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Effects of Temperature Changes in Kamburu Dam Reservoir between 2000 – 2023

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Abstract

This study aimed to determine the effects of temperature changes in Kamburu dam reservoir between 2000 and 2023. Kamburu reservoir has been experiencing low volumes of water with high evaporation rates, hence affecting its hydropower output. This study primarily utilised temperature and Kamburu reservoir data, as well as field survey data collected through questionnaires. Primary data was collected using Questionnaires, checklists, and observation guides. Secondary data sources included Kengen and meteorological department annual reports. The study used simple stratified sampling. The four villages of the Kivaa sub-location were sampled into 20 households, making a total of 80 households; Kengen and meteorological stations sampled every 10 respondents to make a total of 100 respondents. Data from the questionnaires were coded and analysed using SPSS 29. The results of this research showed that the area experiences increasing temperatures of 0.044℃ every year. The research forecasted a decadal increase in temperature of 0.44℃ and a century increase of 4.4℃. The research also showed a decadal decrease in reservoir volume of 92.2M^3, translating to a century decrease of 922M^3. The research concluded that climate change has greatly affected the Kamburu reservoir volume and, subsequently, hydropower output in the Kamburu power plant. The research recommends putting rules and regulations for watershed management, greenhouse emission control, upgrading the Kamburu dam infrastructure to be climate-resilient and expanding the capacity of the dam.

Key terms: Climate change, evapotranspiration, greenhouse gases, hydropower, Kamburu catchment.

1.0 INTRODUCTION

Climate change is one of the great challenges of the 21st century. At the 21st United Nations Framework Convention on Climate Change (COP21) in Paris, socio-environmental challenges arising from the anticipated effects of global warming, such as the increased risk of droughts and flooding, were identified, and nature-based solutions for combating these effects were discussed, (Siciliano, 2023). Evapotranspiration is the sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration (Evapotranspiration and the Water Cycle, 2019).

Greenhouse gases (also known as GHGs) are gases in the earth's atmosphere that trap heat. Human activities are changing the earth's natural greenhouse effect with a dramatic increase in the release of greenhouse gases. Scientists agree greenhouse gases are the cause of global warming and climate change (National Grid, 2023). Kamburu catchment area is the study area, which is located between the border of Machakos and Embu counties and which is known for generating hydropower.

Climate change is an indisputable fact, mainly caused by human activities, especially the combustion of fossil fuels that directly result in greenhouse gas emissions. As the issues surrounding climate change have become more and more serious, most countries in the world have been gradually reducing their dependence on fossil fuels and have been seeking other cleaner energies and technologies (Fan et al., 2023). Global warming, mainly caused by greenhouse gas (GHG) emissions, is one of the most severe effects of climate change. GHG emissions continue to increase at an accelerated pace as citizens of all countries consume more fossil fuels. There is an urgent demand to decelerate the rate of GHG emissions to help ease conditions favourable for global warming (Shu et al., 2018).

In Africa, the demand for power because of population growth, rapid economic development, and urbanisation has increased over the past decade. Hydropower remains the dominant source for the increasing electricity demand for the expanding industries and service sectors in the African continent. Studies done on the effects of temperature increase on dam volume in Ghana's electricity found that two hydropower plants at Akosombo and Kpong are highly affected by temperature changes. Climate change was found to be one of the defining challenges to sustainable hydropower generation in Africa (Kabo-Bah et al., 2016).

Hydropower is one of Kenya's important energy sources. The main hydropower project in Kenya is located in the Upper Tana River basin. There has been a fluctuation in power generation due to climate change over the years. Studies done by Musyoka (2018) found that increasing temperatures have led to declining Masinga dam volume. Results from this study were useful in explaining the trend in hydropower generation in the basin. The findings show how the hydropower generation correlates to dam levels and temperature changes, which in turn is incorporated for planning of hydropower supply (Musyoka et al., 2018).

Kenyan studies on Hydropower development found that hydropower generation could significantly be undermined by climate change, especially in instances where critical resources such as water are threatened and the incidence and severity of climate extremes such as droughts and temperatures are increased (Ochieng et al., 2021). Only a few studies on the impacts of climate change on hydropower reservoirs have been published (David et al., 2024). This is because the surface area covered by hydropower reservoirs is low globally (Hunt et al., 2020). No research has been conducted on how Kamburu Dam has been affected by temperature change for the past years or since its establishment. This research, therefore, sought to examine the effects of temperature changes in the Kamburu dam reservoir between the years 2000 and 2023.

2.0 LITERATURE REVIEW

Climate change is one of the world's greatest challenges of the 21st century; there is an agreement in the scientific community that the world is turning to get warmer in the future, and the average weather patterns are expected to take major shifts (Godbole, 2014). High concentrations of greenhouse gases resulting from human carbon dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O) have increased over the last few centuries since the 21st century has contributed to the high concentration of greenhouse gases in the atmosphere adding more gases as a result of human activities and further influencing directly climate change (Obiero, 2014).

Greenhouse gas (GHG) contractions in the atmosphere are a primary driver of climate change. There have been many efforts put in place to eliminate climate change effects, such as the reduction of GHG emissions. These efforts can be traced back to the United Nations Framework Convention on Climate Change (UNFCCC) (UNDP, 2017). As man continues to harness the existing surface resources through the creation of dams for hydropower generation, the extreme climate change resultant events such as floods, drought and cyclones are devastating most socioeconomic and Environmental Structures. Substantial temperature rides in the 21st century are projected because of the projected increase of greenhouse gases (GHGs). Concentration levels (Hamududu & Kihingtuelt, 2014).

Global climate change, related to greenhouse gas emissions, impacts hydroelectric power generation mainly due to the increase in air temperature and changes in precipitation patterns. Consequently, it affects the basin evapotranspiration process, runoff, sediment transport as well as evaporation of reservoirs (De et al., 2018). As a result of climate change, the intensity, duration and spatial extent of droughts are projected to significantly increase during the 21st century in Southwest Australia and some parts of Asia (Jenkins & Warren, 2014).

