Original Research Article

EFFECT OF CLIMATE CHANGE ON DRINKING WATER UTILITIES IN NZOIA RIVER BASIN, KENYA.

ABSTRACT

Climate change is already having noticeable effects on water utilities in Nzoia River Basin. Extreme weather and climate-related occurrences are becoming more common and intense, as predicted before. Because most water utilities are unprepared, the repercussions might be severe. The water supply infrastructure is built for resiliency and sustainability of operations during weather events or other circumstances that could potentially interrupt services; but when events that were historically considered to be “100-year” events happen more and more frequently, utilities must prepare for a new normal. These extreme events are occurring or being exceeded more regularly, and as a result, the past may no longer be a reliable predictor of the future. In Nzoia River Basin, the water supply infrastructure currently designed for historical climate conditions is more vulnerable to future weather extremes and climate change. This study assessed the effect of climate change on drinking water utilities in Nzoia River Basin. A cross-sectional survey design was used. Three counties were randomly selected from the basin for study with Busia representing the lower catchment, Kakamega middle catchment and Trans Nzoia upper catchment. The study was carried out from May, 2017 to September, 2017. In-depth expert interviews and brainstorming sessions were used to identify the climate change impacts affecting drinking water utilities experienced in the last ten years in the basin. A carefully selected team of water and climate change experts consisting of decision makers, practitioners, managers, scientists and technology adopters were used to rank the severity of the climate change impacts. Climate change occurring in Nzoia River Basin is expected to have a wide range of consequences for drinking water utilities. By assessing its potential impacts on water utilities, we become better positioned to make improvements today to decrease the future risks. The results of this study provide valuable insights for the national and county governments in preparing to effectively anticipate and respond to the relevant issues that they can expect to face in the coming century.

Keywords: Nzoia River Basin, Climate change, Drinking water utilities.

1.0 INTRODUCTION

Global warming is changing climate on both global [1] and regional [2] scale. The Intergovernmental Panel on Climate Change (IPCC) [3] found that the average trend of global temperatures from 1880 to 2012 was 0.85 degrees Celsius (with a degree of uncertainty ranging between 0.65^{0}C and 1.06 ^{0}C). The rise in temperature during the last decade (2003–2012) was +0.780°C (with minimum tempratures at 0.72 ^{0}C and maximum tempratures at 0.85 ^{0}C). The National Climatic Data Center (NCDC) considers 2014 to be the warmest year ever recorded, with a temperature anomaly of +0.69 ^{0}C estimated over the period 1880–2014 [4]. According to the World Meteorological Organization (WMO) [5], the years 2011–2015 were the hottest on record, with 2015 being the hottest year since modern measurements began in the late 1800s. Rainfall is predicted to increase in many locations throughout the world as the global temperature rises. Under the impact of high temperatures, the hydrological cycle may accelerate, resulting in increased rainfall and evaporation [6]. Africa is one of the most vulnerable continents to climate change and variability, a condition made worse by the interaction of several factors at various levels, as well as a lack of adaptation capacity [7].

The continent of Africa is now warmer than it was 100 years ago [8]. According to Niang et al. [9], the mean annual temperature over much of the African continent has likely increased during the 1900s. According to Hulme et al. [8], Africa has warmed at a pace of around 0.5°C per century since the 1900s, however Hussein [10] claims that Africa warmed at a rate of 0.7°C during the same time period. Minimum temperatures, on average, are rising at a faster rate than maximum temperatures [9]. Anyah and Qiu [11] indicate considerable temperature rises in the equatorial and southern areas of East Africa since the 1980s. Climate and weather variability are expected to become more variable as the world warms. Changes in the frequency and severity of extreme climate events, as well as weather pattern variability, will have substantial implications for human and environmental systems.

Conway et al. [12] found significant fluctuation in rainfall and river flows in Sub-Saharan Africa during the twentieth century. East Africa's rainfall is notorious for its inter-annual variability, which has exacerbated deadly droughts and floods [9]. The ElNino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) [13] and migration of the Inter-Tropical Convergence Zone (ITCZ) [14] are all linked to large-scale climatic variability in this region as observed by several other studies. Warming of the ocean temperature causes an increase in rainfall and a change in the direction of the ITCZ, and ENSO has many effects on precipitation in this region. Lim and Hendon [15] noted that, “IOD, on the other hand, represents the sea surface temperature variability in the tropical Indian Ocean and this change significantly affects the climate of East Africa, Indonesia, India, and some parts of Australia and Asia’’. In general, large-scale climate forcings and changes in sea surface temperature influence rainfall variability in East Africa, notably inter-annual variability, which impacts rainfall volume (e.g., decrease during the long-rain season; March-May) through changing wind patterns and moisture fluxes [16]. Many African regions lack complete long-term rainfall data from the past century, making it difficult to draw any conclusions about annual rainfall trends during this time; additionally, many regional datasets differ when compared to one another, making it difficult to draw any conclusions about annual rainfall trends during this time [17; 18; 19]. Rainfall patterns in East Africa show a rising tendency in those locations with complete long-term data; yet, rainfall patterns in East Africa are significantly characterized by temporal and spatial variability due to numerous components [20; 9].

Nicholson et al. [21] claim that since the 1970s, trends of increasing aridity in rainfall over the Sahel area have been seen.

