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Human Impacts on Two Wetlands in the Nairobi National Park, Kenya

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Abstract: Environmental gradients in physico-chemical properties and distance to human settlements at two wetlands (around Hyena and Nalogomon dams) in the Nairobi National Park were studied. Ordination showed that over 84% of the variation in both wetland waters and soils was accounted for by twelve parameters (physico-chemical properties and distance to settlements). In wetland waters, Cu and Mn contributed most to variation that was related to distance to nearest urban settlements. This means that the concentration of the two elements increased as distance to settlements decreased. Elements Cu and Mn are pollution indicators and their increased concentration during the wet season in wetlands close to urban areas could be due to run-off or storm waters from the settled areas finding its way into the wetland. Critically, P and Cu varied along the distance gradient, being highest closest to urban settlements. The ordination plots on the wetland soil/sediment show a clear gradient, that is, a distance to urban settlements gradient that separates the two wetlands.

Key words: Wetlands, gradient analysis, human impacts.

Introduction

Wetlands are areas of land whose soil is saturated with moisture either permanently or seasonally (Mitsch and Gosselink, 2007). Such areas may also be covered partially or completely by shallow pools of water. They are generally distinguished from other water bodies based on their levels of water table and on the types of plants that thrive within them. Specifically, wetlands are characterized as having a water table that stands at or near the land surface for a long enough period each year to support aquatic plants.

Wetlands differ in their soil, landscape, climate, water regime and chemistry, vegetation and human disturbance. Generally, African wetlands are classified into two general categories: marshes (dominated by herbaceous vegetation and frequently or continually inundated with water) and swamps (dominated by woody plants such as trees and shrubs and saturated with water during the rainy season, but may dry out in the heat during the dry season) (Howard-Williams and Gaudet, 1985).

Changes in water quality can alter the whole wetland ecosystem, including fauna, around it. Aquatic organisms are sensitive to changes in the water quality of the water they live in (Brix and Schierup, 1989). Water quality is considered degraded when physico-chemical conditions change so that many types of resident organisms are negatively affected. Major physical factors that usually affect the wetlands significantly include temperature, pH, electrical conductivity, dissolved oxygen, mineral nutrients and water depth (Boney, 1989).

The pH of water determines the solubility and biological availability of chemical constituents, for example phosphorus, nitrogen, potassium, sulphur and carbon; and heavy metals for example lead, copper and cadmium (Gaudet, 1979). pH can also determine the type of aquatic life that can use a water body. Electrical conductivity is a measure of the amount of dissolved

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ions in water and the higher the concentration, the higher the conductivity of water.

Waters moving into a wetland run over rocks or soil in the catchment area, dissolving chemicals including salts that form ions such as cations (for example Na^+, Ca^{2+} and Mg^{2+}) and anions (for example CO_3^{2-}, SO_4^{2-}, NO_3^- and PO_4^{3-}). Both nitrogen and phosphorus are essential to life (Reynolds, 1984), but while there are many sources of nitrogen, phosphorus is often in short supply and therefore limiting to plant growth (Hecky and Kilham, 1973; Moss, 1980; Goldman and Horn, 1983; Burgis and Morris, 1987).

Land use activities around wetlands in Nairobi National Park are dominated by wildlife grazing and human settlements. In the Park, wetlands are of vital ecological importance (where they provide vital ecosystem goods and services such as animal feed during the dry season and drinking water) to the biodiversity that inhabits the park ecosystem. However, no previous ecological studies on wetlands found in the Nairobi National Park have been carried out.

The main objective of the study was to determine the environmental status of two wetlands in the Nairobi National Park, namely around Nalogomon and Hyena dams. Specific objectives of the study were to determine the environmental relationship between the physico-chemical properties of water and soil/sediment and human settlements around the park.

