

Spatial patterns of pollutants in water of metropolitan drain in Lahore, Pakistan, using multivariate statistical techniques

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Abstract The present study was conducted to investigate the pollutant load in surface water of the Sattukatla drain in Lahore, Pakistan. This drain is receiving high volumes of pollutants from industries and municipal sewage. To study the pollution status of this urban drain, different parameters such as pH, EC, TDS, BOD, NO₃, PO₄, COD, K, Mg, Ca, Ni, Fe, Co, Pb, Cu, Cd, and Zn were analyzed. These 17 parameters were monitored along the longitudinal gradient of drain consisting of 15 key sampling sites. The studied parameters were subjected to hierarchical cluster analysis (HCA) and factor analysis (FA). The HCA divided 15 sampling sites into three zones, i.e., low pollution, medium pollution, and high pollution. The PCA identified three major contributors, industrial followed by municipal sewage and agricultural sources. The trend of heavy metal levels was observed as Cu > Zn > Fe > Pb > Co > Ni > Cd. The results indicate levels of pollutants above the permissible limits described by NEQS, Pakistan for wastewater. There is an urgent need to address the issue and install treatment plants to reduce the pollution load on this urban drain in Lahore city.

Keywords Drain water quality · Hierarchical cluster analysis · Heavy metals · Industrial wastewater · National Environmental Quality Standards

Introduction

Urban wastewater is a mixture of the water, litters removed from commercial institutions and residential areas together with surface water and runoff water (Al Enezi et al. 2004). As urban centers expand in developing countries, residents pursue improved living conditions/standards, therefore larger volumes of freshwater are diverted to commercial, industrial, and domestic sectors, which produce even greater amounts of wastewater (Lazarova and Bahri 2004; Metcalf et al. 2007; Qadir et al. 2008). Most wastewater is discharged with minor or no treatment into natural water bodies, which can turn out to be highly contaminated with the passage of time. Cleanup of commercial, industrial, and domestic wastewater is a vital prerequisite under the Environmental Protection Act, which recommends acceptable levels of numerous contaminants for discharge and dumping into surface waters or onto lands (EPA, P, 2005). This suggests suitable management of sewage/wastewater before its final removal or disposal.

Most trace metals are present in urban discharges of wastewater. The concentration of trace metals in drinking and wastewater is linked to its main source and urban consumption practices. In major urban centers, manufacturing and engineering activities use trace metals extensively in production (Afzal et al. 2014;

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Tchounwou et al. 2012). Major contributions to urban sewage water contain industrial effluents, household effluents, atmospheric deposition, and transportation associated pollutants (gasoline and oil leakage, vehicle exhaust, tires, and brake linings). These pollutants are washed with rainstorm water into the sewerage system (Karvelas et al. 2003; Wang et al. 2005). In urban areas, only 20–25% of freshwater withdrawn or diverted is used and the remaining water is returned to the urban hydrologic system in the form of wastewater. Urban wastewater is mostly a blend of stormwater, industrial water, and domestic wastewater.

Industrial wastewater mostly consists of high concentrations of heavy metals, volatile or semi-volatile compounds, and metalloids, whereas domestic or residential wastewater is most harmful due to its sheer volume. Wastewater ejections mostly hold health compromising pathogens, chemical elements, and carcinogenic substances such as heavy metals and trihalo-methanes (THMs) which may bring adverse environmental effects such as polluted drinking and groundwater (CCME 2006; Canada 2001). In many African and Asian countries, population expansion has overtaken improvements in public health and sanitation, wastewater infrastructure, etc., thus creating a great challenge for urban wastewater management. In India, 24% of waste/sewerage water from domestic and industry is treated, whereas in Pakistan, only 2% of waste/sewerage water is properly treated before its final disposal (Mandal et al. 2011; Qadir et al. 2010).

Like many other developing countries, Pakistan constructed open combined sewer systems (CSSs) in which a single channel is used to transport stormwater, flood water, industrial and residential wastewater to a chosen disposal or dumping location. Due to rapid industrialization and population growth, these drains mainly collect the municipal and industrial discharges of the varied composition thus resulting in growing pollution concentrations. The wastewater drains are going through a process of deterioration and degradation mainly due to untreated domestic and industrial effluents in Pakistan. Finally, the outcome of this misuse appeared in the form of extensive and widespread deterioration of surface water quality of rivers (Anyanwu 2015; Vitkar 2014).

The Sattukatla drain is one of the largest tributaries of the Hudaira drain, originating in the most densely populated part of Lahore. To date, no study has inspected the spatial variation and identification of sources of pollutants in the Sattukatla drain. Moreover, no effort

has been made to monitor and assess its surface water quality. Thus, with the current study initiated, the main objectives were to identify the surface water quality of Sattukatla drain and to show spatial differences in water quality by multivariate analyses and GIS techniques.

Materials and methods

Study area

The current study was conducted in Lahore city which is the capital of Punjab province, Pakistan. It is the second largest metropolitan city of Pakistan and ranked the 18th most populous city in the world. The city of Lahore is located between 31.5546° N and 74.3572° E along the eastern bank of the Ravi River with 1772 km² total area at 217-m elevation. According to Census (2017), the total population of Lahore is 11.13 million with 3% annual growth rate. The average population density is 6300 persons per square kilometer. Approximately 2200 industries have been registered by the government in the past few decades (Rana and Bhatti 2017). The average annual rainfall is 240 mm. A major portion of rainfall occurs during the monsoon period (June to August). The climate of Lahore is cold in winter and hot/humid in summer. The hottest months are June and July, with maximum temperatures above 42 °C. During winter, the temperature may fall to 2 °C. The drainage system in Lahore consists of 8 major and 75 subdrains or tributaries with a total transport volume of 7474 Cusecs. The total length of surface drains in Lahore district is 212 km with four pumping stations having a total volume of 665 Cusecs. All the drains in Lahore dump their wastewater directly or indirectly into the Ravi River within a vicinity of about 65 km (WWF 2007).

The Sattukatla drain is the largest wastewater stream of Hudaira drain. It starts as an ADA drain from the new airport, and then, it takes the name of Sattukatla drain while crossing Ferozpur Road. The total length of the Sattukatla drain is 26.5 km. The drain lies between the latitude of 31° 23' 42" N–31° 31' 0" N and a longitude of 74° 13' 10" E–74° 24' 24" E Pakistan. The total flow of the Sattukatla drain is 7500 (m³/h) near the downstream end (WWF 2007). The Sattukatla drain joins the Hudaira drain near Bhabharian Chowk on the Raiwind Road, and it then joins the Ravi River, which is

approximately 8 km west of the Multan Road, Lahore (Fig. 1). The Quaid-e-Azam Industrial Estate (QIE) discharges its industrial effluents into the Sattukatla wastewater drain through the Kotlakhpat drain, which is 2.5 km in length. The QIE consists of 477 industries spread over 565 Acres of land (Hina et al. 2011). Industries such as chemical, auto parts, pharmaceutical, steel, plastic, surgical, textile, garment, dyeing and printing, food and beverages all exist here. These industries discharge huge volumes of untreated industrial effluent into this drain. It was once a stormwater channel, but now it is a polluted wastewater drain due to an unselective discharge of untreated industrial effluent and sewage waste (Baysal et al. 2013; Khattak et al. 2012; Mahmood and Malik 2014).

Sampling program and chemical analysis

A field survey was conducted for the sampling of drain water during April, 2015. A total 15 samples were collected, 13 samples from the Sattukatla drain, and 2 samples

from the Kotlakhpat drain (a tributary of the Sattukatla drain). These samples were tested and then mapped through different GIS techniques. Finally, the results were analyzed to evaluate the spatial concentration of heavy metals in the study area. Drain water samples were collected after every 2 km using the grab sampling technique. Each sampling site was identified with the help of GARMIN eTrex 30 GPS (global positioning system). Water samples were collected in pre-cleaned 0.5-L plastic polyethylene bottles. The samples were preserved immediately by adding 2 ml/L concentrated nitric acid (HNO₃) and stored at 4 °C. All analysis was performed according to (APHA/AWWA/WEF 2006) standards.