Williams and Funk [22] show that rainfall in East Africa has declined over the long rainy season (March/May/June) over the last three decades, confirming this trend. Lyon and DeWitt [23] also report that seasonal rainfall in East Africa has reduced during the same time period. The increased warming of the Indian Ocean [22] is one possible explanation for this drying trend, and this warming trend is thought to amplify the drying effect of warm ENSO episodes in the region [20]. It's also likely that the increased frequency and persistence of intense ENSO occurrences recorded in recent years is as a result of global warming [20]. However, according to Nicholson et al. [21], this tendency should not be interpreted as a long-term trend toward aridity, but rather as a series of historical rainfall changes. The extent to which human-induced changes in land cover and climate change contribute to fluctuations in African rainfall is yet unknown [8; 20]. Funk [24] notes that, " in Kenya there has been substantial declines in rainfall between 1960-2009, (during the long-rain-season, March to June) and argues that if these observed changes would last until 2025, extensive parts of Kenya would experience more than a 100 mm decline in the long rain-season''. In addition, the Kenyan government states that rainfall amounts over the long rain season have been lower in recent years than they were in the early 1960s [25].

Extreme weather events have become more common all over the world, and they are projected to intensify in the twenty-first century [3]. Several studies, Awuor et al.[26]; Shongwe et al. [27]; Williams and Funk [22]; Lyon and DeWitt [23]; have found that the frequency of extreme events such as droughts and heavy rainfalls have increased across Eastern Africa during the last 30-60 years. According to Williams and Funk [22], the Indian Ocean's warming has led to increased frequency of East African droughts in the spring and summer seasons during the last 30 years. However, Lyon and DeWitt [23] state that it is unclear whether the aforementioned changes are the result of human activities or natural variability. The residents of Nzoia River Basin face a significant problem as a result of climate change. Climate change is causing the basin to experience increasingly irregular rains, as well as the complete failure of seasonal rains. It is a basin with large differences across regions which are reflected in its climatic vulnerability. The lowlands are vulnerable to increased temperatures and prolonged droughts which may affect human economic activities. The highlands may suffer from more intense and irregular rainfall, leading to erosion, which together with higher temperatures leads to lower total agricultural production. This, combined with an increasing population puts the basin at greater risks of climate change. Water utilities in the basin will equally face the consequences of climate change. Assessment of the potential impacts of climate change on water utilities in the basin is intended to equip the water sector stakeholders with information to make improvements today to decrease the future risks.

2.0 MATERIALS AND METHODS

2.1 Study area

The study area, Nzoia River Basin lies entirely within Kenya along the border with

Uganda in the Lake Victoria Basin. It's situated between latitudes $1^{0}\ 30'$ N and $0^{0}\ 05'$ S and longitudes 34^{0} E and $35^{0}\ 45'$ E with an area of 12,959 km^2 and a river length of 334 km up to its outfall into Lake Victoria.

