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Assimilation of Pollution Loading on Sosiani River in Eldoret Municipality, Kenya: As a Wastewater Management Strategy

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Abstract In this study, the pollution loading on Sosiani River, in Uasin Gishu County, Kenya, was assessed. The aim of this study was to determine assimilation of pollution loading by the two wastewater treatment plants located in the Eldoret Municipality. Samples were collected from six points along the river, influents and effluents of the treatment plants. Faecal and Total Coliforms, heavy metals; Pb, Cd, Cu and Zn, anions; Cl^-, F^-, NO^{3-}, PO_4^{3-} and SO_4^{2-}, flow and pollution loading points, PLP, were determined. The parameters were determined using experimental procedures. The PLP was 800 and the river's tolerance limit 10 %, hence a threshold of 880 PLP. Heavy metals' levels were; Pb 0.583 - 0.970 mg / L, Cd 0.081 – 0.112 mg / L, Cu 0.038 - 0.105 mg / L and Zn 0.097 - 0.116 mg / L. Faecal and Total Coliforms were 25 - 1144 and 120 - 1555 Cfu / 100 ml, respectively. Chemical parameters were in the range; F 0.0125 - 0.469 mg / L, Cl 141.800 - 529.390 mg / L, NO_3 2.990- 6.495 mg / L, PO_4 0.038 - 4.052 mg / L and SO_4 0.319 - 6.424 mg / L. The river flow range was 13920 - 70560 L / minute. The effluent flows were 1560 and 3960 L / minute. The coliforms exceeded the nil Cfu / 100 ml limit. Chloride levels at S2, S4, S6 and phosphate at S6 exceeded the 275 and 0.11 mg / L limits, respectively. The study will provide information on the contribution of the treatment plants to the pollution loading into the river. It will highlight the role of a river volume in determining its assimilative capacity and this will inform decisions made by water service providers on effluent volume.

Keywords: *wastewater, pollution loading, water resource, assimilation, tolerance limit*

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1. Introduction

Pollution load is defined as an amount in volume and parameter concentrations of effluent released into a given water body or natural environment [1]. Effluent is defined as liquid discharging from a containing space, untreated, fully treated or subjected to partial treatment into a river or lake or environment. Assimilation means the capacity of a water resource to accommodate effluent without negative environmental impact to aquatic life or the environment. The threshold is 'maximum volume and concentration of parameters of effluent that should be released into a specific water body [1]. The treatment of wastewater is carried out to reduce the level of pollutants before disposal or discharge into the receiving water resource [2]. A major challenge for developing countries in achieving safe drinking water is finding ways to provide a sustainable water supply and basic sanitation in small towns and rural areas. According to World Health Organization, WHO, 1.1 billion people have no access to safe drinking water [3]. In urban areas, off-site wastewater treatment systems are a common practice in which wastewater is collected and transported to wastewater treatment plants for treatment [4]. Wastewater if not treated properly may lead to problems in the receiving waters as the waste discharges may contain toxic substances such as heavy metals which may affect the use of the receiving water [5].

Research work by [3] along Sosiani River showed average counts of faecal Coliforms above the WHO limits of nil Cfu / 100 ml with the increasing trend downstream. Although there was microbiological contamination of the river, no contamination source was identified and further research was recommended. It was in this background that this study sought to find out the contribution of the treatment plants on pollution loading into Sosiani River and its assimilation. The Kenya Government has received complaints from the public about the poor water quality, which impacts negatively on human and ecosystem health [6]. About 1.8 million children under five years die every year due to waterborne diseases. Water sources are deteriorating and focus on drinking water and sanitation without due attention being paid to wastewater management systems may have worsened the situation experienced worldwide [7,8]. Kenya is expected to implement Goal 6 of the United Nations Sustainable Goals (SDGs) of ensuring improved sanitation and water is available to all by 2030 [9] To actualize this vision will require adequate wastewater management systems and minimizing pollution load into receiving water resource [1,10]. The evaluation of wastewater treatment is very important as it provides information on how under loaded or overloaded the system is and how the loading of the system can be safely adjusted to fit the prevailing situation [5].

The study will provide information on the contribution of the treatment plants to pollution loading into the river water. It will highlight the direct relation between the assimilative capacity of a river and its volume and this will have a bearing on decisions made by water services providers on effluent volume discharged into a water body. The findings will help Environmental Agencies such as National Environment Management Authority (NEMA) to delineate a deep modeling of the river to choose appropriate remediation methods.

