ASSESSMENT OF THE WATER QUALITY STATUS OF SASUMUA WATERSHED, KENYA

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Abstract
This study focuses on Sasumua watershed (107km^2) of the Upper Tana basin and source to 20% of Nairobi's water supply where intensification of human activity has resulted in increased pollutional load to Sasumua reservoir with implications on water treatment costs for Nairobi Water and Sewerage Company (CNWSC). The objective of the study was to determine the physico-chemical and bacteriological characteristics of the water entering Sasumua reservoir and to assess the relative importance of the various sources of contamination. Water samples were collected at distinct land use boundaries, at reservoir entry/exit points, and at the surface of the reservoir during both dry and wet seasons. These were analysed to determine total suspended solids, total dissolved solids, turbidity, dissolved oxygen, faecal coliforms, nutrients, heavy metals and pesticides. Analysis was done as per the standard method of analysis and evaluation based on World Health Organisation (WHO) standards. For both dry and wet seasons most parameters were within WHO standards except Ming'utio River which showed exaggerated levels of potassium, iron, lead, manganese, pH and turbidity. For the wet season both turbidity and pH values were above WHO standards for most samples analysed. No pesticides were detected but samples showed signs of contamination with human waste indicating unsuitability for domestic use without treatment. Turbidity and pH were the major issues of concern because of their bearing on water treatment costs. The study contributes towards understanding the water quality status of the contributing rivers and reservoir and can be used by planners to devise ecologically-sound watershed management plans, or by policy makers to evaluate alternative land management options that can abate pollution of water bodies.

Key words: Pollutants, Sasumua, water quality, watershed, WHO

1.0 Introduction

Rivers are the most important sources of fresh water for man. The social, economic and political developments have largely been related to the availability and distribution of fresh waters contained in riverine systems. Water quality problems have intensified over time in response to increased growth and concentration of populations and industrial centres. Polluted water is an important vehicle for the spread of water related diseases with 1.8 million people, mostly children dying every year especially in developing countries (WHO, 2004). Outbreaks of waterborne disease continue to occur in both developed and developing countries, leading to loss of life, disease and economic burden for individuals and communities. Improvements in water quality and personal hygiene can therefore be expected to deliver substantial health gains in the population.

Economic and demographic growth in agricultural watersheds often leads to intensive land use and increased generation of point and non-point source pollutants. These pollutants, which include pathogens, nutrients, toxic contaminants, and sediments are then transported by runoff to water bodies causing serious environmental effects (Johnes and Burt, 1991). Many types of fish and other aquatic animals cannot survive in environments with high amounts of oxidizable organic pollutants that can cause levels of dissolved oxygen to drop below 5 ppm (Chapman, 1992). When this occurs, aquatic organisms are killed in large numbers leading to significant disruptions in the food chain. Organic or inorganic materials enter waterways in many different forms from terrestrial ecosystem or/and from the atmosphere. The major sources of terrestrial water pollution can be classified as municipal, industrial, and agricultural. Municipal water pollutants consist of wastewater from homes and commercial establishments. Agricultural land including commercial livestock and poultry farming is the source of many organic and inorganic pollutants in surface and ground waters (Chapman, 1992). These contaminants include both sediment from eroded croplands and compounds of phosphorus and nitrogen that partly originate from animal wastes and commercial fertilizers. Animal wastes are high in oxygen demanding, nitrogen and phosphorus, and they often harbour pathogenic organisms. High nutrient loadings may lead to eutrophication of water bodies. Intensive agricultural practices have the potential to introduce heavy loads of sediment, nutrients, and faecal contamination into surface waters with resultant water quality problems.

