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Spatial and Temporal Changes in Land Use/Land Cover and their Driving Forces in Kahe Forest, Northern Tanzania

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Abstract
Deforestation is one of the major changes in terrestrial landscapes that affect the environment. It is caused by anthropogenic activities and a myriad of natural factors which cause a global loss of natural biodiversity and alteration of ecological processes and services across different ecosystems. An analysis of the spatial temporal changes in land use and land cover was done in Kahe Forest. Moderate resolution land satellite images were downloaded from the United States Geological Survey (USGS) archives and analyzed using the random forest (RF) algorithm and mapped in ArcGIS 10 software to ascertain the changes that took place in land use and land cover in Kahe Forest from 1998 to 2018. A questionnaire and key informant interviews were used to collect data. Findings show that, agricultural land and grassland increased by 7% and 14%while the forest area decreased from 85% to 51%due in the same period caused by escalation of human activities. The underlying causes of the changes include rapid population growth, wild fires, climate change and variability as well as human activities. It is recommended that adoption of sustainable forest-management strategies such as enforcement of the existing conservation laws and regulations and of alternative environment-friendly sources of livelihoods mainly community based forest management should be enhanced all stakeholders including the government and the community.

Keywords: Spatial-temporal change, drivers of land cover change, Kahe Forest Reserve

1. Introduction

One of the major changes which affect terrestrial landscapes is deforestation. Deforestation results from both natural causes such as pests and diseases, forest fires and occurrences of invasive species, and non-natural factors such as human activities and rapid population growth. The decline in forest cover causes the loss of biodiversity (both flora and fauna), increases soil degradation, disrupts water cycles and causes greenhouse emissions, which lead to climate change (Brambilla *et al*., 2010; FAO, 2010). It is estimated that, globally, about 8.3 million and 5.2 million hectares of forests were lost per year for the periods 1990–2000 and 2000–2010, respectively. This occurred in rich natural tropical forest areas (FAO, 2010; Kundilwa *et al*., 2016).

Understanding changes in land use/land cover is very important to sustainable forest management especially in developing countries, where the majority of people in both rural and urban areas depend on forests for their livelihoods (Msofe *et al*., 2019). Normally, a change in land use is associated with sustainable development in a certain geographical space and influenced by the flow of energy, landscape conditions, and biotic conditions as well as chemical and physical characteristics. In addition, the changes are associated with the intensification of natural factors and anthropogenic activities such as climate change and climatic variability and soil erosion. Land-use/land-cover changes have certain negative effects on the environment as they stimulate soil erosion, land and habitat degradation, as well as the loss of biological diversity species (Millennium Ecosystem Assessment, 2005; Msofe *et al*., 2019). In order to examine land-use /land-cover changes, it is imperative to look at both natural and human factors which have become focal points in research on all land-use/land-cover changes (Msofe *et al*., 2019).

Land-use/land-cover changes directly impact biodiversity, biosphere–atmosphere interactions, the ecosystem and sustainable utilization of natural resources (Liu *et al*., 2014; Msofe *et al*., 2019). These effects make a range of international organizations and scholars in the world research on the driving forces of LULCC (Geist and Ambin, 2006; Msofe, *et al*., 2019). In order to achieve sustainable land-use management, it is necessary to understand the LULCC processes that happen in the use of land resources over time and to identify the major driving forces of land us and cover change. This will increase efficiency in land-resource use, mitigation of the negative effects of changes on landscape associated with LULCC, as well as the promotion of sustainable landscape ecosystem-management practices. In order to make informed local and national decisions on sustainable land use, facilitate environmental monitoring and support national reporting on global conventions and frameworks, it is vital to examine the spatial and temporal processes of LULCC and their driving forces (Leemhuis *et al*., 2017; Msofe *et al*., 2019).

Globally, forests are among aspects of the ecosystem that are endangered because of land-use/Cover changes as they occupy approximately 31 % of the earth's surface. It is estimated that they contain more than half of all the terrestrial plant species, the great majority of which are in the tropics. At country wise scale studies revealed that forests cover 39.9% of total land area in Tanzania, 43% of Mozambique, 12.4% of Uganda, and 6.99% of Kenya comprise of montane, mangrove acasia coastal woodlands and miombo woodland (GOM 2018; MENR 2016). As one of the largest forest protected areas, Kahe Forest (KF) is home to terrestrial biodiversity and has social, cultural and spiritual significance. It provides important goods and services. For example, it is a source of energy, especially firewood and charcoal. It is also a source of construction materials and medicinal products (Milledge *et al.,* 2015; Nahashon, 2013).