1.1. Effluent Discharge Quantity Classification

To properly manage effluent pollution, the Kenyan government has established quality standards that effluent dischargers should follow. The government has established the "Polluter-pays principle "and a rebate is offered to facilities that make efforts to minimize effluent pollution [1]. It is after meeting the established quality standards that approval is obtained from WRMA and the permit issued for discharge. Wastewater discharge is classified into four categories, namely A, B, C, & D, based on the level of impact that the discharge has on the water body receiving it. The effect of wastewater released to a water body depends on the volume of the effluent as well as the volume of the water body receiving wastewater. There will be less dilution if the volume of the receiving water body is less compared to the effluent volume and the impacts will be severe [1]. Categories of effluent discharge are a reflection of the scale of impact on the water resource. The categories of effluent discharge are based on the quantity of effluent discharged into the water resource. It is a percentage of effluent volume to the volume of the water body receiving it and is expressed as Effluent Discharge Points (EDP). If the quantity of effluent discharged is less than 5% of the receiving water resource, then it accrues 10 EDP, 5 – 25 % accrues 20 EDP, 26 – 50 % accrues 50 EDP and above 50% accrues 100 EDP hence they fall under categories A, B, C and D, respectively. Category A has the lowest risk while D has the highest risk of impacts on a water resource.

1.2. Effluent Discharge Facility Classification

Effluent discharge facilities are classified according to their potential pollution impacts. The facilities therefore are generally classified from parameters to be monitored for ease of administration and then coded. Effluent discharge facility classification has five categories coded as: FC1, FC2, FC3, FC4, and FC5 [1]. The codes show the increasing potential of pollution impact of the effluent discharge quality through the type and number of parameters to be monitored and ranges from Code FC1 where only the basic Compulsory Parameters (C.P.) for water quality evaluation are monitored, to Code FC5 where the parameters monitored include heavy metals and pesticides. The Compulsory Parameters include Total Coliforms, pH, Temperature, Turbidity, BOD, Flow, DO, COD, TDS, Total Nitrogen and Total Phosphorus. Chemical Parameters include fluoride, sulphur, chloride, phosphates, nitrates, sulphates, carbonates, magnesium, calcium and salinity. Table 1 shows the effluent discharge facility classification.

1.3. Effluent Discharge Quality Classification

The effluent discharge quality just like the effluent discharge quantity is assessed and graded according to effluent parameters, thereby gaining Accruing Quality Points (AQP). The AQP indicates the severity of the potential impact of the effluent discharge on the quality of the water resource. Low AQP indicates that the water resource quality is less altered by effluent discharge emanating from facilities classified in that particular code. For example, in Code FC1 (Facility Category 1), only Compulsory Parameters (CP) are monitored and has 10 AQP. Table 2 illustrates effluent quality classification.

Table 1. Effluent discharge facility classification

FACILITY	PARAMETER FOR MONITORING	CODE
Domestic waste (WSP_A, Water Service Providers with no industries) Nyeri, Embu, Nanyuki e.t.c, Hospitality industries, Slaughter houses	Compulsory Parameters (C.P) = Feacal coliforms, pH, Temperature, Colour, Turbidity, DO, Flow, TDS, BOD, COD, (Total N, Total P where applicable)	FC1
Agro Processing Factories (Tea,Coffee, Sugar, Dairies, Sisal)	C.P. + Chemicals (NO_3, PO_4, F, S, SO_4, Cl)	FC2
Hydroelectric Generating PowerCo. Lodges & Hotels, PaperIndustry, Fish, Dairies	C.P+ Chemicals + TPH+ Oil & Grease & Surfactants	FC3
Oil Refineries, Cement Industry,Tanneries, (Limuru, Thika, Eldoret,)	C.P + Chemicals + TPH+ Oil & Grease & Surfactants + Heavy metals (Zn, Mn, Hg, Cr, Cd, Pb, Se, As, Cu, Sn, Fe, Co,)	FC4
Irrigation Schemes, Cities WSP_B (Nairobi, Thika, Nakuru, Kisumu, Mombasa), Geothermal Power Generators, Floriculture	C.P + Colour+ Chemicals + TPH + Oil & Grease &Surfactants + Heavy metals + Pesticides, Radioactive	FC5

Source: [1].

Table 2. Effluent discharge quality classification

CODE	PARAMETERS	ACCRUING QUALITY POINTS
FC1	Compulsory parameters (C.P)	10
FC2	Compulsory parameters + chemicals	20
FC3	Compulsory parameters + chemicals +oil and grease and surfactants	40
FC4	Compulsory parameters + chemicals + oil and grease and surfactants + heavy metals	80
FC5	Compulsory parameters +chemicals +oil and grease & surfactants + heavy metals + pesticides	100

Source: [1].

