

Physico-Chemical Characterization of Sludge from the Goudel Drinking Water Production Plant in Niamey (Niger)

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Abstract

Population growth and increasing needs make our current societies a considerable source of environmental threats. Going towards sustainable cities where harmony exists between economic, socio-cultural and environmental issues is a necessity that is essential if we want to bequeath a livable world to future generations. Cities produce huge quantities of domestic and industrial waste, the management of which is becoming a growing problem for city managers. Located on the banks of the Niger River, the city of Niamey, capital of the Republic of Niger, is supplied with drinking water from this river. Significant quantities of sludge are produced by the plant following the treatment of this water. This study focuses on the physico-chemical characterization of this sludge which is now directly discharged into the Niger River. A total of 12 samples of pasty sludge taken from the pre-settling ponds were analyzed. The samples were previously dried, crushed, sieved and packaged. Physical (pH, EC and particle size), chemical (Ca, Mg, Na, K, CEC, AE, P, C, MO and N) and metallic trace elements (Pb, Ni, Cu, Zn, Cd, Mn) parameters and Al) were analyzed in the laboratory. The results show that the sludge is weakly acidic (pH between 4.16 and 5.71), conductive (<0.35 mS/cm) and rich in fine elements (12.1% to 77.71% clay). The nutrient content is low in nitrogen (<0.25%), phosphorus (<2.5 ppm), potassium (between 1 to 188 Mèq/100g) and organic matter (less than 2.88%). The concentrations of ETM comply with the values admissible in residual materials (French decree of 08/01/1998). This sludge can be recovered, especially in agriculture.

Keywords

Sludge, Potable Water, Water Treatment, Niger River, Niamey

1. Introduction

As a result of rapidly increasing population, urbanization and industrialization, wastewater production and sewage sludge generation have increased manifold [1]. Thereby, the quantities of residual materials to be managed safely have undergone considerable increases [2] [3]. Industries are frequently accused of environmental pollution [4]. Waste management, whether bio-solid, liquid or gaseous, must be part of a logic of sustainable development. Sludge and sediment are a quantitatively important material flow [5] often containing harmful substances such as heavy metals [6]. Sludge and sediment constitute a quantitatively significant flow of materials whose management and treatment costs can be high in the event of high contamination, in particular heavy metals, PAHs, dioxins, phosphorus, pathogenic organisms, etc. [5]. Sludge's components are very different among types of sludge [7]. Sludge, a muddy, solid, semi-solid or liquid residue [8] can be managed in multiple ways. The use of sludge is currently done according to different traditional channels: agricultural use, spreading, landfilling, incineration, co-incineration, separation of the sandy fraction, use in the form of backfill, recycling into building materials construction. The first sectors mentioned are subject to increasingly strict standards [9] and have some disadvantages [10]. In low-income countries, financing the sludge treatment link remains a topical challenge, with users, operators and elected officials seeing little interest in it. However, the recovery of faecal sludge is a partial funding option in particular, among the fees from emptying, the fee on the drinking water bill, municipal taxes, etc. [11]. To limit the environmental impact of sludge, it is important to define a policy taking charge of the prevention, production and management of the latter while adopting management methods favoring the analysis of the life cycle of the elements that compose it. Sludge management presents a sustainable management challenge [12] [13]. The objective of this study is to perform the physico-chemical characterization of the sludge from the Goudel drinking water production plant in Niamey, Niger.

2. Material and Methods

2.1. Sample Collection and Analysis Methods

Twelve (12) wet sludge samples were taken from the settling basins (**Figure 1**) of the Goudel water production plant, including six (6) samples during the rainy season and six (6) during the rainy season dried (**Figure 2**). The samples are transported to the Faculty of Agronomy of Abdou Moumouni University where they are dried in the shade, crushed (**Figure 3**), sieved, stored in bags and then labeled (**Figure 4**). The physicochemical and particle size analyzes were carried out at the Soil Laboratory of the National Institute for Agronomic Research of Niger (NIARN). Metallic trace elements (MTE) were analyzed at the Geography Laboratory of Umaru Musa Yar'adua University in Katsina (Nigeria).

The physico-chemical parameters analyzed are: pH, particle size, electrical conductivity, calcium, magnesium, sodium, potassium, cation exchange capacity



Figure 1. Basin.



Figure 2. Sample taking.



Figure 3. Crushing.



Figure 4. Conditioning.

(CEC), exchange acidity (EA), assimilable phosphorus, total phosphorus, carbon, organic matter, nitrogen and carbon/nitrogen ratio. Eight (8) metals were analyzed: lead, nickel, copper, iron, zinc, cadmium, manganese and aluminum. The methods used are listed in **Table 1**.

