Assessment of the Life Cycle Environmental Impact of Sewage Sludge from Treatment Plant in the City of Saida – Algeria Based on Deep Learning Algorithms

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Abstract
The present study is part of the environmental analysis of the wastewater treatment sector and the production of sludge in the wastewater treatment plant that is located in the small town of Rebahia in the Wilaya (Province) of Saida in Algeria using the Life Cycle Analysis which is a practical tool for the global and multi-criteria assessment of the environmental impacts.the physicochemical analysis of the wastewater revealed the existence of a high concentrations of chemical oxygen demand (COD = 483.42), suspended matter (SM = 229.01) and 5-day biochemical oxygen demand (BOD5 = 290.56). These data clearly show that the sludge from urban wastewater treatment is loaded with pollutants. Indeed, the results of the leaching test conducted on this slurry indicate that it is rich in phosphates, heavy metals, and sulphates. These pollutants, contained in the sludge under study, were found to have negative impacts on the environment. Finally, this study made it possible to identify the main sources of pollution and those, which respect the environment, using inventory data, the deep learning model was used to predict some study data.
Keywords: Wastewater treatment plant; Sludge; Life cycle analysis; Technical landfill center, deep learning model

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1. Introduction

It is widely acknowledged that global environmental problems, such as climate change, destruction of the ozone layer, acid rain, decrease in biodiversity or even desertification, are characterized by a global dimension with increasing uncertainty about their development and consequences [1]. With the growing awareness of the authorities for these environmental issues in recent years, the urgent integration of environmental management into industrial practices has become increasingly important. For all these reasons, over the last few years, various environmental assessment tools, such as the environmental risk analysis (ERA), material flow analysis (MFA), ecological footprint (EF), and others, have developed. Indeed, these tools turned out to be very helpful to actors in the public and private sector as they can provide them with the answers they need in their decision-making process. The life cycle analysis (LCA), which is increasingly used by private industry and the public sector, is one of these multiple tools [2].

Furthermore, it is widely acknowledged more developed knowledge is needed today in order to have a better overview of environmental problems, in particular those having impacts related to the composition, manufacture, use and end of life of products. Industries must therefore integrate the environmental requirements with the prerequisites of product design and production, such as costs, customer expectations, technical feasibility, etc. For this, it is highly recommended to take into consideration the environmental issue throughout the design phase of products (goods or services) while taking into account its entire life cycle. This process is called eco-design [3]. This strategy denotes the desire to design products while respecting the principles of sustainable development and the environment. According to the Environment and Sustainable Development Virtual University, eco-design is currently viewed as a booming process; it represents a real lever for innovation and eliminates the boundaries between technology and ecology [4]. Note also that the life cycle analysis (LCA) was developed as one of the main objectives of eco-design. Indeed, today, LCA has become a valuable tool for studying the environmental profile of a product.

At the Johannesburg conference, which was held in June 2002, the life cycle analysis (LCA) was mentioned in a report by the World Summit on Sustainable Development (WSSD) which confirmed that environmental quality should be viewed as one of the pillars of sustainable development [3]. Finally, following the Cancun negotiations in China (2010), many initiatives were proposed and decisionswere taken on climate change, particularly the one related to reducing greenhouse gas emissions by 20%. Other decisions were alsoadopted regarding the environmental considerations within companies [3]. As such, Figure 1 illustrates the most important and significant stages of life cycle analysis (LCA) development [5].

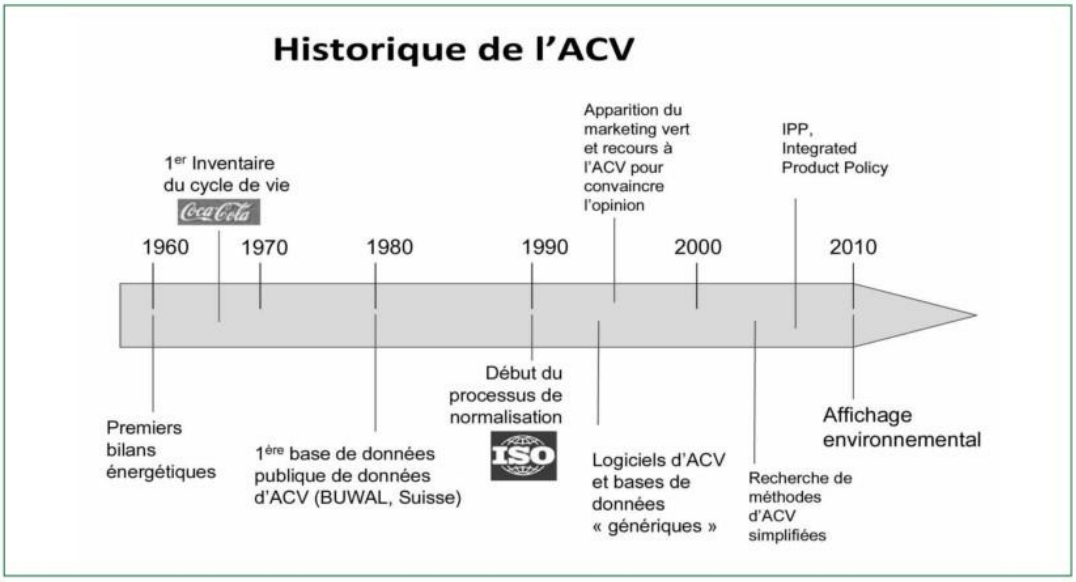

Figure 1: History of Life Cycle Assessment [6].

Life cycle analysis (LCA) is a very comprehensive process, in particular because the product or service under consideration includes all the stages necessary for its design, i.e. from the raw material extraction to the end of life of the product or service. Adopting this method will push us to study a wide range of environmental impacts linked to inputs from the environment, such as resource extraction, and to outputs emitted into the environment, such as gas emissions into the air, water and soil [7].

Life cycle analysis (LCA) has already been used by several authors in order to know the environmental impacts of the numerous sludge treatment and recovery channels. The comparison of the studies carried out by these authors is often complicated due to the discrepancies that exist between the different methodologies applied,and also between the definitions of the boundaries that could exist between the system and the functional unit. The analysis of these different publications made it possible to establish a number of methodological peculiarities that are related to the life cycle analysis (LCA) and to the end of life of a product as well. Both of these tools need to be explored further. In this context, only four studies, i.e. Arthur [8], Suh [9], Houillon [10], and Hospido [11], could therefore be compared quite easily since they all focused on the same systems, and also used the same functional units. In this regard, this study aims to assess the impacts of wastewater treatment and sludge recovery from wastewater treatment on the environmental quality of wastewater treatment plants, using the life cycle analysis (LCA) tool while adopting the balance sheet principle.[12]

The deep learning model (LSTM) was used to predict data of Characterization of thickened sludge for the year 2017 to 2018. [13, 14]

