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Coastal Groundwater Quality Evaluation and Hydrogeochemical Characterization Using Chemometric Techniques

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Abstract: The physicochemical parameters and heavy metals concentration in the groundwater of the coastal region of Lasbela, Baluchistan were investigated. Cations and anions were determined through ion chromatography. The concentration levels of eight heavy metals (Cr, Cd, Pb, Zn, Fe, Cu, and Mn) in the groundwater were analyzed through the analytical procedures of atomic absorption spectrophotometry. The cations were present in the descending order of magnesium > sodium > calcium > potassium and anions as bicarbonate > sulfate > chloride. Two parameters (bicarbonate and total dissolved solids) were above and other physicochemical indices of groundwater were below the threshold limits of the WHO. Positive correlations of pH and electrical conductivity were observed with cations and anions. The significant positive correlation between sodium and bicarbonate (0.427) indicated the dissolution of carbonate rocks. The concentration of heavy metals (Cu, Cd, Mn, Cr, Pb, Fe, Zn, and Ni) ranged from 0.1 to 0.4, 0.02 to 0.09, 0.04 to 0.9, 0.03 to 0.5, 0.01 to 0.91, 0.05 to 1.30, 0.01 to 0.60, and 0.02 to 0.90 mg/L. The highest concentration of Pb (0.21 mg/L) and Cd (0.16 mg/L) were approximately 20 and 50 times higher than the permissible limits of the WHO. Hierarchical cluster analysis classified the twelve physicochemical parameters into four clusters and the eight heavy metals into seven clusters. Principal component analysis extracted eight latent components for physicochemical properties and heavy metals with eigenvalues greater than 1.0 that had positive loads of fluoride, iron, electrical conductivity, sodium, cadmium, and sulfate. Major pollutants in the groundwater were accounted for by PC 1, and the main factors that affected the water quality were Pb, Cr, and Cu. Fe had a modest impact on the water quality in this region. From the findings, it can be concluded that the coastal groundwater of the region has a higher concentration of heavy metals, which makes it unfit for drinking purposes.

Keywords: groundwater contamination; physicochemical properties; correlation analysis; latent components

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1. Introduction

Groundwater is constantly consumed by human beings for drinking and other domestic purposes. The quality of water is related to its mineral composition. The mineral content analysis of groundwater gives information about the water–rock interface, the structure of the aquifers, the processes that occur in the aquifers, and the duration of water in aquifers. Unhygienic practices and natural aquifer processes such as mineral closure and precipitation can affect groundwater. The interaction between the lithosphere and hydrosphere of coastal zones makes groundwater rich in minerals [1]. Industrial development in the commercial and urban sectors over the last few years has created both organic and inorganic pollutants in coastal zones. The pollutants then naturally dissolve during the hydrological cycle. Anions, cations, and inorganic salts, which are used in

industrial processes, are serious water contaminants are also released into aquatic systems. Essential cations such as Na^+, Ca^{2+} $Mg^{2+,}$ and K^+ are required by living organisms, and when their concentration in drinking water exceeds the permissible limit, they can cause severe diseases. Heavy metals are introduced into the aquatic environment through anthropogenic activities [2,3]. Heavy metals are potentially toxic due to their low degradation rate and environmental persistence [4,5]. Three heavy metals (Pb, As, and Hg) are potentially hazardous and can cause cancer even at low concentrations. Heavy metals (HMs) bind to organic materials and sediments that are introduced into marine ecosystems from various sources. Marine sediments are vulnerable to pollution and toxic elements found in riverine, coastal, and estuarine habitats [6]. The geochemistry and aquatic atmosphere analysis of regional and temporal variations showed that heavy metals accumulate through different sources [7,8]. Principal component analysis (PCA), cluster analysis (CA), and correlation analysis are multivariate statistical techniques that have been often used to differentiate pollutant sources into natural and anthropogenic, identify processes, and quantify heavy metal pollution in the marine surroundings [8,9]). The PCA method is frequently used for the separation of the origins of heavy metals into natural and industrial sources [8]. Hierarchical cluster analysis (HCA) is used to examine the relationships between the variables in the monitoring analysis. Correlation analysis is used for the classification of variables and their interrelationships. Several statistical techniques can be applied to complicated data sets of geochemical profiles.

Pakistan's coastline surrounds an area of around 1050 km along the Northern Arabian Sea [2]. Pakistan's continental margin is separated into the Ormara, Hub, and Indus topographies, which correspond to the country's geological structure. The coastal region of Pakistan contains a variety of ecosystems, including rocky and sandy beaches, the Indus delta, and the estuary environment. The water table in Baluchistan is falling by 3.5 m yearly. In many areas of Baluchistan, tube wells are the primary supply of groundwater, and the water that they provide is utilized for cultivation as well as human use. However, Baluchistan is experiencing a water shortage as a result of tube wells drying up due to overuse for agriculture and other purposes. The groundwater table of Baluchistan is in a critical condition, and, in the near future, it will become more severe. The water quality has declined as a result of the limited supply and excessive demand. The groundwater management techniques heavily depend on the physicochemical factors [10]. Water quality indices are developed and extensively used all over the world for the assessment of the suitability of water for irrigation and drinking purposes [11]. Such indices provide groundwater quality information to the public and relevant agencies that is extremely effective for the purpose of managing water resources. Limited information is available about heavy metal contamination in the coastal area of the Arabian Sea [12]. The Lasbela district is situated between the longitudes of 65°12′11″ and 67°25′39″ east and the latitudes of 24°53′02″ to 26°39′20″ north. The Arabian Sea and the district of Khuzdar both share its northern and southern boundaries, respectively. The district's eastern border is shared with the Baluchistan districts of Gwadar and Awaran, as well as the Dadu, Malir, and Karachi West districts of Sindh province. There are six industrial estates in Lasbela: the Hub Industrial and Trading Estate, the Marble City, Gaddani, the Windar Industrial & Trading Estate, the Special Industrial Zone, Windar, the Uthal Industrial Estate, and the Uthal Industrial Estate II [13]. Among Pakistan's total production of bauxite (50,000 metric tons), roughly 3000 tons are produced in the districts of Labella and Khuzdar. Therefore, the objective of this research was to assess the physicochemical properties and heavy metals in the groundwater of Lasbela, situated in the north of the Arabian Sea coast. The multivariate statistical approach was used to differentiate pollutant sources into natural and anthropogenic, identify sources, and quantify heavy metal pollution.