These pollutants reach streams through surface, sub-surface and ground water flow depending on the type of pollutant. Surface runoff is the major pathway for organic and inorganic sediments and particulate-bound nutrients such as phosphorus (Chittleborough *et al.*, 1994; Lal, 1990). Sediments may also be important for the transport of organic forms of nitrogen, particularly when surface runoff is the dominant storm water pathway (Schuman *et al.*, 1973; Hubbard *et al.*, 1982). Surface runoff may also be the major transport mechanism for soluble pollutants, especially after applications of agrochemicals or livestock waste (Neilsen *et al.*, 1982; Roberts, 1987; Smith, 1989; Bengtson *et al.,* 1988, 1990; Schlefield and Stone, 1991). Most water pollutants are eventually carried by rivers into oceans, reservoirs and other water bodies.

Sediments and nutrients in water bodies may also originate from roads, bank erosion, re-suspension, production processes (for nitrogen), and fluvial erosion. In the case of streams, high flow and change in the direction of the current are responsible for bank erosion, re-suspension and fluvial erosion. Birot (1968), Tricart (1972) and Louis (1964) observed that most of the humid tropical rivers do not erode vertically into the material below them. Also on a global scale several researchers (NEDECO, 1959; Webb and Walling, 1985) reported average contribution of bedload ranging between 5 to 10 %. This range of values is conveniently considered as insignificant, thus most estimates of net erosion rely wholly on suspended loads.

Atmospheric pollutants (wet or dry) are transferred to water bodies by precipitation. For several Western countries, about 20-40% of the total phosphorus load is deposited by rain (Sharpley *et al.*, 1994). The relative contribution of atmospheric input compared to the terrestrial sources depend on pollutant type, areal coverage of the water body, the size of the terrestrial ecosystem, connectivity of its watersheds, and the type of activity both at local and regional scales. Apart from natural factors such as precipitation, evaporation, geology, soils influencing water quality, human activities such as domestic and agricultural practices impact negatively on river water quality. It is therefore important to carry out regular water quality assessments for sustainable management of water bodies and watersheds.

Kenya's water resources, like other developing countries, have been under increasing threat of pollution in recent years due to rapid demographic changes, which have coincided with the establishment of human settlement lacking appropriate sanitary infrastructure (Verma and Srivastava, 1990). Sasumua watershed is crucial for the production of ecosystem services, not only for the local population but also for Nairobi City dwellers because

Nairobi derives 20% of its water needs from the watershed. Land use changes, driven by agricultural production have contributed to degradation of watershed functioning. This has resulted not only in degradation of hydrological functioning of the regime, but also in lowering of soil productivity which has impacted negatively on the livelihood of the rural communities. Because of increased population, farming has intensified in order to produce enough food for the population with farmers using more inorganic fertilizers, pesticides, and herbicides. Other than food production, however agricultural watersheds are also expected to provide ecosystem services such as clean and regular flow of water to people living downstream. With intensification of agriculture, it is expected that water quality and quantity will be affected with serious ramification on the livelihoods of both local communities and NWSC. Ensuring proper hydrological functioning of the watershed is therefore of critical importance to the future water supply of Nairobi.

Sasumua River with its tributaries runs through farmlands and rural communities before entering Sasumua reservoir the major source of water for Nairobi. Although NWSC regularly treats its water before transmission to Nairobi, no water quality studies have been done on the rivers before the water enters the reservoir to determine the relative importance of various sources of contamination and their contribution to the overall water quality. Understanding the nature of sources of contamination and how these contaminants enter the water supply is critical for assuring water safety. The study aims at determining the water quality status of Sasumua watershed and to provide physico-chemical and bacteriological characteristics of the water and therefore contribute to the formulation of ecologically-sound watershed management plans for abating pollution of Sasumua reservoir and its contributing rivers.

