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Multidimensional analysis of developed water sources in the health zone of Lukula in the Democratic Republic of the Congo

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Abstract : In this investigation, principal component analysis (PCA), hierarchical ascending classification (HAC), and multiple correspondence factor analysis (MCFA) were used to assess the water quality and the impact of human activities on it. PCA transformed the physicochemical parameters into new uncorrelated variables, and the PC1 and PC2 axes revealed that 64,05% of the total variance was influenced by parameters such as chlorides, sodium, potassium, phosphates, sulfides, pH, turbidity, and nitrates. After projecting the samples onto the factorial plane defined by PC1 and PC2, water sources were characterized based on their properties, which allowed for the identification of saline and hard waters, enabling decisions regarding their use and treatment methods. HAC grouped the water sources according to their similarity in terms of salinity and hardness, providing an understanding of the similarities and differences between these waters. MCFA identified significant correlations between certain parameters, measuring the linear relationships between multiple quantitative variables. We used R software to perform this multidimensional analysis of water sources. The statistical methods were performed to assess water quality, gain a better understanding of its characteristics, and make informed decisions regarding its management and treatment**.**

***IndexTerms* - Component,formatting,style,styling,insert.**

I. Introduction

The establishment of a potable water supply system in healthcare is of paramount importance to meet the diverse needs of patients and physicians practicing in the Lukula region. Due to the scarcity of potable water in the healthcare zone, patients are compelled to travel to various nearby water sources. Therefore, conducting a comprehensive study on the quality of water sources is imperative to determine the necessary treatments to be applied to these water sources located in proximity to health care.

It is crucial to preserve and sustainably manage the resources to ensure the continued availability of water and preserve the balance of aquatic ecosystems. The assessment and characterization of water resources are crucial steps in the management of water as a resource. To achieve this, it is important to use appropriate analytical methods to understand the characteristics of water sources, identify the factors influencing their quality, and make decisions for good management. We used the R software to perform a multidimensional analysis of water sources, specifically to investigate whether there is a correlation between the parameters of the water samples that deviates from zero.

In this study, we methodically examine the use of three statistical analysis methods: principal component analysis (PCA), hierarchical ascending classification (HAC), and multiple correspondance factor analysis (MCFA) to evaluate and characterize water sources. PCA reduces data dimensionality and identifies the most significant variables, while HAC groups water samples into homogeneous clusters based on their similarities. MCFA, on the other hand, is used to study the relationships between different water source characteristics (Karimi,H. et al.,2004, Kamtchueng,B.T et al., 2016, Lavoie, L. and Dillon, P.J., 2006, Loughead, V.L. et al, 2001, Reavie, E.D. and Smol,J.P., 1998, Szoszkeiwicz,K. et al.,2014). By using these analytical methods, it becomes possible to obtain valuable information on water quality, the chemical components present, environmental factors, and many other relevant parameters. These data are essential for effective water management, enabling preventive measures to be taken to preserve water quality for future generations (Kamtchueng,B.T et al., 2016, Szoszkeiwicz,K. et al.,2014).

The multidimensional analysis of the water sources developed in the health zone provides a comprehensive context for understanding the various aspects related to water in a specific region. It enables the availability, quality, socio-economic aspects, and environmental implications of the use of these water sources to be assessed. This approach is essential for guiding water management policies, development decisions, and interventions aimed at improving access to clean, safe water for the local population (Kamtchueng, B.T et al., 2016).

III. MATERIALS AND METHODS

3.1 MATERIALS

Study environment is located in the Democratic republic of Congo, central Kongo province, in the Lukula health zone (figure 1). The names of the villages included in this study, as well as the geographical coordinates of their respective sources.

