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Analysis of Indus Delta Groundwater and Surface water Suitability for Domestic and Irrigation Purposes

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Abstract

The present study was conducted to analyze the suitability of groundwater and surface water of the Indus Delta, Pakistan for domestic and irrigation purposes based on the concentrations of arsenic (As), total dissolved solids (TDS), and chloride (Cl). Around 180 georeferenced groundwater and 50 surface water samples randomly collected were analyzed and mapped spatially using ArcGIS 10.5 software. The results were compared with their respective WHO and FAO guidelines. The analysis revealed that as in groundwater and surface water samples ranged up to 200, and 25 µg/L respectively. Similarly, the TDS in the groundwater and surface water ranged from 203 to 17, 664 mg/L and 378 to 38,272 mg/L respectively. The Cl in groundwater and surface water varied between 131 and 6,275 mg/L and 440 to 17,406 mg/L respectively. Overall, about 18%, 87% and 94% of the groundwater, and 10%, 92% and 56% of the surface waters possessed higher concentrations of As, TDS, and Cl, respectively. The higher levels of Cl in the samples are attributed to subsurface seawater intrusion in the delta. Analysis results and GIS mapping of water quality parameters revealed that in most of the delta, the quality of water was not suitable for drinking and agricultural purposes, thus should be properly treated before its use.

Keywords: Coastal Areas; Arsenic; Chloride; TDS; Spatial Analysis; GIS; Statistical Analysis.

1. Introduction

Water is one of the important natural resources, commonly used for domestic, agricultural, industrial, hydroelectric power generation, recreation, and other development purposes [1]. Arslan et al. [2] reported that groundwater is a significant source of drinking water which is not only withdrawn for drinking purposes but also to supply water for irrigation purposes. Further stated that increasing stresses on water supplies resulted in groundwater contamination issues in many parts of the globe. Sener et al. [3] reported that surface water quality is also a very sensitive and critical issue in many countries around the globe. Due to the rapid and unsystematic growth of population, mismanagement, and excessive consumption for irrigation and industrial purposes, water resources are under a serious threat [4-5]. The quality of water changes, when undesirable materials come into water [6]. It makes the environment harmful and adversely affects human health [7-8]. Safe and affordable drinking water is one of the basic human rights, and an essential step towards improving living standards all over the world [9]. Water is a universal solvent, hence, it is a major source of infection [8]. As per the World Health Organization (WHO) reports [10], contaminated drinking water is the main cause of 80% of all diseases. In various under developing countries of the world including Pakistan, drinking water in most of the areas does not confirm the WHO guidelines [11]. Mixing of domestic and industrial wastes are reported as one of

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the potential causes of water pollution. Untreated industrial wastes dumped into rivers, lakes, water bodies contaminate the surface water bodies. Contaminated water is a major cause of various diseases, such as gastro, diarrhea, typhoid, cholera, vomiting, skin, and kidney problems [12]. Whereas, Haseena et al. [8] have reported domestic sewage, industrialization, fertilizers, pesticides, population growth, urbanization, use of plastic bags, poor water management system as major sources of water contamination.

It is also reported that in many parts of the Sindh province of Pakistan including coastal areas, water resources are deteriorating due to elevated concentrations of arsenic [13]. Groundwater and surface water in the Indus delta, Pakistan is being used for drinking as well as agricultural purposes [14]. However, the quality of this precious resource of the area is deteriorated 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. The presence of arsenic in the groundwater has become a major public health concern around the globe. Globally, arsenic is recognized as one of the most toxic contaminants of drinking water. It is also an emerging issue of Pakistan, especially in Sindh province. Ahmed et al. [15] and Baig et al. [16] reported that around 16 to 36% of the population of Sindh province of Pakistan is exposed to higher levels of arsenic in groundwater. Memon et al. [17] reported the presence of higher concentrations of total dissolved solids in drinking water of three districts, i.e., Thatta, Badin, and Tharparkar of Sindh, Pakistan. Moreover, it has been suggested that regular monitoring of drinking water resources should be ensured to tackle the water-related health issues in the area. Sener et al. [3] stated that a water quality monitoring program is necessary for the protection of freshwater resources.

