Chapter

A Critical Analysis of the Water Quality Impacts on Water Resources in the Athi River Drainage Basin, Kenya

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Abstract

This paper presents a critical analysis of the water quality changes and their impacts on water resources within the Athi River Catchment and its implications of the people's livelihoods. The paper analyses the effects of land use activities on water quality in the headwater areas of the basin which has a profound impacts on the downstream water uses within the basin. The paper in addition makes an attempt to relate the impacts of human activities on water quality degradation trends within the basin against the available and potential water resources in the basin. The Athi River is the second largest in Kenya and traverses areas of diverse land use activities from the more agricultural head water areas through the industrial hub of Kenya in Nairobi to the Indian Ocean discharging its waters near Malindi town north of Mombasa. The paper gives a detailed analysis of the impacts of human activities on the water resources in regard to water quality degradation, pollution and mitigation measures. The study was based on field data collection and measurements and laboratory analysis. The researcher used 10 sampling points located within the Nairobi sub-basin and distributed along the river profile to examine the trends in water quality degradation and its implication on human livelihoods in the basin. The researcher noted a declining trend in water quality status downstream the river profile. A close analysis of the water situation in the basin paints a blink future on the available water resources in the basin against the projected water uses and increasing population compounded by the impacts of water pollution and climate change. This is likely to increase incidences of water shortage and food insecurity in many parts of the basin. The researcher recommends more investments in water harvesting infrastructure, environmental conservation and adoption of modern water management technologies.

Keywords: Water resources, water quality critical analysis, livelihoods, increasing water demands

1. Introduction

The Athi River drainage basin is the second largest basin in Kenya after the Tana River drainage basin [1]. Furthermore, the river traverses agro-ecological zones of diverse climatic characteristics and land use activities. The river draws most of its headwaters from the Kenya Highlands (Kikuyu and Ondiri springs) flowing through the dry and semi-arid lands of Kenya and discharging its waters into the Indian Ocean, north of Malindi town.

In addition, the Kenya highlands are endowed with vast water resources but land use activity changes in these areas have led to water quality degradation in addition to affecting the flow characteristics of the rivers in the basin. Within the basin, there are two major urban and industrial centres from Kenya. Nairobi city, which lies at the upper catchment areas, and Mombasa, which is located on the southern outlet of the basin. Most of the upper-Athi river tributaries and the three main streams investigated (Ngong, Nairobi and Mathare) drain the Kikuyu escarpment through the city (now Nairobi County) and joining before the Kilimambogo hill (Donyo Sabuk) to form the main Athi-Sabaki River as shown in **Figure 1**.

The Athi River Catchment area borders the Tana Catchment area in the north and is located in the southern part of the country as shown in **Figure 1** and borders the Indian Ocean in the east, Republic of Tanzania in the south, and the Rift Valley in the west. In addition, the Aberdare Range, one of the Five Water Towers, lies in the northern edge of the area. The basin occupies a total area of 58,639 km^2, which corresponds to 10.2% of the country's total land area. Based on the Kenya National Bureau of Statistics report [2] the recent Census 2009, population of the basin in 2010 was estimated at 9.79 million people or 25.4% of the total population of Kenya with a population density of 167 persons/km^2.