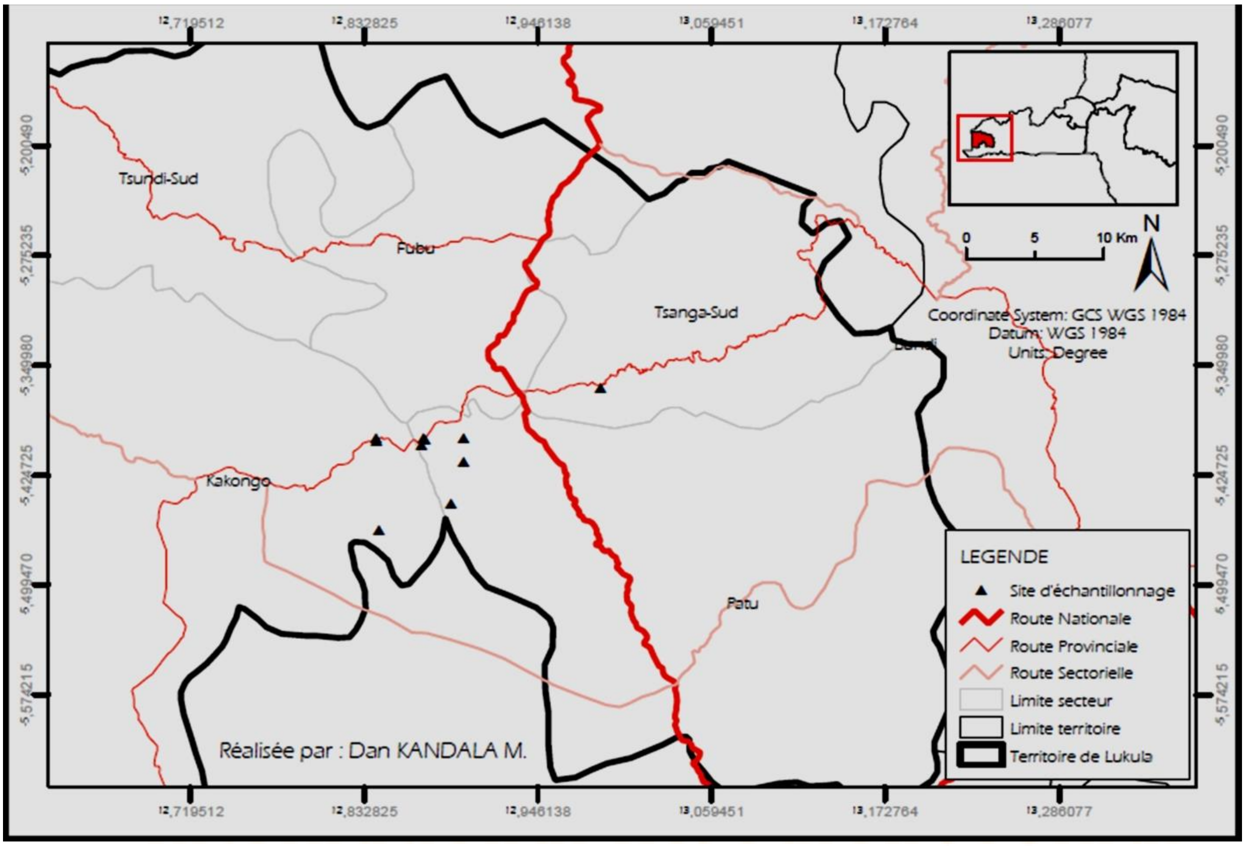

Figure 1 : Location of the study site

According to (Shima Ngoy,T. et al.,2020), the data in tables 1 and 2, including the geographical coordinates of the study area and physico-chemical measurements, can be used to enrich the multidimensional analysis of water sources in the health zone and the samples were taken in april and december 2018.

Tableau 3.1 : Geographical coordinates of village water points in the Lukula health zone

N°	Sites	Latitude Sud	Longitude East
S1	KINDUKA	05°24’53,6”	012°53’50,1”
S2	KILONDE	05°26’37,2”	012°53’21,5”
S3	KILONDE I	05°27’40,5”	012°50’31,4”
S4	KIALA MONGO I	05°24’02,7”	012°50’26,9”
S5	KIBINONGA	05°23’57,3”	012°52’16,9”
S6	KINGOLA FUKA	05°24’14,9”	012°52’12,9”
S7	KIYANGI I	05°23’59,5”	012°52’20,4”
S8	KIZINGA	05°23’57,9”	012°53’50,1”
S9	TUIDI YILA	05°21’55,8”	012°59’13,7”
S10	KIALA MONGO II	05°23’58,1”	012°50’24,6”

The following physico-chemical characteristics were studied: pH, chlorides (mg/l), sodium (mg/l), potassium (mg/l), sulfates (mg/l), phosphates (mg/l), iron, organic matter (mg/l), turbidity (NTU), total dissolved solids (mg/l), conductivity (µ/cm), total, total hardness (°F), calcium (mg/l), bicarbonates (mg/l), magnesium (mg/l), temperature (°C), total alkalinity (°F), and nitrates (mg/l) for individuals in then spring water samples.

