Water Practice & Technology

 Water Practice & Technology Vol 18 No 8, 1791 doi: 10.2166/wpt.2023.109

Spatial distribution and water quality index of Lahore Canal, Pakistan

Muhammad Irfan Jalees [a,*], Iffat Irfan[a], Asif Ali[b] and Madeeha Batool[c]

[a] Institute of Environmental Engineering and Research, University of Engineering and Technology, Lahore 54890, Pakistan
[b] Agricultural Information Department, Research Information Unit, Faisalabad, Punjab, Pakistan
[c] School of Chemistry, Punjab University, Lahore, Pakistan
*Corresponding Author. E-mail: irfan611@gmail.com

MIJ, 0000-0003-3762-3124

ABSTRACT

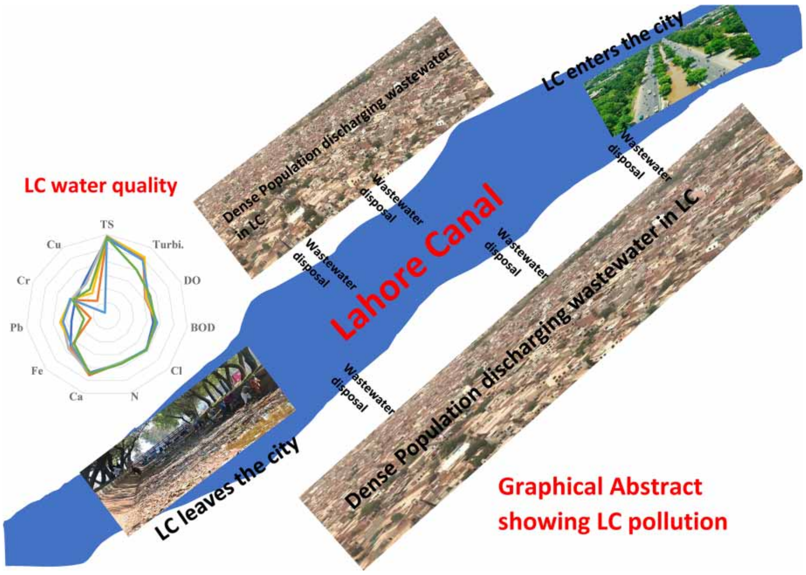
The Lahore Canal (LC) in Lahore city of Pakistan, with the discharge of 402 cusecs, runs along the city's centre. With rapid urbanization and population growth, the LC water is deteriorating. This study determined the water quality index and spatial distribution of pollutants. Three months of sampling from six separate locations were performed. Water quality parameters were analysed. The results indicated that pH, solids, turbidity, hardness, alkalinity, and chlorides were within guidelines, but DO BOD and nitrogen were beyond guidelines. Moderate BOD values (2.24–8.06 mg/L) and low DO values (0.13–3.56 mg/L) indicated a low oxygen environment. Heavy metal concentration was as follows: Fe > Pb > Cr > Cu. The Pearson correlation coefficient indicated ± poor to moderate (0.3–0.7) correlation. The ANOVA result supported the alternative hypothesis, i.e., the pollutants originated from the same source. Principal component analysis and cluster analysis showed three primary sources for the different pollutants based on loading of variance and Euclidean distance, respectively. The WQI of LC at all locations was above 300, indicating that LC water is not suitable for any usage. The spatial distribution of parameters indicated the effects of urbanization and commercialization (small household industries) at Location-4. The poor water quality of LC needs immediate government attention.

Key words: Lahore Canal, spatial distribution, statistical modelling, water quality index

HIGHLIGHTS

- The Lahore Canal (LC) showed an abundance of organic matter as untreated wastewater is discharged continuously in it.
- The source and correlation study indicated various urban and domestic sources as a point of origin.
- The water quality index of LC was above 300 indicating the LC water is not suitable for any activity.
- The spatial distribution of parameters indicated the effects of urbanization and commercialization.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Surface water in developing countries like Pakistan is constantly added with pollutants through various sources like domestic and industrial wastewater and animal excretions (Asghar 2018). Such pollutant addition is deteriorating the quality of surface water. In addition, the water ecosystem is also disturbed and somehow destroyed. Therefore, water management is necessary. Precautionary planning, prohibition, and restriction for wastewater discharge, levies, charges, and awareness campaigns, are steps that need to be taken (Jalees *et al.* 2021a). A recent study by the Pakistan National Council of Research showed that more than 70% of Pakistan's drinking water is unsuitable for drinking based on chemical, physical, and biological analysis (Azizullah *et al.* 2011). Surface water (canals and rivers) is a significant source of groundwater recharging through seepage (Jalees *et al.* 2021a). Polluted canals and rivers are also responsible for the deterioration of groundwater. The Lahore branch canal is one of the sources of recharging of groundwater in Lahore City, Pakistan (Mumtaz *et al.* 2010, 2015).

Lahore Canal (LC) is present in Lahore city, the second largest city in Pakistan. It is used as irrigation water for 4,00,000 acres of agricultural land. The LC water is saline, having a 55 ft water table. The canal passes through Lahore city's centre, a congested residential and commercial area. The people from these commercial and residential areas continuously discharge the wastewater into LC without any treatment. Although the local Government issued the regulation (Law and Parliamentary Affairs Department, G. o. P. (2016)), the Government failed to implement it properly, which resulted in the deterioration of the quality of LC water (Mumtaz *et al.* 2010, 2015). The LC is approximately 60 km long, east of Lahore city. The detail of LC is given in Table 1. This study deals with the pollutants present in LC. The concentration of pollutants (17 parameters) was used for statistical

Table 1 | Basic information on Lahore Canal

Discharge	402 cusec
Bed width	38 ft average
Full supply depth	4 ft average
Culturable command area	4,206 acres
Earthen/lined	Brick lined
District	Lahore
Number of bridges	20 No.
Number of underpasses	13 No
Land width/right of way	350 ft (175 ft from the centre of the canal)

modelling and to determine Water Quality Index (WQI). In addition, the spatial distribution of selected pollutants was also studied to understand the impact of pollutants better.

2. MATERIALS AND METHODS

2.1. Sampling location and analysis

Sampling is performed per standard methods (American Public Health Association 2005). A total of six locations were selected along the LC (Table 2). These locations were selected based on population density. At location-1 (L-1), the population density is very low as it is the point where LC enters the city (Figure 1); after that, the population gradually increases. The L-4 and L-5 are maximum populated areas, whereas L-6 is the exit point of the city. Five samples from each location were collected using a water sampler (WS700-10G Composite). The sampler was placed in LC water, and the timer was set to collect 1 L of the sample every 1 h for 8 h at each location with an interval of 1 day. The sampling took 3 months, starting from January to March.

