



WATER-BORNE BACTERIAL PATHOGENS IN SURFACE WATERS OF NAIROBI RIVER AND HEALTH IMPLICATION TO COMMUNITIES DOWNSTREAM ATHI RIVER

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ABSTRACT

The quality of surface water in Nairobi River and the adjacent river Athi was assessed to ascertain whether it meets local and international microbiological standards for safe human consumption. Standard bacteriological techniques were used to describe bacteria content from water samples collected from the two confluent sources. The waters were highly contaminated with human pathogenic bacteria. The most dominant bacteria in combined waters of the two rivers was *Escherichia coli* ($1.0 \times 10^4 \pm 2.6 \times 10^3$ / 100 mL) while the least was *Shigella flexneri* ($1.2 \times 10^1 \pm 1.2 \times 10^1$ / 100 mL). Other bacteria were *Klebsiella aerogenes* ($7.4 \times 10^1 \pm 1.8 \times 10^1$ / 100 mL), *Enterococcus faecalis* ($3.6 \times 10^3 \pm 3.2 \times 10^3$ / 100 mL), *Salmonella typhi* ($2.1 \times 10^2 \pm 1.3 \times 10^2$ / 100 mL), *Pseudomonas aeruginosa* ($6.5 \times 10^2 \pm 1.1 \times 10^2$ / 100 mL), *Salmonella paratyphi* ($1.6 \times 10^1 \pm 1.1 \times 10^1$ / 100 mL), and *Vibrio cholerae* ($5.6 \times 10^2 \pm 1.0 \times 10^2$ / 100 mL). Microbiological quality of the surface water was unacceptably high above compliance level of national standards, and the World Health Organization (WHO) guidelines for drinking water and agricultural use. The water from these rivers is not potable, and poses a health risk to communities that rely on the rivers as primary sources of domestic and subsistence irrigation use. These findings in water scarce region of the world underline the challenges a number of developing countries are facing currently and in long-term into the future. Lessons learnt in this study would suggest appropriate measures are necessary to control pollution of similar rivers in sub-Saharan regions in particular and developing countries in general to ensure availability of clean water supplies to large concentrated populations in cities within the Millennium Development Goals.

KEY WORDS: Microbiological water quality, bacterial pathogens, low-income countries, water scarce region.

INTRODUCTION

Pollution of river waters with deleterious microbes, including bacteria, viruses, parasites, as well as fungi, has been on steady increase in the recent past (Niyogi, 2005; Abraham *et al.*, 2007). The major source of microbes in water is faeces from human and other mammals. Entry of pathogens into rivers can occur either from a point source, non- point sources or both. Non- point

source microbial pollution of rivers occurs from rainwater surface run-offs, storm sewer spillages or overflow, while point-source pollution comes from discharge of untreated or partially treated effluents from wastewater treatment plants (Petersen *et al.*, 2005; Donovan *et al.*, 2008). The impact of river pollution on human health depends mainly on the water uses, as well as the

concentration of pathogens in the water (Niyogi, 2005). Waterborne pathogens present a greater health risk to people using river water for drinking, bathing, irrigation of crops eaten raw, fishing, and recreational activities (Liu *et al.*, 2006; Hellweger and Masopust, 2008). In order to reduce waterborne disease outbreaks World Health Organization (WHO) developed microbiological quality guidelines based on intended water uses. The guidelines stipulate that faecal coliforms (FC) should not exceed 10^3 per 100 mL of water to be used in irrigation of crops that are eaten uncooked, sports fields, and public parks in unrestricted regions (WHO, 1989). Environmental Protection Agency (EPA) standard is stricter, and requires zero (0) FC / 100 mL of water to be used in irrigation of any food crops not commercially processed including crops eaten raw (EPA, 1992). Kenya standard for drinking water quality states that no *Escherichia coli*, *Shigellae*, *Pseudomonas aeruginosa* or coliforms should be detectable in 250 mL of drinking water (WASREB, 2006). The Nairobi River traverses Nairobi, a city with population over 3 million, and flows along a number of informal settlements such as Mathare, Korogocho, and Dandora that are inhabited by poor people with young children. It receives effluent discharged from the city sewage treatment plant, before emptying its water into Athi River that runs for over 400km to the Indian Ocean. Wastewater generated by inhabitants of megacities contaminates rivers traversing them (Abraham, 2010). Yet, human pathogen content of Nairobi River is unknown. The combined waters of Nairobi and Athi rivers are extensively used by an estimated 4 million people, for drinking, and agricultural irrigation downstream. Residents of the capital city and nearby towns use the crops irrigated with the river water. Most of the farm produce grown with contaminated water including tomatoes, onions and carrots are eaten raw. Epidemiologic reports show a correlation between use of river water contaminated with pathogenic bacteria and disease outbreaks (Nyogi, 2005; Hammer *et al.*, 2006; Abraham *et al.*, 2007). It is important to assess the human pathogens associated with the Nairobi and Athi rivers with the aim of reducing and controlling disease burdens of downstream communities.

