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The Multivariate Statistical Analysis of the Environmental Pollutants at Lake Nyamagoma

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Abstract
Results from multivariate statistical analysis of the environmental pollutants conducted during the wet season at 8 accessible sampling sites in Lake Nyamagoma are discussed. Standard methods were used to determine the levels of pollutants from the filtered water samples. Physical parameters including DO, EC, pH turbidity, temperature and transparency were measured in situ using appropriate gears whilst NO_3^-, PO_4^{3-}, SiO_2, Fe^{2+}, HCO_3^-, SO_4^{2-}, Cl^- and major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were determined in the laboratory. Data show that the variation of the environmental pollutants at the sampled sites is controlled by the factors including increased primary productivity, redox conditions, dissolution, nitrification, denitrification, mixing and reduction processes along with the anthropogenic activities. Future work is recommended to focus on the intensive seasonal studies using statistical approaches on the hydro-bio-chemical parameters to address the climate change impacts for sustainability of Lake Nyamagoma.
Keywords: Multivariate statistics, environmental pollutants, factors, anthropogenic activities, Lake Nyamagoma.

1. Introduction

Lake Nyamagoma has existed since 1930s and 1940s and it expands over time due to the rainfall regime in the area. It is inflowed by the rivers Moyowosi, Igombe and Kigosi along with Malagarasi River which drains the lake during the wet season. The lake falls within the Malagarasi-Moyovosi Wetland located in the northwestern Tanzania (Nkotagu & Athuman, 2008). The wetland is recognized for its economic, social and environmental importance. The wetland complex apart from lakes and rivers also includes permanent swamps, seasonally-inundated floodplains and large areas of miombo woodland (Nkotagu & Athuman, 2004). In the past, wetlands were significantly devalued by being considered wastelands (Goldstein, 2004). Huge areas of wetlands were destroyed due to this illusive notion. However, the fact does not hold true to the Malagarasi-Muyovosi wetland ecosystem. The wetland constitutes important sources of natural resources utilized by the local communities, fulfill several critical hydrological functions and it is internationally recognized as the area of high biodiversity. Varieties of flora and fauna such as fish of which 50 species are known with some being endemic, crocodiles, hippopotamus and other micro-organisms are found at this precious ecosystem.

The major threats to the wetland include the continuing clearance of woodlands to create new agricultural land (notably for tobacco cultivation) and to provide grazing areas for livestock, the unsustainable - and often illegal - use of the wildlife, forest, grassland and fisheries resources, the settlement of long-term refugees bordering, and within, protected areas, the widespread incidence of bush fires and the quasi-absence of any effective controls and/or integrated natural resource management planning.

Recently, Lake Nyamagoma has undergone large chemical and physical changes consequent to growing human interference (Athuman, 2012a; Athuman & Nkotagu, 2012; Nkotagu & Athuman, 2004). At the catchment scale encroachment and deforestation are common especially for the purpose of increasing the size of settlements and agricultural fields. Deforestation mostly results from fuel-wood gathering and livestock grazing in the *miombos*. The use of fire to regenerate grasslands is practiced haphazardly and frequently resulting in a decreasing fertility of grasslands for livestock grazing. Next to impacts from pollution, domestic and agricultural activities leading to deterioration of water quality, shallowing of the lake is increasing at a fast rate. The lake is being plagued by an excessive growth of aquatic macrophytes. In any lake such invasions presage early eutrophication and alteration of both quality and water body amenities (Hecky & Bugenyi, 1992).

Various authors (e.g. Athuman, 2012; Athuman & Nkotagu, 2012, Nkotagu, 2008; Joseph, 2005; Enger & Smith, 2004; Wetzel, 2001; Jackson & Jackson 2000; Hecky & Bugenyi, 1992) have pointed that, human activities, mainly agriculture has significantly accelerated the deforestation in the tropical ecosystems. These ecosystems play a central role in the lives of all organisms. Human beings, in their struggle to meet basic needs and to better their lives, through agriculture, lumbering wood for fuel, and in finding space for settlement, have depleted more of the environment than they replenish (Athuman, 2012b; Easton, 2011; Joseph, 2005). Rapid changes in global patterns of land-use threaten even the biological diversity (Joseph, 2005; Mader, 2003). Easton (2011) adds that the threats from land-use practices today, stand as driving forces to the deterioration of the water sources as a result of increased environmental pollutants into the ecosystems. According to Nebel and Wright (1998) ecosystems are the functional units of sustainable life on Earth due to the fact that no organism can live apart from its environment. The present study therefore truckled down the multivariate statistical analysis of the environmental pollutants in Lake Nyamagoma for sustainable functioning of the Malagarasi-Muyovosi Wetland Ecosystem.

