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Pedogeochemical assessment of wetland soils in Hadejia- Jama'are river basin in the Nigerian Sahel savanna

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Abstract
Understanding the pedo-geochemical assessment of wetland soils in the Hadejia/Jama`are river basin in the Sahel savannah of Nigeria is paramount for efficiently planning the long-term sustainable use of the wetlands and is paramount for reliably estimating soil contamination. Namely, five (5) different wetland sites were selected; Masama 1 and 2, Sinamu 1 and 2, and Tandanu while one from the Drylands of Tandanu. A pit was excavated to a depth of 1.5 m at each site, except where there is an elevated water table or impenetrable stratum, and soil samples were collected from three identifiable horizons (Bt_2, Bt_1, and Ap, respectively). The results of principal component and cluster analysis showed that total and labile Pb, total Zn, and labile Cr were considered the most influential heavy elements for identifying pedogenic and sedimentological processes in the wetlands of the study area. It also showed that Pb, Zn, and Cr came from the same source in all soils examined. Therefore, we concluded that the soils in all the wetlands studied are at high risk of toxic effects from Pb and Zn contamination. It is strongly recommended that heavy metals be decontaminated at all surveyed sites before further use for agricultural purposes.

Keywords
Pedogeochemical assessment, Wetland soils, Hadejia-Jama'are river basin, Sahel savannah, Nigeria

Introduction

Wetlands are distributed worldwide and are considered to be the most biodiverse ecosystem type. Wetlands cover about 6% of the Earth's land surface, or about 2 billion acres (800 million hectares) (Anderson *et al.*, 2000). Nigeria has eight major wetlands basins, including those in Chad, Middle Niger, Sokoto, Cross River, Kaduna, Lower Benue, Upper Benue, and Hadejia-Jama'are (World Banks, 2006).

The Nigerian wetland has both fertile and productive soils, providing farmers with a good opportunity to grow products with greater values outside of the growing season (Amrate *et al.*, 2005). The pedogeochemistry of the wetland will evolve through time from the initial composition of the bedrock to chemistry that reflects the type of reactions that occur in the soil (Schlesinger *et al.*, 2000). Trace elements, in addition to their pedogenic origin, can be released into the environment through anthropogenic activities such as agriculture,

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mining, industrial processes, and the burning of fossil fuels (Abdu, 2010).

The Hadejia-Jamaare River Basin has a total population of about 2 million, most of whom are farmers. This area is known for heavy vehicular traffic, poor transport infrastructure, and intensive agricultural activities that result in environmental pollution of trace elements through the burning of fuel and agricultural additives (Wang *et al.*, 2003). According to Abdu and Yusuf (2007), heavy elements from anthropogenic sources are more harmful due to their instability and solubility, leading to increased toxicity.

There is sparse or no information about the pedogeochemistry of wetlands in the Nigeria Savanna. Wet areas around the world are faced with a variety of problems, including pollution, excessive intensification of agricultural activity, industry, and urbanization. This study is important because it has applications to maintain wetlands. Some of the problems with wetlands are due to a lack of surveillance, sustainability measures, and knowledge of the residents about the deterioration of the wetlands and possible contamination (Olalekan *et al.*, 2014).

Therefore, research into the pedo-geochemical properties of wetland soils (animal, human, and agricultural soils) is crucial due to the ecological and health effects of mineral nutrients on living species. Such information is critical for effective planning of long-term sustainable wetland use, as well as for accurately estimating soil pollution and enacting environmental protection legislation (Amorosi and Sermantino, 2011). The study main aim was to identify the fate and status of heavy metals (Cd, Cu, Cr, Pb, and Zn) in the soil of three naturally occurring wetlands in the Nigerian Sahel savanna.

Materials and methods

Study Area location

The Hadejia Nguru Wetlands (Fig. 1) are located in the Sahel region in northeastern Nigeria. It lies just upstream of the confluence of the Hadejia and Jamaare rivers that form the Yobe river. There are several hills and steep slopes in the area. The alluvium is found throughout much of the river, including the Hadejia and Jamaare rivers. The onset of significant runoff occurs in late June or early July, while peak runoff often occurs in August. *Acacia spp* (especially *Acacia albida*), *Ziziphus spp*, *Balanites aegyptica*, *Tamarindus indica, Adonsonia digitata, Khaya senegalensis*, and other tree species occur in the study areas (Kolawole *et al.*,1995).

