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Assessment of Industrial Wastewater Discharged into River Nile by Assalaya Sugar Factory—Solution & Strategies

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Abstract

Pollution of drinking water in many developing countries causes various diseases, especially epidemics. The Nile River is the primary drinking water source for most of the population of Sudan. This paper determined the pollution load exerted by the Assalaya sugar factory on the River Nile, and the main characteristics of the wastewater were assessed for pollution control. Wastewater samples were collected in plastic containers with labels. Systematic wastewater sampling was done at selected points along the drainage channel at 20, 50, and 80 meters, respectively. The samples were collected from the channel around midday during the dry and wet seasons for eight months, from September 2022 to April 2023. The samples were taken to the laboratory in Sudan, and 216 tests were conducted. Samples were analyzed according to the American Public Health Association (APHA 2005) method. The parameters analyzed were pH, COD, BOD, TSS, Pb, Cu, Zn, and EC. The study results were compared with the Sudanese national standards. The results of this study revealed that most of the pollutants were above the Sudanese industrial wastewater permissible limits. The mean for each parameter for the entire study period was as follows; pH (4.78 ± 0.19), BOD (1477.54 ± 271.21 mg/l), COD (2041.42 ± 190.94 mg/l), TSS (1226.04 ± 95.97 mg/l), Cu (0.46 ± 0.09 mg/l), Pb (0.56 ± 0.11 mg/l), Zn (1.39 ± 0.5 mg/l), and EC (622.92 ± 53.57 μS/cm). From these results, Zinc was found to be within the permissible limits. These findings raise concerns about the level of contamination of the Nile River. With the pollutants that exceed Sudanese limits, it is necessary for further research to be conducted to develop immediate intervention measures and management techniques to restore the river water quality. Under Sudanese guidelines for wastewater treatment facilities and the acceptable limits for treated wastewater, it is recommended that this Factory establishes a wastewater treatment facility utilizing conventional technology to treat its wastewater effluents.

Subject Areas

Wastewater Pollution

Keywords

River Nile, Water Quality, Pollution Sources, Wastewater Effluents, Water Pollution

1. Introduction

Rapid population growth, coupled with massive urbanization and the development of industrial and agricultural activities worldwide, has resulted in the discharge of significant amounts of waste that is usually not environmentally friendly and is discharged directly into water bodies [1]. Most of the wastewater generated, estimated at more than 80% [2], is released into the environment without proper treatment, especially in developing countries, due to a lack of infrastructure, technical expertise, institutional capacity, and funding. Untreated wastewater severely threatens the environment and human health [3].

Sudan is one of the developing countries facing increasing wastewater generation due to rapid population growth, urbanization, and the fast development of agricultural and industrial activities [4]. Most cities in the country do not have an established sewage treatment system. Therefore, direct sewage discharge into the environment causes many environmental problems and contributes to the eutrophication of aquatic lakes, as evidenced by Lake Abu Dakana in Central Sudan [5]. Besides that, there is no national policy mandating the reuse of all treated wastewater effluent, and little has been achieved in this direction [6]. However, no comprehensive studies play a significant positive role in the national economy and advancing the development and process of all kinds of life, positive or negative aspects that would affect human, animal, and plant life, as well as all different components of the environment.

During the last two decades, the population growth of the capital city has been highly increased due to colossal migration resulting from civil wars in many parts of the country [7]. In addition, Khartoum is a hub for communication, innovation, and creativity and plays a significant role in economic development [8]. Sudan has two sewage treatment plants located in Khartoum: The Soba wastewater treatment plant, which can manage the waste of 80,000 people and produces 33,500 cubic meters of wastewater per day and 483.8 tons of sludge annually. It is attached to residential and minor industrial sectors. The second one is the Wad Dafiah Wastewater Treatment Plant which has a water output of 14,500 cubic meters per day and 1581.6 tons of sludge annually. Water treated in the two water treatment plants was estimated at 48,000 m^3/day with 2065.4

tons/year of sludge. Therefore, for this inventory, wastewater and sludge were estimated by interpolation from the input and output of the two plants related to urban and rural populations, assuming that a person in rural areas utilizes 1/3 of the quantity urban persons utilize. Based on this approach, the total wastewater and sludge were estimated at 3880376.28 cubic meters per day and 4169393.41 tons per year, respectively. The wastewater and sludge generated by the urban population were estimated at 2454840.69 cubic meters per day and 2637954.87 tons per year, respectively, while that of the rural population was estimated at 1425535.59 cubic meters per day and 1531438.45 tons of sludge per year, respectively. The total volume subjected to treatment is less than 10% [9].

Agricultural production and sugar manufacturing consume much water during the cleansing and processing. The wastewater generated by this process is characterized by significant BOD and suspended solids pollutant load. This results from sucrose leakage during processing and mud accumulation during washing [10].

Sugar cane is used as a raw material in these industries, which are commonly found nearby to the banks of either the Blue or White Niles. Furthermore, this siting led the sugar sector to assume that the River Nile is the spot to dispose of the untreated effluents. Water is used extensively in the sugar industries for manufacturing and irrigation (*i.e.*, cane washing, cleaning water, condensers, boiler water, floor washing, and other various cleaning processes). Consequently, a significant amount of wastewater is produced from the factories [11].

