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Research article

The Impact of Wadefea Sewage Treatment Plant Effluents on the Surrounding Environment, Khartoum North, Sudan

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Abstract

The impact of Wadafea (Khartoum North, Sudan) sewage treatment plant effluent on the surrounding environment was investigated under laboratory conditions using standard methods. Two soil samples from each of three depths (0 – 30cm, 30 – 60cm and 60 – 90cm) covering the sewage affected plant soil (PS) and the non-affected control soil (CS) areas were collected. Two samples of water: well water (WW) and network tap water (TW) (as control) were also collected. Moreover, background (secondary) data pertaining to the sewage effluent characteristics during previous years (2009 – 2010), obtained from the station records were included in this study as well. The results revealed that the electric conductivity is relatively higher (1.6-19 dS/m) for the affected soil than for the non - affected soil (0.4-1.2 dS/m). High nitrate level (98 mg/l), violating the highest permissible level of 50mg/l, was noticed in well water while in network tap-water nitrate level is only 14 mg/l. The high effluent levels of BOD, COD, T.S.S and the high soil content of *E. coli* and total viable count of bacteria is indicative of insufficient treatment. The viable count of bacteria is higher in well water than in tap water. The detection of fecal streptococci bacteria in well water is indicative of fecal pollution.

It may be concluded that Wadefea wastewater treatment plant has negative impact on the surrounding environment since its effluent characteristics did not meet the recommended limits set by the local, regional and the international guidelines which renders it unsuitable for the various purposes in addition to the public health concern.

Keywords: Sewage effluent; treatment; disposal; standards.

Introduction

The excessive immigration of people from rural areas to the capital Khartoum as result of civil conflicts and desertification exerted a high shortage on the currently available public service facilities of the City, especially with respect to liquid wastes (sewage) treatment and disposal. The industrial facilities discharge a wide variety of liquids in the plant under the study. This has led to a decrease in the efficiency of waste treatment disposal and consequently deteriorated the surrounding environment. According to WHO (2004) wastewater obtained from industries is generally much more polluted than the domestic or even commercial wastewater.

Many previous studies reported that the use of wastewater in agriculture is a source of exposure to pathogens. Crop irrigation with untreated wastewater causes a significant increase in intestinal nematode infections among crop consumers and field workers, thus sewage treatment is necessary before sewage can be disposed of without producing undesirable or even harmful effects (Joseph & Salvato, 1992, Abdel Magid, 1996 and 2001, Abdel Magid and Al-Oud, 2000, Abdel Magid and Mohammed Ahmed, 2011). The air emissions and contaminants such as pathogens and volatile organic compounds that may be released from the wastewater treatment plant under the study become a health concern for the neighbors and a nuisance concern for the whole surrounding area. Therefore, the general objective of this study is to assess the impact of Khartoum North (Wadafea) wastewater treatment plant on soil and groundwater (well water) quality, whilst the specific objectives:

- To investigate the physico - chemical and bacteriological characteristics of the soil in the vicinity of the station.
- To determine the groundwater (well water) quality in the vicinity of the station.

Study Area:

Location:

The study site is in the suburb of El-hag Yousif about 8km North East of Khartoum North industrial area, Khartoum State, Sudan. It is bounded by longitude 32° 45\` 00\`\` - 32° 20\` 00\`\` N, and latitude 22° 15\` 00\`\` – 22° 40\` 00\`\` E.

Climate:

The climate of Khartoum State is semi-desert, with a hot summer and a warm winter. During summer thunderstorms associated with the northward movement of the intertropical convergence zone, produces rainfall with an average of 121.3mm (Meteorological Dept., 1971 – 2003). The average annual temperature is 30C$^{\circ}$, the highest monthly mean value is in May (41.8 C$^{\circ}$) and the lowest is in January (15.7 C$^{\circ}$). The average relative humidity is 31.1% with the highest mean value of 48% in August, and the lowest is 14.5% recorded in April.

Population:

According to the Central Bureau of Statistics (Analytical Report 2006), the population in Khartoum State has increased from 2,802,000 (1986) to 3,512,000 (1996) and to 5,522,000 in 2006. Khartoum State has the highest population density (169 person / km^2) in the year 2006 as it embraces the three largest cities in the country (Khartoum, Omdurman, and Khartoum North) beside the displaced people.

