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Impact of Climate Change on Drinking Water Resources in Nzoia River Basin, Kenya

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Climate change is one of the greatest threats to mankind's survival in the twenty-first century, and has a number of consequences for the Nzoia River Basin's drinking water resources, including increased dry spells, flooding associated with heavy rainfall events, degraded water quality, and changes in water demand. This study examines the impact of climate change on drinking water resources in Nzoia River Basin, Kenya. A cross-sectional survey design was used in this study. Busia (lower), Kakamega (middle) and Trans Nzoia (upper) were the three counties chosen randomly for survey in the basin. The research was conducted from May to September of 2017. The 400 households surveyed by questionnaires were chosen using multistage random sampling. The Author conducted the questionnaire survey with the help of trained University students. The interviewers also utilized observation checklists to gather information on the households and the community. The study results revealed the climate change drivers affecting drinking water resources in the basin as changes in rainfall patterns, increasing temperatures and seasonal Lake Victoria level risings. These drivers have been reviewed and ranked in order of severity across the basin by a team of water and climate change experts through in-depth interviews and brainstorming sessions. The influence of climate change on infrastructure investment initiatives is becoming increasingly important at County and National Government levels in the basin. National and County governments in the basin should begin re-evaluating drinking water development initiatives by including climate change into infrastructure design, capital investment, service provision planning, and operation and maintenance. Most water utilities face climate change

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variability and uncertainty in their daily operations and long-term planning. Most utilities are starting to consider the impact of climate change on their water supplies, as well as the technical, financial, operational, and institutional ramifications. These difficulties are exacerbated by the fact that utilities have more pressing needs, such as increasing coverage and dealing with high levels of non-revenue water, all of which compete with the development of climate change adaptation solutions.

Keywords: Nzoia river basin; climate change; drinking water resources.

1. INTRODUCTION

Climate change is the most serious concern of the twenty-first century, and water specialists believe that people all over the world will be affected significantly by its impacts through water supplies [1]. The increase in average surface temperatures owing to anthropogenic greenhouse gas (GHG) emissions by the end of the twentieth century had already reached the critical threshold for many aspects of the climate system [2]. Current climate policy prioritizes long-term carbondioxide reductions, and even if carbondioxide emissions cease, climate change will be essentially irreversible for the next 1,000 years [3]. A number of avenues have been created in order to develop strategies for reducing the negative effects of climate change. The United Nations Framework Convention on Climate Change (UNFCCC) was created in 1992 to offer a framework for policies aimed at mitigating climate change by stabilizing atmospheric greenhouse gas levels to avert hazardous anthropogenic climate effects.

The twenty-first Conference of Parties to the UNFCCC held in Paris in December 2015, saw governments agree to limit temperature rises to no more than 2 degrees Celsius above pre-industrial levels, with a goal of 1.5 degrees [4]. Even if this is accomplished, major changes are likely to occur, posing increased dangers to drinking water supplies. Even if the temperature rise is limited to 1.5 degrees Celsius, major changes in precipitation patterns are projected [5]. These changes in precipitation will have an impact on local hydrology and, as a result, groundwater, which will have serious consequences for drinking water resources [6].

