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Effectiveness of a Wastewater Treatment Plant located at EPZ in reducing Pollutants Discharged into River Athi, Kenya

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Abstract: Information about effectiveness of a wastewater treatment plant is vital in ensuring the quality of water discharged into water bodies and the environment in general meet set standards. In this study, the performance of a wastewater treatment plant located at the Export Processing Zone (EPZ) along River Athi in Machakos County, Kenya was assessed because the final effluent from the treatment plant is released into the river where water is used downstream. Effectiveness of the plant was assessed through the reduction percentage of pollutants between influent and effluent during the dry and wet seasons. Samples of water were collected from the following points i.e. inlet, outflow pool, outlet and along the river. The samples were analyzed for heavy metals, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), organic nitrogen, phosphate, color, temperature, pH, and total coliforms. The resulting data was compared with the established standards. Standard methodologies of laboratory analysis were employed as per Kenyan regulations of 2006 on waste water treatment and discharge. From the results, the waste water treatment plant was not effective in reducing nitrates, phosphates, TDS, TSS, color, and heavy metals i.e. mercury, lead, selenium, copper and cadmium. The inefficiency was more pronounced in rain season. Nitrates (-2.04%), phosphates (-66%), mercury (-48%), lead (-48%), selenium (-2.29%) and copper (-9.75%) were high in the effluent after treatment process during the rains than in the influent. However, the treatment plant was effective in reducing Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). Some parameters like pH, conductivity, temperature, color and TSS were within allowable values described by Kenyan and International standards for effluent discharge into public waters. The study recommends expansion or re-designing of the treatment plant and better monitoring of the sources or types of wastewaters received at the plant for efficient and proper treatment process. Further research required on the seasonal fluctuation of pollutants along River Athi to reduce pollution of the waters. This should be coupled with studying the role of river gradient in self-cleansing of the pollutants.

Key words: Efficiency, wastewater, treatment plant, pollution, River Athi, export processing zone.

1. Introduction

The availability of good quality water resources is considered an essential element for socio-economic development of any country [1]. Most untreated waste waters from the municipalities/local governments, agriculture and industries are discharged into the freshwater sources [2, 3] leading to further reduction of available freshwater for drinking, domestic use and ecosystem conservation. Globally, over 2.1 billion people lack quality water for drinking, about 4.5 million lack access to safely managed sanitation while 792 million people still practice open defecation which end up polluting fresh water sources [2]. The use of polluted water leads to 1.5 million deaths annually around the world [4].

Kenya, like many other countries is a water scarce country with renewable water resources being 21-100 trillion m^3/year, where the proportions of water

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withdrawals are at 3.7% for industrial, 79.2% for agriculture and 17.1% for municipal use [5]. Similarly, the country is experiencing increased water pollution from both point and non-point sources from agriculture, urbanization and industries which discharge pollutants into the water courses [3, 6, 7]. Furthermore, pollution from domestic and municipal effluents is mainly sewage and garbage but also soil erosion and mining activities contribute significantly [8]. In Kenya, local government municipalities like Nairobi and Machakos constitute the largest sources of both treated and untreated waste water discharges [7]. The discharges pose great health hazards to humans and the environment as their pollution levels are beyond acceptable levels prescribed globally by the World Health Organization (WHO) or the Kenyan regulations (2006). In addition, improperly treated waste water effluents increase the prevalent occurrences and outbreaks of water-borne diseases [9].

Industrial development is considered important in transforming Kenya's economic status into a middle economy class as stipulated in the development blue print of Vision 2030 [10]. This amplifies the past initiatives which established the Export Processing Zones Authority in 1990 through the Export Processing Zone Act (Cap 517). This led to designation of certain areas as Export processing zones around Athi River near Nairobi among other cities and towns within the country [11]. These industrial zones discharge wastes into water bodies which pose environmental hazards if not well treated. The Waste Water Treatment Plant (WWTP) located at the Export Processing Zone (EPZ) near Athi River township, Machakos County was constructed to handle domestic sewage but currently handles industrial effluents too. The growth in human population and increased industrial activities has contributed to tremendous increase in waste water discharge into the treatment plant [12]. In addition, the plant had an initial output capacity of 6,500 m^3 of treated water per day against the current demand of 10,000 m^3 [12]. Therefore, this means that the plant is not only overstretched but also from its design, may lack the capacity to effectively treat industrial wastes to permitted safe levels for final discharge into River Athi.

Despite the regulations being in place, public outcry concerning the water quality of River Athi has been witnessed [7, 9, 13] with manifestations of algal blooms downstream. Confounding sources of contaminants of the river include: urban pollution from townships nearby which discharge untreated domestic waste water or water from septic tanks [13]; soil erosion from the upstream, land degradation and industrial effluents from industrial zones such as EPZ [14].

A number of existing studies in Kenya have focused on assessment of water quality or the pollution of major rivers in isolation [6, 7, 13, 15]. This means that even though pollution of River Athi originates from different sources and sub-catchments, the contribution and effectiveness of the wastewater treatment plant at EPZ in maintaining water quality in relation to other sources of pollution remains unknown. Therefore, information from this study is important in making decisions towards the improvement of the design of the treatment plant for increased efficiency. It is therefore against this backdrop that the study was carried out to assess the effectiveness of the waste water treatment plant located at the EPZ to reduce pollutant levels and enhance safe and quality water along River Athi.

2. Materials and Methods

2.1 Study Site and Scope

This study was restricted to the Waste Water Treatment Plant (WWTP) at the Export Processing Zone (EPZ) in Muthwani Ward near Athi River town, Mavoko Sub-county in Machakos County. The EPZ is on the banks of River Athi, 30 km from Nairobi city, 19 km North-East of Athi River town and 15 km from the Jomo Kenyatta International Airport. Its GPS co-ordinates are -1.355374, 37.050251 and elevation of 1,591m above sea level [12] (Fig. 1). The area falls within the River Athi basin and the Kapiti Plateau underlain by volcanic rocks from the Cenozoic era [12, 16] with black cotton soils (pellic Vertisols). Annual temperatures vary between 18 °C and 29 °C with dry spells occuring between January to March and June to September. Long rains are experienced from April-May while short rains fall from October-December with a mean annual rainfall of 600 mm. The site is within the Upper midlands (UM) 5-6 agro-ecological zones [12].

Evaluating the effectiveness of the waste water treatment plant involved analyzing the parameters outlined in the Third and Sixth schedules of the Kenya water quality regulations of 2006 [17], for influent and effluent samples. To find out the pollution contribution of the waste water treatment plant to River Athi, assessment also included checking the quality of the effluent at the discharge point into the river waters.

2.2 Description and Design of the WWTP at EPZ, Athi River

The WWTP at the EPZ employs the pond techniques for wastewater treatment. The plant has three parallel cycles with each having 4 anaerobic ponds each of 3,239 m^3 holding capacity (Fig. 2; Table 1). Box drain of 1.2 × 1.2 m size is laid from EPZ to convey the wastewater for treatment. Domestic wastewater is also conveyed through the exhausters and let out into the inlet chamber of the plant [12]. The effluents of the EPZA are discharged into River Athi with very low water flow drains.