Table 1 : The phiscicochemical parameters of spring water

Echantillons	Cond .	T	pH	STD	Turb.	TAC	Mo	HCO3	Cl	SO4	NO3	PO4	Na	K	Ca	Mg	THT	Fer
S1	178	26.1	7.67	89	0.157	8.2	3.5	100	32.2	2	6.05	0.29	18.01	11.25	23.21	<0.01	7.22	0.08
S2	180	26.2	7.46	90	0.142	7.8	3	95	39	2.81	8.31	0.31	22.04	5.01	23.71	<0.01	8.91	0.12
S3	22	26.5	7.13	11	0.214	2.6	4.6	31	46	2.56	7.01	0.11	25.6	11.01	7.21	<0.01	2.96	0.3
S4	34	25.9	7.12	17	0.025	2.5	1.9	30.52	35	2.34	4.22	0.15	20	6.21	7.65	<0.01	2.91	0.08
S5	24	26.9	7.14	12	0.605	2.4	4	29.21	28	3	2.25	0.21	16	3.7	7.34	<0.01	2.81	0.15
S6	80	27.1	7.24	40	0.17	2.6	4.3	32	49	2.22	4.11	0.11	27.21	8.01	8.01	<0.01	3.21	0.25
S7	208	26.6	7.62	104	0.136	8.6	4.6	104	48	3.01	5.06	0.22	27.42	2.96	26.01	<0.01	8.45	0.35
S8	168	26.6	7.60	84	0.047	4.2	4.3	39	99	2.05	5.23	0.1	54.43	17.42	9.71	<0.01	3.22	0.25
S9	42	27.1	7.50	21	0.016	2.5	2.9	30	49	2.51	3.12	0.12	27.33	8.01	7.51	<0.01	2.87	0.07
S10	43	27.5	7.42	21	0.036	2.4	2.5	29	35.07	2.8	4.11	0.09	19.74	6.3	7.31	<0.01	2.82	0.1

3.2 METHODS

3.2.1 Statistical analysis

The R software is essential for the multidimensional analysis of water sources, offering functionalities for data collection, pre-processing, multiple component analysis, classification, multiple correspondence factor analysis, and data visualization to enable the user to make the necessary decisions using this statistical tool (Lafaya de Micheaux, P. et al., 2015).

3.2.2 Principal component analysis (ACP)

Principal component analysis was performed on a data matrix consisting of ten samples. To process the data using principal component analysis, we used some eighteen variables: The following physico-chemical characteristics were studied: pH, chlorides, sodium, potassium, sulfates, phosphates, iron, organic matter, turbidity, total dissolved solids, conductivity, total hardness, calcium, bicarbonates, magnesium, temperature, total alkalinity, and nitrates for individuals in ten spring water samples. .

Analysis of the PC1 and PC2 factorial plans shows that over 64,05% are recorded. The PC1 axis gives a variance of 42,61%, expressed as chlorides, sodium, potassium, sulfates, phosphates, iron, organic matter, turbidity, pH, total dissolved solids, conductivity, total hardness, calcium, bicarbonates, magnesium, temperature, full alkalimetric titre, and nitrat. The PC2 axis has a variance of 21,44% expressed as full alkalimetric titre, calcium, bicarbonates, total hardness, total dissolved solids, conductivity, magnesium, phosphates, pH, nitrates, temperature, iron, turbidity, sodium, potassium, chlorides, organic matter, and sulfates.

The resolution or analysis of the projection of individuals on the PC1 and PC2 factorial planes has given the following characteristics of water sources (Figure 2);
Correlated positively with the PC1 axis, these S8 and S6 water sources are characterized by saline waters. Negatively correlated with the PC1 axis, S5 and S4 are less saline and have a bitter taste and unpleasant odor.
Correlated positively with the PC2 axis, these S3, S1, and S7 water sources are characterized by herd water. Negatively correlated with the PC2, with the less hard. water sources of S10, S9, and S2 having relatively high temperatures.

