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

Godfrey Wafula, Mwakio Tole, Najma Dharani and Stanley Nadir
1. National Environment Management Authority (NEMA), Nairobi 67839-00200, Kenya
2. Pwani University, Kilifi 195-80108, Kenya
3. Kenyatta University, Nairobi 43844-00100, Kenya
4. Kenya Forestry Research Institute (KEFRI), Nairobi 20412-00200, Kenya

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 m³/year, where the proportions of water

Corresponding author: Godfrey Wafula, M.Sc., environmental scientist, research field: environmental science and natural resource management. E-mail: gwafula2004@yahoo.com.
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).
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 occurring 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 m³ 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.
Effectiveness of a Wastewater Treatment Plant located at EPZ in reducing Pollutants Discharged into River Athi, Kenya

![Diagram of WWTP layout and design](image)

**Fig. 2 Layout and design of WWTP.**
A1-A4: anaerobic ponds; P1-P3: primary facultative ponds; S1-S3: secondary acultivate ponds; M1-M3: maturation ponds. Source: EPZ Authority Effluent Discharge Control Plan (2015).

| Pond category               | Retention period (days) | Length (m) | Width (m) | Depth (m) | Volume (m³) |
|-----------------------------|-------------------------|------------|-----------|-----------|-------------|
| 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

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 X1) just before the anaerobic ponds, at the outlet (marked X2), and at the overflow marked X5. 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 X3 and X4 respectively (FigS. 3 & 4).

Sampling after the last maturation pond (X2), was 500 m from the point where the fourth pond should discharge into (X3) 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).
Effectiveness of a Wastewater Treatment Plant located at EPZ in reducing Pollutants Discharged into River Athi, Kenya

![Diagram of sampling design and methodology]

**Key**
- Inlet
- Outlet
- No direct effluent into the river

**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        | TSS (Total Suspended Solids) (mg/L) | Gravimetric      | Multi 9620 IDS  |
| Lead, Pb (ppm)        | Atomic absorption spectrophotometer             | Shimadzu        | TDS (Total Dissolved Solid) (mg/L) |                 |                 |
| Arsenic, Ar (ppm)     | Atomic absorption spectrophotometer             | AAS 7000        | BOD (Biological Oxygen Demand) (mg O₂/L) | Respirometric-10099 |                 |
| Chromium, Cr (mg/L)   | Atomic absorption spectrophotometer/            | AAS 7000        | Odor and colour        | Visual method    |                 |
|                      | Chroma Ver 3: 8023                              | Shimadzu        |                        | Smell            |                 |
| Cadmium, Cd (mg/L)    | Atomic absorption spectrophotometer/            | FAAS 8000       | E. coli counts/mL (CFU) | Membrane filtration | AQL/TM/BACT-001 |
|                      | ISO 5961                                         |                 |                        |                  |                 |
| Selenium, Se (mg/L)   | Atomic absorption spectrophotometer             | AAS 7000        | Copper, Cu (mg/L)      | Atomic absorption spectrophotometer | AAS 7000 |
| Nitrate (mg/L)        | Cadmium reduction azo dye methods               | Hanna HI83399   |                        |                  | Shimadzu        |
2.4 Data Collection and Analysis

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

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

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 \textit{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 \textit{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 Solids (TDS), Total Suspended Solids (TSS), color and odor. However; conductivity, temperature, color
The Effectiveness of a Wastewater Treatment Plant located at EPZ in reducing Pollutants Discharged into River Athi, Kenya

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 | ND | ND | ND | ND |
| Selenium (ppm) | 7,713 ± 0.58 | 7,739 ± 5.21 | 6,759 ± 0.58 | 7,916 ± 30 | 0.01 ppm | 0.01 | ND | -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) | 35 °C (± 3) ambient temperature | -18.53 | -11.42 |
| Temperature (°C) | 27 ± 0.01 | 24 ± 0.11 | 28 ± 0.024 | 23 ± 0.2 | 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    | 2.26 ± 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.
Effectiveness of a Wastewater Treatment Plant located at EPZ in reducing Pollutants Discharged into River Athi, Kenya

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

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

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.

Acknowledgement

Special thanks go to the EPZ management for permission to access the WWTP for study.

Conflict of Interests

The authors declare that they have no competing interests.

