ASSESSMENT OF POLLUTION IN NDARUGU RIVER DUE TO RUNOFF AND AGRO-INDUSTRIAL WASTEWATER DISPOSAL

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Abstract
River Ndarugu is a tributary of Athi River in Kenya and is one of the main sources of fresh water for domestic use to the villages along the river bank and Nairobi City. It traverses Juja Township in Kiambu County, Central Kenya. During its course through the different agricultural and industrial areas of Gatundu, Gachororo and Juja farms, it receives untreated agro-industrial waste discharges, effluent from coffee and tea factories, and other agricultural activities in the catchment area. This paper aims at assessing the level of pollution due to these activities. Water samples were collected from seven sampling points during the dry season in July and short wet season in November and December and analysed in situ and at Jomo Kenyatta University Environmental laboratory for eight parameters. These include pH, temperature, electrical conductivity (EC), Turbidity, Nitrogen, Phosphorous, Biochemical oxygen demand (BOD_5) and dissolved oxygen (DO).The samples were collected at 15cm depth (to avoid floating materials) and geographical positioning system (GPS) device was used to spatially locate the sampling sites. Samples were taken from upstream and downstream of point and non- point sources of pollution. Results indicated that most physical parameters were within the WHO limits for drinking purpose. $BOD_5$and EC levels increased from 12mg/l to 22mg/l and55µS/cm to 85µS/cm respectively but DO level decreased from 6.3mg/l to 3.4mg/l moving downstream in dry season. Turbidity was above the allowable limit in both seasons Nutrient levels were within the limits and no phosphorus was detected. There is need for proper control of wastewater by various techniques, and preliminary treatment of waste discharges prior to effluent disposal. Care should be taken in application of inorganic fertilizers. Management of the watershed is also necessary so as to protect the river from the adverse impacts of agricultural activities and save it from further deterioration.

Key words: biochemical oxygen demand, dissolved oxygen, electrical conductivity, pollution

1.0 Introduction

Rivers are the most important freshwater resources for human being. Social and economic developments have been largely related to the availability and distribution of freshwaters contained in river systems. Nowadays, catchments are becoming polluted by various human activities, including littering, pouring chemicals down drains and agro-industrial discharges, all of which are washed into creeks and storm water drains. Water quality is generally related to surrounding land use. There is a clear link between population growth, urbanization, industrial development and human activities that are likely to generate pollution (Nhapi *et al.*, 2011). Polluted water is an important means for the spread of diseases. In developing countries about 1.8 million people, majority children, die every year as a result of water related diseases (WHO, 2004).

Environmental pollution is a major global concern. When sources of water pollution are enumerated, agriculture is, with increasing frequency, listed as a major contributor. As nations make efforts to correct abuses to their water resources, there is a need to determine the causes of water quality degradation and to quantify pollution contributions from many sources. Until such time as adequate facts are made available through research to delineate causes and sources, conflicting opinions continue to flourish and programmes to control and abate pollution will be less effective and efficient in the use of limited resources (Ongley, 1996).

Generally sources of water pollution are categorized as point and non-point sources. The major sources of river water pollution during dry season are categorized as point sources through which the polluting substance is emitted directly into the waterway. The non-point (diffuse) sources, occurring during rainy season, are runoffs from the catchment area which wash away fertilizers, pesticides and other polluting substances in to the river.

Existing knowledge indicates that agricultural operations can contribute to water quality deterioration through the release of several materials into water: sediments, pesticides, animal manures, fertilizers and other sources of inorganic and organic matter. Many of these pollutants reach surface and groundwater resources through widespread runoff and percolation and, hence, are called "non-point" sources of pollution. Identification, quantification and control of non-point pollution remain relatively difficult tasks as compared to those of "point" sources of pollution (Ongley, 1996).

Water pollution due to industrial and agricultural activities has become a serious problem both globally and in surrounding environment. A huge amount of domestic, agricultural and industrial wastewaters discharges to water bodies all around the world. Discharging raw wastes, with high levels of contaminants, washing away to rivers of pesticides and fertilizers are among the worst pollution sources to rivers.

