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Potentials of Sludge from Drinking Water Treatment Plant for Use as Source of Soil Nutrients for Reclamation of Degraded Land

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Abstract
The residuals from Gubi drinking water treatment plant are usually discharged directly into the nearby streams without any form of treatment. The decomposition of the organic materials contained in the untreated sludge has caused the production of malodorous gases and unsightly condition in the area. The disposal of this sludge in an environmentally friendly manner is therefore not only desirable but necessary. The aim of this investigation was to assess the feasibility of utilizing the residuals from Gubi water treatment plant as a source of nutrients for reclamation of degraded lands especially those arising from mining activities. The study was carried out at Gubi water treatment plant located in the vicinity of Gubi Dam water reservoir.Ten sludge samples were collected from each of the three clerifiers. Important sludge properties that are known to aid nutrients status of soil were analyzed using standard laboratory procedures. The means of various soil quality parameters recorded in the WTRs were 6.8, 20.06g/kg, 34.90g/kg, 1.65g/kg, 2.30g/kg, 13.45mg/kg, 2.50Cmol/kg, 2.10Cmol/kg and 28Cmol/kg for pH, Organic C, Organic Matter, K, Total N, Olsen P, Ca, Mg and CEC respectively. The means of all the parameters analysed falls within the ranges considered good for vegetation growth. The heavy metals concentrations recorded in the residual were 1.8mg/kg, 0.1mg/kg, 2mg/kg, 29mg/kg, 66mg/kg, 15mg/kg, 8.7mg/kg, 6.2mg/kg and 0.03mg/kg for As, Cd, Pb, Cu, Zn, Ni, Co, Cr and Hg respectively. The concentrations of all the metals did not exceed the acceptable threshold limits recommended by regulatory authorities. Considering the enormous amount of plant nutrients and absence of excessive toxic metals in Gubi WTRs, it is safe to conclude that the residual can be use as a source of soil nutrients for reclamation of degraded land.
Key words: Sludge, Soil Nutrients, Degraded Land, Reclamation

1.0 Introduction

Water purification is the process of removing undesirable chemicals, materials, and biological contaminants from raw water. Most water is purified for human consumption however the purification may also be designed for a variety of other purposes, including meeting the requirements for agricultural, chemical and other industrial applications. The goal of water purification therefore is to produce water fit for its intended uses.

The Gubi water treatment plant in Bauchi State, Nigeria was constructed with the goal of removing existing contaminants in the water or reducing the concentration of such contaminants so that the water becomes fit for drinking. The methods used in Gubi water treatment plant include physical, biological and chemical processes.

The purification process of water reduces the concentration of suspended particles, parasites (bacteria, algae, viruses, fungi) and a range of dissolved and particulate material derived from the minerals the water may have contacted after falling as rain. These suspended particulate matters settled in a clarifier to form sludge referred to as Drinking Water Treatment Residual (DWTR). Khopkar (2004) therefore defined DWTR as any solid, semisolid, or liquid residue generated during drinking water treatment works. DWTR is therefore considered one of the principal products of water treatment process.

However, one problem that remains after the treatment process is finding an economical and efficient way to get rid of the residual solids that were filtered out. Current sludge regulations limit its disposal alternatives based on the treatment level provided, pathogen removal, and metals content. At the same time, practical disposal options for sludge involve some form of reuse of the product, whether by direct land application, stabilization, composting, or pelletizing (Kadam *et al.,* 2008).

The DWTR from Gubi is usually discharged directly into the nearby streams without any form of treatment. The decomposition of the organic materials contained in the untreated sludge discharged into the stream led to the production of malodorous gases and unsightly condition. It was also observed that eutrophication has already begun because of the excess nutrients and microorganisms contained in the deposited sludge. For this reason, the disposal of the DWTR obtained from Gubi water works in an environmentally friendly manner is not only desirable but necessary.

According to Makris and Harris (2005) DWTR have potential for environmental remediation as a soil amendment. Land application of the residuals according to Metcalf and Eddy (2003), entails spreading the biosolids on or just below the soil surface. Biosolids may be applied to agricultural or disturbed land. DWTR is a potential plant growth medium because of its high organic matter and other nutrient contents (Skene *et al.,* 1995; Mahdy *et al.,* 2007).

