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Analysis of physiochemical and microbial quality of waters of the Karkheh River in southwestern Iran using multivariate statistical methods

Mehrnaz Asefi[a], Rasool Zamani-Ahmadmahmoodi[b,*]

[a]*Department of Environmental Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran*

[b]*Department of Fisheries and Environmental Sciences, Faculty of Natural Resources and Earth Science, Shahrekord University, Shahrekord, Iran*

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ABSTRACT

Rapid population growth as well as agricultural and industrial development have increased the contamination of Iranian rivers. This study utilized principal components analysis (PCA) to determine the degree of significance of qualitative parameters of water resources in the Karkheh River in southwestern Iran. Cluster analysis (CA) grouped the monitoring stations based on the water quality data under measurement. The first three components obtained from the PCA accounted for 39.68, 35.04, and 17.76% of the total variance, respectively; these three components explained a total of 92.49% of the variance of the data sets. The PCA factors indicated that the parameters influencing changes in water quality were generally related to weathering and land washing in response to floods, organic contamination from household wastewater, waste from sand washing, and runoff from chemical fertilizers. Moreover, the PCA results indicated that the relative quality of the river water in the downstream areas, when compared with upstream areas, was worse due to the greater concentration of contamination sources in the vicinity of the monitoring stations. Given Iran's water crisis, the preservation and reclamation of this valuable resource require greater attention from the relevant authorities.

1. Introduction

Rivers are the most important water resource for Rivers are the most important water resource for household, industrial, and irrigation purposes [1], which are central to human development [2]. However, rivers become contaminated due to the dumping of sewage, industrial waste, and various human activities which all affect their physiochemical and microbiological quality [2]. Studies have been performed on the contamination of ecosystems resulting from anthropogenic activities. The results obtained from long-term water quality monitoring are a matrix of large and complex data of numerous physiochemical parameters; the interpretation and plotting of these significant results are difficult [3]. Some methods take numerous existing variables into account; a comprehensive guide is presented in which the most important parameters and key monitoring stations are specified [4]. Accordingly, multivariate statistical methods such as CA and PCA can interpret the complex matrix of data sets for a better understanding of the qualitative status of water and the ecological state of the studied systems. They provide the possibility to identify the factors influencing water systems and are valuable tools for reliable management of water resources; they also present a quick solution for contamination problems [5-15]. In addition, these methods aid in efforts to analyze and interpret the qualitative data sets of river water, evaluate water quality, discern spatiotemporal variations, and identify latent contaminating sources. Accordingly, they have been widely welcomed [16]. [17]used the multivariate acoustical methods of PCA and principal factor analysis (PFA) to

*Corresponding author. Tel: +98-38-34424423
E-mail address: rasoolzamani@yahoo.com
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identify the most suitable parameters to explain water quality. The results showed that it would be possible to decrease the number of water quality measurement stations from 22 to 19 stations. [18] used PCA and CA to evaluate qualitative variations in the water of the Nhue River and one of its peripheral branches, the To Lich in Hanoi, Vietnam, in terms of the concentration of heavy metals, pH (level of acidity), SS (Suspended Solids), and TOC (Total Organic Carbon) from October 2005 to June 2006. [19] Employed CA and PCA to estimate the spatial and seasonal variations of the input wastewater of the Ganges River, located in northeastern India. For this purpose, they collected wastewater samples from five stations along the river's coast from March 2010 to February 2011. The main purpose of the present study was to determine the degree of significance of qualitative parameters of water resources in the Karkheh River in southwestern Iran using multivariate statistical methods.