2. Materials and Methods

2.1 Study Area

The study was conducted at Lake Nyamagoma within the Malagarasi - Moyovosi Wetland in Western Tanzania during the wet season. A total number of 40 water samples were collected from 8 accessible sampling sites (Fig. 1). The lake is shallow (maximum depth *ca.* 2.5 m) and chocked by macrophytes and swampy areas at the inflows and outflows (Athuman, 2012).

2.2 Geology and Soils of the Study Area

The study area is located predominantly in the mesoproterozoic sandstones of about 1,200 million years old with the lithology covering shales, quartzites, dolomitic limestones, migmatite, utramafic rock and the sediments of the Kavirondian Supergroup (Athuman & Nkotagu, 2012; Nkotagu & Athuman, 2008; Pina *et al.,* 2004). These rocks are exposed differently at various places within the catchment thus influencing the geomorphology of the lake accordingly (Fig. 2). A large part of the study area is covered by high pseudopodsolic soils and ferrisols on sand stones. These infertile soils are easily eroded, and their agricultural potential without fertilizers is generally low.

2.3 Field work

Sampling was conducted during wet season at 8 accessible sites (See Fig. 1) following Crosby and Patel (1995). *In situ* physical parameters including Electrical Conductivity (EC), Dissolved Oxygen (DO), pH and temperature were measured at each sampling site using a Multi Probe meter 340i model. Turbidity was measured using a HACH turbidimeter 2100P model. A total of 40 water samples were collected depth wise using a 2-Litre water sampler, filtered using 0.45µm size filter membrane, kept into half-litre plastic bottles and then transported immediately to the laboratory for chemical determination.

2.4 Laboratory work

Water samples were stored at 4°C before analysis. Unfiltered water samples were tested for alkalinity using a titrimetric method with 0.1 N HCl and results expressed as HCO_3^- (mg l^{-1}) as explained by APHA *et al.* (1998). Nutrients including SiO_2, NO_3^-, PO_4^{3-} and Fe^{2+} were determined from the filtered water samples using a HACH Spectrophotometer DR/2010 model according to HACH (2002). The major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were measured from filtered water samples using the Inductively-Coupled Plasma (ICP) machine following Lin (2007), APHA *et al.* (1998) and WHO (1993).

2.5 Data analysis and interpretation

The data were analyzed using the Statistical Package for Social Scientists version 11.0 (SPSS 11.0). The interpretation was performed by both the univariate and the multivariate statistical analyses to yield the descriptive statistics, correlation, factor and cluster analyses following Lind *et al.* (2011), Doane and Seward (2010), Francis (2008), Bluman (2007), Gupta (2006), Kothari (2004), Davis (1986), Drever (1982), Kaiser (1958), Tryon (1939) and Thurstone (1931).

3. Results and Discussion

3.1 Descriptive Statistics

Descriptive statistics is used as a first stage of statistical processing (Kothari, 2004; Davis, 1986). The main aim is initial analysis of the distribution of particular chemical parameters by statistics such as mean and standard deviation. In the present study, the mean results for the descriptive statistics of the pollutants show a significant variation (Tab. 1). The values for turbidity, NO_3^-, PO_4^{3-}, Ca^{2+}, Mg^{2+}, Na^+ and K^+ are higher. The observed elevated values of the pollutants are attributed to fertilizer flush down from the farm fields especially at Chagu and the upstream areas along Moyowosi River. However, the mean pH value (7.87) and its small standard deviation (0.79) indicate that the water is well buffered as supported by the high mean alkalinity values.

3.2 Correlation Analysis

Correlation analysis is defined as a measure of association between two parameters (Kothari, 2004; Davis, 1986; Drever, 1982). The two-tailed Pearson correlation method was used to measure such associations, by measuring the linear relationship denoted as "r" between two parameters. According to Kothari (2004), Davis (1986) and Drever (1982), the value of "r" varies between +1 and -1 with -1 or +1 indicating perfect linear inverse or positive relationships respectively, and r = 0 indicating no relationship in the parameters.

