Unlocking the Potential of Ecohydrology in Climate Stressed Water Bodies: Experience from Mara River Basin, Tanzania

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Abstract

Mara River is a transboundary water body between Tanzania and Kenya that drains into Lake Victoria. This transboundary water body is crucial for various ecosystem services for the local communities along the catchment. Despite its ecological and economic significance, the river is under increasing pressure and losing many of its important functions with serious consequences in aquatic biodiversity, significant reduction of livelihood opportunities, water eutrophication, changed water regimes and increased water use conflicts. This study identify the drivers of climate change and environmental degradation, effects of mining activities on water quality, effects of agricultural activities on stream discharge and establish approaches for river basin management and environmental conservation. Socio-economic data were collected through household questionnaires, interviews and participant observation. Ecological data on water quality, flow and heavy metals concetration were obtained from gauging stations and Lake Victoria Basin Offices for analyses. The Statistical Packing for Social Sciences and Microsoft Excel were used in the analyses. The study revealed that environmental degradation along the Mara River Basin is caused by direct and indirect drivers. Direct drivers for environmental degradation are identified as agriculturel (41%), mining (34%), livestock keeping (13%) and deforestation (12%). It is found that impairment of water quality is due to excessive NO3- and PO43- concentrations that exceed the recommended in most sites by direct drivers which cause adverse impact on the ecosystem. Ecohydrology and management framework that encompasses integrated water resource management along the entire basin should be applied and also, developing new species susceptible to the impacts of climate change.

Keywords: Water regimes, Agriculture activities, Hydrological services, Mara River Basin, Tanzania

1. Introduction

With increasing population and related economic activities, the earth's natural resources and the environment are increasingly stressed. More virgin land is being turned into agricultural land, watershed hosting endemic flora and fauna being degraded and forests are being felled for timber, fuel wood and other uses at a pace faster than they are being replenished and degrading water resources. In recent years, it has been documented that (Lalika *et al.,* 2015a; b; Lalika *et al.,* 2017) the impact of increased human population on the natural ecosystems has been threatening the basic foundation upon which humans depend for steady supply of ES essential for human survival and ecological integrity.

The Ecohydrology is a relatively new and rapidly growing nature-based solution for solving water and environmental problems around the globe. It is a trans-disciplinary science, a nature-based solution and a problem-solving science derived from the larger earth systems science movement and examining mutual interactions of the hydrological cycle and ecosystems (Zalewski, 2002; Zalewski *et al.,.*2010). It is also an applied science focused on problem solving and providing sound guidance to catchment-scale integrated land and water resources management. The main scope of ecohydrology include (i) climate-soil-vegetationgroundwater interactions at the land surface with special implications for land use, food production and climate change; (ii) riparian runoff, flooding, and flow regime dynamics in river corridors with special implications for water supply, water quality, and inland fisheries; and (iii) fluvial and groundwater inputs to lakes/reservoirs, estuaries, and coastal zones with special implications for water quality and fisheries.This study was carried out along Mara River, a transboundary water body between Tanzania and Kenya which drains into Lake Victoria. Mara River Basin (MRB) is essential in ecological and economic aspects, the river is under increasing pressure due to significant loss of water quantity due climate change and human activities. In recent years it has lost its important functions with serious consequences in aquatic biodiversity, livelihood opportunities, changed water regimes and increased water use conflicts (Mango *et al.,* 2011).

Despite the fact that MRB is very important in supporting the livelihood of communities living around, the river has been altered through agriculture, mining and water abstraction. Small scale farmers and domestic users rely less on conveyance systems and more on the resource in the channel. Mining and agriculture are the largest user of freshwater resources along the MRB. However, mining activities are both cause and victim of water pollution through its discharge of pollutants (mercury, arsenic, phosphorous, sulphur and nitrate), also during rainfall it causes soil run off and sedimentation which contains heavy metal direct to the river and poor agricultural practices along the river banks. These actions often create a legacy of poor water quality, siltation, effect on aquatic biodiversity, effect on riparian biodiversity and poor stream discharge, disrupt channel systems and also cause eutrophication. Agricultural activities affect the quality of water if not managed well. Some of activities are; cultivating along the river banks, fertilizer application, pesticides application, irrigation etc. these activity affect physical, chemical and biological characteristics of water (Dafter *et al,.* 2019). The cutting down of trees (deforestation) along MRB watershed and other activities activate river banks erosion leading to high levels of turbidity in rivers and siltation of bottom habitat. Forests and Savannah glassland have been cleared and converted into agricurtural land (IUCN, 2000). Attribute the decline to increased human activity in the basin and climate change which they claim has resulted to erratic rainfall pattern (Dessu and Mellesse, 2012). Disruption and change of hydrologic regime often with loss of perennial streams causes public health problems due to loss of potable water.

The study is important since it focuses on future and current environmental conservation in the area and development of the different ways to reduce effects caused by human activities along the rivers. Besides, it would address the negative issues of human activities and immediate control measures for Sustainable Development Vision 2030.The study is important in the area; since there is a pressure of human activities and environmental degradation (pollution) which needed urgent address from both stakeholders and the government. As a result, information on water quality of the river is needed for the planning of its management and the control of eutrophication in the river and Lake Victoria in general (WWF, 2006; Nile Basin Initiative, 2007). The result will help not only information of similar interventions ,but also in the implementing of policies that will be used to address issues on water resources for sustainable use. As an ecological tool for conservation, ecohydrology practices increases resilience of river basins by managing multi-dimensional parameters such as water, biodiversity, ecosystem services for society and resilience to climatic changes in order to achieve sustainability in both ecosystems and human population (Zalewski, 2015). The study was carried out to: identify drivers for climate change along MRB; determine and assess the effects of mining activities on water quality;

examine the effects of agricultural activities on stream discharge and establish Ecohydrology approaches for river basin management and environmental conservation.