References

[1] Waswa, F., Otor, S., and Mugendi, D. 2007. Environment and Sustainable Development: A Guide for Higher Education in Kenya, Vol. 2. School of Environmental Studies and Human Sciences, Kenyatta University.

[2] United Nations (UN). 2018. Sustainable Development Goals Report. Waters Sustainable Development Goal 6 Synthesis Report on Water and Sanitation 6 Geneva. http://dialogue.unwater.org/app/uploads/2018/05/SDG6-Synthesis-Report-full-manuscript-2-May-2018-v2.pdf.

[3] Edokpayi, J. N., Odiyo, J. O., and Durowoju, S. O. 2017. “Impact of Wastewater on Surface Water Quality in Developing Countries: A Case Study of South Africa.” In Water Quality, edited by Tutu, H. InTech. doi: 10.5772/66561. https://www.intechopen.com/books/water-quality.

[4] United Nations (UN). 2019. Global Environmental Outlook Report: Healthy Planet Healthy People, 6th ed. New York: Cambridge University Press. https://www.unenvironment.org/global-environment-outlook.

[5] Jaoko, O. B. 2014. “Assessing Water Quality and Demand Management in Industries and Commercial Enterprises in Athi River Town, Machakos County.” M.Sc. thesis, Kenyatta University.

[6] Nadir, W. S., Jaoko, V., Osano, P., and Ongugo, P. 2019. “Status of Water Quality in Mt. Elgon, Cherangany Forested Ecosystems and Entire River Nzoia Catchment in Kenya.” Journal of Environmental Science and Engineering B 8: 37-54. doi:10.17265/2162-5263/2019.02.001.

[7] Kithiia, S. M. 2012. “Effects of Sediments Loads on Water Quality within the Nairobi River Basins, Kenya.” International Journal of Environmental Protection 2 (6): 16-20.

[8] Government of Kenya (GoK). 1992. The National Water Master Plan. Final report, Ministry of Water Development, Nairobi.

[9] Muindi, J. M. 2007. “Enhancing Protective Control Measures for Reduction of Diarrhoecal Disease in Athi-River, Kenya.” M.Sc. thesis, Jomo Kenyatta University of Agriculture and Technology. http://41.204.187.24:8080/handle/123456789/1340 on 23/12/2018.

[10] Government of the Republic of Kenya (GoK). 2013. National Development Plan: Kenya Vision 2030; Second Medium-Term Plan (2013-2017): Transforming Kenya. Ministry of Devolution and Planning. Nairobi.

[11] Export Processing Zone Authority (EPZA). 2013. Strategic Plan for 2014-2013. Nairobi.

[12] Export Processing Zone Authority (EPZA). 2016. Project Report for a Proposed Construction of Phase 2 EPZA Waste Water Treatment Plan. Vol. 1, Kenya.

[13] Gichuki, K. A. 2014. The River Pollution Profile for Mbagathi River. Nairobi: University of Nairobi.

[14] Nyika, J. M., Karuku, G. N., and Onwonga, R. N. 2017. “Water Balance for Mbagathi Sub-catchment.” Journal of Water Sustainability 7 (3): 193-203.

[15] Musyoki, A. M., Abednego, M., Suleiman, M. A., Mbithi, J. N., and Maingi, J. M. 2013. “Water-borne Bacterial Pathogens in Surface Waters of Nairobi River and Health Implication to Communities Downstream Athi River.” International Journal of Life Sciences and Pharma Research 3 (1): 4-10. ISSN 2250-0480.

[16] Water Resources Authority (WRA). 2019. Strategic Plan 2018-2022. Nairobi, Kenya.

[17] Environmental Management and Coordination (EMCA). 2006. Water Quality Regulations of 2006 in Kenya. Kenya Gazette Supplement No. 68 of 29 September 2006, 1-25. https://www.nema.go.ke/images/Docs/water/water_quality_regulations.pdf.

[18] Water Services Regulatory Board (Wasreb). 2008. Guidelines on Drinking Water Quality and Effluent Monitoring. Nairobi: Wasreb Publication.

[19] Teck-Yee, L., Norliza, G., Chen-Lin, S., Lee N., Siiong-Fong, S., and Jongkar, G. 2017. “Seasonal Changes and Spatial Variation in Water Quality of a Large Young Tropical Reservoir and Its Downstream River.” Journal of Chemistry 2017 (2): 1-16. https://doi.org/10.1155/2017/8153246.