When it comes to the effects on water resource availability, there is considerable uncertainty. As a result of changes in precipitation, rising temperatures, rising demand, and lower quality of water resources owing to pollution, global projections frequently suggest greater shortages [7]. These analyses, on the other hand, ignore available groundwater storage [8] and mounting evidence that groundwater recharge could rise in future climate scenarios [9]. As the extent and complexity of climate change's challenges to water resources become better understood and documented, more adaptive management is becoming important [10]. Despite their importance to human health and associated socio-economic activities, little consideration has been paid to how climate change impacts will affect drinking water resources and management. Under goal 6 of the Global Sustainable Development Goals (SDGs), target 6.1 aims at attaining universal access to drinking water supply. Target 16 and 17 demand for higher levels of service which call for much higher quantities of water. The SDG 6 through target 6.3 also calls for improved water quality; 6.4 improved water use efficiency; 6.5 implementation of intergrated water resources management; and 6.6 the restoration of water ecosystems. Climate change is likely to pose serious challenges to the achievement of these targets. The majority of the research on the impact of climate change on water focuses on water resources, but there is now a growing body of knowledge about the hazards to drinking water supplies. A global assessment of the resilience of water and sanitation technology and management systems is provided by Howard et al. [11] and Howard & Bartram [12]. They evaluated the technology's resiliency in the face of a variety of climate change scenarios. A growing number of studies are being conducted on specific vulnerabilities, such as the dangers posed by climate change to secure water supply in glacierized basins in the Andes [13]. Groundwater storage has an important role in enhancing the resilience of small, community-managed water supplies to climate change, according to a study conducted in Nepal [14]. Changes in temperature and precipitation, which lead to changes in hydrology and water demand, as well as storm events that disrupt water and electricity supply, are all hazards posed by climate change [15]. These changes may occur at different periods in the same location.

Understanding how climate change is impacting drinking water resources is important to identify measures to be implemented in the future, hence this study examined the impact of climate change on drinking water resources in Nzoia River Basin, Kenya.

2. MATERIALS AND METHODS

2.1 Study Area

Nzoia River Basin extending from longitudes 34^0 E to $35^0 45'$ E and latitudes $1^0 30'$ N to $0^0 05'$ S, is located in the Republic of Kenya along the boarder with Uganda (Fig. 1). Originating from the Cherengani hills and Mount Elgon, Nzoia river is one of the major rivers in Western Kenya emptying its waters into Lake Victoria [16]. It has a total length of 334 km with 12,959 km^2 drainage area [17].

The topography of Nzoia River basin is varied with hilly (Cherangan hills) and mountainous (Mt. Elgon) landscapes at elevations of 4,300m above mean sea level from where the fastest flowing streams of Kuywa, Sioso Ewaso, Rongai and Koitobos are found. Flowing in a north-easterly to south-westerly direction from its upper catchments, we arrive at the lower reaches into Lake Victoria at an elevation of about 1,000 m [18]. This zone is exposed to periodic flooding. Climate in the basin is tropical humid. Day temperature varies from 16 °C in the highground areas to 28 °C in the lowland areas around Lake Victoria. Annual rainfall is 600-2700 mm. The most common soil types are light clays with good drainage and good moisture capacity high in fertility. The dominant landuse is agriculture [19].

2.2 Methodology

A cross-sectional survey design was used in this study. Busia (lower), Kakamega (middle) and Trans Nzoia (upper) were the three counties chosen randomly for survey in the basin. The 400 households surveyed by questionnaires were chosen using multistage random sampling. The Author conducted the questionnaire survey with the help of trained University students. The interviewers also utilized observation checklists to gather information on the households and the community. The research was conducted from May to September of 2017. The head of each

