Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol 2, No.10, 2012 www.iiste.org

Effects of sediment and water quality on the distribution and abundance of aquatic weeds of Jebba Lake, Nigeria

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Abstract:

Nutritional factors affecting the occurrence and distribution of aquatic weeds were monitored on Jebba Lake between June 1999 and May 2001. The result showed that bottom sediments quality and lake water chemistry impact the aquatic weed growth and development directly while shoreline chemical parameters impact more on the terrestrial vegetation. Chemical variables in bottom sediments, which directly affected abundance of aquatic weeds during the wet season include total nitrogen ($r = 0.54$), magnesium ($r = 0.52$), and ECEC ($r = 0.45$). However, during the dry season, aquatic weed occurrence and distribution were positively affected by total nitrogen ($r = 0.65$), organic matter and organic carbon ($r = 0.64$), potassium ($r = 0.54$), calcium ($r = 0.53$) and ECEC ($r = 0.52$) and pH of the sediment ($r = 0.50$). During the wet period, very low positive correlation existed between the aquatic weed abundance and the assayed physico-chemical parameters of water. During the dry season, weed abundance on the lake was principally affected by phosphorus and total nitrogen ($r = 0.47$) and to a lesser extent by sodium ($r = 0.45$) and calcium ($r = 0.42$).

Key words: Aquatic ecosystem, macrophyte/weed, ecological interaction, plant nutrient, sediment quality

INTRODUCTION

The littoral zone is an important component of a lake ecosystem (Ozimek *et al* 1990) characterized by the presence of aquatic macrophytes. The littoral zone stabilizes bottom sediments and binds nutrients (Maceina *et al*., 1992) as well as providing food and habitat for macro vertebrates and fish (Cry and Downing, 1988; Savino and Stein, 1989). The littoral zone also reduces turbidity in water column by increasing the sedimentation rate (Petticrew and Kalf 1992). Aquatic macrophytes/weeds in the littoral zone play a dominant role in influencing series of complex interactions taken place within this zone of aquatic ecosystems. Introduction of non-indigenous aquatic plants into the littoral zone therefore may alter the complex web of biotic and abiotic interactions. Dense canopies formed by non-indigenous species have been reported to reduce plant diversity and abundance (Madsen et al 1991). The reduction of habitat complexity also results in reduced macro vertebrate diversity and abundance (Keast, 1984) and growth reduction in fishes (Little and Budd, 1992).

Factors responsible for the infestation and manifestation of aquatic macrophytes/weeds in the littoral zones include: flooding (which is influenced by hydrological pattern of a water body), water current (an index of the topography of the water underlay), wind speed and direction and the nutrient status of the water body (Thyagarajan 1984; Akinyemiju and Imevbore, 1990 and Olaleye and Akinyemiju 1999). The objective of this study is to relate the effect of the sediment and water quality component of Jebba Lake which is one of the largest artificial lake in Nigeria. The data collected will serve as an aquatic management tool for future intervention.

MATERIALS AND METHODS

Study sites

The study was carried out on Jebba Lake which lies between longitude 4° 30’ to 4° 50’E and latitude 9° 10’ to 9° 55’N. It has a drainage basin extending from Kainji Reservoir to Jebba area (approximately 100 km). The six major rivers which empty into the lake are Oli, Wuruma, Moshi, Awuru on the western side and Kontangora and Eku on the Eastern part as described by Adesina *et al* (2007).

Selection of Research Plots

Field reconnaissance survey was carried out along the eastern and western sides of Jebba Lake to determine the extent of aquatic macrophyte/weed coverage. During the survey, sampling was carried out at the interval of approximately 3 km such that 68 stations were sampled for the herbaceous vegetation both at the shore and open water locations. The manifestations of aquatic plants species on the lake was then considered based on data collected on the abundance from each sampling plot or station (Adesina *et al*., 2002). The seasonal distributions of weed species per plot in each sampling location throughout the period were subjected to Correspondence Analysis. Based on the result of the of the reconnaissance survey, systematic –sampling technique was adopted for the study. With the aid of line transect, twenty sampling points were established at 10 km interval round the lake for a total of 10 sampling points for each of the eastern and western sides of the lake. Each point was located with the aid of a Geo Positional System (GPS Garmin Version). Based on the hydrological pattern of the lake and seasonality, data collection was carried out between June 1999 and May 2001.