Examining the drivers of land-use/land-cover changes in Kahe Forest is important for ensuring sustainable land use. Several studies conducted on land-use/land-cover changes used various mathematical models, statistical models and, recently, GIS and remote sensing data to examine the alteration of land use/land cover in various parts of the world (Msofe *et al*., 2019; Nzunda *et al.,* 2013). However, in many cases, analyses of land-use changes do not use a mix of different methodologies. Thus, this study analyzed spatial and temporal changes in land use and the driving forces with respect to Kahe Forest by integrating geo-spatial data, population data and socio-economic data.

2. Materials and Methods

2.1 Location of the Study Area

Kahe Forest (Figure 1) is located in Moshi Rural District in Kilimanjaro Region at the northern tip of Tanzania. It lies between Latitudes 3^{o} 15' and 3^{o} 20' south of the Equator and Longitudes 37^{o} 15' and 37^{o} 30' east of Greenwich. The area is bordered by Hai District in the north, Same District in the south, Moshi Urban District in the west and Kenya in the east. The area is found between 1000-1200m above sea level with a mean annual rainfall of 700mm-900mm and average temperature of 30^{o} C (Mndeme, 2016). The area was selected because the dwellers relied on the forest as their main source of energy, which, in turn, causes much forest degradation (URT, 2003). The adjacent villages are Oria, Mwangaria, Mawala, Ngasinyi "A" and Ngasinyi "B".

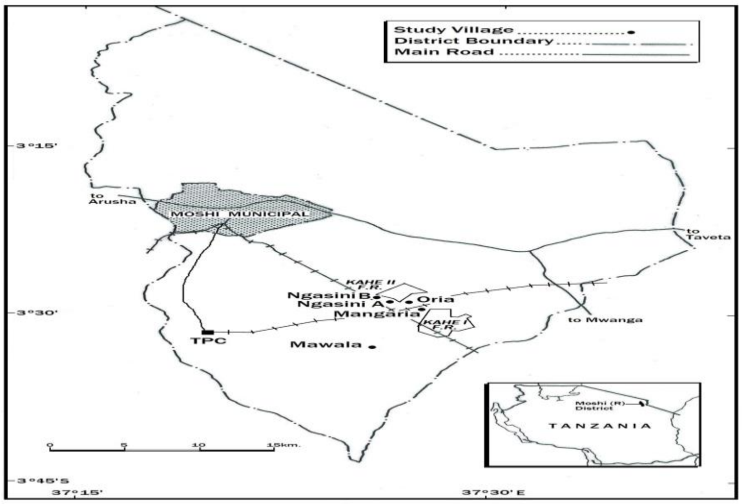

Figure 1: Moshi (R) District Showing the Study Area
Source: UDSM Geography Department, Cartographic Unit (2020)

2.2 Sample Size and Sampling Procedures

A total of 150 households out of 19,142 households in the five villages were involved in this study. Other informants were the village and ward executive officers. The sample size was obtained using the following formula suggested by Nassiuma (2000).

$$n = \frac{NC^2}{C^2 + (N-1)e^2}$$ ....Equation 1

n = sample size
N = population size (19,142)
e = standard error/sampling error (1%)
C = variation coefficient (12.5%) - ranges from 10% to 20%
From above equation 1 the sample size for this study was obtained as follows;

$$n = \frac{19{,}142\,(12.5)^2}{12.5^2 + (19{,}142-1)(1)^2} = 150.24 \sim 150$$ ....
Equation 2

Therefore, the sample size included 150 household heads and five key informants presented in Table 1 below. Each village was represented by 30 households. Therefore, the total sample size consisted of 155 participants.

After obtaining the total sample size for this study as stipulated in equation 2, the next step was to obtain the study villages and specific individuals who responded to the questionnaires by filling in the required information. This sampling process involved major two procedures. The first procedure was to identify the study villages. This was done through judgmental sampling where the villages were selected basing on their proximity to Kahe forest. The selection of study villages was done following the prior visitation in the study area by the researcher. Before actual data collection the researcher visited the buffer zone of Kahe forest and identified nine villages among which five were more proximal to the forest. The five sampled villages are Mawala, Mwangoria, Ngasinyi A, Ngasinyi B and Oria. Being close to the study forest, residents form selected villages claimed to have a direct contact with forest resources a situation which is associated with the dynamics of the forest land cover in the study area.

