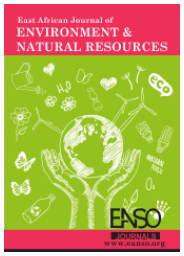

East African Journal of Environment and Natural Resources
eajenr.eanso.org
Volume 6, Issue 1, 2023
Print ISSN: 2707-4234 | Online ISSN: 2707-4242
Title DOI: https://doi.org/10.37284/2707-4242

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Impact of Climate Change on Water Resources and its Implications on Biodiversity: A Review

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Article DOI: https://doi.org/10.37284/eajenr.6.1.1063

Date Published:

27 January 2023

Keywords:

Diversity, Interactions, Phenology, Species Distribution, Reproduction, Water Shortages

ABSTRACT

Climate change-related impacts on water resources can significantly lead to biodiversity loss. Species with specific water resource adaptations, including threatened and endemic species, are in danger of going extinct. The effect of climate change on biodiversity related to water scarcity or shortages has received less attention despite being acknowledged. This paper provides up-to-date collective information and knowledge gap on the impact of climate change on water and how it impacts biodiversity with a particular focus on the connection between climate change impacts, water resources, and the species biodiversity. Sixty (60) original peer reviewed research or review articles, and reports were reviewed to highpoint the impact of climate change on water resources and its implications on biodiversity including human being. We highlight that the impact of climate change on water resources (e.g., water scarcity and shortages) exerts more pressure on biodiversity conservation as it directly affects the growth and behaviour of species and modifies their habitats, population size, composition, interactions, timing of reproduction, reproductive phenology, and growing season. Furthermore, being the part of earth's biodiversity, humans are also affected by the climate change water-related problems. This review earmarked that water shortages due to climate change puts the human population at great risk in terms of crop productivity, food security, and a variety of economic activities. Well–designed infrastructure to harvest water, mitigate and adapt to climate change is vital for protecting biodiversity from climate risks i.e., water shortages. This review paper is useful to government agencies charged with climate change and environmental conservation and policymakers mostly in developing nations to widen goals where the impact of climate is more noticeable. In addition, several deaths of animals and human due to water shortages have been reported.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1063

APA CITATION

Ojija, F., & Nicholaus, R. (2023). Impact of Climate Change on Water Resources and its Implications on Biodiversity: A Review. *East African Journal of Environment and Natural Resources*, *6*(1), 15-27. https://doi.org/10.37284/eajenr.6.1.1063.

CHICAGO CITATION

Ojija, Fredrick., and Regan Nicholaus. 2023. "Impact of Climate Change on Water Resources and its Implications on Biodiversity: A Review". *East African Journal of Environment and Natural Resources* 6 (1), 15-27. https://doi.org/10.37284/eajenr.6.1.1063.

HARVARD CITATION

Ojija, F., & Nicholaus, R. (2023) "Impact of Climate Change on Water Resources and its Implications on Biodiversity: A Review", *East African Journal of Environment and Natural Resources*, 6 (1), pp. 15-27. doi: 10.37284/eajenr.6.1.1063.

IEEE CITATION

F. Ojija, & R. Nicholaus. "Impact of Climate Change on Water Resources and its Implications on Biodiversity: A Review", *EAJENR*, vol. 6, no. 1, pp. 15-27, Jan. 2023.

MLA CITATION

Ojija, Fredrick., & Regan Nicholaus. "Impact of Climate Change on Water Resources and its Implications on Biodiversity: A Review". *East African Journal of Environment and Natural Resources*, Vol. 6, no. 1, Jan 2023, pp. 15-27, doi:10.37284/eajenr.6.1.1063.

