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Evaluation of drinking water quality using the water quality index (WQI), the synthetic pollution index (SPI) and geospatial tools in Thatta district, Pakistan

Ghulam Shabir Solangi[a,*], Altaf Ali Siyal[a], Muhammad Munir Babar[a], Pirah Siyal[b]

[a] *U.S.-Pakistan Center for Advanced Studies in Water (USPCAS-W), Mehran University of Engineering and Technology, Jamshoro, Pakistan, Tel. +92 3013617394, email: solangi_shabir@yahoo.com (G.S.Solangi), Tel. +92 3353340405, email: aasiyal.uspcasw@faculty.muet.edu.pk (A.A. Siyal), Tel. +92 301504344, email: mmunirbabar.uspcasw@faculty.muet.edu.pk (M.M. Babar)*

[b] *National Centre of Excellence in Analytical Chemistry, Jamshoro, Pakistan, email: pirahaltaf@chemist.com (P. Siyal)*

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ABSTRACT

The objective of the present study was to evaluate the quality of groundwater in the deltaic region of the Indus River in district Thatta, Pakistan. In the region, the groundwater is widely used for drinking purposes. Due to excessive abstraction rates of groundwater, a significant amount of seawater intrudes into the aquifers. The situation is, furthermore aggravated by dwindling flows of freshwater from the river Indus. Thus, groundwater samples (100) were analyzed for different physicochemical parameters. A number of water quality parameters crossed the WHO guidelines. The WQI model revealed that 8%, 57%, 20%, and 15% of the samples were good, poor, very poor and unsuitable for drinking purposes, respectively. Likewise, the SPI model indicated that 10%, 55%, 19%, and 16% were slightly polluted, moderately polluted, highly polluted and unsuitable for drinking. Though the model's input is different, the proportionate of ranking revealed a significant correlation (R^2 = 0.78) between the outcomes of both models. The geospatial mapping of physicochemical parameters, WQI, and SPI model outcomes indicated that most of the groundwater resource in the study area is contaminated, thus not suitable for drinking purposes. The methodology developed in this study is extendable to other similar environments in the world.

Keywords: Coastal aquifers; Arsenic; Spatial analysis; Water quality index models; Factor and principal component analysis

1. Introduction

Elsewhere in the world and Pakistan, groundwater is one of the critical resource extensively used for drinking, irrigation and industrial purposes. According to Alamgir et al. [1], in Pakistan, more than 90% of the total water withdrawal is used for irrigation purposes. Lashari et al. [2] reported that in the country, about 60–70% of domestic water demands are met through groundwater resources. Due to increasing pressure on water supplies, groundwater pollution issues are also growing in many areas of the world [3,4]. The situation is worsening in under developing countries like Pakistan, where most of the people use contaminated drinking water. UNICEF and WHO [5] reported that about 2.5 billion people living in under developing countries do not have proper sanitation facilities, whereas, about 780 million people have no access to safe drinking water. As a result, about 2.3 billion people across the world are suffering from water-related diseases [6]. According to Amin et al. [7], about 70% of the rural population in Pakistan have no access to safe drinking water. As a result, patients suffering from water-related diseases occupy about 20–40% of the beds in the hospitals, and one-third of all deaths in the country occur due to use of contaminated water [8]. In the country, every year, about 39,000 children die due to waterborne diseases [9]. To control and mitigate water-related diseases, assessment and monitoring of drinking water quality are essential. This article focusses on the assessment

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*Corresponding author.

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of the groundwater quality in the deltaic region of the Indus River in district Thatta of Sindh province. In the region, the groundwater is widely used for drinking and irrigation purposes. Due to excessive withdrawal of groundwater, a significant amount of seawater intrudes into the aquifers. The situation is aggravated furthermore by dwindling flows of freshwater from the river Indus and diminishing precipitation rates due to climate change effects [10].

Several researchers have conducted studies to depict the correlation between various water quality parameters [11]. However, Ebrahimi et al. [12] reported that, since the quality of drinking water is contaminated by various factors, hence its quality must be assessed by using specific standards. The water quality index (WQI) is a mathematical tool [13], which converts a complex number of environmental parameters into a single term representing the overall status of the water quality [14]. Hence, instead of traditional methods of water quality assessment, the WQI serves as an effective tool for managing and evaluating the overall quality of water. It is considered as one of the beneficial, powerful and rapid tools for assessing the quality of water resources in a single term. Various researchers [15–21] have applied different types of water quality index models for evaluation of water quality. Geographic information system (GIS) is also a powerful computer-aided tool used for spatial analysis of water quality data [11]. It is also used around the world by many researchers such as El-Hoz et al. [11]; Shabbir and Ahmad [15]; Sener et al. [18]; Arulbalaji and Gurugnanam [19]; Solangi et al. [22]; Abbasnia et al. [23] to delineate the spatial variations in the quality of ground and surface water.

The review of the literature indicated that, so far, only a few studies for groundwater quality assessment of coastal areas of Sindh, Pakistan have been carried out [24–27]. A radiological assessment of water samples and marine sediments of the Karachi coast is reported by Qureshi et al. [28]. Alamgir et al. [1] reported that groundwater is unsuitable for human consumption in coastal regions of Pakistan. Memon et al. [29] reported about drinking water contamination in the Southern districts of Sindh province of Pakistan. Kalhoro et al. [30] and Zia et al. [31] reported about seawater intrusion into the aquifers of deltaic areas of Pakistan. Recently Khuhawar et al. [27] assessed water quality of seven sampling stations of the Indus Delta and reported about contamination of most of the sampling stations. However, some studies are focused only on physicochemical parameters while in other studies only the biological parameters in groundwater are observed. These studies, however, do not consider the entire district but rather a part of it. However, detailed studies on the status of groundwater quality of Thatta district by the application of WQI models and geospatial tools are still lacking.