2. Materials and Methods

2.1. Sampling Site Description and Procedure of Sampling

Lasbela is situated in the coastal region of Baluchistan, with a 17,355 km^2 area situated 130 km north of Karachi (north of Arabian Sea). The four sub districts of Lasbela are Bela, Uthal, Hub, and Dureji and are the focus area of this research study. The industries in Lasbela include steel, food/beverages, engineering, chemical/pharmaceuticals, and textiles. Samples of groundwater were collected in June 2021, and the sampling locations are given in Figure 1. The water samples were collected from tube wells and manually dug boreholes. The districts of Khuzdar and Lasbela are the primary sources of barite in Pakistan [14]. Figure 2 shows the impact of barite mining, milling, and the drilling process on the contamination of the groundwater in Lasbela. The current research was carried out in regions with high levels of Cd in the groundwater, in contrast to locations with significant amounts of lead, copper, and zinc deposits, which are present throughout Baluchistan.

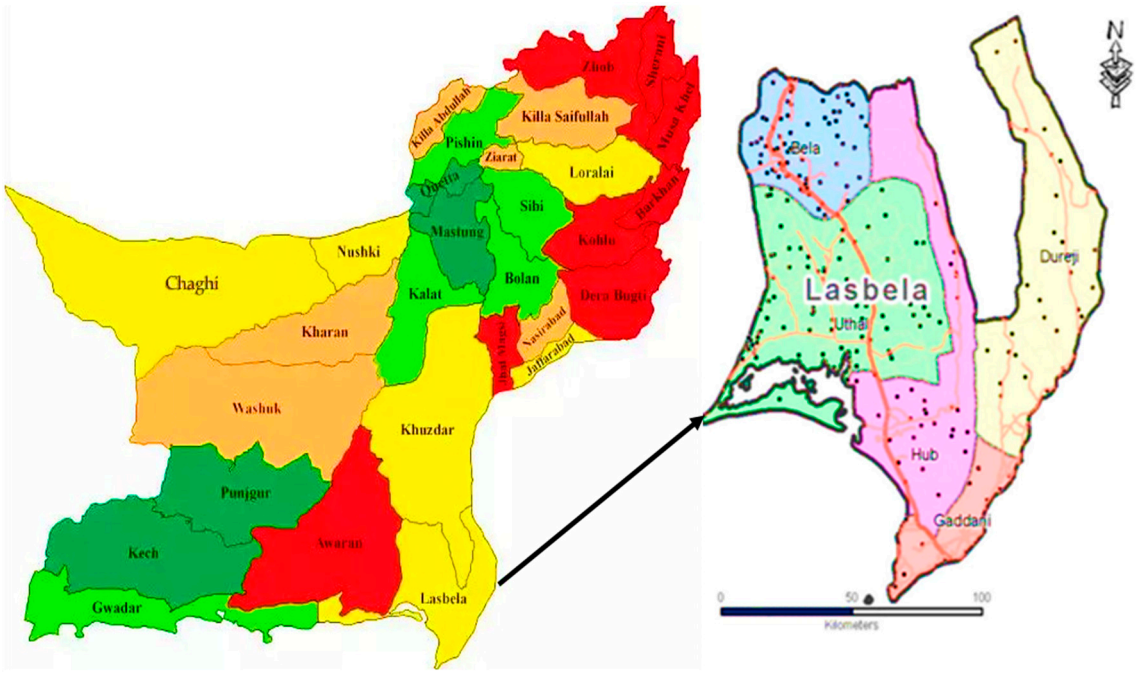


Figure 1. Map showing the research area of Lasbela, coastal region of Baluchistan, Pakistan.

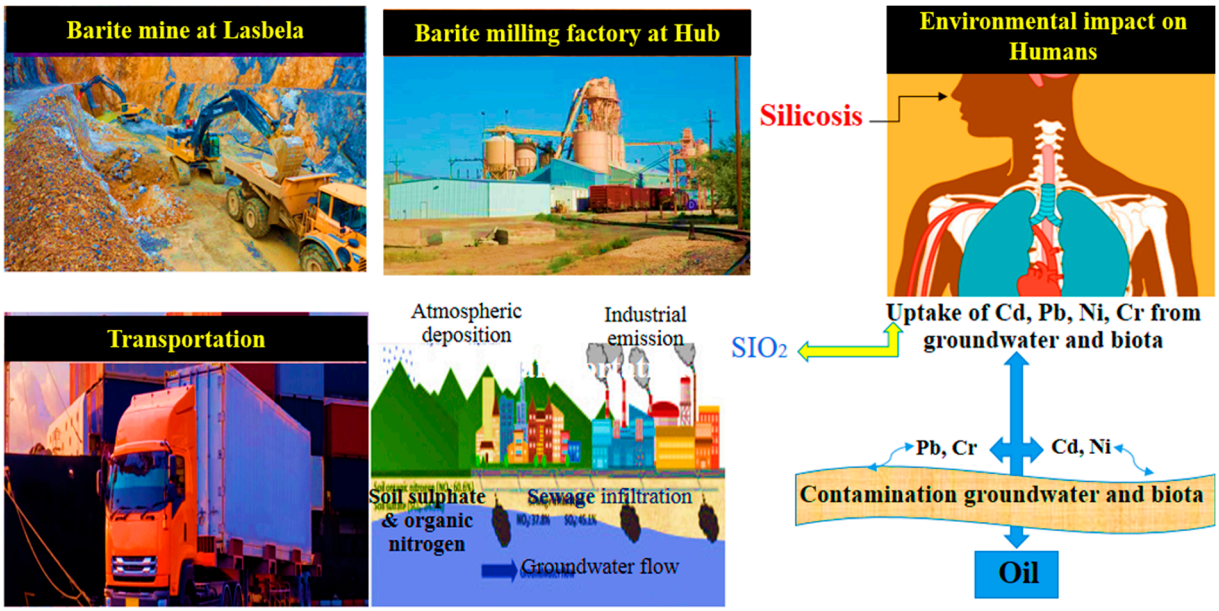


Figure 2. Schematic model showing the impact of barite mining, milling, and the drilling process on the groundwater in Lasbela.