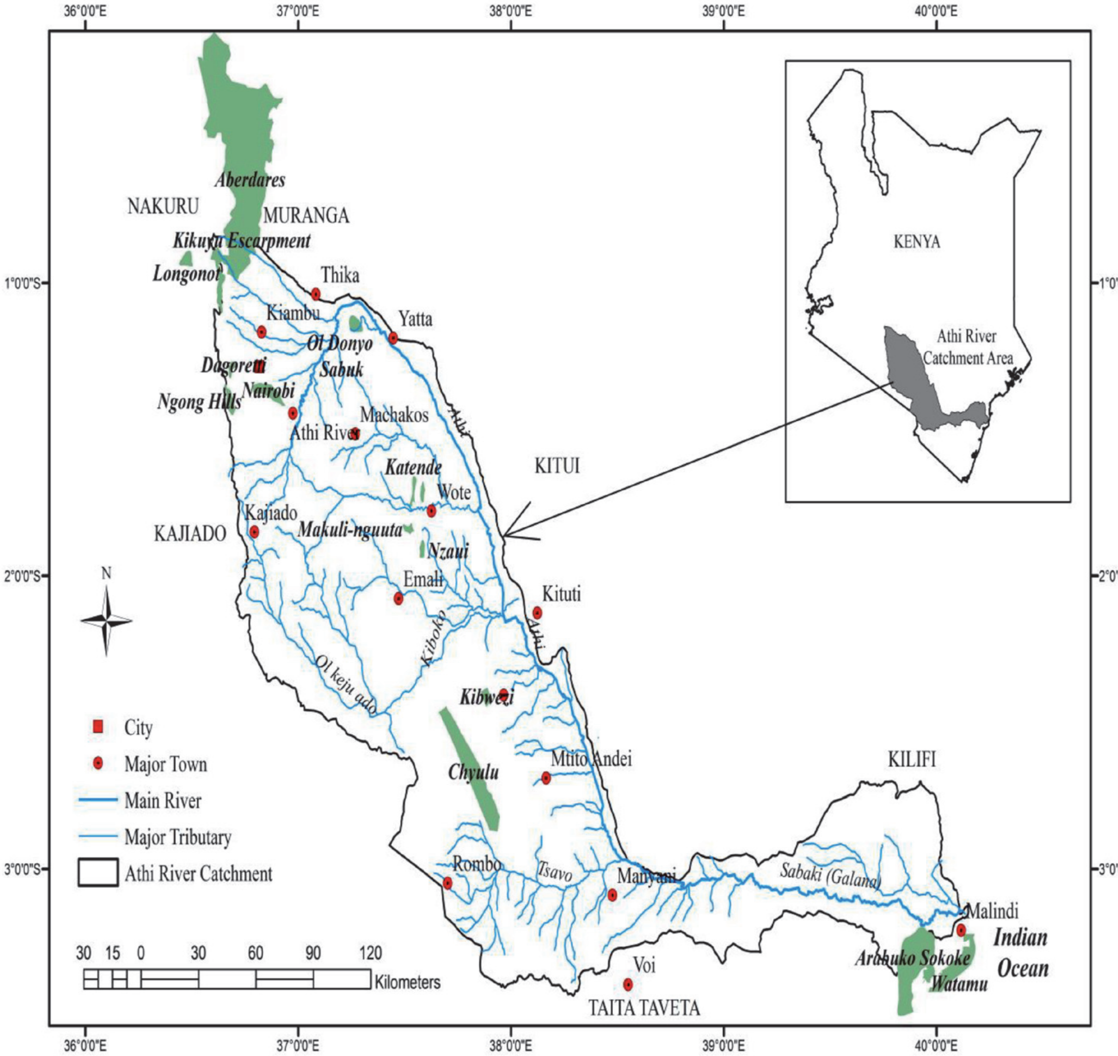

Figure 1.
Athi River catchment basin and main tributaries.

The catchment basin varies in topography ranging from 2,600 masl in the Aberdare Range to the sea level in coastal area. The basin covers three zones in altitude, with the upper zone at 2600–1500 masl, middle zone at 1,500–500 masl, and coastal zone at 500–0 masl.

The upper catchment area (headwaters area) is the centre of commercial production with many industrial and agricultural activities, which discharges their waste waters onto the river system. This pollutes the water that is used further downstream for irrigation purposes and rural domestic water supply. The continued discharges of effluents into the river system are a major concern for sustainable agricultural farming in the downstream areas and hence affecting the peoples' livelihoods and food security.

2. Study area characteristics

The Athi River flows from the southeast and north-eastward in the upstream reaches of the City County of Nairobi and then turning to the southeast in the north of Ol Doinyo Sabuk hill and flows along its boundary with Tana River drainage basin. The total drainage area is about 37,750 km^2 representing 64.4% of the Athi River Catchment Area. Some of its tributaries such as Lumi River, Lake Jipe, and Lake Chala flow into Tanzania and the Umba River flows from Tanzania to Kenya. Others such as the Rare, Mwachi, Pemba, and Ramisi rivers flow into the Indian Ocean making a total drainage area of 19,493 km^2. Several springs exist in the basin such as Mzima, Kikuyu, Njoro Kubwa, Nol Turesh, etc., whose waters are used both for Municipal and domestic water supply.

The mean annual rainfall in the basin ranges between 600 mm in the central part of the area to 1,200 mm in the upstream area of the Athi River with an overall average mean annual rainfall of 810 mm. The JICA [1] report calculated the renewable water resource, which is defined as precipitation minus evapotranspiration, at 4.54 BCM/year in 2010 for the basin and per capita renewable water resources at 464 m^3/year/capita. This is an indication that the basin is tilting towards a water scarcity scenario since the per capita value is less than the global accepted value of 1000 m^3/year/capita (UN [3, 4]). According to the World Bank Survey [5], Kenya's renewable internal freshwater resources stood at 412cubic metres per capita.

The main land use activities in the basin include urban, residential, industrial, transport in the main urban centres (Nairobi and Mombasa) and agricultural and livestock keeping both in the middle and lower reaches of the river as shown in **Figure 2**. These various land use activities have significant impacts on the water resources in the basin. They cause significant water quality degradation in the basin, reduce the available water resources in the basin while increasing competition in water usage and conflicts. The overall implication is reduced water availability for various uses in the basin and hence affecting people's livelihoods potential and leading to increased vulnerability to climate change. This calls for better adaptive strategies to cope with reducing water availability and re-innovation of sustainable methods of water resources exploitation and use.

These various land use systems contribute significantly to pollutants, pollution and water quality degradation as well as to changes in river hydrology, which is worth investigation. The land use changes in a spatial manner from the rich agriculturally based system, through residential and urban to industrial, making it ideal for investigation of gradual water quality degradation downstream the river systems. The present study on land use changes and their effects on the water quality and livelihoods in the drainage basin is an eye opener to the problems related to the land-water nexus and development in the county and country in general [6].