2. Life cycle analysis of urban sewage sludge in the town of Saida

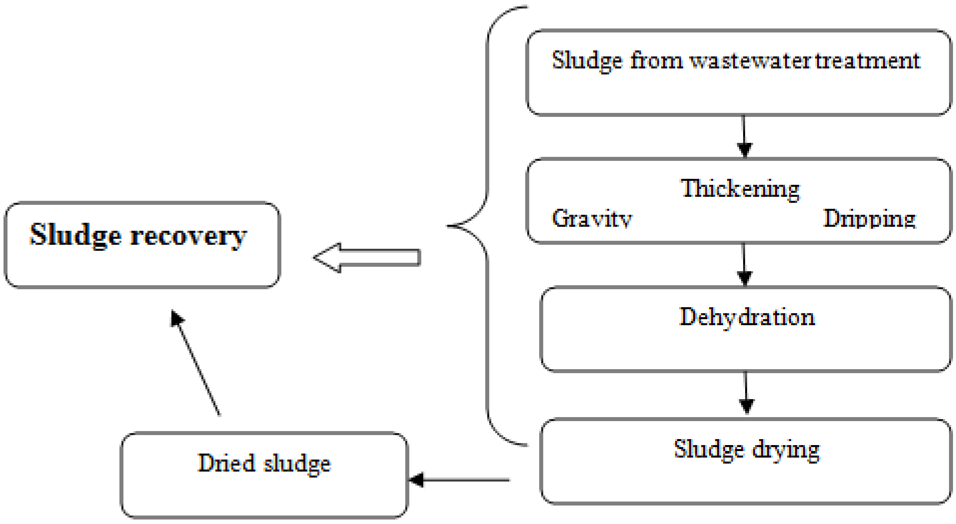

Figure 2: Boundary of the studied system

3. Carrying out the life cycle inventory

The inventory analysis is the longest step in alife cycle analysis applied to sludge treatment processes. Indeed, this phase involves the compilation and quantification of inputs and outputs for a given system during its life cycle. In other words, it is a census of flows. In addition, the quality of the life cycle assessment (LCA) results depends on the quality of the inventory data. Moreover, this phase consists in carrying out the balances of the flows entering and leaving the system under study. It is worth specifying that the data were provided by the wastewater treatment plant (WWTP) of Rebahia (Wilaya of Saida) for the years 2017 and 2018. In addition, the results of sludge analysis for the past five yearswere also collected.

3.1. Characterization of the sludge produced

a) Determination of the chemical composition of sludge

Sludge management has become more and more directed towards recovery and valorization while respecting the technical, environmental and economic criteria. It should be noted that sludge recovery can be of interest in several areas, depending on its characteristics. The chemical composition of the sludge used in this work is given from the year 2014 until the year 2018.

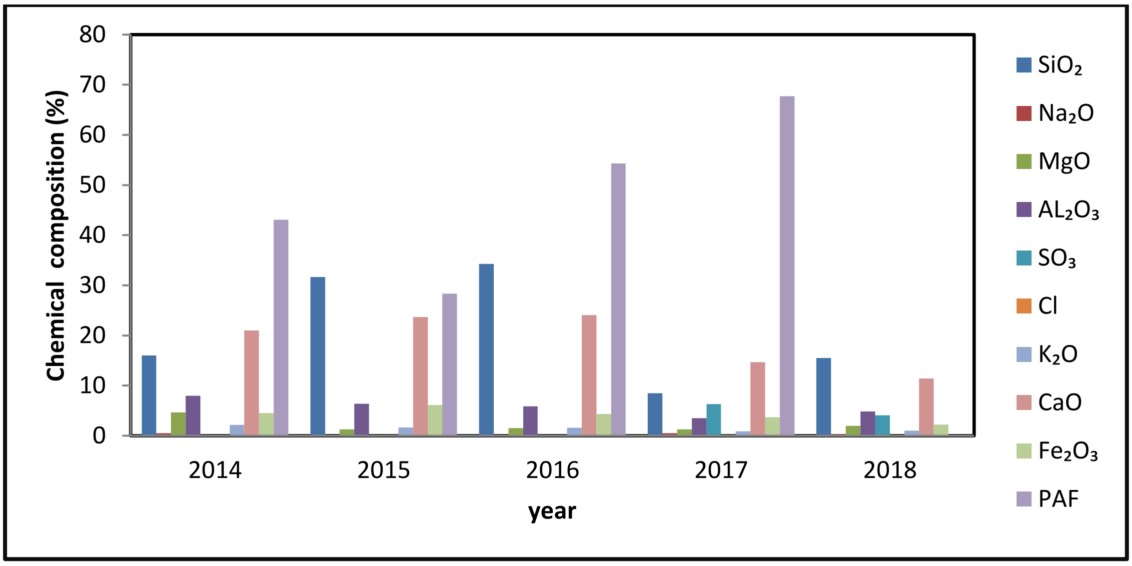

Figure 3: Chemical composition of the sludge from the wastewater treatment plant of Rebahia in Saida.

From the results obtained, it was noticed that the studied sludge exhibited a fairly high loss on ignition (LOI) value, which means that this sludge contains a high percentage of organic matter. In addition, the amount of lime (calcium oxide - CaO) was found to be greater in comparison with other oxides. This lime can be in the form of carbonates considering the high loss on ignition rate.

On the other hand, the sludge was found to contain silica (SiO_2), sulfur trioxide (SO_3), alumina (Al_2O_3) as well as ferric oxide (Fe_2O_3).

Furthermore, the presence of alkalis was noted, but in negligible quantities. The same observation was made for halogens. In addition, it was found that the sludge possessed a fairly large mineral fraction.

b. Heavy metal analysis

The heavy metal analysis bulletin was provided to us by the Quality Control Laboratory at the wastewater treatment plant (WWTP) of Rebahiain Saida. However, for the year 2018, the analyses were carried out at the Laboratory for Inorganic Chemistry and Environment, at the University of Tlemcen. The different concentrations of heavy metals present in the sludge are reported in Figure 4 [15, 16].

