Chapter 19
Application of Principal Component Analysis and Analytical Hierarchical Process in Surface Water Quality Assessment in Hatta Catchment, Emirate of Dubai, UAE

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Abstract United Arab Emirates is a water-scarce country in terms of availability of conventional water resources. Water experts always explore sustainable demand–supply management through Integrated Water Resources Management. With this preview, a detailed surface water quality monitoring programme was carried out to assess its suitability for intended use. Statistical treatment of large water quality dataset helps in understanding of various processes involved in chemical alteration of water resources. Principal Component Analysis (PCA) is data reduction technique attempts to explain the correlation between the observations in terms of the underlying factors which are not directly observable. The results showed that all samples could be analysed by three main components, which accounted for 85.86% of the total variance. PCA technology identified important water quality parameters and revealed that the agricultural activities and domestic discharges are the main causes of water pollution in the study area. Analytic Hierarchical Process (AHP) is a decision support tool widely used in management of natural resources. It compares all possible pairs of criteria and determines most suitable criterion to develop irrigation water quality index. Study infers that water lies in good to moderate suitable classes. Any negative change in the form of qualitative or quantitative surface water resources would directly affect the shallow groundwater. This necessitates the urgent requirement to protect surface water from pollution threats to help integrated water resources management.

Keywords Surface water quality · Analytical Hierarchical Process (AHP) · Irrigation water quality · Principal Component Analysis (PCA)

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1 Introduction

Managing water scarcity is a major problem in the arid regions, continuously increasing demand makes sustainable development of water resources a challenging task (Murad et al. 2007; Abdalla and Chan 2017; Alsharhan and Rizk 2020). Water Planners are constantly working to develop UAE's Integrated Water Resources Management strategy (Dawoud 2013; Ahmed et al. 2019). Water quality monitoring is an important part of almost all water resources management policies. Chemical analyses of water provide crucial information in relation to water quality status, which enables efficient Demand Side Management (DSM) decision-making. Use of statistical methods in Water quality data helps in providing key information. There are numerous researches presenting quality status of the water resources (Umar and Ahmed 2007; Umar et al. 2009; Nazzal et al. 2014, 2015). From simple statistical operations, e.g. range, distribution, deviation, outliers, missing values, correlations to complex statistical treatment, e.g. Principal Component Analysis help the researchers in many ways. Bivariate plots and graphical presentation do need certain statistical treatment of dataset. This helps in revealing evolution trends, source genesis, spatial distribution, impact caused due to landuse activities, and suitability for specific criteria.

Water quality analyses have two main objectives, i.e. finding genesis of the water and evaluating suitability for any specific usage. It is important to adopt suitable statistical methodology when analysing water quality data to draw relevant conclusion. Multivariate statistical methods have been widely applied in interpretation of multiparameter large water quality dataset. Cluster analysis (CA) and factor analysis (FA) are used for water quality analysis which helps in chemical evolution of water types (Singh et al. 2004a, b). It has been used to characterize water quality for spatial and temporal changes due to natural or manufactured environments (Singh et al. 2006; Bhat et al. 2013).

Core water quality findings and complex processes involved in it are of little interest for policy makers hence water planners require to generate a Water Quality Index (WQI) based on which prompt decision can be taken. Quality status of surface water is a dynamic process due to its vulnerability to receive contaminants. Therefore, the water quality index should be capable of addressing pertaining variables as well as suitability for specific usage. In view of this, water quality data is further classified into relevant criteria to establish a unique water quality index employing Analytical Hierarchical Process (AHP). AHP was developed in the 1970s by Thomas L. Saaty and has since been widely used for unbiased decision-making (Bhushan and Rai, 2004). AHP is multi-criteria programming for decision-making for large number of variables or criteria based on the prioritization.

The present study performed to serve as a baseline for surface water resources, inferring genesis and contamination trends using 25 water quality parameters from the rain-fed surface water reservoirs. The study investigates the current status of water pollution; carryout PCA for the spatial and temporal changes of water quality and finding possible pollution sources and using AHP technique to develop a suitable WQI.

2 Materials and Methods

2.1 Description of the Study Area

Hatta, a mountainous region, is being developed as a peri-urban excellent centre for adventure sports and tracking without compromising its traditional and historical values. Rainfall is highly unpredictable in terms of frequency and magnitude. A mean annual rainfall of 125.6 mm and a mean temperature of 27.8 °C characterize the area. Historically, Hatta's inhabitants do traditional farming by growing mainly dates, fruits, vegetables, fodder, etc. Traditionally, surface water remained the source of irrigation. With the advent of water extraction technology, the mode of irrigation shifted towards the groundwater resources. Surface water is stored in dam's reservoirs, which increases aesthetic values and help recharging groundwater. This can also serve as source of water supply in emergency time.