2. Materials and methods

2.1. Study area and evaluated data

The Karkheh River is located in Khuzestan Province in southwestern Iran, a significant river of the Persian Gulf basin and Oman Sea. The Karkheh River, with a basin area of 50000 km^2 and average annual discharge of 177 m^3/s, is the third largest waterfall river in Iran after the Karun and Dez Rivers. The Karkheh basin is situated in the middle and southwestern regions of the Zagros Mountains in western Iran and is one of the second-degree basins of the Persian Gulf basin. This basin is surrounded by the Sirvan, Sefidrood, and Ghare-Chai river basins from the north, by border basins of Iran and Iraq from the west, and by part of the southern border of Iran from the south [20]. Figure 1 represents the location and wastewater discharge points to this river within the studied area. This study recorded the relationships between the physiochemical and microbial parameters, measured by Khuzestan Water and Power Authority, from October 2010 to September 2011 from five sampling stations on the Karkheh River. Subsequently, the continuity and frequency of this sampling was examined; the water quality data from October 2010 to March 2011, for which complete and continuous data was available over this six-month period, were selected for PCA and CA analyses. This study focused on determining the most important qualitative parameters in the contamination of the Karkheh River's waters, to identify key stations in water quality monitoring, and to categorize the results from the sampling stations. In this research, the water quality parameters included 13 parameters: T (Temperature), TA (Total Alkalinity), Phosphate (PO_4), Turb. (Turbidity), TSS (Total Suspended Solids), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), DO (Dissolved Oxygen), NO_3 (Nitrate), NO_2 (Nitrite), NH_4^+ (Ammonium), FC (Fecal Coliform), and TC (Total Coliform). The water quality data was evaluated monthly. Following the categorization of the data, the six-month average of the parameters was prepared and employed for analysis.

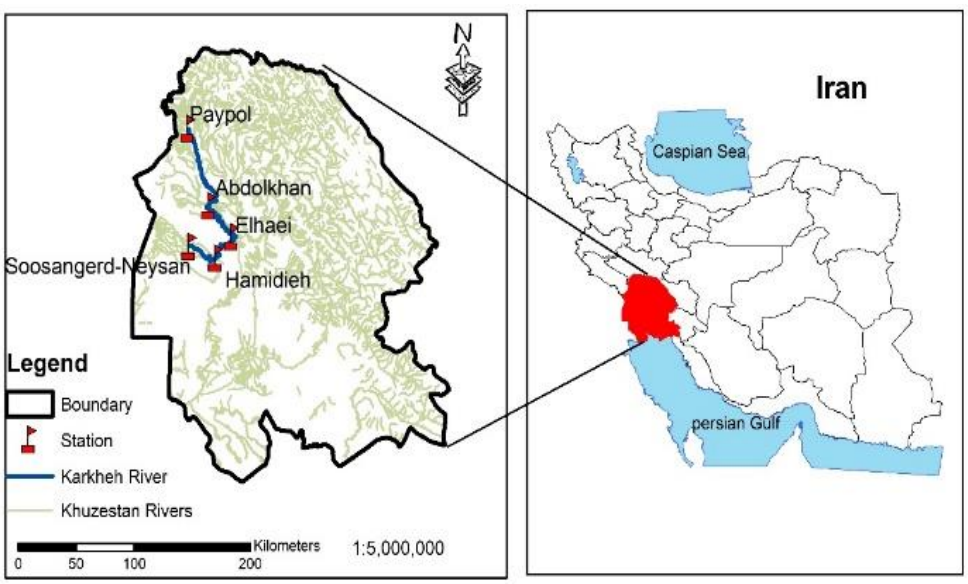

Fig. 1. Location of sampling stations on the Karkheh River

2.2. Preparation of water quality data and multivariate statistical methods

SPSS 17 was used to analyze the investigated statistical relationships. The Kaiser-Meyer-Olkin (KMO) and Bartlett's test were employed to study the suitability of the data for PCA. The changes in the Karkheh River water quality data were evaluated by PCA and CA.

2.3. Principal components analysis (PCA)

PCA is a method to decrease the number of variables and identify temporal variations in water quality. Numerous studies have evaluated water quality using PCA [21-24], [12-13], [25-27], [14].

2.4. Cluster analysis (CA)

Hierarchical agglomerative clustering is the most common CA method, providing intuitively similar relationships between each of the samples and among entire data sets, usually demonstrated by a dendrogram [28]. The Euclidean distance customarily represents the similarity between two samples [29]. In various studies, the CA method has been used to evaluate water quality [30-33].

3. Results and discussion

To gain an adequate understanding of the status of water quality parameters of the Karkheh River within the period of October 2010 to March 2011, the mean and standard deviation of the parameters measured in the sampling stations located on this river are presented (Table 1). Next, the results related to PCA and CA are presented (Table 2, Table 3, and Figure 2).