Sampling Procedure

A sampling plot of 25 m^2 was established at each location extending from open water (with depth between 5-10 m) up to the lake bank. Across each sampling plot, a perpendicular line transect was laid and 1 m^2 quadrat was then laid at 1 m intervals to facilitate complete data collection both at the littoral and pelagic zone of the lake. Herbaceous plants both from the upland and the open water, and woody species within the transect were identified to species level according to Akobundu and Agyakwa (1987). Vegetation within were also identified. Enumeration of each species was then done subsequently.

Water Sample Collection and Analysis

Sub-surface water samples were collected in 1L plastic bottles using a transparent Van Dorn water sampler. The samples which were collected at the sub surface level (because of non- significance ($P > 0.05$) in the levels of the physico-chemistry along the depth profile of the lake) were later stored in an ice chest for onward transportation to the laboratory. Water temperature, transparency and pH were measured *in situ* while the other parameters which include total nitrogen (TN), total phosphorus (TP), and biogenic cations (Ca, Mg, Na, and K) were assayed in the laboratory. All analysis was carried out using laboratory techniques (APHA *et al*, 1985).

Soil sample collection and analyses

Within each sampling plot at the u[pland locations around the lake, Five (5) soil samples were collected on sampling days using a bucket soil auger. Bottom soil samples were also collected with an Ekman Grab ranging from 2-10 m. In the laboratory, chemical and physical parameters of the soil were determined by standard laboratory techniques and these parameters include: organic carbon, organic matter, biogenic cations (Ca, Mg, K, and Na), exchangeable acidity (Al^{3+} and H^+), total nitrogen and total phosphors.

Data Analysis

Data collected from each location were sorted according to seasonal variations. For statistical analyses, an Epistat and Ecostat Statistical Package as well as in interactive Basic Programming (PCA.BAS) (Lugwig and Reynold, 1988) were used for statistical analyses.

RESULTS

The manifestation of the weed species on Jebba Lake were considered based on the abundance data from each sampling plot or station; the distribution of weed species per plot in each sampling location during either wet or dry season throughout the experimental period were subjected to correspondence analysis. Ordination of these locations was done to show the closeness of each location by subjecting the weed abundance data to correspondence analysis. The coordinates for each station were used to plot an ordination graph of weeds in each season as shown in Figures 1 and 2.

Figure 1 is the ordination graph of the weeds during the wet season. About 5 major grouping of closely associated stations can be identified from the clusters formed by the stations. These stations include 3, 14, and 18 along axis II; stations 6, 8, 13 and 15 formed another cluster. The stations in the third cluster are 2, 4, 5, 17, 19, and 20 while the last cluster consists of three stations (10, 11 and 12). Stations 1, 7 and 16 formed outliers, which stay far away from other clusters. The ordination graph for stations during the dry season shows a different pattern from the rainy season, all the stations are scattered from each other but despite this, about 4 groups can be identified. Stations 2, 5, 6, 14, 15 and 17 formed the first cluster followed by 4, 16 and 19 in another cluster. The third group comprises of stations 7, 13 and 20 while the last cluster includes stations 1, 10 and 11. Station 8, 9 and 12 stood out from other stations (Figures 2).

Correlation between Sediment and water quality and aquatic macrophyte/weed abundance

Correlation matrices between the bottom sediment chemical quality and aquatic macrophyte abundance (Table 1) during the wet seasons showed that ECEC, Mg^{2+} and total nitrogen (TN) directly correlated with aquatic plant manifestations. During the dry seasons however, aquatic weed abundance directly correlated with the levels of Al^{3+}, Na^{+}, Ca^{2+}, ECEC, organic carbon (OC), organic matter(OM), pH, total phosphorus (TP)and total nitrogen (TN). The analyses also showed that the level of pH affected the release of Al^{3+}, Na^{+}, K^{+}, Mg^{2+}, and availability of OM , OC, and TN to the aquatic weeds irrespective of season. Table 2 shows the seasonal correlation matrices between some physico-chemical parameters of water and from the Jebba lake and aquatic weed abundance. Analyses showed that during the wet period, none of the assayed parameters directly affected aquatic weed abundance. During the dry season however, aquatic plant presence was directly influenced by the levels of Ca^{2+}, TP, Na^{+} and TN. Analyses also showed that the levels of TP and TN were highly correlated with the concentrations of Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} in the lake water.

