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ENVIRONMENTAL POLLUTION FROM CANE SUGAR FACTORIES: A STUDY OF CHEMICAL FEATURES VARIATIONS IN THE WASTEWATER

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ABSTRACT

Sugar industry processes release large amounts of wastewater and pollution concentrations. This study focuses on environmental pollution produced by a cane sugar factory (Sampling Assalaya factory) with particular emphasis on the chemical properties of wastewater as an essential feature identifying water pollution in the study area. The study aims to analyze wastewater's chemical features and disparity based on the Sudanese Standards and Metrology Organization (SSMO) standards. The systemic random sampling method collected twenty samples for each parameter (pH, Total Hardness, PO_4, BOD, and COD). Analyses were conducted in the laboratory according to the standard methods for examining water and wastewater (USA). Results revealed significant variations in wastewater features at different sampling sites as pH values ranged between 4.55 to 8.39 and PO_4 ranged between 0.097 ppm to 670 ppm in the selected sites. Results also pointed out that Total hardness ranged between 50ppm to 470ppm, BOD ranged between 15ppm to 390ppm, whereas the COD in 80% of the tested samples exceeded the SSMO standard (150ppm). The article concluded that these levels are highly exceeding the recommended level by SSMO. The leading causes of such alarming pollutant levels are related to the effluent of the Assalaya sugar factory in the study area. To reduce such effluent pollution levels, suggestions are made for the Assalaya cane sugar factory to treat its effluent by introducing appropriate technology and methods, such as anaerobic treatment. The Assalaya sugar factory ought to keep up with the transformation to green production as an integral part of its policy to achieve sustainability.

Keywords: Assalaya; cane sugar factory; chemical features variations; effluent; SSMO; wastewater

INTRODUCTION

Sugarcane is the main crop cultivated worldwide for sugar production. Therefore it is considered the primary tool for economic development and growth (Carvalho et al., 2021). It is a strategic commodity for the most producing countries (Jesus et al., 2019). Sugarcane is a critical economic crop manufacturing and contributes approximately 80% of the global sugar output (Wang et al., 2020).

Industrial wastewater is generated from anthropogenic activities and originates from raw materials and manufacturing processes (De Gisi & Notarnicola, 2017). Sugarcane is one of the most significant energy crops widely grown globally (Awe et al., 2020). About 60% to 80% of globally produced sugar is from sugarcane, and the rest comes from sugar beet (Kaab et al. 2019a; Wang et al., 2020; Oliveira et al. 2021).

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Sugarcane is perennial grass belonging to the genus *Saccharum L* (El Chami et al., 2020). It is a treasured raw material providing bioenergy and byproduct (Hiloidhari et al., 2021)India under different scenarios. Altogether 20 scenarios were developed taking four sugarcane seasons (adsali, ratoon, preseasonal and suru, as bioethanol production generates vinasse. Vinasse is the byproduct of bioethanol distillation. Vinasse generated is about 10 L of vinasse per 14 L of ethanol (Nivetha et al., 2019). Besides producing sewage sludge, vinasse requires anaerobic digestion for treatment (Tao et al., 2015).

The sugarcane industry in Sudan is reputable as the country is considered the third-largest producer of sugar in Africa, next only to South Africa and Egypt. Integrating agriculture and the environment in sugar factories produces biofuel (ethanol) from molasses and electricity from bagasse (Fachinelli & Pereira, 2015; Batlle et al., 2021). The sugarcane industry contributes to socioeconomic development (Ranjan et al., 2021). Besides, it has a possible benefit that bioenergy production comprises rural and economic development (Azanha et al., 2015). In Sudan, there are six sugar factories with a total capacity of 750,000 tons annually (Ahmed & Alam-Eldin, 2015).