2.2 Water Resources

Hatta catchment is one of the east coast catchments that form one of the major five hydrological zones in the UAE. The entire region generates surface water runoff during rainy seasons. The annual rainfall in the northern areas is relatively higher, i.e. 150 mm/year, compared to the middle and southern parts of the country that receive about 110 mm/year (Sherif et al. 2011). Groundwater remains the most promising source for agricultural works. Rainfall induces surface water storage which in turn lead to quick groundwater level fluctuations and increase in baseflow in wadi channels. Falaj, an ancient subsurface water supply network rejuvenates aftermath of the rain events. This is all indicative of hydrodynamic connectivity between surface water and groundwater. Falaj is subsurface horizontal channel receiving groundwater from up gradient and all along the channel, which is available at the tail end to be used for the irrigation in downstream region.

2.3 Sampling and Analytical Techniques

Sixteen samples were collected from all surface water repositories including 04 water reservoirs and the Falaj water during the year 2019 sampling campaign (Fig. 1). Representative surface water samples were collected on quarterly frequency

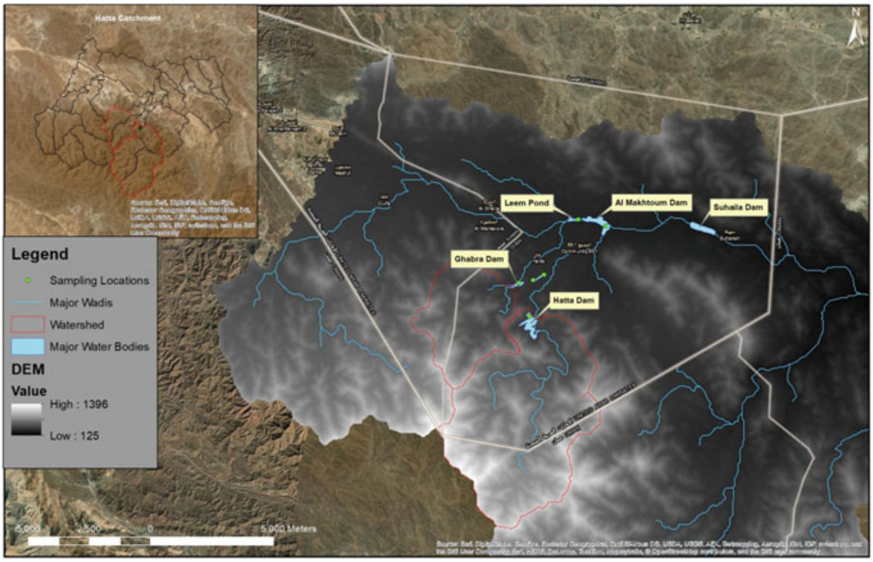

Fig. 1 Base map showing Hatta Catchment and water sampling locations

from each location following standard sampling procedures and protocols (USGS 2018). Samples were preserved and transported to Dubai Central Laboratory (DCL). Samples were analysed for pH, EC, TDS, Turbidity, Alkalinity, major elements (Ca, Na, K, Mg, Cl, SO_4, HCO_3, NO_3), Trace elements (Fe, Zn, Cu, Co, Cr, As, Ni, Cr, Pb, Mn), pathogens (Total Coliform, E. Colie) using standard analytical techniques (APHA 2005).

Sampling results are tested for analytical inaccuracies for electro neutrality condition using the below equation.

$$IB = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} \times 100$$

IB is ion balance error in percentage, cations and anions are denoted by sum of all cations and anions, respectively, expressed in meq/L and IB error should be less than 10% (Domenico and Schwartz 1990).

Interpretation of the results was done using Min, Max, mean, median, Standard deviation, kurtosis, skewness, and coefficient of variation were calculated using statistical technique.

Mean is the average of all the numbers and then divide by the total number. Median gives the middle values and mode is the value occurring maximum number of times. Standard deviation is a measure of variability of the sample. However, kurtosis means the degree of flatness and skewness denotes the symmetry of the data. The coefficient of variation is a measure of relative variability of the samples. Principal Component analysis (PCA) was performed using SPSS 25. Analytical hierarchical Process (AHP) is used for assigning relative weights of the selected criteria.