To obtain water for home use, wells with a lesser diameter were outfitted with a straightforward rope and bucket. Additionally, several boreholes in the area, also known as tube wells, were examined. According to reports, they were built and dug to depths of around 400 m, with diameters of approximately 300 mm. Turbine pumps powered by diesel engines are often installed in boreholes. Only a few locations have a diesel–electric generator set installed beside an electric submersible pump. The boreholes were built properly to block the entry of surface water contaminants. The groundwater resource was split into two parts as the initial phase of the sampling technique. Following this, the sampling locations were ranked in order of suitability for human use and consumption. For the chemical examination of water, the samples were taken in pre-sterilized bottles. As soon as possible after collection, water samples were placed in a refrigerator for preservation; however, in some cases, there was a delay of several hours. They were delivered in insulated containers to the Gomal University Dera Ismail Khan Institute of Chemical Sciences for the ensuing physiochemical and heavy metal analysis using the standard approach of [15].

2.2. Water Sample Collection and Preparation

Groundwater (144) samples were taken from the 36 different pre-selected sample locations in Lasbela, Baluchistan, in polythene bottles pre-washed with 5% conc. HNO_3. The samples of water were collected from hand pumps and tube wells installed at different depths ranging from 50 to 400 feet. Every well was purged for 10 min before sampling to ensure that the water samples taken were representative [16]. The water samples from each point were taken in two separate bottles, (i) the first for physicochemical parameters and (ii) the second for heavy metal determination. The groundwater sample collection and analysis were carried out using standard protocols [15]. Portable equipment for EC, pH, and TDS was calibrated before measurement. Before measuring the pH values of water samples, the pH meter was calibrated using three standard solutions with pH values of 3, 7, and 10. The samples were examined for hardness (HCO_3^{-1}), sodium, calcium, magnesium, potassium, chloride, fluoride, and sulfates. On-site tests of EC were carried out using an Inolab pH meter (Inolab pH 7110). Chloride was calculated through a formula [15]. Using the EDTA titrimetric technique, the hardness of HCO_3^{-1} was determined for water samples [15]. Sulfates and TDS were determined in the samples using the gravimetric technique [15]. Through a statistical program, physicochemical parameter data and heavy

metal concentrations were statistically examined for descriptive analysis (mean, minimum, maximum, standard deviation, standard error, skewness, and kurtosis).

2.3. Major Cations, Anions, and Heavy Metal Analysis

Cations such as K^+, Ca^{2+}, Na^+, and Mg^{2+} and anions such as F^-, Cl^- $NO_3{}^-$, and $SO_4{}^{-2}$ were determined by means of an ion chromatograph. The instrument was calibrated using the Dionex-6 Cation-2 standard and 7-Anion-2 standard from Thermo Fisher Scientific Waltham, USA. An atomic absorption spectrophotometer (Model No. AA 7000) was used for trace element determination (Pb, Mn, Zn, Cr, Fe, Ni, and Cu) in groundwater samples. Each sample was examined three times, with the average value serving as the basis for justification. De-ionized water was used for the dilution of the certified 100 mg/L (Merck, Germany) reference solutions of the elements.

2.4. Chemometric Analysis for Identification of Pollution Sources

Hierarchical cluster analysis (HCA), principal component analysis, and correlation analysis were performed.

The physicochemical characteristics of water quality were subjected to further analysis using Pearson's correlation analysis through IBM SPSS software (v. 20) to determine the association between the physicochemical parameters and heavy metal contamination/pollution and source identification in the research region. If correlation value (r) > 0.7, the correlation is strong, and if r < 0.5, then the correlation is weak. PCA was used to extract components using the Kaiser criterion. The components of the factors were extracted using Kaiser normalization in Varimax rotation, and the actual number of factors could be determined using the Kaiser criterion [17,18], which excludes factors with eigenvalues less than 1. The HCA statistical technique is primarily used to assess quality factors for the clustering and grouping of samples of comparable quality.

3. Results and Discussion

Table 1 summarizes the physicochemical features of groundwater and their comparison with the WHO recommended limits [19]. Physicochemical parameters are of significant importance in determining the nature and level of pollution in water. The findings indicated that the water is relatively alkaline, having a pH range of 5.9 to 7.9, with a mean value of 7.11, and it was compared with a previous study conducted in Southern India [20]. The calcareous properties of the study region's aquifers may be the reason for the alkaline pH [21]. The pH of water samples was within the permitted range (6.5–8.0) of the WHO (2011). The average EC value of the groundwater was 826 s/cm, within the permissible limits [19,22]. The reason for this is that the research area's water–rock interaction does not significantly affect the suspension of minerals in the groundwater, as reported by [23]. TDS had a mean value of 805, with a range of 679 to 923 mg/L, and exceeded the threshold limits of the WHO, showing that the area contains geogenic supplies of several minerals. The average values for Cl, $SO_4{}^{-2}$, and HCO_3 were 64.3, 214.0, and 295.6 mg/L, respectively. The results showed that the mean values for cations (Na^+, K^+, Mg^{+2}, and Ca^{+2}) were 90.0, 4.65, 105, and 21.28 mg/L. Mg^{+2} had the highest value among the cations, at 105 mg/L. Significant cations were present in the following temporal order: $Mg^{+2} > Na^+ > Ca^{+2} > K^+$. Meanwhile, the major anions were $HCO_3{}^- > S\,O_4{}^{-2} > Cl^-$. $HCO_3{}^-$ and Mg^{+2} had the highest concentrations, indicating that carbonate minerals had been dissolved in the groundwater of the studied area [24]. Chloride (Cl^-), which was found in groundwater samples, had the second-highest concentration of the examined anions, caused by either natural or anthropogenic activities [25]. The sulfate content was consequently below the highest threshold advised [19]. It was noted that the highest concentration found for the cations in underground water samples was distributed among the $CO_3{}^-$ dissolved region.

