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Evaluation of Groundwater Quality from Shah Faisal Town, Karachi employing SPSS and GIS-IDW Techniques

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Abstract

To assess the quality of groundwater, selected samples from Shah Faisal Town, Karachi have been evaluated employing spatial and multivariate analyses using ArcGIS-Inverse Distance Weighted (IDW) method and SPSS-factor and cluster techniques. All samples exhibited alkaline pH; samples adjacent to local drain revealed very high TDS due to contamination of groundwater. Majority of the samples exhibited $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, $Cl^- > SO_4^{2-} > HCO_{3-} + CO_3^{2-}$, however on the Piper diagram; bulk of the samples demonstrated NaCl-type hydrogeochemical facies. Samples plotted on Gibbs' diagram displayed the impact of intrusion and evaporation in the area. The spatial analysis of pH, SAR and PI revealed that entire study area is good for irrigation water, though less suitable for drinking purpose. The distribution of WQI, K^+, SSP, Na% and KI values showed that samples collected from the region away from Chakoar Drain is more suitable for industrial and irrigation applications. Very strong to strong positive correlation matrices are found between EC, TDS, Na^+, Cl-, and TH, SO_4^{2-}, Mg^{2+}; Na^+ and Cl-; Mg^{2+} and SO_4^{2-}; SSP with Na%; Cl- with Na% and SSP; SO_4^{2-} with K^+; Mg^{2+} with MAR; Na^+ with Na%, KI and SSP. However, RSC showed a very strong to strong negative correlation with EC, TDS, TH, SO_4^{2-}, and Mg^{2+}. Strong positive correlation was noted between all irrigation parameters except RSC and MAR. Overall it is reflected from the present study that groundwater quality was not good alongside the drains of Shah Faisal Town while away from drains the quality become better.

Keywords: Water Quality Index, Irrigation quality, Shah Faisal Town, GIS-Spatial distribution, SPSS.

1. Introduction

Groundwater is an important source of consumable water available on Earth (El-Rawy et al., 2023). It has been estimated that around 30% of Earth's total water content is groundwater (Shamsudduha, 2013). Groundwater is a copious, easy-to-use, and clean water supply, played a significant role in the development of human society for thousands of years (Iddrisu et al., 2024; Kouacou et al., 2024). Large numbers of industrial sites and multitudinous farmers are being contingent on groundwater for their water source (Kemper, 2004). With rising urbanization, groundwater resources are considered an inevitable source of fresh water (Khan et al., 2023); but simultaneously as a result of increased human activity, including urbanization, industry, landfilling, and agricultural developments, anthropogenic pollution flows into the aquifers, degrading water resources and limiting their potential uses (Badr et al., 2023).

In Karachi, the largest metropolitan city in Pakistan, groundwater consumption is progressively increasing and because of over-utilization, level of groundwater is decreasing within the city (Ahmad et al., 2023). Karachi city has 41 major drains; different colonies are situated on and adjacent to them. Generally, the water collected from the vicinity of drains and sewage is found highly contaminated with heavy metals as well as with coliform bacteria (Rahman, 1996). The study area, Shah Faisal town, a part of Karachi, is located in the neighborhood of Malir River. The Chakoar Drain is an important drain flowing through the study area (Fig. 1); plunges into the Malir River (Fig. 1d, and 1e) and then into the Arabian Sea. Natha Khan and Drigh Road are the prominent localities of the study area where it passes.

These two drains are chiefly responsible for the groundwater recharge in the area. The habitants consume this water for their daily usage. According to Guriro (2017), Shah Faisal Town is counted in those areas of Karachi city that are highly affected by rainwater and flooding. Shah Faisal Town is located in the district Korangi and covers an area of 11.68 km2. It is situated on the left bank of the Malir River (Ali and Khan, 2021).

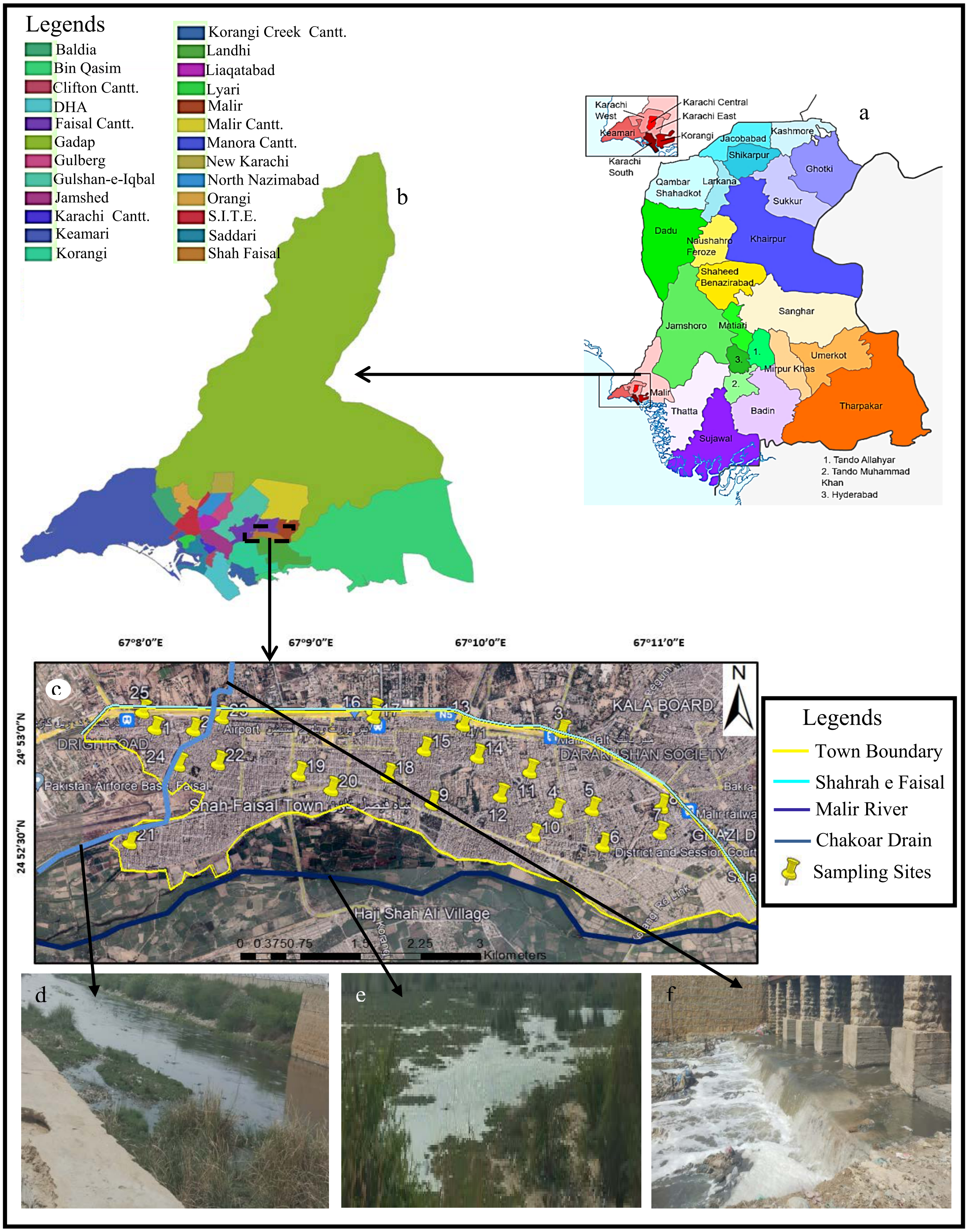


Fig. 1. Map of study area; a) Sindh; demarcating district boundaries b) Karachi displaying town boundaries and location of study area; c) satellite image showing sampling sites; d) ending point of Chakoar Drain; e) Malir River; f) starting point of Chakoar drain in study area.