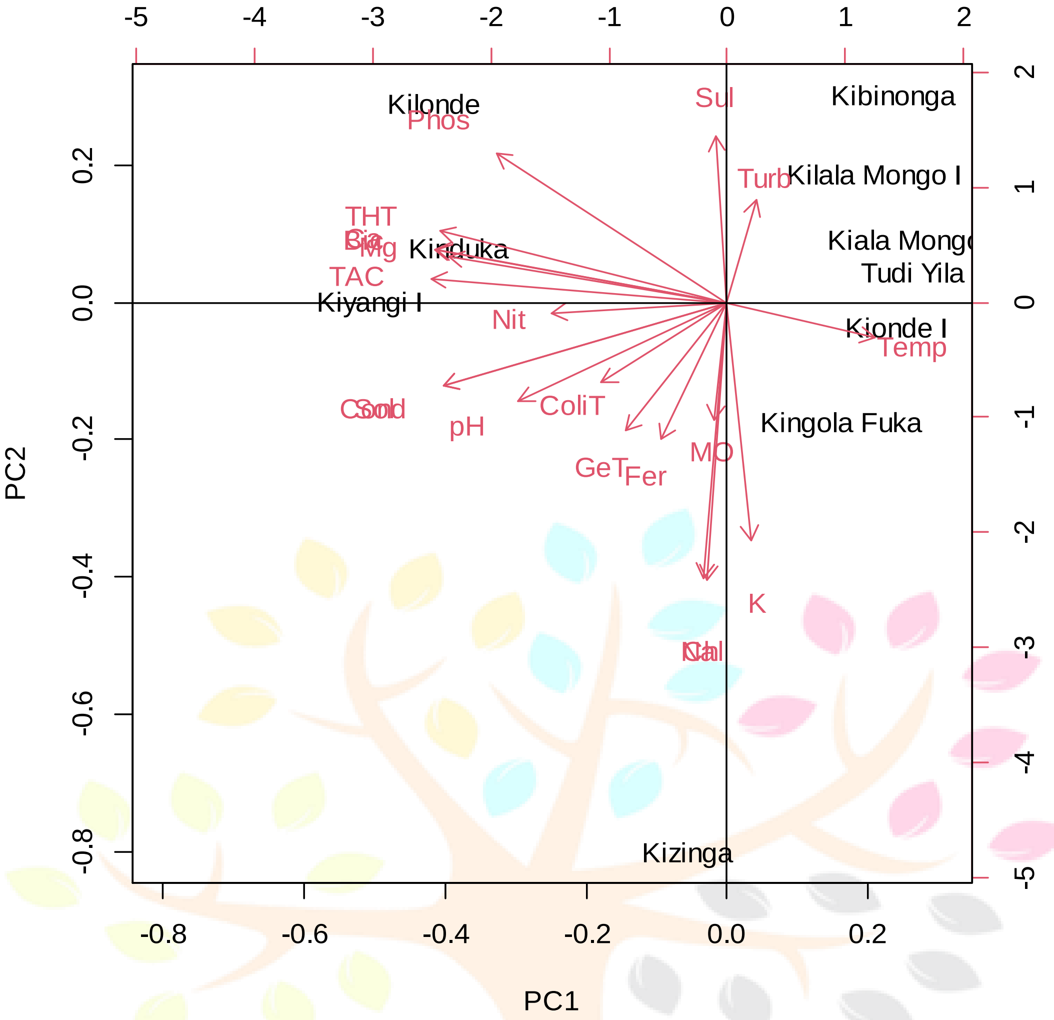

Figure 2 : Representation of variables on the palne PC1 ×PC2

VI. RESULTATS AND DISCUSSION

4.1 Hierachical ascendante classification HAC

The hierarchical ascendante classification HAC was used to group waters with similar salinity and hardness characteristics. This classification provides an understanding of the similarity and dissimilarity between water sources, which can be useful in making decisions about the use of these sources and water treatment needs. Figure 3 shows that there are three groups of water sources;

The first group is made up of springs S6, S9, S4, S10, S2, and S5, which are characterized by less saline and less hard water.

The second group consists of the S8 water source, which is characterized by saline water.

This group includes the S7, S1, and S3 springs, which are characterized by hard water.