Topsoil is needed for the reclamation of disturbed sites such as abandoned strip mines and road construction sites. Mining native topsoil for these purposes is environmentally unsound because it creates more disturbed sites. The beneficial use of municipal or industrial residuals as soil substitutes is a potential source of topsoil and may provide an economical disposal option for residuals (Dayton and Basta, 2001). For a residual material to be considered as a soil substitute, it must function like a soil. Soil quality according to Doran and Parking (1996) is the capacity of a soil to function, within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health. The biosolids characteristics that affect their suitability for application to land and for beneficial use include organic content, nutrients, pathogens and toxic metals (Metcalf and Eddy, 2003).
With increase in more disturbed sites due to solid minerals mining activities and road construction projects in Bauchi State there is the need to place emphasis on using the sludge from Gubi water treatment works in land application for vegetation restoration because of its possible nutrient quality rather than disposing it. The aim of this investigation was to assess the feasibility of utilizing the DWTR from Gubi water treatment plant in Bauchi State, Nigeria as a source of nutrient for reclamation of degraded lands arising from mining activities scattered in various parts of the state.

2.0 Materials and Methods

2.1 Study Area

The study was carried out at Gubi water treatment plant located in the vicinity of Gubi Dam water reservoir. The Dam was constructed in 1979 with the aim of providing water for irrigation, dairy farming and domestic water supply to Bauchi metropolis. The Dam has four major tributaries namely Tatimari (Shadawanka and Dinya), Suntum, Kumi and Larkari. Located in the northern part of Bauchi city, North-eastern Nigeria, the Water

Treatment Plant at Gubi Dam lies within the boundaries of Longitude 10°25'N to 10°26' and Latitude 9°51'E to 9°52'E (BASWB, 1990) The area has a climate marked clearly by the dry and rainy season. The average annual rainfall is 1300mm. The wettest months are July, August and September. Dry season starts in November and ends in April. This is a period of harmattan, when the dust loaded North Eastern trade wind from Sahara desert has a marked drying effect on the vegetation and general climate of the area (BOD, 2007).

2.2 Sampling Strategy

Ten sludge samples were collected from each of the three clerifiers. The samples were kept for 24 hours to settle and the excess water floating on top decanted. The air dried samples were grounded using a previously acid washed porcelain mortar and pestle. The samples were then kept in desiccators to attained constant weights before being transferred into air-tight plastic bottles. All the samples were sieved with a 200 µm sieve before analysis.

2.3 Analysis of Sludge for Nutrients and heavy metals Content

Important sludge properties that directly aid nutrient status of soil as documented by Brady and Weil (1999) were analyzed. The sludge chemical analyses were performed using standard laboratory methods as follows: Sludge pH determined using a pH meter (a soil/water ration of 1:1). Total nitrogen content was determined by wet-oxidation (wet digestion) procedure of Kjeldahl method (Iwuafor *et. al.*, 1990). Organic Carbon was determined using Walkley and Black method as described by Iwuafor *et. al.* (1990). The organic matter was determined by multiplying the organic content by a factor 1.72 (Agboola and Obatolu, 1993). Available Phosphorous determined using Bray-1 method (Iwuafor et. al., 1990). The exchangeable cations and the cation exchange capacity (CEC) of the soil were determined after extraction with 1 N ammonium acetate (pH 7). Exchangeable K and Na in the extract were measured by flame photometer while calcium and magnesium were measured using EDTA titration method. Heavy metals content of the dried sludge were measure using Atomic Absorption Spectrometer (AAS) after extraction with Aqua-regia.

3.0 Results and Discussion

In order to assess the suitability or otherwise of the sludge for use as a source of soil nutrients, the concentration of the nutrients in the sludge were compared to the physico-chemical parameters/nutrients level required by most plants in a typical soil as shown in Table 1.

Table 1. Mean nutrient content of dried WTRs obtained from Gubi water treatment plant Bauchi

S/N	Parameters	Water Treatment Sludge	Typical Soil
1	pH-w (1:1)	6.8	5 – 8
2	Organic C (%)	2.77	2 – 10
3	Organic Matter (%)	4.78	2 – 10
9	K (g/kg)	1.65	1.85
4	Total N (g/kg)	2.30	> 2
5	Olsen. P (mg/kg)	13.45	> 2
7	Ca (Cmol/kg)	2.50	2.0 – 5.0
8	Mg (Cmol/kg)	2.10	> 1
11	CEC (Cmol/kg)	28	> 25

pH

Soil pH refers to the concentration or activity of hydrogen ions in the soil solution surrounding soil particles and plant roots. When the soil pH is 7.0, it means that the soil is neutral in reaction. Soil with a pH below 7.0 is acidic and soil with a pH above 7.0 is alkaline. While the pH of a soil refers to the concentration of hydrogen ions in that soil, it is the effect of the pH on the solubility and availability of many of the elements in the soil that is important rather than the actual concentration of hydrogen ions. (Ref).The mean pH of 6.1 was recorded for the WTRs. The value according to Bohn, *et al.,* (1985) falls within the typical range of 5.0 to 8.0 adequate for plant growth and development.