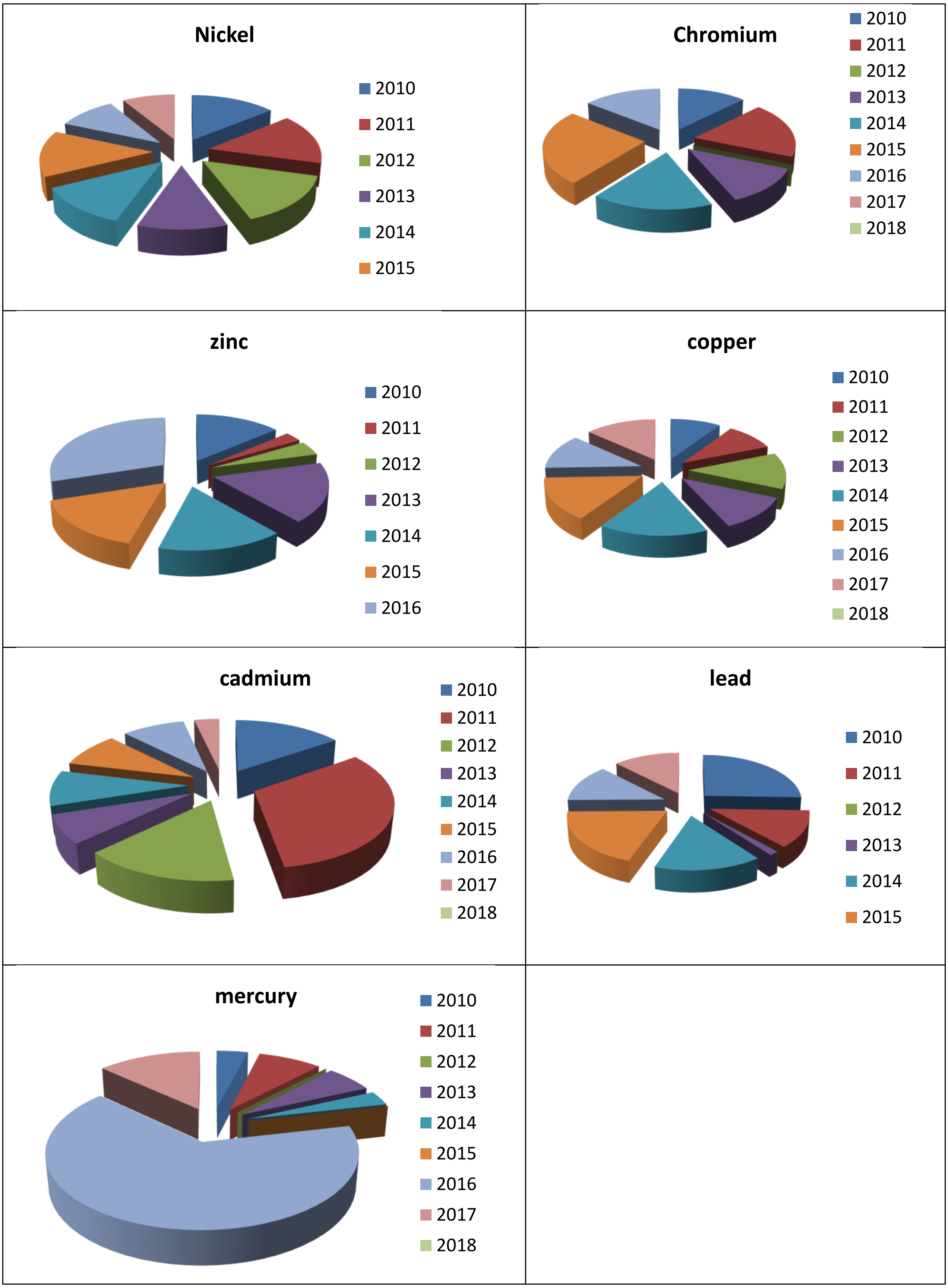

Figure 4: Concentrations of various heavy metals present in the sludge from the wastewater

treatment plant in Rebahia (Saida)

Figure 4 presents separately the levels of the different heavy metals that are predominant in the sludge, based on the data provided to us. The sludge analysis results comply with the applied standards. It was found that the sludge under study generally contained quite significant lead concentrations. In the soil, lead is adsorbed in the form of hydroxides and carbonates [17].

c) Characterization of thickened sludge

Most sludge treatment circuits begin with the thickening step which improves the digestion efficiency (if provided) and reduces the capital, stabilization and dewatering costs. In addition, this step also makes it possible to reduce the volume of sludge to be disposed of, and also to favor the economy of the dehydration systems. Therefore, techniques such as the decantation or the gravity thickening can then be used. The thickened sludge characterization analysis report was provided to us by the quality control laboratory of the WWTP of Rebahia,for the period from 2017 to 2018. Figures 5 and 6 show the characteristics of the thickened sludge, during these two years.

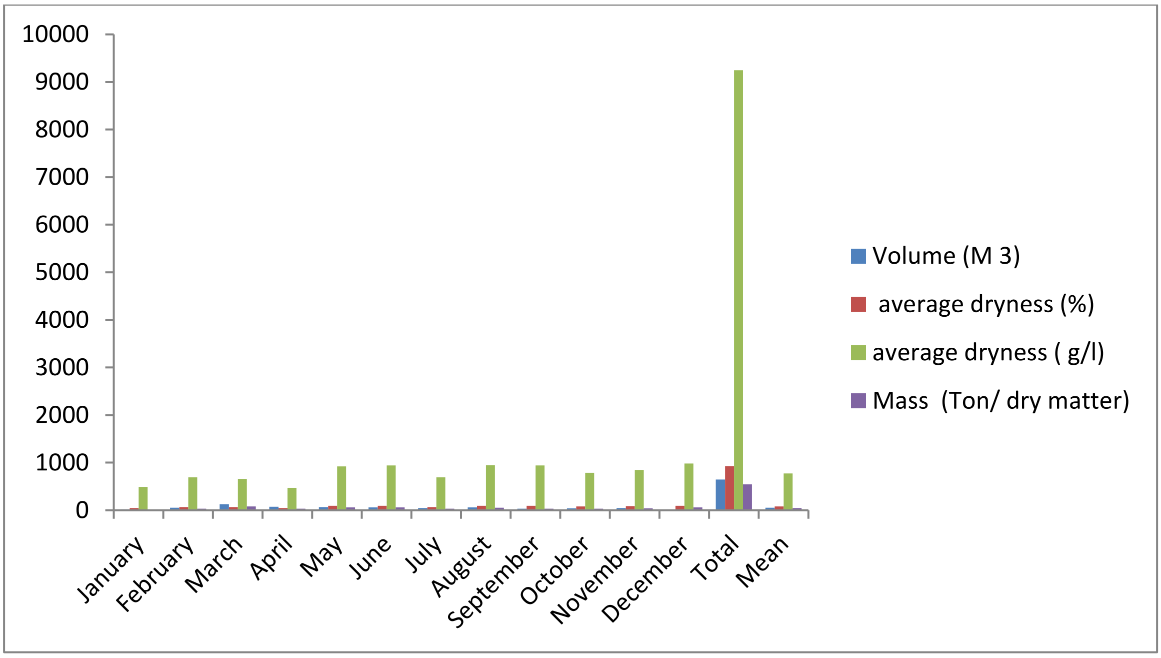

Figure 5: Characterization of thickened sludge for the year 2017

According to the results of the year 2017, the volume of sludge produced was significantly higher in the month of March. It was also noticed that there is a difference between the values recorded during the month of December (minimum value 10m^3/month) and those of the month of March (maximum value 127m^3/month), which allows concluding that the high volume of sludge produced was certainly due to the fact that the water entering the WWTP during that period was highly polluted.

