WATER RESOURCES AUTHORITY

WATER RESOURCES SITUATION REPORT

AUGUST 2019

July 2018 to June 2019

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Abbreviations and Acronyms

ACA	Athi Catchment Area
ACFC	Agro Chemical Food Company
ASAL	Arid and Semi-Arid Land
ASDS	Agriculture Sector Development Strategy
BOD	Biochemical Oxygen Demand
CETRAD	Centre for Training and Integrated Research in ASAL Development
ENNCA	Ewaso Ng'iro North Catchment Area
ENNCA	Ewaso Ng'iro North Catchment Area
GAWASCO	Garissa Water and Sanitation Company
IMU	Intra Management Unit
ITCZ	Inter Tropical Convergence Zone
IWASCO	Isiolo Water and Sanitation Company
KENSOTER	Kenya Soil Terrain
KWSCRP	Kenya Water Security and Climate Resilience Project
LVNCA	Lake Victoria North Catchment Area
LVSCA	Lake Victoria South Catchment Area
MAM	March-April-May
MCM	Million Cubic Meters
MODIS	Moderate Resolution Imaging Spectroradiometer
MU	Management Unit
NAWASCO	Nanyuki Water and Sanitation Company
NDVI	Normalized Difference Vegetative Index
OND	October-November-December
RGS	Regular Gauging Station
RUSLE	Revised Universal Soilloss Equation
RVBA	Rift Valley Basin Area
RVCA	Rift Valley Catchment Area
TBA	Tana Basin Area
TCA	Tana Catchment Area
TDS	Total Dissolved Solids
TP	Total Phosphorus
TSS	Total Suspended Solids
UPOPs	Unintended Persistent Organic Pollutants

WRA	Water Resources Authority
WRUA	Water Resource Users Association

Foreword

Kenya is categorized both as a water scarce and a water stressed country making it a very highly contested commodity by the growing population. This poses a big challenge in the management of this finite resource. The challenges are associated with water resources data collection and information generation, water scarcity and variability, water pollution, poor/lack of enforcement of water laws, catchment degradation and climate change impacts. The magnitude of the issues, challenges and the severity of the water crisis that face Kenya cut across most sectors of the economy; hence, making water resources management of high priority.

The management of the water resources is a multi-sectoral affair, with very many players being involved and therefore its management is key. Water resource is an enabler and a driving force to achieving a stable economy and more so the current Government Big 4 Agenda. Its availability both in good quality and quantity is of global importance. In Kenya, there are six water catchment areas endowed with water resources. The available water and the demands vary significantly across the drainage basins with the total demand projected to rise to 21,468MCM/year in the year 2030 against available 26,634MCM/year.

One of the key mandates of Water Resource Authority (WRA) is the regulation of water use to ensure fair and equitable allocation and apportionment of the available water resources. To effectively carry out this mandate, WRA determines the supply in respect to surface and ground water quantity and quality so as to attain efficient and economic use, social equity and environmental sustainability. In addition to water allocation and apportionment, WRA also monitors and assesses water resources, gathers and publishes information on water resources, receives and determines application for water permits and collects water use charges.

The water resource situation status in Kenya for the period July 2018 to June 2019 has been analysed based on surface water and ground water quantity, quality and allocation and flood/drought events. This report therefore presents the status of Kenya's water resources between July 2018 and June 2019. Though the hydrological year for Kenya runs through January to December, the report considers the Financial year calendar in the analysis.

1 INTRODUCTION

1.1 Background Information

Globally, the human population depends heavily on water resources, not only as a drinking water but also for crops, agriculture, livestock, fishing, industries and other uses. For example, wetland grasses are used to feed and keep livestock. Kenya, as a country has a total land area of ~582,646km^2 of which 97% of it is land while 3% is water. Approximately 490,000 km^2 of the land area is the arid and semi-arid land (ASAL) while the remaining area of about 81,000 km^2 represent the non-arid and profitably usable lands, sustaining a substantial portion of Kenyan economy and human population.

Kenya's population is estimated at ~47.8 million people in 2018 with reference to the latest census figures and the figures are expected to escalate to over 52 million by 2030. According to trading economics, Kenya's population represents 0.6% of the world's total population which arguably shows that one person in every 168 people is a Kenyan resident. These figures clearly indicate that Kenya's population is expanding steadily, and this paints the picture of the socio-economic and political situation in the country, which are important factors in understanding the Kenya's environmental situation. Agriculture being the backbone of the Kenyan economy, contributes 1/3 of the GDP and therefore a large portion of Kenya's water resources is used.

The availability of water is often a key factor in determining the patterns of human settlements and socio-economic development. Within the Arid and Semi-Arid Lands, there is a critical limitation on water resources endowment. The limited endowment of water resources places an added financial burden on the Kenyan population compared with other countries. This is compounded by the impacts of extreme weather events including floods and droughts which are frequent. For instance, in the year 2019, the long rains expected to start in the month of March delayed only to be realised in April and on average the amount was lower than the annual mean. This and many other factors including poor infrastructure, deforestation, settlement and urbanization and pollution of water quality put a lot of pressure on the available finite water resources in such a developing country.

The magnitude of the issues, challenges and the severity of the water crisis that face Kenya cut across most sectors of the economy; hence, making water resources management of high priority. The challenges are associated with water resources data collection and information generation; water scarcity and variability; water pollution; enforcement of water laws; catchment degradation; and climate change impacts; weak governance and corruption, unemployment and under-employment and many more.

Water resources is an enabler to achieving a stable economy when well managed in such a diversified country.

Kenya's climate is influenced by three major factors including temperature, rainfall and humidity all of which depend on altitude. Although the coastal strip and the area along the shores of Lake Victoria are exceptional in that they experience hot periods with high rainfall and humidity. A relatively wet and narrow tropical belt lies along the Indian Ocean coast. Behind the coastline stretches large areas of semi-arid and arid lands. The rainfall in Kenya is affected by large water bodies like Lake Victoria, complex topography with the Great Rift Valley and high mountains like Mt. Kenya and Mt. Elgon. Kenya generally experiences two seasonal rainfall peaks of long rain (March – May) and short rains (October - December). Mean annual rainfall over the country is 680 mm. It varies from about 200 mm in the ASAL zones to about 1,800 mm in the humid zones.

Kenya has five major basins namely, Lake Victoria, Rift valley, Athi, Tana and Ewes Ng'iro North. The largest is Ewes Ng'iro North with a drainage area of 210,223km^2, i.e. 25% of Kenya, followed by Rift Valley with a drainage area of 130,452km^2. Tana, Athi and Lake Victoria basins constitute 126,026km^2, 58,639km^2 and 31,734 km^2 respectively. The available surface and ground water yields are shown in Table 1-1 while presents the water demand in Kenya estimated for the years 2010, 2030 and 2050. The total water demand in 2010 was 3,218 MCM/year against available 22,564 MCM/year. The demand will rise to 21,468 MCM/year in the year 2030 against available 26,634 MCM/year.

Water resources availability determines the patterns of human settlements and socio-economic development. The available water resources in all the basins in Kenya have been assessed in the National Water Master Plan 2030. Table 1.1 gives the projected water resources for the years 2010, 2030 and 2050. The increase in available water resources in the six basins is attributed to the projected increased rainfall due to impacts of climate change.

1.2 Overview

Kenya depends on both surface water and groundwater. But in the recent past, over-reliance on surface water is growing steadily. Surface water is the backbone of big projects such as hydro-electric power generation, major irrigation schemes and water supplies. Examples are the 7 forks hydropower schemes in the Tana River basin, Bura, Mwea, Kano and Perkerra irrigation schemes supply major cities (Nairobi, Mombasa and Kisumu) and other Urban and Rural Water Supplies such as Eldoret, Nakuru, Nyeri and Embu.

Ground water resources also play a key role in development of domestic, agricultural, industrial, municipal and rural settlements. It is a major source of water for Mombasa, Nakuru and Nairobi. Most of the drinking water supplies especially in the rural arid areas are sourced from groundwater systems.

The quality of both surface water and ground water resources for different uses is highly dependent on the physical and chemical composition. Point and non-point water pollution is a key challenge in ensuring accessibility of safe water resources in Kenya. Therefore, to sustain the growing demands, the quality of the water through pollution control is vital and eradication of vices such as catchment degradation and encroachment of riparian land areas besides climate change. Also, equitable allocation and efficient use of these water resources is vital to ensure maintenance of the environmental flows on all the river systems.

Water Resources Authority (WRA) has an obligation to ensure equitable access to water in the right quality and quantity for the production, environment and basic human needs. This is achieved through water allocation planning, catchment rehabilitation programs done in partnership with WRUAs though the implementation of Sub- Catchment Management Plans and effluent discharge control plans.

Table 1-1:Available Water Resources by basins (Units in MCM/yr.)

Catchment Area	**Area (sq.km)**	**2010**	**2030**	**2050**
LVNCA	18374	4742	5077	5595
LVSCA	31734	4976	5937	7195
RVCA	130452	2559	3147	3903
ACA	58639	1503	1634	2043
TCA	126026	6533	7828	7891
ENNCA	210226	2251	3011	1810
Total	575451	22564	26634	28437

Source: *National Water Master Plan (NWMP 2030)*

Table 1-2:Water Demand per Region (Units in MCM/yr.)

Catchment Area	**Area (sq.km)**	**2010**	**2030**	**2050**
LVNCA	18374	228	1337	1573

LVSCA	31734	385	2953	3251
RVCA	130452	357	1494	1689
ACA	58639	1145	4586	5202
TCA	126026	891	8241	8476
ENNCA	210226	212	2857	2950
Total	575451	3218	21468	23141

***Source**: National Water Master Plan (NWMP 2030)*

1.3 This Report

Water resources situation report is one of the reporting tools on information gathered on the water resources situation which is done after the lapse of every quarter culminating into an annual water resources situation report at the end of each financial year. The report together with other reports facilitates the tracking of the achievements realized in executing the Authority's functions anchored towards water resources regulation which can in turn be used in national water resources policy formulation. This water resources situation report therefore serves to satisfy a legal requirement as well as tracking the progress made in water resources regulation in general with an emphasis on water quality.

The functions of the Authority as provided in Water Act 2016 are to regulate the management and use of water resources 12(b) and provide information and advice to the Cabinet Secretary on formulation of policy on national water resources management, water storage and flood control strategies among others.

This report presents the water situation in the six catchment areas for the period of July 2018 - June 2019. It presents the rainfall, water levels, groundwater rest levels, water quality, water use as well as river flow regimes for the hydrologic year. The report comprises of the introduction, which gives background information of the country's socio-economic, political and environmental situation with respect to the water resources and its management. Other chapters include surface water resources and flood situation, groundwater resources, water use and the water quality situation.

Chapter 2 and 3 discusses climate and water resources respectively detailing the monitoring network, an overview of the improvements done and a detailed analysis of climate trends and flow regimes. It also gives highlights on climate situation, ranging from rainfall, evaporation and weather trends and the situation of floods in the country for the past one year. Chapter 5 discusses surface water quality with emphasis on the monitoring network, improvements to the network infrastructure and data quality and the assessments of the water quality. Chapter 7 and 8 discussion is on geology and hydro-geological settings, groundwater occurrence and hydro-geology, groundwater quality and major challenges and the dynamic decline of groundwater levels. Chapter 10 gives highlights on water use and permits for surface water and groundwater. Finally, the emerging trends, captioned under the challenges, conclusions and the recommendations.

1.4 Data Availability

The Authority collects all information on water resources, analyses, stores and disseminates it. This information is critical for water allocation, water resources investment decision making and modeling to enact scenarios to better understand the impact of climate change in future. The water resource data comprise of Water Quality data, Surface Water data and Ground Water data. The data sets are collected and digitized at the sub-regional offices and transmitted to the Regional offices for storage. Thereafter, the data is sent to a centralized, national database domiciled at the WRA Headquarters in Nairobi. The National database aggregates backups from the regional data bases.

The WRA hydrological year book provides information on available data in WRA data base for each monitoring station and can be viewed in the Water Resources Authority website; www.wra.go.ke. Over the years, Mike Basin has been utilized as the core Water Resources Information System. It is anticipated that MIKE INFO, which is currently being rolled out will assume and enhance administration, analysis and management of data in WRA. Figure 1.1 shows the number of operational stations countrywide during the period 2018/2019 according to data type.

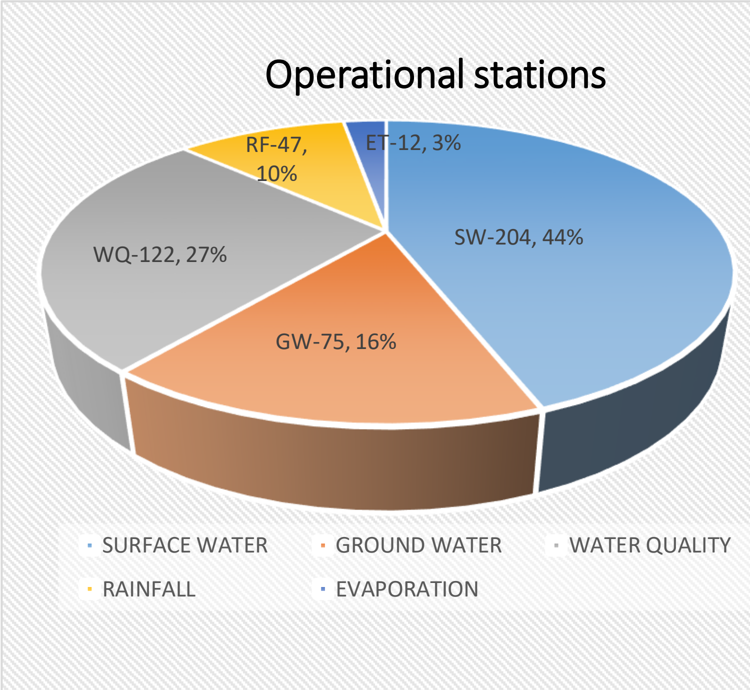


Figure 1.1:Number of operational stations countrywide during the period 2018/2019 according to data type.

Table 1-3:The summary of the data types, no. of operational stations, percentage of submitted data and frequency of update

Type of Data	No. of Operational Stations	% of data submitted based on operational stations	Frequency of Update
SW	204	56	Monthly
GW	61	34	Monthly
WQ	36	45	Monthly
RF	47	77	Monthly
EV	12	68	Monthly

Table 1-4:The summary of the regions, data types, data gaps, percentage of data submitted and frequency of updates.

Region	**Operational stations**					**% of data submitted to Database**					**Frequency of update**				
	SW	GW	WQ	RF	EV	SW	GW	WQ	RF	EV	SW	GW	WQ	RF	EV
LVNCA	36	21	Nil	3	1	59	44	Nil	78	100	M	M	Nil	M	M
LVSCA	18	3	Nil	Nil	7	35	8	Nil	Nil	44	M	Nil	Nil	Nil	M
RVCA	65	20	21	11	Nil	35	38	36	92	Nil	M	M	M		Nil
ACA	31	17	15	25	4	63	47	54	78	92	M	M	M	M	M
TCA	22	10	51	5	Nil	66	43	19	43	Nil	M	Nil	Nil		Nil
ENNCA	32	4	35	6	Nil	76	67	21	94	Nil	M	Nil	Nil	M	Nil
Total	204	75	122	47	12	56	34	45	77	68					

2 CLIMATE

2.1 Description of Monitoring Network

Water Resources Authority operates a weather monitoring network comprising of rainfall, evaporation and climate stations. During the year under review, 125 out of 272 rainfall stations were operational, 46 out of 65 evaporation stations were operational and 16 out of 34 climate stations were operational. The regional breakdown is given in the Table 2-1.

LVSCA has a total of 79 hydro-met stations out of which 52 stations are working. At the various stations manual rain gauges, class A evaporation pans, logging rain gauges and automatic weather stations have been installed to collect daily and hourly data. The number and type of stations and operation status are shown in Table 2-1. ENNCA has a total of 39 hydromet stations although only 15 are currently operational. Six stations are currently installed with Automatic Weather Stations (Marsabit, Gataragwa, Rumuruti, Kangeta, Naromoru and Ol Maisor) which records rainfall, air temperature, evapo-transpiration, relative humidity, barometric pressure, solar radiation, wind speed and wind rose at hourly intervals. But only Rumuruti station is submitting data. The others consist of manual rain gauges read in the morning (8.30 am) and Rumuruti MoW and Lamuria MoW are manual full met stations read at 8.30 am and 3.00 pm daily with records of records rainfall, evaporation, air temperature and wind speed.

RVCA region has a total of 34 hydro-met stations, out of which 29 stations are working. South Rift has 6 rainfall stations, 2 evaporation stations and 2 climatic stations, Lakes Naivasha/Nakuru and Lakes Baringo/Bogoria has 8 rainfall stations, 1 evaporation station and no climatic stations, Upper Turkwel has 3 rainfall stations, 1 evaporation stations and 1 climatic station while Lower Turkwel has 2 rainfall stations, 2 evaporation stations and 4 climatic stations. TCA region has 68 hydro-met stations out of which 41 stations are operational during the period under review. The rainfall stations in the region operated well and the data received was input into the database. All stations require to be upgraded by automating for effective acquisition of data. ACA has a total of 59 hydro-met stations out of which 33 stations are operational while LVNCA has a total of 87 stations out which 34 stations are operational. Most of the stations are not functional due to vandalism and lack of regular maintenance.

Table 2-1: Description of weather monitoring network

	Rainfall	No. Operational	Evaporation	No. Operational	Climate	No. Operational	
ACA	47	28	10	5	2	0	**59**
ENNCA	26	11	4	2	9	2	**39**
LVNCA	72	30	10	3	5	0	**87**
LVSCA	47	20	20	20	12	10	**79**
RVCA	23	20	44	5	4	4	**34**
TCA	52	30	14	11	2	0	**68**
Total	**278**	**125**	**65**	**46**	**34**	**16**	**377**

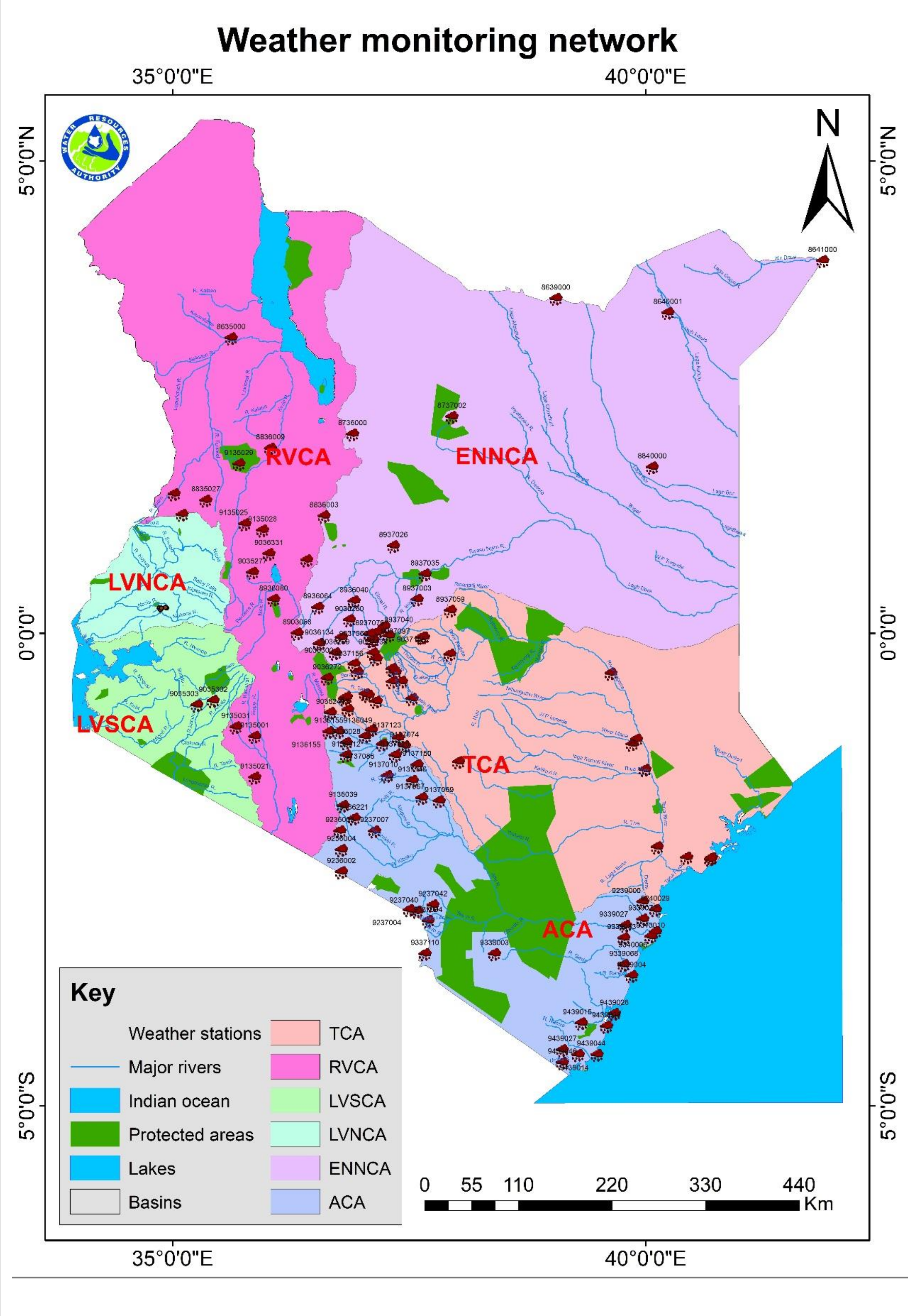


Figure 2.1:Rainfall monitoring network and Kenyan water catchments

2.2 Improvements to the Network

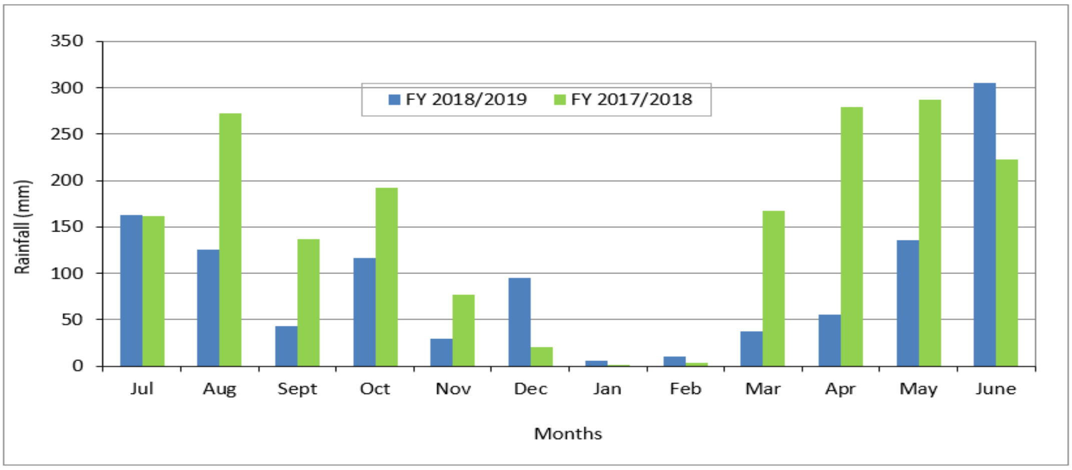
For the LVSCA, LVNCA and ENNCA, no met station station was rehabilitated during the 2018/2019 hydrologic year. However, ENNCA entered into an agreement with Cetrad to obtain a link into their 6 No. Telemetric weather stations. Currently the office is able to get real time data from these stations (Nyanbene, Naromuro, Nyahururu, Wamba, Kangeta and Marsabit). At RVCA, Lodwar sub met-86350001 was assessed and rehabilitated. For TCA, 3 No. weather stations were assessed and rehabilitated. They include; Sagana state lodge met station 9036017, Mwingi Water office Hydro Met station 168 and MWO-Murang'a 9036017. Figure 2.2 shows Murang'a met station before and after installation.

Figure 2.2: Murang'a Met station before and after installation

2.2 Analysis of Rainfall, Evaporation & Climate

2.2.1 Lake Victoria North Catchment area

Lake Victoria North Catchment Area receives bimodal rainfall pattern with long rain season experienced between March and May while short rains come between September and November. The driest months are December, January and February. The amount of rainfall received during the period July 2018 to June 2019. The analysis was based on two rainfall stations including Kitale DWO-WD659 and Kwangamor KMD-8934169. For Kitale, in general the station experienced lower rainfall amounts in the FY 2017/2018 than FY2018/2019. In both cases January and February recorded the lowest rainfall amounts. For Kwangamor KMD, during the FY 2017/2018 high amount of rainfall compared with FY 2018/2019 was experienced. In the FY 2017/2018, the months of August, April and May received the highest amounts of rainfall which was not the same in the FY 2018/2019. In both years, January and February received the least amount of rainfall.



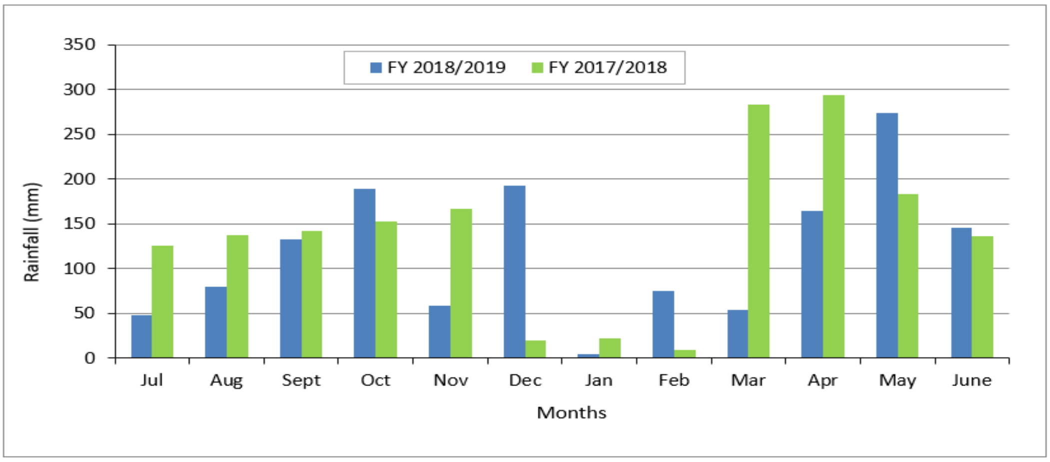


Figure 2.5: Rainfall trends at LVNCA between 2017/2018 and 2018/2019 for Kitale and Kwangamor Stations.

2.2.2 **Lake Victoria South Catchment area**

For LVSCA, the long term analysis of rainfall in the catchment was represented by the following stations; Maseno Vet, Ahero, Olenguruone and Bomet w/s. Maseno Vet and Ahero represent areas around the lake and the western half of the catchment, Olenguruone represents the eastern half of the catchment and Bomet w/s represents South Eastern side of the Catchment. The stations were chosen based on the availability of data both for long term and for this financial year. The rainfall received in Maseno from July 2017 to June 2018 was about 2920mm, Kipkelion water supply had about 1608 mm from July 2017 to May 2018. The dry months of the year in the long term are December to February while March to

June was wettest period. For the Year to long term comparison the year was generally relatively dy as compared to the long-term average. This is as represnted by Bomet station.

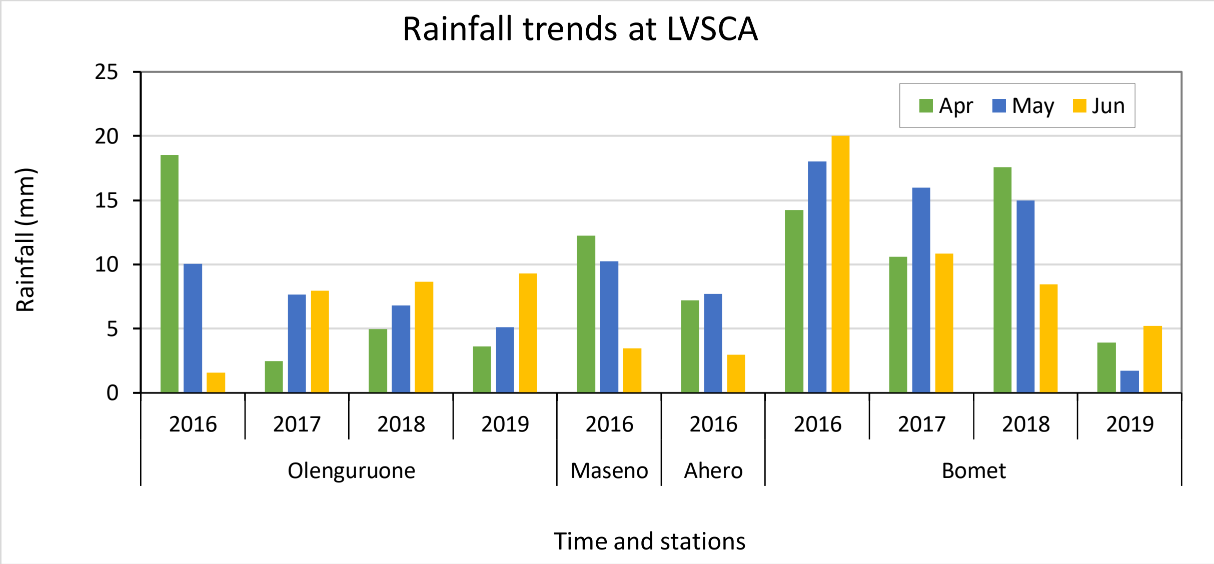


Figure 2.2:Rainfall trends at LVSCA

2.2.3 Rift Valley Catchment area

For RVCA, in general the region received less rainfall in the FY 2018/19 as compared to FY 2017/18 as it can be seen in the charts below, Figure 2.3. The rainfall in the stations can be assumed to represent the status in the Rift valley catchment area. The catchment has a mean annual rainfall range between 200 mm to about 1200mm in the upper catchment. At Kapenguria and RVCA yard Met station, an average of 10mm of rainfall was received. More rainfall amounts were recorded in the year 2019 as compared to 2017 and 2018 at RVCA.

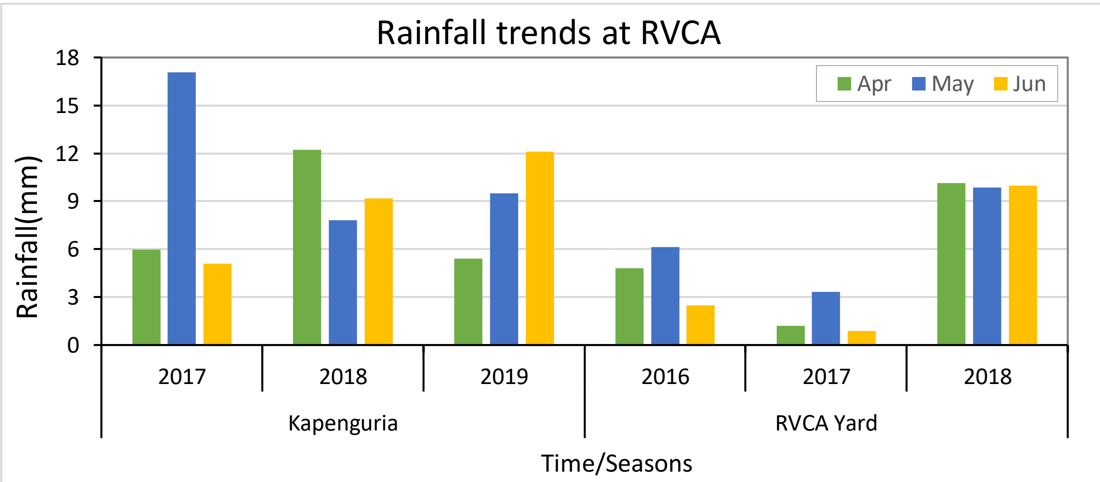
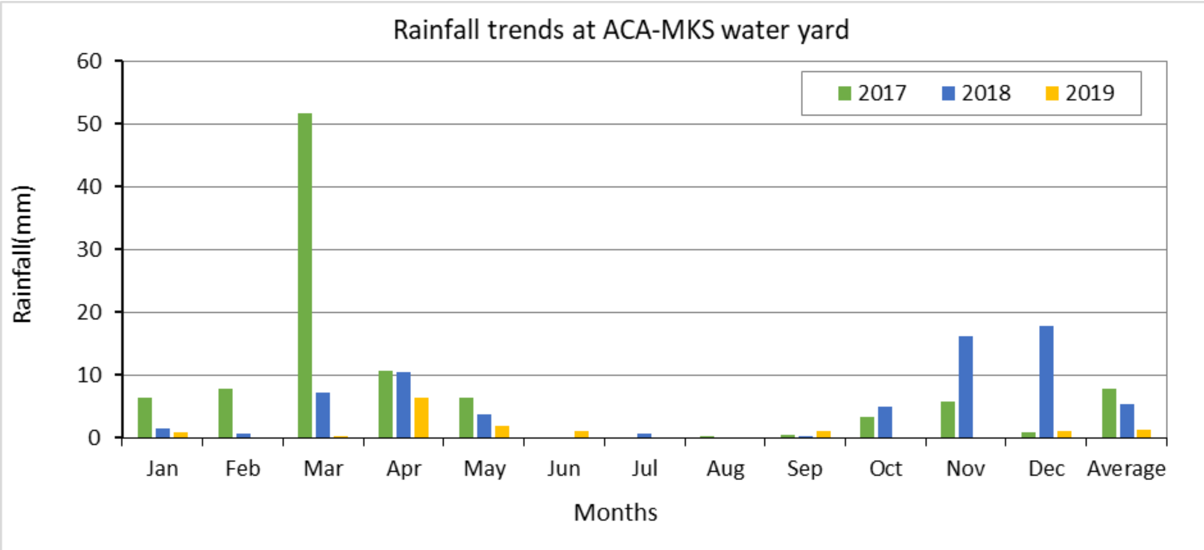


Figure 2.3:Rainfall trends at RVCA

2.2.4 Athi Catchment area

For ACA, analysis was based on rainfall data for the MKS water yard station for the years 2017, 2018 and 2019. The rainfall in the station can be assumed to represent the status in the Athi catchment area. On average basis, more rainfall amounts were received in 2017, (7.8 mm) compared to 2018 that had 5.29 mm and 2019 that had 1.24 mm. From the monthly averages, 2019 was a drier year with the onset of the long rains (MAM) delaying only to be realized in April 2019 and consequently the following months did not experience substantial amounts of rainfall. This is shown in Figure 2.4.



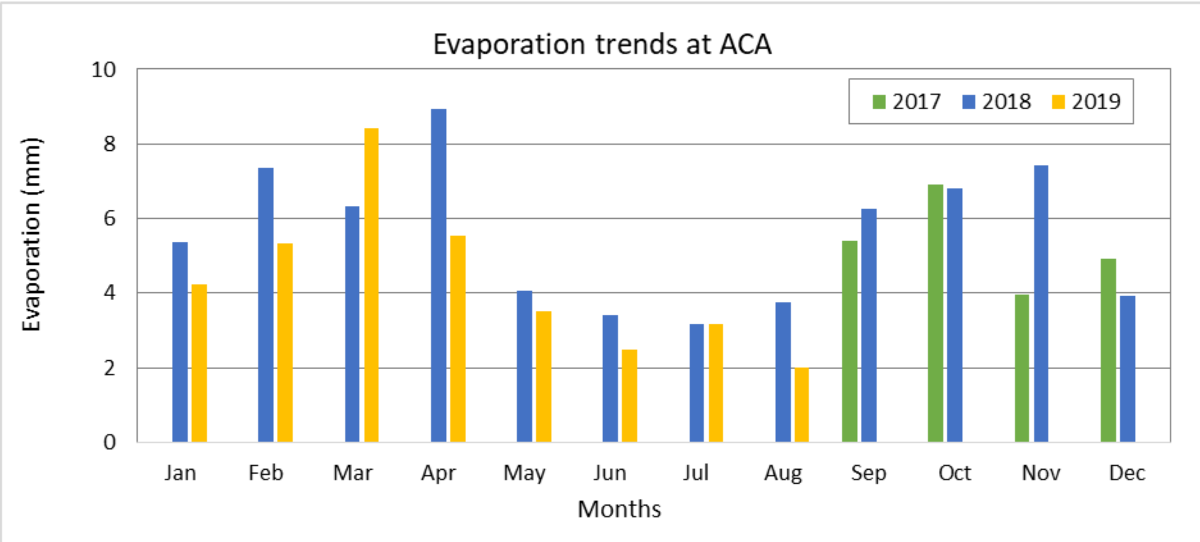
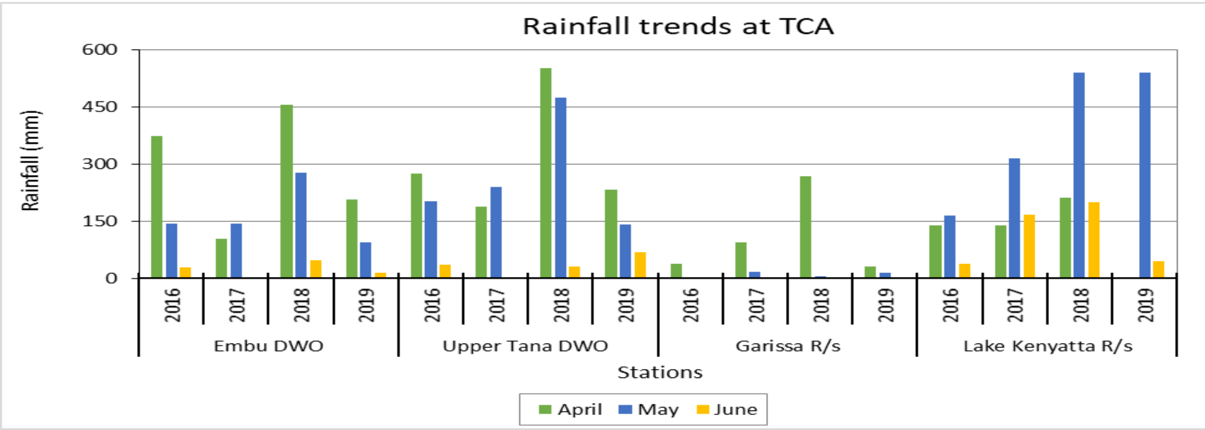


Figure 2.4: Rainfall and Evaporation trends at ACA

2.2.5 Tana Catchment area

For TCA, an analysis of the Long-term rainfall averages for the years 2016, 2017, 2018 and 2019 was done to get an overview of the rainfall trends for the Tana region. With reference to the chart below, (Figure 2.5) 2018 April received the highest monthly rainfall of 455mm followed by 2016. DWO Murang'a Rainfall station at Upper Tana for the year 2018 in the months of May and June had the highest and most years had recorded above 400mm which can be attributed to occurrence of floods during period. For Lower Tana at Garissa, there is an indication that the rainfall received during the period under review was very low with June recording zero rainfall but in lake Kenyatta flash floods were experienced.