It has been reported that the sugar industry is the primary contributor to pollution [12]. Currently, most sugar industries contaminate the Nile by discharging untreated wastewater containing pollutants into the river, which included the accidental spill of 500 tons of molasses from the North West Sennar Sugar factory into the Blue Nile in March 2006, which led to severe fish kill [13], as well as contaminated drinking water and vegetables irrigated with sewage have been the primary causes of the outbreaks of diarrhea disease in the last summer of 2010, which coincided with epidemics in the White Nile state, particularly in Kosti and Rabak towns [14]. Wastewater management in Sudan is one of the most challenging problems affecting the environment and people's health [15]. Therefore, to achieve sustainable solutions to this problem, it must be addressed sustainably and collaboratively for all sugar factories in Sudan. Assess the environmental impact by determining the effects of these untreated influents on the water body and the surrounding community.

However, the Assalaya Sugar Factory in Sudan has received limited attention in previous studies. The focus of these earlier studies was primarily on investigating the wastewater characteristics from the Factory and its impact on irrigation water [14]. In addition, little attention was given to examining the potential effects of wastewater on drinking water, which is a significant concern as it puts human health at risk due to the potential transmission of diseases through contaminated drinking water. It is worth noting that some residents in the area use the wastewater that empties into the River Nile for drinking purposes without any treatment. This practice increases the population's vulnerability to waterborne diseases, considering that the untreated wastewater from the sugar factory may contaminate the River Nile. The lack of comprehensive studies on wastewater discharge from the sugar factories in Sudan addressing the impact on drinking water quality poses a significant knowledge gap and highlights the urgent need for further research. Thus, this study provides a comprehensive analysis of some of the wastewater parameters such as PH, Biological Oxygen Demand, Chemical Oxygen Demand, Total Suspended Solid, Electrical Conductivity, and Heavy metals (Zinc, Copper, and Lead) from the Assalaya Sugar Factory. By analyzing the results of this research, the study aimed to establish a scientific foundation for determining wastewater discharge standards guidelines in the sugar industry. The study concluded that such measures are vital to enhance environmental protection efforts and promote adopting sustainable practices within the sugar industry in Sudan.

2. Methodology

2.1. Study Area

As shown in **Figure 1**, the Assalaya sugar factory is one of the sugar factories in Sudan located in the city of Assalaya in the municipality of Rabak on the eastern bank of the White Nile (White Nile State), 280 km south of the Sudanese capital Khartoum and 5 km north of the city of Rabak. Assalaya Sugar Factory was constructed in 1974 and started operating in 1980. The Factory's design capacity is 6500 tons of cane daily, equivalent to 110,000 tons of sugar produced annually [16].

The Nile River is the longest in the world, shared by 11 countries that comprise the Nile Basin countries, including Sudan. The river extends 6695 km from its source, the Kagera Basin in Rwanda and Burundi, to the Nile Delta in Egypt, which empties into the Mediterranean Sea. The Nile Basin covers about 10% of the African continent, and more than 160 million people depend on it for food, irrigation water, domestic water supply, hydroelectric power generation, tourism, transportation, and fishing. According to a 1959 agreement with Egypt, Sudan receives 18.5 km^3 of water per year from the Nile River, as well as the Nile provides around 73% of Sudan's fresh water and flows through the entire country from south to north. Sudan also serves as the location of the convergence of the White Nile and the Blue Nile, which creates the main Nile and gives Sudan a significant historical and cultural role [17].

Despite its great importance, the Nile River is witnessing an increasing deterioration in water quality. The various industrial activities, agriculture, mining, steady population growth, and other factors exacerbate river water pollution. In Sudan, especially in central Sudan, where agricultural and industrial activities are intense, and the population is high, the river is exposed to pollution from unknown sources, such as chemicals and sediments from agricultural practices and highly toxic materials from mining activities [18]. In addition, there is severe point source pollution from domestic and industrial discharges, especially

