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Enhancing Adaptation and Mitigation Measures to Impacts of Climate Change on Natural Resources in Pwaga Village, Mpwapwa District, Dodoma Region, Tanzania

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Abstract:

Climate change poses significant threats to human livelihoods, with rural farming communities being among the most vulnerable due to their reliance on agriculture and natural resources. The severity of these impacts largely depends on farmers' awareness and their capacity to adopt appropriate adaptation strategies. Notably, extreme temperatures and rainfall brought on by climate change have disproportionately affected Tanzania's rural areas, posing hazards to their ability to live, work, and feed their populations. Although Tanzanian rural populations rely heavily on natural resources, the effects of climate change on these resources are poorly documented in these locations. The objective of this study was to assess the impacts of climate change on natural resources and develop the enhancement measures for better adaptation and mitigation in Pwaga village, Mpwapwa District, Dodoma Region, Tanzania. Data were collected through document review, physical observations, interviews, and focus group discussions. The study revealed that there is a significant climatic shift and its consequential impacts on natural resources over the past years. Climate change has increased competition for natural resources due to limited access, availability, and affordability. Hence, the study recommends the increasing use of renewable energy sources, intensification of awareness programs, afforestation, agroforestry, installation of rainwater harvesting systems, and proper waste management.

Keywords: Drought, Rainfall, Resilience, Temperature.

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1. Introduction

Climate change is a pressing global challenge that transcends borders and affects diverse regions in unique ways (Yeh *et al*., 2020; Adaptation Without Borders, 2021). Over the past decade, the climate has undergone significant transformations due to human activities such as burning fossil fuels and deforestation (Abbass et al., 2022). Also, industrial processes and agricultural intensifications have been among the factors and this is due to an increased concentration of greenhouse gases such as carbon dioxide (CO_2), Methane (CH_4), and Nitrous oxide (NO_2) and the fluorinated greenhouse gases such as perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and Nitrogen trifluoride (NF_3) (Ritchie *et al*., 2023; New York State DEC, 2023).

According to the World Health Organization (2023), climate-related challenges include prolonged droughts, erratic rainfall, an increase in the frequency and intensity of extreme weather events, and wildfires. These challenges contribute to food insecurity, loss of biodiversity, increased vulnerability to diseases, natural resource degradation, income inequality, malnutrition, and compounding injustices (Mirzabaev *et al*., 2022; O'Neill *et al*., 2022) as they affect resources that our livelihood depends on, such as water, energy, transportation, wildlife, agro ecosystem, and human health. Additionally, the heightened frequency and intensity of extreme weather events further contribute to the vulnerability of conflicts within communities, damaging infrastructure, and displacing populations (IMF, 2023).

Climate change has profound implications for food security across Africa, with impacts varying across regions and socio-economic settings (Bedeke *et al*., 2023). In sub-Saharan Africa, shifting rainfall patterns often lead to droughts or floods, both of which threaten agricultural production and contribute to widespread food insecurity. Prolonged droughts in East Africa, for example, have been associated with reduced crop yields and livestock losses, while rising temperatures across the Sahel intensify water scarcity, soil degradation, and heat stress on crops and animals (Yeboah, 2024).

Extreme weather events, such as cyclones, further compound these challenges, particularly in coastal regions where storms can wipe out crops, infrastructure, and livelihoods, as seen with Cyclone Idai in 2019, which devastated Mozambique, Zimbabwe, and Malawi (Charrua *et al*., 2021). The vulnerability is greatest among smallholder farmers who depend on rain-fed agriculture and lack access to resources, technology, and financial support needed for adaptation. In contrast, large-scale commercial farms are relatively more resilient, as they often have the means to invest in irrigation, insurance, and other adaptive measures to mitigate climate-related risks (Yeboah, 2024).