Drain water samples were studied for 17 different parameters like pH, total dissolved solids (TDS), electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD), zinc (Zn), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), cobalt (Co), iron (Fe), potassium (K), magnesium (Mg), calcium (Ca), nitrate (NO₃), and phosphate (PO₄). Water pH, EC, and

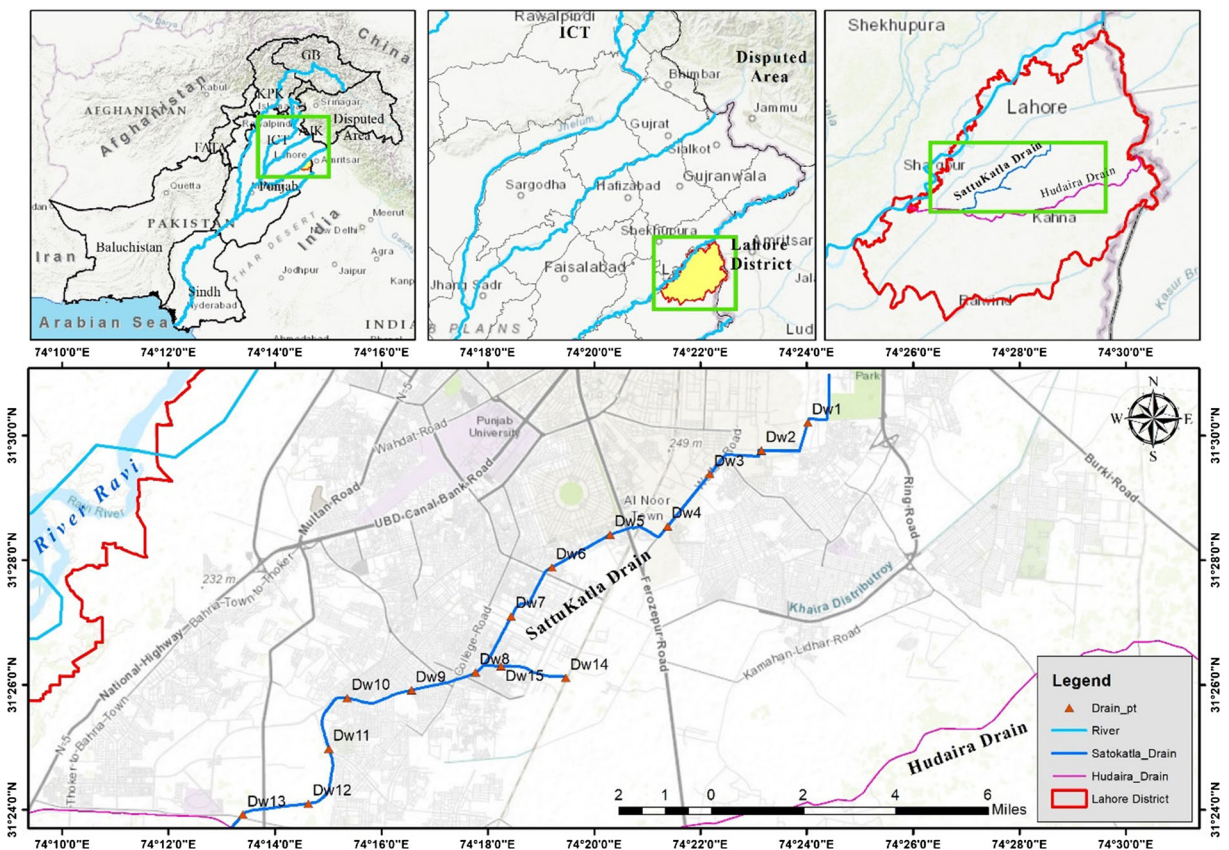


Fig. 1 Map of the Sattukatla drain showing sampling sites

TDS were determined by EUTECH instruments PC510 (HACH Method 8160, 8156). BOD was determined through a JENWAY 970 DO2 meter (HACH Method 8215, 8043), and COD was determined by a LOVIBOND RD 125 (HACH Method 8000). NO_3 and PO_4 were determined by ion chromatography. All wastewater samples were properly digested on a hot plate in Environmental Science Lab of Kinnaird College for Women, Lahore. For heavy metal analysis, a mixture of nitric acid (HNO_3), hydrochloric acid (HCl), and hydrogen peroxide (H_2O_2) was used for digestion. Analysis of metals such as Zn, Cd, Cu, Ni, Co, Fe, K, and Ca was carried out using a Buck Scientific 210 VGP Atomic Absorption Spectrophotometer, whereas the analysis of Pb and Mg was performed through a Perkin Elmer AAnalyst 800 Atomic Absorption Spectrometer. The prepared metal standards were thoroughly checked by SRM (standard reference material) acquired from Fluka. For each determination, an average of three replicates was taken. The accuracy of analytical measures is stated in the relative standard deviation (RSD) which ranged from 5 to 10%, and the average mean value was used in statistical analysis. The obtained results were matched with National Environmental Quality Standards (NEQs 2000).

Statistical analysis

Data obtained was evaluated with various univariate and multivariate statistical techniques: Inter-metal relationship (Pearson correlation), hierarchical cluster analysis (HCA), and factor analysis (FA). All statistical and mathematical calculations were performed using Microsoft Office MSeExcel 2013, SPSS (PASW Statistics ver. 18.0), and STATISTICA (StatSoft ver. 10.0). Spatial maps of important parameters were produced in ARC Map, ArcGIS ver. 10.1 (ESRI 2012).

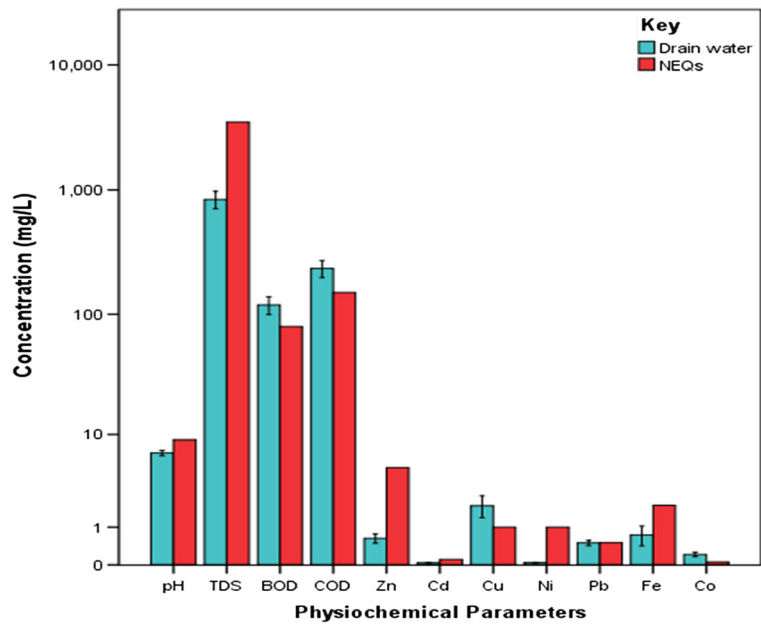
Results and discussion

Physiochemical variations in drain water of the Sattukatla drain

Physiochemical parameters of surface water in the Sattukatla drain with NEQs values are shown in Fig. 2 and descriptive statistics (mean, median, standard deviation, range, minimum and maximum) of all the variables are shown in Table 1. The pH ranged from 6.36 to 8.94 with an average mean value of 6.85, all