Table 1. Summary of statistical analysis of the parameters measured in the sampling stations of the Karkheh River, October 2010 to March 2011

Parameter (unit)	Min	Max	Mean±SE
T (°C)	17.83	20.17	18.51±0.43
TA (mg/L)	137.25	147.33	142.11±1.72
PO_4 (mg/L)	0.02	0.03	0.02±0
Turbidity (NTU)	2.17	22.67	11.54±3.55
TSS (mg/L)	20.00	40.00	29.79±3.41
BOD (mg/L)	2.83	3.16	2.98±0.05
COD (mg/L)	9.20	13.13	11.37±0.77
DO (mg/L)	6.98	8.60	7.74±0.25
NO_3 (mg/L)	2.17	4.56	3.85±0.43
NO_2 (mg/L)	0.01	0.03	0.02±0
NH_4^+ (mg/L)	0.40	0.64	0.50±0.03
FC (MPN/100)	2185.17	6357.14	4267.46±817.42
TC (MPN/100)	5571.67	23600.00	12321.85±3222.14

3.1. The most important water quality parameters

Table 2 presents the results from correlating the physiochemical and microbial water quality parameters in the first stage of PCA. The correlation matrix demonstrated a relationship at a significance level of 0.05 (confidence level of 0.95) between the parameters. Furthermore, there was a significant relationship (confidence level of 0.95) between the physical and chemical parameters (e.g., temperature) with BOD as well as DO with NO_3. In addition, a significant relationship was observed between the microbial parameters of FC and TC with the physical parameter of TSS. The existence of a high correlation between the physiochemical and microbial parameters of the water quality of the Karkheh River suggested a strong overlap between the qualitative parameters measured within the studied statistical period. In order to determine the most important parameters accounting for the water quality of the Karkheh River, 13 physiochemical and microbial parameters were measured and evaluated. PCA was employed for the extraction of the components. Table 3 provides the factor load of each of the parameters for membership in the three major components. In other words, the factor load represents the correlation between variables (water quality parameters) and the introduced components [17]. In the first component, which had the greatest variance explanation (Table 3), TSS, TC, FC, turbidity, and PO_4 parameters had the greatest correlation. The correlation among these members suggested the existence of a relationship between the qualitative parameters and microbial parameters of the river water. Table 3 shows that TSS had the greatest factor load (0.990), and so it was selected as the main parameter of the first component. TSS is a parameter that justifies the greatest variance of the changes in river water quality. The determination of this parameter as the main parameter in the first component suggested the existence of large amounts of suspended solids in the water and increased turbidity of the river water. These conditions were due to land weathering and the incidence of sudden floods which resulted from rainfall in the winter (natural processes), given the studied statistical period and the input wastewater resulting from the sand washing conducted around the river.

Table 2. Correlation matrix between physicochemical and microbial parameters in the studied area

	T	TA	PO4	Turbidity.	TSS	BOD	COD	DO	NO3	NO2	$NH4^+$	FC	TC
T	1.000												
TA	.085	1.000											
PO4	.380	.248	1.000										
Turbidityy.	-.346	-.122	.660	1.000									
TSS	-.078	-.319	.717	.808	1.000								
BOD	-.822	-.633	-.398	.388	.262	1.000							
COD	-.269	.567	.698	.681	.549	-.091	1.000						
DO	-.232	-.670	-.828	-.525	-.304	.517	-.785	1.000					
NO3	.252	.378	.981	.700	.670	-.370	.810	-.901	1.000				
NO2	.248	.361	.791	.368	.662	-.402	.732	-.580	.783	1.000			
$NH4^+$	-.013	.454	.655	.374	.597	-.259	.825	-.536	.695	.956	1.000		
FC	-.260	-.010	.637	.701	.897	.211	.756	-.348	.650	.807	.845	1.000	
TC	-.258	-.498	.524	.806	.965	.502	.421	-.100	.479	.468	.436	.840	1.000

Correlation is significant at the 0.05 level.