INTRODUCTION

Water supplies are under constant and increasing pressure from climate change (Mwabumba, 2022). A rise in temperature, change in precipitation patterns and snow cover, and an increase in the frequency of flooding and droughts are the main threats of climate change to water resources (Pearce, 2008; Wiig et al., 2008). When water is scarce, it impacts on wildlife, which usually like getting fresh, good-tasting water (McCluney et al., 2011; Turner et al., 2022). Over the past few decades, biodiversity (plants and animals) and ecosystems have concurrently been impacted by the increasing influences of climate change on water availability and quality in many different parts of the world (Fonseca, 2022; Leal Filho, 2019; Meng et al., 2016). Climate variability and the associated extreme droughts (e.g., El-Nino events) and frequent short-period rainstorms (e.g., La-Nina conditions) have negative impacts on river flows and lake levels (Meng & Xiong, 2018; Mwabumba, 2022). Species with specific water resource adaptations, endangered species, and endemic species are in danger of going extinct due to climate change-related water scarcity (Leal Filho, 2019; Taylor & Kumar, 2016; Wiig et al., 2008). When there is a lack of water, it is more likely that animals will gather and drink near waterholes because it is less likely that they will locate water (McCluney et al., 2011; Valeix et al., 2010, 2008). Similarly, during this time of water shortages, there are fewer acceptable foraging and drinking spots, and thus, animals cover greater distances in search of pasture and water (Valeix et al., 2008). Though acknowledged, the effect of climate change on biodiversity related to water resources has received less attention from researchers. Thus, this work focuses on the effects of climate change-related water scarcity on biodiversity. Overall, the goals of this review are to pinpoint and summarize the connection between the impact of climate change, water resources, and biodiversity, as well as on human being perspective.

IMPLICATION OF CLIMATE CHANGE ON BIODIVERSITY

Climate change can lead to water scarcity or shortages and subsequently, loss of water quality and biodiversity (Coffinet et al., 2018; Muluneh, 2021; Mwabumba, 2022). This is associated with extreme temperature and rainfall patterns, which exacerbate droughts and floods. As the severity and frequency of these climate change-induced events increase, the amount and quality of water changes, thereby affecting plants and animals. While floods

Article DOI: https://doi.org/10.37284/eajenr.6.1.1063

tend to contaminate and ruin water quality, droughts decrease the available amount of water needed for animals and plants to survive (Muluneh, 2021). Previous scientific studies claim that climate change is having an increasing impact on biodiversity as it negatively affects water resources (Fonseca, 2022; Sternberg et al., 2015; Talukder, 2022) by increasing droughts as a result of long-term evaporation, floods, ocean warming and acidification (Boone & McCleery, 2023; Muluneh, 2021).

As the climate becomes drier, it puts more strain on wildlife communities that already have limited access to water because increased evaporation reduces the quantity and quality of the water (Cui & Corlett, 2016; Engelbrecht et al., 2015; Tietjen et al., 2009). Also, wild animals will need more water during droughts since they will have to rely more on evaporative cooling to remove extra heat (Turner et al., 2022). Furthermore, changes in species' geographic ranges, growing seasons, reproductive phenology, primary production, and diversity are among the anticipated effects of climate change on water supplies (Fonseca, 2022; Habibullah et al., 2022; Moullec, 2022; Numata et al., 2022; Ornelas et al., 2018). Thus, any change in water resources (i.e., quantity and quality) brought on by the effects of climate change on precipitation might result in biodiversity loss (Fonseca, 2022; Habibullah et al., 2022; Nyembo et al., 2022); change in animal behaviour and physiology (Turner et al., 2022); and many other negative impacts (*Table 1*).