Climate change scenarios, diminishing Indus River flows, and resulting seawater intrusion into the Indus Delta, Pakistan has spoiled water resources of the area [18]. The review of the literature depicts that the use of geospatial tools for water quality assessment has so far not been investigated thoroughly in the coastal areas of Pakistan. Looking at the gravity of the problem, and concerns of the civil society, the present study was conducted to analyze the suitability of groundwater and surface water for domestic and agriculture purposes. Water quality data were also analyzed statistically using descriptive statistics, Pearson correlation, and principal component analyses. The study findings will be useful for policymakers, public health engineers, and water managers for taking remedial measures against such contamination of water resources of the area.

2. Materials and Methods

2.1. Study Area

The Indus River forms its delta when it empties into the Arabian Sea. It stretches in three administrative districts of Southern Sindh province of Pakistan, i.e. Thatta, Sujawal, and Badin districts (Figure 1). However, most of the deltaic area lies in Thatta and Sujawal districts. It comes under arid tropical region having an average rainfall of about 220 mm, and temperature between 24 ºC to 29 ºC [14]. In the study area, groundwater and surface waters are extensively used for domestic and agricultural uses. River Indus is the main source of groundwater recharge in the delta, which remains almost dry, due to the diversion of its excess volumes through dams, and reservoirs, canals built at its upper sides. Due to a shortage of freshwater in the area, groundwater aquifers are often recharged through highly saline water of the Arabian Sea [19-20]. Once this coastal area was famous in the country due to its prosperity, but at present, it is one of the poorest regions of Pakistan [21]. Diminishing Indus River flows, erratic rainfall patterns, and resulting seawater intrusion into the region are among the potential causes of such degradation.

2.2. Water Sampling

Around 180 georeferenced groundwater and 50 surface water samples were randomly collected from the study area. Groundwater samples were collected from hand pumps, boreholes, and electric motors installed at public places, such as schools, hospitals, bus stops, etc. [20]. However, surface water samples were collected from natural lakes, depressions, ponds, canals located within the delta. Samples were collected in one-litre plastic bottles [22], which were washed and rinsed well with distilled water before use. The sampling bottles were serially numbered along with the date of collection as well as location. A handheld Garmin GPS 62s was used to record the sampling location coordinates [9]. GIS maps of sampling locations of groundwater and surface water are shown in Figures 2(a) and 2(b) respectively. All the standard procedures were followed from the collection, transportation, and analysis of water samples.