According to Mariola (2018), in a changing climate with a warming trend in air temperature, river water temperature increases as a result of heat exchange with the atmosphere. Moreover, of the different types of anthropogenic activity impacting rivers, the construction of dams appears to have multi-dimensional effects on the river environment, and it especially affects the thermal condition of rivers. The study aims to identify and assess the impact of these two distinct sources of water temperature distortion concerning the natural thermal conditions of rivers. In the study, linear trend analysis and a complex wavelet transform are used (Mariola & Łukasz, 2018).

Studies done by Hassan et al. (2018) established that Egypt is one of the countries facing high temperatures, and as a result, Lake Nasser is a man-made freshwater reservoir, and its evaporation losses are an important contributing factor to the lake water budget. Although no universally recognised method is known for evaporation estimation, reliable evaporation data are necessary for efficient management of the reservoir and the scarce water resources.

The catchment temperature rise is one of the main climatic variables affecting catchment water balance and vegetation (Xu et al., 2012). Therefore, increasing catchment temperature trends will, in the long life, affect the catchment's rain pattern and intensity and vegetation health and intensity. This affects the HEP generation in two ways. First, the reservoir levels decline and increased sediment loading reduces the reservoir's storage capacity, directly affecting long-term HEP generation output.

Temperature projections based on mean minimum and maximum annual temperature trends designate accrued temperature rises at 0.780C and 0.450C, respectively, in about 50 years. It is important to be alive to the fact that increased temperatures equivocally would yield greater evapotranspiration rates and diminishing surface water availability. Resultant increases in precipitation due to temperature rise may not essentially yield surplus water because evapotranspiration rates and water conservation efforts are major determinants of the water balance scenarios in specific areas, thus directly affecting water availability. This temperature rise rate in the upper catchment, coupled with declining trends of precipitation intensity, would result in a water deficit, which greatly hampers the hydroelectric output capacity of the plants, especially during dry seasons. However, the increase in temperature in the Kamburu area is an intricate phenomenon that can be accredited to both artificial and natural processes (Martin & Bunyasi, 2012).

The main resource for hydropower generation is runoff, which hugely depends on precipitation. Temperature and precipitation effects from global climate change could alter future hydrologic conditions in the upper Tana River basin (Musyoka, 2016). According to Musyoka (2016), with a focus on the seven forks, hydropower generation in Kenya is affected by changing climate with dam's low levels because of high evaporation rates. A simple approach assumes that hydropower systems will reduce generation if water volume in dams reduces because of extreme temperatures, and vice versa.

3.0 METHODOLOGY

Physical Set-Up of the Study Area

The area under study is the Kamburu dam and its surrounding area, which is found at the border of Machakos and Embu County. The Kamburu dam and its surrounding area are on the arid and semi-arid areas on the borders of Machakos and Embu counties. It lies in the extreme borders of Machakos and Embu counties. The area under study is in Kivaa ward with the following villages: Kivaa, Mukusu, Utithini,and Kamunyu (MCID, 2023). It is situated at coordinates $0.8064° S, 37.6861° E$ (KenGen, 2015). Kivaa and Machang'a are the markets near the dam (Figure 1).

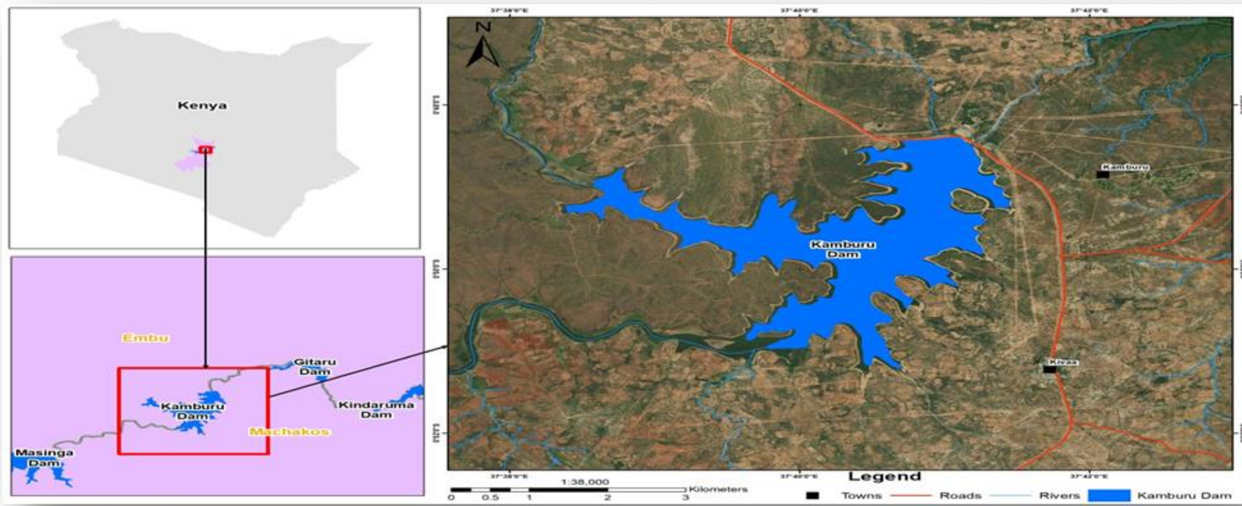

Figure 1: Map of Kamburu Reservoir and its Catchment Area
Source: GIS maps, 2025

Research Design

The research design refers to the overall strategy that one chooses to integrate the different components of the study coherently and logically, thereby ensuring you will effectively address the research problem; it constitutes the blueprint for the whole research thesis (Sovacool et al., 2018). This study has used descriptive research design to get in-depth social data from the respondents as well as get information for other studies. This design employed the following approaches: pre-field work, fieldwork, Review of relevant materials and documents, Data collection, Data analysis and interpretation.

Nature and Source of Data

Data for this study included the changes in temperature around the Kamburu dam area. Since this is the area this is the catchment area for Kamburu reservoir and Kamburu reservoir volume over the years, two types of data were collected: primary and secondary data. Primary sources of data included data on the perception of people around the dam on climate change, data collected from Meteorological officers through interviews, and resource persons from Kengen staff. Secondary data sources for this study included data from Kengen and meteorological stations, publications, annual and quarterly reports on climate and hydropower, books, journals, periodicals and existing spatial information like maps of the study area.