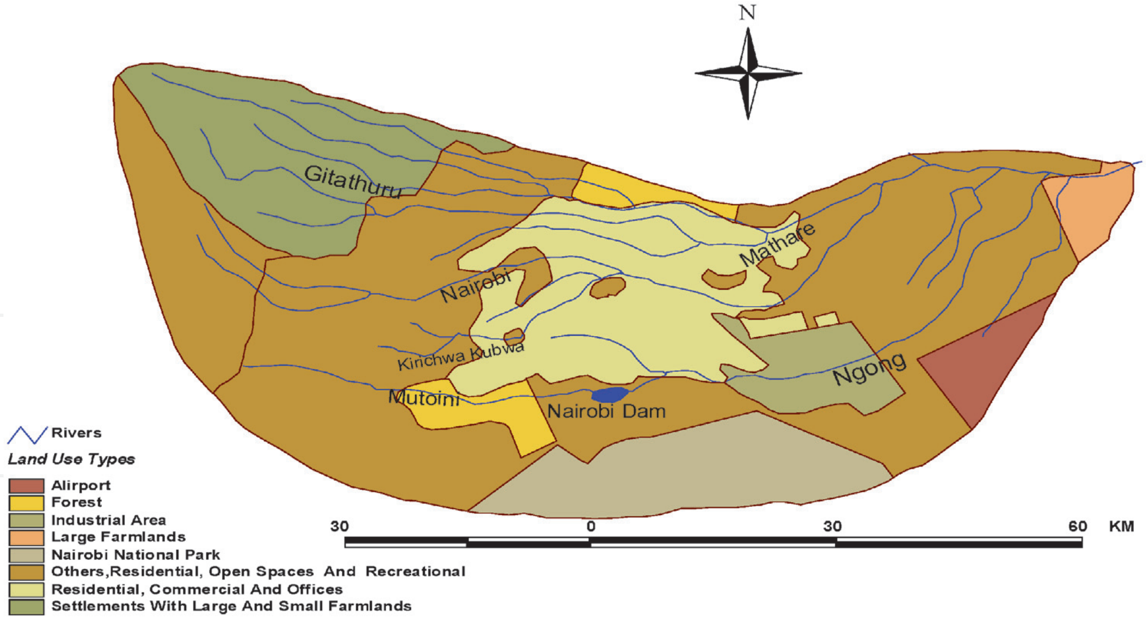

Figure 2.
Land use systems in the upper catchment area (Nairobi sub-basins). Source: Field data (2006–2017) and adapted from Kithiia [6].

3. Hydrology of the Athi River drainage basin

The Athi River basin is drainage basin number three (3) of the Kenya's drainage basins and is about 540 km long. The river drains a catchment area of about 70,000 km^2 (66,837 km^2) representing 12% of Kenya's total land area. The mean annual run-off is about 1294×10^3 with annual rainfall of 550 mm translating to 19 $m^3\ s^{-1}$ mean annual runoff for the whole basin [6, 7].

The Athi River originates and drains the southern slopes of Aberdare ranges and comprises the southern part of the country east of the Rift valley. It covers large parts of Kiambu, Nairobi, Machakos and Makueni Counties. The river flows through a country of basement complex rocks, the areas being mostly semi-arid and subject to long drought periods. Its tributaries from the highlands flow in deep valleys close together, almost forming a parallel drainage system.

The main tributaries are Ruiru and Ndarugu. Other minor tributaries but of great hydrological importance are Ngong, Nairobi, Mathare, Mbagathi, Riara and Gitathuru. Ngong, Nairobi and Mathare tributaries drain the upstream areas and traverse the Nairobi city and its environs. After being joined by its tributaries, the Athi River flows down steeply in a series of falls and rapids in a metamorphic formation. It goes down reducing in capacity due to underground seepage as a result of geological configuration; e.g. 95 $m^3\ s^{-1}$ above Kwaa, 65 $m^3\ s^{-1}$ at Kibwezi (161 km) downstream, 40 $m^3\ s^{-1}$ 70 miles (113 km) above the confluence of Tsavo (Republic of Kenya, [8]). Further down, it becomes reinforced by Tsavo River from Mt. Kilimanjaro and Mzima springs of the Chyulu hills which provide dry weather inflows after where it changes its name into Galana or Sabaki and flows in a series of meanders over sandy beds until it drains its waters to Indian Ocean north of Malindi as indicated in **Figure 1**.

The river carries with it an enormous volume of suspended sediments because of erosion and other human activities in its upstream reaches. The total amount of sediments discharged by the river into the Indian Ocean is estimated at 2,057,487 tonnes/year as indicated in **Table 1**. The heavy sediment loads discharged into the Ocean are responsible for the highly colored beaches of Malindi, which have changed totally to brownish therefore affecting the tourism industry by polluting

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Code	River	River Profile section	Suspended Load	
			Mean (ppm)	Annual (t yr.$^{-1}$)
3AA04	Mbagathi	Upper drainage area (Headwaters)	193	4,456
3BAA22	Nairobi		57	2,231
3BB10	Riara		118	1,474
3CB05	Ndarugu		202	29,356
BDA02	Athi (Twake Conf.)	Middle reaches	153	131,089
3F02	Athi (Tsavo)		549	753,627
3HA12	Athi (L.falls-mouth)	Lower reaches	859	2,057,487

Source: adapted from NWMP [9] report Vol. 1, Table 2.31 & [6]

Table 1.
Suspended load (t yr.$^{-1}$) and its volume of some selected streams in the Athi river drainage basin.

the sand beaches around Malindi town. The heavy sediment loads further adversely affect marine life by reducing light penetration and fishery. This in turn affects local fishing activities and livelihoods by reducing fish catches and sales, which the local communities relies on. Kithiia [7], Aketch and Olago [10] and Mavuti, [11], highlighted an increasing trend in water quality degradation within the basin. This complemented the findings of the present study.

4. Study basin characteristics

4.1 Water resources and water demands

A critical analysis of water resources in the basin indicates that water resources are affected by the different water use demands and their allocations. This indicates a close relationship between the available water resources against various water use activities, and how the water resources are allocated. This minimizes the possibility of water depletion and scarcity in the basin to enable a sustainable use of the water resources. Water resources in the Athi Catchment Area (ACA are mainly used for agricultural production (irrigation), domestic water supply, industrial uses and municipal uses in the several urban and municipal towns in the basin. The JICA [1] report summarized the available water resources as estimated in basin for year 2010 and projected for year 2030 as presented in **Table 2**.

