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Groundwater Quality Assessment for Drinking Purpose of Taluka Chachro, Thar Desert, Pakistan; Using Water Quality Indices, and Geospatial Techniques

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Abstract: Groundwater quality of taluka Chachro was investigated by analyzing thirty-two groundwater samples for drinking purpose. Multivariate statistical approaches with GIS interpolations (IDW) were applied for the identification of significant geochemical processes governing the groundwater quality.. Results showed the concentrations of physiochemical parameter in the study area exceeded the prescribed level of WHO guidelines. The EC and TDS varied from 2593-18950 µS/cm and 1659-12128 mg/l, respectively. The Ca, Mg, Na, and K range from 36-288, 17-272, 420-3280, and 9.5-101 mg/l, respectively. While, Cl, HCO_3, SO_4, and NO_3 varied from 539-5738, 210-1150, 79-870, and 6.66-17.13 mg/l respectively. The mean values of EC, TDS, Na, Cl, HCO_3, SO_4, and NO_3 were higher than the prescribed level of WHO 2011. Higher concentrations above the acceptable limits were recorded for K 96.15%, SO_4 88.46%, and HCO_3 82.16% of analysed samples. Multivariate statistical analysis suggested that the input of natural processes have influenced groundwater quality which resulted in changing the groundwater chemistry of taluka Chachro. The results revealed the dominant trend among the cations was Na>Ca>Mg>K while among the anions it was Cl>HCO_3>SO_4. Based on the drinking water quality index 50% were unsuitable for drinking.

Keywords: Thar desert, groundwater, WQI, GIS interpolation, geochemical processes.

Introduction

Groundwater is the major natural resource providing freshwater worldwide. However, due to rapid urbanization, advanced agronomics and irresponsible industrialization practice threaten the quantity and quality of groundwater (Barzegar et al., 2019; Kumar et al., 2020). Quality of groundwater is described with significant technique i.e. water quality index (WQI) for understanding the suitability of groundwater for human consumption (Kumar and Sangeetha, 2020). WQI is illustrated as the ranking scale that reverberates the composite force of various parameters of the quality of groundwater (Siddha and Sahu, 2020). Water Quality inspects the relevance of physical, biological, and chemical properties of water consistent with the intended uses and to the set of standards (Judran and Kumar, 2020). The groundwater quality deteriorated through key pollutants introduced by natural processes (chemical reactions) and anthropogenic activities (Chen et al., 2019; Liu et al., 2020). Among the natural processes, rock-water interactions within aquifer is a key contaminant source (Chen et al., 2019; Umar et al., 2013). Naturally, if the groundwater hold pollutants above the recommended limits of WHO that may cause fatal effects on ecology, crops production, soil fertility, urbanization, industrialization, and economic growth of the area (Khanoranga and Khalid, 2019; Mumtaz, 2017; Umar et al., 2013).

In agriculture, various advanced methodologies such as the application of different brands of fertilizers and pesticides to enhance crop production lead to degradation of groundwater quality. Whereas, inappropriate industrialization and urban waste management without sufficient pretreatment may also impact the groundwater quality (Barakat et al., 2020).

Groundwater quality is evaluated with diverse techniques, like water quality index, ionic ratios, multivariate statistical techniques, and geospatial tools, (Karroum et al., 2017; Singh et al., 2017). Water quality index (WQI) generally explain condition of groundwater resources through shifting water quality parameters amount into numerical value using mathematical approach (Barakat et al., 2020). Among the various water quality indices, the drinking water quality indices (DWQI) was developed to classify water resources used for human utilization (Barakat et al., 2020). Hierarchical cluster analysis (HCA), correlation matrix and principal component analysis (PCA), is a statistical approach applied to organize the complex figures by taking out new uncorrelated elements (Bodrud-Doza et al., 2019; Khanoranga and Khalid, 2019).