Target Population

The study population consisted of KENGEN, meteorological staff and household people living near the Kamburu dam. This provided the information needed to meet the study objectives. The Kamburu dam area has an estimated population of 13,539(KNBS, 2019).

Sample Size

The sample size was determined using the recommended formula by (Nassiuma et al., 2021) as follows;

$$n = \frac{NCv^2}{(Cv^2 + (N-1)e^2)}$$

Where n=sample size

N=population (13,341)

Cv=Coefficient of variation (take 0.5)

e=Tolerance of the desired level of confidence, take 0.05 per cent at 95 per cent confidence level.

Based on the above formula, my sample size was 99.3, rounded off to 100 persons. The study, therefore, gathered field data from 80 households and 20 from relevant institutions (KENGEN and meteorological stations).

Methods and Tools of Data Analysis and Presentation

This research used both qualitative descriptive and quantitative methods to analyse the information, which was collected from the field and respondents. Quantitative techniques were used by coding the data. The questions were coded and entered into a statistical package for social sciences software (SPSS) IBM version 31. The data was then presented using bar graphs, line graphs, pie charts, frequency tables and percentages.

Sampling Techniques and Procedures

This research study employed both purposive and stratified random sampling to collect the desirable and valid data for the study. Purposive sampling represents a group of different non-probability sampling techniques (Mugenda & Mugenda, 2013). This sampling is also called judgmental, selective or subjective sampling; purposive sampling relies on the judgement of the researcher when it comes to selecting the units (e.g. people, cases/organisations, events, pieces of data) that are to be studied(Mwendwa, 2014). The table below shows the sample distribution;

Table 1: Distribution of Sampled Population

SAMPLED GROUP	**SAMPLE SIZE**
Households	80
KENGEN officers	10
Meteorological officers	10

Source: Author 2025

This sampling method enabled the researcher to focus on particular characteristics of the population that are of interest. The researcher selected respondents based on the age factor, experience with the climate of the area and hydropower, as well as the number of years the respondent has lived in the Kamburu catchment area. This purposive sampling was done based on the researcher's judgements on the interest of data to be collected.

Data Analysis and Interpretations

Temperature data of the study area was obtained from the Kenya Meteorological Department (KMD) situated at Embu. The data acquired include temperature records for the years between 2000-2023 periods, making a total of 24-year study period. Kamburu reservoir levels and power output for the years were acquired from Kenya's electricity generating company (KenGen). Data on soils, land use and topography was downloaded from the World Resource Institute (WRI) and the County government of Machakos (2023).

4.0 RESULTS AND DISCUSSION

Temperature and Precipitation Trends from 2000 to 2023

Specific climate change indicators and their effects on hydropower output based on the Kamburu dam reservoir have been summarised in the subthemes tables and graphs below. The tables represent the catchment's average maximum, minimum, and mean annual temperatures in degrees Celsius. Rainfall and temperature trend analysis was carried out through the acquisition of rainfall and temperature data for the period running from the year 2000 to 2023 across several areas in the study area. For the temperature, minimum, maximum, mean monthly and mean yearly temperatures were calculated and plotted against time, and the resulting trend was observed and analysed. The mean monthly and yearly precipitation data collected at several rainfall stations in the study area were plotted against time, and the precipitation trend was analysed. The trends in precipitation and temperature were used as indicators of climate change in the Kamburu dam area.

The study established that the area has been highly hit by the effects of climate change. Most respondents in the study area (80%) have the perception that there has been climate change in the area (Table 2)

Table 2: Climate Change Perception of the People

VIEW OF CLIMATE CHANGE	PERCENTAGE RESPONSE
YES	80
NO	08
DON'T KNOW	05
NO RESPONSE	07

Source: *Field survey 2025*

The residents acknowledged that the area's climate is so different from the one that used to be there a long time ago. About 8 per cent of the respondents said the climate has not changed, 7 per cent of the respondents said that they don't know if the climate has changed or not, and 5 per cent of the respondents did not give a response (Table 2). Similarly, studies done by Rankoana (2018) about the perception of climate change revealed a general perception of changes in temperature and rainfall over the past 24 years, with negative consequences on the community's indigenous livelihood resources and that climate change has slowly been encroaching. The findings also concur with Wasti et al. (2022), who observed that climate change has been there and that the impact of climate change on the hydropower sector is difficult to predict and not globally uniform.

Temperature Trends in Kamburu

The study examined historical temperature data, revealing the trends and modifications that have moulded the regional climate. This dataset, which contains records of daily, monthly, and annual temperature observations, is a veritable gold mine of knowledge. These recordings cover twenty-four years, which has allowed the researcher to identify long-term patterns and variances.

To acquire insights into the underlying temperature changes, the research focused on yearly mean temperatures and monthly mean temperatures. To find instances of extreme temperature events, the researcher examined the historical data and evaluated their frequency and intensity over time. The extreme temperatures were only during severe droughts like the ones witnessed in the years 2010, 2019 and 2023 (Figure 2), which could lead to water reduction, leading to a power output decrease. The data pointed out that there have been no extremes such as heat waves witnessed over time or extreme cold snaps.

The mean monthly and annual temperatures in the Kamburu dam catchment show an increasing trend. The mean maximum and minimum annual temperature trends indicate that the catchment temperatures are rising from 2000 to 2023, except in some exceptional years (Figures 2 and 3). The general atmospheric temperatures have been on the rise for almost all the years. Both mean minimum and mean maximum temperatures have been on the rise, making the area too hot and further affecting the hydrology of the catchment area. The increase in Kamburu catchment temperature is a complex phenomenon which can be attributed to both natural processes and anthropogenic activities. It is important to note the fact that increased temperatures would equally yield greater surface evaporation rates, diminishing surface water availability and water storage in the Kamburu dam, further leading to a severe change in hydropower generation operations. These findings concur with Ieda's (2020) observation that there have been many GHG emissions which have caused an increase in surface temperatures at a rate of 8.6 per cent to 10.8 per cent worldwide. Similarly, Wang et al. (2021) observed that the surface temperature of his study area in 2019 was higher than it was in 2004. This suggests that world temperatures, including those of the Kamburu area, have been rising at an alarming rate as a result of climate change.