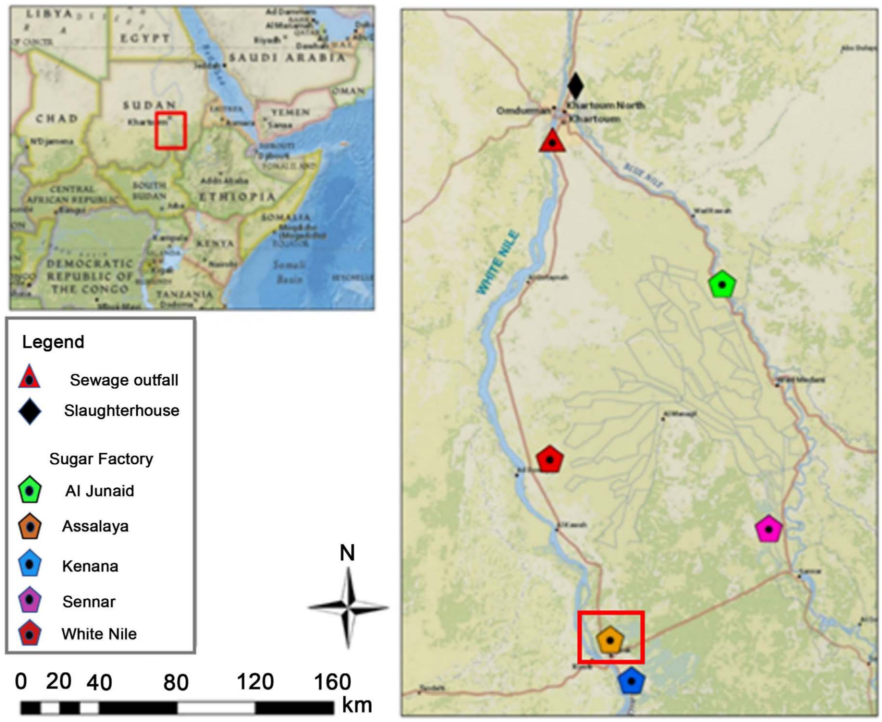

Figure 1. A map of the study area.

in urban areas. In addition, the lack of adequate water stations exacerbated the pollution problems with sewage, industrial, and agricultural water [19]. The map below depicts Sudan's most significant sources of Nile water pollution.

2.2. Sampling and Treatment

Wastewater samples were collected in plastic containers with labels (See Figure 2). Systematic wastewater sampling was done at selected points along the drainage channel at 20 meters, 50 meters, and 80 meters. The samples were collected from the channel around midday during the dry and wet season. The samples were taken to the construction and environmental labs in Khartoum, Sudan, to analyze pH, BOD, COD, TSS, EC, Cu, Zn, and Pb. The laboratory analysis was carried out according to the American public health association (APHA 2005). Figure 3 describes the methodology adopted for the wastewater characterization, and Table 1 shows the instruments used for the physicochemical analysis of wastewater samples collected.

2.3. Determination of pH

The electrometric method was used to determine pH using the laboratory pH meter Hanna model HI991300. The pH electrodes were then rinsed in a small beaker with some samples after the electrodes were cleaned with distilled water and dried. A small beaker was filled with enough samples to allow the points to emerge of electrodes to a depth of approximately 2 cm. The beaker's sides and bottom were at least 1 cm from the electrode. The dial for temperature adjustment was set accordingly. The pH meter was activated, and the sample's pH was noted.

Figure 2. Wastewater samples collected.

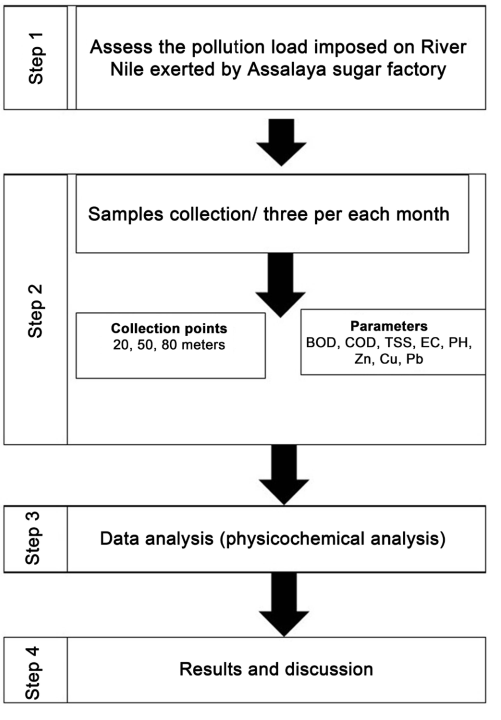

Figure 3. Research methodology.

Table 1. Instruments for Physicochemical Analysis of wastewater samples.

Parameters	Instruments	Supplier
pH	meter Hanna model HI991300	HANNA, Romania
EC	Conductivity Meter DDS-307-PH meter	WINCOM COMPANY LTD.
TSS	TSS Glass Fiber Filter Pore Size 1.5 μm, Diameter 47 mm, 100/pk	HACH, USA
COD	DR 2800 Hach Lang	HACH, USA
BOD	Hach HQ440d benchtop meter	HACH, USA
Heavy metals	Atomic Absorption Spectrometer (AAS)	PerkinElmer, USA

2.4. Biological Oxygen Demand (BOD)

The bio-assay method, which determines the quantity of dissolved oxygen in mg/l consumed by the water microorganisms while digesting and oxidizing the organic matter under aerobic circumstances, is the basic foundation for BOD study. In this approach, distilled water was air-saturated by aeration for one to two hours, and then 2 ml of any combination of $FeCl_3$, $CaCl_2$, $MgSO_4$, and phosphate buffer was added. A temperature of 20˚C was applied to the sample. The water and wastewater sample volume were put into a volumetric flask measuring 1000 ml, and the BOD dilution water was added to the mark. Three portions of the diluted sample were divided evenly, incubated at 20˚C, put into a BOD bottle, and then determined using the Hach HQ440d benchtop meter.

2.5. Chemical Oxygen Demand (COD)

In order to completely oxidize all of the organic matter and some of the oxidizable inorganic components in the sample, an equivalent concentration of oxygen must be present, which is what is measured by COD. A 15 ml sample of the untreated water was obtained, diluted to 20 ml with distilled water, and mixed well to determine the COD of the water under study. 10 ml of potassium dichromate solution (1 N) and 30 ml of concentrated sulfuric acid were added to the diluted sample, and the combination was then heated to a high temperature under a condensation apparatus for about two hours. A ferrous ammonium sulfate solution (0.25 N) titration was then performed on the product.