Table 3 provides second component parameters and factor loadings. The elements of this factor suggested organic compounds and nutrients in the water that resulted from contamination by urban and agricultural wastewater. Such contamination arose from the overuse of toxins, animal and chemical fertilizers on agricultural lands, and wastewater effluents from fish farms. In the second component, the TA parameter had the greatest factor loading, and so it was selected as the main parameter of the variations in the water quality of the river. In the third component, the parameters of temperature and BOD had the greatest factor loading among the studied parameters, suggesting that river water temperature affected the level of BOD.

Table 3. Variables and factor loadings after varimax rotation for studied data (mean of 6 months)

variable	Component		
	1	2	3
T	-.087	-.024	.996
TA	-.446	.892	.068
PO_4	.650	.574	.452
Turbidity	.798	.294	-.271
TSS	.990	.135	.012
BOD	.343	-.475	-.807
COD	.439	.872	-.211
DO	-.206	-.845	-.271
NO_3	.589	.700	.321
NO_2	.559	.649	.313
NH_4^+	.482	.734	.047
FC	.838	.414	-.178
TC	.983	-.054	-.175
Eigenvalue	7.090	3.452	1.481
% of total	5.159	4.555	2.309
% of Variance	39.681	35.041	17.763
% of	39.681	74.723	92.486

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

3.2. Analysis of water quality monitoring stations

In order to investigate the quality of water in the monitoring stations accurately, CA was used to separate and group their results based on similar information recorded in the region. Figure 2 reveals the dendrogram obtained from the CA, separating the monitoring stations into groups. The Paypol and Soosangerd-Neysan stations have a shorter sub-branch length in comparison with other stations, suggesting intragroup similarities among these branches, although the Hamidieh station has a longer branch length. Consequently, the water quality measurement stations were classified into three groups: the Paypol and Soosangerd-Neysan stations were classified into one group, owing to their similarity to each other; the Hamidieh station was classified by itself; and the Elhaei and Abdolkhan stations were in the third group. In Figure 2, the CA dendrogram shows that the Paypol station had better water quality compared with the other water quality monitoring stations. This could be due to fewer contamination sources concentrated around the station, when compared with the other hydrometric stations studied. However, due to agricultural activates located at the margin of the river in the vicinity of the station and the wastewater discharged into the river, the water quality in this area requires greater management and legislation based on environmental principles. The position of the Paypol and Abdolkhan stations along the river and the contamination sources within their range are such that no urban wastewater discharge takes place in this area. This has enhanced the water quality of Karkheh River. The sources contaminating this portion of the river are mainly from agricultural wastewater [36] and, to a small extent, the wastewater of the sand washing factory and that of rural areas. Due to soil salinity with little vegetation and the fish farms in the vicinity of the river within the range of the Abdolkhan and Hamidieh stations, the levels of suspended solids, cations, and anions are significant and reduce the water quality in this area.

Similarly, the water quality within the range of the Hamidieh and Soosangerd-Neysan stations has decreased because of the presence of numerous agricultural drains, fish farms, and discharge of urban wastewater as well as nitrate, phosphate, and microbial contamination of the river. With the low quality of groundwater in this area, large-scale water utilization from the river further reduces its water quality.