Table 2 | Reach distance and no. of samples for each location

Sr.	Sample code	Location	Reach distance
1	L-1	Bhambhanwala Ravi Badian Depalpur	00 km + 000 m
2	L-2	Harbanspura underpass	7 km + 300 m
3	L-3	Dharampura underpass	14 km + 100 m
4	L-4	New campus underpass	22 km + 200 m
5	L-5	Thokar Niazbaig underpass	29 km + 800 m
6	L-6	Chung mohga	37 km + 000 m

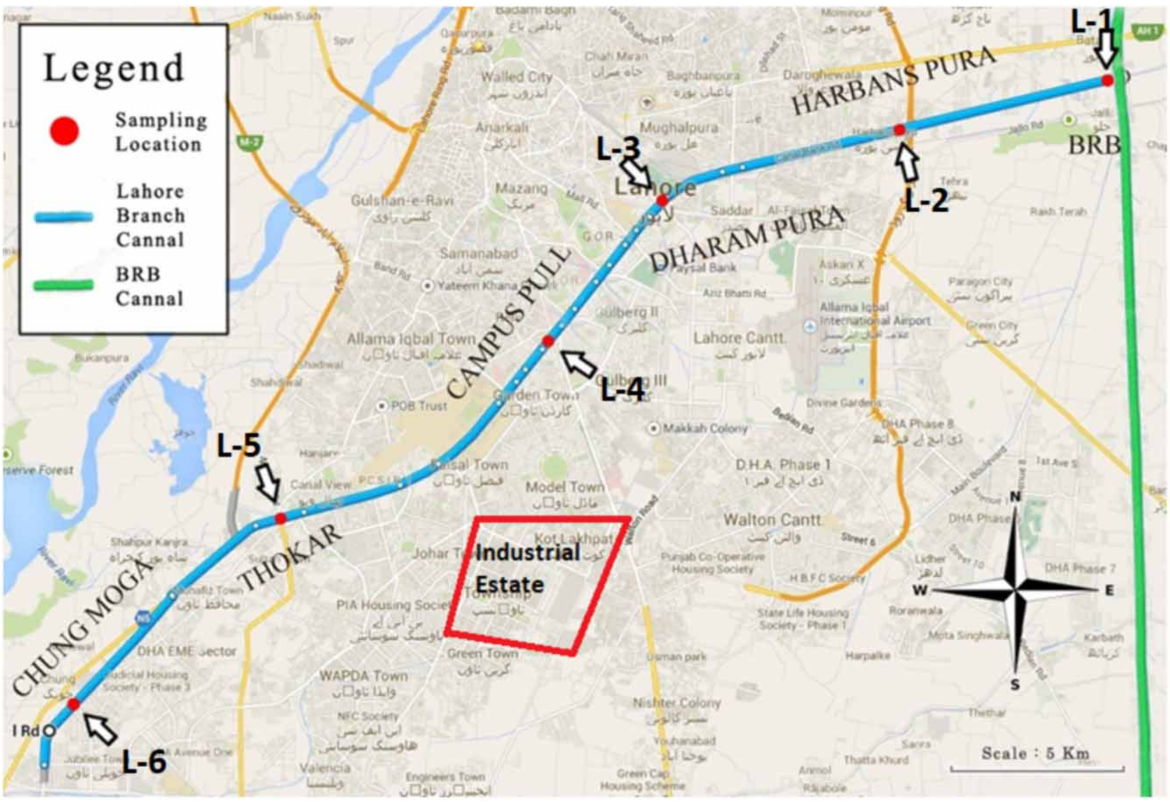


Figure 1 | Location of samples in Lahore Canal.

The samples were stored in the ice chest and transported to the laboratory for analysis. The chemicals and solutions used in the analysis are of analytical grade (purchased from Merck, Pakistan). The analysis details can be found in the reference, whereas the method number and parameter details are given in Table 3. Control and blank samples and spiked samples analysis were also performed for quality assurance. The samples were run in triplicate, and the average values were used for further analysis. The concentrations of pollutants were used for the source and correlation purposes. Descriptive statistics, Pearson correlation, and analysis of variance (ANOVA) are the well-established models used in this study for correlation, whereas principal component analysis (PCA) and cluster analysis (CA) were used for the source origin. WQI was used to categorize LC water for any usage, and the spatial distribution of pollutants was used to understand the impact of urbanization. All mathematical models and calculations were performed using Minitab® Software.

Table 3 | Details of parameters and standard method used in the analysis of water samples

Sr.	Parameter	Standard method
1.	pH	4500-H^+ B
2.	TSS	2540 C
3.	TDS	
4.	SS	
5.	TS	
6.	Turbidity	2130 B
7.	DO	4500-C
8.	BOD	5210-B
9.	Cl	4500 Cl^- C
10.	Hardness	2340-C
11.	N	4500-N
12.	Alkalinity	2320-B
13.	Ca	3111 B
14.	Fe	
15.	Pb	
16.	Cr	
17.	Cu	

3. RESULTS AND DISCUSSION

The samples collected from LC were analysed in triplicate. The results obtained were then subject to statistical analysis for correlation. In addition, spatial distribution and WQI were also studied.

3.1. Physical parameters

The total suspended solids increased along the canal from 95 to 295 mg/L (Table 4, Figure 2) due to throwing floating particles or natural storm dust particles (Nishanthi *et al.* 2021). Total dissolved solids (TDS) are the main contributor to pollution in the water body. The values of TDS were between 79 and 535 mg/L (Table 4), which is within guideline values, i.e., 1,000 mg/L (Panhwar *et al.* 2022). The total settled solids (TSS) ranged from 0.1 to 1.0 g/L. Values of TSS increase along the canal, the same as TDS. The values of total solids are the sum of all solids, and obviously, it follows the same trend as TDS and TSS, with values ranging from 400 to 992 mg/L. turbidity of the samples is directly associated with suspended and settleable solids. The turbidity of LC is in the range of 8.8–195 NTU. The high value of turbidity is because of silt, organic debris, and soil. Although the values were high, it is within NEQ (National Effluent Standards), i.e., 25–50 NTU (Azizullah *et al.* 2011).

Table 4 | Descriptive analysis of all the parameters from six different locations of the Lahore Canal

