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Urban wastewater treatment by infiltration-percolation on sand and gravel based on Typha plant filters

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ABSTRACT

Phytodepuration is one of the most widely used techniques for treating wastewater, thanks to its specific characteristic of simplicity of design. The main objective of this study is the treatment of domestic wastewater from a district in Nouakchott, using a macrophyte lagooning system. Several physico-chemical parameters were measured before and after treatment. Average abatement rates were recorded for biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and suspended solids (SS), with progressive acceptable values of 26.57%, 28.60% and 59.45%. Treatment efficiencies for nitrogen and ortho-phosphate ($P\text{-}PO_4$) are generally low. In general, our results show that this natural lagoon achieves a good purification efficiency of organic pollutants, which indicates the importance of the role of purifying plants in reducing the organic and particulate pollutant load. As well as the role of the various substrates used in the experimental set-ups.

Keywords: lagooning, physico-chemical characteristics, phytodepuration, domestic wastewater.

INTRODUCTION

Population growth in urban areas not accompanied by a consistent urbanization plan, combined with a lack of appropriate sanitation facilities, are the causes of wastewater and excreta discharges in most large African conurbations. The city of Nouakchott, like many developing countries, is faced with sanitation problems.

Indeed, septic tanks, ventilated improved pit (VIP) latrines and cesspools proposed for autonomous sanitation do not ensure sufficient treatment of wastewater and excreta, and generate faecal matter whose lack of management is a source of pollution of the environment and of surface and groundwater resources (Kone et al., 2009, Tilley et al., 2008, Wethe et al., 2003), resulting in the persistence of water-borne diseases such as diarrhoea, typhoid fever, cholera, etc. Infiltration-percolation beds -are an alternative in non-collective sanitation, in both rural and urban areas. Wastewater in Nouakchott is of various types, destinations and risks. Some is dumped on the ground or stored in ponds, cesspools, latrines or septic tanks. Others stagnate on public roads and in low-lying areas. Still others are evacuated by tanker trucks or into the urban network, or reused raw or recycled in urban agriculture. Better wastewater treatment is essential to guarantee the health of human beings and ecosystems, as well as fishery resources on the Atlantic Ocean to the west of the city of Nouakchott.

Many costly techniques can be used to purify non-conventional water, but there is a need for simple, economically competitive techniques that can preserve the characteristics of ecosystems, such as the application of phytodepuration in wastewater treatment. Phyto-purification is an operation that consists in purifying water, i.e. ridding it of pollutants. It relies on natural processes, of biotic and/or abiotic origin, set in motion by plants, microorganisms in the rhizosphere and the substrate in which they evolve, a wide variety of floating, emergent or submerged aquatic plants, grouped here under the generic term "macrophytes", can be used for phytodepuration, both for their direct and indirect roles (Guittonny-Philippe, 2014).

With this in mind, we have experimented with the treatment of loaded domestic wastewater such as that received by the Nouakchott lift station. The aim of the present study is to test the purification capacity of the Typha plant, a macrophyte with purification potential and contaminant absorption capacity. To ensure the elimination of chemical oxygen demand. Five-day biological oxygen demand, organic matter and nutrients from wastewater by the local aquatic plant. And to highlight its potential for purifying wastewater taken from a spring.

In Mauritania, the field of purification by macrophyte planted filters, or Phyto purification of urban wastewater, is still under development, but no plant of this type has yet been built. That's why we decided to look into the question of testing the purifying power of to eliminate organic pollutants. Our hypotheses are as follows: the first is to evaluate the purifying power of a plant as a function of the substrate used; the second is to identify the effect of substrate on purifying power.

MATERIALS AND METHODS

Experimental devices

The experimental devices consist of three cylindrical drums with a capacity of 200 L, a diameter of 0.54 m and a height of 0.90 m (Figure 1). Each filter is fitted with a pipe at the bottom, preceded by a valve to regulate the flow rate discharged. The 0.9 m height of the filters enabled the material to be lined to a height of 0.7 m.

Composition of flowerbeds

Two filters are filled with layers of gravel in decreasing succession, from the largest diameter at the bottom to the smallest diameter at the top of sand (Figure 2). Sampling was carried out over a five-month period. The filters were prepared with the aim of first assessing the purifying power of the plants. Two filters are filled with gravel (transition layer and drainage), with a sand filtration layer. The water level was maintained at 20 cm above the substrate surface (Table 1). And an unplanted control tank.