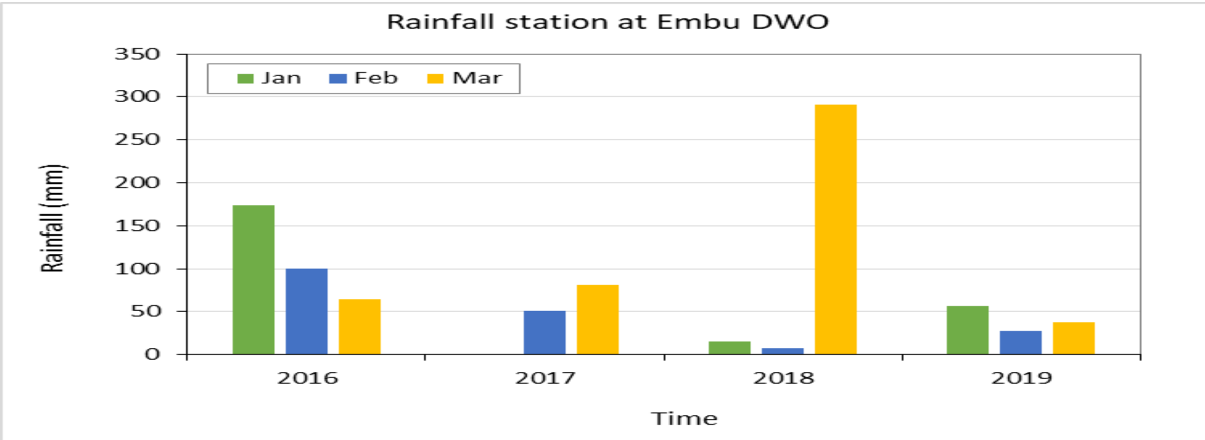


Figure 2.5:Rainfall trends at TCA

2.2.6 Ewaso Ng'iro North Catchment area

For ENNCA, analysis of rainfall data was dictated by data availability. Only four stations had complete data set for the period under review. Therefore, the analysis done was for the four stations as indicated below which included data got from Cetrad telemetric stations for Nyambene, Archers Post, Naromoru, Wamba, Kangeta and Marsabit. The rainfall in the stations can be assumed to represent the status in the

Ewaso Ng'iro North catchment area. The rainfall variability and monthly rainfall have been analysed for the four stations. In all the four stations, in the year under review they received lesser rainfall than previous year 2017/2018. This resorted to rivers having lesser flows. For the preceeding months before the onset of the short rains it is expected that the river flows will be at their minimum. If no rains, for the month of July farmers who depend on rain fed agriculture may witness crop failure.

The figures below (Figure 2.7) represents the analysis done for ENNCA for the periods between 2016 and 2019 for themonths of April to June.

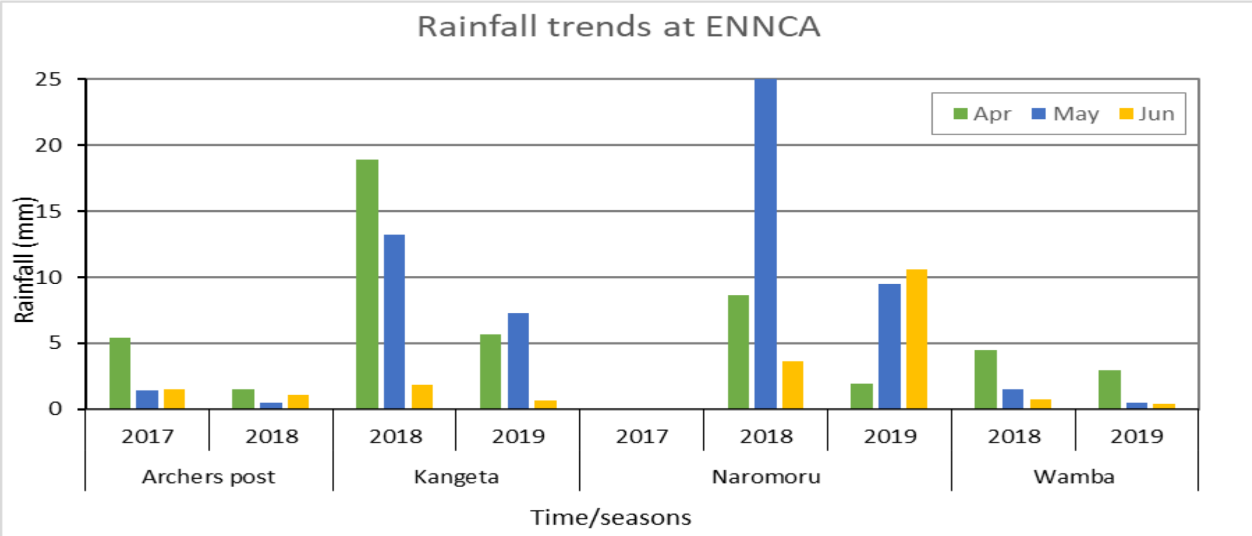


Figure 2.6:Rainfall trends at ENNCA

2.3 Comments on Special Events

At TCA, rainfall distribution within the Sub-catchment was very low throughout the quarter under review. Comparison of rainfall for the last four years same period for Ndakaini rainfall station indicate a delayed downpour within the catchment. The average rainfall amount ranges between 2000 and 2500 mm annually. Generally, rainfall was inadequate to recharge the rivers hence most rivers recorded low flows during the period and therefore the reservoirs storage was threatened due to low inflows. During the dry spells at Tana, there is usually a high demand for irrigation purposes and therefore most users violate the water permit conditions of using the 90 days reservoir.

For RVCA, flood prone areas which include Narok

and perkerra did not experience serious floods during the period under review. In terms of drought, most rivers recorded low levels in the months with some even drying up. The onset of the long rains was delayed as compared to previous years which brought confusion in the agricultural sector with some farmers planting twice as the 1st planting did not materialize. This can be seen in Figure 2.7 where the rains started in April while the previous year it started in late February. Some rivers dried up violating the

reserve flows. These included Rongai 2EC2, Nderit 2FC22, Makalia 2FC14, Molo 2EG3, Mereroni 2FA02, Mereroni 2FA08, (Kinja 2 GC11, Gilgil 2GA01, Kerio 2C08, Waesege 2EB5 and Mereroni 2FA8.

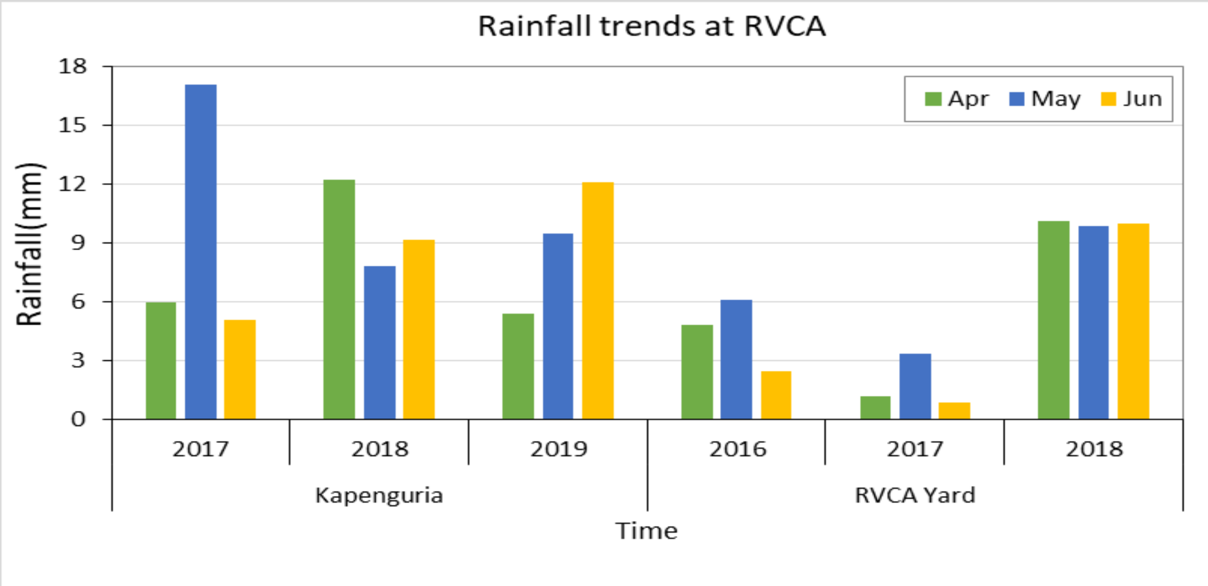


Figure 2.7:Rainfall trends on yearly basis at RVCA

At LVSCA, the basin was affected by a dry period that resulted in significant reduction in water avilability between Nov 2018 and April 2019. At ENNCA, from the rainfall station data analysed it informs that rainfall in the period under review was below the mean. It was also noted that the rains delayed and, in some areas, setting as late as May. Overall, the surface water situation in the region could be classified as "alert" during this period. There were a number of water related conflicts which was as a resultt of water scarcity.

Figure 2.8:Dry Mereroni river (2FA08) at RVCA

During the year under review, no special studies were done regarding climatic issues in most of the catchments. Figure 2.8 shows dry Mereroni river (2FA08) at RVCA

3 SURFACE WATER RESOURCES

This section presents an overview of the surface water situation. Description of the surface water monitoring network, analysis of streamflow characteristics, reserve situation and special studies and special events are presented.

3.1 Description of Monitoring Network

There are four categories of monitoring stations including National, Management Units, Intra Management Units and special stations as tabulated in Table 3-1. The status of the stations is as tabulated in Table 3-2.

Table 3-1: Categories of monitoring network

S/No.	Station categories	Description
1.	National Stations	These are stations that are of national importance which does not only capture the interest of a single catchment. According to the categorization, the stations include the lakes in RVCA and all trans-boundary stations
2.	Management Unit Stations (MU)	These are the stations that serve the interest of a hydrological unit.
3.	Intra Management Unit Stations (IMU)	These are stations within a hydrological unit e.g. the last stations before a tributary drain into the main river. They serve the interest of a subunit.
4.	Special Stations	These are stations serving special purposes not necessarily a hydrological unit.

Table 3-2:Monitoring Stations and Operational Status

Region	Category				Total	% Operational
	National	**MU**	**IMU**	**Special**		
LVNCA	5	6	10	7	28	78.6
LVSCA	5	14	26	2	47	60
RVCA	7	13	21	1	42	61.5
ACA	3	4	21	3	31	73
TCA	1	7	21	18	47	85

ENNCA	1	5	33	1	40	72.5
Total	22	49	132	32	235	71.77

3.2 Description of the surface water resources monitoring networks per catchment

3.2.1 Lake Victoria North Catchment Area

LVNCA has a total of 28 surface water stations. LVNCA is comprised of five major River systems namely, Nzoia, Yala, Malaba, Malakisi, and Sio. The largest is Nzoia river with a drainage area of 12,853 km^2, i.e 70% of LVNCA, followed by Yala river with a drainage area of 3,259 km^2. The remaining rivers account for 2,301 km^2, i.e 12.5% of LVNCA. Malakisi and Malaba rivers are trans-boundary originating in Kenya and flowing through Mbologoma wetland into Lake Kyoga in Uganda while Sio River flows into Lake Victoria.

3.2.2 Lake Victoria South Catchment Area

Surface water monitoring network in LVSCA consists of 47 regular gauging stations (RGS) distributed within the six river basins with 60% of the stations being operational. The major basins are Nyando, Sondu, Gucha-Migori and Mara. Others are the Northern and Southern shoreline streams. Each of the major basins has a station at the outlet, referred to as National RGS. The Management and Intra Management Unit stations (MU and IMU respectively) are installed in each of the river systems. There are two special stations in the Nyando River located at the Nyando Bridge and Nyangores river at Chepalungu High School.

3.2.3 Rift Valley Catchment Area

The surface water monitoring network comprises 42 RGS with 61.5% being operational. The RVCA stretches from Lake Turkana to Shompole Swamp upstream of Lake Natron in Tanzania and covers an area of 130,452 km^2. It is the second largest catchment area in the country with 7 major lakes in the catchment as entailed in Table 3-3.

Table 3-3:Lakes in RVCA

S/No.	Lakes	Description
1.	Turkana	Rivers Turkwel and Kerio on the Kenyan side and Omo on the Ethiopian side
2.	Baringo	Rivers Molo, Perkerra and oralabel
3.	Bogoria	RiversWasseges (Subukia) and Emsos Spring
4.	Nakuru	Rivers Njoro, Makalia and Nderit

5.	Elementaita	Rivers Mereroni and Kariandusi
6.	Naivasha	Rivers Malewa, Gilgil and Karati
7.	Magadi	River Ewaso Kedong

3.2.4 Athi Catchment Area

The surface water monitoring network comprises 31 RGS. The major rivers of this basin are; Athi also known as Galana and Sabaki at the lower coastal reaches, Ndarugu, Ruiru, Thiririka, Nairobi, Mbagathi, Stony Athi, Thwake, Kaiti, Muooni, Kiangini, Kikuuni, Kibwezi, Thange, Kambu, Mtito Andei, and Tsavo all draining into the Athi. Other important rivers of this basin include; the Lumi, Mwatate, Voi, Rare, Ndzovuni, Pemba, Ramisi, Mukurumudi and Umba. There are also other small rivers that drain into the Indian Ocean or dry up in the hinter land. The catchment has some major springs which are important sources of water to towns and other populations. The springs include, Kikuyu (supplying water to Nairobi city), Mzima (supplying water to Mombasa and other urban centers), Njoro kubwa(supplying water to Taveta and source of water for irrigation), Marere (supplying water to Mombasa and Kwale), Nol-turesh (supplying water to Kajiado/Makueni and Machakos Counties), Rombo, Kimana and Olpsare springs, Umani, Kiboko Springs. The catchment has Trans-boundary lakes including lakes Chala and lake Jipe (sharing with Tanzania). The shared rivers are the Lumi and Umba.

3.2.5 Tana Catchment Area

The surface water monitoring network comprises 47 RGS with 85% of the stations being operational. The Tana River itself and its tributaries form the main rivers of the Catchment. The main perennial tributaries are Nairobi, Amboni, Gura, Ragati, Chania, Mathioya, Thiba, Kathita, Mutonga, Sabasaba, Maragwa, Thika, Ena, Ura and Runjeweru. The ephemeral tributaries include Tiva, Laga Kokani. The tributaries emanate from Mt. Kenya the Aberdares and the Nyambene Hills forming dendritic drainage system dominated by Tana River which is the largest river in Kenya.

3.2.6 Ewaso Ng'iro North Catchment Area

The surface water monitoring network comprises 40 RGS classified as national, management unit, intra-management unit and special with 72.5% of the stations being operational. In addition, 1 non-CMS station has been installed at the proposed Kianjuri dam to develop a water availability record for the Ruguthu River before the dam is constructed. The stations are installed with conventional gauge plates. Ewaso Ng'iro, 5ED01 (National station) was telemetered and it is transmitting data to the National office. For Isiolo River 5DA07 (MU), the telemetric installations were vandalised, and re-installation is yet to be done. The region has no adequate equipment for measuring all flows, both high, medium and low flows. Rumuruti and Nanyuki sub regions currently have no functional flow measurement equipment. ADCP is used for high non turbulent flows. ADV and Velocimeter are used for low to medium flows while the OTT current meters measure very low, medium to high flows from bridge or using dingy boat.

3.3 Improvements to Network Infrastructure

During the year under review 52 Regular (River) Gauging Stations were rehabilitated, 17 Stations upgraded to Telemertry and 5 new stations established.

3.3.1 Rehabilitation

For LVSCA, 22 stations were assessed but 7 No. stations were rehabilitated. They include Nyando-1GD03, Kipchorian/ Nyando-1GC03, Ainamutua-1GB05, Kipsonoi-1JF08, Mara at Emarti-1LA06, Riana-1KA09 and Gucha-1KB03. For ENNCA, during the period under review 8 No. regular gauging stations were assessed and rehabilitated including; Ewaso Ngiro 5ED01, Ngare Dare 5DA02, Ewaso Narok 5AA17, Pesi 5AB02, Equator 5AA05, Teleswani 5BE05, Sirmon 5BE22, Naromoru 5BC02.

For RVCA, during the year, 13 No. RGS stations and 1 No. Met station were rehabilitated. They include; Molo 2EG3, Waseges 2EB5, Perkerra 2EE7B, Malewa 2GB03, River Ewaso Ngiro (Mosiro),2K10, River Siyiapei 2K06, Ewaso Ngiro (Magadi) 2K04, Kitiri 2GC05, Weiwei 2B28, Suam 2B05, Suam 2B33, Koruk 2B34, Wanjohi 2GB09 and Lodwar sub met 8635000,

For TCA, 6 No. RGS and 3 No. Met stations were assessed and rehabilitated. They include; Mutonga 4EA07, Nyamindi 4DB5, Tana at Garissa 4G01, Tana at Garsen 4G02, Mutonga 4EA06, Kimakia 4CA11, Sagana state lodge met station 9036017, Mwingi Water office Hydro Met station 168, MWO-Murang'a 9036017.

For ACA, 8 No. stations were rehabilitated. They include; Athi Wamunyu 3DB1, Kibwezi River 3F06 Kibwezi River 3F09, Nolturesh 3GA01, Ngarelen 3GA02, Athi 3DA2, Ndarugu 3CB5 and Olchoro 3JA07. At LVNCA, 6 No. stations were rehabilitated. They include; Kabutie 1FC02, River Yala 1FG03, Malakisi 1AD02, Malaba 1AA01, Olare Onyokie ICC01 and River Yala 1FE01. However, Malakisi 1AD02-Malakisi was washed away by flash floods less than a month after installation. The station will be re-installed once the water levels recede. RGS 1AA01-Malaba is yet to be rehabilitated although it was among the RGSs earmarked for rehabilitation. Figure 3.1 and Figure 3.2 shows the status of the stations before and after the rehabilitation.

Figure 3.1:Yala-1FE02;Before (Erection of the pillar) and after (1st & 2nd gauges installed) the installation.

Figure 3.2: Edzava-1FF03; Before (Erection of the pillar) and after (1st & 2nd gauges installed) the installation

Table 3-4: Activities conducted during rehabilitation at RVCA

	Station Name	Stn ID	Activities conducted during rehabilitation
1	WeiWei at Sigor	2B28	Installed 2No metric gauges (0-1.50m and 1.5-3.0m) River cross section profile survey Discharge measurement Reconditioning of benchmark
2	Suam at Kacheliba	2B33	Installed 2No metric gauges (1.5-3.0m and 3.0-4.5m) River cross section profile survey

			Discharge Measurement,
3	Suam at Suam Uganda-Kenya border	2B05	Installed 2No metric gauges (0-1.5m and 1.5-3.0m) River cross section profile survey Discharge measurement Operationalized the station
4	Koturuk at Makutano	2B34	Installed 1No metric gauge(0-1.50m) River cross section profile survey Discharge measurement Re-installed the benchmark Operationalized the station
5	Molo	2EG3	Installed with 1st and 2nd gauge and cross section taken; river was dry
6	Waseges	2EB5	Installed with 1st and 2nd gauge and cross section taken; river was dry
7	Perkerra	2EE7B	Installed with 2nd and 3rd gauge, discharge measurement undertaken
8	Seyapei	2K06	Installed with 1st, 2nd and 3rd gauge, discharge measurement undertaken
9	Ewaso Ngiro South	2K04	Installed with 1st, 2nd and 3rd gauge, discharge measurement undertaken
10	Ewaso Ngiro South at Mosiro		Re- Installation of 1st post and replacement of plate (0.0- 1.5) Replacement of plate No 5. Levelling and back filling done
11	Malewa	2GB4	Desilting of tones of deposition
12	Kitiri	2GC05	Installation of gauge on a concrete pillar, establishment of benchmark, cross section done
13	Turasha	2GB9	Desilting of tones of deposition

3.3.2 Establishment of new stations

A total of 5 No. RGS stations were established. These include Upper Kipkaren 1CD01, Turasha 2GC04, Kibwezi 3F07, kithima 5DA03 and Mbagathi 3AA06.

3.3.3 Upgrading of Stations to Telemetry

A total of 17 No. stations were upgraded to telemetry, 7 of which were Automatic Water Level (AWL) while 10 Automatic Weather Stations (AWS). These include 7 Automatic Water Level (AWL) Stations namely: Kuywa at Matisi-1DB01A, Nzoia at Froi-1DA(New), Kipkarren-1CE01, Sosiani-1CB05, Larger Nzoia-1BD02, Koitobos-1BE06 and lusumu-1ED01 and 10 Automatic Weather Stations (AWS) namely: Butere Girls H.S, Nzoia Sugar, Malava, Turbo NYS, Ndalu, Ndalat, Kapcherop, Chebororwa, Naiberi and Mt. Elgon Flowers

Figure 3.3:At Njoro and Mala Telemetric stations

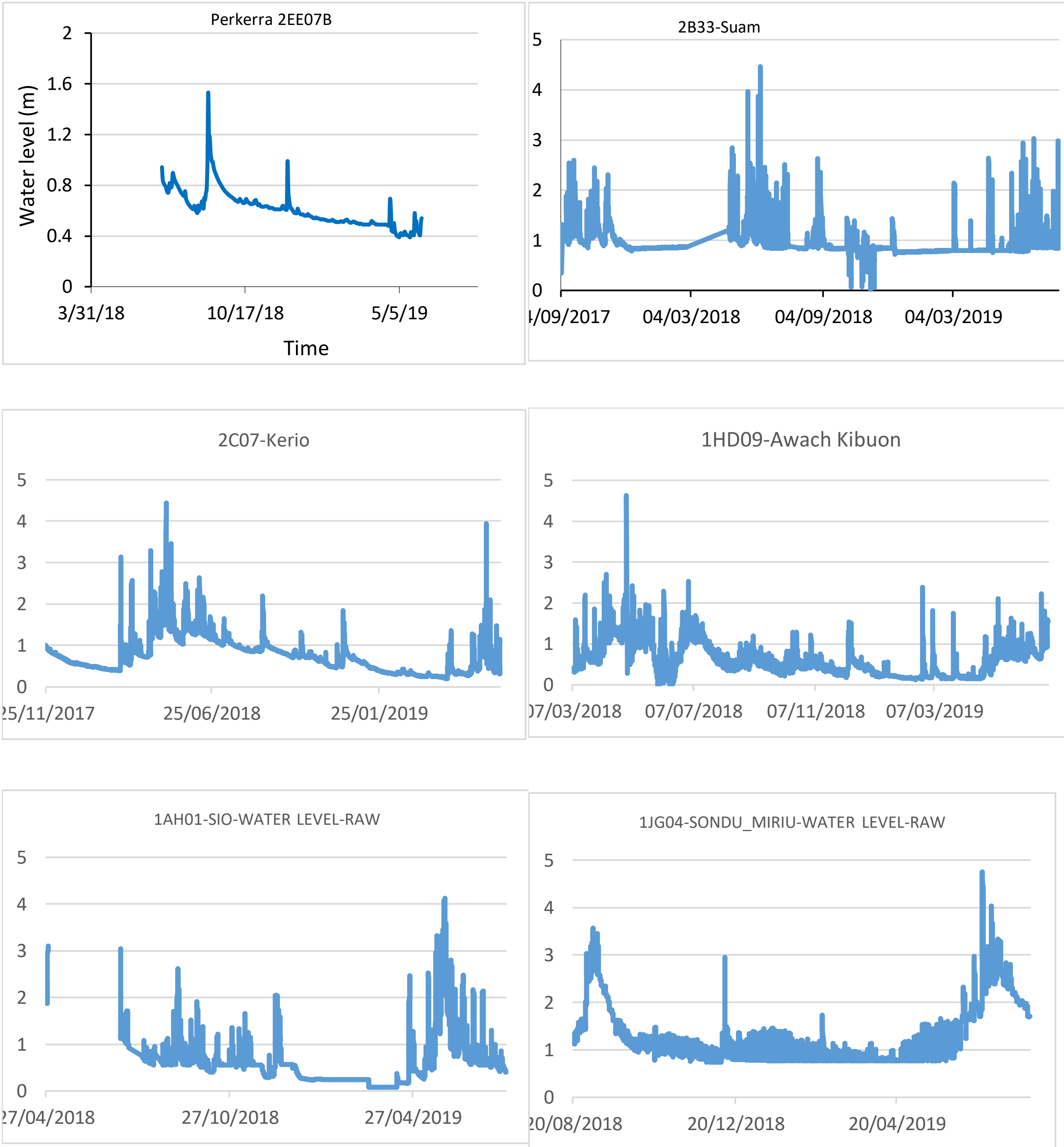
3.4 Improvements to Data Quality

The River Gauging Stations established provide daily water level data. This data is manually entered in the booking sheets by Gauge Readers nationally. This data is entered to the system and data checks are undertaken for quality control purposes and also check readings taken when an RGS station is visited for counter checking with the gauge readers figure.

Gauging campaign is done to validate and improve rating equations. The gauging plan for the regions entail sustained discharge measurement at the installed, newly installed or rehabilitated stations in order to develop and/or improve the rating curves.

For ENNCA, a total of twenty-three (23) discharge measurements were carried out during the 2018/19 FY. The number of stream flow gaugings carried out recorded a decline of (43) compared to 2017/18. But still, it was far below the expectation since there should be at least one region-wide discharge measurement expedition to capture flows during all seasons, i.e low, middle and high flows. Most of the discharges were conducted in Upper Ewaso Ng'iro. The other sub regions either did not have the flow measuring equipment or the capacity.

The availability of Telemetric system of data logging has ensured near real time data transmission to the server. The manual gauge readings are used as a reference to validate the gauge readings acquired from the telemetric stations. They are also used to configure the readings for the telemetric equipment. These telemetric stations require regular maintenance to check and change batteries promptly to avoid losing data. The charts below (Figure 3.4), displays water level data for various telemetric stations. The trends of the data are quite good.



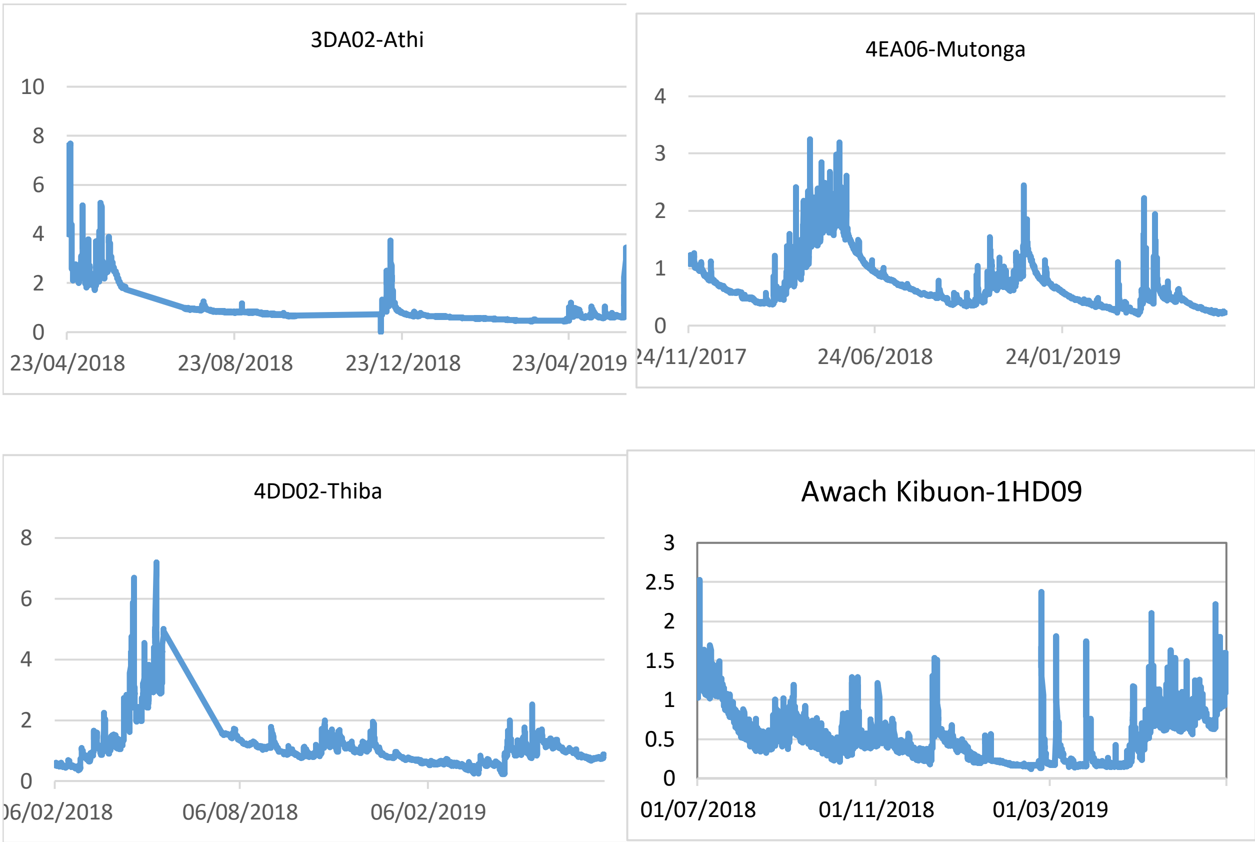


Figure 3.4:Telemetric stations water levels.

Validation of the water level data transmitted through the Telemetric system of data logging with the manual gauges which are taken as the reference point is key for quality control. 1AH01, 1FG02, 2C07 and 2FC19 were some of the stations sampled for validation. 1AH01 had an R^2 of 0.648 surpassing the allowable limit of 0.6, 1FG02 had an R^2 0.1813 which is way below the acceptable limit of 0.6 but this is attributed to the availability of manual data relevant for the comparisons. 2C07 had an R^2 of 0.9031 showing an exemplary performance as compared to the rest of the stations. 2FC19 had an R^2 of 0.556 indicating a good performance though relevant configurations of the system are recommended. Their validation with the baseline data, (manual RGS) shows that the correlation coefficient (R^2) is beyond the limit of 0.6. This shows that the data being collected ia accurate and of the right quality.

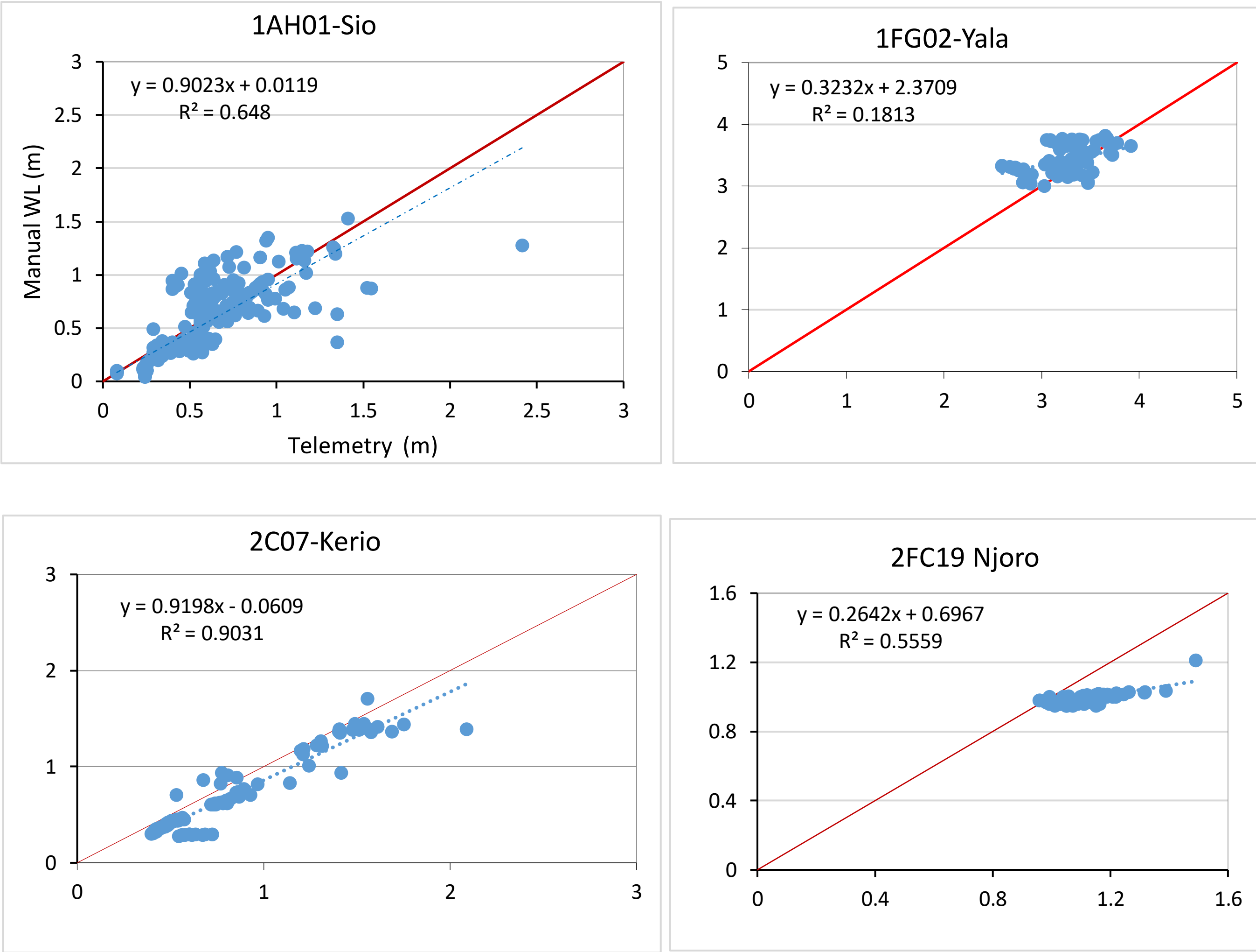
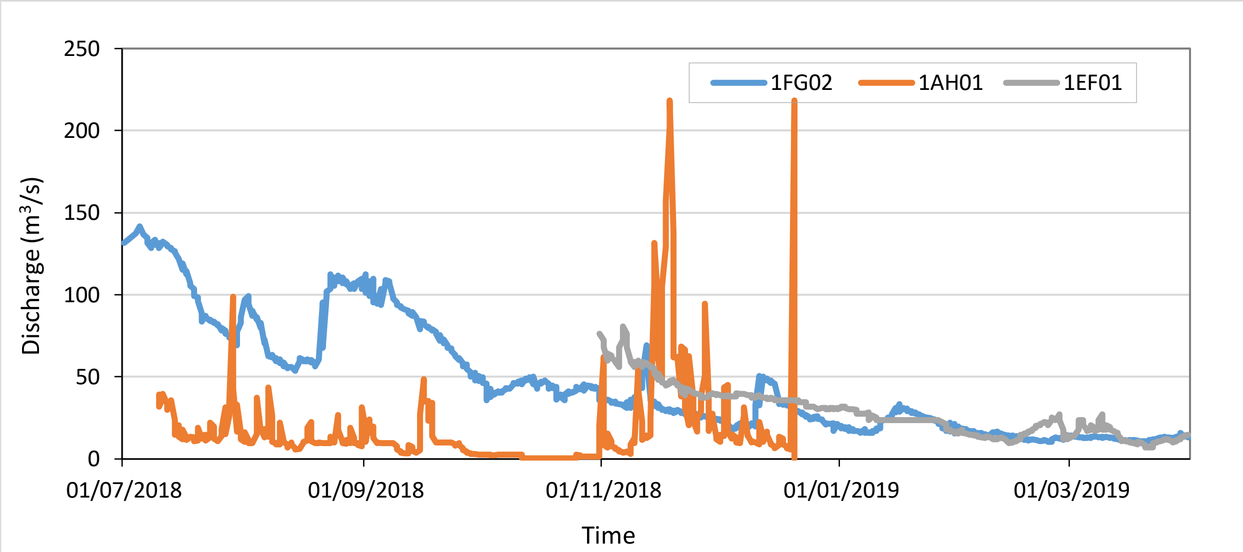


Figure 3.5:Graphs showing validation of the telemetric water levels with the manual gauges.