	pH	TSS (mg/L)	TDS (mg/L)	SS (g/L)	TS (mg/L)	Turbi (NTU)	DO (mg/L)	BOD (mg/L)	Cl (mg/L)	Hard. (mg/L)	N (mg/L)	Alkal (mg/L))	Ca (mg/L)	Fe (mg/L)	Pb (mg/L)	Cr (mg/L)	Cu (mg/L)
L-1																	
Average	7.61	162.8	334	0.38	528	76.9	2.41	2.92	7.3	114.4	4.36	75.2	24.40	3.54	0.44	0.38	1.12
Min	7.41	128	270	0.2	450	71	1.88	2.24	5.5	106	2	66	21.38	2.69	0	0.26	0.06
Max	7.71	210	420	0.6	610	81	2.67	3.47	11	122	5.8	80	26.88	4.8	2.18	0.55	3.5
L-2																	
Average	8.06	169.2	371	0.4	712	94.84	1.3	5.00	7.6	123.2	4.36	75.2	39.72	3.626	0.02	0.64	0.02
Min	7.35	100	310	0.1	570	84.3	0.13	3.06	5.5	98	2.8	66	26.25	2.23	0	0.46	0
Max	8.32	235	435	0.7	820	109	2.36	6.53	9.5	148	6.2	84	75.94	4.3	0.08	0.71	0.1
L-3																	
Average	8.03	177.4	391.4	0.57	768.6	136.8	1.45	5.99	7.5	130.2	3.92	62.6	29.54	5.53	2.09	0.76	0.68
Min	7.8	95	220	0.4	595	97	1	4.23	6	89	3.06	37	26.96	2.44	0	0.71	0
Max	8.25	295	510	0.7	980	183	2.3	8.06	9.5	198	5.7	82	31.16	7.8	5.71	0.84	3.4
L-4																	
Average	7.42	176.2	398.6	0.79	762.4	135.4	1.74	5.32	6.7	146.4	5.19	69	27.72	2.44	3.0	0.87	0.1
Min	7.01	130	237	0.5	499	71	0.9	3.53	4	103	3.95	39	21.81	1.6	0.14	0.8	0
Max	8.35	247	535	1	992	195	2.8	7.5	10	195	7.25	97	34.5	3.5	5.71	0.92	0.37
L-5																	
Average	8.44	190.8	344.8	0.68	666	75.92	2.48	5.39	6.4	140.4	5.16	91.2	27.86	2.59	1.85	0.93	0.02
Min	7.29	125	79	0.15	400	15.6	1.8	2.81	4.5	70	4	63	24.74	1.16	0.14	0.84	0
Max	9.2	250	490	1.05	907	99	3.2	8.06	8.5	207	5.9	114	33.12	5	4.04	1	0.01
L-6																	
Average	7.44	192	86	0.18	575.6	11.54	3.36	4.14	7.7	81.2	5.2	104	30.82	1.52	0.05	0.61	0.21
Min	7.33	160	84	0.1	450	8.8	3.23	3.7	7	74	4.2	96	26.68	0.75	0	0.02	0
Max	7.58	240	89	0.3	713	13.3	3.56	4.56	8.5	88	6	106	33.24	3.72	0.14	1.04	1.04
Irrigation water standards																	
Values	6.5–8.5	–	1,000	–	–	–	>4	8	100	–	–	–	–	5	0.1	0.01	0.2
Remark	✓	–	✓	–	–	–	×	✓	✓	–	–	–	–	×	×	×	×

✓, suitable for irrigation purposes.
×, not suitable for irrigation purposes.

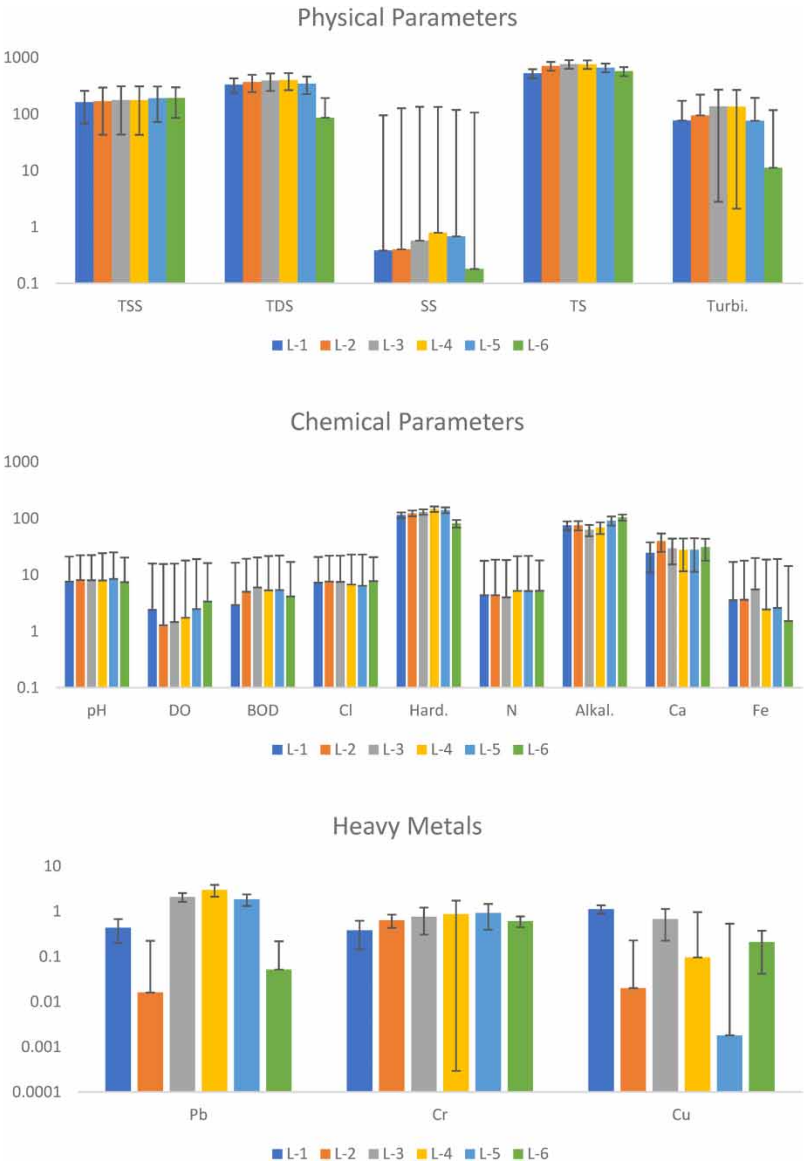


Figure 2 | Variation in heavy metals, physical and chemical parameters of Lahore branch canal at various locations.

3.2. Chemical parameters

The chemical parameters (Table 4) showed the presence of organic matter and other pollutants. The pH of LC at all locations varies from 7.01 to 8.35 (Figure 2, Table 4), which is within the standard value (Bauder *et al.* 2011). Microbes for nitrogen reduction or ammonification needs DO values ≤ 5 mg/L. The dissolved oxygen (DO) values were significantly less (0.13–3.23 mg/L), which indicated low activity of oxidizing microbes and favourable conditions production of ammonia (Yafuso & Fisher 2017, Keerio *et al.* 2020). The DO values increase from L-2 to L-6 with the addition of pollutants from urban areas, whereas at L-1, the DO was maximum because the L-1 is outside the urban areas. The lower DO values are not suitable for irrigation water as per the criteria given by the Ministry of Climate Change, Pakistan (WWF-Pak 2007). The biochemical oxygen demand (BOD) of LC was in the range of 2.24–8.06 mg/L, which is within NEQ (80 mg/L). Low BOD values suggest low organic matter. The LC has low BOD values due to seasonal silt, soil, and other solid waste cleanings, from November to January every year. The chloride concentration was 4–11 mg/L, within the guideline values (Rowe & Abdel-Magid 1995). The values of Cl^{-1} remain the same, and not much variation was observed. The hardness values of LC were in the range of 70–198 mg/L, which is within the guideline values (Rowe & Abdel-Magid 1995). There is not much variation was observed in all sample locations. The total nitrogen content was from 2 to 7.25 mg/L. Although algal bloom is still far away, these values suit algae growth (Mumtaz *et al.* 2010). The alkalinity of samples from LC has values of 37–106 mg/L, within the NEQ (Mumtaz *et al.* 2010). The trend of alkalinity was the same as hardness, as both are directly associated with bicarbonates (American Public Health Association 2005). The Ca values were 21.38–75.94 mg/L, >10 mg/L (guideline value) (Panhwar *et al.* 2022). Such a high concentration favours bacterial growth in terms of the stability of the cell membrane by preventing amino acid leakage from the cell (Elad *et al.* 2021). The values of Fe were in the range of 0.75–7.8 mg/L, which is very close to the guideline's upper limit, i.e., 8 mg/L (Asghar 2018).