3 Results and Discussions

3.1 Surface Water Quality Evaluation

Several factors like topography, geology, landuse, seasonal variations, aridity index, and rainfall can influence the surface water quality. Chemical alterations of surface water begin soon after it starts flowing as runoff over different surfaces interacting with anthropogenic influences, landuse activities of the catchment, soil, and bare rock interactions. The nature and general conditions at reservoir conditions have great influence on the water's chemistry. The water quality analysis is used to identify the processes affecting the surface water quality of the study area. Seasonal changes in the water flow rate and biological activity contribute to differences in the chemical composition of surface water (Augustyn et al. 2012). Table 1 shows the chemical concentration of selected variables in the water samples.

The groundwater has low to moderate EC values ranging from 366 to 2774 μS/cm and average value of 730.04 μS/cm. pH is ranging from 7.6 to 10 with an average value 8.8, indicative of slight alkaline nature. The possible reason for high pH may be diurnal temperature change. The photosynthesis often raises respiration as a result CO_2 is extracted from the water which in turn may raise pH levels. The photosynthesis decreases in night time, leading to fall in pH values as respiring organisms add CO_2 to the water.

Like the elevated pH values, water is characterized by high alkalinity and hardness with an average value of 294.3 and 413.8, respectively. The general dominance of cations is Na > Mg > Ca > K while anions are in the order of HCO_3 > Cl > SO_4 > NO_3.

Dominance of Na^+ and Cl^- in water is a characteristic feature of most arid regions (Ahmed et al. 2019; Nazzal et al. 2014). Bicarbonate seems to acquire from recent biochemical reactions after rainfall events (Umar et al. 2009). Ca^{2+} and Mg^{2+} are found naturally in surface and ground water, and the only other elements that occur in greater abundance are Na^+ and Ca^{2+} cations. Na^+, Mg^{2+}, and Cl^- concentrations in ground and surface waters increase as those elements are washed out from bedrock. The sediments collected in wadi channel confluences to main dam reservoirs. Reservoir water gets mineralized through periodic evaporation and dilute after episodic runoffs.

Na^+ and Cl^- exhibit large variations and so is the standard deviation. Likewise, Ca^{2+}, Mg^{2+}, and $SO_4{}^{2-}$ show high variation and high standard deviations. First inference, which can be made from these observations, is that the several factors influence the water quality of the study.

Table 1 General statistical analysis of surface water quality

Parameter	n	Min	Max	Mean	Median	Sd	Skew	Kurtosis
pH	16	7.64	10.06	8.77	8.68	0.81	0.39	−1.12
Alk	12	116	410	294.33	377.00	126.45	−0.43	−2.06
Tur	16	0.49	30	6.74	3.30	9.00	2.07	3.40
EC	16	366	2774	1275.00	1500.00	730.04	0.45	−0.33
TDS	16	175.44	1919.09	887.71	1079.82	507.93	0.17	−0.63
K	16	0.56	6.07	4.17	4.55	1.54	−1.18	1.29
Na	16	9.17	260	100.77	109.25	76.27	0.47	−0.40
Ca	16	11.06	38.12	23.73	26.74	8.97	−0.01	−1.63
Mg	16	29.15	148	83.95	94.30	36.44	0.01	−0.97
Cl	16	20.4	1133	282.51	286.00	287.79	1.94	4.60
SO_4	16	47	332	92.31	56.40	94.04	2.44	4.67
HCO_3	16	21	500	293.25	325.00	195.03	−0.19	−1.92
F	16	0	1.8	0.21	0.10	0.43	3.93	15.57
NO_3	16	0	16	6.81	6.30	6.63	0.09	−2.12
Zn	16	0.009	0.0357	0.01	0.01	0.01	3.99	15.95
Fe	16	0.049	0.1727	0.06	0.05	0.03	4.00	16.00
Ni	16	0.00031	0.0167	0.00	0.00	0.00	3.30	11.97
Mn	15	0.00049	0.0089	0.00	0.00	0.00	3.41	12.35
Cu	16	0.009	0.02	0.01	0.01	0.00	3.86	15.17
As	16	0.00049	0.0022	0.00	0.00	0.00	0.74	−1.17
Ba	16	0.009	0.0489	0.02	0.01	0.01	0.81	−0.78
Cr	16	0.0023	0.0125	0.01	0.01	0.00	0.02	−2.13
T Coli	16	0	2421	1315.06	1327.00	1096.24	−0.10	−2.02
E Colie	16	0	2421	301.25	2.00	632.32	2.92	9.12

The striking feature emerged out from the statistical analysis is major elements vary widely evident from the high standard deviation. Trace elements show highest Skewness and kurtoses. Skewness is a measure of symmetry of data which in other words also the absence of symmetry. A distribution is called symmetric if it appears the same to the left and right from the centre, i.e. having a 0 value. On the other hand, the kurtosis parameter is a measure of the combined weight of the tails relative to the rest of the distribution.