Methodology:

Soil and water samples collection:

To determine the impact of wastewater on soil and groundwater (well water) samples of both soil and water were collected as follows: Two soil samples from each of three depths (0 – 30cm , 30 – 60cm and 60 – 90cm) covering the sewage affected plant soil(PS) and the non- affected control soil (CS) areas were collected. Two samples of water: well water (WW) and network tap water (TW) (as control for comparison) were also collected.

Data Collection:

Secondary experimental data of Wadafea plant were collected from the sewerage system corporation, Ministry of physical planning and public utilities – Khartoum State. The characteristics of sewage effluent during the years 2009 – 2010 were obtained from the station records.

Assessment of the soil and groundwater (well water) quality:

Physico-chemical analysis:

These analyses were carried out according to the standard Methods for the Examination of Water & Wastewater (APHA, 1998) and Richards (1954). In these analyses, pH was measured by pH - meter (Model: 211- Hanna Instruments.).Electrical conductivity (EC, dS/m at 25 ^{o} C) was measured by conductivity meter (Model: Kent EIL 5007, Jenway- England). Sodium (Na^+) and potassium (K^+) were determined by flame photometer (Model: PFP7, Jenway- England) according to the APHA (1998). Calcium (Ca^{+2}) and magnesium (Mg^{+2}) were determined by titration with ethylenediaminetetra acetic acid (EDTA) disodium salt solution (0.02N). Nitrate (NO_3^-) was determined by the cadmium reduction method. Total dissolved salts (TDS), as reported in the results and discussion section, were determined by multiplying the EC value obtained by 640 according to Rhoades (1982). Particle size distribution (sand, silt and clay) was determined according to the pipette method adopted by the laboratory of the Dept. of Soil and Environment Sciences, Faculty of Agric., University of Khartoum, Sudan.

Bacteriological analysis:

Total viable count was carried out by using the pour plate method. The three - tube procedure using lactose broth (Difco) was used for estimating the most probable number (MPN) of coliform organisms. Tubes were incubated at 37°C for 48hr and the MPN was obtained according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1998, Harrigan, 1998). The confirmed coliform test was done by culturing positive tubes into brilliant green broth (Difco) and incubating at 37°C for 48hr.

Statistical analysis:

The results obtained (Tables 4 and 5) were statistically analyzed by using the computer programme (Excel software) to estimate the mean, range and standard deviation. The means obtained for the various parameters measured were evaluated according to the local SSMO (Sudanese Standards and Metrology Organization) (2002) standard and the international WHO (World Health Organization) 1993 standard.

Results and discussion

As shown in table (1), the pH values of the control soil (CS) ranges from7.9 at the 0-30cm depth to 8.2 at the 60-90cm depth, while that of plant soil (PS) ranges from 8.8 at the 0-30 cm depth to 9.5 at the 60-90 cm depth i.e., in both CS and PS the pH increases with depth. According to Arceivala & Asolekar (2007) soil pH values higher than 8.5 indicate the presence of sodium carbonate and/or high exchangeable sodium which may lead to high sodium adsorption ratio(SAR), a characteristic not desirable in agricultural soils. Ayers and Westcot (1994) indicated a pH range of 6.5 – 8.0 as normal for utilization of wastewater for irrigation. The SSMO (2006) adopted a pH range of 6 – 10 for disposing wastewater into rivers and recreational beaches. The salinity as EC (dS/m) of plant soil ranges from 1.6(dS/m) (TDS=1024mg/l) at the 0 – 30cm depth to 19 dS/m) ((TDS=12160mg/l) at the 0 – 60cm depth , at the 60 – 90cm depth the EC (dS/m) was 4.5 (TDS=2880mg/l) while that of the control soil is lower in magnitude than that of plant soil at all depths and it ranges from EC 0.4 (TDS=256mg/l) to 1.2 (TDS=768mg/l). According to the data obtained from the station records the salinity range as EC(dS/m) or TDS(mg/l) as shown in tables 4 and 5 for effluent from (Wadafea) treatment plant ranged between EC 0.20 – 6.2 (TDS =128 – 3968mg/l) with a mean TDS value of 1000 mg/l during the year 2009 (Table 4), while it ranged from EC 1.4 – 2.2 (TDS = 896 – 1408 mg/l)with a mean TDS value of 1081 mg/l during the year 2010. This confirms the high level of salinity in plant soil as mentioned above. The treatment station has not kept any records or data pertaining to the influent sewage. Abdel Magid and Mohammed Ahmed (2011) indicated that sewage effluent from Khartoum State wastewater plant at Soba which has a mean TDS range of 1008-1621 mg/l is well above the allowable recommended standards for land disposal and irrigation reuse as set by the SSMO (2006).