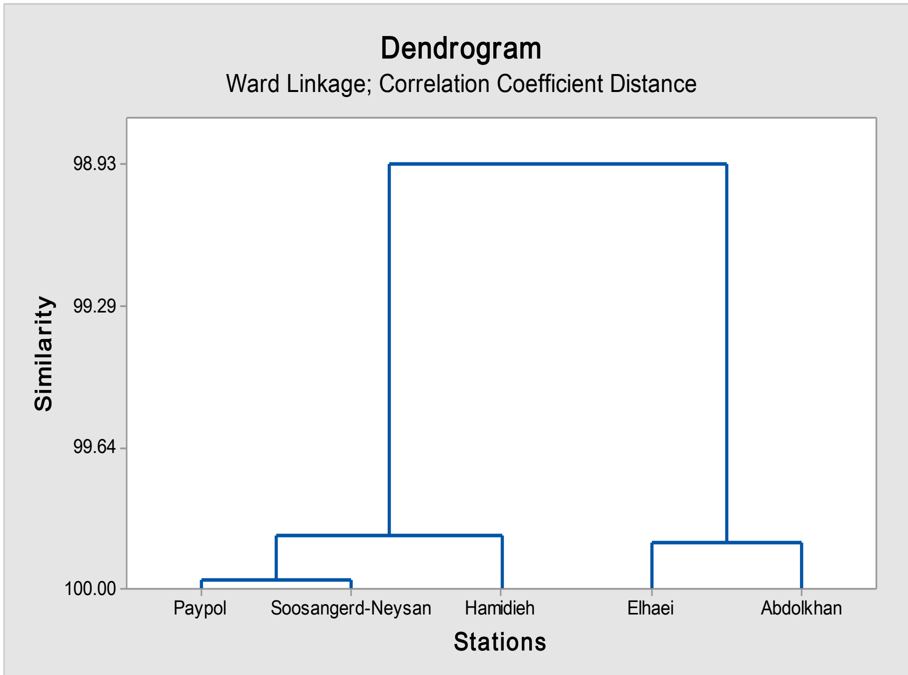

Fig. 2. Dendrogram of the stations from Karkheh River

When the location and type of contamination sources situated near the stations were analyzed, it was apparent that when moving upstream to downstream, the upstream agricultural and urban wastewater sources are more concentrated when compared with those of the downstream areas of the river. The results indicated that the wastewater from agricultural, urban and fish farm activities are among the most important factors in the declining water quality of the Karkheh River. The PCA results revealed high factor loads of PO_4, TA, COD, BOD, NH_4^+, NO_3, NO_2, FC and TC parameters, confirming the validity of the above conclusion. The high value of the factor load of the microbial parameters of FC and TC suggest high levels of coliform contamination in the Karkheh River, and this is one of the main reasons for its low water quality. The decline in its water quality can also be attributed to the discharge of urban wastewater. Statistical multivariate methods including PCA and CA have been used in many hydrological and environmental studies to determine the main parameters accounting for altered river water quality [3,17,24,34,35]. The results obtained from the study by Ouyang (2005) indicated that among the 22 evaluated monitoring stations, three stations were found to be the least significant in the explanation of the variance of the data sets, and thus were identified as nonessential stations. This study demonstrates that PFA and PCA are useful parameters for identifying the most important stations and parameters for monitoring the quality of surface waters. [12] employed multivariate statistical techniques, including CA, PCA, factorial analysis, and detection analysis, to evaluate spatial and temporal variables and complex qualitative data sets of water collected from the Songhua River basin in northeastern China. For this purpose, 14 different parameters of water quality were evaluated within a seven-year statistical period (1998-2004) across 14 stations. Eventually, three main sampling locations (stations with low, medium, and high contamination) were determined by CA. This study indicated that the major reason for the deterioration of the Songhua's water quality was the discharge of household and industrial wastewater. [14] Used PCA and CA to investigate the water quality of Iran's Jajrood River and to determine the degree of the relationship between human effects and natural effects on the quality of its waters. Monthly over a three-year period, 18 qualitative parameters (16 physiochemical parameters and two biochemical parameters) were evaluated across 18 different stations, achieving similar results. The PCA results in the study by [36] revealed that all qualitative variables selected during their statistical period were important to the investigation of the water quality of the Karkheh River. These parameters had almost the same significance in each study.

4. Conclusions

In spite of its high flow rate and self-purification abilities, the water quality of the Karkheh River is unacceptable because of the excessive amounts of contaminants. Therefore, the river fails critical health and environmental standards. To protect this valuable resource, strict legislation should be applied and firm environmental management should be established in the region. These steps would enable this resource to provide for the water needs of its current population and respond to the needs of future generations. The PCA results indicated that the relative quality of the river's water in the downstream areas as opposed to the upstream areas is worse, due to the greater concentration of contamination sources in the vicinity of the monitoring stations. The multivariate statistical analysis supports these goals by simultaneously processing a large volume of complex water quality data. For this reason, it was used as a support instrument and a suitable quantitative solution in the investigation of the qualitative changes in the water resources in this study; it can also be employed by decision-makers and water managers everywhere.

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