2.6. Determination of Electrical Conductivity (EC)

The EC was determined using American Public Health Association 2510 B guideline Model DDS-307. The sample was rinsed with at least three sections in the conductivity cell. The sample's temperature was then changed to 20˚C ± 0.1˚C. The electrodes of the conductivity cell were submerged in a sufficient volume of the sample. The sample's conductivity was measured after the conductivity meter was turned on.

2.7. Determination of Total Suspended Solids (TSS)

The TSS in the samples was calculated using the filtration method. The samples were initially filtered using 45 m glass-fiber filters and vacuum suction. The clean-dried filters were oven-dried at 105˚C for 4 hours until a steady weight was obtained. After that, the filters were put in a desiccator. The dry, clean filters were weighed, and measurements were taken to the closest milligram following standard examination methods (ASTM, 2000).

2.8. Determination of Heavy Metals

A few drops of HNO_3 were added to the 1L bottles of water samples to measure heavy metals. The HNO_3 acid technique was used for digestion (APHA, 2005). After being labeled for analysis, the digests were diluted to 100 cm^3 in a volumetric flask and put into an acid-washed plastic container. The standard solutions, made in the range of 100 mg/l, were slightly acidic. The standard solutions' absorbances (2, 4, 6, 8, and 10 mg/l) were measured. The samples were aspirated into cups (5 cm^3) one at a time, intermittently. Atomic Absorption Spectrophotometer (AAS) analysis was performed in Khartoum, Sudan's construction and environmental labs.

2.9. Statistical Analysis

All data obtained were organized, analyzed, and visualized using Microsoft Excel2021 and OriginPro 2023 (OriginLab Corporation, Northampton).

3. Results and Discussion

The water pollutants examined included: pH, BOD, COD, TSS, Copper (Cu), Zinc (Zn), Lead (Pb), and EC, which were analyzed and carried out according to the American public health association (APHA 2005). The results of the analyses discussed within the Sudanese Standards for Industrial Wastewater. Furthermore, several standards and guidelines have been established for the permissible limits of pollutants resulting from wastewater. The researcher used the Sudanese standards for their suitability to natural conditions, human activities, and the research case. The results of the wastewater examination of the industrial wastes in the Assalaya sugar factory showed a significant level.

3.1. Result of pH

The results of the pH measurements showed that the pH was below the normal range for industrial wastewater and below the permissible limits of wastewater according to the Sudanese and WHO permissible limits shown in **Figure 4** and **Table 2**. Therefore, water with a pH lower than seven is considered acidic according to WHO standards of 6.5 to 8.5. Samples were taken during the wet and dry seasons, and the findings of the pH all tests indicated a drop in pH.

The low pH can adversely affect the plants, the process of growth, flowering, or fruiting because low pH in water causes a decrease in soil permeability due to the number of soluble salts remaining in the surface soil, and as a result, blocks the pore spaces preventing water from reaching the root zone which negatively affects plants.

The high acidity of the wastewater was likely caused by the high hydrogen ion (H^+) concentration in the effluents when low-pH effluents enter water bodies [20].

The low pH values result from the different manufacturing processes in the sugar industry because some units employ the remelt carbonation process, which produces acidic sulfur compounds, and impurities are coagulated using a clarify of chemicals. Juices are clarified, and pH is raised by using calcium oxide.

Additionally, the lower pH of the effluent is caused by a more significant concentration of organic acids, including CH_3COOH, created during the metabolic

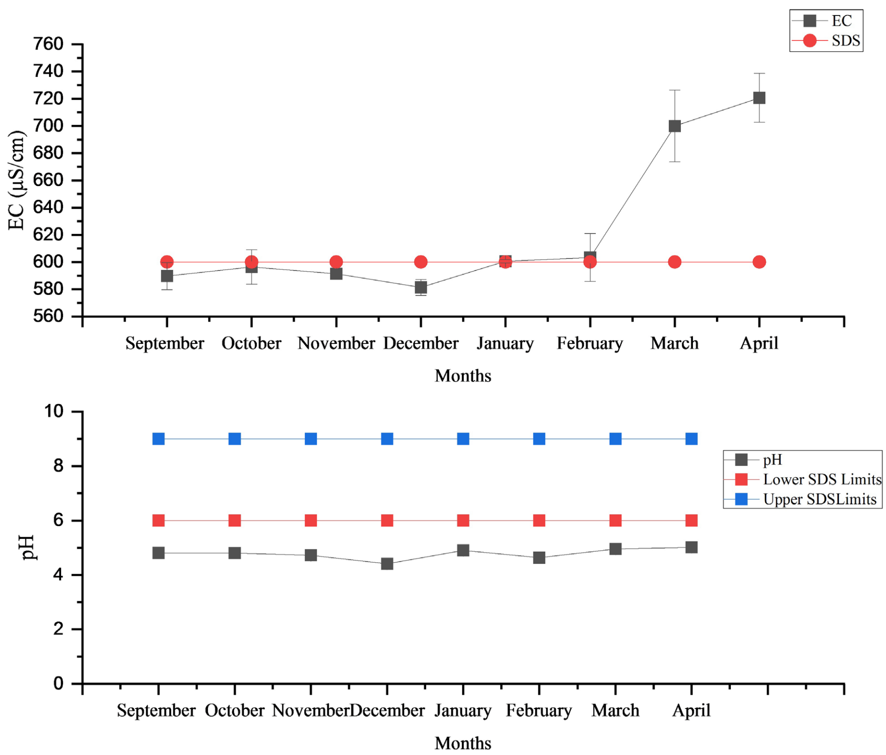

Figure 4. Comparison of EC and pH results with Sudanese standards.