Cane sugar factories play a paramount role in promoting and ameliorating the host population's incomes by providing more significant opportunities for occupation and employment, particularly in the tropical and subtropical zoon worldwide (Turinayo, 2017; Silalertruksa et al., 2017). Despite this, the cane sugar industries generate water pollution. Its processes demand substantial water and generate plenty of wastewater during production (Sahu, 2018). Wastewater is polluted and considered unserviceable due to its discharge in surrounding areas near river streams (Sahu et al., 2017). The sugarcane industry has substantial waste generation and high economic, social, and environmental ramifications (Torres de Sande et al., 2021). This industry uses chemical substances which have massive consequences on the ambient environment by releasing toxic pollutants (Varjani et al., 2020). Water pollution and wastewater are physio-chemical parameters for which Environmental Impact Assessment (EIA) is a must. It is a solid instrument to identify the intended consequences on the environment (Kaab et al. 2019b).

Water pollution ranked as the second pollution problem, following air pollution. Industrial wastewater effluent is becoming one of the most crucial issues challenging human beings and industries. The World Bank considers sugar mills the significant polluting plants (Tiwari, 2016). They significantly contaminate water sources and arable land by emitting substantial amounts of wastewater (Geme, 2014). It also generates enormous amounts of waste (Bhatnagar, 2016). Sugar mills require massive amounts of water, releasing untreated water into surface drains. The effluent generates problems when percolating in the soil. Sugar cane is also famous for its byproducts during the sugar process, with high demand in the market; bagasse being utilized as a source of energy to generate electricity and steam power; and molasses, with different types of utilities. Such activities generate substantial amounts of wastewater during the manufacturing processes. The effluent contains massive amounts of pollutants in the form of organic matter, biological and chemical oxygen demand, mud, and other materials (Yadav & Daulta, 2014). During the production process of sugar, there are equally significant amounts of Total Suspended Solids (TSS), Organic Matter (OM), sewage, sludge, press clay, bagasse, and others (Muthusamy et al., 2012). The generation of such an amount of wastewater comes from the fact that milling one ton of cane requires 2000 liters of water and the disposal of about 1000 liters of wastewater (Tiwari, 2016). Sugar mills expressively harm the environment by generating different kinds of wastewater, emissions, and solid wastes. Wastewater has several sources, such as washing, condensation, leakage, and spillage from valves and pipelines, syrup, and molasses in different segments and sections (Sahu & Chaudhari, 2015). Disposing of wastewater in the ambient environment creates a suitable ground for chemical and microbial contamination in downstream areas and drinking water (Wang et al., 2017). This pollution is a modification in water's feature, making it unwanted, unsafe, and malevolent for human and animal health (Ahmed et al., 2017). The wastewater discharged from sugarcane processing has a significant role in altering the chemical characteristic of water and causing severe issues in the ambient environment (Marinho et al., 2014; Comwien et al., 2015; Sahu, 2016; Anastopoulos et al., 2017; Galvis et al., 2018). Wastewater that holds a high level of organic elements needs specific treatment because it has various components of pollutants as a mixture of carbohydrates, fats, and salts which increase the amount of BOD, COD, and other features of chemical components. (Comwien et al., 2015).

To test out the wastewater pollutants, the various physical, chemical, and biological features can be considered (Sahu et al., 2017; Sahu, 2019). The chemical features are significant in the process of analyzing wastewater pollutants. Wastewater encompasses plentiful types and concentrations of pollutants depending on its origin, source, and level of treatment (Elgallal et al., 2016). Certain aspects of water and waste are probed to identify chemical features of water and waste, including pH, total hardness, PO_4, and Chemical and Biological Oxygen Demand. The analysis should be understood within the frame of the input types of chemical substances used during production (Ali et al., 2014). The general aim of this research is to study and assess the chemical elements found in wastewater from the sugar production process and to analyze the discrepancies of elements among the features and their concentrations. Such elements include pH at 21.1C^0, total Hardness, Phosphate (PO_4), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). These parameters impact the chemical features of water variations and water quality in the study area. Other parameters that contribute to wastewater are not within the scope of this study (Halder & Islam, 2015).