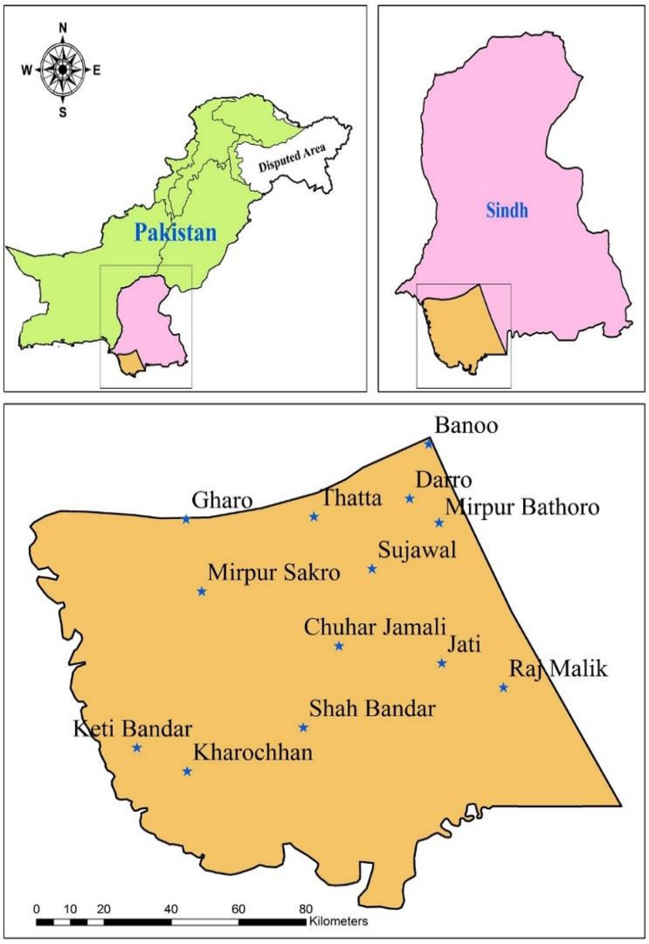

Figure 1. GIS Map of Study Area (Indus Delta)

2.3. Analysis of Water Quality Parameters and Geospatial Mapping

All the collected ground and surface water samples were analyzed for concentrations of arsenic (As), total dissolved solids (TDS), and chloride (Cl) using Merck Arsenic Kit, TDS meter, and titration method, respectively. The results of the analyzed water quality parameters were compared with their respective guidelines suggested by the WHO and FAO for drinking and irrigation purposes. The results were compiled in MS Excel worksheet, which was then imported into ArcGIS 10.5 software. Interpolated thematic maps were prepared for most of the parameters of groundwater using the IDW (inverse distance weighted) approach. The area of interest was extracted using 'extraction by mask' tool [19, 23]. The methodology adopted for the present study is depicted in the form of the flowchart as shown in Figure 3.