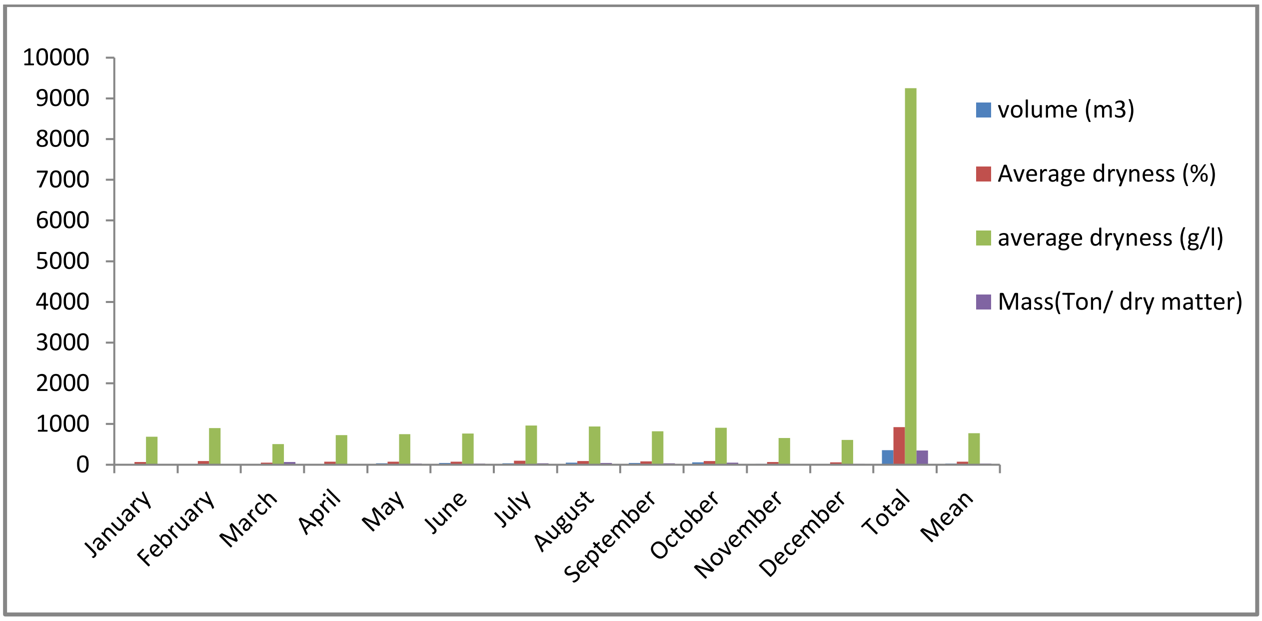

Figure 6: Characterization of thickened sludge during the year 2018

Furthermore, the results obtained allow noting that the average dryness measured was 96% (in the month of July), and the extreme values were, 51% as a minimum value (in the month of March), and 96% as the maximum value (in the month of July). This leads us to conclude that the dryness value of sludge in winter was lower than those recorded in other seasons. This can certainly be attributed to the fact that the sludge in winter gets wet from rain and cold water.
On the other hand, in summer, the dryness value was quite high, even maximum. This was probably due to the high temperatures and the absence of rainwater. These two elements induce a high dryness value.
A simple comparison between the two figures allows us to conclude that the mean value is convergent. In addition, it should be known that most sludge processing circuits start with a thickening step that allows improving the digestion efficiency, reducing the investment costs, and also decreasing the volume of sludge to be taken care of.The sample analysis results indicate that the station of Rebahia (Saida) is highly efficient in treating polluted wastewater; it is characterized by a verygood purification performance.

3.2. Electricity consumption at thewastewater treatment plant of Rebahia

The table below shows the data on the electricity consumption at thewastewater treatment plant of Rebahia in Saida, for the years 2017 and 2018 (according to the invoices of the National Electricity and Gas Company).

Table 1: Electricity consumption at the WWTP of Rebahia

Year	consumptionKwh /year
2017	1628097
2018	1442263

By way of comparison, it is noted that the electricity consumption during the year 2017 was higher than that of the following year 2018

3.3. Evaluation of the energy consumption data relating to the transport of sludge between the wastewater treatment plant and the technical landfill center

In order to assess the impact of sludge transport on the monitoring of the system under study, it was decided to estimate the distance separating the wastewater treatment plant (WWTP) from the technical landfill center (TLC) that is located in Ben-Adouane, a small town in the Wilaya de Saida. This distance is approximately 12 km. The sludge was transported using a Renault brand dump truck. It is also worth specifying that the quantities of sludge transported during the years 2017 and 2018 were similar and equal to 20 tons. However,the number of sludge waste transport trips made in 2018 was smaller than that of 2017 .

Table 2: Transportation data of sludge wastes from the WWTP to the technical landfill center for the year 2017

Product transported	Quantity Ton / year	Quantity of dried sludge delivered by transport in ton	Number of transports / year	Calculation in Tons. Km
Driedsludge(year2017)	300	20	15	240
Driedsludge (year 2018)	100	20	5	240

The results obtained show that the quantity of sludge that entered the technical landfill center in 2017 was three times higher than that of 2018. The transport distance (12 km) is very close to that used in the study conducted by Arthur Andersen [8]. In addition, it should be mentioned that transport activities and transportation systems have significant environmental impacts ranging from air pollution, dispersion of toxic substances in the air, and acidification.

4. Life cycle impact assessment [18-20]

It is widely admitted that impact may be defined as the direct action of a source system on a target system. The source system considered here is the human activity. The target system is any component of the environment (human, fauna, flora and ecosystem).

The methods used for the evaluation of the potential impacts in life cycle analysis (LCA) services are traditionally applied according to the results of the inventory. The 5-day biochemical oxygen demand (BOD_5) of the stored sludge can be calculated. The results obtained are collated in Table 3 given below.

Table 3: BOD_5 contents of stored sludge

year	BOD_5 of raw water entering(mg/lO_2)	DBO_5 ofstored sludge(mg/lO_2)
2017	3392.56	339.256
2018	3581	358.1

The table explicitly shows that the sludge produced is rich in biodegradable organic matter, whichis confirmed by the value of the estimated biochemical oxygen demand (BOD). Regarding the emission of methane from sludge, and according to the inventory data, the stored sludge poses a risk of greenhouse gas emissions, as it is rich in easily biodegradable organic matter.

4.1. Assessment of the different impacts selected

Based on the inventory analysis and the collected data, the following assumptions could be made:

a) Impact on the areacovered with sludge

According to the data provided by thewastewater treatment plant of Saida, the quantities of dried sludge (in tons)that were sent to the storage center were significant.

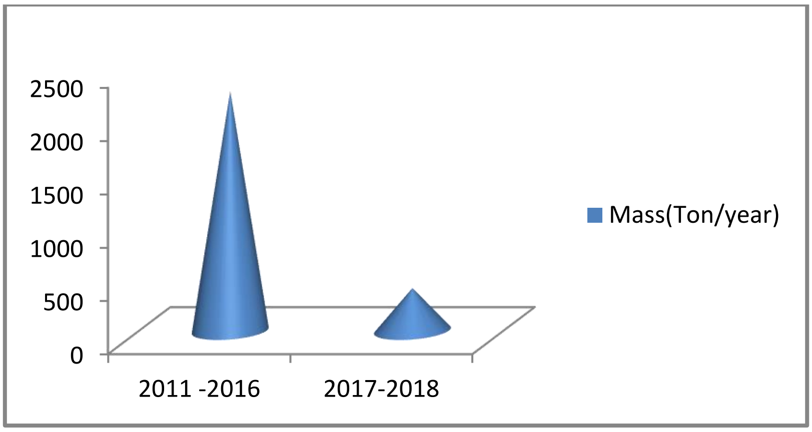

Figure 7: Presentation of the quantities of sludge produced by the wastewater treatment plant of Saida

Furthermore, it is worth indicating that according to information from the above mentioned wastewater treatment plant, the sludge stored in the WWTP is distributed over 20 drying beds,of dimensions (30 x 15) m, with a thickness of 30 cm. Note also that the sludge evacuated to the technical landfill center(TLC) is not taken into account.

Based on these data, one mayeasily see that the sludge produced by the WWTP requires considerable space; it also gives off foul odors and emits greenhouse gases.

b) Estimation of toxicity - Impact of incoming and outgoing flows

The sludge under studyresults from the treatment of wastewater from the wastewater treatment plant (WWTP) of the town of Saida. Examination of the incoming and outgoing flows of this wastewater and the analysis of parameters, such as the chemical oxygen demand (COD), biochemical oxygen demand (BOD), and suspended matter (SM), indicate that the treated wastewater is relatively biodegradable, which is confirmed by the low values of the parameters recorded after treatment.

