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Assessment of Drinking Water Quality from the Malakisi River in Western Kenya

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Abstract:
The scarce water resources globally are being polluted by mainly human activities, making accessibility to clean water a major challenge due to the high cost of conventional water treatment methods and lack of frequent monitoring of pollution levels. A study has been done on Malakisi to establish its quality. Coliforms, chemical oxygen demand (COD), biological oxygen demand (BOD), fluorides, pH, conductivity, total hardness, nitrates, phosphates, sulphates, turbidity and heavy metals (Zn, Cu, Mn and Fe) were analyzed. For Coliforms, endo agar media were carefully prepared and placed in an incubator upside down and set at 44^{o}C for faecal coliform and 37 ^{O}C for total coliform and then left for 24 hours in the thermostat and results recorded as cfu/100 ml. COD was measured by mixing 2 ml of each sample with the low range reagent mixture of $K_2Cr_2O_7$, $AgSO_4$, $HgSO_4$ and H_2SO_4 and the mixtures tested in a COD reactor, which was already set at a temperature of 150^{O}C and left for 2 hours. For BOD, the BOD Track test procedure was used. Fluoride was analyzed using the SPADNS method while pH was determined by the potentiometric method using digital pH model sension-51938. The conductivity meter was used to measure conductivity. Total hardness was determined using the colorimetric method at a wavelength of 522 nm. A 1.0 ml of Ca and Mg indicator was added to 100 ml of the prepared sample followed by one drop of 1 M EDTA solution. Total hardness was the sum of mg/l Ca as $MgCO_3$ plus mg/l Mg as $CaCO_3$. Total nitrogen, phosphates and sulphates was determined by Hach spectrophotometer DR/4000 at wavelengths of 400 nm, 890 nm and 450 nm, respectively. For turbidity, 5 ml of sample was poured into the Pocket Turbid meter and turbidity measurements were recorded in nephelometric turbidity units. The levels of heavy metals were determined using a UV- spectrophotometer, Hach DR/4000. The following concentration levels of the pollutants were established in river water: Zn (0.3 mg/l), Cu (0.08 mg/l), Mn (0.3 mg/l) , Fe (0.61 mg/L), coliforms (38 Cfu/100 ml), pH (7.1), NO_3^- (0.28 mg/l), PO_4^{3-} (0.43 mg/l), SO_4^{2-} (0.545 mg/l), F^- (0.40 mg/l), BOD (13 mg/l), COD (26mg/l), turbidity (124 NTU), total hardness (2.30 mg/l) and conductivity (204 µs/cm). From the results, all the parameters analyzed were within the WHO required limits except coliforms, turbidity, Mn, Fe and Cu which were found at levels higher than the WHO maximum required limits. The Malakisi river is thus polluted and preliminary treatment of the water is required. Coagulation of the water by adding alum, chlorination, boiling, use of solar powered water filters or purifiers and creation of buffer zones along the river system to allow growth of river line macrophytes are some of the measures that could help improve the quality of water.

Keywords: *Water quality, turbidity, heavy metals, coliforms, treatment*

1. Introduction

Water quality has an impact on both the public health and aesthetic value of water (Pink, 2006; West, 2006). The most common sources of water in Kenya are surface and ground water. In majority of the rural parts of Kenya, over 60 percent of local people depend on rivers and groundwater aquifers for water (WASREB, 2002). Apart from health impacts to humans, water contamination place other resources such as fisheries and land resources at risk. In most cases, down-stream fish and vegetable crops become heavily contaminated with heavy metals.

Piped water supply is rare in Bungoma west, Teso and Mount Elgon sub- County in western Kenya. The only water treatment plant which had been constructed along the Malakisi River upstream at Chesikaki in Mount Elgon failed to work several years ago due to poor piping, lack of new technology, poor gravity, lack of engines, generators among others. The plant was to provide clean water for residents of Mount Elgon, Teso and Bungoma west sub counties. As a result, the residents do use raw water from the river and springs for drinking and other domestic purposes. However, the quality of this water has never been done and the number of people suffering from water related diseases is on the rise and thus is of great concern (http://westfm.co.ke/mobile/index.php?page=news&id=7593:

2012-15th april). Despite the fact that Mt. Elgon is a water catchment area, lack of piped water and incidences of typhoid and other water related diseases have been witnessed in some schools and health centres (Kapchangablogsport.com/2012-11-archive.html). The main purification technology is where drinking water from the river is stored in clay pots. Others like boiling, chlorination, solar disinfection, flocculation, use of bio sand filters among others are rarely practised.