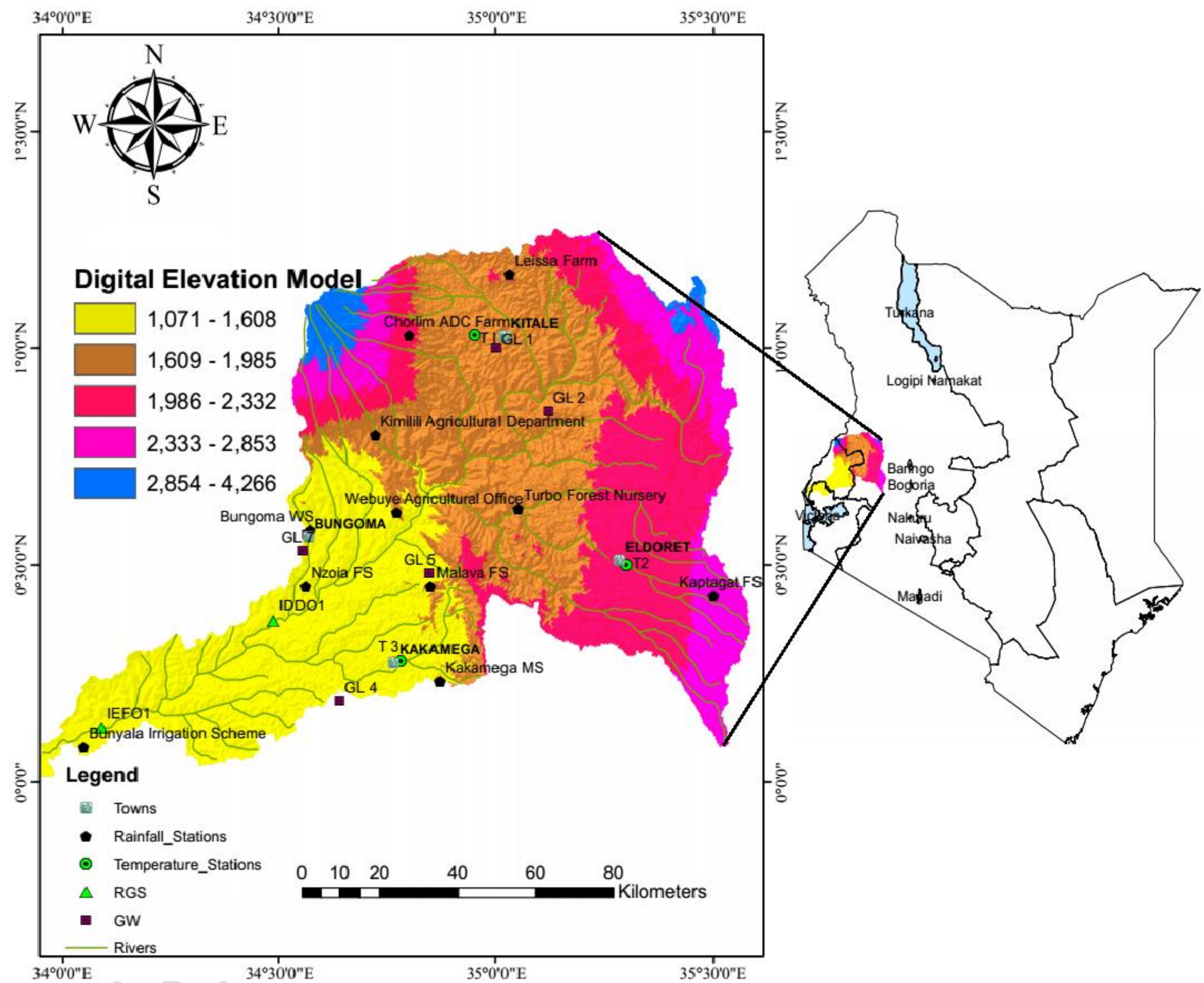

Figure. 1: Map of Nzoia River Basin, Kenya

This study was carried out in three counties of the basin; Trans Nzoia in the upper catchment, Kakamega in the middle catchment and Busia in the lower catchment. Nzoia River Basin has a population of about 3.7 million people and falls within the Lake Victoria basin of Kenya which is one of the regions in the world with the poorest and fastest growing populations [28]. The basin is made up of nine counties; Elgeyo/Marakwet, West Pokot, Trans Nzoia, Uasin Gishu and Nandi (in former Rift Valley province); Kakamega, Bungoma and Busia (in former Western province) and Siaya (in former Nyanza province).

2.1.1 Water resources

Nzoia River originates from Mt. Elgon and Cherengani hills forest. Mt. Elgon forest catchment is located north of Lake Victoria on the border between Kenya and Uganda. The National Park and Forest Reserves protect the forest belt; and Elgon forms the upper catchment area for two major rivers, Nzoia and Turkwel rivers. It also provides water to the Malakisi and Malaba rivers that cross the small farming area south of the mountain before it drains into Lake Kyoga in Uganda.

Nzoia river is one of the largest rivers in Western Kenya which drains into Lake Victoria contributing to the waters that form the source of River Nile. It's catchment area comprises of distinct drainage areas originating from Mt Elgon area; Cheranganyi, Bungoma, Kimilili and Nandi hills including Kakamega area and the Lower Nzoia area up to Lake Victoria. Nzoia River Basin seats astride, between the Lake Victoria and Lake Turkana basins. Streams to the west of the watershed Cheranganyi feed the Nzoia river system, which flows into Lake Victoria, while streams to the east flow into the Kerio river system. Nzoia river and its tributaries provide permanent water supply, but the flows vary by seasons of the year. The main streams of the river flow from the western side of the Elgeyo escarpment (Sergoi, Sosiani and Kipkelion tributaries) and the Cherengani hills (Chepkotet and Kaisungur tributaries) from an elevation of approximately 2,286 m above sea level. It has several tributaries with an average basin elevation of 1,917 m asl. The tributaries which flow from the high slopes of Mt. Elgon attain a maximum elevation in the river basin at 4,300 m above sea level. The tributaries in Mt. Elgon include Kuywa, Sioso Ewaso, Rongai and Koitobos. The River is from a north-easterly to south-westerly direction with a mean slope of 0.010% from source to discharge into Lake Victoria at about 1,000 m.

Nzoia river enters Lake Victoria a short distance to the north of Yala Swamp and the plains at the downstream reaches of this river are susceptible to floods. The main tributaries of Nzoia river include, Moiben, Kapolet, Koitobos, Rongai, Kimilili, Kipkaren, Lusumu, Isiukhu, and Wuoroya. The mean discharge of Nzoia river basin is about 118 m3/s, the lowest flow is 2.8 m3/s and the maximum probable flood is 1,000 m3/s and the 100 year flood is 930 m3/s. The river average channel width is 40 m and the average gradient is 1 in 240 m.

Groundwater is the main drinking water resource, supplying 78.8% of the residents leaving 21.2% for surface water resources. Many of the large piped schemes supplying the towns and rural areas have their intakes built on Nzoia river and its tributaries. On the existing sources of domestic water supply, 62 % of the residents of Nzoia River Basin use improved water sources. Out of these, 3 % use piped water into dwellings, 7 % water piped into compound, yard or plot, 3 % public tap/standpipe, 6% tube well or borehole, 11% protected dug well, 31% protected spring and 1% rainwater collection. Those using non-improved sources are 38%. Out of these, 10 % use unprotected dug well, 19 % unprotected spring, 1% tanker truck/cart with small tank, 8 % surface water (river, dam, lake, pond, stream, canal, irrigation channel) and 0 % bottled water. Individuals frequently have to wait for long periods of time to draw water from point water sources, especially during the dry season. The people of Nzoia River Basin have strong preferences for safe, clean drinking water, and will sometimes walk long distances past alternate sources to get drinking water from sources deemed safe. Women and children collect water for drinking and cooking and transport it home in pretty standard-size 20 liter jerricans for adults and 5-10 liter jerricans for youngsters. Adults and older children in some villages still prefer to bathe in rivers, despite the fact that children under the age of five are routinely bathed at home in basins. Nzoia River Basin water sector still lacks suitable infrastructure as well as the requisite operational and management structures and capacities [29].