According to Figure 2 below, the mean minimum annual temperatures record a steady increase with some exceptional years. The year 2019 recorded a high minimum temperature, while the year 2000 recorded the lowest temperatures. The graph shows a rise in minimum temperatures from the year 2000 to 2023. According to the graph trend line equation Y=0.0407x+13.76 (Figure 2), the minimum annual temperatures rise at 0.0407℃. This gives a decadal mean minimum annual temperature of 0.41℃ and, if the trend is sustained, a rise of 4.1℃ in a century. This shows that the area has been receiving very high minimum temperatures per year.

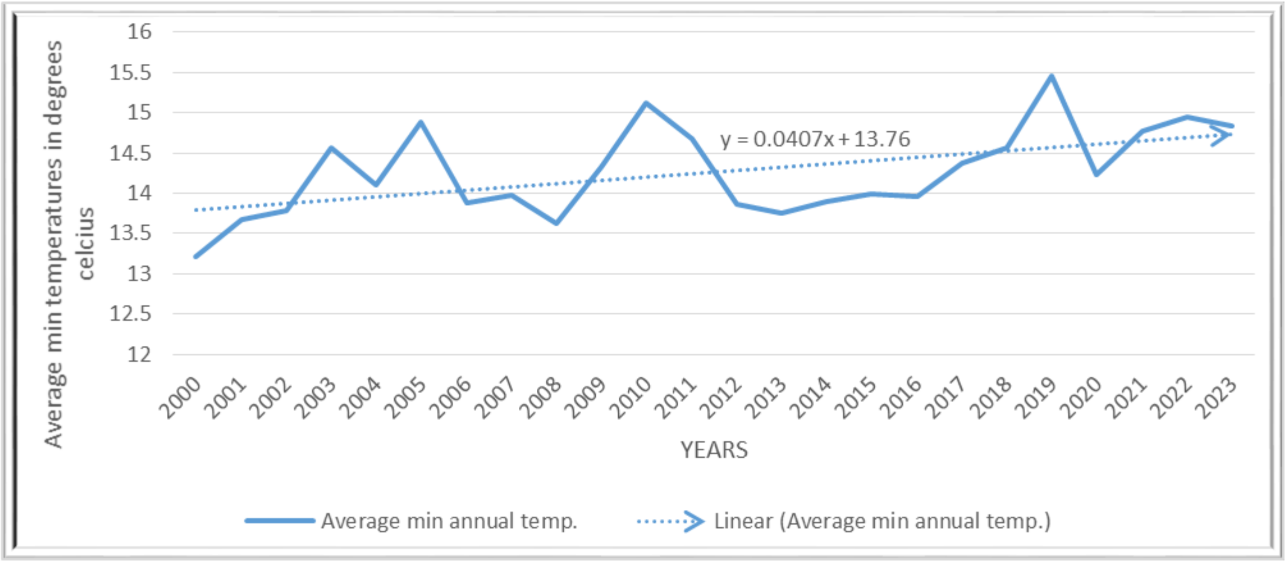

Figure 2: Mean Minimum Annual Temperatures for Kamburu Catchment
Source: *field survey 2025*

According to Figure 2 below, the Kamburu catchment mean maximum temperatures record a steady increase with some exceptional years. The years 2022 and 2023 recorded a high maximum temperature, while the years 2014 and 2016 recorded the lowest temperatures. According to the trend line of this graph, maximum mean temperatures rise steadily with a positive equation of Y=0.0305x+24.657. This gives a maximum annual rise of 0.031℃, a decadal rise of 0.31℃ and a century rise of 3.1℃. Such temperature rise is quite high and is a threat to the area's hydrology. Rising temperatures cause high evaporation rates from plants, soil and water resources. This, in turn, puts stress on Kamburu reservoir water since it evaporates at a high rate, leading to its reduction and, therefore, affecting the hydropower generation at the site.

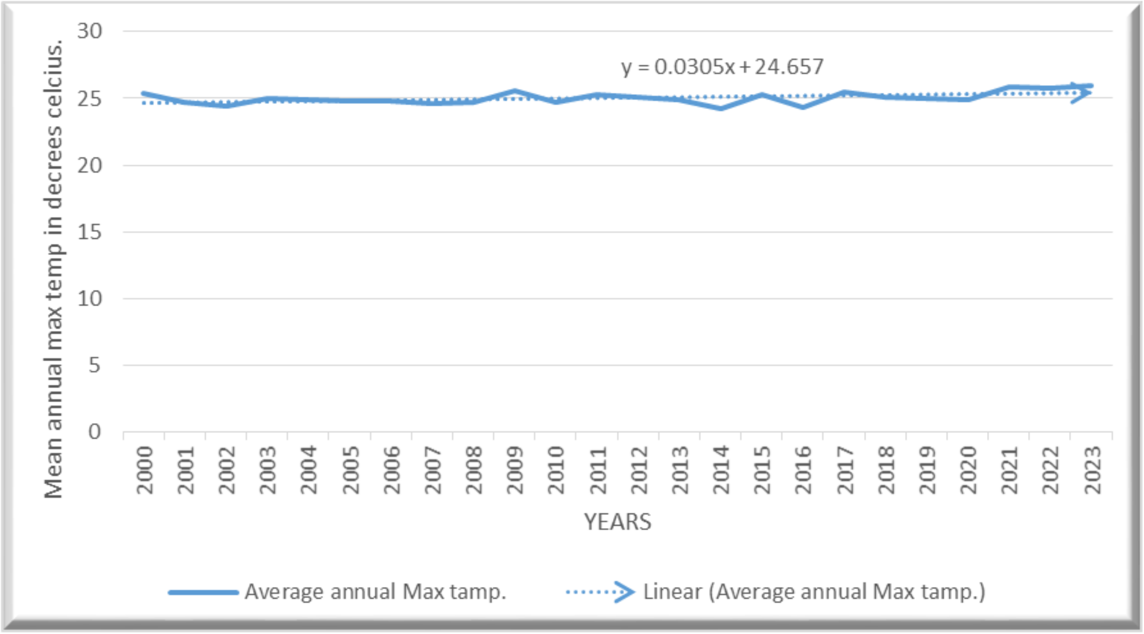

Figure 3: Mean Annual Max Temperature for Kamburu Catchment
Source: Field study 2025