MATERIALS AND METHODS

Study area

The study was carried out in Nairobi River, which traverses Kenyan capital city, Nairobi. The samples were taken from 500 meters (m) upstream of the largest sewage treatment plant, Dandora Sewage Treatment Plant (DSTP), to a major tributary, Athi River that is about 23 kilometers (km) downstream. The Nairobi River has its catchment on the Kikuyu and Limuru Hills that are to western side, and within the outskirts of the city. Beyond the city, the river flows along six informal settlements composed of shacks built out of cardboards, iron sheets, and gunny bags. The informal settlements include: - Mathare, Korogocho, Kyambiu, Soweto, Dandora, and Njiru. At the DSTP site in Ruai the river receives partially treated effluent (UN-HABITAT, 2007). The combined Nairobi and Athi river water constitute the primary source of water for domestic and agricultural farming by downstream communities in urban centres of Machakos, Makueni, Kitui, Taita Taveta and Malindi before emptying into the Indian Ocean as river Sabaki.

Study design

The study design was purposive. Sampling points were deliberately chosen to account for the microbial loads in the Nairobi River before and after discharge of DSTP, and bacterial load that enter the receiving waters of Athi River. The sampled wastewater volumes and depth of sampling were as recommended by standard methods for water and wastewater examination (APHA, 1998). Five sampling points were mapped in the Nairobi and Athi rivers. Sampling points in the Nairobi River were located 500 m upstream and downstream of the treatment plant effluent, and downstream, 500 m confluence with the Athi River. In Athi River sampling points were located 500 m upstream before entry of Nairobi River and 500 m downstream after confluence.

Wastewater sampling procedures

Four duplicate samples were taken weekly from each sampling point from January to June, 2010. A total of 120 bacteriological samples were collected in clean sterile screw capped 250

millilitres polypropylene bottles. The samples were then transported to DSTP laboratory in ice packed cooler boxes and analyzed within two hours of collection.

Isolation and characterization of bacterial isolates

Bacterial types were determined by serial dilution and plating of water samples on differential culture media. The isolates were identified and biochemically characterized following the methods described in Bergey's Manual of Systematic Bacteriology (Krieg and Holt, 1984).

2.5 Data Analysis

Statistical Package for the Social Sciences (SPSS) version 16 for Windows was used to calculate

means and Standard Deviations and the data is tabulated. Student *t* - test is used to test the significance of microbial loads in river Nairobi and Athi.

RESULTS

Bacteria in Nairobi River

The bacterial types found in river Nairobi, 500 meters upstream of DSTP effluent were *Escherichia coli*, *Klebsiella aerogenes*, *Enterococcus faecalis*, *Salmonella typhi*, *Salmonella paratyphi*, *Pseudomonas aeruginosa*, *Vibrio cholerae*, *Vibrio parahaemolyticus*, *Proteus mirabilis* and *Shigella flexneri* (Table 1).

