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Evaluation of surface water quality using the water quality index (WQI) and the synthetic pollution index (SPI): a case study of Indus Delta region of Pakistan

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ABSTRACT

Under changing climate scenario, groundwater aquifers in the Indus Delta, Pakistan are spoiled due to seawater intrusion, and thus people living in the deltaic area are compelled to use contaminated water of surface water bodies for their daily domestic needs. The present study was thus carried out to assess the water quality of the surface water bodies using numerical indices, that is, the water quality index (WQI) and the synthetic pollution index (SPI). Fifty water samples collected from natural lakes, ponds, and depressions were analyzed for different physicochemical parameters using standard methods. The physicochemical analysis revealed that most of the sampled surface water bodies contained unsafe water for drinking as well as for irrigation purposes. The WQI identified that water of 82% of water bodies was unfit for drinking purpose while remaining 18% was classified as very poor. Whereas SPI revealed that water of 2% of surface water bodies was moderately polluted, 20% severally polluted, and remaining 78% was unfit water for drinking purpose. The study highlights the significance of using WQIs for evaluation of water quality for domestic use and a healthy ecosystem in the similar deltaic areas of the world.

Keywords: Physicochemical parameters; Water pollution; Surface water; Water quality; Indus River Delta

1. Introduction

Freshwater is a vital resource for the existence of life and healthy ecosystem on the planet of Earth. Rivers, lakes, glaciers, and aquifers are the primary sources of freshwater [1]. Water contamination is a global environmental issue, limiting sustainable socioeconomic development and establishing adverse impacts on the human health [2]. Water quality concerns until the current past were disregarded since the supply of good quality water was sufficiently accessible, and the adverse impacts of some substantial metals on public health were not fully comprehended [3]. However, due to the discharge of untreated industrial and domestic waste into the surface water bodies, it is now essential to assess the quality of water before use for various purposes [4,5].

The quality of water based on individual water quality parameter is not readily understandable [6]. Often, it is difficult to interpret the results when various water quality parameters are analyzed for the assessment of water quality, since each parameter may show different quality class [7]. Hence, there is a need to interpret the results in a simple and object-oriented manner by combining a complex data set into a single term. The suitability of water for domestic purpose is described in terms of water quality index (WQI), which is widely used to reflect the overall impact of water pollutants on the quality of water [8]. It describes the quality of water in a single and simple reproducible dimensionless term [9]. It converts several data from various sources and combines them to build up an overall status of a water system [10,11] which can

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be of extraordinary help in the choice of suitable water-treatment method to address the issue of contamination [12].

Several WQIs have been developed throughout the globe which can quickly and proficiently assess the overall quality of water within a specified area [6]. Initially, Horton [13] introduced the WQI, and subsequently, other ideas were proposed as improvements to the original method [12]. Around the globe, several researchers have developed and used WQIs with some statistical variations of different physicochemical parameters [14–16]. Hoseinzadeh et al. [8] applied three standard WQIs such as National Sanitation Foundation WQI, river pollution index, and forestry water pollution index to evaluate the quality of Aydughmush River, Iran. The indices were estimated using results of physical, chemical, and biological parameters of river water collected from eight different locations for a period of 1 year. Hoseinzadeh et al. [17] determined the water quality of 50 wells in Rumeshgan site of western Iran using two numerical indices such as WQI and nitrate pollution index. Results were delineated through geographic information system contour mapping. Also, different ordinary kriging models such as spherical, exponential, Gaussian, linear, and circular models were used to estimate suitable locations for new wells containing minimum harmful pollutants in the study area. Popovic et al. [7] applied the water pollution index to access the ecological status of Sava River, Serbia based on the analysis of physical, chemical, and biological parameters. Hoseinzadeh et al. [18] used multivariate statistical techniques such as factor, principal component, and cluster analyses to evaluate the quality of rainwater in the city of Khorramabad, Iran.

It is reported that in most of the areas of the Sindh province of Pakistan including the Indus River Delta, the groundwater is not suitable for drinking purpose [4,19]. Hence, people usually use surface water to accomplish their domestic water demand. Natural wetlands, lakes, ponds, irrigation canals, and natural depressions are the primary sources of fresh surface water in the Indus Delta. These freshwater sources are exposed to a variety of pollutants originating from the point and nonpoint sources such as domestic and industrial sewage, agricultural and industrial wastes which are difficult to control, evaluate, and monitor [20]. The water quality of any specific area either surface or subsurface is ascertained by the chemical, physical, and biological parameters of water [12]. The concentration of such parameters beyond permissible limits is hazardous for human health as well as for agricultural produce.

