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WASTEWATER MANAGEMENT AND DEVELOPMENT IN KHARTOUM LOCALITY, SUDAN

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ABSTRACT

The fast-growing population in Khartoum Locality of Sudan has resulted in increasing the volume of wastewater generated by domestic, industrial and commercial sectors. This study aimed to assess two wastewater treatment alternatives based on two technologies, stabilization ponds and Moving Bed Biofilm Reactor (MBBR), decentralized and centralized wastewater treatment systems to support decision-making for selecting the most suitable and practical alternative for wastewater treatment in Khartoum Locality, as well as to rank the two wastewater treatment technologies based on the following three scenarios: (1) land requirement (2) cost and (3) citizens' opinion about the wastewater treatment system. Software of MapInfo, GPS Area Calculator, BioWin and GIS were used to reach the targets. Results of laboratory analysis showed that the quality of wastewater exceeded environmental limits. Centralized west Soba Plant, Biochemical Oxygen Demand (BOD: 160), 90% of population did not agree to establish a sewage plant in the neighborhood. The cost of centralized system treatment in Khartoum Locality is 155599$. The BioWin results illustrated that the capacity of each alternative is similar in terms of domestic wastewater treatment efficiency. As well results showed that a centralized wastewater treatment system is more suitable than decentralized wastewater treatment systems based on their environmental impacts. These findings provide evidence for decision-makers to select a suitable alternative for wastewater treatment in order to promote access to safe sanitation and sustainable urban wastewater management in Khartoum Locality.

KEYWORDS: Centralized, decentralized, wastewater collection and treatment disposal: BioWin; Khartoum Locality.

1. INTRODUCTION

Access to safe water and sanitation is intrinsically connected to the issue of sustainable development worldwide. Today over half of the global population lack access to safe sanitation services and only an estimated 20% of wastewater generated globally receives treatment (WHO/ UNICEF 2019, UN2017) [1]. The globe faces many risks due to the continued deterioration of the urban environment which created a number of environmental challenges that have become difficult for the most important efforts to achieve urban sustainability. The majority of people suffer from a lack of safe sanitation, but the fastest growing cities such as Khartoum are the hardest hit because they grow faster than the supply of services to their population [2]. It is necessary to upgrade and improve the accessibility of safely managed sanitation services and suitable wastewater treatment systems and to promote the international targets of sustainable development goals (SDGs) of Article 6 [3] and the international strategy for water, sanitation and hygiene for 2016–2030 [4]. An approximated 800 children under the age of five die every day from diseases due to poor sanitation, hygiene or unsafe drinking water (WHO 2019) [5]. The same water and sanitation-related diseases can cost some countries up to 5% of their annual GDP, and interventions of basic sanitation in developing countries have proven to give at least five times the return (WHO, 2019; Hutton, et al., 2015).[6] Therefore, to find appropriate technology potentials for wastewater treatment and sustainable environmental development, socio-economic and environmental conditions have to be considered for each specific region. Particularly, Khartoum State faces an issue of municipal wastewater management due to lack of suitable sanitation and wastewater treatment systems, including a sewerage network system. Most of the wastewater from domestic, commercial and industrial areas in Khartoum Locality is directly discharged into River Nile (White Nile and Blue Nile). Khartoum is a city in a real crisis with regard to wastewater disposal. From the perspective that the development of the sewage system is the most serious problem facing the State of Khartoum, the indicators are numerous. The situation is very late for Sudan compared with other countries [7]. As reflected in the report prepared by the World Bank, which was described as follows: hundreds of effluents are discharged from the domestic wastewater disposal tank in the sub soil, so that flies and mosquitoes are multiplying, creating high rates of water-related diseases. The authorities permit the discharge of sewage from the septic tanks in groundwater, despite its characteristics of being unsafe. Almost all wastewater discharged from the septic tanks in Khartoum Locality finds its way into the shallow depths of the aquifers' layers, which are not confined after infiltration through wells drilled to penetrate soil layers to connect with the upper surface of the water table. The tolerance in the use of septic tanks made the residents find a solution to their problem and ease the pressure on officials and became the category capable not contribute. The critical issue appears in that the wastewater quality from average households has a biochemical oxygen demand (BOD) concentration of grey water discharged without treatment ranges from 250 to 160 mg/L [2]. Those concentrations are higher than the national standard of discharged BOD concentrations from households (BOD < 15 mg/L) based on the National Environmental Standard in Khartoum Locality, 2018[2]. The aim to study wastewater management planning and development in the studied area is to enhance the efficiency of the environmental protection of water and human health qualities in Khartoum Locality.

