eISSN 2345-0363
Journal of Water Security, 2018, Vol. 4
Article Number: jws2018003
DOI: https://doi.org/10.15544/jws.2018.003

REVIEW ON WATER RESOURCES MANAGEMENT AND KEY THREATS IN RWANDA, EAST AFRICA

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Submitted 06 July 2018; accepted 17 November 2018

Abstract. Water is important for human health, industry, agriculture and ensuring the integrity and sustainability of the ecosystem. The water resources are the top affected by climate variability and population growth. The current population of Rwanda is about 12 million heading to about 25 million in 2050 under the changing climate, where since 1970 temperature rose by 1.4°C and is predicted that in 2050 to be about 2.5°C with severe effects on water resources in Rwanda**.** Thereby, this study reviewed the status and causes of water quality problems and suggested appropriate options to undertake for sustainable water resources access, employ and management in Rwanda. It was noticed that among others, the key threats to water quality in Rwanda, include not limited to climate change causing rainfall patterns which generated flooding, landslides and periodic droughts, which loaded pollutants into water. In addition, water quality is jeopardized by the rapid population growth, agrochemicals, industrialization, urbanization, soil steepness and land mismanagement. Accordingly, the reviewed water quality indicate that the water quality pollution likelihood is increasing over time. These facts reveal that the water quality soon or late will be highly polluted and calls for further adaptation and management measures.

Keywords: *climate change, population growth, water resource, water quality, Rwanda.*

Introduction

Water is the most important for human health, agriculture, industry and in ensuring the integrity and sustainability of the ecosystem. Most parts of the world, particularly poor regions face water scarcity, pollution and lack of mitigation and adaptation capabilities (Muhirwa *et al*., 2010; Piao *et al*., 2010). The world population considerably grew after the industrial revolution, from 3.7 billion in 1970 to 6.08 billion in 2000, heading to about 9.7 and 11.2 billion by 2050 and 2100, respectively (Akresh *et al*., 2011). Therefore, balancing the available water and its growing needs, mainly driven by population growth and the changing climate can be a good alternative for water resources management (Kiptum, Sang, 2017).

In Rwanda, water resources are basic to many sectors including power generation, agriculture and fishery. Nevertheless, water resources are the top affected by climate variability and population growth (Arsiso *et al*., 2017; Vörösmarty *et al*., 2000; Piao *et al*., 2010). Observable and potential effects of climate change on water resources in Rwanda include flooding, landslides, change in the periodic droughts (Urama, Ozor, 2010; Bizimana, Sönmez, 2015).

Hydrology of Rwanda

Description of the study area

Rwanda occupies a surface of 26,338 km^2 on the eastern shoulder of the Kivu-Tanganyika Rift in Africa. It lies between 1°4' and 2°51' south latitude and 28°53' and 30°53' east longitude (Karamage *et al*., 2016). Rwanda has two rainy seasons; the first begins from March to May and the last begin from October to November with an average rainfall of 110-200 mm per month. The first and short dry season starts from December to the end of February, while the longer one lasts from June to early September. Rwanda's average temperature ranges between 19 to 27°C (Abimbola *et al*., 2017, Nahayo *et al*., 2016, Ndayisaba *et al*., 2016).

Rwanda is made up of five administrative subdivisions locally known as provinces (Northern, Southern Eastern and Western Province and Kigali City, the capital); each province is further subdivided into five to eight districts (Fig. 1).

Rwanda is relatively rich in water resources; about 188,190 ha are occupied by lakes (Table 1 and figure 1); approximately 7,260 ha are for rivers, while wetlands seize an approximate area are 77,000 ha. The surface water generally has a pH ranging between 6 and 8 (Nsengimana *et al*., 2012; Cavallo *et al*., 2013). This expresses that Rwanda has many water resources being lakes, rivers and marshlands.

However, rapid population growth, cropland expansion and agrochemicals, inappropriate household and industrial wastewater management and rainfall harvest, insufficient water quality monitoring and few researches along with soil topography (steep slope) that facilitate the sediments and nutrients transport into watershed are the major water pollutants in Rwanda (Fidèle *et al*., 2015; Sekomo *et al*., 2011; Wronski *et al*., 2015; Mupenzi *et al*., 2009).