1.4. Pollution Loading Point Correlation

The Effluent Discharge Quantity (EDP), Effluent Discharge Facility (FC), Effluent Discharge Quality (AQP) may be correlated to give the overall pollution load on a given water resource [1]. The pollution loading point correlation table shows the consideration of all the three aspects (quality and quantity of effluent, quantity of receiving water body) in establishing pollution loading, a given water resource may accommodate. It also allows for the calculation of the tolerance or thresholds of effluent being discharged into a given water resource. A given facility will attain low or high PLP based on the quality and quantity of its effluent discharge and the quantity of the receiving water resource. Thus, if a given water resource has a low quantity of water compared to effluent discharged into it (high EDP), its threshold, (capacity to accommodate effluent), would be low and only low quantity of 'good quality' effluent will be discharged into it [1]. Table 3 shows pollution loading correlation.

Table 3. Pollution loading correlation

	QUALITY (PARAMETERS TO BE ANALYZED) (AQP)					
QUANTITY (EDP)	Category (points)	FC1(10)	FC2 (20)	FC3 (40)	FC4 (80)	FC5 (100)
	A (10)	100	200	400	800	1000
	B (20)	200	400	800	1600	2000
	C (50)	500	1000	2000	4000	5000
	D (100)	1000	2000	4000	8000	10000

Source: WRMA [1].

1.5. Threshold Tolerance Range

Pollution Loading Points (PLP) may be used to estimate or establish thresholds for each category of effluent to be discharged. The threshold may be expressed as tolerance or the range in percentage or PLP. For example a discharger within the 100 PLP may be allowed a tolerance of 20% of PLP, hence 120 PLP. The discharge threshold will be 0-120 PLP since it is a low impact Class.

Table 4 illustrates class of permit and threshold tolerance range.

Table 4. Class of permit and threshold range

Class of Permit	Pollution Loading Points	Potential Impact	Tolerance (%)
A	0-200	Low impact	20
B	201-1600	Moderate impact	10
C	1601-4000	High impact	5
D	4001-10000	Very high impact	0

Source: WRMA [1].

1.6. Threshold on Parameter Pollution Loading

Thresholds or tolerance range of pollution parameters compliance will be treated in a similar manner as Table 4 above. This implies that, if COD's permissible level is 50 ppm, then a facility in Class 1 will be allowed a tolerance of 20%, giving a maximum of 60 ppm, that of Class 2, a maximum of 55 ppm, Class 3, a maximum of 52.5 ppm while that of Class 4, a maximum of 50 ppm. This allows the flexibility and tolerance that discriminate those that do not pose serious threats to the water resources against those that would impact heavily were they to deviate even slightly from the allowable. It also affords the water resource accommodation of the effluent (threshold).

2. Materials and Methods

2.1. Research Design

The study adopted experimental design in which water quality parameters such as Faecal and Total coliforms, heavy metals (Pb, Cd, Cu and Zn), anions (Cl^-, F^-, NO^{3-}, PO_4^{3-}, SO_4^{2-}), flow and pollution loading were determined.

2.1.1. Study Area

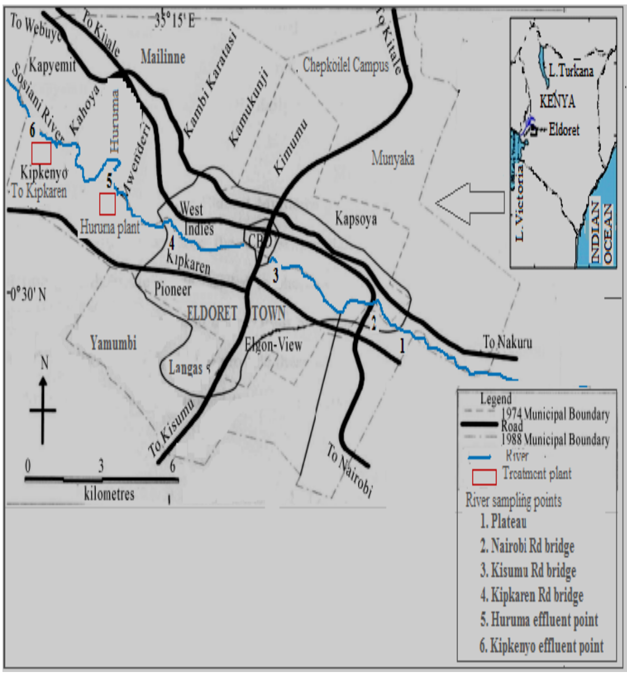

Figure 1. Map showing sampling points in Sosiani River and estates within Eldoret (Source: [11])