Nitrate levels can be high in streams and rivers due to runoff of nitrogen fertilizers from agricultural fields and urban lawns. Nitrate levels above 10 ppm have been reported to present a serious health concern for infants and pregnant or nursing women (Dara, 2004).

pH values higher than 8.5 have been known to interfere with chlorination during water treatment. pH outside range of 6.5- 8.5 reduces the diversity in the stream by stressing the physiological systems of most organisms, thereby reducing reproduction (Williams *et al.*, 2006).

Presence of heavy metals in high concentration levels in water has been found to have adverse effects to human health and living organisms. Different body organs have been reported to have been affected by heavy metal pollutants. A high level of manganese exposure has been linked to Wilsons Parkinson's disease, a serious and progressive impairment of nerve cells in the brain. Effects of high levels of copper metal include irritation of the nose and liver damage. Water colour has been known to be affected by the quality of organic matter and the prevalence of iron. Browning of inland waters over large parts of the northern hemisphere and has been a phenomenon with both ecological and societal consequences (Kritzberg and Ekstrum, 2012). In drinking water supplies, iron (II) salts are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as a rust- coloured silt. Turbidity and colours have been discovered to develop in piped systems at iron levels above 0.05 mg/l. staining of laundry and plumbing also takes place due to iron concentrations above 0.3 mg/l (WHO, 2008). Sources of heavy metals in river water could be due to discharge of effluents from industries (Jonathan, 2010) or geological origin (Enuneka *et al*., 2013). Use of weed killers, fungicides, insecticides and rat poison has been mentioned as one of the sources of Zn and Mn (Lawrence, 2011). Iron is used as a construction material, inter alia, for drinking water pipes. Iron oxides are used as pigments in paints and plastics. It is also used as food colours and for treatment of iron deficiency in humans. Various iron salts are used as coagulants in water treatment.

Sulphate levels in natural waters have been found to be between 2 and 80 mg/l but higher than 1,000 mg/l near industrial discharges or in arid regions where sulphate minerals, such as gypsum, are present. High concentrations (> 400 mg/l) may make water unpleasant to drink (Johathan, 2010).

Fluoride concentrations in natural waters have been established to vary from 0.05 to 100 mg/l, with most fresh waters having less than 0.1 mg/l. Very high concentrations of fluoride, far exceeding the WHO guideline value of 1.5 mg/l have been encountered in volcanic aquifers and lakes in the East African Rift system and in Hawaii. A high concentration fluoride is toxic to humans and animals and can cause bone diseases. However, a slight increase in natural concentrations can help prevent dental caries although, at higher concentrations (above 1.5-2.0 mg/l), mottling of teeth can occur (Kahama *et al*., 1997; Ayoob & Gupta, 2006).

Biological oxygen demand (BOD) is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. High BOD levels in a stream or a river accelerates bacterial growth, which consumes the available oxygen levels in the river. The oxygen may diminish to levels that are lethal for most fish and aquatic insects. Chemical oxygen demand (COD) is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD values are always greater than BOD values. COD measurements can be made in a few hours while BOD measurements take five days (Schindler and Vallentyne, 2008). BOD > 6 mg/l have been classified as grossly polluted, BOD between 3 – 6 mg/l as moderately polluted and rivers with BOD < 3 mg/l as relatively polluted (Bhardwas & Scientific, 2005).

Fertilizers, failing septic system, wastewater treatment plant discharges, and wastes from pets and farm animals are typical sources of excess nutrients of phosphates and nitrates in surface waters. Phosphates have been considered as the primary cause of eutrophication, where it promotes excessive plant growth and decay, favouring simple algae and plankton over other more complicated plants, and causes a severe reduction in water quality. Phosphates adhere tightly to soil, and hence is mainly carried by erosion and once translocated to lakes or rivers, the extraction of phosphates into water has been found to be slow and hence difficulty for reversing the effects of eutrophication. Health problems have been identified to occur where eutrophic conditions interfere with drinking water treatment (Selman, 2007).