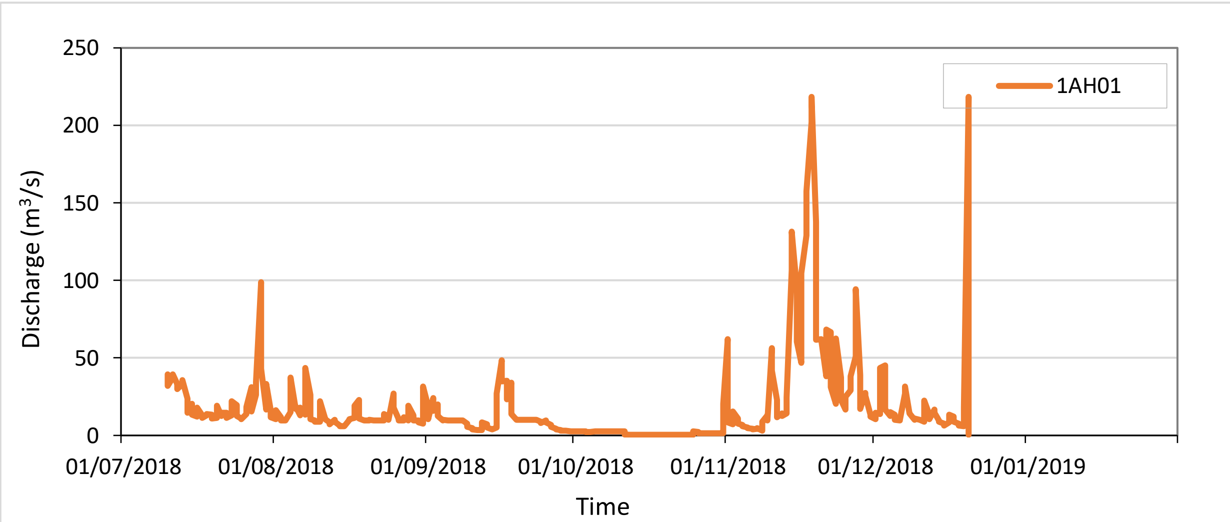
3.5 Assessment of Surface Water Resources

3.5.1 Lake Victoria North catchment area

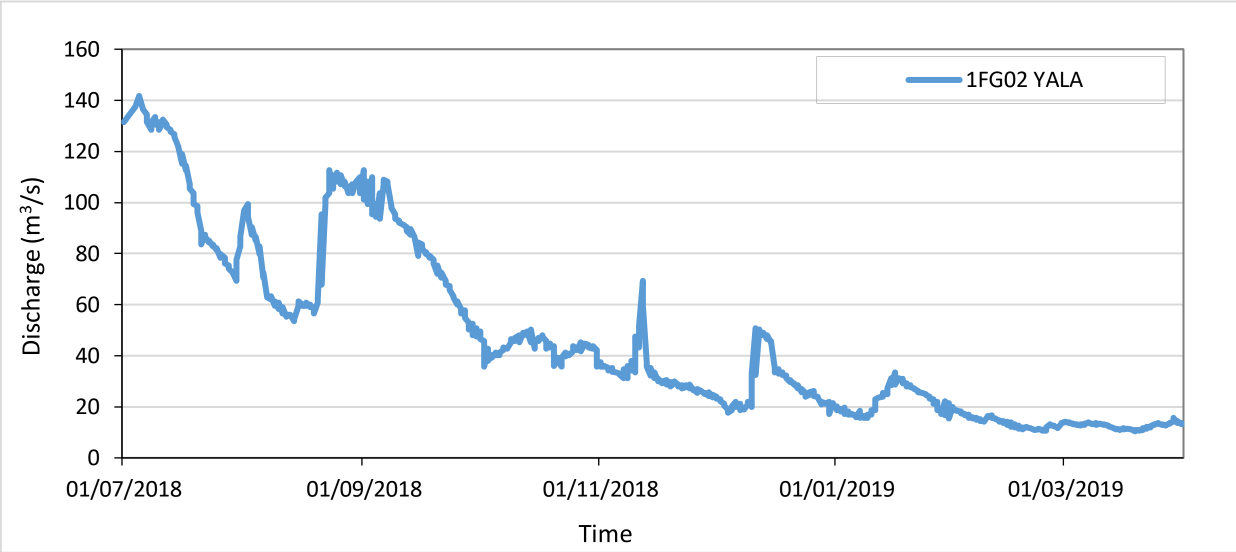
For LVNCA, 1FG02 (Yala) and 1AH01 (Sio) and 1EF01 (Nzoia) RGS stations were used for analysis. This was based on data availability. Comparing Yala, Sio and Nzoia daily flows show that there was more flow in the Yala River on average basis but compararing the three river systems based on maximum flows Sio river had the highest maximum flows compared to Yala and Nzoia. Sio had 218.42 m^3/s while Yala and Nzoia had 141.71 m^3/s and 80.73 m^3/s respectively. Sio river had the lowest minimum daily flows of 0.42 m^3/s followed by Nzoia river (7.05 m^3/s) and then Yala river with 10.39 m^3/s. The reserve flows in most of the rivers was not violated.



250
200
150
100
50
0
Discharge (m3/s)
1FG02
1AH01
1EF01
01/07/2018
01/09/2018
01/11/2018
01/01/2019
01/03/2019
Time



250
200
150
100
50
0
Discharge (m3/s)
1AH01
01/07/2018
01/08/2018
01/09/2018
01/10/2018
01/11/2018
01/12/2018
01/01/2019
Time



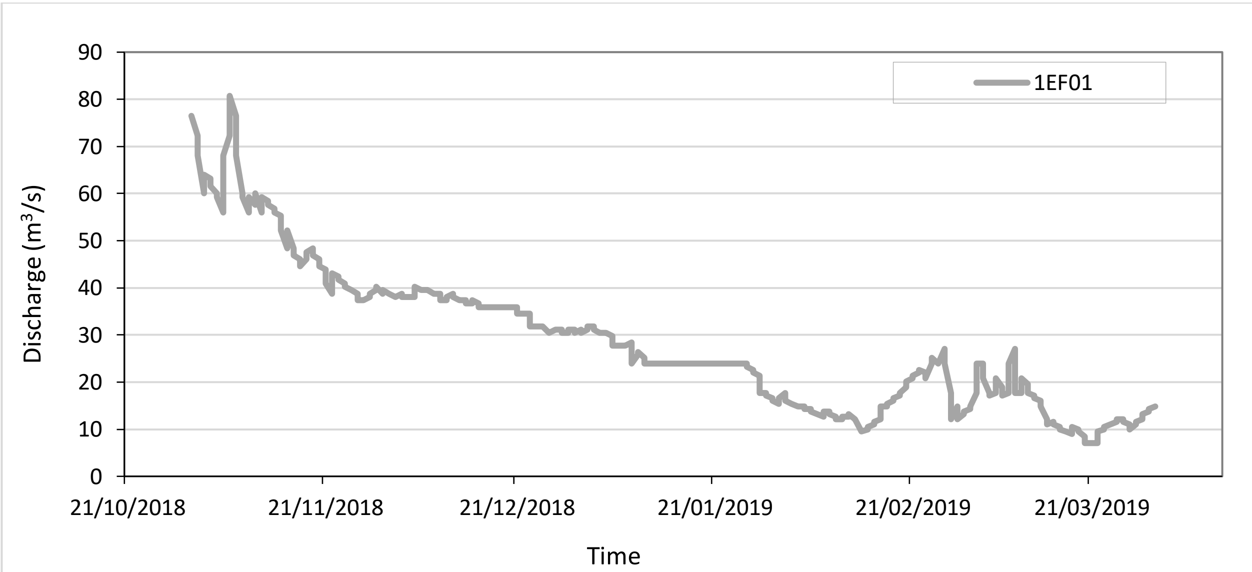
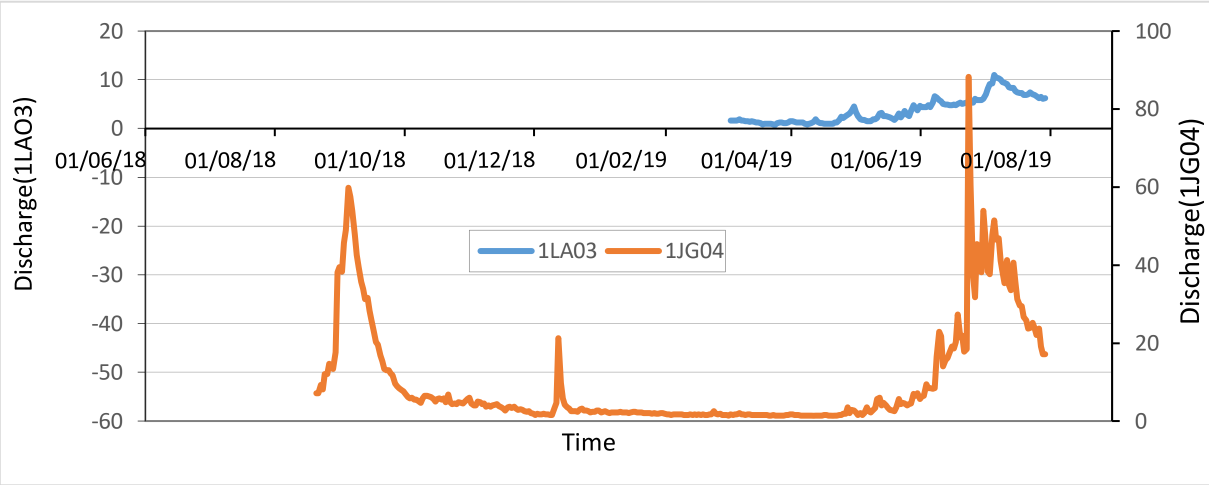
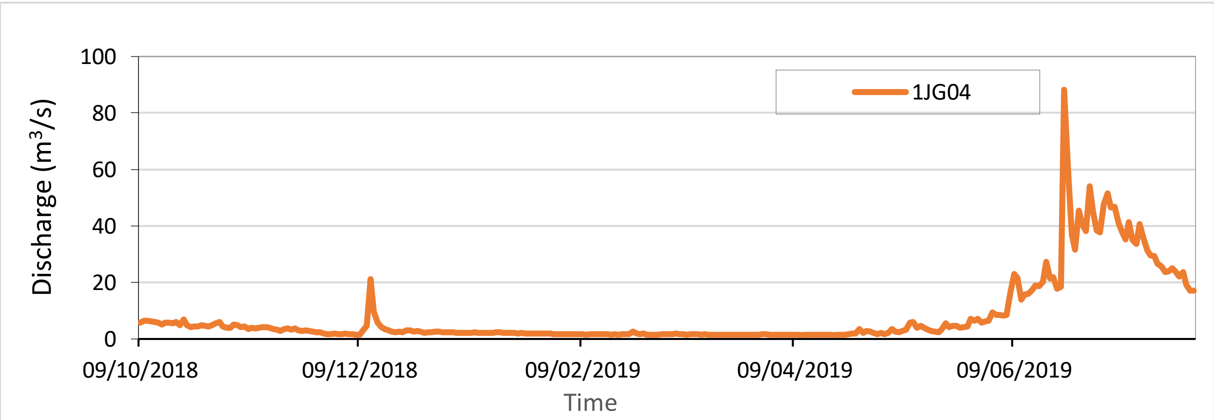


Figure 3.6:Daily flow trends at LVNCA

3.5.2 Lake Victoria south catchment area

For LVSCA, catchments 1JG04, 1GD03 and 1FG02 were used for the analysis. This was based on availability of data for the analysis period. For Nyando, 1GD03 the flow was relatively good with reduced flows during the dry periods and increased flows during the rainy seasons. Comparing Nyando, Sondu and Mara shows that there was more flow in the Sondu River compared to Nyando and Mara Rivers. However, the basin had more water for the better part of the year but reduction in flow volume started in November and December and this trend was sustained to the end of the hydrologic year. This implies that there was water in the Rivers, pans and other storage facilities that averagely satisfied the requirements for all uses. However, the dry season led to water stress for crops and other users.





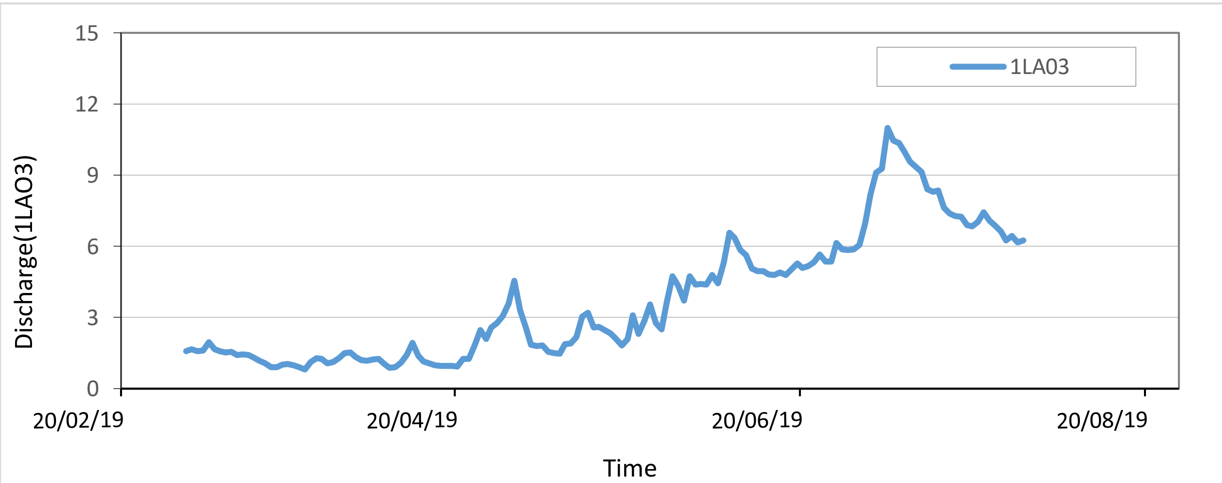
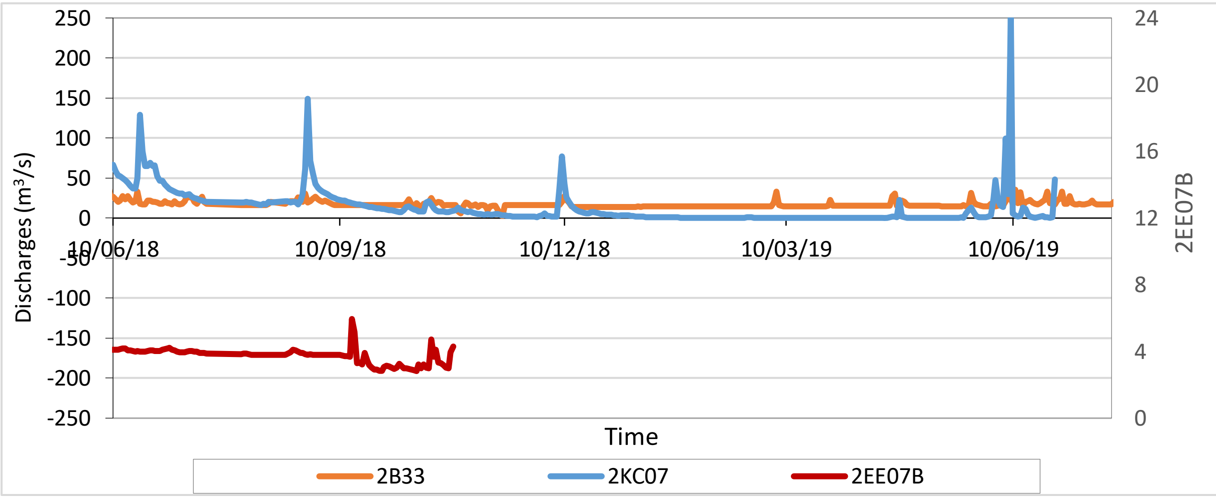
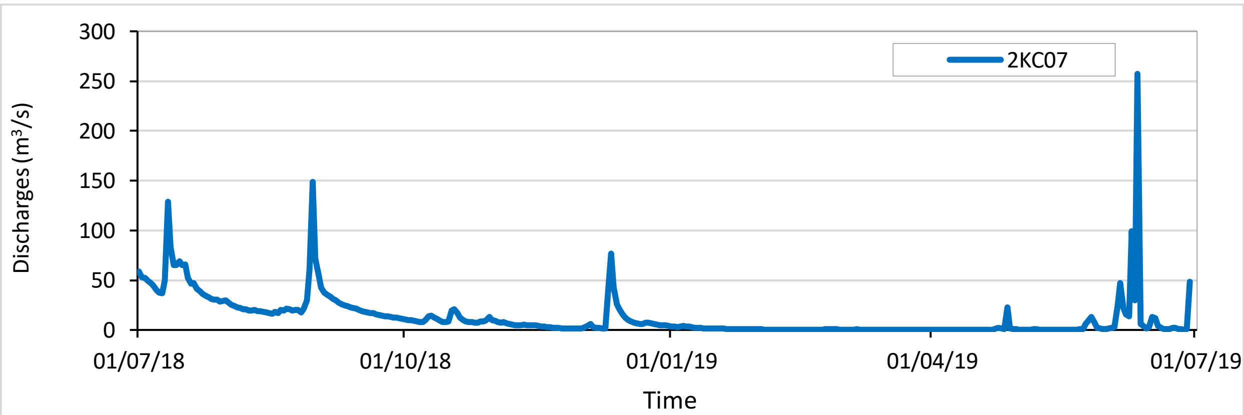


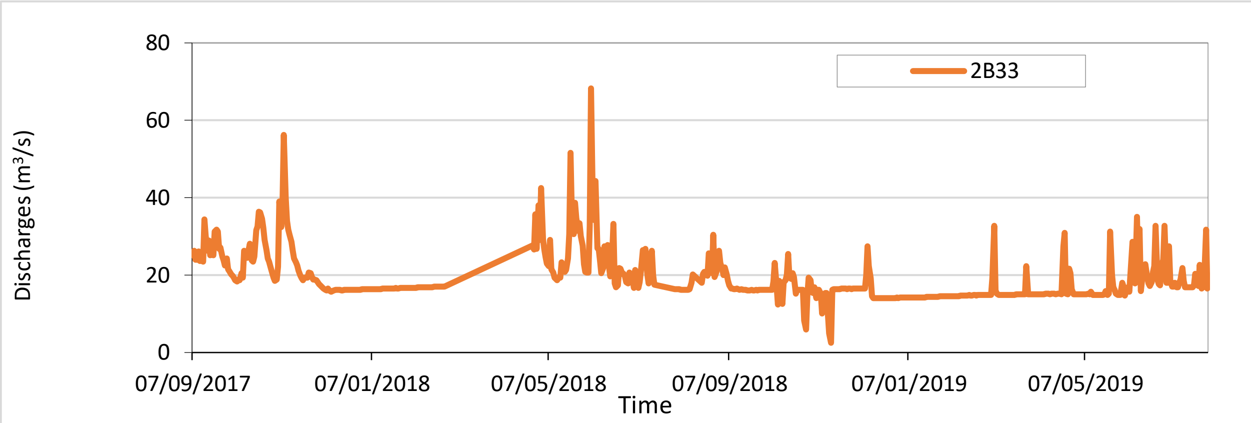
Figure 3.7:Daily flow trends at LVSCA

3.5.3 **Rift valley catchment area**

RVCA is the second largest Kenyan catchment which is an internal drainage basin with its streams flowing into its constituent lakes. Water scarcity is highly linked to over-dependence on surface water resources, as it is estimated that surface water and ground water are only 12% and 88% respectively. In certain occasions the region becomes highly vulnerable to drought during the dry period and flooding during the wet periods. 2C07, 2B33 and 2EE07B stream flows at RVCA were used to analyse the trend in the flows and as a representation of the basin.Flow variations were experienced at different river systems as evident from KC07, KB33 and and 2EE07B.An average of 12.73, 16.95 and 5.11 m^3/s were received at KC07, KB33 and and 2EE07B stations respectively. While 2KC07 had the highest maximaum flows, it also receives the lowest minimum flows of $0.12 m^3/s$.







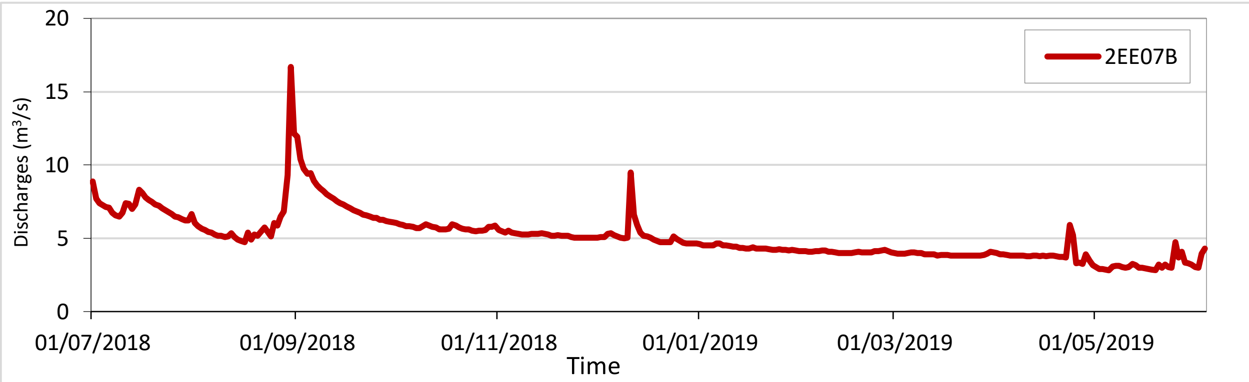
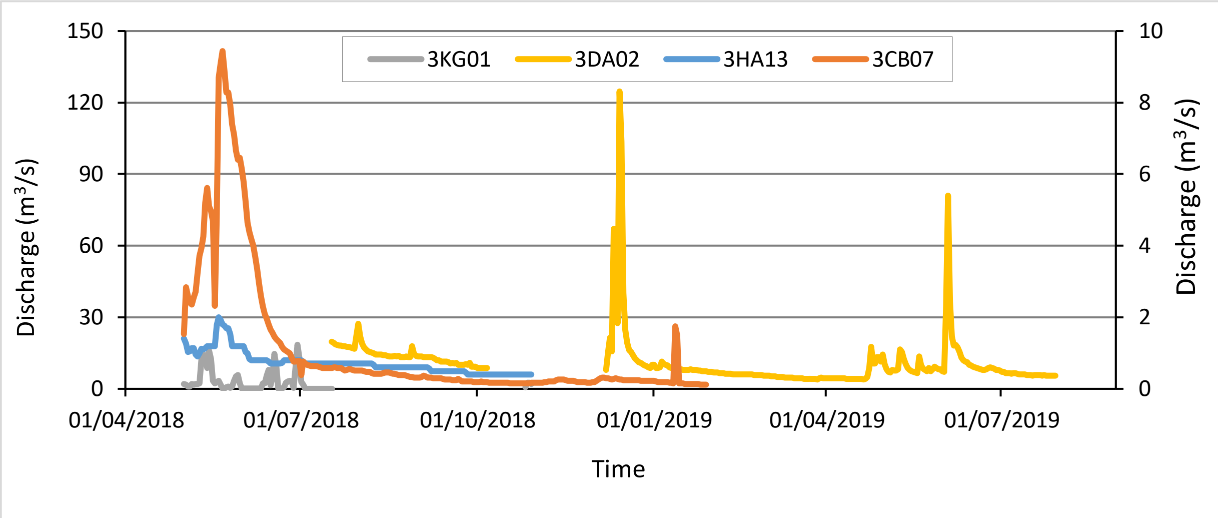


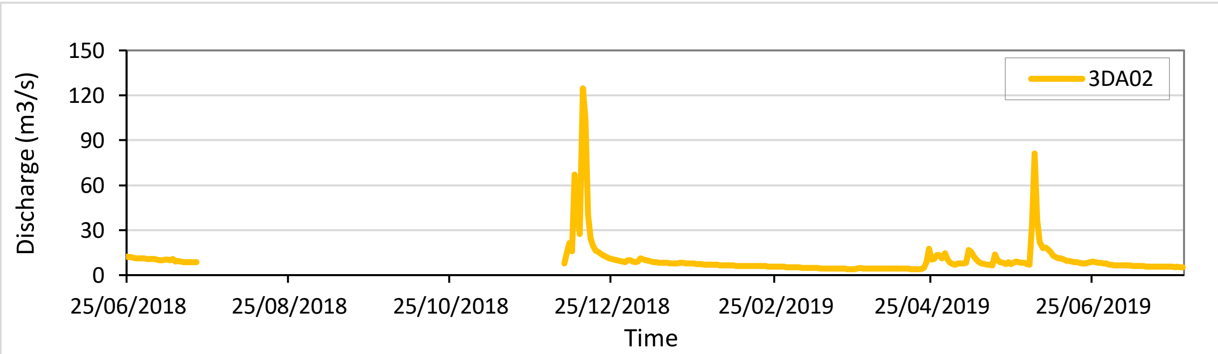
Figure 3.8:Daily flow trends at RVCA

3.5.4 Athi catchment area

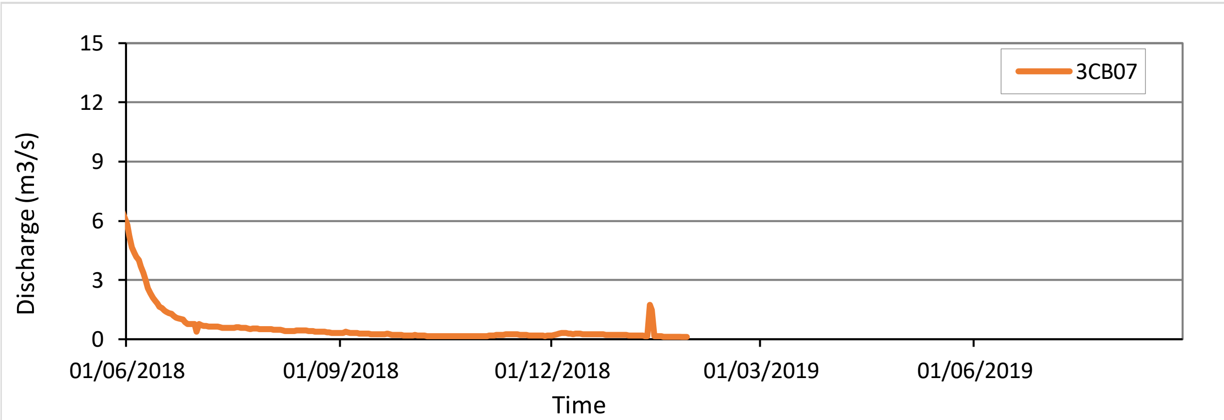
For the ACA, 3DA02, 3CB07, 3KG01 and 3HA13 were used for the analysis. The graph depicts considerable flows in both the short and the long rains seasons. 3DA02 (124.672m^3/s) had the highest maximum flows especially in the months of December 2018 and June 2019 while 3HA13 had the least maximum flows (2m^3/s). 3DA02, 3CB07, 3KG01 and 3HA13 had average flows of 10.92m^3/s, 1.09m^3/s,2.97m^3/s, 0.73m^3/s respectively. The minimum flows for the analysed stations, 3DA02, 3CB07, 3KG01 and 3HA13 were 3.92 m^3/s,0.11 m^3/s, 1.16 m^3/s and 0.4 m^3/s respectively. The reserve flows in most of the stations was not violated.



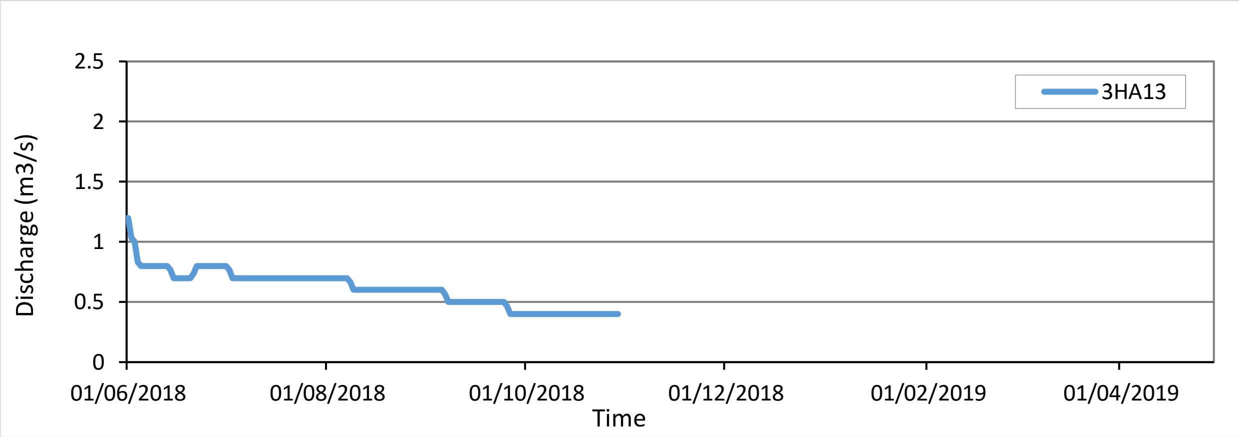
3KG01
3DA02
3HA13
3CB07
150
120
90
60
30
0
10
8
6
4
2
0
Discharge (m³/s)
Discharge (m³/s)
01/04/2018
01/07/2018
01/10/2018
01/01/2019
01/04/2019
01/07/2019
Time



3DA02
150
120
90
60
30
0
Discharge (m3/s)
25/06/2018
25/08/2018
25/10/2018
25/12/2018
25/02/2019
25/04/2019
25/06/2019
Time



3CB07
15
12
9
6
3
0
Discharge (m3/s)
01/06/2018
01/09/2018
01/12/2018
01/03/2019
01/06/2019
Time



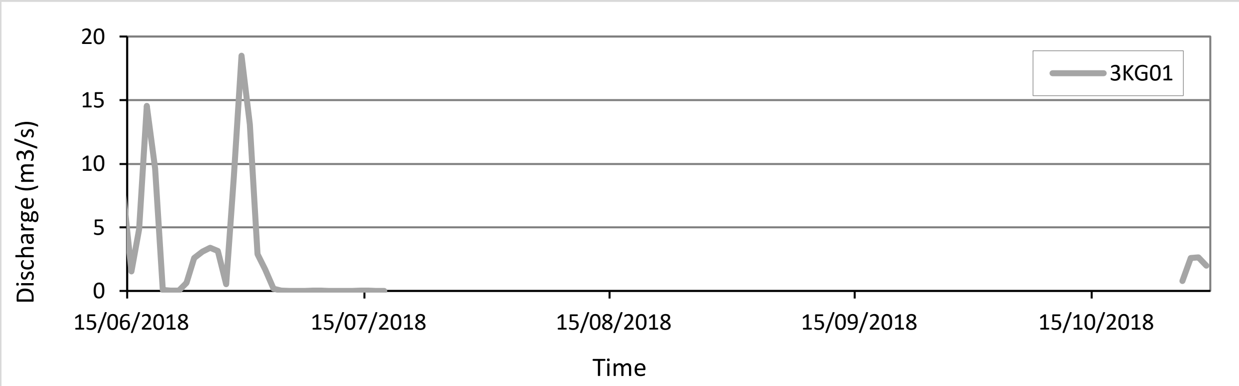
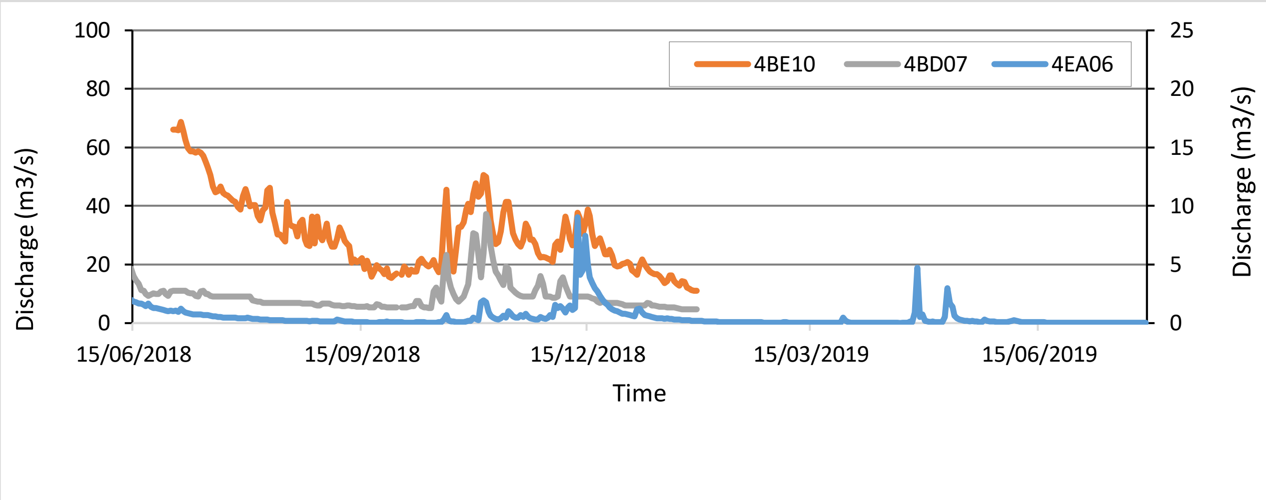


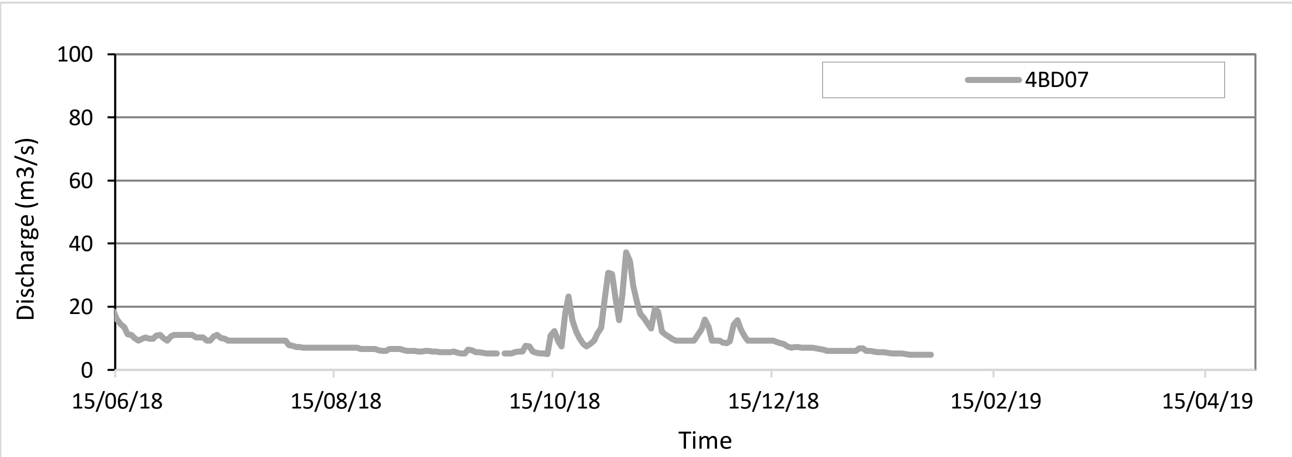
Figure 3.9:Daily flow trends at ACA

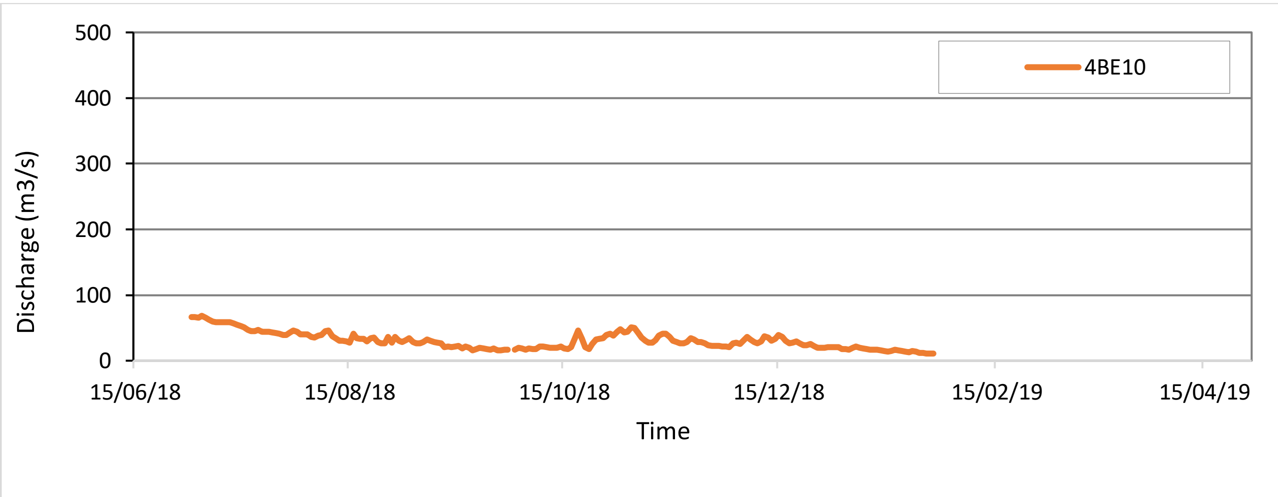
3.5.5 Tana catchment area

For the TCA, 4EA06-Mutonga, 4BE10-Rukanga and 4BD07-Mathioya were used for the analysis. On average basis, 4BE10-Rukanga, had the highest daily flows of ~30.28 m^3/s followed by 4BD07-Mathioya (9.04 m^3/s) and then 4EA06-Mutonga with a discharge of 0.42 m^3/s. 4BE10-Rukanga, had the highest maximum daily flows of ~68.76 m^3/s followed by 4BD07-Mathioya (37.24 m^3/s) and then 4EA06-Mutonga with a discharge of 9.06 m^3/s.