This study was carried out in Eldoret Municipality along Sosiani River, in Uasin Gishu County, Kenya. Eldoret is located at a latitude of 0°31'N and longitude of 35°17' E. The altitude ranges between 1700 - 2100 metres above sea level [3]. Eldoret Water and Sanitation Company is the water service provider contracted by the Lake Victoria North Water Services Board (LVNWSB) to serve on its behalf [12]. Eldoret is served by two sewerage treatment plants, namely, a conventional sewerage treatment known as Boundary Treatment Plant (BTP) at Kipkenyo and Quarry Treatment Plant (QTP) stabilization ponds at Huruma [13]. Figure 1 illustrates map of the study area.

2.2. Wastewater Sampling and Pretreatment

Sampling was carried out three times during the month of April and May. The sampling points included six sites along the river (S1 to S6) and the treatment plants' influent and effluent (Figure 1). The samples were subjected to water quality analyses in a bid to determine pollution load in the river. Sampling points along the river were selected based on access, potential sources of pollution, waste disposal activities and in anticipation that the water quality varied downstream.

The sample bottle was washed twice using the river water before collecting samples and sealing. For bacteriological tests, the sample containers were sterilized at 121°C at a pressure of 20 psi for 45 minutes in an autoclave. For other tests, water samples were collected in 1- litre plastic bottles, which had been pre-cleaned with 5% nitric acid and rinsed with deionized water. Samples were immediately stored on ice in a cooler [14]. Sample bottles were labelled based on sampling site, then maintained in the ice cold cooler box. The contents of the cooler-box were moved to the laboratory for analyses [15]

2.3. Water Quality Parameters

The following parameters were tested based on the methods described by [16].

2.3.1. Chloride and Fluoride

An Argentometric method was used and chloride concentrations worked out in the pH range of 7 - 9 by titrating with standard $AgNO_3$ and K_2CrO_4 indicator. The AgCl was precipitated and at end point red colour of silver chromate (Ag_2CrO_4) appeared.

$$Chloride\ (mg/L) = (A-B)\ x\ N\ x\ 35.45\ x\ 1000\ x\ V^{-1} \tag{2.1}$$

Where:
A = ml $AgNO_3$ required for sample
B = ml $AgNO_3$ required for blank
N = Normality of $AgNO_3$ used
V = ml water sample used.

For fluoride ion concentration, selective electrode method was used.

2.3.2. Sulphate

Nephelometric method was used in this analysis in which sulphate level turbidity was determined against the levels of standard sulphate solution turbidity. Barium chloride was used to produce turbidity caused by formation of barium sulphate. A solution mixture of sodium chloride and Glycerol was used to stop turbidity settling.

2.3.3. Phosphate

Phosphate was measured spectroscopically as described by [17]. Yellow colour was produced in the reaction between phosphates and molybdate ion in the strong acidic medium. The strength of colour was positively correlated to the sample phosphate level.

2.3.4. Nitrate

Nitrate was determined using phenoldisulphonic acid (PDA) method outlined by [17]. Nitrate reacts with PDA to yield nitro derivatives that rearrange its structure in alkaline solution to form a yellow coloured product with traits which follow Beer's law. Chloride interference was eliminated by precipitating chloride with Ag^+.

2.3.5. Biochemical Oxygen Demand (BOD)

For S1 - S6, 432 ml of sample and 97 ml of influent and effluent were measured. Dilution factor for influent and effluent was 20, using de-ionized water. The magnetic stirring rod was put into sample bottle, a rubber quiver inserted in the neck of the bottle. A Multimeter probe was tightly screwed directly on sample bottle and initial value of oxygen recorded. The sample bottle with the probe put on was kept for 5 days at 20 °C in an incubator. After 5 days the final Oxygen reading was recorded and the difference in initial and final values of oxygen gave BOD_5 (mg/ L).