2.2. Data Processing

GenStat version 9 software was used for the analysis of variance. When the null hypothesis is rejected at the 5% threshold, the comparison of the means is carried out with the Newman-Keuls test. The Microsoft Excel 2016 spreadsheet was used for the construction of the graphs.

Chemical characteristics of sludge.

3. Results

3.1. Physical Characteristics of the Sludge

The averages values of physical parameters (pH, conductivity, and particle size) make a strong change according to the seasons (**Table 2**). The sludge produced in rainy-season are most acids (pH = 4.16) than those produced in the dry season (pH = 5.7) contrary to pH, the Electric Conductivity is high in rainy-season (0.352 ms/cm) and in dry season (0.222 ms/cm). On the particle size plan, the sludge produced in dry-season has a coarse texture with a silt-sandy dominance is dominated by coarse sands and fines follow up by the silt the content in clay is

Table 1. Parameter analysis methods.

Parameters	Methods
pH	pH meter with soil/water ratio 1/2.5
Granulometry or particle size	Bouyoucos method
Carbon	Method of Walkley and Black (1934)
Nitrogen	Kjeldahl method
Phosphorus	Bray's method I
Cation exchange capacity (CEC),	Ammonium acetate method pH = 7
Exchangeable bases	Automatic extraction method
Exchange acidity and aluminum	Method by automatic extractor and titration with sodium hydroxide
ETM	Dissolution and reading by Atomic Absorption Spectrophotometer

Table 2. Physical quality of sludge.

	pH	EC (ms/cm)	Texture (%)			
			Clay	Silt	Fine sand	Coarse sand
Rainy-season	4.16	0.35	77.71	10.57	4.14	7.58
Dry-season	5.71	0.22	12.1	22.13	31.27	34.50

inferior at 15%. Otherwise, the sludge of the rainy-season have a fine texture with the contents in clay (up to 77%). The contents in silt, fine sands and coarse sands, are relatively weak with the contents respectively of 10.75%; 4.14% and 7.58%.

3.2. Chemical Characteristics of the Sludge

✚ Organic matter

The main parameters measured to characterize the fertility of the sludge are: carbon (C), nitrogen (N) and the C/N ratio. The analysis results (**Table 2**) show that the sludge produced in the dry season has a low percentage of C/N (8%) and a high percentage of carbon (1.68%), organic matter (2.89%) and in nitrogen (0.21%). The sludge produced in the rainy season has a high percentage of C/N (10.83%) and low in carbon (0.64%), organic matter (1.11%) and nitrogen (0.06%).

✚ Exchangeable Bases

We note a strong variation in the average values of the following exchangeable bases (K^+ , Mg^{2+} , Na^+ , Ca^{2+}) between the two seasons (**Table 3**). Thus, the sludge produced in the rainy season (SP) has higher contents than those produced in the dry season (SS). The calcium content is high regardless of the season (5.47 meq/100g in the rainy season and 3.79 meq/100g in the dry season). The contents of magnesium (1.31 meq/100g in SP and 0.075 meq/100g in SS), sodium (0.61 meq/100g in SP and 0.19 meq/100g in SS) and potassium (1.36 meq/100g in SP and 0.58 meq/100g in SS) are low.

✚ Phosphorus

We observe a strong variation in the average values between the two seasons (**Table 3**). Total phosphorus is high in the sludge produced in the dry season (2535 ppm), while it is low in the rainy season (578 ppm). The reverse is true for assimilable phosphorus: low in the rainy season (0.563 ppm) and high in the dry season (2.108 ppm).

✚ Cation Exchange Capacity (CEC)

Sludge produced in the dry season has a low CEC value (4.78 meq/100g), while that produced in the rainy season has a higher value (14 meq/100g).

✚ Exchange Acidity (EA)

There is a strong variation in mean values between the two seasons (**Table 3**).

Table 3. Values of the chemical parameters of the sludge.

	Meq/100g							Phosphorus ppm			%		
	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	EB	ECC	EA	Assim P	Tot P	Carbon	OM	Nitrogen	C/N
Rainy-season	5	1.31	0.615	1	9	14	5.49	2.11	578	0.64	1.11	0.06	10.8
Dry-season	379	0.08	0.19	188	4640	4772	0.17	0.56	2535	1.68	2.9	0.2	8.0
Cv %	53.1	12.8	23.3	343	47.8	45	14	19.2	24.2	9.1	9.2	19.0	24.4

Cv: Coefficient of variation; EB: Exchangeable bases; ECC: Exchange cationic capacity; AE: Acidity exchange and aluminum; Assim P: Assimilable phosphorus; Tot P: Total phosphorus; OM: Organic matter; C/N: Link C/N.

Sludge produced in the dry season has a low EA value (0.17 m \dot{e} q/100g), while that produced in the rainy season has a high value (5.49 m \dot{e} q/100g).