2.1.2 River Basin geology

The geology of Nzoia River Basin is quite varied ranging from metamorphic basement rocks, volcanic rocks, to quaternary sedimentary rocks. The areas around Mt. Elgon are characterized by tertiary volcanic rocks mainly phonolites and agglomeratic tuffs. The plateau zones including Uasin Gishu and parts of Nandi are also characterized by Tertiary volcanic rocks which consist of phonolites and agglomeratic tuffs. The middle zone within the catchment is covered by metamorphic basement rocks consisting mainly of the gneissic rocks. These areas include Kitale, parts of Bungoma and West Pokot. The lower parts of the catchment are characterized by volcanic rocks of the Kavirondian system. These consist of meta-sediments, grits and conglomerates. This type of geological formation is noted in such areas like Busia, Butere and parts of Bungoma and Webuye. The kavirondian system rocks are intruded in some places by granitic rocks (Mumias granite). Certain parts of the lower Nzoia River Basin such as Siaya are characterized by volcanic rocks consisting of the Nyanzian system rocks which are composed of basalts, rhyolites, andesites and rhyolitic tuffs. The volcanic rocks are known to overlie the basement rocks within the larger catchment [29].

The basin is characterised by three physiographic regions namely; the highlands (characterised by Mt. Elgon and Cherangani hills); the upper plateau (which includes Eldoret and Kitale); and the lowlands (which includes Busia that experiences the majority of flooding in the basin).The dominant topography consists of rolling hills and lowlands in the Eldoret and Kitale plains. The upper Nzoia River Basin has soils that are described as light clay with good drainage and good moisture capacity and are characterized with high fertility. Nzoia River Basin has the soil type textures forming: clay (77%), loamy (9%) and sandy (14%). In the basin, the Ferralsol form well drained soils found mostly on level to undulating land. The Acrisols in the basin form clay-rich soils associated with humid tropical climates and supports forestry; whereas Nitisols compose deep well-drained red tropical soils found mostly in the highlands occupying more than 75% of the catchment [29].

2.1.3 Climate and Land use

The Climate of Nzoia river basin is predominantly tropical humid and is characterized by day temperatures that vary from 16 °C in Cheranganyi and Mt. Elgon areas to 28 °C in the lower semi- arid plains of Bunyala. Night temperatures vary from 4 °C in the highlands to 16 °C in semi-arid lowlands. The highest rainfall ranges from 1100 – 2700 mm annually. Lowest rainfall ranges from 600 – 1100 mm annually.

Agriculture is the dominant land use in the region with the main food crops grown as maize, sorghum, millet, bananas, groundnuts, beans, potatoes, and cassava while the cash crops include coffee, sugar cane, tea, wheat, rice, sunflower and horticultural crops. The inhabitants of the basin also practice dairy farming together with traditional livestock keeping [30].

2.2 Methods

The study adopted a cross-sectional survey design. Three counties were randomly selected from Nzoia River Basin for study with Busia representing the lower catchment, Kakamega middle catchment and Trans Nzoia upper catchment. The study was carried out from May, 2017 to September, 2017. In-depth expert interviews and brainstorming sessions were used to identify the climate change impacts affecting drinking water utilities experienced in the last ten years in the basin. A carefully selected team of water and climate change experts consisting of decision makers, practitioners, managers, scientists, technology adopters, etc; were used to rank the severity of the climate change impacts affecting drinking water utilities based on a scale of 1-3, where, 1.-LOW, 2.-MEDIUM, and 3.-HIGH severity. The study also used secondary data which entailed the collection and analysis of published materials and information. The collected data were summarized and carefully analyzed.

3.0 RESULTS AND DISCUSSION

3.1 Effect of climate change on drinking water utilities in Nzoia River Basin

The impact of climate change on the design of infrastructure investment projects in the water sector is becoming increasingly important. Growing evidence indicates that the water sector will not only be affected by climate change, but that it will deliver many of its impacts through floods, droughts, or extreme rainfall events. Water resources will fluctuate in quantity and quality, and storms, floods, and droughts will cause more damage to water utility infrastructure. Climate change will cause operational challenges, service disruptions, and an increase in the cost of water services. As a result, national and county governments should rethink water utility development programs and adjust strategies to account for climate change in infrastructure design, capital investment projects, service provision planning, and operation and maintenance.

Climate change brings variability and uncertainty to water utilities' day-to-day operations as well as long-term planning. The problem is exacerbated by the fact that urgent needs, such as extending coverage and reducing non-revenue water, compete with the development of effective climate change adaptation plans, particularly in poor and middle-income nations. Water utilities that are weak and financially strapped are still grappling with long-standing concerns such as water management, coverage, and efficiency in service delivery. Well-performing utilities are now beginning to explore strategic solutions to address climate change concerns based on monitoring, analysis, and the use of climate models, which is a significant distinction between financially sustainable utilities and those that are suffering. Some of the current steps being implemented by a number of utilities are largely designed to address short-term issues. Long-term initiatives appear pricey or impossible due to perceived complexity, a lack of scientific information, and a lack of coordination with other authorities on related issues such as watershed conservation, resource protection, and flooding.