The surface water in the Indus deltaic area of Sindh province of Pakistan is being used for different purposes, such as drinking, raising animals, fishing, and irrigation. However, the quality of surface water bodies is deteriorating under changing climate due to decline in river and canal flows in the delta, the disposal of untreated industrial water in canals at upstream, low rainfall and high evaporation rates in the area. It is also reported that in many parts of the Sindh province including coastal areas, drinking water resources are deteriorating due to elevated concentrations of arsenic [19]. The literature reveals that the applicability of WQIs for surface water quality assessment has so far not been investigated thoroughly in the Indus river delta. Keeping in view the gravity of the problem and the importance of water quality, the present study was conducted to evaluate the water quality status of surface water bodies in the Indus Delta using numerical indices, that is, weighted arithmetic WQI and the synthetic pollution index (SPI). A detailed analysis of multivariate statistical techniques, such as factor analysis (FA), principal component analysis (PCA), and Pearson correlation analyses were also used to uncover the latent information of various water quality parameters [18,21]. The outcome of the study provides guidelines to the policymakers and local communities of the river delta for efficient utilization and management of water resources.

2. Materials and methods

2.1. Description of the study area

The Indus River forms a shape of the delta as soon as it approaches the Arabian Sea (Fig. 1). The River Indus Delta is reported as the seventh largest delta of the world, which provides a home for 97% of Pakistan's mangrove forests [22]. It stretches in Sujawal, Thatta, and Badin districts of Sindh province of Pakistan, however, most of the area lies within boundaries of Sujawal and Thatta districts. The active Indus Delta covers an area of about 0.6 million hectares along the coastal line of about 250 km [23]. The climate of the area is dry and tropical, and on average it receives about 220 mm of rainfall [23], while temperature ranges between 23.8°C and 28.7°C [24]. Southwesterly gusty winds blow during the summer, while northeasterly winds blow during the winter and have a significant impact on the erosion of coastline. Agriculture and fishing are the main resources of earning for most of the inhabitants of the Delta. Due to seawater intrusion into the delta, its freshwater resources are contaminated, agricultural lands are degraded, mangrove cover, and its ecosystem is severely affected. As a result, many people have migrated, and many villages are abandoned.

2.2. Water sampling and analysis

The surface water samples were collected from 50 different surface water bodies, namely, lakes, ponds, canals (except irrigation channels), and natural depressions located in the Indus Delta (Fig. 2). The locations of surface water bodies were recorded using the handheld Garmin GPS (62s) [5]. Water samples were gathered in 1-L plastic bottles following standard methods of water sampling. The water samples were analyzed for different physicochemical parameters, namely, turbidity, electrical conductivity (EC), pH, total dissolved solids (TDSs), calcium (Ca), magnesium (Mg), total hardness (TH), chloride (Cl), alkalinity (Alk), and arsenic (As) using standard methods and compared with water quality standards set by World Health Organization (WHO) and Food and Agriculture Organization (FAO) for drinking and irrigation purposes, respectively. Water quality parameters, namely, turbidity, EC, hydrogen ion concentration, and TDSs were observed in situ [7,25] using turbidity, EC, pH, and TDS meters, respectively. Calcium, magnesium, hardness, chloride, and water alkalinity were determined in the laboratory through standard methods [26], whereas arsenic was determined using Merck arsenic kit. All the standard methods were followed from water sample collection, preservation, transportation, and analysis of water samples in the laboratory.