The importance of this study is manifested in contributing to and protecting the environment and society from externalities that severely affect the environment, resources, humans, and animals. Society must be prevented and protected from factory consequences by several means. A preliminary visit to the Assalaya sugarcane factory shows a considerable amount of effluent discharged into the study area. The researches on this topic are meager. There is very little research on the topic in the area. The available research highlighted the problem of environmental health impacts of the wastewater in the study area (Ahmed et al., 2017). The researchers understand that the sugarcane factory has an important role and contribution to the national economy; nevertheless, the study analysis demonstrates the chemical features variations in the wastewater produced by the Assalaya sugarcane factory, which affects the society and development in the study area. The importance of this research is exhibited by the fact that its analysis shed light on the untreated effluent discharged in the White Nile, which is a primary source of drinking water for both humans and animals, and this may sooner or later affect the health of the local community as well as development plan in the study area. This research is also expected to be an essential source of information and knowledge for planners and decision-makers who made and remade health and environmental policies at the local and country levels.

METHODS

The methods of this study have been performed in several stages, including the data collection stage, selection of sample sites and measured parameters, determining the reference level, and finally, the analysis stage. These can be detailed as follows.

Two sources of data were used for this study. First, the primary data for this research were collected from the field, where twenty (20) wastewater samples were taken during January-March 2021 from the outlet of the Assalaya sugarcane factory to the downstream. Second is the secondary data published materials as well as the reference level, which are based on recommendations of the Sudanese Standard Metrological Organization (SSMO)

The sample sites for measuring chemical features variations of wastewater were selected based on systematic sampling techniques for the selected site, using Global Positing System (GPS). The first sample site was picked up from the factory outlet at intersection of longitude 32^0 39’ 57’ and latitude 13^0 17’ 53’, while the last sample site was taken from downstream at intersection of longitude 32^0 39’ 21’ and latitude 13^0 17’ 44’ (40 kilometers from the first sample site). The distance between each sample site and the next one was two kilometers, as shown in Figures 1 and 2A, 2B, 2C, and 2D. The samples from the second to sample no fifteen presented the wastewater course until the mouth of the wastewater canal, where it enters into the White Nile River (meeting area). Besides, the study has taken one (1) sample from the upstream direction of the White Nile River (50 Meters) from the wastewater mouth. In addition, four other (4) samples were taken from the downstream direction of the river body at 50 M and 150 M from the wastewater mouth.

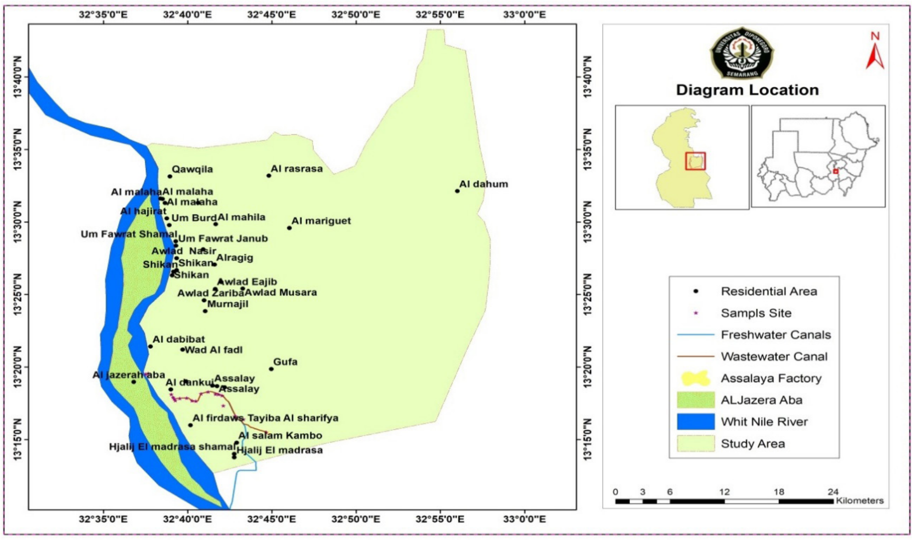

Figure 1. Sample Sites

Figure 2A presents the first wastewater sample at the factory outlet. While figures 2B, 2C, and 2D present wastewater samples were taken from the wastewater course.