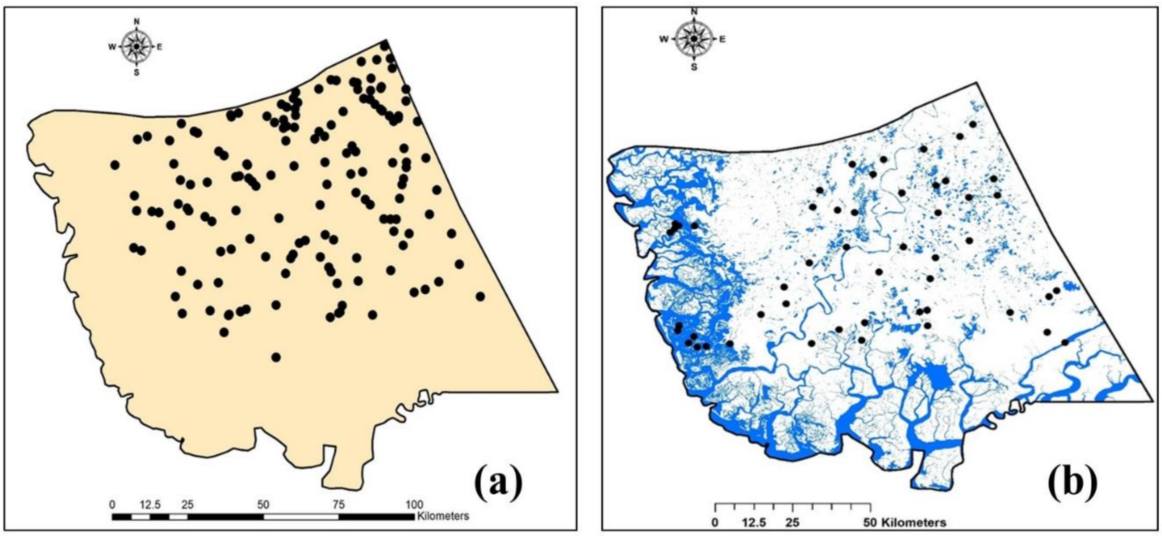

Figure 2. Sampling Location of (a) Groundwater, and (b) Surface water

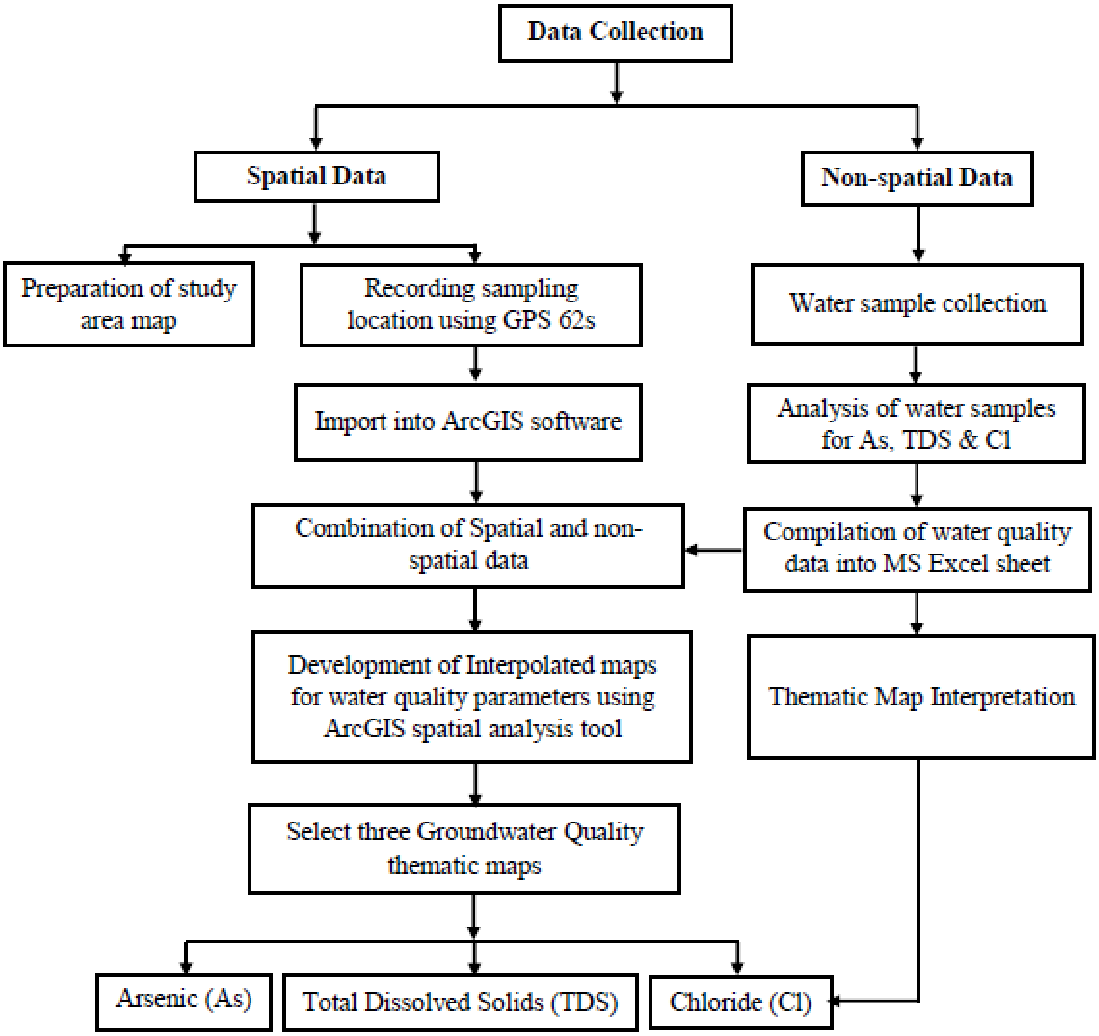

Figure 3. Flowchart of the adopted methodology [19, 24, 25]

2.4. Statistical Analysis

Ground and surface water quality data are statistically described in terms of descriptive statistics, such as minimum, maximum, average, mode, standard deviation (STD), and confidence interval (CI). The data were also statistically analysed for Pearson correlation, and principal component analysis using IBM, SPSS 22 software package [26].