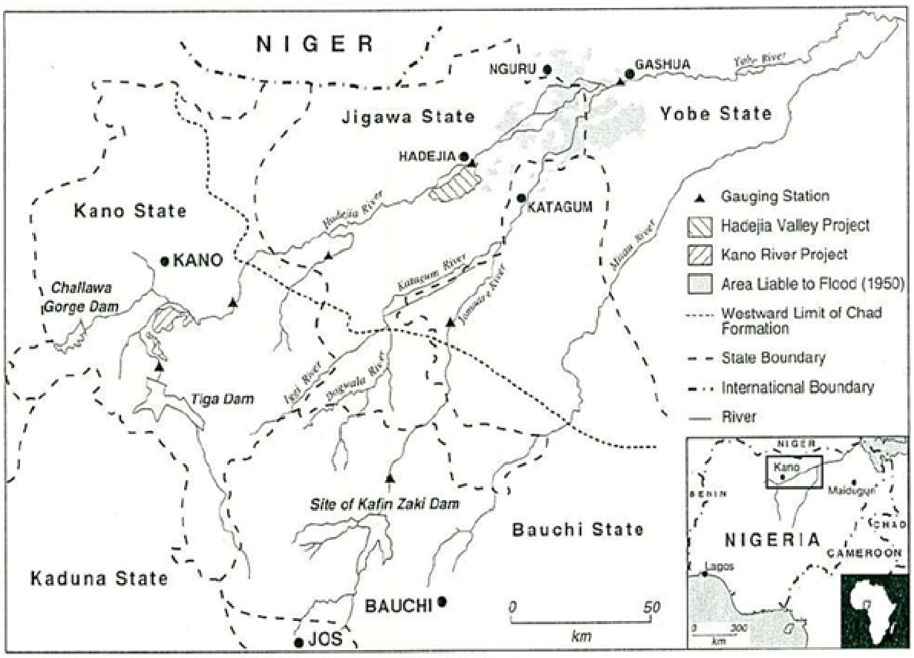

Figure 1. *The Hadejia-Jama'are Basin*

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Soil Sampling and preparation

The soils (Entisols, Inceptisols and Vertisols) of the Hadejia-Jama'are wetland were selected for the study. Soil samples were collected from five (5) different locations in the Hadejia Local Government Area of Jigawa State (Masama 1 with coordinate of 12.45N and 10.10E, Masama 2; 12.50N and 10.11E, Sinamu 1; 12.45N and 10.04E, Sinamu 2; 12.450N and 10.10E, Tandanu 1, 12.45N and 10.10E. Soil samples were taken in triplicate from each horizon, starting at the bottom and working up. The soil samples were lightly crushed, allowed to dry in the open air, and then passed through a 2 mm sieve.

Laboratory Analysis

The hydrometer method (Gee and Bauder, 1986) was used to determine the particle size distribution of the soil sample. Unmodified core samples were oven dried in the laboratory to estimate bulk density as described by Blake and Hartge (1986b). Particle density was determined after entrapped air in soils was removed using the pycnometer method described by Blake and Hartge (1986b). Soil pH was measured both in water and in a 0.01 M $CaCl_2$ solution at a soil/water or solution ratio of 1:1. Exchangeable bases (Ca, Mg, K, and Na) were calculated using Thomas's (1982) NH_4OAc saturation method. Titration of the extract with a typical NaOH solution allowed us to calculate the total exchange acidity (H^+ and A1) in the sample (Thomas, 1982). Cation exchange capacity (CEC) was calculated using the neutral (pH 7.0) NH_4OAc saturation method and base saturation was also assessed (Rhoades, 1982).

A Wheatstone bridge was used to measure electrical conductivity at 25 C and a soil-to-water ratio of 1:2.5. The Walkley-Black dichromate wet oxidation method reported by Nelson and Sommers was used to measure organic carbon (1982). Total soil nitrogen was determined using the micro-Kjeldahl technique developed by Bremer and Mulvaney (1982). Available phosphorus was measured using the Bray-1 extraction method as reported by UTA (1979). (Bray and Kurtz, 1945).

Heavy metal analysis

The total of selected heavy metals (Pb, Zn, Cu and Cr) in soils was determined by weighing 0.5 g of finely ground soil into digestion tubes in replicates. This was followed by the addition of 1 ml 60% $HC1O_4$, 5 ml conc. HNO_3 and 0.5 ml conc. H_2SO_4 to the bottom of the tube. The digestion tube was gently swirled and the samples were digested slowly over moderate heat by gradually increasing the temperature of the digestion block. The samples were digested until white vapours appeared, after which the digestion was continued for a further 10 to 15 min as described by Agbenin (1995). The concentrations of Pb, Cd and Zn in soils were determined by atomic absorption spectroscopy (AAS). The labile Pb, Zn, Cu and Cr concentrations were determined using the DTPA chelate method as described by Lindsay and Norvell (1978). The concentrations of Cd, Pb and Zn in the extract were determined by AAS. The devices were calibrated daily with analyzed certified reference materials and matrix correction according to DPR (2002).