Conductivity is the ability of a substance to conduct electricity. The conductivity of water is a function of the concentration of dissolved ions. A sudden increase of the conductivity of a stream indicates that there is a source f dissolved ions in the vicinity. Hence, conductivity measurements can be used as a quick way to locate potential water quality problems (Williams *et al*., 2006).

Turbidity is another indicator of the amount of material suspended in water. It measures the amount of light that is scattered or absorbed. Suspended silt and clay, organic matter, and plankton contribute to turbidity. Photoelectric turbid meters measure turbidity in nephelometric turbidity units (NTU). Researchers have established that native fish populations can only be maintained in rivers and streams if random monthly values of turbidity never exceed 100 NTU. Turbidity of 10 NTU or less represent very clear waters, 50 NTU or greater represents cloudy water and river water with a turbidity range of 100-500 is very cloudy and muddy. In drinking water, the higher the turbidity level, the higher the risk that people may develop gastrointestinal diseases, where contaminants such as viruses or bacteria can become attached to the suspended solids. The suspended solids have also been discovered to interfere with water disinfection with chlorine because the particles act as shields for viruses and bacteria. Similarly, suspended solids can protect bacteria from ultraviolet (UV) sterilization of water. Topography, vegetation, geology, agricultural activities, and precipitation greatly influence raw water turbidity (Goransson *et al*., 2013; Younus & Enaam, 2014).

Fecal coliform (FC) are the most common pollutant in rivers and streams (Dagne *et al*., 2006; Manta *et al*., 2013; Oliver & Ismaila, 2011). Coliforms or indicator microorganisms are present in the intestinal tracts of warm blooded animals, including humans and can

be excreted in the feces of these animals. Indicator organisms are commonly used to assess the quality of surface waters where FC is the most commonly used bacterial indicator of fecal pollution. The coliforms are indicative of the general hygienic quality of the water and potential risk of infectious diseases (Edberg *et al.*, 2000). High FC and total coliform (TC) counts in water are usually manifested in the form of diarrhea, fever and other secondary complications (Sivaraja & Nagarajan, 2014).
The general classification for hardness of water is 75 –150 mg/l of $CaCO_3$ for soft water and 150 mg/l and above as for hard water (Kuforiji & Ayandiran, 2013).
In this work, an assessment of level of metal concentrations, phosphates, conductivity, turbidity, coliforms, nitrates, chlorides, sulphates, fluorides BOD, COD, hardness and pH in the surface water of Malakisi River, Western Kenya was done in order to assess the quality of the river and ways of ensuring access to clean quality water from the river were recommended.

2. Methods and Materials
Water was sampled from the Malakisi river and levels of pollutants determined. Physical-chemical parameters like conductivity, pH, turbidity, total hardness, chemical oxygen demand, biological oxygen demand were analyzed. Sulphates, nitrates, fluoride and phosphates were also determined. Metals analyzed in this study were copper, zinc, iron and manganese. Faecal coliforms were also analyzed.