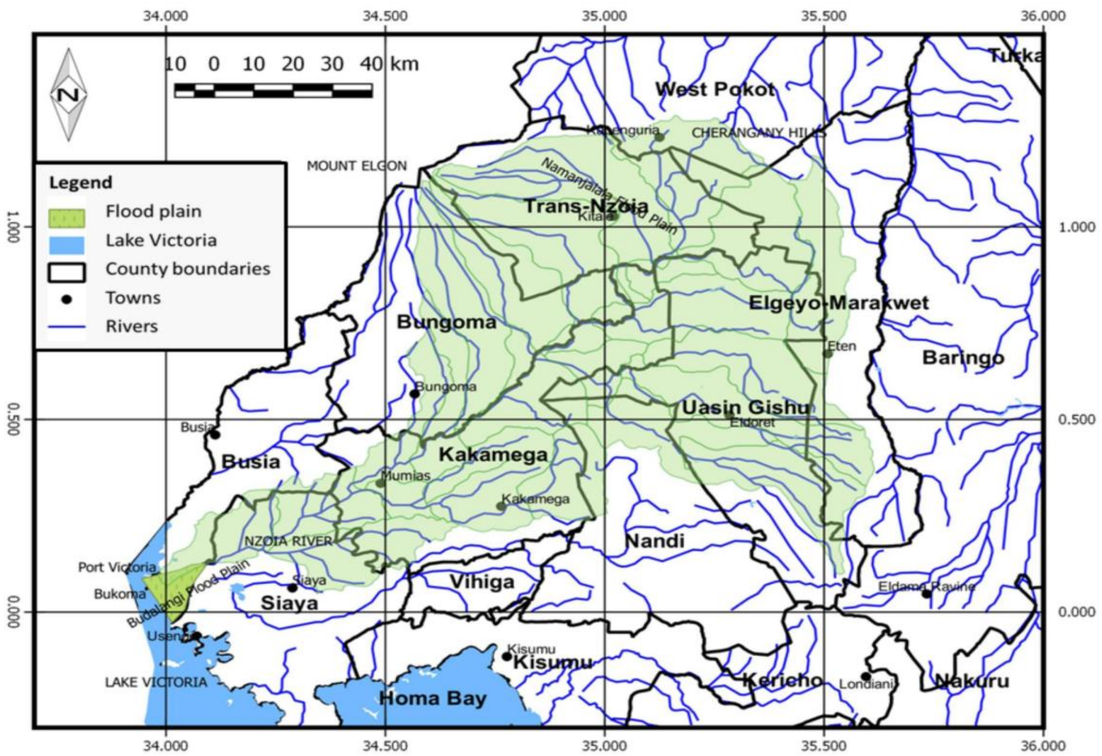

Fig. 1. Map of Nzoia River Basin, Kenya

household was the eligible participant for the interview. The three main climate change drivers affecting drinking water resources in the Nzoia River Basin were reviewed using in-depth expert interviews and brainstorming sessions (changes in rainfall patterns, increasing temperatures, and seasonal Lake Victoria level risings). On a scale of 1-3, where 1.- LOW, 2.- MEDIUM, and 3.- HIGH severity ranking/rating, a group of water-climate change proffessionals made up of decision makers, practitioners, managers, scientists, technology adopters, etc. ranked the severity of climate change drivers (changes in rainfall patterns, increasing temperatures, and seasonal Lake Victoria level risings) across the basin. Secondary data was also utilised in the study, which comprised the gathering and analysis of previously published materials and information. The information gathered was compiled and thoroughly examined.

3. RESULTS AND DISCUSSION

3.1 Effect of Climate Change on Drinking Water Resources in Nzoia River Basin

This study investigated the climate change drivers affecting drinking water resources experienced in the last ten years in Nzoia River Basin and the results are shown in Table 1. The climate change drivers affecting drinking water resources experienced in the last ten years in Nzoia River Basin are: changes in rainfall patterns, increasing temperatures and seasonal Lake Victoria level risings. 71% (284) of the households showed changes in rainfall patterns, 26% (104) increasing temperatures and 3% (12) seasonal Lake Victoria level risings. Climate change will have numerous direct and indirect effects on both quantity and quality of water. Higher temperatures and lesser rainfall will result in reduced water supplies and higher water demands, potentially deteriorating the quality of water in freshwater bodies and putting pressure on many countries' already fragile supply-demand balances [20].

Simulations of the Global Climate Model (GCM) have been used to predict projected climate changes under various climate change scenarios, as well as to assess the impact of climate change on water supplies. Climate change implications on water resources have been found in studies to vary by region, depending on regional geographic factors and climate [21]. As a result, these consequences will vary "depending on the type of water resources (groundwater, surface water, etc.) and the region (both because climate change will have distinct effects and because water demand is diverse and originates from different sources)". Even if precipitation does rise, there is no guarantee that it will do so at a time when it will be advantageous. The majority of these research show that more flooding is likely in the future [22].