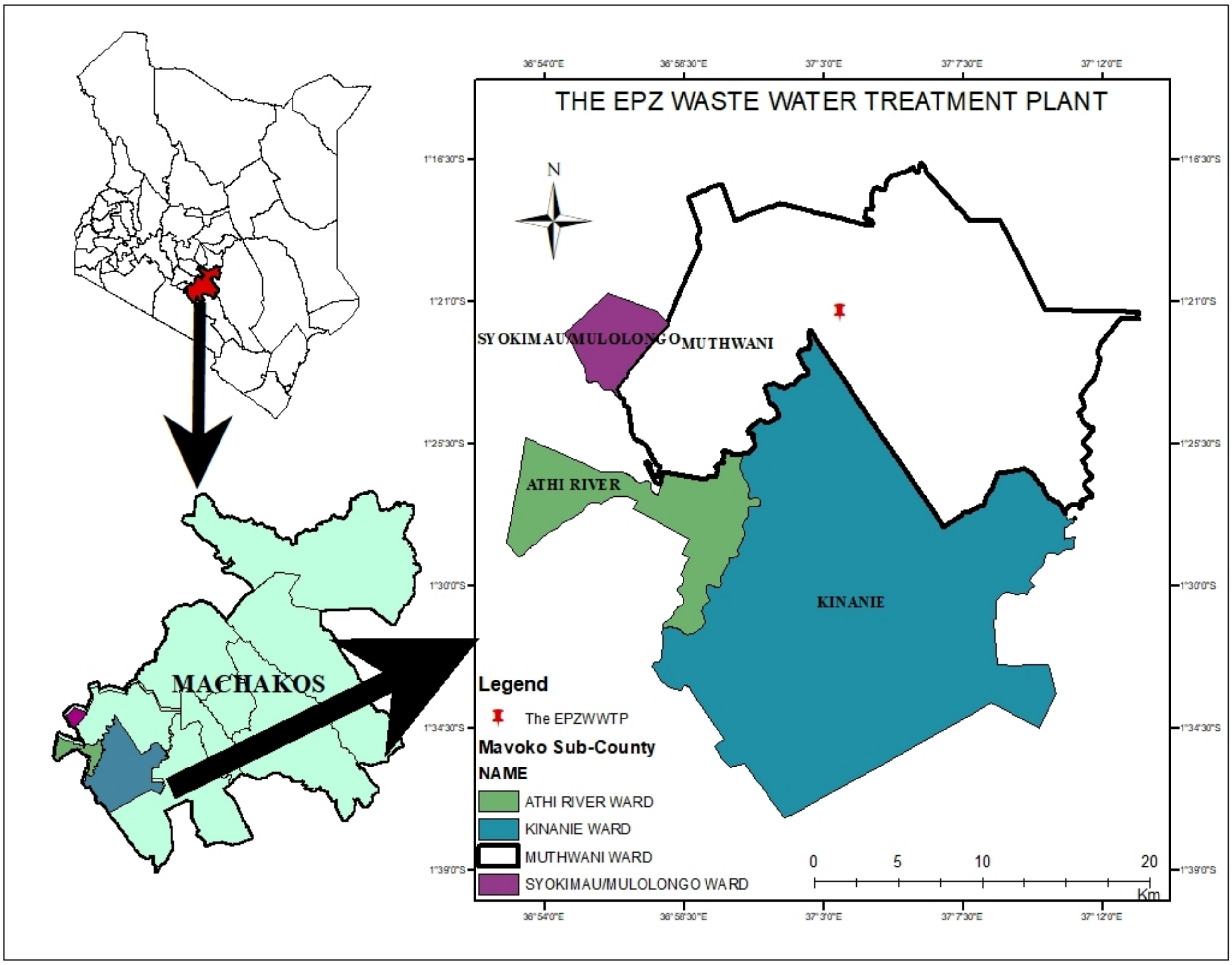

Fig. 1 Location of the WWTP.

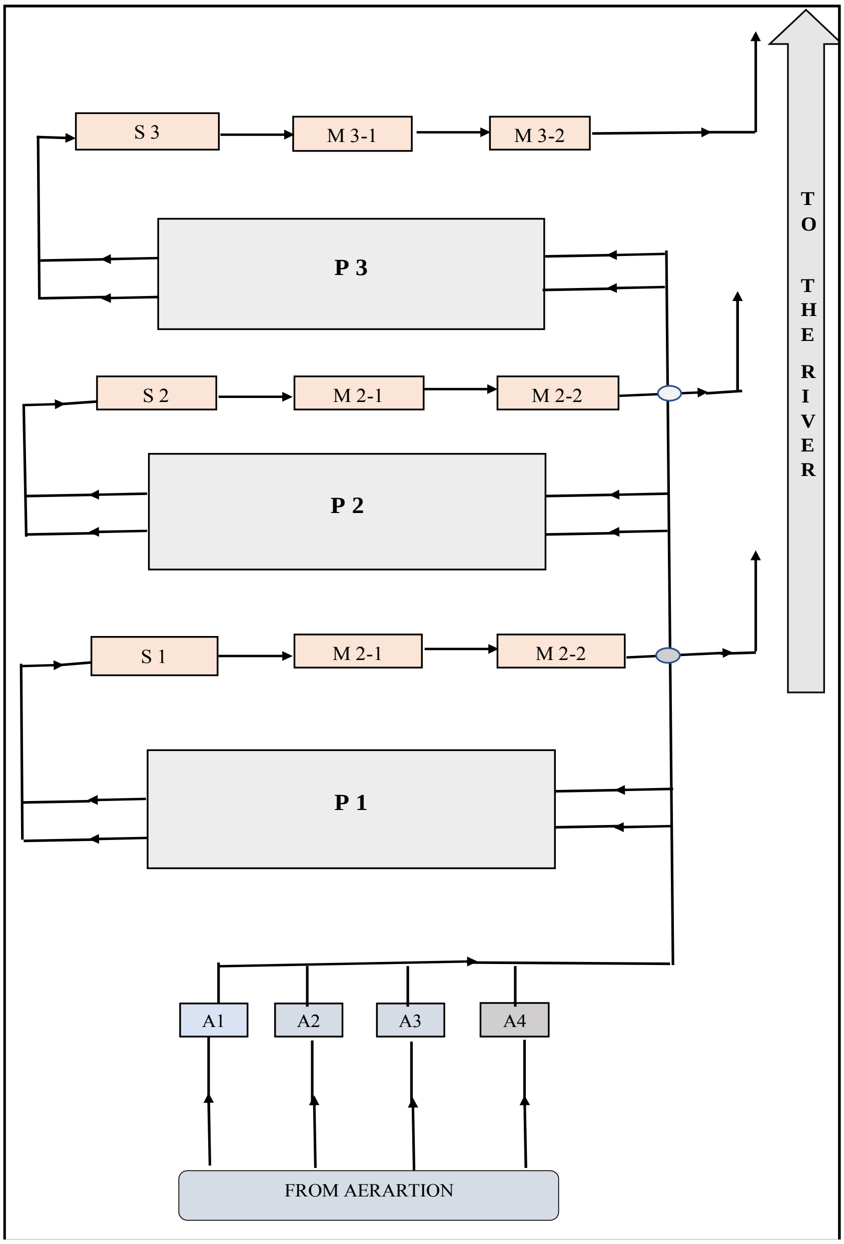

Fig. 2 Layout and design of WWTP.

A1-A4: anaerobic ponds; P1-P3: primary facultative ponds; S1-S3: secondary acultative ponds; M1-M3: maturation ponds. Source: EPZA Effluent Discharge Control Plan (2015).

Table 1 Design dimension and retention periods of waste stabilization ponds of the WWTP.

Pond category	Retention period (days)	Length (m)		Width (m)		Depth (m)	Volume (m^3)
		Top	Bottom	Top	Bottom		
Anaerobic ponds	2	63	54	33	24	3	3,239.81
Primary facultative ponds	9	379	375	128	125	1.75	75, 895
Secondary facultative ponds	4.7	140	136	52	48	1.75	10,072
Maturation	3						7,197

Source: EPZ authority.