2.1. The Malakisi River -Sampling Stations

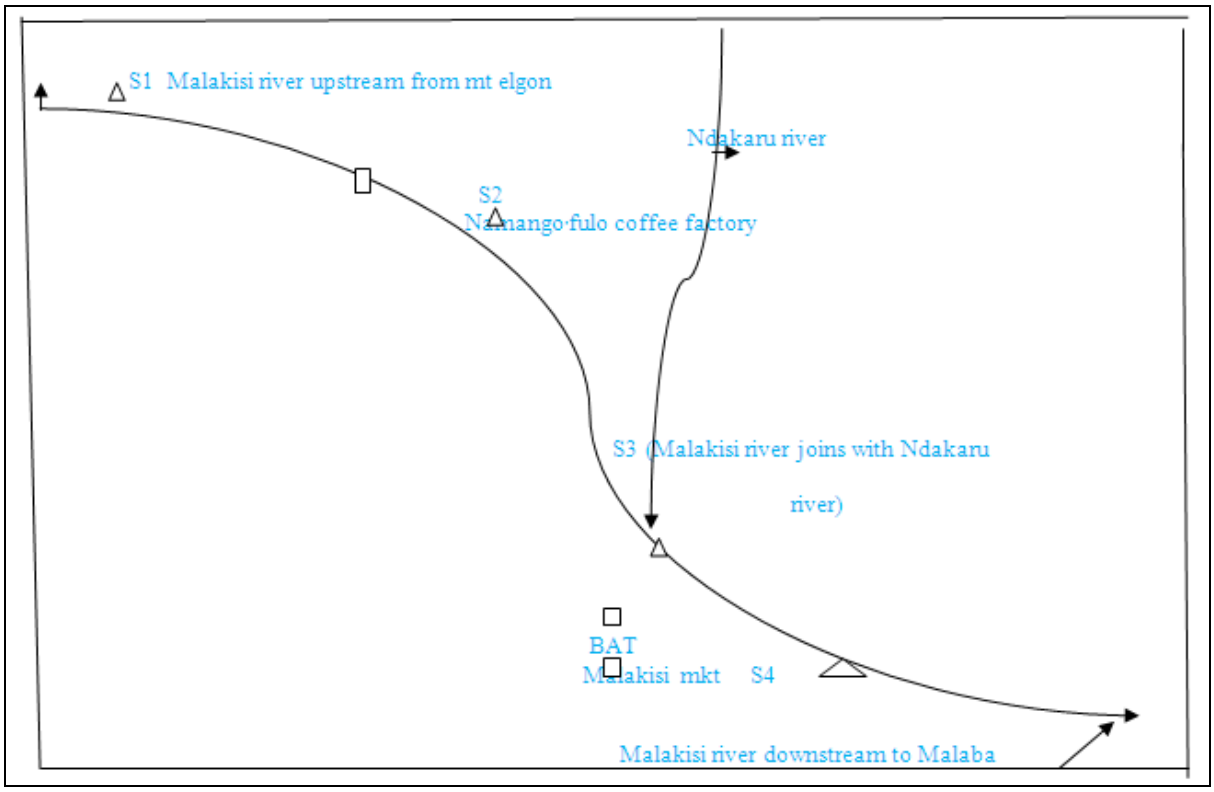

Figure 1: Sampling stations along the Malakisi river

In figure 1, four sampling stations were selected starting from the farthest upstream in Mount Elgon to the lowest downstream to Malaba at intervals of 4 km a part. The stations were designated S1, S2, S3 and S4. The isokinetic sampling technique was used to ensure that samples obtained had identical constituent concentrations. Each unit of the river discharge was equally represented in the sample by dividing the river cross section into intervals of equal width (EWI). Thirty water samples were collected from each station during wet and dry seasons for six months, midstream in triplicates. The samples were transported to the laboratory in ice boxes containing ice and were analyzed within 48 hours of sampling. Samples for Coliform analysis were collected in sterile containers and were analyzed within six hours after sampling. All samples were analyzed at the Eldoret Water and Sanitation Company (ELDOWAS).

2.2. Experimental Procedures
A 1.66 g of endo agar media placed in 40 ml of the sample was heated to boil and then autoclaved for 15 minutes. A 10 ml of sample was placed to sterilized petri dishes and left to solidify. A 100 ml of sample was filtered using a 0.45µm filter paper. The prepared culture were placed in an incubator upside down and set at 44^{o}C for faecal Coliform and 37 ^{O}C for total Coliform and then left for 24 hours in the thermostat (APHA, 2002).

The COD in the samples was determined using the standard method (APHA, 2002). The low range reagent mixture of $K_2Cr_2O_7$, $AgSO_4$, $HgSO_4$ and concentrated H_2SO_4 were used. A 2 ml of each sample was pipetted and each homogenously mixed with the reagent and placed in a COD reactor at a temperature of 150^OC and left for 2 hours. The results were recorded in mg/l.

The BOD Track test procedure was used to test for BOD in the samples (APHA, 2002). The sample was heated to 2^OC of its incubation temperature (20^OC, 68F) and 420 ml was measured and poured into a BOD track sample bottle. A 3.8 cm (11/2 inch) magnetic stir bar was placed in each sample where the contents of one BOD nutrient buffer pillow was added to each sample bottle for optimum bacterial growth. The bottles were stoppered carefully and placed on the chassis of the BOD track which was appropriately connected to the sample bottle and the cup firmly tightened and placed in the incubator at a temperature of 20^OC for the BOD test. A 0-35 mgl-1 range was selected and the results in mgl^{-1}were read after 5 days.