The study went ahead and conducted severity rating for the climate change drivers affecting drinking water resources across the basin and the results are shown in Table 2. The severity rating for changes in rainfall patterns and increasing temperatures is high across the basin. The rating for seasonal Lake Victoria level risings is Medium in the lower catchment and low in both middle and upper catchments. The climate change driver of Seasonal Lake Victoria level rising was cited by a small number of people in Busia county (lower catchment) in the sub-counties of Samia and Bunyala boardering Lake Victoria. These people are sometimes affected by rising seasonal lake levels in the years when the lake catchment areas receive more than the usual rainfalls (compared to the long term average); and this consequently affects drinking water resources. The main impacts of climate change on water supply are floods and droughts. Climate change has an impact on surface water quality in addition to these quantitative effects. Water quality is influenced by many factors, including climate change. Land use changes, reduction in forest cover, urban expansion, and area waterproofing, all of which are incorporated within the global change concept, may also contribute to lowering the quality of water. But, more often than not, water pollution is caused by human activities such as urban developments, industrialization, or agricultural operations; and climate change could have an indirect impact on surface water quality as a result of these activities.

The ambient (air) temperature and the rise in extreme hydrological events are the key climate change variables affecting water quality. Cycles of soil drying and rewetting, as well as an increase in solar radiation, may be considered to have effects on drinking water resources. The main factor controlling practically all physico-chemical equilibriums and biological responses is temperature. It is commonly known that all physico-chemical "constants" change with temperature, with endothermic reactions

Table 1. Climate change drivers affecting drinking water resources in Nzoia River Basin, Kenya

Climate change drivers	Frequency	Percentage
Changes in Rainfall patterns	284	71
Increasing Temperatures	104	26
Seasonal Lake Victoria level rising	12	3
Total	**400**	**100**

Table 2. Severity rating for the Climate change drivers affecting Drinking water resources across Nzoia River Basin, Kenya

Climate change drivers	Severity rating across the basin		
	Lower Catchment	Middle Catchment	Upper Catchment
Changes in Rainfall patterns	HIGH	HIGH	HIGH
Increasing Temperatures	HIGH	HIGH	HIGH
Seasonal Lake Victoria level rising	MEDIUM	LOW	LOW

frequently rising. For a temperature increase of 10 °C, the kinetic of a chemical process can be doubled, according to the Arrhenius law. Hence, as water temperature rises, numerous water-related transformations or processes, such as dissolution, solubilization, complexation, degradation, and evaporation, may be favored.

3.1.1 Changes in rainfall patterns

The study sought to establish how changes in rainfall patterns affect drinking water resources in Nzoia River Basin and rank the severity across the basin. The results are shown in Table 3. Severity ranking for increase in the frequency and intensity of droughts; increase in the intensity of rains, on short periods; and variability in patterns are high all over the basin. These are clear manifestations of climate change. Degradation of drinking water quality parameters (physical, chemical and biological) is moderate all over the basin. More precipitation has resulted from increased evaporation due to rising temperatures, which rose over the land north of 30 ^{0}N from 1900 to 2005 but has mostly fallen over the tropics since the 1970s, and there has been no statistically significant overall trend in precipitation over the past century, with wide variability in patterns by region and over time [23]. The spatial patterns of annual precipitation trends (as a percentage per century or per decade) demonstrate that [24]; for the decades 1901–2005 and 1979–2005, "(1) Annual precipitation has increased in most of North America, particularly in high-latitude regions of Canada, with the exception of the southwestern United States, northwestern Mexico, and the Baja Peninsula, where dryness has prevailed in recent years; (2) Increasingly rainy conditions were seen throughout the Amazon Basin and southeastern South America, including Patagonia, whereas annual precipitation trends

were observed to be negative over Chile and areas of the continent's western coast; and (3) The Sahel and West Africa have the most significant negative changes in yearly precipitation".

The energy budget of the troposphere constrains global annual mean precipitation, whereas the atmospheric moisture content constrains extreme precipitation [25]; changes in extreme precipitation are higher than those in mean precipitation. In models [26], increased extreme precipitation events as opposed to total precipitation amounts resulted.