2.0 Materials and Methods

2.1 Study Area

Sasumua watershed lies between longitudes 36.58°E and 36.68°E and latitudes 0.65°S and 0.78°S with an altitudinal range of 2200 m amsl to 3850 m amsl. Apart from Njabini Township and other market centres where there are commercial activities; farming is the main socio-economic activity in the watershed with potatoes, cabbages, kales, garden peas and carrots being grown for the Nairobi urban market. The ready market for these products has led to increased use of inorganic fertilizers, pesticides and fungicides making water pollution from these agro-chemicals a challenge in the watershed. The steep slopes and heavy rainfall in the watershed make much of its area vulnerable to degradation- a problem exacerbated by population pressures. Large scale immigration to the area in recent years combined with intrinsic growth has resulted in a population explosion in the area. As the population has increased, so has the demand for key natural resources, such as land, water and energy, heightening risks of ecosystem degradation. These anthropogenic processes have led to significant decline in water quality in Sasumua watershed during the last four decades (Mireri, 2009). Climate in the watershed varies with altitude, with rainfall increasing while temperatures decreases as elevation increases. The mean annual rainfall in the watershed ranges from 1000-1600 mm, with an increasing gradient from South-West to North-East. The distribution of rainfall is binomial with long rains occurring from March to May and short rains occurring from October to December, (Gathenya *et al.,* 2009) with sufficient amounts in most of the other months. The mean monthly temperature is 11.54°C while annual potential evaporation ranges from 1180mm to 1322mm (Woodhead, 1968).

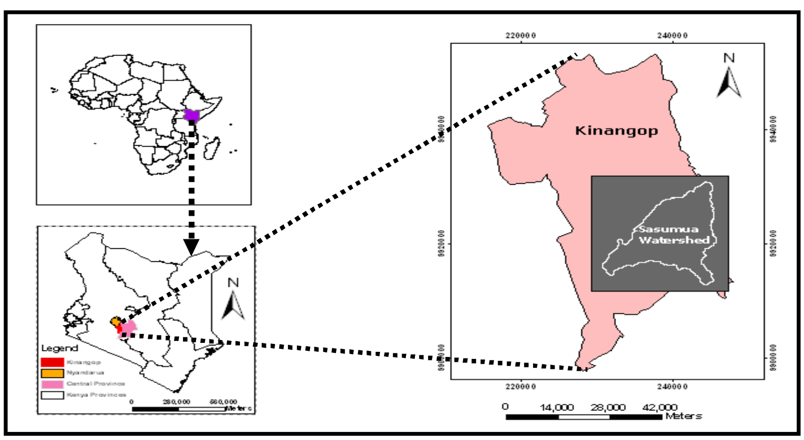

Figure 1: Geographical Location of the study area

The total population of the watershed is about 19,000 (2009 census) in two divisions of Nyakio and Njabini.