The effluent quantity discharged indicated an average daily flow of 6,480 m^3 and peak flow of 25,920 m^3 as at the year 2000. As at 2010, when Phase II of the plant was added, an average daily flow of 61,943 m^3 and peak flows of 185,830 m^3 were recorded [12].

2.3 Sampling Design and Laboratory Analysis

Sa Samples were collected from five points. The sample points included: Inlet works, analysis at the pre-treatment stage (inlet from the four anaerobic ponds) provided reference during effluent quality analysis at the outflow of the treatment plant in order to determine the effectiveness of the plant in reducing pollutants. This inlet was at the point (marked X_1) just before the anaerobic ponds, at the outlet (marked X_2), and at the overflow marked X_5. The fourth and fifth sampling points were within the River Athi at 500 m either sides of upstream and downstream from the overflow points marked as X_3 and X_4 respectively (FigS. 3 & 4).

There was no direct discharge from the treatment plant into Athi River, but instead the effluent was contained in the series of ponds and embankments before release into the river. Sampling after the last maturation pond (X_2), was 500 m from the point where the fourth pond should discharge into (X_3) was 500 m downstream from the point of discharge into the river which overflows during the rainy season.

Before collection, sample collection bottles were thoroughly cleaned with deionized water to avoid any contamination with foreign solutions and particles. A representative sample consisting of five random samples of equal volumes from each sampling points was taken. Samples were taken at 50 mm or 5 cm below the surface and packed into clean tightly sealed translucent, low density poly-tetrafluoroethylene bottles and transported in cooler boxes for laboratory assessment within a period of 6 h or for further preservation and pre-treatment.

The samples were refrigerated at a temperature not exceeding 4 °C in order to retard biological activities after excluding air. Samples for COD measurement were preserved separately by addition of sulphuric acid to a pH < 2 and maintained at temperature of 4 °C. The analyses were done at Kenya Forestry Research Institute (KEFRI), Muguga. Some parameters such as pH, temperature, salinity, and electrical conductivity were analyzed onsite during sampling (Table 2).

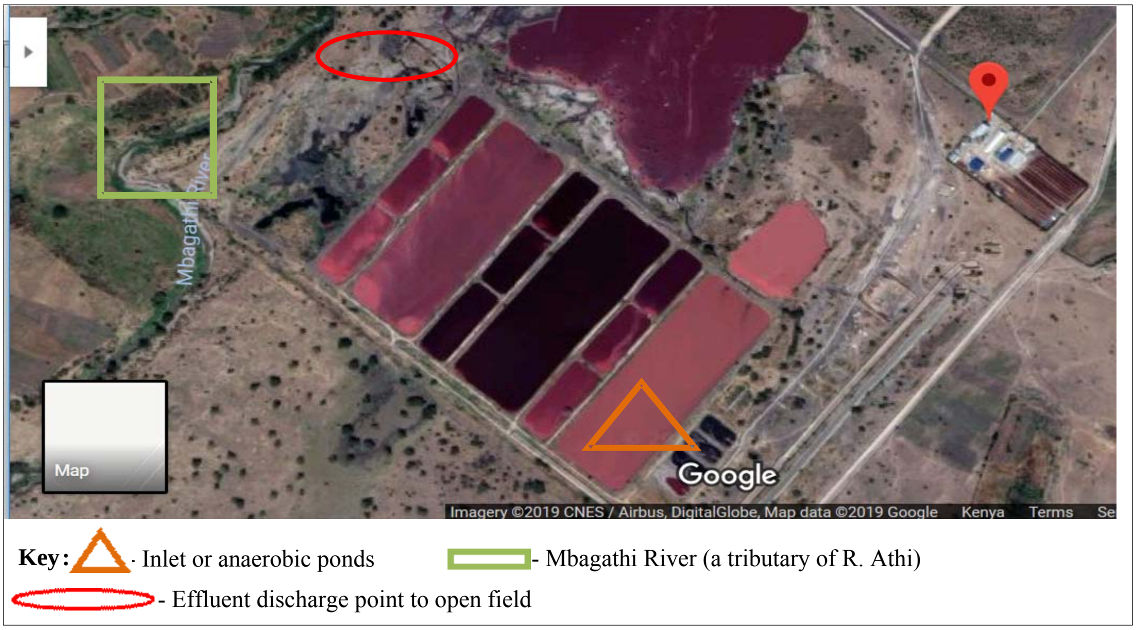

Fig. 3 Google Earth image of plant design layout with discharge point on River Athi.

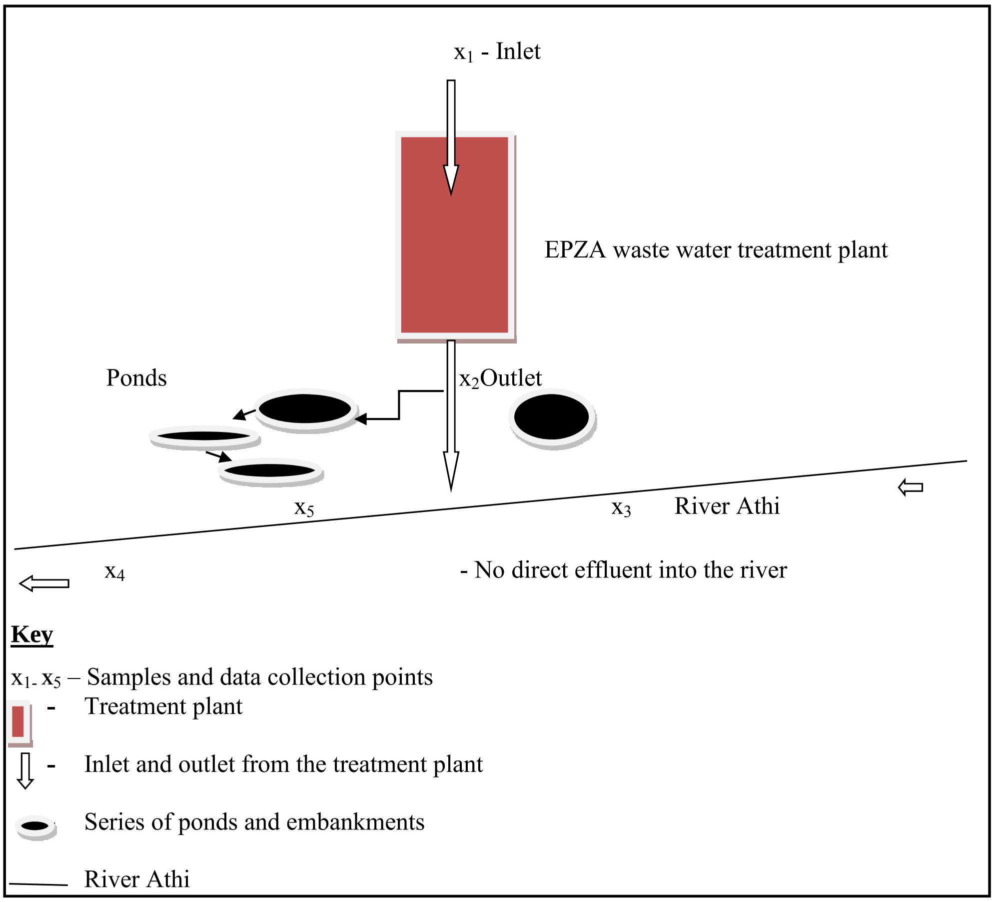

Fig. 4 **Sampling design and methodology.**

Table 2 **Methods for testing the quality (physical, chemical and biological) of waste waters.**