Figure 2A. Factory Outlet

Figure 2B. Ten Kilometers from the Factory Outlet

Figure 2C. Fifteen Kilometers from the Factory Outlet

Figure 2D. Twenty Kilometers from the Factory Outlet

The measured parameters include pH at 21.1C^0, Total Hardness, Phosphate (PO_4), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD).

The reference level is based on SSMO (2008) recommended levels, as shown in Table 1. pH is a significant parameter of industrial discharge that must be controlled within the standard limit, which is significant for various chemical and biological processes in the treatment of wastewater (Wang et al., 2019). The pH measurements reflected in acidity, alkalinity, or neutrality based on the results of measurements.

The study of water and wastewater hardness classification is critical (Kaya & Kaya, 2015). Water hardness can be classified as 0-60, 60-120, 120-180, 180-200, and > 280 for soft water, medium-hard, hard, extremely hard, and unsuitable for drinking water, respectively (Ali et al., 2014). Total hardness in this study is classified based on the value obtained in the analysis. Phosphate plays a vital role in the industrial process and plant/animal metabolism; consequently, it can produce waste by-products. High concentrations of nutrients can cause many problems with the water quality, such as acidification, eutrophication, and impairing the aquatic organisms' survival and growth (Mohsin et al., 2013).

The measurement of BOD is essential for aquatic organisms and for saving the life of microorganisms (Ma et al., 2020). The BOD is the amount of oxygen consumed by microorganisms for breaking down the organic substance (Kumar et al., 2019). Biodegradable organic matter in water provides nutrients for the growth of bacteria and other microorganisms (Gorde & Jadhav, 2013). As far as COD is concerned, a high level of COD indicates high level of pollutants and an increase in the consumption of oxygen by aquatic organisms that produce Chemical Oxygen Demand for wastewater (Shahata & Mohamed, 2015).

Table 1. Measured Parameters and Reference Levels

Measured parameters	pH	T. H	PO_4	BOD	COD
SSMO recommended levels	6.5-8.5	0-120 PPM	2 PPM	80 PPM	150 PPM

Analyses were conducted in the central laboratory for technical services & calibration (CLTSC), according to the standard methods for examining water and wastewater of the American Public Health Association (2017). Several parameters were measured to present the chemical features of wastewater variations and compared with the SSMO reference level, as shown in Table 1. Several instruments were used in data analysis to measure the determining parameters, such as a pH meter to measure pH concentrations and a BOD sensor to identify Biological Oxygen Demand. The study also used Microsoft Office Excel to probe the level of the variations of the chemical concentrations at different sample sites.

RESULTS AND DISCUSSION

By conducting chemical examinations of wastewater on the 20 samples collected, the study revealed differences in concentrations of the measured wastewater parameters, as shown in Table 2.

Table 2. Results of Measured Parameters

Sample site No.	Sample sites		Measured Parameters				
	Longitude	Latitude	pH	T. H	PO_4	BOD	COD
1	32^0 39' 57'	13^0 17' 53'	5.59	Nil	400	107	49000
2	32^0 39' 34'	13^0 17' 52'	4.55	80	670	390	6600
3	32^0 40' 30'	13^0 17' 40'	5.28	470	38	76	2750
4	32.67119	13.29508	7.86	50	0.22	15	20
5	32.67973	13.30269	7.39	280	18.5	112	860
6	32.7007	13.30044	5.58	70	0.7	40	330
7	32.69744	13.30215	5.41	90	0.36	117	320
8	32.6974	13.30222	5.47	75	0.59	70	330