3.3. Heavy metals

The LC samples were analyzed for heavy metals, i.e., Pb, Cr, and Cu. The values of metals were beyond the NEQ (Asghar 2018). The concentration of Pb was 0–5.71 mg/L, which was way above the guideline value of 0.5 mg/L. When LC water is used for irrigation, such high Pb values will deposit in plants and pose a cancer risk (Jalees *et al.* 2021b). The values of Cr in LC samples were 0.02–1.04 mg/L, slightly above the guideline values of 1 mg/L (Asghar 2018). Such high Cr contents can pose a cancer risk if LC is used for irrigation. The values of Cu were in the range of 0–3.5 mg/L, which is above the guideline values of 1 mg/L. Regarding irrigation water criteria, the heavy metals are above the guidelines values, making LC water unsuitable for irrigation (WWF-Pak 2007). The heavy metal trend and source of pollution will be discussed in the coming section.

3.4. Statistical modelling

To access the information about the source and correlation of various pollutants, statistical tools were used, i.e., Pearson correlation, ANOVA, PCA, and CA. Average values of all tested parameters were used for this.

3.4.1. Pearson correlation coefficient

The Pearson correlation was used to get information about the probable source of pollutants. It is a regression analysis used to understand the correlation of experimental data (Jalees & Asim 2016). The results of the Pearson correlation are given in Table 5. The coefficient (r) > 0.7 indicates a strong relationship; $r = 0.3$–0.7 indicates a moderate relationship, while $r < 0.3$ indicates a poor one. The positive and negative signs indicate a direct and inverse relationship, respectively (Jalees & Asim 2016). A strong positive relationship indicated that the pollutant may have originated from the same source. In Table 5, a positive moderate to poor correlation was observed in SS with pH & TDS and vice versa; in turbidity with pH, TDS, SS, and TS; in hardness with Pb, TDS, and SS. The negative moderate to poor relationship is observed in TDS with pH; in DO with TDS, TS, and turbidity; in alkalinity with Pb and TDS. These findings suggested a hypothesis that the parameters (pollutants) originated from the same source. This hypothesis was further studied using ANOVA.

3.4.2. Analysis of variance

To evaluate correlations between the pollutants, a *null hypothesis* was formulated as per the literature (Jalees & Asim 2016). The null hypothesis statement was 'no correlation among the parameters studied in LC, i.e., $r = 0$'. Contrary to it, an *alternative hypothesis* was also formulated, which stated that 'there is some correlation between the pollutants in LC, i.e., $r \neq 0$″. The results of ANOVA (single tail) are given in Table 6. It generated two parameters, i.e., 'F_{crit}' and 'p.' If $p > F_{crit}$ then the values are not significant and if $p < F_{crit}$ then the values are significant. Significant values further suggested that pollutants/parameters correlate with them, i.e., $r \neq 0$ (Jalees & Asim 2016). The values in Table 6 showed that the $p < F_{crit,}$ which means correlation among the pollutants and hence the results of Pearson analysis were confirmed.

3.4.3. Principal Component Analysis (PCA)

The PCA is an imaginary eigenvalues-based system. In this system, the eigenvalues < 1 are ignored, and greater values > 1 are grouped based on the same source. The data are divided into groups known as components. The component which explains most of the results is termed as 1st component of PC-1, the 2nd component in line is termed PC-2, and so on (Nguyen *et al.* 2020). Parameters having the same source or origin are grouped in the same component. The results of PCA are given in Table 7. PCA obtained three components, i.e., PC-1, PC-2, and PC-3. Collectively these three components explain 55.05% of the variance. PC-1 explains 29.88%, PC-2 explains 14.14%, and PC-3 explains 10.91% of the total variance. The PC-1 showed

Table 5 | Results of Pearson correlation coefficient for the various parameters studies in Lahore Canal

	pH	TSS	TDS	SS	TS	Turb	DO	BOD	Cl	Hard	N	Alkal	Ca	Fe	Pb	Cr	Cu
pH	1.00																
TSS	0.35	1.00															
TDS	0.53	−0.17	1.00														
SS	0.61	0.14	0.64	1.00													
TS	0.59	0.42	0.42	0.61	1.00												
Turbidity	0.51	0.13	0.71	0.68	0.75	1.00											
DO	− 0.49	−0.21	−0.57	−0.29	−0.58	−0.77	1.00										
BOD	0.18	−0.16	0.38	0.22	0.11	0.22	−0.29	1.00									
Cl	− 0.13	0.01	−0.39	−0.21	−0.16	−0.15	0.10	−0.27	1.00								
Hardness	0.41	−0.06	0.52	0.49	0.24	0.29	−0.25	0.31	−0.20	1.00							
N	0.07	0.06	−0.01	0.11	0.01	−0.14	0.17	−0.02	−0.01	0.12	1.00						
Alkalinity	0.02	0.30	−0.54	−0.21	0.16	−0.32	0.37	−0.34	0.10	−0.40	0.07	1.00					
Ca	0.14	−0.23	0.05	−0.12	−0.05	−0.01	−0.16	0.05	0.24	−0.10	0.01	0.01	1.00				
Fe	0.20	0.00	0.26	0.18	0.26	0.44	−0.45	0.16	0.04	0.34	−0.37	−0.33	−0.15	1.00			
Pb	0.21	−0.07	0.35	0.43	0.01	0.20	−0.13	0.37	−0.12	0.52	0.27	−0.59	−0.16	−0.09	1.00		
Cr	0.32	0.00	0.16	0.36	0.23	0.18	−0.18	0.39	−0.11	0.24	0.18	−0.04	0.01	0.01	0.33	1.00	
Cu	− 0.18	−0.29	0.03	−0.24	−0.25	−0.08	0.10	−0.33	0.17	−0.03	0.03	−0.33	−0.09	−0.06	0.35	−0.17	1.00

Table 6 | Analysis of variance to verify the null hypothesis of $r = 0$

ANOVA

Source of variation	SS	df	MS	F	P-value	F_{crit}
Between-groups	14,283,855	16	892,740.94	271.42	0.00	1.66
Within-groups	1,621,551	493	3,289.15			
Total	15,905,406	509				

Table 7 | PCA for source correlation in LC samples

Rotated component matrix[a]				Component	Initial eigenvalues			Rotation sums of squared loadings		
					Total	% Of variance	Cumulative %	Total	% Of variance	Cumulative %
	1	2	3	1	5.08	29.88	29.88	3.95	23.26	23.26
Total loading	3.95	3.00	2.41	2	2.43	14.27	44.14	3.00	17.63	40.89
% of variance	23.26	17.63	14.17	3	1.86	10.91	55.05	2.41	14.17	55.05
Cumulative %	23.26	40.89	55.05	4	1.40	8.23	63.28			
pH	0.50	0.42	0.46	5	1.31	7.70	70.98			
TSS	0.05	0.00	0.70	6	1.00	5.85	76.84			
TDS	0.71	0.47	−0.14	7	0.79	4.65	81.49			
SS	0.49	0.62	0.28	8	0.72	4.25	85.74			
TS	0.59	0.22	0.63	9	0.61	3.56	89.31			
Turbidity	0.86	0.22	0.19	10	0.57	3.33	92.64			
DO	−0.83	−0.07	−0.13	11	0.37	2.20	94.84			
BOD	0.28	0.47	−0.13	12	0.32	1.90	96.74			
Cl	−0.12	−0.37	−0.05	13	0.24	1.44	98.18			
Hardness	0.39	0.59	−0.16	14	0.15	0.90	99.09			
Nitrogen	−0.43	0.56	0.12	15	0.08	0.49	99.58			
Alkalinity	−0.47	−0.29	0.72	16	0.04	0.26	99.84			
Ca	0.05	−0.14	−0.01	17	0.03	0.16	100.00			
Fe	0.72	−0.22	−0.10							
Pb	0.10	0.76	−0.40							
Cr	0.05	0.60	0.17							
Cu	−0.06	−0.05	−0.62							