According to Brown and Jonse (2008) calcium is important in soil structure and other soil prosperities. The total calcium in soil commonly ranges between 0.10 mg/l to 10.0 mg/l, however, this study table 1 revealed that soils affected with sewage effluent have values amounting to 80.2 mg/l (0 – 30cm), 501.3 mg/l (30 – 60 cm) and 100.3 mg/l (60 – 90 cm). The highest level for Ca^{+2} was obtained in the second depth, while the non - affected soil have Ca^{+2}levels amounting to 40.1 mg/l (0 – 30 cm), 60.2 mg/l (30 – 60 cm) and 80.2 mg/l (60 – 90 cm). The excessively high level of Ca^{+2}in plant soil (affected soil) as compared to the non – affected soil (control soil) may be attributed to industrial wastewater disposed on land in the vicinity of the treatment station. On the other hand, the level of magnesium in plant soil amounted to 12.2 mg/l, in the first depth, 170 mg/l in the second depth and 12.2 mg/l in the third depth. It is clear from table 1 that the highest concentration of Mg^{+2} was obtained in the second depth, however, for the non - affected soil the levels were 12.2 mg/l, 12.2 mg/l and 24.3 mg/l for the three depths, respectively. Jepperson and Solley (2003) indicated that Mg^{+2} in soils varies from less than 0.05mg\l to over 1.0mg\l. Magnesium and it’s salts are used in many industrial processes and thus can be found in streams carrying effluents from these industries. Calcium plus Mg^{+2} were essential elements in assessing the soil suitability (fertility) for agriculture. The Ca^{+2}+ Mg^{+2} levels in plant soil were 92.4 mg/l, 671.3 mg/l and 112.5 mg/l in the three depths, respectively (Table 1). It is clear that the highest magnitude of Ca^{+2}+ Mg^{+2} was in the second depth for both of the affected and non – affected soils . In the control soil the levels of

Ca^{+2}+ Mg^{+2} were 52.6 mg/l, 72.4 mg/l and 1045 mg/l in the three depths, respectively. The increase in the magnitude of Ca^{+2}+ Mg^{+2} levels in affected soil may be attributed to continuous wastewater discharge to the neighboring soils.

According to table 1 the level of Na^+ in the affected soil at the various depths investigated amounted to 322 mg/l in the first depth, 3887 mg/l in second (high magnitude) and 966 mg/l in the third depth, while in the non - affected soil 161 mg/l, 483 mg/l and 230 mg/l were recorded for the three depths, respectively. This variation between the affected and the non - affected soil may be attributed to wastewater discharge, mostly of industrial origin.

The magnitude of K^+ in affected soil amounted to 4.3 mg/l (first depth), 72.3 mg/l (second depth) and 8.7 mg/l (third depth), while in the unaffected soil the levels of K^+ 19.6 mg/l, 1.6 mg/l and 4.9 mg/l were obtained, respectively. Jousma and Walter (2003) pointed out that the total K^+ in soil generally, ranges between 0.05 mg/lto 2.5mg/l.

In this study the magnitude of NO_3^- in the affected soil amounted to 110 mg/l, 250 mg/l and 210 mg/l for the three depths, respectively. (Table 1), while for the unaffected control soil the levels are 10 mg/l, 100 mg/l and 50mg/l for the three depths, respectively. The NO_3^- level obtained for tap-water was 14mg/l, while that for well water was 98mg/l. Both the WHO (1993) and the SSMO (2002) guideline values for the maximum NO_3^- level in drinking water is 50mg/l. The high level of NO_3^- may be attributed to sewage effluent usually disposed of to the land in the vicinity of the station and it may contaminate the groundwater by percolating in study area in the long run. The saturation percentage of affected soil amounted to 59.9, 30.99 and 33.8% for the three depths, respectively, while that of unaffected control amounted to 28.4, 25.5 and 30.0%, respectively (Table 1). This variation in saturation percentage may be attributed to the variation in the soil texture at the various depths, sandy clay (0 – 30 cm), or sandy loam (30 – 60 cm and 60 – 90 cm). The soil texture of untreated soil was sandy clay loam in the first depth, sandy loam for second and third depths. It is warranted that soil and crop production specialists should investigate to what extent does the presence of these elements is hazardous to plant growth and development.