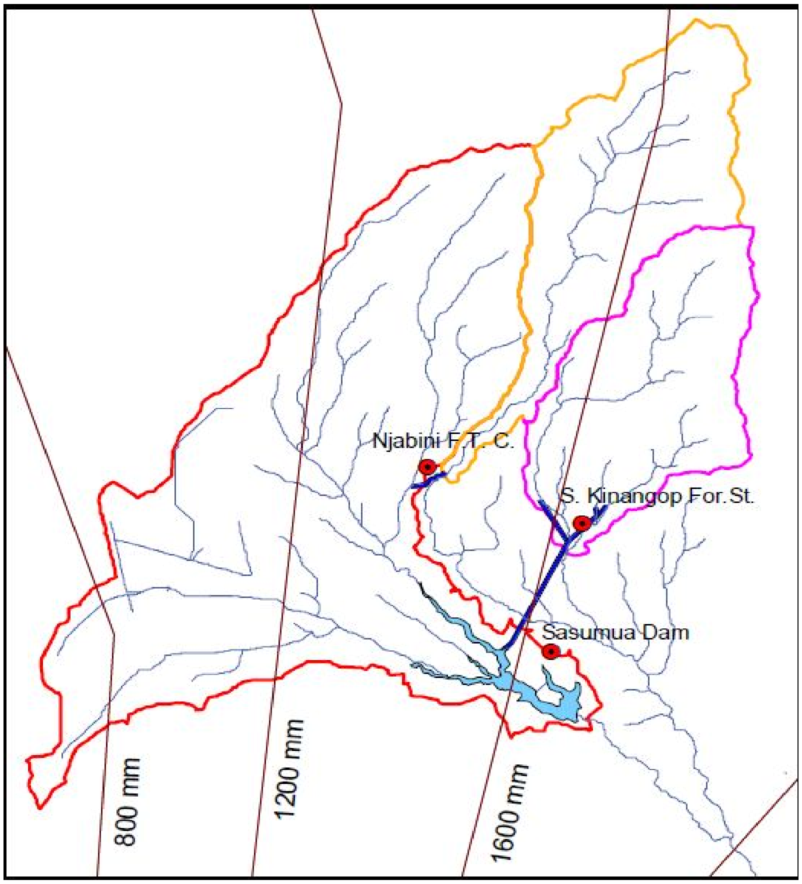

Figure 2: Mean annual rainfall distribution and rainfall stations

2.2 Sampling

Surface water samples for physico-chemical analysis were collected midstream at a depth of about 20cm directly into clean 500ml plastic bottles. Temperature and pH were measured *insitu*, using a temperature probe and a portable pH meter, respectively. Electrical conductivity (EC) and total dissolved solids (TDS) were determined on site using total dissolved solid (TDS) and conductivity meter Jenway model 4076. Dissolved oxygen (wet season only) was determined on-site using multi-meter electrochemical analyzer Jenway, model 3405. Wet season turbidity was measured on site using TR-3Z KRK Turbidimeter meter model 1042 while dry season turbidity was measured in the laboratory. Samples for bacteriological analysis were collected at Ming'utio and Sasumua Rivers and at Kwa-Haraka town into sterilized 1-litre plastic bottles while ensuring no air bubbles were present, stored in an icebox at 4°C and transported to the laboratory for analysis within the stipulated time of 6 hours. Microbiological analysis of these samples was carried out using the standard methods (APHA, 1998) and the experiments performed in triplicates. The plates were incubated at 35^{o}C for 24 hrs and bacteria counts (both feacal and total coli forms) in the water samples enumerated using the membrane filtration technique. The choice of sampling points was based on entry points of major rivers into the reservoir, exit of water from the reservoir and areas where distinct land use changes occurred (Figure 3). It was carried out both during the dry and wet seasons. Twelve sampling points were selected for both the dry and wet seasons. The geographical location of these points was determined using a geographical positioning system (GPS). The samples were collected in 500ml pre-washed and labeled polypropylene bottles which were thoroughly washed and rinsed with tap and distilled waters. They were again rinsed with river water before actual sample collection and filled to the top to eliminate air bubbles and then firmly corked. Samples for trace metals analysis were acidified to PH <2 by addition of nitric acid while those meant for anion analysis were collected in the same way but without the need for acidification. Five sampling points were selected for pesticide analysis. Temperature, pH, electrical conductivity, and total dissolved solids were determined on site using total dissolved solids (TDS) and Electrical conductivity meter Jenway model 4076.