In Mpwapwa District, located in the Dodoma Region, central part of Tanzania, climate change has manifested in several ways, thus impacting the area's environmental and weather patterns (Myeya, 2021). Erratic rainfall, water scarcity, and prolonged drought have become more prevalent, posing substantial challenges to the agricultural sector, which is a vital component of the Dodoma rural economy (Gillo et al., 2017). Farmers face difficulties in crop cultivation due to changing precipitation patterns that disrupt traditional planting and harvesting seasons. This leads to increasing pests, diseases, food costs, and malnutrition, impacting millions of smallholder farmers who depend on rain-fed agriculture (Hussein et al., 2024). The scarcity of water resources also hampers livestock management, affecting the pastoralist way of life prevalent in the village. This is because major rivers have become increasingly unpredictable (Palmer et al., 2023; Opere et al., 2019). Overall, this situation is intensified by the community's high dependence on irrigation- and rainfall-fed agriculture, which is alarming and underscores the need for adaptation measures crucial for sustaining livelihoods and ensuring food security in the locality.

The Pwaga village faces increased economic stress as the changing climate disrupts traditional income sources, making it challenging for residents to adapt (O'Neill et al., 2022). Addressing the impacts of climate change in the village's ecology requires a multifaceted approach that combines sustainable agricultural practices, water management strategies, and community resilience initiatives (IFAD, 2017). Since fewer studies have been conducted on this aspect in Tanzania, this study intends to assess the climate change adaptation and mitigation measures on Pwaga village ecology and to provide enhancement measures to address the problem of climate change.

2. Methods

2.1. Case study selection

Pwaga village is found within Lumuma ward in Mpwapwa District, being one of the seven districts of the Dodoma Region in Tanzania. According to the 2022 census, Lumuma ward had a population of 4,339 people, of whom 2,138 were male, and 2,201 were female. The village is bordered by Itende to the north, Kitati to the east, Mgoma to the south, and Kidenge to the west (Figure 1).