3. Results and Discussions

3.1. Analysis of Groundwater and Surface water of the Indus Delta

Statistical summary of concentrations of arsenic, TDS, and chloride in groundwater and surface water of the Indus delta is given in Table 1.

Table 1. Statistical summary of concentrations of arsenic, TDS, and chloride in groundwater and surface water of the Indus Delta

Parameter	Unit	Minimum	Maximum	Average	Mode	STD	CI
(a) Groundwater							
Arsenic	µg/L	---	200	12.2	---	28.7	4.20
TDS	mg/L	203	17664	1281	384	818.3	165.6
Chloride	mg/L	131.2	6274.7	1136.1	257.15	910.3	133.1
(b) Surface water							
Arsenic	µg/L	---	25	4	---	7	2
TDS	mg/L	378	38, 272	9,590	19,328	9,657	2,650
Chloride	mg/L	440	17,406	2197	---	3,300	905.7

3.1.1. Arsenic

The analysis revealed that arsenic concentration in groundwater samples ranged up to 200 µg/L (micrograms per liter). Overall, about 18% of the groundwater samples possessed higher values of arsenic. Groundwater collected from some areas of union councils (small administrative areas) of Jango Jalbani, Goonghani, Chuchar Jamali, Kinjhar, Ladyoon, Jhoke Sharif, Darro, Laiqpur, Banoo, Darya Khan Sohu, Mirpur Bathoro, Sahibani, Bachal Gugo of district Sujawal was found contaminated with higher values of arsenic. Whereas, groundwater collected from Garrho, Buhara, Mirpur Saakro, Sukhpur, Kotri Allah Rakhio Shah, Karampur, Ghullamullah, Keti Bandar, Chhato chand union councils of district Thatta was found contaminated. The arsenic concentrations in the groundwater of the study area were mapped spatially (Figure 4a) using the GIS spatial interpolation technique to provide guidance to the local communities.

However, arsenic concentration in surface water samples ranged up to 25 µg/L. The arsenic concentration in the 10 (20%) out of 50 sampled surface 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. Das et al. [27] reported that arsenic contaminated water is highly toxic to human health, and causes heart, cardiovascular, liver, ocular, and neuropathies diseases. The higher levels of arsenic in the water resource of some areas of the Indus delta is an alarming situation for the people who use such toxic water to fulfil their domestic needs. Husain et al. [13] have reported the presence of arsenic in groundwater of coastal areas of Sindh, Pakistan. Baig et al. [16] have also reported about the presence of arsenic in groundwater of Sindh province of Pakistan.

3.1.2. Total Dissolved Solids

Total dissolved solids (TDS) is the main parameter used to describe the suitability of water for various purposes, such as drinking, agriculture, as well as industrial uses, etc. The analysis revealed that the TDS concentration in the groundwater of the study area ranged from 203 to 17, 664 mg/L with a mean value of 1,281±818.3 mg/L. However, its concentration in the sampled surface water bodies ranged between 378 and 38,272 mg/L with a mean value of 9,590±2,650 mg/L. Overall, about 87%, and 92% of the groundwater, and surface water samples possessed higher values of TDS respectively. Patil et al. [28] reported that the TDS concentration in drinking water beyond the permissible limits gives an unpleasant taste to water, causes gastrointestinal irritation in the human body. Whereas, Adamu [29] reported that as per FAO [30] guidelines, the water having TDS 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 [29]. Ewaid [31] reported that water containing more than 500 mg/L of TDS is not comfortable for drinking water supply. 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. Memon et al. [17] have reported high concentrations of TDS in groundwater and surface water of three districts of Southern Sindh province of Pakistan, i.e., Badin, Thatta, and Tharparkar. Alamgir et al. [20], Khuhawar et al. [26] have reported higher values of TDS in groundwater of coastal areas of Sindh, Pakistan. The spatial distribution of TDS in groundwater of the Indus delta is portrayed in Figure 4b.