Disposal of these wastewaters into the rivers with little or no treatment prior to discharge is common in many developing countries. Rivers and streams are among the main sources of fresh water that suffer a big amount of pollutant loads and wastewater, due to influx of pollutants without prior treatment, around the world. This has caused a serious concern over the deterioration of river water quality. These discharges of degradable wastewaters in water bodies result in decrease in water quality in general and DO (Dissolved Oxygen) concentrations in particular.

Ndarugu River is one of the main sources of fresh water for domestic use to people of many villages and towns along the river bank. Being a tributary of Athi River, it also contributes to water supply of Nairobi City. It traverses Juja Township in Thika District, Central Kenya. During its course through the different agricultural and industrial areas, it receives untreated agro-industrial waste discharges such as effluent from coffee and tea factories and other activities situated on the catchment of the river.

The main objective of this research was therefore to evaluate effects of agricultural wastewater and runoff on water quality along River Ndarugu**.**

2.0 Materials and Methods

2.1 Description of Study Area

2.1.1 Location

Ndarugu River traverses Juja Township in Kiambu County, Central Kenya. The study area is bounded between UTM 264449.71 meters to 296000.52 meters easting and 9874667.88 meters to 9889393.88 meters northing at an average altitude of 1560 meters above sea level. The drainage area is coded by the Government of Kenya as 3CB sub catchments in Athi Basin. Ndarugu River is one of the tributaries of Athi River. Ndarugu sub-catchment extends from Kieni and Kinale forest eastwards and parts of ridges of Aberdares to Juja farm all the way to Munyu where it is joined by River Komu before it joins Athi River (Fig.1). River Ndarugu is a perennial river with its source in the Kikuyu escarpments. It meanders through farmed slopes of Gatundu and Thika District before joining Athi River at Munyu near Kilimambogo. The tributaries of Ndarugu River are Ruabora, Githobokoni and Karakuta rivers.

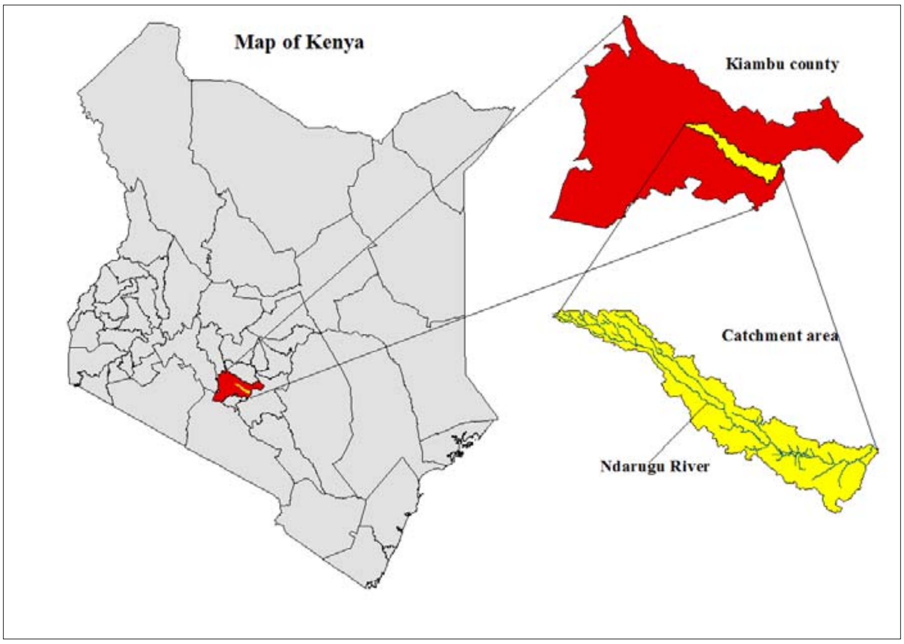


Figure 9: Location map of the study area

2.1.2 Climate

The mean annual rainfall for Ndarugu sub-basin is 1126mm. Air temperatures are moderate with monthly average low temperatures varying from 12 to 15^{o}C and average high temperatures varying from 23 to 28^{o}C. March is the hottest month with mean of 21.5^{o}C and July is the coldest month with a mean of 17.5^{o}C. Mean annual maximum is 25.7^{o}C and mean annual minimum is 13.6^{o}C.Water temperatures vary seasonally from 13.5 to 19.5^{o}C.