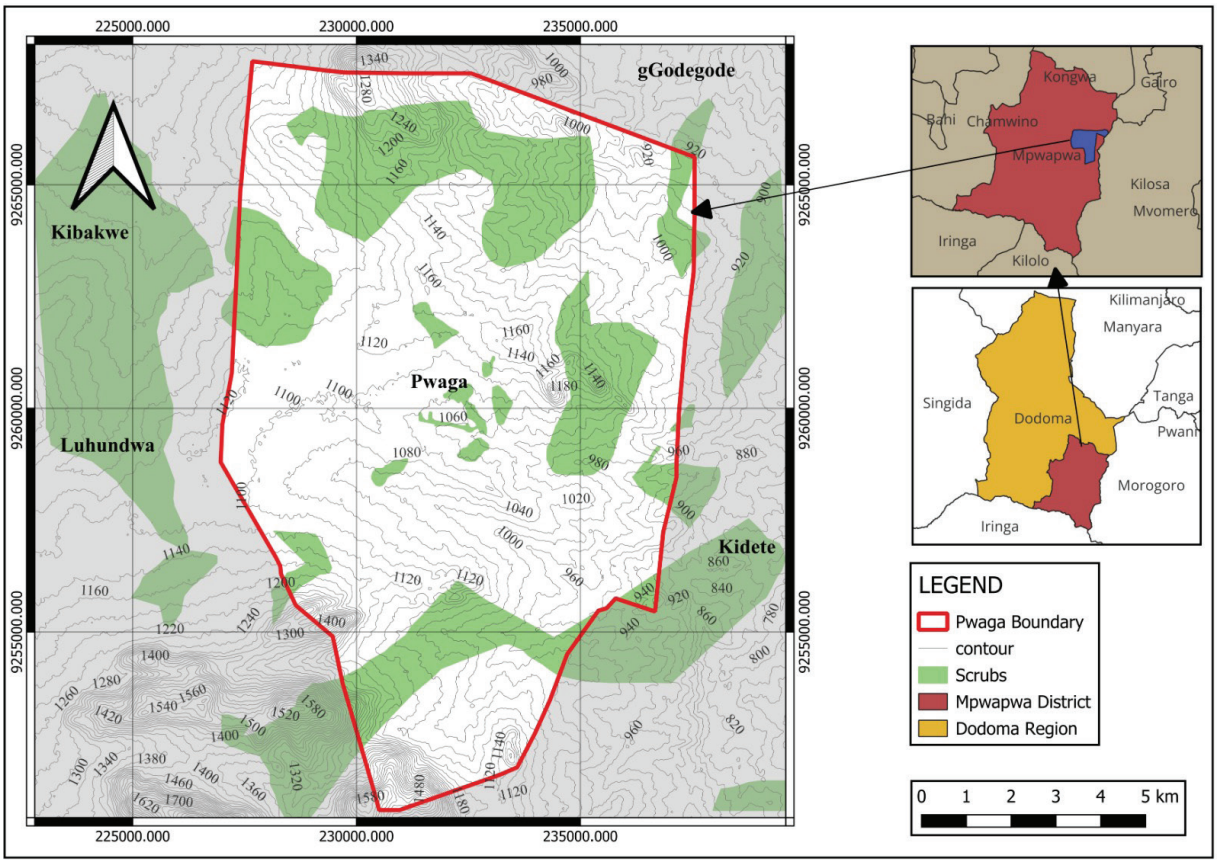


Figure 1: Pwaga village-Case study area

Due to its geographical position, and accelerating changes in climate, the village is characterized by i) Semi-arid area with prolonged dry seasons ii) Reduced availability, accessibility, and affordability of natural resources useful to human daily life activities such as water, forests which are affected by climate changes iii) Potential impacts due to existing climatic conditions inclined with natural resources present in the area. These key features contributed to the study's interest in exploring further how the population in this village adapts to and mitigates climate change impacts

2.2. Data collection and analysis methods

The study was conducted from March 2024 to August 2025. Both primary and secondary data were collected in this study. The primary data were collected using interviews, questionnaires, and physical observation; the secondary data were collected through document review. A total of 50 respondents were randomly sampled and were administered a questionnaire. Based on the willingness to participate in the study, the most knowledgeable person in the household was preferred for the interview. The respondents were selected to cover the whole village, in which 49% were male, and 51% were female. The dominant education status was primary level. Also, 55% of the respondents were elderly, while 45% were youth. The study used meteorological data collected from the Tanzania Meteorological Agency (TMA). The data were the maximum and minimum monthly temperature and rainfall data from 1993 to 2024. This study used a remote sensing satellite, Worldview, to assess the spatial and temporal variation of vegetation cover in the village from 2013 to 2024. Each vegetation cover was digitized to get polygons. The areas were automatically generated

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by the ArcGIS 10.3.1 software. Also, the study used the Checklist, Semi-Automatic Plugin, ArcGIS, and the Mann-Kendall test as tools for data analysis. To assess statistical significance, the Mann-Kendall test was used to examine trends in the recorded annual precipitation at Pwaga village in Mpwapwa District.

3. Results and Discussion

3.1. Rainfall and temperature trends for the past 30 years

3.1.1. Rainfall trends

The annual total rainfall trends that were recorded for the past 30 years (1993 to 2024) are presented in Figure 2. The analysis demonstrates that annual total rainfall data for the Mpwapwa District have a significant variability. In addition to increasing tendencies in certain years, rainfall patterns have also indicated diminishing trends in other years. The fluctuations are similar to the worldwide occurrences of warm and cold episodes.

According to a study conducted by Myeya (2021) in the districts of Bahi and Mpwapwa in the Dodoma region, rainfall data analysis using the Mann-Kendall test revealed insignificant decreasing trends ($p = 0.532$ and $p = 0.473$) for the two stations for the 1961–2013 period. With a slope of 1.673 mm y^{-1}, the rainfall decline for Mpwapwa station indicates a 2.5% decrease in variance over the study period, while the decline for Bahi station indicates a 3.7% decrease in variance between 1961 and 2013.