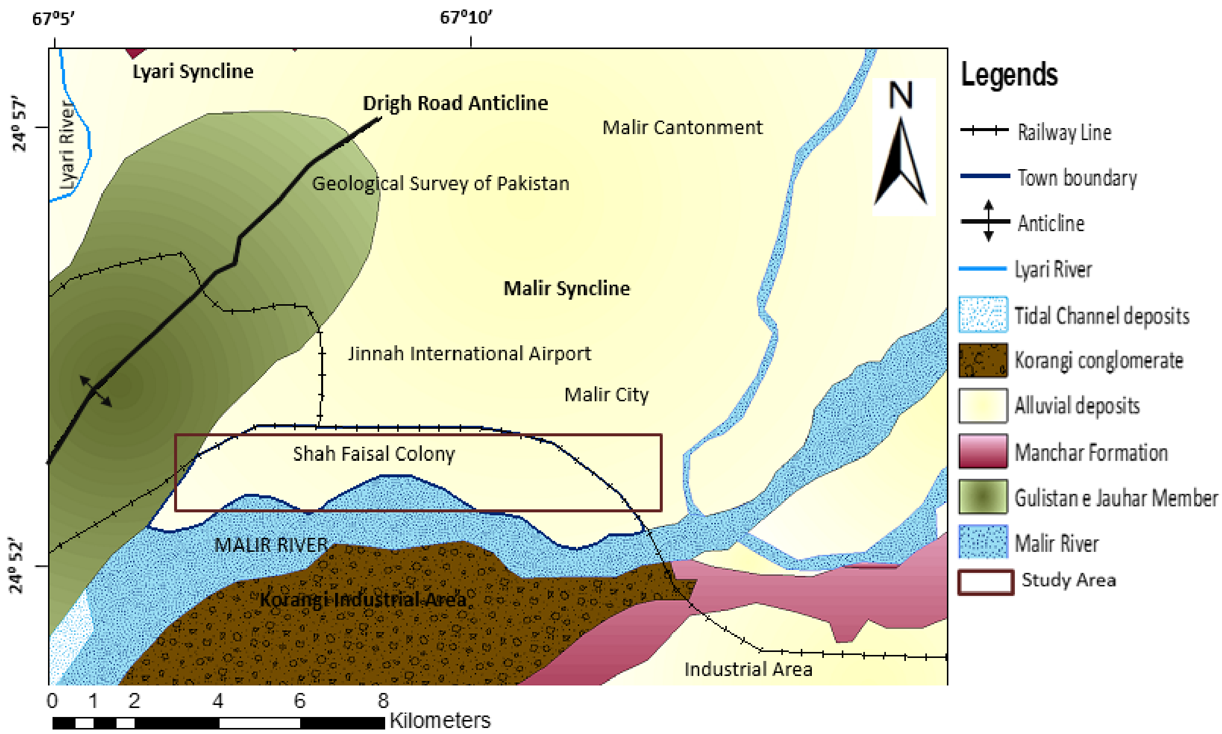


Fig. 2. Geological map of the study area (after Qureshi et al., 2001).

Estimation of variation in physicochemical parameters of groundwater and their spatial distribution is the core objective of the present study. Statistical analysis, Piper and Gibbs diagrams, and ArcGIS techniques are employed to examine the chemical properties of groundwater and the variables that influence it. The estimated parameters are compared with different standards to define their suitability for domestic usage. To give a scientific foundation for the assessment of quality, the irrigation water parameters are also evaluated to determine the type and suitability of groundwater of Shah Faisal Town for agricultural uses. The study demarcates the areas that are suitable for domestic and irrigation consumption along with depth of water which benefits the habitants to manage the availability/accessibility of groundwater.

2. Materials and Methods

A total of 25 well water samples were collected from different localities of Shah Faisal Town (Fig. 1). Colour and depth of the wells were noted at the sampling sites (Table 1). All samples were collected in 1-liter polyethylene bottles which were properly washed (Iddrisu et al., 2024) and further rinsed thrice before taking groundwater samples at the site to avoid any contamination (Aduojo et al., 2024). Samples were collected directly through an electric pump to obtain fresh water samples as suggested by Khan and Qureshi (2018). The random sampling method was adapted for sampling (Singh et al., 2019). All parameters were determined in the laboratory of the Department of Geology, University of Karachi. The pH, TDS, and EC were determined by using Denver Instrument; Model 50. Calcium, Mg^{2+}, CO_3^{2-}, and HCO_{3-} were estimated by volumetric titration, Cl- through argentometric titration, Na+ and K+ were analyzed through a flame photometer (Mokhtar et al., 2022) and SO_4^{2-} was analyzed by Sulphate digital meter. Total hardness was estimated by using Ca and Mg parameters (Nag and Das, 2014). Using estimated chemical constituents, irrigation quality parameters were computed using formulae given in Table 2.

To elaborate the analytical results various software were utilized; zeta ware software for the construction of stiff diagrams and Easy-Quim 5.02-012 for Piper diagram. ArcGIS 10.8 version was used to create spatial variation distribution patterns and maps (Gang et al.,

2023) whereas IBM SPSS software was utilized for multivariate analysis.

3. Geology of Study Area

The study area Shah Faisal Town lies in the Korangi District, Karachi. In Karachi arc and its surroundings, sedimentary rocks of Jurassic to Recent age are exposed (Malkani and Zafar, 2016). However, Kirthar, Nari, Gaj, and Manchar formations are well exposed in and around Karachi city along with sub-recent to recent deposits. Nearby vicinities of the study area are covered by alluvium and exposures of Gaj and Manchar formations (Fig. 2).

Gaj Formation of Miocene age is comprised of variegated and gypsiferous shale, cross-bedded, calcareous, ferruginous sandstone, and fossiliferous, argillaceous limestone (HSC, 1960). Ahmed et al. (1983) have divided the Gaj Formation into four members, younger to older, Drig Clay, Talawa Limestone, Jhil Limestone, and Metan Clay. Later, Qureshi et al. (2001) revised the division of the Gaj Formation and introduced Mundro (oldest), Mol, and Gulistan-e-Jouher (younger) members. The exposures of Gulistan-e-Jouher member are found on the northwest side of the study area (Fig. 2). It is correlated to Drig Clay Member of Ahmed et al. (1983). Manchar Formation is made up of thin strata of conglomerate produced in the Pliocene to Pleistocene age, interlayered with alternate sand and siltstone (HSC, 1960). Conglomerates comprise pebbles and nodules of sandstone and limestones (Agheem et al., 2020). The formation is overlain by alluvial, sub-recent to recent deposits. Alluvial, stream deposits, are comprised of poorly sorted gravels, sand, and silts (Nabi et al., 2019).

According to Ali and Khan (2021), regions that are located along the Malir River including the study area are generally covered by recent alluvium and are underlain by the Manchar Formation which is further followed by Gaj Formation. Surrounding of study area below the Malir River, the coastal deposit of Korangi Conglomerate of sub-recent to recent age is also present (Fig. 2). Chakoar Drain is another prominent drain that passes through the different areas of Shah Faisal Town has a length of 23,080 ft which disperses into Malir River (Fig. 1 d-e) and then plunge into the sea. Natha Khan and Drigh Road are the prominent localities of the study area where it passes.

4. Results

The data of the physic-chemical parameters of studied groundwater samples are presented in Table 1. The pH values of samples range from 7.9 to 7.3 having a mean value of 7.65. The TDS, conductivity and total hardness ranges from 6000 to 1350mg/l, 1929 to 8571S/cm and 2833-410mg/l, with an average of 3345mg/l, 4779S/cm and 954mg/l respectively (Table 1). Concentration ranges (mg/l) of chemical constituents in the studied samples are: Na^{+} (1595-180); Ca^{2+} (78-310); K^{+} (23-5); Mg^{2+} (550-45); Cl- (2500-295); SO_4^{2-} (2200-200); HCO_3^{2-} (665-85). The carbonate was reported in 11 samples out of 25; ranging from 0-33 mg/l (Table 1). The value of the Water Quality Index of studied samples lies in between 47.29-119.77. Other parameters for the assessment of the adequacy of groundwater for irrigation include residual sodium carbonate (RSC), permeability index (PI), Kelly Index (KI), magnesium absorption ratio (MAR), sodium percent (Na%), sodium absorption ratio (SAR) and soluble sodium percent (SSP) (El-Rawy et al., 2023). Suitability of irrigation quality parameters of the studied samples and their appropriateness are stated in Table 2. The calculated values are: SAR (3.11-20.48); Na% (34.51- 79.57); SSP (33.83-78.86); RSC (-3.84 to -46.33); PI (37.87-82.66); KI (0.52-3.86) and MAR from 27.27 to 80.08% (Table 3).

5. Discussion

The pH is the parameter that highly influences all physical, chemical, and biological aspects of environments (Tariq et al., 2016). The pH vales of studied samples reflect alkaline nature and lie in the permissible range as per different standards (Table 1). The TDS of all the samples are beyond the limit prescribed by NSDWQ (2008) and WHO (2017) which is <1000 mg/l, however, samples 1, 4-8, 11 are within the permitted range of BIS (2012). High conductivity in the sample indicates a high ionic concentration (Popek, 2018). Crops appear in physiological drought when electrical conductivity becomes high. For suitable irrigation water, it should be <700 µS/cm (Asadi et al., 2019). Total hardness is interlinked with the Ca and Mg contents of groundwater. Sample 2 which is close to Chakoar Drain has the highest value of TH 2832.6mg/l which shows the contamination of groundwater whereas samples 13-16, 18, and 25 have TH values >1100mg/l because these samples are also close to local drains and Malir River as well (Table 1; Fig. 1). All the water samples are categorized as very hard water; which is less suitable for drinking and domestic uses.

Table 1: Physicochemical parameters of studied groundwater samples and their comparison with standards produced WHO (2017), NSDWQ (2008) and BIS (2012).