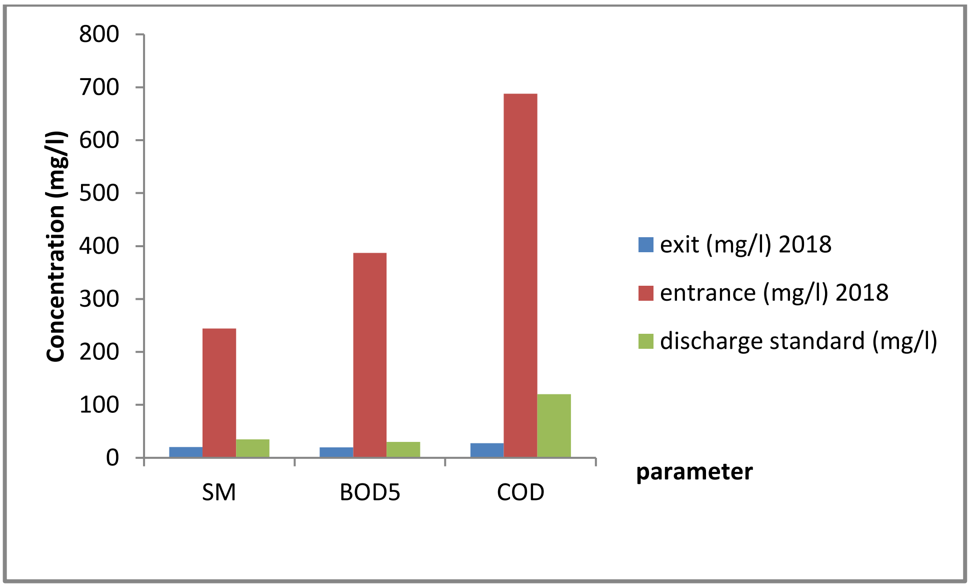

Figure 8: Impact of the flows of water to be treatedduring the year 2018

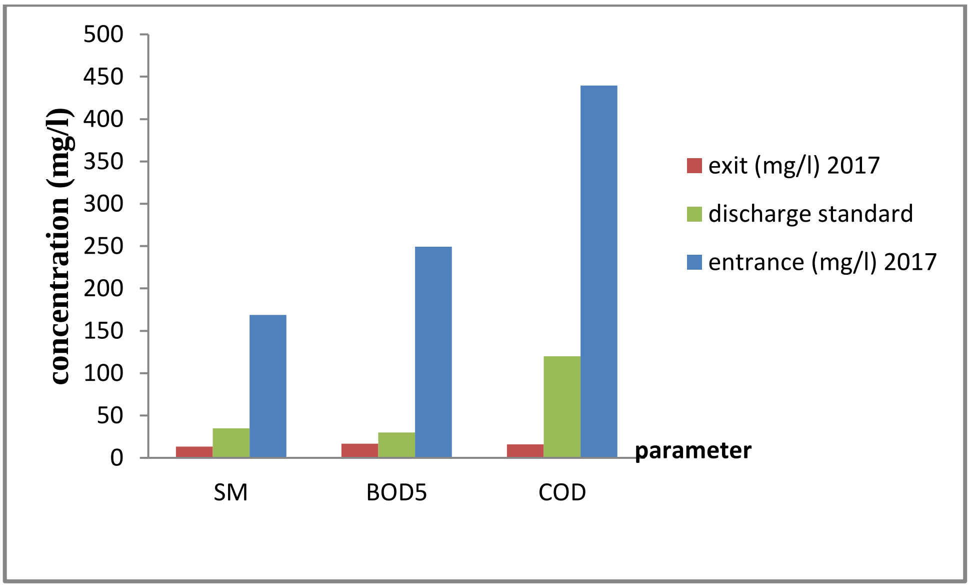

Figure 9: Impact of the flows of water to be treated during the year 2017

c) Estimation of greenhouse gas emissions during the thickening and storage of sludge

The carbon contained in the sludge is of biogenic origin. It can turn into carbon dioxide (CO_2)

and re-enter the natural carbon cycle. These CO_2 emissions are said to be short or biogenic. On the other hand, CH_4 emissions, which result from the transformation of biogenic CO_2, must be taken into account because the global warming potential (GWP) of CH_4 gas is greater than that of CO_2**[20, 21].** In the present case, two types of gas emissions must be considered: direct emissions, which are due to sludge treatment, and indirect emissions, which are attributed to energy consumption, transportation, and fuel used by the machinery.

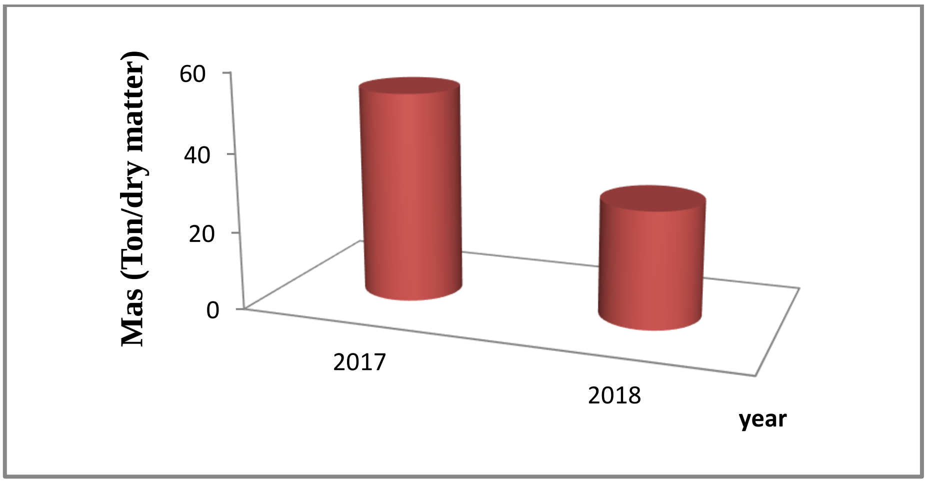

Figure 10: Impact of sludge thickening during wastewater treatment

A simple comparison of the results recorded during the two years 2017 and 2018 shows that the quantity of sludge produced in 2017 was significantly greater. This means that the wastewater entering the WWTP during that year was more polluted.

It is widely acknowledged that the thick sludge is rich in organic and mineral matter. In the present study, the dryness of the sludge was found to be higher in 2017 than in 2018. It should also be noted that the sludge produced keeps a quite high degree of humidity.

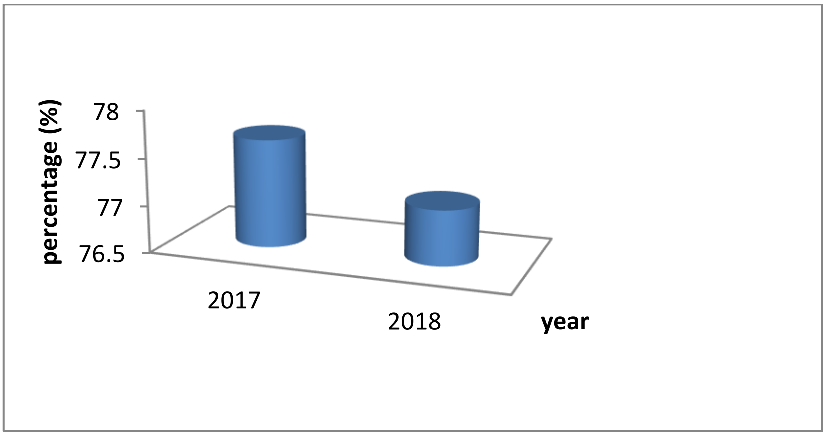

Figure 11: Relationship between greenhouse gas emissions and dryness

d) Energy impact

The sludge life cycle analysis inventory made it possible to quantify the energy consumption. Figure 14 shows that electricity consumption was much lower in 2018 than in 2017, confirming the decrease in indirect emissions of polluting gases.