Sample site No.	Sample sites		Measured Parameters				
	Longitude	Latitude	pH	T. H	PO_4	BOD	COD
9	32.7007	13.30045	7.24	80	0.80	45	86
10	32.7007	13.30044	7.7	105	0.56	67	320
11	32.70069	13.30044	7.85	100	0.33	56	420
12	32.70069	13.30044	7.13	100	0.16	26	210
13	32.70071	13.30047	7.35	95	0.57	48	125
14	32.70073	13.30052	7.25	110	0.56	29	230
15	32.70073	13.30054	7.4	85	0.39	50	26
16	32.7007	13.30055	7.19	100	0.097	64	1000
17	32.70052	13.30067	7.93	135	0.97	21	360
18	32.68704	13.30497	8.39	170	0.86	51	420
19	32.65502	13.2975	7.38	115	0.37	53	60
20	32^0 39' 21'	13^0 17' 44'	7.13	100	0.28	48	100

The pH values vary between moderate acidic and alkaline, and these values are within the permissible limit except for one location with alkaline traces in the 18^{th} site, as shown in Figure 3. The SSMO, 2008 emphasizes that the pH standard is 6.5-8. The pH values depend on several aspects, mainly the geology of the river catchment, river flow, and wastewater discharges. The wastewater with high pH values can facilitate the solubilization of ammonia, heavy metals, and salt materials, while low levels of pH show an increase in the concentrations of carbon dioxide and carbonic acid. Hence, posing, therefore, it can cause problems for aquatic life when the concentration is below the standard required. Overall, the acidity concentration in outlet sites and the areas ranged from 4.55 to 5.47; meanwhile, 5% of the samples are alkaline compared with the SSMO standards.

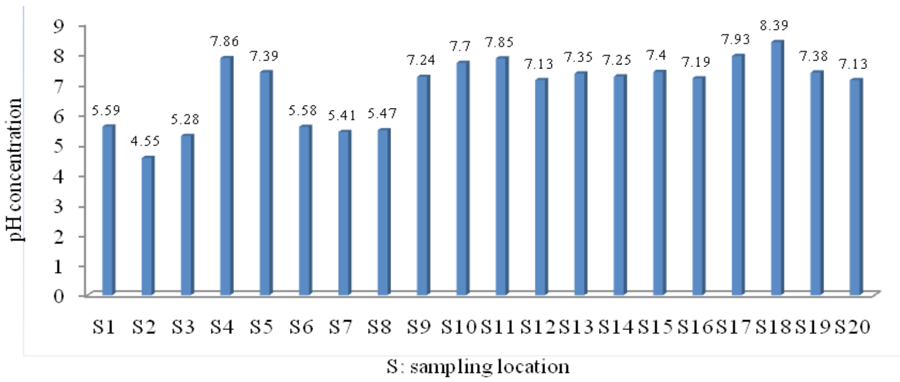

Figure 3. The pH Values in the Study Area

Wastewater in the study area has a significant impact on pH. Comparing the pH readings in the study area with wastewater in India, it is found that the Indian control pollution central guides for sugar industries are within the range of 6.5 - 8.5; such readings conform with the SSMO, which ranges between 6.5 - 8.6. Based on the results for pH, it is found that seven locations do not conform to the standard range, six of them are acidic (sites number 1, 2, 3, 6, 7, and 8), and one site is alkaline (site number 18). The pH in the first site is acidic because of its vicinity to the outlet, and the second site is next to the wastewater ponds. This study's results are similar to those of the study conducted by Magadum et al. (2017); pH ranges from 5.2 - 8.6.

Total hardness, i.e., measurement of minerals (divalent calcium and magnesium) content in wastewater, oscillates from one site to another, ranging between soft, medium-hard, hard, extremely hard, and unsuitable. All the locations have a percentage of hardness except the first site, with a value of 0, as indicated in Figure 4. If we scan through SSMO, the percentages of hardness oscillate from 0-60, 61-120, 121-180, and > 180 for soft water, medium-hard, hard water, extremely hard, and unsuitable for drinking water, respectively (Lin, 2014).