Table 1. Statistical analysis of physicochemical parameters of groundwater samples collected in coastal region of Baluchistan, Pakistan.

Parameter	Minimum	Maximum	Mean	S.D.	Variance	NWQS (Pak)	WHO (2011)
pH (on scale)	5.9	7.9	7.114	0.511	0.26	6.5–8.5	6.5–8.0
EC (µS/cm)	689.0	981.0	826.88	81.46	6636.1	1200	1500
TDS (mg/L)	679.0	923.0	805.0	62.67	3927.3	1000	300
HCO_3^{-1} (mg/L)	201.0	395.0	295.66	58.31	3400.1	500	500
Na^+ (mg/L)	44.0	172.0	90.05	27.20	740.2	200	200
Ca^{+2} (mg/L)	17.2	25.6	21.28	2.46	6.09	75	75
Mg^{+2} (mg/L)	70.0	153.0	105.72	23.59	556.4	150	50
K^+ (mg/L)	1.9	7.9	4.65	1.69	2.85	12	12
Cl^- (mg/L)	41.0	88.0	64.63	12.02	144.52	250	250
SO_4^{-2} (mg/L)	151.0	276.0	214.0	35.29	1246.05	250	250

3.1. Heavy Metal Concentration in Groundwater

The average level of heavy metal contamination in the Lasbela district's groundwater is displayed in Table 2. The average Pb content was 0.21 mg/L, with higher and lower values of 0.90 mg/L and 0.04 mg/L, respectively. The WHO permitted limit of 0.01 mg/L and the Pak-EPA limit (0.05 mg/L) were greatly exceeded by the mean Pb value in the district of Lasbela. The highest Pb concentration in Lasbela (0.21 mg/L) was approximately 20 and 30 times higher than the maximum values listed by Pak-EPA and the WHO, respectively. All water samples taken from various locations had Pb concentrations that were higher than the levels of [19] and [26]. In the studied region, there are small galena deposits along with barite deposits. In the area near Khinyar in the district of Lasbela, high Pb content has been reported [27]. The mean Cd (0.16 mg/L) content in Lasbela groundwater was below the detection limit (BDL) of 0.18 mg/L. The mean and highest Cd content levels were higher than the acceptable allowed threshold suggested by the WHO (0.003 mgL^{-1}). However, the mean Cd content was within the Pak-EPA-set upper limit of 0.01 mg/L. All of the water samples had greater Cd concentrations when compared to the WHO recommended level (0.003 mg/L). Earlier investigators have found higher concentrations of Cd (3 µg/L) in drinking water in Winder town in the district of Lasbela, Baluchistan [28]. Most of the Lasbela sites have high groundwater Ni concentrations. The Ni content in Lasbela groundwater was found to range from 0.02 to 0.90 mg/L, with an average of 0.14 mg/L. The WHO limit values of 0.07 mg/L and 0.02 mg/L were exceeded by the mean and maximum Ni levels found in the groundwater samples. The range for the mean Cu content in the groundwater was 0.03–0.50 mg/L; the Cu level of 2.0 mg/L in drinking water is the permitted limit for all mean concentrations of Cu. Thus, it may be concluded that there is an extremely minimal likelihood of Cu groundwater contamination at the district level. Mn values in water samples ranged from 0.01 to 0.91 mg/L, with a mean of 0.29 mgL^{-1}. In the district of Lasbela, the average Mn content in the groundwater was below the permissible level of 0.5 mg/L [29]. While most of the samples had Mn concentrations below the recommended limits, certain areas in the district of Lasbela revealed greater Mn concentrations than the limit value.

Table 2. Statistical analysis of heavy metals in groundwater samples collected in coastal region of Baluchistan, Pakistan.

Parameter	Minimum	Maximum	Mean	S.D.	Variance	Skewness	Kurtosis		WHO (2011)
Cd	0.1	0.40	0.16	0.12	0.01	0.29	1.21	10	(3 µg/L)
Cr	0.02	0.09	0.03	0.02	0.05	0.38	−1.07	50	50 (µg/L)
Pb	0.04	0.90	0.21	0.24	0.05	1.32	0.78	50	10 (µg/L)
Cu	0.03	0.50	0.07	0.10	0.01	2.89	9.16	2000	2000 (µg/L)
Mn	0.01	0.91	0.29	0.26	0.06	0.78	0.49	500	400 (µg/L)
Fe	0.05	1.30	0.34	0.38	0.14	1.09	−0.07	300	300 (µg/L)
Zn	0.01	0.60	0.25	0.13	0.01	0.04	0.15	5000	3000 (ug/L)
Ni	0.02	0.90	0.14	0.14	0.02	4.67	24.9	20	(70 µg/L)