2. Materials and Methods

2.1. Description of the study area

The study was conducted in three villages (Nyangoto, Nyabichune and Matongo) along MRB Tanzania. MRB is the Trans-boundary shared between Kenya and North Western Tanzania at between longitudes 33˚47'E and 35˚47'E and Latitudes 0˚28'S and 1˚52'S and (MRB) is home to more than 1.28 million people in Kenya and Tanzania and supports a number of critically important wildlife areas. (African Barrick Gold, 2013; MTL Consulting Company Limited, 2011;Zermoglio *et al.*, 2019).

2.1.1. Hydrology and drainage patterns

There are two distinct wet seasons, namely the 'long rains', from March to May and the 'short rains', from November to December. The average annual rainfall is approximately 1320 mm,the wettest month is April and the driest month is July. The study area is largely enclosed by the Nyarero Escarpment, which is observed to exceed 1,700 m a.m.s.l. in the eastern portions, and as such, the valley (referred to as the Kiribo Plains) drains from east to west towards Lake Victoria via a large wetland area (referred to as the Masirori Swamp also a known as a critical nursery for economically important fish species of Lake Victoria (LVBC and WWF-ESARPO, 2010; MTL Consulting Company Limited, 2018). While various other drainage lines within the study area, including those typically representative of smaller wetland systems (e.g. Nyabuchichibu, Nyamaku, etc.), direct water toward the Mara River and the aforementioned wetland area, the most prominent of these features is the Thigithe River, which also discharges into the Masirori Swamp, also all these tributaries discharges into MR towards lake Victoria.

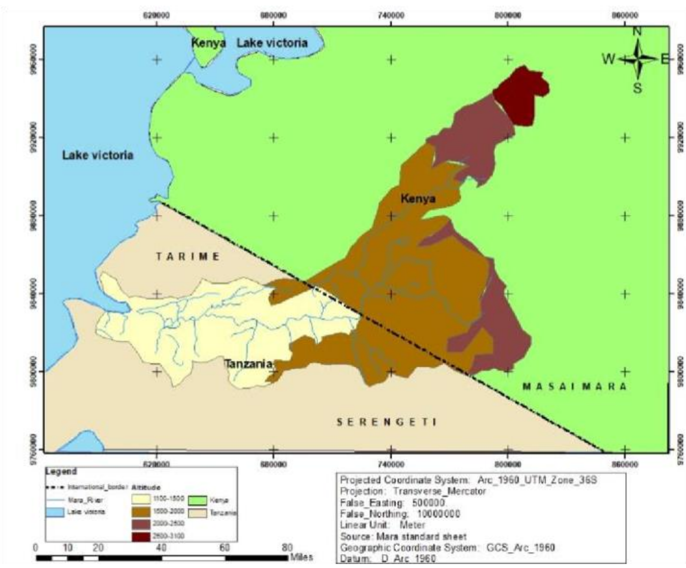

Figure 1. Location of Mara River Basin (Source: Omary Matyangala Cartographic 2021).

2 .1.2. Vegetation and ecological systems

The upper part of Mara basin consists of protected forest and woodland within the gazette area of Mau Forest Complex. Some of the areas which were originally forest have been cleared for cultivation. The middle part consists of grassland and bush land which is in the Serengeti National Park in Tanzania or Maasai Mara National Reserve in Kenya. Some of it is also under large-scale farming or ranching or small scale agriculture. The lower part in Tanzania consists also of agricultural land. Wetlands are found in the area close to Lake Victoria. The Mara basin has been subject to rapid changes in land cover over the last 50years. The forest provides honey, forest employment and forest farming, firewood, medicinal herbs.

2.1.3. Land use and socio-economic activities

The dominant and important land uses in the MRB are: forests conservation, especially in the catchment (expanding tea farms); A number of settlements and villages which surrounds MRB and conduct mining activities (or hamlets) within the immediate vicinity of the mining areas Includes Matongo, Nyabichune, Nyangoto and other village are like, Genkuru, Kerende, Kewanja, Nyakunguru and Nyamwaga are previously known as a prominent artisanal and small-scale mining (ASM) area and as such, agro-pastoral activities were regarded as a secondary livelihood (African Barrick Gold, 2013; MTL Consulting Company Limited, 2011). However, these activities have since been observed to dominate the surrounding land-use activities in terms of cultivated lands, livestock rearing and other general domestic uses. The basin has experienced substantial land use changes in the past 30 years that has seen a shift from forest and bush-land to agricultural farming (Mango *et al.,* 2011). Gold mining is an important source of revenue and a major employer in the Tanzania segment of Mara River Basin. ACACIA Gold mine (North Mara Gold Mine) located in the segment which is important that it is quoted on the New York Stock Exchange. Trade and commerce on the other hand is a feature of urban centers' like Tarime and Musoma. A majority of economic activities in the basin thrive because of the availability of water in basin. Any major negative changes in the quality and quantity of the basin's water may have an impact on the economy of the area.