Materials and Methods

This study was conducted at two wetlands located around Nalogomon and Hyena dams, in Nairobi National Park, Kenya. The dams are located in the upper reaches of the park (1° 20' S and 36° 48' E) at a distance of about 2.4 km from each other and are fed by separate water sources. The water flowing into Nalogomon Dam originates from an upland forest and the vegetation around the dam is dominated by *Typha domingensis* Pers., *Hyparrhenia rufa* Nees Stapf. and *Themeda triandra* Forssk. The water flowing into Hyena Dam originates from urban settlements and the vegetation around the dam is dominated by *Cyperus dives* Del., *T. domingensis* and several floating macrophytes (*Gunnera perpens* L., *Enhydra fluctuans* Lour. and *Ludwigia abyssinica* A. Rich.). The animal species found in and around the two dams include the Nile crocodile (*Crocodylus niloticus* Laurenti, 1768), hippopotamus (*Hippopotamus amphibious* Linnaeus, 1758), various waterfowls, common warthog (*Phacochoerus africanus* Gmelin, 1788) and various types of gazelles.

Samples of water and soil/sediment were collected from four points at each wetland at intervals of two weeks during the dry and wet seasons over a four-month period starting in February and ending in May 2011. Using a grid along each water body, four sampling points for Nalogomon wetland were randomly selected. For Hyena wetland, three points were selected around the dam while the fourth point was selected some 750 m upstream from the dam and 300 m to the nearest human settlement (the Carnivore Hotel and Restaurant) along the water channel. This point was selected in order to gauge the influence of human urban activities on the quality of water flowing into the dam. Twelve samples of soils/sediments, three per sampling point, were collected at a depth of 15 cm using a hand auger and kept in labelled bags. Three water samples were also collected at each of the four sampling points per wetland and stored in plastic bottles. The soils/sediments and water samples were stored in an ice-cube filled cool box and transported to the laboratory for chemical analysis. In the laboratory, the three samples of soils/sediments per sampling point were mixed to form a composite from where samples for analysis were obtained. The same was done for the water samples. pH, extractable phosphorus, electrical conductivity, total nitrogen, exchangeable sodium, calcium, magnesium and potassium were determined as described by Okalebo et al. (2002). The SO_4-S was determined by the turbidity method (APHA, 1998).

Plant species diversity within the wetlands was determined by laying two line transects across each wetland. Each line transect was 100 m long on both side of each wetland. Sampling was done in 1 × 1 m quadrants placed after every 10 m along the sample transects. All the species located in the quadrants were identified and their percentage ground cover determined by the Braun-Blanquet method (Kent and Coker, 1992). The total count of each species along transects in each wetland was used to calculate the Shannon-Weiner index using the standard equation (Kent and Coker, 1992; Ludwig and Reynold, 1988). Plant species were identified using taxonomic keys in Agnew and Agnew (1994), Beentje (1994), Ibrahim and Kabuye (1987) and Haines and Lye (1983). Plant species abundance and rank frequency were determined using PC-ORD version 5 (McCune and Mefford, 1997).

Principal Components Analysis (PCA) and Canonical Correlation Analysis (CCA) were used to identify important environmental gradients in the wetlands (Stevens, 1986; Kent and Coker, 1992; Rencher, 2002). PC-ORD version 5 (McCune and Mefford, 1997) was also used to analyse the ordination data.

Results

Table 1 shows the parameters used in PCA and CCA analyses. These parameters included distance to the nearest human settlement, exchangeable bases and electrical conductivity. Table 2 shows how much of the variation in the water and soil/sediment data is explained by PCA and CCA. Table 3 shows the most important variables that explain the covariance. The first three ordination axes, which are considered the most important, extracted 84.06% of the total variation (Table 2), and this is considered good in PCA. Copper (Cu), a heavy metal associated with pollution, and manganese (Mn) linked with fossil fuels and oils, accounted for the highest variation in the wetland waters (Table 3). Phosphorous (P) an element that strongly influences diversity in grasslands, and copper that is associated with pollution contributed to the highest variation in the wetland soil/sediment (Table 3).