The annual water demands estimated for the year 2010 and projected for 2030 in the basin are further summarized in **Table 3**. The projection given for 2030 followed the national development targets of Kenya Vision 2030 and socioeconomic framework [1], but without considering the available water resources.

The present study used ratios of available water resources and water demands and water deficits to show increasing water deficit trends due to increasing water demands in the basin. These are shown in **Tables 3** and **4** respectively. This will have far reaching implications on peoples' livelihoods as trends in decreasing water resources are likely to affect human activities such as irrigation activities and other water related production activities.

The present study notes that the water demands of 1,145 MCM/year in 2010 as presented in the JICA [1] report are equivalent to 76% of the available water resources (water stress ratio) as indicated in **Table 4**. This ratio far exceeds the severe water stress ratio of 40% indicating that the Athi catchment area is already

Year	Surface Water	Groundwater	Total
2010	1,198	305	1,503
2030	1,334	300	1,634
Ratio of 2030 to 2010	111%	98%	109%
Source: JICA Study Team [1].			

Table 2.
Estimated and projected annual available water resources (ACA) in the Athi river basin (unit: MCM/year).

Year	Water Demands (MCM/year)						
	Domestic	Industrial	Irrigation	Livestock	Wildlife	Fisheries	Total
2010	519	93	498	25	3	7	1,145
2030	941	153	3,418	59	3	12	4,586
Source: JICA Study Team [1].							

Table 3.
Estimated and projected water demands by sub-sector (ACA) in the study basin.

Description	2010	2030
Available Water Resources (MCM/year)	1,503	1,634
Water Demands (MCM/year)	1,145	4,586
% Water Demands/Available Water Resources	76%	281%
Water Deficits (MCM/year)	745	4,153
% Water Deficits/Water Demands	65%	91%
Source: JICA Study Team [1].		

Table 4.
Ratios of water demands/available water resources and water deficits/water demands (ACA).

experiencing severe water stress. The expected water stress ratio is projected to increase to 281% by 2030. The estimated water deficits of 745 MCM/year in 2010 are projected increase to 4,153 MCM/year by the year 2030 as indicated in **Table 4**. The study envisages that the water demands that can be covered by the available water resources are as presented in **Table 5** taking into account the allocated amounts of the surface water and groundwater to satisfy the 2030 water demands as given in the JICA [1] baseline report.

The present study notes that due limited water resources and to afford a viable irrigation system and sustainable food production in the basin and enhanced livelihoods, the projected target of new irrigation development area of 233,628 ha for 2030 need to be reduced to 46,108 ha based on the water resources allocation plan and used as the data base for the future water resources management plan of the Athi catchment area [1]. In general, the Athi basin is likely to experience enormous water shortages within the projected period. This scenario compounded with the increasing trends of water demands, intensive irrigation projects, competition in water uses and increasing water quality degradation means that proper water use strategies should be put in place to avert a looming danger of severe water scarcity in the basin. This is likely to have negative impacts on the people’s livelihood in the basin since majority relies on rain fed agriculture.

Subsector	Water Demand (2030)	Water Resources Allocation	
		Surface Water	Groundwater
Domestic	941	819	122
Industrial	153	77	76
Irrigation	917	*882	35
Livestock	59	59	0
Wildlife	3	3	0
Fisheries	12	12	0
Total	2,085	1,852	233

**Including water demand to be supplied by water resources of Tanzania of 154 MCM/year.*
Source: JICA Study Team [1].

Table 5.
Water resources allocation plan for water demands in 2030 after balance water study (ACA) (unit: MCM/year).

5. Study methodology

The present study employed both field data collection and secondary data sources to advance the researcher's opinion that due to the increased human activities and water quality degradation, the basin is likely going to experience severe water shortages and scarcity (hence affecting people's livelihoods).

Field and laboratory analysis and observations, standard empirical formulae for the determination of suspended sediment loads and discharge measurements were used to analyze the collected data. The used quantitative methods included principal component analysis, time series and chemical methods in determination of the water quality status.

Data on water quality and river discharge was necessary as well as the information on land use changes over time and space. This is relevant to the study since it is a factor associated with changes in river flow characteristics and quality degradation. Monthly data on river flow characteristics and water quality parameters were used, some of which were measured in the field during the period of investigation. Water sampling points indicated in **Figure 3** were used both for field samples and river gauging stations for secondary data.

The collected water samples were analyzed in the laboratory to quantify the sediment loads and the water quality deterioration changes along the river profiles. The total suspended sediments concentrations (TSSC) were determined on two replicate samples by gravimetric method according to Mcgrave [12] and Woodroffe [13]. The filtration was carried out by suction in which two vacuum flasks were run off one pump with open filter holders being mounted on each flask. After the determination of the water volume, sediment-water mixture was filtered through pre-weighed Whatman GF/C filters (4.7 cm wide, pore size 0.4 μm, thickness 260 μm) and kept in individually numbered aluminum packs. These were handled at the edges using flat-bladed tweezers. Following the filtration, the filtrates were washed with filtered distilled water and dried in oven at a temperature of 105°C for 24 hours. After removal from the oven, the filters were left to cool to room temperature for about 2 hours before they were reweighed using a sensitive electronic balance to the nearest 0.0001 g. Whatman GF/C filters of 47 mm diameter were used because they have a high flow rate and take a high sediment load [12]. Heavy metal analysis for mercury, chromium, cadmium, zinc, nickel, copper, iron,