Sample #	Depth	pH	EC	TDS	TH	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^2	K^+
	(ft)		(µS/cm)	(mg/l)									
1	100	7.3	2671	1870	685	12	580	490	200	200	45	315	9
2	180	7.48	7857	5500	2833	0	665	1100	2200	228	550	680	23
3	250	7.9	5143	3600	865	0	480	1500	370	180	101	950	7
4	165	7.69	2571	1800	802	0	390	355	500	201	73	225	6
5	100	7.67	1929	1350	629	0	300	295	350	130	74	180	6
6	150	7.57	2443	1710	715	0	310	415	460	95	116	265	7
7	180	7.63	2357	1650	653	0	320	430	380	105	95	270	10
8	170	7.64	2357	1650	694	0	280	412	450	95	111	275	7
9	130	7.71	3857	2700	687	0	435	980	345	135	85	640	7
10	180	7.57	2929	2050	439	18	190	875	225	85	55	565	8
11	220	7.78	2571	1800	417	0	245	498	450	78	54	427	5
12	160	7.77	4036	2825	1020	0	360	787	805	120	175	564	7
13	150	7.8	5714	4000	1239	24	289	1087	1300	188	187	874	13
14	155	7.55	5786	4050	1337	21	419	1298	978	148	235	846	10
15	160	7.42	8571	6000	1449	15	350	2500	1100	132	272	1595	15
16	180	7.75	8571	6000	1382	0	218	2464	1200	158	240	1595	9
17	250	7.68	6057	4240	1044	18	110	1773	895	105	190	1115	7
18	140	7.71	7386	5170	1130	9	85	2250	980	245	126	1425	11
19	150	7.74	5357	3750	797	15	170	1625	605	138	110	1010	7
20	80	7.67	5971	4180	1077	33	140	1650	915	128	184	1065	13
21	110	7.78	3571	2500	601	9	185	1005	400	165	46	645	19
22	120	7.88	3429	2400	410	21	128	890	500	85	48	700	8
23	200	7.31	6114	4280	700	0	299	1600	850	150	79	1250	19
24	110	7.82	6143	4300	1099	0	360	1600	845	300	85	1045	13
25	180	7.42	6071	4250	1149	0	311	1600	850	310	91	1020	15
Minimum	80	7.3	1929	1350	410	0	85	295	200	78	45	180	5
Maximum	250	7.9	8571	6000	2833	33	665	2500	2200	310	550	1595	23
Mean	159	7.65	4779	3345	954	8	305	1179	726	156	137	782	10
WHO	-	6.5-8.5	750	<1000	500	N/A	120	600	400	200	150	200	12
NSDWQ	-	6.5-8.5	N/A	<1000	-	N/A	N/A	<250	N/A	N/A	N/A	N/A	N/A
BIS	-	6.5-8.5	N/A	2000	600	N/A	N/A	1000	400	200	100	N/A	N/A

N/A=Not Available

Table 2: Formulae of quality parameters of groundwater; ranges, classification; and estimated values of studied samples. All parameters were calculated in meq/l except hardness calculated in mg/l.

	PARAMETERS	FORMULA	Ranges	Water Suitability	No. of Samples	Percentage
DRINKING	Total Hardness	TH= 2 .497 Ca+4 .115Mg (Badr et al., 2023; Nag and Das, 2014)	0-75	Soft	-	-
			75-150	Moderately hard	-	-
			150-300	Hard	-	-
			>300	Very Hard	25	100%
DRINKING / IRRGATION QUALITY	Water Quality Index	$WQI= \Sigma W_nQ_n/ \Sigma W_n$ (Alam and Singh, 2023; Wekesa and Otieno, 2022)	02-5	Excellent	_	_
			26-50	Good	2	8%
			51-75	Poor	13	52%
			76-100	Very Poor	8	32%
			>100	Unsuitable	2	8%
IRRGATION QUALITY	Residual Sodium Carbonate	$RSC= (CO_3+HCO_3)-(Ca+Mg)$ (Wang et al., 2023)	<1.25	Safe	25	100%
			1.25-2.50	Marginal	-	-
			>2.5	Unsuitable	-	-
	Sodium Percent	$Na\%=\frac{Na+K}{Na+K+Ca+Mg}x100$ (Din et al., 2023)	<20	Excellent	-	-
			20-40	Good	3	12%
			40-60	Permissible	6	24%
			60-80	Doubtful	16	64%
			>80	Unsuitable	-	-
	Permeability Index	$PI=\frac{Na+HCO3}{Ca+Mg+Na} x\ 100$ (Berhe, 2020)	<25	Unsuitable	-	-
			25-75	Good	19	76%
			>75	Excellent	6	24%
	Kelly Index	$KI=\frac{Na}{Ca+Mg}$ (Gaagai et al., 2023)	<1	Suitable	7	28%
			>1	Unsuitable	18	72%
	Magnesium Absorption Ratio	$MAR=\frac{Mg}{Mg+Ca}x100$ (Gaagai et al., 2023)	<50	Permissible	10	40%
			>50	Unsuitable	15	60%
	Sodium Absorption Ratio	$SAR=\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$ (Wang et al., 2023)	<10	Excellent	9	36%
			10-18	Good	12	48%
			182-6	Doubtful	4	16%
			>26	Unsuitable	-	-
	Soluble Sodium Percent	$SSP=\frac{Na}{Na+K+Ca+Mg}x100$ (Mokhtar et al., 2022)	<50	Good	7	28%
			>50	Bad	18	72%

Table 3: Univariate analysis of irrigation quality parameters of studied samples.

Sample #	WQI	RSC	Na%	PI	KI	MAR	SAR	SSP
1	47.29	-3.84	50.32	61.14	1.00	27.27	5.22	49.48
2	119.77	-46.33	34.51	37.87	0.52	80.08	5.53	33.83
3	72.73	-9.55	70.43	75.12	2.37	48.33	14.00	70.13
4	51.86	-9.74	38.11	47.50	0.61	37.71	3.44	37.52
5	49.17	-7.75	38.65	49.01	0.62	48.68	3.11	37.90
6	50.79	-9.33	44.80	53.11	0.80	67.05	4.29	44.11
7	61.75	-7.92	47.67	56.33	0.89	60.13	4.58	46.65
8	53.21	-9.41	46.43	54.32	0.85	66.07	4.52	45.75
9	60.61	-6.70	66.94	73.20	2.01	51.20	10.58	66.51
10	56.02	-5.12	73.71	78.84	2.78	51.89	11.69	73.10
11	52.46	-4.38	69.00	76.28	2.21	53.57	9.06	68.52
12	64.60	-14.68	54.55	59.75	1.19	70.85	7.64	54.15
13	91.13	-19.45	60.54	63.79	1.52	62.37	10.75	60.02
14	72.58	-19.41	57.85	61.79	1.36	72.58	10.01	57.45
15	95.30	2-3.03	70.44	72.75	2.37	77.45	18.13	70.05
16	88.12	2-4.33	71.38	73.25	2.49	71.68	18.57	71.14
17	69.90	-18.68	69.77	71.62	2.30	75.10	14.93	69.51
18	88.45	2-1.06	73.23	74.54	2.72	46.15	18.37	72.90
19	68.38	-12.78	73.29	76.00	2.73	57.05	15.49	72.99
20	87.67	-18.34	68.21	70.28	2.13	70.55	14.05	67.73
21	100.12	-8.75	70.25	74.23	2.32	31.72	11.41	69.05
22	69.25	-5.45	78.79	82.42	3.69	48.48	14.99	78.26
23	93.73	-9.18	79.57	82.66	3.86	46.75	20.48	78.86
24	92.48	-16.18	67.45	70.89	2.06	32.08	13.67	66.96
25	84.58	-17.98	65.96	69.12	1.92	32.85	13.05	65.39
Minimum	47.29	-46.33	34.51	37.87	0.52	27.27	3.11	33.83
Maximum	119.77	-3.84	79.57	82.66	3.86	80.08	20.48	78.86
Mean	73.68	-13.98	61.67	66.63	1.89	55.51	11.10	61.12

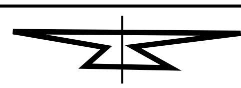
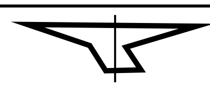
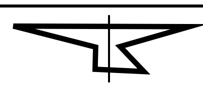
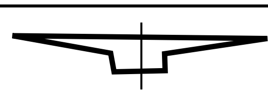
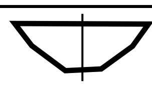
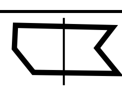
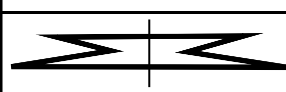
The values of Na^+ in the samples exceed the permissible limit (200 mg/l) of WHO (2017) except sample 5 (Table 1). Sodium concentration is increasing away from drains. The mechanism of cation exchange is also the cause of high sodium in groundwater in aquifers (Ram et al., 2021); similar observations were also made in studied samples. Samples 1, 2, 4, 18, 24, and 25 are beyond the permissible limit (200 mg/l) of Ca^{2+} for drinking purposes (Table 1). The desirable and permissible limits of Mg^{2+} are 50 and 150 mg/l respectively (WHO, 2017; Alrowais et al., 2023). Majority of the samples are within the prescribed limit (Table 1). Magnesium concentration affects the hardness of the water body (Alamgir et al., 2019) which ultimately damage water quality for domestic use. Only three samples (2, 21 and 23) are found far beyond the desirable limit of K^+ set by WHO (2017), five samples are slightly beyond while the remaining 68% of samples are within the prescribed limit (Table 1). The primary sources of potassium are the leakage from sewer pipes and septic tanks; and the leaching of potassium fertilizer through the soil (Kom et al., 2022).