Parameter	Methodology	Equipment brand	Parameter	Methodology	Equipment brand
Organic nitrogen, N (mg/L)	Kjeldhal method	Hanna HI83399	pH	Potentiometric	Multi 9620 IDS
Phosphate, (mg/L)	Spectrophotometric	Hanna HI83399	Electrical conductivity (mS/m)	Conductivity meter	Multi 9620 IDS
COD (mg/L)	Reactor digestion	Hanna HI83399	Temperature. Max (°C)	Potentiometric	Multi 9620 IDS
Mercury, (ppm)	USEPA-245	AAS 7000 Shimadzu	TSS (Total Suspended Solids) (mg/L)	Gravimetric	Filtration (Mass difference)
Lead, Pb (ppm)	Atomic absorption spectrophotometer	Shimadzu	TDS (Total Dissolved Solid) (mg/L)		Multi 9620 IDS
Arsenic, Ar (ppm)	Atomic absorption spectrophotometer	AAS 7000 Shimadzu	BOD (Biological Oxygen Demand) (mg O_2/L)	Respirometric-10099	
Chromium, Cr (mg/L)	Atomic absorption spectrophotometer/ Chroma Ver 3: 8023	AAS 7000 Shimadzu	Odor and colour	Visual method Smell	
Cadmium, Cd (mg/L)	Atomic absorption spectrophotometer ISO 5961	FAAS 8000	*E. coli* counts/mL (CFU)	Membrane filtration AQL/TM/BACT-001	
Selenium, Se (mg/L)	Atomic absorption spectrophotometer	AAS 7000 Shimadzu	Copper, Cu (mg/L)	Atomic absorption spectrophotometer	AAS 7000 Shimadzu
Nitrate (mg/L)	Cadmium reduction azo dye methods	Hanna HI83399			

2.4 Data Collection and Analysis

Performance of the treatment process in terms of the percentage pollution reduction efficiency was calculated as follows:

$$Reduction\ Efficiency\ (\%) = \frac{(\text{Influent concentration} - \text{Effluent concentation})}{Influent\ concentration} \times 100$$

To determine the seasonal difference in the pollution level discharged for different parameters during dry and wet season, the concentration levels of the parameters were measured at the influent, the overflow and effluent points.

Data interpretation included comparing results of laboratory analysis and inferences made to the standards prescribed by the third and sixth schedules of the Kenya Environmental Management and Coordination Water regulations of 2006 [17] for release of treated water into the aquatic and public environment, and the Guidelines on Drinking Water Quality and Effluent Monitoring by Water Services Regulatory Board [18]. References were also made to World Health Organization (WHO) standards against the findings.

3. Results

The performance of the waste water treatment plant (WWTP) was not effective in reducing pollution load in terms of chemical pollutants specifically nitrates, phosphates and heavy metals i.e. mercury, lead and selenium. The ineffectiveness or inefficiency was more pronounced in rainy season. Nitrates (-2.04%), phosphates (-66%), mercury (-48%), lead (-48%), selenium (-2.29%) and copper (-9.75%) were high in the effluent than influent after treatment process during the rains.

In addition, copper and cadmium recorded negative reduction in both dry and wet seasons further indicating the ineffectiveness as shown in Table 3. After the treatment process, the nitrates reduced in concentration by 27% in April but in July, plant's performance only achieved 2.2% reduction. Phosphate levels were reduced by 6.75% treatment in the plant in April whereas in July, the concentration increased by 67% after leaving the treatment plant.

However, the treatment plant was effective in reducing pollution load for Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). The COD was highly reduced by the treatment plant in April (dry conditions) by 80% and 31% in July. This was attributed to possible contamination with no-biodegradable organics during the rainy season of July into the plant especially run-off spillage into the effluent after the treatment process. The BOD level reduced by 45% in April and by 100% in July and could not be detected after the treatment process.

The reduction percentage for biological parameters (total coliforms and the *E. coli*) was low in April but highest in July. The number of coliform colonies in both influent (160,000) CFU/100 mL and effluent (160,000 CFU/100 mL) remained unchanged (100%) and were only detected especially in dry periods of April (Table 3). The total coliforms were not reduced at all in April whereas in July they were reduced to nearly 100% to non-detectable levels. The same was recorded for *E. coli* for both seasons where, no conversion percentage was recorded in April but highest in July perhaps due to rains.

Furthermore, there was high concentration of mercury, lead, selenium and copper and very low to undetectable levels of arsenic and cadmium in the influent from the EPZ. There was a positive reduction percentage of mercury at 10.9% in April and rise of -48.02% in July. Copper also increased in concentration showing low reduction percentage by the treatment plant in both seasons. Chromium reduced only by 2% in April and rose even further in July after passing through the treatment plant. The same trend was recorded for lead.

For physical parameters, the waste water treatment plant performed poorly by not reducing Total Dissolved Dolids (TDS), Total Suspended Solids (TSS), color and odor. However; conductivity, temperature, color

Table 3 The reduction efficiency of the pollution parameters (chemical and biological parameters).

Parameters	Influent April	Influent July	Effluent April	Effluent July	Water regulations standards (NEMA)	WHO Standards (drinking)	Reduction percentage in April (%)	Reduction percentage in July (%)
Nitrates (mg/L)	0.1 ± 0.02	0.1 ± 0.0012	0.07 ± 0.007	0.15 ± 0.01	100 mg/L	40	27	-2.04
Phosphates (mg/L)	149 ± 5.24	30 ± 0.62	139 ± 3.8	50 ± 4.2	2 mg/L	0NILL	6.75	-66.95
Mercury (ppb)	767 ± 2.17	69 ± 2.8	684 ± 1.01	103 ± 0.5	5 ppb	0.001	10.9	-48.57
Lead (ppm)	ND	1,166 ± 1.76	ND	1,726 ± 3.2	0.01 ppm	0.01	ND	-48.027
Arsenic (ppm)	ND	ND	ND	ND	0.02 ppm	0.01	ND	ND
Selenium (ppm)	7,713 ± 0.58	7,739 ± 5.21	6,759 ± 0.58	7,916 ± 30	0.01 ppm	0.01	12.36	-2.29
Copper (ppm)	5,221 ± 0.58	4,638 ± 3.61	5,720 ± 0.88	5,090 ± 0.5	2 ppm	2	-9.55	-9.75
Chromium (mg/L)	2.2 ± 0.12	ND	1.99 ± 0.01	2.22 ± 1	2 mg/L	0.05	9.54	Negative > infinite
Cadmium (mg/L)	1.95 ± 0.06	< 0.001	2.42 ± 0.023	ND	0.01 mg/L	0.003	-47	> 100
COD (mg/L)	4,685 ± 1.53	905 ± 4.8	1,788 ± 1	1,222 ± 11	50 mg/L	0	80.68	31.62
BOD (mg/L)	700 ± 6.12	392 ± 0.88	380 ± 125	ND	30 mg/L	0	45.71	> 100
Total coliforms (CFU/100 mL)	160,000	ND	160,000	510	30 count /100 mL	0	0	> 100
Escherichia coli (CFU/100 mL)	160,000	ND	160,000	480	0	ND	0	< 100

ND: not detectable.

Table 4 The reduction efficiency of the pollution parameters (chemical and physical parameters).