The present study was thus designed to evaluate the quality of groundwater in the entire district of Thatta. The methodology consists of randomly collecting groundwater samples from the already existing boreholes and hand pumps in the study domain. All the water samples were analyzed for different physicochemical parameters using standard procedures. The results obtained for physicochemical parameters are compared with WHO guidelines available for potable water. The concentrations of various physicochemical parameters are also geo-spatially mapped [15] using ArcGIS 10.3 software to identify the vulnerable areas with regard to groundwater quality in the study area. Besides, two types of standard water quality index models, i.e., water quality index (WQI) and synthetic pollution index (SPI) [32–34] are used to evaluate the groundwater quality from the perspective of human health. Using descriptive statistics, Pearson correlation, factor, and principal component, the water quality data were statistically analyzed. The results obtained from the study shall be useful for policymakers, executive government agencies and private sectors for adopting remedial measures.

2. Materials and methods

2.1. Study area

The study area comprises of entire terrain of the district Thatta. The region lies between longitudes of 67°08′58″ to 68°20′59″ and latitudes of 23°56′55″ to 25°26′40″, is located in southernmost part of the Sindh province of Pakistan. The study area is located on the right-hand side of river Indus, and from the south-west, the boundary of the study area meets the Arabian Sea. Thatta district (study area) and its neighboring district; Sindh province; Pakistan and its neighboring countries are shown in Figs. 1a, b, c, respectively. In the area, the average annual rainfall is about 220 mm, while temperature ranges between 23.8–28.7°C [22,30]. In the area, the groundwater is the primary source of potable water, which is contaminated gradually due to seawater intrusion. Most of the areas of the district are near to the coast of Sindh, and topmost layer is composed of sand (about 15 m), followed by clay and bedrock that belongs to lower Goru formation of early Cretaceous period [1]. The predominant source of groundwater recharge is the Indus River. Geomorphologically, a shallow aquifer system exists in the area that may have a variable thickness, as it is common in neighboring district Sujawal and its sub-district (Jati) [35]. The recharge to the aquifers received through precipitation is very low [1]. The major source of recharge is the Indus River, which remains most of the time dry below the Kotri Barrage (a last barrage before the district) due to the construction of dams, reservoirs and hydropower projects on its upper side [10,27]. As a result, a significant amount of seawater intrudes into the aquifers converting fresh aquifers into saline. Due to seawater intrusion into the area, socioeconomic conditions of the local communities are under constant threat. Fisheries and agriculture are the primary sources of livelihood of the area. Agriculture thrives on irrigation water, which is met through surface and ground waters.

2.2. Groundwater sampling and water quality parameters

In the study area, in total, one hundred samples of groundwater were collected at various points. The samples were collected randomly from the hand-pumps and boreholes that already existed in the area (Fig. 2a). During sampling, all sampling points were geo-referenced. All the water samples were analyzed for different physicochemical properties, viz. pH, electrical conductivity (EC), turbidity (TUR), total dissolved solids (TDS), calcium (Ca), magnesium (Mg),

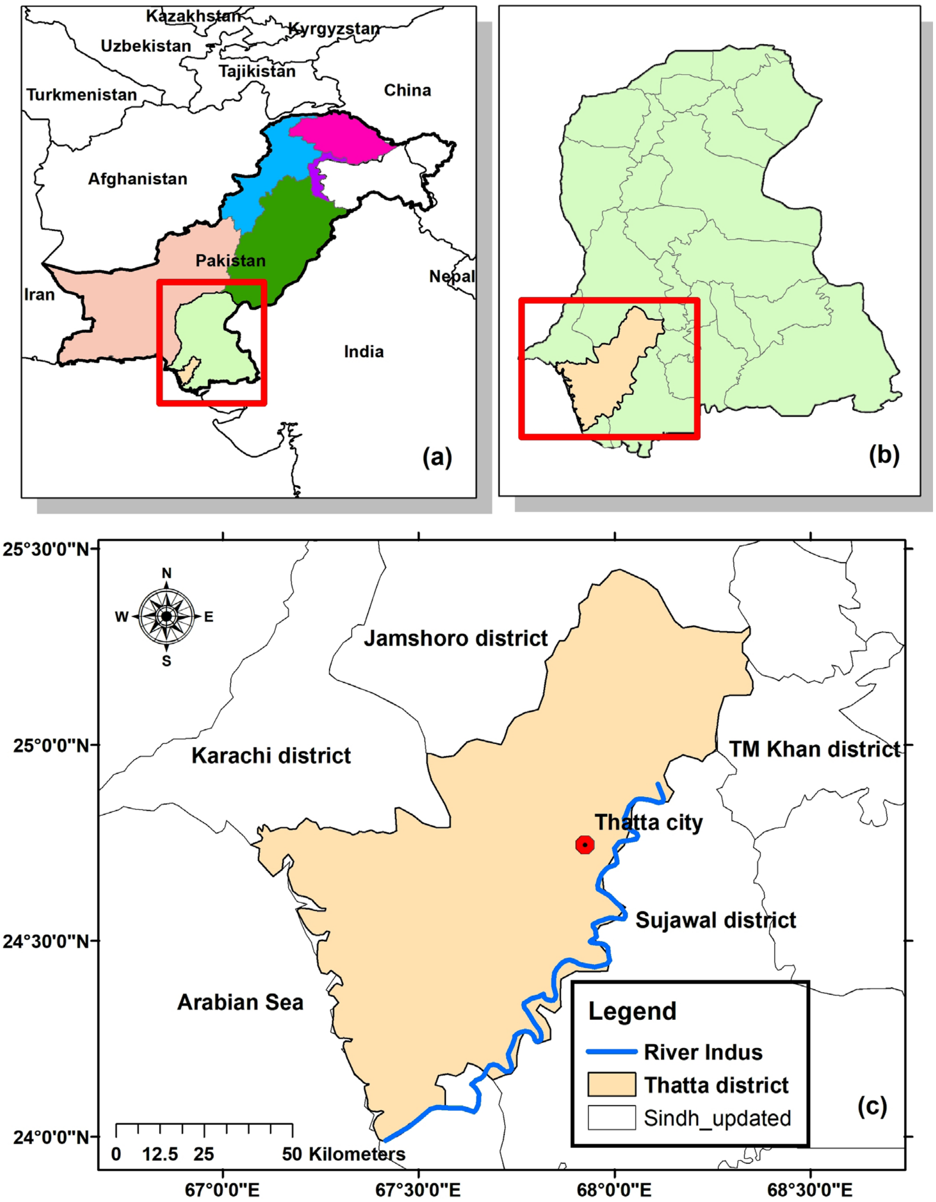

Fig. 1. Location map of district Thatta (Study Area).