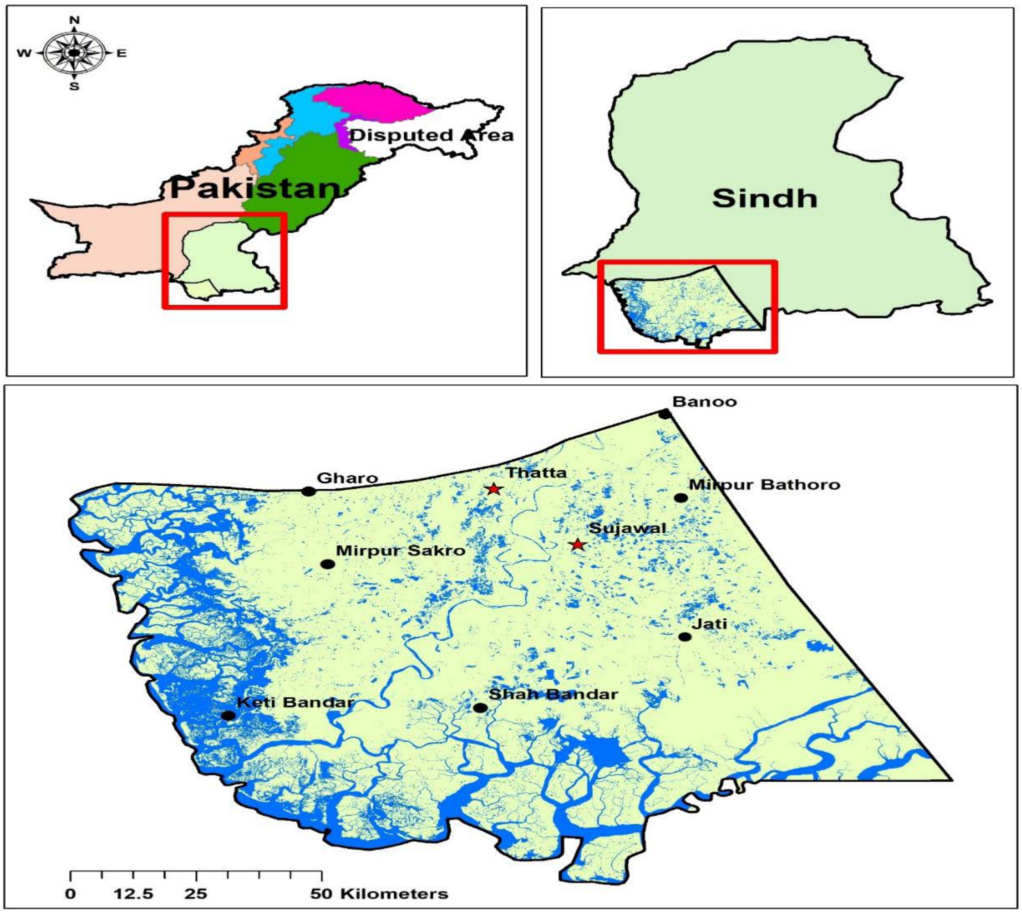

Fig. 1. Location map of the study area (Indus Delta).

2.3. Water quality indices

WQIs provide an overall picture of the suitability of water for various purposes. However, it is difficult to simplify the quality of ground or surface water to a specific index [21]. However, the WQI and the SPI are reported as very useful and efficient tools for assessing the quality of water [27,28]. Currently, these indices are being used by many researchers, water managers, and scientists around the globe. Hence, in the present study, quality of surface water bodies of the Indus Delta was assessed by the applications of these two numerical indices.

2.3.1. Arithmetic WQI

An arithmetic WQI method initially proposed by Horton [13], developed by Brown et al. [29], and then by Cude [30] was used in the present study for assessment of water quality. Weighted arithmetic WQI requires less number of parameters in comparison with all water quality parameters used for the particular purpose [1,31]. It can be applied to assess the suitability of both surface as well as subsurface water from the perspective of human consumption [1]. In the present study, the index was mathematically calculated using results of analysis of physicochemical parameters, namely, turbidity, hydrogen ion concentration, calcium, magnesium, TH, TDSs, chloride, alkalinity, and arsenic for 50 surface water bodies of the Indus Delta. Following three equations were used for calculation of WQI [12]:

$$Q_i = \frac{\left(V_o - V_i\right)}{\left(V_S - V_i\right)} \times 100 \tag{1}$$

where Q_i, V_o, V_i, and V_S are the subindex of the *i*th parameter, observed value, ideal value, and standard value for each of the *i*th parameter. The ideal value for the hydrogen ion concentration (pH) was taken as 7 and, for other parameters, V_i is equal to zero [11,12].

$$W_i = \frac{K}{V_S} \tag{2}$$

where W_i is the unit weightage of the *i*th parameter which was determined as a value inversely proportional to the standard value (V_S) suggested by WHO standard for each of the observed physicochemical parameter [12]. However, K is a constant taken as unity for all the observed physicochemical parameters [12]. Then, WQI based on simple arithmetic average was developed using Eq. (3):

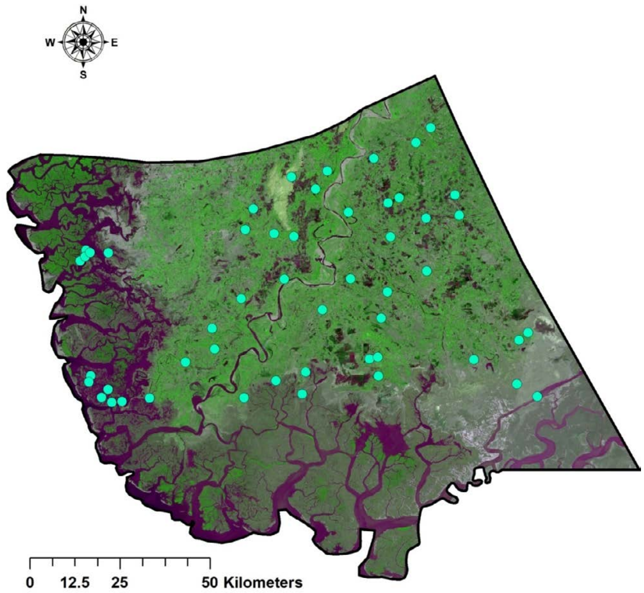

Fig. 2. GIS map of water sampling locations.

$$\mathrm{WQI} = \sum_{i=1}^{n} \frac{W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (3)$$

Calculations of unit weightage (W_i) based on the constant (K), and standard values (V_S) are summarized in Table 1.

Based on the calculated WQI, the water quality is classified into different categories [1] as given in Table 2.

2.3.2. Synthetic pollution index

To determine the suitability of surface water bodies in the Indus Delta, the SPI [21,32] was also computed. The index was calculated using results of physicochemical water quality parameters, namely, turbidity, hydrogen ion concentration, TDSs, calcium, magnesium, TH, chloride, alkalinity, and arsenic. The index was computed using the following three relations. In the first step, the constant of proportionality (K) was determined using the following approach:

$$K = \frac{1}{\left(\sum_{i=1}^{n} \frac{1}{S_i}\right)} \quad (4)$$

where S_i is the standard level for the ith parameter and n denotes the number of parameters. In the second step, the weight coefficient (W_i) was calculated using the following approach:

$$W_i = \frac{K}{S_i} \quad (5)$$

Finally, the SPI was computed using the following approach:

$$\mathrm{SPI} = \sum_{i=1}^{n} \frac{C_i}{S_i} \times W_i \quad (6)$$

where C_i is the observed concentration for each of the determined physicochemical water quality parameters.