observed values were within permissible limit of the NEQs. The highest pH value observed was at site Dw15 which was located in the Kotlakhpat drain and carrying the industrial effluent of the Quaid-e-Azam industrial area, Lahore. The EC ranged from 1303 to 1762 $\mu\text{S}/\text{cm}$ with an average mean value of 1500 $\mu\text{S}/\text{cm}$. The highest EC value was recorded at site Dw8, which was located in the Sattukatla drain but within the vicinity of Quaid-e-Azam industrial area. The TDS value ranged from 649 to 1440 mg/L with a mean value of 842 mg/L. The highest value was noted at location Dw15 which was collected from the Kotlakhpat drain. The biological oxygen demand (BOD_5) indicates the level of biodegradable organic content of water. It is generally used to estimate the amount of contamination in the water. The BOD_5 concentration ranges from 98 to 232 mg/L with the mean value of 119 mg/L. The chemical oxygen demand (COD) is the amount of oxygen needed by organic material present in water for oxidation. A COD test was performed to evaluate the amount of contamination in wastewater, which ranges from 187 to 438 mg/L with a mean value of 234.8 mg/L. The amount of BOD_5 and COD was highest at sites Dw14 and Dw15 due to the industrial effluents of the QIE, as shown in Fig. 3. The average values of BOD_5 and COD were above the limits set by the NEQs as shown in Fig. 2. Nergis et al. (2012) and Hamid et al. (2016) observed similar higher values of BOD_5 and COD in the sewer systems of Karachi and Rohi Nullah, Lahore. In the present study, the COD level was higher in comparison with Qadir et al. (2013). Higher concentrations of BOD_5 and COD in the Sattukatla drain indicate that there is a high organic load due to an excessive input of industrial effluents. The concentrations of K fluctuate between 0.009 and 0.379 mg/L with a mean value of 0.162 mg/L. The highest K concentration was observed at site Dw15 which was located at the hub of the QIE and carries industrial effluents. The amount of Mg ranged from 2.75 to 9.5 mg/L with a mean value of 4 mg/L. The highest Mg concentration was verified at site Dw7 which was located in the Sattukatla drain but within the neighborhood of the QIE area. The amount of Ca ranged from 18.9 to 33 mg/L with a mean value of 25.9 mg/L. The highest value of Ca was observed at site Dw10, which was lower than the study of (Paul 2011). The sources of Mg and Ca could have been derived from the domestic source, whereas the amount of NO_3 and PO_4 ranged from 5.33 to 14.62 and from 2.25 to 5.88 mg/L with maximum values at Dw11 and Dw15, respectively, shown in Fig. 4. Common sources of NO_3 and PO_4 in drain water are

Fig. 2 Physiochemical parameters of surface water in the Sattukatla drain with NEQs values



agrochemicals and municipal waste (Adesuyi et al. 2015; Qadir et al. 2013).

Heavy metal contribution

The concentration contribution of each heavy metal is shown in Figs. 5 and 6. The concentration of heavy metals (mg/L) shows the general trend Cu > Zn > Fe > Pb > Co > Ni > Cd. The concentration of Cu ranged from 0.342 to 3.68 mg/L with highest values at sites Dw14 and Dw15. Cu concentrations were higher throughout the study area, apparently due to corrosion and leaching of plumbing, copper polishing, electronics plating, paint manufacturing, wood preservatives

production, wire drawing, and printing processes, etc. Mahmood and Malik (2014) reported higher levels of Cu in the wastewater drains of Lahore due to the heavy dumping of industrial waste. The concentration of Zn ranged from 0.139 to 0.881 mg/L, which was within the limits of NEQ guidelines. Fe concentration ranged from 0.035 to 0.759 mg/L. Fe values were within the limits of NEQ guidelines throughout the drain. The concentration of Pb ranged from 0.323 to 0.821 mg/L. Forty-seven percent of sampling sites along the drain has a high level of Pb due to activities such as battery production, manufacturing of paints, production of electronic devices, and lead plumbing in old houses. Sarker et al. (2015) and Duzgoren-Aydin (2007) observed a higher level of Pb due to industrial

Table 1 Descriptive statistical data of water quality parameters in the Sattukatla drain, Lahore, Pakistan

	pH	EC (μ S/ cm)	TDS (mg/ L)	BOD (mg/ L)	COD (mg/ L)	Zn (mg/ L)	Cd (mg/ L)	Cu (mg/ L)	Ni (mg/ L)	Pb (mg/ L)	Fe (mg/ L)	Co (mg/ L)	K (mg/ L)	Mg (mg/ L)	Ca (mg/ L)	NO ₃ (mg/ L)	PO ₄ (mg/ L)
Mean	6.855	1500	842	119	234.8	0.626	0.024	1.97	0.035	0.494	0.529	0.206	0.162	4	25.9	8.908	4.032
Median	6.71	1497	765	108	215	0.716	0.029	1.63	0.033	0.459	0.639	0.106	0.134	3.5	25.7	8.65	3.62
Std. dev	0.702	147.8	241.2	35.41	66.88	0.246	0.014	1.07	0.014	0.132	0.251	0.091	0.101	1.66	3.81	2.722	1.344
Range	2.58	459	791	133	251	0.742	0.037	3.34	0.056	0.498	0.724	0.269	0.370	6.74	14.1	9.29	3.63
Min.	6.36	1303	649	98	187	0.139	0.004	0.342	0.002	0.323	0.035	0.103	0.009	2.75	18.9	5.33	2.25
Max.	8.94	1762	1440	232	438	0.881	0.041	3.68	0.058	0.821	0.759	0.372	0.379	9.5	33	14.62	5.88
NEQs (2000)	6–9	–	3500	80	150	5.0	0.1	1.0	1.0	0.5	2.0	0.05	–	–	–	–	–

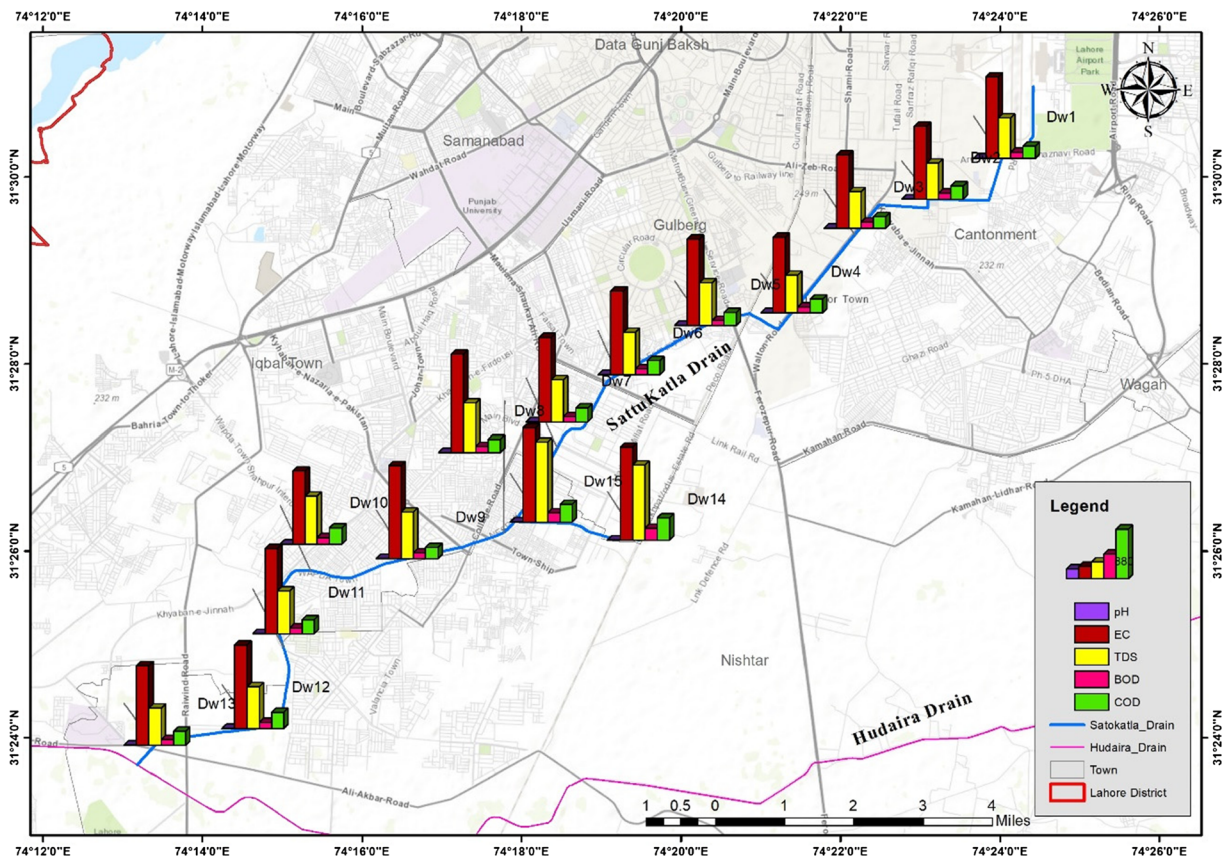


Fig. 3 Spatial map of physiochemical parameters of the Sattukatla drain with study sites

