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Biomass, Carbon Stock and Sequestration Potential of Kahe Forest Reserve, Northern Tanzania

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ABSTRACT

This paper explores the significant yet underreported contribution of Kahe Forest Reserve (KFR) in Northern Tanzania to climate change adaptation and mitigation, focusing on biomass stock, carbon stock, carbon dioxide sequestration, and untapped carbon trade profit. Utilizing NAFORMA methodology and geospatial analysis, the study reveals that KFR holds approximately 48,300 tonnes of biomass, 22,710 tonnes of carbon stock, and sequesters an estimated 83,300 tonnes of carbon dioxide. This translates to an untapped carbon trade profit of approximately US$ 333,200. The findings underscore KFR's crucial role in carbon sequestration and its importance in climate change mitigation efforts. The forested areas within KFR dominate its carbon sequestration capacity, highlighting the necessity of preserving the reserve. Despite this, the increasing human population up by 141.4% from 1967 (538,107 people) to 2022 (1,298,838 people) in adjacent districts poses significant pressure on the reserve. Illegal agricultural activities within KFR further threaten its integrity, leading to habitat degradation and biodiversity loss. To address these challenges, the study recommends that the government and other stakeholders strengthen policy enforcement, enhance community engagement and education, promote sustainable agricultural practices outside the reserve, implement restoration initiatives, and integrate KFR into carbon markets.

Key words: Biomass stock, Carbon stock, Carbon dioxide sequestration, Economic profit

1. Introduction

Forests play a crucial role in the global carbon cycle by serving as significant carbon sinks that absorb atmospheric carbon dioxide (CO_2), which is a major contributor to global warming (IPCC, 2022). Forests have a crucial role in stabilizing the climate by storing carbon in biomass and soil, which helps to decrease greenhouse gas concentrations (FAO, 2022). Due to the increasing worldwide concern about climate change mitigation, scientists have been dedicating more attention to measuring the amount of biomass, carbon stored, and potential for carbon sequestration in forests. The data is essential for comprehending the ways in which forests can contribute to the reduction of greenhouse gas emissions and for developing strategies to enhance their effectiveness in mitigating climate change (Brown & Zarin, 2023).

The Kahe Forest Reserve (KFR) in Northern Tanzania, which is located in the biologically varied Eastern Arc Mountains, provides a distinct chance to investigate carbon dynamics because of its intricate ecology and wide range of tree species (WWF, 2023). Unfortunately, there is a lack of scientific data regarding the biomass, carbon stock, and sequestration capability of KFR. This lack of information is impeding the ability to effectively manage and conserve the forest (Mwampamba et al., 2023). It is crucial to address this lack of understanding in order to establish policies that can effectively utilize the forest's capacity to absorb carbon dioxide, thereby promoting local conservation efforts and mitigating global climate change.

The objective of this study is to measure the overall biomass of KFR, which includes the living vegetation, dead organic matter, and soil carbon. Additionally, the study attempts to assess the forest's ability to capture and store carbon dioxide over a period of time. The UNEP (2023) examines the future carbon absorption capacity of KFR and its possible economic advantages in carbon trading markets. The study utilizes a blend of on-site measurements, remote sensing, and modeling methods that are based on the National Forest Resources Monitoring and Assessment (NAFORMA) strategy. The methodologies described enable a thorough comprehension of KFR's biomass and carbon content, as well as the ability to make projections about its future sequestration capacity by considering forest growth rates (Liu et al., 2023).

The results will provide backing for well-informed strategies in forest management that improve KFR's capacity to store carbon, in line with international climate objectives such as the Paris Agreement (UNFCCC, 2023). The project will enhance effective conservation measures and emphasize the significance of KFR as a crucial resource for carbon sequestration and environmental sustainability by addressing important data deficiencies.

2. Methods

2.1 Description of the study area

The Kahe Forest Reserve (KFR) is situated in the Moshi District of the Kilimanjaro Region, Tanzania. It is positioned between latitudes 3°15' and 3°20' south and longitudes 37°15' and 37°30' east (Mndeme, 2016). The region is adjacent to Hai District in the north, Same District in the south, Moshi Municipal in the west, and Kenya in the east. KFR, situated at an elevation of 1000-1200 meters above sea level, receives an annual precipitation of 700-900 mm and maintains an average temperature of 30°C. These conditions foster a wide range of plant and animal species (Mndeme, 2016). The neighboring populations depend on the forest as a source of firewood, resulting in substantial deterioration (URT, 2003). The KFR region is situated among the Eastern Arc Mountains, renowned for its exceptional biodiversity and ecological importance (WWF, 2023). The objective of this research on KFR is to measure the amount of biomass, carbon stored, and the potential for carbon sequestration. This data will be useful for managing forests and mitigating climate change, as stated by the IPCC (2022) and UNEP (2023). Gaining a comprehensive understanding of these dynamics is of utmost importance in order to formulate efficient conservation measures that are in line with global climate objectives.