The second procedure during sampling process involved the selection of specific individual household heads who are the unit of analysis in this study. This was done through systematic sampling were the total population (19,142 households) was divided by the sample size (150) and the obtained figure (127) was used as the sampling interval for selection. This sampling technique ensured that the population under study is sufficiently represented and thus the findings are realistic and convincing in drawing the conclusion. Moreover, due to the nature of the study which intended to analyse the spatial and temporal changes in land use/land cover and the driving forces in Kahe Forest as a complete ecological zone, similarly the researcher found that it is worth studying the surrounding sampled villages as complete buffer zone. Additionally, basing on the similarities of the five study villages in both physical, geographical, economic and social characteristics and their relations with Kahe forest the researcher found that it is meaningful to study all five sampled villages holistically. With this regard the names of household heads from all sampled villages were obtained from villages' authorities and were listed down by following the villages' alphabetical order. Form the list of household heads every 127th name was picked ready for questionnaire survey.

The study used two main types of data: spatial and non-spatial data. Spatial data comprised information obtained using satellite images produced from 1998 to 2018 which were used to detect changes in land use cover change over time in the study area. The images were imported onto Arc GIS software to determine the changes in land use/land cover which happened over a period of 20 years. The study also analyzed non-spatial data, which was obtained using a socio-economic survey, meteorological data as well as population data to complement the information obtained from the spatial data.

2.3.1 Data Collection Methods

2.3.1.1 A Remote Sensing Technique and Geographical Information System (GIS)

Spatial data included satellite images produced at different times, which were downloaded from the United States Geological Surveys (USGS-GLOVIS) and Earth Explorer. The satellite images were used to map and explore changes in land use, to determine the state of the forest, to assess the rates and trends of deforestation and to update the existing forest maps that could play a vital role in making decisions and making sustainable land-use plans. The land-use map of 2012, forest type maps, the population size, the forest boundaries and other socio-economic data that covered the whole study area were also used in doing a geospatial analysis of land-use/land-cover changes.

In order to detect types of land use/cover changes and to determine the rate of changes, the study uses satellite land sat image of 1998 and rapid eyes of 2018. The images were obtained from the department of urban planning in Tanzania (DoSUP) down loaded Department of Survey and Urban Planning (DoSUP) Tanzania. Downloaded from Earth Resources Observation and Science (EROS) at (http://glovis.usgs.gov) of the Geological Survey of the United States of America. Similarly, population data which were obtained from the National Bureau of Statistics in 2012 were used to assess the influence of population in land use change and resource use consumption.

2.3.1.2 Household Questionnaire

The 150 household heads from the area where the study was conducted (Oria, Mwangana, Mawala, Ngasinyi A and Ngasinyi B) completed a semi-structured questionnaire. The purpose was to get their perceptions of the drivers of land-use/land-cover changes and the natural reasons for the changes, and to investigate the influence of human activities on the changes.

2.3.1.3 Key Informant Interviews

The interviews were conducted with five local government officers who were believed to have much knowledge of and experiences in the changes in land use/ land cover, as well as the forces behind them.

2.4 Data Analysis

2.4.1 Non spatial data

All non-spatial data were carefully examined for consistency. The data were also edited to ensure that they were accurate, consistent and well-arranged so that they could be coded and entered in the data analysis software. Data from the interviews were put into specific categories. Then, the data were carefully cross-checked so as to get rid of all unnecessary information.

As for the satellite data, image restoration, image enhancement and image classification were conducted. Image restoration involved correcting and calibrating the images in order to get high quality images and to remove degradation effects. Further radiometric restoration and geometric restoration were done. The images were enhanced by optimizing their appearance. This involved contrast stretching, composite generating and digital filtering. Then, the images showing land-use/ land-cover changes were manually put into five groups, namely woodland, bushland, grassland and agricultural lands. A supervised classification method in Arc GIS was used to put the images into five classes. This technique was chosen because of its precision in land-cover categorization. The first step was to select training sites; Arc G.I.S image classification software was used to identify the categories of land cover in all the images. The second step involved creating a signature file. The classification of land cover was based on the spectral signature defined in the training set and minimum-distance classification was used for classification alogarithims. Finally, five categories of land cover which include forest (land covered by low density trees, woodlands (land covered with low density and scattered trees as well as farms), Bushland (land covered with bushes and shrubs), Grass land (land covered by grass) and agricultural land (land on which farms are located were obtained.

2.4.2 Spatial data

The data obtained using the socio-economic survey were quantitatively analyzed using the statistical package for the social sciences (SPSS) version 20 software to get the frequencies and percentages of responses. Qualitative information was analyzed using content analysis techniques.