total hardness (TH), chloride (Cl), and arsenic (As) using standard procedures. The groundwater samples were collected in one-liter polythene bottles by observing standard sample collection methods. The bottles were washed and rinsed properly with distilled water to remove any possible contamination [36]. The physicochemical parameters, such as TUR, EC, pH, and TDS were observed in situ [37,38] using turbidity, EC, pH, and TDS meters, respectively. However, Ca, Mg, TH, and Cl were determined in the laboratory using the titration method [15], whereas arsenic was determined using Merck arsenic kit [36]. The results obtained for physicochemical parameters were compared with WHO [39] guidelines available for potable water. The statistical summary of observed concentrations of various physicochemical parameters is presented in Table 1. The concentrations of various physicochemical parameters are also mapped spatially using ArcGIS 10.3 software to indicate the vulnerable areas with regard to quality of water in the area.

2.3. Assessment of water quality based on water quality index models

A water quality index model is an important and accepted tool to assess the overall quality of water [15,18]. It synthesizes the composite effect of various water quality parameters in a simple and single reproducible number [40,41]. The literature reveals that it is hard to simplify the quality of water with a specific water quality model [15]. Thus, in the present study, two standard water quality models, namely, the water quality index (WQI) and the synthetic pollution index (SPI) models were used. At present, these

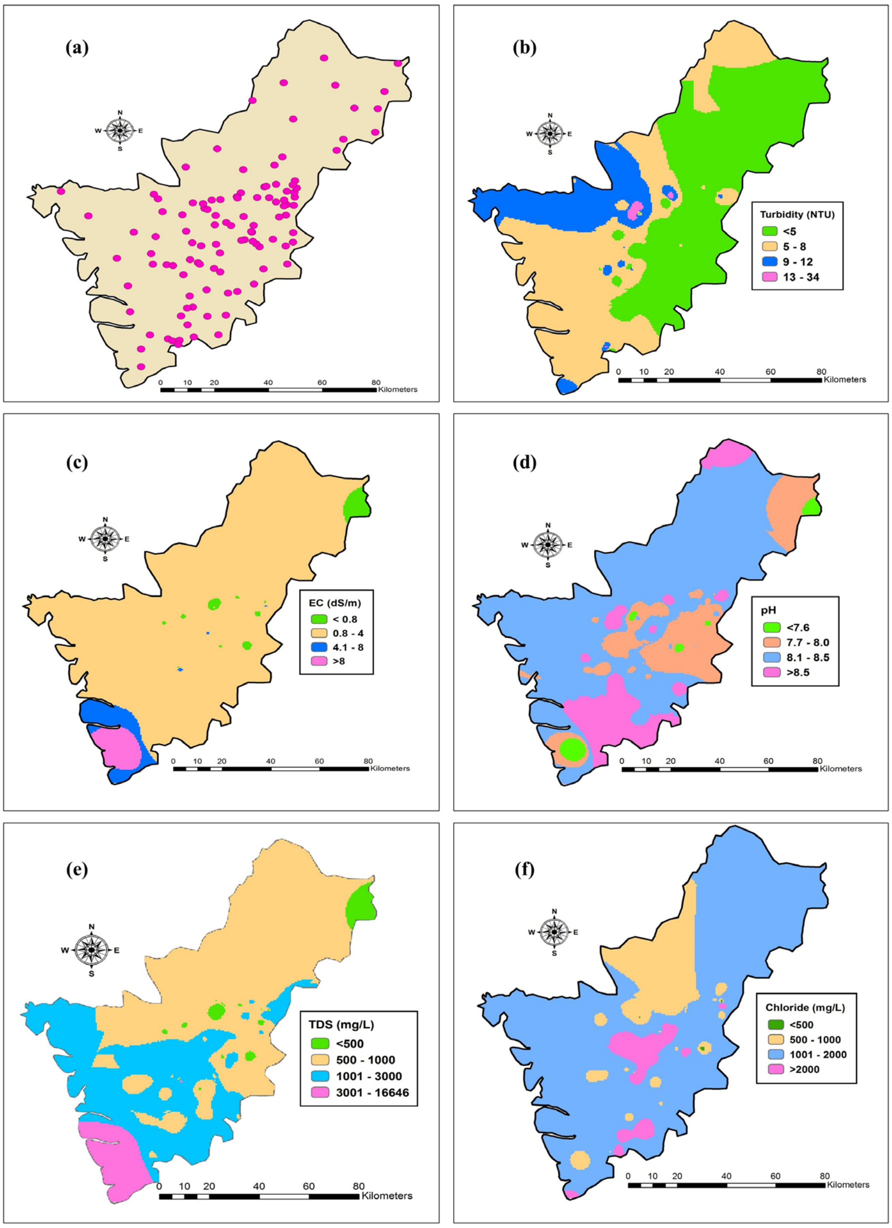

Fig. 2. Spatial distribution of sampling points (a), TUR (b), EC (c), pH (d), TDS (e), Cl (f).