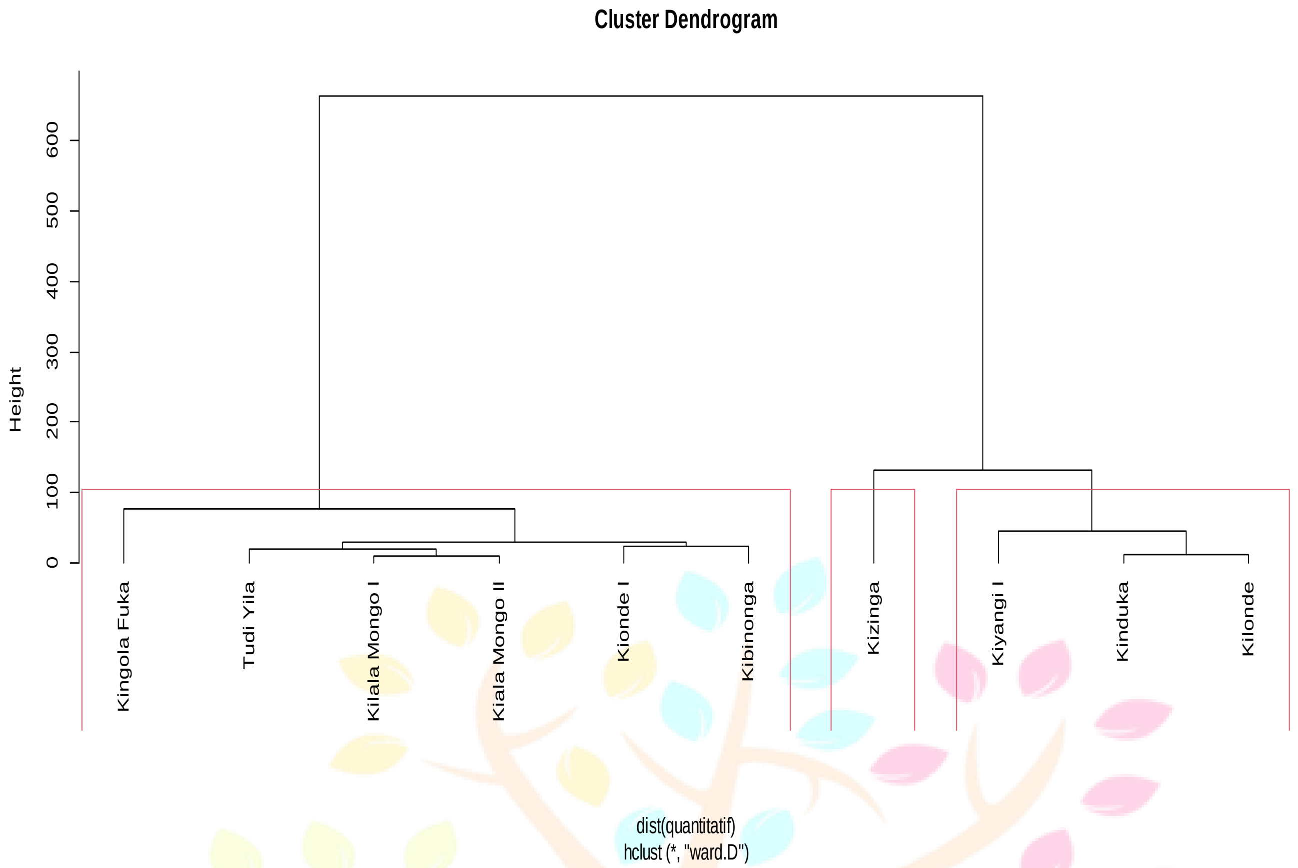

Figure 3 : classification dendrogram for different water sources

4.2 Multiple coreespondence factor analysis MCFA

The Pearson correlation test generally uses a Student statistic to compare the means between two independent groups, and the P value associated with the hypothesis test indicates the probability of obtaining a correlation as high or higher than that observed, if the alternative hypothesis is true. The Pearson correlations show that the variables are very significantly correlated positively and negatively in pairs at $p<0.05$, regardless of whether the alternative hypothesis is that the correlation is different from zero. The values of the correlation coefficients are close to those in tables 3 and 4.