The lowest minimum flow was displayed at 4EA06-Mutonga with a discharge of 0.007 m^3/s, while 4BD07-Mathioya and 4BE10-Rukanga had 4.81 m^3/s and 10.95 m^3/s respectively. The reserve flows were not violated during the period under review.


4BE10
4BD07
4EA06
Discharge (m3/s)
Discharge (m3/s)
Time
15/06/2018
15/09/2018
15/12/2018
15/03/2019
15/06/2019


4BD07
Discharge (m3/s)
Time
15/06/18
15/08/18
15/10/18
15/12/18
15/02/19
15/04/19


4BE10
Discharge (m3/s)
Time
15/06/18
15/08/18
15/10/18
15/12/18
15/02/19
15/04/19

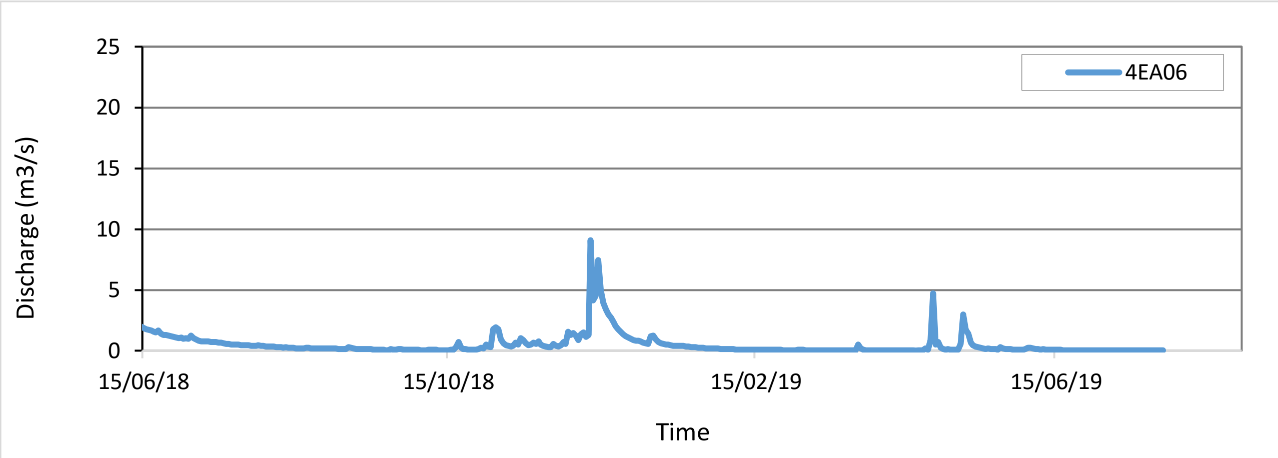
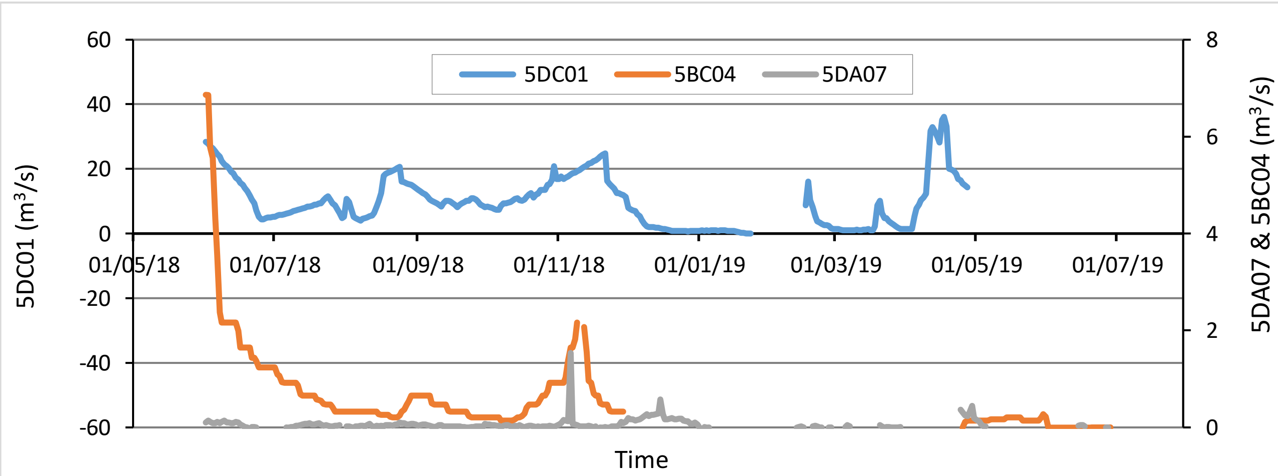
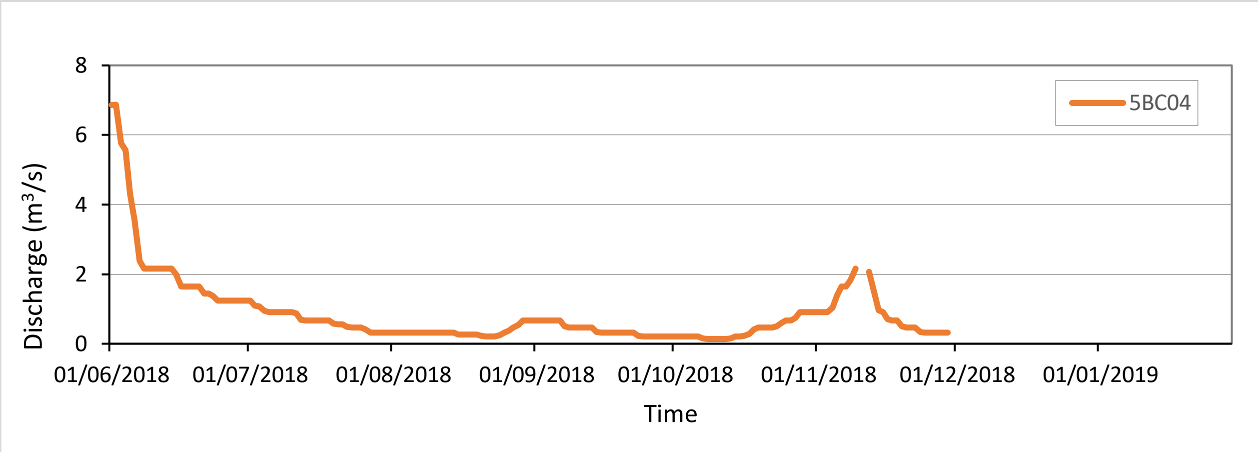


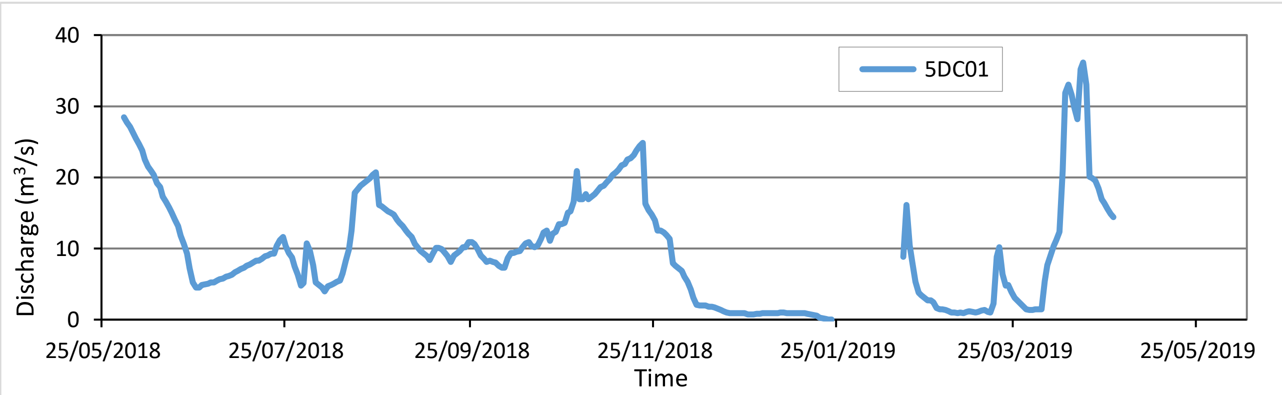
Figure 3.10:Daily flow trends at TCA

3.5.6 Ewaso Ng'iro North catchment area

For ENNCA, 5DC01-Ewaso Ng'iro, 5DA07-Isiolo and 5BC04-Ewaso Ng'iro were used for the analysis. On average basis, 5DC01-Ewaso Ng'iro had the highest amount of daily flows of 9.088 m^3/s, while 5DA07-Isiolo had the minimum flows of 0.071 m^3/s. 5DC01-Ewaso Ng'iro also had the highest maximum flows ~36.14 m^3/s , followed by 5BC04-Ewaso Ng'iro (2.16 m^3/s) and 5DA07-Isiolo with a discharge of 1.54 m^3/s. The three stations analyzed depicted different stream flow characteristics throughout the year.







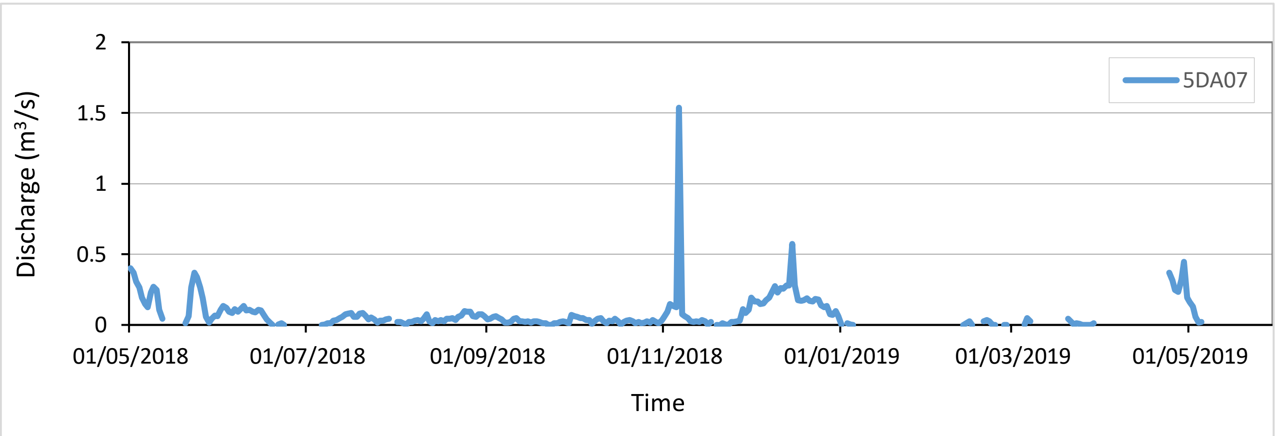
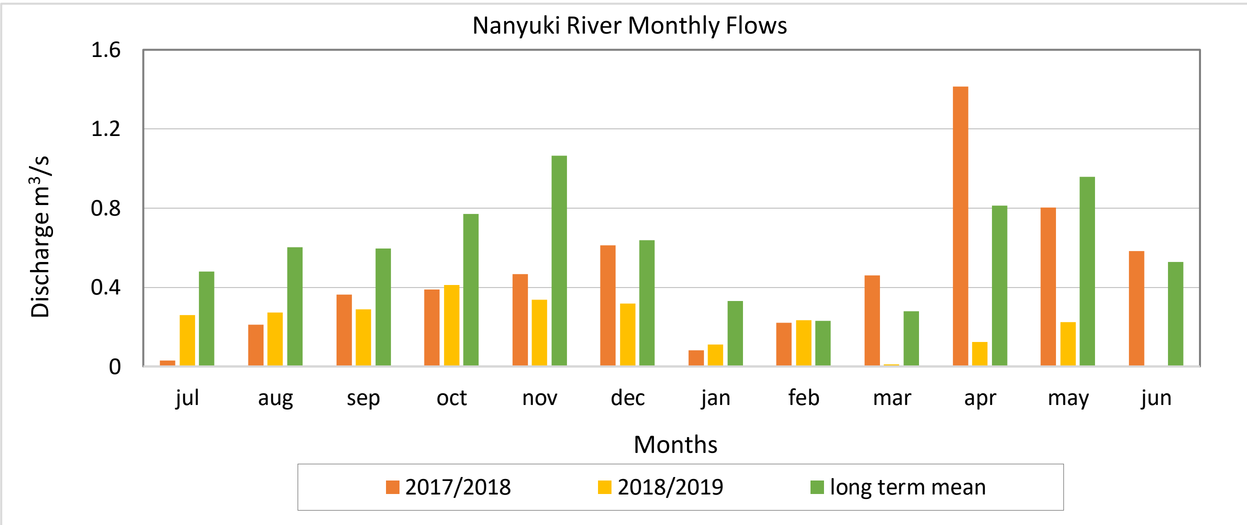


Figure 3.11:Daily flow trends at ENNCA

Comparison of long term mean flows versus mean monthly flows for 2017/2018 and 2018/2019 at 5BE01-Nanyuki River and 5AC15-Ewaso Narok River show that the long term mean monthly flow was above the mean monthly flows in the year under review except for the months of April and May. The flows as observed had sharp rise which should have caused flash floods in the months of April and May. The flow pattern was in tandem with the long term mean in all the stations. Only that the flows in the year under review period were below the mean. This could be attributed to the low rainfall amounts experienced in the entire catchment area. Apart from Ewaso Narok whose flows almost compares with the previous year, 5BE01-Nanyuki show relatively lower flows. The situation could be considered as stable as at now but could very soon slide into alert considering the amount of rainfall received. For ENNCA, where analysis of flow was carried out, they experienced depressed discharge in the months of January, February and March compared to the long-term discharge. During these months incidences of reserve violation were experienced with the rivers drying up completely at some points. Due to the delayed onset of the long rains and the rains received being below the mean, the situation of the water resources availability could not be considered as stable but at an 'alert' level.



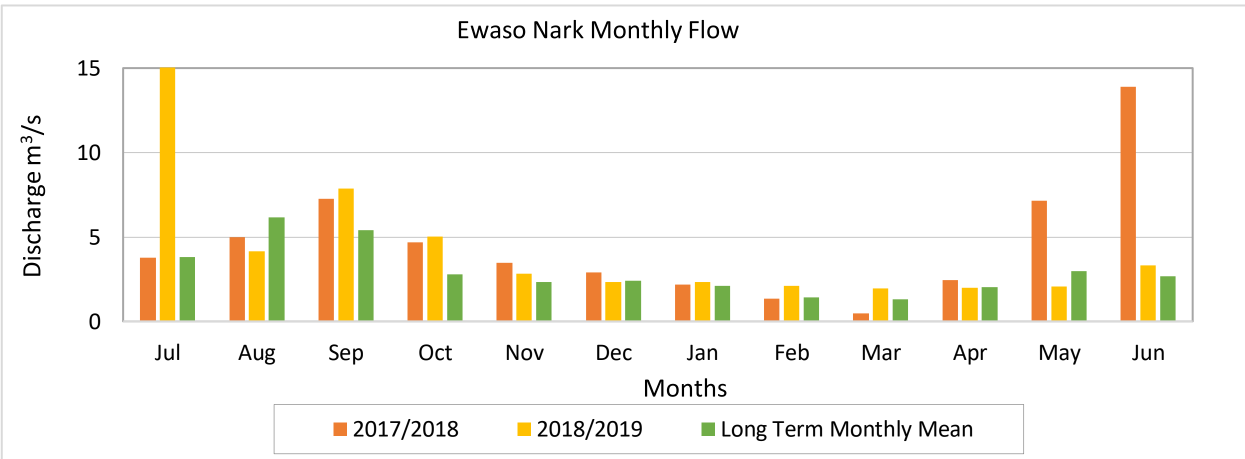


Figure 3.12:Comparison of long term and monthly mean for 2017/2018 and 2018/2019 at 5BE01-Nanyuki and 5AC15-Ewaso Narok

3.6 Comments on Special Events

The floods caused by the current rains have had varied impacts in different areas. Among the flood prone parts of LVSCA, LVNCA, TCA, RVCA, ATHI and ENNCA which include, Lower Nyando, Awach Kano, Lower Sondu, Lower Tana and Lower Gucha Migori, Perkerra and Lower Sabaki the most affected locations during the current floods are Nyando, Lower Tana and Gucha Migori.

For LVSCA, the catchment had water stress cases reported in Nyando, Sondu and Gucha –Migori. These were however contained with the use of water resources user's association forums. Kamagaga and Kakola were affected when Nyando River burst its banks downstream of the National Irrigation Board Intake while Nyora and Kabuto were affected when the Gucha-Migori River burst its banks downstream of Wath Ong'er. The highest recorded flow levels at Nyando River-1GD01 was 2.9 m overtopping Ahero Bridge. It affected the residents of Obiayo village. At Gucha - Migori River-1KB05 at Wath Ong'er was 4.70 m. Due to timely and adequate early warnings issued through WRA Offices and LOGUMI WRUA, general losses and damages were considerably reduced.

For TCA, at lower Tana there were flush floods experienced along River Tana around Garissa town for two days at the end of April. Tana River at Garissa (4G01) has had an early flood warning system that continuously gives the downstream communities early warning alerts every time the water levels reach the flood mark of 3.50 m and by 16th April 2018 the flood mark was 5.6 m. The early alerts are also relayed to the local administration officers and other disaster management stakeholders like Red cross, UNICEF and water suppliers for precautionary measures.

For the RVCA, most rivers recorded low levels in the months of April & May which is normally a high flow period. The onset of long rains was delayed. For ACA, impacts of flash floods in Buna, Habaswein, Modogashe, Khoromey and Ramu in Mandera in which the flash floods destroyed the roads and cut off communication were reported.

For ENNCA and LVNCA no special events were experienced. The flood situation gives us an opportunity to collect data and information which will eventually help WRA and other stakeholders to work towards establishing effective structural and non-structural measures for the mitigation of floods in the flood prone areas and at the same time becoming resilient to climate change. The following photos (Figure 3.13) show flood impacts across the country.

1GD01 at Ahero Bridge

Destroyed crops at Nyando

Wath 'Onger Logger house submerged

Evacuating to Nyora School

Flooded Widsor estate in Garissa

Road destruction in Garissa

Flash floods at Suswa

Flash floods at Narok town

Figure 3.13:Photos showing flood impacts across the country

3.7 Special Studies

At LVSCA special studies carried out included kisumu city and Migori with their environs abstraction and pollution surveys. There were no special studies in the other regions.

4 EMERGING ISSUES

4.1 Challenges

For ENNCA, the biggest challenge has been lacking funding for water resources monitoring and related activities. This has led to partial collapse of the monitoring network. PDB support is not always given prompt attention by HQ. In ENNCA Effluent discharge permitting is not being undertaken due to problems in the PDB which have taken years without being addressed.Lack/ inadequate facilitation for surveillance and enforcement is a major set – back since inspections on works was an activity to be undertaken as an item in the PC and work plan

4.2 Conclusions

For ENNCA, from the analysis, the flows in the rivers are slightly low and could not satisfy all water needs and maintain the reserve. However, from the rainfall data and flow hydrographs of the stations in the entire catchment, it is evident that the rivers could hold enough water to satisfy the reserve and other uses if prudent measures are put into place. There is need therefore to control abstractions in these rivers so that they can flow consistently and meet all the desired needs. For LVSCA, there was not much observed change in the hydrologic cycle pattern in the year compared to other years safe for the low volumes of flow and low annual total rainfall. It was observed that the high rainfall could be linked to the changing rainfall patterns related to climate change.

4.3 Recommendations

The following recommendations are given for consideration:

- In view of the low number of operational climatic stations in the regions, it is hoped that more financial resources can be availed for the implementation of the CMS in the region.
- There is need to consider training more staff on operation of modern hydrometric equipment since there are plans to install more telemetric stations within the regions.
- There is need to consider provision of appropriate means of transport that can handle the regions' tough terrain. Finances for their operations with respect to fuel, repair and maintenance is too low or sometimes lacking absolutely. Improvement is therefore needed with respect to suitability of vehicles and the associated operational cost.
- Need to consider deploying technical staff in ground water, surface water and water quality in stations which lack this expertise.
- For the RVCA, Surface water monitoring is paramount, but the region has a shortage of monitoring equipment with three offices lacking measuring equipment like current meter or flow

tracker i.e. Kabarnet, Lodwar and Regional office. Naivasha office also a faulty current meter. The office requests for supply of the equipment.

- For TCA, the following are the conclusions;

i) Timely releasing of funds to facilitate timely undertaking of PC activities – inspection, and enforcement activities

ii) Intensify enforcement of compliance of permit conditions through regular inspections of works

iii) Step up awareness creation to WRUAs on common intake construction.

iv) There is need to develop water allocation plan for Rivers Sub catchment where Abstraction and pollution survey has been undertaken.

v) Working tools to be enhanced for flood capturing and alertness.

- For LVSCA, these are the recommendations;

i) Riparian land and wetland area need to be marked for management and riparian landowner need to be educated in management and good use of the riparian land. The eucalyptus plantation in wetland, along the water course and within the riparian land need to be discouraged

ii) The informal settlements along the rivers in the urban areas need to be relocated or provided with better sanitation facilities. Sand harvesting along the rivers and in the lake needs to be discouraged.

iii) More effort be put on acquisition of data in good time and capturing of important and major hydrological events. Facilitation for data collection and payment of the gauge readers to be effected.

iv) The identified illegal abstractors need to be sensitized and brought to compliance with the law while the persistent ones be prosecuted

5 SURFACE WATER QUALITY

5.1 Description of Monitoring Network

Table 5-1: Description of Monitoring Network

	National	MU	Intra-MU	Special	Total	% Operational
ACA	3	6	31	3	43	
ENNCA	1	5	30	4	40	**90**
LVNCA	5	16	15	2	38	**100**
LVSCA						
RVCA						
TCA	1	18	16	29	64	**74**
Total						

LVNCA has 38 No. of surface water monitoring stations and 16No. Ground water monitoring stations, only 28No. and 11No. of stations are operational respectively. In all regions full implementation of the Water Quality Monitoring Schedule was however hampered by inadequate funding.

The water quality management issues in Athi region are varied and complex due to the fact that the region comprises two of the three major cities in the country, Nairobi and Mombasa. This gives rise to industries, headquarters and offices for Central Government and Non- Governmental Organizations. As a result, there is population influx into the cities. The City Council housing development is not able to provide housing to keep pace with the population influx. This gives rise to informal settlements which lack proper sanitation facilities. The Athi catchment Water Quality situation can be categorized into three zones; the Upper, middle (Galana) and lower Zones also known as Sabaki.

The Water Quality in Upper Athi is influenced to a large extent by partially treated or untreated effluents from industries and informal settlements which lack proper sanitation facilities. In addition, poor land use management exacerbates water quality deterioration. Use of excess fertilizers and herbicides lead to nutrients washed away by surface run-off into the rivers. This causes growth of invasive weeds e.g Water hyacinth in some water bodies like Nairobi Dam, River Athi at RGS 3DA2 and 3BD1. In Nairobi, slums are constructed in riverine areas. In Kiambu and Kajiado districts; streams, rivers and wetlands have been encroached into for agricultural use.

In Middle Athi, water resources are prone to pollution emanating from bare land that has been cleared of its vegetation cover to give way to settlements and agriculture in order to accommodate the growing population. This results to soil erosion from uncovered loose topsoil. During the rainy seasons the topsoil is carried away by surface run-off into the watercourses. These impacts negatively on the water quality of the resources leading to highly coloured water with high loads of Total Suspended and Dissolved Solids and siltation of dams and lakes.

In the lower Zone (Sabaki), sand harvesting, agriculture, sisal decortications and over abstraction of ground water resulting to Sea Water intrusion are the main activities that contribute to water quality deterioration. Below are Surface Water and Ground Water monitoring network.

Nolturesh Lumi sub-catchment is characterized by much agricultural activity and deforestation. The sub-catchment is characterized by flooding with high sediment loads. The water quality is affected by sediment quality and pesticides used for agriculture.

5.2 Improvements to Network Infrastructure

During the year there was a redesign of the sediment monitoring network in LVNCA. This followed a World Bank recommendation that sediment monitoring should be impact oriented in order to capture the impacts of intervention measures being undertaken by the WRUAs. Sediment monitoring program was financed by World Bank through KWSCRP.

5.3 Improvements to Data Quality

During the year, Water Quality staff in the region participated in the training and roll out of MIKE INFO, a DHI Software Platform for managing data and information for water resources planning and management. The objectives of the roll out were:

- Installation and configuration of the Mike Info system
- Capacity building the responsible staff accordingly so that they can be able to manage the MIKE INFO Water Resources Information Management system.

The proposed migration from Mike Basin to Mike Info would improve the management of quality of data. Both laboratory and field equipment were calibrated before use. Quality Assurance and Quality Control practices were applied in the laboratory where blanks are analysed alongside the samples in all of the sample analysis while some samples are analysed in duplicates and necessary corrections made.

5.4 Assessment of Surface Water Quality

5.4.1 Ewaso Ng'iro North catchment area

Table 5-2: Turbidity for the last monitoring period

Station	Data sets	Turbidity for the last monitoring period	Long Term Mean	Maximum Recorded Value	Minimum Recorded Value
5ED01(Achers Post)	22	4780	837.2	6180	**5.8**
5DA07 (Isiolo)	16	227	86.13	786	**0.81**
5BC04(Ewasong'iro)	26	30.72	168.7	798	**13.51**
5BE20(Nanyuki)	20	0	57.8	357	**0**
5DC01(Ewasong'iro)	**2**	**48.3**	**26.5**	**48.3**	**4.78**

5.4.2 Lake Victoria North Catchment Area

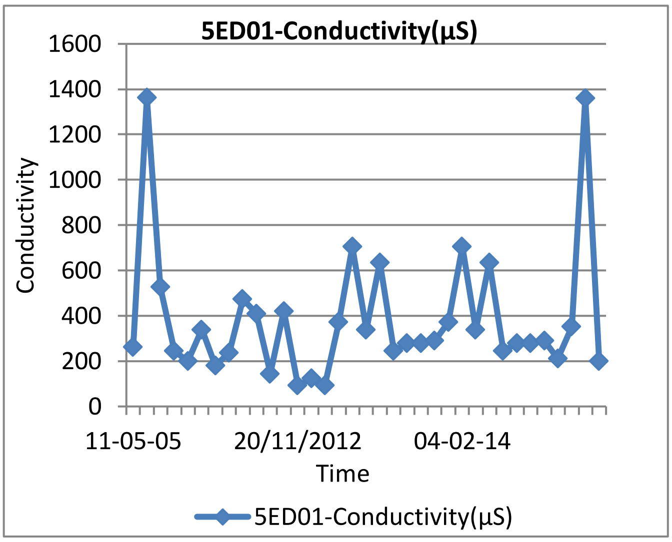
Table 5-3: Mean for the year 2018/2019 for sediment tons/day

	Station	Mean for the year 2018/2019 for sediment tons/day	Long term mean	Maximum recorded values	Minimum recorded values
1.	Malakisi (1AD02, N)	47.61	137	614	1.35
2.	Malaba (1AA02, N)		228	3,688.2	1.09
3.	Sio (1AH01, N)	21.90	245	608	20
4.	Nzoia at Ruambwa (1EF01, N)		3,363	14592.84	26.38
5.	Yala at Bondo (1FG02, N)		242	550	21
6.	Koitobos (1BE02, MU)	109.57	168	3110	3.2
7.	Nzoia at Mumias (1DD01, MU)		1,661	12963.88	44
8.	Isiukhu (1EB02, MU)		158	1,376	2.82

9.	Nzoia at Brigadier (1BD02, MU)	691.4	70	93	4.2
10.	Lusumu (1ED01, MU)		571	4,321	2.63
11.	Wuroya (1EG02, MU)		74	210	0.7
12.	Kipkaren (1CE01, MU)	168.72	73	349	4
13.	Nzoia at Webuye (1DA02, MU)	4388.47	860	4388.47	34
14.	Kuywa at Matisi (1DB01,		286	393	60
15.	Noigamaget	332			
16.	Kamukuywa		12.23		
17.	Nzoia @ Mois Bridge	553.26			
18.	Rongai	56.14			
19.					
20.	Sio (1AH01)		245	608	48
21.	Nzoia at Ruambwa		3,363	5,362.30	88.61
22.	Yala at Bondo		242	550	21
23.	Ellegerine				
24.	Nundoroto				
25.	Olare Onyonkie				
26.	Kimondi R	17.48			
27.	Mokong	11.12			
28.	Garagoli				
29.	Edzawa R				

5.4.3 Results

1. **Ewaso Ng'iro River at 5ED01- National station at Archers Post**



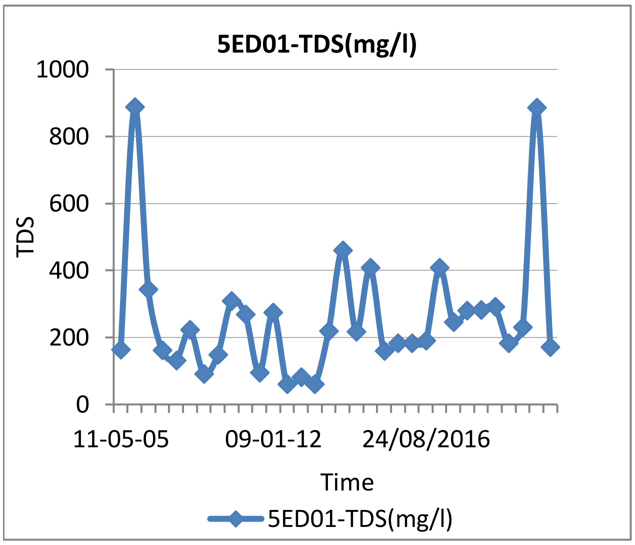


Figure 5.1: Conductivity and Total Dissolved Solids Ewaso Ng'iro River at 5ED01

Considering the national station Ewasong'iro River at 5ED01, it is obvious from the above graphs that there is almost a direct correlation between Conductivity and Total Dissolved Solids. This is more so since one parameter can be empirically deduced from the other. Both parameters exhibits a very gradual increasing trend with only two high peaks in May and Febryary of the year 2005 and 2018 respectively .

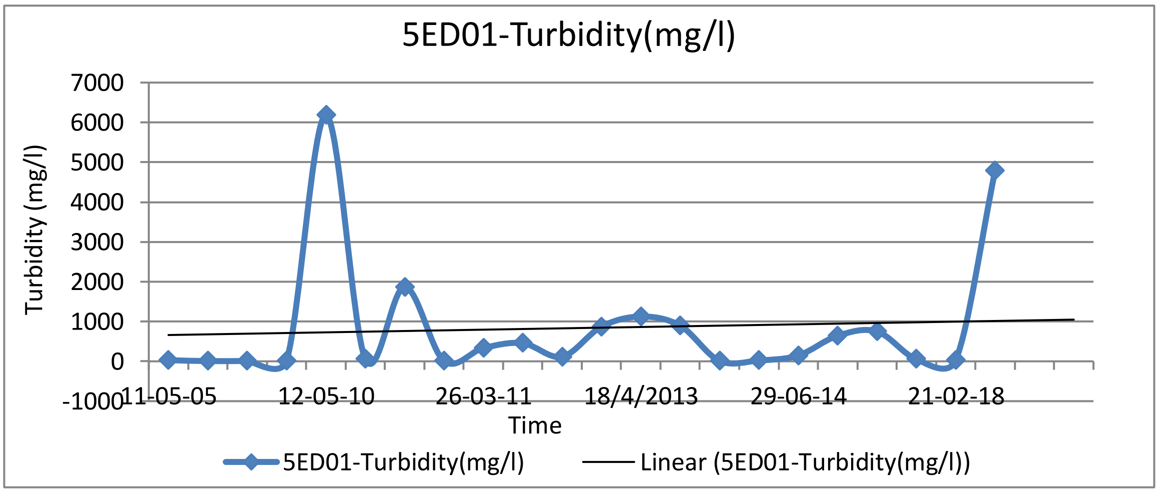


Figure 5.2: 5ED01-Turbidity(mg/l)

Turbidity exhibits an inresaing trend as contrased from the last quarters a situation brought about this quarters peak of 4780NTU which in turn has been contributed by the seasons heavy rains.

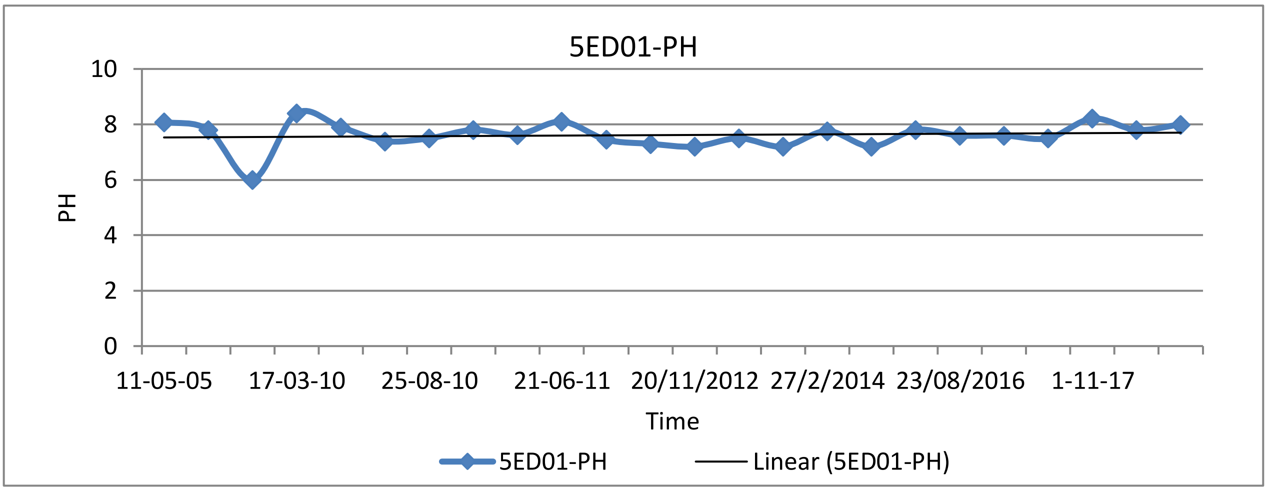


Figure 5.3: 5ED01-PH

The degree of seasonal variation of this parameter is within a very narrow margin and slightly above the neutral point.The parameter is insignificantly rising with time.

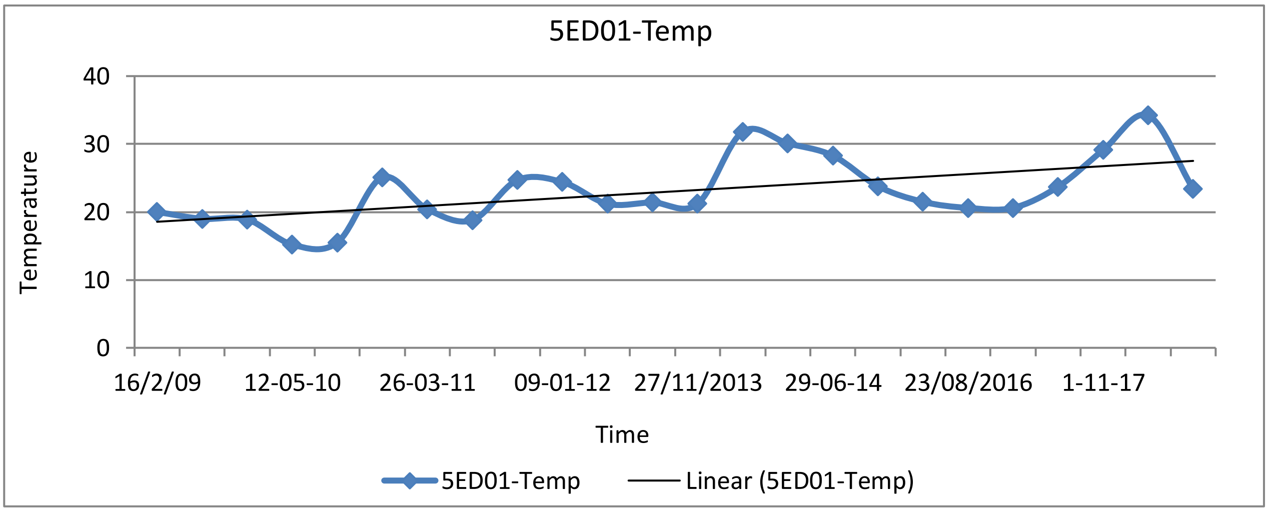


Figure 5.4: 5ED01-Temperature

The temperature varies between 15°C to 34°C, the highest being recorded in the last monitoring period and dropping again in the current reporting period. Initially, all parameters used to be investigated in the lab (cool weather) as compared to the present situation where some parameters like temperature are done in situ (Hot weather). The general trend cannot therefore be used to explicitly define the temperature trends of the water in the station under consideration.