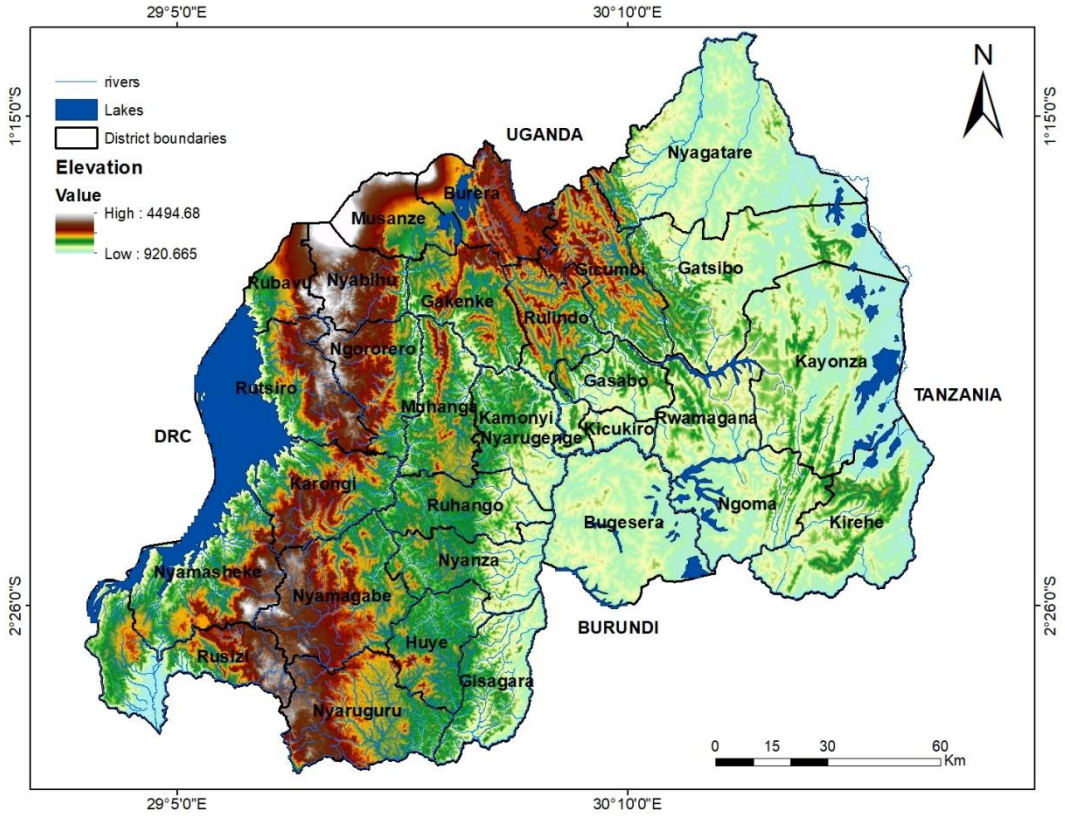

Fig.1. Water resources network of Rwanda.

Table 1. Rwanda major lakes and their characteristics (International..., 2018)

Lakes	Surface area, km^2	Surface area in Rwanda, km^2	Mean elevation above sea level, m	Maximum depth, m	Mean depth, m
Kivu	2700	1330	1460	480	220
Muhazi	34.6	34.6	1443	13.8	10.1
Burera and Ruhondo	28	28	1862	3.9	2.1
Cyohoha South	630	100	1553	11	5.2
Mugesera	40	40	1300	3.8	2.2
Rweru	100	20	1160	2.1	3.9
Ihema	90	90	1292	7.0	5.0

These phenomena have multiple repercussions on the quantity and quality of water, like reducing the river flows and lake levels, drying up of some water sources and undermining water biodiversity. Therefore, this expresses the problem of water quality in Rwanda despite its abundance and calls for appropriate adaptation measures.

Thereby, the objectives of this study review are to indicate status and causes of water quality problems and suggest appropriate options to undertake for sustainable water quality access, use and management in Rwanda.