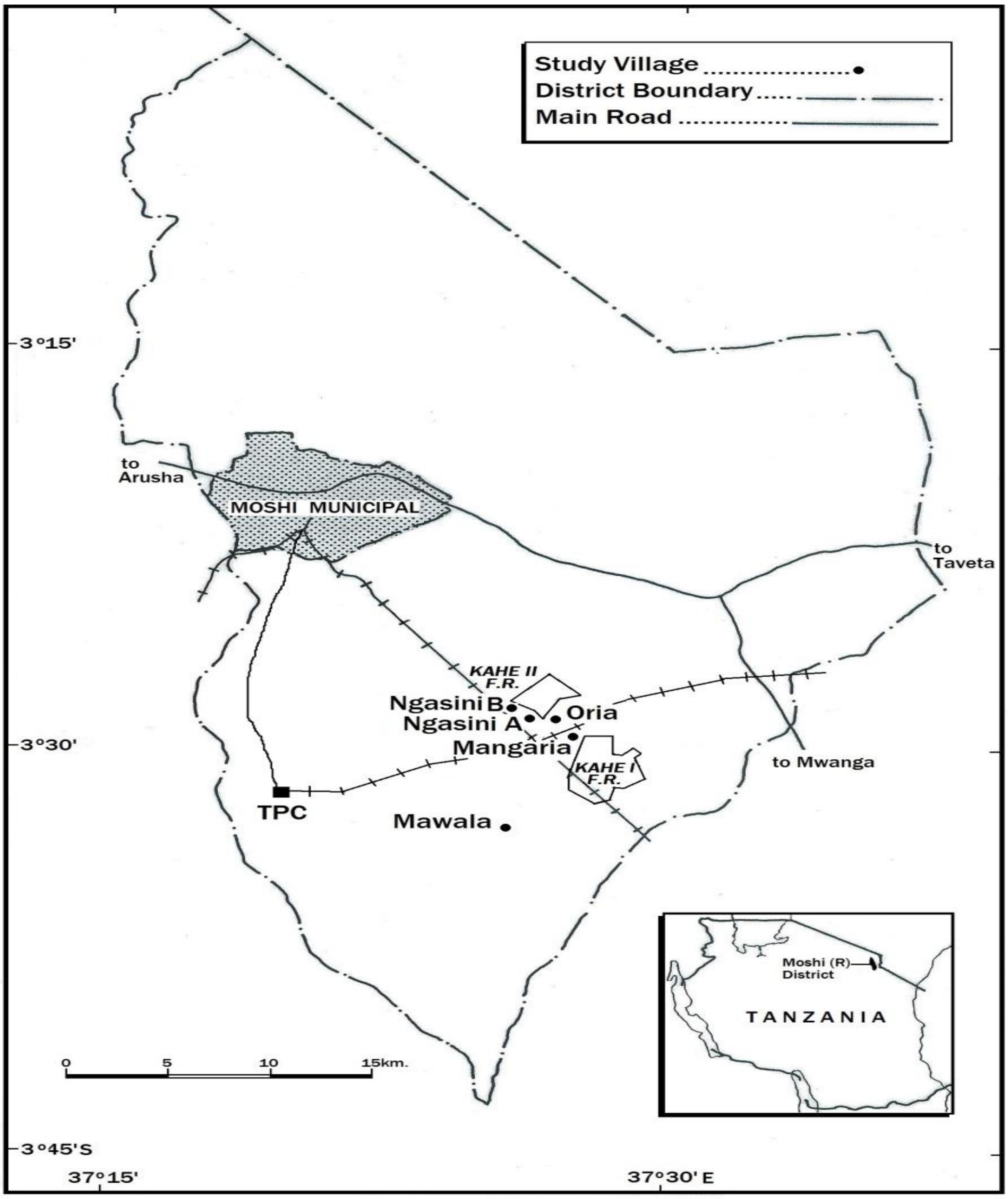

Figure 1: Moshi District showing the study area

2.2 Data used and methods

Figure 2 below shows the flow chart of the methodological approach used in this study for the estimation of the biomass, carbon stock and sequestration, and economic profit from carbon trade for the year 2023.