Table 1
Summary of various physicochemical parameters for groundwater samples

Parameter	TUR	EC	pH	TDS	Cl	Ca	Mg	TH	As
Permissible range	5 NTU	0.75 dS/m	8.5	1000 mg/L	250 mg/L	75 mg/L	50 mg/L	500 mg/L as $CaCO_3$	10 µg/L
Minimum	0.5	0.5	6.8	304	372.2	33.6	24	56.6	–
Maximum	34.1	26.1	8.9	16704	6274.7	683.2	755.8	883.2	150
Average	5.4	2.4	8.2	1517.3	1504.6	162.9	155.5	216.3	11.7
Mode	9.6	1.2	7.6	768	584.9	96.0	68.2	164	–
SD	5.4	3.33	0.42	2130.6	1095.6	125.2	25.1	124.5	27.4
CI	1.4	0.84	0.11	539.1	277.2	31.6	6.35	31.5	6.9
SE	0.7	0.43	0.05	275.1	141.4	16.2	3.24	16.1	3.5

models are widely used to evaluate the quality of water around the globe [36].

2.3.1. WQI model

While developing the WQI model, each of the physicochemical parameter specified in section 2.2 was assigned a numerical value (weighting factor). The value of the weighting factors (w_i) was assigned in line with the undesirable impact of a physicochemical parameter on human health [15,20]. For instance, arsenic was assigned the highest weighting factor, i.e., 5, while, for the rest of the parameters, the value of weighting factor varied from 2 to 5. The steps outlined below were used to compute the WQI.

Step 1: Relative weight (W_i):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (i = 1, 2, 3, \ldots\ldots, n) \qquad 1)$$

where w_i is the numeric value of a weighting factor assigned to an i^{th} physicochemical parameter and n is the total number of physicochemical parameters analyzed under this study.

By using Eq. (1), the relative weights (W_i) calculated for each physicochemical parameter are presented in Table 2.

Step 2: Water quality rating (q_i):

$$q_i = \frac{C_i}{S_i} \times 100 \quad (i = 1, 2, 3, \ldots\ldots, n) \qquad (2)$$

where C_i is the concentration observed for an i^{th} physicochemical parameter, S_i is the threshold value for an i^{th} physicochemical parameter as per WHO [39] guideline for potable water and n is the total number of physicochemical parameters analyzed under this study.

Step 3: Water quality index (WQI):

$$WQI = \sum W_i \times q_i \quad (i = 1, 2, 3, \ldots\ldots, n) \qquad (3)$$

Based on the WQI, generally, the water quality is classified into five categories, i.e., excellent, good, poor, very poor, and unsuitable. If the WQI value, is less than 50, ranges from 50–100, 100–200, 200–300, and, is greater than 300, then, the quality of water is rated as excellent, good, poor, very poor, and unsuitable, respectively [19,40].

Table 2
Relative weights (W_i) for each physicochemical parameters

Parameters	WHO guidelines	Weight (w_i)	Relative weight (W_i)
TDS	1000	3	0.12
Cl	250	3	0.12
As	0.01	5	0.2
Ca	75	2	0.08
Mg	50	2	0.08
TH	500	2	0.08
TUR	5	2	0.08
pH	8.5	3	0.12
EC	0.8	3	0.12
Σ		25	1.00

2.3.2. SPI model

The derivation and calculation of SPI involve, the steps outlined below [16,36]:

Step 1: Constant of proportionality (K_i):

$$K_i = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}} \quad (i = 1, 2, 3, \ldots\ldots, n) \qquad (4)$$

Step 2: Weight coefficient (W_i):

$$W_i = \frac{K_i}{S_i} \quad (i = 1, 2, 3, \ldots\ldots, n) \qquad (5)$$

Step 3: Synthetic pollution index (SPI):

$$SPI = \sum_{i=1}^{n} \frac{C_i}{S_i} \times W_i \quad (i = 1, 2, 3, \ldots\ldots, n) \qquad (6)$$

In Eqs. (4), (5) and (6), S_i is the threshold value for an i^{th} physicochemical parameter as per WHO [39] guidelines and n is the total number of water quality parameters considered for analysis.

Likewise WQI, on the basis of SPI, the water quality is classified into five categories, viz. suitable, slightly polluted, moderately polluted, highly polluted, and unsuitable. If the SPI value, is less than 0.2, ranges from 0.2–0.5, 0.5–1.0, 1.0–3.0, and, is greater than 3.0, then, the water quality is rated as suitable, slightly polluted, moderately polluted, highly polluted, and unsuitable for drinking purposes, respectively [16,34].

In this study, the results of various physicochemical parameters such as TUR, EC, pH, TDS, Ca, Mg, TH, Cl, and As were used for calculation of both models.

2.4. Statistical analysis

Basic descriptive statistics such as the minimum, maximum, average values, mode, standard deviation (SD), confidence interval (CI), and standard error (SE) for each of the water quality parameters were calculated. Correlations between various physicochemical parameters, water quality index models were calculated using MS Excel 2013 [27]. For data reduction and validation, multivariate statistical techniques such as factor and principal component analyses were also made using IBM SPSS Statistics 22 software package.

3. Results and discussion

3.1. Analysis based on physicochemical parameters

Turbidity is the measure of the relative clarity of the water. Organic and inorganic matters such as clay, silt, algae, colored compounds make the water turbid. Turbidity provides food and shelter to various bacteria and pathogens, thus enhances the growth rate of pathogens in water distribution systems. Turbidity causes waterborne diseases such as gastroenteritis, etc. As per WHO [39] guidelines, the maximum permissible level of turbidity in potable water is 5 NTU; whereas, in the study area, the turbidity in groundwater was observed to vary from 0.5 to 34.1 NTU with a mean value of 5.4±5.4 NTU. Fig. 2b shows the spatial distribution of turbidity in groundwater in the study area. Higher turbidity levels in groundwater of some areas of the district are likely due to the use of poor quality strainer filter material in the suction line [22]. The high turbidity in the groundwater in the study area is similar to levels of turbidity found in the Southern districts of Sindh province of Pakistan by Memon et al. [29].