effluents in the Bhaluka industrial area, Mymensingh, Bangladesh, and Guangzhou, China. The Co concentration ranged from 0.103 to 0.372 mg/L, with a mean of 0.206 mg/L. The Co concentrations were above the acceptable limit set by the NEQs (0.05 mg/L). In the present study, the Co levels were higher in comparison with the study of Mahmood and Malik (2014). The Cd and Ni concentrations fluctuated between 0.004 and 0.041 and 0.002 and 0.058 mg/L, respectively, which were within the limits of NEQ guidelines. The concentration of Cd and Ni in Sattukatla drain was below than the study performed by Qadir et al. (2013) in Nullah Palkhu, Pakistan.

Inter-relationship among pollutants

The Pearson correlation coefficient (r) measures correlation between any two parameters, as shown in Table 2. It shows the relationship among any two chosen parameters. If the correlation coefficient (r) is closer to +1 or -1, it indicates a perfect linear association between any

two selected parameters (Manta et al. 2002). A very strong positive correlation was observed between pH and TDS ($r = 0.94$), pH and COD ($r = 0.83$), pH and Pb ($r = 0.88$), pH and Mg ($r = 0.83$), TDS and BOD ($r = 0.85$), TDS and COD ($r = 0.87$), TDS and Pb ($r = 0.80$), TDS and Co ($r = 0.87$), BOD and COD ($r = 0.99$), Cu and Ni ($r = 0.83$), Cu and Co ($r = 0.97$), respectively.

Hierarchical cluster analysis (HCA)

HCA is the most common method used, offering spontaneous relationships and associations between any single sample and the complete data set, and is normally presented by a tree diagram known as a dendrogram (Wang et al. 2013). It delivers a pictorial statement of the grouping procedures, through their closeness or proximity, with a decrease in the proportion of the actual data. The Euclidean distance generally shows the resemblance among two samples which can be shown by the difference among the observed values (Varol et al. 2012).

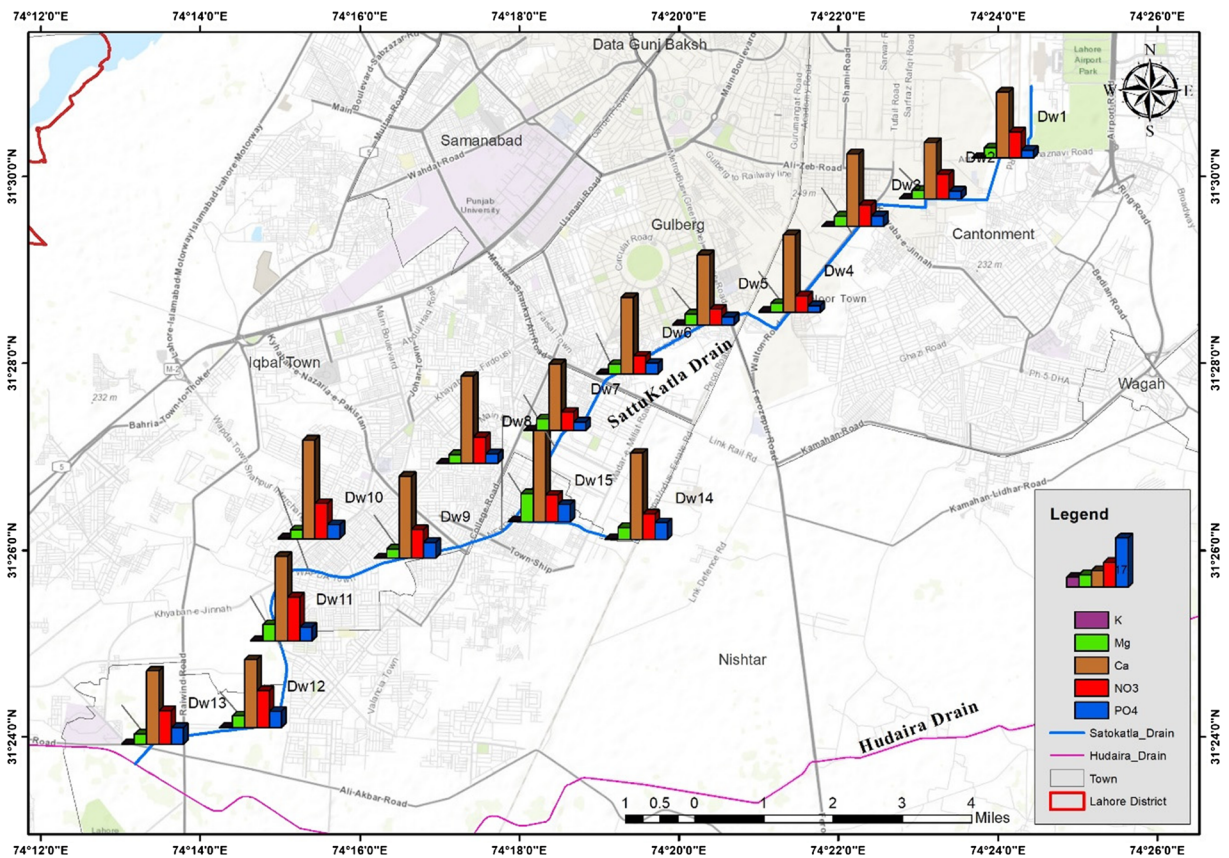


Fig. 4 Spatial map of Cations and Anions in surface water of the Sattukatla drain with study sites

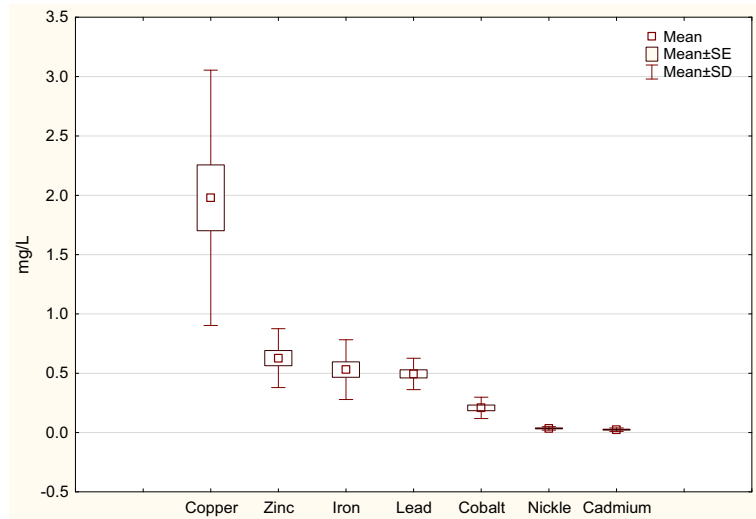
The HCA grouped the observed locations into clusters (known as zones) on the basis of resemblances within a zone and variations among different zones of drain water characteristics. The outcomes of CA helped in understanding and interpreting the data through indicating similar patterns of objects (Zhang et al. 2012). Clustering technique (at the level of $Dlink/Dmax = 15$) was used on a normalized data set through Ward’s method and Euclidean distances, which are used as degrees of resemblance and similarity to identify the zones. Three zones were identified using CA (Fig. 7). The first zone was the “low pollution zone” which was made up of four sites Dw1, Dw2, Dw12, and Dw13. It was situated in low population zone as compared to other two zones. This zone was characterized by higher values of BOD (102–113 mg/L), COD (193–233 mg/L), Cd (0.012–0.039 mg/L), Cu (0.342–1.735 mg/L), and Pb (0.323–0.558 mg/L) which exceeded the standard NEQs guidelines.