Table 2. The mean and standard deviation of physiochemical parameters.

Months	EC	S. Dev	SDS	Months	pH	S. Dev	Lower SDS Limits	Upper SDS Limits	WHO
September	589.67	10.02	600	September	4.81	0.02	6.00	9.00	8.50
October	596.33	12.66	600	October	4.80	0.01	6.00	9.00	8.50
November	591.33	1.53	600	November	4.72	0.02	6.00	9.00	8.50
December	581.33	5.86	600	December	4.41	0.01	6.00	9.00	8.50
January	600.67	1.15	600	January	4.90	0.01	6.00	9.00	8.50
February	603.33	17.56	600	February	4.64	0.02	6.00	9.00	8.50
March	700.00	26.46	600	March	4.96	0.04	6.00	9.00	8.50
April	720.67	17.93	600	April	5.01	0.01	6.00	9.00	8.50

conversion of highly biodegradable organic matter. Using phosphoric acid and sulfur dioxide during the purification of sugar cane juice contributed to the wastewater's acidity [21].

Since this study found that acidity is associated with wastewater pH, controlling this acidity of pH can be done by neutralizing it with alkalis, which Increases the pH and neutralizes the acidity of the wastewater by adding alkaline materials. Alkalis commonly used include caustic soda (sodium hydroxide) and soda ash (sodium carbonate). Implement biological treatment methods like biofiltration or activated sludge as well. In these systems, specific microbes naturally assist in regulating and stabilizing pH values within a desirable range.

3.2. Electrical Conductivity (EC)

The conductivity of water is used to measure its salt content or overall ionic species concentration. Electrical conductivity is essential for wastewater systems since that provides information on the water's total dissolved solids (TDS), chemicals, and minerals. The conductivity increases with the number of pollutants present in the water. An increase in electrical conductivity in wastewater treatment facilities shows that there are pollutants in the water [22].

As per the Sudanese Standards (SDS), the acceptable electrical conductivity limits are 600 μ/cm. The effluent samples displayed varying levels of electrical conductivity, with some exceeding the permitted limits while others falling within the acceptable range. Untreated wastewater exhibited an average electrical conductivity of 720.67 μ/cm (highest) and 589.67 μ/cm (lowest), as depicted in **Figure 4** and **Table 2**.

These fluctuations can be attributed to disturbances in the production process, wherein the effluent's composition may change due to inconsistencies or fluctuations occurring in the different stages and processes of sugar production. Additionally, the divergent EC values can be attributed to disparities in the production procedures.

Moreover, an increase in electrical conductivity showed in the dry season, and it is anticipated that during the drought season, the industrial process faces certain fluctuations in production or wastewater effluent, affecting the total EC for the tested drain water. Wastewater drainage may encounter higher evaporation rates during the dry season as well. Higher EC values result from the concentration of dissolved solids in wastewater as water evaporates, which increases.

3.3. Biological Oxygen Demand (BOD)

The BOD concentration in this study was exponentially above the recommended limits by the Sudanese industrial wastewater standards, which is 50 mg/l. The effluent concentration was found to be excessive BOD, with an average of 1328.67 mg/l as a lower result and 1888.67 mg/l. As an upper result in **Figure 5** and **Table 3**. Thus, BOD results may have resulted from spills of organic materials such as fermented molasses, juice from sugar processing, and remaining wash from distilleries.

In addition, caustic soda and hydrochloric acid are used to clean the heat exchangers and evaporators to prevent the buildup of scale on the surface of the tubing. Soda and acid wash pollution are significant sources of organic and inorganic contaminants.

BOD tests increased during the rainy season, considering the open drainage channel allows it to receive much precipitation. In addition to leaves, soil fragments, and other trash, this rainwater also transports a variety of organic and inorganic elements. These organic substances cause higher BOD levels in wastewater. Additionally, because certain agricultural and industrial activities