Trends in water quality in Rwanda

Climate change and population growth is the most considerable factors that are affecting the ecosystems consequently, the impact of climate change on water quality is ascribed to changing hydrology and air temperature (Hosseini *et al.*, 2017; Liu, Chan, 2016). The water quality in Rwanda is being exposed to several degrading and polluting forces being natural and man-made. Previous reports on the water physico-chemical parameters and heavy metals (Nahayo *et al.*, 2016; Usanzineza *et al.*, 2011; Mupenzi *et al.*, 2009; Muhirwa *et al.*, 2010; Uwimpuhwe *et al.*, 2014) estimated low pH level 5.9 at the Nyabugogo River compared to the standards of the World Health Organization and European Union (pH 6.0-8.0). Moreover, the total suspended solids of the Rweru-Mugesera wetland, Congo and Nile basins (Rwandan side), 67.91, 920.90 and 162.86 mg/l, respectively, were above the standards (<30 mg/l). Whilst, the estimated concentration of Iron, Manganese and Lead were higher in the Lake Muhazi, Cyohoha, Akagera Transboundary and Nyabugogo rivers (Sekomo *et al.*, 2011; Nshimiyimana *et al.*, 2010). The below table 2 represents the average of heavy metal pollution of water sources analyzed by Water and Sanitation Corporation Limited (WASAC Ltd) of Rwanda.

Table 2. Averaged heavy metals in comparison with WHO Standard (Nahayo *et al.*, 2018).

Sampling sites	Ca	Fe	Mn	Cu	Al	Zn
	mg/l					
Nyagatare	20.28	0.35	0.25	0.45	0.95	0.20
Kabarondo	21.05	0.13	0.26	0.49	0.10	0.31
Kibungo	21.32	0.18	0.19	0.59	0.10	0.80
WHO Standards	80	0.30	0.10	1.0	0.20	3.0

According to the drinking water quality standards of the World Health Organization, recent study on drinking water quality (See Table 2) which analysed heavy metals pollution in the Eastern province showed that drinking water is mainly polluted during rainy season.

This exposes consumers to several risks as far as some parameters like manganese and iron values are higher than WHO suggested standards for drinking water quality. Consequently, this may cause cancer, liver, heart and pancreatic to consumers. This is congruent with the report of Sekomo *et al.* (2011) which indicates that drinking water sources are more polluted during rainy season than dry season where sediments and other wastes easily load into waters.

The assessment on microbiological water quality in Kigali city, the capital of Rwanda (Table 3) revealed the presence of Klebsiella, Enterobacter, Staphylococcus and Escherichia coli in river water and ground water (Uwimpuhwe *et al.*, 2014; Rutanga, 2014; Nigatu *et al.*, 2015). Although the drinking water seems polluted, the Government of Rwanda through her Ministry of health recommends citizens to drink boiled water and use of Sûr'Eau (water purification product, commonly used in Rwanda) in order to minimize the pollution resulting risks from the water being consumed. While bench terraces are used on steep slope land to minimize the runoff which transports pollutants into water sources.

Table 3. Microbiological analysis (Rutanga, 2014)

Type of Sample	P/A of *Klebsiella sps*	P/A of *Enterobacter sps*	P/A of *Staphylococcus aureus*	P/A of *Escherichia coli*
River water	+	+	+	+
Spring water	-	-	-	-
Tap water	-	-	-	-

(+) P – presence; (-) A –absence.

In addition, Kivu lake, the biggest lake of Rwanda as previously reported (Mupenzi *et al.*, 2017) gets it source from 23 Rwandan rivers drain into the Lake Kivu. These rivers are polluted at different scale, where those rivers near by the forestland are less polluted than those which move around farmland. In addition, the water quality in Rwanda, as previously reported highlighted (Habiyaremye *et al.*, 2011; Bendito, Twomlow, 2015; Karamage *et al.*, 2017; Mupenzi *et al.*, 2017) is threatened by the rapid population growth, agrochemicals, steepness of Rwandan soil and land mismanagement, climate variability together with lack of proper rainfall harvest which leads to sediments transport and consequently pollute the water quality. This expresses that the water quality soon or late will be highly polluted and calls for further adaptation and management measures.