2.1.4. Climate and ecological zones

Tanzania has a tropical climate with large regional climatic variations influenced by several factors, a coastline, a substantial section of the Great Rift Valley, some mountains and a central plateau (Nathan, C. *et al.,* 2019). There are usually three main air masses that significantly influence the rainfall regime of the Mara River Basin. The apparent movement of the InterTropical Convergence Zone (ITCZ) determines the seasons on the basins, which receives annual rainfall. The temperature variations in the MRB are determined by altitudinal as well as rainfall variations, such that in elevated areas with high rainfall amount the temperatures drop to 20.6oC, while the lowlands in the central and southwestern parts of the basin the temperatures rise to 23.5oC. Temperatures are lowest in the wet months of March to May and the highest in the dry months of July and August . In general temperatures increase southwards and decrease northwards (North Mara Gold Mine Report, 2018).

2.2. Sampling procedure

Purposive and random sampling was used to select study villages and respondents in each village. While purposive sampling was used to select villages located along the MRB, random sampling was used to select respondents in each study area. Purposive sampling is important because it removes the bias when reselecting the respondents. In other words, it has the ability to remove bias and it gives an equal opportunity to each respondent to be sampled / selected for the study. In each sampled village, households were randomly selected in order to get respondents. These respondents were picked from a village register book where all households' members are listed. A total of 60 respondents were interviewed, i.e. 30 from each village. According to Bailey (1994), 30 individuals are recommended for a social research to meet a reasonable statistical analysis.

2.3. Data collection methods

While primary data were collected through household questionnaires, checklist for key informants, interviews and direct observation. Secondary data were collected through reading relevant literatures from previous studies in library, publications, books, journals and records. the water samples including as physical and chemical parameters of water quality were analysed through environmental laboratory from North Mara Gold Mine. The parameters for monitoring in water samples include physical parameters, cyanide compounds, metals, cations, anions, hydrocarbons, and microbiology. Also, some of the parameters for onsite and offsite data included pH, Conductivity, Dissolved Oxygen (DO), Total dissolved solid, Temperature, Salinity and Redox potential.

2.4. Data analysis

The data were collected, coded, classified, entered and tabulated where by analysis was done using Statistical Packing for Social Sciences (SPSS) version 20.0. Furth more Microsoft Excel was used to draw, charts, tables, and construct figure. Supplementary information, which was obtained from field visits, was used to cross check the information obtained from questionnaire and the secondary data which were obtained from various sources.

3. Results

3.1. Drivers for climate change and environmental degradation along Mara River Basin

Climate chnage and environmental degradation has continued to occur all over the world for years at rate increasing. Climate variability and change will multiply these pressures on water resources. This climate change vulnerability assessment for the MRB aims to shed light on the pressures that face the MRB and to offer insights on priority vulnerabilities of the MRB as a whole (Zermoglio *et al.,* 2019). Natural habitat and are being destroyed and

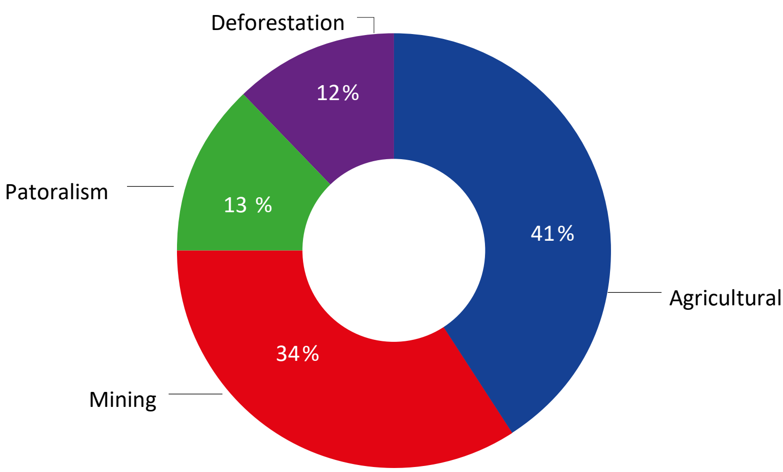

Figure 2. Drivers for climate change and environmental degradation along MRB

evidences of contamination in most part in the world become vivid (Matel, 2000). The study revealed a number of drivers for climate change and environmental degradation. They include agricultural (41%), mining (34%), livestock keeping (13%) and deforestation (12%).

3.2. Effects of mining activities on water quality

The findings in Table 1 show that 75.0% of respondents involves in mining activities which are small scale and large-scale mining. While 25% said that they not involved in mining activities. Mining activities involved the use of water in all operations including separations of minaral through chemical process, physical separation of materials such as in centrifugal separation. Majority of the community members who are involved in mining activities along MRB use water from Mara River for their daily activities.

Table 1: Mining activities along Mara River Basin

Mining activities	Frequency	Percentage
Yes	45	75.0
No	15	25.0
Total	60	100

3.2.1. Water pollution from mines is often cited as a major concern among stakeholders

Table 2. Concentrations (mg/l) of heavy metals in Mara River

Heavy metal	2015	2016	2017	2018	WHO
Cu	0.01	0.06	0.01	0.06	2
Fe	1.14	0.62	0.19	0.79	1
Cd	<0.02	<0.02	<0.02	<0.02	0.003
As	0.08	-0.01	0.06	0.01	0.01
Hg	<0.001	<0.001	<0.001	<0.01	0.006
Zn	0.08	0.01	0.01	0.06	0.02

Concentration ranges and means of heavy metals Cd, Fe, Zn, Hg, As and Cu measured in water samples from 8 sites of MRB are summarized in table 2. The results from the table show that the heavy metals varied over distinguishable range of concentrations. This range reflect the impact of varying settings, characteristic water and soil in land use practices spread over different sub-catchments in the Basin. Sources of these metals may therefore be attributed to the nature of the catchment areas, mining waste discharge, agrochemicals, geological weathering of parent rocks and atmospheric sources.