The occurrence of anions is reported as Cl^- $>SO_4^{2-}$ $>HCO_{3-}$ $>CO_3^{2-}$ (Table 1). The Cl- of all samples are out of the range prescribed by NSDWQ (2008); however, 28% samples are within permissible limit (600) of WHO (2017), and 40% of samples (2, 3,4,5,6,7,8,9,10, 22) have >1000 mg/l and are in the range given by BIS (2012) which is 1,000 mg/l (Table 1). Samples 3,5,7,9, &10 have <400 mg/l SO_4^{2-} content (Table 1); are within the permissible limit as per the guideline by WHO (2017) and BIS (2012). High concentrations of sulfate are most likely due to spilled sulfur compounds from an area (Ram et al., 2021), wastewater leakage; sewage treatment. Only two samples (17 and 18) have HCO_{3-} within the limit while all other are far beyond the permissible limit. The maximum content of CO_3^{2-} is found in sample# 20 collected from the shallowest depth (80 ft) among all the samples (Table 1). Possibly it may be due to some localized anthropogenic activity.

5.1 Stiff diagram

One of the fundamental tools for the spread of ions in water is the stiff diagram (Nugrah et al., 2023), which helps to identify the flow path and changes in the ionic composition of water over time and place (Onwuka et al, 2019). For convenience, the examined samples are categorized into seven groups according to concentration patterns and variations in the chemical constituents. All the samples (Group 1-6) display Na^++K^+ and Cl- as leading ions having higher concentrations except sample 2 (Group 7) in which Mg^{2+} and SO_4^{2-} are the major ions (Table 4). About 48% of samples congregated in Group 1 demonstrate Mg^{2+} and SO_4^{2-} as the second major pair of ions after Na^++K^+ and Cl- mimicking the pattern of seawater with a slight impact of the geology and anthropogenic activities prevailing in the area. Five, 2 and 3 samples are found in groups 2, 3, and 4 respectively and one each in groups 5, 6 and 7 (Table 4). All these samples exhibit minor variations in their ions. Samples in groups 1, 4, and 6 are controlled by the Malir River with variation due to local geology, whereas samples around Chakoar Drain and other small drains are included in categories 2, 3, 5, and 7 (Fig. 1).

Table 4: Samples categories based on the composition on the stiff diagram

Group	Composition	Stiff patterns	Samples plotted in category	% of samples
Group 1	$Na^++K^+>Mg^{2+}>Ca^{2+}$, $Cl^->SO_4^{2-}$ $>HCO_3^-+CO_3^{2-}$		6-8, 11-17, 19, 20	48%
Group 2	$Na^++K^+>Ca^{2+}>Mg^{2+}$, $Cl^->SO_4^{2-}$ $>HCO_3^-+CO_3^{2-}$		5, 8, 21, 24, 25	20%
Group 3	$Na^++K^+>Mg^{2+}\geq Ca^{2+}$, $Cl^->SO_4^{2-}$ $>HCO_3^-+CO_3^{2-}$		22, 23	8%
Group 4	$Na^++K^+>Mg^{2+}\geq Ca^{2+}$, $Cl^->HCO_3^-$ $+CO_3^{2-}\geq SO_4^{2-}$		3,9,10	12%
Group 5	$Na^++K^+>Ca^{2+}>Mg^{2+}$, $Cl^->HCO_3^-$ $+CO_3^{2-}>SO_4^{2-}$		1	4%
Group 6	$Na^++K^+>Ca^{2+}>Mg^{2+}$, $Cl^-=SO_4^{2-}$ $>HCO_3^-+CO_3^{2-}$		4	4%
Group 7	$Mg^{2+}>Na^++K^+>Ca^{2+}$, $SO_4^{2-}>Cl^->$ $HCO_3^-+CO_3^{2-}$		2	4%

5.2 Hydrogeochemical Facies

A piper diagram is used to identify different hydrochemical types present in the groundwater basin, water facies identification based on dominant ions, hardness and alkalinity (Kouacou et al., 2024; Nugrah et al., 2023), sulfate reduction, and other allied hydrochemical hitches (Barua et al., 2021; Madhav et al., 2018; Bashir et al., 2017).

As seen on the cation triangle, 76% samples are classified as Na-type, 20% as mixed type and only one sample as Mg-type; while on the anion triangle, most of the samples (68%) appeared as Cl-type; 28% of samples are plotted in the center field reveal combine effect of all anions and categorized as mixed type, one sample is of SO_4 type (Fig. 3). On the central diamond of the Piper diagram, 76% the studied samples are clustered in NaCl type which represent saltwater; 20% in the CaMgCl field and one sample in CaCl type. It displayed ascendancy of strong acid radicals above weak acid radicals and the supremacy of alkali over alkaline earth elements in most of the samples. A modified Piper diagram (Kelly, 2006) is employed to enlighten the levels of conservative mixing and intrusion of seawater and freshwater (Gueddari et al., 2022). All studied samples are plotted above the conservative mixing line, drift towards the top of diamond shape; reflecting minor impact of seawater intrusion in the study area (Fig. 3).

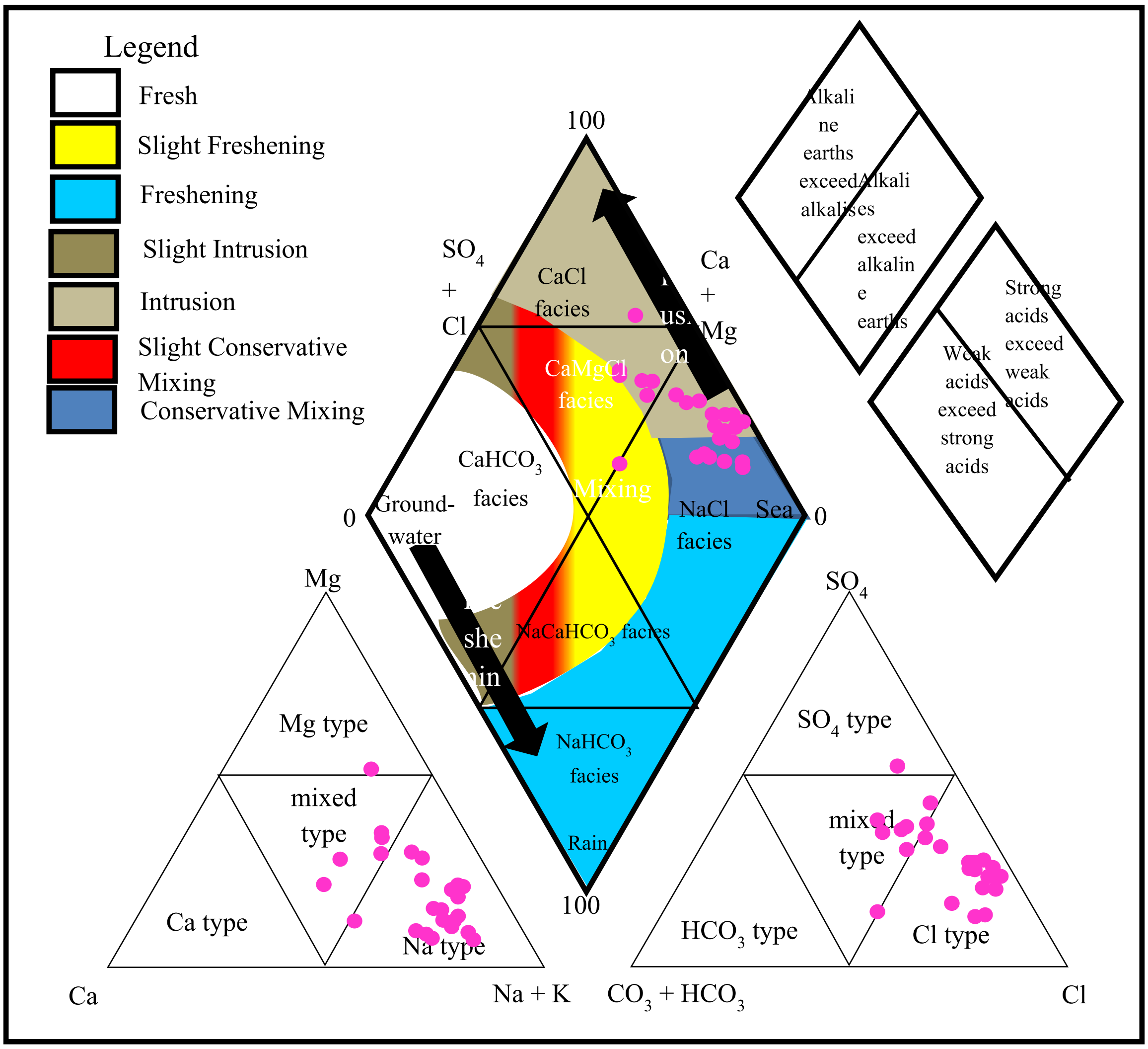


Fig. 3. Piper diagram of studied samples demonstrates water classification and impact of geological processes influencing samples (modified after Kelly (2006) and Gueddari et al. (2022).