To check the inter-ionic link in commonly existing ions, present in solutions of normal distribution, correlation coefficients were used as shown in Table 3. In the current study, there was a substantial positive association between pH and EC, TDS, Na, $^{-}$,K, F^{-}, and Cl^{-}, demonstrating that pH plays a significant role in regulating the groundwater chemistry and that the concentrations of major cations and anions rise any time the pH lowers (acidity rises). Additionally, it was shown that the majority of the main cations and anions had positive correlations with the TDS values, indicating that TDS rose as the concentration of significant ions increased (cations and anions). For instance, the correlation between Mg^{2+} and HCO_3 and TDS is quite high (r = 0.361 and 0.405, respectively), but the correlation between K^{+} and Ca^{2+} and TDS is mild (r = 0.102 and −0.207, respectively). Cl^{-} and $SO_4{}^{2-}$ are weakly linked, whereas $HCO_3{}^{-}$ is strongly linked with TDS. The total quantity of components that are dissolved in the groundwater and the TDS values suggest [30] the increased dissolution of underground rock in groundwater fluids. The bivariate plots between the main ions and TDS may be used to describe the geochemical processes that lead to groundwater mineralization. The bivariate plots for a number of ions (including Cl, K^{+}, Ca^{2+}, and Na^{+}) and TDS that have high correlations indicate that particular ions and flow paths result in the mineralization of water. Additionally, our results show that sodium ions have a notable positive correlation with chlorine ions (0.140), $SO_4{}^{2-}$ (r = 0.423), and HCO_3 (r = 0.427), suggesting that the impacts of vaporization on groundwater are dependent on agricultural activities [31]. Ca^{2+} and Na^{+} have a weak positive correlation (r = 0.118), suggesting that they may also engage in the same geochemical processes. The most significant positive correlation between Na^{+}, $HCO_3{}^{-}$, and F^{-} was found to be 0.427 and 0.398, respectively, indicating the dissolution of carbonate rocks (dolomite), which may have been present in a sedimentary state. Heavy metals correlation analysis showed that Mn, Pb (0.374), Fe, Pb (0.471) and Ni, Mn (0.434) showed significant correlation as shown in Table 4. A Piper diagram was constructed to determine the basic chemistry of the water samples from all four sampling areas with regard to the presence of anions such as bicarbonate, sulfates, chlorides, and fluorides, as well as alkali and alkaline cations (Na^{+}, K^{+}), (Ca^{+2}, Mg^{+2}), as shown in Figure 3. NaCl dominates in the Piper diagram, preceded by mixed CaMgCl-type facies (Figure 3). This mechanism suggests that alkalis (Na^{+} + K^{+}) and strong acids ($Cl^{+}SO4^{-2}$) predominated over alkaline earth (Ca^{2+} + Mg^{2+}) and weak acids. The elevated Na^{+} content in conjunction with the low Ca^{2+} concentrations show that the Ca^{2+} and Na^{+} ion exchange mechanism is an essential geochemical activity for Na-Cl groundwater. Figure 4A–F indicate the spatial distribution of heavy metals (Cd, Cr, Mn, Fe, Zn, and Ni) in the study area of Lasbela.

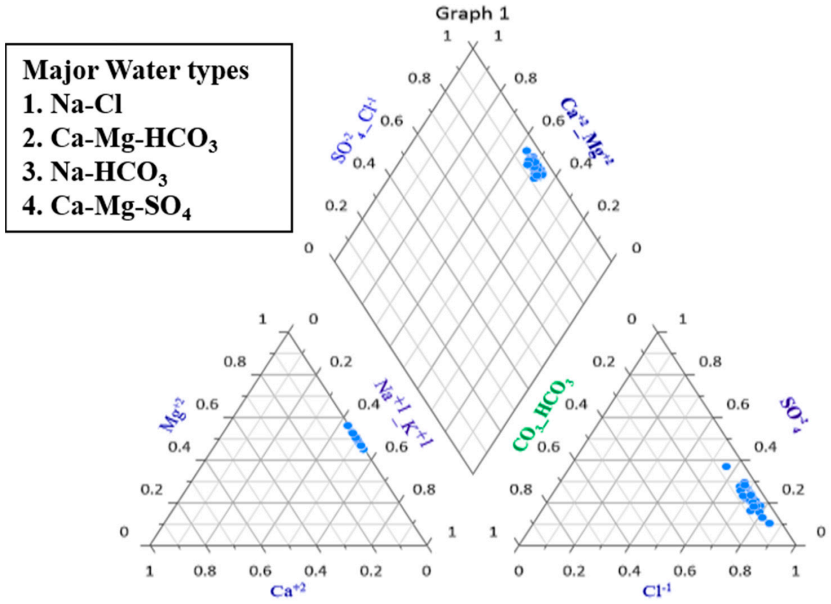


Figure 3. Piper diagram shows different groundwater types, including Na-Cl, Ca-Mg-HCO_3, Na-HCO_3, and Ca-Mg-Cl types of coastal water. Mean values of cations and anions are indicated as circles and triangles, respectively, in the four sampling areas of Lasbela (northern region of Arabian Sea, Pakistan).

Table 3. Correlation analysis of physicochemical parameters of groundwater samples collected from coastal area of Baluchistan, Pakistan.

Para Meter	pH	EC	TDS	HCO_3^-	Na^+	Ca^{+2}	Mg^+	K^+	F^-	Cl^-	SO_4^{-2}	NO_3^-
pH	1.0											
EC	0.158	1.0										
TDS	0.144	0.178	1.0									
HCO_3^-	0.161	0.49 *	0.405 *	1.0								
Na^+	0.107	0.404 *	0.304	0.427	1.0							
Ca^{+2}	0.052	0.227	−0.207	0.097	0.118	1.0						
Mg^+	−0.04	0.273	0.361 *	0.226	0.105	0.100	1.0					
K^+	0.41 *	0.271	0.003	0.148	0.223	0.102	0.043	1.0				
F^-	0.358 *	0.507 **	0.271	0.398 *	0.443 **	0.114	0.006	0.475 **	1.0			
Cl^-	0.66	−0.142	−0.297	−0.183	0.140	0.010	−0.158	0.229	0.068	1.0		
$SO4^{-2}$	0.158	0.091	0.299	0.164	0.423	0.247	0.165	−0.027	0.033	0.065	1.0	
NO_3^-	0.222	0.554 **	−0.016	0.202	0.147	0.085	−0.314	−0.019	0.498 **	−0.039	−0.016	1.0

* correlation is significant at the 0.05 level; ** correlation is significant at the 0.01 level.