Table 1: Climate change's impact on biodiversity associated with water resources

Negative impacts on wildlife species and habitats	References
Shifts in species geographic ranges, migration, movement patterns, expansion and/ or contraction of species ranges	(Caten et al., 2017; Fonseca, 2022; Loarie et al., 2009; McCluney et al., 2011; Muluneh, 2021; Nunez et al., 2019; Sushant, 2013; Vásquez-Aguilar et al., 2021; Wiig et al., 2008)
Causes a decrease or loss of biodiversity, desiccation, and mortality	(Habibullah et al., 2022; Muluneh, 2021; Sternberg et al., 2015; Talukder, 2022; Turner et al., 2022)
Change in species reproduction timing, reproductive phenology and growing season,	(Leal Filho, 2019; Numata et al., 2022; Nunez et al., 2019; Prato, 2009; Talukder, 2022)
Causes physiological stress to species, and lower primary production	(Fonseca, 2022; Habibullah et al., 2022; Hunninck et al., 2020; Rose et al., 2014)
Change in species population, ecosystem functioning and homogenization	(Boone & McCleery, 2023; Chhaytle et al., 2022; Loarie et al., 2009; Muluneh, 2021; Tsalyuk et al., 2019; Valeix et al., 2008)
Changes wildlife communities, species compositions and distribution	(Boone and McCleery, 2023; Caten et al., 2017; John et al., 2020; Muluneh, 2021; Nunez et al., 2019; Rose et al., 2014)
Increase animals' body water balance stress	(Tietjen et al., 2009; Turner et al., 2022)
Diseases and death of wildlife due water contamination	(Muluneh, 2021; Ojija et al., 2017)
Affects the growth, and survival of plant and animal species	(Meng et al., 2016; Muluneh, 2021; Prato, 2009; Trinkel et al., 2004)
Modify animal behaviour, physiology, and species interactions	(Crosmary et al., 2012; McCluney et al., 2011; Turner et al., 2022; Valeix et al., 2010)
Alterations in the dynamics of wildlife species and reproduction patterns	(Leal Filho, 2019; Sternberg et al., 2015)
Loss of genes and species, desiccation, and mortality of species e.g., shrubs and trees	(Sintayehu, 2018; Sternberg et al., 2015)

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Change in Species Reproduction Timing, Phenology, and Growing Season

Wildlife, i.e., plant and animal species, requires water resources to reproduce, grow, and thus survive (Prato, 2009; Vásquez-Aguilar et al., 2021). However, because of the fast-changing climate, wildlife communities in particular are likely to change in response to a change in water resources, i.e., scarcity and shortages (Chhaytle et al., 2022; El-Fakharany & Salem, 2021; Prato, 2009). A change in the amount and/or quality of water resources due to a changing climate could interrupt species' reproduction timing, phenology, growing season, and primary production (Coffinet et al., 2018; Prato, 2009; Tietjen et al., 2009). The availability of rainfall and thus water resources fuels primary production, which in turn stimulates animal reproduction (Muluneh, 2021). However, the decrease in food availability due to water scarcity and shortages could cause the death of animals and/or change their physiological processes (Caten et al., 2017; Mwabumba, 2022). For instance, some animals may hibernate and/or stop reproducing until water resources are available.

Severe water shortages due to droughts can further lead to a relative decline in the population of some species and even their local extinction, especially for the most vulnerable ones (Hulme et al., 2013; Hunninck et al., 2020; Meng et al., 2016). Changes in water quality due to flooding and higher temperatures in lakes, rivers, seas, and oceans can result in changes in the nutrient dynamics that affect aquatic species (e.g., productivity) (Dueñas et al., 2021). For instance, it was claimed that alterations to the Amazon's yearly flooding cycles had a detrimental effect on the Giant South American Turtle's ability to successfully lay its eggs (*Podocnemis expansa*) (Eisemberg et al., 2016). Also, most of the species that live and reproduce either in cold or warm water can alter their reproduction and growth rates as a result of severe increasing or decreasing temperatures (Prato, 2009; Wiig et al., 2008). Similarly, their offspring might die or fail to grow as a result of changing favourable water parameters (Eisemberg et al., 2016; Muluneh, 2021; Wiig et al., 2008).