Extraction method: PCA.
Rotation method: Varimax with Kaiser normalization.
[a]Rotation converged in nine iterations.

strong loading moderate to strong loading for pH (0.5), TS (0.5), TDS (0.71), Turbidity (0.86), DO (-0.83), and Fe (0.72). It suggested that the source of these parameters may be the same (Jalees & Asim 2016). PC-2 showed moderate to strong loading for SS (0.62) and Pb (0.76), while PC-3 showed moderate loading for TS (0.63) and Cu (−0.62). The parameters with moderate to strong loading and the same PC are assumed to originate from the same source (Jalees & Asim 2016). To verify this, CA was performed.

3.4.4. Cluster analysis

CA, also known as a dendrogram, is a diagram that shows the hierarchical relationship between parameters. It is created as an output from hierarchical clustering (Zhang *et al.* 2016). The Wards method groups the parameters based on their Euclidean distance, whereas horizontal or vertical lines represent the parameters having the same distance. The more the distance, the differences will be the origin/source of pollutants

(Zhang *et al.* 2016). The CA was performed on all samples of LC, and the results are shown in Figure 3. The results of CA showed three groups of pollutants (confirmed the results of PCA) having the same origin. The horizontal distance line linked G-1, G-2, and G-3 parameters. In G-1, SS, Cr, Cu, Pb, DO, pH, Cl, BOD, N, Fe, and Ca were grouped; in G-2, Turb, Alk, Hardness, and TSS are grouped; in G-3, TDS and TS are grouped.

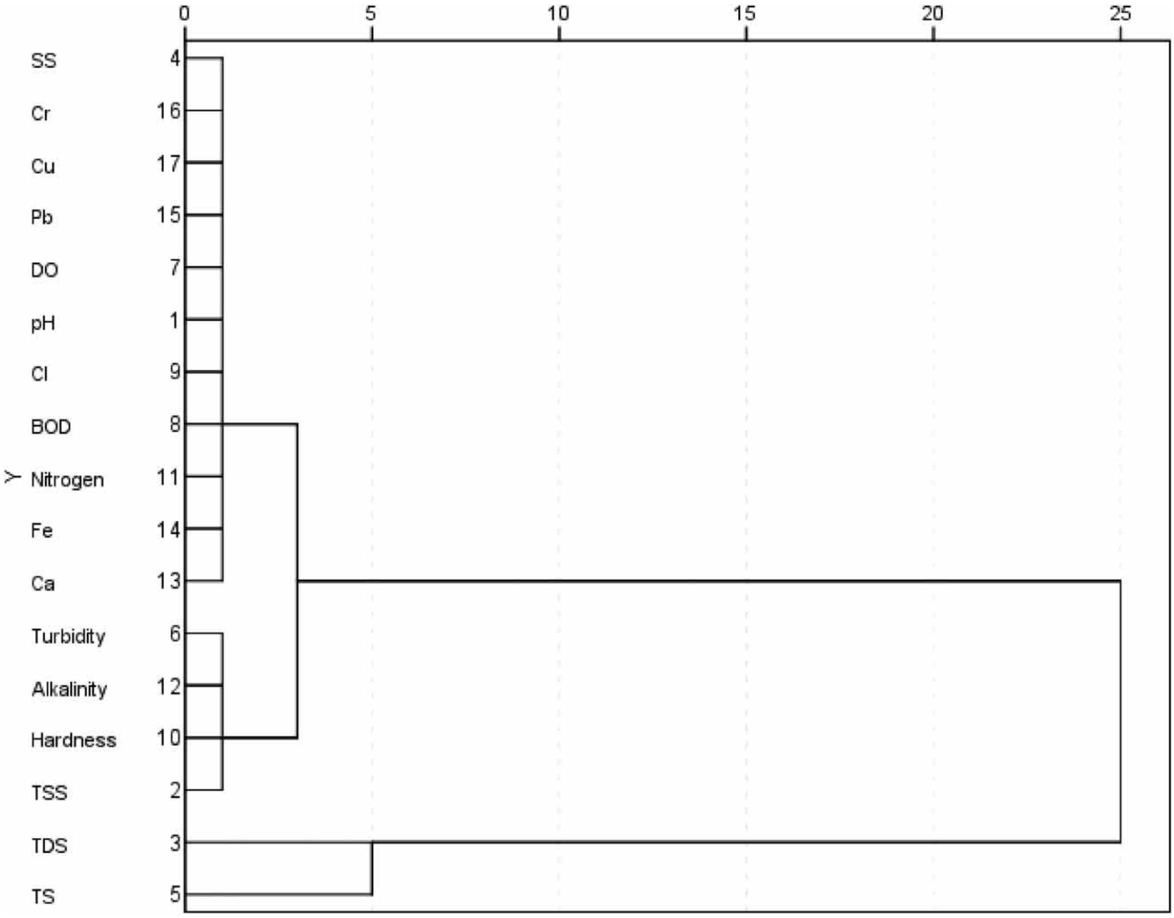


Figure 3 | Results of CA for the parameters under study in LC.

3.5. Water quality index

The WQI is a mathematical solution to change complex analysis into simple information that a layperson can understand. It is derived from analysing various pollutants/parameters determined in the LC under study. A single parameter cannot be used to explain the pollutant load of any water sample; hence, WQI is derived. The values of WQI are in digits (numbers) which can be used to classify the water quality (Piyadasa & Meegaswatte 2022). The WQI, in this study, was calculated using a deductive approach (Poonam *et al.* 2013). The deductive approach assigns each parameter a relative rank W_i (Equation (1)).

$$W_i = \frac{W_r}{\sum W_r} \tag{1}$$

where W_i is the relative weight rank; W_r is the weight of each parameter based on its harmful effect; $\sum W_r$ is the sum of the weight of all parameters.

The second step of calculations is to assign a quality rating scale (Q_i) using the following equation.

$$Q_i = \left[\frac{C_i}{S_i}\right] \times 100 \tag{2}$$

where Q_i is the quality rank of a parameter; C_i is the concentration of nth parameter in the water sample; S_i is the standard permissible value of the water quality parameter.