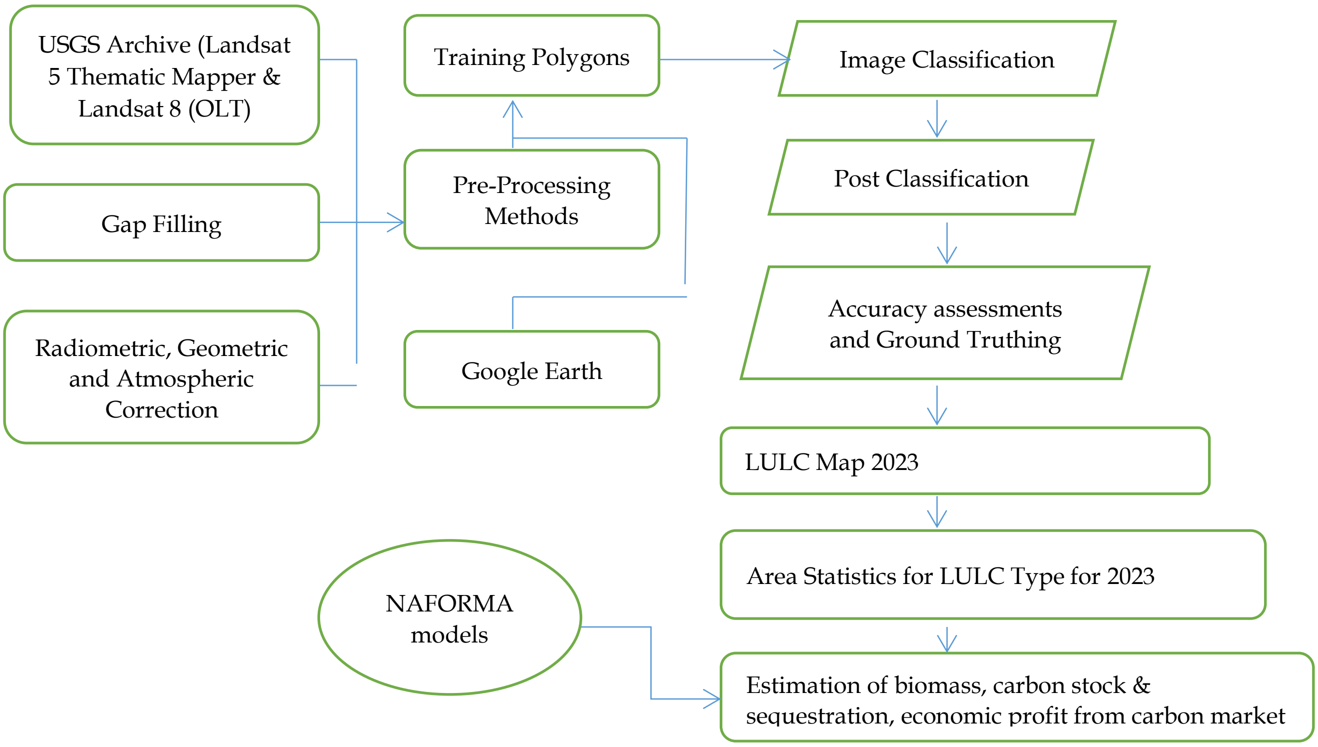

Figure 2: Flowchart of the methodological approach for this study

2.2.1 Spatial data

The study utilized various spatial data sets to analyze biomass, carbon stock, and sequestration potential in Kahe Forest Reserve. Key among these were satellite images from the United States Geological Surveys (USGS-GLOVIS) and Earth Explorer, essential for mapping land use changes, assessing forest conditions, evaluating deforestation trends, and updating forest maps for sustainable land-use planning (USGS, 2023). Landsat images of 2023, obtained from the Department of Urban Planning in Tanzania and the Earth Resources Observation and Science (EROS) Center, were crucial for detailed geospatial analysis of land-use/land-cover (LULC) as shown in Table 1 and Figure 3, providing insights into land use impacts (EROS, 2023; DoSUP, 2022).

Table 1: Analysed geospatial LULC (ha) of Kahe Forest Reserve for the year 2023

LULC	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
2023	507 (51)	136 (14)	177 (18)	64 (7)	95 (10)	979 (100)

Figure 3: LULC map for Kahe Forest Reserve, 2023

2.2.2 Socio-Economic and population data

The study used socio-economic and population data, in addition to spatial data, to evaluate the impact of human activities on land use change and resource consumption. The population statistics collected during the 1967, 1988, 2002, 2012, and 2022 census, which were received from the National Bureau of Statistics, proved to be quite beneficial in comprehending demographic patterns and their correlation with forest degradation and deforestation. The demographic information presented in Figure 4 was crucial for establishing a connection between population pressures and alterations in land use and forest coverage. This data provided a thorough understanding of the socio-economic factors that drive environmental changes in the Kahe Forest Reserve (NBS, 2023).

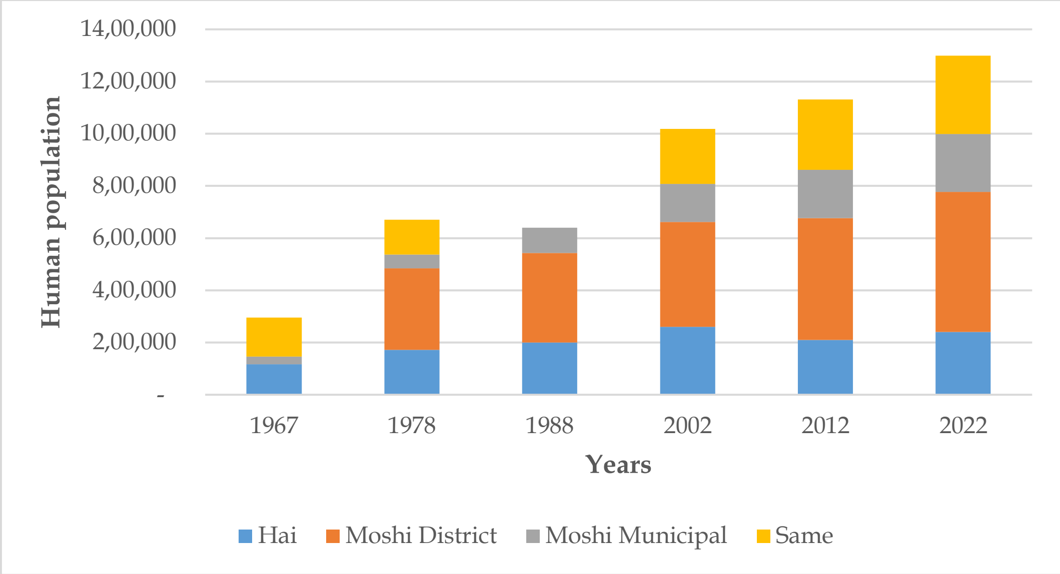

Figure 4: Population statistics adjacent to Kahe Forest Reserve for the Period 1967-2022