Moreover, the increase in acidification and salinity in water bodies, especially in marine ecosystems, is posing threats to aquatic biodiversity (Muluneh, 2021; Pearce, 2008; Talukder, 2022). Preceding studies reveal that ocean acidification affects the reproduction and development of various animal species through a range of physiological responses (Leal Filho, 2019; Sternberg et al., 2015). These include reallocation of resources, fertilization rates, sperm motility, and velocity, e.g., in copepods and sea stars (Eisemberg et al., 2016; Talukder, 2022). Other studies show that acidification alters metabolic activity and fatty acid composition of some species (e.g., predatory snails), and respiration rates and timing of reproduction of cold-water corals and Antarctic fish, respectively (Talukder, 2022). Because of this, the growth season and development of aquatic species are equally affected (Leal Filho, 2019). For instance, increasing acidification makes it difficult for shellfish and corals in the ocean to build shells and rigid skeletons, making corals particularly vulnerable (Talukder, 2022).

In the case of plants, those species that are intolerant to drought or warm weather usually wilt or die due to water scarcity and shortages (Sternberg et al., 2015). Some of them tend to alter their flowering and growing seasons, i.e., by extending their seed dormancy (Numata et al., 2022). Previous reports show that numerous blooming plants, particularly those in tropical rainforests, have been observed to be affected by climate change's impact on water availability and rainfall patterns, which further affect their reproductive phenology (Numata et al., 2022; Sternberg et al., 2015). As a result, their blooming and fruiting trends have been declining (Numata et al., 2022). Also, the desiccation and death of plants are further effects of decreased total rainfall and a water deficit (Sternberg et al., 2015). In general, wilting, change in flow, and growing

Article DOI: https://doi.org/10.37284/eajenr.6.1.1063

season of plants pose a significant negative impact on wild animals that forage on vegetation and their ecology.

Change in Species Migration and Population

Climate change's impact on water resources is the most critical factor that can determine species' distribution and ranges on the planet (Fonseca, 2022; Gonçalves, 2021; Pacheco et al., 2010; Sternberg et al., 2015). It is posing a threat to the population and migration of wildlife species and their habitats by altering the hydrology, circulation, and availability of water resources (Chhaytle et al., 2022; Nunez et al., 2019). The combined effects of water shortages and an increase in temperatures cause wetlands (i.e., lakes, ponds, streams, riparian ecosystems) to dry out, decreasing the amount of water resources available to support a diversity of species (Engelbrecht et al., 2015; Mkiramweni et al., 2016; Salehi, 2022). Owing to water scarcity, animals are forced to migrate and expand their home ranges to areas with enough water resources (Gonçalves, 2021; Tietjen et al., 2009; Turner et al., 2022). Because of this, animals compete for available water and food resources, and the weak ones will eventually die (i.e., 'survival of the fittest'). Furthermore, aquatic species that live in cold water would be forced to expand their home ranges or leave warm water areas (Brown et al., 2020; Muluneh, 2021); and decreasing water depth due to droughts could affect animals that live in deeper water and even those found in shallow water. While adaptable species to water scarcity and flooding will survive, and others migrate, the end result will be biodiversity loss (Muluneh, 2021; Turner et al., 2022). In general, wildlife species have been compelled to shift to or seek out suitable locations with water supplies and vegetative communities due to the declining water resources caused by the warming climate (Muluneh, 2021).