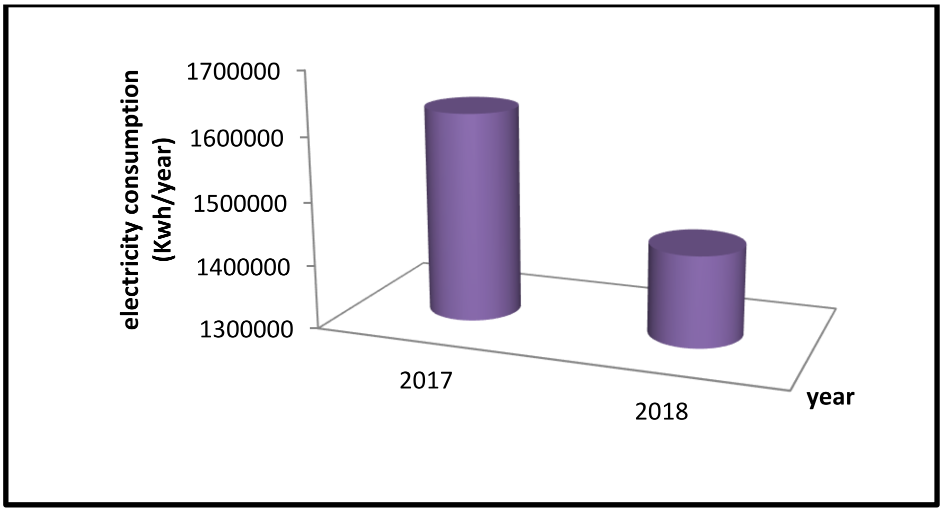

Figure 12: Impact of electricity consumption in the WWTP of Rebahia in the Wilaya of Saida

e) Impact of heavy metals and greenhouse gas emissions when sewage sludge is recovered and valorized through spreading on agricultural land

The ecotoxicity potential risks of sludge during the agricultural spreading process are mainly attributed to the emission of zinc, chromium and lead. As these chemical elements are present in high concentrations, they can be transferred to soils and then to humans. These facts have made the agricultural valorization of sewage sludge strictly prohibited.

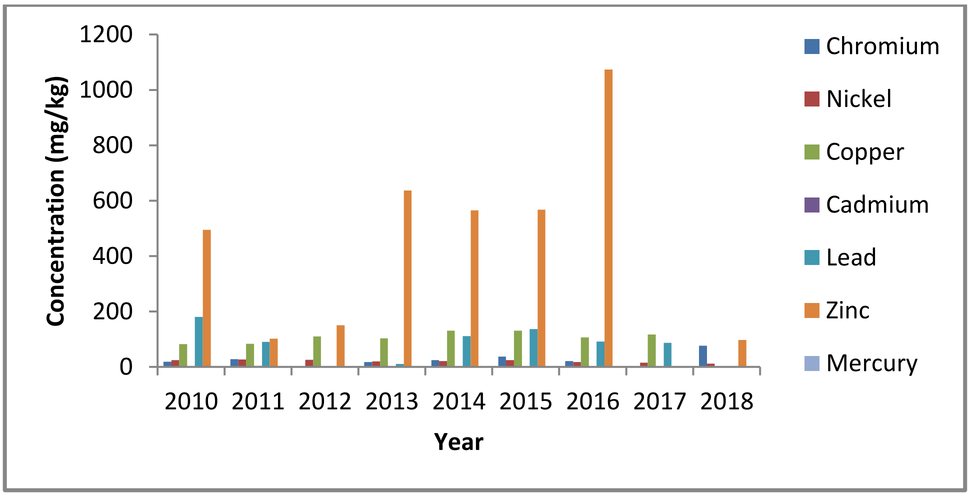

Figure 13: Impact of metallic elements on agricultural valorization

e) Transfer of pollutants contained in sludge

Eutrophication usually occurs simultaneously with acidification. This is a phenomenon that has a negative effect on biodiversity because it is a source of methane. In our study, a quite large quantity of phosphorus is found in the solid sludge, while nitrogen is transformed into ammonium, nitrite and then nitrate, to ultimately pass into the gaseous form and be emitted in the atmosphere.

The phosphate content of sludge is also quite high due to the use of detergents or phosphate detergents, agricultural products (fertilizers), industrial products, human excreta, etc.

In order to effectively take action against eutrophication and acidification, it is necessary to reduce the intake of nutrients containing nitrates (nitrogen) and phosphates (phosphorus) and sulfur compounds.

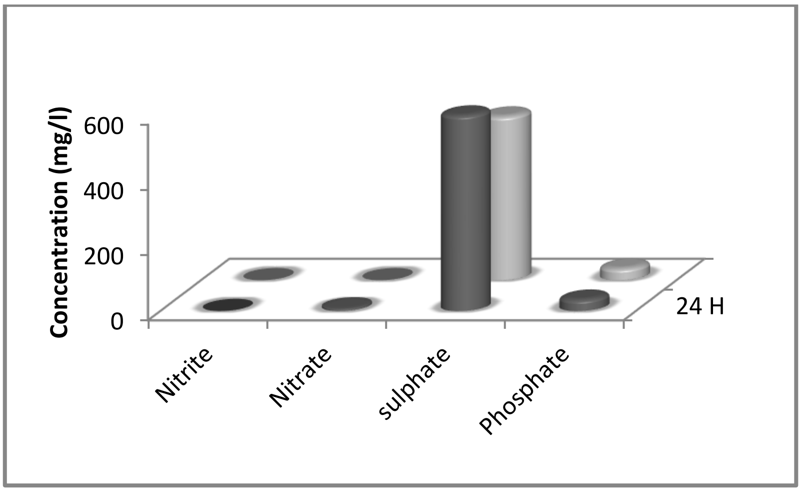

Figure 14: Impacts of pollutants contained in sludge

f) Greenhouse gas emissions during the sludge transferfrom the WWTP to the technical landfill center

The quantity of carbon dioxide emitted into the atmosphere depends on the amount of energy consumed by the machinery and also on the quantity of diesel fuel used up during sludge transportation from the WWTP to the technical landfill center (TLC).

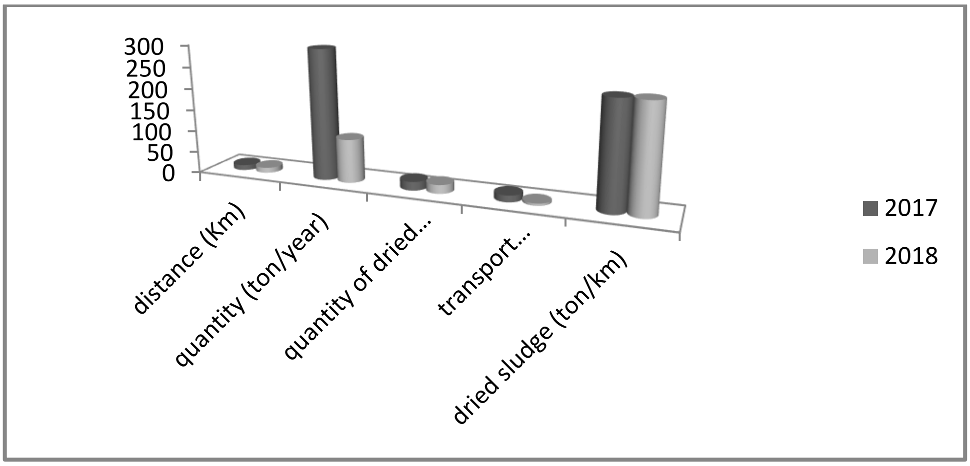

Figure 15: Study of the impact of sludge transportation from the WWTP to the technical landfill center

The findings show that when the quantity of sludge evacuated to the technical landfill center (TLC) decreases, the quantity of greenhouse gases emitted at the TLC level is lower. However, the pathogen risk of sludge treatment remains quite high because the treatment technique is not very suitable due to the decomposition of organic matter contained in the sludge, in addition to the emission of unpleasant odors.

g) Impact of landfilling

The sludge landfilling technique is currently prohibited by the European legislation; however it still remains possible for sludge that cannot be recovered and valorized in the agricultural sector, and which has a dryness percentage greater than 30%. The environmental impact assessment, which is linked to the burial of sludge resulting from wastewater treatment, is quite complicated because this sludge is generally associated with household waste which requires several years to decompose.