2. **Isiolo River at 5DA07- MU station**

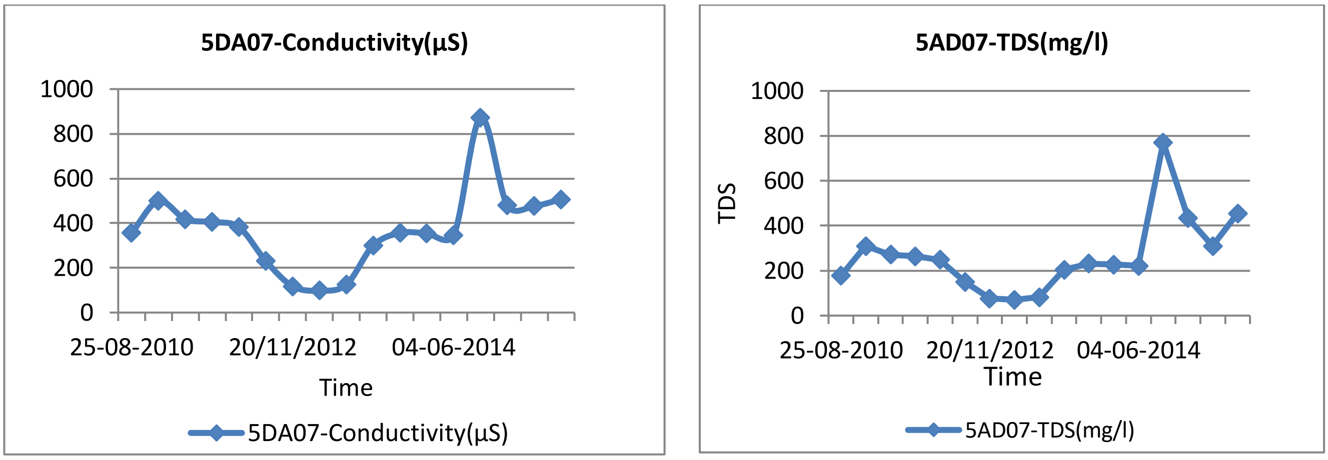


Figure 5.5: Isiolo River at 5DA07- MU station

This station is in the neighbourhood of the national station 5ED01 and the trend in these parameters are on an increasing trend.

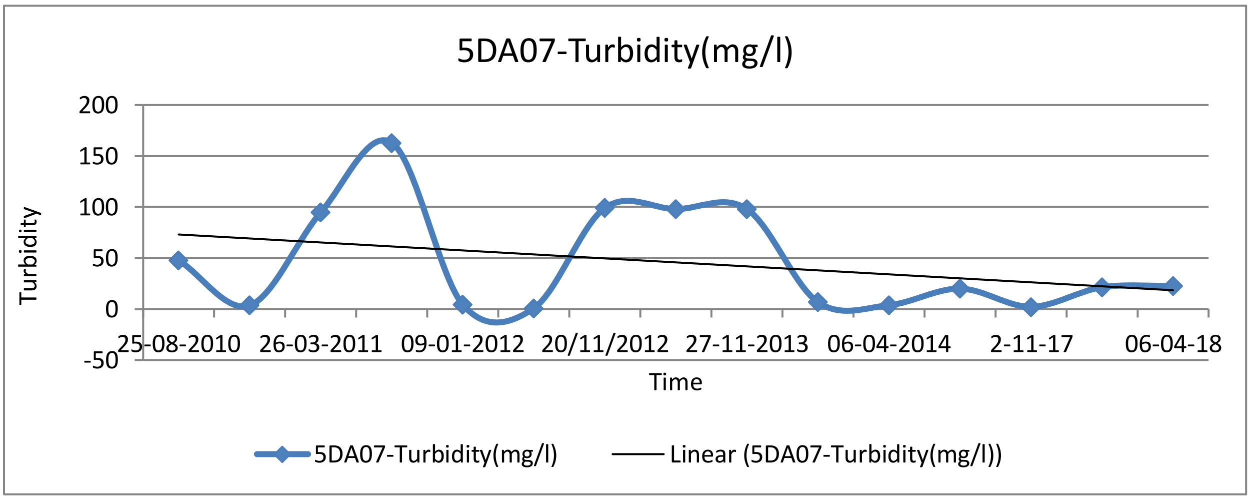
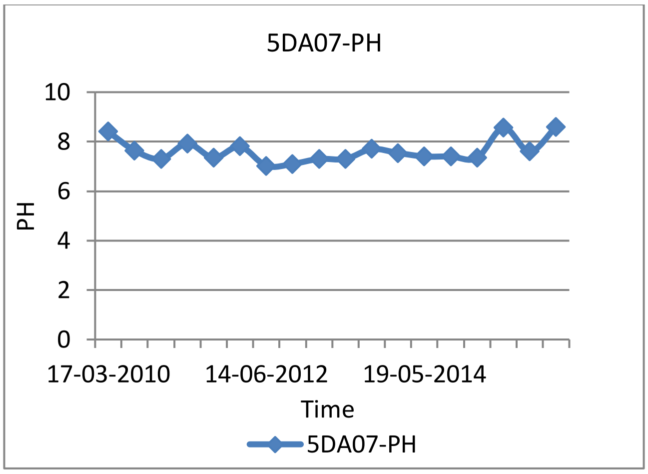


Figure 5.6: 5DA07-Turbidity(mg/l)

The decreasing trend in turbidity can be considered normal when the rain is considered to be decreasing. Contribution of this parameter to the national station is insignificant since it is the last permanent tributary to Ewasongiro River and both quality and discharge values are very low compared to the national station in order of magnitude.



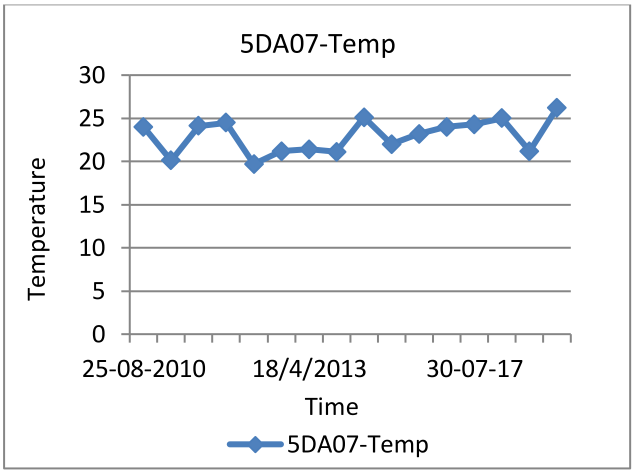
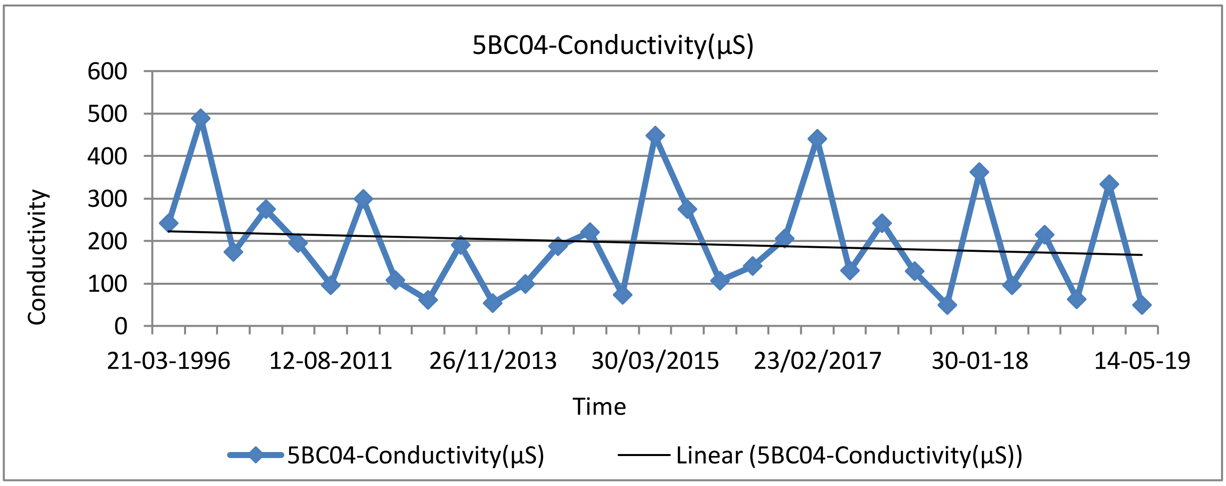


Figure 5.7: PH and Temperature at 5DA07

Both of the above parameters are exhibiting an increasing trend. This is a shift from the previous observation where pH was declining. The ranges between minima and maxima are closer as compared to the national station (Ewasongiro River 5ED01)

3. Ewaso Ng'iro River at 5BC04



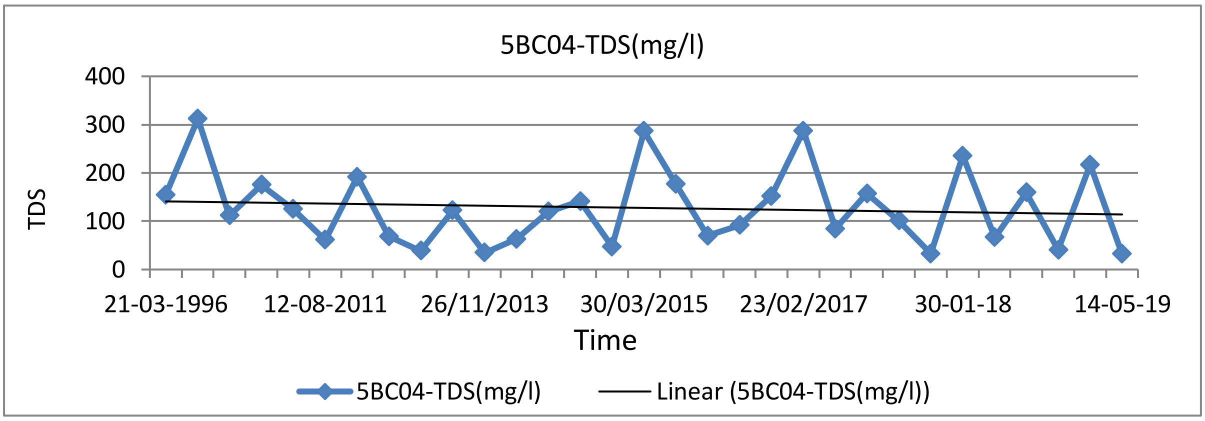


Figure 5.8: Cvonductivity and TDS at Ewaso Ng'iro River at 5BC04

This station monitors part of abadare and part of Mt. kenya river systems. The trend in both conductivity and TDS are insignificantly declining with time.

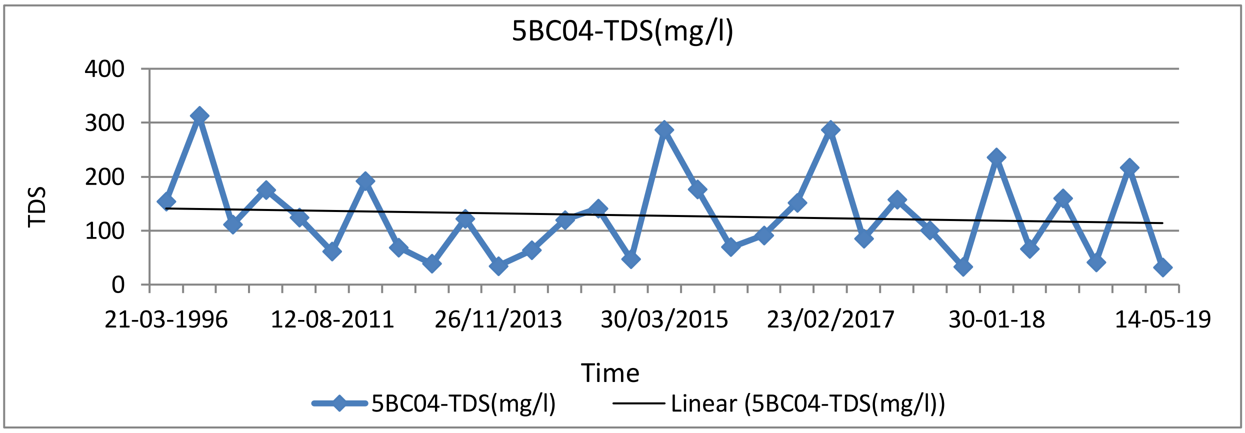
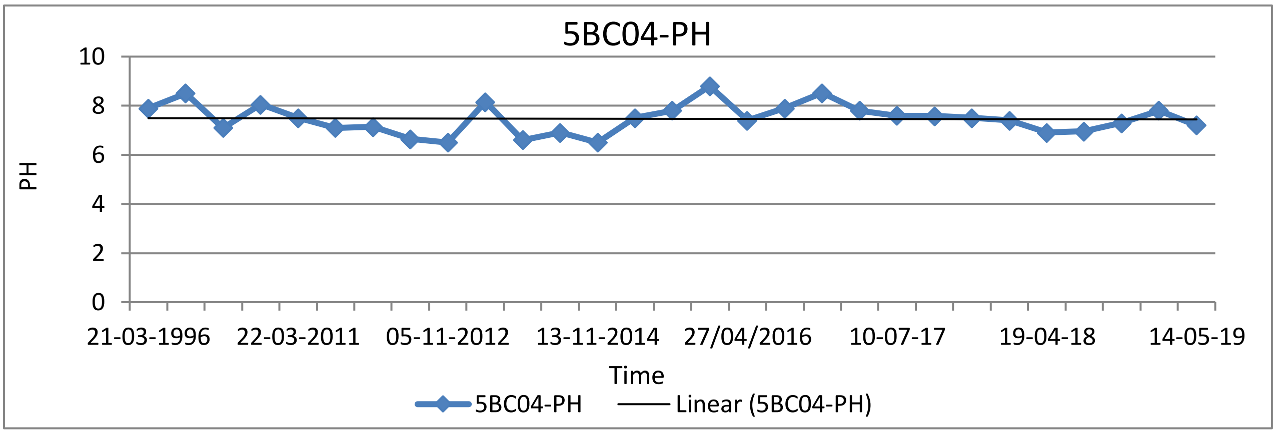


Figure 5.9: 5BC04-TDS(mg/l)

Turbidity exhibits an insignificant declinng trend. Increased rains results in decreased conductivity and an increase in turbibity. This is also true in most cases when rains are low. A deviation from this interacting trend may be associated with a well conserved catchment.



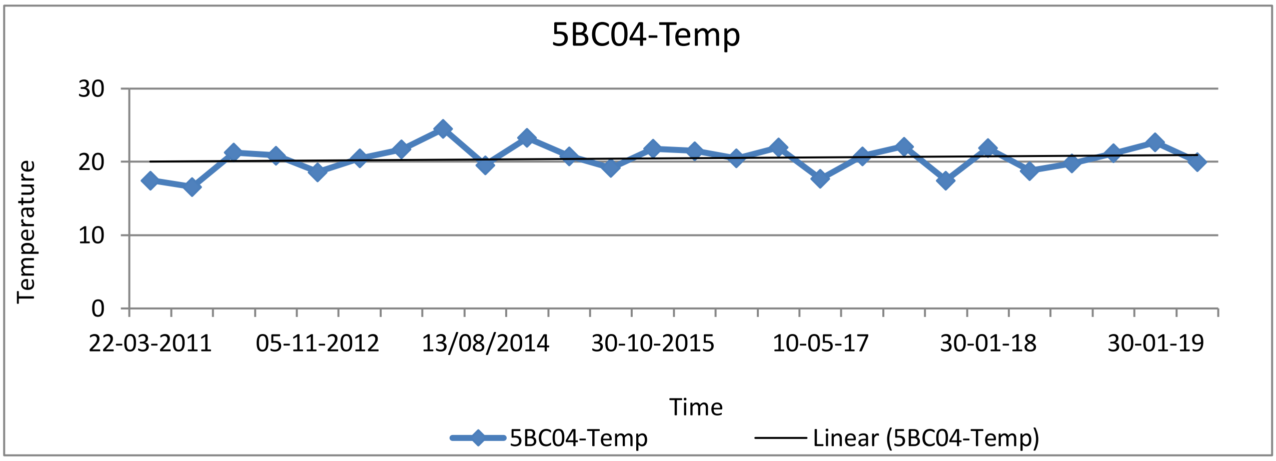
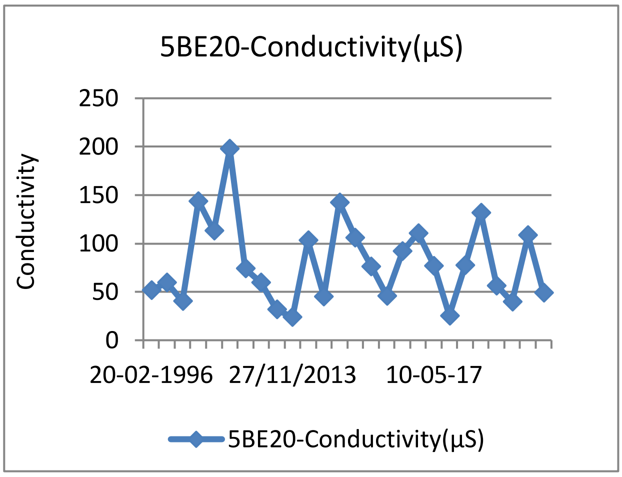


Figure 5.10: 5BC04 PH and Temperature

As in most of the stations, pH and temperature variation is within a very narrow range and does not raise any suspicion on unusual happenings within the river system or its environs. The parameters are exibiting insignificantly declining and increasing trends respectively.

1. **Nanyuki River at 5BE20**



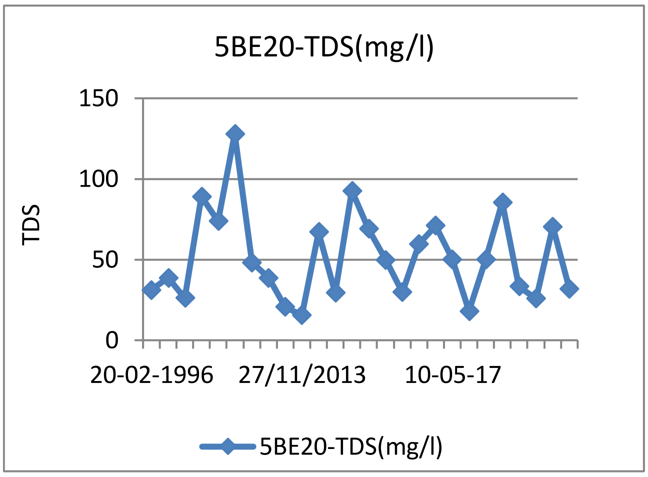


Figure 5.11: 5BE20-Conductivity(µS) and TDSS

This station monitors waters from Mt. Kenya river systems. Both conductivity and TDS are generally decreasing insignificantly with time but with seasonal variations.

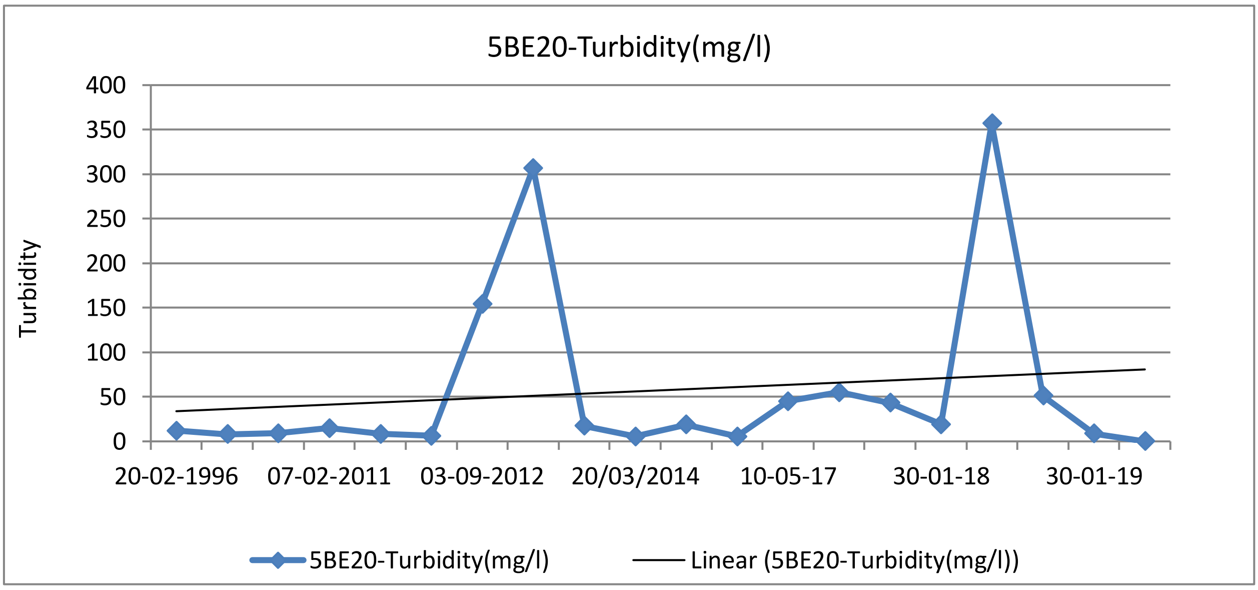
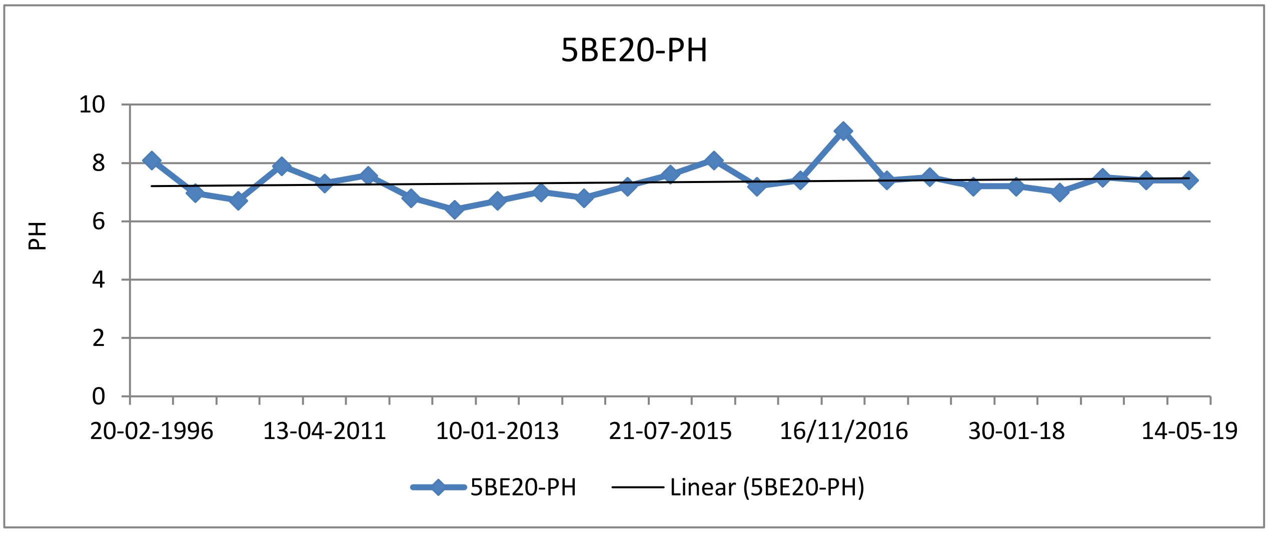


Figure 5.12: 5BE20-Turbidity(mg/l)

Turbidity values are low (≤15NTU) in the beginning of monitoring period and sharply rising reaching a peak of 307mg/l in Nov 2012 with a sharp drop and then rising again to a peak of 357mg/l in April 2018 and then falling in the last two monitoring periods.



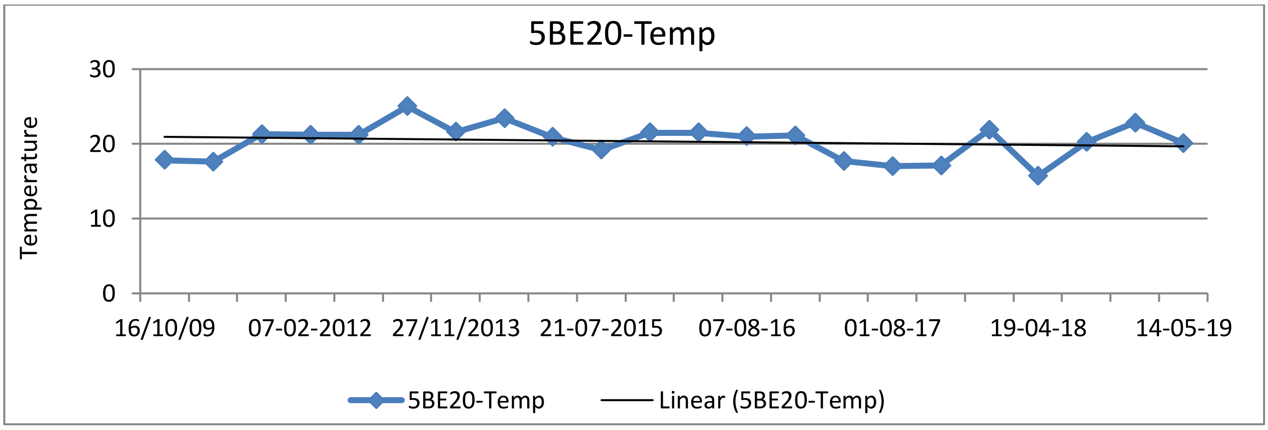


Figure 5.13: 5BE20-PH and Temperature

As in most of the stations pH and temperature variation is within a very narrow range and figures accomodative within surface water quality monitoring expectations. While the trend on pH is on the rise , temperature is decreasing

5.4.4 Athi Catchment Area

Table 5-4: Distribution of Surface Water Monitoring Network, Athi Catchment (RGS Stations

STATION ID		STATION NAME	APRIL	MAY	JUNE	TOTAL
Nairobi Sub-Region						
1.		Ngong River at Nairobi Dam	×	×	×	**0**

2.	3AA04	Mbagathi River at Rongai Bridge	✓	×	✓	**2**
3.	3BA10	Ruiruaka at Runda Bridge	✓	×	✓	**2**
4.	3BA29	Nairobi River at Museum Hill	✓	×	✓	**2**
5.		Riara R U/S Effluent	✓	✓	×	**2**
6.		Kiambu Final Effluent	×	×	×	**0**
7.		Riara R D/S Effluent	✓	✓	×	**2**
8.	3BC08	Ruiru River	✓	✓	×	**2**
9.	3BB12	Kamiti River	✓	✓	×	**2**
10.		Kiu@Thika Road	✓	✓	×	**2**
11.		Komo River	×	×	×	**0**
12.		Kiu River @ mwihoko	✓	✓	×	**2**
13.	3DA02	Athi-River	✓	✓	×	**2**
14.	3CB05	Ndarugu River	✓	✓	×	**2**
15.	3CB35	Ndarugu	✓	✓	×	**2**
16.	3BD04	Thiririka	×	×	×	**0**
17.	3BD05	Thiririka River	✓	✓	×	**2**
18.	3CB07	Ruabora	✓	✓	✓	**3**
19.	3BC15	Gatamaiyu River	✓	✓	×	**2**
20.		River Athi @ Baricho	×	×	×	**0**
21.	3MH26	Marere Spring	×	×	×	**0**
22.	3KG01	Umba R.	×	×	×	**0**
23.	3KD06	Mkurumudzi River	×	×	×	**0**
24.		Voi River	×	×	×	**0**
25.		Ngoni River	×	×	×	**0**
26.		Mwache/Pemba River	×	×	×	**0**
Total			**31**			

Table 5-5: Electrical conductivity (EC) comparison for selected stations

Station	Years of Data	Mean for Year EC (µS/cm)	Long Term Mean	Maximum Recorded Value	Minimum Recorded Value
Athi at Baricho (3HA13)	2012 2013 2014 2015 2016 2017 2018	455 405 547.9 487.75 480.4 685.94 713.12	539.30	782	**298.3**
River Ramisi (3KB01)	2014 2015 2016 2017	1794.2 2088 3552 1889.75	2330.99	3559	**774.8**
Umba River (KG01)	**2014** **2015** **2016** **2017**	**1838.2** **1367.48** **1420.27** **1309.17**	**1483.78**	**2422**	**763**

Table 5-6:PH comparison for selected stations

Station	Years of Data	Mean pH for the year	Long Term Mean	Maximum Recorded Value	Minimum Recorded Value
Athi at Baricho (3HA13)	2012 2013 2014 2015 2016 2017 2018	8.05 8.18 8.25 8.45 8.81 8.82 6.74	8.18	10.90	**6.69**
Marere Spring (3MH26)	2012 2013 2014	6.8 6.65 6.31	6.65	8.16	**5.69**

	2015	6.58			
	2016	5.78			
	2017	7.78			
	2018	7.48			
River Ramisi	**2014**	**7.19**			
(3KB01)	**2015**	**7.78**			
	2016	**9.53**	**8.22**	**9.66**	**7.04**
	2017	**8.40**			

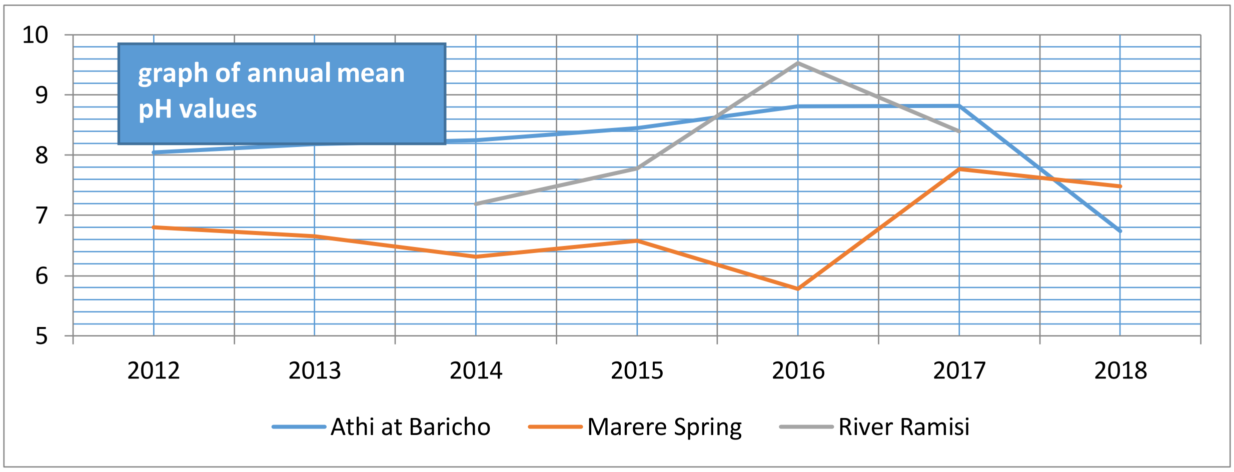


Figure 5.14: PH Trend for selected stations

- pH values in River Ramisi has increased from an annual average value of 7.19 in 2014 to 7.78 in 2015 after which there has been a sharp increase to an average of 9.53 in 2016 before a slight drop to 8.40 in 2017. The pH is still highly alkaline and beyond the maximum allowable Kenyan standard of 8.5. It is an indication of contamination by highly basic materials around the river catchment, whose source should be established, and mitigation measures put in place.

- pH values in Athi River at Baricho (3HA13) remained relatively constant between 2012 (pH 8.18) and 2014 (pH 8.25) after which a gradual gentle increase is noted until 2016 (pH 8.25 to 8.81) before a decrease in the average value of 8.82 in 2017. The highest value for the station has also been recorded in 2017 at 9.3. This is an indication of increased loading of the river with basic chemical materials from upstream locations from a combination of point and non-point sources. Adequate corrective measures should be done upstream. The value of 2018 was taken during the wet season and this explains the low value.

- pH in Marere Spring has gradually varied downwards from 6.8 in 2012 to 6.31 in 2014 before rising to 6.58 in 2015 and decreasing again to 6.55 in 2016, however there is an upward trend to an average value of 7.77 in 2017, an increase of 1.22 pH units from the 2016 values. The highest pH for the station was recorded during the period at a value 8.16, an increase of 0.02 units from the pH value of 8.14 recorded in 2017. The pH value is within the Kenyan standards for drinking water.

a) Electrical Conductivity for selected stations

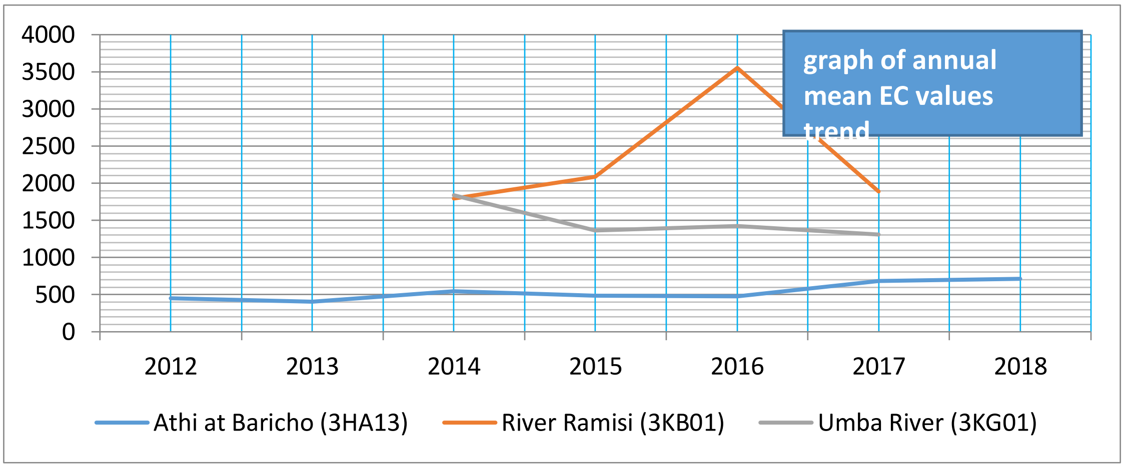


Figure 5.15: Electrical Conductivity for selected stations

- Conductivity levels in Athi River at Baricho (3HA13) oscillated around 500 µS/cm between 2012 and 2016. From 2016 onwards however, there is recorded an increasing trend, from annual mean 0f 480.4µS/cm recorded in 2016 to 713.13 µS/cm recorded in 2018. The highest value of 782µS/cm was also recorded in 2017. This is an indication of increasing mineralization of the river upstream that has resulted to a cumulative impact downstream.
- Conductivity in Umba River has continually dropped from 1838.2µS/cm in 2014 to 1367.48µS/cm in 2015 after which gradual increase has been experienced up to a value of 1420.27µS/cm in 2016.The EC value has eventually dropped below an annual mean of 1067.67µS/cm in 2017. The river catchment should be constantly monitored to mitigate the effects of the non-point sources contaminating the river system.
- Conductivity in River Ramisi gradually increased from annual average of 1794.2µS/cm in 2014 to 2088µS/cm in 2015 respectively, before a sharp increase to an annual average of 5684µS/cm in 2016. In 2017, however, data collected during the dry season yielded an average annual value of 1890µS/cm. This is an indication of reduced levels of salinity to the river system. Studies to identify the source of salinity to the river system **need to be done and recommendations done.**

5.4.5 Tana Catchment Area

Table 5-7:Year to Long Term Comparison

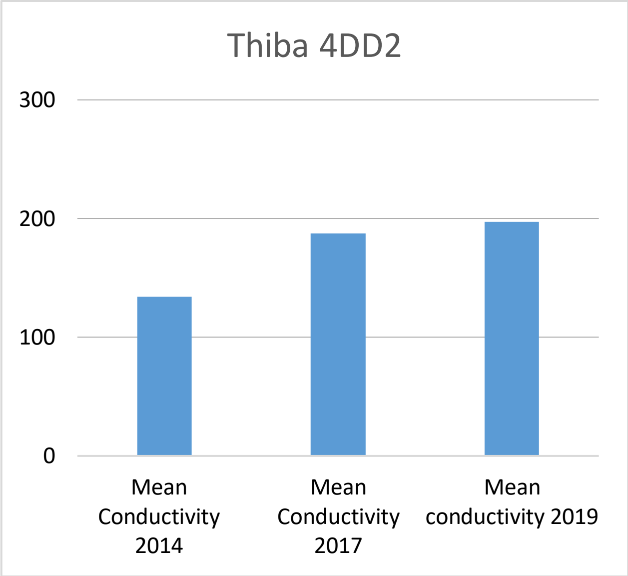
Station	Years of Data	parameter	Mean for Year XX for certain parameter	Long Term Mean	Maximum Recorded Value	Minimum Recorded Value
Murubara	July 2015-Dec 2018	Temp	21.52	21.52	24.7	20.3
4DA05	July 2015-Dec 2018	pH	7.9	7.9	8.1	7.7
	July 2015-Dec 2018	Turbidity	59.5	59.5	106	23
	July 2015-Dec 2018	Cond	184.6	184.6	211	129
	July 2015-Dec 2018	TDS	96.9	96.9	106	99
Murubara	July 2015-Dec 2018	Temp	21.02	21.02	23.5	20
4DA06	July 2015-Dec 2018	pH	8.4	8.4	8.6	7.9
	July 2015-Dec 2018	Turbidity	83.4	83.4	190	25.7
	July 2015-Dec 2018	Cond	247.7	247.7	362	135
	July 2015-Dec 2018	TDS	134.3	134.3	181	70
Nyamindi	July 2015-Dec 2018	Temp	17.3	17.3	18.3	16
4DB05	July 2015-Dec 2018	pH	7.6	7.6	8.19	7.2
	July 2015-Dec 2018	Turbidity	24.1	24.1	52	11
	July 2015-Dec 2018	Cond	65	65	90	48
	July 2015-Dec 2018	TDS	34.9	34.9	45	29.8
Rwamuthambi	July 2015-Dec 2018	Temp	20.4	20.4	23.4	19
4BC05	July 2015-Dec 2018	pH	8.2	8.2	8.5	7.9
	July 2015-Dec 2018	Turbidity	14.7	14.7	17.1	8.5
	July 2015-Dec 2018	Cond	83.3	83.3	93	60
	July 2015-Dec 2018	TDS	43.6	43.6	47	37.2
Thiba	July 2015-Dec 2018	Temp	22.1	22.1	23	21.3
4DD02	July 2015-Dec 2018	pH	8.15	8.15	9.15	7.62
	July 2015-Dec 2018	Turbidity	83.2	83.2	127	37.5
	July 2015-Dec 2018	Cond	154.2	154.2	244	90.5
	July 2015-Dec 2018	TDS	92.4	92.4	135.8	65