2. MATERIALS AND METHODS

2.1 Study area: Khartoum locality is located geographically at the confluence of the Blue Nile and the White Nile. It is bordered to Jebel Aulia locality to the west, Al-Jazeera State to the south and Blue Nile in the east (Fig: 1). Khartoum is relatively flat, at elevation of 385 m. The total area of the locality is 135.33 km^2. The population is 834,573 people.

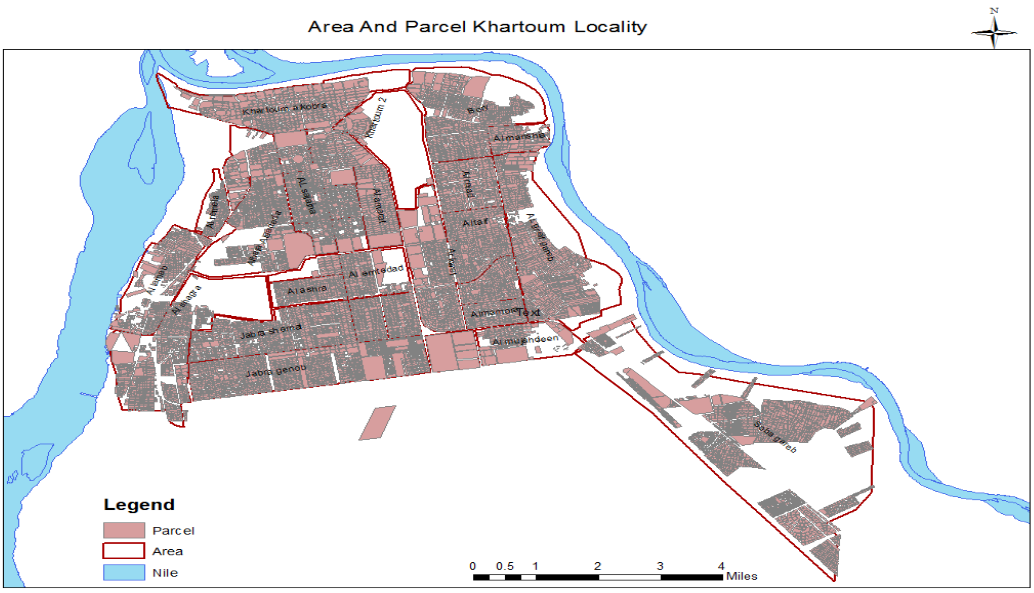

Fig (1): Khartoum Locality Area.

2.2 Data collection

The data used for designing and modeling of a wastewater treatment system were the population in the study area, the raw wastewater parameters in the influent and the daily water and wastewater generation. The software programs used were MapInfo, GPS Area Calculator, BioWin and GIS. An integrative approach for wastewater treatment and reuse projects is exemplified wastewater issues.

2.2.1 Questionnaire survey

A questionnaire survey was conducted to collect information about agreement of the population for constructing Wastewater Treatment Plant (WWTPs) and will be used as a decision support tool to inform future program planning. Drawings on a sample of 1000 questionnaires were completed in Khartoum Locality - Khartoum State, Sudan.

2.2.2 Treatment plants

Evaluation of the efficiency of wastewater treatment systems for the purpose of selecting the appropriate system should be related to several conditions, such as environmental, economic and social parameters [8]. In this paper, three factors were taken into consideration to choose a suitable wastewater treatment system: land requirements, cost and citizens' opinion about the wastewater treatment system. The tests for wastewater before and after the treatment in west Soba station, which treats sewage by ponds and Arkwet Hospital Al-galeb Plant, which treats sewage by MBBR, were conducted. The program used were MapInfo, GPS Area Calculator, BioWin and GIS to reach. These factors were examined for decentralized and centralized treatment systems. The results obtained were to be compared by standard values for network design. Figure (3) presents a flowchart for the analysis of this study.