The standard index (SI) is calculated using the following equation in the third step.

$$\mathrm{SI} = W_i \times Q_i \tag{3}$$

In the fourth step, all standard indexes of each parameter are added to get a single value known as the water quality index (WQI) using the following equation.

$$\mathrm{WQI} = \sum_{n}^{i} \mathrm{SI} \tag{4}$$

where $n = 1, 2, 3, \ldots\ldots n$ the values of WQI are to categorize water suitability for drinking and irrigation purposes (Gaytán-Alarcón *et al.* 2022). For the excellent category, the WQI value is <50; for the good category WQI value is 50–100; for the poor category WQI value is 100–200; for the very poor category WQI value is 200–300 and for the unsuitable category, WQI value is >300 (Poonam *et al.* 2013). The WQI values of all locations of LC are summarized in Table 8 and Figure 4. The WQI values exceeded 300, indicating that LC water's quality category is unsuitable. The highest value of WQI was observed at L-4, the main part of Lahore city, which is the main industrial and residential area of Lahore. The industrial and residential wastewater is added in the LC which resulted in high WQI. The residential area is also located at L-3 and L-5, but the population density is less as compared to L-5; therefore, the WQI values at L-3 and L-5 are high (<300) but less than L-4.

The values of WQI of LC were compared with the literature data. Many authors from India, China, Iran, and Iraq have studied the rivers, canals and lakes for WQI. The data showed that the water quality of LC is severely deteriorated as compared to other literature-available data (see Table 9). It suggested that the Government should immediately consider the remedies for LC.

3.6. Spatial distribution of pollutants

The concentration of different pollutants was used to have a picture of the distribution of pollutants at various locations. The location coordinates of the sample location and the concentration of pollutants were used to draw the spatial distribution (Figure 5). The diameter of the circle at various locations represents the concentration. The larger the diameter, the greater will be the concentration of pollutants. Out of 17 parameters, 9 parameters having environmental effects were selected for the spatial distribution study, which includes heavy metals (Cu, Cr, Pb), iron, calcium, TDS, total suspended solids (TSS), pH, and BOD. The concentration of Cu decreases along the LC (downstream). The maximum value was the L-1, the outskirts of Lahore city where farmhouses and industries are abundant and contribute to copper pollution due to using copper-based paints (Bhuiyan *et al.* 2011). The concentration of Cr gradually increased from L-1 to L-4 due to small electroplating plants working inside the residential areas discharging the plating wastewater into the LC without any treatment (Jalees & Asim 2016). The concentration of Pb was maximum at L-4 compared to other locations under study. This high Pb concentration indicated that urbanization and anthropogenic activities were at their peak (Jalees *et al.* 2021b). Like any other developing country, the water distribution system pipes are also made up of iron in Pakistan. These decades-old pipers are poorly maintained and, with time, due to rust Fe leached out in wastewater and drinking water pipelines. The same was observed in the study area. The concentration of Fe increases with an increase in population density along LC. Calcium (Ca), regarding the hardness of groundwater, is also a significant contributor to the study area. Its concentration was present in LC. BOD and pH play an especially key role in ecological stability of canal ecosystem. Aquatic microbes, animal, and plants are directly associated with variations in the pH. The DO quantity (DO level) will decrease with pH variation hence making it difficult for aquatic life to survive. Continuous discharge of domestic and industrial wastewater moves the pH from 7. In the study area, pH remains above 7, i.e., basic. The addition of wastewater containing organic matter also affects the DO level and BOD values. The more organic matter, the lesser the availability of DO for aquatic life. Less DO will increase the BOD values, and chances of eutrophication will increase, destroying

Table 8 | Values of relative weight and quality rank for the determination of the WQI of LC at various locations

				L-1		L-2		L-3		L-4		L-5		L-6	
Parameter	**Guideline[a]**	W_r	W_i	Q_i	SI	Q_i	SI	Q_i	SI	Q_i	SI	Q_i	SI	Q_i	SI
pH	7.5	4	0.06	101.44	6.06	107.44	6.41	107.04	6.39	105.89	6.32	112.51	6.72	99.23	5.92
TSS	25	4	0.06	651.20	38.88	676.80	40.41	709.60	42.36	704.80	42.08	763.20	45.56	768.00	45.85
TDS	500	4	0.06	66.80	3.99	74.20	4.43	78.28	4.67	79.72	4.76	68.96	4.12	17.20	1.03
SS	25	4	0.06	1.52	0.09	1.60	0.10	2.28	0.14	3.16	0.19	2.72	0.16	0.72	0.04
TS	750	4	0.06	70.40	4.20	94.93	5.67	102.48	6.12	101.65	6.07	88.80	5.30	76.75	4.58
Turbidity	5	4	0.06	1,538.00	91.82	1,896.80	113.24	2,736.00	163.34	2,708.00	161.67	1,518.40	90.65	223.08	13.32
DO	4	5	0.07	60.30	4.50	31.95	2.38	36.35	2.71	43.40	3.24	62.00	4.63	84.00	6.27
BOD	1	5	0.07	292.00	21.79	500.60	37.36	598.80	44.69	532.00	39.70	539.00	40.22	414.00	30.90
Cl	100	3	0.04	7.30	0.33	7.60	0.34	7.50	0.34	6.70	0.30	6.40	0.29	7.70	0.34
Hardness	300	2	0.03	38.13	1.14	41.07	1.23	43.40	1.30	48.80	1.46	46.80	1.40	27.07	0.81
N	10	5	0.07	43.60	3.25	43.58	3.25	39.82	2.97	51.90	3.87	51.60	3.85	52.00	3.88
Alkalinity	300	2	0.03	25.07	0.75	25.07	0.75	20.87	0.62	23.00	0.69	30.40	0.91	34.67	1.03
Ca	5	2	0.03	488.04	14.57	794.64	23.72	590.72	17.63	554.40	16.55	557.16	16.63	614.44	18.34
Fe	5	4	0.06	70.88	4.23	72.52	4.33	110.56	6.60	48.80	2.91	51.72	3.09	30.32	1.81
Pb	0.1	5	0.07	436.00	32.54	16.00	1.19	2,085.80	155.66	2,997.80	223.72	1,849.20	138.00	51.40	3.84
Cr	0.05	5	0.07	764.00	57.01	1,280.00	95.52	1,524.00	113.73	1,736.00	129.55	1,856.00	138.51	1,220.00	91.04
Cu	0.2	5	0.07	561.60	41.91	10.00	0.75	340.00	25.37	48.00	3.58	0.90	0.07	104.00	7.76

[a]Standard guideline values provided by World Health Organization and Pakistan Effluent Quality Standard.

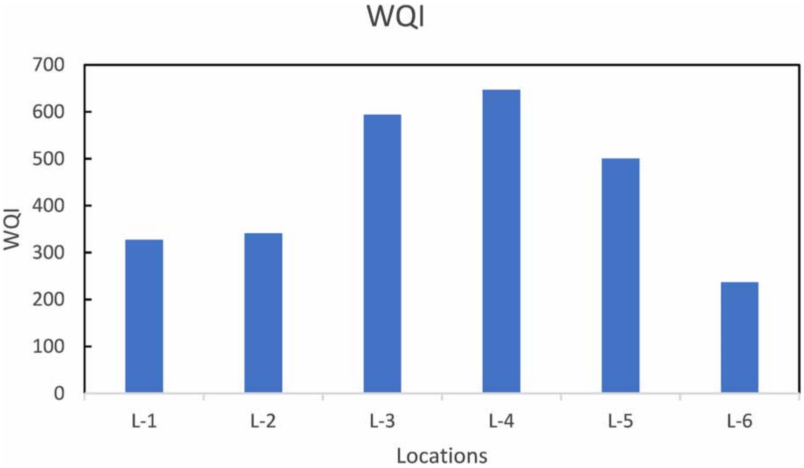


Figure 4 | Variation in WQI along the LC at various locations.