Table 1
Bacterial types in Nairobi River

Bacteria Type	Upstream DSTP	Downstream DSTP	Before Athi River
<i>Escherichia coli</i>	$9.8 \times 10^4 \pm 1.3 \times 10^4$	$1.0 \times 10^5 \pm 1.1 \times 10^4$	$1.2 \times 10^4 \pm 2.0 \times 10^4$
<i>Enterococcus faecalis</i>	$4.4 \times 10^4 \pm 1.0 \times 10^4$	$6.3 \times 10^4 \pm 2.1 \times 10^4$	$3.7 \times 10^3 \pm 1.7 \times 10^3$
<i>Pseudomonas aeruginosa</i>	$1.6 \times 10^3 \pm 2.0 \times 10^2$	$3.5 \times 10^3 \pm 1.8 \times 10^3$	$6.5 \times 10^2 \pm 2.0 \times 10^2$
<i>Salmonella typhi</i>	$1.6 \times 10^3 \pm 1.1 \times 10^3$	$1.3 \times 10^3 \pm 2.1 \times 10^2$	$1.6 \times 10^2 \pm 9.0 \times 10^1$
<i>Vibrio cholerae</i>	$1.5 \times 10^3 \pm 1.7 \times 10^2$	$1.1 \times 10^3 \pm 1.0 \times 10^3$	$5.7 \times 10^2 \pm 1.0 \times 10^0$
<i>Shigella flexneri</i>	$2.1 \times 10^2 \pm 2.7 \times 10^1$	$1.4 \times 10^2 \pm 1.0 \times 10^2$	$2.3 \times 10^1 \pm 5.0 \times 10^0$
<i>Salmonella paratyphi</i>	$1.6 \times 10^2 \pm 2.0 \times 10^1$	$1.0 \times 10^2 \pm 1.3 \times 10^1$	$3.3 \times 10^1 \pm 2.0 \times 10^1$
<i>Klebsiella aerogenes</i>	$1.6 \times 10^2 \pm 1.1 \times 10^2$	$1.7 \times 10^2 \pm 1.3 \times 10^2$	$5.9 \times 10^1 \pm 1.1 \times 10^1$
<i>Proteus mirabilis</i>	$1.6 \times 10^1 \pm 1.3 \times 10^1$	$1.1 \times 10^1 \pm 1.3 \times 10^1$	0
<i>Vibrio parahaemolyticus</i>	$1.3 \times 10^1 \pm 4.0 \times 10^0$	$5.0 \times 10^0 \pm 2.0 \times 10^0$	0

The concentration of *Escherichia coli* in Nairobi River increased by tenfold after discharge of DSTP effluent, while *V. parahaemolyticus* level decreased by the same magnitude. The concentration of the other bacterial types remained similar after the effluent. Downstream

the DSTP effluent, about a distance of 23 km to Athi River, the levels of all bacterial types reduced by tenfold, and *P. mirabilis* and *P. parahaemolyticus* were not found in water entering Athi River.

Table 2
Bacterial types isolated from Athi River

Bacteria Type	Mean Count (CFU / 100 mL)	
	Before entry of Nairobi River	After entry of Nairobi River
<i>Escherichia coli</i>	$1.1 \times 10^2 \pm 1.3 \times 10^2$	$1.0 \times 10^4 \pm 2.6 \times 10^3$
<i>Salmonella typhi</i>	$7.6 \times 10^1 \pm 1.0 \times 10^1$	$2.1 \times 10^2 \pm 1.3 \times 10^2$
<i>Enterococcus faecalis</i>	$6.5 \times 10^1 \pm 1.7 \times 10^1$	$3.6 \times 10^3 \pm 3.2 \times 10^3$
<i>Vibrio cholerae</i>	$4.9 \times 10^1 \pm 1.2 \times 10^1$	$5.6 \times 10^2 \pm 1.0 \times 10^2$
<i>Klebsiella oxytoca</i>	$3.4 \times 10^1 \pm 1.4 \times 10^1$	$7.4 \times 10^1 \pm 1.8 \times 10^1$
<i>Pseudomonas aeruginosa</i>	$5.0 \times 10^0 \pm 2.0 \times 10^0$	$6.5 \times 10^2 \pm 1.1 \times 10^2$
<i>Salmonella paratyphi</i>	0	$1.6 \times 10^1 \pm 1.1 \times 10^1$
<i>Shigella flexneri</i>	0	$1.2 \times 10^1 \pm 1.2 \times 10^1$