Population growth in Rwanda

Population is the one of the fundamental elements of sustainable development but also the vulnerability to water resources. The reports of the United Nations (Gerland *et al.*, 2014) and National Institute of Statistics of Rwanda (National…, 2014) indicate that both Rwandan rural and urban population rapidly grew. The current population is about 12,501,156 with population density of 474.64 per kilometer square and it is projected to be about 28 million in 2095 (Fig. 2).

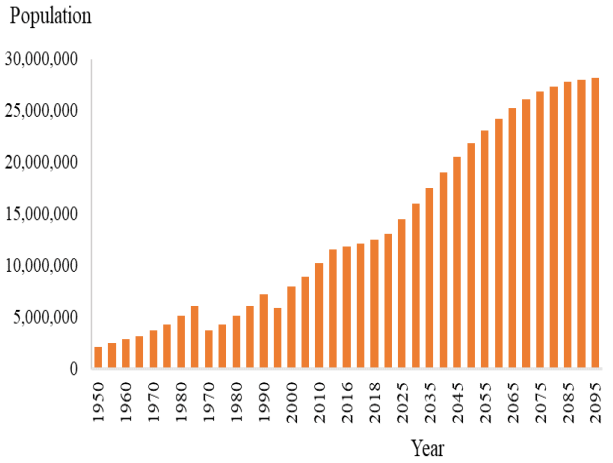

Fig. 2. Rwandan population growth (from 1950 to 2095)

This rapid population growth is assigned to high fertility, culture and illiteracy along with refugees who came back from neighboring countries after the 1994 Genocide. Moreover, it is worthy noted that, population growth is correspondingly associated with water demand for daily uses such as bathing, cooking and other socio-economic development activities requiring water such as agriculture, industry, public utilities, etc. The following table 4 illustrates how water demand in urban will be increasing compared to rural settings.

Table 4. Water demand per settlements in Rwanda between 2012 and 2040 (l/home/day) (Consultancy…, 2014)

Types of settlements	2012	2020	2030	2040
Rural	40	60	80	90
Urban	60	70	80	100

This, additionally can be associated to previous reports (Majaliwa *et al*., 2012; Cavallo *et al*., 2013) on water resources exploitation in Rwanda, indicating that all available water resources (ground and surface water) including rainfall are not fully exploited, meaning that the higher rural to urban migration, the higher water demand, and this implies more investments for maximum available water use; otherwise, the available water resources might be subject to overexploitation and degradation due to increasing demand.

Urbanization and industrialization

The report of the United Nation (UN, 2014) indicates that the world urban dwellers grew from 746 million in 1950 to 3.9 billion in 2014 and will surpass six billion in 2045. Much of this planned urban expansion will take place in developing areas, particularly Africa. However, these urban dwellers' water demand and the source of water used are still unknown (McDonald *et al*., 2014, Barthel, Banzhaf, 2016). Moreover, estimates show that 22% of the world water is used by industries, while their improper wastewater management is polluting water quality (Chae *et al*., 2015; Ouyang *et al*., 2006; Maharjan *et al*., 2016). This lack of proper determination of water sources used and improper wastes management affects its quantity and quality management.

The total population of Kigali, the capital city of Rwanda, gradually grew from 357 in 1907 to 236,000 inhabitants in 1991 and reached 1,000,000 and 1.132 million in 2010 and 2012 respectively (National…, 2014). This however, affects the municipal wastes management due to informal settlements, expansion of the city and industrialization whose final results is water quality degradation and pollution as well (Mohammed *et al*., 2017; Uwimbabazi, Lawrence, 2011). Despite the present Governmental initiative (which is not yet fully completed) of re-allocating industries from or near watersheds to appropriate and well equipped location (Rwanda Special Economic Zone), their former location led to immense wetland and biodiversity degradation (Etale, Drake, 2013; Nhapi *et al*., 2011). In addition, the report of the Kigali City Conceptual Master Plan (Kigali…, 2007) indicates that the city will keep expanding in size and its inhabitants will almost triple in the next 25 years. For this fact, it is good to envisage appropriate municipal wastewater treatment facilities and adaptive measures for the water quality enhancement.