The satellite images were analyzed using Quantum GIS (Open source software). Before a change was detected, the images which had been classified were checked for accuracy levels by doing post processing. Then, an error matrix table was produced to show a land-use /land-cover classification report and overall accuracy levels of the satellite images. The accuracy level accepted for this study was 80%. Then, a semi-auto classification plug-in was used to calculate the changes in land use. The product of this process was a change trajectory map showing what has changed and what has not changed, and cross tabulation statistics tables showing the extent of the changes and annual changes. The summation of loss and gain was used to calculate and identify the net changes of each type of land use. Overall changes were calculated by dividing net changes by the number of years – from 1998 to 2018 – to get the annual land-use changes. The following formula was used to calculate the annual land-use changes:

$$r = \frac{\left[\ln\left(A_{t_1}\right) - \ln\left(A_{t_v}\right)\right]}{t_1 - t_v} \times 100$$

r = rate of annual change, A_{t_1} = land use area in the initial , A_{t_v} = land use area in final year or time, t_1 = initial time (year), t_v = final time (year), ln = constant (Kashaigili and Majaliwa 2013)

The data obtained from the analysis of land use and the satellite images were presented in the form of tables and maps, which show land-use/land-cover changes. The data obtained using the questionnaire and interviews were presented as descriptive statistics which include frequencies, percentages and figures.

3. Results and Discussion

3.1 Spatial and Temporal Changes in Land Use and Land Cover in Kahe Forest from 1998 to 2018.

The maps on land use/land cover for 1998 and 2018 are presented in Figures 2 and 3. Generally, the maps show variations in Land use/land cover from 1998 to 2018. Table 4 presents the spatial distribution of five classes of land-use/land-cover for the period between 1998 and 2018.

Table 1: Estimated Area (ha) of LULCC in Kahe Forest from 1998 to 2018

LULC Type	1998 (ha)	%	2018 (ha)	%
Agricultural land	26	3	95	10
Bushland	50	5	136	14
Forestland	833	85	507	51
Grassland	41	4	177	18
Woodland	29	3	64	7
Total	**979**	**100**	**979**	**100**