A correlation statistics of the sampled data brings interesting hidden facet into the front (Table 2). TDS correlated well with most major elements having good correlations with K, Na, Mg, and Cl, moderate correlation with Ca, SO4, and Ba. The good correlation implies that the increase in total dissolved salts in a function of these elements. While TDS is a collective indicator of water chemistry, individual correlations often provide good inferences. Na correlates well with Cl and Mg while Ca correlates well with HCO3 and NO3. These individual correlations show basic

Table 2 Pierson Correlation coefficient of important parameters

	TDS	K	Na	Ca	Mg	Cl	SO_4	HCO_3	F	NO_3	Zn	Fe	Ni	Ba	Cr	Tcoli
TDS	1.00															
K	**0.74**	1.00														
Na	**0.98**	**0.73**	1.00													
Ca	*0.60*	0.49	0.59	1.00												
Mg	**0.99**	**0.78**	**0.98**	0.66	1.00											
Cl	**0.91**	*0.61*	**0.92**	0.28	**0.88**	1.00										
SO4	*0.59*	0.38	*0.65*	0.05	0.57	**0.82**	1.00									
HCO_3	0.36	0.38	0.26	*0.69*	0.37	−0.04	−0.52	1.00								
F	0.16	−0.13	0.16	0.08	0.14	0.10	−0.08	0.20	1.00							
NO_3	0.44	0.31	0.36	**0.73**	0.45	0.08	−0.42	**0.95**	0.23	1.00						
Zn	0.11	−0.19	0.12	0.04	0.09	0.06	−0.13	0.20	**0.99**	0.22	1.00					
Fe	0.11	−0.19	0.12	0.03	0.09	0.06	−0.12	0.19	**0.99**	0.21	1.00	1.00				
Ni	−0.21	−0.19	−0.20	−0.19	−0.23	−0.13	−0.01	−0.22	0.16	−0.20	0.15	0.15	1.00			
Ba	0.57	0.43	0.47	0.61	0.57	0.46	0.36	0.30	−0.15	0.36	−0.22	−0.22	−0.15	1.00		
Cr	0.49	0.35	0.40	**0.73**	0.49	0.12	−0.38	**0.96**	0.32	**0.97**	0.32	0.31	−0.26	0.36	1.00	
Tcoli	0.49	0.42	0.40	**0.75**	0.51	0.16	−0.22	**0.84**	0.31	**0.86**	0.28	0.27	−0.28	0.58	**0.87**	1.00

affinity of the cations towards the anions counterpart and also indicative of similar source genesis (Umar et al. 2009). Cr good correlations with Ca (0.73), NO_3 (0.97), and HCO_3 (0.96) is another striking feature of the statistical analysis which is indicating a common genesis of these parameters. Na:Cl shares good bonding (0.92), Cl:SO_4 shares good correlation (0.82) but Na:SO_4 shares moderate correlation (0.62) designating a different evolution mechanism and source genesis.

Weathering of limestone, dolomite, and sulphate-containing sediments such as gypsum and anhydrite contain Mg-Ca-SO_4. Large quantities of magnesium are released to groundwater from sedimentary rocks, mainly dolomite. In a complex geological set up consisting of ophiolites, ultramafic rocks, chert, limestone, and quaternary-alluvium are highly disturbed and seems to acquire complex relationship with the water quality that is difficult to trace out.

Piper diagram is widely used plot for describing water quality to help in understanding the sources of the dissolved constituents in water (Piper 1944). The major ions were plotted in the Piper Diagram to understand the main water facies occurring in the region (Fig. 2). The cationic triangle show significant presence of Mg ions followed by Na ions while the anionic triangle show dominance of HCO_3 ions followed by Cl-ions. Dam 1 is represented by Mg-HCO_3 type water. Two samples