Fluoride was analyzed using the SPADNS method at a wavelength of 580 nm using HACN DR 4000 spectrophotometer (HACN DR 4000 spectrophotometer. Operating Manual). A 10 ml of the sample was pipetted into a dry sample cell. A 10 ml of the deionized water was also pipetted and placed into the second dry sample cell and labeled as the blank. The sample and the deionised water were maintained at the same temperature. A 2 ml of SPADNS reagent was carefully measured and added into 10 ml of the sample in each sample cell and the mixture swirled to mix and fluoride measured in mg/l (HACN DR 4000 spectrophotometer operating manual).

Phosphate analysis was achieved using the spectrophotometer at wavelength of 890 nm. A 10 ml of each sample was measured. The phosphate was measured through phosphorous as an orthophosphate. Phosver 3 reagent was added to each sample where blue colour indicated presence of the phosphate after 2-3 minutes. Phosphate levels were recorded in mg/l. while total nitrogen was determined by Hach spectrophotometer DR/4000 at wavelength of 400 nm.

Total hardness was determined using the colorimetric method at a wavelength of 522. The pH adjusted to between 3 and 8 with 5.0 N sodium hydroxide standard solution before analysis. A 100 ml of the sample was measured and 1.0 ml of calcium and magnesium indicator added. A 25 ml solution of each of the sample was measured and each poured into three sample cells. One drop of 1M EDTA solution was added to one cell which was used as the blank and another drop of EDTA was added to the prepared sample. Total hardness was the sum of mg/l Ca as $MgCO_3$ plus mg/l Mg as $CaCO_3$ (APHA, 2002).

Sulphates were analyzed using a Hach spectrophotometer DR/4000 at wavelength of 450 nm while the pH was determined by potentiometric method, using digital pH meter model sension-51935. Calibration of the electrode was done with 2 buffer solutions of pH 4 and 7 prior to its use. The results were displayed in pH units. The conductivity level in the sample was analyzed using conductivity meter and the results recorded in micro Siemens. Turbidity was measured by pouring 5 ml of sample into the Pocket Turbid meter sample cell, capped and turbidity measurements were recorded in nephelometric turbidity units (APHA, 2002).

3. Results and Discussion

The results of various parameters are recorded in tables 1-3.

	Zn		Cu		Mn		Fe	
Sampling Stations	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
S1	0.240-0.258	0.2-0.266	0.015-0.04	0.045-0.061	0.130-0.3	0.196-0.26	0.69-0.73	0.75-0.86
S2	0.161-0.169	0.192-0.200	0.04-0.076	0.059-0.093	0.234-0.291	0.3-0.34	0.33-0.426	0.357-0.434
S3	0.460-0.490	0.517-0.621	0.071-0.083	0.084-0.100	0.211-0.276	0.3-0.342	0.861-1.0	0.968-1.121
S4	0.200-0.240	0.245-0.251	0.082-0.123	0.106-0.133	0.237-0.242	0.3-0.348	0.289-0.3	0.268-0.31
WHO Limits	1.5		0.05		0.1		0.3	

Table 1: Levels of metal ions in the river (mg/l) during wet and dry seasons

WHO
Limits 1.5 0.05 0.1 0.3

From table 1, the concentration values for Zn during dry season at the four sampling stations ranged between 0.16 mg/l – 0.50 mg/l and 0.20 mg/l – 0.60 mg/l during wet season. High values of Zn were observed upstream at sampling station S1 but reduced downwards at sampling station S2 and then increased drastically at sampling station S3 and then reduced at S4. Reduction of Zn concentration at S2 could be due to the rivers self dilution (Ajibade, 2004). Sampling station S3 is where Ndakaru river meets Malakisi river and hence higher values could be of Ndakaru river. Reduction of Zn levels at S4 again could be due to dilution of the river downstream. There were slightly higher Zn levels during dry season compared to wet season. However, the concentration of Zn at all the sampling stations was within the WHO recommended limits although they were slightly higher than those of Owan river in Nigeria which had Zn levels of 0.10 – 0.13 mg/l (Enuneka et al., 2013).