Several other findings include the following, “a larger rise in tropical precipitation intensity due to increasing water vapor, whereas increases in mid-latitude intensity are linked to circulation changes that impact the distribution of additional water vapor [27]; in warm climates, the most intense precipitation occurs [28]; with no changes in total precipitation, higher temperatures contribute to a bigger fraction of total precipitation in heavy and very heavy precipitation events [29]. If the frequency remains constant, total precipitation increases, with a bigger proportion falling in heavy and very heavy storms, as proved empirically [30]. and theoretically [31]; increases in temperature that are expected to increase moisture content faster than total precipitation, resulting in an increase in storm intensity [32]; increases in observed extreme precipitation over the United States,

Table 3. Effect of changes in rainfall patterns on drinking water resources in Nzoia River Basin, Kenya

Changes in rainfall patterns	Lower Catchment	Middle Catchment	Upper Catchment
Increase in the frequency and intensity of droughts	HIGH	HIGH	HIGH
Increase in the intensity of rains, on short periods	HIGH	HIGH	HIGH
Variability in patterns	HIGH	HIGH	HIGH
Degradation of drinking water quality parameters (physical, chemical and biological)	MEDIUM	MEDIUM	MEDIUM

which are similar to changes projected as a result of greenhouse warming [33]".

Increase in the frequency and intensity of droughts in the basin will decrease river flows and aquifer recharge for groundwaters resulting into reduced availability of drinking water resources to the residents. Increase in the intensity of rains, on short periods resulting from changes in rainfall patterns has the effect of reduced water infiltration in soils. This leads to reduced soil water moisture, falling groundwater levels and recharge. Changes in rainfall patterns in the basin leads to variability in water resources availability, hence the effect on drinking water supplies.

In Nzoia River Basin, changes in rainfall patterns will have a more indirect impact on water quality, although some direct effects will include enhanced environments for microorganisms and changes in physico-chemical conditions, which will affect biodiversity and ecosystem services. Indirect effects include reduced dilution, greater pollutant leaching, the need for more water treatment and redesigned water infrastructure among others. Droughts will become more frequent and intense, reducing river flows and aquifer recharge, resulting in less dilution of possible contaminants, greater turbidity and sedimentation, and higher water temperatures (due to less dilution of thermal discharges from cooling circuits). This will have far-reaching consequences for the basin's drinking water resources. Increased flood frequency and severity will increase pollutant loads washed off soils on agricultural farms and urban areas as well as sewer overflows, posing serious threats to the basin's drinking water supplies. Floods will become more frequent and intense, posing a greater risk of damage to water supply and treatment infrastructure, jeopardizing the long-term availability of drinking water. Increased groundwater levels may raise the potential of pollution discharges from polluted soils and landfills into the Nzoia River Basin's drinking water resources.

Conway et al. [34] propose that there is anecdotal evidence of increased flooding in historically drought-prone locations like Ethiopia, with higher variability in precipitation patterns, notably in intensity and duration, for changes in flooding and drought patterns in Sub-Saharan Africa. However, a number of factors are already adjusting demand patterns in response to changes in water demand. Population expansion, land use change, economic growth, and technological change are all examples. The most major shift is projected to occur in the agricultural sector, where changes in precipitation, runoff, and evapotranspiration rates will raise future water demand as a result of climate-related factors. The demand for irrigation is expected to rise. Climate change is expected to have a little impact on household and industrial water demand, with increases of less than 5% in some parts of the world by the 2050s [10].

However, there are two major tendencies in connection to climate change-induced water stress that do not take adaptation into account: one, water stress will increase or decrease. This can involve an increase or decrease in physical scarcity, as well as the physical scarcity replacing present economic and social scarcity. Impacts on the hydrological system caused by climate change will drive these changes. Two, economic and social scarcity will become more prevalent. The impact of climate change on water demand will drive these adjustments. Climate change, according to Arnell [35], may cause lower runoff in some parts of the world, resulting in greater water resource stress. Similarly, Menzel et al. [36] predict that the number of people living in places with severe water stress will rise from 2.3 billion in 1995 to 3.8-4.1 billion in the 2020s and 5.2-6.7 billion in the 2050s, up from 2.3 billion in 1995.