3.1.3. Chloride

The analysis revealed that the chloride (Cl) concentration in the groundwater varied between 131 to 6,275 mg/L with an average of 1,136±133 mg/L. However, its concentration in the surface water varied between 440 to 17,406 mg/L with an average of 2,197±906 mg/L. As per WHO [10] guidelines, the allowable limit of chloride concentration for drinking water is 250 mg/L. In this regard, about 94% of the groundwater and 56% of the surface water samples possessed higher values of chloride.

The higher concentration of chloride increases the corrosive nature of water, adversely affects human health, and causes eye and nose irritation, and stomach problems [28]. The irrigation water having chloride concentration higher than 350 mg/L causes severe problems for most of the crops [32]. Based on this criterion, most of the sampled waters could not be used for agriculture purpose. Karanth [33] reported that rainwater contains lower values of chloride, whereas, its concentration increases in groundwater of desert tracts, and coastal areas. The exceptional high levels of chloride in the sampled water are attributed to subsurface seawater intrusion in the delta [34]. Figure 4c portrays the spatial distribution of chloride concentrations in groundwater of the Indus delta. Khuhawar et al. [26] have reported higher concentrations of chloride in water collected from the Ramsar site of Sindh, Pakistan. Our results of chloride concentration in the groundwater are also in agreement as reported by Alamgir et al. [20] for groundwater of the Thatta district of Sindh, Pakistan.