Figure 4: Sampling for water quality at Sasumua reservoir

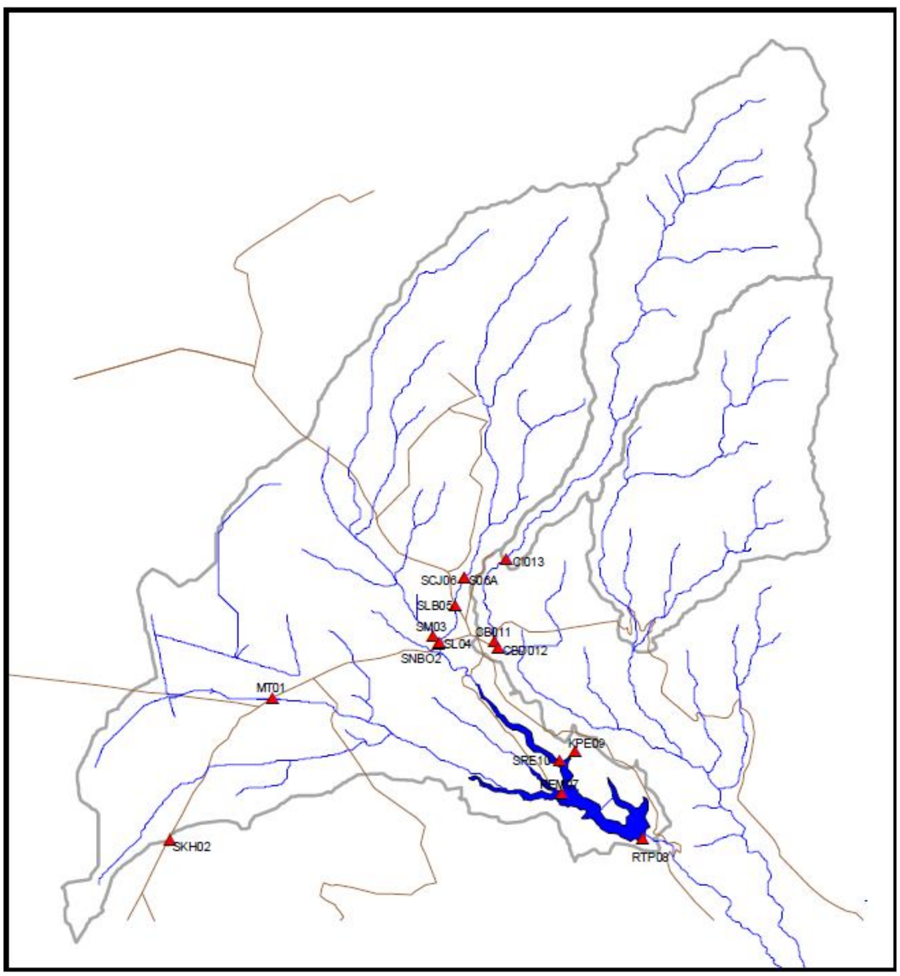

Figure 3: Water quality sampling points in Sasumua watershed

Table 1: Sampling points within Sasumua watershed

Code	Description	UTMX	UTMY
MT 01	Ming'utio River at the bridge	235063	9918772
SNB 02	Sasumua river at the Njabini-Nairobi Bridge	238074	9919782
SM 03	Main Sasumua River	237983	9919930
SL 04	Little Sasumua River and Chania tunnel junction	238101	9919818
SLB 05	Little Sasumua + Tunnel at Bridge to Engineer	238394	9920508
SCJ 06	Little Sasumua + Tunnel at junction	238557	9921024
REM 07	Reservoir at entry of Ming'utio river	240318	9916954
RTP 08	Reservoir at tower point	241812	9916122
KEP 09	Entry of Kiburu pipe at reservoir	240570	9917772
SRE 10	Reservoir entry of Sasumua River	240282	9917588
CI 013	Chania Intake	239321	9921368
SKH 02	Kwa-Haraka township	233185	9916113

2.2.1 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 all physico-chemical parameters. Total suspended solids (TSS) were measured gravimetrically after drying in an oven to a constant weight at 105°C. Total and faecal coliforms were determined by membrane filtration method using M-Endo-Agar Les at 37°C and on MFC Agar at 44°C, respectively. Sodium and potassium were analysed using the flame emission photometry; calcium and magnesium by EDTA titration; and chloride by argentometric titration. Analysis of Mg, Ca, and heavy metals (Fe, Mn, Cu, Zn, Pb and Cd) were done using atomic absorption spectrophotometer (AAS) Buck Scientific – 210 VGP (air – acetylene flame). Analysis of sodium (Na) and potassium (K) were done using Flame emission spectrophotometer using Corning 400 ; Na^+ at 590nm and for K^+ at 770nm. Analysis of organochlorines and organophosphates was done by Gas Chromatography GC-ECD/NFD at KEPHIS analytical laboratory (A SANAS Accredited Testing Laboratory No.T0209.