Rather than declining water supply, increasing water pumping as a result of growing population and improving economic conditions will be the primary source of increased water stress. Climate change will increase runoff in other water-stressed areas of the world, such as southern and eastern Asia. Water availability would increase per capita, but access would be determined by the success of capturing and storing the resource for home and agricultural usage [35]. Increased runoff in the rainy season may exacerbate flooding, whereas decreasing runoff in dry seasons may induce a future increase in drought frequency and intensity if there aren't enough adaptation mechanisms in place to regulate supply. Economic water shortage could worsen if ground water levels fall as a result of over-abstraction by some users, raising the cost of water. Climate change projections suggest that the current drivers of scarcity will be superimposed by climate change, which will likely replace areas of economic scarcity (much of Africa) with physical scarcity.

3.1.2 Increasing temperatures

The study sought to establish how increasing temperatures affect drinking water resources in Nzoia River Basin and rank the severity across the basin. The results are shown in Table 4. Severity rating for increased water demand; and increased evaporation and evapotranspiration are high all over the basin. The IPCC affirms categorically in its fourth assessment report that the Earth's climate is warming [37]. The Earth warmed by about 0.6 degrees Celsius over the last century, with the most of the warming occurring between 1920 and 1940 and in the last 30 years. The temperature of the Earth's surface and atmosphere has risen, yet this warming is not uniformly spread over the planet. The warming of land masses is outpacing that of the oceans. Higher northern latitudes have witnessed bigger rises, with the Arctic's average temperature rising at about double the global average rate over the last 100 years [37]. Several places, including mountain peaks, have lost their ice cover.

Surface temperatures have risen by 0.74 degrees Celsius on average over the last 100 years (between 1906 and 2005), with a rise (0.35 degrees Celsius) in the global average temperature from the 1910s to the 1940s, a slight cooling (0.1 degrees Celsius), and then a rapid rise (0.55 degrees Celsius) to the end of 2006 [38]. It's worth noting that the slope for recent times is steeper, indicating accelerated warming. Global-scale variations in surface temperature have been estimated by several research groups around the world [39]; such as the melting of mountain glaciers across the globe [40]; Snow cover reductions, early plant spring flowering, and greater melting of the Greenland and Antarctic ice sheets [41]. For many researches, notably the National Climatic Data Center (NCDC) [42], the operational version of the Global Historical Climatology Network (GHCN); observations made on long-term temperature changes are in general accord with NASA's Goddard Institute for Space Studies (GISS) [43] and better analysis of CRU/Hadley Centre gridded land-surface air temperature version 3 (CRUTEM3) [44-45]. Data from Global Historical Climatology Network and two editions of world weather records, as well as other sources; indicates that annual trends in minimum and maximum land surface air temperature averaged over regions were 0.20 degrees Celsius per decade and 0.14 degrees Celsius per decade, respectively, from 1950 to 2004, with a trend in the diurnal temperature range of 0.07 degrees Celsius per decade [46]. Climate change is anticipated to increase precipitation in the tropics and at higher latitudes (eastern Africa, northern Central Asia, and the equatorial Pacific Ocean), while lowering it in the subtropics (Mediterranean and Caribbean regions). Extreme precipitation patterns are more predictable than average precipitation patterns. There is limited data on changes in evapotranspiration and soil moisture, making it difficult to do a trend analysis. Any changes in this area are likely to be mostly due to changes in plant cover as a result of land use change and other human development causes.