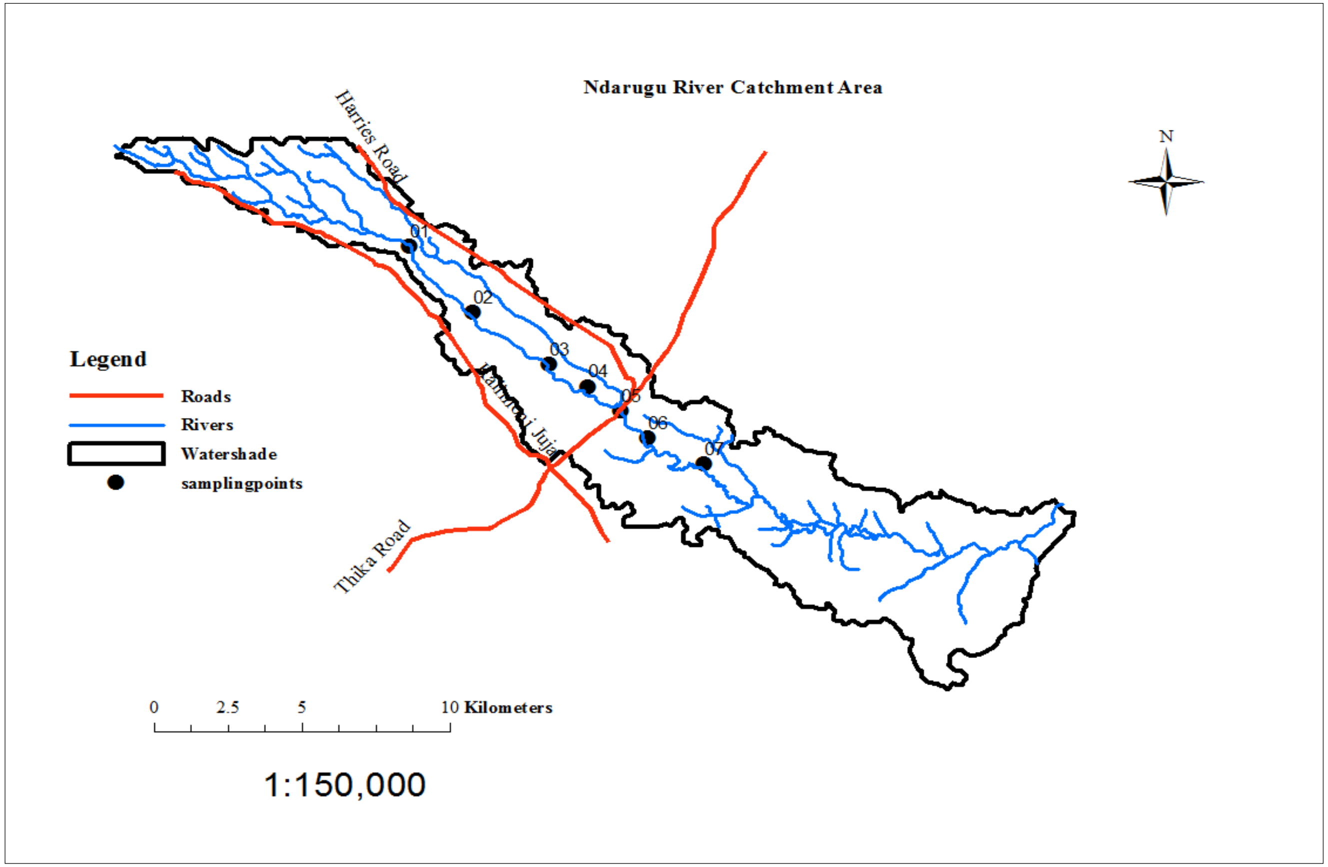
River Ndarugu is recognized for its diverse flora and fauna. The area surrounding the river also offers a mild climate and natural beauty. Its freshwater is both ecologically and economically valuable to residents of the area. One of its social economic values is that it provides water for domestic and agricultural use to people within its surroundings (Ndegwa *et al.*, 2008).