In study area the groundwater is a primary source for the drinking, domestic purposes and the economy of this region depends on by keeping animals like camels, goats, sheep, cows and limited agriculture. The prime objective of this study was to understand and identify key factors that deteriorate groundwater quality and the potential threats to residents.

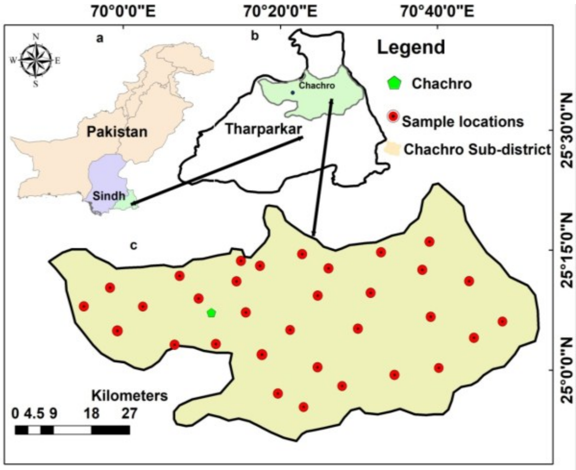

Fig. 1 Location map of the study area and sampling points.

Materials and Methods

Study Area

Research area was taluka Chachro of Tharparkar district has a total geographical area of 4103 km square and 351263, population based on the 2017 census (http://www.citypopulation.de/php/pakistan-distr-admin.php?adm1id=819). Taluka Chachro extends between 24.8521° and 25.389° North latitude and 69.8421° and 70.8815° East longitude. The groundwater is present in dug wells at normal depth of 10 to 100 meters.

Geologically Thar desert consists of sand dunes (Resent deposits) and outcrops of Precambrian rocks of igneous and metamorphic origin known as Nagarparkar igneous complex (NPIC) (Abdul Shakoor et al., 2019; de Wall et al., 2018).It is prosperous in mineral deposits like kaoline and igneous rocks black gold (coal) and salts. These minerals have interaction with groundwater quality and water is saline. Geological study specifies four geological units i.e., sand dune (Recent deposits), sub-Recent (alluvial deposits), Bara Formation of middle Palaeocene age and rocks of Precambrian age known as igneous rocks. Figure 2 represents the general geology of Tharparkar or Thar coalfield (Fassett and Durrani, 1994; Khuhawar et al., 2019; Rafique et al., 2009; Zaigham et al., 2012)

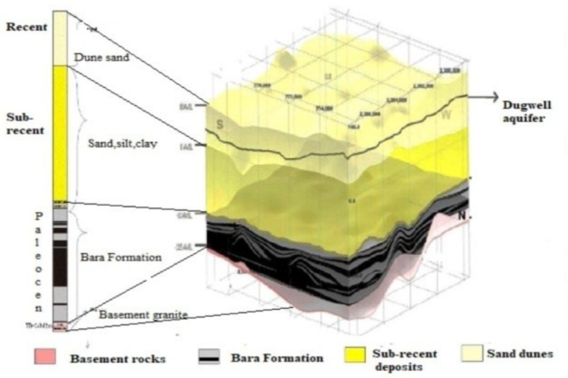

Fig. 2 The 3D geological model and general lithology of the Tharparkar (Butt, 2018; Munir et al., 2018).

Sampling

Thirty-two dug well water samples were taken mainly from various villages of taluka Chachro of district Tharparkar. Collected sample from dug well was defined with identification number (ID), village location, and with latitude and longitude of area using Global positioning system (GPS). Before sample collection the plastic bottles were socked and rinsed in 2% nitric acid overnight to control over contamination, and again three time rinsed with deionised water and were kept in oven for drying. Composite samples were collected by combining the nearest water samples for representing the hole area of water quality regaining geological unit. Some physical parameter, like Ph, temperature, bicarbonates, and conductivity was measured insitu. Each sample was divided into two portions one was used for the measurement of parameters other than the metals and second part was acidified and preserved for the analysis of metal contents in groundwater.