According to the Intergovernmental Panel on Climate Change (IPCC) [3], average global temperatures could rise by 1.1 to 6.4°C by the end of the twenty-first century, which would be 1.8 to 4.0°C higher than the average temperature from 1980 to 2000. The most likely consequences of rising temperatures are rise in sea levels and more frequent and intense extreme weather events, such as droughts and floods [7]. These anticipated changes will have an impact on water supply and water utility operations in the near and long run. Higher temperatures and lower precipitation levels, in the case of water and wastewater utilities, will result in supply limitations due to slower replenishment rates of subsurface water resources and/or reduced availability of surface water. Water service providers would have to alter their operating systems and institutional arrangements to account for increased climate changes, which will be a challenge. Climate change will have a long-term impact that exceeds the current design margins that allow utilities to maintain functioning on a daily basis. Many utilities throughout the world are already dealing with increased climatic variability that exceeds estimates based on historical records and hydrologic modeling, and some have begun to address the issue through their planning procedures. However, in the vast majority of cases, these attempts are still in their infancy and are frequently haphazard. This is partly due to the fact that management techniques are still dependent on historical climate data, which is widely acknowledged as being insufficient for projecting changing precipitation and run-off patterns, as well as their impact on water quality and quantity.

Extreme weather events caused by climate change may result in short-term water supply shortages, forcing utilities to implement water conservation measures and possibly resort to unpopular demand management tactics like water rationing and intermittent supply. Intermittent supply and related hydraulic shocks cause long-term damage to existing water systems, networks, pumps, and gates, reducing the functional life of water infrastructure. Wastewater systems constructed using historical design parameters, such as minimum flow levels or storm water capacity, will become obsolete, necessitating rebuilding rather than rehabilitation. Meeting ambient water standards following dilution of wastewater treatment plants' effluent may become more challenging with decreasing flow in receiving water, resulting in the need for additional treatment standards. Climate change will force water and wastewater service providers to perform more regular technical maintenance, undertake unplanned rehabilitation, and, in some cases, scale back operations at their facilities, reducing service to their customers. All of this suggests that the utility will incur increased costs. The utility could save money by implementing better planning, monitoring, and maintenance systems, passing the cost on to customers, allowing parts of the system to deteriorate, or providing reduced service levels, or a combination of all of the above. The problem is exacerbated by the fact that local governments' ability to adopt adequate climate change adaptation plans is still constrained by political, institutional, and budgetary constraints, particularly in low- and middle-income nations.

Because of the high degree of uncertainty in data and modeling parameters, it is impossible to make precise forecasts on how the climate will change in the Nzoia River Basin. However, there is widespread consensus that climate change will manifest itself differently in different parts of the basin. Mean annual temperatures will increase throughout the basin, with the highest increases expected in the semi-arid lowlands boardering Lake Victoria in Busia. With regard to rainfall, some contrasting results are observed between the upper, middle and lower catchments. There is a general trend towards increased rainfall in the upper carchment, (where the two high ground areas of Mt. Elgon and Cherengani hills occur) and reduced rainfalls in the middle and lower catchments. Rainfall is also strongly influenced by elevation with greater amounts occurring in the high ground areas [31]. The water utility impacts experienced in the basin can be broadly categorized as: (1) water quantity impacts, (2) water quality impacts, (3) operational reliability impacts, and (4) financial and institutional impacts.

3.1.1 Water quantity impacts

The study established the water quantity impacts affecting drinking water utilities experienced in the last ten years in Nzoia River Basin as shown in Table-1. The carefully selected team of water and climate change experts consisting of decision makers, practitioners, managers, scientists, technology adopters, etc; after a lengthy brainstorming session and making consultations, ranked the severity of water quantity impacts affecting drinking water utilities in Nzoia River Basin based on a scale of 1-3, where, 1.-LOW, 2.-MEDIUM, and 3.-HIGH severity as shown in Table-1. The results reveal that, from the identified water quantity impacts affecting drinking water utilities in the basin, the lower cathchment experiences the highest vulnerability followed by the middle and then the upper catchment. Changes in groundwater levels, increased frequency and severity of droughts and water scarcity, and changes in soil water moisture present high vulnerabilities to water utilities across the basin. In Nzoia River Basin, increasing temperatures and changing rainfall patterns including intensity and seasonality will affect water utilities through the direct impacts of: changes in river flows; changes in groundwater aquifer recharge; changes in groundwater levels; changes in soil water moisture; changes in water levels at surface water dam/ponds/pans; changes in water demand with abstraction rates, increased frequency and severity of floods, and increased frequency and severity of droughts and water scarcity. The term drought may refer "to a meteorological drought (precipitation well below average), hydrological drought (low river flows and low water levels in rivers, lakes and groundwater), agricultural drought (low soil moisture), and environmental drought (a combination of the above)". Droughts may have socioeconomic consequences due to interactions between natural and human variables such as changes in land use, land cover, and water demand and consumption. Drought can be exacerbated by excessive water withdrawals.