The findings in Figure (3) and (4) lead the conclusion that most of heavy metal are dangerously to the climate and environmental even if in low concentration.

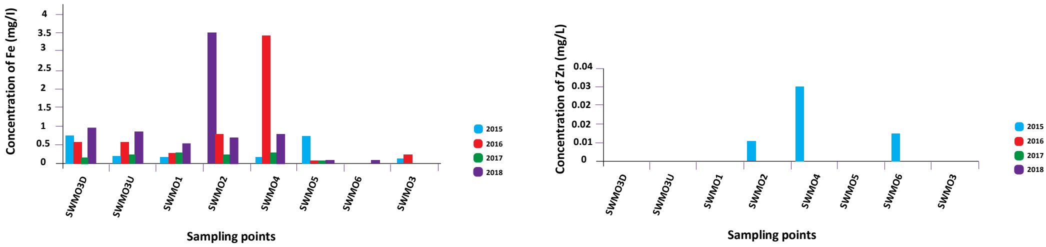

Figure 3 & 4. Iron and zinc concentration in Mara River

3.3. Effects of agricultural activities on stream discharge

Agricultural activities are among of the main activities conducted along MRB, look at Table 3 reveals that most of the people in the community engaged in agricultural activities along MRB.

Table 3: Agricultural activities

Agricultural activities	Frequency	Percentages
Yes	40	66.67
No	20	33.33
Total	**60**	**100**

Majority of communities within the MRB are mainly farmers engaged in mixed cropping and livestock husbandry, or both.

Table 4: Codes for Mara River monitoring point

SWMO1	Mara upstream of SWM2 GO VIA Mrito
SWMO2	Mara upstream of abstruction point go via the back of Rama dump
SWMO3	Mara at water abstraction point
SWMO3D	Mara river below Pipe line discharge
SWMO3U	Mara River immediately Upstream of SWMO3(Control site for Ingwe Discharge) water abstraction point
SWMO4	Mara River down of SWM3
SWMO5	Mara d/s Mine (back water channel)
SWMO6	Mara d/s Mine (back water channel)
SWMO7	Mara d/s Mine (Kirumi bridge)

3.3.1. Concentration of Phosphorous in Mara River

As figure 5 indicates, Phosphorous is a limiting plant nutrient and rarely found in high concentrations in fresh waters.

Table 5: Mean concentration ±Standard deviation (mg/l).

Sample code	2015	2016	2017	2018
SWM03D	11.8 ±4.0	3.9±2.9	6.2±6.2	
SWM03U	10.0±4.3	6.8±1.2	6.7±4.9	9.1±3.7

SWM03	17.4±17.4	10.8±1.85		
SWM02	14.5±.86	9.6±6.4	9.0±4.5	9.6±5.2
SWM05	0.1±.6.0	3.0±2.2	4.9±2.7	5.8±4.2
SWM01	60.3±40.4	12.2±.8.0	9.5±6.7	6.6±4.1
SWM04	51.0±.40.1	9.9±4.7	7.1±4.9	7.7±3.1
SWM06	4.9±4.9			

Mean concentration of Nitrate in river water of Mara River Basin

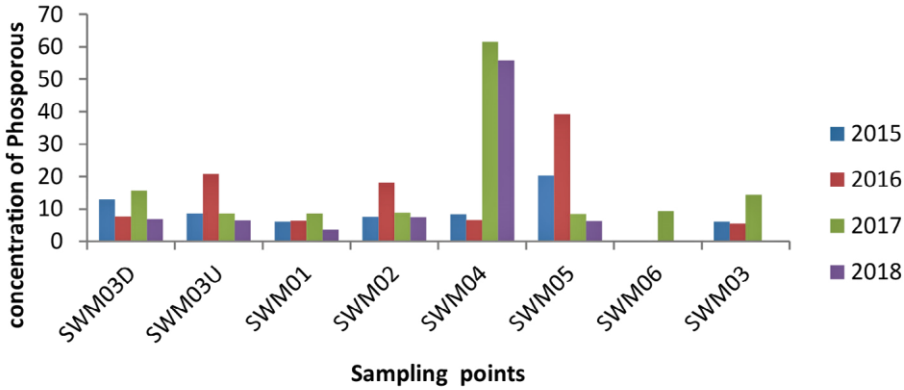

Figure 5. Phosphorous concentration in Mara River

3.4. Ecohydrology approaches for river basin management and environmental conservation.

In the table below the study found that only 33.3% of the community members engage themselves towards conserving the MRB by planting trees along MRB, and raise awareness on conservation activities, where most people in the community they were not engaged in. Also, the table below reveals that 66.7% of the respondents did not engage at all in conserving the MRB.

Table 6: Participations of community in Mara River Conservation.

Participation	Frequency	Percentages
No	45	67
Yes	15	33
Total	**60**	**100**

4. Discussion

4.1. Drivers for climate change and environmental degradation along Mara River Basin

Agricultural and Mining activities are the most drivers for climate change and environmental degradation along MR. Figure (2) reveals that most of the people in the community engaged in agricultural and mining activities along MRB. All these leads to the enrichment of nutrients

(Eutrophication) in MRB and change of river flow and frequent floods. One of the serious problems is the contamination of water resources by toxic chemicals like mercury, cyanide, pesticides, fertilizers, livestock chemicals and the byproducts that originate from mining and agriculture site (Kihampa, and Wenaty, 2013).