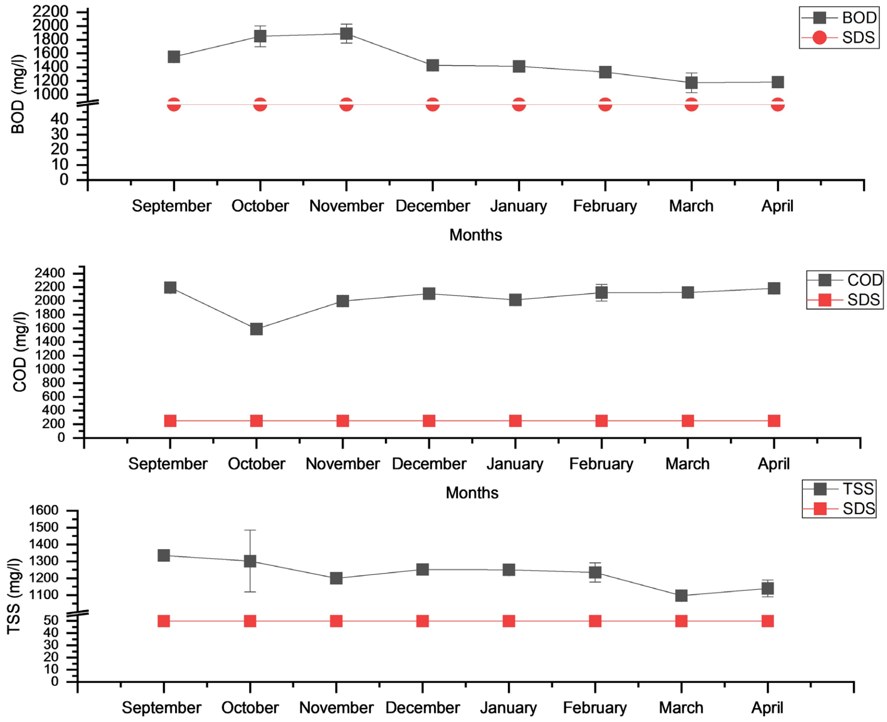

Figure 5. Comparison of BOD, COD, and TSS results with Sudanese standards.

Table 3. The mean and standard deviation of Organic parameters.

Months	BOD	S.Dev	SDS	Months	COD	S. Dev	SDS	Months	TSS	S. Dev	SDS
September	1551.67	1.53	50	September	2194.67	45.62	250	September	1334.33	14.01	50
October	1851.33	152.00	50	October	1591.33	1.15	250	October	1301.67	182.93	50
November	1888.67	136.62	50	November	1998.00	5.20	250	November	1199.33	21.01	50
December	1427.67	24.01	50	December	2106.67	5.77	250	December	1252.33	2.52	50
January	1414.00	12.17	50	January	2015.00	13.23	250	January	1250.33	10.79	50
February	1328.67	30.09	50	February	2120.00	121.24	250	February	1234.00	56.67	50
March	1174.67	143.74	50	March	2121.67	50.58	250	March	1097.00	22.07	50
April	1183.67	16.50	50	April	2184.00	30.05	250	April	1139.33	49.86	50

are nearby, the stream is subject to runoff from nearby surfaces, which can carry pollutants, including oil, grease, fertilizers, pesticides, and other surfaces such as roofs and highways. BOD and the organic content of wastewater are both dramatically raised.

However, High BOD levels may accelerate the loss of dissolved oxygen in the water body, harming aquatic life. Fish and other species that rely on dissolved oxygen for existence could die from a lack of oxygen. In addition, High BOD levels indicate poor water quality. It may result in odor issues, color changes, and diminished water clarity. Due to this degradation, the water may become unusable for various purposes, affecting its aesthetic appeal [23].

3.4. Chemical Oxygen Demand (COD)

It was found that the concentration of COD observed is 2194.67 mg/l as the highest average, and 1591.33 mg/l as the lowest average, and all analyses revealed significant concentrations were above the Sudanese limits for industrial wastewater. It exceeds the Sudanese standards of 250 mg/l for sugar industries by hundreds, as shown in **Figure 5** and **Table 3**. Many solids released from wastewater from the sugar industry may have a high COD concentration, indicating higher contaminants in wastewater.

Several causes can be attributed to the high COD levels in this study for wastewater from the Assalaya Sugar Factory. Sugar industry effluent frequently contains molasses, a byproduct of sugar manufacturing. Because of its abundance in organic materials, molasses has a high COD and BOD. As a result of its high organic content, wastewater that contains molasses significantly increases the COD levels when it is released. Furthermore, Organic material, primarily from sugarcane or sugar beet processing, can be found in substantial amounts in wastewater used in sugar operations. Sugars, molasses, residual plant matter, and other sugar-processing byproducts are all included in this organic component. These ingredients contribute to explaining whether the wastewater has high COD levels.

Additionally, the process of producing sugar requires the extraction of sugar from raw materials using various techniques, including crushing, milling, and extraction. Wastewater from this procedure contains significant amounts of sugars and carbohydrates. These organic substances raise COD levels when they are found in wastewater [24].

Moreover, as indicated in **Figure 5**, all of the test findings for COD revealed high concentrations, except one result revealed a slight decrease that might be attributed to the effect of dilution during the rainy season. Rainwater has a considerable impact on lowering the sample's contaminant concentration. It might explain the lower result than other tests if a specific test with a drop in COD is run on a sample that has been extensively diluted with rainfall.

However, one of the most significant essential problems associated with high COD is the increase in the growth of algae in the water, which leads to environmental and health problems such as the growth of algae, which lowers the water's oxygen content and is essential for the survival of many aquatic creatures. The oxygen dissolved in water is essential for fish, other aquatic life, and the algal bacterium, which requires oxygen to survive. Therefore, the competition for oxygen is increased by rapid growth and high reproduction rates, which causes an imbalance in the aquatic ecosystem and the suffocation of aquatic creatures like fish. More aquatic animal deaths mean more food for the algae, which accelerates their growth and, over time, degrades the quality of aquatic life [25].