Gravel

Gravel is used to prevent the soil from piling up at the bottom of the troughs, which can lead to root asphyxiation due to excess water, disrupting the development and normal physiological

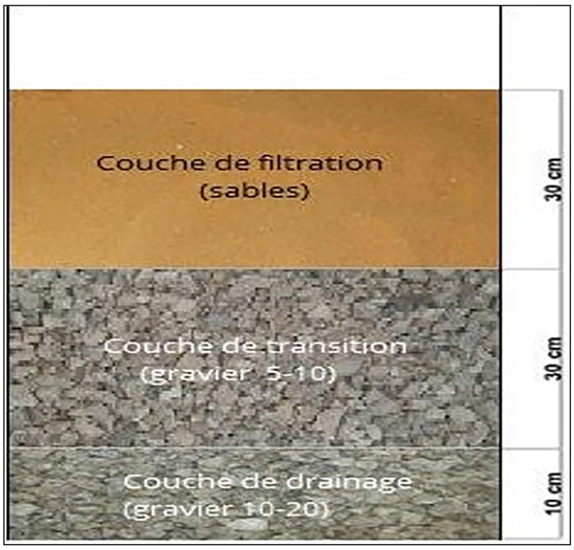

Figure 2. Substrate arrangement in test filters

Figure 1. Pilote view

Table 1. Characteristics of substrate layer

Libelle	Diameter (mm)	Height (cm)	Volume (m)^3
Layer (1) filtration	Sand 0.04 to 0.08	30	0.18
Layer (2) transition	5/10 gravel	30	0.18
Layer (3) drainage	Gravel 10/ 20	10	0.06

functioning of the plants (Tiglyene et al., 2005). The gravel serves as a support for the development of aerobic micro-organisms and also facilitates drainage in the event of emptying.

Sand

Because of its particle size, soil has an obvious role to play in filtering the suspended solids present in wastewater. Its effectiveness in this role depends to a large extent on the texture of the material, which is approached through its granulometry, and which has a particular influence on the hydrodynamic characteristics of hydraulic conductivity in saturated or unsaturated media (AERMC, 1999).

Source of domestic wastewater

The pilots are fed under the same conditions with domestic wastewater from the Office National de l'Assainissement's PR no. 1 pumping station, which collects wastewater from the residential area in downtown Nouakchott. The filters were planted with young Typha macrophytes one month beforehand. After an adaptation period of one month, during which the plants were well developed, the filters were filled with raw domestic wastewater. Experimental measurements were carried out from February to June 2024. Macrophyte establishment was by rhizome transplantation, with four plants per filter in an area of 0.159043 m². Rhizomes taken from peripheral sites colonized by Typha. The roots and rhizomes provide a large soil-wastewater contact surface, whose root development increases the fixation surface for the development of micro-organisms and for precipitation reactions (AETMC, 2005). These roots produce exudates that are toxic to pathogenic bacteria (Bensmina et al., 2010).

Speed and hydraulic load rate

Domestic wastewater is drawn from a 5m-deep concrete discharge tank through a pump delivering 8 m water column at a flow rate of 30 l/min, and then discharged into a control tank, where the domestic wastewater flows to the planted filters. The control tank ensures gravity flow to the planted filters and fills them with the same domestic wastewater. The continuous flow rate is 9540 l/min, the intermittent flow rate is 1.191 approx. 2 l/min, and the hydraulic loading rate is approx. 32 $L \cdot m^{-2} \cdot J^{-1}$. These filters ensure a retention time of three to five days and provide an initial reduction in BOD_5 and TSS, as well as polishing the various parameters in general.

Typha plant

Typha, commonly known as cattail, is a member of the Typhaceae family (Figure 3). Stem height varies from 100 to 270 cm, and leaf size from 6 to 25 mm. With no scent or nectar, they are described as linear, with staminate spikes and summer flowering. They originate in temperate and warm regions of both hemispheres, and can be found in Europe, Asia, America and Africa (Figure 4). They colonize marshes and shores saturated with fresh water. Indeed, they cannot tolerate brackish water and prefer a neutral pH (Gagnon, 2012). These plants produce a lot of biomass, and their long stems ensure oxygenation of the substrate. They form a network that retains debris and builds soil, thus reducing erosion (Figure 1). Their leaves are designed to reduce wind and, consequently, evapotranspiration.