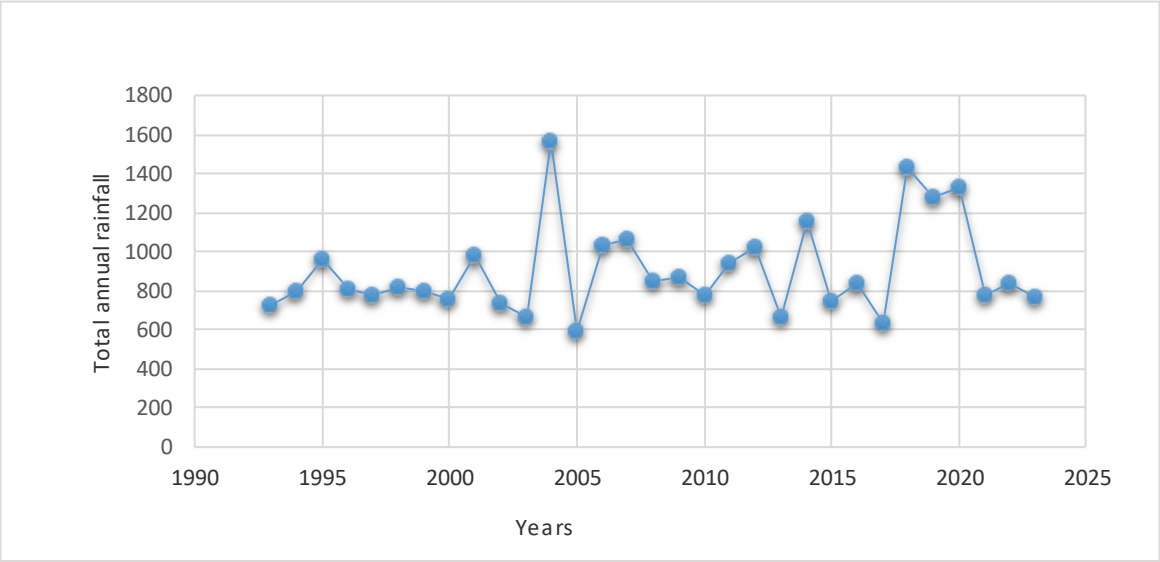


Figure 2: Temporal distribution of total annual rainfall (1993-2023)

3.1.2. Temperature trends

Temperature measurements were recorded and analyzed into two categories: the mean annual minimum temperature (to represent the average lowest temperature readings recorded in each month) and the mean annual maximum temperature (to represent the average highest temperature readings recorded in each month) for the past years.