The data in the present study significantly show positive and negative correlation between the pollutants as shown in table 2. This phenomenon may be consequent to hydrochemical and biological differences. Most of the data show a significant negative correlation with depth, indicating the strong effect of inputs from the catchment area into the lake water. Nevertheless, the data show a positive correlation between depth and Fe^{2+}. This may be probably due to reducing conditions. Likens (1984) pointed out that, the reduction is usually influenced by anaerobic condition and microbial activities in the sediments of the lake.

Temperature correlates positively with DO and weakly with SiO_2. This indicates that warm surface waters result in increased photosynthetic activity leading to high primary productivity (Horne & Goldman, 1994). The positive correlation between pH and HCO_3^- in the dry season and between pH and NO_3^- in the wet season supports the observed relationship. The higher alkalinity values seem to favour the presence of increased nutrients in water as shown by the strong positive correlation between HCO_3^- and NO_3^-, PO_4^3 and SiO_2. Fe^{2+} correlates positively with turbidity indicating the increased primary productivity. Horne and Goldman (1994) added that, most of the primary productivity acquires iron from the food. SO_4^{2-} correlate positively with turbidity, NO_3^-, PO_4^{3-} and SiO_2 suggesting that as the decomposing particulate matter settles down the sulphur mineralization is subsequently taking place.

The observed positive correlation among the nutrients NO_3^-, PO_4^3, SiO_2 and Fe^{2+} suggests that these nutrients have a common source (mainly anthropogenic). The strong positive correlation between the cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) may be consequent to cation exchange thus contributing to the salinity of the lake water. This observation is supported by the strong positive correlation between SiO_2 and Ca^{2+}, Mg^{2+} and Na^+ along with the negative correlation between SiO_2 and the salinity.

3.3 Factor Analysis

Factor analysis presents the structure of studied data by means of their grouping and classification as well as for space dimension reduction of the analyzed parameters (Kothari, 2004; Davis, 1986; Kaiser, 1958; Thurstone, 1931). Factor rotation with Kaiser Normalization was done as explained by Davis (1986) in order to improve the initial results. The interpretation of values for rotated varimax was conducted following Kaiser (1958) and implies that loadings in excess of 0.71 are rated as excellent, 0.63 as very good, 0.45 fair, 0.32 poor and 0.30 un-interpretable. In this study, four factors were extracted as the controlling measures to the environmental pollutants within the lake catchment (Tab. 3).

3.3.1 Factor 1

This factor is highly enriched positively with depth, turbidity, Fe^{2+} and Mg^{2+}, and negatively enriched with temperature, DO, HCO_3^- and Cl^-. The factor supports the primary productivity phenomenon at the sampling sites in the lake. This indicates that there is high turbidity throughout the water depths leading to dilution effect as indicated by negative Cl^- values along with a decreased photosynthetic activity as indicated by negative values of DO and HCO_3^-.

3.3.2 Factor 2

Factor 2 is highly loaded with Ca^{2+}, Na^+ and K^+, and negatively loaded with PO_4^{3-}, $NO_3^-$and HCO_3^-. This supports the bio-geo-chemical interactions between the macrophytes and the aquatic organisms, and indicates the presence of cation exchange process in the lake bottom waters.

3.3.3 Factor 3

Factor 3 is highly positively loaded with turbidity, pH, DO, NO_3^-, PO_4^{3-}, SO_4^{2-} and $Cl^-$and negatively loaded with depth. This is generalized as a primary productivity factor. This factor clearly demonstrates the depth variation phenomenon of the pollutants at the sampling sites, and thus contributing to the varied water quality within the lake. This factor further indicates that, nutrients might be coming from the catchment as supported by the positive NO_3^- and PO_4^{3-} values.

3.3.4 Factor 4

Factor 4 is positively loaded with, EC and Cl^-; and negatively loaded with SO_4^{2-}. This factor supports the reduction process indicating that the reduction of SO_4^{2-} is favoured primarily by the increased salinity in the lake water.