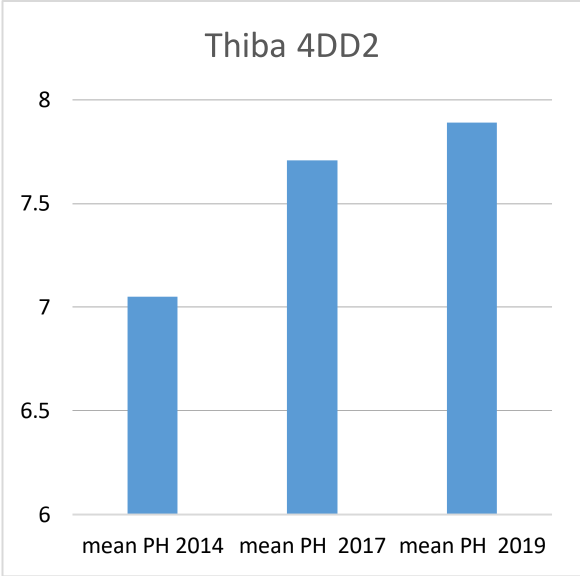
Nyamindi	July 2015-Dec 2018	Temp	18.6	8.6	19.4	17.5
4DB05	July 2015-Dec 2018	pH	8.13	8.13	8.7	7.5
	July 2015-Dec 2018	Turbidity	47.4	47.4	118.1	22.2
	July 2015-Dec 2018	Cond	62.23	62.23	72	41.91
	July 2015-Dec 2018	TDS	33.7	33.7	42	25
Rupingazi	Jan 2018 -Mar 2019	Temp	21.2	21.2	23	19.4
4DC03	Jan 2018 -Mar 2019	pH	7.3	7.3	7.9	6.7
	Jan 2018 -Mar 2019	Turbidity	88.4	88.4	166	10.7
	Jan 2018 -Mar 2019	Cond	173.6	173.6	271	76.2
	Jan 2018 -Mar 2019	TDS	102.5	102.5	168	37
Thiba 4DA11	Jan 2018 -Mar 2019	Temp	23.2	23.2	24.8	21.5
	Jan 2018 -Mar 2019	pH	6.9	6.9	7.04	6.77
	Jan 2018 -Mar 2019	Turbidity	13.3	13.3	19.5	7.1
	Jan 2018 -Mar 2019	Cond	60.2	60.2	63.6	56.8
	Jan 2018 -Mar 2019	TDS	37.3	37.3	39.4	35.2
Thiba 4DD2	2014 - 2019	Temp	22.4	22.4	23.1	22
	2014 - 2019	pH	7.55	7.55	7.89	7.05
	2014 - 2019	Turbidity	28.7	28.7	46	13
	2014 - 2019	Cond	172.9	172.9	197	134
	2014 - 2019	TDS	107.2	107.2	122.1	88.1
Rwamuthambi	2014 - 2019	Temp	21.9	21.9	24.6	19.7
4BC05	2014 - 2019	pH	7.34	7.34	8.05	6.87
	2014 - 2019	Turbidity	37.1	37.1	43.3	34
	2014 - 2019	Cond	90.2	90.2	146	49.7
	2014 - 2019	TDS	55.9	55.9	90.5	30.8
THEGU 4AA2	2018 - 2019	Temp	19.24	19.24	24.1	16.71
	2018 - 2019	Turbidity	20.87	20.87	97.6	2.21
	2018 - 2019	pH	8.48	8.48	10.39	6.9
	2018 - 2019	Cond.	222.46	222.46	731	35
SAGANA	2018 - 2019	Temp	19.74	19.74	23.7	15.8
4AA5	2018 - 2019	Turbidity	39.38	39.38	187	4
	2018 - 2019	pH	8.911	8.911	12.4	7.74
	2018 - 2019	Cond	358.67	358.67	820	143

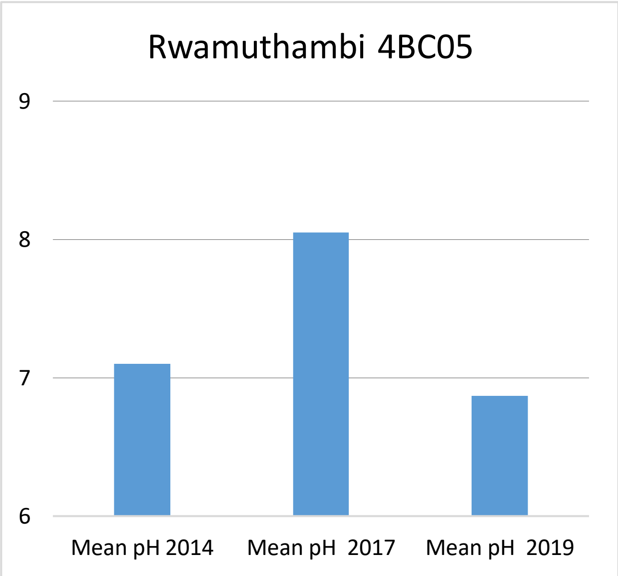
SAGANA 4AC3	2018 - 2019	Temp	19.17	19.17	22	15.8
	2018 - 2019	Turbidity	48.12	48.12	176.9	2.91
	2018 - 2019	pH	8.62	8.62	9.44	8.1
	2018 - 2019	Cond.	130.45	130.45	132	111.8
CHANIA 4CA2	2018 - 2019	Temp	19.93	19.93	22.85	17.4
	2018 - 2019	Turbidity	32.4	32.4	153	1.4
	2018 - 2019	pH	9.24	9.24	9.97	6.97
	2018 - 2019	Cond.	93.85	93.85	194	52
GITHIKA 4BC6	2018 - 2019	Temp	15.9	15.9	20.47	11
	2018 - 2019	Turbidity	8.51	8.51	39.7	2.9
	2018 - 2019	pH	7.73	7.73	10.04	6.37
	2018 - 2019	Cond.	54.38	54.38	204	17.66
CHANIA 4CA3	2018 - 2019	Temp	16.44	16.44	21.79	13.2
	2018 - 2019	Turbidity	37.98	37.98	202	3.5
	2018 - 2019	pH	7.74	7.74	9.05	6.65
	2018 - 2019	Cond.	57.59	57.59	89	33
GURA 4AD1	2018 - 2019	Temp	19.29	19.29	25.85	15.6
	2018 - 2019	Turbidity	19.99	19.99	58.3	2.14
	2018 - 2019	pH	9.04	9.04	11.85	7.5
	2018 - 2019	Cond.	123.53	123.53	115	45
RAGATI 4BB1	2018 - 2019	Temp	19.81	19.81	19.6	16.48
	2018 - 2019	Turbidity	83.5	83.5	81.9	8.1
	2018 - 2019	pH	7.91	7.91	8.58	7.32
	2018 - 2019	Cond.	74.8	74.8	83	55
NAIROBI 4AA4	2018 - 2019	Temp	17.82	17.82	23.43	14.24
	2018 - 2019	Turbidity	54.98	54.98	259	1.49
	2018 - 2019	pH	8.13	8.13	9.14	7.2
	2018 - 2019	Cond	170.91	170.91	795	48
MURINGATO 4AB1	2018 - 2019	pH	8.6	8.6	10.91	7.84
	2018 - 2019	Temp	17.41	17.41	19.94	15.64
	2018 - 2019	Turbidity	80.72	80.94	219	26.5
	2018 - 2019	Cond	250.4	250.4	340	183
	2018 - 2019	Temp	18.39	18.39	20.16	15.2

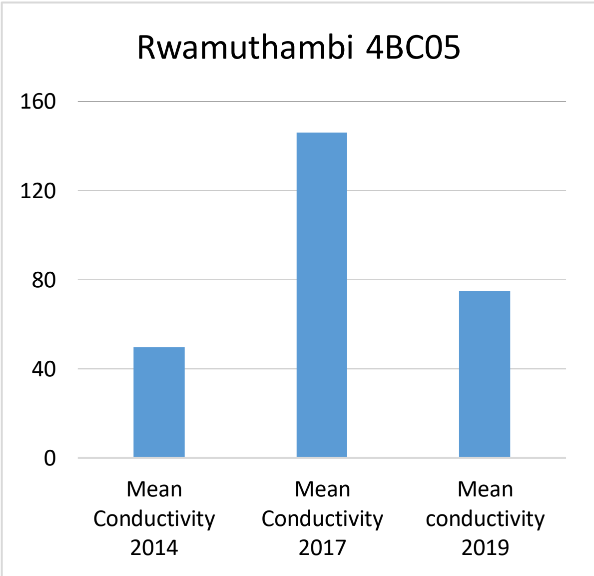
AMBONI 4AB6	2018 - 2019	Turbidity	45.01	45.01	13.1	8.7
	2018 - 2019	Cond.	206.71	206.71	178	90
	2018 - 2019	pH	8.4	8.4	9.8	7.61
SABASABA 4BF1	2018 - 2019	pH	7.9	7.9	8.79	7.41
	2018 - 2019	Temp	20.61	20.61	23.41	17.9
	2018 - 2019	Turbidity	1185.89	1185.89	12000	34.4
	2018 - 2019	Cond.	201.58	201.58	270	88.7
THIKA 4CB4	2018 - 2019	pH	8.13	8.13	10.26	6.87
	2018 - 2019	Temp	20.5	20.5	25.05	14.6
	2018 - 2019	Turbidity	50.21	50.21	219	3.7
	2018 - 2019	Cond.	111.2	111.2	196	63.3
THIKA 4CB5	2018 - 2019	pH	8	8	10.07	6.84
	2018 - 2019	Temp	16.16	16.16	20.4	13.1
	2018 - 2019	Turbidity	8.32	8.32	39.2	1.17
	2018 - 2019	Cond.	61.67	61.67	372	14.42
THIKA 4CB7	2018 - 2019	pH	7.18	7.18	7.76	6.32
	2018 - 2019	Temp	16.6	16.6	18.1	13.58
	2018 - 2019	Turbidity	13.07	13.07	47.8	2.32
	2018 - 2019	Cond	22.14	22.14	31	14.42

The figures below show year to Long Term Comparison for 4DA02, 4BC05 and 4BE01.


Thiba 4DD2
300
200
100
0
Mean Conductivity 2014
Mean Conductivity 2017
Mean conductivity 2019


Thiba 4DD2
8
7.5
7
6.5
6
mean PH 2014
mean PH 2017
mean PH 2019


Rwamuthambi 4BC05
9
8
7
6
Mean pH 2014
Mean pH 2017
Mean pH 2019


Rwamuthambi 4BC05
160
120
80
40
0
Mean Conductivity 2014
Mean Conductivity 2017
Mean conductivity 2019

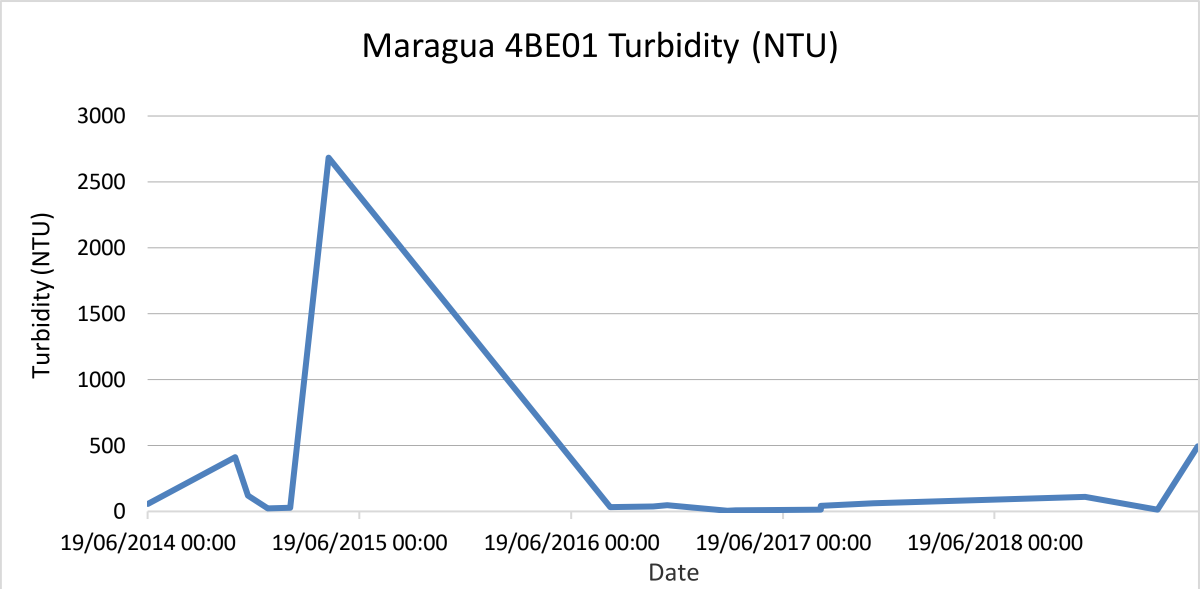


Figure 5.16: Year to Long Term Comparison for 4DA02, 4BC05 and 4BE01

5.4.6 Lake Victoria North Catchment Area

i. pH

PH is a unit for expressing the acidity or basicity of a solution. The pH scale runs from 0 to 14; a pH value of 7.0 indicates a neutral solution. Values above 7.0 pH indicate basicity (basic or alkaline solutions); those below 7.0 pH indicate acidity (acidic solutions). pH value can also change as a result of pollution and is used to monitor the entry of any new item into the water resource.

During the year under review, average pH ranged from 5.4 to 7.74 compared to 6.33 to 7.25 in previous year. Stations with relatively high pH included R. Rongai, Nzoia at Moi's Bridge and Noigamaget. All these are belonging to the larger Nzoia system. Stations with relatively lower pH included R. Garagoli, R. Yala at Tindinyo and Kimondi. Again, these happened to be all in the Yala system. Yala system therefore appeared to be generally slightly acidic than the Nzoia system. WHO has put pH range from 6.5 to 8.5 as the acceptable range for drinking water. There were no reported cases of negative impacts as a result of unfavourable pH. Figure 4.4. 3 shows pH for some of the stations in the region during the year under review

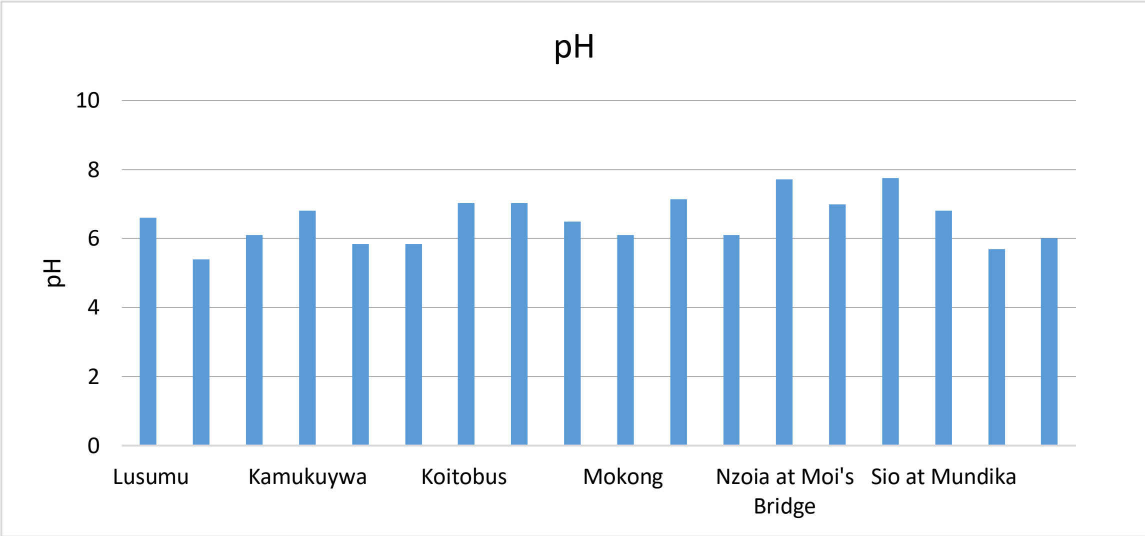


Figure 5.17: Average pH for selected stations in LVNCA

Compared to the previous year, pH in the year under review was lower than in the previous year in many of the monitored stations. This is illustrated in figure 4.4.4

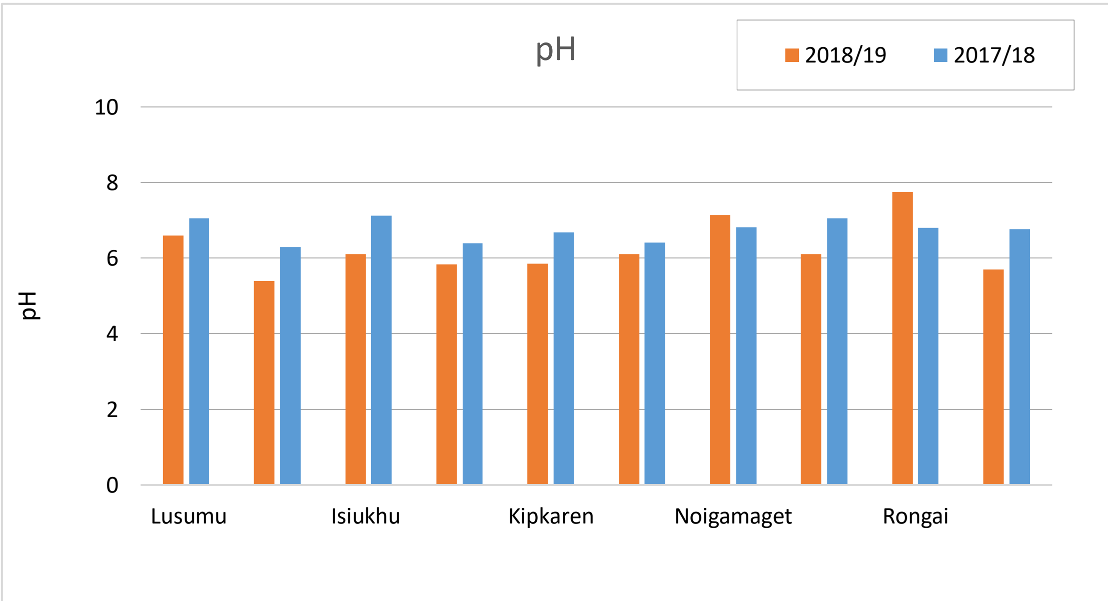


Figure 5.18:Annual average pH for some key stations during 2017/18 and 2018/19

ii. Electrical Conductivity

Electrical conductivity (EC) is measure of the ability of water to conduct electric current. It measures the salt content of water and is expressed in micro siemens per cm (µS/cm). The conductivity of fresh water is normally low but may rise if the water is receiving large quantities of surface run off or polluted wastes e.g. industrial and domestic effluent. It therefore can indicate some measure of pollution. Ec is a measure of Total Dissolved Solids in a water sample.

During the year under review the average Electrical Conductivity ranged from 78.8 µS/cm – 307 µS/cm with average of 150 µS/cm. The low range of Electrical Conductivity signifies low mineral contents in most of the surface water. WHO thresholds for drinking water is 2500 µS/cm. Figure 4.4.5 shows the Electrical Conductivities for some stations in LVNCA.

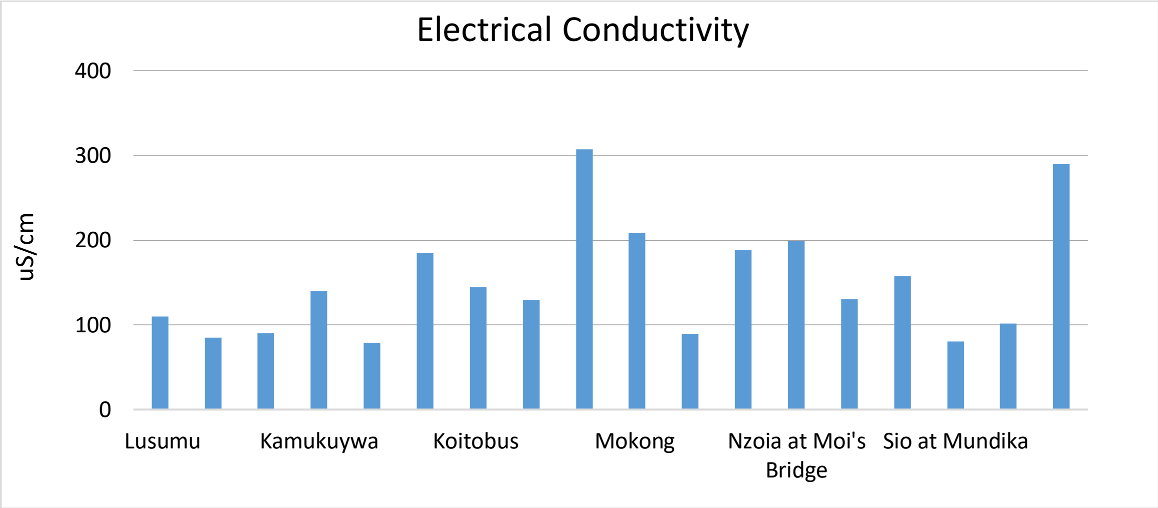


Figure 5.19: Electrical Conductivity surface water for some stations

Stations with relatively high Electrical Conductivity were Moiben, and Sosiani. Sosiani drains Eldoret town and therefore the impacts of the town and its wastewater treatment facilities could be the reason for high Ec. Low values were observed in the Yala system of Garagoli and Kimondi. Low average Conductivity was also observed in R. Sio.

Compared to the previous year, no trend was established as there were stations that recorded higher values in the previous year while other recorded lower values. Outstanding observations were in R. Mokong and Kipkaren where the differences were so unique. This is represented in figure 4.4.6

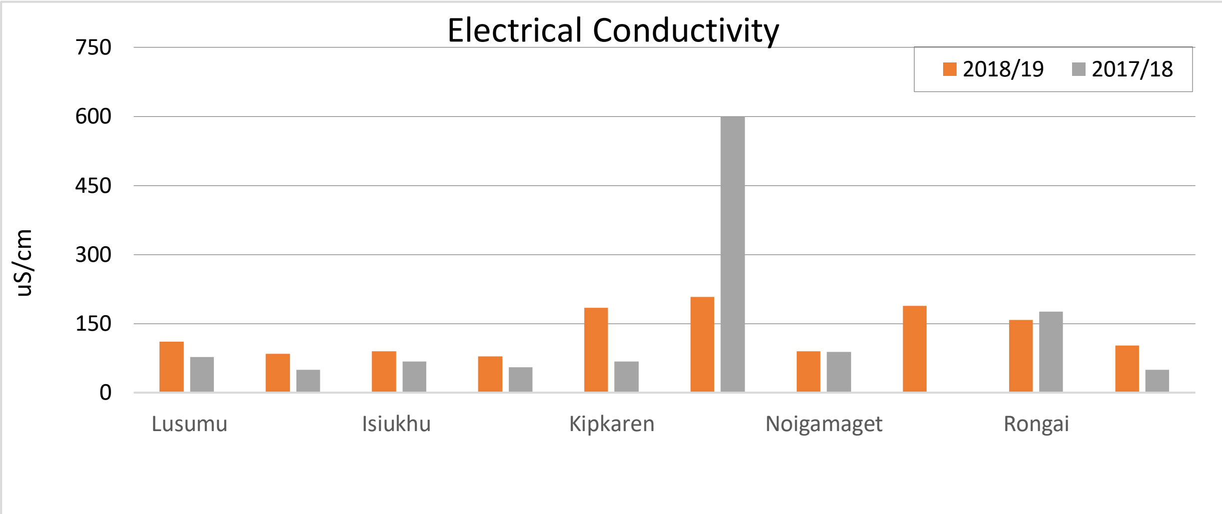


Figure 5.20:Electrical Conductivity for selected rivers in 2016/17 and 2017/18

iii. Turbidity

This is a measure of the reduced clarity of water due to suspended material. The term "turbid" is applied to waters containing suspended matter that interferes with the passage of light through the water. The turbidity may be caused by suspended materials, such as clay, silt, organic and inorganic matter, soluble colored organic compounds, and planktons amongst others.

Turbidity in water has public health implications due to the possibilities of pathogenic bacteria encased in the particles and thus escaping disinfection processes during water treatment. Turbidity also interferes with water treatment (filtration) and affects aquatic life. Excessive amounts of turbidity also make water aesthetically objectionable.

Figure 4.4.7 shows the average Turbidity for some major stations in the catchment during the year. The average turbidity ranged from 5.3 NTU to 740 NTU at Moiben and Moi's Bridge respectively. Stations with high average Turbidity were R. Nzoia at Moi's Bridge, Koitobus and Kamukuywa. The range was much higher than those observed in 2017/18. This could be due to the surface run off occasioned by the rains and facilitated by other factors in the catchment. The rivers which were relatively clear during the year included Moiben, Garagoli, Sosiani and Yala at Tindinyo.

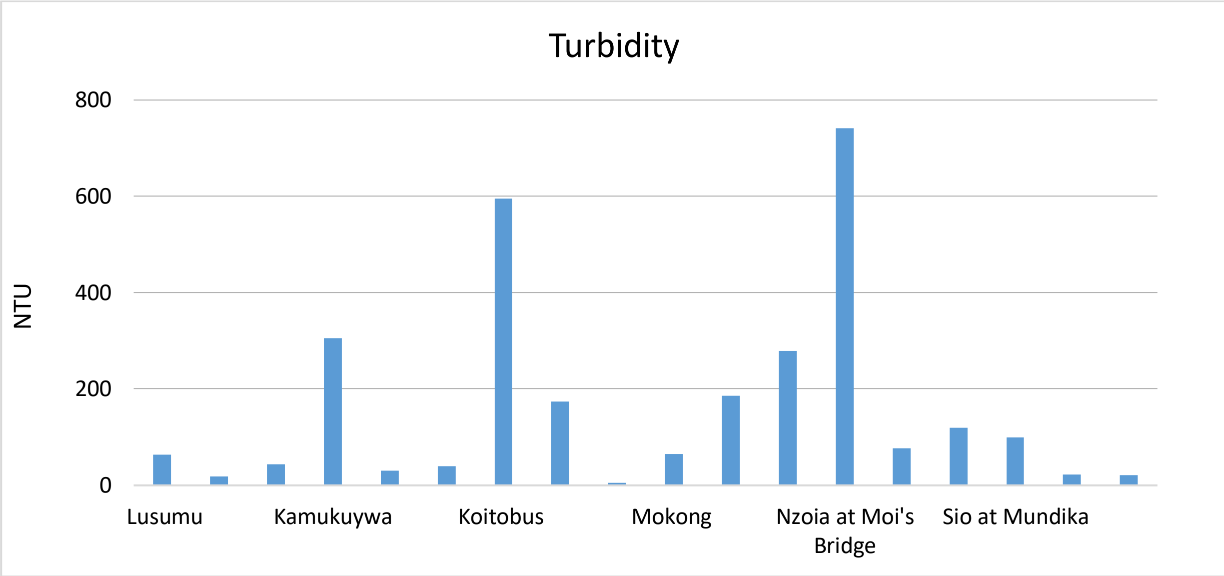


Figure 5.21:Average Turbidity for some rivers in LVNCA

Compared to the 2017/2018, there was a general drop in Turbidity in 2018/19 compared to 2017/18 as shown in figure 4.4.8. Large differences were however observed R. Lusumu, Mokong and Tindinyo. The three stations recorded significantly low turbidity during the year.

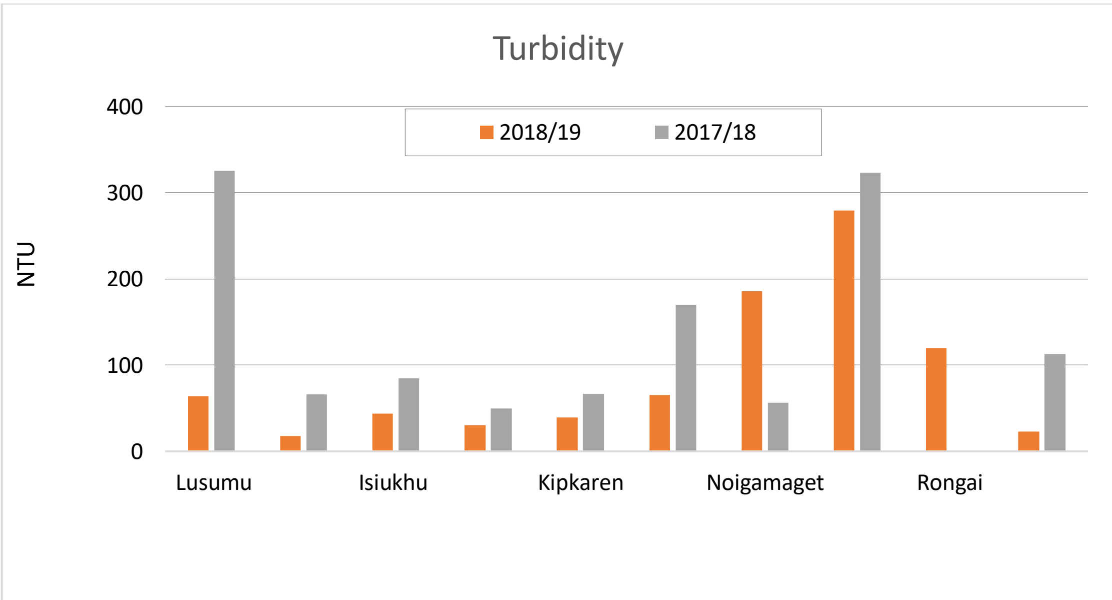


Figure 5.22:Turbidity of some of the stations.

iv. Nitrates

Sources of Nitrates include mainly domestic sewage, agricultural run-off and agro-industrial effluents. Its excessive presence in surface waters usually indicates domestic or agricultural pollution. Nitrate salts are used as fertilizers to supply nitrogen source for plant growth. Nitrate addition to surface waters can lead to excessive growth of aquatic plants. High groundwater nitrate levels can cause health problems to infants.

Figure 4.4.9 shows the concentrations of Nitrates in some of the stations in the catchment. The average concentrations of Nitrates (NO_3) in ranged from 0.44 to 4.4 mg/l compared to 1.03 mg/l to 7.24 mg/l during 2017/18. The year under review recorded a lower range than the year 2017/18. The ranges were however within the acceptable limits proposed by the WHO which is 50 mg/l for drinking water.

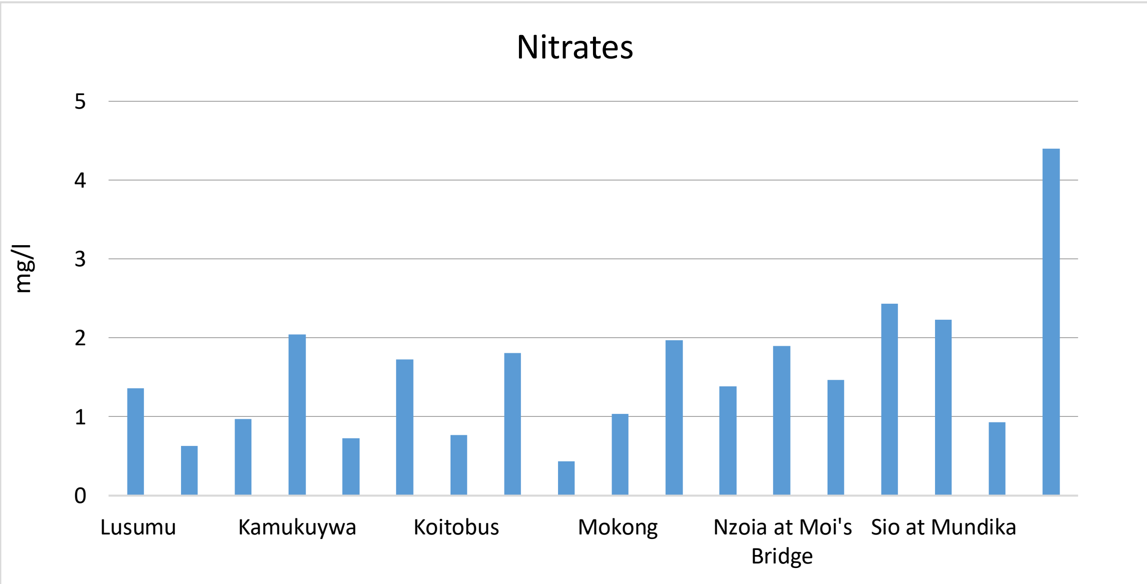


Figure 5.23:Concentrations of Nitrates

Compared to the previous year, the concentrations of Nitrates in 2018/19 were generally lower than the previous year. Noigamaget and Rongai however recorded higher concentrations. Figure4.4.10 shows the comparative concentrations of Nitrates between 2017/18 and 2018/18.

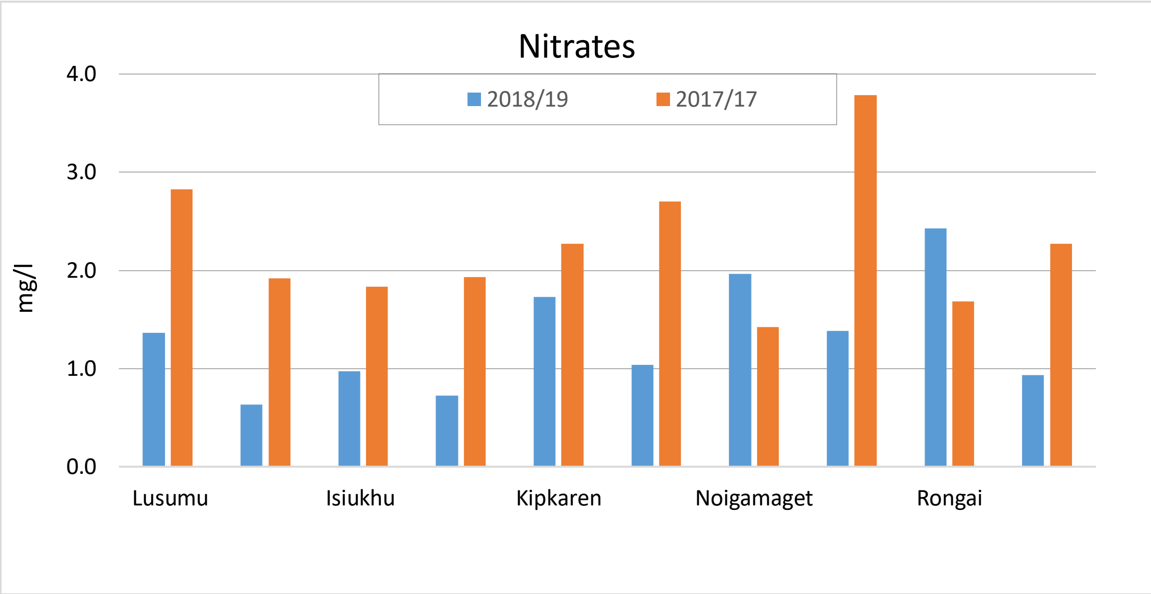


Figure 5.24:Concentrations of Nirates in 2018/19 and 2018/19

v. Total Suspended Solids

Total suspended solids is a water quality measurement usually abbreviated TSS.
It consists of materials originating from the surface of the catchment area, eroded from riverbanks and or re-suspended from the riverbeds which can be removed by filtration. TSS is important because it acts as transport agent of most pollutant and shows the degree of catchment degradation. It influences turbidity and transparency of a water body. The severe the degradation, the higher the TSS loads. Figure 4.4.11 shows the average concentrations of TSS in some of stations in the region during the year.