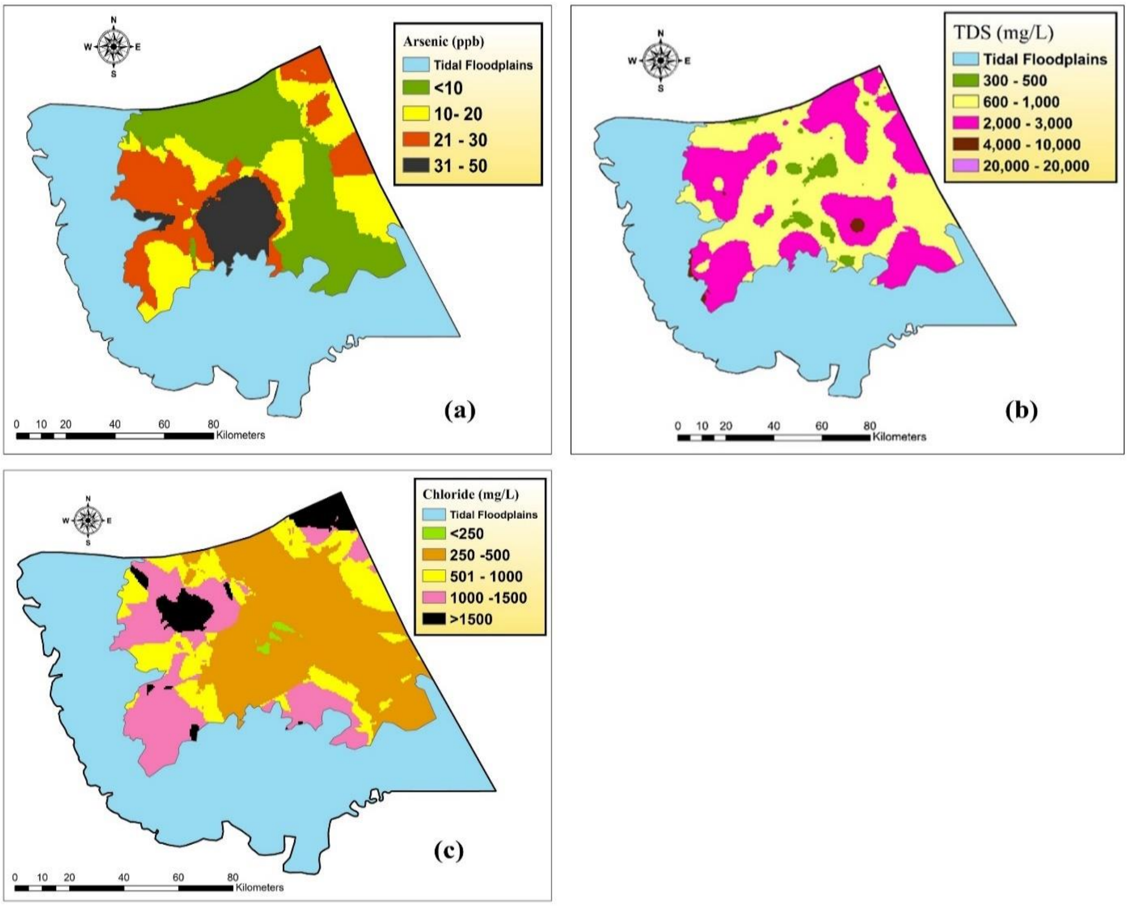

Figure 4. Spatial Distribution of Arsenic (a) TDS (b) Chloride (c) in Groundwater

Percentage of the groundwater and surface water samples possessed higher values of arsenic, TDS, and chloride comparison to WHO guidelines are described in Figure 5.

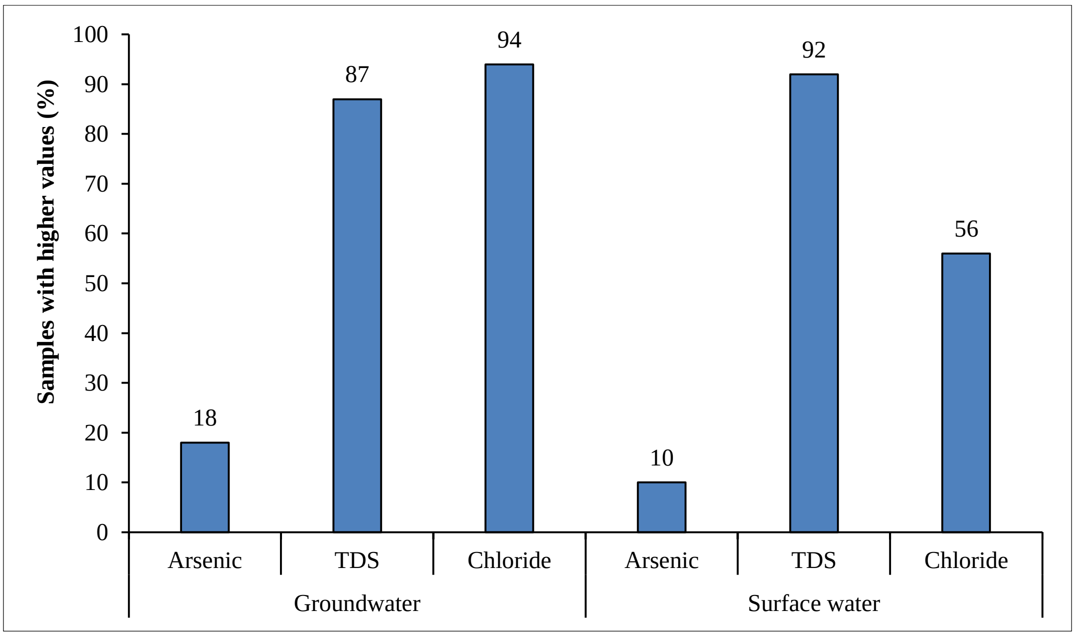

Figure 5. Percentage of GW and SW Samples having higher values of As, TDS, and Cl

Figure 5 shows that 18%, 87%, and 94% of the groundwater, and 10%, 92%, and 56% of the surface water samples possessed higher values of As, TDS, and Cl, respectively. Most of the area of the Indus delta has unsuitable water for domestic, and agricultural uses. Hence, water should be properly treated before its use for domestic and agricultural uses.