Table-1: Severity Rating for Water Quantity Impacts affecting Drinking Water Utilities in Nzoia River Basin, Kenya

Water Quantity Impacts affecting Drinking Water Utilities	**Lower Catchment**	**Middle Catchment**	**Upper Catchment**
Changes in River flow both increase and decrease	HIGH	HIGH	MEDIUM
Changes in water levels at surface water dam/ponds/pans both increase and decrease	HIGH	MEDIUM	MEDIUM
Changes in groundwater levels both increase and decrease	HIGH	HIGH	HIGH
Increased frequency and severity of droughts and water scarcity	HIGH	HIGH	HIGH
Increased frequency and severity of floods	HIGH	MEDIUM	LOW
Changes in water demand with abstraction rates both increase and decrease	HIGH	HIGH	MEDIUM
Changes in groundwater aquifer recharge both increase and decrease	MEDIUM	MEDIUM	MEDIUM
Changes in soil water moisture both increase and decrease	HIGH	HIGH	HIGH

Changes in surface water sources as a result of climate change will have a big impact on drinking water supply and wastewater treatment. When rainfall is concentrated into heavy events, the requirement for storage and conveyance may increase to help balance out variations in rainfall and river flows between places, as well as to ensure supply throughout time. Changes in climate have already resulted in changes in water flows in several regions of the world [32]. The El Nino–Southern Oscillation is already creating considerable variations in river flows in the Nzoia River Basin, and climate change will exacerbate this variability. Many low- and middle-income countries have long needed to invest in water storage to deal with current climate variability [33]. Natural infrastructure is also undervalued in terms of buffering rainfall variability and adapting to longer-term change [34; 35]. When developing surface water storage to cope with growing variability, it is important to consider the increased problems posed by more intense rain events, as storage volumes may need to be increased in order to capture enough water. As a result, evaporative losses from bigger water bodies may increase. When increased rainfall intensity is combined with land-use change that reduces plant cover, the risk of silt accumulation in reservoirs increases. This stresses the importance of combining and properly sequencing natural and constructed infrastructure investments in climate change adaptation. When preventative measures are not adopted, the building of reservoirs has been related to negative health outcomes, such as increasing incidence of malaria and schistosomiasis.

Changes in groundwater aquifer recharge expose water utilities across the basin to medium risks. Groundwater supplies are usually projected to be less affected by climate change, and groundwater is often regarded to be the foundation of adaptation efforts, as it buffers against more erratic rainfall [36]. Increased demand for groundwater, as well as changes in groundwater recharge, are expected to have an influence on groundwater resources. According to Kundzewicz and Doll [36], worldwide groundwater recharge is unlikely to alter by more than 10%, however this could have significant repercussions in some already dry places. The development of groundwater resources, particularly in Africa, has been identified as critical to the resilience of community water supply. This is owing to the significant buffering effect of groundwater due to aquifer storage capacity, which smooths out short-term changes in water availability (e.g., seasonal or annual). According to Kundzewicz and Doll [36], overall understanding of groundwater resources is insufficient, making it difficult to draw clear conclusions on the ability of groundwater to sustain water supplies in a given location.

3.1.2 Water quality impacts

The study established the water quality impacts affecting drinking water utilities experienced in the last ten years in Nzoia River Basin as shown in Table-2. The carefully selected team of water and climate change experts consisting of decision makers, practitioners, managers, scientists, technology adopters, etc; after a lengthy brainstorming session and making consultations, ranked the severity of water quality impacts affecting drinking water utilities in Nzoia River Basin based on a scale of 1-3, where, 1.-LOW, 2.-MEDIUM, and 3.-HIGH severity as shown in Table-2. The results reveal that, from the identified water quality impacts affecting drinking water utilities in the basin, vulnerability is uniformly spread across the basin. Extreme precipitation events create well-known water treatment challenges by increasing sediment and pathogen loads, urban stormwater runoff, and combined sewer overflows. Source water quality will likely be impacted by other, more gradual processes such as more widespread and persistent algal blooms, changes in watershed vegetation, and increased water temperature with associated increases in eutrophication, disinfectant demand, and regrowth potential. In coastal areas, rising sea levels and associated salt water intrusion may increasingly impact groundwater resources. Increases in suspended solid loads in rivers may mean drinking water treatment systems are unable to cope without significant upgrading. Where coagulation is used, doses can be adjusted to cope with higher suspended solids but may reach a point where the suspended solids load exceeds removal capacity and the works must be shut down. Failure to shut down coagulation units in a timely manner will lead to breakthrough of suspended solids into subsequent filtration units, which is likely to cause clogging, underperformance, and ultimately breakthrough into the final water tanks and distribution system. Treatment units (in developed or developing countries) that are either not permanently staffed or are operated by relatively unskilled members of a community may struggle to cope with short term changes, leading to failures in water quality [37]. High suspended solid loads will reduce the effectiveness of chlorination and other disinfection systems. Even short-term failures in treatment may result in elevated public health risks [38]. The key management response to these risks is often to link failures to rapid (often automatic) shutdown in order to prevent substantive breakthrough. Such systems are the norm in high-income developed countries but not in many developing countries, even in large utility supplies. The use of automated systems able to shut down systems in low-resource settings could reduce risks.