Furthermore, water scarcity and shortages due to rising global temperatures and increasing floods potentially affect wildlife populations over longer time periods by altering what can grow and exist within a community (Fonseca, 2022; Nunez et al., 2019; Talukder, 2022). As climate change impacts water resources, it interferes with food supply, migration, and breeding timing of species (Crosmary et al., 2012; Prato, 2009). This is because, with water scarcity, many plants could die out, causing a lack of food for wild animals and thus affecting their population health (Eguiguren-Velepucha et al., 2016; Ojija et al., 2017). Also, extreme temperatures cause water supplies (i.e., rivers, streams, and ponds) to dry up, which in turn causes water scarcity in many terrestrial ecosystems (Turner et al., 2022). A shortage of water can alter animal physiology and behaviour, as reported by McCluney et al. (2012). When water runs dry, animals cannot get enough to drink, which therefore increases body water balance stress (Turner et al., 2022). Thus, they must modify their physiology and behaviour in order to survive. If the frequency and intensity of water scarcity and the occurrence of flooding increase, it may further lead to the death of many species (*Figure 1*) and a change in their population (Nunez et al., 2019). Plant and animal species that are intolerant to drought or warm weather could eventually go extinct, which in turn affects the population and community structure of those species (Coffinet et al., 2018). Therefore, it is not only droughts that are affecting species' population structures but also extreme rainfall and floods as a result of climate change (Eisemberg et al., 2016). Overall, these events affect essential food resources and water supply to support biodiversity (Rhodes, 2019, 2014).

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Figure 1: The effect of water scarcity or shortage

a dead (a) buffalo in the park, Zimbabwe (https://guardian.ng/news/world/drought-hit-zimbabwe-to-transfer-thousands-of-animals/)

b) baby elephant in Amboseli National Park, Kenya (https://news.mongabay.com/2009/10/kenyas-pain-part-two-decades-of-wildlife-decline-exacerbated-by-drought/) due to drought.

Global warming can make water contaminated and unfit for consumption, which could have a negative impact on wildlife populations (Rhodes, 2014; Tietjen et al., 2009). The wild animals' normal bodies would not function without water, and a shortage of vegetation can cause a spread of additional problems (Turner et al., 2022). A lack of adequate water will affect vegetation growth, resulting in hunger, the death of wild animals (Fig 1), and a decline in the wildlife population (McCluney et al., 2011). Also, animals would suffer from diseases due to contamination of water bodies (Ojija et al., 2017). A scarcity of water could result in wild animals migrating from one place to another in search for greener pastures and water to drink, thereby affecting their local population (McCluney et al., 2011). Moreover, changes in ocean temperatures can lower oxygen levels in marine ecosystems, thereby affecting populations of some species, e.g., the sea star *Pisaster ochraceus* (Habibullah et al., 2022), and insects such as mayflies, which live in oxygenated cool water (Nunez et al., 2019; Talukder, 2022). Also, other previous research has found that the availability of water resources has a significant impact on the migration and movement patterns of wild animals (e.g., Loarie et al., 2009; Tsalyuk et al., 2019).

Change in Species Distribution and Interactions

As climate change alters the distribution of water resources (McCluney et al., 2011), the availability of water (e.g., precipitation, fog, soil moisture, surface water) greatly alters the distribution and interactions of species (Loarie et al., 2009; McCluney et al., 2011; Tsalyuk et al., 2019). As a result of this, most animals commonly disperse or gather together around water sources, i.e., streams, ponds, or pools (Valeix et al., 2010, 2008), which in turn attracts predators and puts their lives in danger (Trinkel et al., 2004; Valeix et al., 2008). In addition, Valeix et al. (2010) revealed that huge herbivores tend to congregate around sparse water sources in African semi-arid and desert savannas. Because of this, interactions between and among species, as well as competition (Ferry et al., 2020) for water and other resources, are high at these waterholes (Crosmary et al., 2012; Valeix et al., 2010). Areas around waterholes commonly have aggressive interactions, which can result in fighting and/or loss of life for some wild animals (McCluney et al., 2011; Tietjen et al., 2009; Tsalyuk et al., 2019). Aggressive interactions for water sources have been observed in elephants (Loarie et al., 2009; O'Connell-Rodwell et al., 2011; Tsalyuk et al., 2019), and between predators and other ungulates

Article DOI: https://doi.org/10.37284/eajenr.6.1.1063

(Ferry et al., 2020; Périquet et al., 2021). Because of these interactions, most African herbivores of various species have been found to adjust their drinking habits in response to predation danger and water availability (Valeix et al., 2008). In addition, a reduction in drinking frequency or time in many animals around waterholes has been linked to an increased predation risk (Valeix et al., 2010, 2008). Subsequently, most wild animals move or relocate to other areas to meet their water resource requirements, avoid fierce competition, and also avoid predators.