3.5. Total Suspended Solid (TSS)

The untreated wastewater analyses for total suspended solids from the Assalaya sugar factory exceeded the stipulated standard limit for total suspended solids (TSS) set by Sudanese Standards, 50 mg/l, where the highest concentration was 1334.33 mg/l, and the lowest concentration was 1097 mg/l shown in **Figure 5** and **Table 3**.

These high results of TSS in Sugar Factory Wastewater findings can be attributable to various sugar production process-related factors. The sugarcane processing method produces a high fly ash and bottom ash production rate, which raises TSS. Additionally, the bagasse stacking facility has coarse particles that could boost TSS.

In order to produce sugar, plant materials, including sugarcane or sugar beets, must also have their sugars extracted. Bagasse, plant fibers, and other solid wastes are produced during this process. High TSS levels in wastewater can be attributed to these solid substances, soil particles, and other detritus.

Additionally, sugar production uses the washing and cleaning processes to clean and wash equipment, storage tanks, and machinery that may accumulate suspended particles. These solids increase the TSS content as they are cleaned off and suspended in the wastewater. Furthermore, wastewater from sugar production may contain suspended particles that settle insufficiently or slowly. These may be due to the wastewater's acceptable particle content or the characteristics of the wastewater itself, such as its high viscosity or organic content.

However, Total suspended solids (TSS) are recognized as one of the primary pollutants that deteriorate water quality, raising water treatment costs, reducing fish availability, and affecting the general appearance of the water. Water's transparency and turbidity are influenced by suspended particles, which are caused by suspended solids, which in turn affect the light strength of water [26].

3.6. Heavy Metals (Pb, Zn & Cu)

As depicted in **Figure 6** and **Table 4**, the results of the conducted tests revealed that the levels of Lead in all examined samples exceeded the maximum acceptable limits set by the Sudanese standard specifications (0.2 mg/l). The highest recorded value for Lead was 0.72 mg/l, while the lowest was 0.32 mg/l. Interestingly, the findings indicated that lead concentrations in wastewater from sugar production could vary significantly during the dry season when the water supply is limited and contaminants are more pronounced. Despite the sugar-making process requiring less water, the resulting effluent becomes more concentrated, potentially leading to higher levels of Lead. Furthermore, modifications to the production process could also contribute to these variations. During the dry season, certain production procedures, such as cleaning and maintenance tasks, may occur more frequently or intensively. Due to greater contact with lead-containing materials or equipment, these activities may cause wastewater to contain higher quantities of Lead.

During the dry season, particular agricultural procedures include spraying pesticides or fertilizers. Therefore, these agricultural practices may cause or contribute to elevated levels of Lead because an increase in dust and other airborne

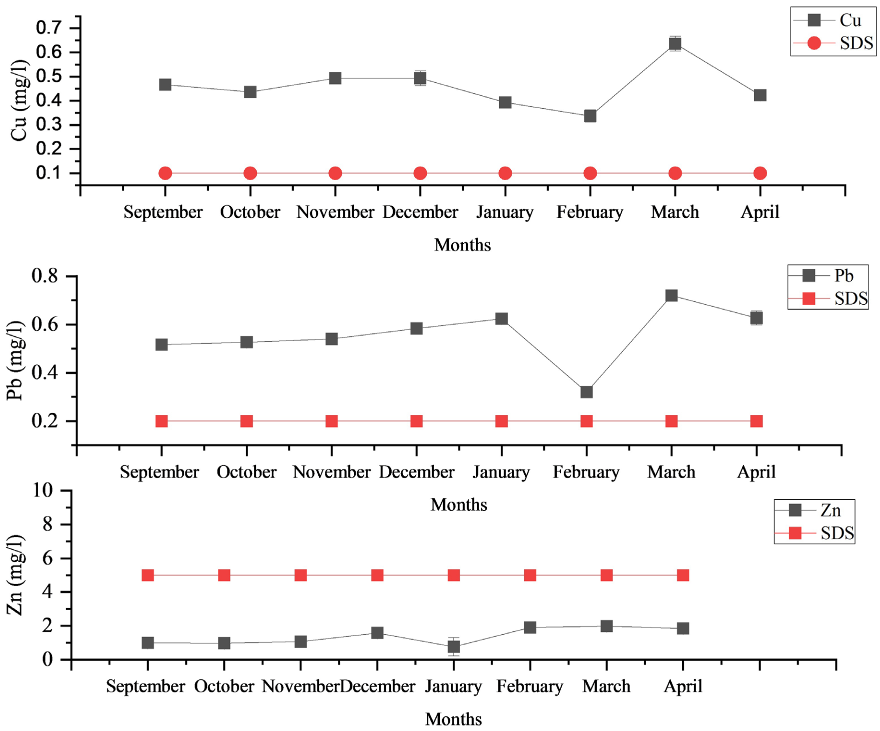

Figure 6. Comparison of Cu, Pb, and Zn results with Sudanese standards.

Table 4. The mean and standard deviation of heavy metals.