Sample collection and analysis

A weekly sample of urban wastewater was taken for analysis. For the hydraulic load, an average 7-day sample was taken at the pilot outlets, and the following parameters were analyzed: COD, BOD_5, suspended solids (SS), $PO4^{-3}$, pH and Kjeldahl nitrogen (NTK). COD is determined by oxidation with potassium dichromate in an acid medium. The absorbance value is read spectrophotometrically. BOD5 is determined by the manometric method using Oxitop manometers;

TSS is obtained by vacuum filtration on a GF/C glass microfiber filter. Phosphorus concentration is determined using a spectrophotometer. Kjeldahl nitrogen is determined after mineralization of organic matter in an acid medium and in the presence of a catalyst. pH was measured directly using a pH-electrometer (Table 2).

RESULTS AND DISCUSSION

Pilot purification performance

Treatment performance was assessed on the basis of reductions in the various parameters between the filter outlet and inlet. Abatements were calculated according to the following formula:

$$(\%) = CE - CS\ CE \times 100 = 100\ CS/CE \times 100 \quad (1)$$

where: CE – average pollution concentration at filter inlet, CS – average pollution concentration at filter outlet.

Evolution of chemical oxygen demand COD

The COD load of treated wastewater fluctuates considerably between 35 mg/l and 223 mg/l, with maximum values recorded in June and minimum in February (Figure 5). These COD values recorded for treated wastewater are considerably lower than those for raw water (223 mg/l and 309 mg/l). These results are lower than those confirmed by (Ababsa et al., 2020). The COD values recorded exceed WHO standards for treated

Figure 3. Illustration of an emerging Typhaceae plant

Figure 4. Experimental area for phytodepuration

Table 2. Physical-chemical characteristics of input parameter (E) and output parameter (S)

Parameter	Input parameters (E)						Output parameters (S)					
	BOD5 mg/l (E)	COD mg/l (E)	MES mg/l (E)	Nitrogen mg/l (E)	PO_4^{-3} mg/l (E)	pH (E)	BOD_5 mg/l (S)	COD mg/l (S)	MES mg/l (S)	Nitrogen mg/l (S)	PO_4^{-3} mg/l (S)	pH (S)
February	227	309	286	496	94	7.8	33	48.5	33	116	34	7.8
March	219.5	283	190	132.5	67	7.5	26	35	50.5	49	48.5	7.9
April	108.5	186	157.5	86	58.5	7.66	63	89	48	39.5	35.5	7.7
May	74	194.5	472	73	88	7.5	36.5	194.5	135	73	24	7.5
June	120	223	296	50	31.5		120	223	176	50	31.5	
Min	74.0	186.0	157.5	50.0	31.5	7.5	26.0	35.0	33.0	39.5	24.0	7.5
Max	227.0	309.0	472.0	496.0	94.0	7.8	120.0	223.0	176.0	116.0	48.5	7.9
Moyenn	149.8	239.1	280.3	167.5	67.8	7.6	55.7	118.0	88.5	65.5	34.7	7.7
Standard deviation	69.2	54.5	122.7	186.1	25.0	0.1	38.6	85.8	63.2	30.8	8.9	0.2
Variance	4789.3	2970.3	15065.5	34629.0	624.8	0.0	1488.5	7359.4	3995.8	948.8	79.1	0.0
Skewness	0.3	0.5	1.0	2.1	-0.6	0.7	1.6	0.4	0.8	1.5	0.8	-0.8
Kurtosis	-2.8	-2.4	1.1	4.5	-0.4	-1.9	2.3	-2.8	-1.9	1.9	1.9	0.3

water < 90 mg/l. This wastewater treatment technique ensures a COD removal rate of 12.36% in March and 47.84% in April.

Evolution of biochemical oxygen demand BOD_5

Biological oxygen demand (BOD) values for treated wastewater$_5$ range from 26 to 120 mg/l. Maximum values are recorded in June at the filter inlet, while minimum values are recorded in June at the filter outlet (Figure 6). The reduction in BOD_5 values observed at the filter outlet may be due to the degradation of organic matter by purifying microorganisms (Kahim and Idabdallah, 2013). The BOD treatment efficiency$_5$ was lower, with carbonaceous pollution removal reaching a maximum of 58.06% in April, and a minimum of 11.84% in March. These results are not comparable with the efficiencies observed by (Laabassi et al., 2016), and the BOD values$_5$ recorded remain not far off. The value recorded in February is below WHO standards < 30 mg/l.

Trends in COD / BOD_5 ratios

The measured COD/BOD5 ratio of 1.60 indicates that the wastewater discharged is of purely domestic origin. As a result, the natural lagoon treatment system can easily be adopted as a suitable solution for wastewater treatment in the study area.