2.2 Sampling

Surface water samples for physico-chemical analysis were collected from seven sampling sites of the river during the dry season and short rainy season in 2013.Sampling bottles made of plastic each of size 500ml were used to collect the water samples. The bottles were rinsed few times with the river water before taking the samples and touching the rim was avoided to prevent from any contamination of the samples. The samples were taken at a depth of 15cm using the rinsed and clean bottles. Each bottle was placed inverted in the body of water then turned horizontal facing in the direction of to the flow of water. Air entrapping was avoided as much as possible in order to get the actual DO of samples. A sampling pole was used to get a sample from the running water in the main body of the river since it gives the best overall sample unlike the water at the edges or that held in pools, which is likely to have a variation from the running water. The running water in the centre of the river was sampled to give the best overall sample. Global Positioning System (GPS) was used to determine the exact locations of each sampling points so that each time samples were taken from the same place. The sampling sites were selected based on the presence of point source of pollution from domestic wastewater and industries like coffee processing and tea factories (Fig. 2).The first site was chosen at the upstream site near the Mitaro Estates diversion and the last site was at Juja farm (Downstream). The last (seventh) sampling point was at 15kilometers downstream of the first sampling point. The description, elevation and UTM coordinates of the sampling points are given in Table1.

Table 2: Location of Sampling Points in Universal Transverse Mercator (UTM) coordinates

Sampling Point. Code	**Sampling Location**	**Elevation (m) A.S.L.**	**UTM-X(East) (m)**	**UTM-Y(North) (m)**
01	Mitaro estates diversion	1495	274472.37	9885428.23
02	Azania estates	1481	276601.39	9882997.45
03	Benifer bridge	1454	279199.82	9881136.68
04	JKUAT intake point	1449	280481.44	9880392.92
05	Juja water company	1435	281633.98	9879394.94
06	Kenya Plant Production	1419	282601.16	9878382.41
07	Juja Farm	1402	284470.28	9877526.10


Ndarugu River Catchment Area
N
Harries Road
Thika Road
01
02
03
04
05
06
07
Legend
Roads
Rivers
Watershade
samplingpoints
0 2.5 5 10 Kilometers
1:150,000

2.3 On Site and Laboratory Analysis

The methods outlined in the standard methods, for the examination of water and waste water, (APHA, 1998) were followed for the analysis of the physico-chemical parameters. Temperature, pH and Electrical Conductivity (EC) were measured in-situ using a temperature probe (thermometer) and a portable Microprocessor pH meter (pH-211) and a portable conductivity meter (Palintest) respectively. Turbidity was measured using Turbidi-meter (Nephelometric NTU, TR-3Z). Nitrates, Nitrites and Phosphorous were measured using Multi-parameter photometer (HI-83099). DO was measured on site using a portable DO meter (DO-5509) and BOD_5 was measured using titration method. Sampling and analyses were done for ten days in dry season and ten days in the short rainy season at an interval of two days. The range and average values of each parameter in each season were calculated and presented in the result section.

3.0 Results and Discussion

The physico-chemical characteristics for the seven sampling points of Ndarugu River which has an average flow rate of 2.5m^3/s in dry season and up to 6 m^3/s in rainy season in the study period are presented in Tables 2, 3 and 4.