Increased biological activity in soil; and degradation of drinking water quality parameters (physical, chemical and biological) present medium severity over the basin. Increased temperatures in the basin will lead to increased water demand prompting higher water abstraction rates from both surface and groundwater sources. Increased evaporation and evapotranspiration and higher water use by the vegetation is already occurring in the basin. This will have the cumulative effect of reduced river flows and reduced aquifer recharge that may translate into reduced streamflows and soil moisture content in the basin. Increased temperatures in the basin will also lead to increased biological activity in soil prompting reduced infiltration. This will impact drinking water resources through reduced aquifer

Table 4. Effect of increasing temperatures on drinking water resources in Nzoia River Basin, Kenya

Increasing temperatures	Lower Catchment	Middle Catchment	Upper Catchment
Increased water demand	HIGH	HIGH	HIGH
Increased evaporation and evapotranspiration	HIGH	HIGH	HIGH
Increased biological activity in soil	MEDIUM	MEDIUM	MEDIUM
Degradation of drinking water quality parameters (physical, chemical and biological)	MEDIUM	MEDIUM	MEDIUM

recharge in Nzoia River Basin. Increasing temperatures in the basin will have a number of effects on the quality of drinking water resources. Increased temperatures will make it easier for bacteria, parasites (such as amoeba), and viruses to flourish in water. Temperature-dependent biological and chemical processes will change as the temperature rises (e.g. lower oxygen dissolution). Increased temperatures will accelerate the release of particles from drinking water network pipes and plumbing systems. Rising temperatures cause higher evaporation, which reduces river flows and aquifer recharge, resulting in less dilution of possible contaminants, increased turbidity, and sedimentation, all of which have negative consequences for drinking water resources. Increased temperatures stimulate increased forest growth, which promotes increased organic material reserves in the soil, resulting in increased humus leaching, which has an impact on drinking water supplies. Increased and altered insect presence on agricultural fields may result from rising temperatures, necessitating increased and altered pesticide use. Pesticides like this could endanger our drinking water supplies. As the temperature rises, we may see more soil movement as a result of wetting and drying cycles. Water supply and treatment infrastructure will be disrupted as a result of this. Rising temperatures may hasten the breakdown of certain pesticides and other organic pollutants, resulting in decreased levels of contamination in water bodies. In the Nzoia River Basin, rising temperatures may reduce the efficacy of some pollutant treatment techniques.

3.1.3 Seasonal Lake Victoria level rising

The study sought to establish how seasonal Lake Victoria level risings affect drinking water resources in Nzoia River Basin and rank the severity across the basin. The results are shown in Table 5. Severity ranking for contamination of drinking water sources is medium in the lower catchment and low in both middle and upper catchments. Lake Victoria is Africa's largest lake, covering an area of 69,295 km2 [47], and the world's second-largest freshwater lake, supporting nearly 42 million people in its basin [47]. It's in the Lake Victoria basin, which is in the Nile River basin's southern (geographically) section [48]. The lake, which is located upstream of the Nile, receives 20% of its water from input rivers including Kagera, Gurumeti, Simiyu, Nzoia, etc. and 80% from rainfall [49]. The Lake Victoria Basin is surrounded by mountains except in the north. Multiple variables such as severe rainfall, human activity, environmental deterioration, and urbanization have recently created extraordinary changes in the lake environment, resulting in a large water level rise [50-51]. Deforestation and poor farming practices have increased silt and influx streamflow in the lake [49]. Due to its sensitivity to rainfall and evaporation, climate change has had a considerable impact on the lake [52].

Since 1960, the lake's temperature has increased by 0.5°C, and its hydrological cycle has shifted to balance temperature and rainfall [53]. Extreme climatic occurrences (e.g., 1997 El Nino and 2007 ENSO rainfall effect) have been reported to have risen in frequency and strength [54]. Due to the lake's vulnerability to extreme and frequent climatic influences, they emphasize the significance of continuous and accurate water storage monitoring. The lake's water level has risen dramatically in the last two years (2019–2020), resulting in floods, effects on drinking water resources and sanitation systems, an increase in water-related diseases, and consequences on hydroelectric power facilities [48].