Standard stock solutions for each metal analyte were prepared using respective analar grade reagents for each analyte which was dissolved in distilled water and from which dilutions calibration curves were prepared.

Each of the analyte (NO_2^-, NO_3^-, PO_4^{2-}, and SO_4^{2-}) was analyzed using calorimetric technique. Analytes (NO_2^- , PO_4^{2-}, and SO_4^{2-}) were analyzed using visible spectrophotometer (Pharmacia Biotech – model Nova spec II) while NO_3^- was analyzed using Shimadzu 1700 UV-visible Spectrophotometer (Vogel, 1989). All reagents used were of analar grade while distilled water was used for preparation of standards.

3.0 Results and Discussions

The results of the analysis are presented in tables and those above WHO standards are shown in bold. The mean pH for most samples was neutral (7.10) which is the range associated with most natural waters (6.0 to 8.5), stipulated for drinking and domestic purposes (Chapman, 1992). The conductivity of the water at sampling points ranged between (0-180). The turbidity of the water ranged from 2.0 to 142.0 during the wet period which is the most critical period and which was expected considering most runoff occurs during the rainy season and which carries alot of silt. Low turbidity facilitates water purification process like flocculation and filtration resulting in reduced treatment costs. Dissolved oxygen (DO) levels varied from 6.3 to 11.90 during wet season and this could be attributed to availability of limited organic waste in the waters. Measurement of DO gives a rough indication of the quality of the water (DFID, 1999) as most polluted waters have DO below 5mg/l making them unsuitable for existence of aquatic life. Nitrate and Nitrite levels were within levels recommended by WHO. High concentrations of these ions pose health risks particularly in pregnant women and bottle-fed infants (Kelter *et al.,* 1997).

Ming'utio sampling point (MT 01) showed high phosphate, iron, lead and manganese concentrations and because of the sensitivity of high concentration of lead, all sampling points that showed traces of lead and cadmium were re-tested at the Institute of Nuclear Science and Technology University of Nairobi and at

KEPHIS analytical laboratory. Although in both cases the levels were below WHO standards there was still cause for concern as these elements are not normally removed by conventional water treatment methods. Nutrient levels were low during the dry season but increased significantly during the wet season. The bacteriological quality of water sampled was poor rendering it unsafe for domestic purposes without treatment. The poor bacteriological quality may be due to contact with human or animal waste.

Although most of the physico-chemical parameters for water quality were within the acceptable guideline limits of the World Health Organization (WHO) for potable water, there is still cause for concern especially with regard to some elements which are not removed during normal treatment and possible sources of these elements should be indentified and preventive measures taken to prevent their discharge into rivers.

Table 2: Pesticide results for wet season

Sampling Site	*Pesticide screening*	*Concentration (mg/l)*
SNB 02	Organophosphates Organochlorines	< Limit of detection <Limit of detection
MT 01	Organophosphates Organochlorines	<Limit of detection <Limit of detection
CB 11	Organophosphates Organochlorines	<Limit of detection <Limit of detection
SL 04	Organophosphates Organochlorines	<Limit of detection <limit of detection

Table 3: Coli form test results on water samples

Sampling site	*eColi MPN index per 100ml*	*WHO standard*
MT 01	>1100	0
SKH 02	>1100	0
SNB 02	43	0

Table 4: Nutrient concentration in Sasumua reservoir and contributing rivers (Wet season mg/l)