Bottom sediment quality and aquatic weed manifestations

Bottom sediment quality and lake water chemistry directly impacted on the growth and development of aquatic vegetation on the lake. Analyses of the results showed that chemical qualities of the shoreline soil impact more on the terrestrial vegetation than on the aquatic weeds. Data analyses (by simple linear regressions of the principal component coordinates) showed that the some important chemical variables in the bottom sediments directly influenced aquatic weed manifestation and abundance. Analyses of the data collected during the wet season showed first and second components (Axis I and Axis II) exerted about the same effect on the aquatic macrophyte manifestation and distribution both at the littoral and pelagic zone of the lake (r^2 = 0.70 and 0.74 respectively) (Table 3).ECEC was the most important chemical variable in the first component where it contributed about 26.3% followed by pH (19.1%) and sodium ion (10.2%) respectively. On Axis II (Second component), ECEC still contributed the highest percentage (23.8%) followed by calcium ion (19.8%) and total nitrogen (TN) (18.7%). From the regression coefficient values obtained, the second component (Axis II) had more influence on the aquatic weed manifestation during the period of study (Table 3) than the first component.

Chemical variables constituting the first component (r^2 = 0.785) were responsible for about 79% of the aquatic weed occurrence and distribution on the lake during the dry period. Analyses also revealed that organic matter and organic carbon contributed about 90% of the chemical constituents responsible for aquatic weed occurrence. The chemical variables in the second component (Axis II) (r^2 = 0.653) were also responsible for around 65% of the aquatic weed occurrence and distribution on the lake with organic matter and organic carbon accounting for about 79.8% of the most dominant variables (Table 3).

Influence of physico-chemical component of the Jebba Lake water on the aquatic weed occurrence.

The seasonal contributions of some selected physico-chemical parameters of Jebba Lake water regressed against the coordinates derived from the correspondence analysis of weed abundance data showed that the first component (Axis 1) contributed about 60% to the macrophyte spread on Jebba lake ((r^2 = 0.586) during the wet season compared to 51% from the second component (Axis II) (r^2 = 0.511) Table 4. Irrespective of season, each of the physico-chemical components contributed significantly to the regression coefficient values along the two axis. In the first component, (Axis I), magnesium and phosphorus contribute 24.9% and 22.0% respectively compared to the second component (Axis II), where the largest contributor to the r^2 value was total nitrogen content (57.5%) and phosphorus (15.1%) (Table 4). Analyses of the dry season data using linear multiple regression (Table 4) showed that the two axes contributed less than 50% to the aquatic weed occurrence observed on the lake during the period of study. Phosphorus with about 52.2% made the largest contribution on axis I (First component) followed by sodium with 27.7% contribution. However, on Axis II (second component), the highest contributor among the physico-chemical variables of water was sodium with 38.9% contribution followed by total nitrogen with 32.6% contribution.

DISCUSSION

The seasonal weed manifestation and distribution within Jebba Lake could be attributed to several interacting factors (Hutchinson, 1953). Apart from the expected vectorial, coactive and reproductive effects, the chemistry of the bottom sediments and some physico – chemical variables of water exerted other stochastic effects on the aquatic weed population. The result of ordination showed seasonal disparity in the aquatic weed abundance between the twenty sampling points established on the lake.

Regression analyses of the effect of the chemical variables in bottom sediments on the aquatic weed occurrence during the rainy season showed that the second components (Axis II) which accounted for 74% of the distribution ($r^2 = 0.74$) had more influence on the aquatic weed spread. Specific implicated factors on the axis to be positively correlated to aquatic weed abundance were ECEC, calcium and total nitrogen. Since the ECEC is a measure of the general fertility status of growth medium (Brady, 1984), the high nutrient factor of the Jebba lake bottom sediment probably supported the mass proliferation of the emergent aquatic weed on the lake. Nitrogen and calcium which were other elements which contributed significantly ($p<0.05$) to the bottom sediment quality have also been reported to be very crucial to plant growth and development (Brady, 1984). During the dry period, first component (Axis I) was found to be more relevant to the aquatic weed manifestation on the lake. Within the component, broad spectrum of variables found to be responsible for the aquatic weed spread include nitrogen, organic matter and carbon content. To a lesser extent ECEC also played a minor role in aquatic plant occurrence and distribution on the lake during the period of study.