Statistical Analysis

All data were subjected to cluster, factor, and principal component analysis using IBM SPSS version 20.0 (2012). These were used to identify elements with comparable geochemical behavior and to classify the soils according to their geochemical affinities.

Results and discussion

Processes affecting pedogenic, sedimentological, and elemental affinities in wetland soils

Two principal components (1 and 2) with 99.46 percent variation were found in the factor plot (Fig. 1 and Table 1) of the analyzed wetland soils when trace elements were taken into account regardless of other soil parameters. This difference could be attributed to long-term pedogenic processes occurring in soils formed on Chad formation rock in the studied area. A cumulative proportion of more than 50% (Tabachnick and Fidella, 2007; Chittamart *et al.*, 2010; Hair *et al.*, 2014) indicates the presence of trace element affinity groups, which demonstrate the influence of pedogenic and sedimentological processes on the pedogeochemistry of trace elements in wetland soils. The factor with an eigenvalue larger than one is regarded as the most important (Kaiser, 1960).

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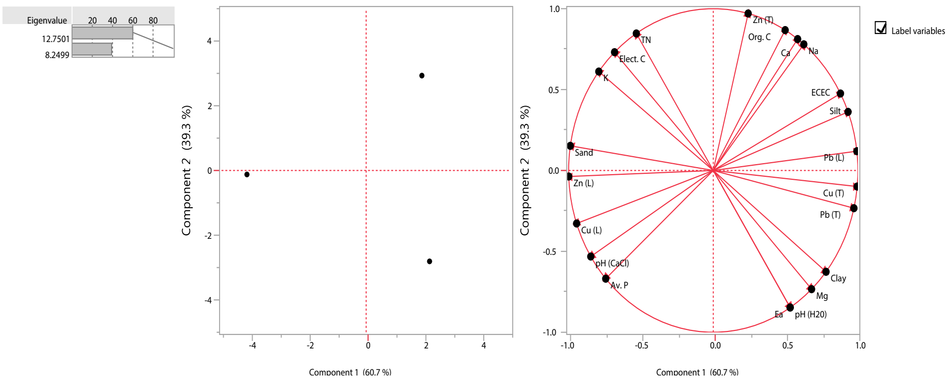

Figure 1. *Wetland soil factor plot of elements and affinity groupings*

Parameter	Factor 1	Factor 2
Org. C	0.497	**0.868**
Elect. C	-0.682	**0.731**
Avail. P	-0.743	-0.669
TN	-0.531	**0.847**
pH(H_2O)	**0.532**	-0.847
pH($CaCl_2$)	-0.847	-0.532
Na	**0.626**	**0.780**
K	-0.791	**0.612**
Ca	**0.583**	**0.812**
Mg	**0.680**	-0.733
Ea	**0.532**	-0.847
ECEC	**0.880**	0.476
Clay	**0.780**	-0.626
Silt	**0.932**	0.362
Sand	-0.988	0.152
Pb (T)	**0.973**	-0.233
Pb (L)	**0.993**	0.119
Zn (T)	0.241	**0.970**
Zn (L)	-0.999	-0.037
Cu (T)	**0.995**	-0.099
Cu (L)	-0.945	-0.328
Cr (T)	0.297	0.171
Cr (L)	0.216	0.162
Eigenvalue	**12.750**	**8.250**
% value	**60.715**	**39.285**
Cumm. %	**60.715**	**99.46**

Table 1. *Rotated factor loading for elements in five wetlands and one dryland control soil.* Components in bold are considered to be the most significant (>0.5).

Using the loading matrix (Gotelli and Ellison, 2004) (Fig. 1 and Tab. 2), two factors appear to be relevant, and the higher the eigenvalue of a principal component (PC) or factor, the greater the contribution of that particular factor to the variability of soil chemistry in wetlands (Vaalgama and Conley, 2008). Consequently, these two variables together accounted for 99.46% of the variation (Fig. 1). This percentage indicates high geochemical affinity (Tabachnick and Fidella, 2007; Chittamart *et al.*, 2010). This is probably related to the fact that the research area is saturated. Chittamart *et al.* (2010) made a similar observation. The ultimate variance or eigenvalues for the first factor were 12.750 and 8.250 for the second factor. Table 2 shows that both factors (1 and 2) accounted for 99.46% of the total variation.