The bacteriological analysis of affected soil as presented in table (2) indicated that the total viable count of bacteria was 5.4×10^5 cfu/g in the first depth, 1.60×10^5cfu/g for the second depth and 8.2×10^4 cfu/g in the third depth, while for the unaffected soil it was 3.6×10^4cfu/g, 3.4×10^4cfu/g and 2.7×10^4 cfu/g for the three depths, respectively.

Ottossn and Strenstorm, (2002) mentioned that the total coliform group has been extensively used as an indicator of water and soil quality. Moreover, total coliforms were recognized as a surrogate for *E.coli* to indicate fecal contamination of water and soil. The results obtained in this study (Table 2) showed that the total coliform count of sewage soil affected was 120MPN/g for the first depth, 93MPN/g for the second depth and 28MPN/g for the third depth, while that of the un affected soil was15 MPN/g, 7 MPN/g and 0.0MPN/g at the respective depths. This may be attributed to the disposal of inefficiently treated wastewater.

In this study fecal streptococci were detected in affected soil at the various depths viz 24 MPN/g at the first depth, 19MPN/g at the second depth and 6MPN/g at the third depth. No streptococci cells were detected in non - affected soil (Table 2).According to Abu al Hassan (2009), fecal streptococci (enterococci) are a valuable bacterial indicator for contamination. The test for salmonellae in sewage affected soil showed positive results in first and second depth, but they were not detected in either the third depth or the non - affected soil (Table 2).Hassan (2003) maintained that salmonellae are associated with faecal contamination, they have been isolated from sewage polluted surfaces and groundwaters.

The bacterial analysis of water from different sources in the vicinity of the sewage treatment plant under study (Table 3) showed that the total viable count of bacteria for tap water was 3.0×10^3 cfu/ml and that for well water was $1.80\times10^{5.}$cfu/ml. Moreover, the results obtained indicated that tap water is free from coliform organisms, while well water showed a count of 93MPN/ml and 28MPN/ml for total coliform and *E.coli*, respectively. The WHO (1996, 2004) guidelines indicated that the total viable count of safe water should be less than 1×10^3cfu/ml. The fecal streptococci count amounted to 15MPN/ml in well water, but was not detected in tap water (Table 3). Abu al Hassan, (2009) mentioned that fecal streptococci are a valuable bacterial indicator for determining the extent of fecal contamination of recreational surface waters. Abdel Magid etal. (1984) reported that microbial contamination with coliform and faecal colifrom is higher in surface wells and in the Nile river, they revealed that the logarithm of the colony count ranges from zero for mineral water to 6.8 for water from the White Nile. Salmonellae cells were not detected in both tap and well water.

According to the scanty records of the station under study the effluent quality parameters are shown in tables 4 and 5. The mean for BOD (mg/l) for the year 2009 (Table4) ranges between 916 and 1837 (mean 1375.5 mg/l) while that for the year 2010 (Table5) ranges between 402 and 2950 (mean =1212.6).

Al-Odat and Basahi (1985), Abdel Magid (2001), Abdel Magid and Al-Oud (2000) stated that for the maximum contamination level the quality standard limits for unrestricted and restricted irrigation in Saudi Arabia is a BOD level of 10 and 20 mg/l, respectively. The S.S.M.O. (2006) standard recommends a maximum allowable BOD level of 35 mg/l for discharge into rivers and beach after final treatment. However, Metcalf and Eddy (2003) reported, BOD levels of 10 and 30 mg/l for tertiary and secondary treatments, respectively.

The mean effluent COD (mg/l) in the years 2009 (Table4) ranges between 955 and 9000 (mean=2469.8) while that for the year2010 (Table5) ranges between 520 and 6000 (mean = 2113.8)5).It is clear that the magnitude of the COD is very high when compared with the Jordan Standards (1998) for the maximum concentration of reclaimed water for reuse in agriculture (COD level of 500 mg/l). No COD standard has been set by the S.S.M.O. (2006) for the COD level but, generally, it seems that the mean efficiency of the COD removal is lower than that of the BOD removal.

The monthly mean effluent T.S.S levels in the years 2009 and 2010 (Tables 4 and 5) were 439.2 mg/l and 305.8 mg/l, respectively. It is clear that the magnitude of the T.S.S is very high when compared to the SSMO (2006) drafted standard which recommends a T.S.S. of 40 mg/l as the maximum allowable level for disposing treated wastewater into river and recreational beaches .The mean pH of the effluent in the years 2009 and 2010 (Table 4 and 5) were 6.46 and 6.44, respectively. These values lie barely within the normal range for utilization of wastewater for irrigation because the USEPA (1992) guidelines for treated wastewater reuse and disposal in rivers and recreational beaches is a pH range of 6 – 9.The SSMO (2006) set a pH range of 6 – 10. The data records obtained from the station laboratory for the ions content (Table 4 and 5) are very scanty and are not a good representative of the efficiency of the effluent treatment and are , therefore, not included in the discussion, however, they are good indicators of an eminent pollution problem.