Parameters	Influent April	Influent July	Effluent April	Effluent July	Water regulations standards (NEMA)	WHO standards (drinking)	Reduction percentage in April (%)	Reduction percentage in July (%)
pH	7 ± 0.02	7 ± 0.11	8 ± 0.05	8 ± 0.006	6.5-8.5	6.5-8.5	-6.02	-8.85
Conductivity (S/m)	10 ± 0.03	8 ± 0.08	13 ± 0.003	10 ± 0.09	550 S/m (Pass)	0	-18.53	-11.42
Temperature (°C)	27 ± 0.01	24 ± 0.11	28 ± 0.024	23 ± 0.2	35 °C (± 3) ambient temperature	0	13.44	-13.23
TDS (mg/L)	11 ± 0.03	8,943 ± 8.82	13 ± 0.03	10,036 ± 14	1,200	1,000	-118	-12
TSS (mg/L)	2.6 ± 0.18	1,014 ± 7.45	2.10 ± 0.8	834 ± 30	30	0	2.7	17
Odour	NILL	Pungent smell	NILL	Mild pungent smell	Odorless 15H units	0	0	No change
Colour	No color	Darkish brown	No color	Pale reddish brown	No color	0	No change	No change

and odor were within allowable set standards in Kenya excluding TDS and TSS. The TDS values recorded -118% and -12% negative reductions for April (dry) and July (wet) periods respectively with July influent registering 8,943 mg/L above the acceptable values of 1,200 mg/L (Table 4). TSS was above acceptable limits of 30 mg/L registering up to 834 mg/L for the July effluent. Conductivity, pH and temperature increased in the effluents but were within the acceptable standards in Kenya for effluent discharged into to public waters. For color and odor, there was little change in color (brown) and smell (pungent smell) in effluents after treatment (Table 4).

Seasonal weather changes significantly affected the concentration of pollutants in waste water treatment plant (WWTP). Phosphates, mercury, COD, BOD and coliform bacteria were high during dry season (Table 5, Figs. 6, 7, and 11) while; nitrates, lead and selenium increased during rains (Figs. 5, 8 and 9). Copper remained relatively unchanged for both seasons although the concentration was high beyond acceptable limits of 2 mg/L (Fig. 10). For heavy metals, the concentration of lead and selenium increased during the wet season which was attributed to point sources of pollution, mostly industries at the EPZ. Mercury, copper and cadmium reduced during rainy season which were attributed to dilution effect caused by high water fluxes. Conductivity, pH and temperature increased in the effluents but were within the acceptable standards in Kenya for effluent discharged into to public waters. For color and odor, there was little change in color (brown) and smell (pungent smell) in effluents after treatment (Table 6).

TDS and TSS increased during July rains with the influents recording 8,943 mg/L and 1,014 mg/L respectively (Table 6). Both TDS and TSS concentrations were still above acceptable limits of 1,200 and 30 mg/L respectively as prescribed by both Kenyan standards for effluent and the World Health Organization (WHO) standards for drinking water.

Table 5 Seasonal variations in pollutant levels from the treatment plant into River Athi.

Parameters	Influent April	Influent July	Effluent April	Effluent July	Overflow April	Overflow July
Nitrites (mg/L)	7 ± 0.8	ND	21 ± 1.86	ND	84 ± 5.24	-
Arsenic (ppm)	ND	ND	ND	ND	ND	ND
Silver (ppm)	ND	ND	9,588 ± 2.19	ND	ND	ND
Iron (ppm)	ND	ND	ND	ND	1,685 ± 2.67	1,685 ± 1.15
Chromium (mg/L)	2.2 ± 0.12	ND	1.99 ± 0.01	2.22 ± 1.0	2.261 ± 0.3	0.5 ± 0.06
Cadmium (mg/L)	1.95 ± 0.06	< 0.001	2.42 ± 0.023	ND	1.70	ND
BOD (mg/L)	700 ± 6.12	392 ± 0.88	380 ± 125.08	ND	700 ± 40	ND
Total coliform (count/mL)	160,000	ND	160,000	ND	900,519	ND
Escherichia (count/mL)	160,000	ND	160,000	480 ± 1.20	900,519	ND

ND: not detectable.

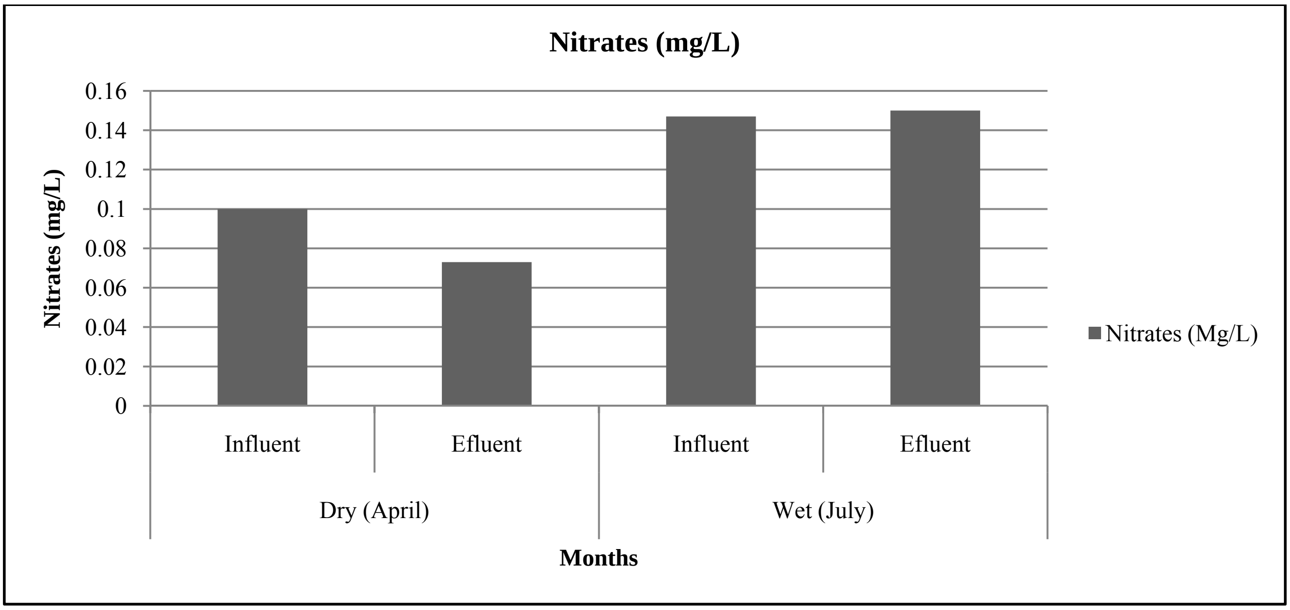

Fig. 5 Effect of seasonal weather changes on nitrate levels in the waste waters.

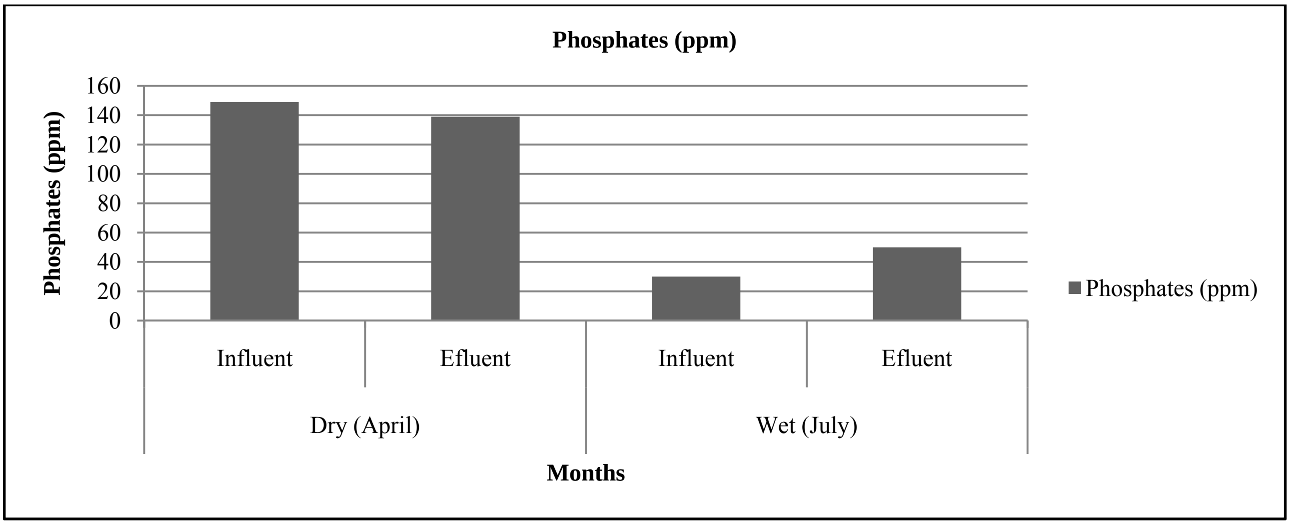

Fig. 6 Effect of seasonal weather changes on phosphate levels in the waste waters.