Source: Human Population Censuses of 1967, 1988, 2002, 2012 and 2022

2.2.3 Geospatial analysis tools

The research of Kahe Forest Reserve utilized advanced geospatial analysis methods, specifically Geographic Information System (GIS) software, to combine various data sets. GIS software utilized spatial data to process and analyze information, facilitating the generation of intricate maps that depict land-use and forest types. The use of GIS software in this context allowed for the clear representation of changes in land use over time and the identification of areas that have been particularly affected by deforestation and degradation (GIS Software, 2023). The integration of geographical and socio-economic data yielded a holistic comprehension of forest dynamics and the capacity for carbon sequestration. The utilization of satellite images, population statistics, and socio-economic data facilitated rigorous analysis and guided the development of successful conservation strategies and sustainable land-use plans (USGS, 2023; EROS, 2023; DoSUP, 2022).

2.3 Data analysis

2.3.1 Estimation of biomass stock of Kahe Forest Reserve

The assessment of biomass stocks in the Kahe Forest Reserve (KFR) include the computation of live biomass, which is further categorized into above-ground biomass (AGB) and below-ground biomass (BGB), in addition to dead wood (DW) biomass. Together, these components provide a thorough comprehension of the forest's capacity to store carbon. Above-ground biomass refers to the collective mass of all living parts of trees that are situated above the earth, encompassing the trunks, branches, and foliage. The estimation of aboveground biomass (AGB) in KFR is conducted using the technique established by the United Republic of Tanzania (URT) in 2015. This approach is a component of the National Forest Resources Monitoring and Assessment (NAFORMA) framework. Equation 1 displays the formula that is utilized.

AGB (tonnes/ha) = Tree stem volume (m^3/ha) * wood density/1000……………………1

The volume of a tree stem is quantified in cubic meters per hectare (m^3/ha), and the density of wood is unique to each tree species, guaranteeing precise measurement of aboveground biomass (URT, 2015; Liu et al., 2023). The estimation of below-ground biomass, which includes tree roots, is calculated as a portion of above-ground biomass (AGB) using a standard root-to-shoot ratio of 0.25. Alternatively, particular ratios can be used if they are available. The formula is specified in equation 2.

BGB (tonnes/ha) = AGB * 0.25 (as default), or root to shoot ratios………………………...2

This standardized methodology offers a comprehensive evaluation of the carbon storage in the forest (FAO, 2023; Brown et al., 2023). Dead wood biomass encompasses both standing dead trees and fallen timber. Estimating dead wood (DW) entails quantifying its volume and then converting it into biomass by applying density parameters. Equation 3 use the Smalian formula to calculate the volume of logs with irregular shapes.

$V = 0.5L\ (A_1 + A_2)$………………………………………………………………………………3

Where; V is the volume of the log, L is the length of the log, and A_1 & A_2 are the cross-sectional areas at the two ends of the log

The calculated volume is subsequently multiplied by the wood density to estimate the biomass, as stated in equation 4. The wood density utilized for KFR is 619 kg/m^3, which is derived from regional averages and studies (IPCC, 2023; Chidumayo, 2012, as quoted by URT, 2015).

DW (tonnes/ha) = V × Wood Density………………………………………….……………...4

The 2015 NAFORMA report by the URT emphasizes the very small amount of deadwood biomass in Tanzanian forests, mainly because it is extensively gathered for fuel in easily reachable regions such as woodlands (URT, 2015). Conversely, areas with excessive water retention have elevated levels of deadwood because it is less accessible and decomposes at a slower rate, which ultimately improves the long-term storage of carbon. The report highlights the significance of environmental variables in assessing carbon reserves. NAFORMA offers standardized techniques and conversion factors to precisely estimate biomass in various habitats in Tanzania. These approaches are described in detail in Table 2 (URT, 2015) and are essential for comprehending the contribution of forests to carbon sequestration and for developing appropriate management plans.

Table 2: Living tree stemwood and dead wood biomass by primary vegetation type

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land
AGB(t/ha)	59.5	11	2.9	27.7	5.9
BGB (t/ha)	18.2	4.4	1.1	9.5	2.1
DWB(t/ha)	5.09	0.77	0.36	1.89	0.96

2.3.2 Estimation of carbon stock of Kahe Forest Reserve

Accurately determining the amount of carbon stored in Kahe Forest Reserve (KFR) is essential for comprehending its contribution to carbon sequestration and efforts to mitigate climate change. Carbon stocks in terrestrial ecosystems are determined by measuring the biomass and then using a conversion factor to estimate the amount of carbon in both living and dead organic matter. The formula specified by the United Republic of Tanzania (URT, 2015) is presented in equation 5.