✚ Concentrations of metallic trace elements (MTE)

In the dry season the sludge is richer in metals than in the rainy season (5 elements out of 8 analyzed). The dominant elements are aluminum, iron and copper, followed by nickel and lead. Manganese, zinc and cadmium are in relatively low levels (less than 30 mg/kg regardless of the season). The difference in values between seasons is only statistically significant for Ni (0.010). It is not significant for lead ($P < 0.084$), copper ($P < 0.148$), zinc ($P < 0.938$), cadmium ($P < 0.239$), magnesium ($P < 0.696$) and aluminum ($P < 0.133$). In the sludge collected in the dry season, the highest average concentrations were recorded for aluminum (218.59 mg/kg), copper (148 mg/kg) and nickel (93.3 mg/kg). The average cadmium concentration is the lowest (13.83 mg/kg). They are 72.7 mg/kg and 17.29 mg/kg respectively for lead and zinc. **Table 4** shows the metallic trace element contents of the sludge according to the two seasons.

4. Discussion

Residual sludge has a composition that varies according to the seasons. The analysis of the physicochemical parameters of the sludge showed a significant difference between the two seasons. Thus, the sludge produced in the dry season has an average pH of 5.7 while that produced in the rainy season has an average pH of 4.1. As a result, the sludge produced in the dry season is less acidic than that produced in the rainy season. Nevertheless, these values are close to the pH range (5.5 to 6.5) for which the solubility of most microelements is optimal for crops [14]. The pH of the sludge in the dry season (5.7) is lower than that obtained by [15] in Algeria, which was 6.38, that of [16] in Algeria which was 7.78, that of [3] which was 6.35 in secondary sludge from Haute-Bécancour and 6.24 in sludge from the Bowater paper mill in Donnacona (Quebec), that of [17] which was 7.05 ± 2 in activated sludge. The difference in pH may be due to the treatment steps which may be different from one station to another, depending on the origin and quality of the water to be treated. Regarding electrical conductivity, it gives an idea of the salinity of the environment [16]. Statistical analysis shows a non-significant difference between the two seasons. The variation in the CE of the sludge from the Goudel plant is low: 0.222 ms/cm in the dry season and 0.352 ms/cm in the rainy season. These results are lower than that obtained

Table 4. Metallic trace elements content of sludge.

	Metallic trace elements in mg/kg						
	Pb	Ni	Cu	Zn	Cd	Mn	Al
Dry season	59.9 \pm 12.6	75.8 \pm 3.8	170.6 \pm 27.9	17.4 \pm 0.7	13.6 \pm 0.3	25.8 \pm 2.6	105 \pm 30.8
Raining season	72.7 \pm 6.5	93.3 \pm 8.1	148.2 \pm 26.0	17.3 \pm 2.87	13.83 \pm 0.3	27.5 \pm 11.4	1025 \pm 203.4
Cv %	15.5	9.0	14.2	11.2	1.8	26.3	157.5

by [15] who was 1.117 ms/cm and who thought that it was the moderate presence of a few ions that gave sludge a low electrical conductivity value. They are also lower than those obtained by [3] which were 2.31 S/m and 0.93 S/m, respectively in secondary sludge from Haute-Bécancour and in sludge from the Bowater paper mill in Donnacona. On the other hand, they are higher than 0.072 ms/cm obtained by [16], who estimated that the sludge is weakly conductive, thus denoting this low salinity.

The particle size analysis showed that the sludge produced in the rainy season has a higher percentage of clay (77.71%) than that produced in the dry season (12.1%). On the other hand, the sludge produced in the dry season has a higher percentage of silt (22.13%), fine sand (31.27%) and coarse sand (34.50%) than that of the sludge produced in the rainy season, which is 10.57%, 4.14% and 7.58% respectively. As a result, the sludge produced in the rainy season has a clayey texture and that of the dry season has a sandy-loamy texture. This high content of clay in the sludge produced in the rainy season could be explained by the supply of the river with water from the tributaries of the right bank whose watersheds have soils sensitive to water erosion. It may also be linked to the degradation of natural resources in the Niger basin following the continued aridification of the climate, associated with strong anthropogenic pressure [18]. The high clay content has the advantage of being able to reinforce the structural stability of soils [19]. The physical quality of this sludge differs from that of the sewage network and the dredging of canals which contain mainly sand and earth (70% to 90%) and also from that of septic tanks which contain mainly biodegradable organic substances (55 at 80% dry weight [7]. Exchange Acidity (EA) also varied seasonally with a statistically significant difference.