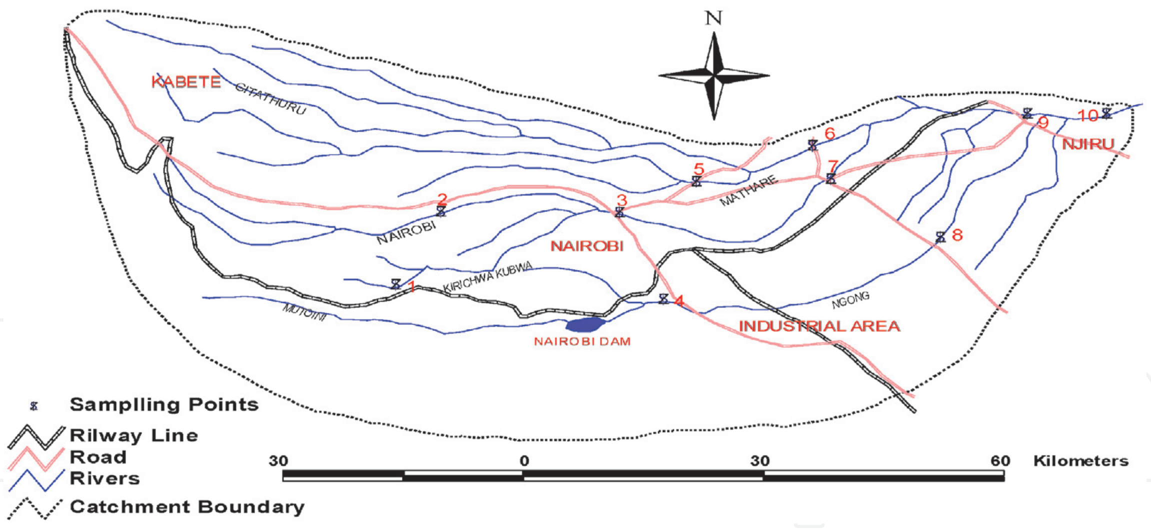

Figure 3.
Water sampling points in the Nairobi River sub-basin (upper Athi catchment basin).

manganese and fluoride was done to establish the concentration variations along the stream course distance-wise before and after the rivers pass through the city of Nairobi (urban/commercial areas) or part of its environs using the same method.

Water samples for water quality determination were collected in a depth integrated manner at the middle of the river. Each sample was taken according to the standard laboratory analysis and the concentration of each parameter determined. The basic method applied in the determination of each metallic cations was the Atomic absorption spectrometry (AAS). Measurement of other water quality parameters was done using standard laboratory methods and included BOD_5, COD, TSS, pH, Total Alkalinity, Total dissolved solids, Conductivity, Calcium, Magnesium, Sodium, Potassium, Chloride, Fluoride, Total hardness and Turbidity.

BOD_5 was determined over 5 days for biochemical oxidation of organic substances at 20°C. The detection limit was set at about 5 mg l^{-1} and the same was done for the chemical oxygen demand (COD). The total dissolved solids (TDS) concentration was done through evaporating the water sample on a previously weighed dish and the residue dried at 180°C and then weighed again to allow for the concentration to be determined while suspended solids (SS) were determined by filtration of a well mixed sample on a standard glass-fiber filter disk (0.45 mm filter; detection limit SS ≤5 mg l^{-1}). Fluoride was determined by titration of the water sample with a standard Thorium nitrate in a solution buffered at about 2.9–3.3, using sodium alizarin sulphonate as indicator. Volumetric analysis or otherwise filtration method was used in the analysis of most of the other water quality parameters since it is usually more rapid than the gravimetric analysis if the filtrate reagent is specific for the water quality constituent. The sensitivity and/or precision may also exceed that of a gravimetric analysis for some determinants. It was widely used in the present study for the analysis of water quality parameters as pH, total hardness, and alkalinity according to Mancy [14]. Their results were used to group the parameters into three main categories; chemical, biological and physical related water pollution parameters. In addition, their magnitude values (concentrations) were used to infer on whether there was water quality deterioration or not.

6. Sediment measurement

Water samples for suspended sediment analysis were collected at the middle and both sides of the river banks using USDH48 sampler. At each point, a depth integrated (equal transit rate) water-sediment mixture samples were taken. The samples were stored in a 3 liters sample bottle and taken to the laboratory for suspended sediment concentration determination according to American Public Health Association [15–17] techniques and methods. Sediment discharge (mg l^{-1}) at the cross-section was computed by multiplying suspended sediment concentration (mg l^{-1}) with the river discharge $m^3\ s^{-1}$), and the correction factor of 0.0864 [18]. The total sediment yield in tonnes for the days (n) sampled was computed according to Jorgensen and Vollenweider, [19] and Sharma [18] as:

$$S = 0.0864 \sum_{i=1}^{n} C_i\, Q_r \tag{1}$$

Where:

S is the sediment yield in t day^{-1}, C_i is the measured suspended sediment concentration in mg l^{-1} and Q_r is the cross sectional river flow in $m^3\ s^{-1}$. This procedure was used to calculate the sediment yields and mass loadings in the sub-basins investigated and as means for sediment loading downstream the river profile.