The relationships between species, i.e., their interactions, are significantly influenced by the availability of water (Ferry et al., 2020; Loarie et al., 2009; Tietjen et al., 2009). Species interactions, such as those between predators and prey, plants and other plants, and plants and herbivores, are thought to play a significant role in how ecosystems and ecology evolve as water resources vary (Ferry et al., 2020; Périquet et al., 2021). Predator-prey, plant-plant, and plant-herbivore interactions are therefore impacted by variations in water availability in many ecosystems (McCluney et al., 2011; Valeix et al., 2010, 2008). Also, it has been observed that changes in water availability have a significant impact on species interactions, particularly in dryland environments (Ferry et al., 2020; McCluney et al., 2011; Tietjen et al., 2009). For instance, research reveals that plant-plant interactions in dryland environments can change based on water availability from facilitation to competition, and the outcomes of plant-herbivore interactions can change from mutualistic to herbivorous (McCluney et al., 2011; Tietjen et al., 2009; Valeix et al., 2010, 2008). Additionally, these interactions might affect how species migrate and how their populations change (Loarie et al., 2009; Trinkel et al., 2004). Therefore, species with specific water resource adaptations, including endangered and endemic species, are in danger of going extinct.

Impact of Climate Change-Related Water Shortage on Humans

Climate and water on the planet Earth are closely linked such that any change in the climatic system causes a change in the water system (Kundzewicz, 2008). Climate change will affect the world future freshwater resources in regard to freshwater quality, availability, quality, and destructive potential. The water-related issues are brought about by climate change which impacts humans as part of the biodiversity on the planet (Agnes et al., 2021). Water shortages, or simply droughts, are a result of the relationship between basin-level water and climate change. Because it makes it harder to obtain clean water for drinking, cooking, bathing, and growing food, it has an impact on people's wellbeing. Due to this, a rising number of people worldwide do not have access to enough water (Agnes et al., 2021). According to a 2017 UN estimate, 2.2 billion people worldwide face a water deficit, and by 2025, that number is predicted to rise to 2.5 billion. The demand for water for home, industrial, agricultural, and recreational uses will increase as the human population continues to grow, placing an increasing strain on the limited freshwater sources available. Therefore, continuing climatic change is anticipated to result in more economic collapse, disease outbreaks, and other water-borne illnesses. In various regions of the world, battles over water rights for commercial exploration have been provoked by ongoing climate change. Additionally, due to water shortages brought on by climate change, nearly 2.2 billion people worldwide lack access to safe drinking water, according to UNICEF and WHO (2019).

In Sub-Saharan Africa, 400 million people lack access to drinking water as a result of climate change (Kummu et al., 2016). In addition, over 50% of the world's population now spends at least one month of the year in areas that may lack access to clean water. This number is anticipated to rise to 5.7 billion from 4.8 billion by 2050 (Burek et al., 2016). According to the United Nations' Sustainable

Article DOI: https://doi.org/10.37284/eajenr.6.1.1063

Development Goals (SDGs), water shortages have a negative impact on food security, water quality, sanitation, and educational prospects for those with low incomes (Hou et al., 2021). In general, crop productivity, food security, and a variety of economic activities are all jeopardized by water shortages caused by climate change.

CONCLUSION AND RECOMMENDATION

Global warming due to climate change is expected to make water shortages and their severe effects, including drought, famine, and diarrhoea, worse. Both humans and biodiversity may suffer as a result of this. Rainfall harvesting, water loss reduction, intelligent water systems including irrigation, dew harvesting, runoff catching, wastewater reuse, and the use of artificial intelligence are just a few of the cutting-edge techniques that must be used to manage water shortages.

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