Figure 4 below shows the monthly temperatures in the Kamburu catchment area. According to the data, it is clear that the area receives high monthly temperatures throughout the year except for some months within the year. The month with the highest temperatures is March, while the one with the lowest is July. The area has a temperature range of 9℃, which is high, translating to high temperature. These high temperatures spread out over a year make the annual temperatures very high, hence gross effects on water resources in the area. These high monthly temperatures ensure that the evaporation of water at the reservoirs is high throughout the year, hence leading to a decrease in water levels at the Kamburu reservoir. This effect subsequently leads to disturbance of the hydropower generation operations.

The dry period between January and March recorded the highest mean maximum temperatures over the study period (Figure 4). Since this follows a wet season, it leads to rapid depletion of water resources, thereby affecting Kamburu reservoir levels in a negative way and hydropower generation. In this area, the hottest months occur in the month of January to March, while the coldest occur in the months of June to August. The hottest month is March, with mean monthly temperatures of 30.5℃, while the coldest month is the month of July, with temperatures of 21.5℃. Increased catchment temperatures lead to changes in the water balance around the Kamburu area (Figure 4).

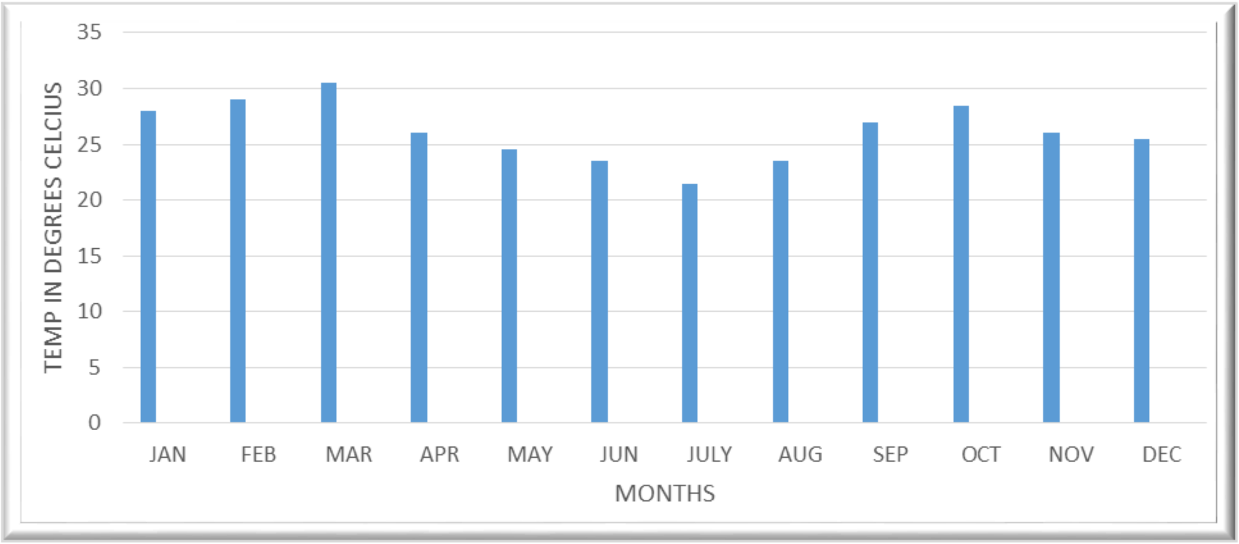

Figure 4: Mean Monthly temperatures in Kamburu catchment area
Source: Field survey, 2025

Increased temperatures will possibly lead to increased soil erosion in the catchment because the catchment area is likely to become barer because of the dry conditions brought about by the increasing temperatures. Increasing soil erosion rate will consequently result in higher reservoir sedimentation, which will, in turn, affect hydropower generation by reducing the storage capacity of the dam, thereby raising the dam's floor. It is important to note the fact that increased temperatures would equally yield greater surface evaporation rates on both the land and on water resources, diminishing surface water availability and water storage in the Kamburu dam, further leading to a severe change in hydropower generation operations in the station.

The graph below (figure 5) also indicates that, in general, temperatures have been rising steadily in the catchment area. According to the data collected from the field study, the annual mean temperatures in about 100 years will be very disturbing to the environment and water resources in general, hence a prediction of the future risk of global warming and its effects.