High values of Mn, greater than the WHO maximum limit of 0.1 mg/l were noted at all the sampling stations. The concentration levels of Mn ranged between 0.1 – 0.35 mg/l during both dry and wet seasons at the four sampling stations. Higher levels were observed during wet season. Sampling station S4 had the highest Mn levels compared to other sampling stations. This could be due to tobacco

farming, which is the main cash crop at the catchment area of S4 where Mn ethylene bisdithiocabamate is highly used as the main insecticide among the tobacco farmers. Higher values of Mn greater than WHO maximum limits at all the sampling stations during wet season could be as a result of fertilizer application and runoff. Although Mn levels at all the sampling stations of the Malakisi river were higher than WHO maximum limits, studies done on other rivers show even higher Mn levels. Kikwe river in Zimbabwe had Mn levels of 125.21 mg/l (Jonathan, 2010), while in Nairobi river at Museum station, Ngong river near Embakasi, Nairobi river near Dandora, Kasarani river at kasarani and kamiti river at kamiti, all from Nairobi, Kenya had Mn concentration levels of 1.6 mg/l, 1.65 mg/l, 2.5 mg/l, 2.1 mg/l and 2.8 mg/l, respectively (Mulei, 2012). Mn levels of 0.01 – 4.08 mg/l during dry season, 0.01 – 0.98 mg/l during wet season were observed in another study that was done to establish the pollution level of Sasumua river in Kenya (Gathenya et al., 2009). Although slightly higher Mn levels above WHO maximum limit were established in Malakisi river water, this level was very low compared to rivers within Nairobi city which has many industries. Thus Mn pollution in Malakisi river could be mainly from agricultural insecticide application with higher values observed during wet planting seasons. The Mn levels in water samples at stations S2, S3 and S4 were all found to be above 0.3 mg/l, while slightly low Mn values were established upstream at sampling station S1. This could be due to tobacco farming at sampling stations S2, S3 and S4 respectively, where the main pesticide – dithane M-45 or Mancozeb fungicide is the main pesticide and fungicide frequently used. Mancozeb (dithane) is a product of Zn ion and Mn ethylene bisdithiocabamate with % compositions of 7.4 % Mn2+ and 0.9 % Zn2+, respectively.

The concentration values for Fe and Cu were also higher than the maximum WHO limits of 0.3 mg/l and 0.05 mg/l respectively. The levels of Fe at the sampling stations S1, S2, S3, and S4 ranged between 0.330 - 1.121 mg/l, with very high values being observed at S1(0.690- 0.860 mg/l) and S3 (0.861- 1.121 mg/l). High values at S3 could be due to the geological origin where the water is always brown in colour, while higher concentration values at S1 could be due to both geological origin and runoff during wet season. This augment is similar to that observed by (Davies, 1996, Kritzberg and Ekstrum, 2012) where it was observed that most surface waters in Western Kenya are coloured as a result of high concentration of Fe and Mn. The level of Fe at all the sampling stations was higher than WHO maximum limit of 0.3 mg/l. According to WHO, 2000, the median Fe concentration in has been reported to be 0.7 mg/l. Similar studies to establish the level of Fe in rivers Nairobi and Ngong both showed Fe concentration levels of 1.99 mg/l and 1.30 mg/l, respectively which are slightly higher but close to that of Malakisi river (Mulei, 2012). Fe concentration range of 0.08 – 1.84 mg/l was established in Sasumua reservoir and contributing rivers during wet season and 0.17 – 18.46 mg/l during dry season. In Owan river in Nigeria, the level of Fe was 1.16 -1.49 mg/l (Enuneka et al., 2013), while Fe levels of 7.61 mg/l was established in river Kikwe in Zimbabwe (Jonathan, 2010). Cu levels in the same Sasumua river was; 0.01 - 0.02 mg/l during wet season and 0.01 -0.31 mg/l during dry season. Malakisi river had lower Cu levels than Sasumua river ranging from 0.01 – 0.13 mg/l which was also slightly lower than what was established by Mulei in the rivers Nairobi (0.01 – 0.20 mg/l) and Ngong (0.15 mg/l) (Mulei, 2012, Gathenya et al., 2009). However, these levels were slightly higher than those established in natural waters of Kerio Valley area (Mn < 0.2 mg/l, Cu 0.03 mg/l, Fe 0.1 – 0.4 mg/l), in river Gucha (Mn 0 mg/l, Cu 0.04 mg/l, Fe 0.4 mg l) and in Nzoia river(Fe 0.2 – 0.4 mg/l, Cu 0.01 – 0.20 mg/l), but lower than those in natural waters in Thika area (Fe 0.883 mg /l, Mn 0.442 mg/l, Zn 0.01 – 2.996 mg/l) and Nyando river (Mn 1.5 mg/l, Fe 4.4 mg/l) (Davies, 1996).