2.3 Data Analysis

The data collected in Arabic from the survey and were translated into English and entered into Microsoft Office Excel “version 2016". Data were transferred to and analyzed using Map Info to calculate the number of houses, Excel to calculate the amount of wastewater, GPS Area Calculator to calculate agricultural areas, BioWin wastewater treatment process simulator designing, upgrading, optimizing wastewater plants and was used for illustrating treatment plant and analysis, GIS to determine location of waste water stations and their accessories and suggest a preliminary location for treatment plants in the Khartoum Locality. Several preliminary operations, such as reviewing, coding and data entry were performed before data analysis.

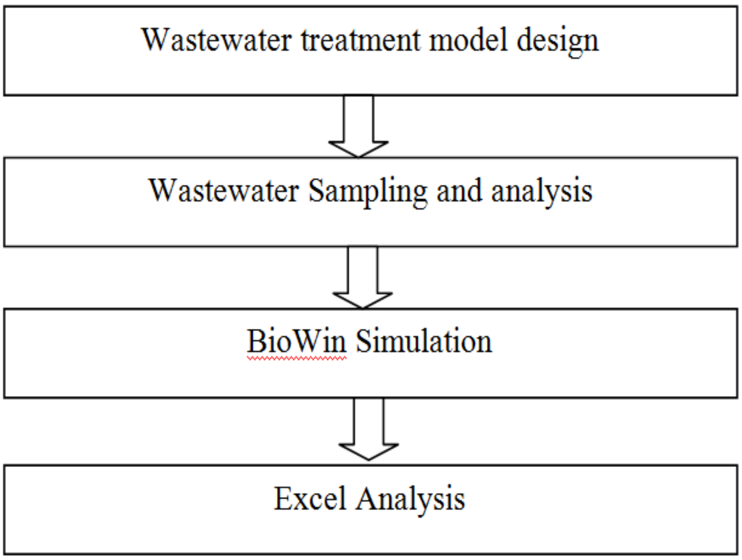

Figure 2: Analysis flow chart for the optimized design of a wastewater treatment system in Khartoum Locality.

2.3.1 Wastewater Estimation

In general, the wastewater ratio is assumed to be 80% of the supplied water in the generated wastewater use discharged as wastewater according to wastewater engineering [16] and the preliminary feasibility report of wastewater management in Khartoum Locality [2]. Therefore, the domestic wastewater flow was calculated as shown in Table (1) as follows: For defining the capacity of WWTPs, 5 plant types were designed in the study area. The future population in 2048 is estimated to be 1,855,998 people, therefore, in this research; a household size of 7 people was adopted for calculating the wastewater flow for all plants. Table 2 shows the required number of WWTPs and their design capacities based on the population projection and designed plant types.

Table 1: The quantity of wastewater to be treated and the available empty agricultural lands in Khartoum locality.

No	Name of plants	Open irrigated space (acre)	Waste water m^3/day	Design m^3/day	Unit price ($)	Station cost ($)
1	Soba west	682.65	5483.5	10000	1000	10000000
2	AL-Jerif gareb	1033.3	19685.23	20000	800	16000000
3	Soba Plant	-	19685.23	20000	800	16000000
4	Al ghaba (forest)	286.35	35318.304	40000	800	32000000
5	Al Guoz	412.28	38076.88	40000	800	32000000
6	Total	1897.9	118249	130000	-	106000000

2.4 Wastewater Treatment Model

The wastewater treatment systems considered for decentralized, and centralized systems consist of two models based on decentralized and centralized systems that are available in developed and developing countries. In particular, two technologies, stabilization pond and MBBR, among many others were selected and utilized for the analysis of each system as illustrated in Figures 3, 4 and 5) because they are easy on operation and maintenance, highly efficient and appropriate technology. The three wastewater treatment models considered in the BioWin simulations.