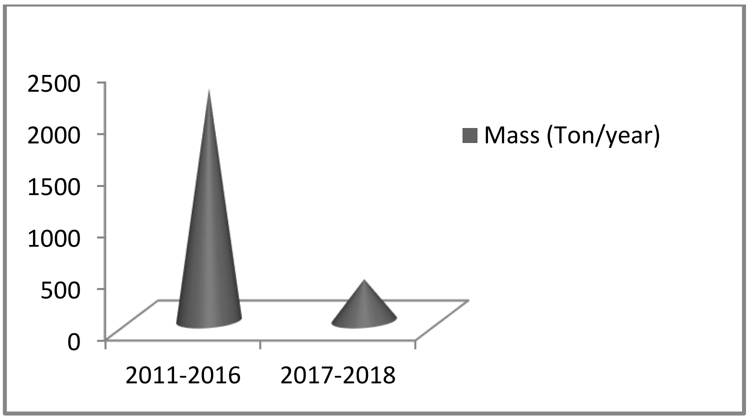

Figure 16: Quantities of sludge transferred from the WWTP to the technical landfill center

According to the data provided by the WWTP of Rebahia in Saida, the quantities of dewatered sludge transported to the waste storage facility arequite high, without taking into account the sludge that remains at the wastewater treatment plant. In addition, whatever the nature of that sludge, its disposal is accompanied by complex phenomena arising from the interactions occurring between the sludge components and the rainwater that infiltrates into the soil. The landfill itself should be seen as a constantly changing environment; it is a site where several physicochemical and biological reactions can take place. The direct consequences of these reactions are, among others, the release of gas and the formation of leachate.

4.2. Deep Learning Model(LSTM) stages

Figure 1 illustrates the stage of LSTM model. First, stage of normalization followed by the process of splitting the data of characterization of thickened sludge during the year from 2017 to 2018. The next step is to train the data. In the last step, the model is evaluated.

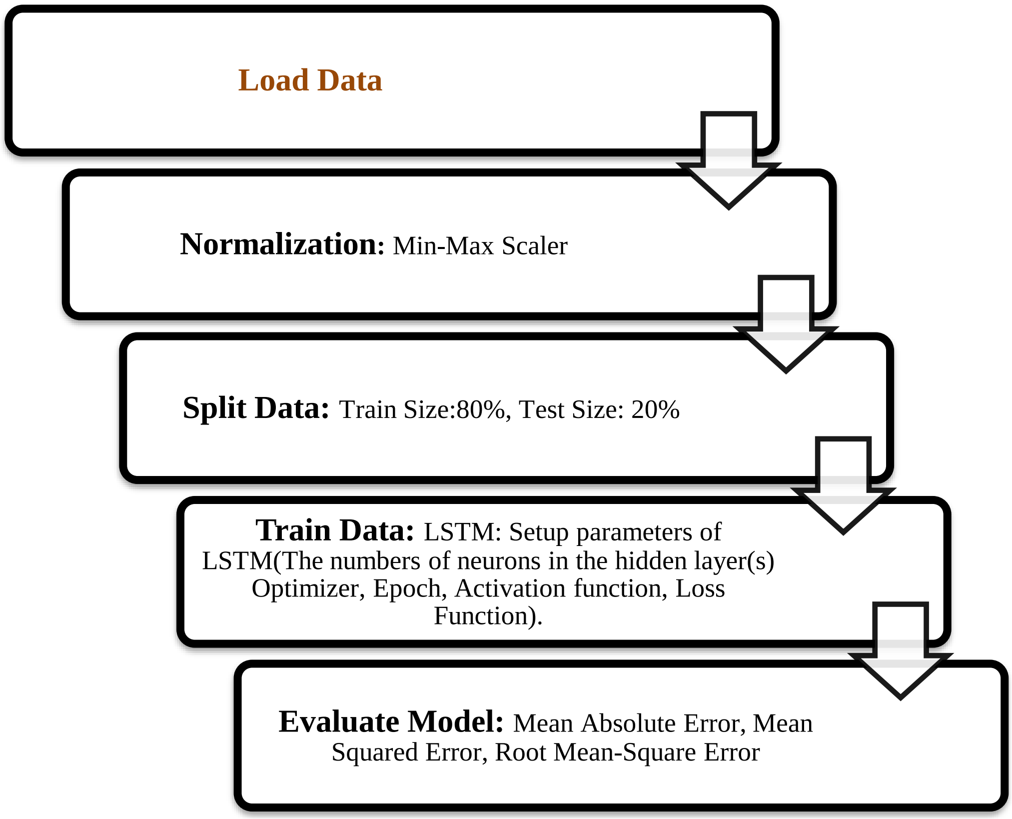

Figure 17: Deep Learning Model(LSTM) stages

a) Load Data

As seen at Figure 18. The data that was used in the forecasting process are represented in the data of characterization of thickened sludge during the year from 2017 to 2018. The database used includes two sections: Date, Characterization of thickened sludge.