Sample site	NO_2^-	NO_3^-	SO_4^{2-}	PO_4^{2-}	Na^+	K^+	Mg^+	Ca^{2+}	Cu^{2+}	Fe^+	Pb^{2+}	Mn^{2+}	Cd^{2+}
MT01	0.13	59.28	53.52	0.74	16.85	13.81	1.10	2.21	0.00	1.84	0.06	0.87	0.00
SNB02	0.01	35.88	71.83	0.32	2.66	1.84	0.87	2.61	0.01	0.20	0.16	0.02	0.00
SM03	0.04	88.92	14.79	0.96	10.64	6.44	1.24	1.81	0.00	3.26	0.02	0.98	0.02
SL04	0.02	62.40	16.20	0.21	3.55	1.84	0.85	2.31	0.01	0.28	0.01	0.04	0.00
SLB05	0.02	65.52	50.70	0.53	79.84	234.70	0.84	2.71	0.01	0.13	0.10	0.05	0.00
SCJ06	0.02	17.16	14.79	0.43	3.55	1.84	0.85	2.24	0.00	0.17	0.01	0.04	0.00
REM07	0.00	0.00	8.45	0.32	3.55	1.84	1.04	2.98	0.01	0.18	0.00	0.05	0.00
RTP08	0.02	37.44	12.68	0.43	4.44	1.84	1.22	2.44	0.01	0.08	0.07	0.02	0.00
KEP09	0.05	62.40	13.38	0.74	3.55	1.84	1.06	1.50	0.01	0.23	0.00	0.01	0.01
SRE10	0.03	49.92	9.86	0.74	3.55	1.84	1.00	2.25	0.02	0.23	0.08	0.04	0.00
CI013	0.02	46.80	11.27	0.32	3.55	1.84	0.94	2.54	0.02	0.11	0.00	0.02	0.00
SKH01	0.00	0.00	67.61	0.74	13.31	8.28	0.38	1.21	0.02	0.75	0.13	0.5	0.00
SKH02	0.05	477.38	10.56	0.63	67.42	59.83	1.97	51.23	0.00	0.23	0.01	0.23	0.00
WHO	350	250	0.2-3	5	200	30	50	250	1-2	0.3	0.01	0.4	0.003

Table 5: Nutrient concentration in Sasumua reservoir and rivers flowing into it (Dry season mg/l)

Sample site	SO_4^{2-}	NO_2^-	NO_3^-	PO_4^{2-}	Na^+	K^+	Mg^+	Ca^{2+}	Cu^{2+}	Fe^+	Pb^{2+}	Mn^{2+}	Cd^{2+}
MT01	56.50	0.50	8.90	9.69	20.62	21.08	1.75	1.89	0.31	18.46	0.23	4.08	0.00
SNB02	7.21	0.78	7.52	0.68	4.48	4.58	1.54	2.70	0.00	0.49	0.07	0.23	0.00
SM03	71.50	0.30	7.85	0.25	11.65	11.92	1.13	1.83	0.00	2.87	0.00	2.51	0.01
SL04	28.64	0.17	7.14	0.39	4.48	4.58	1.63	2.15	0.00	1.19	0.01	0.43	0.00
SLB05	76.50	0.70	7.55	1.52	3.59	3.67	1.51	3.17	0.00	0.35	0.02	0.11	0.00
SCJ06	31.50	0.17	7.69	0.25	4.48	4.58	1.35	2.51	0.01	0.14	0.01	0.03	0.00
REM07	20.07	0.04	7.93	1.52	5.38	5.50	1.25	1.96	0.01	0.72	0.01	0.21	0.01
RTP08	55.07	0.17	7.55	0.25	4.48	4.58	0.78	0.96	0.00	0.47	0.00	0.00	0.00
KEP09	22.93	0.58	6.88	0.25	4.48	4.58	1.48	1.53	0.02	0.66	0.04	0.10	0.00
SRE10	21.50	0.34	7.54	0.68	4.48	4.58	1.48	2.31	0.00	0.18	0.18	0.17	0.01
CI013	60.79	0.05	7.16	0.39	3.59	3.67	1.09	2.40	0.00	0.17	0.01	0.01	0.00
WHO	0.2-3.0	350	250	5	200	30	50	250	1-2	0.3	0.01	0.4	0.003

