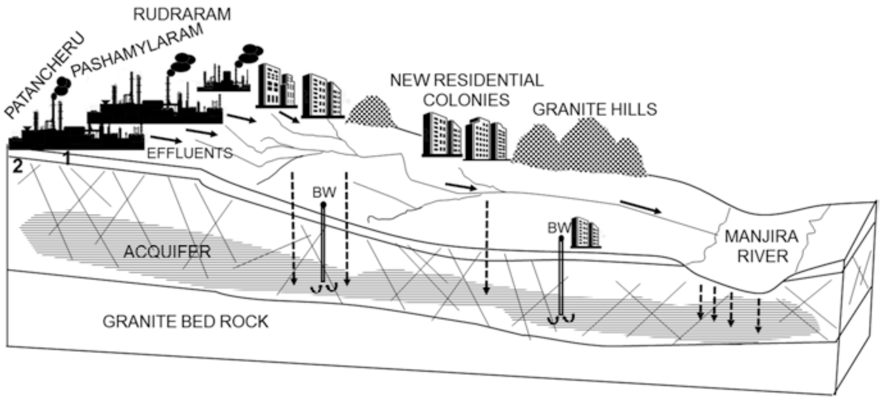

Fig. 15.7 Pictorial representation showing the process of groundwater contamination in the study area 1. Top layer containing mix of soil and weathered rock at places. 2. Fractured rock BW, bore well (not to scale)

6 Conclusions

This investigation showed that there has been a tremendous change in the landscape in the northwestern part of Hyderabad city in the past three decades. An intense urbanization three times more than that in 1985, in addition to the existing industries, has been noticed. The groundwater analysis (n = 30) revealed that a highly mixed type of groundwater exists in the area which is attributed to severe contamination. The geospatial analysis showed that the Patancheru and Pashamylaram industrial areas have a high concentration of heavy metals such as Cr, Fe, Ni, Pb, Mn, and Ni while Bi and Cd are not detected in the analysis. The physicochemical parameters show no correlation to each other owing to the influx of strong effluents of different compositions from multiple industrial sources, insufficient recharge, poor sanitation system, erratically increasing residential colonies irrespective of terrain morphology, and so many other anthropogenic activities. The geogenic factors have nil or negligible influence on the groundwater contamination. The natural drainage system is observed to be disturbed at a faster rate by the ever-increasing residential colonies. The lockdowns or temporary shutdown of industries due to recent COVID-19 pandemic or surplus rainfall in the last few years have no impact to improve the quality of groundwater which is already severely contaminated through decades of time.

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