2.3.6. Total Coliform Count and Faecal Coliform Count

Water samples were obtained aseptically in sterilized sampling bottles. The samples were then moved to the microbiology laboratory in an ice cold cooler box for 2 hours. Each sample bottle was shaken thoroughly in readiness for filtration. A small amount of 70 % ethanol was evenly spread on the inner surface of the Buchner funnel and lit for 2 minutes to sterilize it. Using a sterile forceps, a sterile filter paper was placed over the porous funnel. The sample was passed through the filter paper under partial vacuum until all the 100 ml sample was drained off into the volumetric flask. The soaked membrane filter was removed immediately with a sterilized forceps and placed carefully on the surface of the solidified media in a rotating motion to avoid entrapment of air. The culture dish was incubated for 23 hours at 37°C for Total Coliforms and 43°C for Faecal Coliforms. Coliform forming units (Cfu) per 100 ml of sample were recorded.

2.3.7. The Water pH

pH was measured according to the method described by [18]. A water sample was taken in a small beaker then the pH meter probe dipped into the sample, left to stay for a while until a stable value was obtained.

2.3.8. Quantitative Determination of Heavy Metals

The heavy metals Pb, Cd, Zn and Cu contents were analyzed using the AAS method as described by [19]. A

100 ppm stock solution was prepared for Pb, Cd, Cu and Zn, and then 0, 1, 2, 3, 4 and 5 ppm solutions were prepared by serial dilution of the stock solutions of the respective metal ion. The wavelengths for the metal ions were Pb 283.3 nm, Cd 228.8 nm, Cu 324.8 nm, and Zn 213.9 nm. Appropriate calibration was performed using the standards, after which samples were analyzed for the various heavy metals.

2.4. Effluent and River Flow

The flow of the effluent from the treatment plants and that of Sosiani River water was determined using standard procedures as described by [20].

The length (L) and width of the effluent channel was measured together with the depth of the effluent in the channel. A float was placed on the effluent at the upper end of the length of the channel and time taken to cover the L distance by the float was recorded. The procedure was the same for the river water.

The effluent flow rate was determined using the formula;

$$Flow\ rate = ALC / T \tag{2.2}$$

Where:
A = average cross-sectional area of the channel (channel width multiplied by the average depth of wastewater
L = channel length
C = channel's rocky-bottom correction factor (0.8)
T = time (seconds) taken by float to cover L distance.

2.5. Pollution Loading

Pollution loading was determined according method described by [1]. .

The effluent volumes for BTP and QTP were determined by measuring the time taken for a float to cover length (L) and cross-section area of effluent tunnel. This gave a volume of effluent discharged into the river per second. The volume of the river water at effluent discharge points and sampling points were determined using the same procedure as the effluent. The percentage of effluent volume to the river volume was used to determine EDP. The treatment plants in Eldoret are classified under FC 4 (Table 1) and give the corresponding AQP (Table 2). The pollution loading points (PLP) were obtained by pollution loading correlation (Table 3).

$$PLP = EDP * AQP \tag{2.3}$$

Where:
PLP = Pollution loading points
EDP = Effluent Discharge Points
AQP = Accruing Quality Points.

Pollution loading points were used to determine the potential impact and threshold on parameter loading (Table 4). The effluent quality parameters such as Coliforms, heavy metals (Pb, Cd, Cu and Zn), and anions (Cl^-, F^-, NO^{3-}, PO_4^{3-} and SO_4^{2-}) were determined. The effluent parameter concentrations were used to determine pollution load from the treatment plants into the river.

2.6. Quality Assurance

Suitable quality assurance measures and precautions were adopted to safeguard results validity. Extra care was taken when handling samples to prevent contamination and apparatus were cleaned properly using hydrochloric acid then rinsed with deionized water. Chemicals were of analytical specification and the study ensured the use of deionized water [21].

2.7. Reproducibility Tests for Methods

Reproducibility test was done by analyzing standards for the test parameters where applicable. The mean, standard deviation and % recovery were calculated. The instruments were calibrated using linear regression methods.

3. Results and Discussions

3.1. Heavy Metals

The concentrations of the heavy metals were as indicated in Table 5. There was a general increase trend in heavy metal concentration downstream. This was attributed to less polluted water upstream which emanate from natural sources and with riparian vegetation cover. The concentrations of lead and cadmium exceeded Kenya standards for limits into public water of 0.01 for both Pb and Cd. This was attributed to deposits from exhaust gases of automobile engines due to the proximity of the river to the roads.