7. Results and discussions

This sections details the results of the field data observations and the laboratory analysis on the water sampled collected. It was intended to give an overall picture of the water quality status against the available water resources, human activities and land use changes in the basin.

The results in **Table 6** and **Figure 4** clearly indicate a close link between river flow characteristics and rainfall patterns within the basin and the entire catchment area. The high flows were noted to occur in the months of April–May and replicated in the months of October to December corresponding quite well to the rainfall patterns in the basin.

From **Table 7**, it can be observed that downstream the river profiles, the amount of total sediment load increases. The exception only occurs at Njiru 2 sampling point, which is the outlet of all the three streams investigated where the value of TSS was calculated to the value of 5166.23 t $year^{-1}$. This was attributed to widening of the river channel, sedimentation and dilution effects, which may have resulted to the deposition of the sediment loads and combined stream discharge increase from the three streams at this point.

Sub-basin River	Mean monthly river flows per sub-basin in $m^3\ s^{-1}$ within the upper catchment area											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Nairobi	1.3	0.6	1.6	2.8	2.7	3.6	1.7	0.8	0.7	1.9	5.8	2.9
Ngong	0.2	0.4	0.6	0.8	1.0	1.4	0.7	1.3	0.8	0.5	1.2	0.3
Mathare	1.0	0.2	0.9	1.0	1.1	0.8	—	—	2.1	0.9	2.3	1.8

Source: field data (1998–2017).

Table 6.
Measured mean monthly river discharge sub-basin^{-1}.

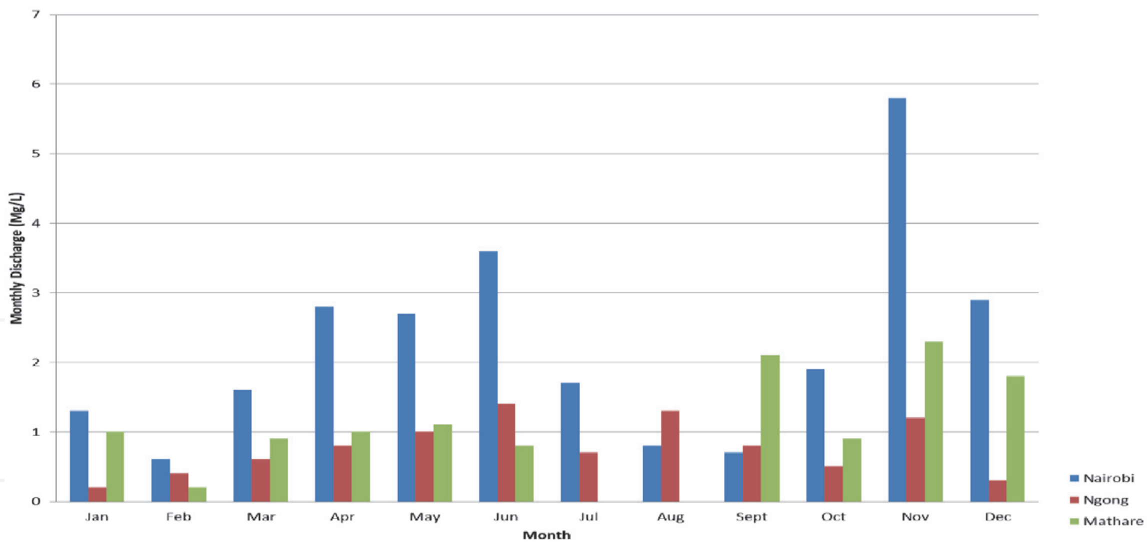

Figure 4.
Mean monthly river discharge per sub-basin in the upper sub-basins (m^3/s). Source: filed data (1998–2017).

Sampling Stations	Station Number	Main river	TSS Values ($t\ year^{-1}$)
Langata rd Bridge	4	Ngong	189
Embakasi rd Bridge	8		1853
Thika rd Bridge	5	Mathare	1295
Outering rd Bridge	6		3167
Muthangari	2	Nairobi	989
Museum	3		1855
Outering road	7		6618
Njiru 1 after Mathare Confluence	9		14720
Njiru 2 All streams joined	10		5271
Source: field data (1998–2017).			

Table 7.
Mass loadings of total suspended sediments (TSS) in the Nairobi river sub-basins in tonnes per year.

8. Impacts of land use activities on river hydrology

Land use changes in the upper catchment areas through the city to the lower areas were observed as the causes of water quality degradation [6, 20]. This is further attributed to increased storm water, reduced infiltration rates and hence flooding in the urban areas.

Poor land use and management impacts on the hydrology of the catchment resulted to surface run-off increases which then determined the increased discharge of the rivers. In the sub-basins investigated and downstream the Athi River Catchment area, physical water quality parameters increased with discharge downstream the river courses while metallic ions decreased or increased depending on river sub-basin as shown in **Table 8**.

The study noted a general trend of increase in total suspended sediments with increase in river volume (discharge) and consequently more pronounced water turbidity. The reverse, it may be attributed to river widening in channel size and more settling or deposition of the sediments. In addition, the study noted that away

Sampling point	River	Mean Concentrations				
		Q ($m^3 s^{-1}$)	TSS ($mg l^{-1}$)	COND (μcm^{-1})	TDS $mg l^{-1}$)	TUR (N.T.U.)
Muthangari	Nairobi	0.772	157.6	392.1	239.7	69.4
Museum	Nairobi	1.376	129.4	397.7	244.2	69.3
Outering Rd.	Nairobi	2.140	255.7	564.5	290.9	65.5
Njiru 1	Nairobi	5.083	199.2	509.5	310.9	67.8
Njiru 2 (10)	Nairobi	5.341	95.5	474.8	298.8	28.5
Thika Rd.	Mathare	0.738	161	352.2	215.5	35
Outering Rd.	Mathare	1.371	251.2	527.1	349.9	85
Kibera slums	Ngong	0.110	164	233	88	98
Langata Rd.	Ngong	0.305	59	598.8	59	42
Embakasi	Ngong	0.949	180	611.7	174.4	71

Source: field data (1998–2017); COND-Electric conductivity, TDS-Total dissolved solids, TSS-Total suspended sediments, TUR-Turbidity.