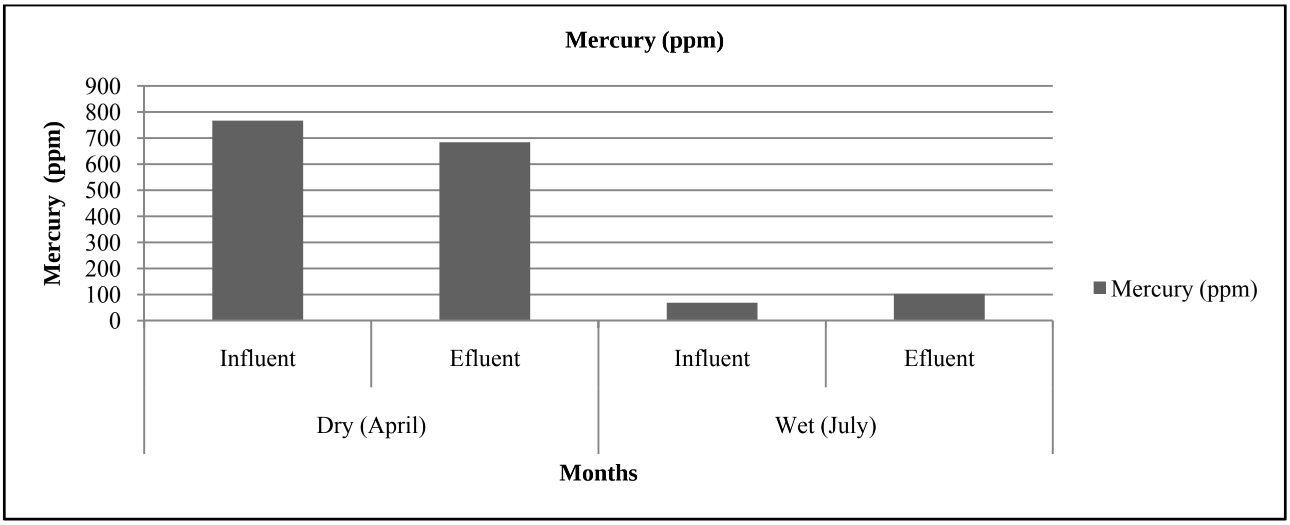

Fig. 7 Effect of seasonal weather changes on mercury levels in the waste waters.

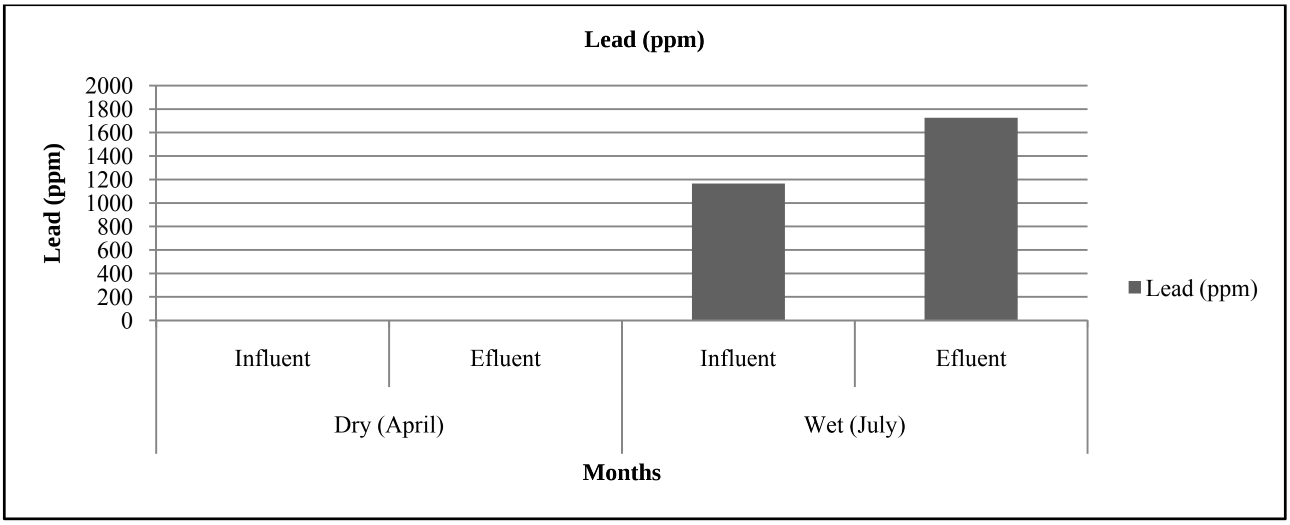

Fig. 8 Effect of seasonal weather changes on lead levels in the waste waters.

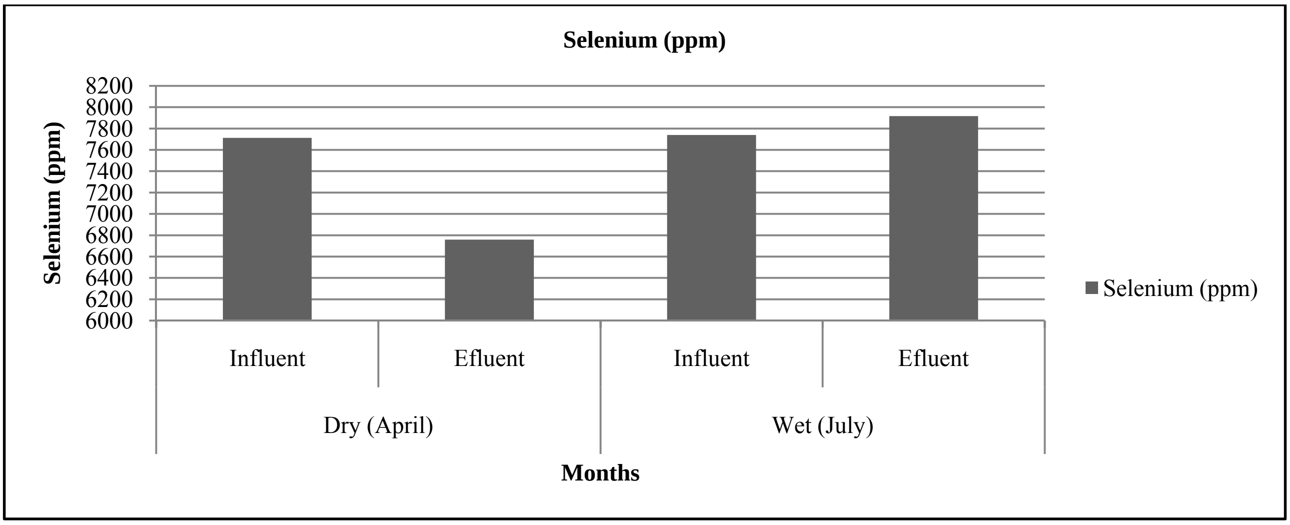

Fig. 9 Effect of seasonal weather changes on selenium levels in the waste waters.