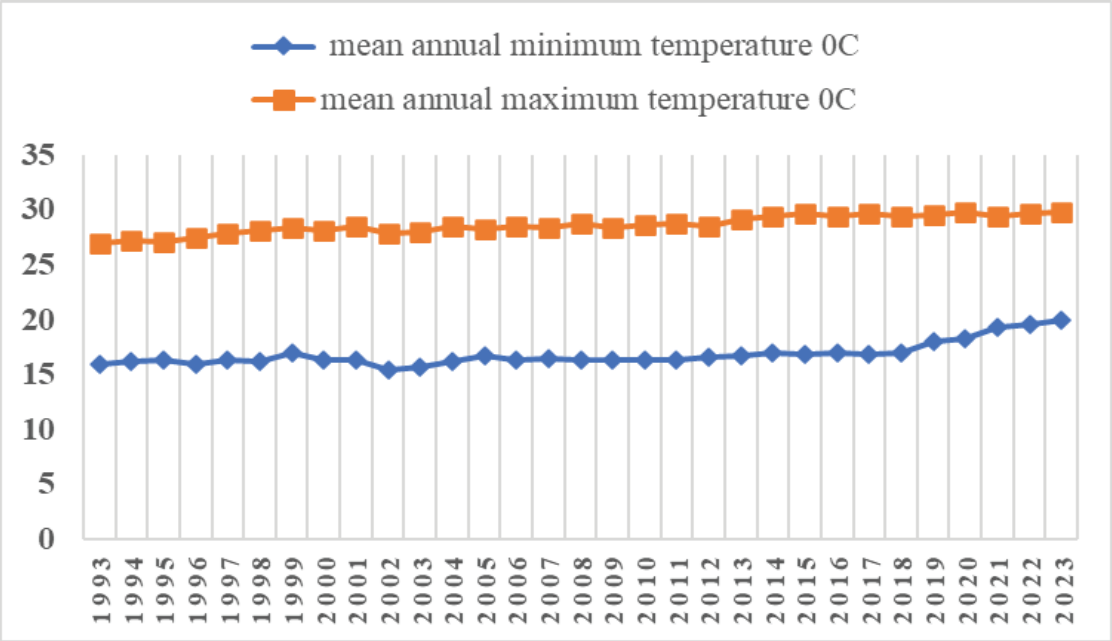


Figure 3: Temporal distribution of mean annual maximum and minimum temperatures

Also, analysis using the Mann-Kendall test reveals an increase in both the mean annual minimum and mean annual maximum temperatures. Both p-values for the mean annual minimum and maximum temperatures (P = 4.24E-3 and P = 8.23E-3) respectively are less than the 0.05 significance level, indicating a statistically significant increasing trend in temperature. Study done by Myeya (2021) in Bahi and Mpwapwa Districts reported that, the increased values for both the mean annual minimum and maximum temperature with the fitted linear trends in the minimum temperature (T_{min}) and maximum temperature (T_{max}) are statistically significant at the 0.05 level of significance (p = 0.000, p = 0.001) respectively. Based on these results, it was noted that over the past 53 years (1961- 2013), the minimum temperature in the Dodoma region has increased more rapidly than the maximum temperature. This had an implication on the increase in hot days as compared to cold ones.

On Climate change awareness, 20% of respondents were aware of climate change and its effects, while 54% of the respondents had moderate knowledge of climate change, and 26% responded with minimal knowledge of climate change and its effects on the environment. This is caused by a lack of education, traditional beliefs, and practices overshadowing scientific explanations, making it harder to change the behaviors and attitudes of some of the villagers toward climate change. Therefore, climate education is crucial for enabling informed decision-making and fostering sustainable development (UNESCO, 2017).

3.2. Climate change impacts on natural resources

The insignificant decrease in rainfall trends and increase in temperature in the region have impacted the natural resources in terms of availability, accessibility, and affordability. This has been discussed depending on the degree to which the village is susceptible to or unable to cope with the impacts of climate change.

3.2.1. Water usage