Food Demand

In Rwanda, agriculture employs about 80% of the total population. This sector encountered a decline due to the 1994 Genocide, and this caused many socio-economic failures (Lovell, Tumuri, 1999). However, as indicated by the report of Organization & UNICEF in 2015 after the 1994 Genocide, high food demand-imposed cropland expansion from 13,150 to 18,425 km^2 in 1990 and 2013, respectively, growing crops at appropriate and productive area (Crop Intensification Program, CIP) with selected seeds and fertilizers which increased from 6,537 tons in 2000 to 44,264 tons in 2012. However, despite this agricultural progress, its practices are reported to pollute the watersheds (Falkenmark, 2013; Sekomo *et al*., 2011).

Furthermore, Rwandan agriculture is subsistence, and farmers own small plot land cultivated for household consumption and mostly located near or in watersheds. Additionally, a large cropland is on steep slope soils, easily exposed to erosion, floods and landslides which are major soil and water quality problems in Rwanda (Bizoza, 2014; Nahayo *et al*., 2017; Rugigana *et al*., 2013). Moreover, marshland over-exploitation, high volumes of agrochemicals, and lack of approach to farmers on appropriate and timely fertilizers' application are leading to watersheds degradation and pollution (Bucagu *et al*., 2013; Fidèle *et al*., 2015). Therefore, as water quality management is concerned under rising food demand, agriculture-environmentally friendly practices need to be envisaged for water quality management in Rwanda. In addition, as illustrated in figure 3, the periodical change on personal prediction land, it predicted that in 2050 one person will use only 0.10 ha.

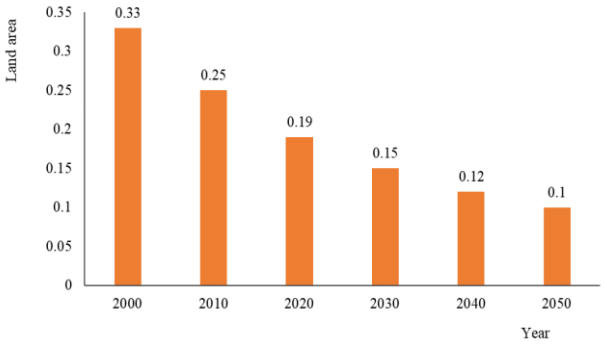

Fig.3. Change on individual land per decade in Rwanda (UN, 2014)

This expresses that the food demand will be rare same as the water resources will be affected by insufficient area to cultivate.

Climate change in Rwanda

The changing climate in Rwanda extant very serious national challenges and risks transversely various sectors such as agriculture and water resources.The report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the climate is changing; the global average temperature is rising with shifting rainfall patterns, whereas the glaciers, arctic sea ice and Greenland ice sheet are melting, primarily due to greenhouse gases emitted in the atmosphere (Mahmood *et al*., 2016; Myhre *et al*., 2013). It is predicted that warm sea temperature and less precipitation may increase drought and desertification in the subtropical and equatorial Eastern Africa and consequently, these alterations will seriously

impact on the quantity and quality of water, economy, food security and social welfare of poor countries mainly the Sub-Saharan countries including Rwanda. The following figures 4 and 5 details the projected changes in temperature and rainfall in Rwanda.

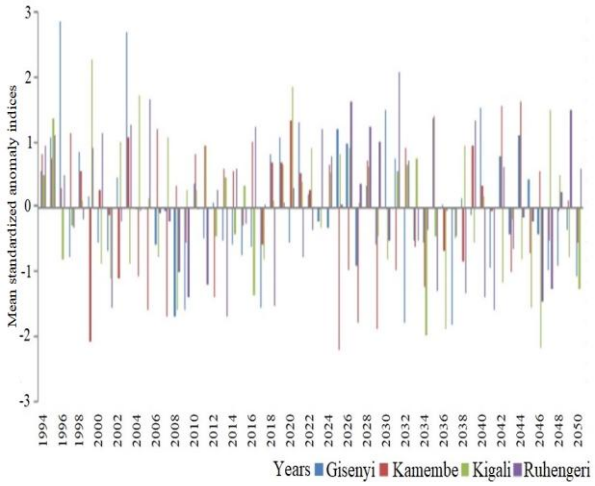

Fig. 4. Projected temperature patterns and rainfall in Rwanda adopted from (Isidoro, Grattan, 2011).