The EC is the measure of the conductance of electrical current through an aqueous solution [19]. It exhibits the concentration of TDS into the water and is the primary parameter generally used for assessment of the suitability of water for various purposes, such as for drinking, agriculture, and industrial purposes, etc. In the study area, the magnitude of EC for the water samples varied from 0.5 to 26.1 dS/m with a mean value of 2.4±3.3 dS/m, whereas, the allowable limit of EC for potable water as per WHO guidelines is 0.75 dS/m. The higher values of EC in groundwater are attributed to seawater intrusion into the aquifers from the neighboring Arabian Sea. The spatial distribution of EC in the study area is presented in Fig. 2c. Possible reasons for higher concentrations of the EC in the groundwater of the district might be low rainfall, high evaporation rate, higher abstraction than recharge, and the intrusion of saline water from the Arabian Sea into the region. Memon et al. [29] reported a similar trend of EC concentrations in the groundwater of Southern districts of Sindh province of Pakistan.

The pH indicates acidity or alkalinity extent in water. Excess of pH value in potable water may cause nausea, vomiting, etc. [42]. As per WHO guidelines, the safe range of pH value for potable water is 6.5–8.5. From the data, it was observed that the pH value in the study area ranged from 6.8 to 8.9 with a mean value of 8.2±0.42. Fig. 2d shows the spatial distribution of pH; thus, in most of the areas, the pH value is identified to vary within the permissible range. The results of pH are in agreements with Alamgir et al. [1] for groundwater of coastal areas of Sindh, Pakistan. The findings of Khuhawar et al. [27] about pH values in the groundwater of coastal areas of Sindh, Pakistan are in line with the present study.

The concentration of TDS is one of the primary parameters used for the assessment of water quality. TDS in water occurs due to the presence of dissolved organic and inorganic substances [43]. According to WHO [39] guidelines, permissible limit of TDS for potable water is 500 mg/L. In the study area, TDS were observed to vary from 450 to 16704±2130.5 mg/L with a mean value of 1517 mg/L. The maximum value of TDS was observed in Keti Bandar area, which is also in close proximity of the Arabian Sea. Seawater intrusion and increased concentration of dissolved solids are the responsible factors for a higher level of TDS in the area [44]. Fig. 2e depicts that in most of the areas of the study region, TDS are higher than the permissible limit. Husain et al. [45] and Alamgir et al. [1] reported higher concentrations of TDS in the groundwater of deltaic areas of Pakistan. Khuhawar et al. [27] also described the higher values of TDS in the groundwater collected from Keti Bandar, a coastal area of Sindh province of Pakistan.

Chloride is one of the minor constituent found in the earth's crust; however, it is a major dissolved constituent in most of the natural waters [19]. As per WHO [39] guidelines, the acceptable level of Cl concentration for potable water is 250 mg/L. In rainwater, normally the Cl is less than 10 mg/L, whereas in coastal and desert areas its magnitude is much higher [44,46]. In the study area, the amount of Cl ranged between 372 and 6275 mg/L with an average value of 1505±1095.6 mg/L. Fig. 2f shows that in most of the areas, the Cl concentration is higher than the permissible limit suggested by the WHO [39]. The higher concentration of Cl is attributed to seawater intrusion from the neighboring Arabian Sea. Alamgir et al. [1] and Khuhawar et al. [27] reported higher values of Cl in the groundwater of coastal areas of Pakistan.

The Ca concentration in the groundwater samples was observed to vary from 34 to 683 mg/L with an average value of 163±125.2 mg/L, while the maximum permissible limit for Ca concentration is 75 mg/L. The spatial distribution of Ca concentration in the study area is presented in Fig. 3a. The permissible level of Mg concentration for potable water is 50 mg/L. In the water samples analyzed under this study, the Mg concentration varies from 24 to 756 mg/L with an average value of 156±25.1 mg/L. The higher level of Mg concentration is possibly due to the inherent geological formation. Fig. 3b depicts the spatial distribution of Mg concentration.

The total hardness (TH) is the measure of the presence of excessive quantities of Ca and Mg in water. According to the WHO [39] guidelines, the permissible level of hardness in water is 500 mg/L. If the TH, is less than 75 mg/L, vary between 75–150, 150–300 and, is greater than 300 mg/L; the quality of water is categorized as soft, moderately hard, hard, and very hard, respectively [47]. In the present study, the TH varied from 57 to 883 mg/L as $CaCO_3$ with an average value of 216±124.5 mg/L as $CaCO_3$. Of the total water samples collected under the study, about 3%, 26%, 60% and 11% of the samples were identified as soft, moderately hard, hard, and very hard, respectively. Fig. 3c shows the spatial distribution of TH. Alamgir et al. [1] reported similar results of TH for groundwater in most of the areas of the coastal region of Pakistan. Husain et al. [45], Memon et al. [29] and Khuhawar et al. [27] have reported a similar trend of hardness in the groundwater of Southern districts of Sindh province of Pakistan.