Microorganisms found in the Athi River water samples were similar to those found in Nairobi River, 500 m upstream, before the two rivers join each other (Tables 1 and 2). In Athi River *S. paratyphi* and *S. flexneri* were isolated only after confluence with Nairobi River. The concentration for all bacteria types, except *K. aerogenes*, increased by 1 to 2 tenfold after entry of Nairobi River water. In general, the concentration of bacteria in Athi River was significantly lower than observed for Nairobi River ($F = 13.638$; $p = 0.009$).

DISCUSSION

In this study, we assessed the bacteriological quality of the river of metropolitan capital city of Kenya in East Africa, Nairobi River. Water sampling was started from 500 m upstream of Dandora Sewage Treatment Plant (DSTP) effluent to a 400 Km long Athi River that is about 23 km to the east of the city. River Athi flows and empties into the Indian Ocean. Bacteriological quality of river Athi was tested from 500 m before entry, and similarly after the entry of river Nairobi water. It was found that the two rivers to be highly contaminated with pathogenic bacteria (Tables 1 and 2). These results are in agreement with those of Doughari *et al.* (2007) and Niyogi (2005) in Gudu stream in Abuja, Nigeria and Tieté River in Brazil

respectively. However, the bacterial concentrations in both rivers Nairobi and Athi were higher than that reported in Gudu stream, Nigeria. This suggests that the microbial pollution to the two rivers in Kenya is greater than that in Gudu stream. The bacteria numbers and their respective concentrations of samples obtained upstream of the DSTP in the Nairobi River were higher as compared to those found in river Athi before confluence of the two rivers. River Nairobi receives rain water surface run-offs from the city as well as wastewater pollution from the informal settlements located alongside its course in addition to the effluent from the sewage treatment plant (Hide *et al.*, 2001; UN-Habitant, 2007). The informal settlements include Dagoretti, Waithaka, Riruta, and Kagemi, Mathare, Korogocho, Dandora, Njiru, and Soweto. River Athi does not flow through the Nairobi City, but it is about 25 Km in southeast of the city. The river mainly receives domestic and industrial pollution from Mavoko town (UN-HABITAT, 2006) before confluence with river Nairobi to the east side of the city. The difference in the bacterial levels in the two rivers suggests the role played by the city surface runoff and informal settlement, as well as DSTP effluent discharge in the microbial pollution river Nairobi. Lack of proper sanitation in urban cities has been cited as the main cause of high bacterial pathogens in rivers traversing major world cities

(Abraham, 2010). For instance, an estimated that 200 million liters of untreated human sewage from Varanasi city in India are discharged into the Ganges River every day, with consequent high bacterial concentration of up to 10^8 per 100 mL being reported downstream (Hamner *et al.*, 2006). The bacterial concentration reported in Ganges River is higher than that obtained in the river Nairobi during this study even though the Varanasi City population of more than one million is lower than the Nairobi city population (3.5 million). Hide *et al.* (2001) reported microbial levels higher than the current study at Njiru Bridge, approximately 10 kilometer upstream of DSTP. The difference in results of these studies suggest a positive impact of a massive clean-up campaign of river Nairobi which was being undertaken by National Environmental Management Authority (NEMA) in conjunction with the Ministry of Metropolitan and the City Council of Nairobi (CCN) during the period of the current study.