Table 8.
Mean measured values of physical water quality parameters at various sampling points.

from the main land use activities, water in the streams was found to be less polluted both physically and chemically. This implies much of water quality degradation in the upper catchment areas was attributed to changes in land use activities.

9. Present water supply situation of in the Athi River catchment area (ACA)

Data from the KNBS [2] indicates that the population of ACA in 2010 stood at 9.79 million including an urban population of 6.51 million and a rural population of 3.28 million. This population is concentrated in both Nairobi area and Mombasa area, which are the major metropolitan areas in the basin. A study by the JICA team [1] and adopted by this present study estimated the current situation of water connection and supply of ACA as shown **Table 9**.

Table 9 clearly indicates that 24% of the population in the basin gets water from unregistered water vendors, streams, lakes and ponds without proper treatment, which are designated as an unimproved drinking water sources. Around 22% of the population gets water from springs, wells or boreholes, which are considered safe for water supply. A considerable proportion of the population (54%) is supplied with water by water service providers through pipes indicating a good trend in

Type	Piped by WSPs	Spring/Well/ Borehole	Water Vendor	Stream/Lake/Pond/ Others
Urban Population	63%	17%	17%	3%
Rural Population	28%	34%	3%	35%
Total Population	54%	22%	13%	11%

Source: JICA Study Team based on Census 2009 data [1].

Table 9.
Current situation of water connection (ACA).

water provision in the basin. However, with a projected urban population of 11.22 million and decrease of rural population by 0.47 million as a result of rural–urban migration in search of better living conditions and employment, water provision and supply remain a big challenge.

The urban population in the basin is well served with piped water representing 63% and this ratio is the highest in all six catchment areas. The implication of this is that the catchment requires implementing a large-scale urban water supply system development to cope with the urban population increase of 1.08 million and achieve the target coverage ratio of 100% as envisaged in the JICA study team report. It also calls for a proactive water resources development strategy that includes investments in water harvesting and conservation of water catchment areas through re-afforestation programmes.

10. Water resources development strategy

The ACA is divided into three areas in terms of water supply zones, such as Nairobi surrounding area, Mombasa surrounding area and other area for urban water supply systems (UWSS) considering the characteristics of the three areas. The present study, which is in line with the JICA report, noted that in overall Urban Water Supply Systems (UWSS) are planned for 32 Urban Centres (UCs) within the basin. Out of the 32 UCs, 16 are planned for Nairobi and satellite towns and nine UCs in Mombasa and coastal surrounding area while one water supply system is planned to cover several UCs.

The projected water supply capacity required for UWSS in ACA in 2030 is 2,260,000 m^3/day against the current water supply capacity (including capacity under construction) of 699,000 m^3/day. This implies that, additional capacity of 1,560,000 m^3/day need to be developed by 2030. This is proposed to be undertaken through the following three types of projects as recommended in the JICA [1] report.

a. Rehabilitation of existing UWSS: This is to be achieved by installing water meters in all households and replacement of old pipes of existing UWSS of the 30 UCs. In addition, the rehabilitation shall include repair and replacement of mechanical and electrical equipment in water treatment plants and pumping stations.

b. Expansion of UWSS: The projected total planned capacity of expansion is 1,542,000 m^3/day in 28 UCs out of the above 29 UCs to meet the water demand in 2030.

c. Construction of new UWSS: The total capacity of new construction is estimated at 19,000 m^3/day.

d. There are 31 plans of urban water supply development projects to cover 21 UCs and surrounding areas in ACA with an estimated 1,215,000 m^3/day of total water supply capacity. This is planned to augment urban water supply systems in the basin.

e. Proposed Water Supply Development Plan.

The development strategy of water resources in ACA for the proposed UWSS is presented in **Table 10**, while those proposed for LSRWSS and SSRWSS are in

Type of Project		Target Area	Total Capacity (m^3/day)	Service Population (million persons)
Urban Water Supply	Rehabilitation	30 UCs	699,000	17.01
	Expansion	29 UCs	1,542,000	
	New Construction	2 UCs	19,000	
	Total	32 UC	2,260,000	
Rural Water Supply	LSRWSS	10 Counties	209,000	4.04
	SSRWSS	10 Counties	110,000	
	Total	10 Counties	319,000	

Note: The water supply development plan of ACA includes Thika with 0.51 million population in 2030. Thika is located in TCA, but it has been covered by water supply system in ACA. LSRWSS- Large Scale Rural Water Supply System and SSRWSS- Small Scale Rural Water Supply System.
Source: JICA Study Team [1].

Table 10.
Proposed water supply development plan (ACA).