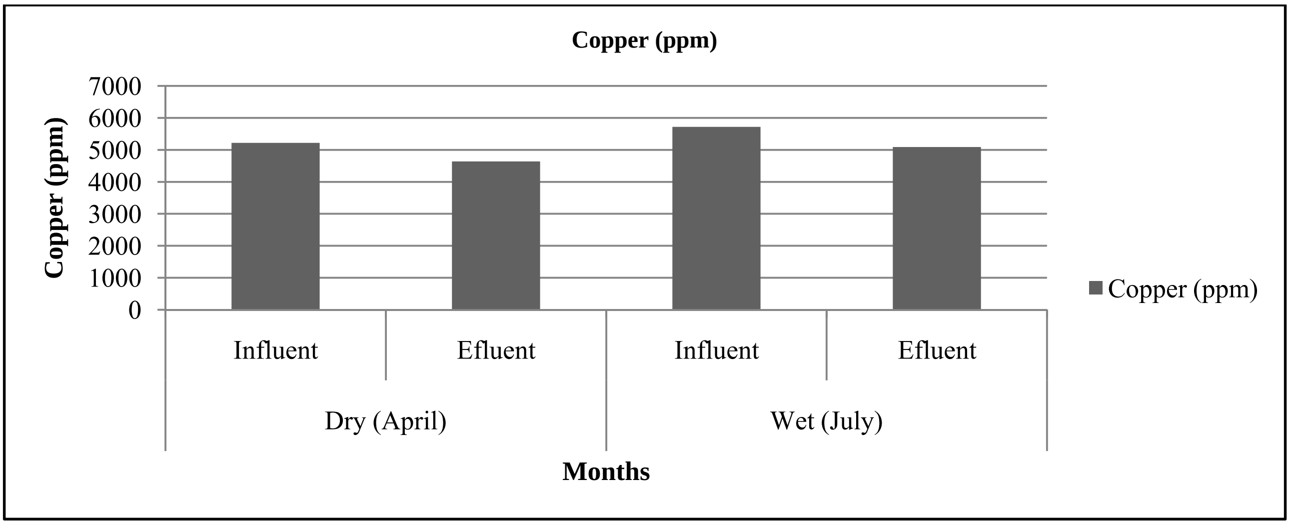

Fig. 10 Effect of seasonal weather changes on copper levels in the waste waters.

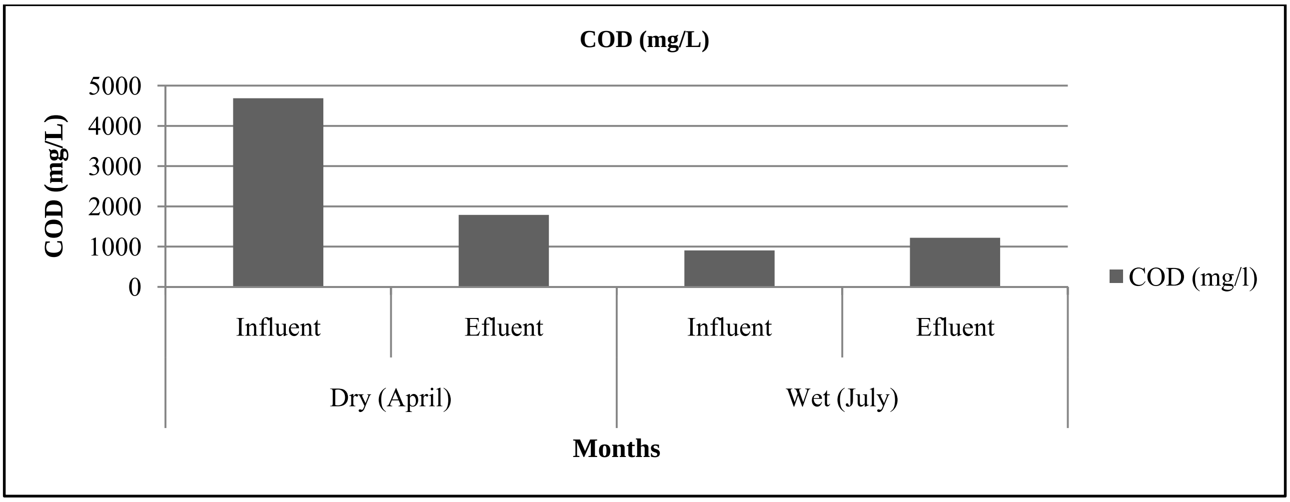

Fig. 11 Effect of seasonal weather changes on the COD levels in the waste waters.

Table 6 The variation in seasonal pollution levels from the treatment plant into Athi River.

Parameters	Influent April	Influent July	Effluent April	Effluent July	Overflow April	Overflow July
pH	7.8 ± 0.02	7.61 ± 0.11	8.2 ± 0.05	8.29 ± 0.57	9.18 ± 0.103	7.8 ± 0.03
Conductivity (S/m)	10 ± 0.03	8.8 ± 0.08	13 ± 0.03	10.08 ± 0.09	34 ± 0.35	25 ± 0.01
Temperature (°C)	27 ± 0.01	24.2 ± 0.11	27.9 ± 0.024	23.43 ± 0.20	32 ± 0.09	22.3 ± 0.3
Salinity	6.1 ± 0.03	4.9 ± 0.008	7.3 ± 0.03	5.6 ± 0.01	21.6 ± 0.23	4.7 ± 0.003
TDS (mg/l)	10 ± 0.03	8,943 ± 8.8	12.8 ± 0.03	1,0036 ± 14	34.4 ± 0.47	8,443 ± 27
TSS (mg/l)	2.62 ± 0.18	1,014 ± 7.4	2.1 ± 0.28	834 ± 30.31	3.4 ± 0.35	913 ± 49.6
Color	Clear	Darkish brown	Clear	Pale Reddish brown	Reddish brown	Highly turbid
Odor	No smell	Pungent smell	No smell	Mild pungent smell	Rotten egg pungent smell	Odorless

4. Discussion

The quality of water from waste water treatment plant was observed to vary seasonally in tandem with changes in temperature and rainfall. The high precipitation during the wet season can either decrease the pollutant concentration by dilution or deteriorate the water quality due to increased surface runoff from anthropogenic activities [19].

In this study, the waste water treatment plant was not effective in reducing pollutants specifically nitrates, phosphates and heavy metals i.e. mercury, lead and selenium. The inefficiency was more pronounced in rain season. However, the plant was effective in reducing Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). Heavy metals increased during the wet season which was attributed to point sources of pollution, mostly industries at the EPZ. For Mercury, Copper and Cadmium reduction, this was largely attributed dilution effect caused by high water fluxes during rainy seasons. For physical parameters, the waste water treatment plant performed poorly by ineffectively not reducing Total Dissolved Solids (TDS), Total Suspended Solids (TSS), color and odor which above the allowable values described by Kenyan [17] and World Health Organization standards [20]. Conductivity, pH and temperature increased in the effluents but were within the acceptable ranges.