The dominant water source in the village is a borehole that depends on rainfall to recharge, which brings about a great challenge of less water availability in the village. Most of the villagers, about 74% uses less than 20 L/person/day of water, 22% uses 20 L/person/day to 40 L/person/day, and 4% uses more than 40 L/person/day for household activities. These results show that most people use less water than the World Health Organization (WHO) recommendations, which is a minimum of 50 L/person/day. This indicates an increased risk of waterborne diseases and other health issues to vulnerable groups such as children, women, the elderly, and those with pre-existing health conditions. The situation may be worse in the

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future due to the decreasing trend of rainfall and increasing temperature in the area, leading to water shortage.

Residents of Pwaga village have been subjected to traveling a long distance of about 5 km to 9 km during the rainy season and the prolonged dry season, respectively, to fetch water from the river using power tillers and bicycles to carry the gallons and barrels. The river is a permanent one connected with the Wami Ruvu basin, thus supplying water annually. Villagers spend a lot of time fetching water, which indicates time and productivity loss since the substantial time spent on water collection reduces time available for education, work, and other productive activities. The United Nations Development Program (UNDP) states that "inequitable access to water resources exacerbates social and economic inequalities within communities" (UNDP, 2016).

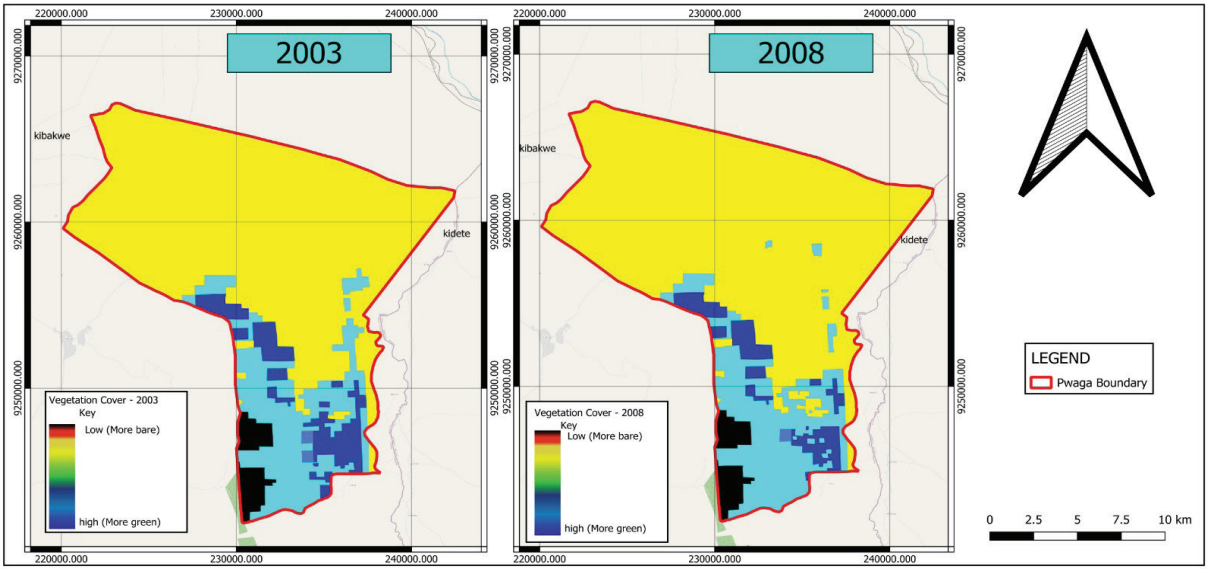
There has been an increase in the cost of buying resources, especially clean water, due to difficulty in accessibility and availability. This brings about a burden in households since it subjects poor families to reduced spending on other essential needs such as food, healthcare, and education. Also, as water becomes expensive, households have reduced their consumption, compromising hygiene and sanitation practices. A report from the United Nations Environment Program (2013) highlights that companies face increased operational costs due to rising water charges caused by scarcity. Also, the World Health Organization reported that access to affordable water is crucial for maintaining public health, and rising costs can lead to negative outcomes, specifically on health concerns (WHO, 2023), and the Sustainable Development Goals (SDGs), specifically SDG 6.1, aim to ensure universal and equitable access to safe and affordable drinking water for all by 2030.