Arsenic is a natural ingredient found in earth's mineral deposits; it is dissolved in groundwater. Arsenic in its inorganic form is extremely toxic to human health; likewise, the drinking water contaminated with As is highly toxic to human health. Its longtime exposure causes cancer, ocular diseases, neuropathies, skin problems, diabetes as well as cardiovascular diseases [48]. According to the WHO [39] guidelines, the maximum permissible level of As for potable water is 10 µg/L. In the study area, about 20% of the groundwater samples were identified as contaminated with arsenic by its range up to 150 µg/L with an average value of 11.7±27.4 µg/L. The areas with a higher level of the As indicated alarming situation for the community who consume such water for domestic purposes. Possible causes of arsenic in groundwater of the district may likely be the nature of geological strata, which contains enough arsenic compounds [45]. The spatial distribution of As con-

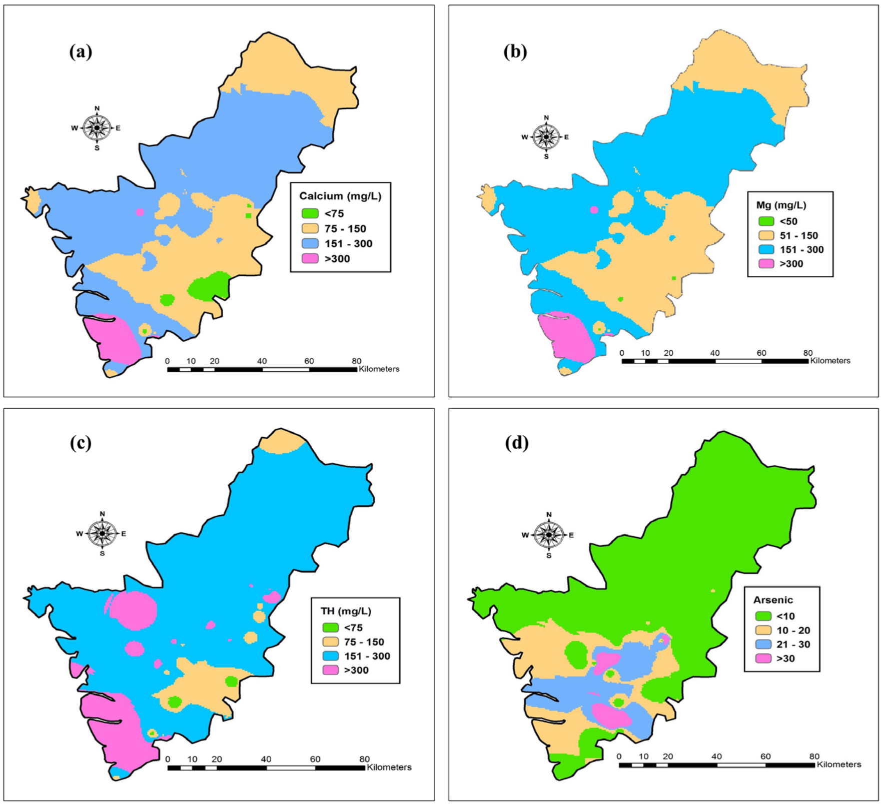

Fig. 3. Spatial distribution raster maps for Ca (a), Mg (b), TH (c), As (d).

centration in groundwater of the study area is depicted in Fig. 3d. Husain et al. [45] reported the presence of arsenic in the groundwater of the deltaic areas of Pakistan. Ahmed et al. [49] and Baig et al. [50] reported that around 16–36% of the population of Sindh province of Pakistan is exposed to higher levels of arsenic in groundwater.

3.2. Analysis based on water quality models

3.2.1. Analysis based on the WQI model

The results obtained through the analysis of water samples for the assessment of groundwater quality and its categorization using WQI model are presented in Table 3. While the spatial mapping of the WQI is displayed in Fig. 4a.

Based on the WQI model, about 8% of the water samples are identified as good, 57% as poor, 20% as very poor and 15% as unsuitable for drinking purposes (Table 3).

3.2.2. Analysis based on the SPI model

The results obtained through the analysis of water samples for the assessment of groundwater quality and its categorization by means of SPI are summarized in Table 4. While the spatial mapping of SPI is presented in Fig. 4b.

Based on the SPI model, about 10%, 55%, 19%, and 16% of the water samples were identified as slightly polluted, moderately polluted, highly polluted, and unsuitable for drinking purposes, respectively (Table 4).

Based on interpolated GIS maps of various water quality indicators, outcomes of both models, it is obvious that groundwater in most of the areas of the study region is not as per drinking water quality guidelines suggested by WHO. The areas near the coast are more affected by water contamination. The intrusion of saline water from the Arabian Sea into the aquifers of the area is one of the potential causes of such contaminations [27].

3.2.3. The relationship between WQI and SPI models

To establish a relationship between the WQI and SPI models [36]; the categories of water indicated by the two models were correlated through regression analysis, Eq. (7). The relationship shows a good correlation between both models ($R^2 = 0.78$).

$$\mathrm{SPI} = 0.9207 \times \mathrm{WQI} + 0.1819 \tag{7}$$

3.3. Statistical analysis of physicochemical parameters

Under the study, the physicochemical parameters were also analyzed using multivariate statistical tests viz. Pearson correlation, principal component, and factor analyses.

3.3.1. Pearson correlation

To identify the relationship between various water quality parameters, Pearson correlation analysis was carried out.