The result shows that invasion of agricultural is the most activity that contributes to climate change and environmental degradation within the study area accounting for about 41%. Agricultural activities have been shown contributing immensely to climate change as it ranks third after energy consumption and chlorofluorocarbon production in enhancing green house emissions. In fact, emissions from agricultural sources are believed to account for some 15% of today's anthropogenic greenhouse gas emissions (Kihampa, and Wenaty, 2013). Land use changes, often made for agricultural purposes, contribute another 8% or so to the total (Ozor and Nnaji, 2011). The results from the figure (2) above imply that improper animal grazing along the MRB contributes significant climate change and degradation of environmental vegetation and land through regular feeding and trampling. Cutting down of trees for feeding livestock as well as normal feed by livestock reduce vegetative cover which act as a barrier for soil erosion since surface sediments become more exposed, therefore unstable and subject to weathering and erosion (Ziervogel *et al*., 2008). Livestock trampling cause soil compaction which prevents infiltration, which in turn prevents the groundwater table from recharging and therefore increases surface runoff. This increases the likely chance of a change of river flow and frequent floods. Improper cultivation is rampant along the MRB due to inadequate knowledge on how to perform sustainable agriculture within the area; this therefore leads to environmental degradation and climate change . A study by Kashaigili. (2011) shows that agriculture is the major land use by the indigenous community living close to this wetland where irrigated agriculture was found in the lower Ruvu and the western slopes of the Uluguru Mountains.

On the other hand, the result shows that mining in MRB was ranked as the second significant driver to environmental degradation and climate change within the study villages. The residents mention mining activities is one of the sources of income for both small scale and large scale miners along MRB. Mining activities involves different stages from starting point (exploration ,mining, and processing), through this stage activities like clearing vegetation, removing top soil, ,blasting are done and contribute to environmental degradation and climate change. While this was confirmed by local testimony of a few local by-passers, the extent of the contamination and its potential effect are unclear, especially since the cause of the spillage was believed to be vandalism of the liners at the Gokona Leachate Ponds. (Nathan,C. *et al.,* 2019).

Villages such as Nyangoto, Nyabichune and Matongo which lie close to MRB, results from the figure show that livestock grazing has contributed to the environmental degradation due to the lack of restrictions on land use. However, the deforestations is among of contributers to the environmental degradation and climate change along the MRB, the deforestation is lead by cutting tress to make charcoal, settlements and shifting cultivation . Negative impacts of deforestation and forest degradation include loss of ecological services (such as biodiversity and watershed), the loss of many goods such as timber, fuel wood, charcoal and None Wood Forest Products (Lamb et al., 2005), and the loss of livelihood sources for more than 80% of rural Tanzanians (URT, 2005). Generally, the study found out climate change and environment are being threaten by over-exploitation of its functions, products and services from increased anthropogenic activities including agricultural, mining, livestock grazing by immigrants from various regions of Tanzania. Deforestation as well as growing population in different cities, towns and township from the country and neighbour country like (Kenya) lead to increased demand for food, income, and areas for settlement. Inappropriate grazing regimes and stocking rates associated with increasing livestock population, increasing irrigation activities as well as lack of proper environmental management policies and strategies continue to threat MRB areas in different parts of the world causing changes in the services and goods accrued from Environmental resources (URT, 2007).

4.2. Effect of mining activities on water quality

Heavy metals concentration ranges and means of heavy metals Cd, Fe, Zn, Hg, As and Cu measured in water samples from 8 sites of MRB are summarized in Table 2 as well Figure 2and Figure 3,respectively. The results from the tables show that the heavy metals varied over distinguishable range of concentrations. This range reflect the impact of varying settings, characteristic water and soil in land use practices spread over different sub-catchments in the Basin. The study by North Mara water management stratergy project (2016), cources of these metals may therefore be attributed to the nature of the catchment areas, mining waste discharge, agrochemicals, geological weathering of parent rocks and atmospheric sources . For instance Cd, Cu and Zn are reported to be a component of pesticides and fertilizers which attach to organic materials that can be released through surface runoff during the rainy season (Fulekar and Chhotu 2009; Okoro *et al*., 2012). Air from mining activities is reported to be a source of Pb, which is attached into dust particles that eventually settled in surface water (NMGM Report , 2017). Hg has been reported to be Part of the components of reagents used in mineral processing most in small scale around MRB .Mining also result in loss of vegetation and topsoil which causes climate change, flooding, and the water emerging from the debris contains toxic solutes which include metals. Generally, mining water is complex in nature and of widely varying metallic composition (Msagati and Mamba 2011).

According to the laboratory analysis of *North Mara Gold Mine,* the Table 2 above shows some of the secondary data of heavy metals concentrations found in Mara River at different sampling point, within four years. The contents of the heavy metals in water unlikely related to the corresponding contents in the sediments phase, In general there were higher concentrations in sediments than in water samples (Kihampa and Wenaty, 2013) .This has to be expected, because metals are slow to degrade, in water are adsorbed onto suspended particles and eventually settle to the sediments which are particular 'sinks' where chemicals tend to concentrate (Oruma, 2012).