Carbon (tonnes)=Biomass (tonnes)×0.47……………………………………………………...5

This factor signifies that 47% of the weight of dry biomass consists of carbon, which is a commonly used approach in assessing carbon levels in forests (Liu et al., 2023; IPCC, 2023). Living tree biomass includes both above-ground biomass (AGB) and below-ground biomass (BGB), which can be further categorized into above-ground carbon (AGC) and below-ground carbon (BGC). The estimation of deadwood carbon (DWC) is based on the usage of the same factor as deadwood biomass (DWB). The calculation of total carbon is determined according to equation 6.

Total C (tonnes) =AGC (tonnes) +BGC (tonnes) +DWC (tonnes)………………………….6

The calculations presented in Table 3 provide a thorough assessment of carbon stock in KFR, which can assist in developing effective forest management and conservation plans. Comprehending carbon storage aids in creating strategies to improve carbon sequestration and establish sustainable land-use strategies, so reducing the effects of climate change and fostering the resilience of forest ecosystems (UNEP, 2023; FAO, 2023).

Table 3: Living tree stemwood (Aboveground + Belowground) and dead wood carbon

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil
AGC(t/ha)	27.97	5.17	1.36	13.02	2.77	27.97
BGC(t/ha)	8.55	2.07	0.52	4.47	0.99	8.55
DWC(t/ha)	2.39	0.36	0.17	0.64	0.64	0.11

2.3.3 Estimation of carbon dioxide (CO_2) sequestration of Kahe Forest Reserve

To estimate the carbon dioxide (CO_2) sequestration potential of Kahe Forest Reserve (KFR), it is necessary to convert the total carbon stock into CO_2 equivalents. This conversion is important for gaining a clear picture of the forest's role in mitigating climate change. The Intergovernmental Panel on Climate Change (IPCC) offers instructions for this conversion, utilizing a factor of 3.67, which signifies the molecular weight ratio between CO_2 and carbon (IPCC, 2006; IPCC, 2023). The formula is specified in equation 7.

CO_2 (tonnes)= Carbon (tonnes)×3.67………………………………………………………….7

By applying this method to the estimated carbon stocks of both live and dead biomass in KFR, the potential for CO_2 sequestration may be determined, as shown in equation 8.

Total CO_2 (tonnes) =AGCO_2 (tonnes) +BGCO_2 (tonnes) +DWCO_2 (tonnes)………………8

This thorough assessment showcases KFR's ability to capture and store CO_2, underscoring its importance in mitigating climate change. Quantifying the forest's potential by converting carbon stocks into CO_2 equivalents helps in developing effective conservation and management plans to enhance its role as a carbon sink. The results emphasize the need of conserving and enlarging forests as a means to counteract climate change (UNEP, 2023; FAO, 2023).

2.3.4 Estimation of Economic profit from carbon trade of Kahe Forest Reserve

To estimate the potential profit from carbon trading for Kahe Forest Reserve (KFR), one must calculate the economic value of the carbon that is stored or absorbed by the forest. The analysis employs the carbon market pricing, which are commonly accepted and established, at around US$ 4 per ton of CO_2, as indicated by Jenkins (2014) and Lobora et al. (2017), with reference to the World Bank (2023). The total amount of carbon dioxide (CO_2) sequestered is determined by converting the carbon stock into CO_2 equivalents using the conversion ratio of 3.67 as recommended by the Intergovernmental Panel on Climate Change (IPCC) in 2006. Equation 9 represents the formula for prospective profit.

Carbon Trade Profit (US$)} = Total CO_2 (tonnes) x Carbon Price (US$ 4/ton)…………...9

3. Results

3.1 Biomass stock of Kahe Forest Reserve

The findings in Table 4 indicates that the total biomass of Kahe Forest Reserve (KFR) is 48, 300 tonnes and mainly dominated by forest (86.8%) and lowest in grassland and cultivated area occupied 1.6% and 1.8% respectively. However, the policy, laws, guideline and regulations restricts agriculture activities inside forests reserves in Tanzania. Thus, the cultivated land inside KFR is invaded by adjacent communities. This calls for immediate action to safeguard the Reserve.

Table 4: Biomass stock (10^3 tonnes) of Kahe Forest Reserve

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
AGB (t)	30.2	1.5	0.5	1.8	0.6	34.5
BGB (t)	9.2	0.6	0.2	0.6	0.2	10.8
DWB (t)	2.6	0.1	0.1	0.1	0.1	3.0
Total (t)	42.0	2.2	0.8	2.5	0.9	48.3
Percentage	86.8	4.6	1.6	5.2	1.8	**100.0**

3.2 Carbon stock of Kahe Forest Reserve

The results in Table 5 indicates Kahe Forest Reserve (KFR) to have a total of 22, 710 tonnes of carbon mainly in Forest (86.8%) and lowest in grassland (1.6%) and cultivated land (1.8%). The cultivated land encroached from KFR as long a Reserve is protected using rules and regulations that prohibit anthropogenic activities inside the Reserve. This implies changes of protected areas from private good to public good where tragedy of common exists.