Table 4.1 : Student's t test p-value

Parame-tres	STD	THT	Cond.	Ca	Na	TAC	HCO3	Mg	PO4	K	Fer
Cond.	$2,2*10^{-16}$	0,002105	$2,2*10^{-16}$	0,0008989	0,3259	0,0002079	0,001068	0,002736	0,07216	0,697	0,4402
Cl	0,3383	0,672	0,339	0,741	$1,093*10^{-14}$	0,9486	0,7182	0,8722	0,2233	0,01365	0,2005
HCO3	0,001065	$6,358*10^{-7}$	0,001068	$9,27*10^{-5}$	0,7383	$8,36*10^{-9}$	$2,2*10^{-16}$	$7,622*10^{-11}$	0,002683	0,5973	0,7391
TAC	0,0002069	$4,042*10^{-6}$	0,0002079	$1,854*10^{-8}$	0,9697	$2,2*10^{-16}$	$8,36*10^{-9}$	0,0001156	0,005077	0,774	0,6657
Ca	0,0008972	$9,923*10^{-8}$	0,0008989	$2,2*10^{-16}$	0,7631	$1,854*10^{-8}$	$9,27*10^{-5}$	$2,749*10^{-5}$	0,003085	0,5363	0,7047
Mg	0,002735	$3,365*10^{-5}$	0,002736	$2,749*10^{-5}$	0,9046	0,0001156	$7,622*10^{-11}$	$2,2*10^{-16}$	0,02393	0,3198	0,3636
THT	0,0002069	$2,2*10^{-16}$	0,002105	$9,923*10^{-8}$	0,6931	$4,042*10^{-6}$	$6,358*10^{-7}$	$3,365*10^{-5}$	0,0021	0,4261	0,744
STD	$2,2*10^{-16}$	0,002101	$2,2*10^{-16}$	0,0008972	0,3253	0,0002069	0,001065	0,002735	0,07166	0,6961	0,4389
pH	0,005181	0,07115	0,005078	0,0388	0,2954	0,02175	0,03713	0,07476	0,3497	0,439	0,9989
PO4	0,07166	0,0021	0,07216	0,003085	0,2305	0,005077	0,002683	0,02393	$2,2*10^{-16}$	0,3133	0,5707
Na	0,3253	0,631	0,3259	0,7631	$2,2*10^{-16}$	0,9697	0,7383	0,9046	0,2305	0,01593	0,1924
Mo	0,7184	0,9173	0,7157	0,9968	0,4339	0,9433	0,9955	0,8034	0,4352	0,6474	0,0198
SO4	0,7169	0,5749	0,7188	0,7036	0,2211	0,8857	0,7875	0,346	0,5973	0,005477	0,6807

Table 1 : Pearson correlation analysis

Variables	Cond.	T	pH	STD	Turb.	TAC	Mo	HCO	Cl	SO	NO	PO	Na	K	Ca	Mg	THT	Fer
Cond.	1																	
T	-0,37	1																
pH	0,803	-0,02	1															
STD	0,9999	-0,38	0,802	1														
Turb.	-0,22	0,07	-0,42	-0.22	1													
TAC	0,914	-0,49	0,708	0,915	-0,09	1												
Mo	0,13	0,54	0,142	0,13	0,26	0,026	1											
HCO	0,8699	-0,48	0,66	0,8699	-0,063	0,993	-0,002	1										
Cl	0,34	0,06	0,36	0,24	-0,37	-0,023	0,28	-0,13	1									
SO	-0,13	0,297	-0,19	-0,13	0,14	0,05	0,20	0,098	-0,44	1								
NO	0,52	-0,55	0,245	0,53	-0,26	0,587	0,023	0,58	0,104	-0,12	1							
PO	0,59	-0,57	0,33	0,59	0,298	0,803	-0,28	0,83	-0,42	0,19	0,44	1						
Na	0,35	0,055	0,368	0,35	-0,37	-0,01	0,28	-0,12	0,999	-0,42	0,104	-0,42	1					
K	0,14	-0,12	0,268	0,14	-0,33	-0,104	0,17	-0,19	0,744	-0,79	0,23	-0,36	0,73	1				
Ca	0,88	-0,47	0,657	0,88	-0,07	0,992	-0,001	0,9979	-0,12	0,14	0,57	0,83	-0,04	-0,222	1			
Mg	0,83	-0,36	0,59	0,83	-0,07	0,93	0,09	0,93	-0,06	0,33	0,48	0,70	-0,11	-0,35	0,95	1		
THT	0,84	-0,46	0,59	0,835	-0,06	0,969	-0,04	0,98	-0,15	0,20	0,62	0,845	-0,14	-0,28	0,988	0,95	1	
Fer	0,28	0,072	-0,0004	0,28	0,14	0,16	0,72	0,12	0,44	0,15	0,20	-0,21	0,45	0,12	0,14	0,32	0,12	1

CONCLUSION

Multidimensional analysis was used to provide a comprehensive overview of the water quality from different water sources. The results revealed that one source is saline, while three others are hard, and the remaining six are both less saline and less hard. Furthermore, a highly significant correlation was observed among the parameters of these six sources. This study has provided a better understanding of the characteristics of water sources, thereby demonstrating the usefulness of these statistical methods for assessing water quality and making appropriate decisions in water resource management.

II. ACKNOWLEDGMENT

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