[20] World Health Organization (WHO). 2011. Background Document for Development of WHO Guidelines for Drinking Water Quality. Geneva: WHO Press.
Effectiveness of a Wastewater Treatment Plant located at EPZ in reducing Pollutants Discharged into River Athi, Kenya

[21] Al-Mutaz, I., and Al Ghunaimi, M. 2001. “Performance of Reverse Osmosis Units at High Temperatures.” In Proceedings of the Ida World Congress on Desalination and Water Reuse, October 26-31, 2001, Bahrain.

[22] Droste, R. 1997. Theory and Practice of Water and Wastewater Treatment. New York, NY: John Wiley and Sons, 678-81.

[23] Clesceri, S., Greenberg, A. E., and Franson, M. A. 1995. Standard Methods for the Examination of Water and Wastewater, 19th ed. Washington D.C.: American Public Health Association (APHA).

[24] Kasima, E. 2014. “Efficiency of Municipal Waste Water Treatment Plants in Kenya: A Case Study of Mombasa Kipevu Treatment Works.” M.Sc. thesis, University of Nairobi.

[25] Ling, T. Y., Lee, T. Z. E., and Nyanti, L. 2013. “Phosphorus in Batang Ai Hydroelectric Dam Reservoir, Sarawak, Malaysia.” World Applied Sciences Journal 28 (10): 1348-54.

[26] Gitari, W. M., Tshikovi, F. P., and Akinyemi, S. A. 2017. “Physicochemical Appraisal of Effluents Receiving Streams: A Case Study of Mvudi River, South Africa.” Advances in Environment and Pollution Research 1 (1): 1-17.

[27] Miruka, A. C., Kariuki, D. K., Yusuf, A. O., and Onyatta, J. O. 2018. “Efficiency of a Wastewater Treatment Plant in the City of Nairobi.” International Journal of Sciences: Basic and Applied Research 38 (1): 152-62.

[28] Chen, C. W., Chen, C. F., and Dong, C. D. 2012. “Distribution and Accumulation of Mercury in Sediments of Kaohsiung River Mouth, Taiwan.” APCBEE Procedia 1: 153-8.

[29] Ros, J. P. M., and Slooff, W. 1987. Integrated Criteria Document. Report No. 758476004. Cadmium: Bilthoven, National Institute of Public Health and Environmental Protection.

[30] Ferrara, R., Mazzolai, B., Lanzillotta, E., Nucaro, E. A., and Pirrone, N. 2000. “Temporal Trends in Gaseous Mercury Evasion from the Mediterranean Seawaters.” Science of the Total Environment 259 (1-3): 183-90.

[31] Alloway, B. J. 1995. Heavy Metals in Soils, 2nd ed. Blackie, New York.

[32] Monisha, J., Tenzin, T., Naresh, A., Blessy, B. M., and Krishnamurthy, N. B. 2014. “Toxicity, Mechanism and Health Effects of Some Heavy Metals.” Interdiscip Toxicol. 7 (2): 60-72. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4427717/.

[33] Yi, L., and Wong, P. 2006. “Recent Advances of Conductive Adhesives as a Lead-Free Alternative in Electronic Packaging.” Journal of Materials Science and Engineering 51: 1-35.

[34] Philip, L., Clyde, S., Jeffrey, M., Marianne, F., and Joel, S. 2002. “Environmental Pollutants and Disease in American Children: Estates of Morbidity, Mortality, and Costs for Lead Poisoning, Asthma, Cancer, and Developmental Disabilities.” Environmental Health Perspectives 110 (7): 4-16.

[35] Dennis, P., Brent, F., Fiona, M., Brent, K. 2003. “Human Health Risk and Exposure Assessment of Chromium (VI) in Tap Water.” Toxicology and Health 66: 1295-339.

[36] Pellerin, C., and Booker, S. M. 2000. “Reflections on Hexavalent Chromium: Health Hazards of an Industrial Heavyweight.” Environmental Health Perspectives 108 (9): 108-9.

[37] Fan, X., Cui, B., Zhang, K., Zhang, Z., and Shao, H. 2012. “Water Quality Management Based on Division of Dry and Wet Seasons in Pearl River Delta, China.” Clean Soil, Air, Water 40 (4): 381-93.