Environmental Gradients

The PCA ordination plot (Figure 1) shows that waters at Hyena Dam experienced greater seasonal variation in mineral concentrations than those at Nalogomon Dam. This variation is characterized by increased concentrations in wet season of Cu, Mn and Zn, all indicators of pollution especially in sites close to urban areas, i.e. HW1 and HW2 in the upper left quarter of the

Table 1: Codes and parameters used in PCA and CCA ordination analysis and plots

Wetland codes	
H	Hyena site
N	Nalogomon site
Season codes	
W	Wet season data
D	Dry season data
Parameter codes	
Dist	Distance to urban settlements
Bases	Exchangeable bases (K, Mg, Na, Ca)
EC	Electrical conductivity
Distance to urban settlements of sample sites (km)	
H1 - Hyena next to Carnivore Hotel	1.4
H2 - East of Hyena dam	5.0
H3 - West of Hyena dam	2.5
H4 - South of Hyena dam	5
N1 - North of Nalogomon dam	2.8
N2 - East of Nalogomon dam	9
N3 - West of Nalogomon dam	4.3
N4 - South of Nalogomon dam	4.7

Note: Distances to urban settlements were determined using GPS positions obtained in field.

Table 2: Environmental variation explained by the first seven PCA axes in water and soil/sediment

	Water			*Soil/sediment*		
Axis	*Eigenvalue*	*% of variance*	*Cumulative % of variance*	*Eigenvalue*	*% of variance*	*Cumulative % of variance*
1	3.13	44.68	44.68	3.02	43.13	43.1
2	1.78	25.43	70.12	1.89	27.05	70.2
3	0.98	13.94	84.06	1.00	14.27	84.4
4	0.63	9.04	93.10	0.58	8.34	92.8
5	0.27	3.81	96.90	0.28	3.99	96.8
6	0.16	2.32	99.22	0.16	2.29	99.1
7	0.06	0.78	100.00	0.07	0.94	100.0

biplot. In the dry season, waters of Hyena are characterized by high concentrations of exchangeable bases (at sites HD4, HD1, HD3 and HD2 in the lower right quarter). In contrast, waters of Nalogomon wetlands do not vary strongly between seasons with most samples falling in the upper right quarter of the ordination plots.

The PCA ordination plot on the wetland soil/sediment (Figure 2) shows a clear gradient that separates Hyena and Nalogomon wetland soils/sediments, that is, a distance to urban settlements gradient. Nalogomon soils/sediments which are at the greatest distance from urban settlements (lower left quarter) are characterized by low Cu, P and EC while Hyena wetland soils/sediments at the opposite end of this gradient (HD4, HD1 and HW1) have high concentrations of the same elements in addition to electrical conductivity (EC). It is also observed that seasonal variation in soil/sediment characteristics is less pronounced than in water, that is wet and dry season position of sampling sites are close.

Table 4 presents two sets of outputs from CCA analysis, a summary of the statistics that shows the strength of the relationship between species distribution and environmental data and secondly environmental factors that explain the highest variation in species data. The correlations coefficients shown in Table 4 are interset correlations. Factors contributing to the highest variation characterizing each axis are highlighted in bold in the figure.

The extracted variation in species composition was largely explained by the environmental factors assessed as shown by the high Pearson correlation coefficient and eigenvalue distance to urban settlements and copper levels characterize or explain highest variation the first axis which in turn explains the highest variation in plant species composition. This is an axis reflecting pollution. The second axis is characterized by phosphorous and last by exchangeable bases.

The first CCA axis characterized by a gradient of distance from urban settlements and levels of Cu, P and EC separated species distribution into two broad groups: those that have higher abundance in Nalogomon wetlands

Table 3: Eigenvectors of the first three PCA axes in site wetland and soils

	Water			*Soil/sediment*		
Variable	1	2	3	1	2	3
EC	0.21	0.57	0.47	0.42	–0.10	0.19
P	–0.41	0.24	0.46	0.54	0.02	0.06
Cu	–0.52	0.04	–0.14	0.52	0.12	–0.14
Zn	–0.45	0.16	–0.46	0.13	–0.32	–0.85
Mn	–0.46	–0.09	0.45	–0.07	0.67	0.05
Distance to urban settlement (Dist)	0.25	0.54	–0.16	–0.43	–0.40	0.08
Exchangeable bases	0.20	–0.54	0.33	0.23	–0.52	0.46

Note: The first two variables with highest eigenvectors in each axis are highlighted.