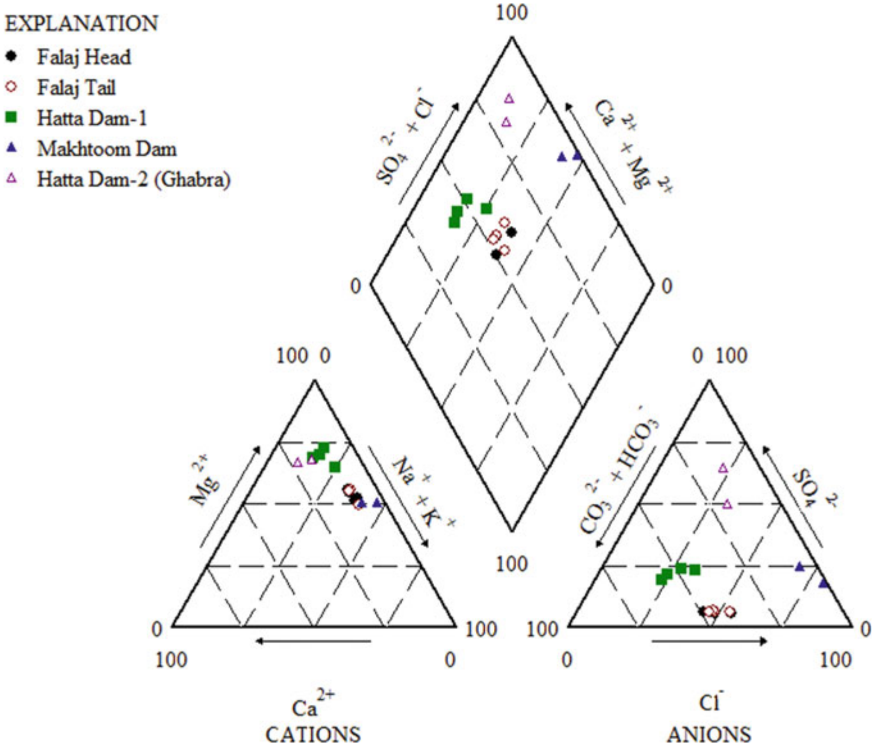

Fig. 2 Piper trilinear diagram for chemical classification of water

from Dam 1 and Falaj water are classified as mixed type water. This striking similarity makes a relationship between Dam 1 and Falaj water. Dam 2 has unique chemical signature Mg-Cl_2 type water. Dam 3 (Makhtoom Dam) is altering its chemical characteristics from Mg-Ca-Cl_2 to mixed type water.

There is a potential health risk due to presence of pathogens in surface water which may enter into the groundwater environment. Pathogens especially in Falaj water are of the major concerns. The major sources of pathogens are sewage effluents, animal waste, and some wildlife species dwelling in surface water or the upper catchment. These pathogens are most common causative factor of intestinal diseases like typhoid, paratyphoid, salmonellosis, cholera. Escherichia Coli are true indicators of fecal contamination because they are only found in feces (WHO 2011). Their presence show recent encroachment as well as gap in monitoring activity.

3.2 Principal Component Analysis/Factor Analysis

PCA is used for identification of the factors that influence water resources and solution for pollution problems (Reghunath et al., 2002; Simeonov et al. 2003). Factor analysis is applied to reduce the dimensionality of interrelated variables. The Principal components are data reduction techniques through linear combinations of the original variables and the eigenvectors. The main benefit of PCA is that it attempts to explain the correlation between the observations in terms of the underlying factors, which are not directly discernable. In the present study PCA of factor analysis was estimated.

In a natural resources environment correlations exist among multi-indicators. PCA converts large inter-correlated indicators into a smaller set of indicators that are uncorrelated variables (Jianqin et al. 2010). The correlation of PCs and original variables is designated by loadings. Scores are the individual transformed observations (Wunderlin et al., 2001). The classification of the factor loadings as ‘strong’, ‘moderate’ and ‘weak’, corresponding to absolute loading values of >0.75, 0.75–0.50, and 0.50–0.30, respectively (Liu et al. 2003). It is imperative to note that loading reflects the relative importance of a variable within the component and does not reflect the importance of the component.

Principle component analysis shows three main components on a rotated component matrix (Table 3). All 3 components are distinct and seem to develop acquiring distinct chemical processes (Fig. 3). PC-1 is represented by HCO_3, NO_3, Ca, Cr, Total coliform, and E Coli. This group shows recent influence by near surface biochemical reaction and anthropogenic influence. This also infers that the meteoric characteristics are not completely obliterated. PC-2 contains common parameters, e.g. EC, Na, Cl, Mg, SO_4, and K, which represent major ions chemistry of the water. PC-3 is represented by heavy metals, e.g. Zn, Fe, F, and Mn indicating a common genesis of these heavy metals.