The coefficient of determination showed that the physico-chemical factors of water contributed less to aquatic plant occurrence compared to what the sediment quality contributed irrespective of season. This was probably due to the fact that bottom sediment which act as nutrient sink absorbs and releases nutrient to the water body in response to the prevailing natural equilibrium occurring in the lake (Cry and Downing, 1988). Whitton (1975) observed that the distribution of plant species in ponds, lakes and rivers was primarily correlated with the nature of the substratum or sediments. According to him substratum is more important in relatively slow nutrient-poor waters where fresh organic and inorganic deposit may be important sources of nutrients. However, the degree of water movement which often affects both plant distribution and sediments quality should not be discountenanced.

The high flushing rate on Jebba Lake (Obot and Mbagwu, 1986, 1988) could have significantly affected the contribution of water quality to the aquatic weed manifestation on the lake. If the lake has a high flushing rate, then the level of organic matter and other nutrients is expected to be very low. Key elements in the lake water which impact positively on the aquatic plant occurrence include nitrogen irrespective of season, phosphorus during the rainy season and sodium during the dry period. Organic matter in the sediments which is a granulator of minerals (Brady ,1984) was probably the source of mineral elements in the lake water and particularly, of nitrogen and phosphorus which are known to be essential for massive aquatic plant growth especially for emergent aquatic plants such as *Vossia cuspidata*, *Echinochloa spp, Vetivera nigritana* and *Sesbania daizeli* (Akodundu, 1987).

During the dry season, dominance of cations like calcium, magnesium and sodium which positively correlate with aquatic plant distribution could be linked to deliberate prevalent annual bush burning around the lake during the dry period when the riparian people prepare farmlands for cultivation.

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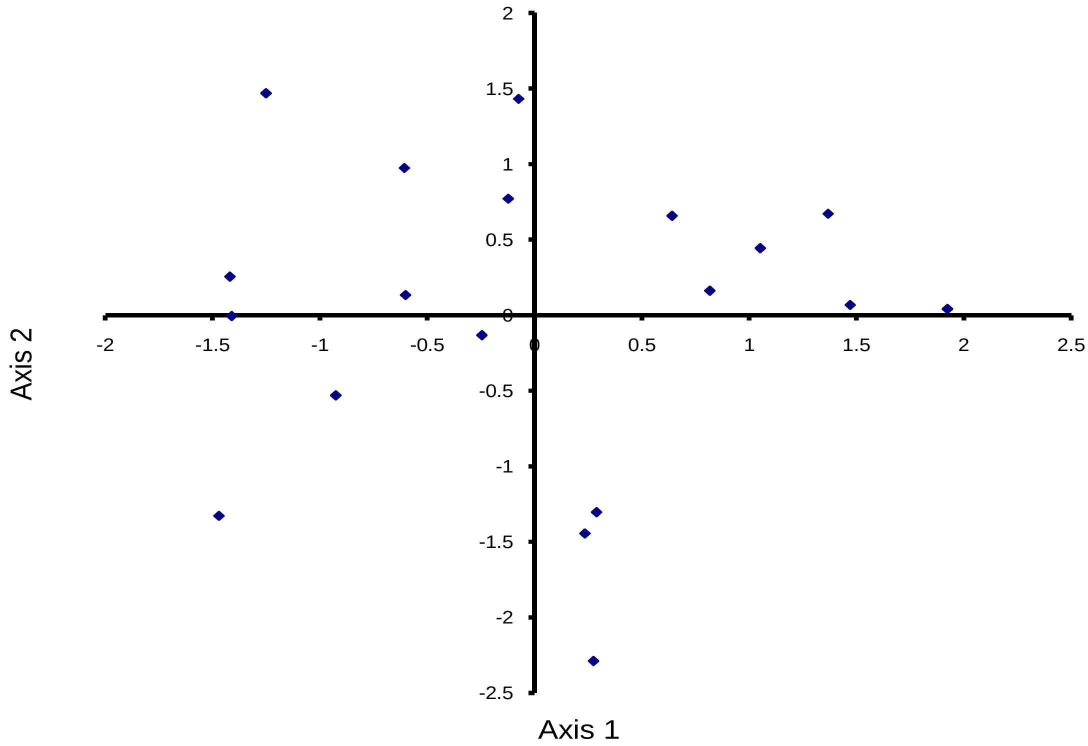

Figure 1: Species abundance - station ordination at Jebba Lake during the wet season.

Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol 2, No.10, 2012

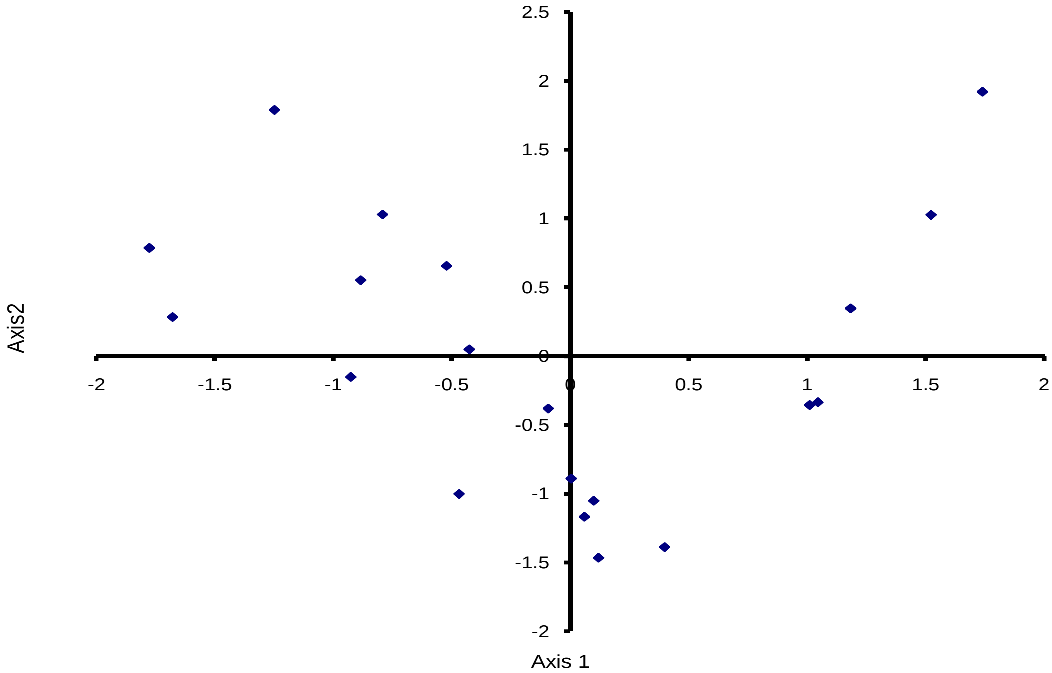

Figure 2: Species abundance - station ordination at Jebba Lake during the dry season.

Table 1`: Correlation matrix of the environmental factors and aquatic weed abundance during the period of study.

	Al^{3+}	Ca^{2+}	ECEC	H^+	Mg^{2+}	OC	OM	pH	TP	K^+	Na^+	TN	MA
Wet Season													
Al^{3+}	1.00												
Ca^{2+}	0.20	1.00											
ECEC	0.38	0.97	1.00										
H^+	0.84	0.51	0.66	1.00									
Mg^{2+}	0.33	0.85	0.89	0.55	1.00								
OC	0.34	-0.09	0.07	0.22	0.16	1.00							
OM	0.28	-0.07	0.09	0.17	0.12	0.97	1.00						
pH	0.66	0.39	0.54	0.61	0.55	0.50	0.51	1.00					
TP	0.43	-0.05	0.06	0.34	0.32	0.67	0.49	0.38	1.00				
K^+	0.63	0.68	0.80	0.84	0.64	0.11	0.12	0.48	0.07	1.00			
Na^+	0.73	0.38	0.54	0.66	0.58	0.52	0.51	0.89	0.47	0.48	1.00		
TN	0.28	0.72	0.73	0.32	0.88	0.24	0.20	0.58	0.35	0.35	0.55	1.00	
MA	0.03	0.44	0.45	0.11	0.52	-0.10	-0.05	0.40	-0.05	0.19	0.23	0.54	1.00
Dry Season													
Al^{3+}	1.00												
Ca	0.72	1.00											
ECEC	0.90	0.91	1.00										
H^+	0.78	0.28	0.62	1.00									
Mg^{2+}	0.54	0.88	0.79	0.11	1.00								
OC	0.55	0.64	0.56	0.17	0.33	1.00							
OM	0.56	0.63	0.56	0.17	0.32	1.00	1.00						
pH	0.77	0.58	0.70	0.44	0.51	0.54	0.55	1.00					
TP	0.74	0.72	0.75	0.31	0.67	0.56	0.57	0.95	1.00				

K^+	0.61	0.80	0.81	0.21	0.87	0.40	0.41	0.64	0.76	1.00			
Na^+	0.80	0.73	0.80	0.40	0.68	0.60	0.61	0.97	0.96	0.76	1.00		
TN	0.71	0.83	0.77	0.23	0.66	0.84	0.84	0.79	0.81	0.66	0.86	1.00	
AWA	0.49	0.53	0.52	0.26	0.34	0.64	0.64	0.50	0.48	0.39	0.54	0.65	1.00

NB: AWA – Aquatic Weed Abundance
TN – Total Nitrogen
TP – Total Phosphorus
OC – Organic Carbon
OM – Organic Matter

Table 2: Correlation matrix of the environmental parameters in water and aquatic weed abundance during the period of study.