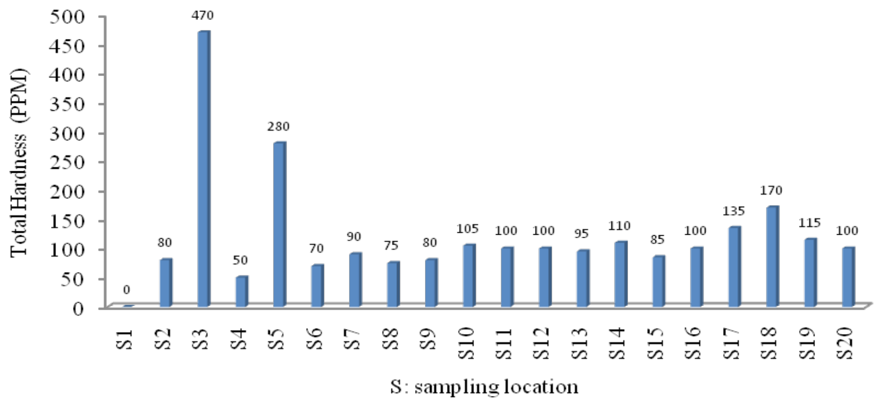

Figure 4. Total Hardness in the Sample Sites

Based on the results, 70% of the samples are medium-hard at sites 2nd,6th,7th,8th,9th,10th,11 th,12th,13th,14th,15th, and 16th. It suggests that calcium content contaminates most of the samples during sugar production due to chemical utilization. Around 10% of the samples were recorded as soft water with 0 and 50, located in the first and fourth sites. The concentration of Nill (0) is located in the outlet where the hardness is not defined. The other sites show the Total hardness with some traces of calcium and magnesium bicarbonate Ca HCO_3+ Mg HCO_3 in the water. Hard water is presented by 10% as well, located in the 17th and 18th sites. Both sites are located downstream where the accumulation of calcium bicarbonate and other elements is not met. The unsuitable water is presented by 10%, with 470 and 280 located in the third and fifth sites. The topographic aspects influence the third and the fifth sites as they are located in the wastewater pond. According to the studies conducted by Lerga and Sullivan (2008) and from a health point of view, Calcium and Magnesium should not be over 40–80mg/L and 20–30mg/L, respectively, with a total water hardness of 2–4 mmol.

The study has depicted the various amounts of Phosphate in water at different sites, as shown in Figure 5. A significant amount of concentrations are found at the factory outlet, where 20% of the samples exceed the standard level for phosphates. The values are gradually decreasing towards the downstream area.