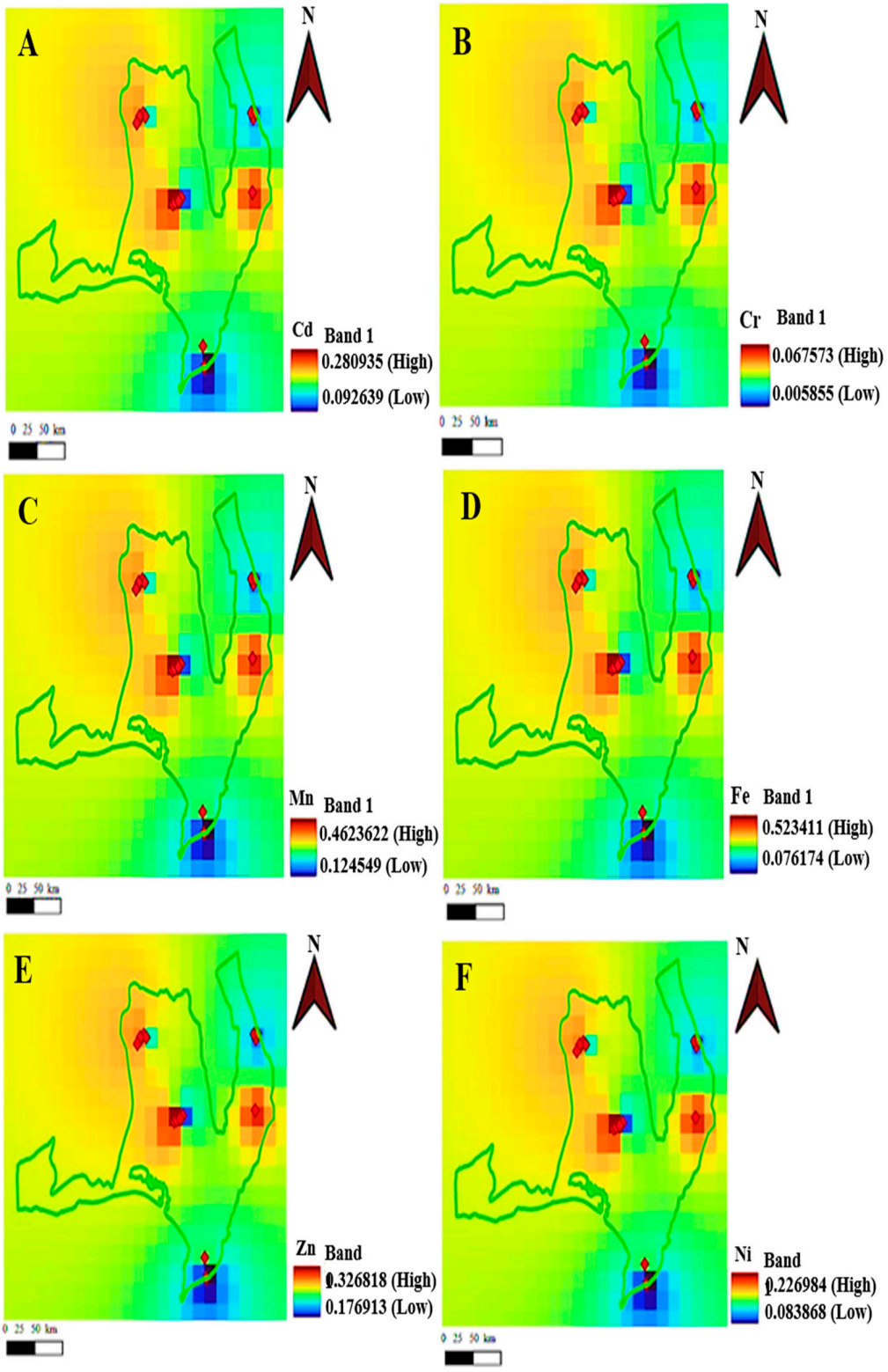


Figure 4. (**A**–**F**) indicate spatial distribution of heavy metals (**A**) Cd, (**B**) Cr, (**C**) Mn, (**D**) Fe, (**E**) Zn, and (**F**) Ni in the study area of Lasbela, coastal area of Baluchistan, Pakistan.

Table 4. Correlation analysis for the concentration levels of heavy metals in groundwater of coastal area of Baluchistan, Pakistan.

Parameter	Cd	Cr	Pb	Cu	Mn	Fe	Zn	Ni
Cd	1							
Cr	−0.083	1						
Pb	−0.122	0.286	1					
Cu	−0.317	0.090	−0.122	1				
Mn	0.143	0.191	0.374 *	0.186	1			
Fe	0.050	0.286	0.417 *	−0.028	0.138	1		
Zn	0.039	0.060	0.133	0.305	0.088	0.064	1	
Ni	0.097	0.130	0.085	−0.082	0.434 **	0.176	−0.067	1

* correlation is significant at the 0.05 level; ** correlation is significant at the 0.01 level.

3.2. Hierarchical Cluster Analysis

The HCA classification of the physicochemical parameters and heavy metal concentrations is shown in Figure 5, and six clusters of heavy metals were formed. There were three main clusters of physicochemical factors found, each containing 50% of the studied samples. The first cluster comprised low-quality water samples (9, 12, 1, 8, 6, 5, 7, and 10) with the following characteristics. Their water quality index classification varied from "good water" to "unsuitable for drinking". These samples are known as being the most exposed to anthropogenic influences and pollution [32]. However, it has been shown that variations in depth, land use, and geology are some of the factors impacting the contamination of water systems in the research region. These borehole samples' high pollution levels indicate that they are likewise susceptible to surface contamination processes, such as polluted springs and rivers. The geology of the research region has been characterized as having alternating friable sands and shales, which is a situation in which aquifer differentiation is predicted; nevertheless, it is implied that these shallow water sources lack constraining layers. Water samples from the second and third cluster include 2, 11, 4, 10, 7 and 6, 5, 7, 10; these are all safe for ingestion by both adults and children. These samples exhibit unique qualities, including the following: they are characterized as suitable drinking water. Due to relatively extensive anthropogenic activities, the geographic analysis showed that poor water quality is predominant in the northwestern and southern regions of the research zone.