Table 5. Heavy metal levels at the ten sampling points

Site	Pb (mg / L)	Cd (mg / L)	Cu (mg / L)	Zn (mg / L)
S1	0.767	0.081	0.041	0.098
S2	0.697	0.082	0.038	0.114
S3	0.637	0.098	0.042	0.116
S4	0.583	0.112	0.050	0.102
S5	0.823	0.118	0.075	0.103
S6	0.970	0.122	0.105	0.097
QTPI	1.375	0.191	0.059	0.253
QTPE	0.667	0.108	0.067	0.085
BTPI	0.780	0.105	0.083	0.091
BTPE	1.087	0.150	0.088	0.098

3.2. Bacteriological Parameters

Bacteriological parameters' concentrations increased downstream and were attributed to faecal and animal waste contamination. Higher Faecal Coliform count at S3 was attributed to anthropogenic activities within the nearby Matatu terminus such as disposal of human waste beneath the Kisumu road bridge. For points S5 and S6, the higher Faecal and Total Coliforms were attributed to effluent from the treatment plants. Blockage of sewer line in residential estates next to the river such as Huruma estate releases raw sewage into Sosiani River. Table 6 illustrates coliform counts in the water.

Table 6. Bacteriological parameters at the ten sampling points

Site	Faecal coliforms (Cfu / 100 ml)	Total coliform (Cfu / 100 ml)
S1	25	286
S2	50	120
S3	572	858
S4	143	1001
S5	1430	1800
S6	1430	1761
QTPI	858	1311
QTPE	1144	1555
BTPI	10400	14300
BTPE	715	858

3.3. Chemical Parameters

The results were as indicated in Table 7 which showed a general increase trend in chemical parameter concentrations downstream. The trend was in agreement with the findings of similar studies by [22] and [2]. Chloride concentrations at S2, S4 and S6 exceeded WHO recommended value of 250 mg/L [23]. This excess chloride level in the river water suggested possible contamination by faecal or animal waste. For S6, it was attributed to contamination by effluent from the treatment plants. Phosphate concentration at S6 exceeded WHO standard limit of 0.1 mg / L and was attributed to effluent from the treatment plants. The BOD values at S2, S5 and S6 were above the WHO recommended limit of 5.0 mg / L and was related to contamination of the river at the sampling points. The pH values in all the sites were within WHO limits of 6.5 - 8.5.

Table 7. Levels of chemical parameters at the ten sampling points

Site	F^- mg / L	Cl^- mg / L	NO_3^- mg / L	PO_4^{3-} mg / L	SO_4^{2-} (mg / L)	BOD_5 mg/L	pH
S1	0.125	142.	3.60	0.038	0.456	3	6.7
S2	0.378	295	3.41	0.064	0.319	7	7.0
S3	0.351	142	3.55	0.048	0.342	0	6.8
S4	0.361	350	2.99	0.048	0.342	0	7.4
S5	0.266	145	3.51	0.061	0.433	7	7.1
S6	0.469	529	6.50	4.052	6.424	13	7.9
QTPI	0.458	205	24.38	7.047	17.36	465	6.4
QTPE	0.310	210	11.57	2.598	0.820	420	7.4
BTPI	0.236	369	26.84	7.716	3.189	322	6.5
BTPE	0.317	295	24.29	6.665	1.663	123	7.7

3.4. Flow

Table 8. Water flow (L / min) at the twelve sampling points

Site	Flow (L / minute)
S1	25020
S2	40080
S3	13920
S4	70560
S5	11580
S6	35220
QTPI	17640
QTPE	3960
RQE	88680
BTPI	14580
BTPE	1560
RBE	33600

RQE- River at Quarry Effluent, RBE- River at Boundary Effluent, QTPI- Quarry Treatment Plant Influent, QTPE- Quarry Treatment Plant Effluent, BTPI- Boundary Treatment Plant Influent, BTPE- Boundary Treatment Plant Effluent.

The flow of the river varied downstream and was attributed to variance in slope as well as water abstraction for various activities. Table 8 shows the flow of the river at sampling points, influent and effluent of the two treatment plants.

3.4.1. Influent Flow

Although BTP's capacity is 10,000 m^3 per day, there were days when the treatment plant's capacity was exceeded as illustrated in Figure 2. This implied that the treatment plant was overloaded and therefore its efficiency was likely compromised. The highest influent flow was 10.308 m^3 on Monday with a general decrease trend throughout the week. This trend was attributed to more activities on Monday after a weekend rest and increased industrial production, which leads to increase in wastewater generation.