Conclusions:

The effluent wastewater from Khartoum North treatment plant at Wadafea suburb does not meet both the local (SSMO) and international (WHO) standards. The high level of some of the parameters studied in this work (for example BOD, COD, TSS, Coliform bacteria … etc.) renders the effluent from Wadafea sewage treatment station as an unacceptable resource for reuse for the various purposes (e.g: irrigation) because of public health and envlronmental concerns environment. To utilize this resource successfully it is imperative to increase the efficiency of this station to avoid eminent environmental hazards.

Recommendations:

1. Further consideration and due attention should be given to the constructional aspects of the plant to cope with the industrial expansion in Khartoum North, because the addition of diverse types of wastewater (domestic, industrial) and from public utilities, for example (hospitals) to the network needs specific treatment and special design for the treatment process to guarantee a safe effluent quality.
2. - Installation of proper pre-treatment units for each factory or for sectors of industries before conveyance of wastewater to the treatment station is deemed necessary.
3. Proper management of industrial effluent through waste minimization procedure and successful reuse of treated effluent.
4. Oxidation ponds should be of high quality specifications in order to prevent the percolation of wastewater pollutants to the groundwater. This may be accomplished by fencing of these ponds and a strict follow-up program of combating diseases causing microorganisms and insects must be inaugurated.
5. Regular testing and monitoring of the quality and quantity of effluent generated from industrial areas is warranted.
6. Diluting wastewater received by or conveyed to the station by establishing a sewage collection network from residential areas and other utilities, bearing in mind that "the" dilution of pollution is not a solution or conversely, the solution of pollution is not dilution. "Communities and municipalities should not rely on disposal of sewage by dilution to avoid environmental and health risks"
7. Developing a Sudanese standard that specify and control the quality of treated wastewater for its reuse for different purposes is critically needed in this era of threatening water shortage and climate change.
8. The sewage handling authorities must be up to the responsibility of undertaking, faithfully, the tasks of sewage treatment and proper disposal.

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Table (1): Physico - chemical analysis of soil (different depths) and drinking water (different sources) of Khartoum North (Wadafea) wastewater treatment plant

Soil Sample (depth) and water (sources)	**pH**		**EC (dS/m) at 25°C**		**Ca (mg/l)**		**Mg (mg/l)**		**Ca+Mg (mg/l)**		**Na (mg/l)**		**K (mg/l)**		**No$_3$ (mg/l)**		**Sp %**		**Clay %**		**Silt %**		**Sand%**	
	P S	CS	P S	CS	P S	CS	P S	CS	P S	CS	P S	CS	P S	CS	P S	CS	P S	CS	P S	CS	P S	CS	P S	CS
0-30 cm	8.8	7.9	1.6	0.4	80.2	40.1	12.2	12.2	92.4	52.6	322	161	4.3	19.6	110	10	59.9	28.4	38.64	28.64	25.0	15.0	36.36	56.36
30-60	9.2	8.0	19	0.8	501.3	60.2	170	12.2	671.3	724	3887	483	72.3	1.6	250	100	30.99	25.5	16.14	36.50	12.5	20.0	71.36	68.36
60-90	9.5	8.2	4.5	1.2	100.3	80.2	12.2	24.3	112.5	104.5	966	230	8.7	4.9	210	50	33.8	30.0	18.64	14.16	12.5	12.0	68.36	70.36
TW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14 mg/l		-	-	-	-	-	-	-	-
WW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	98 mg/l		-	-	-	-	-	-	-	-

PS = Plant soil
CS = Control soil

TW = Tap water
WW= Well water
SP = Saturation Percent
- = Not detectable

Table (2): Bacterial load of soil at different depths of Khartoum North (Wadafea) wastewater treatment plant