The result from Table 2 shows that among seven heavy metals, its highest concentration of Cu in 2016 and 2018 years, Zn in 2015 and 2018 years, As in 2015 and 2017 years and Fe in 2015 year was observed in different stations in four years (it means exceeds the WHO standards limit) .This may attribute to the huge amount of raw sewage, ship breaking, agricultural and industrial wastes water discharge into the river (Abdel, 1997). Overall, As, Cu, and Fe all are highly toxic elements found in downstream sample sites .But some of heavy metal like mercury and Cadmium they not detected due to limitation of the machine cannot detect concentration amount less than 0.002 (<0.002)for cadmium and less than 0.001 (<0.001) for mercury , and this does not mean that there is no mercury or cadmium in Mara River, but in lower concentration which can have effects to some aquatic organism and also this amount once combine with another elements can cause negative impact to the environmental . For instance, the inorganic forms of tin (Sn), and mercury (Hg) are much less toxic or even do not show toxic properties while the alkylated forms are highly toxic (Kapustova, 2009; Sharma *et al.,* 2009).

4.3. Effects of agricultural activities on stream discharge

Majority of communities within the MRB are mainly farmers engaged in mixed cropping and livestock husbandry, or both. In fact, this study found in table 3 that farmers engaging in both intercropping and mixed cropping make 66.67% of the households within the MRB. Agriculture is also significant impacts freshwater, estuarine and coastal environments, leading to sedimentation, eutrophication and ecosystem damage. (Kihampa C. and Wenaty A., 2013). The economy of the upper reaches catchment section of the MRB is based on mixed small-scale, intensive farming due to abundant rainfall. In the middle reaches, however, the economy is mainly driven by nomadic pastoralism, crop plantations and tourism (Zeitler, 2000). Apart from Serengeti National Park, the economy within the lower catchment section of the MRB is dominated by agriculture, livestock production, mining, and to some extent fishing, business and petty trading (Majule, 2010). Data by Makalle et al., (2008) shows that about half (51.8%) of the community members within the basin are engaged in both livestock keeping as well as cultivation while 2.5% relied solely on livestock with a herd size per household of 50-1,000 cattle.

Figure 6. Uncontrolled livestock grazing and deterioration of the MRB © Magdaline Boniphace

These results confirm that subsistence farming is widespread in the lower catchment. Food crops grown in the lower catchment region include: cassava, maize, sorghum, finger millet, paddy, sweat potatoes and beans. Most of the cash crops grown in the MRB include: cotton, coffee, sunflower, tobacco and groundnuts. The production trend of these cash crops shows fluctuating yields, probably due to a corresponding fluctuation in weather conditions in the region (Majule, 2010). Improper cultivation is rampant along the MRB due to inadequate knowledge on how to perform sustainable agriculture within the area; this, therefore leads to water pollution in MRB. A study by Kashaigili (2011) shows that agriculture is the major land use by the indigenous community living close to the river where irrigated agriculture was found in the lower Ruvu and the western slopes of the Uluguru Mountains. As Malatu *et al.,* (2015) pointed out, a decline of upland productivity triggers more pressure to river cultivation which lead to more degradation to the River Basins.

4.4. Concetration of Phosphorous and nitrate in Mara River

Also, the study supported by secondary data from *North Mara Gold Mine (Laboratory analysis),* these physicochemical characteristics of the water: The results of the physicochemical parameters measured at 8 sites within MRB. Some of the North Mara Gold Mine Company expertise and respondents argue that that the amount of concentration, Ph and Nitrate within the MR increased due to agriculture activities by using fertilizer, attributed by the nature of nitrate-nitrogen being the most oxidized chemical form of nitrogen found in the natural systems and in living organism. The impacts are due to the increased use of agrochemicals inputs in order to meet agriculture production demand. Pollution from fertilizers occurs when they are applied more heavily than crops can absorb or when they are washed or blown off the soil surface before they can be incorporated. Excess nitrogen and phosphates can leach into groundwater or run off into waterways (Kihampa, and Wenaty, 2013).

Nitrate is a form of nitrogen that is an essential plant nutrient, but in excess amounts they can cause significant water quality problems. Despite of natural source of nitrate like igneous rock, plant decay and animal debris, in most cases the nitrate pollutions in water are the results of human activities. The normal range of nitrate concentration in natural waters is normally below 5 mg/l, any value above this level is an indication of manmade nitrate pollution (USEPA 2012; WHO 2007; EPA 2009; EU, 2014). Findings in table 5 indicates that limit of nitrate has been exceeded at SWM01 (Mara River upstream) and SWM04 (Mara river downstream) indicating potential contamination of the river waters, this increase of nutrients causes eutrophication. Both sites are surrounded by agricultural activities (tomatoes, green vegetables and livestock), thus possible sources of NO3-N contamination are agricultural runoffs containing fertilizers. Generally, the main contamination sources of surface waters by nitrate are potassium nitrate (KNO3) and ammonium nitrate (NH4NO3), both salts commonly used as fertilizers. Apart from nitrate, nitrogen in terrestrial and aquatic ecosystems can also be found in the form of NO2-N and NH3. The nutrient overload can cause eutrophication of lakes, reservoirs and ponds, leading to an explosion of algae which suppress other aquatic plants and animals

Phosphorous is actively taken up by plants and any excess amounts that are not used by a crop combine with the soil constituents and can be used by later crops. Potential sources of the phosphorus in this area are excessively used inorganic fertilizers, farmland manure and animal waste, particularly because livestock grazing by allowing them into the water source (Mara River) is a common practice (Oruma, 2009). High concentration of phosphorous is downstream (SWM04) in Mara River which causes accelerated plant growth and algae blooms which can then cause rapid oxygen depletion or eutrophication in the water. Increased fertilizers applications to cropland and runoff from soils with high nutrients are some of the major causes of eutrophication (McIsaac *et al.,* 2001). The end product is water with low dissolved oxygen which cannot support aquatic life including certain fish, invertebrates, and other aquatic animals (Oruma, 2009). Regarding health effects, phosphorous in water is not considered to be directly toxic to humans and animals. Any toxic effect caused by phosphorous in fresh water is indirect, such as toxic algal bloom.