The major ions i.e NO_3 and SO_4 were analysed with an ultraviolet visible (VU-VIS) spectrophotometer (Analytik Jena, Jena, Germany). Whereas, chloride and bicarbonate were analysed with titration method. A flame photometer (PFP7, Cambridge shirre, UK) was used to measure the major cations i.e Na^+, K^+, and Fe, Ca, and Mg were analysed with volumetric titration with ethyl diamine tetra acetic acid (EDTA). Sulphate and nitrate were determined by spectrophotometric method. Arsenic was analysed with atomic absorption spectrophotometer AAS Vario 6 (Analytile Jena, Jena, Germany).

Water Quality Index

The analysis of various water quality parameters, WQI is a significant process for estimating groundwater quality for domestic uses (Adimalla, 2020; Talib et al., 2019).WQI is calculated in four steps by taking into account the major physiochemical parameters like pH, EC,TDS,HCO_3,Cl, SO_4, NO_3,Ca, Mg, Na,K, Fe, Zn, and As. Based upon their impact on quality of water, each studied parameter was allocated weight (gi) (Table 1). Equation (1) used for computation of relative weight (Gi)

$$\boldsymbol{Gi} = wi/\sum_{i=0}^{z} \text{gi} \quad (1)$$

Here, Gi is comparative weight, gi is individual weight of parameters and “z” is representing total quantity of physio-chemical parameter.

The water quality ranking scale (qi) equation (2) is figured by dividing the experiential(observed) value of each parameter by pertinent to WHO (2011) standard value after that multiply the answer by 100.

$$\boldsymbol{qi} = \left(\frac{xi}{Yi}\right) * 100 \quad (2)$$

Here "Xi" is observed value and "Yi" is WHO standards. Equation (3) is used to calculate sub-index (SI).

Finally sum of sub-index (SI) equation (4) is corresponding to the water quality index.

$$SI = Wi * qi \quad (3)$$

$$WQI = \sum SI \quad (4)$$

Table 1. Shows individual weight and relative weight of physiochemical parameters.

Parameters	WHO guidelines	Weight (gi)	Relative Weight (Gi)
EC (µS/cm)	1500	3	0.077
pH	6.5-8.5	3	0.077
TDS (mg/l)	1000	3	0.077
Ca (mg/l)	150	2	0.051
Cl (mg/l)	250	3	0.077
Mg (mg/l)	100	2	0.051
Na (mg/l)	200	3	0.077
HCO3 (mg/l)	300	2	0.051
K (mg/l)	12	2	0.051
SO4 (mg/l)	250	3	0.077
NO3 (mg/l)	12	4	0.102
Iron (ppm)	0.3	2	0.051
Zinc (ppm)	0.5	2	0.051
Arsenic(ppm)	10	5	0.128
		∑ wi=39	∑Wi=1

Results and Discussion

Physio-Chemical Parameter Analysis

The pH value of groundwater samples collected from taluka chachro varies from 7.0–8.3 having a mean value of 7.56, and it is within the permissible limit of WHO 2011. Concentration of EC ranges from 2593 to 18950 µS/cm with mean values of 8904.15 µS/cm. Almost, all samples have high concentration of EC than recommended values of (WHO, 2011). TDS values varied from 1659-12128 mg/l respectively, with a mean concentration 5698.70 mg/l higher than prescribed limit of (WHO, 2011). High TDS depicts seawater influence as addition with sub surface water affecting water geochemistry. TDS concentration of almost all sample locations were above the recommended limit of WHO guidelines.

Sodium and potassium ion concentration ranges from 420 to 3280 and 9.5 to 101 mg/l having a mean concentration of 1588.27 and 25.72 mg/l respectively. Mostly rocks consist of Na and K bearing minerals dissolution in water may enhance its concentration (Talib et al., 2019). Almost, all samples having high concentration of Na ion, while, 96.15% samples have high K ion than recommended level of WHO guidelines in the study area.