Trends in suspended solids

TSS concentration values obtained at the wastewater inlet are obviously high, with a concentration of 472 mg/l recorded for the month of April, and in contrast to the filter outlet 33 mg/l in the month of January (Figure 7). The TSS

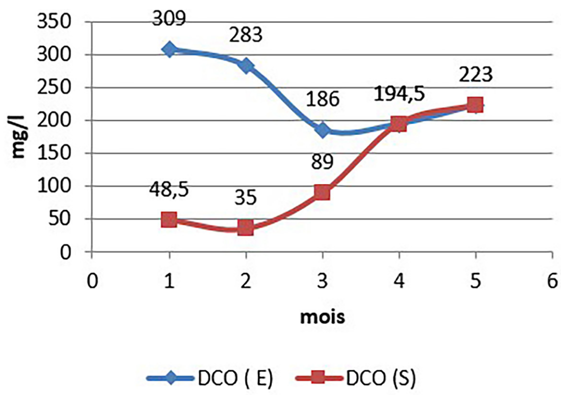

Figure 5. Variation in COD values

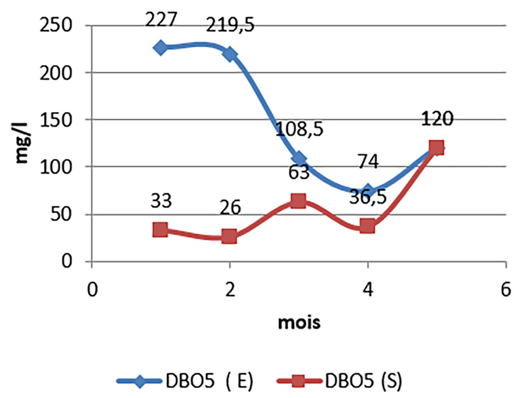

Figure 6. Variation in BOD_5 values

removal rate is 11.53% in January and 59.45% in June, a result similar to that found by (Chennafi et al., 2018). The values recorded exceed WHO standards for treated water < 20 mg/l.

Nitrogen evolution

Raw water is characterized by high ammonium concentrations, with a maximum value of 496 mg/l recorded in January. Ammonium values vary between 49 mg/l and 496 mg/l for raw water, and between 39.5 mg/l and 116 mg/l for treated water (Figure 8). Ammonium purification efficiency reached a high of 45.93% in April, with the remainder below 45.73% and a low of 23.38% in January. The decrease in ammonium content in treated water is due to the assimilation of ammonium by algal photosynthesis following the eutrophication phenomenon that follows self-purification once the ecosystem is enriched in carbon dioxide, ammonium ion and phosphates (Bennabou et al., 2014). These recorded values exceed WHO standards for treated water < 0.5 mg/l.

Evolution of ortho-phosphates P-PO4

Phosphorus concentration values range from 24 mg/l to 48.5 mg/l for treated water, with concentrations decreasing from inlet to outlet, and varying with time (Figure 9). The overall purification efficiency of phosphorus removal rates peaks at 72.36% in March. The high phosphorus removal efficiency can be explained by a biological dephosphorization phenomenon. High levels of bio-available phosphorus can lead to excessive growth of algae and aquatic plants, resulting in eutrophication (Bernier et al., 2001). They could also be due to the direct use of P-PO4 by plants (Urbanc-Bercic and Gabercci, 2004). These results are similar to those reported by (Mergheme