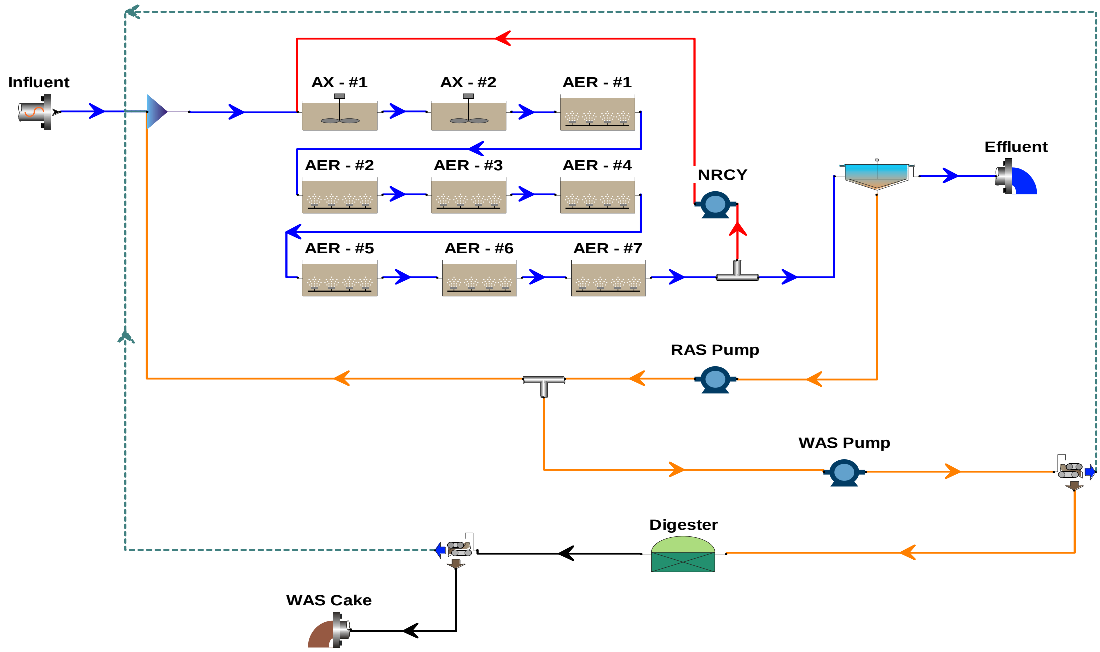

Fig. 3: Al-Jarif ghareb treatment plant with design capacity 20.000 m^3/day.

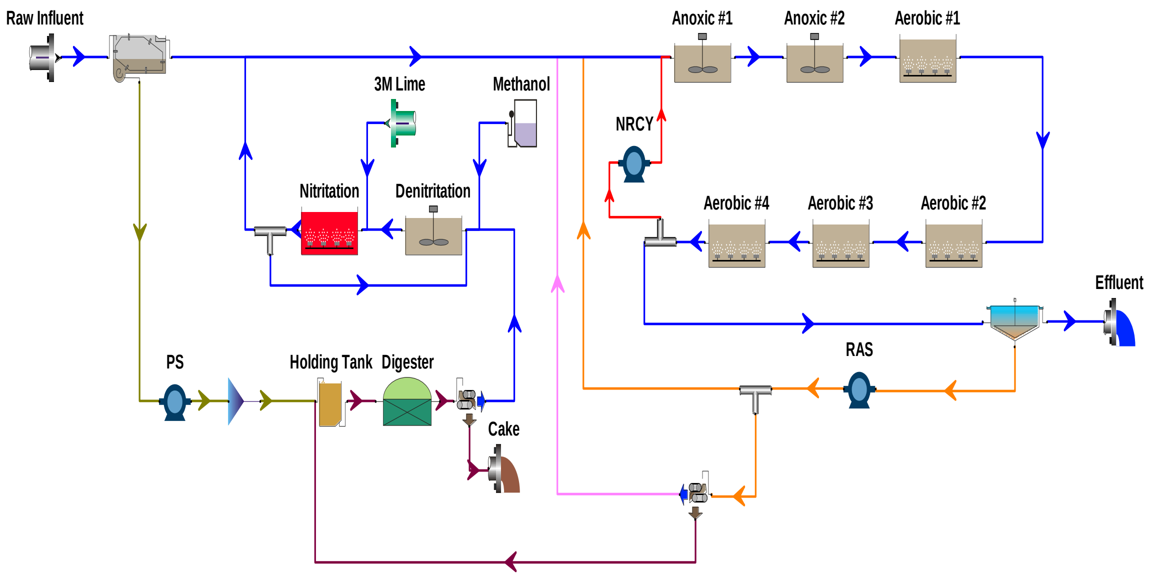

Fig. 4: West Soba treatment plant with design capacity 10,000 m^3/day.