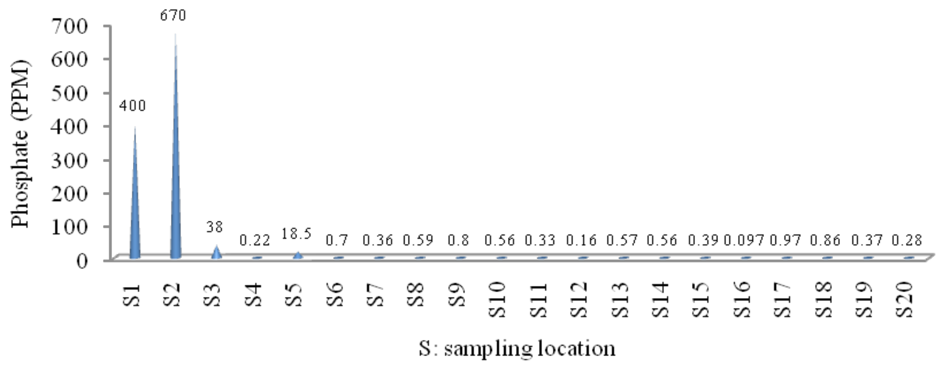

Figure 5. Phosphates (PO_4) in Wastewater

PO_4 in wastewater should contain 2 mg/L, but the results prove that the water in some locations contains PO_4 more than the recommended level. The first site, with 400 ppm, is considered high, located in the factory outlet. The second site, with 670 ppm, is attaining the highest amount among 20 sites as it is located in wastewater ponds. The location of the third site is located near wastewater ponds, and the fifth site is around the street; both have a value of 38 ppm and 18.5 ppm, respectively. Based on a study in Japan, PO_4 can cause massive health concerns such as kidney diseases, acute hypophosphatemia, enemas, acute or sub-acute kidney injury, bone disease, and increasing incidence of kidney disease (Komaba & Fukagawa, 2016). PO_4 in the effluent is due to the use of PO_4 for solubilizing hemicellulose from sugarcane and cane juice purification during sugar production. The study showed that the BOD values are within the standard limits. However, 20% of the wastewater samples exceed the range required. These samples are located at the outlet of discharged water, as shown in Figure 6.

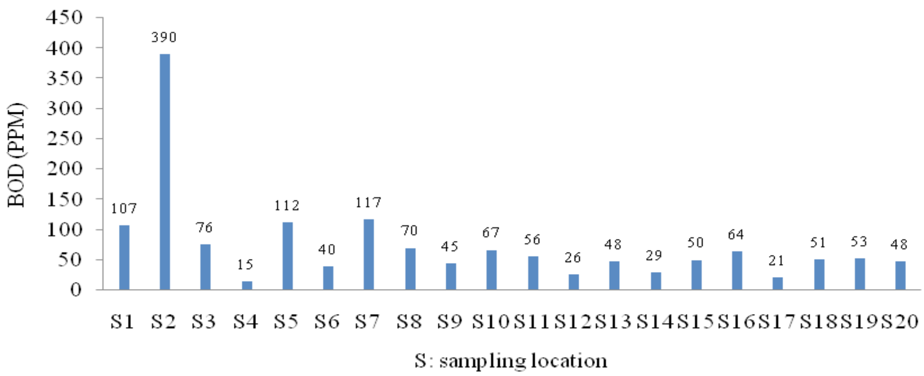

Figure 6. Biological Oxygen Demand

Most locations are within the permissible limit except in four sites, i.e., 1st, 2nd, 5th, and 6th. The second site shows the highest concentration with a value of 390 ppm due to the accumulation of wastewater for an extended time, as it is located in an open area, leading to increased amounts of organic materials triggered by wind causing high amounts of BOD, followed by location number 7 with apparently numerous grasses and weeds inside the canal. The fifth location has a value of 112 ppm; its values are influenced by wastewater discharged by the roadside close to the factory area. The first location shows a record of 107 ppm and is exceeding the standard limits. Sahu and Chaudhari (2015) shows that untreated wastewater effluent of BOD was 1700–6600 mg/l. The values of BOD are pretty significant compared with the current study, with a value of 390 ppm. Another study conducted in Vahirab River found that the BOD standard value for inland surface water was 6 mg/l or less; a higher amount can threaten the aquatic ecosystem (Ahmed et al., 2015).

A substantial amount of chemical materials are dissolved in wastewater, as shown in Figure 7. The study believed that the chemicals found in wastewater are considered a fundamental chemical input in sugar production, such as Calcium, Phosphate, Chloride, and Sodium. According to SSMO, the permissible limit of the COD is 150 ppm. Sahu and Chaudhari (2015) shows that untreated wastewater effluent of COD was 2300–8000 mg/l.