3.2.2. Vegetation cover changes

For the past 30 years, 16% of the Pwaga village land cover (square kilometers) was vegetation. The geospatial analysis for the past 20 years over a range of five years shows a decrease in vegetation cover, causing barren land. The trend is similar to rainfall characteristics in the area. However, these changes are influenced by non-climatic factors, such as deforestation, and climatic factors, such as extreme weather events, such as prolonged drought conditions that suppress the forest growth. Table 1 shows the percentage change of vegetation cover from 2003 to 2023 within Pwaga village, associated with community reliance on fuelwood and charcoal as the primary fuel source for domestic activities, as well as increased temperature and erratic rainfalls that are suppressing forest or vegetation growth. Different maps are presented in Figure 4 showing the change of vegetation coverage from 2003 to 2023 as summarized in Table 1.

Table 1: Land cover change from 2003 to 2023

Year	Total area km²	Reduced %
2003 - 2008	11	3.4
2008 - 2013	11	5.2
2013 - 2018	11	7.4
2018 - 2023	11	16



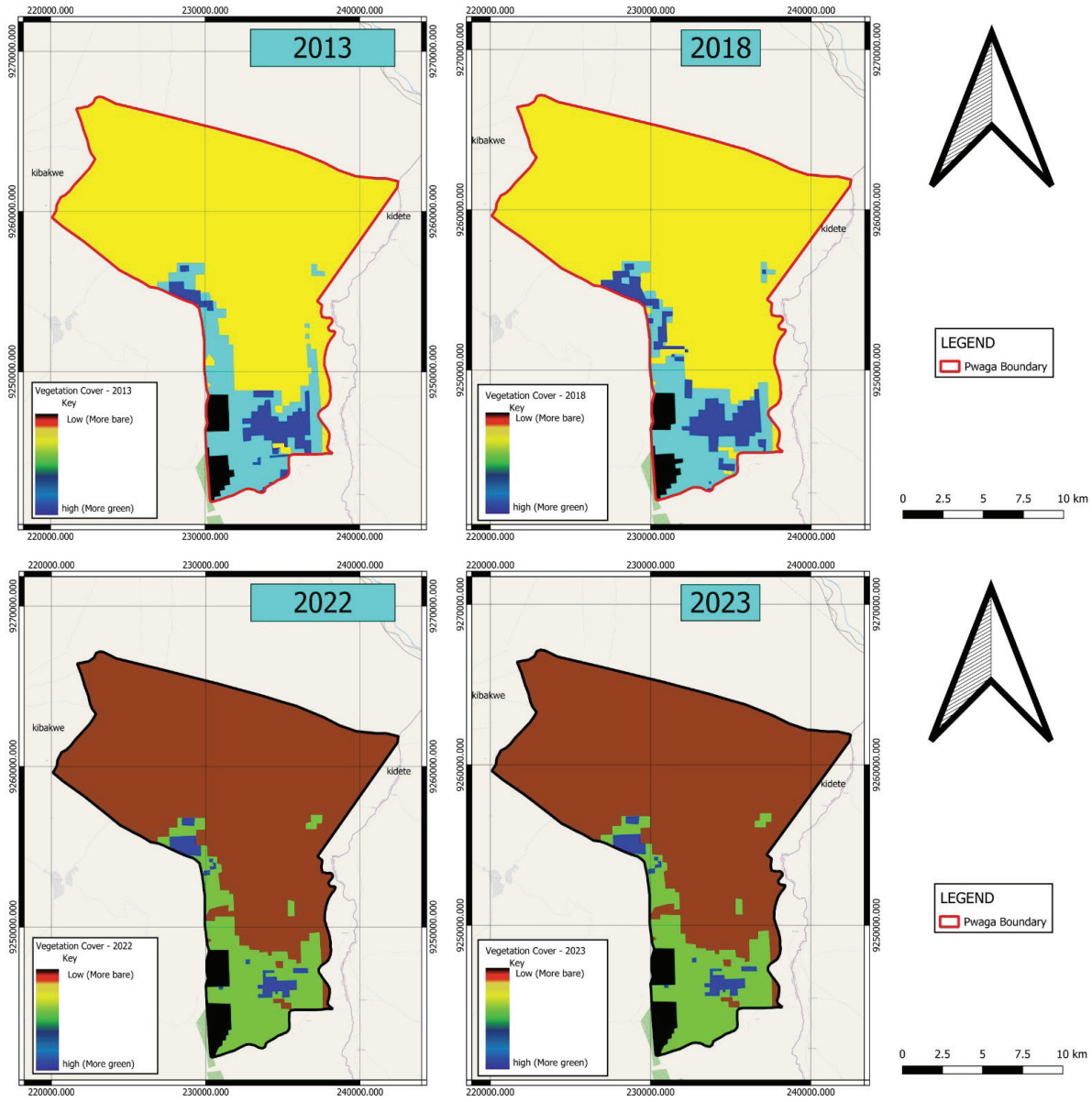


Figure 4: Maps of Pwaga village indicating land cover changes from 2003 to 2023

3.3. Non-climatic factors

According to the household questionnaire, about 88% of Pwaga village residents use wood and charcoal as their primary source of fuel, and only 12% uses liquefied natural gas as their source of fuel for different household activities. Higher usage of wood and charcoal as a source of fuel indicates that there is a high rate of deforestation, which indicates increased vulnerability to climate change impacts. It has been revealed that deforestation for fuel wood collection is a significant driver of forest loss, particularly in developing countries (United Nations Forum on Forests, 2019; Sintayehu, 2025). In effect, the rainfall formation through evapotranspiration and cooling is compromised, exposing people to low rainfall and high ambient temperature.

On the other hand, the land use changes in the area were another factor for the decline of natural resources. The dominant economic activities taking place within the village are small-scale industries (carpentry), agriculture, which involves growing drought-resistant crop varieties such as millet, maize, oilseed crop (sunflower), and groundnuts, together with livestock keeping. The increase in population from the past to the present year has resulted in an increase in demand for agricultural land for growing these crops, where by villagers have been clearing or cutting down trees for obtaining agricultural land, also fuelwood and charcoal as their primary energy sources, in which all these non-climatic factors have contributed in land use changes from past to present year as well.

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3.4. Conflicts on natural resources usage

According to the interviews done among 50 residents in Pwaga village on conflict engagement on natural resources, it was found that 30% of the villagers have never experienced conflicts on natural resources usage, while 70% have at least experienced some conflicts. These conflicts were between farmers and livestock keepers on pasture, also on water usage in different water sources such as Lumuma river, Itende river, and Waturuki boreholes. These conflicts have hindered economic development. It is revealed that borehole water conflicts centered on resource control inequities, with water as a strategic resource causing tensions, particularly among marginalized groups (Mwea & Henry, 2021).