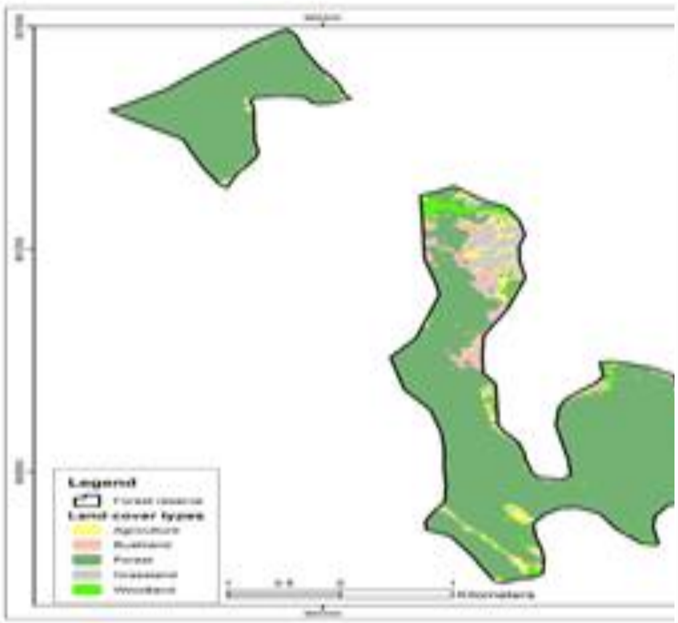

Figure 2: Land Use/Land Cover Map for Kahe Forest, 1998

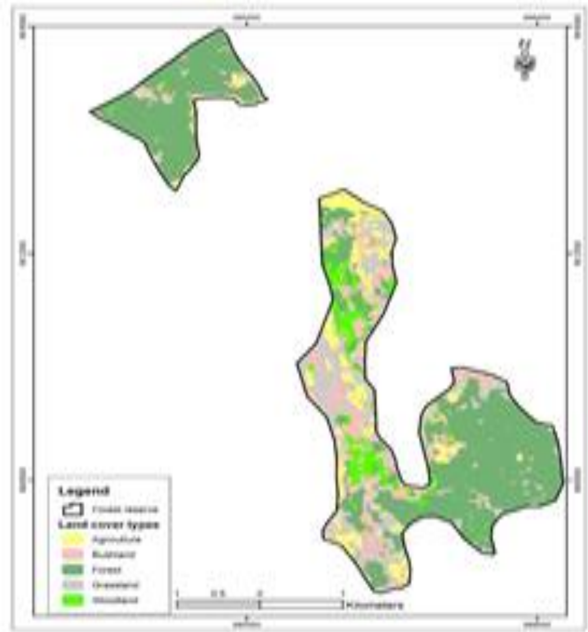

Figure 3: Land Use/Land Cover Map for Kahe Forest, 2018

The results presented in Table 1 and Figures 2 and 3 show that bushland and grassland are among the main types of land cover in Kahe Forest; they constituted 85%, 5%and 4% of the total land cover in 1998 (Table 4). By 2018 agricultural land, grassland, bush land and woodland had increased by 18%, 14%10% and 7%, respectively. However, the area occupied by Kahe Forest decreased from 833 ha (85%) in 1988 to 507 ha (51%) in 2018, a decrease of 34%. The rapid decrease in the size of t he land was caused by the conversion the land to agricultural land, bush land, grassland and woodland. The conversion of the land was mainly influenced by the expansion of agricultural land as well as a rise in the demand for forest products such as timber, fuel wood and charcoal. These findings concur with those in Msofe *et al*. (2019), who note that human activities and a rise in the demand for forest products such as fuel wood and logs were the primary drivers of deforestation in the Kilombero valley.

3.2 Land-Use/Land-Cover Changes from 1998 to 2018

The extent of the changes in land use/land cover, including area change, percentage change and annual rate of change, is shown in Table 2. The increase and decrease of the land use/cover change categories are represented by negative and positive signs (-) and (+), respectively. The results indicate that grassland increased by 14%, bush land by 9% and agriculture land by 7%. The increase of grassland is influenced by its suitability for being grazing land, for the communities are engaged in both farming and livestock keeping. Generally, the increase in agricultural land and grassland can be attributed to much pressure on the land resources. On the other hand, the results show the decrease of forest land to -38% because the land was converted to other uses to support the local communities' livelihood (Table 2).

Table 2: Land-Use /Land-Cover Changes in Kahe Forest from 1998 to 2018

LULC Type	Area Change (ha)	Percentage of Change (%)	Annual Rate of Change (ha/year)
Agricultural land	-69	7	-6.3
Bushland	-86	9	-7.8
Forest	326	-38	29.6
Grassland	-136	14	-12.4
Woodland	-35	4	-3.2

3.3 Drivers of Land-Use / Land-Cover Changes in Kahe Forest (KF)

3.3.1 Community Members' Perceptions on Land-Use / Land-Cover Changes at KF

The results in Table 6 show that 46.7% of the informants noted that the state of Kahe Forest had fallen and 30.7% noted that it had risen. These results imply that the informants have different perceptions of the state of the forest. The reason behind these differences is that there is no clear management regime for Kahe Forest. The findings are similar to the findings of studies conducted by (Munthali, *et al* 2019 and Tanui 2015) as they observed that the local community had noted a rapid decline in forest cover as a result of severe deforestation and land degradation, caused by people's overexploitation of forest resources in Malawi and Nandi Kenya.

3.3.2 Contiguous Drivers of Land-Use Changes at KF

	Village					
Drivers	**Oria n=30**	**Mwangaria n=30**	**Mawala n=30**	**Ngasinyi A n=30**	**Ngasinyi B n=30**	**Total N=150**
Indirect consumption of forest resources	28 (63.3)	19 (63.3)	18 (60)	19 (63.3)	20 (66.7)	94 (62.7)
Direct consumption of forest resources	28(93.3)	28(93.3)	28 (93.3)	28 (93.3)	28 (93.4)	45 (30)
Natural reasons	2 (6.7)	2 (6.7)	2 (6.7)	3 (10)	2 (6.7)	11 (7.3)

The results in Table 7 show that the leading cause of changes in land use in Kahe Forest was indirect consumption of forest resources (62.7%). This consumption of the resources is caused by agricultural expansion, free livestock keeping and the expansion of settlements. This was followed by direct consumption of forest resources such as the extraction of wood for fuel and charcoal-making, while the natural reasons accounted for only 7.3% These results imply that anthropogenic activities are the source of deforestation in all forests. Although Wubie *et al.* (2016) observed that direct consumption of forest resources such as direct extraction of forest resources for the wood used in cooking, heating and lighting accelerates land-use / land-cover changes in Ethiopia, this study notes that indirect causes such as agricultural expansion, free livestock keeping and the expansion of settlements also cause land-use/land-cover changes.