Table 5: Carbon stock (10^3 tonnes) of Kahe Forest Reserve

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
AGC (t)	14.18	0.71	0.24	0.83	0.26	**16.22**
BGC (t)	4.34	0.28	0.09	0.29	0.09	**5.09**
DWC (t)	1.21	0.05	0.03	0.06	0.04	**1.39**
Total (t)	19.73	1.04	0.36	1.18	0.40	**22.71**
Percentage	86.8	4.6	1.6	5.2	1.8	**100.0**

3.3 Carbon dioxide (CO_2) sequestration of Kahe Forest Reserve

Carbon dioxide sequestration equivalent in Kahe Forest Reserve (KFR) estimated to amount of 83, 300 tonnes mostly in forest (86.8%) and lowest in grassland (1.6%) and cultivated land (1.8%) as shown in Table 6. The Reserve loose its uniqueness to invasion of agriculture activities contrary to rules, guidelines and regulation that protect the Reserve. Tanzania Forest Services (TFS) is responsible for safeguarding the Reserve with help of local communities. Furthermore, increasing human population up by 141.4% from 1967 (538,107 people) to 2022 (1,298,838 people) in adjacent districts as indicated in Figure 4 poses significant pressure on the reserve.

Table 6: Carbon dioxide (CO_2) (10^3 tonnes) sequestration in Kahe Forest Reserve

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
$AGCO_2$ (t)	52.0	2.6	0.9	3.0	1.0	**59.5**
$BGCO_2$ (t)	15.9	1.0	0.3	1.1	0.3	**18.7**
$DWCO_2$ (t)	4.4	0.2	0.1	0.2	0.1	**5.1**
Total (t)	72.4	3.8	1.3	4.3	1.4	**83.3**
Percentage	86.8	4.6	1.6	5.2	1.8	**100.0**

3.4 Economic profit from carbon trade of Kahe Forest Reserve

The findings in Table 7 indicates Kahe Forest Reserve (KFR) to have a total of US$ 333, 200 of carbon trade profit. The distribution of money occupies mostly in forest (86.8%), follows woodland (5.2%), bushland (4.6%), cultivated land (1.8%) and lastly grassland (1.6). Having cultivated land in KFR indicates encroachment which automatically hamper carbon dioxide sequestration and affects carbon trade.

Table 7: Carbon trade profit (10^3 US$) of Kahe Forest Reserve

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
$AGCO_2$ (US$)	208.2	10.4	3.5	12.2	3.8	238.1
$BGCO_2$ (US$)	63.7	4.1	1.3	4.3	1.3	74.7
$DWCO_2$ (US$)	17.8	0.7	0.4	0.9	0.6	20.4
Total (US$)	289.6	15.3	5.3	17.3	5.7	333.2
Percentage	86.8	4.6	1.6	5.2	1.8	**100.0**

4. Discussions

4.1 Biomass stock of Kahe Forest Reserve

An estimation of the biomass stock in Kahe Forest Reserve (KFR) provides valuable information on its ecological well-being and its ability to store carbon. The prevalence of forest biomass emphasizes the crucial significance of KFR's forests in the process of carbon sequestration and maintenance of ecological equilibrium. Forests include abundant flora and fully grown trees that store significant quantities of carbon in both the above-ground and below-ground areas (FAO, 2023). The significant biomass density seen in KFR's forests demonstrates a strong capacity for carbon sequestration, highlighting the importance of preserving and sustainably managing these forests (IPCC, 2023). Grasslands and cultivated regions have considerably lower amounts of biomass, which leads to less dense vegetation and fewer fully grown trees. As a result, these habitats have a reduced capacity for storing biomass and carbon (Liu et al., 2023). The negligible contribution of these regions to KFR's total biomass indicates a restricted capacity for carbon sequestration, emphasizing the necessity for targeted conservation endeavors.

The existence of cultivated land within the KFR, in spite of restrictions that forbid agricultural activity in forest reserves, suggests substantial encroachment by neighboring people. The illicit cultivation poses a significant risk to the forest's overall condition, resulting in the deterioration of habitats, decline in biodiversity, and diminished capacity to store carbon (URT, 2015). Agricultural encroachment leads to the loss of forests and the erosion of soil, reducing the forest's capacity to function as a carbon sink. Urgent and efficient actions are required to implement current legislation and safeguard the forest from additional deterioration (UNEP, 2023).

Efficient managerial tactics ought to incorporate community involvement, rehabilitation endeavors, and enhanced surveillance and enforcement. It is crucial to involve local populations in implementing sustainable land use practices and to promote knowledge regarding the importance of forest protection. Restoration initiatives have the ability to revive deteriorated regions, hence improving their capacity to store biomass and carbon. It is essential to enhance the capabilities of forest management authorities in order to effectively monitor and enforce adherence to legislation for protecting forests (FAO, 2023; UNFCCC, 2023). Therefore, the calculation of biomass stock in KFR highlights the significance of wooded regions in the process of carbon sequestration and ecological sustainability. The existence of agricultural encroachment emphasizes the urgency of implementing conservation measures, such as enforcing policies, engaging with the community, and initiating restoration projects, in order to protect KFR and boost its capacity as a carbon sink.