3.1 Physicochemical Characteristics (Parameters)

The pH of the river was neutral at all stations, for the study period, ranging from 6.57 to 7.82. This pH range falls within the range associated with most natural waters which is between 6.5 and 8.5(Chapman, 1992), stipulated for drinking and domestic purposes. The temperature during the study ranged from 17.1^{o}C to 19 ^{o}C. The EC meter used automatically standardizes the readings to 25^{o}C. EC was measured in microSiemens/centimetre (µS/cm). For the raw wastes (effluent) from coffee processing (pulping) factories the EC and BOD_5 varied from 482µS/cm to 620µS/cm and 350mg/l to 600mg/l respectively. These EC and BOD_5values are very high as compared to the EC of the river. The EC of the river ranged from 55µS/cm to 85µS/cm in dry season and from 43µS/cm to 75µS/cm in wet season. The EC of water estimates the total amount of solids dissolved in water i.e. Total Dissolved Solids (TDS). Since the electrical conductivity is a measure of the capacity of water to conduct electrical current, it is directly related to the concentration of salts dissolved in water, and therefore to the TDS. Salts dissolve into positively charged ions and negatively charged ions, which conduct electricity. Since in situ measurement of TDS in the water sample is difficult, EC was used as a measure. TDS (ppm) is calculated as 0.55 to 0.8 times EC (µS/cm), usually 0.7 times EC (Eliot *et al.*, 2004).

The turbidity range of the river was found to be between 18.3NTU and 35.6NTU in dry season and between 38.4NTU and 65NTU in wet season. This is exceeding the desirable limit of 5 NTU and allowable limit of 10 NTU given by WHO and EAI analytical labs. The DO level was ranging between 3.4 and 6.3mg/l in dry season and was observed to increase during wet season to a range of 5.5mg/l to 7.8mg/l due to higher surface re-aeration and dilution of wastes by rain. DO level lower than 5mg/l leads to death of many aquatic animals.BOD_5 increased from upstream to downstream end of the river due to several point sources of pollution. At the source of the river the BOD_5 concentration was 12mg/l and at downstream site BOD_5 was from17.5mg/l to22mg/l in dry season. In wet season, BOD_5 level was within the range of 15.3 mg/l to 20.5mg/l which is not very different from the dry season concentration level.

Table 3: Physicochemical parameters of the water samples in dry season

	pH		**Temperature (oC)**		**Conductivity µS/cm)**		**Turbidity (NTU)**		**DO(mg/l)**		**BOD5(mg/l)**	
S. Point	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**
01	6.57-7.82	7.18	18.0-18.8	18.42	55-78	61.50	18.3-35.1	25.73	5.1-6.3	5.79	17.5-20.8	19.15
02	6.79-7.32	7.10	17.8-18.9	18.24	57-67	58.60	19.3-32	25.11	4.9-6.2	5.57	18.3-20.5	19.19
03	6.73-7.42	7.09	18.0-19.0	18.45	56-69	63.70	19.5-29.3	24.85	4.1-6.2	5.17	18.5-21.1	19.45
04	6.58-7.24	7.06	17.9-18.9	18.40	56-80	66.90	19.8-35.6	25.53	4.1-5.7	4.82	18.0-21.0	19.78
05	7.01-7.35	7.20	17.8-19.0	18.44	60-79	66.10	18.9-26.5	22.09	3.4-4.7	4.14	18.7-21	19.84
06	6.65-7.21	6.93	17.9-19.0	18.37	62-85	67.70	22.8-33.0	28.21	3.6-5.0	4.21	18.7-22	20.24
07	6.78-7.17	6.98	17.7-18.8	18.24	59-84	72.10	19.3-34.2	27.23	3.4-4.3	3.82	20.0-22.0	20.99
WHO	**6.5-8.5**		**-**		**500-5000**		**5**					

Table 4: Physicochemical parameters of the water samples in wet season

	pH		**Temperature (oC)**		**Conductivity µS/cm)**		**Turbidity (NTU)**		**DO(mg/l)**		**BOD5(mg/l)**	
S. Point	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**
01	6.72-7.50	7.22	17.5-18.2	17.90	43-59	52.70	39.5-55.3	49.02	7.5 -7.8	7.64	15.3-18.7	16.90
02	7.19-7.36	7.28	17.0-18.9	18.02	50-63	56.50	42.7-59.6	51. 45	6.8-7.4	7.12	16.7-17.9	17.32
03	6.68-7.25	7.13	17.5-18.1	17.80	56-65	61.10	41.3-64.9	58.36	5.9-6.7	6.40	15.5-19.1	17.45
04	6.89-7.28	7.15	17.6-18.7	18.10	49-68	58.30	38.4-65.0	52.27	6.1-6.8	6.45	17.1-19.3	18.08
05	6.72-7.29	7.04	18.0-19.2	18.54	54-60	56.90	54.3-65.0	63.45	5.9-6.7	6.14	16.4-18.8	17.67
06	6.93-7.15	7.06	17.3-19.5	18.60	57-71	62.70	45.6-63.0	57.90	5.8-6.4	6.12	18.3-20.5	19.32
07	6.82-7.11	6.93	16.4-18.2	17.10	53-75	64.30	49.4-64.3	58.60	5.5-6.3	5.93	18.0-20.4	18.99
WHO	**6.5-8.5**		**-**		**500-5000**		**5**					