Based on the computed levels of the SPI [32,33], drinking water is classified into five categories as described in Table 2.

In the present study, two numerical indices such as the WQI and the SPI were used for validation of the results. Another fact is that both indices are not straight distinctly identical, for example, classification criteria for both indicators is different, and the correlation between both of them is not straightforward.

Table 1
Calculation of unit weightage of surface water bodies of the Indus Delta

Parameter	Standard value (V_s)	Unit weightage (W_i)
Turbidity	5 NTU	0.2
Total dissolved solids	1,000 mg/L	0.001
pH	7.5	0.133
Calcium	75 mg/L	0.013
Magnesium	50 mg/L	0.02
Total hardness	500 mg/L	0.002
Chloride	250 mg/L	0.004
Alkalinity	200 mg/L	0.005
Arsenic	10 μg/L	0.1

3. Results and discussion

3.1. Physicochemical analysis of surface water bodies

The statistical summary of the physicochemical analysis of surface water bodies of the Indus Delta in the form of minimum, maximum, average, mode, standard deviation (SD), and the confidence interval (CI) is summarized in Table 3.

The turbidity of surface water is fluctuated from 1.15 to 129 NTU with a mean value of 15 ± 6.41 NTU. The highest turbidity of 129 NTU was observed in the surface water drain located in the union council (small administrative unit) of Kar Malik, district Sujawal. About 38% of the sampled surface water samples had turbidity values within a safe limit, 62% of

Table 2
Different categories of drinking water based on the computed WQI and SPI

Range of WQI	Water classification	Range of SPI	Water classification
0–25	Excellent water	<0.2	Suitable for drinking
26–50	Good water	0.2–0.5	Slightly polluted
51–75	Poor water	0.5–1.0	Moderately polluted
76–100	Very poor water	1.0–3.0	Severally polluted
>100	Unfit for drinking	>3.0	Unfit for drinking

Table 3
Statistical summary of various physicochemical parameters of surface water bodies

Parameter	Minimum	Maximum	Mean	Mode	SD	CI
Turbidity (NTU)	1.15	129	15	4.55	23.4	6.41
Electrical conductivity (dS/m)	0.6	60	15	30.2	15.07	4.14
pH	7.62	8.64	8.0	7.8	0.28	0.08
Total dissolved solids (mg/L)	378	38,272	9,590	19,328	9,657	2,650
Calcium (mg/L)	24	100	45	–	27.94	7.67
Magnesium (mg/L)	55	305	76	–	79.73	21.88
Total hardness (mg/L)	68	1,354	368	–	361.91	99.33
Chloride (mg/L)	440	17,406	2,197	–	3,300.1	905.72
Alkalinity (mg/L)	44	292	44	–	60.07	16.49
Arsenic (μg/L)	–	25	4	–	7	2

the surface water samples had turbidity values higher than the safe limit of 5 NTU described by WHO for drinking purpose.

The EC is the main parameter [34] which provides a primary indication of suitability of water for drinking and agriculture purposes [35]. The EC values of the collected samples fluctuated from 0.6 to 60 dS/m with an average value of 15 ± 4.14 dS/m. The highest conductivity of 60 dS/m was observed in the surface water drain located in the southeast part of the delta. The study revealed that only one surface water lake located in the union council of Ladyoon had EC value within safe drinking water quality guidelines, while rest of the 49 surface water bodies had EC values beyond the drinking water quality standards. The highest values of EC were observed in those water bodies which are near to the Arabian Sea. It might be due to the high surface evaporation rate, low rainfall, higher abstraction than recharge, leaching of pollutants, lithology of the subsoil strata, and intrusion of saline water from the Arabian Sea into the delta. The EC is also an important indicator for assessing the suitability of water for irrigation purpose as the concentration of total salts is also estimated from EC of water [36,37]. According to the FAO [38], the water having EC of less than 0.7 dS/m is considered suitable for irrigation purpose, while water having EC greater than 3.0 dS/m affects the water uptake capability of most of the plants and thus decreases crop yield. From this perspective, about 66% of the sampled surface water bodies of the study area had EC values higher than 3 dS/m and water could be considered unfit even for the irrigation purpose.

The pH is a scale normally used to evaluate the acidity or alkalinity of water. Most of the aquatic creatures have a restricted range of hydrogen ion concentration (pH), that is, 6–8 [39]. The surface water of the study area was normal to slightly alkaline in nature having pH value between 7.62 and 8.64 with a mean value of 8.0 ± 0.08. For regular irrigation, the pH values should be between 6.5 and 8.5, while pH values greater than 8.5 increase the soil sodicity hazards [40].