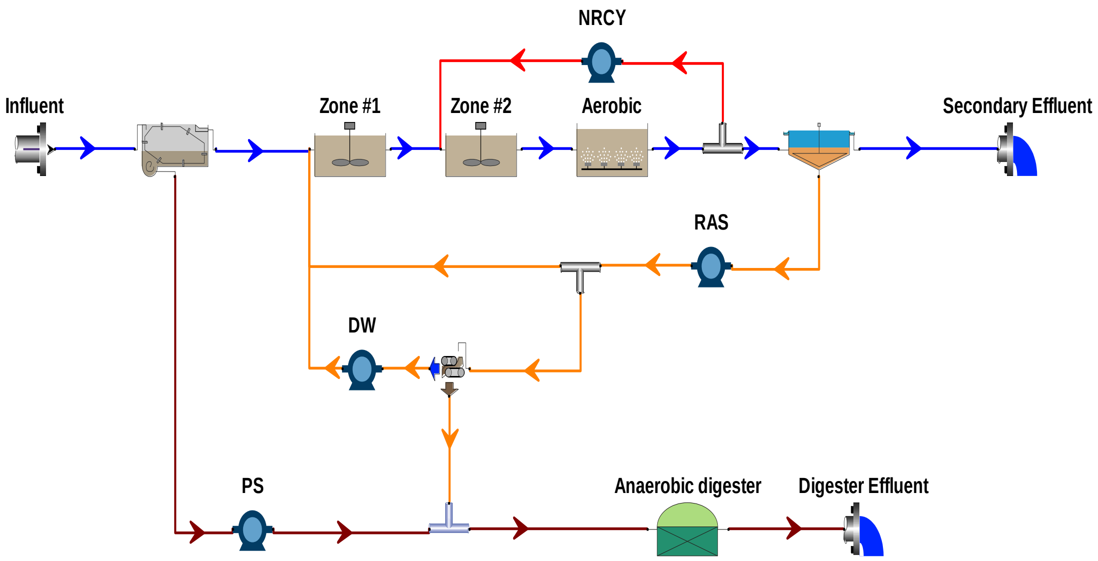

Fig. 5: Centralized West Soba Plant with design capacity 130.000 m^3/day.

When designing the three models, we have thoroughly checked and referred to the following guidelines: A guideline to the Development of On-Site Sanitation[10], On-site Wastewater Systems: Design and Management Manual[11], Design Manual: On-Site Wastewater Treatment and Disposal Systems[12], On-Site Wastewater Treatment Systems Manual[13], Water and Wastewater Calculations Manual[14] and Wastewater Engineering.[15,16,17] All of these are main guidelines and manuals for designing sanitation and wastewater treatment systems for engineers in this research field.

2.5 Decentralized system Scenario (1)

Using the decentralized system for each area separately and draining the treated water inside each area to irrigate the grass and trees, and draining the rest to the Nile according to the required Sudanese specifications. Table (1) represents the quantity of wastewater to be treated in Khartoum locality.

2.6 Centralized West Soba Treatment Plant Scenario (2)

Establishment of a new treatment plant with a capacity of 130,000 m^3/day (activated sludge process) to replace the system of basins that do not have a buffer zone with respect to the residential areas close to the treatment plant. Table (2) shows the cost of centralized West Soba Treatment Plant.

A line from the west Soba central station is to connect proposed area of the west Soba, estimated at 1,000 acres, to drain the treated water, the flow of water inside the network according to the natural slope and not by pumps.

Table 2: The cost of centralized West Soba Treatment Plant in Khartoum locality.