	Ca^{2+}	Mg^{2+}	TP	K^+	Na^+	TN	WT	AWA
Wet Season								
Ca	1.00							
Mg^{2+}	0.92	1.00						
TP	0.89	0.88	1.00					
K^+	0.94	0.96	0.91	1.00				
Na^+	0.83	0.96	0.88	0.88	1.00			
TN	0.97	0.97	0.91	0.97	0.91	1.00		
WT	0.38	0.24	0.24	0.25	0.23	0.33	1.00	
AWA	-0.01	0.03	0.12	0.06	0.07	0.05	0.08	1.00
Dry Season								
Ca	1.00							
Mg^{2+}	0.72	1.00						
TP	0.95	0.72	1.00					

K^+	0.80	0.58	0.90	1.00				
Na^+	0.94	0.71	0.99	0.89	1.00			
TN	0.95	0.73	0.99	0.85	0.99	1.00		
WT	-0.07	0.06	-0.11	-0.15	-0.09	-0.09	1.00	
AWA	0.42	0.17	0.47	0.37	0.45	0.47	0.04	1.00

NB: AWA – Aquatic Weed Abundance
TN – Total Nitrogen
TP – Total Phosphorus
WT – Water Temperature

Table 3: Seasonal variation in the percentage contribution of different chemical variables in the bottom sediment to the coefficient of multiple determination for aquatic weed manifestation.

Chemical Variables	**% Contribution**	
	First Component Axis I	**First Component Axis II**
Wet Season	r^2 **= 0.738**	r^2 **= 0.703**
Aluminum (Al^{3+})	3.3	08
Calcium (Ca^{2+})	6.9	19.8
Effective Cation Exchange Capacity (ECEC)	26.3	23.4
Hydrogen (H^+)	12.6	0.6
Magnesium (Mg^{2+})	4.3	10.7
Organic Carbon (OC)	2.1	7.2
Organic Matter (OM)	1.6	3.9
pH	19.1	2.1
Total Phosphorus (TP)	2.4	2.7
Potassium K^+	4.9	8.7

Sodium Na^{+}	10.2	1.0
Total Nitrogen (TN)	6.4	18.7
Dry Season	**r^2 = 0.785**	**r^2 = 0.653**
Aluminum (Al^{3+})	0.2	0.0
Calcium (Ca^{2+})	1.4	0.7
Effective Cation Exchange Capacity (ECEC)	3.4	7.0
Hydrogen (H^{+})	1.2	5.5
Magnesium (Mg^{2+})	0.4	0.3
Organic Carbon (OC)	44.4	39.1
Organic Matter (OM)	45.6	40.7
pH	0.5	0.8
Total Phosphorus (TP)	0.5	2.2
Potassium K^{+}	0.0	0.1
Sodium Na^{+}	1.8	2.7
Total Nitrogen (TN)	1.2	0.8

Table 4: Seasonal variation in the percentage contribution of physic-chemical parameters Jebba Lake water to the coefficient of multiple determinations for aquatic weed manifestation.

Physico-Chemical Parameters	% Contribution	
	First Component Axis I	**First Component Axis II**
Wet Season	$r^2 = 0.586$	$r^2 = 0.511$
Calcium (Ca^{2+})	13.7	8.6
Magnesium (Mg^{2+})	24.9	2.7
Total Phosphorus (TP)	22.0	15.1
Potassium K^+	7.6	11.3
Sodium Na^+	11.2	4.1
Total Nitrogen (TN)	14.4	57.5
Water Temperature (WT)	6.1	0.7
Dry Season	$r^2 = 0.385$	$r^2 = 0.298$
Calcium (Ca^{2+})	7.3	3.7
Magnesium (Mg^{2+})	0.3	8.4
Total Phosphorus (TP)	52.2	6.4
Potassium K^+	4.3	0.2
Sodium Na^+	27.7	38.9
Total Nitrogen (TN)	7.9	32.6
Water Temperature (WT)	0.3	9.7