4.2 Carbon stock of Kahe Forest Reserve

The estimation of carbon stock in Kahe Forest Reserve (KFR) demonstrates its pivotal function in carbon sequestration and the mitigation of climate change. The high carbon concentration in forested areas highlights their crucial role in carbon sequestration, as forests efficiently store carbon through their thick vegetation and mature trees (FAO, 2023). Forests sequester atmospheric carbon dioxide through the process of photosynthesis and store it in the form of biomass and soil. This emphasizes the importance of implementing efficient conservation and management methods to safeguard these ecosystems (IPCC, 2023). Grasslands and cultivated areas have reduced carbon stocks as a result of sparser vegetation and a smaller number of fully grown trees. This highlights the need to prioritize conservation efforts in forested regions (Liu et al., 2023).

The existence of cultivated land within KFR, in spite of restrictions that forbid such activity, suggests substantial encroachment by neighboring settlements. The illicit cultivation poses a significant threat to the forest's overall condition, resulting in the deterioration of its habitat, the decline of its biodiversity, and a decrease in its capacity to store carbon (URT, 2015). The transition from protected areas operated as privately owned assets to effectively public assets, where the tragedy of the commons dominates, presents a significant obstacle, as individual users misuse communal resources to the extent of exhaustion (Hardin, 2023).

In order to tackle these problems, it is crucial to implement and enforce conservation policies and regulations, increase awareness among local communities regarding the significance of forest conservation, advocate for sustainable agricultural practices, and carry out reforestation and afforestation initiatives to rehabilitate degraded areas and improve their capacity for carbon sequestration (FAO, 2023; UNEP, 2023). It is essential to enhance the capabilities of forest management authorities in monitoring protected areas and ensuring compliance with conservation legislation. Therefore, the assessment of carbon stock in KFR emphasizes the crucial significance of wooded regions in capturing and storing carbon, as well as promoting ecological stability. To protect KFR and maximize its function as a carbon sink, it is crucial to address agricultural encroachment by implementing stricter policy enforcement, involving the community, and undertaking restoration activities.

4.3 Carbon dioxide (CO_2) sequestration of Kahe Forest Reserve

The estimation of carbon dioxide (CO_2) sequestration in Kahe Forest Reserve (KFR) highlights the crucial function of the forest in reducing the impact of climate change by storing carbon. The substantial capacity of KFR's wooded areas to sequester CO_2 underscores the urgent necessity to preserve these ecosystems. Forests efficiently sequester carbon dioxide (CO_2) by absorbing it during photosynthesis and storing it in their biomass and soil (FAO, 2023). These forests are significant carbon sinks that are crucial for mitigating climate change (IPCC, 2023).

The significant capacity of KFR to sequester high levels of CO_2 underscores the need for efficient conservation and management techniques. On the other hand, grasslands and cultivated areas in KFR have considerably lower levels of CO_2 sequestration due to sparser vegetation and a smaller number of fully grown trees (Chave, 2023). This disparity underscores the necessity for targeted conservation endeavors to augment the ecological functionalities of these regions. The existence of cultivated land within KFR, in defiance of regulations that forbid such actions, demonstrates substantial encroachment by neighboring people. This encroachment poses a threat to the forest's integrity and results in the deterioration of habitats, loss of biodiversity, and a decrease in the forest's ability to absorb and store CO_2 (URT, 2015). The task of overseeing protected areas as public resources, where the problem of overuse by individuals arises, highlights the pressing requirement for strong implementation of conservation regulations and sustainable land management methods (Hardin, 2023). Furthermore, the nearby districts have experienced a substantial increase in human population, with a growth rate of 141.4% from 1967 (538,107 people) to 2022 (1,298,838 people), which exerts tremendous pressure on the reserve.

The Tanzania Forest Services (TFS) is tasked with protecting the Key Forest Resource (KFR), however, the active participation of the local population is essential. Utilizing collaborative management strategies that involve and instruct communities can diminish illicit activities and encourage sustainable behaviors, cultivating a sense of responsibility among inhabitants (UNEP, 2023). Efficient approaches encompass increasing public knowledge regarding forest preservation, advocating for sustainable farming practices, executing reforestation initiatives, and enhancing the capabilities of forest authorities to enforce regulations (FAO, 2023; UNEP, 2023). Therefore, the assessment of carbon dioxide sequestration in KFR highlights the crucial significance of wooded regions in storing carbon and mitigating climate change. To protect KFR and maximize its function as a carbon sink, it is crucial to address agricultural encroachment by implementing stricter policy enforcement, involving the community, and implementing restoration projects.

4.4 Economic profit from carbon trade of Kahe Forest Reserve

Forest conservation and sustainable management can be economically incentivized through the potential of carbon exchange. Forest ecosystems, characterized by their abundant vegetation and fully grown trees, possess a remarkable ability to effectively capture and retain carbon dioxide, rendering them significant resources within carbon markets (FAO, 2023; IPCC, 2023). Forests have a higher carbon trading value in the Kahe Forest Reserve (KFR), whereas woodlands and bushlands have a lower capability for storing carbon (Liu et al., 2023).