Concentration of Ca and Mg ranges from 36 to 288 and 17 to 272 mg/l, respectively, having a mean concentration of 117.92 and 108.19 mg/l respectively. Results of Ca and Mg show that, 92.31% and 96.15% groundwater samples are within the prescribed limit of (WHO, 2011). Results of study area for physico-chemical parameter indicated that among the major cation relative abundance pattern was Na>Ca>Mg>K.

HCO_3 values ranged from 210-1150 mg/l, having median value 397.308 mg/l. 88.46% samples of study area have higher amount of bicarbonate concentration than recommended limit of (WHO, 2011). Cl and SO_4 concentration varies from 539 to 5738 and 79 to 870 mg/l, having a mean concentration of 2389.08 and 336.88 mg/l, respectively. Almost all specimens indicates elevated values of Cl than recommended limit of (WHO, 2011), while, 82.16% samples shows high concentration of SO_4 than prescribed limit of (WHO, 2011). Results of current study for physico-chemical parameters indicated that among the anions abundance pattern is Cl>HCO_3>SO_4 (Table 03).

Concentration of NO_3-N varied from 6.66 to 117.13 mg/l having median concentration of 32.18 mg/l. Elevated level of NO_3-N may be due to over usage of agriculture manure and irrigated by sewage water. Fe amount in dug well samples ranges from 0 to 3.36 mg/l with median value of 0.49 mg/l. Concentration of As in study area varied from 0 µg/l to 15.58 µg/l,

Table 2. Shows the results of physico-chemical parameters.

Parameters	Minimum	Maximum	Mean	Standard Deviation	WHO Standards
pH	7	8.3	7.56	0.312	6.5-8.5
EC (µS/cm)	2593	18950	8904.15	3978.15	1000
TDS (mg/l)	1659	12128	5698.69	2546.09	1000
Ca (mg/l)	36	288	117.92	54.71	200
Mg (mg/l)	17	272	108.19	60.31	150
Na (mg/l)	420	3280	1588.26	728.27	200
K (mg/l)	9.5	101	25.71	20.27	12
Cl (mg/l)	539	5738	2389.07	1263.10	250
HCO_3 (mg/l)	210	1150	397.30	192.88	250
SO_4 (mg/l)	79	870	336.88	162.67	250
NO_3 (mg/l)	6.66	117.13	32.18	28.33	10
Fe (mg/l)	0	3.363	0.48	0.668	3
Zn (mg/l)	0	0.522	0.04	0.108	5
As (µg/l)	0	15.58	2.85	3.31	10

Drinking Water Quality Index (DWQI)

The DWQI was calculated to know the quality of groundwater. The DWQI results were found from 133.44 to 637.39. Four samples were found in poor DWQI ranging from 100 to 200 and nine samples were in very poor water category (DWQI ranges from 200-300) and 13 samples were unfit for drinking category (DWQI above 300) (Fig. 4), (Table 3). The work revealed that groundwater of the Chachro sub-district was of very poor water to unfit for drinking purpose.

Table 3. DWQI ranges and status of the water samples.

DWQI	Status	Possible Usage
<50	Excellent	Drinking, irrigation and Industrial
50-100	Good	Drinking, irrigation and Industrial
100-200	Poor	Irrigation and Industrial
200-300	Very Poor	Irrigation
>300	Unfit for drinking	Restricted use for Irrigation

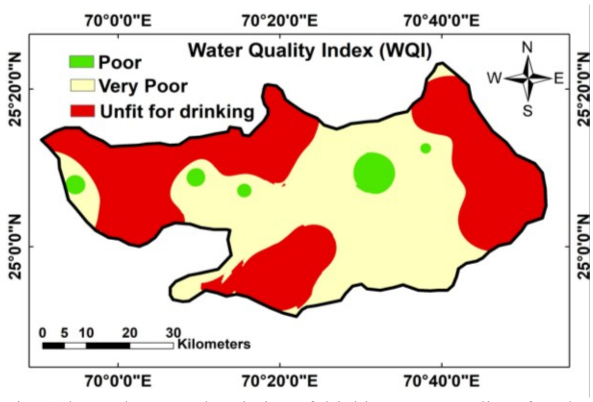

Fig. 4 shows the Lateral variation of drinking water quality of study area.