Table 6: Physical characteristics of Sasumua reservoir water and rivers flowing into it (Wet season)

Sample site	Conductivity (EC mS/cm)	Total dissolved solids (TDS mg/l)	Temperature (°C)	pH	Dissolved Oxygen mg/l)	Turbidity (NTU)
MT01	0.07	51.00	19.00	6.90	8.60	22.00
SNB02	0.03	21.00	12.00	8.00	10.40	7.00
SM03	0.69	54.00	16.80	7.42	7.90	11.00
SL04	0.03	21.00	12.80	7.90	8.60	22.00
SLB05	0.53	28.00	13.40	6.21	8.10	27.00
SCJ06	0.30	25.0	13.50	6.17	7.80	5.00
REM07	0.04	28.00	19.10	8.06	10.80	5.00
RTP08	0.03	28.00	18.00	7.74	7.80	2.00
KEP09	0.37	25.00	13.20	7.63	9.20	30.00
SRE10	0.35	27.00	15.80	8.60	10.80	25.00
CI013	0.02	21.00	13.20	6.39	6.30	1.00
SKH01	0.08	52.70	15.50	5.50	11.90	142.00
SKH02	0.85	62.40	18.00	6.94	9.00	86.00
WHO	500-5000	1000		6.5-8.00		5

Table 7: Physical characteristics of Sasumua reservoir and contributing rivers (Dry season)

Sample site	Conductivity (EC mS/cm)	Total dissolved solids (TDS mg/l)	Temperature (°C)	pH
MT01	180	123	16.00	6.1
SNB02	0	0	12.80	6.2
SM03	70	47	18.20	5.9
SL04	40	30	13.00	6.7
SLB05	40	30	12.80	6.8
SCJ06	40	30	13.50	7.1
REM07	40	27	19.20	8.20
RTP08	30	25	17.60	7.9
KEP09	40	28	13.10	7.6
SRE10	50	3	15.20	7.6
CI013	30	23	13.10	7.8
WHO	500-5000	1000		6.5-8.00

4.0 Conclusions and Recommendations

The results indicated that most of the physico-chemical water quality parameters were within the WHO and KEBS limits for drinking water and the water is therefore suitable for domestic purposes. In contrast however, the bacteriological quality of the water as indicated by the total and faecal coliform counts exceeded the standard (0cfu per 100ml) for portable water. In general the bacteriological quality of the water was unacceptable as it may pose risk to consumers without treatment. The poor quality showed possible contamination with human or animal waste. Inadequate physical infrastructure, especially heavy reliance on pit latrines and weak solid waste management mechanisms. Lack of functioning solid and liquid waste management system in the rapidly growing urban centre represents an important source of pollutants, which may find its way into water resources.

Conductivity and Total dissolved solids (TDS) and other major ions varied from wet to dry season with elevated levels in the wet season. However, 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 exercised by farmers in the application of inorganic fertilizers in order to avoid eutrophication of rivers or even the reservoir. For the sampled points, no organophosphates or organochlorines were detected.

Water resource management is an integral aspect of the preventive management of drinking-water quality. Prevention of microbial and chemical contamination of source water is the first barrier against drinking-water contamination of public health concern. Water resource management and potentially polluting human activity in the catchment will normally influence water quality downstream and this will impact on water treatment steps required to ensure safe water. The influence of land use on water quality should be assessed as part of water resource management which is normally the responsibility of catchment management bodies which implement national policies on integrated water resource management.

From Total Suspended Solids results it is clear that sediments are a major source of pollution and therefore further analysis is recommended to identify the major sources and possible measures to mitigate this possibly using a hydrological model. There is need also to create awareness about the risks associated with poor watershed management and the benefits of effective watershed management among the rural communities. For the urban settlements and town centres, there is need to put in place the necessary infrastructure and systems for solid and liquid waste management.

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