Another way of establishing the impact of geological processes on groundwater chemistry is the Gibbs diagram (Okolo et al., 2024). It is a bivariate plot between the ratio of Na+ + K+/ (Na++ K+ +Ca2+) versus TDS (Gibbs, 1970); helps to understand the control of main processes i.e. evaporation, rock weathering, and precipitation, which affect the chemistry of groundwater (Ganvir, 2023; Gueddari et al., 2022; Shaikh et al., 2020; Madhav et al., 2018). All the studied samples display higher values of TDS and cations ratio; plotted towards the upper right side of the diagram (Fig. 4a), indicating the control of evaporative crystallization (Zhang et al., 2023). Probably the high concentration of ions in the groundwater samples is due to the anthropogenic activities along-with high rate of evaporation, as the study area possesses a warm climate. Using the Gibbs diagram, Marandi and Shand (2018) re-evaluate groundwater systems considering rock-water interaction. It has appeared that the evolution of groundwater samples in the study area is partially governed by seawater intrusion along-with dissolution of evaporates (Fig. 4b). Drought, groundwater pumping, storm surges, high tides that cross low-lying regions, sea level rise, and other natural and man-made phenomena can all in consequence of saltwater intrusion (Venâncio et al., 2023; Gibson et al., 2021). In the study area, the process of seawater intrusion is collectively governed by drought, groundwater pumping, and anthropogenic activities.

In comparison to water-rock interactions, in the vast majority of groundwater flow systems, the influence of evapo-concentration is probably of minor importance to groundwater quality. Changes in the salinity and chemistry of surrounding waters are also caused by the dissolution of evaporative minerals (Sahib et al., 2016), rather than by evaporation in certain instances. The water quality evolution of studied samples concerning groundwater flow-line also revealed the combined impact of seawater intrusion and dissolution of evaporates minerals (Fig. 4c).

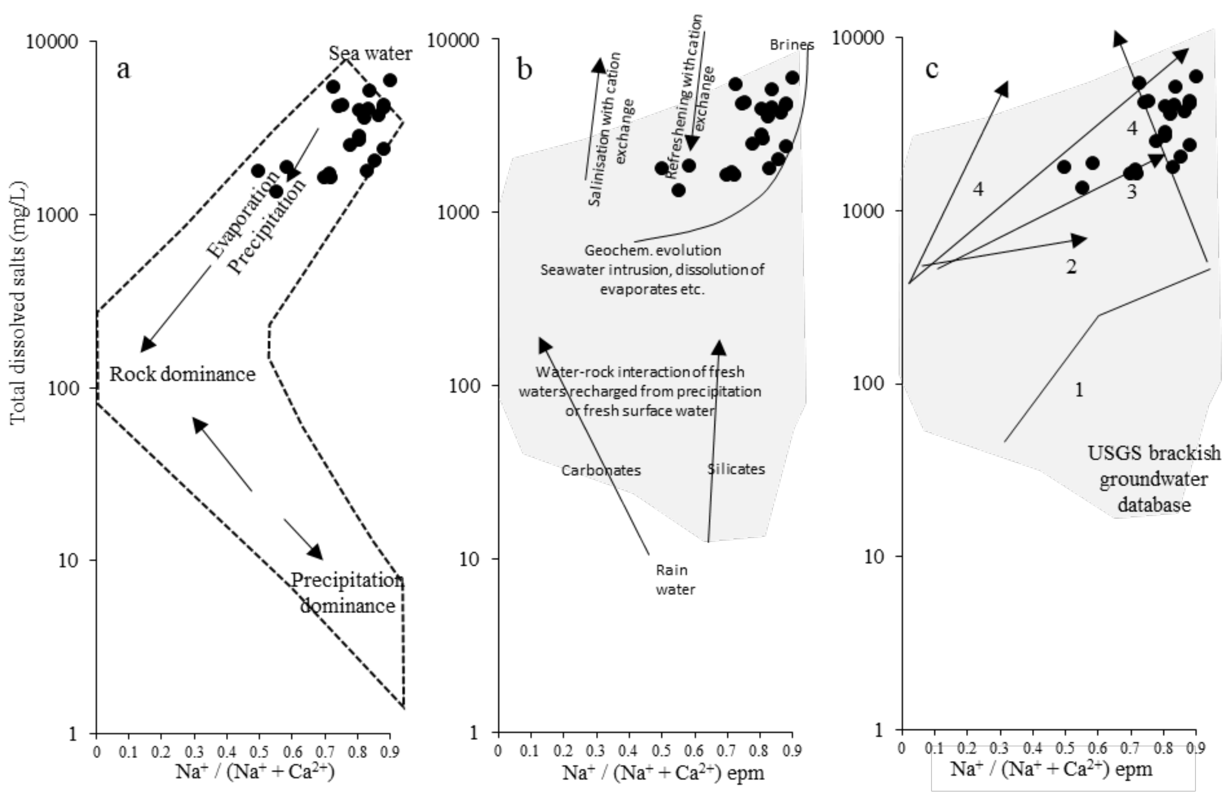


Fig. 4. Gibbs diagram displays a) impact of natural processes, b) water quality evolution of studied samples, c) with respect to groundwater flow line in crystalline rocks (1), carbonate rocks (2), seawater intrusion (3), dissolution of evaporate minerals (4) (after Marandi and Shand, 2018).

5.3 Water Quality Index (WQI)

Water quality is substantial for human health and welfare (Chidiac et al., 2023; Shaikh et al., 2020). Due to numerous human activities, the quality of the water at its source is constantly declining, which is extremely concerning for public health (Nawaz et al., 2023; Siriwardhana et al., 2023). The Water Quality Index is an effective way to classify water quality based on different parameters and specified standard limits to check its suitability for human consumption (Hossain et al., 2024, El Baba et al., 2020; Khan and Rehman, 2017). Brown et al. (1970) proposed the weighted arithmetic index which is one of the most common methods to evaluate the WQI. A total of 9 parameters including pH, TDS, conductivity, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and K^+ were used to assess the WQI of studied samples. Alam and Singh (2023) and Wekesa and Otieno (2022) categorized WQI into five classes to portray the quality status of water based on their possible utilization for drinking, irrigation and industrial purposes. Water having values of WQI between 02-5 and 26-50 are considered excellent and good respectively and can consume for all purposes; water with 51-75 WQI is suitable for irrigation and industrial use, WQI 76-100 for irrigation only, while WQI >100 is unsuitable for all purpose and cannot be used without proper treatment. According to this classification, majority of the studied samples are poor to unsuitable for drinking purposes except sample 1 and 5 (WQI <50); while sample 4, 8, 10 and 11 are marginally good with WQI values in between 50-56 (Table 3). Nearly 52% of groundwater samples are fit for irrigation and industrial uses, 32% are suitable for irrigation only while 8% of samples required proper treatment before using them for either irrigation or industrial purposes (Table 2).

5.4 Irrigation Water Quality Valuation

High sodium content in clayey soil causes swelling and diminishes its infiltration capacity. Sodium Absorption Ratio (SAR) and salinity are considered the most common factors to influence infiltration (Asadi et al., 2019). The structure of soil accumulation can vary due to the greater adsorption effect of Na^+ which can be determined through exceptionally higher SAR value. It occurs when Ca^{2+} and Mg^{2+} ions in soil can be replaced with Na^+ ions (Wang et al., 2023). About 36 and 48% of studied groundwater having SAR>18 are considered excellent and good respectively for agriculture (Table 2), while 4 samples (15, 16, 18 and 23) are classified as doubtful (Table 3). Sodium Percent (Na%) and Soluble Sodium Percent (SSP) are the additional parameters regulated by alkali elements. When alkali reacts with soil causes a reduction of permeability (Barua et al., 2021). Din et al. (2023), on the values of Na%, classified water into four categories; the majority of the studied samples are found in the doubtful range, 24% in permissible range, however 12% are in good category. Likewise, Mokhtar et al. (2022) defined two divisions; good and bad for SSP. About 28% samples have values >50% and are pondered as good while 72% samples are categorized bad for irrigation (Table 2).

Residual sodium carbonate (RSC) helps to assess the alkalinity hazard to the soil. The potential of sodium susceptibility is the reason for an increment of RSC (Shyamala et al., 2021). All samples have RSC values less than 1.25; according to Wang et al. (2023), all are classified as safe for irrigation (Table 2). Other considerable irrigation parameters include Permeability Index, Kelly Ratio, and Magnesium Absorption Ratio. Doneen (1964) evaluated the water suitability for irrigation based on the PI and categorized it into three classes (Barua et al., 2021; Naseem et al., 2010). According to PI limits given by Badr et al (2023), around 76% of samples are good while 24% are found in the excellent category (Table 2). Kelly Index helps to depict the alkalinity hazard. Gaagai et al. (2023) marked KI=1 as a boundary between suitable and unsuitable classes. Nearly 72% samples are deliberated unsuitable while 28% samples are suitable for irrigation purposes (Table 3). Magnesium Absorption Ratio helps to ensure the acceptability of water for irrigation (Bouaroudj et al., 2019). The MAR values revealed that 40% of the samples were in the suitable category for irrigation, reflecting an appropriate concentration of Mg for healthy agriculture while others are unsuitable.