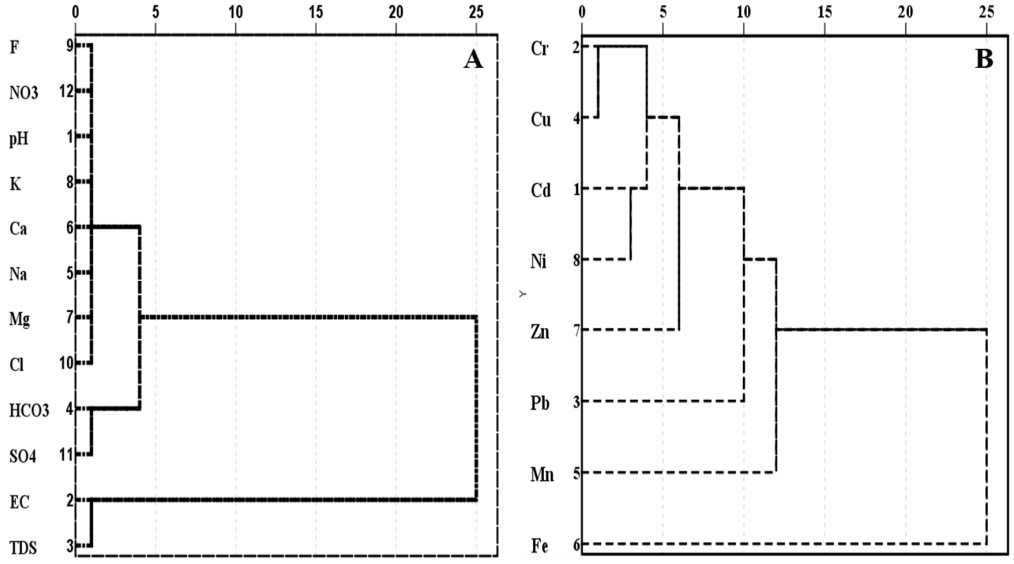


Figure 5. Hierarchical cluster analysis for (**A**) physicochemical parameters of water; (**B**) heavy metal concentration in groundwater.

3.3. Principal Component Analysis

The PCA was linked with the CA in order to obtain detailed knowledge of the sources of the physicochemical parameters and trace elements in the studied samples. The significance of the factor loadings was set at 0.05. The principal component analysis of the physicochemical parameters and heavy metal concentrations of the groundwater is shown in Figure 6. Eight distinct factors of physicochemical parameters and heavy metals were discovered in the current search and are listed in Table 5. Regarding the overall variances in physicochemical parameters and heavy metals, they had explanatory power of 77.71%. F^{-1}, Fe, EC, Na, and HCO_3 are all significantly loaded on PC 1, which has a variance rate of 20.95%. The variables with very strong correlations in the correlation matrix belong to this factor class. Major pollutants in the research region are accounted for by PC 1, and their origins are human activities, such as industrialization, waste disposal activities, and mechanical processes. Additionally, PCA showed that the main factors affecting the water quality and health hazards are Pb, Cr, and Cu. In PC 2, the considerable loading for Cd (0.670), $SO_4{}^{-2}$ (0.634), and TDS (0.537) accounts for 12.35% of the variability. This factor cluster indicates a geogenic origin. According to the geology of the research region, there are no deposits due to industrial, mechanical, and waste disposal activities into the water.

Table 5. Principal component analysis of physicochemical parameters and heavy metals in groundwater in coastal area of Baluchistan, Pakistan.

Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
pH	0.341	−0.356	−0.312	0.198	0.604	−0.101	0.198	0.062
EC	0.731	0.068	0.144	0.157	−0.182	0.008	0.039	0.147
TDS	0.352	0.537	−0.558	0.093	0.037	−0.049	−0.097	−0.005
HCO3	0.605	0.378	−0.132	0.287	−0.024	0.056	−0.118	−0.186
Na	0.616	0.350	0.000	−0.196	0.251	0.270	−0.065	0.055
Ca	0.197	−0.173	0.339	0.389	−0.126	0.385	0.486	−0.184
Mg	0.160	0.522	−0.020	0.541	−0.130	−0.096	0.055	0.191
K	0.547	−0.0168	0.343	0.113	0.485	−0.138	0.038	−0.081
F	0.839	−0.185	−0.126	−0.093	0.121	−0.024	−0.099	−0.064
Cl	−0.178	−0.020	0.500	−0.070	0.650	0.297	−0.295	0.087
$SO_4{}^{-2}$	0.155	0.634	0.033	−0.406	0.113	−0.001	0.103	0.538
Cd	0.000	0.670	0.401	−0.057	−0.032	0.211	0.060	−0.340
Cr	0.461	−0.082	−0.106	−0.481	−0.004	−0.213	0.574	0.082
Pb	0.408	−0.363	0.359	−0.415	−0.316	−0.273	−0.122	0.099
Cu	0.179	−0.383	−0.663	−0.025	0.003	0.438	−0.044	−0.095
Mn	0.442	0.042	−0.041	−0.550	−0.171	0.240	−0.339	−0.355
Fe	0.745	−0.095	0.268	0.190	−0.166	−0.211	0.071	−0.159
Zn	0.166	−0.216	0.083	−0.035	−0.234	0.703	0.198	0.371
Ni	0.385	−0.320	0.108	0.361	−0.212	−0.002	−0.529	0.364
Eigenvalue	3.98	2.34	1.77	1.70	1.43	1.30	1.20	1.10
Total variance	20.95	12.35	9.36	8.97	7.56	6.87	6.34	5.27
Cumulative variance	20.95	33.30	42.66	51.64	659.21	66.09	72.43	77.71