The TDSs are a measure of total dissolved organic and inorganic materials in water [41]. In the sampled surface water bodies, the concentration of TDSs ranged between 378 and 38,272 mg/L with a mean value of 9,590 ± 2,650 mg/L. The lowest value of TDS was observed in a natural lake located in the union council of Ladyoon, whereas the highest concentration was observed in the union council of Kar Malik, district Sujawal. Only a single surface water body (natural lake) had a TDS concentration less than 500 mg/L, while rest of the analyzed surface water bodies had the highest concentration of dissolved solids. The water with TDS concentration more than 500 mg/L becomes unsuitable for drinking purpose [42]. The TDS concentration in drinking water beyond the permissible limits gives an unpleasant taste to water, causes gastrointestinal irritation in the human body [35]. As indicated by FAO [38], the water having TDSs under 450 mg/L is considered as good, and that with more than 2,000 mg/L is considered as unsatisfactory for irrigation purpose also [43]. Hence, under this criterion, the water of 64% of the sampled surface water bodies of the study area had TDS concentration higher than 2,000 mg/L, hence, are not suitable even for irrigation purpose.

The chloride concentration was higher than the safe limit of 250 mg/L described by WHO for drinking purpose in most of the sampled water bodies of the study area. Its concentration fluctuated from 440 to 17,406 mg/L with an average value of 2,197 ± 905.72 mg/L. The highest chloride concentration was detected in the natural lake located in the union council of Gaarho, district Thatta. The higher concentration of chloride increases the corrosive nature of water, adversely affects the human health, and causes eye and nose irritation, and stomach problems [35]. The higher concentration of chloride in most of the surface water bodies of the study area can be considered as an indication of entry of highly saline water into the water bodies [44]. The irrigation water having chloride concentration between 70 and 350 mg/L causes problems to plants, and severe problems are likely to occur if it contains chloride concentration greater than 350 mg/L [45]. Based on this criterion, the most of surface water bodies had higher chloride concentration and could not be used for agriculture purpose.

The calcium concentration in the surface water bodies varied from 24 to 100 mg/L with an average value of 45 ± 7.67 mg/L. According to WHO [46] guidelines, maximum allowable limit of calcium for drinking purpose is 75 mg/L. The magnesium concentration in the water bodies ranged from 55 to 305 mg/L with an average value of 76 ± 21.88 mg/L, whereas its allowable limit for drinking water is 50 mg/L. Severe problems are likely to occur if calcium and magnesium concentrations in water used for irrigation purpose are greater than 200 and 60 mg/L, respectively. However, 51% of the sampled surface water bodies of the study area had calcium and magnesium content beyond the safe limit, hence could be categorized as unsuitable for drinking and irrigation purpose.

The analysis of the water samples revealed that 49% of the sampled surface water bodies of the study area had TH values greater than 300 mg/L and were falling in the categories of hard to very hard. The TH expressed regarding calcium carbonate ($CaCO_3$) ranged up to 1,354 mg/L with an average value of 368 ± 99.33 mg/L, whereas the maximum threshold limit for TH in drinking water is 500 mg/L [46]. The presence of higher concentrations of hardness in water causes poor lathering with soap and deteriorates the quality of clothes [35]. In some of the surface water bodies of the study area, alkalinity values were also higher than the safe limit of 200 mg/L and fluctuated between 44 and 292 mg/L.

The arsenic concentration in the 10 (20%) out of 50 sampled water bodies located in the union councils of Mureed Khoso, Darro, Khan, Tar Khawaja, Kinjhar, Darya Khan Soho, Bijoro, Jar, Karampur, and Uddasi were above the permissible limit which ranged from 10 to 25 μg/L. This shows an alarming situation for the local communities who use such toxic water for their domestic and agricultural use. Arsenic-contaminated water adversely affects the human health, causes heart, liver, ocular, and neuropathies diseases [47].

3.2. Analysis of water quality in terms of WQI and SPI

WQI-based results are depicted in Table 4. The table shows that only nine (18%) surface water bodies are classified as very poor with a WQI level between 76 and 100 [1,12], while rest of the 41 (82%) surface water bodies lie in the category of unfit for drinking purpose with a WQI value exceeding 100.

However, the results based on the SPI are also depicted in Table 4. It indicates that 10 (20%) of the studied surface water bodies are classified as severally polluted with a SPI between 1.0 and 3.0, only one (2%) as moderately polluted and rest of the 39 (78%) sampled surface water bodies lie in the category of unfit for drinking purpose with SPI value exceeding 3.0.

3.3. Multivariate statistical analysis

The multivariate statistical techniques such as Pearson correlation, FA, and PCA were applied using the SPSS software. These techniques are used worldwide [18,48] for evaluation of the quality of surface and groundwater. Those are reported very useful for assessing the variations caused by natural and anthropogenic factors [21,49].