The second zone was the “medium pollution zone.” This zone includes Dw3, Dw4, Dw5, Dw6, and Dw7

sites. These sites were located in densely populated areas. This zone was an urban area which received mainly domestic waste. This zone was characterized by higher values of BOD (98–109 mg/L), COD (187–206 mg/L), Cd (0.004–0.039), Cu (1.12–1.726 mg/L), and Pb (0.343–0.574) which exceeded the standard NEQ guidelines. Higher levels of COD, BOD, and other heavy metals were due to industrial and municipal waste. Similar trends were observed by Khan et al. (2003) in the Hudaira drain, Qadir et al. (2008) in Nullah Aik, and Qadir et al. (2013) in Nullah Palkhu, all of which were contaminated from municipal and industrial waste.

The third zone was the “high pollution zone” which was a highly contaminated site due to untreated industrial discharge. This zone receives water from the QIE, which itself consisted of 447 industries of different kinds. Most of these industries were involved in making of textiles, dyeing and printing, pharmaceuticals, food, auto parts, etc. This zone included sites Dw8, Dw9, Dw10, Dw11, Dw14, and Dw15 which receive large

Fig. 5 Box and whisker plot showing heavy metals in the Sattukatla drain



volumes of industrial effluents throughout the year. This zone was characterized by high ratios of BOD (105–232 mg/L), COD (210–438 mg/L), Cd (0.023–0.041 mg/L), Cu (1.317–3.682 mg/L), and Pb (0.447–

0.821 mg/L), which exceeded the standard NEQ guidelines. Qadir et al. (2013) and Nazeer et al. (2016) pointed out that industrial effluents and municipal waste have increased the COD levels in the surface water. Domestic

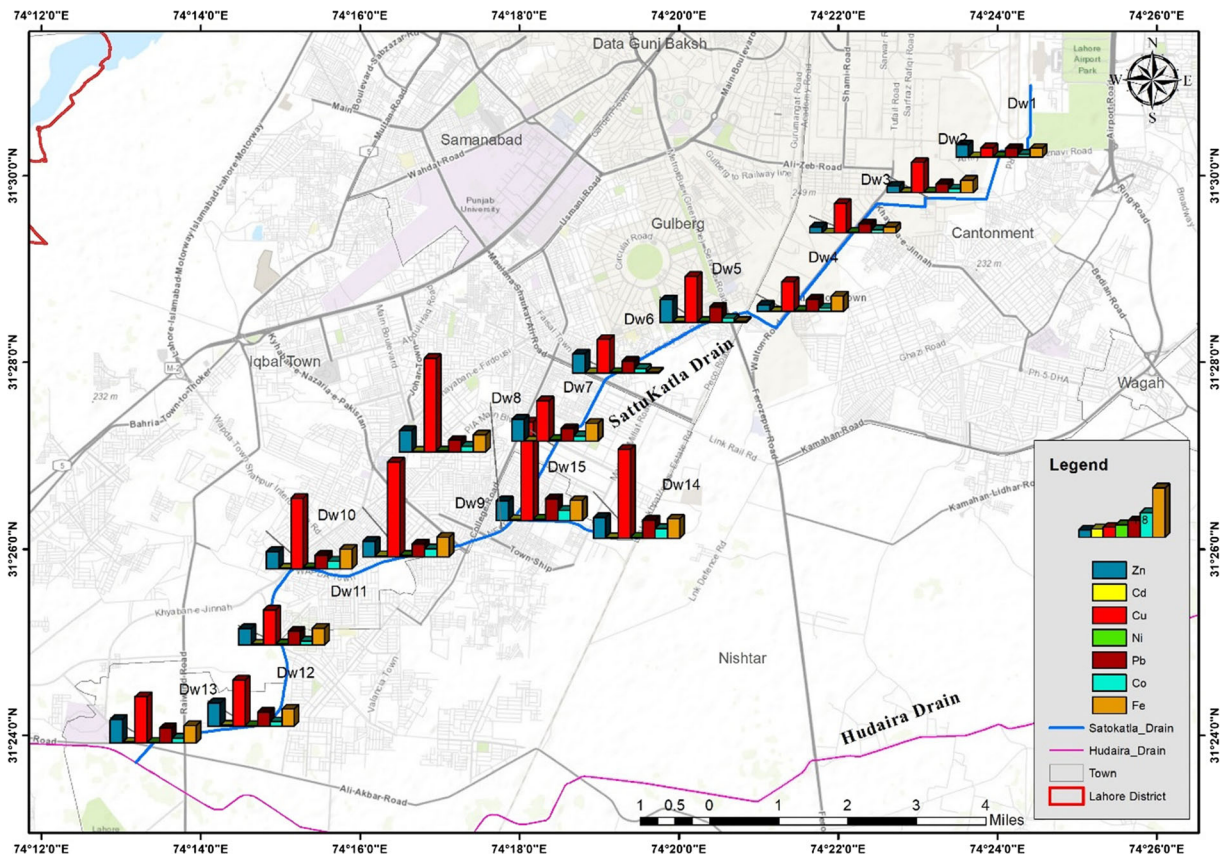


Fig. 6 Spatial map of heavy metals in the Sattukatla drain with study sites

Table 2 Correlation coefficient matrix of the various physiochemical parameters of the Sattukatla drain ($n = 15$)

	pH	EC	TDS	BOD	COD	Zn	Cd	Cu	Ni	Pb	Fe	Co	K	Mg	Ca	NO ₃	PO ₄
pH	1.00																
EC	0.58	1.00															
TDS	0.94 ^a	0.69	1.00														
BOD	0.79 ^a	0.42	0.85 ^a	1.00													
COD	0.83 ^a	0.43	0.87 ^a	0.99 ^a	1.00												
Zn	0.37	0.65	0.38	0.18	0.23	1.00											
Cd	0.62	0.71	0.57	0.39	0.44	0.75 ^a	1.00										
Cu	0.71	0.73	0.78 ^a	0.54	0.61	0.48	0.72	1.00									
Ni	0.55	0.54	0.59	0.38	0.41	0.40	0.53	0.83 ^a	1.00								
Pb	0.88 ^a	0.53	0.80 ^a	0.67	0.71	0.60	0.72	0.64	0.59	1.00							
Fe	0.49	0.34	0.45	0.38	0.44	0.23	0.40	0.61	0.49	0.40	1.00						
Co	0.79 ^a	0.70	0.87 ^a	0.67	0.73	0.47	0.65	0.97 ^a	0.76 ^a	0.68	0.64	1.00					
K	0.42	0.07	0.30	0.17	0.20	0.18	0.05	0.19	0.27	0.57	0.22	0.22	1.00				
Mg	0.83 ^a	0.47	0.70	0.43	0.46	0.28	0.43	0.41	0.39	0.74	0.30	0.46	0.50	1.00			
Ca	0.59	0.41	0.66	0.43	0.49	0.28	0.42	0.71	0.61	0.74	0.46	0.74	0.24	0.44	1.00		
NO ₃	0.20	0.03	0.05	0.06	0.12	-0.24	0.44	0.17	0.00	0.18	-0.55	-0.18	0.20	0.29	0.16	1.00	
PO ₄	0.67	0.36	0.53	0.53	0.60	-0.53	0.70	0.59	-0.44	0.68	-0.55	0.24	0.45	0.48	0.60	0.64	1.00