5.5 Spatial Variation Analysis

GIS technology assists in evaluating large variations of parameters by providing spatial distribution of these parameters (Nistor et al., 2020). For spatial variation analysis, the Inverse Distance Weighted (IDW) method of analysis was used which helps to represent the distribution of water pollutants (Hossain et al., 2024; Shyamala et al., 2017; Adhikary and Dash, 2017). This method can handle the extreme values (outliers) in the datasets and make it easier to explain the results to determine values in unknown areas (Haldar et al., 2020). The spatial distribution of physical parameters considering WHO (2017) permissible and impermissible limits for drinking purposes is shown in Figure 5. The distribution pattern of pH displays values in the permissible limit and it is suitable for drinking and other uses (Fig. 5a). Spatial variation of TDS, Na^+, Cl^-, SO_4^{2-} (Fig. 5b-c, g-h) reveal mimicking patterns intricate that the groundwater collected from entire study area have higher values and are impermissible for drinking purpose while distribution of Ca^{2+} and HCO_{3-} displays few random patches (Fig. 5d) and a single patch of permissible zone (Fig. 5i) respectively. The spatial distribution of Mg^{2+} and K^+ demonstrates little bit different structure; most of the study area has permissible values of Mg^{2+} for drinking except the central region and a small patch confining sample 2 (Fig. 5e); likewise, the western extremity and a small patch in the central part which are affected by Chakoar and some other trivial local drains exhibit impermissible precincts for K^+ (Fig. 5f).

The spatial distribution of WQI is portrayed in Figure 5j. It exhibits that the eastern side and few patches on western side of the study area has moderately low values of WQI confined comparatively suitable zone of groundwater for both irrigation and industrial applications (Fig. 5j). Towards the west, the values of WQI increase, and groundwater is only apt for irrigation purposes, however, the area around Chakoar Drain (samples 2) and other trifling drains (sample17) are more contaminated and need treatment before utilization for any purpose (Fig. 5j).

Spatial analysis of irrigation quality parameters also displays imitating distribution of SSP, Na% and KI (Fig. 6a, d-e); the eastern zone of study area along with few patches on western side lies in permissible and suitable precincts while MAR shows vice versa pattern (Fig. 6c). The SAR exhibits excellent to good zones as moves from eastern to western domain of area (Fig. 6b). The entire study area is suitable concerning PI values which are classified from the range of good to excellent (Fig. 6g).

5.6 Multivariate Analysis

Due to the intensification of groundwater's physical and chemical characteristics, a variety of multivariate statistical techniques, including principal components analysis (PCA), factor analysis (FA), and cluster analysis (CA) are being employed for steadfast data analysis, interpretation, and impact factor determination (Hossain et al., 2024; El-Rawy et al., 2023).

5.6.1 Correlation Matrices

The correlation coefficient matrix is an effective way to evaluate how the parameters are associated with each other by assessing their positive and negative relationships (Fatima et al., 2022). Using a matrix, the dependency between many variables has been evaluated instantaneously (Kouacou et al., 2024). In the studied samples, a very strong positive correlation was observed between conductivity with TDS, Na^+, and Cl^-; TH with SO_4^{2-} and Mg^{2+}; Na^+ with Cl^-; SO_4^{2-} with Mg^{2+} (Table 5); however, TH, SO_4^{2-} and Mg^{2+} show a very strong negative correlation with RSC. The EC and TDS with TH, SO_4^{2-}, SAR showed strong correlations; likewise Cl^- with Na% and SSP; SO_4^{2-} with K^+; Mg^{2+} with MAR; Na^+ with Na%, KI and SSP (Table 5). It is clearly observed that all irrigation parameters except RSC and MAR have very strong positive correlation matrix between each other (Table 5), displays the strong control of alkalies while RSC reflects strong correlation with MAR exhibit role of alkaline-earth contents. It reflected that the increase in TDS level is primarily due to the incorporation of Na^+, Cl^-, supplemented by SO_4^{2-} and Mg^{2+}, possibly because of seawater intrusion. There is negligible impact of the geology of the area. All other relations are moderate to insignificant.

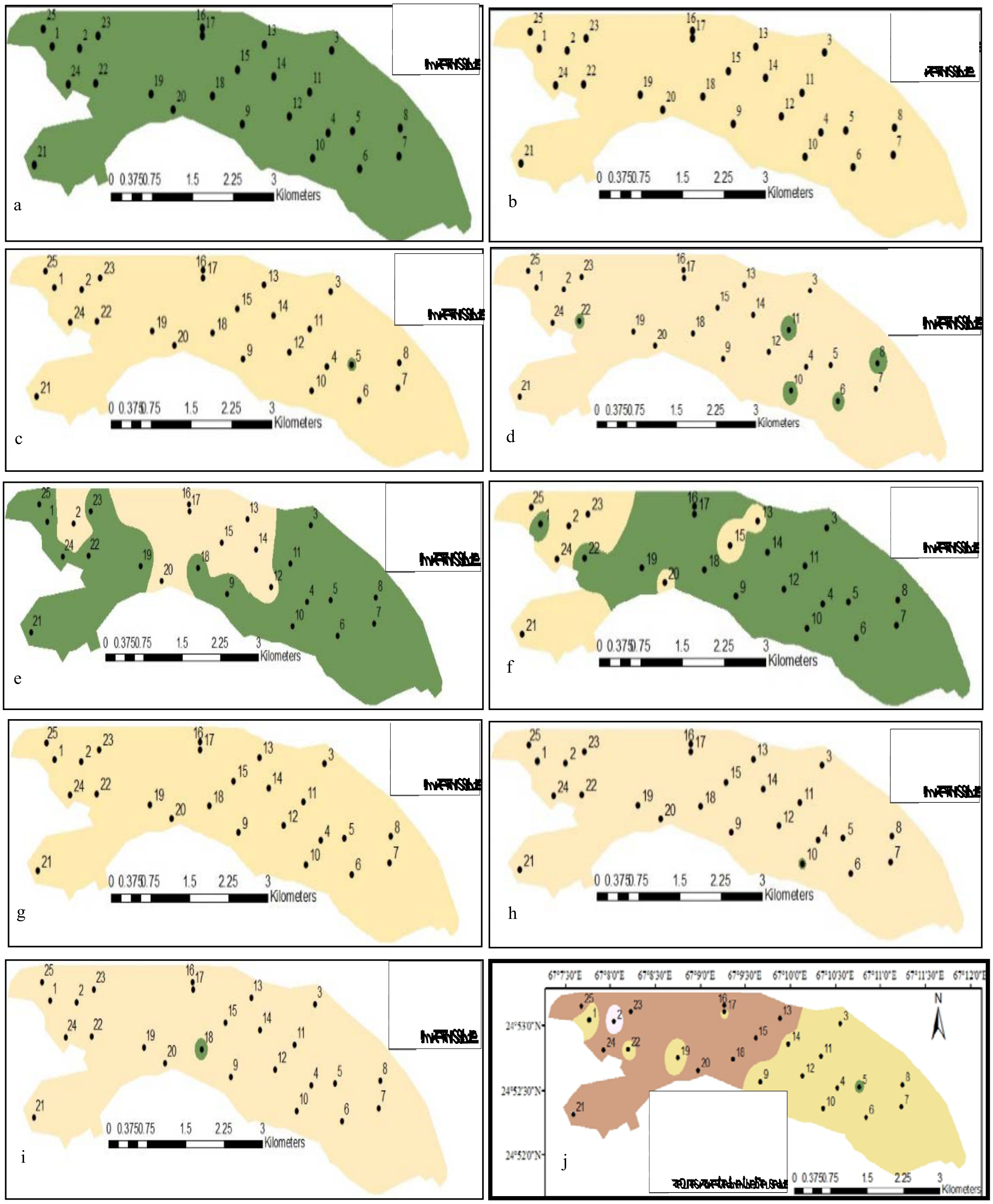


Fig. 5. Spatial variation analysis of physicochemical parameters of groundwater samples reflecting suitable precincts for drinking purpose using WHO Guidelines 2017: a) pH, b) TDS, c) Na^{+}, d) Ca^{2+}, e) Mg^{2+}, f) K^{+}, g) Cl^{-}, h) SO_4^{2-}, i) HCO_3^{-}, j) WQI, Latitude/Longitude and direction of all figures are same as Fig. 5j.