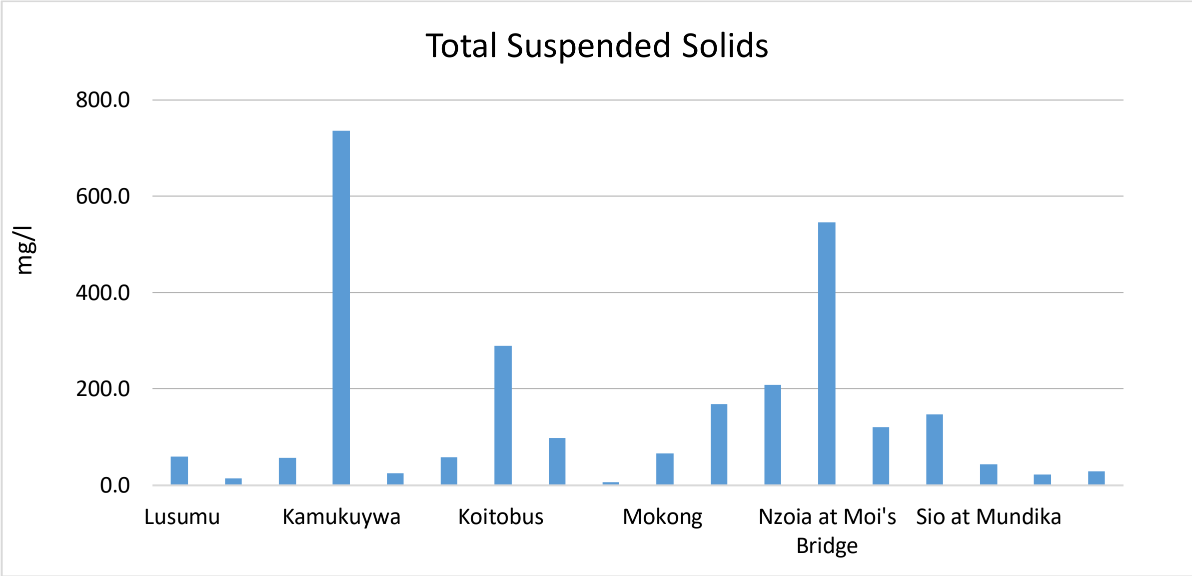


Figure 5.25:Average annual concentrations of TSS

The average annual concentrations ranged from 7.0 mg/l to 736 mg/l compared to 12.3 mg/l to 396.2 mg/l in the year 2017/18. Stations with relatively low concentrations of TSS included Moiben, Garagoli, Yala at Tindinyo and R. Kimondi while stations with relatively high concentrations were Kamukuywa, Nzoia at Moi;s Bridge, Koitobus and Nzoia at Mawe Tatu. Yala system was lower in TSS concentrations than Sio and Nzoia systems.

Compared to last year, the year under review generally registered lower concentrations in most of the stations except in Noigamaget and Rongai. Large differences were observed in R. Lusumu and Yala at Tindinyo where the concentration was lower by about six times from last year's average. This is demonstrated in figure 4.4.12

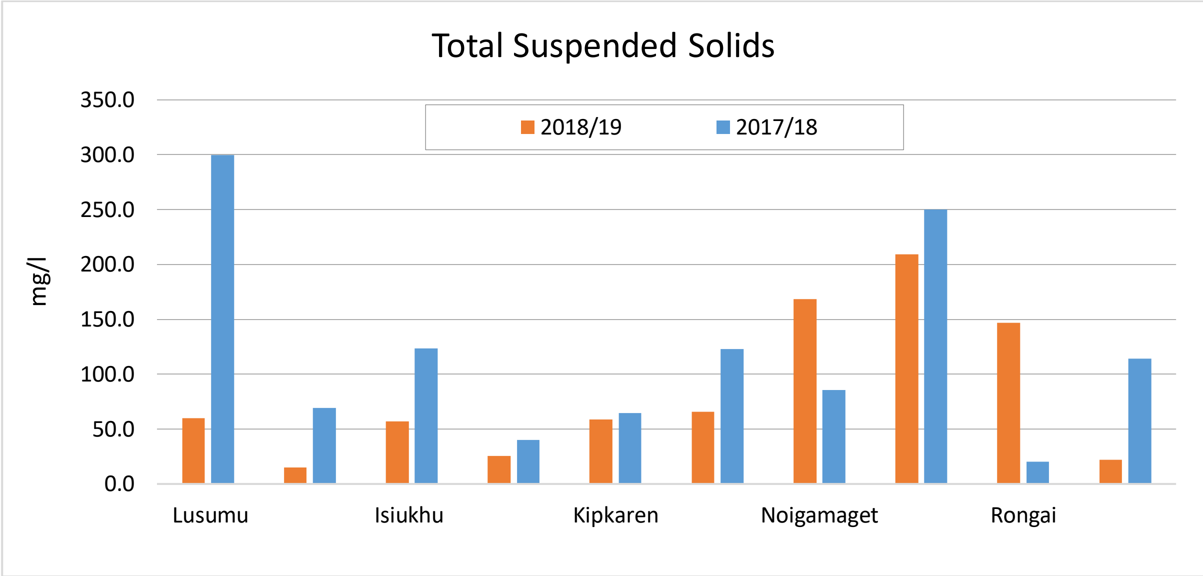


Figure 5.26:Concentrations of TSS in 2016/17 and 2017/18.

vi. Total Phosphorus

Main sources of Total Phosphorus (TP) in water include domestic wastewater containing detergents, industrial effluents and fertilizer run off from the farms as a result of improper farming methods. Phosphorus is transported to the rivers by suspended solids which are also associated with catchment degradations.

The annual average concentrations of Total Phosphorus ranged between 0.10 to 1.1 mg/l compared to 0.13 mg/l and 1.65 mg/l in the previous year. This is however a very low range compared to other areas. Figure 4.15 shows the average concentrations of some of the stations. Nzoia watershed comprising of R. Sosiani, Kamukuywa and Nzoia at Ruambwa recorded higher TP concentrations compared to other stations.

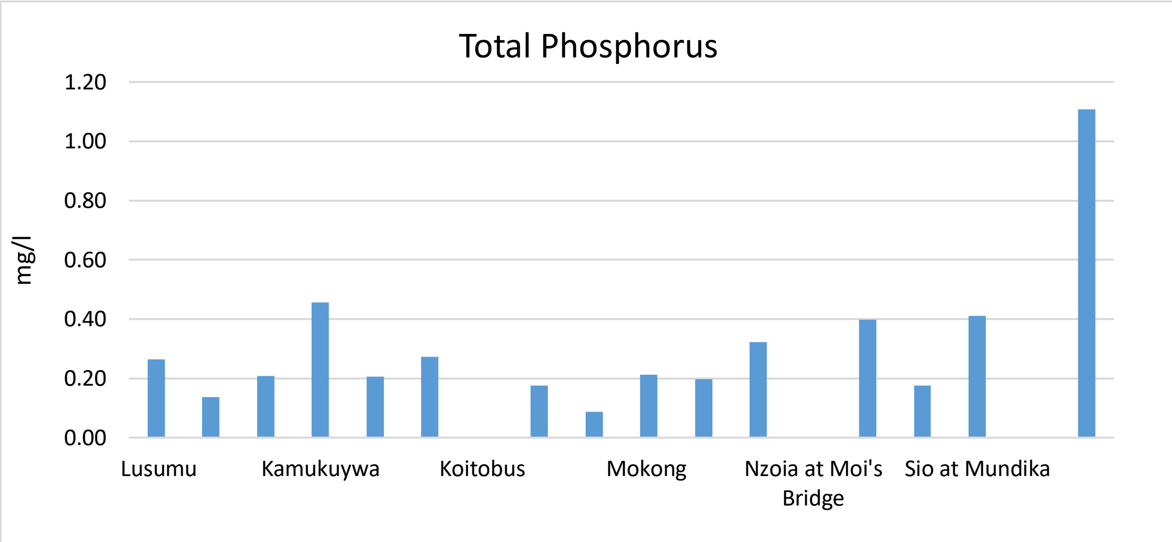


Figure 5.27:Annual average concentrations of TP for some rivers in LVNCA

In general, the surface water quality situation in the region during the year was fairly good. Chemically the water was good though physically turbidity and TSS were high. pH of most surface water sources tended to be on the acidic range but that is natural for the region. Bacteriological characteristics depended on the resource. Rivers and streams were found to be grossly contaminated with both total and faecal bacteria and therefore were not suitable for human consumption without treatment.

vii. Sediment load

Sediment load is a parameter that depicts pollution of water sources by silt from farming activities. It is calculated by the following formula:

Sy =Q x TSS x K, where Sy = Sediment Load, Q = Discharge in m^3/s, TSS = Total Suspended Solids in mg/l, K= a constant (0.0864)

Bacteriological Characteristics

Bacteriological analysis was done on 24 samples from rivers and streams. All were found to be contaminated with General coliforms and 14 out of the 24 (58.3%) had Feacal Coliforms. This means surface water (rivers and streams) generally are at high risk of contamination and therefore not suitable for human consumption without any form of treatment e.g boiling, disinfection or filtration. The high risk is due to the sources being recipients to surface run off, atmospheric depositions and others which contribute heavily to the contaminations.

6.1 Geology and Hydrogeological settings

Akech et al. (2013) grouped Kenyan geological successions into five (5) units namely: (i) the Archean (Nyanzian and Kavirondian), (ii) Proterozoic (Mozambique Belt and Bukoban), (iii) Paleozoic/Mesozoic sediments, (iv) Tertiary/Quaternary volcanic formations and sediments, and (v) Pleistocene to Recent sediments, commonly found along the coast and within the Rift Valley. In terms of hydrogeological settings and simplification, group (i) and (ii) are clustered under the basement systems and the other formations are classified into their respective rock types as either volcanic or sedimentary as illustrated in ***figure 1*** below.

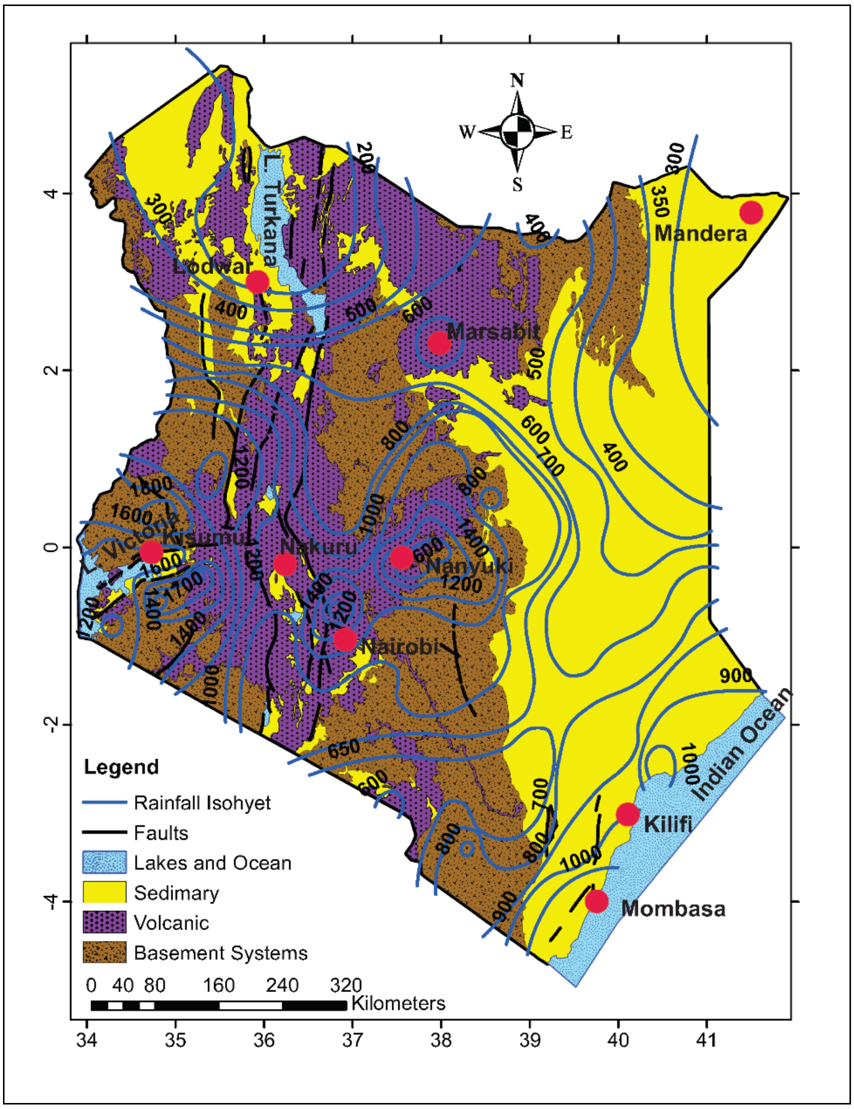


Figure 6.1:Simplified geological map of Kenya into three categories, namely: sedimentary formation, volcanic (Tertiary to Quaternary), and crystalline basement system. Rainfall Isohyet contour lines are overlaid on the geological map, and major towns marked in red circles (Oiro, 2018).

6.2 The basement system

The basement formation in this report represents the Archean and some of the Proterozoic formations. The Archean formations are occupying the western side of Kenya around Lake Victoria and its localities and are of greenstone belt type. The Archean formations are older than the Proterozoic aged Mozambique belt system outcropping on the eastern side of the Rift Valley adjacent to the volcanic rocks. The basement system occupies about 30.5% of the Kenyan geological cover with varying hydrogeological characteristics. The western basement system (Archean) possess comparatively good groundwater potential with a transmissivity range from (20 – 101 m^2/day) compared to the eastern (Mozambique belt) with a slightly lower transmissivity (0.5 – 40 m^2/day) associated with a high percentage of striking a dry well (Oiro, 2018). Prevailing climatic condition dictates groundwater availability as the western part of Kenya experiences plenty rainfall above 1200 mm per year while the average mean annual rainfall on the eastern part over basement system is 700 mm. Rock mineral composition correspondingly underwrites the inequality on hydraulic properties of the compared basement system locations where the western mineral formation is composed of a bimodal mafic-felsic suite (Akech, Omuombo, & Masibo, 2013) while the eastern basement system is mostly acidic and high metamorphic grade. The basic rock minerals weathers easily compared to acidic minerals resulting in denser saprolite with higher secondary porosity/fracture porosity for the western basement system. Consequently, it is suggested that both climatic and lithological conditions favour the boreholes productivity of deeply weathered western basement system associated with higher water table compared to the eastern basement system. The weathering of the lithology determines the transmissivity while climatic condition establishes the saturated thickness of aquifers.

6.3 The sedimentary system

The sedimentary formation occupies 41.6% of Kenya with the varying age from Precambrian (Kavirondo sediments near L. Victoria) to recent deposits. The sedimentary formations also contrast from being consolidated to non-consolidated encompassing limestones, sandstones, shales, and sands. Hydraulic characteristics of the sedimentary rocks vary considerably depending on the pores' interconnectivity. Sedimentary rocks are located on the Eastern part of Kenya covering the area from Somalia in the north to Tanzania on the South adjacent to the coast. Some sedimentary lithologies are found within the Rift Valley basin and within the Kavirondo gulf near L. Victoria.

6.4 The volcanic systems

Volcanic rock formations cover around 27.9% of the country and are mainly distributed within and along the flanks of East African Rift System. The volcanic formations geological age ranges from Tertiary to Quaternary with age series decreasing from North to South (Akech et al., 2013). Of the volcanic formations, basalts comprise of over 50% of the distribution in Kenya with age ranging from Miocene to Plio-Pleistocene period (Akech et al., 2013), while the remaining volcanic rock formations are of tuffs, phonolites, trachytes, and agglomerates types.

6.5 Groundwater occurrence and hydrogeology

Groundwater quality and quantity are naturally controlled by geological formation and precipitation of an area. The sedimentary rocks aquifer systems have varying hydraulic properties and geometry. Kuria (2013), provided wide-ranging characteristics of Kenyan aquifer systems. Groundwater levels below the surface of aquifer systems within the Kenyan sedimentary lithologies ranges from 1 to 40 m. The thickness of the mentioned sedimentary aquifer systems also varies between 2 – 50 m. Recorded transmissivity from boreholes data within the sedimentary formation of Merti aquifer ranges from 26 to 640 m^2/day (Lucien, 2015) and from 2000 – 5000 m^2/day for karst aquifer system of Kenyan Coast (Wangati & Said, 1997). Volcanic layered systems favour groundwater occurrence and are boosted with weathering, fracture zones (Kuria, 2013), coupled with old land surfaces between successive lava flows, hence, making groundwater potential even higher. Well-drained volcanic soils coupled with open faults and fissure zones favours groundwater recharge forming pathways for groundwater flow within the volcanic aquifer systems (Kuria, 2013; Okoth, 2012). Sufficient precipitation on the highlands areas favours groundwater recharge in volcanic uplands compared to lowlands where low rainfall is experienced. This promotes regional groundwater recharge even for the confined units of lowland aquifer formations. Hydraulic properties of the volcanic aquifer systems are not uniform, with areas of high fault density producing great groundwater potential shadowed by areas of interbedded coarse-grained sediments sandwiched by volcanic layers, followed by areas with primary fractures formed during the cooling process of the lava flows, and bottoming the groundwater production sequence are areas of secondary weathering due to voids being filled-up by finer materials thereby affecting voids interconnectivity. The tested transmissivity of various volcanic aquifer systems in Kenya varies tremediously i.e. for Kabatini aquifer in Kenyan Rift Valley, transmissivity differs from 215 to 410 m^2/day (Mwakamba et al., 2014) with total recorded aquifer thickness being approximately 100 m. Basement aquifer systems are the poorest interms of productivity due to low transmissivity values. (Kuria, 2013), likened the poor productivity of the basement aquifer formations as the characteristic of metamorphic rocks. Despite the poor hydraulic properties of the basement systems, some areas of great groundwater potential still exists and are accredited to weathered zones, fractured zones, and within the alluvial deposits controlled by drainage channels (Kuria, 2013).

6.5.1 Groundwater sustainable yield

While carrying out Kenya National Water Master plan, JICA team 2013, considered groundwater resources potential for development by getting the difference between groundwater recharge and groundwater use. JICA (2013), estimated the national annual groundwater recharge at 56 Billion Cubic Meter and recommended a sustainable yield equal to 10% of recharge. Estimated groundwater sustainable yield for different periods is presented in ***table 1*** below.

Table 1: Groundwater estimated sustainable yield in Kenya with values in volumes per year per area (1,000,000 m^3/year/Km^2) modified from JICA (2012).

Place of interest	Area (Km^2)	2010	2030	2050
Kenya	575,451	1,927	1,740	1,728

6.5.2 Groundwater Recharge and potential

Different recharge estimates were calculated in the past under the various projects in the country. The recharge estimates range from 1% to 10% of precipitation of areas under investigations. Groundwater recharge estimate over basement system of Machakos District area is 1% of precipitation (MOWD-TNO 1986). The same group in 1987 estimated groundwater recharge of Baringo District at a maximum of 3% of precipitation. WRAP study estimated groundwater recharge in areas covered by basalts and phonolite in Laikipia District at 3 – 5% using baseflow analysis at two gauging stations. In 1984, Heederik under WRAP project applied FAO guidelines estimated Kikuyu Springs catchment area recharge at 10% of the mean annual precipitation of the area.

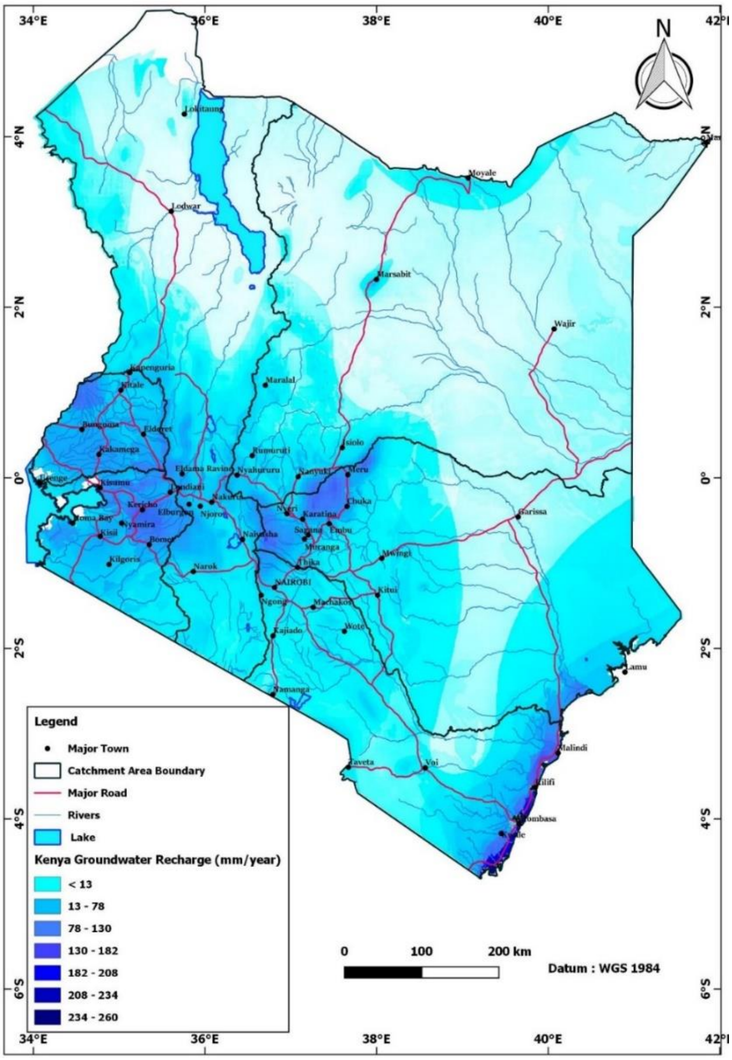


Figure 6.2: Groundwater recharge map from ISC 2019 report

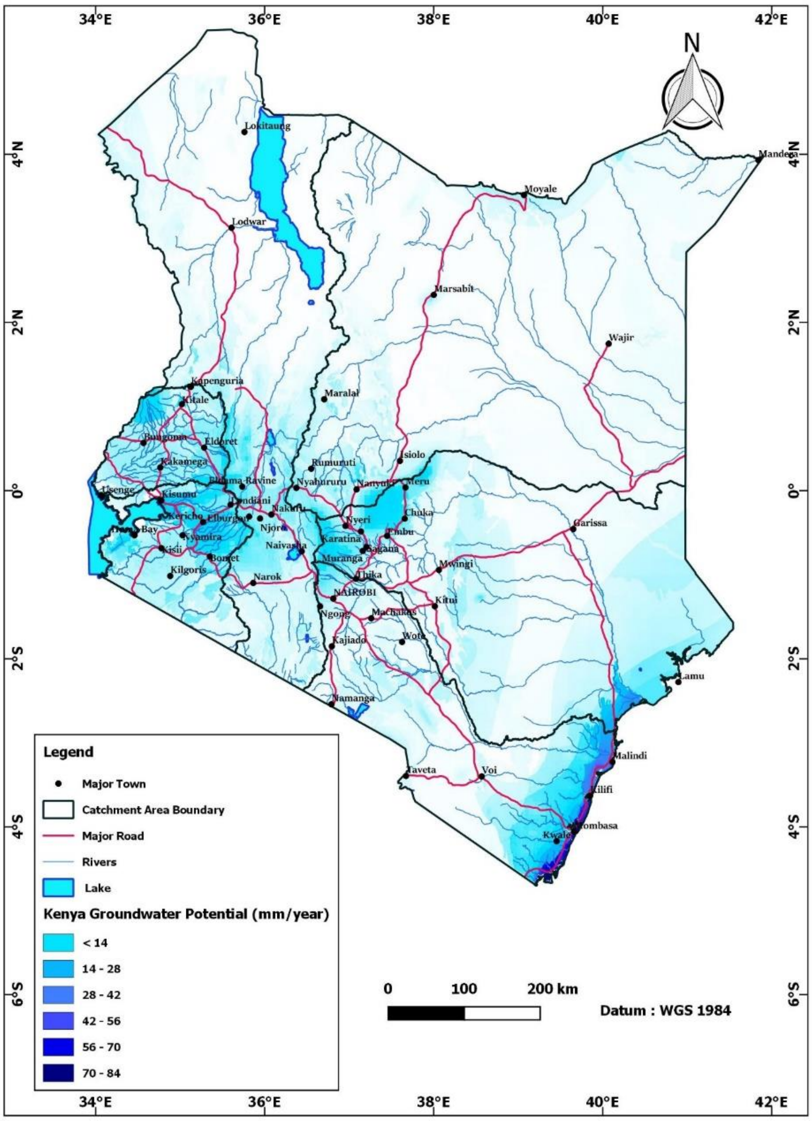


Figure 6.3: Groundwater Potential in mm/year map from ISC 2019 report

International support consultant (ISC) used GIS-based approach to estimate the allowable proportion of recharge that is exploitable producing the following extreme values:

- Very high rated areas in terms of groundwater yield related to abstractable proportion of recharge value of 37.5%.
- Very Low rated areas for all four-groundwater yield-related criteria gives an abstractable proportion of recharge value of 5%.

ISC 2019 report justified their estimated range of 5% - 37% of groundwater yield-related criteria in Kenya to that of Ethiopia and South Sudan reported values obtained by (ENTRO, 2016) to range from ~5 % to ~50 %.

6.5.3 Groundwater Allocation Balance

Table 2 below of groundwater balance was derived by ISC using 2018 groundwater permit data from WRA's Permitting Database in developing estimates of allocated groundwater per sub-basin and for comparison with groundwater potential. Figure 2 demonstrates over allocation in some sub-basins in the Rift Valley and Athi Basins.

Table 2: Summary of Groundwater Use Balance by Basin (ISC, 2019)

Basin	Basin Area	Groundwater Potential	Estimated Use	Groundwater Use Balance	Area of over abstraction
	km^2	**MCM/year**	**MCM/year**	**MCM/year**	**km^2**
LVNCA	18,500	216	11	205	7
LVSCA	26,906	292	11	280	15
RVCA	131,423	400	29	370	2,515
ACA	66,559	559	71	488	3,147
TCA	126,208	693	15	678	484
ENNCA	209,918	449	15	435	821
Total	**579,514**	**2,608**	**152**	**2,456**	**6,989**

From the assessment of groundwater allocation/permit data, ISC concluded that indications of over-abstraction are observed in areas of the Upper Athi (Nairobi and Machakos) and Central Rift Valley (Naivasha and Nakuru). The support team further suggested that there could be a possibility of localised over-abstraction in the low recharge ASAL areas.

Table 3: Summary of Groundwater Allocation Balance by Basin (ISC, 2019)

Basin	Area	Groundwater Potential	Permitted (m3/day)	Balance (m3/day)
	km^2	**MCM/year**	**MCM/year**	**MCM/year**
ACA	65,942	559	157	402

ENNCA	209,259	449	20	429
LVNCA	17,849	216	8	208
LVSCA	25,783	292	5	287
RVCA	122,923	400	127	273
TCA	125,649	693	30	663
Total	**567,405**	**2,608**	**346**	**2,262**

Table 4: Growth Rates and Projected Density Increases to 2018 (from ISC 2019)

Basin	Sub-region	**Growth 1985-2000 (# bh/year)**	**Sub-region Area (km^2)**	Borehole Density Area (km^2)	Growth in Density (bh/year/100 km^2)	Projection to 2018 Baseline			
						From	**Years**	**Increase in # bh**	**Increase in Density (bh/km^2)**
ACA	Kiambu	2.067	2,284	1,375	0.150	2011	7	14.47	0.0105
	Kibwezi	1.333	17,886	3,984	0.033	2002	16	21.33	0.0054
	Loitoktok	1.600	12,678	950	0.168	2002	16	25.60	0.0269
	Mombasa	9.733	29,533	4,306	0.226	2002	16	155.73	0.0362
	Nairobi	16.733	4,219	3,226	0.519	2011	7	117.13	0.0363
ENNCA	Isiolo	4.267	42,659	3,493	0.122	2002	16	68.27	0.0195
	Mandera	0.000	59,276	937	0.000	2002	16	0.00	0.0000
	Marsabit	1.200	91,205	1,942	0.062	2014	4	4.80	0.0025
	Nanyuki	1.800	4,231	1,742	0.103	2002	16	28.80	0.0165
	Rumuruti	3.000	12,636	2,708	0.111	2002	16	48.00	0.0177
	Eldoret	2.333	7,154	2,450	0.095	2002	16	37.33	0.0152
	Kitale	7.333	6,409	2,220	0.330	2002	16	117.33	0.0529

LVNCA	Siaya	15.467	4,848	2,693	0.574	2002	16	247.47	0.0919
LNSCA	Kericho	0.667	11,586	891	0.075	2002	16	10.67	0.0120
	Kisii	7.667	9,590	2,252	0.340	2002	16	122.67	0.0545
	Kisumu	3.533	5,829	2,121	0.167	2002	16	56.53	0.0267
RVCA	Kabarnet	2.667	25,027	2,887	0.092	2002	16	42.67	0.0148
	Kapenguria	0.133	6,931	312	0.043	2002	16	2.13	0.0068
	Lodwar	4.067	75,995	8,358	0.049	2014	4	16.27	0.0019
	Naivasha	2.933	5,514	3,195	0.092	2002	16	46.93	0.0147
	Narok	1.000	17,620	1,191	0.084	2002	16	16.00	0.0134
TCA	Garissa	0.200	69,967	740	0.027	2002	16	3.20	0.0043
	Kerugoya	2.667	4,056	856	0.312	2002	16	42.67	0.0498
	Kitui	0.667	37,436	1,463	0.046	2002	16	10.67	0.0073
	Meru	11.133	9,044	1,615	0.689	2002	16	178.13	0.1103
	Muranga	1.333	5,944	1,810	0.074	2002	16	21.33	0.0118

6.1 Groundwater quality and major challenges

6.1.1 Dissolution of alumino-silicates

Kinetic dissolution of alumino-silicates is the main chemical reaction in groundwater system (Hilley, Chamberlain, Moon, Porder, & Willett, 2010; Oiro, 2011). The weathering of the alumino-silicates can be expressed as:

$$-SiO^- + H^+ \rightarrow -SiOH$$

Due to low solubility of alumino-silicates, their contribution to water composition is relatively limited in the presence of carbonates which possess high solubility. Si isotopes in most cases are removed from the solution by clay precipitation thereby maintaining low nature of its concentration in groundwater (Frings et al., 2015; Pogge von Strandmann et al., 2014). In carbonates absence, alumino-silicates determine the ion chemistry of the water hence resulting in low concentrations due to low solubility of the dissolving alumino-silicates (Walraevens, 2009). A part from lithology and water, chemical weathering of silicates are also influenced by climatic condition (Wu, Zheng, Yang, Luo, & Zhou, 2013; Zhang, Jin, Li, Yu, & Xiao, 2013).

The primary source of dissolved silica in natural water is the chemical breakdown of silicate minerals in rocks and sediments by chemical weathering process (Hem, 1985). It is further explained by Probst (2002) that the silica concentrations are influenced by the amount of precipitation received within the drainage basin and the residence time of groundwater within an aquifer (Saby et al., 2015). Silica is not easily dissolved in water but appears in suspension (Probst, 2002). Due to kinetic inhibition, the silica concentration is not reached as fast as for carbonates. CO_2 from the underground increases the weathering of alumino-silicates through the formation of acid, which aids in the chemical weathering processes (Donnini et al., 2015; Hilley et al., 2010; Ryu, Lee, Chang, & Shin, 2008). Hence, CO_2 concentrations and longer residence time determine the amount of dissolved silica in the groundwater.

Calcium and magnesium are primarily found in groundwater due to the dissolving of limestone (primarily composed of calcium carbonates). In Kisumu groundwater case, the availability of calcium and magnesium have originated from the weathering of alumino-silicates, comprising feldspars and feldspathoids, from the tertiary phonolites, Pre-Cambrian basalts and andesites and granite intrusions (Oiro, 2011).

6.1.2 **Origin of F- in groundwater**

Fluoride is introduced into groundwater through one, two or all of the following processes; a) water – rock interaction, b) anthropogenic activities, and c) groundwater recharge (Abdelgawad, Watanabe, Takeuchi, & Mizuno, 2009; Alarcón-Herrera et al., 2013; Eschauzier, Raat, Stuyfzand, & De Voogt, 2013; Hallett et al., 2015; Hu, Luo, & Jing, 2013; Jadhav et al., 2015; Naseem et al., 2010; Xu et al., 2013) with higher chance resulting from rock water interaction. "*Groundwater with low Ca^{2+} content is sub-saturated with respect to fluorite, and fluorite will have the tendency to dissolve*" (Coetsiers, Kilonzo, & Walraevens, 2008). The authors further explained that the weathering of feldspar consumes protons and causes a rise in pH making it impossible to attain equilibrium with CO_2 hence more HCO_3^- and CO_3^{2-} is produced while more CO_2 dissolves. The precipitation of calcite due to increase in CO_3^{2-} causes a drop in Ca^{2+} making the solution to be sub-saturated compared to fluorite. This leads to fluorite dissolving and its concentrations gets elevated in groundwater (Oiro, 2011). High concentration of fluoride in groundwater is favoured by weak alkaline pH condition (7.2 – 8.2), moderate TDS and water dominated by HCO_3^- and Na^+ ions (He, An, & Zhang, 2013; Li, Gao, & Wang, 2015; Rafique et al., 2009; Sajil Kumar, Jegathambal, Nair, & James, 2015; Su, Wang, Xie, & Li, 2013).

Hydrolysis of F^- bearing aquifer formation in groundwater is the chemical reaction process releasing F^- in facilitation by alkaline condition and longer residence time (Su et al., 2013). Below is the kind of chemical reactions which may have taken place, or which can be used in explaining the processes leading to the concentration of various parameters in groundwater.

Dissolution of alumino-silicates with Na-feldspar (albite) as typical representative:

$$2NaAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 4H_4SiO_4$$ (Appelo & Postma, 2005).

Due to consumption of H^+ by the above reaction, pH is raised thus more CO_2 is dissolved in groundwater. Raising HCO_3^- and CO_3^{2-} concentration in groundwater helps in keeping the equilibrium with constant partial pressure of CO_2 (ρCO_2).

$$CO_2g \rightarrow CO_2aq + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$$

$$HCO_3^- \rightarrow CO_3^{2-} + H^+$$

Solubility controls of calcite and fluorite minerals in hydro-geochemistry determines the concentration of fluoride in groundwater (Rafique et al., 2015, 2009; Su et al., 2013). Therefore, at a certain moment, SI of calcite will be exceeded (> 0) (SI calcite = $(Ca^{2+})(CO_3^{2-})$ and calcite will precipitate. Ca^{2+} concentration in groundwater is regulated by the calcite equilibrium (Coetsiers et al., 2008). The authors further explained that the increase in pH and alkalinity in groundwater deters equilibrium to be attained with calcite and calcite precipitates according to the reaction below.

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

This precipitation of calcite lowers Ca^{2+} in groundwater. This impact heavily on attaining equilibrium with fluorite, hence leading to dissolution of fluorite as the groundwater SI of calcite is < 0.

The solubility of fluorite is shown by the following reaction:

$$CaF_2 \rightleftharpoons Ca^{2+} + 2F^- \quad (1)$$

The dissolution can be affected by temperature, pressure, ionic strength, particle size, polymorphism, complexing capacity of the solution, and kinetic barriers (Nordstrom & Jenne, 1977). For the simplification of the problem, the authors proposed an assumption of equilibrium conditions with no particle size effects. The negative log of the equilibrium constant, *K,* for reaction (1) is

$$pK = -\log K = -log(aCa,^{2+})\ (aF^{-})^{2}$$

Where the equilibrium concentrations are expressed in terms of the activities of dissolved calcium (aCa^{2+}) and dissolved fluoride (aF^{-}), and because the activities are used instead of concentrations, ionic strength effects are taken into account (Nordstrom & Jenne, 1977).

According to (Nordstrom & Jenne, 1977) complexing is time and again the single most important factor which determines the total concentration of fluorite dissolution. The authors further stated that upon the dissolution of fluorite, the ions may associate with themselves to form a monofluoride complex:

$$Ca^{2+} + F^{-} \rightleftharpoons CaF+$$

Gachiri *et al*, (1993), presented an outstanding brief of the geochemistry of fluorine, the distribution of natural fluoride across Kenya, and the significance of volcanic geologies in fluorogenesis. Excessive flouride may also occur in pre-Cambrian Basement geologies (IGRAC, 2004). Both KEBS and WHO standards recommends suitable fluoride concentration of not more than 1.5 mg/L for human consumption.

6.1.3 Dissolved Nitrate (NO_3^{2-}) and Nitrite (NO_2^{-})

Human activities have both positive and negative impacts on the quality of groundwater. To scrutinize the implications of the negative human approaches targeting groundwater resource, NO_3^{-} concentrations have been targeted and mapped. Pit latrines within informal settlements paints a picture of point sources of pollution affecting the shallow wells constructed to almost the same depth as the hand dug wells providing water to the slum dwellers. These pit latrines interact with upper aquifers, hence, causing serious contamination being revealed through high magnitude of nitrate concentration. Household generated sewage and slums localized open waste dumping sites uncontrollably exists in most part of Kisumu thereby polluting water resources through leaching and infiltrating down to the groundwater system (Oiro, 2011). In his 2011 thesis, 7 out of 15 shallow water well analysed produced Nitrate concentrations above the recommended level for human consumption of 50 mg/l. Protracted consumption of such a high concentration of nitrate in water is detrimental to well-being of mankind (Rojas Fabro et al., 2015). Ingestion of water with nitrate concentrations excesses in great quantity by infants leads blue babies' syndrome. The syndrome emerges from nitrate attaching itself to hemoglobin thereby inhibiting oxygen flow with the baby body system as oxygen slot within hemoglobin is filled up with nitrate (Knobeloch et al., 2001).

6.1.4 Saltwater intrusion along coastal aquifers

In Kenyan coast, coastal aquifers are the main source of freshwater supply for all the economic sectors and domestic use and groundwater exploitation has increased with time. The supply of quality freshwater in coastal areas was flagged long ago as coastal communities faced a major challenge of getting quality water of which the need intensified during dry seasons. Until 1972, most water wells within Kenyan south coast were drilled along coastal fringe areas underlain by Pleistocene coral reef. Saline water inteusion is significantly distinct in areas of coral limestone (Tole, 1997) due to conduit systems promoting high permeability. Progressing saltwater intrusion into freshwater aquifers due to over-abstraction have prompted global alert and concern (Ahmed, 2017; Priyanka & Mahesha, 2015; Sonkamble, Chandra, Ahmed, & Rangarajan, 2014) a situation which is not isolated as Kenya is also equally getting concerned.