Months	Cu	S. Dev	SDS	Months	Pb	S. Dev	SDS	Months	Zn	S. Dev	SDS
September	0.47	0.02	0.1	September	0.52	0.02	0.2	September	0.99	0.01	5
October	0.44	0.02	0.1	October	0.53	0.02	0.2	October	0.97	0.02	5
November	0.49	0.02	0.1	November	0.54	0.02	0.2	November	1.07	0.12	5
December	0.49	0.03	0.1	December	0.58	0.01	0.2	December	1.58	0.03	5
January	0.39	0.02	0.1	January	0.62	0.02	0.2	January	0.76	0.55	5
February	0.34	0.03	0.1	February	0.32	0.02	0.2	February	1.90	0.02	5
March	0.64	0.03	0.1	March	0.72	0.01	0.2	March	1.97	0.02	5
April	0.42	0.02	0.1	April	0.63	0.03	0.2	April	1.85	0.04	5

particles frequently accompanies dry seasons. These grits can adhere to surfaces, including those of sugar-producing machinery and infrastructure, potentially introducing Lead into the effluent.

While the findings of Copper in the untreated wastewater ranged from 0.64 mg/l (highest recorded value) to 0.34 mg/l (lowest recorded value), it is crucial to note that these concentrations surpass the acceptable limits established by the Sudanese Standards, which prescribe 0.2 mg/l. Elevated lead levels in untreated wastewater highlight an impending environmental risk, underscoring the urgent requirement for efficient wastewater treatment approaches to alleviate its detrimental consequences.

Furthermore, the outcomes of this investigation shed light on finding regarding the Zinc content within the sugar wastewater samples. The analyses revealed that the highest recorded zinc concentration was measured at 1.97 mg/l, whereas the lowest recorded concentration was 0.76 mg/l. Importantly, these measurements comfortably fall within the acceptable boundaries outlined by the Sudanese standards, establishing a limit of 5 mg/l. Consequently, it can be deduced that the observed Zinc concentration in the sugar wastewater does not pose any discernible negative impact.

However, when heavy metals are released into rivers, lakes, or groundwater, they may harm the ecosystem and the water supply. They have the potential to contaminate aquatic environments, disrupting their vital equilibrium and damaging aquatic life and fauna.

4. Conclusions

Due to the rapid population increase, urbanization, and development of the agricultural and industrial sectors, Sudan is one of the developing nations with rising wastewater generation. The majority of cities in the whole country lack a well-established sewage treatment system. Many environmental issues are brought on by the immediate release of sewage into the environment, which also adds to the eutrophication of lakes. Thus, this study aimed to analyze the impacts of wastewater discharge from the Assalaya sugar factory into the River Nile and its impact on drinking water and aquatic life. I then followed the statistical analysis and review of the findings. Sudanese standards (SDS) were used as local standards for comparing results.

Systematic wastewater sampling was done at selected points along the drainage channel at 20 meters, 50 meters, and 80 meters. The samples were collected from the channel around midday during the dry and wet seasons for eight months, from September 2022 to April 2023. According to the American public health association (APHA 2005), the elements analyzed were pH, chemical oxygen demand, biological oxygen demand, total suspended solids, electrical conductivity, Copper, Lead, and Zinc.

According to the study analysis, the Assalaya Sugar Plant effluents contained higher concentrations of BOD, COD, TSS, EC, Copper, and Lead than the Sudanese standards. Undoubtedly, this can harm the ecosystem and all living creatures, including people, because analysis results revealed that the effluents are not treated with very high concentrations of pollutants. In contrast, the Zinc concentrations were within the permissible limits according to the standards. Additionally, the study shows that high concentrations of heavy metals indicate severe drinking water pollution and threaten human health and aquatic life.

5. Recommendation

This study recommends that this Factory establish a wastewater treatment facility to treat the wastewater. The plant can use various treatment processes, such as primary treatment (mechanical screening and sedimentation) and secondary treatment (biological procedures like activated sludge or trickling filters), to remove pollutants and ensure the treated water complies with Sudanese Standards and Metrology Organization regulations for wastewater. Consequently, a comprehensive monitoring system can be implemented to constantly evaluate the quality of the wastewater released from the facility. The Factory can identify variations from the required guidelines and respond by monitoring essential parameters such as pH, TSS, COD, and BOD.

Additionally, the study recommends putting strict regulations in place to prevent the direct discharge of untreated wastewater into the River Nile or other water bodies and setting up a sanitation law to regulate the industrial sector by regulating the phases of processing industrial wastewater and reusing it in different industries (boilers, cooling units, various consumption units) and adopting incentive programs for water recycling. Also, implementing water pollution regulations such as the Criminal Code of 1991 Article 70 (set by the Sudanese Government) imposes a minimum three-year prison sentence on people who dump contaminants into water sources.

The study strongly recommends creating green belts in Assalaya City to help regulate the climate. Moreover, the use of treated wastewater as an alternative to irrigation could support afforestation while maintaining limited freshwater supplies, even at the level of other cities where the polluting industries of the Nile are situated. Moreover, the study recommends that more studies are needed to examine the waters of the River Nile from various depths and identify the places impacted by industrial activity.

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Conflicts of Interest

The authors declare no conflicts of interest.

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