3.2. Statistical Analysis

3.2.1. Pearson Correlation Analysis

The Pearson linear correlation matrix [35] was developed between three water quality parameters, i.e., arsenic, TDS, and chloride using SPSS IBM Statistics 22 software package. The coefficient of correlation (R^2) among the analyzed parameters is described in Table 2. The analysis revealed a significant trend between observed concentrations of TDS and Cl for groundwater and surface water with a coefficient of determination $R^2 = 0.58$, and 0.62 respectively. However, a non-significant trend was observed between TDS and arsenic, chloride and arsenic for both groundwater and surface water.

Table 2. Pearson correlation analysis between As, TDS, and Cl in (a) Groundwater, and (b) Surface water

(a) Groundwater				
		TDS	**Cl**	**As**
Correlation	**TDS**	1.00		
	Chloride	0.58	1.00	
	Arsenic	-0.44	0.03	1.00
(b) Surface water				
Correlation	**TDS**	1.000		
	Chloride	0.62	1.00	
	Arsenic	-0.36	0.09	1.00

3.2.2. Principal Component Analysis

Principal component analysis (PCA) is a method of data reduction [36]. In this study, PCA was carried out with IBM, SPSS 22 software package. Khuhawar et al. [26] have reported this software as one of the powerful tools that explain the variance of a larger dataset of inter-correlated variables with a smaller set of independent variables. It requires a large number of datasets and performs calculations based on a raw data, correlation calculation matrix. Generally, it is assumed that in PCA, each data set does not possess any measurement error, however, total variance is determined based on the original matrix. Table 3 portrays that for the present study, the eigenvalues of factor variables were greater than unity. The initial eigenvalues for groundwater data were 37.597, 32.739, and 29.664% of the variance. However, initial eigenvalues for surface water data were 50.601, 30.504, and 18.895% of the variance. The cumulative percentage of extraction sums of squared loadings for groundwater and surface water were 37.597%, and 50.601 of the variance, respectively.

Table 3. Analysis results of total variances based on principal component analysis for (a) Groundwater, and (b) Surface water

Total Variance Explained for (a) Groundwater						
Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	1.128	37.597	37.597	1.128	37.597	37.597
2	0.982	32.739	70.336			
3	0.890	29.664	100.000			
Total Variance Explained for (b) Surface water						
1	1.518	50.601	50.601	1.518	50.601	50.601
2	0.915	30.504	81.105			
3	0.567	18.895	100.000			

4. Conclusion

In the present study, the suitability of the groundwater and surface water of the Indus Delta, Pakistan was analyzed for domestic and irrigation purposes. The analysis revealed that arsenic concentration in ground and surface water samples ranged up to 200, and 25 µg/L. Similarly, the TDS concentration in the groundwater ranged from 203 to 17, 664 mg/L. However, the TDS in the sampled surface water bodies ranged between 378 and 38,272 mg/L. The Cl concentration in groundwater varied between 131 and 6,275 mg/L. Similarly, the chloride concentration in the surface water varied between 440 to 17,406 mg/L. Overall, about 18%, 87%, and 94% of the groundwater, and 10%, 92%, and 56% of the surface water samples possessed higher concentrations of As, TDS, and Cl, respectively. The exceptional higher levels of chloride in the samples are attributed to subsurface seawater intrusion in the delta. Analysis results and GIS mapping of water quality parameters revealed that in most of the study area, the quality of water is not suitable for drinking and agricultural uses, thus it proper treatment before its use is recommended. Reduction of freshwater flow in the study area and resulting seawater intrusion from the neighboring Arabian Sea in the study area are the potential causes of contamination of this precious resource of the area.

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6. Conflicts of Interest

The authors declare no conflict of interest.

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