As shown in figure 4, in Rwanda, as evidenced by the Kamembe, Gisenyi, Kigali and Ruhengeri weather stations, there is a mixture of both low and high temperature records in the future. These numbers in figure 4 are congruent with the reports of (Houghton *et al*., 2001) and (Uzamukunda, 2015) that highlight that Rwanda recorded a 1.4°C rise in temperature since 1970, which is predicted to be about 2.5°C in 2050, and this will lead to change in intensity and frequency of rainfall causing either drought or flood, which in turn alter the water quality.

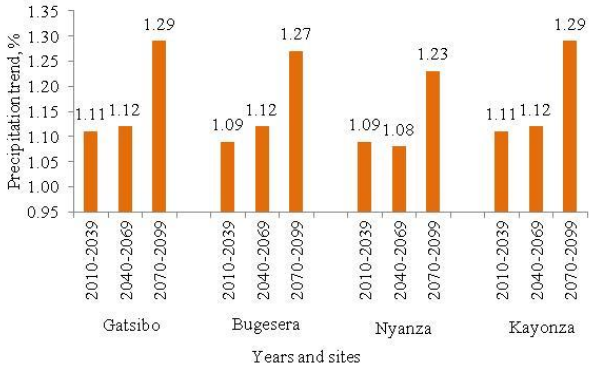

Fig. 5. Precipitation prediction at different sites in Rwanda from 2010 to 2099 (Haggag *et al*., 2016).

As indicated in figure 5, a precipitation trend is obvious from almost 1 to 1.29% of increase within the years of 2010 and 2099. This as a result, is being experienced in Rwanda, where some regions are under water shortage causing its quality depletion and socio-economic failure, while others register high precipitation which generates flooding and transport of sediments into water with pollution and eutrophication likelihood. As far as climate change is impacting on water resources and other associated socio-economic impact (Veraart *et al*., 2017) there is great call in developing appropriate mechanisms including mitigation and adaptation policies, awareness and skilled human resources able to combat and deal with the impact of climate change on water quality.

Conclusion and Recommendations

Water quality and scarcity are widespread problems and its sustainable management is becoming a quite challenge. Even though a range of resolving suggestions have been provided such as provision of investment in water infrastructure maintenance, water reuse, recycle, flotation, chemical precipitation, ion exchange and membrane filtration and coagulation-flocculation, the rapid human population growth, increase on point and non-point water pollution sources are threats to water quality.

The government of Rwanda has launched the Integrated Water Resources Management, an approach of developing, monitoring and managing water resources. Nonetheless, for the policy to be fruitful and sustainable there is a great need of managing the wastewater, the rapid expanding urbanization and informal settlements, industrial and mining activities. Therefore, the followings are suggested for the water quality management in Rwanda under the above-mentioned threats:

1. Rapid population growth is increasingly leading to natural resources degradation; it is advised to set a fixed number of children per family with penalties or tax incentives to those disregarding the policy.
2. Since Rwanda is rich in precipitation throughout the year, it is good to consider maximum rain harvest; this will increase the underground storage and enables local communities to supply water to their infrastructure and reduces sediments carried into watershed.
3. Population growth requires sufficient food, to do so, irrigation is proposed to boost the agricultural production, however, it is good to first check on environmental pros and cons of every irrigation technique (sprinkler and flood irrigation, drip irrigation) before use.
4. Rwanda as a developing country with high water demand, water re-use and desalination would help much, where industrial, saline water and household wastewater can be turned into usable water for other uses such as garden watering, carwash, toilet uses. This will be a good option and reduce the wastewater associated consequences.
5. It is suggested to promote environmental research and education from basic schools; hydrological data sharing and free access for water quality management enhancement.
6. Although the government prioritized Crop Intensification Program (CIP), with one crop at appropriate location, it would be good to initiate and promote break crop system, different crops at once,

this will enhance soil fertility and maintain soil at a level of not demanding high chemical fertilizers, and reduces water pollution.

7. Even though, environmental management is a cross cutting issue at every decision-making level, monitoring and evaluation of its execution and success basing on community's reality and national development plans is highly suggested

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