Table 3 Principle component analysis showing 3 main components

Rotated component matrix^a			
	Component		
	1	2	3
HCO_3	**0.978**		
NO_3	**0.947**		
pH	−0.934		
Cr	**0.928**		
T COLI	**0.859**		
Ca	**0.741**	0.419	
E COLIE	**0.598**		
Cu	−0.457		
Cl		**0.977**	
EC		**0.956**	
Na		**0.953**	
TDS	0.329	**0.933**	
Mg	0.360	**0.927**	
SO_4	−0.512	**0.831**	
K	0.398	**0.706**	
Zn			**0.988**
Fe			**0.987**
F			**0.981**
Mn			**0.978**

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 5 iterations

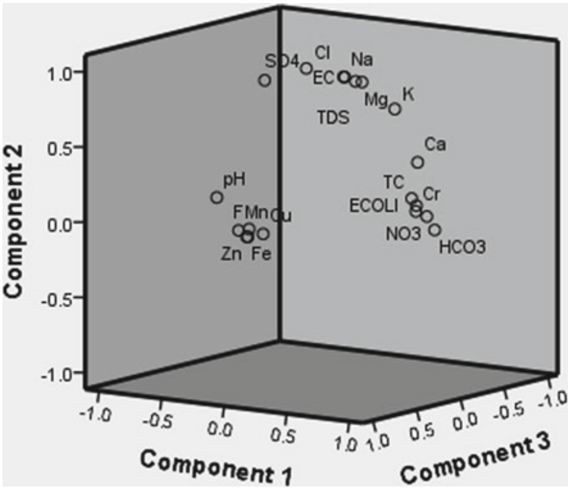

Fig. 3 Components plot in rotated space

3.3 Cluster Analysis

Geographical influences and spatial similarity in surface waters can be detected through Hierarchical Cluster analysis (CA) represented as a dendrogram as shown in (Fig. 4) grouping all the 16 samples into 2 statistically significant clusters. The clustering procedure generated two groups of sites in a logical way. The sites in these groups have similar characteristic features and sources of contamination.

Cluster 1 (Subgroup-1: sample ID 1, 2, 4, 5, 6, 7, 8 Subgroup-2: 3, 13, 14), Cluster 2 (9, 10, 11, 12, 15, 16). Cluster 1 is mainly represented by Falaj water which is basically groundwater and hence tends to be different than surface water characteristics. A small number of samples from Makjtoom dam also fall in this cluster.

Cluster 2 is mainly represented by waters of Dam 1 and Dam 2. These samples are least altered due to the geographical isolation from urban activities and falling in the upper reaches of the catchment.