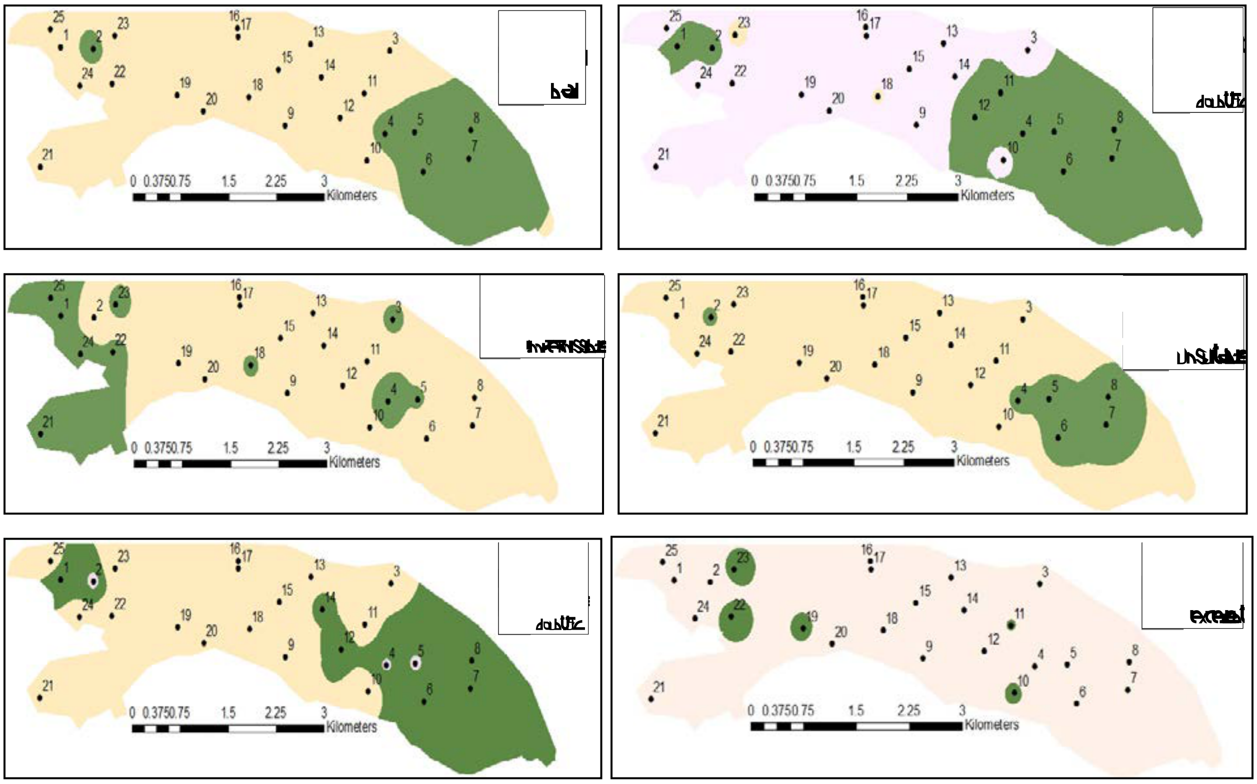


Fig. 6. Spatial variation analysis of irrigation quality parameters of groundwater samples: a) SSP, b) SAR, c) MAR, d) KI, e) Na%, f) PI, Latitude/Longitude and direction of all figures are same as Fig. 5j.

Table 5: Correlation matrix of physicochemical and irrigation quality parameters of studied samples.

	pH	EC	TDS	TH	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	RSC	Na%	PI	KI	MAR	SAR	SSP
Depth	.01	.16	.16	.10	-.30	.05	.15	.12	-.15	.16	.16	-.12	-.11	.14	.12	.15	.28	.17	.14
pH		-.13	-.13	-.23	.04	-.37	-.03	-.15	-.14	-.20	-.03	-.41	.15	.21	.20	.14	-.01	.06	.21
EC			**1.00**	*.73*	.19	-.01	**.92**	*.79*	.45	*.65*	**.91**	.55	*-.79*	.39	.24	.35	.36	*.71*	.39
TDS				*.73*	.19	-.01	**.92**	*.79*	.45	*.65*	**.91**	.55	*-.79*	.39	.24	.35	.36	*.71*	.39
TH					.00	.45	*.42*	**.93**	.46	**.95**	.38	*.60*	**-.98**	-.28	-.43	-.27	.50	.07	-.27
CO_3^{2-}						-.40	.26	.11	-.21	.08	.27	.05	-.07	.36	.32	.31	.23	.31	.37
HCO_3^-							-.28	.21	.32	.38	-.30	.22	-.25	-.57	-.56	-.56	-.02	-.47	-.57
Cl^-								.50	.33	.35	**.99**	.35	-.52	*.63*	.52	.58	.23	**.88**	*.64*
SO_4^{2-}									.38	**.90**	.51	*.63*	**-.96**	-.09	-.25	-.06	.53	.25	-.09
Ca^{2+}										.15	.31	.47	-.42	-.05	-.12	-.09	-.47	.14	-.05
Mg^{2+}											.32	.50	**-.94**	-.29	-.43	-.27	*.72*	.02	-.28
Na^+												.38	-.49	*.68*	.57	*.64*	.22	**.92**	*.69*
K^+													-.59	.07	-.03	.13	.01	.28	.06
RSC														.17	.33	.16	-.54	-.18	.17
Na%															**.98**	**.95**	-.14	**.90**	1.00
PI																**.94**	-.24	**.82**	.98
KI																	-.16	**.89**	.95
MAR																		.03	-.13
SAR																			**.90**

Very strong correlation (**0.8-1**) Strong correlation (*0.6-0.79*) Moderate correlation (0.4-0.59) geology of the area. All other relations are moderate to insignificant.

5.6.2 Factor Analysis

Factor analysis helps to extract the variables into a smaller number of significant parameters and to employ for the analysis of water (Aduojo et al., 2024). A total of 20 physicochemical and irrigation quality parameters are used for PCA and factor analysis. There are five noticeable factor having eigenvalues >1 with a cumulative variance of 91.90% (Table 6). The leading factor 1 accounting for approximately 39.11% of total variance shows strong to moderate positive loading for EC, TDS, Na^{+}, Cl^{-}, SAR TH, Mg^{2+}, SO_4^{2-}, K^{+}, Na%, and SSP while moderate negative loading (-0.659) for RSC (Table 6; Fig. 7). This observation implies that these parameters are a consequence of intrusion processes brought on by anthropogenic activities. Factor 2 describes 30.89% of the total variance, and displays strong positive loading for PI, SSP, KI, Na% and RSC, and negative loadings for TH, Mg^{2+}, SO_4^{2-}, and HCO_{3-}, on the PCA diagram (Fig. 7). The other three factors have relatively low variance; factor 3 has 9.99% variance, linked with MAR (0.824), and Ca^{2+} (-0.785) (Table 6). Factor 4 (6.74% variance) possesses strong positive loading for depth and negative loading of CO_3^{2-} (Fig. 7). Factor 5 with 5.17% variance deals with only one parameter pH (0.827) reflecting there is no significant control of pH on the other parameters. Factor analysis exhibits prodigious correspondence with the correlation matrix.

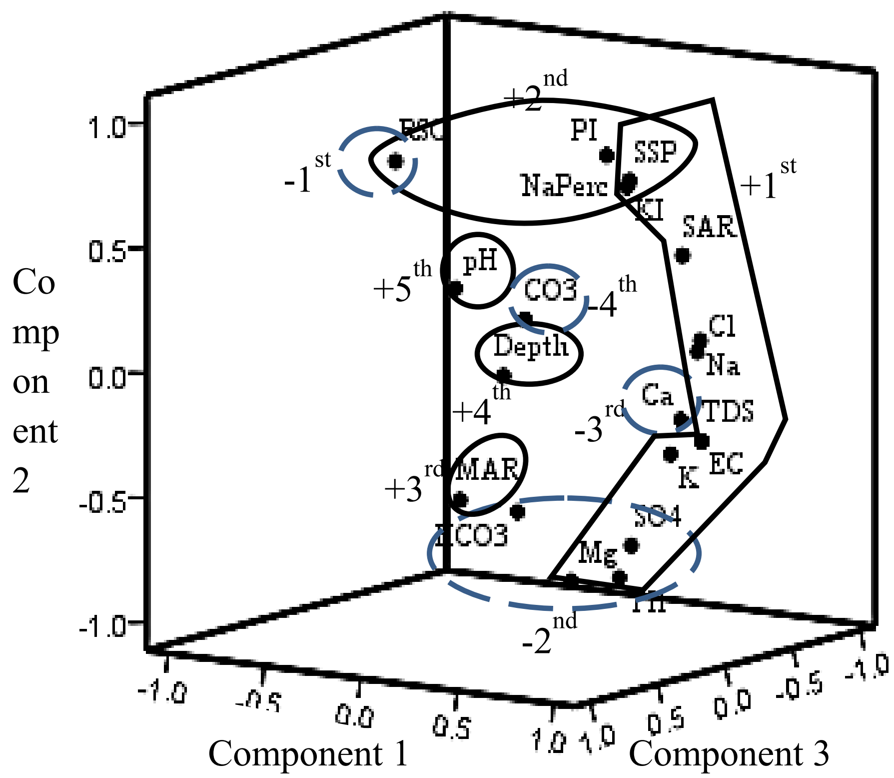


Fig. 7. Rotated Space diagram based on PCA of physiochemical and irrigation quality parameters of groundwater samples (solid circles represent positive loadings and broken circles demarcate negative loading values).