3.4 Cluster Analysis

Cluster analysis is the bewildering assortment of techniques designed to perform classification by assigning observations to groups such that each group is more-or-less homogeneous and distinct from other group (Davis, 1986; Tryon, 1939). It combines different algorithms for classification. The commonly used technique is hierarchical clustering, which joins most similar observations, and then successively connects the next most similar observation to these. First, an n x n matrix of similarities between all pairs of observations is calculated. Those pairs having the highest similarities are then grouped and merged, and the matrix repopulated. This is done by averaging the similarities that the combined observations have with other observations. The process is iterated until the similarity matrix is reduced to 2 x 2. The levels of similarity at which observations are merged were determined and used to construct a dendogram using Ward's method (Davis, 1986).

The clustering shows a significant variation among the environmental pollutants and two main clusters were depicted (Fig. 3). The first cluster is composed of SiO_2, Ca, Na, Mg and depth. This implies that these pollutants originate from the same source and vary depth-wise as favoured by the geology of the study area. This observation agrees with the results by Athuman (2012), Athuman and Nkotagu (2012), Nkotagu and Athuman (2008), Nkotagu (2008) and Nkotagu and Athuman (2007). The second cluster favours salinity to be primarily due to water temperature, DO, NO_3^-, PO_4^{3-}, SO_4^{2-}, pH, HCO_3^- and Cl^-. This association indicates that the dissolution of anthropogenic salts under favourable temperatures and pH may be responsible for the salinity of the water at the sampling sites as depicted at Chagu sampling site.

4. Conclusions and a way forward

Generally, the data from the present study conclude that the variation of the environmental pollutants at Lake Nyamagoma is controlled by the bio-geo-chemical factors including increased primary productivity, redox conditions, dissolution, nitrification, denitrification, mixing and reduction processes along with the anthropogenic activities. For the way forward, it is recommended that future work focuses on the intensive seasonal studies using statistical approaches on the hydro-bio-chemical parameters so as to address the climate change impacts for sustainable monitoring of the Lake Nyamagoma productivity.

5. Acknowledgements

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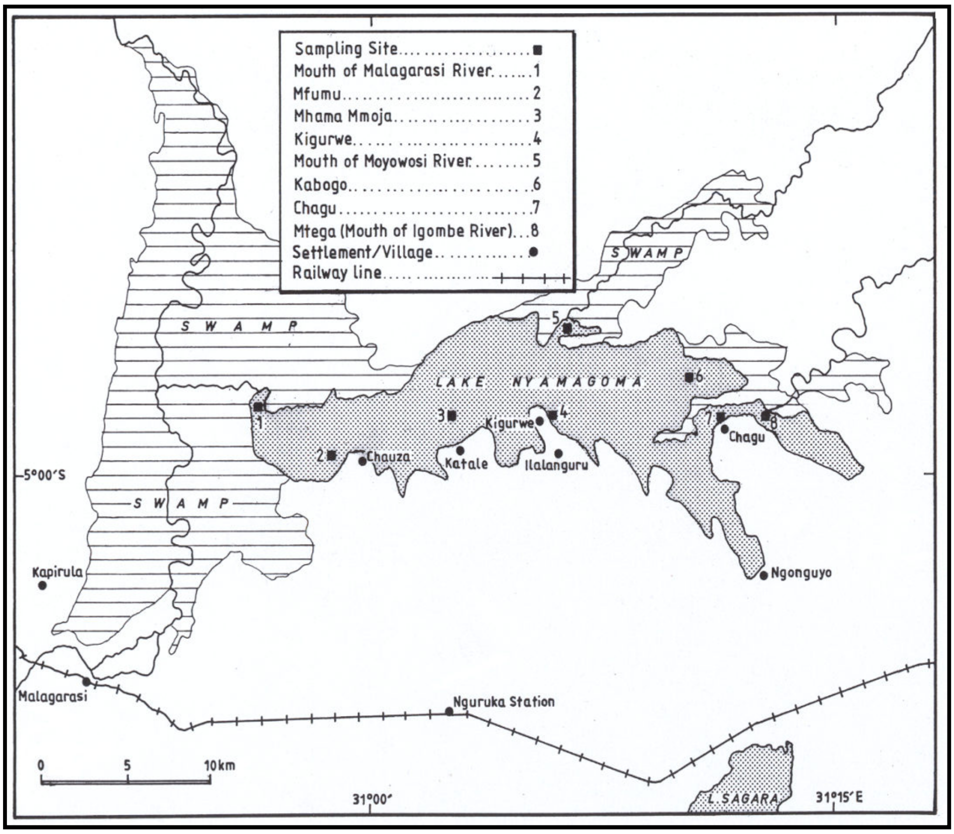