No	Name of plants	design m^3/day	Unit Price ($)	Station cost ($)
1	Centralized west Soba Plant	130,000	800	104000.000
3	Total	130,000	-	104000.000

Table 3: Proposed pumping and lifting stations in Khartoum Locality.

No	Name of lifting station	design m^3/day	Unit Price ($)	Station cost ($)
1	Burry	30240	273.368	8266.666
2	Alsaha Alkhadra	30240	273.368	8266.666
3	West Soba	30240	273.368	8266.666
4	Al-Jarif gareb	30240	273.368	8266.666
5	31	30240	273.368	8266.666
6	32	30240	273.368	8266.666
6	Total	-	-	51599.996

2.7 Geographical Information System (GIS)

GIS was used in determining locations for treatment plants, pumping stations and sewerage network. Fig (6) depicts the suggested preliminary location for treatment wastewater plants in the Khartoum locality.

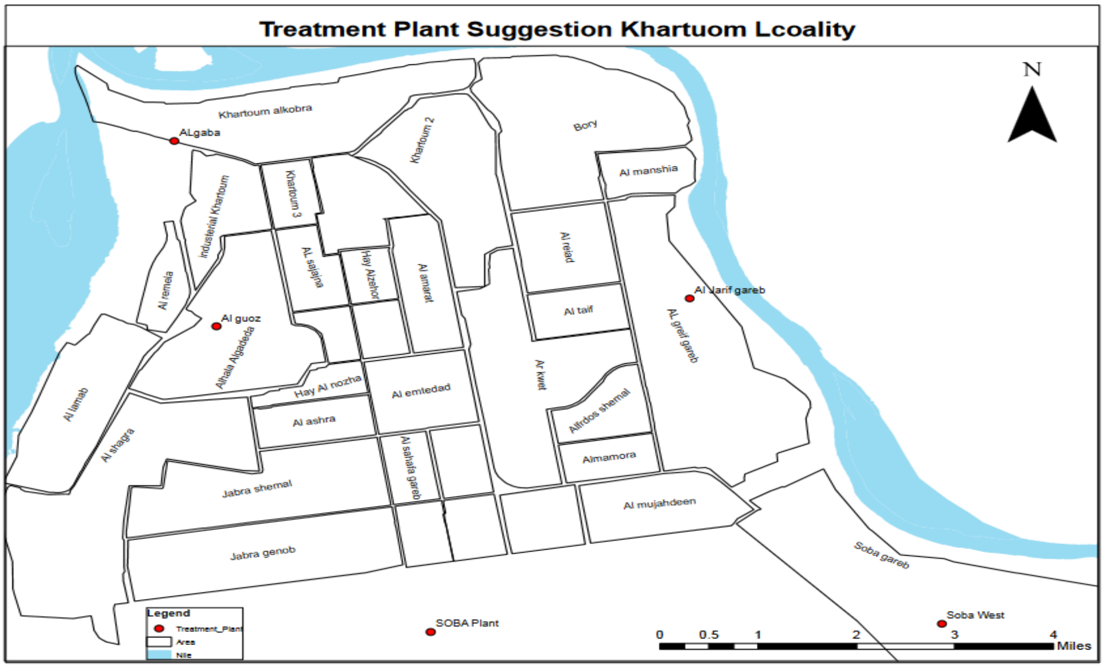

Fig. (6): Suggested preliminary location for treatment wastewater plants in the Khartoum locality.

2.8 BioWin Simulation

BioWin (version 6.0) developed by EnviroSim Associates is well-established computer software for wastewater treatment process simulation. BioWin is used to design, upgrade, and optimize all types of WWTPs with physical, biological and chemical process models [18]. In this study, to produce a reliable result rather than testing various tools, BioWin was applied to create tow wastewater treatment models and each process of each model was operated one by one in the BioWin simulation. The results of the BioWin simulations then were observed to check their efficiencies to determine whether the resulting effluent parameters satisfy the constraints of the Khartoum state standards. First, in the BioWin simulation, the BOD effluent object was used to impose the input data for the raw effluent with constant inflow based on the sampling and analytical results for BOD, COD and TSS concentrations and wastewater engineering. Finally, after defining each element and its parameter in each wastewater treatment model, the BioWin simulations for each model were continuously conducted for five days and the simulation results, such as the effluent concentrations of BOD, COD, and TSS, were evaluated to determine whether or not they satisfy the water pollution control standards of Khartoum Locality. If the effluent concentrations did not satisfy the standards, then the tunable parameters at each step of each model were adjusted and the simulation was repeated until the effluent met the standards.