3.3.1. Pearson correlation of water quality parameters

Pearson correlation method [18] was applied to analyze the relationship between various physicochemical water quality parameters. Table 5 describes the correlation coefficients of various physicochemical parameters of surface water bodies of the delta. It portrays that EC is strongly correlated with TDS (0.99), fairly correlated with chloride (0.62), calcium (0.54), and magnesium (0.55). Chloride is correlated fairly with calcium (0.52) and magnesium (0.62). Calcium is moderately correlated with magnesium (0.55) and TH (0.76). A strong correlation was found between magnesium and TH (0.98). However, a weak correlation was observed among most of the analyzed physical and chemical water quality parameters.

3.3.2. FA and PCA

The multivariate statistical tests such as FA and PCA were used to analyze the water quality data. FA was conducted to extract latent information such as a matrix and factor loadings [18] shown in Table 6(a). Extraction sums of squared loadings indicated the eigenvalues of factor variables are greater than 1. Extraction sums of squared loadings for first, second, and third components were 26.92%, 25.79%, and 15.30% of the variance, respectively. Also, the PCA was applied to the normalized dataset [48] of physical and chemical parameters of water samples. The results of the PCA are described in Table 6(b) and Fig. 3. The first three components together explained 68.01% of the total variance. The first component that explained 26.92% of the total variance was largely a function of chemical parameters including magnesium, TH, chloride, and calcium. The second component with 25.79% of the variance was mainly a function of TDSs, EC, and calcium. The third component explaining 15.30% of the variance was mainly a function of water alkalinity, arsenic, and calcium. Overall, PCA revealed that each component was a mixture of chemical factors.

3.3.3. Correlation between WQI and water quality parameters

The correlation between the computed values of the WQI and different water quality parameters [50] was tried to establish. Strong relationships between WQI and EC, and TDS with a coefficient of determination of R^2 = 0.98 and 0.99, respectively, were found as shown in Figs. 4 and 5, respectively. Thus, it is evident that EC and TDS were the most affecting components for the calculated estimates of the WQI for surface water bodies of the Indus Delta. However, fair and weak relationships were observed among most of the water quality parameters and WQI.

The correlation between computed numerical indices (WQI and SPI) was also developed and found a significant trend between these numerical indices with a coefficient of determination of R^2 = 0.75 with regression Eq. (7).

$$SPI = 1.0623*WQI - 0.0136 \quad (7)$$

4. Conclusion

The present study revealed that most of the sampled surface water bodies of the Indus Delta contained unsafe water for drinking as well as for normal irrigation purposes. However, those water bodies can be used for promoting biosaline agriculture and other related agricultural practices in the study area. The WQI identified that water of 82% of water bodies was unfit for drinking purpose, while remaining 18% was classified as very poor. Whereas the SPI revealed that water of 2% of surface water