Table 4: The influence of environment and human settlements variables on plant species distribution and composition as extracted by CCA

Variance in species data	*Axis 1*	*Axis 2*	*Axis 3*
% of variance explained	49.9	16.4	10.8
Cumulative % explained	49.9	66.3	77.1
Pearson correlation, Spp-Envt*	0.999	0.884	0.854
Kendall (Rank) Corr., Spp-Envt	0.913	0.657	0.712
Eigenvalue	0.698	0.229	0.151
Variable	Axis 1	Axis 2	Axis 3
Electro-conductivity (EC)	–0.388	0.135	0.377
Phosphorous	–0.631	0.446	0.326
Copper	–0.714	0.407	–0.089
Zinc	0.035	–0.066	–0.276
Manganese	–0.383	0.043	–0.313
Distance to urban settlements (Dist)	0.994	0.066	–0.031
Exchangeable bases (Bases)	0.215	0.172	0.539

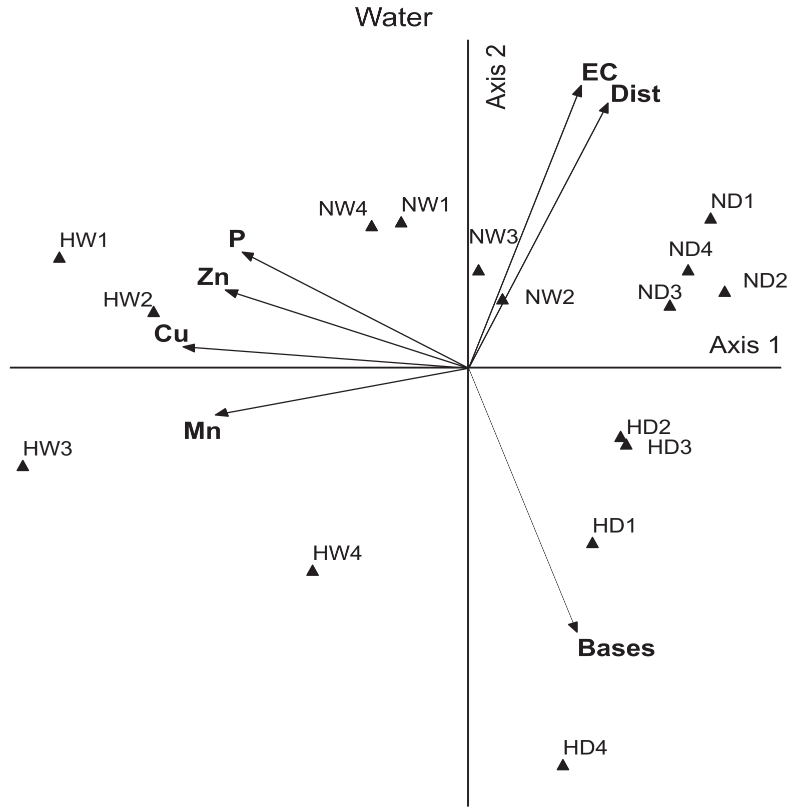

Figure 1: Principal Component Analysis (PCA) based on a correlation matrix of seven water variables collected over two seasons in Hyena and Nalogomon dams study sites (the key to species codes are shown in Table 4).

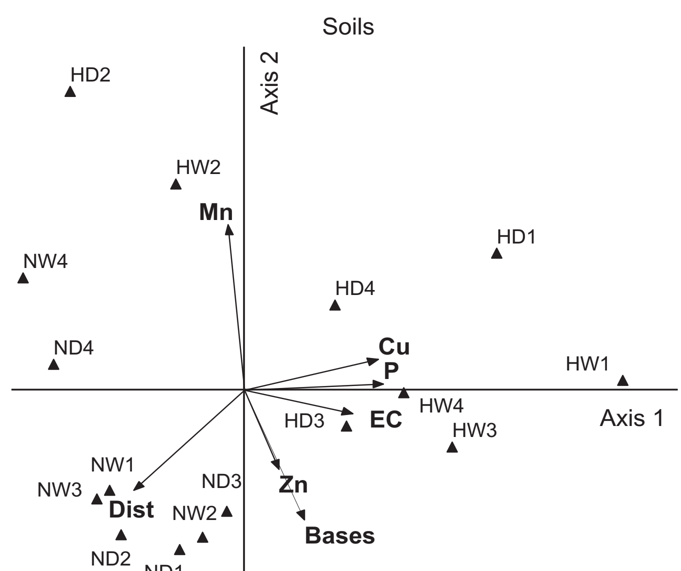

Figure 2: Principal Component Analysis (PCA) based on a correlation matrix of seven soil/sediment variables collected over two seasons in Hyena and Nalogomon dams study sites (the key to species codes are shown in Table 4).