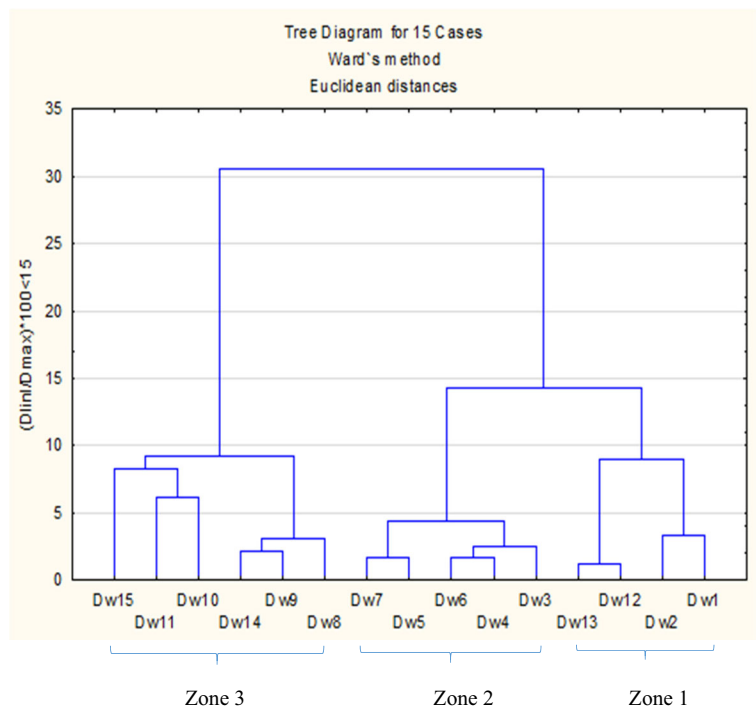
n number of water samples

^aCorrelation is significant at the 0.05 level (two-tailed)

wastewater, fungicides, corrosion process, leaching of plumbing, and wood preservatives were the main

sources of higher Cu concentration (Nazeer et al. 2016). Pb concentration was above NEQ guidelines

Fig. 7 Dendrogram showing clusters of the Sattukatla drain extracted on the basis of water quality parameters



(0.5 mg/L) due to the heavy dumping of auto parts and dyeing industries. In Lahore city, a huge number of iron and steel foundries and rolling mills are utilizing steel scrap and tons of broken ships coated with Pb and Cd. These iron- and steel-related industries are the main sources of discharging Pb and Cd in the wastewater (Mahmood and Malik 2014). According to Waseem et al. (2014), the higher Pb concentration is due to traffic burden and atmospheric deposition in the major cities of Pakistan. Perhaps industries along the Sattukatla and Kotlakhpat drains may not be strictly following national guidelines for dumping wastewater and disposing of their waste without prior treatment (Hina et al. 2011). Significantly important parameters recognized by the HCA are presented through box and whisker plots in Fig. 8a–l, respectively.

Pollution Source Identification

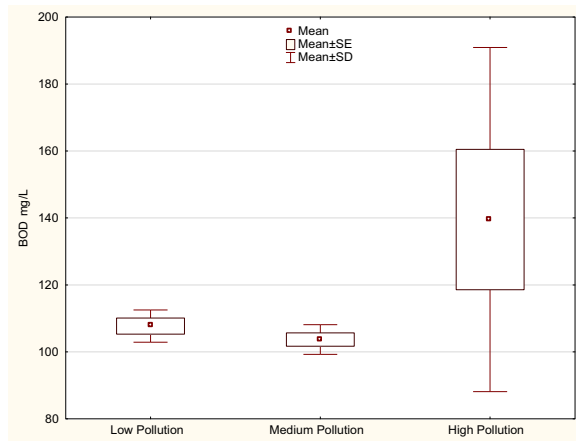
Factor Analysis offers the best way of identifying the source variations in the dataset (McGarigal et al. 2013; Nazeer et al. 2016). It provides information of the most significant parameters with little loss of actual facts and info through defining the entire data set by the data reduction method (Varol et al. 2012; Zhang et al. 2012; Wang et al. 2013). FA with varimax raw rotation was applied on the drain water dataset of three different zones obtained from HCA, i.e., low pollution zone, medium pollution zone, and high pollution zone. The dataset produced three Varimax Factors (VFs) for the low pollution zone and four VFs for the medium pollution, and high pollution zones.

The low pollution zone evolved three factors with eigenvalue > 1 (Table 3) which showed the total variance of 100% for the drain water. VF1 contributed 70.25% of the total variance with 11.94 eigenvalue. It was characterized by high positive loading on pH ($r=0.87$), COD ($r=0.97$), Cd ($r=0.70$), Cu ($r=0.94$), Pb ($r=0.84$), K ($r=0.91$), Co ($r=0.96$), and PO₄ ($r=0.82$) and high negative loadings on Ni ($r=-0.96$) and Fe ($r=-0.93$), indicating miscellaneous sources. This factor showed high levels of heavy metals which originated from industrial effluents and higher levels of organic matter, PO₄ and K originated from municipal sewage and agricultural runoff. VF2 contributed 23.30% of total variance with 3.96 eigenvalue. This factor was associated with high positive loading of EC ($r=1.00$), TDS ($r=0.88$), Mg ($r=0.95$), Ca ($r=0.93$), and NO₃

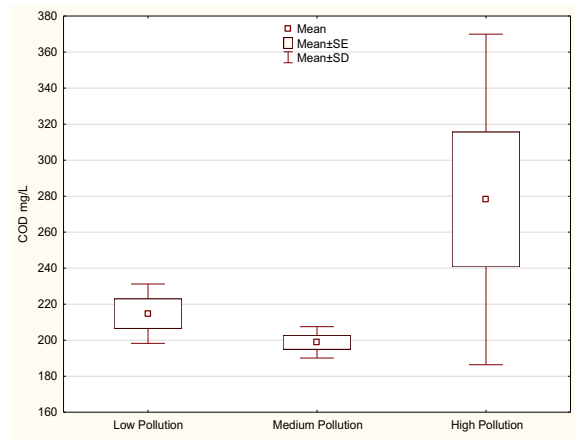
($r=0.71$) and high negative loading on Zn ($r=-0.78$). This factor clearly indicated nutrient reason and the main source of NO₃ was an agricultural runoff (Qadir et al. 2013). VF3 contributed 6.45% of total variance with 1.10 eigenvalue. This factor was associated with high positive loading of BOD ($r=0.88$) only, signifying domestic waste and organic pollution (Nergis et al. 2012).

The medium pollution zone exhibited four factors with eigenvalues > 1 which explained about 100% of the total variance for the drain water. VF1 contributed 58.39% of the total variance with 9.93 eigenvalue. It was characterized by high positive loading on Cd ($r=0.76$) and Fe ($r=0.91$) whereas negative loadings on K ($r=-0.83$). Higher levels of Fe were due to municipal and industrial origins such as electroplating and surgical instrument manufacturing factories (Amin et al. 2013). VF2 exhibited 16.94% of the total variance with 2.88 eigenvalue. This factor displayed high positive loading on Pb ($r=0.84$) and high negative loading on NO₃ ($r=-0.91$) and PO₄ ($r=-0.89$). The reason for this factor could be the agricultural runoff, municipal sewage, and chemical industries which were manufacturing paint by using Pb. Qadir et al. (2013) reported similar studies in the Nullah Palkhu, Pakistan. VF3 contributed 14.93% of total variance with 2.54 eigenvalue. This factor was associated with high positive loading of Mg ($r=0.88$) and high negative loading on Ca ($r=-0.93$) and Ni ($r=-0.96$). This factor signified parental rock material derived from drinking water. VF4 exhibited 9.74% of the total variance with 1.665 eigenvalue. This factor showed high negative loading on BOD ($r=-0.83$) and high positive loading on EC ($r=0.93$), TDS ($r=0.95$), Co ($r=0.92$), and Zn ($r=0.92$) indicating miscellaneous sources such as industrial, municipal, domestic, and agricultural sources. Qadir et al. (2008) indicated in their study that most of the houses and buildings in urban and industrial areas have zinc coated metallic roofs. This Zn readily mobilizes into the waterways and atmosphere when reacting with urban smog and acid rain. In urban areas, the main sources of Zn are human related activities like dumping of solid waste into nearby water bodies (Chauhan et al. 2014).