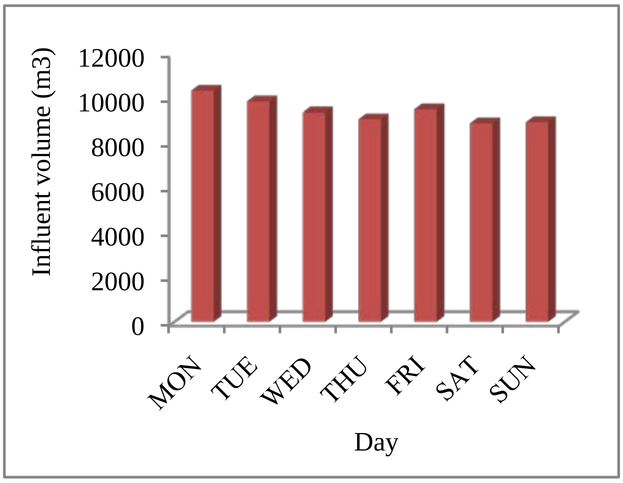

Figure 2. BTP average daily influent flow

3.4.2. Influent Flow Variation with Time

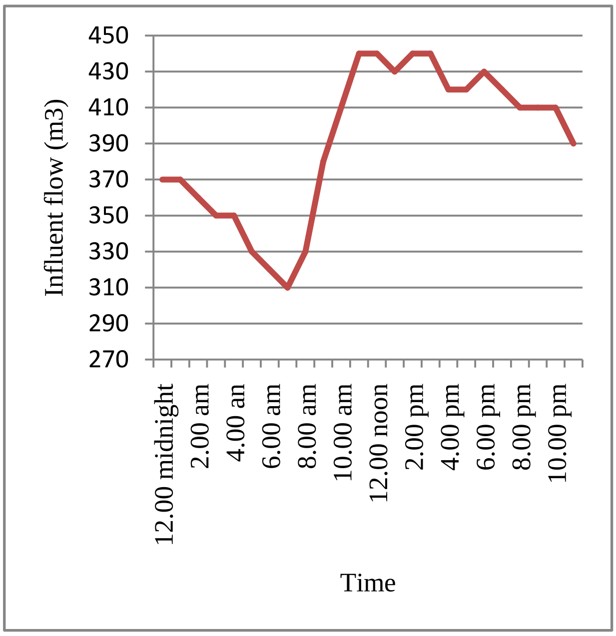

Figure 3. BTP mean hourly influent flow

The influent flow variations are illustrated in Figure 3. There was a decline trend in influent flow from midnight to 7.00 am, the flow showed an increase trend between

7.00 am and 11.00 am. Flow peak was between 11.00 am - 3.00 pm, then decrease pattern followed. At night there are less wastewater generating activities as most people are asleep and industrial processes are not at their maximum capacities. At 7.00 am preparations for the day's activities begin and reaches peak when hotel industries start serving lunch and more wastewater is generated.

3.5. Pollution load

3.5.1. Chemical Parameter Load

Parameters load into the treatment plants was found to be greater than the effluent load into the river from the treatment works. For example, influent was found to load QTP with 429.322 g nitrates per minute while the effluent from QTP had 45.813 g nitrates discharged into the Sosiani River per minute. Table 9 provides information on parameter load in both influent and effluent of the treatment plants.

Table 9. Plants' chemical parameter loading (g / min)

Parameter	QTPI	QTPE	BTPI	BTPE
F	8.432	1.228	3.441	1.327
NO_3	429.322	45.813	391.298	37.891
PO_4	124.309	10.288	112.499	10.397
SO_4	306.195	3.247	46.496	2.594
Cl	3624.491	832.115	5375.354	460.855
Pb	24.255	2.641	11.372	1.696
Cd	3.369	0.428	1.531	0.234
Cu	1.041	0.265	1.210	0.137
Zn	4.463	0.337	1.327	0.153

3.5.2. Bacteriological Parameter Load:

Bacterial loads from QTP into Sosiani River were 45.302 million faecal Coliforms and 61.578 million Total Coliforms counts / minute. The effluent from BTP was found to load the river with 11.154 million faecal Coliforms counts per minute while Total coliform was 13.385 million Cfu / minute. These were above the Kenya guideline values for discharge into public water of nil faecal Cfu / 100 ml and 30 Total Cfu / 100 ml [5]. Table 10 indicates bacterial loads in influents and effluents of the treatment plants.

Table 10. Plants' bacterial load (000,000 Cfu / min)

Sampling sites	Faecal coliform (000,000 Cfu/min)	Total coliform (000,000 Cfu/min)
QTPI	151.351	231.260
QTPE	45.302	61.578
BTPI	1516.320	2084.940
BTPE	11.154	13.385

3.6. Pollution Loading

The quantity of effluent from QTP was 3,960 L per minute (Table 8) and was discharged into 88,680 L of the river water. The QTPE as a percentage of river water at the discharge point (RQE) was 4.46 %. For BTP, effluent volume (BTPE) was 1560 L while river volume at the effluent discharge point (RBE) was 33,600L which gave effluent percentage of 4.64 %. In both QTP and BTP, the percentage of effluent volume to river volume was below 5 %, which yielded 10 EDP and belonged to category A. The treatment plants fall under facility code FC 4 (Table 1) and earned 80 Accruing Quality Points (Table 2).