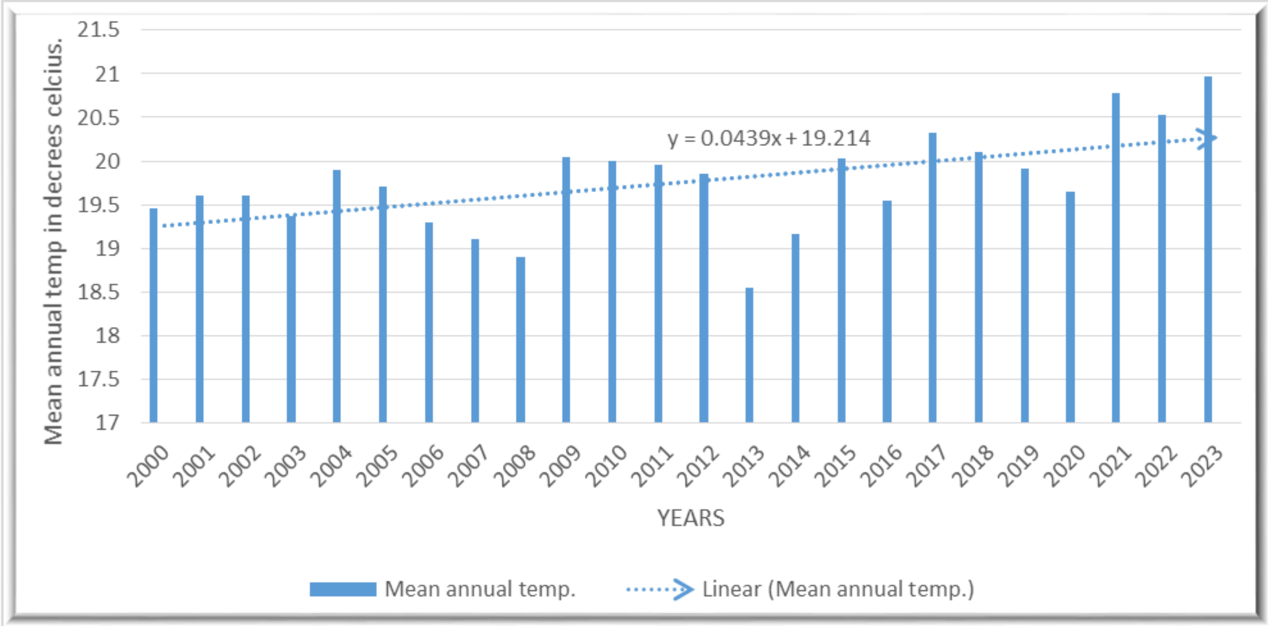

Figure 5: Mean Annual Temperature of Kamburu Catchment
Source: Field study 2025

According to Figure 5 above, the mean annual temperatures of the Kamburu catchment prove a steady rise in the period running from the year 2000 to 2023. The graph trend line has a positive equation Y=0.0439x+19.124. This records a decadal temperature rise of 0.44℃. If this trend is sustained, a 4.4℃ temperature rise will be attained in a century. This record of temperature in the future is so high, which gives a forecast of the effects of climate change and global warming effects in the future. This suggests a high risk in future water resources because of high evaporation and evapotranspiration, leading to the drying up of water bodies and vegetation cover, making areas bare. This, in turn, puts risk on the hydropower generation at Kamburu dam. These findings concur with Imbugwa (2021), who observed that global warming and climate change relate to one another with the increase in average global annual temperatures believed to be naturally caused by anthropogenic activities and that the temperatures have been on the rise leading to effects on hydropower generation systems.

Generally, most of the respondents in the study area felt that the temperatures in the study area have been increasing steadily over the years. Some of the elderly people in the area confirmed that the temperature is incomparable with the temperatures which were there around 25 years ago. This confirms that the climate has been changing over time, with the greenhouse effect. According to Figure 6 below, about 78 per cent of the respondents from the study area said that the temperatures are too high in recent days compared with years ago, while 17 per cent of the respondents said that the area temperatures have been moderate. Further, 5 per cent of the respondents said that the temperatures in the area are low.

Similarly, Kiprotich et al. (2015) findings indicated that 60.38 per cent of the respondents observed that the temperatures in the Kamburu region had increased and it was much hotter, while only 28.30 per cent of the respondents, on the other hand, had asserted that the temperatures were much cooler. Further, 11.32

per cent of the respondents had the perception that the temperatures had not changed much and had stayed the same.

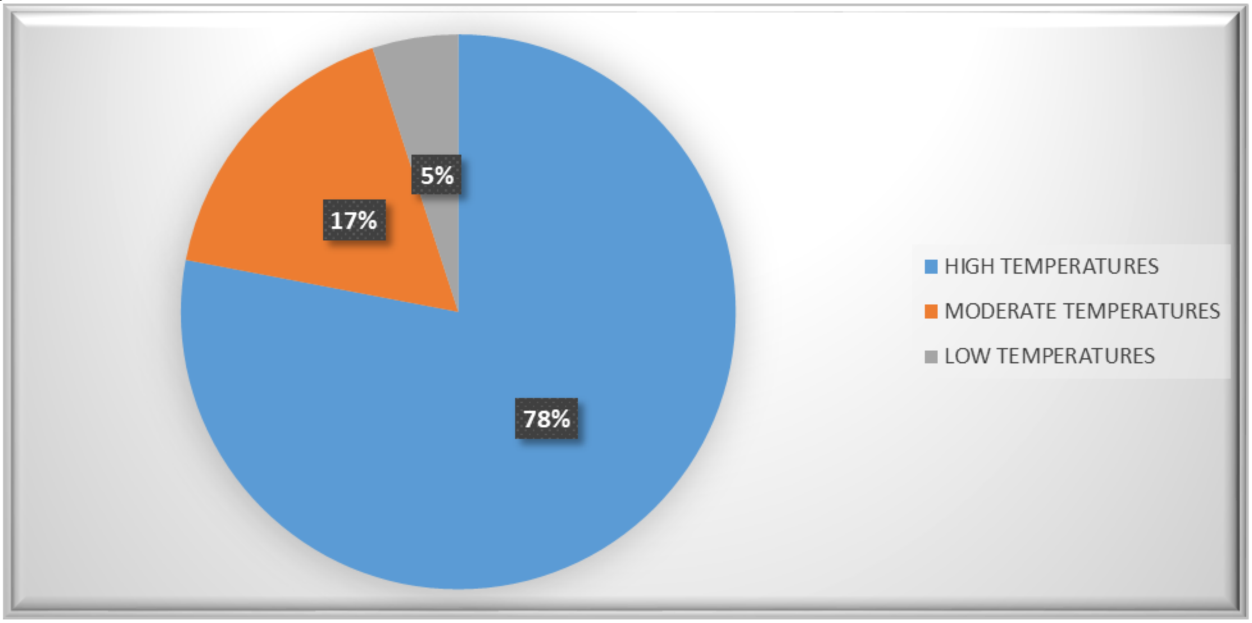

Figure 6: Respondents Perception of the Temperatures in the Area
Source: Field survey 2025

The temperature increase in the Kamburu catchment affects the reservoir inflows and levels through increased evaporation, low precipitation, season shift, and some other times frequency of occurrence of extreme weather events like floods and droughts and biodiversity imbalance. Increasing catchment temperature trend lines conform to global warming effects, which occur as a result of climate change. The results concur with Zahra et al. (2022), who established that high temperatures caused by climate change in many parts of the world have been causing huge evaporations in hydropower reservoirs, affecting the reservoir water levels. Similarly, studies also done by Emad (2017) found that, in particular, Global warming and higher temperatures would lead to higher evaporation rates. This, in turn, will result in less water availability at High Aswan Dam Reservoir (HADR), and the prediction for the evaporation rates for the last 30 years will be approximately 3 per cent to 10 per cent higher by the year 2100.