Figure 1. Location map of the study area (After Athuman & Nkotagu, 2012)

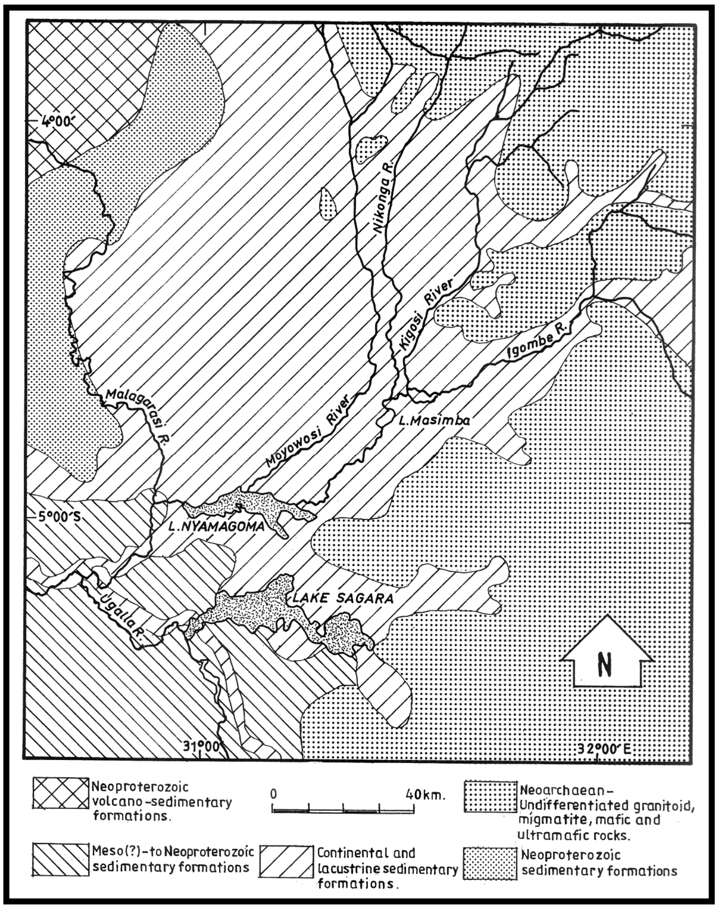

Figure 2. Geological map of the study area (After Nkotagu & Athuman, 2008)

Table 1. Descriptive statistics of the environmental pollutants

Parameter	N	Minimum	Maximum	Mean	Standard Deviation
Depth (m)	40	0.00	2.00	1.00	0.73
Temp (^oC)	40	23.90	28.80	25.69	1.25
pH	40	6.01	8.46	7.47	0.87
Turb (NTU)	40	4.56	15.26	8.83	3.35
EC (μScm^{-1})	40	238.00	663.00	412.75	120.89
DO (mgl^{-1})	40	0.09	8.31	4.98	2.68
HCO_3^- (mgl^{-1})	40	101.90	198.90	151.96	27.66
SO_4^{2-} (mgl^{-1})	40	0.45	1.31	1.01	0.25
Cl^- (mgl^{-1})	40	12.03	34.98	23.55	6.13
NO_3^- (mgl^{-1})	40	1.08	2.73	1.61	0.42
PO_4^{3-} (mgl^{-1})	40	8.02	17.03	12.59	2.54
SiO_2 (mgl^{-1})	40	11.21	29.02	20.18	4.99
Fe^{2+} (mgl^{-1})	40	0.01	0.14	7.60E-02	3.42E-02
Ca^{2+} (mgl^{-1})	40	11.63	34.97	21.16	8.45
Mg^{2+} (mgl^{-1})	40	13.16	18.79	15.28	1.76
Na^+ (mgl^{-1})	40	19.76	40.39	30.16	6.16
K^+ (mgl^{-1})	40	1.65	9.66	4.33	2.83