A general description of the first factor includes pHw, Na, Ca, Mg, Ea, ECEC, clay, silt, Pb(L), Pb(T), and

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Cu(T). This connection between the components suggests that both originate from the same emission source. This result supports the high positive association between these factors. Organization C, TN, Na, K, Ca, and Zn (T) were the features of factor 2. Table 1 shows the relationships between these characteristics. Factors 1 and 2 require an association with anthropogenic causes (i.e. constant supplementation of pesticides and fertilizers). Similar observation was noted by Mohan (2006).

Cluster analysis

A cluster analysis was carried out using the basic information obtained from the principal component analysis. Under this premise, a hierarchical cluster analysis was developed to discover similarities in metal content between the analyzed soil samples (Cheng *et al.*, 2005; Wang *et al.*, 2007; Lin *et al.*, 2011; Hair *et al.,* 2014). The dendrogram in Figure 2 was obtained from a cluster analysis performed on studied parameters using the method and the squared Euclidean distance as a measure of similarity.

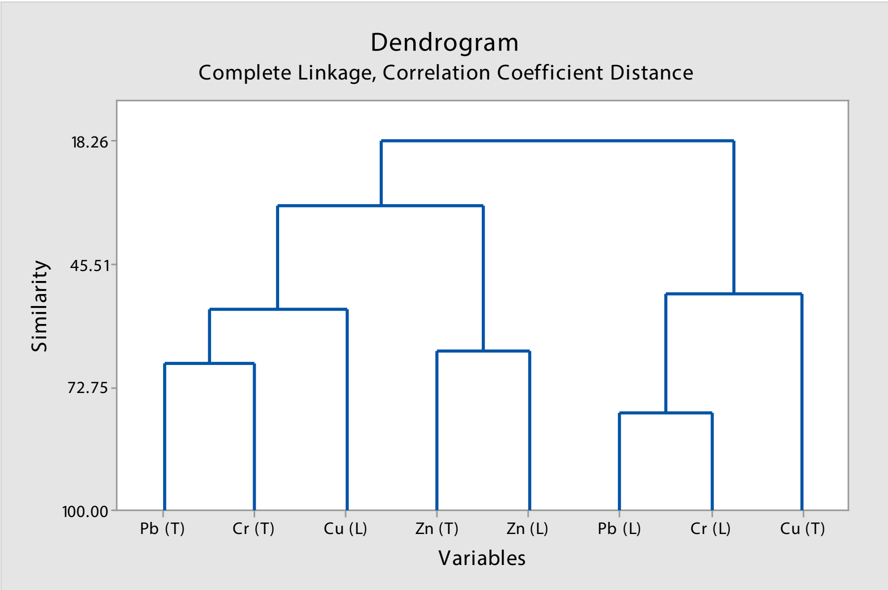

Figure 2
Dendrogram obtained by hierarchical cluster analysis.

The greater the distance cluster value, the less relevant the relationship, or vice versa (Gotelli and Ellison, 2004; Tabachnick and Fidella, 2007; Hair *et al.*, 2014). Cluster 1 comprises Pb (L) and Cr (L), showing that there is a major relationship between these elements and that their sources are parallel. These contaminated components were derived from anthropogenic activity, matching prior findings (Abdu *et al.*, 2011a). This scenario may be related to the places' proximity to local roads with heavy traffic. Cluster 2 is made up of Pb (T) and Cr (T), which form a separate cluster near together, indicating that they come from similar sources (industrial activity and vehicular output, inorganic fertilizer).
However, the third cluster consists of both total and labile Zn and forms a distance cluster at a greater distance, indicating that the Zn contamination was caused by anthropogenic sources (such as inorganic fertilizers, fungicides, and sewage sludge). These results confirmed the results of several other researchers (Li *et al.*, 2001; Bradl *et al.*, 2004; Yalcin *et al.*, 2008).

Conclusions

The study results have enhanced our understanding of heavy metal levels and potential sources in Hadejia Jamaare soils. The general description of the first factors includes pHw, Na, Ca, Mg, Ea, ECEC, clay, silt, Pb(L), Pb(T), and Cu(T). This connection between the components suggests that both originate from the same emission source. Organization C, TN, Na, K, Ca, and Zn (T) were the characteristics of Factor 2. The research regions would have recently encountered the effects of Pb and Zn (present in large quantities). The positions of the samples according to the cluster distribution are determined by hierarchical cluster analysis which revealed that Pb, Cr, and Zn are from the same emission source. The risk of heavy elements should be known

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to the public, and farmers in the research area should give priority to organic fertilizers, and also apply the recommended inorganic fertilizers and insecticides.

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