The dry periods between January and March and July and August have recorded the highest mean maximum temperatures over the years. Since this follows a wet season, it leads to rapid depletion of water resources, thereby affecting Kamburu reservoir levels and further affecting hydropower generation operations. Increased catchment temperatures lead to changes in the water balance.

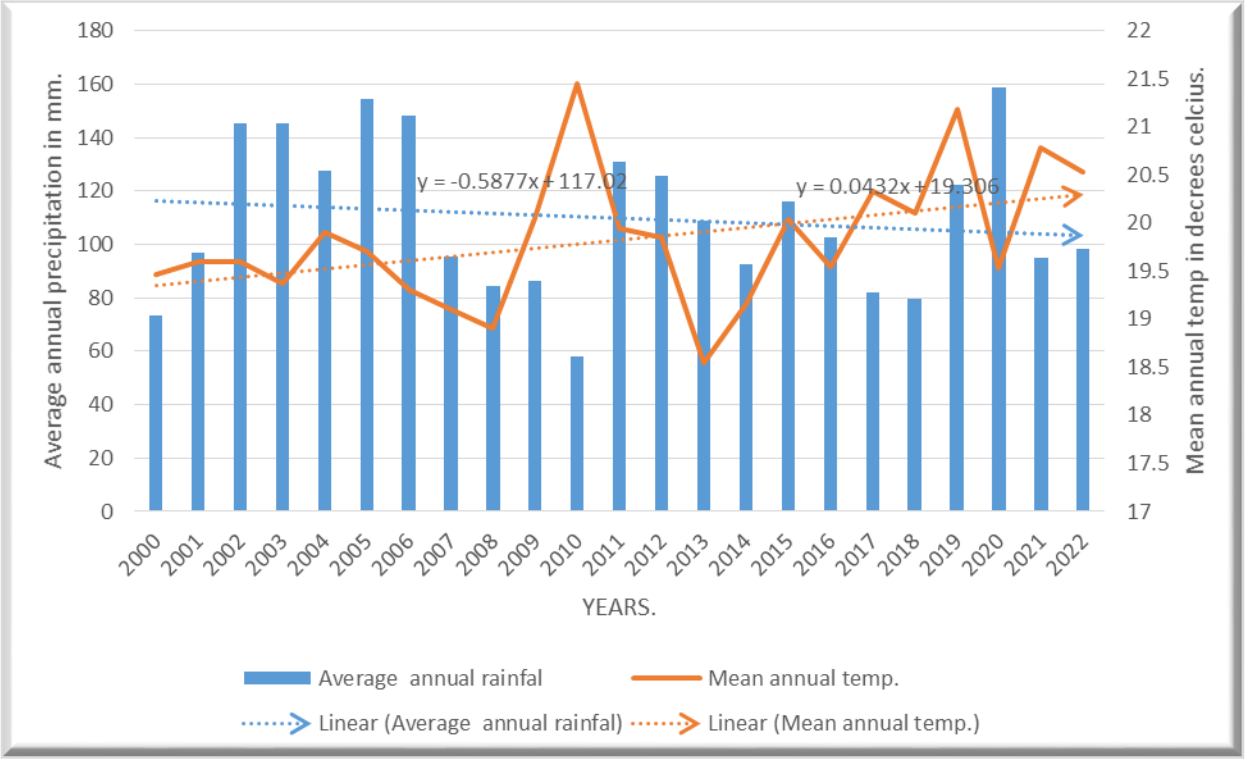

Figure 7: Average temperature and precipitation of Kamburu catchment area
Source: *field survey 2025*

According to Figure 7 above, there is a high interplay relationship between the amount of rainfall received and the temperatures received in the Kamburu catchment area. The two main indicators of climate change, which are precipitation and temperature, show that the area is experiencing extreme changes in weather patterns. The rainfall amounts are decreasing at an alarming rate, as shown by the graph trend line equation Y=-0.5877x+117.02. This negative trend line depicts that the rains have been decreasing over time, with a decadal decrease of 5.9mm of rain and further a long-term forecast of 58.8mm of rainfall in 100 years in future if the trend is maintained. These findings concur with Mainuddin et al. (2022), who established that the temperatures have been on the rise in Bangladesh, which consequently causes a decline in the amount of rainfall received in that area.

The temperatures in the catchment area are increasing at a worrying rate. This is depicted by the graph temperatures trend line with a positive equation of Y=0.0432x+19.306. This records a decadal temperature of 0.4℃ and, further, a rise of 4.3℃ in the next 100 years to come if the rising trend is maintained. The catchment of the study area is highly affected by climate change, with highly reducing rainfall amounts every year and sharp rising temperatures every year. These two aspects have great effects on the hydrology of the area, as the water systems of the area are reducing as a result of reduced rains as well as high evaporation rate diminishing the water resources in the area. This further poses a big challenge to hydropower production in the Kamburu dam as the waters in the reservoir are highly diminishing.

Causes of High Temperatures in Kamburu

The increase in Kamburu catchment temperature is a complex phenomenon, which can be attributed to both natural processes and anthropogenic activities. The household people near the dam confirmed through their responses that human activities have largely contributed to the high temperature. The area people are low-income earners and, therefore, do local income activities. The majority of them confirmed to be cutting down trees for charcoal selling and firewood. Others carry out subsistence crops growing near the dam, which leads to the application of agrochemicals to increase agricultural productivity. These findings concur with Asheem (2018), who found that global temperatures are largely caused by anthropogenic activities.

According to Figure 4.8 below, 60 per cent cut down trees for firewood and charcoal burning, 12 per cent burn fossil fuels, 18 per cent use agrochemicals, 10 per cent are confirmed to be attributed to natural causes and 10 per cent others (Figure 8). This leads to an increase of greenhouse gases in the atmosphere, which in turn raises the atmospheric gases.