Table 2. Correlation matrix of the environmental pollutants

	Depth	Temp	pH	Turb	EC	DO	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SiO_2	Fe^{2+}	Ca^{2+}	Mg^{2+}	Na^+	K^+
Depth	1																
Temp	-.63	1															
pH	-.55	-.04	1														
Turb	.12	-.66	.46	1													
EC	.42	-.25	-.26	-.15	1												
DO	-.81	.66	.48	-.18	-.38	1											
HCO_3^-	-.80	.64	.27	-.27	.10	.68	1										
SO_4^{2-}	-.45	-.15	.59	.72	-.67	.28	.05	1									
Cl^-	-.64	.60	.49	-.27	.16	.70	.77	-.11	1								
NO_3^-	-.56	-.16	.73	.67	-.12	.39	.47	.73	.33	1							
PO_4^{3-}	-.66	.07	.60	.45	-.13	.48	.61	.66	.36	.87	1						
SiO_2	.49	-.38	-.04	.13	-.22	-.31	-.69	-.09	-.29	-.31	-.61	1					
Fe^{2+}	.64	-.85	-.02	.77	.25	-.60	-.54	.22	-.58	.23	.07	.21	1				
Ca^{2+}	.29	.06	-.15	-.34	-.28	-.14	-.48	-.32	-.12	-.58	-.75	.84	-.25	1			
Mg^{2+}	.66	-.74	-.03	.72	-.11	-.58	-.76	.29	-.62	.04	-.25	.62	.80	.22	1		
Na^+	.32	-.02	-.01	-.28	-.04	-.16	-.43	-.44	.08	-.50	-.70	.82	-.18	.92	.20	1	
K^+	.20	.20	.03	-.36	.52	.04	.09	-.67	.57	-.30	-.40	.25	-.21	.38	-.14	.65	1

Table 3. Rotated component matrix of the environmental pollutants

Parameter	**Component**			
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
Depth (m)	***0.754***	0.253	***-0.510***	0.267
Temp (^oC)	***-0.928***	-1.127E-02	-0.107	-4.798E-02
pH	-0.111	7.294E-02	***0.922***	-3.451E-02
Turb (NTU)	***0.702***	-0.154	***0.629***	-0.230
EC (μScm^{-1})	0.219	-0.291	-0.208	***0.889***
DO (mgl^{-1})	***-0.755***	-5.663E-02	***0.476***	-0.138
HCO_3^- (mgl^{-1})	***-0.726***	***-0.486***	0.330	0.209
SO_4^{2-} (mgl^{-1})	0.152	-0.203	***0.648***	***-0.706***
Cl^- (mgl^{-1})	***-0.702***	8.742E-03	***0.498***	***0.480***
NO_3^- (mgl^{-1})	6.089E-02	***-0.418***	***0.869***	-0.107
PO_4^{3-} (mgl^{-1})	-0.143	***-0.649***	***0.686***	-0.158
SiO_2 (mgl^{-1})	0.380	***0.885***	-9.437E-03	-7.441E-02
Fe^{2+} (mgl^{-1})	***0.945***	-0.170	0.132	4.656E-02
Ca^{2+} (mgl^{-1})	-6.039E-02	***0.949***	-0.243	-6.153E-02
Mg^{2+} (mgl^{-1})	***0.878***	0.313	0.110	-0.189
Na^+ (mgl^{-1})	-1.374E-02	***0.952***	-8.945E-02	0.251
K^+ (mgl^{-1})	-0.202	***0.470***	2.373E-02	***0.832***

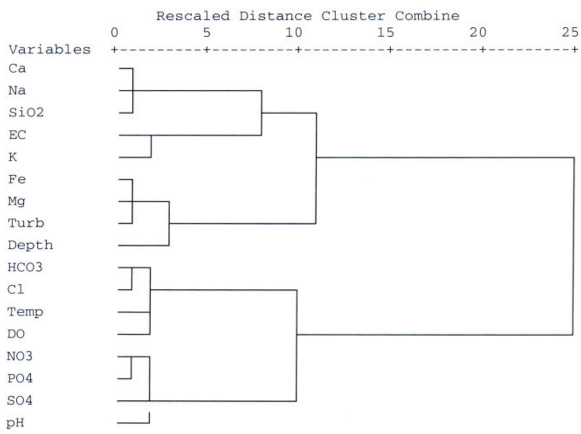

Figure 3. The dendogram results of the environmental pollutants