4.5. Ecohydrology approaches for river basin management and environmental conservation

The study found in table 6, that only 33.3% of the community members are aware on different initiatives of conserving the MRB like planting trees and raising awareness on conservation activities, but most of the people in the community are not participating due to the low knowledge and skill in the tree planting. In other hand the study reveals that 66.7% of the respondents did not engage on conserving the MRB. While a lot of institutions and organizations have initiated projects in the past for the same reason, there is still much to be done. It is certain that these programmes cannot realize all their goals without active participation from all stakeholders, support from governments and a little push from the international community (Dhungana *et al*,. 2017).
Most of the respondents said that the responsibility of water resource management currently rests under the power of the District Executive Director. However; the water user will influence the technical personel responsible as the results we luck the intersectrol coordination and intergrated water resource management within the MRB. For example, agricultural experts are involved if water is to be used for irrigation while livestock experts are involved if water is collected in dams for livestock drinking and District water engineer are involved if water is used for domestic purpose. Ecohydrology uses the dual interaction between biota and hydrology to regret, remidiate and conserve ecosystem. More ever synergistic effects of various ecohydrological measures stabilise and improve the quality of water resources. (UNESCO,. 2006).

One of the major problems is lack of ecohydrology approaches to abstract significant amounts of water for various uses. For example, watering cans, small furrow canals and small powered water pumps are used to draw water from the river. Presently, local communities do not realize water quality could be a problem. However, there is a growing concern from the regional and districts authorities that water is being polluted from different sources mainly gold mining and fishing by using illegal chemicals. With regards to the gold mining, the effectiveness of the waste disposal dam monitoring, but still there challenges of linkages and overflow during the rain season. What is more worrying is the artisanal type of mining involving the use of mercury in gold extraction since the process is undertaken in streams draining into the main river system.

5. Conclusion

Africa is already under pressure from climate stresses which increase vulnerability to further climate change and reduce adaptive capacity. The adverse effects of climate change have a particularly devastating effect on agriculture, which is the mainstay of most African economies (Batima, 2006). The study revealed that most of the cause of environmental degradation and climate change along MRB are direct drivers, such as agriculture, mining and livestock keeping which are the major socio-economic activities in the basin. These activities cause adverse impact on the ecosystem. MRB is experiencing a number of natural resource management problems including deforestation, land degradation and pollution of the river water due to mining and illegal fishing using poison. Furthermore, it was revealed that MRB is grossly contaminated with heavy metals and nutrients contaminants. The concentrations of contaminants in most of the sites were above the recommended international and national limits for drinking and irrigation waters. The discharge of mining and agricultural effluents appears to be the potential source of the heavy metals and nutrients pollution in surface water and sometimes in sediments of MRB. As More land is converted to agricultural and mining activities. Heavy metals and nutrients monitoring is an imperative means in accessing, locating and mitigation main source of these chemical pollutants. The management approaches seem to be sectoral, thus lacking integration. A lack of specific climate change institutions to take on climate change work and the need for a better institutional framework in which to implement adaptation (Ngigi,2009). Also, it is recommended that Ecohydrology and management framework that encompasses integrated water resource management (IWRM) along the entire basin should be applied, Furthermore Ecohydrology, defined as an integrative sustainability science using the interactions between hydrology, biota and natural processes as management tools to reinforce ecosystem services on a broad range of landscapes (Zalewski, 2015*)* and also, developing new species susceptible to the impacts of climate change.

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References

Aboud, A. Obweyere, G. Mutinda, M. and Raini J. A. (2002). A rapid participatory socioeconomic assessment of the River Mara Basin, Mara River Catchment Basin initiative WWW-Eastern Africa, Regional Programmers Office, (EARPO).WWF, Nairobi, Kenya.

African Barrick Gold,. (2013). North Mara Gold Mine: Conceptual Mine Closure Plan (Issue April).

Bailey,K. (1994). Methods of social reserch (4th ed.). New York: The Free Press.

Batima, P. (2006). Climate change vulnerability and adaptation in the livestock sector of Mongolia. Assessments of impacts and adaptations to climate change. International START Secretariat, Washington DC, US.

Charles, K. and Alex, W. (2013). Impact of mining and farming activities on water and sediment quality of the Mara river basin, Tanzania; Research Journal of Chemical Sciences. Vol. 3(7), 15-24,

Dessu, S. B. &Mellesse, A. M. (2012). Modelling the rainfall–runoff process of the Mara River basin using the Soil and Water Assessment Tool.Hydrological Processes.

EPA. (2009). National primary drinking waterregulations. Environmental ProtectionAgency Washington, DC.

EU. (2014). (Drinking water) regulations.European Union Commission. Statutoryinstruments SI No 122

Fernanda, Z. Owen, S. and Mohammed, S. (2019). Vulnerability and Adaptation in the Mara River Basin; https://www.climatelinks.org/projects/atlas

Fulekar, MH. Chhotu, DJ. (2009). Phytoremediation of heavy metals: Recent techniques. Afr J Biotech. 8: 921- 928.