on the right half of the CCA biplot and those that have higher abundance in Hyena wetlands on the left half (Figure 3). Also of interest is the distribution of species in Hyena wetlands; the upper left quarter depicting the most heavily polluted area with lowest distance to urban areas. This site was dominated only by a few species and importantly the presence of invasive *Lantana camara*.

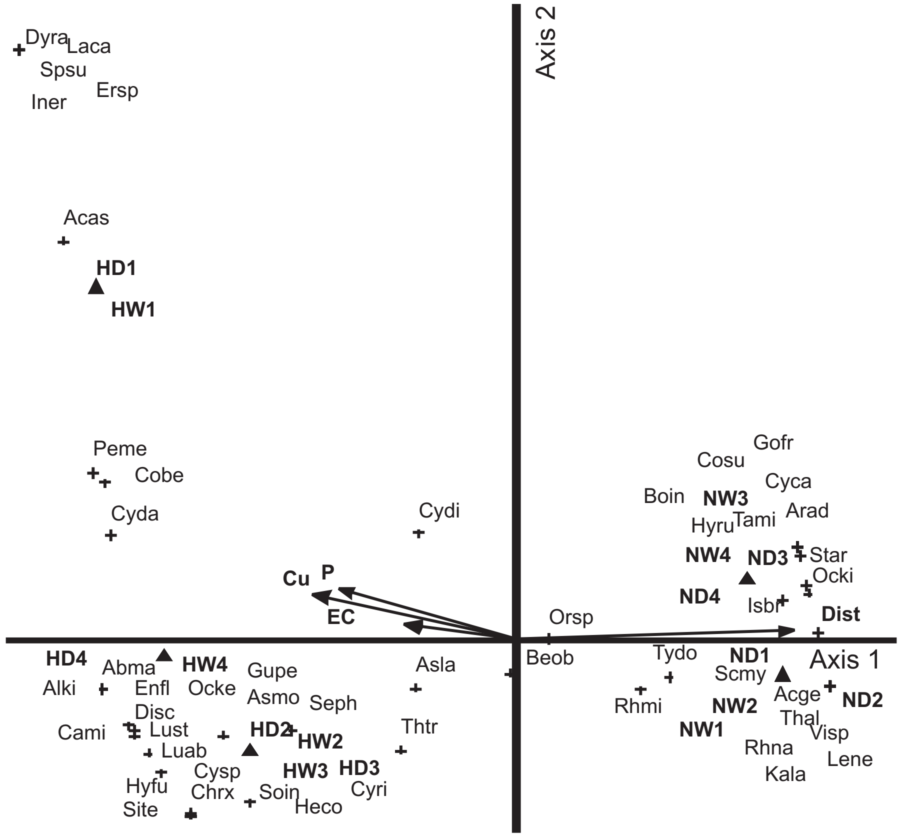

Figure 3: CCA ordination diagram showing the distribution of plant species as influenced by environmental factors assessed (the key to species codes are shown in Table 3).

PCA showed that over 84% of the variation in both wetland waters and soils was accounted for by twelve parameters (physico-chemical properties and distance to settlements). This indicated that important variables responsible for variation in characteristics of wetland waters and soils were assessed. In wetland waters, Cu and Mn contributed most to the variation that was related to distance to nearest urban settlements depicted in second axis (Figures 1 and 2). This means that the concentration of the two elements increased as distance to settlements decreased. Cu and Mn are pollution indicators and their increased concentration in the wet season in wetlands close to urban areas could be due to run-off or storm waters from the settlement areas finding its way into the wetland.