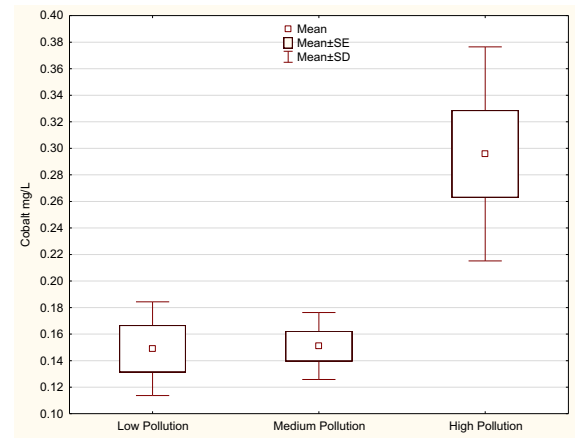
The high pollution zone evolved four factors with eigenvalue > 1 which explained about 93.58% of the total variance for the drain water. VF 1 contributed



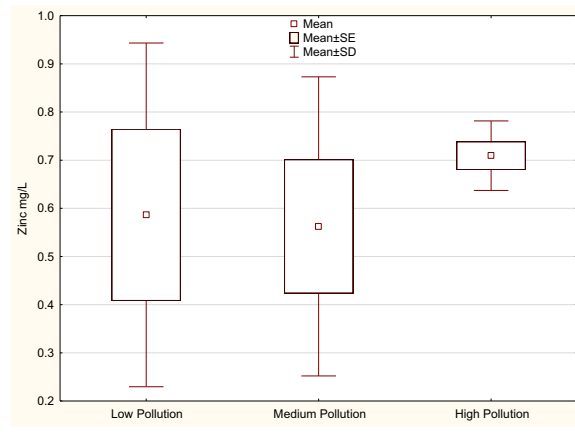
a



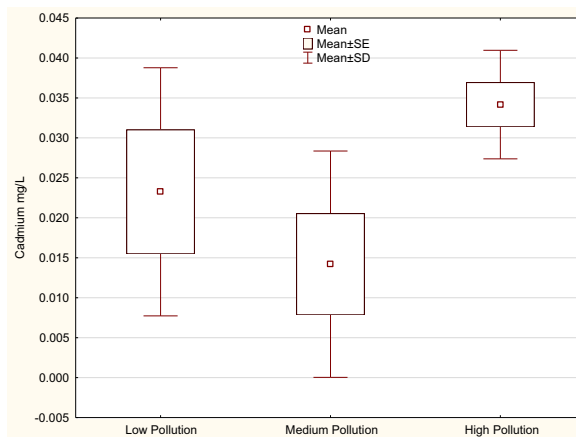
b



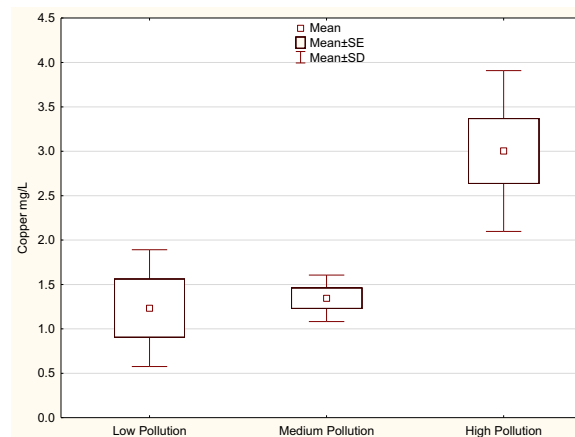
c



d



e

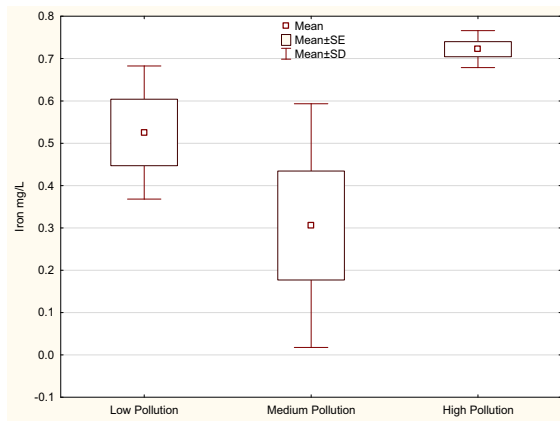


f

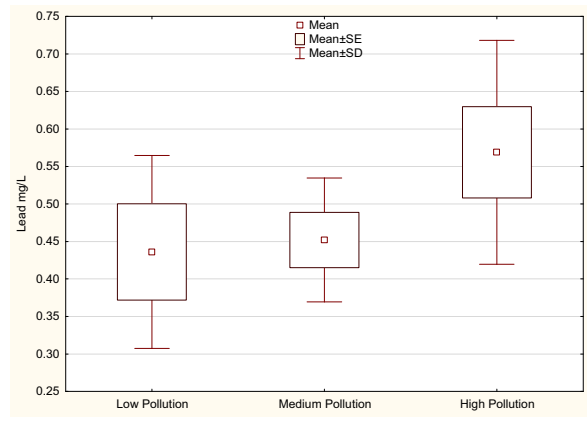
Fig. 8 a–f Spatial variation of parameters identified by HCA in three sampling zones

54.11% of the total variance with 9.21 eigenvalue. It was characterized by high positive loading on Cu

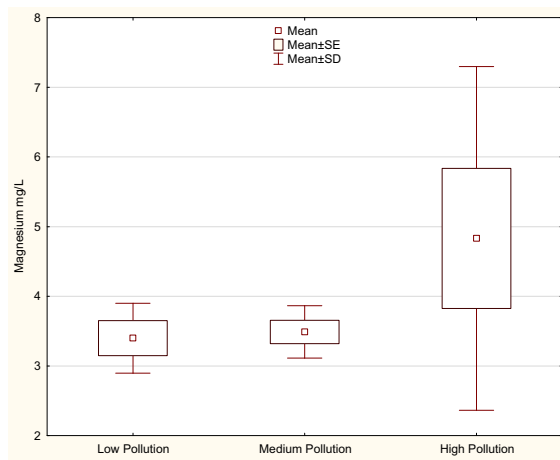
($r=0.96$) and Co ($r=0.89$) whereas negative loading on NO_3 ($r=-0.88$), Ni ($r=-0.77$), and Fe ($r=$