Table 9 | Literature comparison of WQI of the study area with other parts of the world

Location	WQI	Reference
Lahore Canal, Pakistan	236–644	Current study
Al-Gharraf River, southern Iraq	43–88	Ewaid & Abed (2017)
Iraqi Rivers	73	Ewaid *et al.* (2020)
Aydughmush River, Iran	59–100	Hoseinzadeh *et al.* (2015)
River Ravi at Madhopur, India	52–98	Kumar & Dua (2009)
Beheshtabad River, Iran	71–62	Fathi *et al.* (2018)
Lake Taihu Basin, China	55–75	Wu *et al.* (2018)
Taladanda Canal, India	72–81	Samantray *et al.* (2009)
Mahanadi River, India	64–75	
Atharbanki River, India	48–59	

the canal ecosystem. As the residential societies along LC are discharging wastewater without any treatment, the abundance of organic matter is responsible for high BOD values, which deteriorates the quality of LC.

4. CONCLUSION

The physical and chemical parameters of LC were analyzed. The results showed that the physical parameters were within the NEQS of Pakistan. The low DO and high BOD values indicate that low oxygen conditions are dominant in LC. The metal concentrations were beyond Pakistan's NEQ and irrigation water standards. The highest concentration was Ca, i.e., 75 mg/L, and the lowest was for Cu, i.e., 1 mg/L. The metals concentration shows the following trend Ca > Fe > Pb > Cr > Cu. The Pearson correlation coefficient showed a moderate to strong correlation as values were within 0.3–0.7, suggesting that the sources of pollutants were the same. The ANOVA gives $F_{crit} > P$, supporting the hypothesis of a similar pollutant origin. The loadings of PCA were three components with a total variance of 55%, whereas the CA also gave three groups based on Euclidean distance, confirming the hypothesis that the origin of pollutant is from the same source, i.e., small household industries in the study area. The WQI of LC showed values above 300 at all locations, which indicated that the LC water is unsuitable for any usage. The spatial distribution of pollutants

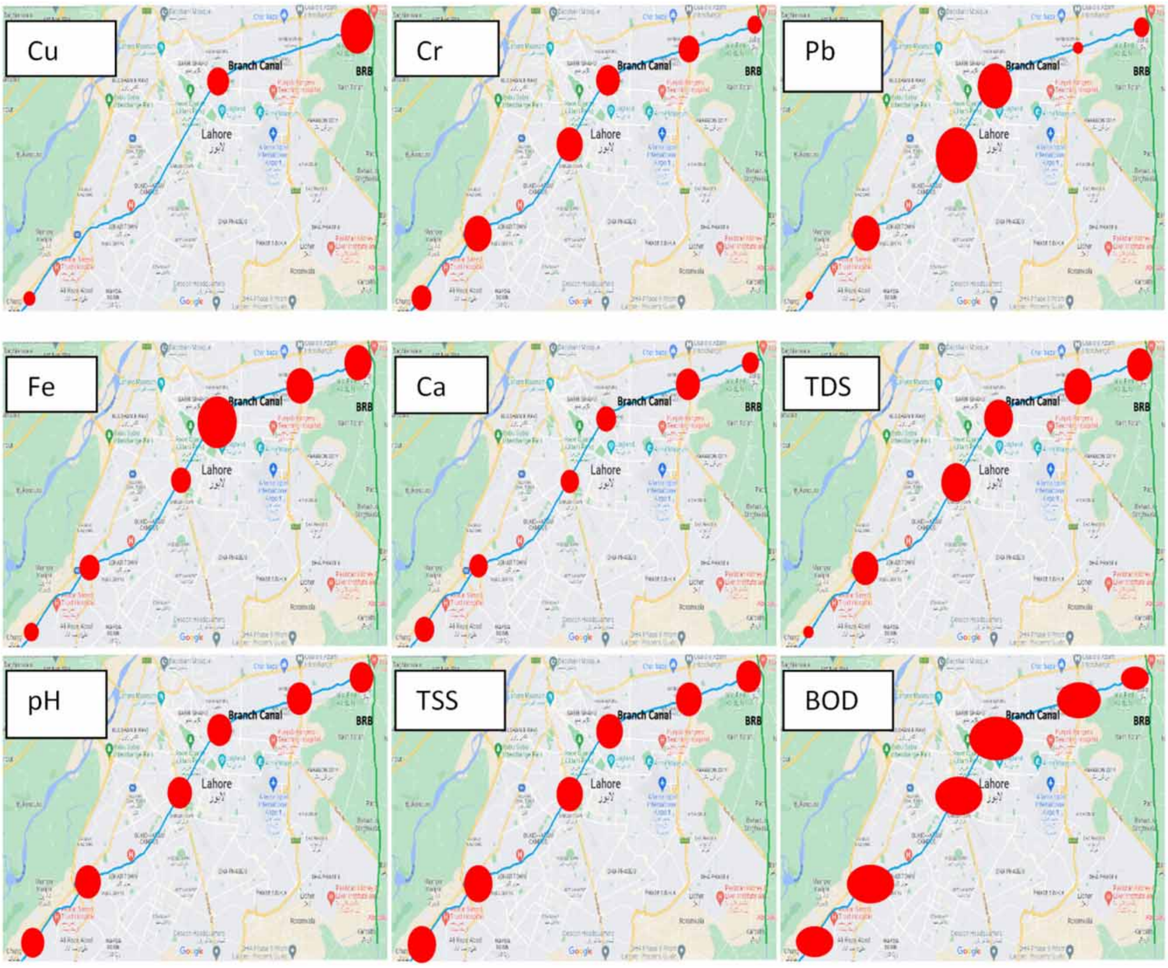


Figure 5 | Spatial distribution of pollutants at various locations under study.

shows variation along LC, although the variation was associated with population density and urbanization. Worse conditions were present at L-4, which is highly populated and has an abundance of small industries. The Government may focus on implementing rules and regulations for water quality; otherwise, the environmental conditions will become more severe.

ACKNOWLEDGEMENT

The authors are thankful to the University of Engineering and Technology, Lahore, for providing the necessary facilities for study.

ETHICAL APPROVAL

No ethical approval is required for this manuscript.

CONSENT TO PARTICIPATE

All authors have given their consent about the content of this manuscript.

CONSENT TO PUBLISH

All authors have been permitted to submit and publication of the manuscript.

AUTHORS CONTRIBUTIONS

Muhammad Irfan Jalees: Original Idea and manuscript writing; Iffat Irfan: Experimental and result compilation; Asif Ali: initial draft; Madeeha Batool: Manuscript review

FUNDING

There was no funding for this research

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

American Public Health Association 2005 *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association (APHA), Washington, DC, USA.

Asghar, M. Z. 2018 Comparative assessment of physico-chemical parameters of waste water effluents from different industries in Lahore, Pakistan. *Proceedings of the International Academy of Ecology and Environmental Sciences* **8**(2), 99.

Azizullah, A., Khattak, M. N. K., Richter, P. & Häder, D.-P. 2011 Water pollution in Pakistan and its impact on public health – a review. *Environment International* **37**(2), 479–497.

Bauder, T. A., Waskom, R., Sutherland, P., Davis, J., Follett, R. & Soltanpour, P. 2011 Irrigation water quality criteria. *Service in action; no. 0.506*.