3.3.2.1 Human Activities that Contribute to Land-Use/Land-Cover Changes in Kahe Forest

The results in Table 3 show that firewood collection and the expansion of crop farming accounted for 38.7% of the total responses and that the expansion of human settlements and of grazing land accounted for 61.3% the total responses. These were followed by charcoal-making, which accounted for 54.7% of the human activities that cause deforestation in Kahe Forest. The results imply that cooking and warming energy is still a problem, although the government is installing electricity in the villages through the Rural Energy Agency (REA) programme.

Table 3: Human Activities that Contribute to Land-Use/Land-Cover Changes in KF

	Rank					
Activity	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**	**Overall N=150**
Firewood collection	58 (38.7)	58 (38.7)	34 (22.6)	0 (0)	0 (0)	150 (100)
Charcoal-making	35 (23.3)	82 (54.7)	33 (22)	0 (0)	0 (0)	150 (100)
Timber-making	11 (7.3)	24 (16)	81 (54)	23 (15.3)	11 (7.3)	150 (100)
Building materials	12 (8)	35 (23.3)	92 (61.3)	0 (0)	11 (7.3)	150 (100)
Expansion of human settlements	0 (0)	92 (61.3)	47 (31.3)	11 (7.3)	0 (0)	150 (100)
Expansion of cultivation land	58 (38.7)	57 (38)	35 (23.3)	0 (0)	0 (0)	150 (100)
Expansion of grazing land	24 (16)	92 (61.3)	23 (15.3)	0 (0)	11 (7.3)	150 (100)

In Kahe Forest deforestation is attributed to the expansion of agricultural land, illegal logging as well as increased demand for such forest products as fuel wood and charcoal. Similarly, Msofe *et al*. (2019) and Geist and Lambin (2002) reported that human activities and increased demand for such forest products as fuel wood and logs were the primary drivers of deforestation. The results of this study also show that agricultural land, bushland and grassland have increased by 7%, 9% and 14%, respectively, mainly owing to high population growth (Table 2). The increase in population has greatly increased pressure on land resources, as shown in Table 4. These findings are supported by the responses from the key informants, one of whom said:

… *the state of Kahe Forest has greatly changed in recent years. Twenty years ago, the forest was thick and trees were tall and had huge trunks. But the forest is no longer thick as the trees are scattered and are not very tall and thick. This situation is caused by the high demand for forest wood products, especially charcoal and timber….* (A Village Executive Officer aged 52)

3.3.2.2 Human Population Growth Adjacent to KF

Kahe Forest is accessed and utilised directly and indirectly by the adjacent villages and districts which include Hai Same, and Moshi urban. Table 9 presents trends in population growth in these districts. The number of people increased from about 538, 107 in 1967, to about 1,131,369 in 2012 and to about 1,259,188 in 2018. This trend in population growth has produced an overall growth rate that ranges between 1% and 8.6% from 1967 to 2018. This rapid population growth almost doubles the size of the population every two decades. The increase in population has increased pressure on natural resources, thereby causing land scarcity and fragmentation. Generally, it could be argued that there is a relationship between population growth and changes in land use at KF, as indicated in Section 3.2.2. Thus, population growth has increased the demand for arable land and caused much environmental degradation. The results agree with the results of (Munthali *et al* 2019, Kindu *et al* 2015 and Chowdhury 2008). They found that there is a relationship between population growth and forest degradation. Population growth caused the decline of forested area by 4.5% between 1990 and 2016. Generally, as population grows, arable land becomes scarce, which makes it necessary for people to intensify agricultural production in Kahe Forest. The results from the data obtained using the questionnaire are supported by what the key informants said. One key informant said:

… I have lived in this village for more than 40 years. When I was younger, the houses were scattered and very few people lived near the forest. But houses are many now and some of them are very near Kahe Forest. The increase in the

number of people in our village has drastically intensified the exploitation of the forest resources…. (One Village Executive Officer aged 54)

These findings are similar to the findings of a study conducted by Mdemu *et al.* (2012), who observe that population growth in peri-urban areas is associated with the expansion of settlements and an increase in the demand for agricultural land. In a similar vein, Debel *et al.* (2014) have reported that population growth has a huge impact on forestry, since it increases the demand for forest products such as timber, firewood and charcoal.