Table 3
Categories of groundwater based on the WQI model results

S. No.	WQI	Class	S. No.	WQI	Class	S. No.	WQI	Class	S. No.	WQI	Class
1	120.1	P*	26	136.6	P	51	289.6	VP	76	105.5	P
2	135.5	P	27	268.9	VP	52	97.7	G	77	245.6	VP
3	157.8	P	28	106.7	P	53	124.7	P	78	108.4	P
4	230.9	VP*	29	237.4	VP	54	159.7	P	79	204.6	VP
5	301.6	US*	30	315.1	US	55	165.2	P	80	103.6	P
6	214.7	VP	31	188.8	P	56	141.8	P	81	156.6	P
7	524.16	US	32	95.8	G	57	227.4	VP	82	167.5	P
8	147.8	P	33	141.6	P	58	308.6	US	83	207.6	VP
9	137.8	P	34	137.3	P	59	124.4	P	84	78.6	G
10	172.7	P	35	94.1	G	60	124.8	P	85	303.6	US
11	120.9	P	36	100.2	G	61	111.4	P	86	106.6	P
12	105.5	P	37	127.9	P	62	134.9	P	87	134.6	P
13	475.52	US	38	155.2	P	63	187.6	P	88	311.5	US
14	224.8	VP	39	122.5	P	64	306.6	US	89	145.6	P
15	140.1	P	40	151.1	P	65	206.7	VP	90	122.7	P
16	510.5	US	41	512.7	US	66	267.6	VP	91	102.4	P
17	153.4	P	42	119.9	P	67	308.2	US	92	306.8	US
18	69.2	G*	43	127.8	P	68	234.5	VP	93	156.5	P
19	225.1	VP	44	1051.1	US	69	167.2	P	94	167.4	P
20	175.4	P	45	112.9	P	70	109.5	P	95	189.7	P
21	141.5	P	46	393.9	US	71	203.5	VP	96	123.6	P
22	162.0	Poor	47	111.6	P	72	67.8	G	97	156.5	P
23	247.3	VP	48	285.9	VP	73	122.5	P	98	105.6	P
24	269.3	VP	49	123.7	P	74	323.5	US	99	122.4	P
25	294.5	VP	50	173.6	P	75	230.5	VP	100	67.7	G

G* = Good, P* = Poor, VP* = Very poor, US* = Unsuitable

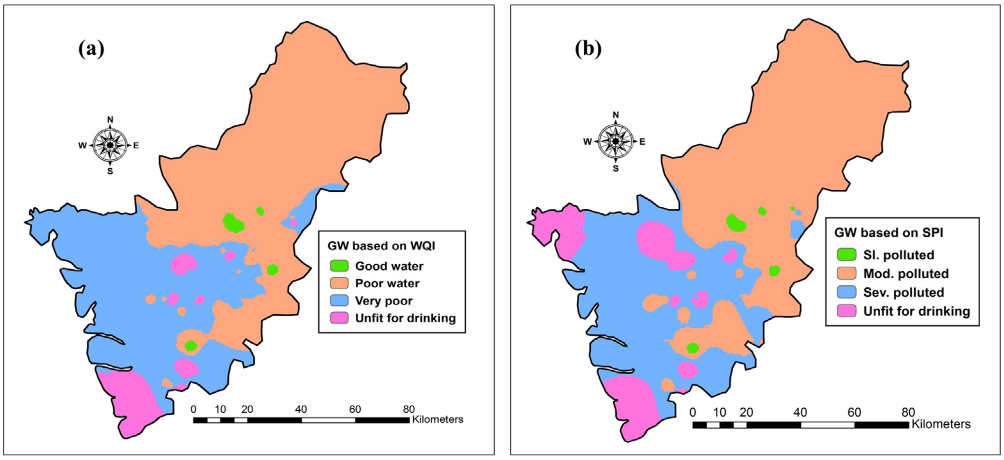

Fig. 4. Spatial distribution groundwater quality maps based on the outcomes of the WQI model (a), and the SPI model (b).

Table 5 presents the summary of such analysis; the analysis shows that the correlation values vary between +1 and –1. The EC shows a strong positive correlation with TDS, while EC and TDS also demonstrate a good positive correlation with Ca and TH. The EC and TDS also show a positive correlation with chloride (0.71). The Ca and Mg also show a strong positive correlation with TH with R^2 value as 0.96 and 0.72, respectively.

3.3.2 Factor and principal component analyses

According to Hoseinzadeh et al. [51], factor analysis (FA) is a technique adopted to extract the latent information about the variables whose relationships are not well defined, while principal component analysis (PCA) is a method of data reduction. In the present study, these tests are performed using the SPSS software. The results of the PCA (Table 6a)

Table 4
Categories of groundwater based on the SPI model results

S. No.	SPI	Class	S. No.	SPI	Class	S. No.	SPI	Class	S. No.	SPI	Class
1	0.51	MP*	26	0.78	MP	51	2.49	HP	76	0.98	MP
2	0.56	MP	27	2.49	HP	52	0.25	SP	77	3.88	US
3	0.89	MP	28	0.72	MP	53	0.93	MP	78	0.54	MP
4	2.87	HP*	29	0.77	MP	54	0.71	MP	79	0.45	SP
5	5.41	US*	30	4.05	US	55	2.02	HP	80	0.98	MP
6	2.77	HP	31	0. 72	MP	56	0.64	MP	81	0.76	MP
7	14.7	US	32	0.37	SP	57	0.66	MP	82	0.91	MP
8	0.58	MP	33	0.87	MP	58	4.10	US	83	3.31	US
9	0. 61	MP	34	0.97	MP	59	0.81	MP	84	0.25	SP
10	0.69	MP	35	0.40	SP	60	0.66	MP	85	6.4	US
11	0.76	MP	36	0.94	SP	61	0.54	MP	86	0.56	MP
12	0.98	MP	37	0.831	MP	62	0.59	MP	87	0.98	MP
13	10.87	US	38	0.59	MP	63	0.91	MP	88	6.92	US
14	2.96	HP	39	0.57	MP	64	5.61	US	89	0.69	MP
15	2.47	HP	40	2.76	HP	65	2.78	HP	90	0.54	MP
16	3.47	US	41	6.09	US	66	2.78	HP	91	0.55	MP
17	0.77	MP	42	0.72	MP	67	2.78	HP	92	5.86	US
18	0.21	SP*	43	0.65	MP	68	3.92	US	93	0.59	MP
19	2.41	HP	44	4.51	US	69	0.87	MP	94	0.57	MP
20	0.53	MP	45	0. 58	MP	70	0.73	MP	95	0.44	SP
21	0.80	MP	46	2.09	HP	71	2.79	HP	96	0.89	MP
22	0. 85	MP	47	0.87	MP	72	0.46	SP	97	0.67	MP
23	2.38	HP	48	2.53	HP	73	0.98	MP	98	0.78	MP
24	2.57	HP	49	0.27	SP	74	5.62	US	99	0.81	MP
25	2.83	HP	50	0.73	MP	75	2.77	HP	100	0.64	MP