Bhuiyan, M. A. H., Suruvi, N. I., Dampare, S. B., Islam, M., Quraishi, S. B., Ganyaglo, S. & Suzuki, S. 2011 Investigation of the possible sources of heavy metal contamination in lagoon and canal water in the tannery industrial area in Dhaka, Bangladesh. *Environmental Monitoring and Assessment* **175**(1), 633–649.

Elad, Y., Kleinman, Z., Nisan, Z., Rav-David, D. & Yermiyahu, U. 2021 Effects of calcium, magnesium and potassium on sweet basil downy mildew (*Peronospora belbahrii*). *Agronomy* **11**(4). doi:10.3390/agronomy11040688.

Ewaid, S. H. & Abed, S. A. 2017 Water quality index for Al-Gharraf River, southern Iraq. *The Egyptian Journal of Aquatic Research* **43**(2), 117–122. https://doi.org/10.1016/j.ejar.2017.03.001.

Ewaid, S. H., Abed, S. A., Al-Ansari, N. & Salih, R. M. 2020 Development and evaluation of a water quality index for the Iraqi rivers. *Hydrology* **7**(3), 67.

Fathi, E., Zamani-Ahmadmahmoodi, R. & Zare-Bidaki, R. 2018 Water quality evaluation using water quality index and multivariate methods, Beheshtabad River, Iran. *Applied Water Science* **8**, 1–6.

Gaytán-Alarcón, A. P., González-Elizondo, M. S., Sánchez-Ortíz, E. & Alarcón-Herrera, M. T. 2022 Comparative assessment of water quality indices – a case study to evaluate water quality for drinking water supply and irrigation in Northern Mexico. *Environmental Monitoring and Assessment* **194**(8), 1–15.

Hoseinzadeh, E., Khorsandi, H., Wei, C. & Alipour, M. 2015 Evaluation of Aydughmush river water quality using the national sanitation foundation water quality index (NSFWQI), river pollution index (RPI), and forestry water quality index (FWQI). *Desalination and Water Treatment* **54**(11), 2994–3002.

Jalees, M. I. & Asim, Z. 2016 Statistical modeling of atmospheric trace metals in Lahore, Pakistan for correlation and source identification. *Environmental Earth Sciences* **75**(9), 1–12.

Jalees, M. I., Farooq, M. U., Anis, M., Hussain, G., Iqbal, A. & Saleem, S. 2021a Hydrochemistry modelling: evaluation of groundwater quality deterioration due to anthropogenic activities in Lahore, Pakistan. *Environment, Development and Sustainability* **23**(3), 3062–3076. doi:10.1007/s10668-020-00703-3.

Jalees, M. I., Farooq, M. U. & Shah, A. T. 2021b Cancer risk assessment and modeling of groundwater contamination near industrial estate, Lahore, Pakistan. *Journal of Water, Sanitation and Hygiene for Development* **11**(2), 314–326.

Keerio, H. A., Bae, W., Park, J. & Kim, M. 2020 Substrate uptake, loss, and reserve in ammonia-oxidizing bacteria (AOB) under different substrate availabilities. *Process Biochemistry* **91**, 303–310. https://doi.org/10.1016/j.procbio.2019.12.023.

Kumar, A. & Dua, A. 2009 Water quality index for assessment of water quality of river Ravi at Madhopur (India). *Global Journal of Environmental Sciences* **8**(1), 49–57.

Law and Parliamentary Affairs Department, G. o. P. (2016). The Punjab Gazette. Punjab Environmental Quality Standards for Municipal and Liquid Industrial Effluents. Lahore, Environmental Protection Department. **L-7532**: 1–5.

Mumtaz, M. W., Hanif, M., Mukhtar, H., Ahmed, Z. & Usman, S. 2010 Evaluation of pollution load of Lahore Canal by quantification of various pollutants through physicochemical characterisation. *Environmental Monitoring and Assessment* **167**(1), 437–446. doi:10.1007/s10661-009-1062-y.

Mumtaz, M. W., Adnan, A., Mukhtar, H., Danish, M. & Raza, M. A. 2015 Determination of toxic metals in water of Lahore canal by atomic absorption spectroscopy. *Journal of Water Chemistry and Technology* **37**(2), 73–77. doi:10.3103/S1063455X15020058.

Nguyen, B. T., Nguyen, T. M. T. & Bach, Q.-V. 2020 Assessment of groundwater quality based on principal component analysis and pollution source-based examination: a case study in Ho Chi Minh City, Vietnam. *Environmental Monitoring and Assessment* **192**(6), 1–13.

Nishanthi, K., Dushanan, R., Mathanraj, S. & Priyadharshini, C. 2021 An assessment of water quality temporal variation in Sri Jayawardenapura Kotte canal, Sri Lanka. *World News of Natural Sciences* **38**, 139–157.

Panhwar, M. Y., Panhwar, S., Keerio, H. A., Khokhar, N. H., Shah, S. A. & Pathan, N. 2022 Water quality analysis of old and new Phuleli Canal for irrigation purpose in the vicinity of Hyderabad, Pakistan. *Water Practice & Technology* **17**(2), 529–536.

Piyadasa, R. U. & Meegaswatte, M. 2022 Assessment of pollution status of Meda ela (Middle Canal) and its influence on Mahaweli River, Sri Lanka. *International Journal of Geography, Geology and Environment* **4**(1), 08–12.

Poonam, T., Tanushree, B. & Sukalyan, C. 2013 Water quality indices-important tools for water quality assessment: a review. *International Journal of Advances in Chemistry* **1**(1), 15–28.

Rowe, D. R. & Abdel-Magid, I. M., Health aspects of using reclaimed water in engineering, in *Handbook of Wastewater Reclamation and Reuse*, 1st ed., Rowe, D.R. and Abdel-Magid, I.M., Eds., CRC Press, Boca Raton, FL, **1995**, p. 107.

Samantray, P., Mishra, B. K., Panda, C. R. & Rout, S. P. 2009 Assessment of water quality index in Mahanadi and Atharabanki rivers and Taldanda canal in Paradip Area, India. *Journal of Human Ecology* **26**(3), 153–161. doi:10.1080/09709274.2009.11906177.

Wu, Z., Wang, X., Chen, Y., Cai, Y. & Deng, J. 2018 Assessing river water quality using water quality index in Lake Taihu Basin, China. *Science of the Total Environment* **612**, 914–922.

WWF-Pak 2007 *National Surface Water Classification Criteria and Irrigation Water Quality Guidelines for Pakistan*. WWF-Pak, Lahore, Pakistan. Available from: https://mocc.gov.pk/SiteImage/Misc/files/National%20Surface%20Water%20Classification%20Criteria.pdf.

Yafuso, E. J. & Fisher, P. R. 2017 Oxygenation of irrigation water during propagation and container production of bedding plants. *HortScience* **52**(11), 1608–1614.

Zhang, J., L.-y. Zhang, M. Du, W. Zhang, X. Huang, Y.-q. Zhang, Y.-y. Yang, J.-m. Zhang, S.-h. Deng and F. Shen (2016). Identifying the major air pollutants base on factor and cluster analysis, a case study in 74 Chinese cities. *Atmospheric Environment* **144**: 37–46.

First received 6 February 2023; accepted in revised form 6 July 2023. Available online 17 July 2023