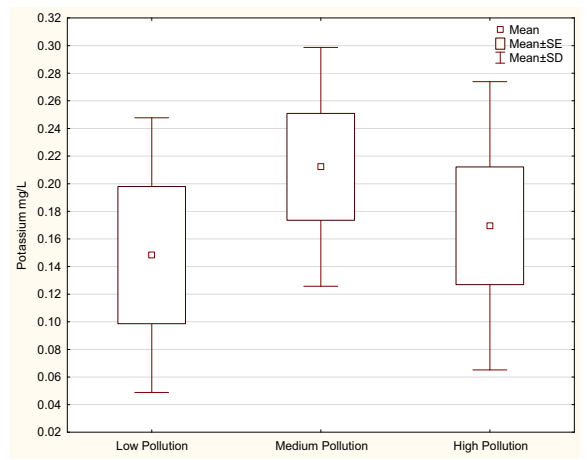
g



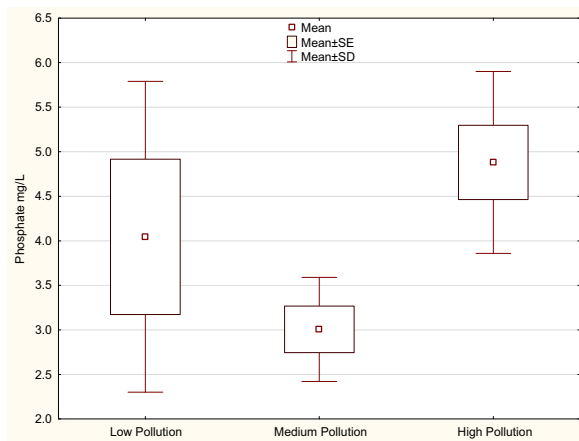
h



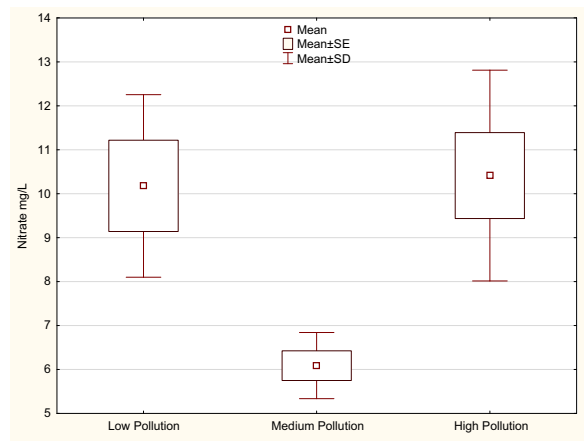
i



j



k



l

Fig. 8 continued.

-0.98), respectively. This factor showed the contribution of industrial effluents. Ni and Fe were

commonly used in the surgical instrument, automobile, and ghee (clarified butter) making factories.

Table 3 Loading of variables on (a) low pollution zone, (b) medium pollution zone, and (c) high pollution zone

Variables	VF1	VF2	VF3	VF4
Low pollution zone (three significant Varimax Factors)				
pH	0.87	0.47	-0.17	
EC (µS/cm)	0.02	1.00	0.00	
TDS (mg/L)	-0.34	0.88	0.33	
BOD (mg/L)	0.47	0.06	0.88	
COD (mg/L)	0.97	-0.24	-0.02	
Zn (mg/L)	-0.61	-0.78	0.10	
Cd (mg/L)	0.70	0.70	0.15	
Cu (mg/L)	0.94	0.15	0.32	
Ni (mg/L)	-0.96	0.11	-0.25	
Pb (mg/L)	0.84	0.54	0.04	
Fe (mg/L)	-0.93	-0.30	-0.22	
Co (mg/L)	0.96	0.17	0.21	
K (mg/L)	0.91	0.38	0.15	
Mg (mg/L)	0.26	0.95	0.16	
Ca (mg/L)	0.26	0.93	-0.25	
NO ₃ (mg/L)	0.67	0.71	0.22	
PO ₄ (mg/L)	0.82	0.57	0.06	
Eigen value	11.94	3.96	1.10	
% Total variance	70.25	23.30	6.45	
% Cumulative variance	70.25	93.55	100.00	
Medium pollution zone (four significant Varimax Factors)				
pH	0.59	0.43	0.44	0.52
EC (µS/cm)	0.20	0.24	0.20	0.93
TDS (mg/L)	0.16	0.20	0.18	0.95
BOD (mg/L)	-0.41	-0.20	-0.31	-0.83
COD (mg/L)	-0.27	-0.46	-0.65	-0.54
Zn (mg/L)	-0.25	-0.16	-0.27	0.92
Cd (mg/L)	0.76	0.49	0.24	0.35
Cu (mg/L)	0.40	0.43	0.53	0.60
Ni (mg/L)	0.01	-0.25	-0.96	-0.14
Pb (mg/L)	0.27	0.84	0.14	0.46
Fe (mg/L)	0.91	-0.13	-0.36	0.16
Co (mg/L)	-0.25	0.01	0.30	0.92
K (mg/L)	-0.83	0.34	-0.45	0.02
Mg (mg/L)	0.07	-0.14	0.88	0.45
Ca (mg/L)	-0.04	0.08	-0.93	-0.34
NO ₃ (mg/L)	0.01	-0.91	0.18	-0.37
PO ₄ (mg/L)	0.40	-0.89	-0.17	0.15
Eigen value	9.93	2.88	2.54	1.66
% Total variance	58.39	16.94	14.93	9.74
% Cumulative variance	58.39	75.33	90.26	100.00
High pollution zone (four significant Varimax Factors)				
pH	0.27	0.78	0.11	0.56
EC (µS/cm)	0.36	0.14	0.91	0.09

Table 3 (continued)

Variables	VF1	VF2	VF3	VF4
TDS (mg/L)	0.43	0.53	0.17	0.69
BOD (mg/L)	0.18	0.18	0.11	0.96
COD (mg/L)	0.22	0.21	0.07	0.95
Zn (mg/L)	-0.61	0.00	-0.58	-0.40
Cd (mg/L)	0.47	0.38	0.75	0.24
Cu (mg/L)	0.96	0.11	0.24	0.12
Ni (mg/L)	-0.77	-0.31	-0.09	-0.01
Pb (mg/L)	0.16	0.77	-0.02	0.62
Fe (mg/L)	-0.98	-0.15	0.07	-0.10
Co (mg/L)	0.89	0.20	0.07	0.41
K (mg/L)	0.34	0.91	-0.13	0.13
Mg (mg/L)	-0.07	0.97	0.15	0.12
Ca (mg/L)	0.24	0.32	-0.84	0.08
NO ₃ (mg/L)	-0.88	-0.02	-0.36	-0.29
PO ₄ (mg/L)	0.04	0.50	-0.16	0.54
Eigen value	9.20	3.33	1.98	1.40
% Total variance	54.11	19.58	11.65	8.24
% Cumulative variance	54.11	73.69	85.34	93.58

Values of dominant heavy metals in each factor is reported in italics

Amin et al. (2013) observed same in his study of Hayatabad Industrial Estate in Peshawar and Gadoon Amazai district Swabi, Pakistan. VF2 contributed 19.58% of total variance with 3.33 eigenvalue. This factor was associated with high positive loading of pH ($r=0.78$), Pb ($r=0.77$), K ($r=0.91$), and Mg ($r=0.97$). This factor indicated industrial effluents where K was used in glass industry as potassium carbonate (K_2CO_3), Mg was used in glass and cement industry and Pb was used in automobile industry and steel rolling mills. Excessive usage of lead batteries, paint manufacturing, incineration of solid waste, and automobile exhaust are the main sources of Pb in the wastewater (Qadir et al. 2013). VF3 contributed 11.65% of total variance with 1.98 eigenvalue. This factor was associated with high positive loading of EC ($r=0.91$), Cd ($r=0.75$), and negative loadings on Ca ($r=-0.84$). This factor indicated anthropogenic activities such as iron and steel foundries where calcium was used in the manufacturing of steel as a deoxidizer and cadmium was used for electroplating steel (Mahmood and Malik 2014). VF4 exhibited 8.24% of total variance with 1.40 eigenvalue. This factor was characterized by high positive loadings on BOD ($r=0.96$) and COD ($r=0.95$) only, signifying high organic load due to an excessive

input of industrial effluents which increases foul odor. This fact was also supported by Singh (2001) in Kanpur, India, and Ukpong (2013) in the state of Akwa Ibon, Nigeria.

Conclusion

The current study is principally related to evaluate the water quality of the Sattukatla drain and to show the spatial variations in the drain water quality. Hierarchical cluster analysis and factor analysis provided the information on the composition of drain water through 3 hierarchical clusters out of 15 sampling sites. HCA produced three zones viz; low, medium and high pollution zones on the basis of pollution load. FA highlighted the industrial and municipal effluents as major sources responsible for variations in drain water quality. The study pointed out that there is an urgent need to eradicate the untreated effluents from the drain water to avoid an adverse effect on the groundwater quality of the surrounding area. Regular monitoring of drain water discharge is needed by the government authorities to save the environment by keeping the pollutants within the prescribed limit set by NEQs.

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