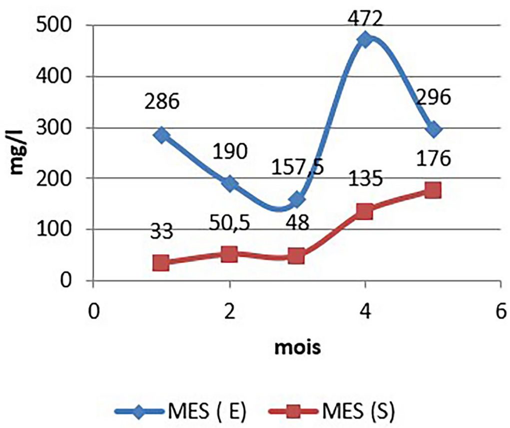

Figure 7. Variation in TSS values

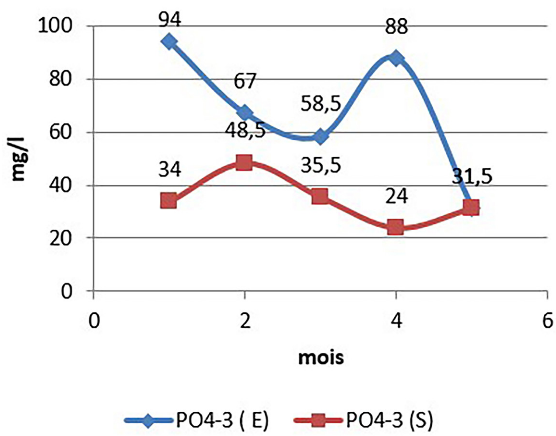

Figure 9. Variation in orthophosphate

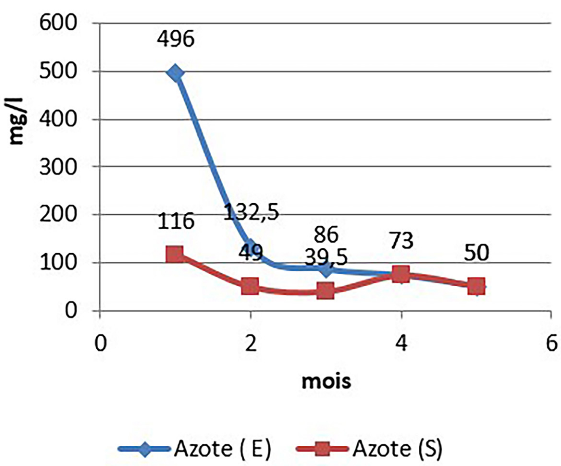

Figure 8. Variation in nitrogen values

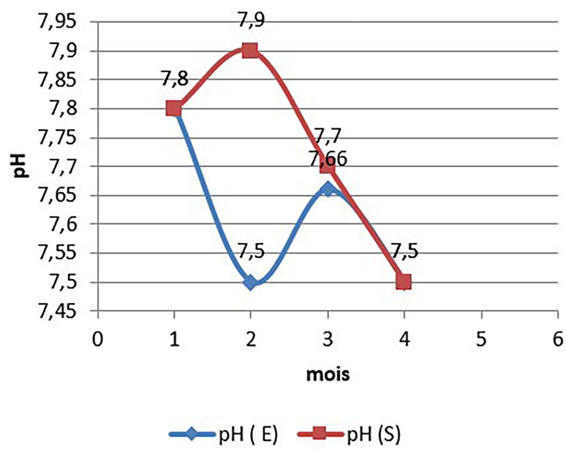

Figure 10. Variation in pH values

et al., 2016). These recorded values exceed WHO standards for treated water < 2 mg/l.

Hydrogen potential

The results shown in Figure 10 reveal that the extreme minimum and maximum pH values are 7.5 and 7.9 respectively. This indicates alkalinity in the wastewater. This is likely to favor the bacterial growth necessary for the biological degradation of organic pollutants (Maiga et al., 2006). Most organisms cannot tolerate a pH above 9.5 or below 4 (Raweh, 2011). Similar results were revealed by (García et al., 2017) and (Chennafi et al., 2018).

CONCLUSIONS

In our study, we developed experimental macrophyte systems for wastewater treatment. This process appears advantageous; less costly, simpler to operate than other treatment systems and environmentally friendly, it constitutes a credible alternative with a contribution to wastewater treatment in small and medium-sized agglomerations of less than 100.000 inhabitants (case of a district in Nouakchott).

This process uses Typha australis-type phytopurifiers to treat wastewater. The roots of these macrophytes support microorganisms capable of degrading organic matter and nitrifying ammoniacal nitrogen. The main objective of this study is to evaluate the purification performance of domestic wastewater from this district using the phyto purification technique.

Results for the main physico-chemical indicators, such as Kjeldahl nitrogen and P-PO_4, revealed very low values. On the other hand, lower purification yields were observed for TSS, BOD_5, COD and phosphates, but the values for the latter parameters were higher than WHO standards for treated water. Our results suggest that this process has succeeded in reducing the quantity of pollutants to low values, thereby minimizing the risk to the receiving environment.

The present study calls for continuity and monitoring throughout the four seasons of the year. It also opens the way for work on:

- Identification of all types of microorganisms, protozoa, metazoa, viruses, etc.;
- To know the effect and role of each bacterium detected in this study in phytodepuration;
- Test the performance of other plants and ornamental premises in purifying wastewater of all kinds.

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