3. RESULTS AND DISCUSSION

3.1 Bio Win Simulation

Table (4) and Figures (7 and 8) illustrates the simulated effluent BOD, COD, and TSS concentrations of the two wastewater treatment models. The constraints of the three wastewater effluent parameters in controlling the discharge of wastewater from households are BOD: 15 mg/L, COD: 75mg/L, and TSS: 30 mg/L. Therefore, all the concentrations do not satisfy the water pollution standards of Khartoum Locality for household wastewater. In terms of land requirements, there are open spaces and public areas, inside the Khartoum locality; it must be irrigated with treated sewage water. In the case of the central sewage treatment system, it is difficult to benefit from the treated water due to increase in the operational cost, while it can be used in the case of a decentralized system, while the central system contains spaces outside the proposed Khartoum locality, it can be used to drain the treated water that is in excess of the area's needs. But in terms of cost, the decentralized system appears less easily, so it is easy to implement at the lowest cost, while the central system shows a high cost. According to the questionnaire (attempting to find solutions to the sewage problem in the state of Khartoum), 90% of residents disagreed to establish a sewage station in neighborhoods, while 20 % agreed.

Table 4: Results of tests for wastewater treatment at two plants.

Test	Unite	West Soba station		BioWin	Arkwet Hospital Al-galeb Plant		BioWin
		In let	Out let	Out let	In let	Out let	Out let
BOD	Mg/L	330	160	19.15	250	90	6.64
COD	Mg/L	650	483.3	67.56	560	256	53.39
TSS	Mg/L	160	100	23.03	220	20	19.51

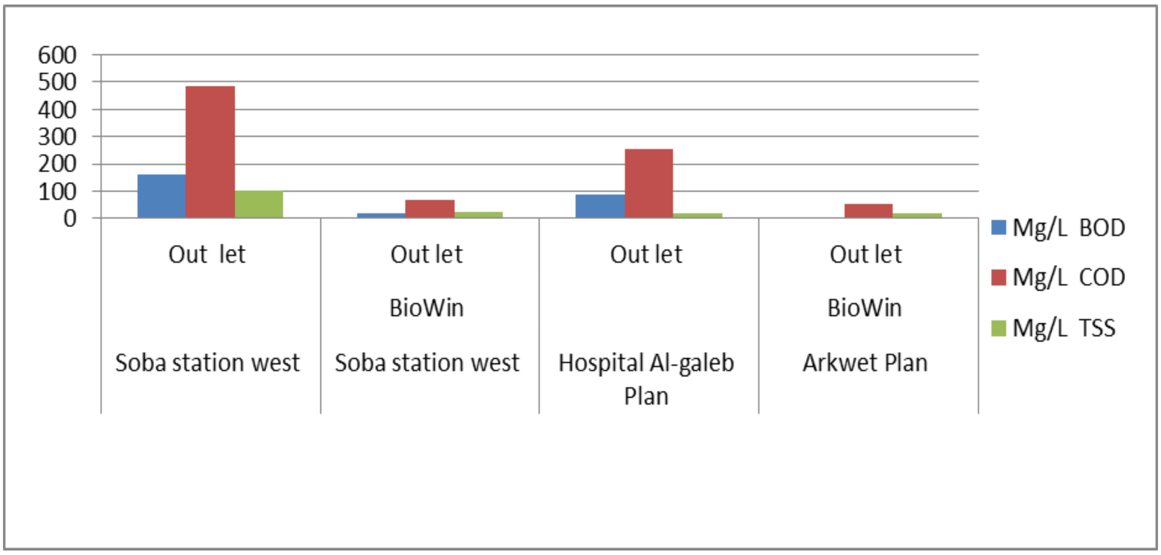

Figure 7: Comparison of plant efficiencies before and after designing BioWin.