Significant Na^+ (0.774) and $SO_4{}^{-2}$ (0.808) loadings are seen in PC 3, which also explains 12.40% of the variation [33]. A significant loading of Ca is present in PC 4 (which accounts

for 10.46% variability) (0.875). However, pH showed a negative loading, indicating that it comes from a different source to HCO_3 and $SO_4{}^{-2}$. Industrial activities and waste disposal in the research region are responsible for the presence of SO_4 in the water supply. On the other hand, HCO_3 and $SO_4{}^{-2}$ might be linked to regional anthropogenic inputs from dumping grounds and inadequate sewage disposal, respectively. According to statistical analysis and the human health risk assessment, despite having different sources of physicochemical parameters besides heavy metals, Fe has a modest impact on the water quality in this region. This assertion is maintained by the fact that it has significant effects on the quality indices that are calculated, strong correlations with Pb and Zn, and a strong loading in PC 1 and PC 4. Finally, Cr has a significant factor loading in PC 1 (0.604). Although the majority of the samples have relatively low Cr amounts, they also carry a significant cancer risk. There are no geological sources known to exist in the research region that may release Cr. As a result, human activities, including industry and agriculture, are considered to be the sources of Cr [34].

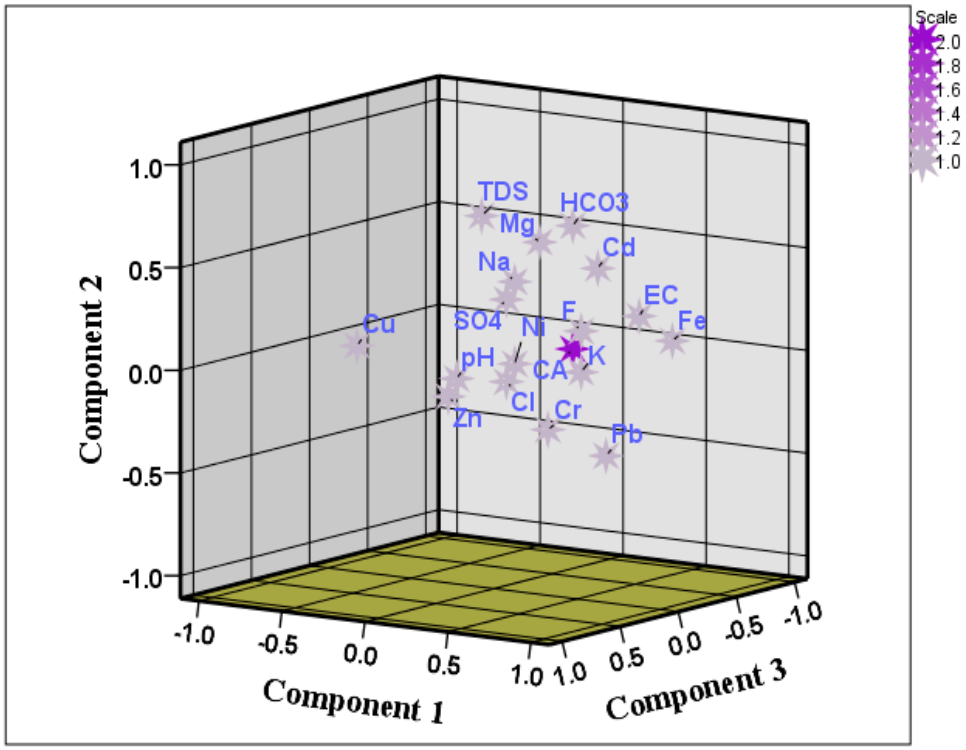


Figure 6. Principal component analysis for physicochemical parameters and heavy metal concertation in groundwater.

4. Conclusion

The findings of the study indicate that the water of the Lasbela coastal region is relatively alkaline. Physicochemical parameters and heavy metal concentrations were compared with the WHO recommended limits. The calcareous properties of the study region's aquifers may be the reason for the alkaline pH. The cations were arranged in the order $Mg^{+2} > Na^{+} > Ca^{+2} > K^{+}$, whereas anions were in the order $HCO_3{}^{-} > SO_4{}^{-2} > Cl^{-}$, respectively. The higher concentration of cations and anions indicated that carbonate minerals had been dissolved in the groundwater. Sulfate content was below the threshold limit. The substantial positive association between pH and EC, TDS, Na^{+}, K, F^{-}, and Cl^{-} demonstrated that pH plays a significant role in regulating the groundwater chemistry. It was shown that the majority of the cations and anions had positive correlations with the TDS values. Ca^{2+} and Na^{+} had a weak positive correlation, suggesting that these were involved in the same geochemical processes. The most significant positive correlation between Na^{+}, $HCO_3{}^{-}$, and F^{-} was found to be 0.427, 0.398, respectively, indicating the dissolution

of carbonate rocks. The datasets obtained from all analyzed geochemical variables were expanded using PCA. Major pollutants in the research region were accounted for by PC 1, and their origins were due to human involvement, such as industrialization, waste disposal activities, and mechanical processes. PCA showed that the main factors affecting the water quality and health hazards are Pb, Cr, and Cu. Fe has a modest impact on the water quality in this region. Finally, Cr had a significant factor loading in PC 1; although the majority of the samples had relatively low Cr content, human activities, including industry and agriculture, are considered to be the sources of Cr. The sources of HM in the water were classified using HCA based on similarities and differences in their concentration levels. From the findings of the research work, it is concluded that the groundwater of the coastal region is unfit for drinking purposes due to the high concentrations of heavy metals and it can cause serious harm to human beings.

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