SP* = slightly polluted, MP* = moderately polluted, HP* = highly polluted, US* = unsuitable

Table 5
Pearson correlation matrix of physicochemical parameters

Parameter	EC	pH	TUR	TDS	Ca	Mg	TH	Cl	As
EC	1								
pH	–0.28	1.0							
TUR	0.05	–0.06	1.0						
TDS	1.00	–0.28	0.05	1.0					
Ca	0.78	–0.27	0.04	0.78	1.0				
Mg	–0.19	–0.08	–0.02	–0.19	0.13	1.0			
TH	0.74	–0.29	0.04	0.74	0.96	0.72	1.0		
Cl	0.71	0.21	0.03	0.71	0.05	0.27	0.10	1.0	
As	0.03	0.12	0.10	0.03	0.03	–0.09	0.01	0.07	1

indicated that for first, second, and third components, the extraction sums of squared loadings were 40.56%, 14.57%, and 13.45% of the variance, respectively. These three elements are capable of change. However, extraction sums of squared loadings show that first, second, and third components had 40.1%, 14.0%, and 13.99% of the variance, respectively. Hence, the three components describe 68.10% of the variance for the total data set. Table 6b describes the contributions of each variable to the components.

Factor analysis (Table 6b and Fig. 5) portrays that for the first component, EC, TDS, Ca, TH had the highest loading rates of 0.94, 0.94, 0.93, and 0.91, respectively. For the second component, Mg and Cl had the highest loadings rates of 0.89, and 0.63 respectively. However, for the third component, pH, Cl, and As had the higher loading rates of 0.77, and 0.58, and 0.50 respectively.

4. Conclusion

The present study revealed that about 30%, 85%, 52%, 85%, and 20% of the water samples collected from the study

Table 6a
Analysis results of factor analysis and variances

Component	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	Variance (%)	Cumulative %
1	3.651	40.564	40.564	3.651	40.564	40.564	3.608	40.085	40.085
2	1.311	14.571	55.136	1.311	14.571	55.136	1.263	14.029	54.114
3	1.210	13.449	68.584	1.210	13.449	68.584	1.259	13.990	68.104
4	1.035	11.499	80.083						
5	0.832	9.246	89.329						
6	0.608	6.756	96.085						
7	0.352	3.915	100.000						
8	1.949E-16	2.166E-15	100.000						
9	4.562E-16	-5.069E-15	100.000						

Table 6b
Water quality factor loading matric for groundwater of the Thatta district

Variables	Components		
	1	2	3
EC	0.944	–0.081	–0.008
TDS	0.944	–0.081	–0.008
Ca	0.929	–0.036	–0.099
TH	0.908	0.144	–0.132
Mg	–0.131	0.892	–0.163
Cl	0.194	0.632	0.578
pH	–0.282	–0.060	0.774
TUR	0.011	0.054	–0.135
As	0.051	–0.160	0.504

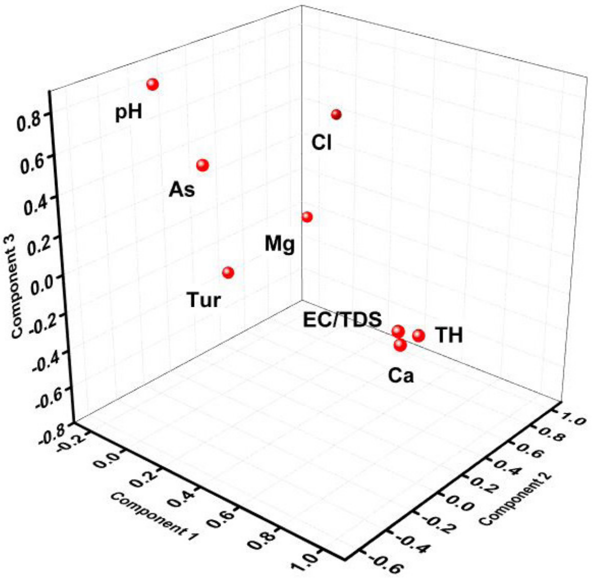

Fig. 5. Three-dimensional plot of three components.

area possess TUR, TDS, Ca, Mg and As concentrations higher than the WHO guidelines, respectively; however, most of the water samples were found as contaminated with Cl. The higher concentration of Cl is probably due to the intrusion of seawater into the aquifers, as most of the area is affected by seawater intrusion. Based on TH data, about 3%, 26%, 60%, and 11% of the water samples were identified as soft, moderately hard, hard, and very hard, respectively. The analysis of water samples based on the WQI model revealed that about 8%, 57%, 20%, and 15% of the water samples were good, poor, very poor, and unsuitable for drinking purposes, respectively. Likewise, the SPI model indicated that about 10%, 55%, 19%, and 16% of the water samples were slightly polluted, moderately polluted, highly polluted, and unsuitable for drinking purposes, respectively. The GIS mapping of spatial concentration and the estimations for water quality parameters based on water quality index models indicated that the most of the groundwater resource in the study area is contaminated, thus not unsuitable for drinking purposes. In general, from the study, it is informed that the quality of groundwater does not conform to drinking water protocols as per WHO guideline. Excessive withdrawal of groundwater and seawater intrusion from the coastal belt are the potential causes of groundwater contamination in the area. Furthermore, the decline in groundwater recharge due to the reduced amount of freshwater flows from the river Indus and diminishing precipitation due to climate change effects have added to the problem of groundwater contamination in the study area. The WQI and SPI models and geospatial tools are effective approaches to provide integral information regarding the overall quality of groundwater as well as surface water bodies. Thus, in the light of the present study, it is concluded that proper treatment of the groundwater is essential for its domestic consumption in the study area.

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