With regard to the chemical characteristics of the sludge, the rate of organic matter shows that the sludge produced in the dry season has percentages of Ca (1.68%), M.O. (2.89%) and N (0.21%) higher than those of the sludge produced in the rainy season which are respectively 0.64%, 1.11% and 0.06%. The proportion of nitrogen in the sludge in the dry season, although higher (0.21%) than in the rainy season, is very low compared to the rate obtained by [16], which was 0.77%. This indicates the low nitrogen content of sewage treatment plant sludge. However, the use of this sludge could have a certain positive consequence in the soil [2]. Indeed, the incorporation of sludge significantly modifies the OM content in amended soils compared to the control [20] and slightly increases their structural stability [19]. The C/N ratio acts directly on soil biology [20]. It is determined from organic carbon and total nitrogen [21]. The lower the ratio, the easier the sludge biodegradation [16]. Thus, the C/N ratio of the sludge produced in the dry season is 8, comparable to that obtained by [16] which is 8.35. These results are lower than 10.83% obtained in the sludge produced in the rainy season (SP). This difference in organic matter results may be due to the low nitrogen and total carbon content of the sludge analyzed.

The analysis of exchangeable bases (EB) shows that the sludge produced in the

rainy season has a greater EB saturation rate with 8.75 meq/100g, while that produced in the dry season has a rate of 4.64 meq/100g. This could be explained by the fact that the saturation rate is proportional to the degree of saturation of the complex in exchangeable cations [22]. The sludge produced in the rainy season has Ca^{2+} (5.47 meq/100g), Mg^{2+} (1.307 meq/100g), Na^+ (0.615 meq/100g), and K^+ (1.36 meq/100g) values higher than those produced in the dry season Ca^{2+} (3.79 meq/100g), Mg^{2+} (0.075 meq/100g), Na^+ (0.191 meq/100g) and K^+ (0.58 meq/100g). These results are lower than those obtained by [16], Ca^{2+} (10.25 meq/100g), Mg^{2+} (3.25 meq/100g), Na^+ (4.15 meq/100g), at the except for potassium K^+ (0.59 meq/100g) which is substantially equal to that obtained from the analysis of the sludge produced in the dry season K^+ (0.58 meq/100g). This difference can be explained by the low saturation rate of the sludge analyzed, but also by the fact that a very high level of one of the basic cations (Ca^{2+} , Mg^{2+} , Na^+ or K^+) can reduce the availability of one or more of these elements for plants [23].

As for the concentrations of metallic trace elements (MTE), although by their physico-chemical compositions, the sludge once spread could increase crop yields, it can also contain compounds whose effects are undesirable, either for soil conservation, or for the food chain, therefore dangerous for the health of humans and animals [24]. This is the case of MTE. These elements, above a certain threshold, can make some sludge unsuitable for agricultural spreading. In addition, discharge of sludge from water works into waters will result in the increased deterioration of water environment [25]. Both in the rainy season and in the dry season, the ETM rates of the sludge fall into the C2 category of fertilizing residual materials (MRF) according to Quebec standards. Indeed, the average rates of Ni, Cu, Cd of the two (2) seasons exceed the allowable rates for category C1 [3] for which the valuation could be done without limit of application. nevertheless in category C2, fertilizing residual materials (MRF) having at least one contaminant between 150 - 500 mg/kg DM for Pb, 62 - 180 mg/kg DM for Ni, 100 - 757 mg/kg DM for Cu, 500 - 1850 mg/kg DM for Zn, 3 - 20 mg/kg DM for Cd and 25,000 - 100,000 mg/kg DM for Al and Fe (Marc-André, 2004), and are significantly lower than the allowable levels according to the French decree of 08/01/1998 [26]. [27] had obtained average concentrations lower than ours for Ni (44 ± 7 mg/kg), Cu (68 ± 18 mg/kg) and higher for Zn (199 ± 71 mg/kg) and Pb (85 ± 25 mg/kg). These metals restrict the use of sludge in agriculture because their accumulation is harmful to the environment and particularly the food chain [28]. As for [29], they obtained concentrations similar to ours for Cu (172.56 mg/kg) and Pb (76.88 mg/kg) but higher for Zn (218.73 mg/kg) and Mn (157.56 mg/kg). Finally, it is knowledge of the composition of the sludge that makes it possible to choose the/or the recovery methods [30].

5. Conclusion

The results of this study showed that the sludge is weakly acidic and conductive,

rich in nutrients and contains moderate levels of metallic trace elements. The particle size showed that the sludge of the dry season presents a coarse texture with silty-sandy dominance, and that of the rainy season, a fine texture with clay dominance. The metallic trace elements contents do not exceed the admissible thresholds in a fertilizing residual material; they are likely to be used for agricultural purposes under previously prospected conditions, taking into account several aspects, including the types of speculation and the soil. Waste recovery is a mandatory practice that is essential in any policy aimed at sustainable development and environmental protection.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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