Organic Carbon (OC) and Organic Matter (OM) Contents

Organic Matter (OM) and Organic Carbon (OC)) are commonly recognized as key chemical parameters of soil quality although quantitative assessment of their contribution to soil quality is often lacking (Schoenholtz *et. al.,* 2000).The OC content of the soil is usually attributed to the decomposition of OM in the soil. Thus under normal circumstances there is a direct relationship between the OC and OM content of soil. The OC content in the WTRs is therefore a result of breakdown of its OM content by microorganisms. The mean OC and OM contents of the WTRs were 2.77% and 4.78% respectively. Both the OC and OM contents of the WTRs falls within the ranges of between 2 – 10% expected of a typical soil (Bot and Benites, 2005). The OM content of the WTRs is also high and considered to be good enough for vegetation growth. It may be concluded therefore that the WTRs if used on derelict land could provide the necessary carbon required by microorganisms to release of vital nutrients thereby enhancing its productivity.

Total N

Among all the essential nutrients, N is the most limiting for proper growth and development of plants. Many soils contained large amount of N. However, most of it is actually tied up in organic form and therefore not easily released for use by plants. Nitrogen is available to plants in two forms, ammonium and nitrate. In most soils, ammonium is quickly converted to nitrate. Nitrate is not held on soil particles and is easily dissolved in water. Thus it is susceptible to leaching. The mean Total N in the WTRs is 2.3g/kg. This value is considered to be adequate for growth and development of plants as it falls within the typical range of 0.2g/kg to 5.0g/kg typical of tropical soil (Brady and Weil, 1996). Soil with Total N content < 2g/kg according to Ewenzor *et. al.*, (1989) is considered to be good for vegetation growth. The high mean N value obtained in this study corroborates the findings of Mahdy *et. al.*, (2007) who recorded as much as 4.20g/kg in residuals obtained from the drinking water treatment plant in Kafr El-dawar, Egypt.

Olsen P content

Most soil P occurs in relatively insoluble minerals and organic matter in the soil. The availability of these forms is very sensitive to soil pH. Phosphorus can be lost from the soil through erosion of soil particles and organic matter containing P. It can also be lost through runoff from soils with very high P levels at the surface exposed due to for example mining activities. The mean Olsen extractable P contained in the WTRs is 13.45mg/kg. This value is <12mg/kg required by most plants for their growth and development (Brady and Weil, 1996).

Ca content

Calcium is present in adequate amounts in most soils. Calcium is a component of several primary and secondary minerals in the soil, which are essentially insoluble for agricultural considerations. These materials are the original sources of the soluble or available forms of Ca. Calcium is also present in relatively soluble forms, as a cation (positively charged Ca^{++}) adsorbed to the soil colloidal complex. The ionic form is considered to be available to crops (Spectrum Analytic Inc. 2013). The mean value of Ca recovered from the WTRs is 2.5 Cmol/kg. According to Ewenzor et al (1989) and Egu (1991), soil that contained between 2.0 Cmol/kg and 5.0 Cmol/kg of Ca is considered have a medium amount of the element adequate to support vegetation growth.

Mg content

Magnesium is abundant in the earth's crust. It is found in a wide variety of minerals. Many common soil minerals contain magnesium, including amphibole, biotite, chlorite, dolomite, montmorillonite, olivine, pyroxene, serpentine, and vermiculite. Soils developed from coarse-grained rocks low in these minerals tend to be low in magnesium. Most fine-textured soils and soils developed from rocks high in magnesium minerals contain adequate amounts (Schulte, 2004). Magnesium becomes available for plant use as these minerals weather or break down (Rehm, *et. al.*, 1994). In derelict land, Magnesium is easily washed out of the soils because it contains little or no clay. The WTRs contained a mean value of 2.1Cmol/kg of Mg. This value is > 1 considered to enough in soil to support plants' growth (Egu, 1991).