Table-2: Severity Rating for Water Quality Impacts affecting Drinking Water Utilities in Nzoia River Basin, Kenya

Water Quality Impacts affecting Drinking Water Utilities	Lower Catchment	Middle Catchment	Upper Catchment
Increased load of pollutants from agricultural soils, contaminated landfills, urban areas and sewer overflows	HIGH	HIGH	HIGH
Improved conditions for waterborne bacteria, parasites and viruses to grow	HIGH	HIGH	HIGH
Changes in the physico-chemical conditions of water	HIGH	HIGH	HIGH
Increased release of particles from pipes and plumbing systems of drinking water network	HIGH	MEDIUM	MEDIUM
Reduced dilution of potential pollutants, increase in turbidity and sedimentation	MEDIUM	MEDIUM	MEDIUM
Increased degradation rate of some pesticides and other organic pollutants	MEDIUM	MEDIUM	MEDIUM
Lower efficiency of some pollutant treatment processes	MEDIUM	MEDIUM	MEDIUM
New conditions requiring changes in existing treatment plants (upgrading with aeration facilities for ammonium oxidation; installation of pre-sedimentation ponds or river bank filters).	MEDIUM	MEDIUM	MEDIUM
Increase in the frequency and intensity of floods	HIGH	HIGH	HIGH
Increase in the frequency and intensity of droughts	HIGH	HIGH	HIGH
Increased water temperature with associated increases in eutrophication	HIGH	HIGH	HIGH

Multistage filtration may also be at risk from increasing suspended solid loads [37]. This again can be managed through improved controls to shut down water intakes with increasing sediment loads and also through physical measures that cause units to stop working, for instance by having a finer layer close to the inlet of prefilters that clogs relatively quickly. Increasing temperatures may favor survival of pathogens associated with piped drinking water supplies and may potentially extend their range. Higher temperatures favor development of biofilms containing pathogens such as mycobacteria, Legionella, and Pseudomonas. As the numbers of households with water piped into homes increase and in-house water systems become more complex, the risks from these pathogens will likewise increase.

Khan et al. [39], notes that climate change may lead to increased risks of cyanobacterial blooms and consequent risks to public health, particularly in health facilities offering dialysis where there is a lack of specific additional treatment for water. This is associated with increases in temperature, but in addition to direct increases there are a number of other processes that may favor the development of blooms. Decreasing flows are likely to lead to increased concentrations of pollutants. Changes in temperature and precipitation may change dissolved organic carbon and lead to an increase in the precursors of disinfectant by-products. Surface waters used as drinking water sources may face additional water quality challenges where they receive wastewater upstream of water supply intakes. The most obvious impact will be increasing concentrations of pollutants if river flows decline. However, where combined sewers are used risks may also increase with more extreme rain events due to storm water overflows.

3.1.3 Operational reliability impacts

The study established the operational reliability impacts affecting drinking water utilities experienced in the last ten years in Nzoia River Basin as shown in Table-3. The carefully selected team of water and climate change experts consisting of decision makers, practitioners, managers, scientists, technology adopters, etc; after a lengthy brainstorming session and making consultations, ranked the severity of the operational reliability impacts affecting drinking water utilities in Nzoia River Basin based on a scale of 1-3, where, 1.-LOW, 2.-MEDIUM, and 3.-HIGH severity as shown in Table-3. The results reveal that, from the identified operational reliability impacts affecting drinking water utilities in the basin, vulnerability is uniformly spread across the basin. Climate change will potentially impact utility infrastructure through a variety of means, including flood damage and pipe breaks due to soil drying and settling. Coastal facilities may be threatened by rising sea level and increased corrosion due to salt water intrusion. Warmer temperatures will likely increase the range and proliferation of invasive nuisance species such as quagga/zebra mussels and milfoil. Reservoir management is likely to be greatly complicated by changes in runoff timing and intensity, particularly for reservoirs that are required to balance both water supply and flood control needs. The threats from climate change in Nzoia River Basin relate to changes in temperature and rainfall, leading to changes in hydrology and water demand, as well as to extreme weather events that damage water supply infrustructure and power supplies. The nature of the threats relates to increasing unpredictability in surface water flows and a consequent change in demand for groundwater, as well as floods and declining water availability. These changes may occur at different times in the same location. Short-term, unpredictable occurrences and slow-onset events can both cause changes. Flash flooding is an example of a short-term event where it may be feasible to foresee which places are vulnerable and, to some extent, when specific episodes will occur. Once they get started, though, these events only provide you a short period of time to react; reducing risks in these types of catastrophes necessitates advance planning and investment in both structural and nonstructural solutions, in accordance with accepted disaster risk reduction principles. Drought and water scarcity, changes in water quality, and some types of flooding are examples of slow-onset disasters. Although prolonged events can have a comparable impact on services as short-term disasters, planned solutions may differ and function on different timescales. Preventive action should be possible, and for individual events there may be time to tailor responses to the specific nature of the event.