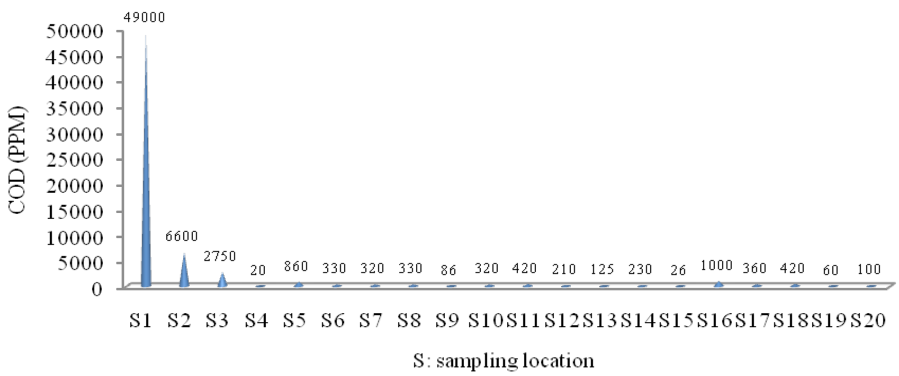

Figure 7. Chemical Oxygen Demand

The first location, with an amount of 49000 ppm, is the highest value since the site falls within the factory outlet with considerable amounts of chemical compounds. The recorded second site is attaining an amount of 6600ppm situated at the wastewater ponds. The most negligible value is 20 ppm, recorded for the fourth site, presented as an acceptable level as it is situated in the central locations due to its flow area toward the downstream. All the values are above the standard range except for sites fourth, ninth, 15th, 19th, and 20th, with respective concentration values of 20 ppm, 86 ppm, 26 ppm, 60 ppm, and 100 ppm. A previous study conducted by Shahata and Mohamed (2015) in Egypt revealed that the COD value was 19.5 mg/l and varied from 18 to 21 mg/l. The allowable level for COD stated by the 48/1982 law is 40ppm. This law was issued by the Ministry of Public Works and Water Resources (MPWWR) of Egypt concerning protecting the Nile River against pollution. Compared to this study, there are some discrepancies in the values and standards limits. The COD in the previous study was 19.5, while the highest one for this study is 49000 ppm. This study shows that increasing soluble chemical materials used as input materials can increase COD and significantly affects the environment (Qureshi et al., 2015; Saejung & Salasook, 2020).

The maximum concentration (49000 ppm) indicates a higher concentration of pollutants (Divya & Belagali, 2012). Untreated wastewater with high COD was found in the outlet of Assalays Sugar factory as the data analysis indicated 49000ppm, 6600ppm, and 2750ppm at the factory outlet besides the second and third sample sites, respectively. This situation is conducive to growing organisms such as Bacteria and algae (Parsaee et al., 2019).

CONCLUSION

The study emphasized that there are variations in chemical features due to the pH concentration that ranged between acidic, alkaline, and neutral. Acidic concentrations are located in sites 1, 2, 3, 6, 7, and 8, and only one site is alkaline (site 18th), while others are with normal concentrations. Concerning total hardness, 70% of the samples have soft-moderately hard values, 10% is soft water, 10% is medium-hard, and 10% is unsuitable. Regarding PO_4 is considered high, located in the factory outlet, the second site with 670 ppm is the highest value among the 20 sites as it is located in wastewater ponds. Concerning the BOD, most of the sites are within the permissible limit except for four sites: first, second, fifth, and sixth. The second site shows the highest concentration due to the accumulation of wastewater for an extended period. As for COD, most values do not conform with the permissible limit of the SSMO reference level. This situation creates a suitable environments for organisms such as Bactria and algae and causes many diseases such as kidney diseases. To mitigate and reduce the effect of wastewater on the environment, it is recommended that biological treatment using anaerobic treatment process to supply and reduce pollutants should be applied in the study area. To benefit from wastewater and furnish an additional source of potable water for human and animal uses, suggestions are made for introducing a purification process to part of the wastewater. However, there are no active laws, regulations, and standards issued by the relevant authorities (SSMO) which should be considered. Finally, it is highly recommended that the factory authorities comply with the various environmental laws, ordinances, and regulations issued by the Sudan Higher Council for Environment and Natural Resources and adopt a green production policy to achieve sustainability.

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