K Content

Potassium is available to plants in soil in two major forms. The first form is referred to as the exchangeable or readily available potassium and is found on the cation exchange sites or in the soil solution. The soil solution potassium is readily taken up by the plants root system and is then replaced by the potassium on the exchange sites. A second form/source of potassium in the soil is the potassium contained in organic matter and within the soil microbial population. This soil source of potassium provides very little of the potassium needed for plant growth. The chemical analysis revealed that the mean K content obtained from the water treatment residual is 1.6g/kg. This value is only slightly lower than the background K concentration of 1.85g/kg found in a typical soil (Mahdy *et. al.*, 2012)

CEC

CEC of soil is defined as the sum of positive charges of the adsorbed cations the soil can hold at a specific pH. The most important exchangeable cations in the soil are Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, H^{+}, Al^{3+} and NH_4^{2+}. The CEC can directly influence the changes in soil pH, because every time the clay particles capture cations release H^{+} and Al^{3+} ions, which in high concentrations acidifies soil. Generally, tropical soils have low CEC, especially for high sandy and low pH soils. Minerals as oxides of aluminum, iron and manganese that are very abundant in tropical soils also contribute to the low CEC. In these cases a greater investment in fertilization, especially with humic compounds becomes necessary (Aprile, F. and Lorandi, R. 2012). The mean CEC of the WTRs is 28Cmol/kg. This value is > 25Cmol/kg considered enough to supply enough to supply cationic elements necessary for growth of plants (Egu, 1991). Similar high CEC values that range from13.6Cmol/kg to 56.5Cmol/kg having a median of 30Cmol/kg were earlier reported by Dayton and Basta (2001)

Heavy metals Content

An important criterion for determining the applicability or otherwise of sludge for use as a soil amendment for agricultural food production or forestry is the level of pollutants contained in the sludge. This is due to the fact that the sludge if not properly handled could be a source of many pollutants especially heavy metals. The beneficial use of the sludge therefore should not be evaluated based on nutrient content alone, but also on other parameters that could be detrimental to the well being of the farmer and the public in general (Metcalf and Eddy, 2003). The sludge characteristic that affect its suitability for application to land should therefore include not only the nutrient content but also pathogens, toxic organics and heavy metals. Heavy metals are particularly more worrisome because of their toxicity and persistence in the environment. The following heavy metals (Table 2) were determined in the sludge to assess it suitability for application to agricultural land.

Table 2 Mean metal content of dried residual obtained from Gubi Water Treatment compared to the Acceptable Thresholds Concentrations (Mg/Kg Dry Weight) of Biosolid Application in Agricultural Land in some countries according to AAFC (1999), FAD, 1998 and PDEP (2014)

S/N	Heavy Metal	Gubi WTRs	Acceptable Thresholds Concentrations		
			Canada	Florida (US)	Pennsylvania (US)
1	As	1.8	75	75	41
2	Cd	0.1	20	85	25
3	Pb	2	500	-	300
3	Cu	29	-	4300	1500
4	Zn	66	1850	7500	2800
5	Ni	15	180	420	420
6	Co	8.7	150	-	-
8	Cr	6.2	-	-	1200
9	Hg	0.03	5	57	17

A critical look at the heavy metals content of the WTRs revealed that none of the metals contained in the residuals exceed the acceptable limit recommended by the regulatory authorities. In may be concluded therefore that the WTRs could be a good source of soil nutrient if appropriately applied. The residual can be use on agricultural land for crop production or to facilitate re-vegetation on disturbed lands. According to Pennsylvania Environmental Protection Department PDEP (2014), water treatment residual may be applied at a rate not greater than 15 dry tons per acre per year**.**

4.0 Conclusion and recommendation

The results presented in this work have shown that Bauchi state Gubi WTRs can be a valuable source of nutrients to facilitate re-vegetation of degraded land. Sun dried sludge can be applied directly on land as organic fertilizer to promote plant growth. Furthermore, the selected heavy metals content were far below the recommended limits set by regulatory authorities. Sun dried residuals if used as organic fertilizer for agriculture will be more economical than commercial inorganic fertilizer. Agriculture dependent developing countries such as Nigeria rely mainly on imported inorganic chemical fertilizers. Thus by products such as water WTRs from Gubi could play a role in the development of the economy in an environmentally friendly manner.

A dried treated sludge organic fertilizer unlike chemical fertilizers has no excessive harmful toxic metals and unlike manure, the nutrients are immediately available to plants without waiting for one or two years for microbial decomposition. Also it does not contain pathogenic microorganisms, worms, weed seeds, heavy metals or objectionable odour.

Based on the results of this investigation, it is recommended that screen house and field trials should be carry out to assess the responses of different plant species to the soils collected from the devastated lands mixed with the nutrients contained residuals, thus in a better position to select the most promising species for used in re-vegetation of the various degraded land in Bauchi state and beyond.

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