Maltivariate Statistical Analysis

Correlation Matrix and Data Analysis

TDS and EC show strong correlation with major cations Ca, Mg, Na and anions Cl, SO_4, (0.83), (0.92), (0.99) and (0.92), (0.79), respectively (Table 4). TDS and EC association was strong to moderate in dug well water samples. These factors add salinity to groundwater (Bashir et al., 2017; Nesrine et al., 2015). HCO_3 shows very weak correlation with TDS, EC, anions and cations. Mg and Ca show strong correlation (0.87) with each other, and with Na, Cl, SO_4,, (0.88 and 0.79), (0.91 and 0.84), (0.77 and 0.76) respectively. Na shows strong correlation with EC, TDS, Mg, Ca, Cl, SO_4, and weak correlation with K and HCO_3, (0.99, 0.99, 0.88, 0.79, 0.98, 0.77) and (0.32, 0.08), respectively. K shows strong correlation with SO_4 (0.70). HCO_3 and NO_3 show very weak correlation with all parameters. SO_4 shows strong correlation with EC, TDS, Mg, Ca, Na, K, Cl and very weak correlation with PH and HCO_3, (0.79, 0.79, 0.77, 0.76, 0.77, 0.70, 0.76) and (-0.39, -0.009), respectively. Moderate to a poor association between calcium and sulfate specify that dissolution of gypsum was not evident instead the elevated level of Ca may be the ion exchange or carbonate weathering (Bashir et al., 2017; Zhang et al., 2014). Positive association of sodium with Cl (0.98), SO_4 (0.78), and Mg (0.88), indicate that Na is supplied from silicate weathering sources other than halite dissolution. (Table 4).

Table 4. Pearson correlation of coefficient of physio-chemical parameters.

Parameters	pH	EC	TDS	Mg	Ca	Na	K	Cl	HCO_3	SO_4	NO_3
pH	1.000										
EC	-0.487	1.000									
TDS	-0.487	**1.000**	1.000								
Mg	-0.422	**0.916**	**0.916**	1.000							
Ca	-0.362	**0.833**	**0.833**	**0.866**	1.000						
Na	-0.474	**0.994**	**0.994**	**0.878**	**0.787**	1.000					
K	-0.227	0.348	0.348	0.420	0.451	0.325	1.000				
Cl	-0.494	**0.992**	**0.992**	**0.914**	**0.838**	**0.985**	0.330	1.000			
HCO_3	0.087	0.029	0.029	-0.084	-0.173	0.078	-0.090	-0.062	1.000		
SO_4	-0.390	**0.794**	**0.794**	**0.767**	**0.760**	**0.770**	**0.695**	**0.760**	-0.009	1.000	
NO_3	0.102	-0.186	-0.186	-0.074	-0.074	-0.239	-0.091	-0.233	-0.174	-0.089	1.000

Conclusion

Statistical data analysis illustrates the pattern Na>Mg>Ca>K for cations and Cl>HCO_3>SO_4 trend for anions. Almost, all samples have high concentration of EC and TDS than recommended limit of WHO 2011 and is not safe for drinking purpose. Almost all samples having high concentration of Na ion, while, 96.15% samples have higher K ion concentration than prescribed limit of WHO. Results of Ca and Mg show that, 92.31% and 96.15% groundwater samples are within the prescribed limit of WHO 2011. Almost all samples have higher concentration of Cl than prescribed limit of WHO 2011, While, HCO_3 and SO_4 are higher than WHO (2011) guidelines in 88.46% and 82.16%, respectively. Calculated results of drinking water quality index describes that 15.38% samples were poor, 34.62% belonging to very poor water' category and 50% samples were unfit for drinking' purpose.

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