According to UN-Habitant (2007), river Nairobi receives improperly treated effluents from the DSTP. This corroborates our finding of one (1) log increase in concentration of *E. coli* after entry of DSTP effluent. Although in seemingly reduced numbers and concentrations, the bacteria isolated from samples drawn after DSTP effluent were also isolated downstream about 23 km into river Athi. This corroborates findings in Tiet'e River in Brazil, where concentrations of pathogenic bacteria including *S. flexneri*, *S. boydii*, and *E. coli* considerably declined after 30 km, although it was still reported about 100 km downstream from São Paulo to Salto (Niyogi, 2005; Abraham *et al.*, 2007). Levels of Bacterial pathogens decline downstream a river as result of river assimilation but they may persist and travel for a long distance posing public health risk to downstream populations relying on the river for primary water source (Abraham, 2010). Although assimilation of bacteria occurs relatively fast, this was not the case in river Nairobi. There was only one (1)-log reduction in bacterial concentration from the treatment plant to river Athi, 23 km downstream except for *P. mirabilis* and *V. parahaemolyticus* that were completely assimilated. This finding is in contrast to that of Okoronkwo and Odeyemi (2003) in Nigeria,

where three (3)-log reductions of bacterial concentration was reported over 10 km stretch. Survival period of pathogens in river water is usually short; however, there may be niches where they survive for longer (Ho *et al.*, 2003). The niches may include animal faeces carried into rivers by rain surface run-off, non-point source pollution (Venglovsky *et al.*, 2009). This explains the low reduction in bacterial concentration in river Nairobi. Agricultural farming including livestock rearing and crop irrigation were evident during this study post-treatment, which suggests the probable sources of microbes in the water analyzed downstream.

The population dependant on river Athi is about 3 million (CBS, 2009). Crops irrigated with this water are consumed locally and some sold to inhabitants of the metropolitan capital City of Nairobi and the environs. Epidemiologic reports have associated use of raw river water with waterborne disease outbreaks. Hamner *et al.* (2006) associated water-borne disease occurrences including acute gastrointestinal disease, cholera, dysentery, hepatitis- A, and typhoid with the use of Ganges River in India for bathing, laundry, washing eating utensils, and brushing teeth. Water from river Athi was highly contaminated with human pathogenic bacteria contrary to the WHO guideline value of zero (0) *E. coli* per 100 mL of drinking water (WHO, 2006), and that faecal coliforms (FC) should not exceed 10^3 per 100 mL water to be used in irrigation of crops likely eaten uncooked, sports fields, and public parks in unrestricted regions (WHO, 1989). Additionally, the water quality was unacceptable as per Environmental Protection Agency (EPA) standard of zero (0) FC / 100 mL of water to be used in irrigation of any food crops not commercially processed including crops eaten raw (EPA, 1992). Kenya standards for drinking water stipulate *E. coli*, *S. flexneri*, *P. aeruginosa* or coliforms should not be detectable in 250 mL of drinking water (WASREB, 2006). This suggest that, the combined water of Nairobi and Athi rivers is not potable or fit for many other purposes, and therefore, it poses public health risk from waterborne-bacterial pathogens. In view of these findings, appropriate measures to control pollution of the two rivers are urgently required. Moreover, regular monitoring of the water microbiological quality, and public health

education to avoid consumption of untreated water from these rivers, are vital to ensure the public health protection.

CONCLUSION

The microbiological contamination of Nairobi and Athi rivers was unacceptably high as per Kenya standards, and WHO guidelines for drinking water and agricultural use. The water is not potable, and it poses a health risk to communities that rely on the two rivers as a primary source for domestic use. The findings suggest that water from these rivers is not potable, and poses a health risk to communities that rely on the rivers as primary sources of domestic and subsistence irrigation use. These findings in water scarce region of the world underline the challenges a number of developing countries are facing currently and in long-term into the future. Lessons learnt in this study would suggest appropriate measures to control pollution of similar rivers in sub-Saharan regions in

particular and developing countries in general to ensure availability of clean water supplies to large concentrated populations in cities within the Millennium Development Goals. Regular monitoring of the water microbiological quality, and public health education to avoid consumption of untreated water from these rivers, are vital to ensure the reduced water-borne disease burden in low-income countries.

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