	S1		**S2**		**S3**		**S4**		**WHO**
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	**limits**
NO3-	0.09	0.2	0.1	0.4	0.07	0.3	0.095	1.0	10
PO_4^{3-}	0.136	1.442	0.065	0.351	0.124	0.548	0.096	0.653	5.0
SO_4^{2-}	0.1	0.6	0.09	0.4	0.456	1.0	0.628	1.1	400
Coliforms	28	35	36	42	42	39	34	46	Nil

Table 2: Mean Nutrient levels in river (mg/l) and faecal Coliforms (Cfu/100 ml)

From Table 2, the levels of nitrates, phosphates and sulphates at all the sampling stations during dry and wet seasons ranged between, NO_3^- (0.07- 1.0 mg/l), PO_4^{3-} (0.06 – 1.442 mg/l), SO_4^{2-} (0.09 – 1.1mg/l) and were very low compared to WHO maximum limits. The NO_3^- and PO_4^{3-} were however slightly higher than those established in Nzoia river (NO_3^- 0.01 - 0.13 mg/l, PO_4^{3-} (0.01 -0.43 mg/l)). Nzoia river, however, had higher SO_4^{2-} level (29.9 -66.7 mg/l) compared to Malakisi river. Thus, point sources of pollution such as fertilizer application, effluents from industries and untreated sewage discharge from septic systems were not the main cause of Malakisi river water pollution. These values were also low compared to nutrient levels of some rivers. A study done by Gathenya *et al*., 2009, to establish the nutrient concentration in Sasumua reservoir and contributing rivers showed NO_3^- concentration levels ranging from 17.16 – 477.38 mg/l during wet season, 6.88 -8.90 mg/l during dry season, PO_4^{3-} concentration levels of 0.21- 0.96 mg/l during wet season, 0.25 – 9.69 mg/l during dry season and SO_4^{2-} levels of 8.45 – 71.83 mg/l during wet season and 7.21 – 71.50 mg/l during dry season. A similar study on Mara river showed PO_4^{3-} levels of 1.21 – 1.15 mg/l (Mulei, 2012; Gathenya *et al*., 2009).

Water from all the four sampling stations had high levels of coliforms during dry and wet seasons which ranged from 28 – 48 cfu/100 ml. Malakisi river is the main source of both domestic and drinking water for animals mainly cows and donkeys. Thus, the presence of faecal coliforms in the water could be due to direct input by the animals. Runoff into the river during wet season could have contributed to slightly higher Coliform levels. All the parameters were below the WHO maximum limits except Coliform levels which were high. Although the Malakisi river is thus polluted due to presence of coliforms hence requiring treatment before drinking, this level is low compared to these other rivers. A study done by Dulo (2008) to determine the levels of physical, chemical parameters of the Nairobi river showed that the river had 35000 cfu/100 ml faecal coliforms.

Sulphate levels in the river ranged between 0.09 – 1.1 mg/l. The SO_4^{2-} levels were very low compared to WHO maximum required limit. According to Davies (1996), surface waters of East Africa contain low levels SO_4^{2-}.

	S1		S2		S3		S4		WHO limits
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
COD (mg/l)	24	20	18	15	33	25	40	33	50
BOD (mg/l)	11	9	9	7	17	12	21	15	20
Total									
Hardness	2.34	2.35	2.36	2.37	2.29	2.27	2.22	2.19	100
Conductivity	166	164	170	169	291	289	191	188	1500
Turbidity	54	60	59	61.5	238	248	134	139	5.0
pH (P^H scale)	7.0	7.2	6.9	7.1	7.1	7.3	6.8	7.1	6.5-8.5
F^-	0.2	0.23	0.49	0.46	0.673	0.64	0.240	0.280	1.5

Table 3: Levels of COD, BOD, Total Hardness, Turbidity, Conductivity, pH and F- in the river