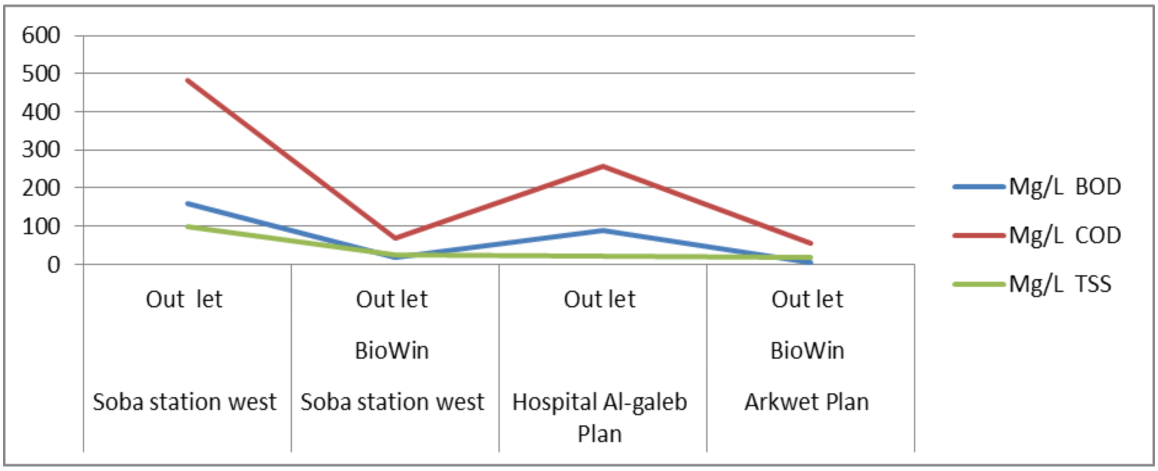

Figure 8: Plants efficiencies before and after the BioWin.

Results of laboratory analysis showed that the quality of wastewater exceeded the legal environmental limits and that all stations operate outside the environmental limits of the system allowed to preserve the water resources of Khartoum Governorate**.**

3.2 Choosing the optimum wastewater treatment system

Designed to study the different impacts of each criterion in terms of land requirements and cost, a decentralized system appears to be better, but according to the survey, the Khartoum state government rejects the sewage flowing into the Nile waters. Accordingly, we believe that the central system is the best wastewater treatment and disposal system in Khartoum locality, according to the questionnaire and the government's opinion.

4. CONCLUSIONS

This study assessed the two wastewater treatment systems based on two technologies, Stabilization Pond and MMPR, for Khartoum Locality, in order to upgrade treatment efficiencies and protect the urban environment through the improvement of sanitation and wastewater treatment for a densely populated area. In the analysis, the main three steps consisted of the wastewater engineering calculation and design, the BioWin simulation to validate the calculation and design and the Excel analysis. The results showed that the wastewater treatment systems can decrease BOD, COD and TSS concentrations in wastewater effluents, achieving the Khartoum Locality environmental control standards. These systems also vary in their efficiencies in terms of environmental impacts, such as land requirement, cost, the population and the government's opinion. Based on the analytical results, model of the centralized treatment system was the most appropriate system among other systems based on treating BOD, COD, and TSS under the criteria. Moreover, the combined wastewater treatment system is the optimum design for wastewater treatment in the growing city of Khartoum Locality in term of environmental impacts. The combined approach between BioWin and Excel is useful for assessing sanitation and wastewater treatment development, as demonstrated in this study. BioWin can be used for validating all processes step-by-step until the final effluent satisfies the target standard of a study site. This research only provides fundamental analysis for wastewater treatment and alternative selections based on environmental protection conditions. Other technologies have to be considered and more criteria, such as sludge management, transportation of sewage to the WWTP, discharge of the treated effluent, and economic cost for installation, operation and maintenance. Furthermore, in the combination of several opinions for technology selection, it is also of importance to provide logically and practically sound weights for criteria, specifically based on the opinions from experts, government and local people in appropriate wastewater treatment selection.

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