Table 4
Classification of sampled surface water bodies based on the WQI and SPI

Sampling stations		Sampling date	Source	WQI value	Water class	SPI value	Water class
Latitude	Longitude						
24°09′45″	67°54′10″	Jul. 30, 2017	Wari sea creek	2,750	UF*	255.25	UF
24°22′24″	67°57′11″	Jul. 30, 2017	Goongani lake	98.3	VP*	2.87	SP*
24°27′04″	68°01′26″	Jul. 30, 2017	Mureed Khoso natural lake	453.2	UF	306.5	UF
24°12′27″	68°05′37″	Jul. 30, 2017	Ladyoon lake	84.0	VP	2.91	SP
24°15′01″	68°04′16″	Jul. 30, 2017	Chach lake	1,764.5	UF	0.42	UF
24°47′30″	68°11′14″	Jul. 30, 2017	Darro wetland	811.6	UF	104.4	UF
24°49′45″	68°13′29″	Jul. 30, 2017	Thari lake	97.0	VP	2.6	SP
24°09′39″	67°27′09″	Aug. 08, 2017	Kori creek	3,936.6	UF	611.7	UF
24°09′08″	67°31′14.9″	Aug. 08, 2017	Tikka lake	1,565.3	UF	15.27	UF
24°14′33″	67°36′39″	Aug. 08, 2017	Ochitonatural canal	99.3	VP	2.4	SP
24°24′05″	67°45′ 03″	Aug. 08, 2017	Mahar lake	294.4	UF	611.4	UF
24°27′01″	67°51′29″	Aug. 08, 2017	Kotri Allah Rakhio Shah natural lake	88.0	VP	2.94	SP
24°33′26″	67°52′55″	Aug. 08, 2017	Pir Patho natural lake	312.2	UF	13.25	UF
24°18′57″	68°28′04″	Aug. 08, 2017	Haji Hassan Samejo natural lake	281.7	UF	103.8	UF
24°17′52″	68°26′43″	Aug. 08, 2017	Allah Dino Samejo natural lake	99.12	VP	2.85	SP
24°09′23″	68°29′29″	Aug. 11, 2017	LBOD drain	4,349.4	UF	126.2	UF
24°11′16″	68°26′23″	Aug. 11, 2017	Kar Malik lake	2,466.7	UF	114.6	UF
24°28′12″	68°12′51″	Aug. 11, 2017	Begnalake	308.3	UF	291.2	UF
24°33′22″	68°07′26″	Aug. 11, 2017	Kinjhar natural lake	974.6	UF	297.3	UF
24°36′35″	68°17′46″	Aug. 11, 2017	Darya Khan Soho lake	1,278	UF	815.7	UF
24°15′19″	68°05′33″	Aug. 11, 2017	Jahan Khan natural lake	1,021.3	UF	162.9	UF
24°25′5″	68°06′59″	Aug. 11, 2017	Kothi natural lake	215.0	UF	254.5	UF
24°11′45″	67°50′14″	Aug. 11, 2017	Jani Shah sea creek	1,472.0	UF	509.3	UF
24°09′11″	67°45′26″	Aug. 11, 2017	Jani Shah subcreek	4,719.0	UF	132.4	UF
24°13′03″	67°54′41″	Aug. 11, 2017	Jani Shah subcreek	3,876.0	UF	213.8	UF
24°30′58″	67°25′06″	Aug. 18, 2017	Patianisea creek	3,854.2	UF	295.3	UF
24°31′20″	67°21′44″	Aug. 18, 2017	Patiani subcreek	3,401.3	UF	366.6	UF
24°29′45″	67°20′51″	Aug. 18, 2017	Patiani subcreek	3,492.2	UF	417.5	UF
24°30′25″	67°21′36″	Aug. 18, 2017	Patiani subcreek	3,260.0	UF	464.6	UF
24°30′59″	67°22′21″	Aug. 18, 2017	Patiani subcreek	3,370.4	UF	529.5	UF
24°45′10″	68°04′57″	Aug. 18, 2017	Bijoro lake	185.4	UF	254.7	UF
24°39′40″	68°17′07″	Aug. 23, 2017	Mehar Shah lake	89.2	VP	0.99	MP*
24°36′11″	68°12′46″	Aug. 23, 2017	Jar lake	351.1	UF	2.85	SP
24°33′52″	67°49′56″	Aug. 23, 2017	Karampur lake	150.3	UF	712.8	UF
24°34′26″	67°45′39″	Aug. 23, 2017	Kalmati lake	707.3	UF	2.93	SP
24°37′32″	67°46′50″	Aug. 23, 2017	Zangyani lake	298.5	UF	117.3	UF
24°08′31″	67°25′36″	Aug. 23, 2017	Hajamro sea creek	3,144.6	UF	427.6	UF
24°10′27″	67°25′02″	Aug. 23, 2017	Hajamro subcreek	3,220.1	UF	519.3	UF
24°12′29″	67°22′27″	Aug. 23, 2017	Hajamro subcreek	3,242.2	UF	641.5	UF
24°11′34″	67°22′11″	Aug. 23, 2017	Hajamro subcreek	3,263.3	UF	824.5	UF
24°09′16″	67°24′04″	Aug. 23, 2017	Hajamro subcreek	3,253.1	UF	977.5	UF
24°39′15″	68°08′42″	Aug. 28, 2017	Jar lake	317.3	UF	916	UF
24°38′26″	68°07′05″	Aug. 28, 2017	Sujawal lake	95.5	VP	2.98	SP
24°37′02″	68°01′06″	Aug. 28, 2017	Jati lake	88.7	VP	2.76	SP
24°43′14″	67°57′59″	Aug. 28, 2017	Kalan Kot river lake	806.5	UF	570.1	UF
24°21′09″	68°06′03″	Sept. 02, 2017	Uddasi lake	431.3	UF	162.9	UF
24°19′35″	67°40′40″	Sept. 02, 2017	Gaarho lake	1,260.4	UF	91.7	UF
24°42′21″	67°52′32″	Sept. 02, 2017	Kalan Kot lake	783.4	UF	152.7	UF
24°40′29″	67°56′11″	Sept. 02, 2017	Aaghmini lake	153.3	UF	224.0	UF
24°14′56″	68°19′56″	Sept. 02, 2017	Jati surface drain	6,685.3	UF	230.5	UF

UF*, unfit for drinking; VP*, very poor; SP*, severally polluted; MP*, moderately polluted.

Table 5
Pearson correlation coefficient matrix of water quality parameters

Parameter	Turbidity	EC	pH	TDS	Cl	Ca	Mg	TH	Alk	As
Turbidity	1.000									
EC	0.215	1.000								
pH	−0.012	0.111	1.000							
TDS	0.215	0.990	0.111	1.000						
Cl	−0.066	0.621	−0.191	0.623	1.000					
Ca	0.030	0.538	−0.192	0.537	0.521	1.000				
Mg	0.004	0.555	−0.056	0.556	0.623	0.553	1.000			
TH	0.009	0.016	−0.088	0.016	0.470	0.759	0.984	1.000		
Alk	0.010	0.381	−0.262	0.382	0.467	0.146	−0.205	−0.158	1.000	
As	0.186	−0.346	−0.387	−0.346	0.067	−0.124	−0.147	−0.157	0.109	1.000

Table 6(a)
Results of factor analysis and variances [18]

Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	2.692	26.921	26.921	2.692	26.921	26.921
2	2.579	25.789	52.709	2.579	25.789	52.709
3	1.530	15.300	68.009	1.530	15.300	68.009
4	1.103	11.028	79.038			
5	0.700	7.001	86.039			
6	0.663	6.628	92.667			
7	0.430	4.299	96.966			
8	0.303	3.034	100.000			
9	3.169E−5	0.000	100.000			
10	4.857E−17	4.857E−16	100.000			

Table 6(b)
Matrix of water quality factor loading for surface water samples (varimax and Kaiser normalization and extraction method)

Variables	Components		
	1	2	3
Tur	−0.019	0.202	0.303
EC	0.005	0.946	0.118
pH	−0.156	0.273	−0.758
TDS	0.005	0.947	0.119
Cl	0.633	−0.434	−0.022
As	−0.159	−0.546	0.535
Ca	0.575	0.419	0.370
Mg	0.957	−0.044	−0.095
TH	0.978	0.041	−0.014
Alk	−0.194	0.070	0.635

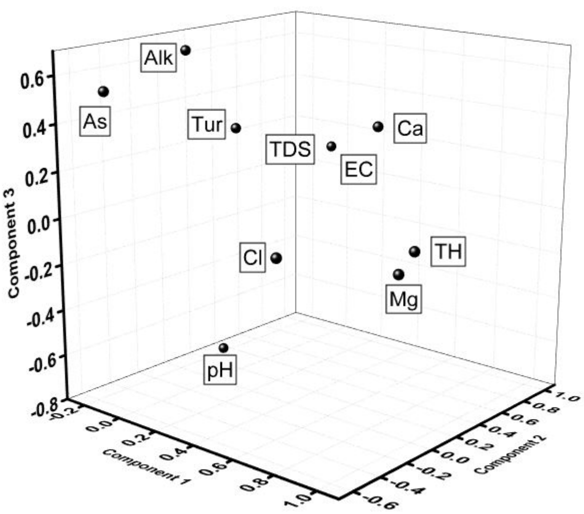

Fig. 3. Three-dimensional plot of all variables of components 1, 2, and 3.

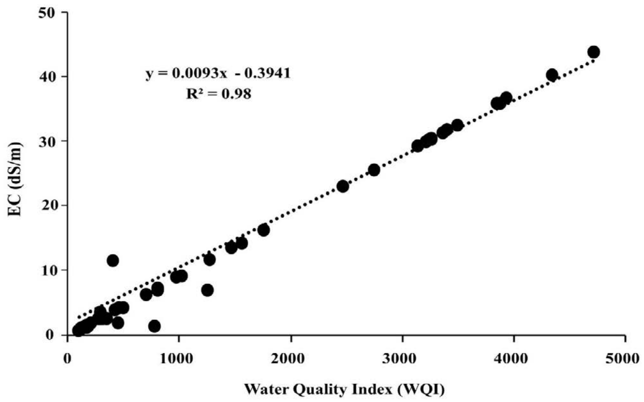

Fig. 4. Correlation between WQI and electrical conductivity.

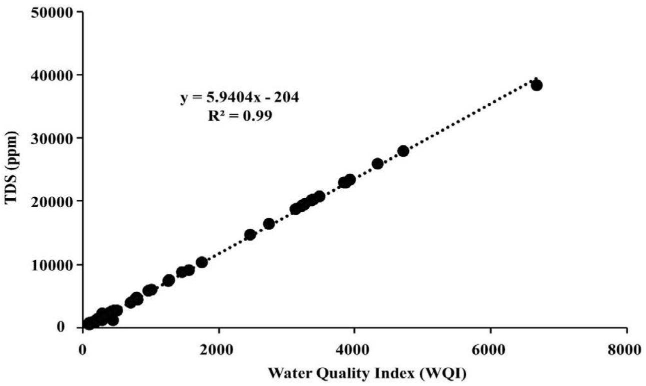

Fig. 5. Correlation between WQI and total dissolved solids.

bodies was moderately polluted, 20% severally polluted, and remaining 78% was unfit for drinking purpose. A significant-positive correlation was found between these numerical indices. The possible causes of such water contamination are various natural phenomena such as seawater intrusion from the Arabian Sea, low rainfall and high evaporation, anthropogenic activities occurring along the coast and the nature of geological strata below the natural surface water bodies. The study demonstrates the significance of using the WQIs in determining the overall quality of water. Extensive public awareness on the water quality vulnerability should be initiated without any further delay to provide safe and clean drinking water to the local community. Such studies in other deltaic regions of the world are recommended to explore the gravity of the problem worldwide.

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Symbols

WQI	—	Water quality index
SPI	—	Synthetic pollution index
WHO	—	World Health Organization
FAO	—	Food and Agriculture Organization
LBOD	—	Left bank outfall drain
EC	—	Electrical conductivity
Tur	—	Turbidity
TDSs	—	Total dissolved solids
Ca	—	Calcium
Mg	—	Magnesium
TH	—	Total hardness
Cl	—	Chloride
Alk	—	Alkalinity
As	—	Arsenic
SD	—	Standard deviation
CI	—	Confidence interval
FA	—	Factor analysis
PCA	—	Principal component analysis
SPSS	—	Statistical Package for the Social Sciences

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