The COD, BOD and conductivity levels of the river water were found to within the range of: COD: 15- 40 mg/l, BOD: 9 -21 mg/l and conductivity: 164 – 291 us/cm3, respectively. These levels were low compared to WHO maximum limit and indicated low organic pollution of the river water. The conductivity levels were also low. These levels were similar to those established in natural valley waters of Kerio Valley (BOD: 9 mg/l, COD: 14 mg/l, conductivity: 141 us/cm3), Gucha river (BOD: 26.3 mg/l, conductivity: 119 us/cm3) and Mara river (Conductivity: 50 us/cm3) (Davies, 1996). The COD, BOD and conductivity levels of river Malakisi were found to be lower than those rivers found in urban areas or within the industrial set up. Githurai river, Nairobi river, rivers within Thika and Nzoia river were found to have BOD, COD and conductivity levels of: Githurai (BOD: 200 – 400 mg/l), Nairobi river (BOD: 182 mg/l, COD: 182.5 mg/l, conductivity: 306.83 mg/l), Thika (BOD: 5- 990 mg/l, COD: 8 -1088 mg/l, conductivity: 70 – 4420 mg/l), Nzoia (BOD: 46.5 mg/l, COD: 60.3 mg/l and conductivity: 85 – 3232 us/cm3) respectively (Dulo, 2008 ; Davies, 1996 ; Kaluli et al., 2006). High BOD levels of 475 mg/l were also established in river Sabarmati in India (Bhardwaj and Scientist, 2005), while BOD levels of 333.2 – 524.2 mg/l were established in river Owo in Nigeria (Kuforiji & Ayandiran, 2013). Although the BOD levels in Malakisi river were slightly below the WHO maximum limit, all the values were above 3 mg/l, hence this can affect coagulation and rapid sand- filtration process in conventional water treatment and thus requiring expensive advanced water treatment (UNEP, 2006). The Malakisi river is also regarded as grossly polluted since all its BOD values were above 6 mg/l (Bhardwaj & Scientist, 2005).

Turbidity levels of the water at all the sampling stations during dry season and wet season ranged between 54 - 238 and 60 – 289 NTU, respectively. The turbidity of Malakisi river alone before joining the Ndakaru river had turbidity levels ranging from 54 – 62 NTU. The level increased drastically after joining with the Ndakaru river where the turbidity level ranged between 238 – 248 NTU. Water from all the sampling stations in Table 3 had high turbidity levels above the WHO maximum limits of 5.0 NTU, with water from the sampling station S3 having the highest values. Wet season had high turbidity levels compared to dry season. In Kenya, many of the streams have been established to be turbid, due to largely soil erosion which is, especially high in the rainy season (Davies, 1996). The turbidity level of the river water was found to be similar to that of Nzoia river (7 – 66 NTU), lower than natural waters of Kerio Valley (5 – 620 NTU) and Mara river (7.1 – 1999 NTU) but higher than that of the Nairobi river (8 – 57 NTU) (Dulo, 2008, Davies, 1996). Very high turbidity levels have been noted in Mesopotamia plain in Iraq. Kharkhas river had turbidity of 5716 NTU, Al-Teeb river, 3408 NTU, while Tigris river had turbidity of 1062 – 1304 NTU (Younus & Enaam, 2014).

4. Conclusions

Water quality of Malakisi river meets the WHO water quality criteria in terms of Zn, pH, $NO_3^-PO_4^{3-}$, SO_4^{2-}, F^-, BOD, COD, total hardness and conductivity. However, the following parameters were found to be higher than WHO maximum required levels; Cu, Mn, Fe, coliforms and turbidity. The Malakisi river is thus polluted and preliminary treatment of the water is required.

5. Recommendations

1. Treatment of the water from Malakisi River is required before being used as drinking water. Coagulation of the river water by adding alum will be required in order to remove turbidity followed by chlorination or boiling in order to remove coliforms. Availability of water filters/purifiers will be of great help.
2. Reduction of manganese, copper and iron metals will require either or conventional or natural water treatment methods such as creation of buffer zones along the river systems to allow growth of river line vegetation such as arrowroots which can take up some of the pollutants and hence reduce water quality degradation and restore quality of the water.
3. Monitoring of the pollution levels in the river should be done continuously in order to follow up properly the pollution parameters so as to enable the right action to be taken at the right time
4. The farmers within the catchment area of the Malakisi river should be advised on the required amounts of agrochemicals to be applied to their farms so that very little or none of the chemicals find their way into the river by runoff. Education on various methods of preventing soil erosion will also be important.

5. Future plans such as setting up communal solar powered water treatment tanks and ensuring availability of piped water to all residents in the affected counties that rely on Malakisi River as the main source of water should be considered by the relevant authorities besides reviving the Chesikaki water treatment plant

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