Items		Urban Water Supply	Large-scale Rural Water Supply	Small-scale Rural Water Supply	Total
Service Population (million)	2010	5.29		2.15	7.44
	2030	17.01	2.04	2.00	21.05
Water Supply Capacity (m^3/day)	2010	699,000	100,000	108,000	907,000
	2030	2,260,000	209,000	110,000	2,579,000
Operating Body		Registered WSPs	Registered WSPs	Individual, Community, etc.	—
Target Towns/ Areas		32 UCs	10 Counties		—

Source: JICA Study Team [1].

Table 11.
Water supply situation in 2030 (ACA).

Table 11. This further demonstrates the situation of urban centers subject to urban water supply system development.

The proposed water supply development plan for ACA is outlined **Table 10**.

It is anticipated that by using the water supply development plan indicated in **Table 10**, the water supply situation of ACA in 2030 will be improved as shown in **Table 11**.

The present study proposes the construction of the eight and five dams within the ACA and TCA respectively as noted in the JICA report [1]. This coupled with the expansion of the inter-basin transfer system from the Tana River Catchment Area (TCA) will ensure adequate water supply to both Nairobi city and its environs will be met.

Three new dams in ACA and expansion of two existing intra-basin water transfer systems are envisaged to increase water supply systems in Mombasa city and the coastal area. More dams are further proposed to cover other areas within the Athi River catchment area (ACA). These efforts are likely to increase land under irrigation within the basin and further help in the improvement people's livelihoods in the basin.

11. Current situation of water resources development

The Athi River basin with a total area of 58,639 km^2 receives an annual rainfall of 810 mm, which is categorized between rather high rainfall of around 1,300–1,400 mm in LVNCA and LVSCA and low rainfall of around 500 mm in RVCA and ENNCA. Rainfall amounts differs spatially within the basin ranging from 500 mm in the southern part near the border with Tanzania to about 1,200 mm in the western part of the country.

As of 2010, the estimated water resources in the basin were to the tune of 1,198 MCM/year for surface water and 333 MCM/year for groundwater while the water resources estimated for 2030 stands at 1,334 MCM/year considering the effect of climate change, while the available groundwater resources is 303 MCM/year which is almost same as the amount of 2010.

On the other hand, water demands in the basin is estimated to be 1,145 MCM/year, which consist mainly of domestic water demands for the population of 9.79 million and irrigation water demands for the irrigation area of 44,898 ha. Most of the population is concentrated in and around Nairobi and Mombasa cities and its area along the coastal belt. This implies that there are increased water demands in these urban centres. The study noted that the existing water resource structures/facilities would not be able to satisfy the greatly increased 2030 water demand because of the uneven distribution of water resources both spatially and temporally. Therefore, new water resources structures/facilities are required to be developed.

More attention needs to be paid to the domestic water supply in Nairobi and satellite towns, and also in Mombasa and coastal areas where future domestic water demands will increase drastically, but the available water resources are limited.

The Strategies for the water resources development in Athi River basin should formulate a well-balanced development plan between water resources and demands, based on the current situation of the catchment area and future water demands. Theses should include:

a. Development and expansion of inter-basin water transfer facilities

b. Construction of both large and small scale dams to augment the existing water sources in the basin

c. Exploration and drilling of boreholes in the basin

d. Investing in rural water harvesting facilities to reduce the pressure on the existing water supply systems and to ensure sustainable water supply in the basin.

12. Water resources use implications in the Athi River basin

This paper has attempted to broadly analyze the available water resources within the Athi River catchment Area (ACA) highlighting the problems associated with water resources use and demands against availability, potential water uses and proposed projects in the basin, strategies to address the scarcity of water in the basin, water pollution trends and their implications on water resources in the basin. An attempt to assess the hydrology of the basin was also performed to give an overview of the present and the projected water use demands and use trends in the catchment area. Evidence of the declining trends in water availability against the various uses was demonstrated in the paper. The results presented in this paper emphasize that improved water supply systems and the expansion of the existing water sources will reduce the pressure on the existing water resources from various water users in the basin. Overall, this is likely to improve and augment the available water and reduce conflicts and further improve on people's livelihoods.

13. Conclusion

The paper concludes that the Athi River Catchment Area (ACA) is endowed with enormous water resources but which is mal-distributed in both space and time. The basin is home to the two major urban centres in Kenya; Nairobi and Mombasa which have seen an increasing demand on water resources as a result of increasing rural–urban migration of the population in search of employment opportunities. The water resources in the basin are faced with increasing water pollution and quality degradation from the various human activities, which affects the various uses of the water. The water resources are being used for irrigation purposes in the lower reaches of the river and industrial and commercial purposes in the upper reaches. These activities generate pollutants that pollute the water and hence reducing its usefulness and in turn affecting the people's livelihoods. The paper notes that efforts by both the national and county government are likely to increase the water supply by investing in water storage structures to augment the water resources in the basin. More irrigation land is also earmarked for expansion implying more opportunities for the residents and enhancing their livelihoods through growing of more value chain crops under irrigation systems.

The paper recommends more investments on water resources structures for rain water harvesting, reducing and monitoring of waste water discharges onto the present water sources. The county governments within the basin should be encouraged to invest in small scale water supply systems such as earth dams and shallow wells. More emphasis of environmental education on the conservation of water resources through new technologies for irrigation projects as well as manufacturing industries to avoid discharging of industrial effluents into the river system. Continuous water quality should be encouraged to ensure the water resources in the basin are not polluted and when harvested are not health hazards. Better land use systems in the headwater areas should be encouraged to avoid generation of sediments by erosion process. This in the overall will help in the sustainability of the water resources in the basin and enhance increased opportunities for the residents and improved livelihoods.

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