Table-3: Severity Rating for Operational Reliability Impacts affecting Drinking Water Utilities in Nzoia River Basin, Kenya

Operational Reliability Impacts affecting Drinking Water Utilities	Lower Catchment	Middle Catchment	Upper Catchment
Flood damage to water supply intake works, pumping stations, treatment plants, storage facilities and distribution pipelines.	HIGH	HIGH	HIGH
Damage to water supply and treatment infrastructure, pipe breakage due to soil movement by wetting and drying cycles	HIGH	HIGH	HIGH
Increased corrosion to water supply infrastructure due to salt water intrusion from rising sea levels	LOW	LOW	LOW
Increased range of invasive nuisance species such as quagga/zebra mussels and milfoil due to warmer temperatures	MEDIUM	MEDIUM	MEDIUM
Complications in reservoir management especially for those reservoirs intended to balance both water supply and flood control due to changes in runoff timing and intensity	LOW	LOW	LOW

The threat from flooding is most acute when flash floods occur, primarily because of their destructive force and limited warning, but slow-onset flooding can also be hugely challenging in Nzoia River Basin as water supply intakes, treatement works and pump stations may be inundated affecting services. Loss of water sources may occur because of reduced rainfall, because of overabstraction, or because intakes or reservoirs are destroyed in flood events. Distribution infrastructure may be damaged by floods. Droughts may increase concentrations of chemicals and pathogens. Contamination may also occur because water treatment systems, source protection measures, or distribution infrastructure fail, or because of disruption to transport and power systems that may cause water supplies to stop functioning or prevent delivery of treatment chemicals. Howard and Bartram [40], observes that, “climate-related threats interact with other aspects of the environment and the current levels of service provision, as the volume of water used by households varies depending on the level of service”. When water availability declines as a result of climate change, utilities that serve people who have water piped into their houses may find it difficult to get enough water. Households with access to water sources outside the home frequently use numerous sources of water to meet their demands throughout the year [41; 42], presenting significant challenges in maintaining acceptable quality and quantity across a diverse variety of sources. This is primarily due to the latter's superior and more sophisticated management systems, more access to funding and technical resources, and, in many cases, higher quality infrastructure [37].

3.1.4 Financial and Institutional impacts

The study established the Financial and Institutional impacts affecting drinking water utilities experienced in the last ten years in Nzoia River Basin as shown in Table-4.

Table-4: Severity Rating for Financial and Institutional Impacts affecting Drinking Water Utilities in Nzoia River Basin, Kenya

Financial and Institutional Impacts affecting Drinking Water Utilities	Lower Catchment	Middle Catchment	Upper Catchment
Reduced revenues	MEDIUM	MEDIUM	MEDIUM
The need for new rate structures to better reflect the increasing value of water	LOW	LOW	LOW
Water affordability issues	LOW	LOW	LOW
Increasing conflict with competing water users	LOW	LOW	LOW
Population shifts that strain utilities by increasing or decreasing their customer base	LOW	LOW	LOW
Enacting regulations on becoming carbon-neutral by minimizing energy consumption, turning to renewable energy sources, and optimizing fleet efficiency	LOW	LOW	LOW

The carefully selected team of water and climate change experts consisting of decision makers, practitioners, managers, scientists, technology adopters, etc; after a lengthy brainstorming session and making consultations, ranked the severity of the financial and institutional impacts affecting drinking water utilities in Nzoia River Basin based on a scale of 1-3, where, 1.-LOW, 2.-MEDIUM, and 3.-HIGH severity as shown in Table-4. The results reveal that, from the identified financial and institutional impacts affecting drinking water utilities in the basin, vulnerability is uniformly spread across the basin. Climate change-induced financial and institutional impacts on water utilities are less well understood, but potentially more important than water supply and operational impacts. Despite the fact that climate change will exacerbate supply and operational issues, most water utilities are used to dealing with them. Reduced revenue, the need for new rate structures to better represent the increasing value of water (and associated affordability difficulties), and more conflict with competing water users may find utilities unprepared. Climate change may, in the long run, result in population shifts that put pressure on utilities by growing or shrinking their customer base. To guarantee that utilities have the resources they need to adapt to climate change, more stakeholder awareness and support will be required. Finally, utilities, like other businesses, will face increased pressure (and maybe regulation) to reduce their carbon footprint by reducing energy use, switching to renewable energy sources, and improving fleet efficiency.

4.0 CONCLUSION

Climate change presents several challenges to drinking water utilities in Nzoia River Basin, including the increased frequency and duration of droughts, floods associated with intense precipitation events, degraded water quality and subsequent changes in demand for water services. In many regions of the basin, increased precipitation intensity and variability are expected to increase the danger of flooding and drought. The frequency of heavy precipitation episodes (or the proportion of total rainfall resulting from heavy falls) will increase resulting into high risks of rain-generrrattted flooding. Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution from sediments, nutrients, dissolved organic carbon, pathogens and pesticides as well as thermal pollution, with possible negative impacts on water utilities reliability and operating costs. Climate change has an impact on how existing water utilities function and operate. Water demand is expected to rise in the future decades, owing to population increase and rising affluence. Current water management strategies may not be able to withstand the effects of climate change on water supply reliability. Water management in many regions is unable to cope properly with current climate variability, resulting into large flood and drought damages. Improved incorporation of present climate variability knowledge into water-related management might help with adaptation to long-term climate change impacts as a first step. Climate change challenges the traditional assumption that, “past hydrological experience provides a good guide to future conditions’’. Climate change will impact the reliability of current water management systems and water-related infrastructure. County governments in Nzoia River Basin need to plan ahead on how these challenges can be addressed. They need to recognize and rise to these challenges with a strong clarity of purpose by developing response strategies, forming coalitions and alliances, and raising awareness among policy makers both in the national and county governments. The national and county governments in the basin should put in place appropriate legislations to increase funding to the water sector to tackle climate change challenges. In Nzoia River Basin, lack of adequate data both quality and quantity for many rivers and aquifers is a major constrain in assessing climate change impacts. Long-term planning is required to deal with weather variability and uncertainty of water resources in the basin.

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