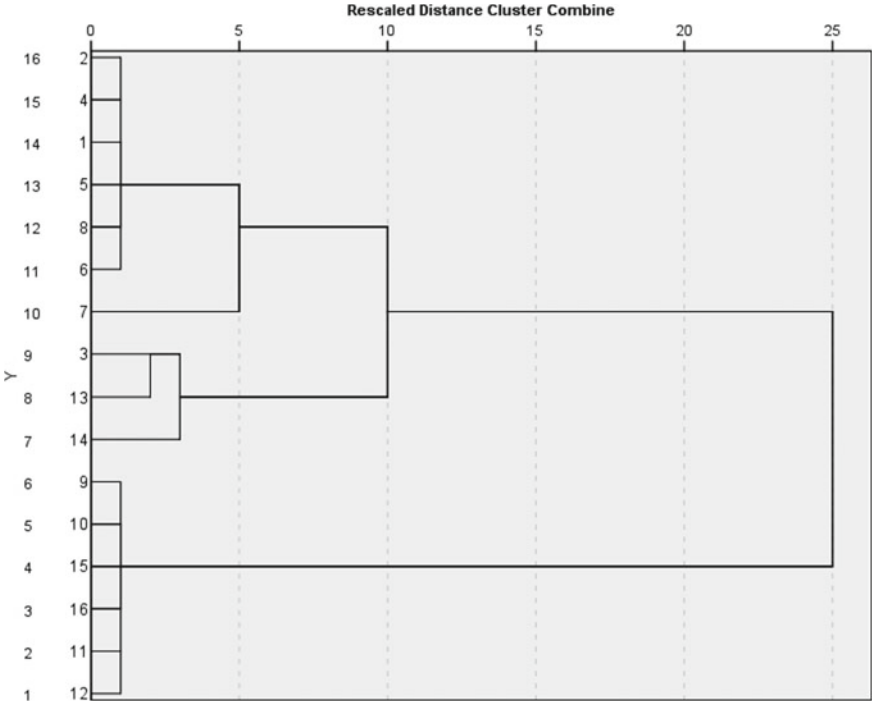

Fig. 4 Classification of water samples on Dendrogram using ward linkage

4 Developing Irrigation Water Quality Index

One of main objectives of water quality monitoring programme is analysing the suitability for specific usage. Monitoring of water sources determines the probable parameters that indicate the type of pollution and its possible genesis. Water pollution is generally caused by waste disposal sewage mixing, animal excrements, storage of waste, animal manure, and artificial fertilizers (Fridrich et al. 2014). Principally, the existing surface water usage defines the criteria for developing the irrigation Water Quality index. Several studies have documented important parameters used to assess irrigation water quality (Zaman et al. 2018). In recent years, Analytic Hierarchy Process (AHP), developed by Saaty (1987, 2004), has been used in environmental management initiatives (Pramanik 2016). It combines and uses pairwise matrices to compare all possible pairs of criteria to determine the maximum priority (Bozdag 2015). The present study used six criteria that influence irrigation water quality, i.e. Electrical conductivity (EC), Sodium Adsorption Ratio (SAR), Magnesium Ratio (MR), Total hardness (TH), Chloride (Cl), and Kelley Ratio (KR).

Presence of salts affects the growth of the crops by limiting the uptake of water through modification of osmotic process, or chemically by metabolic reactions. Irrigation water is classified based on Na concentration. Na reacts with soil to reduce its permeability which intern harm the plant growth and soil properties. The Sodium adsorption ratio (SAR) is an irrigation water quality parameter used in the management of sodium-affected soils (USDA 1954). SAR indicates suitability of water for irrigational use. The water intake capacity of soil and surface run off above certain soil types is determined by the infiltration capacity of the soil. Irrigating land with saline water, i.e. high salt content water will increase infiltration. Water having high SAR values tends to decrease infiltration. SAR is the measure of the amount of Na^{+} relative to Ca^{2+} and Mg^{2+}.

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

The values are expressed in meq/l. It is calculated as follows. Magnesium hazard was <50% can be safely used for irrigation.

$$\mathrm{MR} = \frac{\mathrm{Mg}}{\mathrm{Ca} + \mathrm{Mg}} \times 100$$

Hardness results from the presence of divalent metallic cations, of which Calcium and Magnesium are the most abundant in surface water

$$\mathrm{H_T} = 2.5\mathrm{Ca} + 4.1\,\mathrm{Mg}$$

Na, Cl, and Boron from soil or water accumulate in a sensitive crop to concentrations high enough to reduce yields. Chloride is selected to check specific toxicity.

Kelley's index is calculated by Na measured against Ca and Mg (Kelley et al. 1940). A Kelley 's index of greater than 1 indicates an excess level of Na in water. Values are expressed in meq/L.

$$\mathrm{KI} = \frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg}}$$

4.1 Analytical Hierarchical Process

The AHP is an important decision support tool in natural resource management studies, solving complex problem hierarchically. It examines each level of the hierarchy individually utilizing pairwise matrices to compare all possible pairs of criteria. The AHP tool also determines which criterion has the highest priority (Saaty 1980).

A standard scale was used to describe the relative influence of parameters, where score 1 denotes equal influence of parameters and score 9 denotes extreme influence of a parameter on groundwater recharge compared to the other parameters (Table 4). The application of AHP starts with disintegrating into a hierarchy of different criteria which can analysed easily independently. The decision-makers can use different alternatives by making pairwise comparisons for each of the chosen criteria (Saaty 2008).

Study selected 6 criteria EC, SAR, MAR, TH, Cl, and KR having distinct influence on irrigation water quality. Each criterion reflects a different aspect of water quality. These criteria are given unique weights, which is assigned with good understanding of the water quality and use pattern. Applying relative class rate scale given in Table 5, average relative weights of the selected criteria are developed (Table 6).

Water quality criteria are divided into subgroups and assigned respective ratings (Ayers and Wescot 1994) (Table 6). Considering the selection of each parameter or index on irrigation water quality rate subgroups as 1, 2, and 3 designating no harmful effect, moderate effect, and harmful effect.

Irrigation suitability index of the study area is obtained as suitability score (IW),

$$\mathrm{IW} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{R_i} \times \mathrm{W_i}$$

where Ri is the reclassified rank of individual water quality criterion, Wi is the weight of the individual criterion obtained from AHP, and n is the total number of criteria. The irrigation suitability represents samples into 3 main categories, i.e.