Hilda, D. Rose, K. Kingstone, S. George, C. John,M. and Saulos, N. (2019). Effects of agricultural activities on water quality in rural area rivers. Department of water resources, Malawi University of science and technology.

IUCN. (2000). Forest cover and forest reserve in Kenya. Policy and practice. Working paper no. 5. World Conservation Union (IUCN), Gland, Switzerland.

Kapustova, S. (2009). Heavy metals in the mountains streams. Oecological Montana 18: 27 - 30.

Kihampa, C. and Wenaty, A. (2013). Impact of mining and farming activities on water and sediments quality of the Mara river basin, Tanzania. *Res.J.chem.*Sci.**3** 15-24.

Lalika, M.C.S., Meire, P., Ngaga, Y.M., (2015a). Exploring watershed conservation and water governance along the Pangani River Basin, Tanzania. Land Use Policy 48, 351–361.

Lalika, M.C.S., Meire, P., Ngaga, Y.M., Chang'a, L., (2015b). Watershed dynamics and climate change and climate variability along Pangani River Basin, Tanzania. Ecohydrol. Hydrobiol. 15 (1), 26–38.

LVBC and WWF-ESARPO. (2010). Assessing Reserve Flows for the Mara River.

Mango, LM. Melesse, AM, McClain, ME, Gann, D, and Setegn, SG (2011). Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: Results of a modeling study to support better resource management. *Hydrology and Earth System Sciences*, 15(7), 2245-2258

Matyangala, O. Map of Mara River Basin. 2021.

McIsaac, G.F., M.B David, G.Z.Gertner and D.A. Goolsby. (2001). Nitrate flux in the Mississippi River. Nature 414:166-167.

Msagati, TAM. and Mamba, BB (2011). Development of supported liquid membrane techniques for the monitoring of trace levels of organic pollutants in wastewaters and water purification systems. J. Phys. Chem. Earth 36: 1167- 1177.

MTL Consulting Company Limited. (2018). North Mara Gold Mine: Integrated Environmental Management Plan Update - 2018.

MTL Consulting Company Limited. (2018). North Mara Gold Mine: Integrated Environmental Management Plan Update - 2018.

Nathan,C. Byron, B. and Robel, G. (2019). Baseline Aquatic Biodiversity Assessment at the North Mara Gold Mine, Tanzania

Ngigi, S.N. (2009). Climate change adaptation strategies: Water resources management options for smallholder farming systems in Sub-Saharan Africa. The MDG Centre for East and Southern Africa, the Earth Institute at Columbia University, New York. Pp.189.

Nile Basin Initiative. (2007). Transboundary Environmental Action Project, National Nile Basin Water Quality Monitoring Baseline Report for Tanzania, http://www.nileteap.org/docs/publications/WQ/W

North Mara Gold Mine Report. (2018).

North Mara Water Management Strategy Project Charter,Acacia ,24 June 2016.

Oruma S. Kipampi (2012). The effects of Mau Catchment Degradation on the flow of the Mara River, School of Water Resources, Science and technology, Kenya. Pp.56-57

Ozor, N. and Nnaji, C.E. (2011). The role of extension in agricultural adaptation to climate change in Enugu State, Nigeria. Journal of Agricultural Extension and Rural Development 3 (3): 42 – 50.

Sharma, RK. Agrawal, M. and Marshall, FM. (2009). Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. J. Food Chem. Toxicol. 47: 583 - 591.

Tiffen, M., Mortimore, M., and Gichuki, F. (1994). More people, less erosion: environmental recovery in Kenya. John Wiley and Sons Ltd. Overseas Development Institute, London UNEP.(2006). African Environmental Outlook. UK: Earthscan Ltd

Tran, N, B. Shashwat, D. And Bhatta N 2017. A Case Study on Water Quality and Ecosystem Management in Mara River Basin – Kenya and Tanzania

United Republic of Tanzania. (URT) (2007),"National Adaptation Programme of Action (NAPA)".Vice President's Office, Division of Environment, United Republic of Tanzania.

USEPA. (2012). Edition of the drinking waterstandards and health advisories. USEnvironmental Protection AgencyWashington, DC.

WHO. (2007). Health Risks of Heavy Metalsfrom long-range transboundary airpollution. World Health Organization:Copenhagen. 5-113.

WHO. (2011). Guidelines for Drinking-WaterQuality, Fourth edition World Health Organization, Geneva. 180-365.

WWF-Tanzania Program Office (TPO) (2006). Mara River Basin Management Initiative, Musoma, Tanzania.

Zalewski, M. (2000). Ecohydrology-the scientific background to use ecosystem properties as management tools toward sustainability of water resources. *Ecological Engineering*, 16(1), 18.

Zalewski, M. (2002). Ecohydrology-the use of ecological and hydrological process for sustainable management of water resources. Hydrol sci J 47(5):825-834

Zalewski, M. Urbaniak, M. and Negussie, YZ (2010). Ecohydrological systemic solutions for reduction of siltation, eutrophication and dioxin-induced toxicity.The pilot study of the AsselaBioFarm Park Lake, Ethiopia.*Ecohydrology and Hydrobiology* 10 (2-4): 363 – 368.

Zalewski, M. 2015. Ecohydrology and hydrologic engineering: regulation of hydrology-biota interactions for sustainability. J. Hydrol. Eng. 20 (1), http://dx.doi.org/10.1061/(ASCE)HE.1943-5584.0000999.