Table 4: People Living Adjacent to KF by District for the Period 1967-2018

Year	District				Total
	Hai	Moshi Rural	Moshi Urban	Same	
1967	116, 974	242, 075	29, 423	149, 635	**538, 107**
1978	172, 444	312, 041	52, 066	133, 628	**670, 179**
1988	200, 136	342, 553	96, 838	170, 053	**809, 580**
2002	259, 958	402, 431	144, 836	211, 738	**1,018, 963**
2012	210, 533	466, 737	184, 292	269, 807	**1,131,369**
Est. 2018	234, 318	519, 468	205, 113	300, 289	**1,259,188**

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

Table 5: Human Population Growth Rates in the Districts Near KF for the Period 1967-2018

District	1967 – 1978	1978 – 1988	1988 - 2002	2002 - 2012	2012 - 2018
Hai	4.3	1.6	2.1	-1.9	1.9
Moshi Rural	2.6	1.0	1.2	1.6	1.9
Moshi Urban	7.0	8.6	3.5	2.7	1.9
Same	-1.0	2.5	2.2	2.5	1.9
Total	2.2	2.1	1.8	1.1	**1.9**

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

3.3.2.3 Natural Reasons for Land-Use Changes in Kahe Forest

The findings from the questionnaire survey indicate that the majority (62.7%) of respondents strongly agreed that climate change and variability contributed to land-use changes in KF. They contend that changes in weather, were the main drivers of most human activities in developing countries. On the other side wildfires accounted for about 14.7 %.

Table 5: Natural Reasons for Land-Use Changes in KF

Reason	Rank					Overall
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N=150
Wildfires	22 (14.7)	12 (8)	35 (23.3)	23 (15.3)	58 (38.7)	150 (100)
Climate change & variability	94 (62.7)	22 (14.7)	0 (0)	23 (15.3)	11 (7.3)	150 (100)

Analysis of time series (meteorological) data obtained from the Tanzania Metrological Agency, located at Moshi Airport, which is near KF, from 1987 to 2018, generally shows a slight decline in total annual rainfall. The dependent variables were the parameters of weather and the independent variable was time. The analysis showed a slight change in the pattern of annual rainfall at R2 = 0.0523, $p < 0.05$ (y= 897 – 6.2089x) (Figure 3). Similar results were reported by Lyimo and Kangalawe (2010), who observed that, in Shinyanga Rural District, rainfall was decreasing although at a non-significant rate of R2 = 0.18, F probability > 0.47. Although the decrease was not statistically significant, the amount of rainfall was declining in the area where the study was conducted.

The analysis of time series data from TMA showed a statistically significant increase in maximum and minimum temperature (y = 29.472 + 0.0216x and y = 17.732 + 0.0268x, respectively). Minimum temperature was higher than maximum temperature. For the period 1987-2018, maximum temperature increased at about 1.8oC, while minimum temperature increased by 2.6oC (Figures 4). Generally, it is evident that minimum temperature increased at a higher rate than maximum temperature.

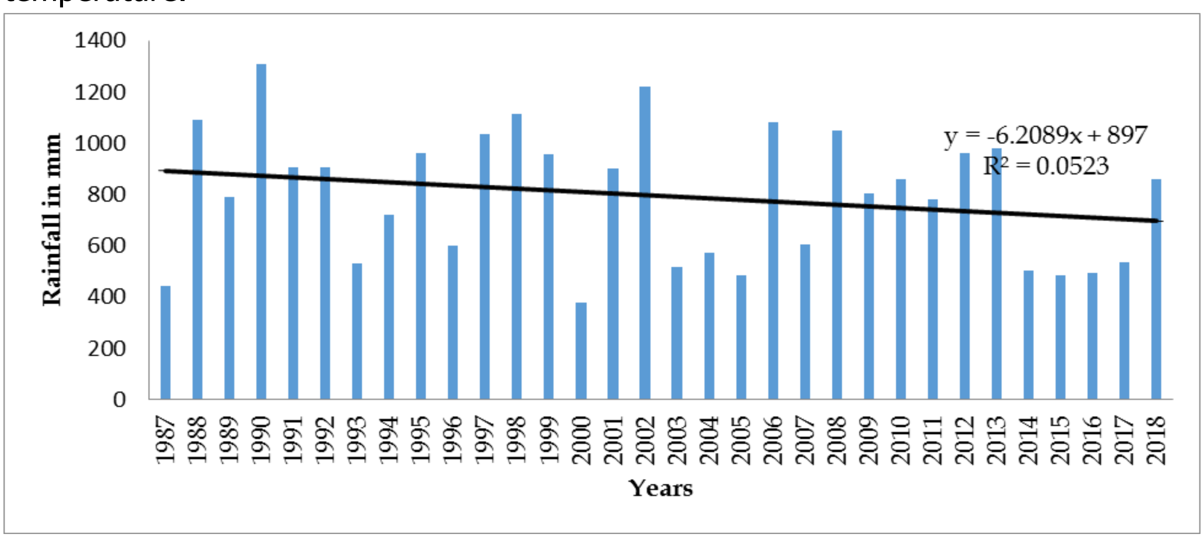

Figure 3: Total Annual Rainfall (in mm) Recorded by the Tanzania Metrological Agency at Moshi Airport