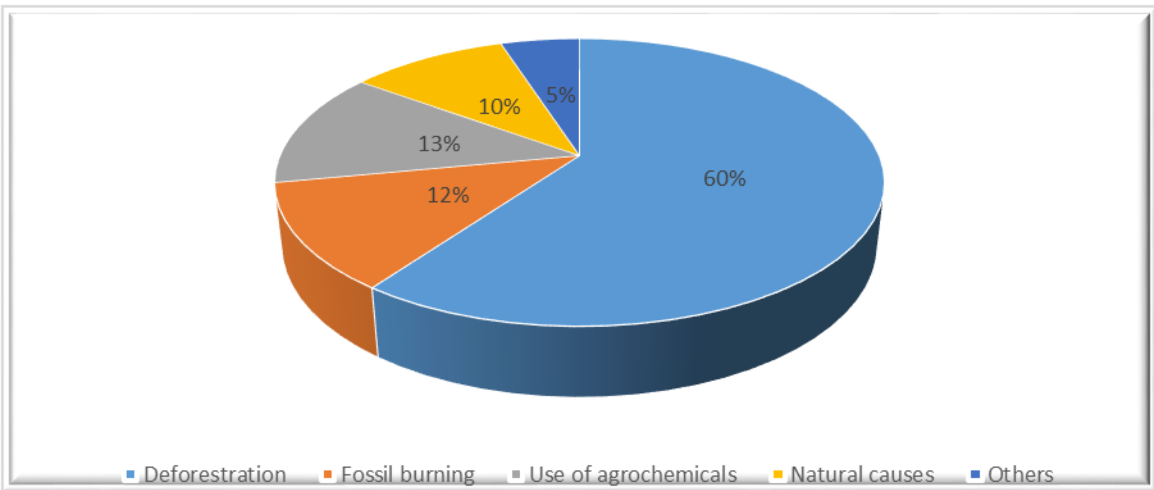

Figure 8: Causes of High Temperature in the Kamburu Catchment Area

Source: field survey 2025

From Figure 8 above, deforestation is the leading human activity, followed by the use of agrochemicals as the leading cause of climate change. This confirms that deforestation as a human activity is very rampant in the area and which is the main human cause of climate change. Cutting down trees has been a result of the need for charcoal for fuel and firewood, the need for land for settlement and put under agriculture and the increasing population in the area. The high temperatures in the region have caused high evaporation of water resources, leading to a decrease in Kamburu dam water levels. These findings concur with Hegerl et al. (2018), who observed that the global temperature rise in the recent past is a result of both human activities (burning of fossils, deforestation, use of agrochemicals) and external forcing (volcanic, solar, greenhouse gases, tropospheric aerosols), changes in clouds, or ocean heat release) which has led to thermal heating and consequently affects climate change

Summary of Findings

The study found that temperatures in the Kamburu catchment area have been rising at an alarming rate as a result of global warming. A high percentage of people living around confirmed that the temperatures have been increasing. The temperatures have been affecting Kamburu dam reservoir levels. The volumes of this reservoir have been declining, with the main factor being evaporation. Reduced reservoir volumes have led to further reduced generation of hydropower in this power plant. Suggestions were given to plant more trees around the dam to assist in thermal regulation as well as wise control of the usage of reservoir water. The study confirmed that the Kamburu reservoir volume had been affected by increasing temperatures, which consequently caused the decline in hydropower generation.

5.0 CONCLUSION AND RECOMMENDATION

Conclusion: Hydropower development could be significantly undermined by climate change, especially where critical resources such as water are threatened and the incidence and severity of climate extremes. The Kamburu dam hydropower plant, which is situated at the section of Tana River and which is fed by other streams, both permanent and seasonal, from the catchment area, is very vulnerable. Data from the Kamburu catchment has shown an increasing trend of temperature for the past 24 years. The minimum temperature has recorded an increase of 0.041℃ every year, with a decadal increase of 0.41℃ and an increase of 4.1℃ for 100 years to come if the tread is sustained. The area has recorded a positive increase in maximum temperatures. The general temperatures at Kamburu catchment have been rising at a worrying rate. The high evaporation rate, coupled with dryness and droughts, has caused the dam to be vulnerable and fail to perform its core production to its optimum. Kamburu reservoir volume has had a decreasing curve, suggesting that the volume levels have been going down for the past 24 years except for some years of variability. This decline in volume is so high and puts the Kamburu dam at high risk in hydropower production. The major ways that the area people believe are the solutions to increase or sustain water volume in the Kamburu reservoir include Planting many trees and forests, recycling water used in running turbines, and desiltation of the dam, among other ways. According to data collected from the Kengen offices, the Kamburu power plant has recorded a decrease in power output for the past 24 years. There is a strong correlation between precipitation and temperature trends, stream flow, dam levels and hydropower generation from the Kamburu power plant and its environments.

Recommendations: Reforestation and afforestation: The local people around the Kamburu reservoir should be encouraged to plant native trees in the neighbourhood to lessen soil erosion and fight deforestation. Kengen Company should carry out Watershed Management to sustain the available dam's water and protect the dam's water source. The county government of Machakos, together with national climate change agencies, should conduct workshops and public awareness campaigns on climate change to inform the Kamburu residents of its causes and implications. This should go along with Educating them on eco-friendly methods to give them power other than reliance on deforestation methods. Kamburu area residents should consider practising Sustainable Agriculture, which is environmentally friendly agriculture by practising organic farming, crop rotation, and agroforestry and abandoning the use of agrochemicals, which to some extent leads to climate change. The county government of Machakos should prioritise Protecting and restoring natural habitats close to the Kamburu dam to preserve biodiversity, which is essential for an ecosystem's resilience. The county government of Machakos should enact laws and Regulations that support sustainable land and water management around the Kamburu reservoir. The researcher after examining all the findings of the research, some gaps were identified, which were proposed as suggestions for further research to research the effects of siltation on hydropower generation in Kamburu Dam and more research on assessing if water can be recycled on dams after generating HEP for sustainability.

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