Discussion

Urban storm water run-off has increasingly been recognized as a substantial source of pollutants to receiving waters (Davis, Shokouhian and Shubei, 2001). Some sources of the heavy metals such as lead (Pb), copper (Cu), cadmium (Cd) and zinc (Zn) include building siding and roofs; automobile brakes, tyres and oil leakage; and wet and dry atmospheric deposition. For copper, building siding and vehicle brake emissions are particularly important (Davis et al., 2001). Other studies have also shown strong circumstantial evidence that manganese pollution occurs along with lead in city environments and is related to traffic density with the most likely sources being automobile exhausts (Joselow et al., 1978). On the other hand, P accounted for one of the highest variation for elements in soils of the wetlands. Omari (2008) found that P contributed to the highest variation in soils characteristics across a wide variation of vegetation types in Nairobi National Park. While our study showed the same was true for wetland soils, it further highlighted the importance of Cu and Mn. It can therefore be said that while P remains the primary contributor of variation in wetland soils they are secondarily modified by Cu and Mn, indicating the effect of water pollution on soils especially close to the urban settlements. The PCA results, therefore, show that increasing levels of pollutants along a gradient of distance to urban settlements was the most important determinant of variation in wetland water characteristics. On the other hand, soil P, like for soils in other ecosystems of the park, was the primary determinant of variation but was secondarily modified by pollutants.

Factors Influencing Plant Species Distribution

Three groups of species as related to environmental gradients were separated, namely: (1) species with highest abundance in sites close to urban settlements and most polluted areas, (2) species farthest from urban settlements and least polluted wetland, and (3) species with highest abundance around the wetland close to urban settlements. CCA identified this separation of species to be principally related to gradients in distance to urban settlements, copper, phosphorous and exchangeable bases. Critically P and Cu varied along the distance gradient, being highest closest to urban settlements mainly the Hyena wetland. A previous study by Omari (2008) demonstrated that high concentrations of soil P was strongly associated with distribution of non-indigenous and invasive species such as *Ricinus communis* L., *Argemone Mexicana* Linn., *Solanum incanum* L., *Tagetes minutam* L., *Opuntia exaltata* A. Berger, *Opuntia ficus-indica* (L.) Mill., and *Caesalpinia decapetala* (Roth) Aston in Nairobi National Park ecosystem. In the present study, *Lantana camara* L. was found in areas of highest P content and closest to urban settlements where there was also the highest disturbance. *L. camara* is rapidly becoming a major threat to conservation areas in Kenya.

Disturbances were noted just outside the park fence and included soil disturbance during the construction of roads and estates, and dumping of the excavated soils. Disturbances including overgrazing and soil disturbance play a critical role in the proliferation of invasive species through alteration of resource supply that is facilitated by influx of resources such as soil nutrients or unusually heavy rains (Mworia, Kinyamario and John, 2008). Pollution can influence species distribution with certain species being indicators of the phenomenon. Indicators of pollution can be placed into several categories, among them: "detectors" which are species occurring naturally in the area which show responses to increased pollution, and "exploiters" species though not occurring naturally in the area their presence indicates probability of pollution. In the present study, some species associated with the most polluted areas included *L. camara, Indigofera arrecta* Hochst. ex A. Rich. and *Dyschoriste radicans* (Hochst. ex A. Rich.) Nees. It was, however, beyond the scope of the study to determine if these plant species did respond to pollution.

Conclusion and Recommendations

It was concluded from the data that pollution coming from human settlements around the park flow into surface waters of Hyena Dam site. The concentration of pollutants was found to increase in waters nearer to human settlements. It can be concluded that Cu and Mn are pollution indicators and their increased concentration during the wet season in wetlands close to urban areas could be due to run-off or storm waters from the settled areas finding its way into the wetland. Critically, P and Cu varied along the distance gradient, being highest closest to urban settlements. It is therefore vital that monitoring of water quality is the first step that can lead to better management and conservation of wetland ecosystems. Management of the two wetlands should be aimed at conservation of their habitats by suitably maintaining the physico-chemical quality of water within acceptable levels. The information and observation of this research will be very useful in formulating management policies on future use of wetlands at Nairobi National Park especially on conservation of wildlife. It is further recommended that all storm water emanating from the nearby urban settlements be channelled into the nearby sewer lines instead of being allowed to flow freely into the streams leading into the park.

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