The natural control effects on saltwater intrusion are observed on the Southwest area of the Kenyan south coast. Groundwater chemistry from the older geological formation of Permo –Triassic Upper maji ya Chumvi beds are relatively high in EC. The geological formation is characterised by soluble mineral and evaporites which increases pore water EC (Oiro et al., 2018). At the coastal fringe however, high EC values (>1000 µS/cm) are ascribed to natural saltwater intrusion from the ocean and are mostly constrained within the coastal reef limestone and slightly in parts of the neighbouring back-reef kilindini sands.

Saltwater intrusion is a common occurrence along the coast and aided by human activities, hence, the condition is also observed along the entire coast of East Africa.

7 THE DYNAMIC DECLINE OF GROUNDWATER LEVELS

7.1 Nairobi Aquifer System water levels

The 10 years of monthly monitoring of groundwater levels in the observation wells of the Nairobi area are shown in ***figure 4***. Long-term decreasing trends for all the wells are observed within between recoveries. Short-term fluctuating levels are common occurrence for most of the wells. The abrupt water level rises, and declines can be ascribed to well recovery during non-pumping periods and drawdowns caused by over-pumping. Majority of the wells are sunk in residential areas and monitoring wells are not only productive wells but also surrounded by actively pumped boreholes. Hence, monitored levels represents an illustration of dynamic groundwater levels rather than steady-state levels. The long-term recorded dropping groundwater level trend is a clear signal of regional groundwater depletion of the Nairobi Aquifer System. The declining groundwater levels from the monitored boreholes are dropping at the rate extending from 0.05 m/year to 2 m/year.

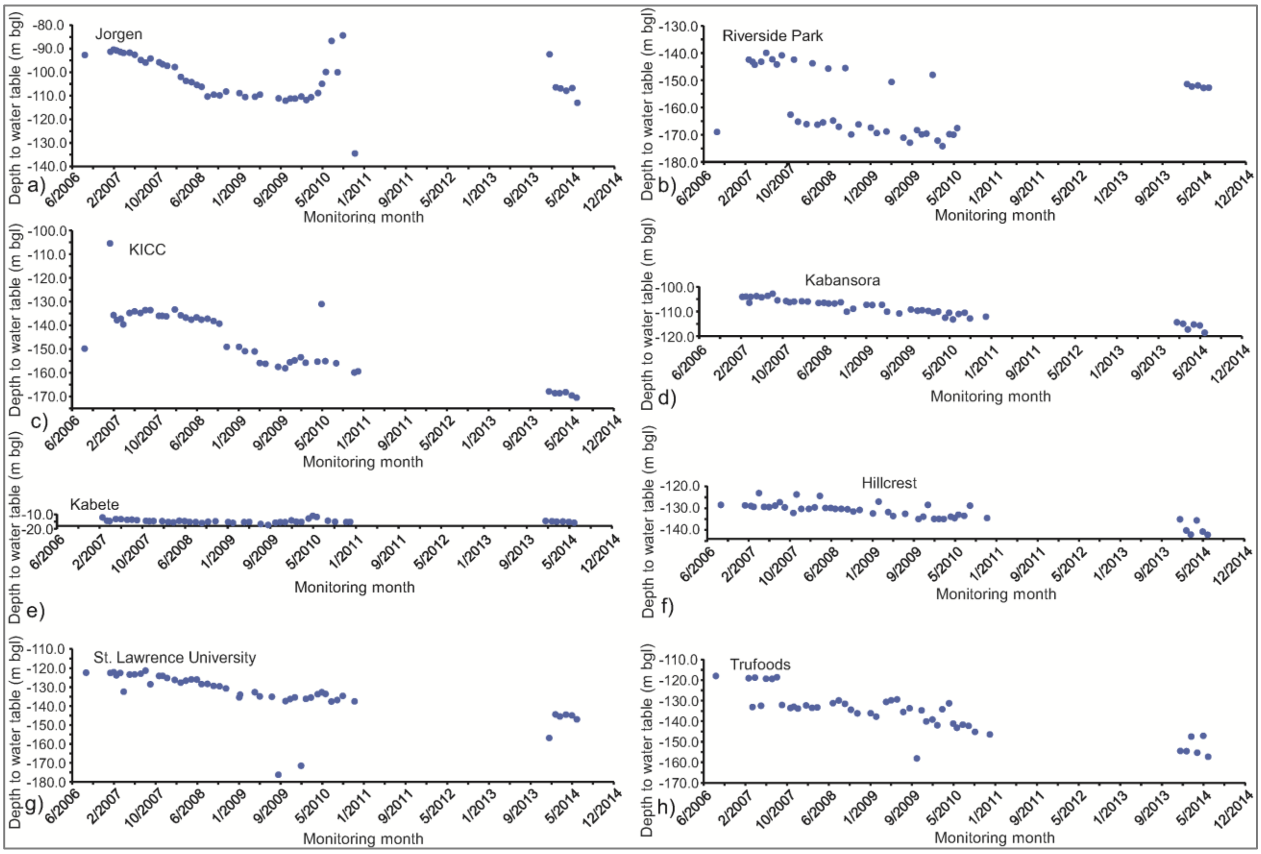


Figure 7.1:Recorded monthly depth to groundwater level from dedicated WRA monitoring boreholes within NAS. (a-h) are eight representative wells representing trends of observation made from year 2007—2014 displaying declining groundwater level with time and demonstrating short term pumping effects on groundwater levels with recovery superimposed to overall long-term declining trends (from Oiro, 2018).

7.2 Rift Valley Basin Area Water levels

For the last 8 years of monitoring, groundwater levels within Rift Valley Basin seem to be stable with some boreholes recording the slight level rise and some recording of slight decline. Wells experiencing level rise include Rubiri, Baharini, Kinyanjui, Kabatini (varying fluctuations), Subati, St. Mary's, Carzan (huge variation), Rift Valley Academy, MOWD, and Marula while those experiencing a slight decline in levels include Cherombai, Ngoswani, Nkairimiran, Panda, Ayub Suleiman, and Katakala. Fluctuations are observed in other wells, as shown in ***figure 5*** below, which can be attributed to pumping activities. Majority of the monitoring wells in Rift Valley Basin are experiencing groundwater level increase (10/17). On the other hand, Rift valley lakes have been expanding over recent years. What is favouring increasing groundwater levels and expanding lakes needs to be investigated and if possible, the interaction between the surface water bodies and groundwater to be established.

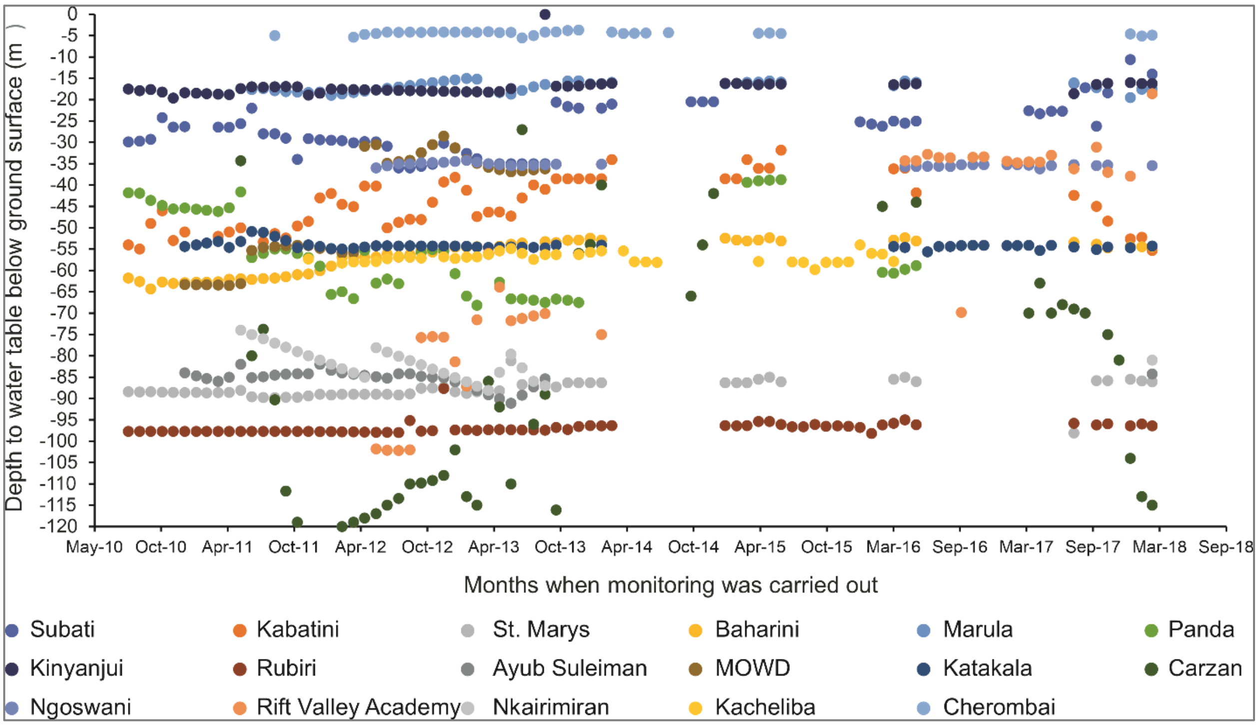


Figure 7.2: Rift Valley Basin Monitoring wells level trends for over 8 years

7.3 Tana Basin Groundwater Levels

Tana Basin area groundwater levels were stable from 2012 to the end of 2015 though observed to experience slight decline apart from Ziwani wells 1&2 (***figure 6 a***) which experienced increased levels in the earlier monitoring stage. Slight recovery from the declining water level was witnessed in the period between early 2014 to October 2015 which was followed by a drastic drop in water level to October 2016 as observed in ***figure 6 b***. The continued monitoring has not recorded recovery to the levels before October 2015 though the levels trends have stabilized. For high altitude areas represented by Nzamabni Boys high school and Parkside hotel in ***figure 6 c***, the significant drop in water levels is observed ranging between 10 m (Parkside hotel observation) to 40 m (Nzambani Boys observation) over the last 3 to 2 years respectively.

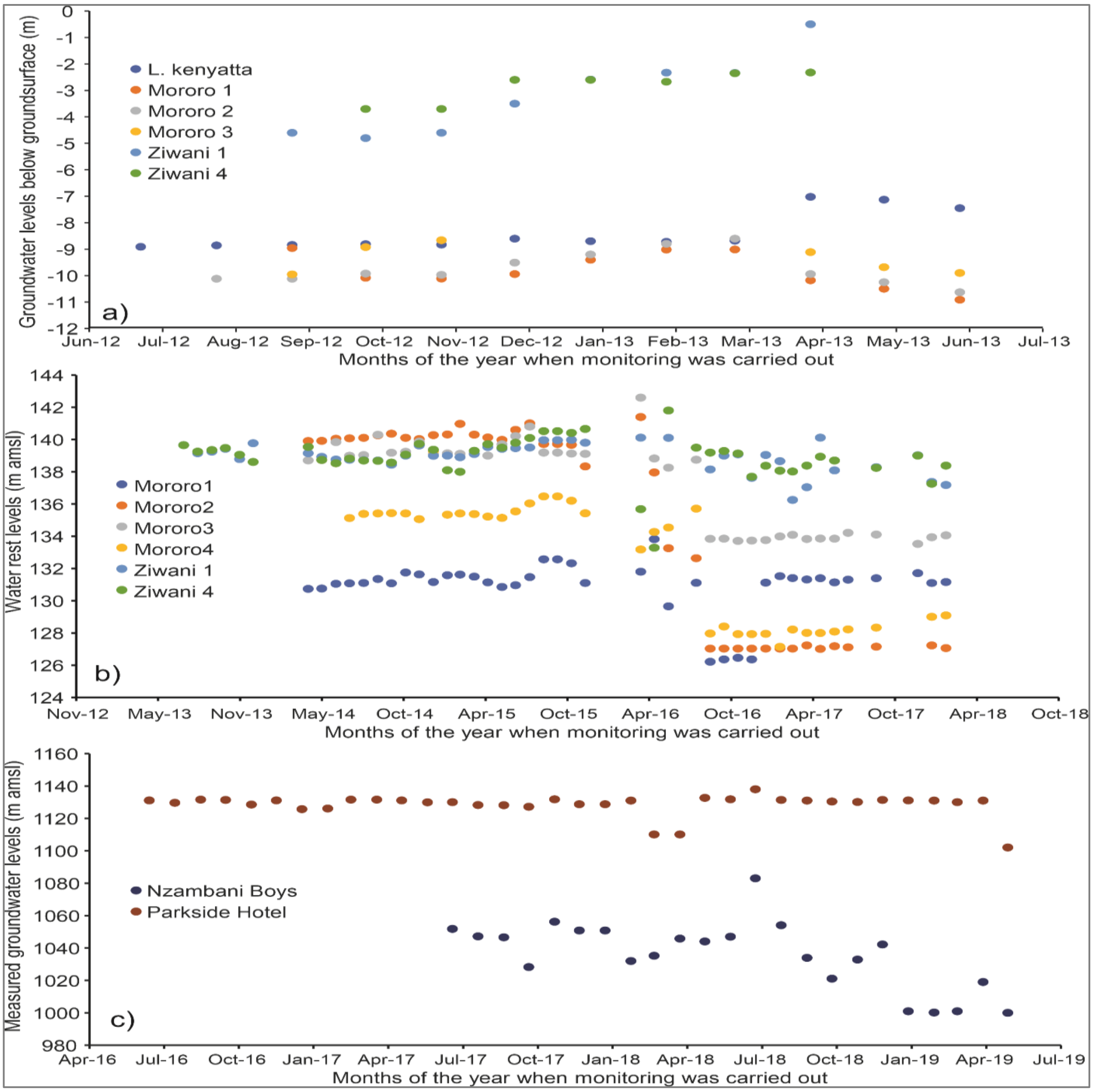


Figure 7.3:Tana Basin Monitoring wells level trends for 8 years

7.4 Lake Victoria North Basin area water level trends

Water levels for shallow aquifers between 1 m to 30 m below ground surface presents a stable water table which can be attributed to replenishing recharge in the basin driven by ample rainfall. Kapsabet Boys and Girls Schools reports stable levels for a period of the first 10 years of observation and the last four years has experienced significant fluctuation between observed levels. The trend observed in Kapsabet can be attributed to changed abstraction rate or over-dependence on the groundwater by the two institutions which could be a deviation from their earlier behaviour. Other observation wells experience slight fluctuations of levels over the 14 years of monitoring with a general trend of the declining level at a slower rate as illustrated in ***figure 7*** below.

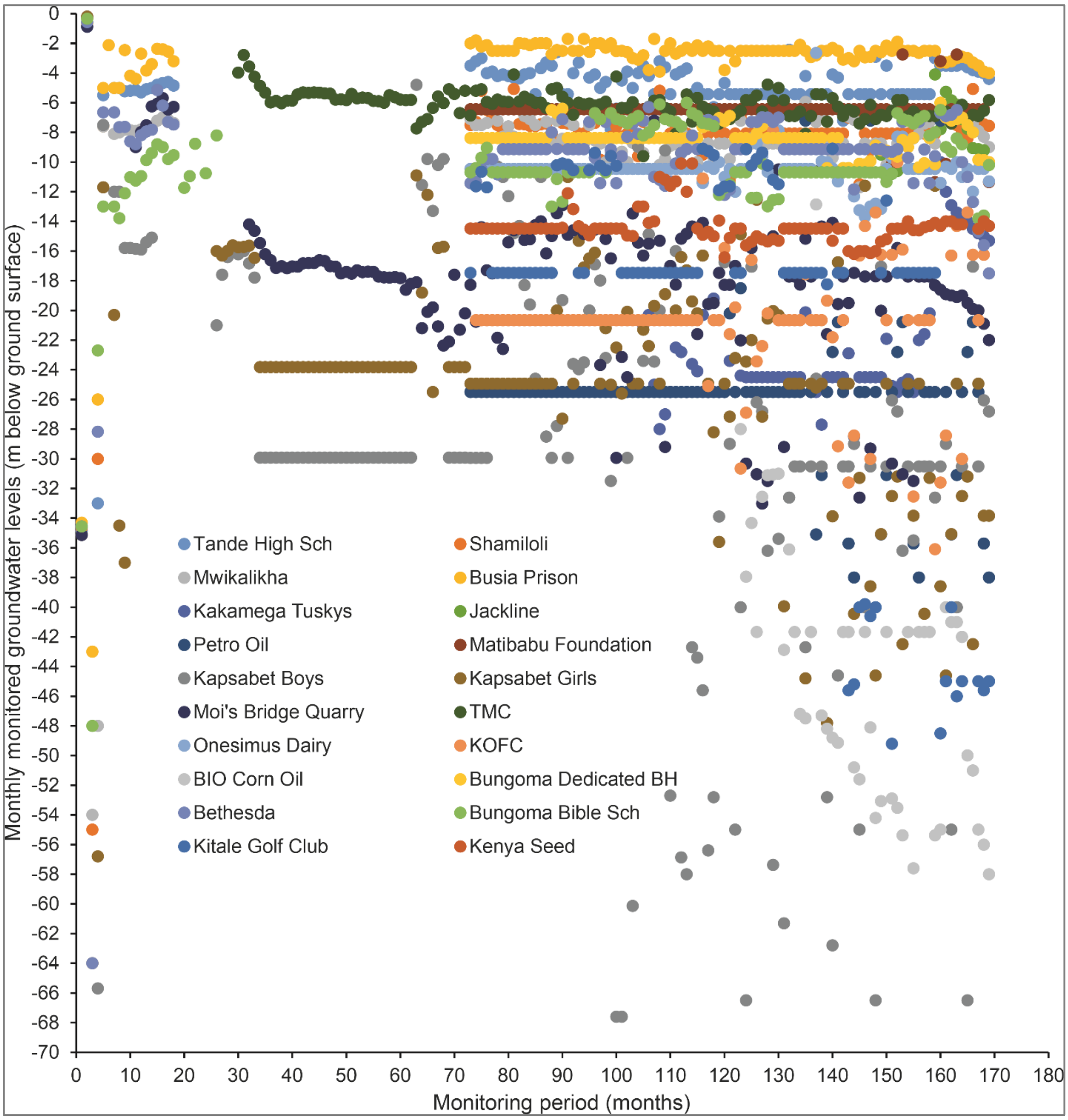


Figure 7.4:Lake Victoria North Basin area monitoring well trends for over 14 years.

8 EMERGING ISSUES

8.1 Conclusions

- ✓ Groundwater resources in Kenya is still not endangered by exploitation
- ✓ Saltwater intrusion is common along the coastal aquifer, but inland intrusion is aided by abstraction and poor designs
- ✓ Localised groundwater level decline is higher compared to regional level change
- ✓ Pit latrines and poor waste management is a threat to shallow upper unconfined aquifers
- ✓ Detailed aquifer mappings and classifications are recommended for all the Kenyan aquifer systems
- ✓ Full-scale hydro-geochemical scanning of every aquifer system is recommended

9 WATER USE

9.1 Permits

Permitting is a tool used in water allocation to ensure equity and transparency. Criteria in water allocation is based on priority of use, where domestic use gets the first priority among the allocated water, when a water permit application is being considered for approval (Water Act, 2016). This is because the reserve, which comprises water for ecological and basic human needs, is not allocated but should be left in the sub basin. The purposes for which water use is allocated are mainly six, comprising public water supply, domestic, livestock, irrigation, industrial and hydropower. Irrigation is usually divided under subsistence and commercial use, where subsistence irrigation is carried out in an area less than a hectare. Subsistence irrigation has priority over commercial irrigation

Table 9-1:Distribution of permitting data across the application process by June 2019

Item description	SW	GW	ED
Applications pending processing	343	933	20
Approvals	597	462	33
Authorizations	1643	21341	49
Valid Authorizations	152	3348	2
Permits	2085	5556	33
Valid permits	1133	3944	11

There were **1092** Approvals nationally, this indicates an increased volume of water allocated for social good. SW (597) and GW (462), while ED stood at 33 approvals. Category **A** approvals for Effluent Discharge have lowest impact on water quality, but they attract

Effluent Discharge fees as a measure to deter dischargers from polluting water resources

Table 9-2: Cumulative Approvals June 2019

Approvals	SW	GW	ED	Total
Number	597	462	33	**1092**

Table 9-2 shows that SW had the highest number at 597 (54%), while GW had 462 (42.31) and lastly Effluent Discharge had 33 (3.02%) in-terms of approval issued in 2018/2019 FY.

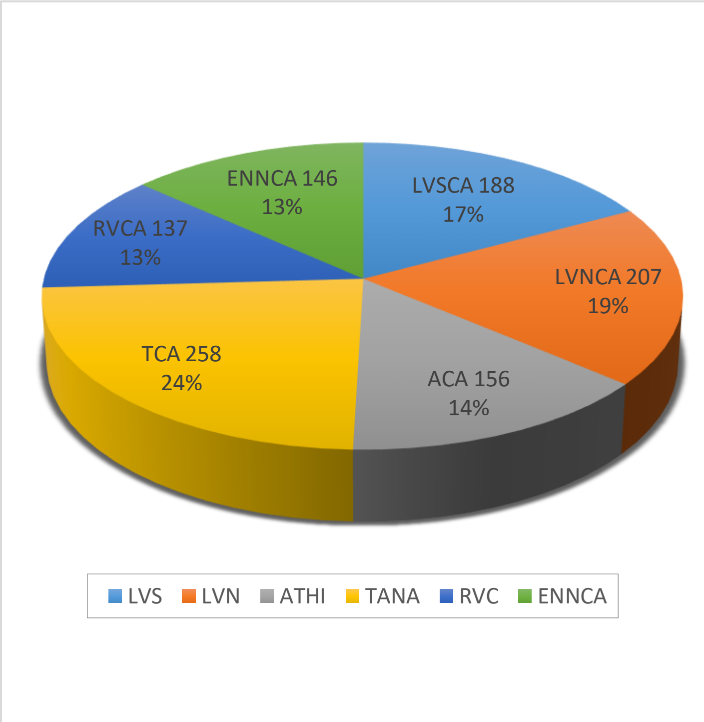


Figure 9.1:Approvals June 2019

Tana had the highest number of approvals at **258**, followed by **LVN** at **207** while **RVC** had the lowest approvals at **137.**

The high values in Tana could be a pointer to larger amounts within category A thresholds, unlike **RVCA** which has lower thresholds. Figure 9.2 shows cumulative authorizations by June 2019.

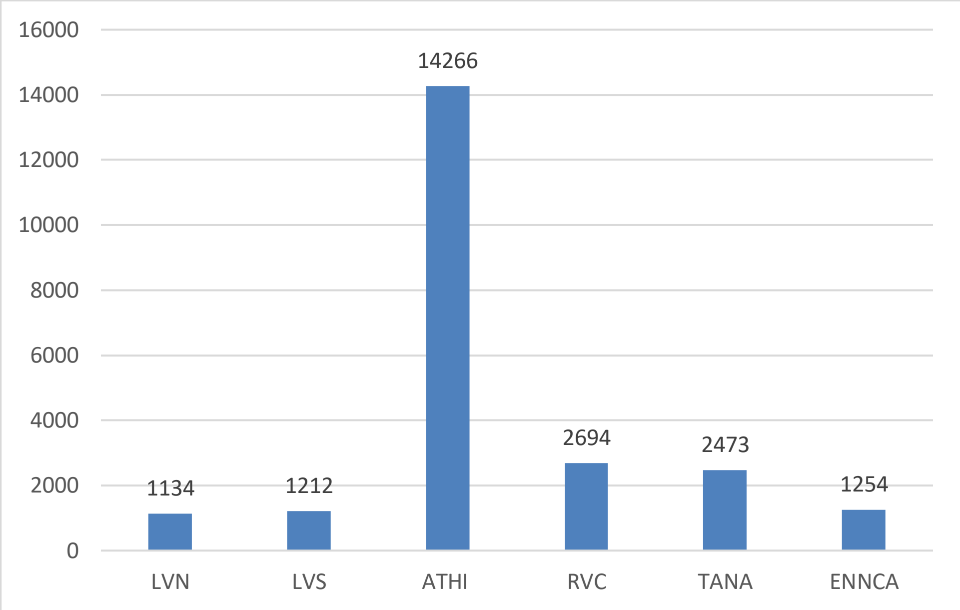


Figure 9.2: Cumulative authorizations by June 2019

During the 2018/19 FY, the cumulative was **23034** nationally. Athi took the lead with (**14,266**) of the total number of authorizations issued, while **LVN** was the last with **(1134)**.

93% (**21341**) were GW authorizations, **70**% (**1643**) for SW, and ED was last with 0.21% **(49)**. The number of authorizations increased while the number of expired authorizations decreased, as compared to the previous reporting year, which is very positive and a pointer to the inspections carried out during the reporting period.

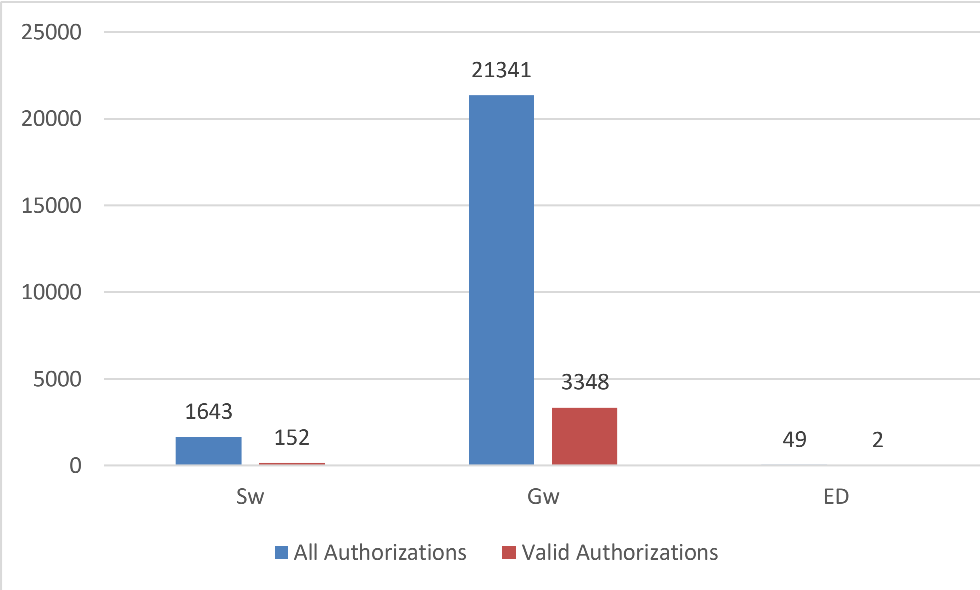


Figure 9.3: Comparison of Authorizations and Permits per region June GW/SW

In the above bar graph ground water had the highest number of Authorization, **21,341**, valid Authorization **3348** while in second place was the surface water all Authorization at **1643**, valid were **152** and lastly the Effluent Discharge all Authorization were **49** while valid Authorization were only 2. Figure 9.4 show comparison of Authorizations and Permits per region June 2019.

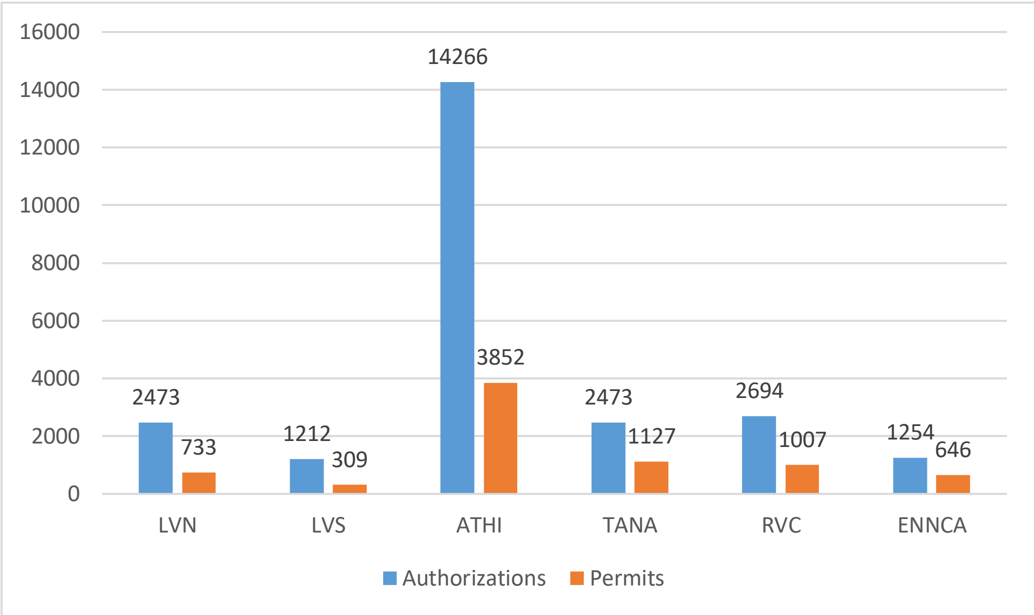


Figure 9.4:Comparison of Authorizations and Permits per region June 2019

There were 23034 Authorizations and 7674 Permits. Athi has the highest number of Authorizations and Permits, followed by RVC and Tana. LVS has the least number of permits.

The numbers also depend on water resources endowment as well as the demand in the various regions.

9.2 Water Use

Table 9-3: Comparison of Permitted volumes and Valid Volumes per region by June 2019.

Regions	**Permitted Volumes**	**(%) of permitted volumes**	**Valid Volumes**	**(%) of Valid volumes**
Tana	82,043,725	91	707,036.37	**11.23**
Athi	550,160.69	0.61	271,017.60	**4.31**
RVC	3,626,976.80	4.04	1,944,149.70	**30.89**
LVN	587,083.58	1	541,657.01	**8.61**

LVS	2,801,003.80	3.12	2,690,587.10	**42.75**
ENNCA	213,221.21	0.24	138,866.74	**2.21**
Total	**89,822,171**	**100**	**6,293,314.52**	**100.00**

9.2.1 Comparison of permitted volumes per region June 2019

Tana had the highest permitted volumes 91% followed by **RVCA** was second in permitted 4.04% in the third place was **LVS** with permitted volume of 3.12% and the least being **ENNCA** at 0.24%

Table 9-4: Comparison of Permitted Volumes and Valid Volumes per region June 2019

Region	All Permits	Valid Permits	Permitted Volumes (x1000 m3/d)	Valid Volumes (x1000 m3/d)
LVNCA	733	641	587.08	542
LVSCA	309	224	2801	2690
RVCA	1007	758	3627	1944
ACA	3852	2522	550	271
TCA	1127	517	82043	707
ENNCA	646	426	213.2	139
Total	7674	5088	89,821.21	6,293

84.6% of the total volume allocated for power is from Tana Catchment. LVN and ATHI follow Tana with a combine 11% of the total water allocated or power. RVC and LVS had less than 5%, with ENN being the least allocation of SW for hydropower generation. Less than 1% was allocated for power from GW. RVC and Athi are the only regions which have allocated GW for hydropower generation, as a result of geothermal development.

Table 9-5: Water allocated for irrigation m3/d June 2019

	IRRIGATION		
	SW	GW	
LVN	9038.03	169.5	9207.53
LVS	19,304.57	501.5	19806.07

RVC	171,188.23	195,818.51	367006.7
ATHI	266,410.47	26841.02	293251.5
TANA	879,082.85	964.4	880047.3
ENNCA	99,599.08	19648.24	119247.3
		Total	1,688,566

Among the consumptive uses, irrigation was the largest water user with **1,688,566** m^3/d allocated to the sector. Tana Catchment has allocated (**879,082.85m^3**/d) of the SW volumes for irrigation, making the catchment the highest water user for irrigation purposes. This could be attributed to the irrigation projects in the catchment. Athi Catchment (**266,410.47 m^3/d**) followed in SW allocated for irrigation, then RVC took the third largest SW user for irrigation with a volume of 171,188.23 m^3/d.

Table 9-6: Water allocated for Public use from SW and GW m3/d June 2017

	Public		
	SW	GW	Total
LVN	88,077.89	673.5	88751.39
LVS	101,748.9	139.09	101888
RVC	9,556.92	54,297.06	63853.98
ATHI	68,262.95	36609.02	104872
TANA	346,174.2	10716.13	356890.3
ENNCA	25595.7	1587.3	27183
		Total	743,438.7

Among the consumptive uses, Public water with **743,438.7** m^3/d allocated to the sector. Tana Catchment has allocated (**346,174.2m^3**/d) of the SW volumes for irrigation, making the catchment the highest water user for irrigation purposes. This could be attributed to the public projects in the catchment. LVS Catchment (**101,748.9m^3/d**) followed in SW allocated for public, then LVN took the third largest SW user for irrigation with a volume **of 88,077.89** m^3/d.

Table 9-7: Water allocated for Domestic use from SW and GW June 2019

	Domestic		
	SW	GW	Totals
LVN	8181.35	10861.97	19043.32
LVS	5661.42	3744.26	9405.68
RVC	25,455.02	15,350.65	40805.67
ATHI	11,777.17	72100.01	83877.18
TANA	482,392.62	6906.78	489299.4
ENNCA	43,455.51	5515.67	48971.18
		Total	691,402.4

Domestic water with **691,402.4** m^3/d allocated to the sector. Tana Catchment had allocated (**482,392.62**m^3/d) of the SW volumes for domestic, making the catchment the highest water user domestic purposes. This could be attributed to the water demand for the public use in the catchment. RVC Catchment (**25,455.02**m^3/d) followed in SW allocated for public, then Athi took the third largest SW user for irrigation with a volume of **11,777.17** m^3/d.

The least volume allocated from consumptive use was for livestock with allocation of **12.1** m^3/d SW and **52.6**m^3/d GW.

Table 9-8: Water allocated for Livestock use from SW and GW June 2019

	Livestock		
	SW	GW	Total
LVN	2008.84	187.37	2196.21
LVS	12.1	52.6	64.7
RVC	4,828.85	1,490.35	6319.2
ATHI	159.42	1942.1	2101.52
TANA	3318.37	321.31	3639.68
ENNCA	6,316.94	787.41	7104.35
		Total	21,425.66

ENNCA allocated the highest amount at 6,316.94 m^3 /d (37.95%) of the total SW allocated for Livestock use, followed by RVCA at 4,828.85M^3/d (29.01%) LVS and Athi were the last in SW allocation for livestock use at 12.1M^3/d. (0.07%) Athi allocated 159.42 M^3/d (0.95%) of the SW volumes.

9.3 Recommendations

There is need for training Permit database users and capacity building to ensure all the relevant users are conversant with the system so that the processing of the: Application, Authorization and permit are processed on time. This will enable the imports and exports done promptly without delay, starting from the Sub-regions, Regions up to the Headquarters.

9.4 Conclusions

The Kenya constitution of 2010, Chapter four of the bill of Rights-Article (43) part (d) which states that it is the right of every person to get clean, safe, equitably and adequate water. That’s why as the Authority we are mandated to do so on behalf of the Kenya government.

10 REFERENCES

(Government of Kenya -The Water Resources Management Rules, 2006)
(Government of Kenya - Water act, 2016)
(WRA-Water Resources Situation Report, 2017)

APPENDIXES

Water use

Table 0-1: Cumulative volume of water allocated for each purpose June 2019

Volume of water by category of water use up to June 2019 (m^3/day)																	
Regi	Public		Domestic		Livestock		Irrigation		Industrial		Power		Other		Total		Combine
	SW	G W	S W	G W	S W	G W	SW	G W	S W	G W	SW	G W	S W	G W	SW	G W	
LVN	88077.9	673.5	8181.35	10861.97	2008.84	187.4	9038.03	169.5	53835	109.5	411506.5	0	1819.03	104.9	574,466.65	12,106.77	586,573.42
LVS	101,748.9	139.09	5661.42	3744.26	12.1	52.6	19304.57	501.5	21200.37	202	2646493.71	501.5	6621.29	60	181,013.36	4800.95	185,814.31
RVC	19556.92	54297.06	25455.02	15350.65	4828.85	1490.4	171,188.2	195818.5	26105.5	2964.6	3126799.68	195818.5	3605.3	7614.2	3,377,539.47	473,353.91	3,850,893.38
Athi	68262.95	36609.02	11777.17	72100.01	159.42	1942.1	266410.5	26841.02	38212.38	24914.9	72.73	26841.0	13577.02	1274	398,472.17	190,522.05	588,994.22
Tana	346174.2	10716.13	482392.6	6906.78	3318.37	321.3	879082.9	964.4	10873.85	117.5	80277558.3	964.4	120330.2	845	81,619,730.42	20,835.51	81,640,565.93

ENN	25595.7	1587.3	43455.51	5515.67	6316.94	787.41	99599.08	19648.24	4277.29	609	182.23	19,648.2	54690.7	1255.2	234,117.45	49,051.02	283,168.47
TOTALS	**649,416.57**	**71,082.1**	**137,675.07**	**114479.3**	**16644.52**	**4781.21**	**1444623.28**	**243943.2**	**154504.4**	**28917.5**	**86462613**	**243773.6**	**200643.5**	**11153.3**	**86,385,52**	**750,670.21**	**750,670.21**