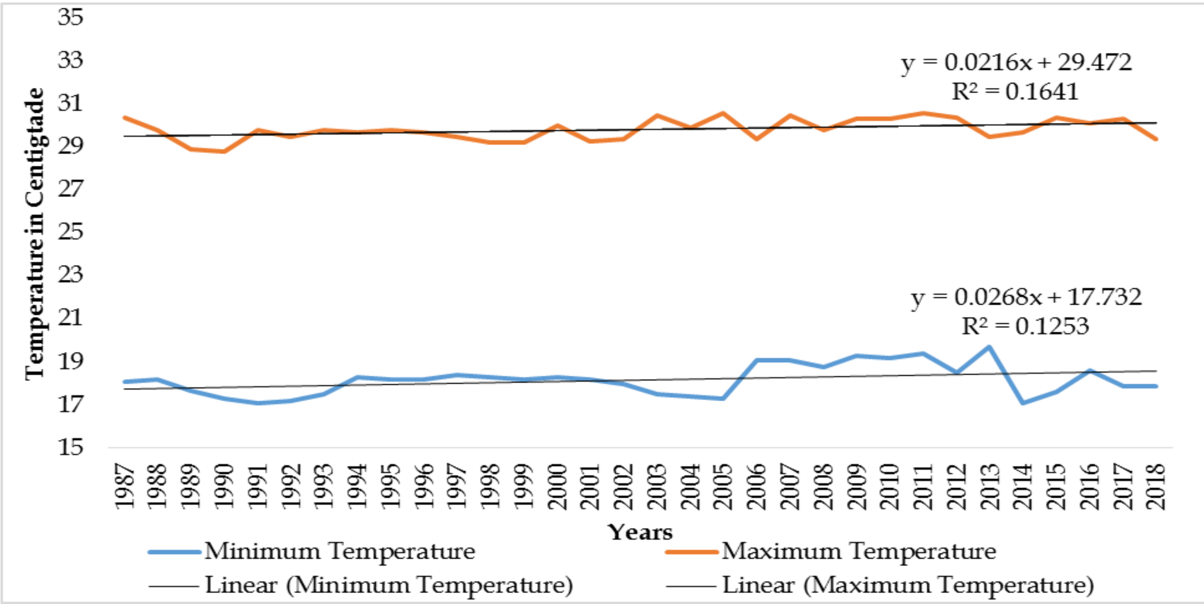

Figure 4: Minimum and Maximum Temperature Recorded by the Tanzania Metrological Station at Moshi Airport

4. Conclusion and Recommendations

4.1 Conclusion

This study concludes that Kahe Forest has experienced spatio-temporal changes in LULCC mainly because of the conversion of land into anthropogenic activities. The activities include agriculture, collection of fuelwood, charcoal-making, and the harvest of timber and other building materials. These activities cause environmental degradation in Kahe Forest. The changes in land use and land cover constitute a complex process that involves the interaction of various factors. Demographic pressure, the influence of markets, biophysical factors and policies are among the factors for the changes. However, the factors act simultaneously and separately at different magnitudes in terms of time and space to influence the changes in question. High demand and higher prices of forest products coupled improved infrastructure influenced the overall process of socio-economic activities as most households depend on farming and livestock keeping as their main sources of livelihoods. Furthermore, if the changes continue, they will adversely affect the ecosystem of the forest.

4.2 Recommendations

In order to ensure that Kahe Forest is sustainably managed and conserved, the changes must be monitored over a long period. In addition, land-use planners and decision makers must properly implement their strategies. Therefore, future management and conservation strategies should include an introduction of alternative, environment-friendly sources of livelihoods such as beekeeping. Other steps could be population growth control, intensification of agricultural land use, promotion of community participation in forest management and provision of education on the importance of conserving the forest. Affordable cooking and warming energy technologies must also be provided to safeguard the forest.

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