3.5. Adaptation & mitigation measures

3.5.1. Adaptation measures

Regarding the water management system, 16% of the respondents installed rainwater harvesting systems while 84% lacks the system to collect rainwater. The failure of installing rainwater harvesting systems is also associated with the level of their economy, since the actual condition of their houses that are built with no iron sheet (covered with dry grasses) or the installed iron sheet is covered with stones as the holding material, indicating the presence of low-income household earners. Most of the villagers opt to use the Waturuki borehole, while others opt to move to the Itende River and the Lumuma River to access water due to the queue at the borehole.

The analysis shows that the effort in afforestation is not fully realized due to land use pressure associated with competing needs for agricultural land, which has led to difficulties in setting aside areas for afforestation or reforestation. Likewise, farmers have adopted drought-resistant crop varieties such as sunflower, millet, and maize, which are more resilient to dry conditions. According to the Dodoma Agricultural Office (2023), the adoption rate of drought-resistant crops has increased by 40% over the past 10 years**.** Despite growing drought-resistant crops, the agricultural yield has still been affected negatively due to increasing changes in the climatic conditions of the area. Similarly, the Dodoma Agricultural office reported that over the past 4 years, the yield of millet, maize, and sunflower has been reduced for 20% due to erratic rainfall.

3.5.2. Mitigation measures

Among 50 respondents, only 26% of the respondents utilize renewable energy, and 74% do not utilize any kind of renewable energy despite having feedstocks from agricultural waste and livestock keeping that can be used in generating bioenergy. This indicates the limited adoption of renewable energy sources within the village, since the community relies heavily on potentially environmentally damaging energy sources. Increasing the use of renewable energy significantly enhances energy security and reduces environmental impacts like emission of Greenhouse gases, which contribute to climate change (IRENA, 2021).

Regarding waste management practices, all respondents showed a lack of proper knowledge and practices of waste disposal, which contribute to environmental pollution. Villagers lack adequate awareness of practices such as recycling, composting, and proper waste segregation. Thus, they end up practicing improper disposal of waste, such as open burning and open dumping of waste, which contribute to the emission of greenhouse gases. According to Li et al. (2022), waste management practices significantly influence greenhouse gas emissions and climate change mitigation efforts.

3.6. Enhancement measures

Addressing the impacts of climate change requires a comprehensive approach that enhances local capacities in water management, agriculture, energy, afforestation, and waste management. This study provides strategic enhancement measures supported by data and successful case studies, aiming to build resilience and sustainability in Pwaga village, ensuring the village's long-term viability in the face of existing climate change.

The enhancement measures are twofold. The enhancement measures for adaptation measures are: i) Increased water resources management by constructing more boreholes and introducing roof-based systems with gutters and storage tanks for harvesting rainwater. ii) employing climate resilient agricultural practices by growing additional drought-resistant crop varieties and improved irrigation iii) practicing the afforestation and agroforestry iv) promoting the public-private partnership wherever possible and applicable. The

enhancement measures for mitigation measures include i) Expansion of renewable energy use by installation of Solar energy and biogas systems, ii) Improving waste management practices by practicing composting. iii) Raising climate change awareness by conducting regular educational/ awareness programs, workshops, and community meetings. iv) Sustainable Agricultural practices by encouraging practices like crop rotation, organic farming, and the use of natural fertilizers made from compost.

4. Conclusion and Recommendation

The study aimed at assessing the impacts of climate change on natural resources and developing the enhancement measures for better adaptation and mitigation in Pwaga village, Mpwapwa District, Dodoma Region, Tanzania. The study found that because of restricted access, availability, and affordability, climate change has increased the competition for natural resources, particularly water, firewood as an energy source, and waste management. There are a number of adaptation and mitigation strategies in place, but they are not yet meeting the demands. To enhance adaptation and mitigation measures against the impacts of climate change on natural resources in Pwaga Village, Mpwapwa District, the government of Tanzania, in collaboration with local authorities, should prioritize integrated resource management that combines sustainable groundwater use, afforestation, and soil conservation practices. Policies should encourage the adoption of renewable energy technologies such as solar and biogas to reduce pressure on forest resources, while promoting climate-smart agriculture to ensure food security and resilience of rural livelihoods. Furthermore, strengthening community-based awareness programs, capacity building, and the establishment of local climate action committees will foster inclusive participation in decision-making and ensure long-term sustainability of natural resources in the face of changing climatic conditions.

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