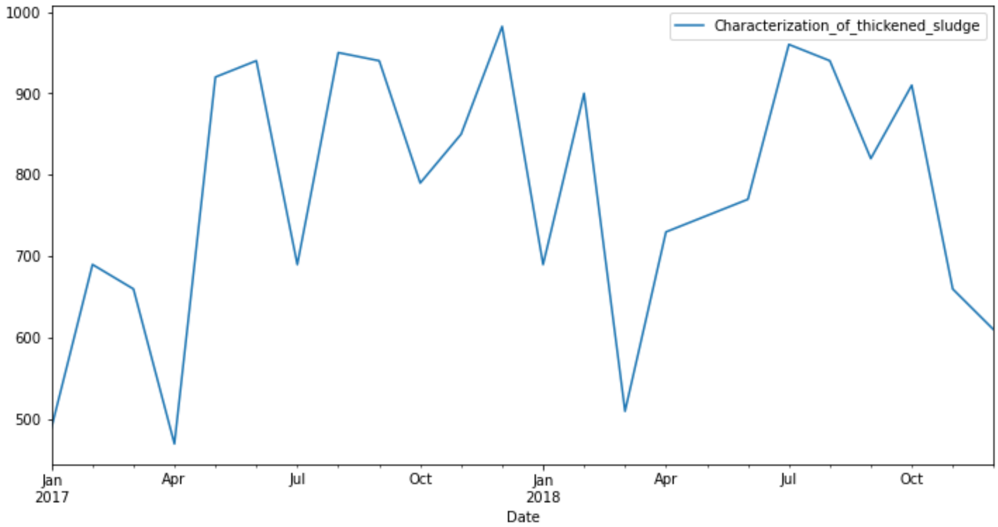

Figure 18: Characterization of thickened sludge for the year 2017 to 2018

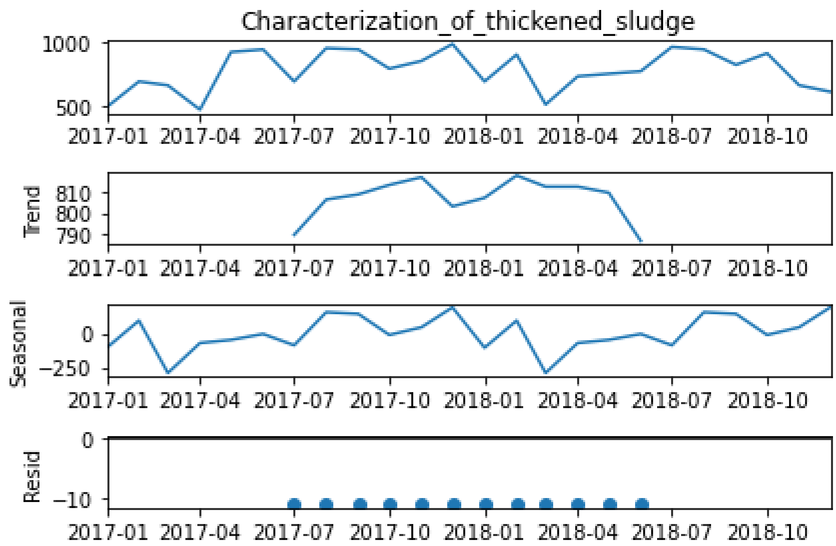

Figure 19: Seasonal decompose of Characterization of thickened sludge

b) Normalization

In this step the input data obtained in the previous step is normalized. Then the Min-Max scaling method is used to transform the input data into a range [0, 1], and the resulted normal data expressed as $s_n(t_i)$, and $\{s_n(t_i), i = 1,2,\cdots, N\}$ is a time series with length N.

$$s_n(t_i) = \frac{s(t_i) - \min(s)}{\max(s) - \min(s)} \quad (1)$$

Where $\min(s)$ is the minimum value of s and $\max(s)$ is the maximum value of s.

c) Split Data

In this step, the instances are divided into two separate groups (training data set (80%) and test data set (20%)) including the train and test sets 19 and 5 respectively. The train set is input to the LSTM model to obtain forecasting model. The test set is used for evaluating the predictive power of the built model in terms of performance metrics.

```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
lstm_1 (LSTM)                (None, 100)               40800
_________________________________________________________________
dense_1 (Dense)              (None, 1)                 101
=================================================================
Total params: 40,901
Trainable params: 40,901
Non-trainable params: 0
_________________________________________________________________
```

Figure 20: Keras structure for the LSTM model

d) Train Model

The Kerasis used to establish the proposed models, Keras is a library written in Python. Figure 20Shows a Keras structure for the LSTM model. Where, during the training phase. All possible combinations are tried of a manually defined subset of parameters to select parameters for LSTM. Then, the number of cycles epoch was selected as 100, we chose Adam optimization. In addition, use the mean square error as the loss function. Finally, LSTM model used the hidden 100 layers. Each layer contains the neurons. The dense layer used sigmoid activation function.

e) Evaluate Model

AfterLSTMmodel trained, to be evaluated the performance of it using measurementaccuracy, which was 96%, and the loss was 4% as shown at figure 21, this accuracy makes the model able to predict efficiently as shown in Figure 22.

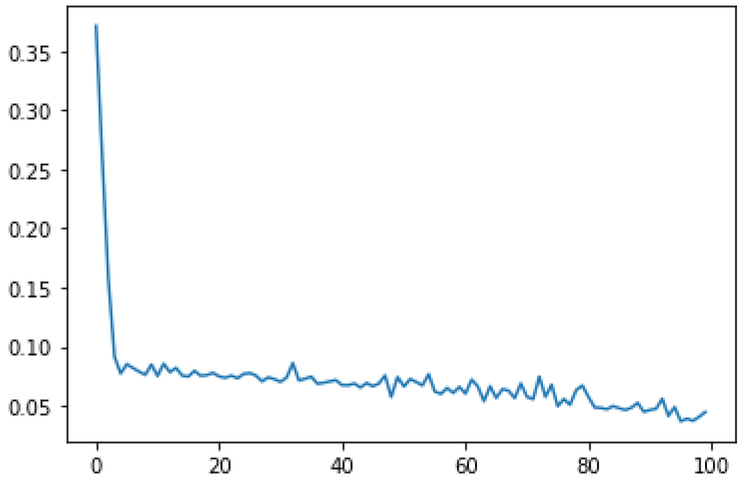

Figure 21: Loss of Model (LSTM)

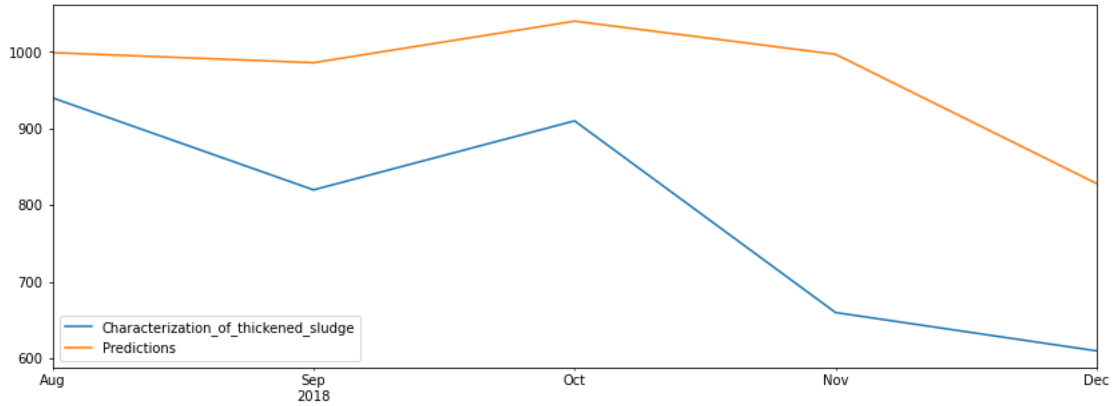

Figure 22: Model (LSTM) Predict

5. Conclusion

Close examination of the life cycle of sludge allows concluding that once the wastewater is treated, the problems linked to sludge landfilling then arise. This sludge disposal method poses many risks to the environment, both for the air and for the soil. The results found in this study can serve as a decision support tool to be applied in the sector under study. In addition, it turned out that the impacts of sludge transportation on the environment, and particularly on the atmosphere, are significant. Moreover, landfilling of solid sludge was revealedto be the worst-case disposal scenario as it produces greenhouse gases. It also contributes to the acidification and toxicity of environments. The presence of metallic trace elements in the sludge engenders negative effects for agricultural land application, which means that the fertilizers actually employed cannever be replaced by sludge. Note also that the life cycle analysis (LCA) results suggested that the real systems under study are quite complex. On the other hand,the agricultural spreading may be an initiative that can be considered; it may be an acceptable solution for the disposal of sludge produced by wastewater treatment plantsprovided that this sludge does not contain trace metal elements in high percentages. The model of LSTM achieved excellent results on the Characterization of thickened sludge dataset.

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