Responding to the increased runoff during 2019-2020, the water level in Lake Victoria rose to a new record level of 13.42 m in May 2020, surpassing the 13.41 m mark recorded in 1964. Most of the recharge into Lake Victoria is from rainfall. The amount of regional rainfall, therefore, regulates the water levels in the lake. In comparison to the long-term average, rainfall increased significantly in October by 79 percent,

Table 5. Effect of seasonal lake Victoria level rising on drinking water resources in Nzoia River Basin, Kenya

Seasonal lake Victoria level rising	Lower Catchment	Middle Catchment	Upper Catchment
Contamination of drinking water sources	MEDIUM	LOW	LOW

November by 56 percent, and December by 74 percent in 2019. In comparison to the long-term average, observed rainfall in 2020 increased by 83 percent in January, 25 percent in February, 43 percent in March, and 33 percent in April. A positive Indian Ocean Dipole (IOD) was the cause of these significant increases in rainfall in the Lake Victoria sub-basin. As a result, Eastern Africa saw above-average rainfall and flooding. In the early 1960s, extremely heavy rainfall were blamed for a rise in Lake level; in the last six months of 1961, 2323 mm of rain was recorded, over 100 percent more than the average amount. The first six months of 1962 recorded 1884 mm/year, (around 50-60% over average), 1963 (1739 mm), and 1964 (1739 mm) which were extremely heavy rainfalls. As a result, lake levels climbed to 13.41 m in 1964, the highest level ever recorded before 2020. Lake levels continued to plummet from 1964 onwards, with few isolated increases (e.g., in 1982 and 1997/98) until reaching a minimum of 10.4 m in 2006 [55].

According to Olaka et al. [56], the Lake Victoria basin will see a significant increase in mean annual minimum temperature under various climate projections, resulting in considerable river discharge variability. They came to the conclusion that in the future, stronger transboundary river management will be required. Sitoki, et al. [57] also mentioned the impact of climate change on the lake's region, reporting a temperature increase of more than 1 ^{0}C since 1927. The fact that precipitation and evaporation play the most critical roles in the lake's water storage may explain its sensitivity to climate changes. Droughts or floods can be caused by major variations in these water components, which can have a significant impact on the lake region. Paul [58] addressed the importance of monitoring lake water changes, particularly those produced by extreme weather events, in order to better understand their impact on water quality and circulation in the context of climate adaptation and regional development. The effects of the extreme climate event in 2019–2020 on various water components (surface and subsurface) are yet to be studied.

4. CONCLUSION

The warming climate system is confirmed by scientific observations of rising air and ocean temperatures, as well as the disappearing of snow and ice. The impacts of this warming have been recognized on drinking water resources both at global, regional and local scales. The hydrological cycle will be accelerated by rising temperatures in the basin. Annual rainfall and streamflows in the basin show both increasing and decreasing trends. Climate change will affect seasonal variations in rainfall and streamflows. Rainfall will become more frequent and intense as a result of climate change. The availability of groundwater for drinking water resources in some parts of the basin will be affected by climate change. The main climate change drivers affecting drinking water resources in the basin are changes in rainfall patterns, increasing temperatures and seasonal Lake Victoria level risings; and a likely increase in the frequency of flooding and droughts. Climate change will have a wide range of implications on drinking water resources, depending on the region. Flooding and drought hazards are projected to increase in many parts of the basin as rainfall intensity and variability increase, with significant effects on drinking water resources. Sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt, and thermal pollution will all be impacted by climate change due to increasing water temperatures, precipitation extremes, flooding and drought events; leading to deterioration of drinking water quality. Climate change will exacerbate the stress on freshwater systems already strained by population growth and increased water demand, shifting economic activities, changes in land use, and urbanization. Through a deeper knowledge of the uncertainties anticipated to increase the implications of climate change on drinking water resources, better decision making based on efficient modeling of climate change connected to the hydrologic cycle is required. National and County governments in the basin should integrate climate change into water development programs with specific provisions to address adverse effects.

CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

COMPETING INTERESTS

Author has declared that no competing interests exist.

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