Table 6: PCA extraction method of component matrix based on physicochemical and irrigation quality parameters of groundwater samples.

	Component				
	1	2	3	4	5
Depth	.177	.002	.306	.842	-.151
pH	-.066	.328	.313	.041	.827
EC	.961	-.230	-.041	.035	.060
TDS	.961	-.230	-.041	.035	.060
TH	.569	-.809	.011	-.008	.065
CO_3^{2-}	.311	.247	.339	-.717	-.132
HCO_3^-	-.198	-.673	-.332	.240	-.191
Cl^-	.943	.127	-.035	.045	.074
SO_4^{2-}	.690	-.655	.095	-.057	.069
Ca^{2+}	.332	-.316	-.785	.017	.326
Mg^{2+}	.514	-.787	.292	-.015	-.044
Na^+	.957	.172	-.036	.048	.041
K^+	.539	-.380	-.414	-.202	-.285
RSC	-.659	.721	-.088	.044	-.123
Na%	.600	.780	-.021	.034	-.048
PI	.461	.862	-.050	.058	-.086
KI	.578	.750	-.036	.050	-.130
MAR	.313	-.408	.824	.013	-.125
SAR	.853	.502	-.052	.058	-.035
SSP	.605	.777	-.015	.038	-.043
Variance %	39.11	30.89	9.99	6.74	5.17
Cumulative %	39.11	70.00	79.99	86.73	91.90

5.6.3 Cluster Analysis

Cluster analysis is helpful to demonstrate the similarity and bunching of the datasets, the equality and overlap of the clusters, and the reasons for change across parameters or originate from the same place (Hossain et al., 2024; El-Rawy et al., 2023; Kim et al, 2005). The dendrogram of groundwater samples from the study area revealed four major clusters along with several minor clusters (Fig. 8). Cluster 1 comprised of 14 out of 20 parameters including all irrigation parameters (RSC, SAR, SSP, Na%, KI, PI and MAR), with few physico-chemical parameters (depth, pH, Mg^{2+}, K^+, Ca^{2+}, CO_3^{2+}, and HCO_{3-}); reflecting that all the irrigation parameters are regulated by the concentrations of these physic-chemical parameters which ultimately used to elaborate basic chemistry of groundwater. They have strong correlation with each other as observed by the distance of minor agglomeration which provides a true picture of their mutual relationships (Fig. 8). Cluster 2 includes TH, Na^+, Cl^- and SO_4^{2-}, representing the irrigation parameters mainly controlled by Na concentration. Cluster 3 grouped cluster1 and 2 and displays a moderate relationship with the parameters constituting clusters 1 and 2 (Fig. 8). Cluster 4 embraces EC and TDS, both are strongly interlinked and have moderate to weak relationship with all other parameters. The outcomes of cluster analysis were consistent with the relationships displayed in the factor analysis and correlation matrix; pinpoints that the application of a combination of variable multivariate techniques to evaluate groundwater quality is a versatile and practical approach that provides novel perspectives and exceptional results.

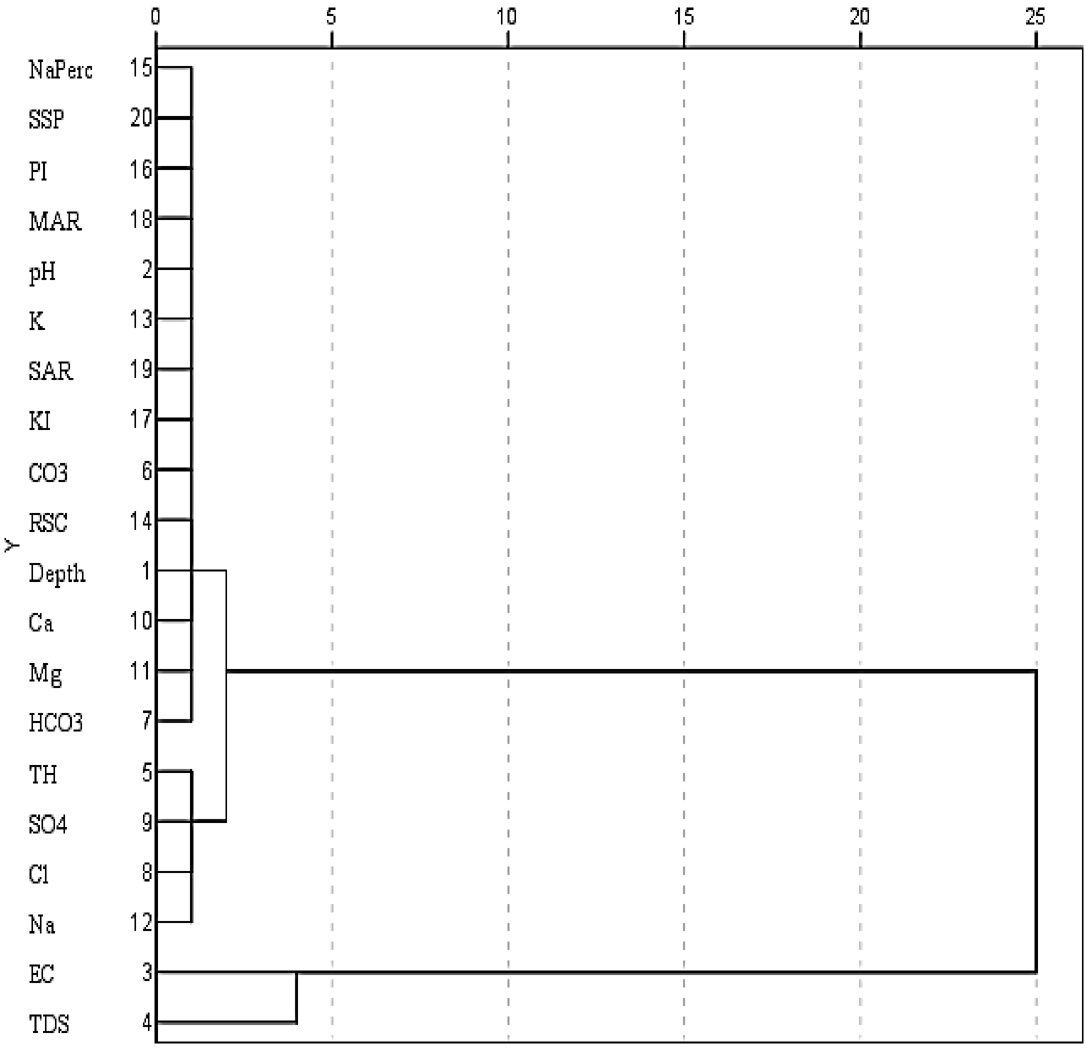


Fig. 8. Dendrogram using average linkage (between groups) based on physicochemical and irrigation quality parameters of studied area.

5. Conclusion

Assessment of groundwater quality of Shah Faisal Town concluded that 60% of groundwater samples are categorized as a poor type while 40% are classified as an unsuitable for drinking purpose. Based on irrigation quality parameters; RSC, SAR and PI majority of the samples are placed in the good to excellent categories. Cations graph versus TDS show that all samples are in the category of seawater intrusion/evaporation dominance and the hydrogeochemical facies of water is NaCl type. The maximum number of samples show an ionic tendency of Na^{+}+K^{+}>Ca^{2+}>Mg^{2+}, Cl^{-} >SO_4^{2-}>HCO_{3-}+CO_3^{2-}. Spatial Analysis concluded that the pH of entire study area is suitable, however, TDS, Na^{+}, HCO_{3-}, SO_4^{2-}, Cl^{-}, and Ca^{2+} concentrations, confining the area as impermissible zone for drinking purpose. The distribution of WQI values clinched that samples collected from the region away from Chakoar Drain is comparatively more suitable for industrial and irrigation applications. Likewise, K^{+}, SSP, Na% and KI also reflected that as moves westward towards Chakoar Drain the water becomes impermissible while SAR and PI displayed entire area good for irrigation. Multivariate analysis shows that a very strong positive correlation was observed between conductivity with TDS, Na^{+}, Cl^{-} and RSC; Na% with SSP, PI, KI, and SAR. Na and Cl are maximum interlinked with each other while KI and SSP show a positive correlation with a very high coefficient value. It has been recommended from the research that without treatment, the domestic use of groundwater adjacent to the Chakoar Drain should be avoided to prevent health issues in the community.

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Authors Contribution

Erum Bashir involved in write up, data processing and preparation of figures. Maria Abdul Wasay, collected samples, analysis and did mapping. Shahid Naseem, proposed the main concept and support in analysis. Maria Kaleem did review before submission and proof read of the manuscript. Bushra Shahab did provision of relevant literature review.

Conflict of Interest

All authors declare no conflict of interest.

Data Availability Statement

The data sets generated and analysed during the current study are available in the main body of the paper.

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