Nevertheless, the existence of cultivated land within KFR signifies substantial intrusion by neighboring populations, in spite of restrictions that forbid such actions. The intrusion poses a significant risk to the forest's overall condition, diminishes its ability to store carbon, and adversely affects the financial advantages derived from carbon trading (URT, 2015). Unlawful agricultural practices result in the deterioration of habitats, the decline of biodiversity, and a reduction in the forest's ability to store carbon, so weakening its function as a carbon sink. This scenario exemplifies the tragedy of the commons, a situation in which commonly shared resources are excessively exploited due to a lack of effective regulation, resulting in the depletion of those resources

(Hardin, 2023). The Tanzania Forest Services (TFS) has a vital role in protecting KFR, but the participation of local communities is as significant. Effective agricultural encroachment mitigation requires the implementation of collaborative management strategies, such as community engagement and education. By cultivating a sense of responsibility and care among the local populace, it is feasible to diminish illicit activities and advocate for sustainable practices that are advantageous to both the environment and the community (UNEP, 2023).

Efficient management strategies should encompass activities such as increasing knowledge and understanding of forest preservation, advocating for sustainable farming methods, carrying out projects to restore degraded areas through reforestation and afforestation, and enhancing the capabilities of forest management authorities to oversee and enforce compliance with conservation regulations (FAO, 2023; UNEP, 2023). Therefore, the calculation of the monetary worth of carbon trading for KFR highlights the substantial economic opportunity of preserving forests through carbon markets. Forests play a significant role in the carbon trade value, underscoring their crucial role in carbon sequestration. Nevertheless, the expansion of agriculture poses a significant risk to this promising opportunity. To protect KFR and improve its function as a carbon sink and economic asset, it is crucial to enforce policies, involve local communities, and carry out restoration projects.

5. Conclusion and Recommendations

5.1 Conclusion

The investigation has yielded crucial insights into the ecological and economic importance of this forest ecosystem. KFR has a biomass of over 48,300 tonnes and a carbon stock of around 22,710 tonnes. This makes it an important player in carbon sequestration, making a considerable contribution to efforts to mitigate climate change. The carbon sequestration capability is mostly controlled by the forested areas in KFR, highlighting the significance of conserving these regions. The forests in KFR have a large amount of plant and animal material and store a significant amount of carbon. This suggests that they have a strong ability to capture and store carbon, which is important for decreasing the levels of carbon dioxide in the atmosphere. Nevertheless, the existence of cultivated land within KFR, in spite of current rules, underscores the difficulty of agricultural invasion. This illicit behavior not only jeopardizes the authenticity of the woodland sanctuary but also reduces its ability to absorb carbon, resulting in the deterioration of the natural environment and the decline of biodiversity.

Furthermore, the economic capacity of KFR to benefit from carbon trading has not been fully utilized. If forests in KFR were incorporated into carbon markets, they could yield substantial economic benefits. The present market price for carbon, which is around US$4 per ton of CO_2, indicates that KFR has the potential to offer significant financial rewards for conservation and sustainable management.

5.2 Recommendations

5.2.1 Strengthen policy enforcement

In order to prevent future degradation of the KFR, it is crucial to enhance the enforcement of current conservation rules. This entails more rigorous surveillance and control of illicit activity within the forest reserve. Furthermore, it is imperative to bolster the capabilities of forest management agencies, such as Tanzania Forest Services (TFS), in order to boost their ability to oversee protected areas and ensure adherence to conservation legislation. These objectives can be accomplished by allocating more resources, providing more training to forest rangers, and implementing advanced surveillance tools like drones and satellite imaging.

5.2.2 Community engagement and education

Community awareness programs aim to increase local populations' understanding of the significance of forest protection and the economic advantages of carbon trading, so promoting a sense of responsibility and care. It is important for educational programs to prioritize highlighting the enduring advantages of sustainable land use practices compared to the immediate profits gained by unlawful cultivation. Furthermore, implementing collaborative management strategies that engage local populations in the governance of KFR might effectively mitigate illicit activity. This include the implementation of community-based forest management (CBFM) strategies that enable local communities to actively engage in conservation initiatives.

5.2.3 Sustainable agricultural practices

Advocating for sustainable farming techniques can promote agricultural practices that do not infringe upon forest land, thus achieving a balance between community needs and conservation objectives. Agroforestry, the practice of incorporating trees and shrubs into agricultural environments, can serve as a feasible alternative. Moreover, implementing alternative livelihood initiatives can offer alternative employment opportunities for people engaged in illicit farming within the Key Biodiversity Areas (KFR), so alleviating the strain on the forest. This encompasses instruction in sustainable agriculture, eco-tourism, and other environmentally conscious income-generating endeavors.

5.2.4 Restoration initiatives

Implementing reforestation and afforestation programs in degraded regions of KFR can boost the forest's biomass and carbon sequestration capacity. It is important to give priority to native species in these endeavors in order to preserve ecological balance. Similarly, the process of rehabilitating deteriorated lands involves aggressively implementing soil conservation methods and reintroducing indigenous plants in order to restore the ecological functions and carbon storage capacity of the forest in KFR.

5.2.5 Integration into carbon markets

The development of carbon trading systems, namely the establishment of mechanisms to integrate KFR (Knowledge, Flows, and Relationships), can unlock its economic potential inside carbon markets. This entails establishing a system for certifying and trading carbon credits, guaranteeing the actualization of the financial advantages of carbon sequestration. In addition, establishing connections with international carbon markets can provide KFR access to a wider platform for selling carbon credits. This has the potential to allure investment and offer continuous financial support for conservation endeavors.

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