3.2 Nutrient characteristics (Nitrates Nitrites and Phosphorous)

The nitrates, nitrites and phosphorous content of the water samples were analysed using the Multi-parameter photometer (HI-83099). Maximum values of Nitrates and Nitrites Nitrogen in the water samples were 4.8mg/l and 6mg/l in dry season respectively. These values increased to 6.8mg/l and 7.8mg/l in wet season respectively. All nitrate concentration values within Ndarugu River are below the maximum permissible value for drinking water of 10mg/l. Phosphorus was detected as 0.1mg/l only in three samples. When the average value was taken for the ten replicates in each season, it was zero for all the sampling points. Previous studies done by Okungu John and Opango Peterlis in ten rivers in the Kenyan catchment of Lake Victoria also showed similar results of low phosphorus. The nitrate and nitrite concentrations for both dry and wet seasons are presented in Table 4.

Table 5: Nitrate and nitrite concentrations in dry and wet season

Sampling Points	Sampling Season	NO_3-N (mg/l)	NO_3^- (mg/l)	NO_2-N (mg/l)	NO_2^- (mg/l)	$NaNO_2$ (mg/l)
01	Dry season	4.2	18.6	4.0	12.0	20.0
	Wet season	5.7	25.3	5.5	16.3	27.2
02	Dry season	4.6	20.4	6.0	21.0	31.0
	Wet season	6.2	27.7	7.5	28.5	36.4
03	Dry season	4.3	19.3	4.5	13.5	21.0
	Wet season	6.4	26.1	5.4	17.2	26.8
04	Dry season	4.0	17.6	4.0	12.0	18.0
	Wet season	6.5	28.0	5.9	18.0	27.0
05	Dry season	4.2	19.2	5.0	17.0	24.0
	Wet season	6.5	28.2	6.2	19.0	28.2
06	Dry season	4.1	18.1	4.5	15.0	21.0
	Wet season	6.6	28.5	6.6	20.6	29.3
07	Dry season	4.8	22.2	5.5	16.5	26.4
	Wet season	6.8	28.9	7.8	28.7	36.0
WHO		5-10	50		30	

4.0 Conclusion and Recommendation

The results indicated that most of the physico-chemical water quality parameters for Ndarugu River were within the WHO and KEBS limits for drinking water and the water is therefore suitable for domestic purposes. The pH of river was within the range of 6.5 and 8.5 both seasons. However wastewater disposal without any treatment caused the river to reduce its dissolved oxygen content due to the high biochemical oxygen demand of the incoming wastes. The DO in dry season was significantly depleted and reduced due to the mixing of these wastewaters even though re-aeration (replenishing with dilution and surface re-aeration) is expected at the surface of the river. Turbidity level varied from wet to dry season with higher levels in the wet season and was higher than the WHO and KEBS limits for drinking water throughout the study period. Electrical conductivity level reduced slightly during wet season due to the dilution from the runoff. Nutrient levels were generally low during the study period although they were higher during the wet season. However despite these low levels care should be taken in the application of inorganic fertilizers in order to protect the river from eutrophication.

There is need for proper control of wastewater by various techniques, such as constructing an oxidation pond at estate level and preliminary treatment of waste discharges prior to effluent disposal. The wastewater can be retained in these oxidation ponds for several days so that the BOD can be reduced considerably. Management of the watershed is necessary so as to protect the river from the adverse impacts of agricultural and industrial activities and to save it from further deterioration.

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