Soil Sample depth	Total viable count of bacteria (cfu/g)		Coliforms MPN/g of plant soil						Coliforms MPN/g of control soil						Faecal streptococci (MPN/gram)		Detection of salmonellae	
	Plant soil	Control soil	5Total coliform			*E.coli*			Total coliform			*E.coli*			Plant soil	Control soil	Plant soil	Control soil
				Lower limit	Upper limit		Lower limit	Upper limit		Lower limit	Upper limit		Lower limit	Upper limit	—	—	—	—
0-30 cm	$5.4x10^5$	$3.6x10^4$	120	30	380	39	7	130	15	3	44	15	3	44	24	0.0	+	_
30-60	$1.60x10^5$	$3.4x10^4$	93	15	380	28	10	150	7	1	23	7	1	23	19	0.0	+	_
60-90	$8.2x10^4$	$2.7x10^4$	28	10	150	9	1	36	0.0	0.0	0.0	0.0	0.0	0.0	6	0.0	_	_

- =Not detected

Table (3): Bacterial load of drinking water (from different sources) at Khartoum North (Wadafea) wastewater treatment plant

Sample code	Total viable count of bacteria (cfu/ml)	Coliforms MPN/ml						Faecal streptococci (MPN/ml)	Detection of salmonellae
		Total coliform			*E.coli*				
			Lower limit	Upper limit		Lower limit	Upper limit		
TW	$3.0x10^3$	0.0 MPN/ml	0	0	0.0 MPN/ml	0	0	0.0 MPN/ml	-ve
WW	$1.80x10^5$	93 MPN/ml	15	380	28 MPN/ml	10	150	15MPN/ml	-ve

TW = Tap water(Public network)

WW = Well water(Ground water)

Table (4): Characteristics of sewage effluent in Khartoum North (Wadafea) wastewater treatment plant during the year 2009

Year/month	BOD mg/l	COD mg/l	T.S.S mg/l	pH	Mn mg/l	NH_3 – N mg/l	NO_3 – N mg/l	CL- mg/l	SO_4^{-2} mg/l	EC dS/m
January	916	960	180	6.65	-	-	-	-	172.87	-
February	1250	3400	300	5.32	-	3.36	-	299.9	-	3.52
March	1837.5	6000	410	5.62	-	3.52	7.84	269.9	269.9	1431
April	1133	1760	520	7.29	-	-	-	-	102.9	-
May	1350	9000	400	5.91	-	-	-	0.007	-	358
June	1750	800	300	6.19	-	-	eman-	-	-	450
July	1550	980	550	7.38	-	-	-	-	-	340
August	1300	1200	280	6.87	-	-	83.23	-	-	1320
September	1550	1733	260	6.15	-	-	-	-	-	6.22
October	1220	1500	520	5.92	-	-	-	-	-	240
November	1010	1350	700	7.02	-	-	-	-	70.12	-
December	1640	955	850	7.22	0.430	-	-	-	-	280
Mean	1375.5	2469.8	439.2	6.46	0.430	3.44	45.5	189.9	153.9	1.57
SD	291.4	2529.9	197.2	0.7	0	0.11	53.3	165.2	88.4	2.04

Source: Sewage system incorporation – Khartoum State, Sudan.

BOD = Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, T.S.S = Total Suspended Solids

- = Not determined.

Table (5): Characteristics of sewage effluent in Khartoum North (Wadafea) wastewater treatment plant during the year 2010

Year / month	BOD mg/l	COD mg/l	T.S.S mg/l	pH	Mn mg/l	NH_3– N mg/l	NO_3^- – N mg/l	CL^- Mg/l	SO_4^{-2} mg/l	EC dS/m
January	1837.5	6000	4/0	5.62	-	3.52	7.84	269.9	82.32	1431
February	1400	1500	280	5.87	-	-	-	-	-	-
March	500	1466.6	320	5.92	-	-	-	-	-	-
April	402	933.3	160	6.29	0.44	-	-	-	-	-
May	751	1200	360	6.01	0.362	-	-	-	-	-
June	800	253.3	120	6.50	-	-	-	-	-	-
July	1966.6	3334.3	450	7.26	-	-	-	-	336.5	2.21
August	1837.5	6000	410	5.62	-	3.52	7.84	-	82.32	1431
September.	2950	520	340	7.16	0.09	-	-	-	90.55	-
October	1000	1200	300	6.53	2.26	-	-	159.9	181.1	-
November.	550	1040	260	6.96	0.074	-	-	139.95	-	-
December.	667	1920	260	7.56	-	-	-	-	148.17	-
Mean	1212.6	2113.8	305.8	6.44	0.64	352	7.84	189.9	153.5	1.69
SD	982.2	1971.3	98.9	0.66	0.92	0	0	70	98.4	0.45

Source: sewage system incorporation – Khartoum state, Sudan

BOD = Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, T.S.S = Total Suspended Solids.

- = Not determined.