Table 4 AHP relative class rate scale according to Saaty (1980)

Importance	Equal		Weak		Moderate		Moderate plus		Strong		Strong plus		Very strong		Very, Very strong		Extreme	
Scale	1		2		3		4		5		6		7		8		9	
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9	
	Less important								More important									

Table 5 Average relative weights assigned to selected 6 criteria

Criteria	Weight	Consistency check
EC	0.312	OK 1%
SAR	0.279	
Cl	0.202	
KR	0.106	
TH	0.063	
MR	0.038	

Table 6 Ratings of the selected criteria

Irrigation criteria	Range	Water class/Restriction	Rank
EC	<0.7	None	1
	0.7–3	Slight to Mod	2
	>3	Severe	3
SAR	<3	None	1
	3–9	Slight to Mod	2
	>9	Severe	3
Cl	<140	None	1
	140–350	Slight to Mod	2
MAR	>350	Severe	3
	<50	Suitable	1
	>50	Unsuitable	3
KR	<1	Suitable	1
	>1	Unsuitable	3
TH	<75	Soft	1
	75–150	Mod	2
	150–300	Hard	2
	>300	Very hard	3

suitable (IW = 1.00 – 1.33), moderately suitable (IW = 1.34 – 2.33), or unsuitable (IW = 2.34 – 3.00). IWS estimates of water samples are presented in Table 7.

5 Conclusions and Recommendations

Most countries of the Arabian region are falling in arid and semi-arid areas, therefore, facing severe pressures due to limited water resources. Water scarcity is expected to increase with increased per capita water use associated with life style and high pace of development. Based on WHO (2003) criteria for recreational use, Hatta surface water qualifies in very good category with the exception of Falaj water. Falaj water

Table 7 Showing Irrigation Water Suitability (IWS) Classes

	IWS-season	IWS-location	Class-location	IWS-overall	Class-overall
HD1-Q-1	1.139	1.139	Suitable	1.66125	Mod suitable
HD1-Q-2	1.139				
HD1-Q-3	1.139				
HD1-Q-4	1.139				
HD2-Q-1	1.418	1.418	Mod suitable		
HD2-Q-2	1.418				
HD2-Q-3	Dry				
HD2-Q-4	Dry				
MD-Q-1	2.197	2.197	Mod suitable		
MD-Q-2	2.197				
MD-Q-3	Dry				
MD-Q-4	Dry				
HFH-Q1	1.716	1.716	Mod suitable		
HFH-Q2	1.716				
HFH-Q3	1.716				
HFH-Q4	1.716				
HFT-Q1	1.918	1.83625	Mod suitable		
HFT-Q2	1.716				
HFT-Q3	1.995				
HFT-Q4	1.716				

is polluted with fecal pollution and hence categorized as fair to very good at the upstream side and poor to good at the downstream side. This indicates that the Falaj water is getting polluted while enroute to discharging point. Water quality is mainly influenced by geology of the area, evaporation, landuse pattern, and anthropogenic factors.

Dam 1 is falling in Suitable Irrigation Water Quality class. Slightly higher SAR values in Dam 2 make it into ‘moderately suitable class’ for irrigation. Relatively high EC and Cl values make Dam 3 water into ‘moderately suitable class’ for irrigation. Relatively high EC, Cl, and hardness values makes Fallaj water into ‘moderately suitable class’ for irrigation.

Pollution of surface water is a problem itself and that may be threat to fresh groundwater resources as both are found hydrodynamically connected. Apart from that it can find ways to enter the food chain directly or indirectly posing a risk to human health. It is evident that with few exceptions, surface water is not used for anything except recreational usage. This makes the problem of bacteriological contamination less problematic. Although, contaminants presented in the surface water may enter the groundwater resources. This highlights the need of restricting human interactions with the surface water bodies which may be protected through several options while fenced boundaries wherever possible may be one such option.

It is further recommended to adopt controlling measures to prevent microbiological contamination of surface water especially within the Falaj. Bats and other wildlife should be prevented to enter into the Falaj's ducts. Makhtoom dam should be cleaned for sediments and salt encrust that have been deposited after multiple drying panning of past rain events. Makhtoom dam can also be investigated for artificial rainwater recharge through recharge shafts. It is recommended to continue keep track of surface water quality monitoring programme. Statistical treatment and graphical presentation help in better understanding of processes involved in chemical alteration of waters.

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