Pollution loading points (PLP) for both QTP and BTP was 800 (Table 3 and equation 2.3) and was used to establish thresholds for each effluent discharging facility (Table 4). The two treatment plants' effluent volumes were of moderate potential impact to the ecosystem, when based on quantity. The tolerance limit was 10% and this implied, for example, that the river volume (RQE) could accommodate effluent volume of 4356 L per minute from QTP without negative impact to the environment. In terms of PLP, the tolerance for both the treatment plants was 880 PLP. Table 11 gives pollution loading and threshold for each effluent discharging facility.

Table 11. Pollution loading for the two treatment plants

Facility	EDP	AQP	PLP	Potential Impact	Tolerance (%)
QTP	10	80	800	Moderate	10
BTP	10	80	800	Moderate	10

Threshold on parameter pollution loading was established using the results in Table 11 and the WHO recommended water quality parameter limits. Chloride levels exceeded the river tolerance limit of 275 mg / L at S2, S4 and S6. Phosphate concentrations were above the river threshold of 0.11 mg / L at site S6.There is pollution of the river from pollution loads emanating from the treatment plants and worsens with decrease in river water quantity. The study provides evidence that consumers of Sosiani River water risk exposure to waterborne diseases as a result of higher coliform load. In all the sampling points, the levels of faecal and total Coliforms exceeded the WHO/ NEMA recommended levels of nil Cfu / 100 ml and was in agreement with the findings of a similar study by [3] on Sosiani River. The parameter tolerance limits within Sosiani River were as indicated in Table 12.

Table 12. Parameter tolerance limits

Parameter	WHO permissible level (mg / L)	Tolerance 10 % (mg / L)
Chloride	250	275
Phosphate	0.1	0.11
Fluoride	1.5	1.65
Nitrate	50	55
Sulphate	500	550
Cd	0.003	0.0033
Pb	0.010	0.011
Cu	0.020	0.022
Zn	3.000	3.300
BOD5 at 20°C	5.000	5.500

3.7. Conclusions and Recommendations

All the sampling points of the river had faecal and total coliforms above the tolerance limit of nil Cfu / 100 ml and therefore the faecal coliform and total coliform loading exceeded the assimilative capacity of the water resource. The chloride concentrations at S2, S4 and S6 exceeded the threshold of 275 mg / L and assimilation was not possible. Phosphate levels at S6; BOD at S2 and S5 were above the assimilative capacity of the river of 0.11 mg / L and 5.5 mg / L for phosphate and BOD, respectively The coliform, chloride and phosphate loading on the river per minute by the treatment plants were above the assimilative capacity. The water resource was not able to assimilate the heavy metals emanating from the treatment plants except Zn. The favourable conditions for coliforms multiplication can lead to health problems to consumers downstream. Impacts of effluents from the plants worsen with a decrease in the water body volume.

Further research studies are necessary to determine the impact of wastewater discharge on the environment.

Water from Sosiani River is not safe for human consumption and there is a need to sensitize the community using the water on its quality and the potential danger it poses to human health.

The policy of the "polluter-pays" system should be implemented by the WSP on all wastewater generators to the sewer system to ensure compliance with Kenya guideline values for discharge into public sewers.

NEMA and WSPs should work jointly to address the challenges of river water abstraction upstream so as to mitigate the impacts of effluent discharged into the river.

Statement of Competing Interests

The authors had no competing interests.

List of Abbreviations

AQP – Accruing Quality Points
BOD – Biochemical Oxygen Demand
BTP – Boundary wastewater Treatment Plant
BTPE – Boundary wastewater Treatment Plant Effluent
EDP – Effluent Discharge Points
LVNWSB – Lake Victoria North Water Services Board
NEMA – National Environment Management Authority
PLP – Pollution Loading Points
QTP – Quarry wastewater Treatment Plant
QTPE – Quarry wastewater Treatment Plant Effluent
RBE – River at Boundary Effluent
RQE – River at Quarry Effluent
WASREB – Water Services Regulatory Board
WHO – World Health Organization
WRMA – Water Resources Management Authority
WSP – Water Services Provider

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