There are quite a number of explanations for the increase in conductivity, pH and temperature during the treatment process. From other studies like [21], it has been reported that during the preliminary stages of water treatment, sulphuric acid is used to maintain influent's pH value of about 6.5 so that any precipitated material is filtered. In addition, the acid is used to avoid calcium carbonate precipitation which increases pH from 5.9 to 6.4. However, correction of pH during the treatment process is done using sodium carbonate to a range of 7.5 to 8.0 to achieve desired water quality [21]. The addition of salts such as sodium compounds may have led to the rise of pH value but it was still within the acceptable maximum value of 6.5-8.5 recommended for Kenya and the World Health Organization standards for effluent discharge in environment and drinking water respectively.

The pH of waste water in the treatment plant determines occurrence of either methanogenesis or acidogenesis processes in the anaerobic ponds. For instance, the optimum pH for methanogenesis is between 6 and 8. Acidogenic populations are more tolerant to pH variation which explains why acidogenic fermentation is more prevalent than methanogenic. Therefore, it's advised that the treatment systems should contain sufficient buffering capacity to counteract the production of unstable acids and carbon dioxide that dissolve at the working pressure [22]. The range of natural pH in fresh waters extends from around 4.5, for acid, peaty upland waters, to over 10.0 in waters where there is intense photosynthetic activity by algae.

However, the most frequently encountered range is 6.5-8.0 in waters with low dissolved solids, which consequently have a low buffering capacity. Changes in pH induced by external affect may affect the palatability of water.

The electrical conductivity is caused by presence of mineral salts such as sodium and calcium. The influent and effluent in both seasons were within the recommended Kenyan standards of range of 5-50 S/m. High electrical conductivity means high Total Dissolved Solids. Total soluble salts refer to the estimate the quantity of ions and other particulate matter dissolved in water and waste water. They may include mostly chlorides, sulfates, nitrates sodium, phosphates and hence, high values of TDS in waste waters indicate presence of high amounts of these salts.

The total amount of TDS in given waters is of importance as it influences osmosis and diffusion in the cells of organisms. High concentrations of TDS are normally responsible for reduced rate of photosynthesis in plants growing water [23]. It has been reported by Al-Mutaz and Al Ghunaimi [21] that the chemical process such as acidification and addition of salts in the treatment plant may have led to a rise in conductivity of the waste waters. Temperature determines the rate of reactions in the anaerobic ponds during waste water treatment process. Anaerobic reactions occur to produce methane forming bacteria at an average temperature of 20 °C. These bacteria have different optimum levels of temperature requirements, with mesophilic bacteria developing at temperatures range between 20 to 45 °C while thermophilic ones develop at between 45 to 75 ^{o}C [22]. However, water temperatures are known to be influenced by altitude and prevailing seasonal weather conditions like sunshine intensity reaching water bodies.

The Total Suspended Solids (TSS) refers to particles present in a given water sample, and which can be trapped by filtration. In water treatment process, the size of the aperture, the width of the filters, nature of the materials and their sizes determine the separation of suspended solids with aquatic life especially microbial decomposition [24]. High amounts of TSS in water affect light penetration which might interfere with aquatic life especially microbial decomposition. Increased level of TSS leads to a rise in temperatures of the surface water since the suspended solids absorb heat. The suspended solids are mostly composed of organic matter to industrial wastes and even sewage**.** The time of sampling also determines the amount of TSS especially during dry or rain periods. In rain season, river volumes are high and most materials are washed and this could explain why downstream recorded higher values than upstream in this study.

The COD was highly reduced during dry conditions (80%) compared to 31% in wet season. COD is used to estimate the amount of non-biodegradable organic material in wastewaters. In the case of biodegradable organics, the COD is normally in the range of 1.3 to 1.5 times the BOD. From literature, when the result of a COD test is more than twice that of the BOD test, then there is a significant portion of the organic material in the sample that is not biodegradable by ordinary microorganisms. Furthermore, in this study; BOD, Total coliforms and *E. coli* had the same trend; having a high reduction percentage in July during rains. However, the number of coliform colonies in both influent and effluent remained unchanged (100%) and were only detected especially in dry periods of April. The BOD levels reduced by 45% in April and by 100% in July after the treatment process. The trends in these pollutants were attributed to dilution factor during rains which caused high river volumes.

The decrease in concentration of phosphates and some heavy metals in water were largely attributed to the high volume of water during rainy season causing dilution hence low detection.

From literature, soluble inorganic and organic salts from mostly surface runoff, fertilization or industrial wastes are known to increase nitrates, phosphates and dissolved solids in water. The increase in these salts from anthropogenic activities deteriorates water quality on a reservoir or the stream. Findings by Ling, et al. [25] are in agreement in this study whereby, there were seasonal variations in water quality of reservoirs and treatment plants due to changes in temperature and rainfall. In addition, Ling, et al. [25] recorded high levels of total phosphorus in a reservoir during the dry season which agrees with the findings of this study. Phosphorus concentration in water bodies is influenced by phosphorus sources outside water and is stored in sediments as sinks. Similar findings in Kenya have been reported in Kariobangi treatment plant [26, 27] for seasonal pollution concentrations under similar environmental and social dynamics.

For heavy metals such as cadmium and mercury present in waste waters, originate from mostly anthropogenic activities such as agriculture, municipal and industrial wastewater discharges, mining etc. [28]. The solubility and the form of particular heavy metal determine its toxicity or classification as a pollutant. For instance, the solubility of cadmium in water is influenced by its acidity [29]. Mercury as a pollutant exists mainly in different forms i.e. metallic element, inorganic salt and as an organic compound with each form possessing toxicity and bioavailability. It has been estimated that the amount of mercury emission into the environment is 2,200 metric tons annually [30]. Both cadmium and mercury pose health hazards in the environment. Accumulation of cadmium in crops has a significant effect on the consumers, although its toxicity is determined more by its form and not its concentration [31].

Mercury is a hazardous metal and its toxicity is known to cause acute heavy metal poisoning. Just like mercury and cadmium, lead and chromium in natural waters or reservoirs comes from industrial processes, mining and welder discharges or corroded lead pipes.

Lead is an environmental contaminant causing health problems [32]. Natural water has lead concentration of about 5 μg/L and is poisonous to humans [33, 34]. The concentration of chromium in natural waters is low due to its low solubility [35]. Discharge of waste water to rivers with high chromium levels will end up destroying aquatic life. In human beings, Chromium has been associated with respiratory health problems, impaired immunity, birth defects, infertility and tumor formation although the chromium III is reported to have benefits to humans [36]. In conclusion, high levels of water quality parameters or pollutants have been reported during dry seasons or conditions [37]. These seasonal variations have been attributed to mostly sources of pollutants and their forms whereby, during dry seasons, effluents were mainly from the industries, domestic sewerage or salt water intrusions but in wet season, runoff from cultivated lands and livestock farms contributed immensely to water pollution.

5. Conclusion

The waste water treatment plant was not effective in reducing pollutants i.e. nitrates, phosphates, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), color, and heavy metals (mercury, lead, selenium, copper and cadmium). The inefficiency was more pronounced in rain season. Nitrates, phosphates, mercury, lead, selenium and copper were high in the effluent after treatment process during the rains.

However, the treatment plant was effective in reducing Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD). Some parameters like pH, conductivity, temperature, color, TSS were within allowable values described by Kenyan standards for effluent discharge in environment. Seasonal weather changes significantly affected the concentration of pollutants in the waste waters i.e. phosphates, mercury, COD, BOD and coliform bacteria were high during dry season. Nitrates, lead, selenium, Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) increased during rains. The study recommends expansion or re-designing of the treatment plant and better monitoring of the type or sources of wastewater received at the plant for efficient and proper treatment process. Further research required on the seasonal fluctuation of pollutants along River Athi to reduce pollution of the waters. This should be coupled with studying the role of river gradient in self-cleansing of the pollutants.

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Conflict of Interests

The authors declare that they have no competing interests.

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