The Cradle of Knowledge: African Journal of Educational and Social Science Research
AJESSR - ISSN 2304-2885-p, 2617-7315-e
Volume 11, Issue 2, 2023
P.O. Box 555 (00202) Nairobi. Kenya
editor@serek.or.ke

SOCIETY OF EDUCATIONAL RESEARCH AND EVALUATION IN KENYA

Impact of Climate Change on Flora and Fauna of Mount Kilimanjaro, Tanzania

Janeth Mjema[*1], *John Bosco Namwamba*[2], *Joseph Malusu*[3], *Kelvin Kiwale*[4], *and Lucinda Kangwana*[1]
[1]*Department of Urban Forestry and Natural Resources, Southern University and A&M College, 102 Fisher Hall, Baton Rouge, Louisiana, USA*
[2]*Department of Accounting, Finance & Economics, Southern University and A & M College, Baton Rouge, Louisiana,70807 USA*
[3]*Department of Postgraduate Education, Mwenge Catholic University, P.O. Box 1226 Moshi, Kilimanjaro, Tanzania*
[4]*Department of Public Policy. Nelson Mandela College of Government and Social Sciences. Southern University and A&M College, Higgins Suite 409. Baton Rouge, Louisiana, USA*
Email: *janeth.mjema@sus.edu; ernestjaneth@gmail.com*

Abstract
Mount Kilimanjaro, a giant volcanic mountain in Tanzania, Africa, is the highest mountain in the continent. It has experienced observable changes as this paper will discuss. The objective of this study is to describe Mount Kilimanjaro's climate, ecosystems, geology, the impact of climate change on its flora and fauna and model the mountain's lateral cliff retreat with respect to years. Mount Kilimanjaro serves as the source of several water systems in both Kenya and Tanzania. Global warming's impact on the mountain's glacier affects the river systems through flood occurrences. The impact is also felt on the mountain as temperatures rise above the optimum temperatures of normal body activities of many species (both flora and fauna). The data was extracted from a publication. The researchers used the model to predict the elevation in 2040.This could result in suppression of some species and enhancement for those that are able to adapt to warmer temperatures. Invasive species may also be introduced to this environment and thrive. This study found that climate change dictated changes in patterns of large animals' migration and changes in flora and fauna species' population and structure.
Key words*: Mount Kilimanjaro; Climate change; flora; and Fauna*

1. Introduction

Tropical mountains have been found to be centers of biodiversity. Hence, they are important habitats for plants and animals and microorganisms, which all perform vital functions such as carbon storage, nutrient retention in soil, water supply, pollination, and pest control. Sadly, tropical mountain regions are increasingly under threat by overexploitation and the spread of agriculture.

Mount Kilimanjaro is the largest isolated tropical mountain in the world. It is also a large volcano and the highest mountain in Africa. The mountain has three main peaks, with Kibo **19,341** ft (5,895m), being the most recent, having been last active during the Pleistocene. It still has minor fumaroles and consists of a pair of concentric craters of 1.9 x 2.7 km and 1.3 km in diameter with an ash pit of depth of 350m in the center. Mount Kilimanjaro's base stands over an area base of about 388,500 ha. Before discussing the impact of climate change on the flora and fauna of this region, description of the areas' geology, soils ecological zones, and climate are briefly presented as follows.

1.1 Climate of Mount Kilimanjaro

Mount Kilimanjaro has two wet seasons. One in November to December and another in March to May. The mountain experiences dry months between the months of August and October. Studies show that rainfall decreases rapidly with increase in altitude. The average precipitation is about 2300mm at the elevation of about 1,830m in the forest belt, 1300mm at Mandara hut on the higher edge of the forest (2,740m), it is 525mm in the moorland zones (elevation about, 3,718m), at Horombo hut. At Kibo hut (4,630m), it is less than 200mm hence, resulting in desert-like conditions (Schüler, 2012).

The prevailing winds through the mountain are influenced by the trade winds, blowing in the southeast direction. North-facing slopes experience significantly less rainfall. The warmest months in Mount Kilimanjaro range from January to March. At elevations above 4000m atmospheric conditions can be extreme. Much of the mass is often enveloped by mist. However, the former dense cloud cover has recently become rare. The ice cap and glaciers are shrinking rapidly with time, (Hastenrath, 2017), by farm clearances and by fires set by honey-harvesters. Laser-scanning of terrestrial surveys of the cliff facing south of the northern Ice field on the summit Mount Kilimanjaro's crater were taken on three occasions, namely: September 2004, January 2006, and August 2008. Through comparison of the three scans, the rates of lateral cliff retreat and surface lowering can be assessed. For the period 2004–2006, the average lateral retreat was found to be 1.39 m per year, falling to 0.89 m per year for the period 2006–2008.

1.2 Geology of Mount Kilimanjaro

According to Minja (2014), the mountain is composed of both shield and volcanic types of eruption. Different flows have produced a variety of different rock types over time. The predominant rock types on Shira and Mawenzi the predominant rock types are trachybasalts. The later lava flows on Kibo manifest a gradual change from trachyandesite to nephelinite. Several intrusions such as the massive radial and concentric dyke-swarms on Mawenzi and the Shira Ridge, and groups of nearly 250 parasitic cones formed chiefly from cinder and ash also present. Evidence of past glaciation is manifested on all three peaks, with morainic debris found to exist as low as 3,600m.

The mountain has however, lost 82% of its ice cap since 1912 and 55% of its remaining glaciers since 1962. Kibo still retains permanent ice and snow and Mawenzi also has patches of semi-permanent ice. Mount Kilimanjaro was however, predicted to lose its ice cap by 2015. The mountain remains a critical water catchment for both Kenya and Tanzania. However, the receding ice cap and deforestation, several rivers have dried up, affecting the forests and farmland below. Mount Kilimanjaro is encircled by mountain forest. Myriads of fauna are found in the park, with some being classified as endangered species (Akinsemolu, 2020).

1.3 Mount Kilimanjaro ecological zones, flora, and fauna

Ecologists view high mountain areas as being regions of a favorable environment for the survival of significant proportions of global biodiversity, and support approximately one third of earth's biodiversity (Spehn, 2011). Kilimanjaro has five distinct ecological zones, each about 1000m in 'height'. At 800m to 1800m bush land with villages exists. Farms and grassland are also to be found here (Hemp, 2006).

The next 'level' is composed of vegetation comprising dense rainforest at 1800m – 2800m. This green zone receives an annual rain of 1000 to 2000mm. Some of the species found here include huge tree ferns, sycamore trees, junipers, as well as moss also known as "old man's beard". The humid zone is ideal for multitudes of plants, some of which are endemic like the "impatiens Kilimanjaro" (Butynski & de Jong, 2018).

The semi-alpine heath and moorland zone of Mount Kilimanjaro is found in the range, 2800m to 4000m. Species such as the strange giant groundsel, Senecio trees, Lobelias and the colorful red- hot pokers exist here (Spehn, 2011). The main source of the indirect precipitation in this zone comes in the form of mist which can envelope you without warning. Temperatures here can drop to 0°C. At heights exceeding 4000m, the alpine desert zone dominates, with little rainfall and extreme temperature variations from night today. Here a wide variety of plants is not found. One may find here some everlastings and a few yellow daisies.

From 5000m upward, one enters the frozen moonscape of the arctic zone, with only rock and ice.

The nights here are quite cold, and the sun's radiation is extreme. Practically no life is found here and the lichens that do survive grow about 0.5mm a year (Spehn, 2011). Steep environmental gradients, particularly temperature and precipitation gradients, characterize mountain ecosystems. They are high-elevation habitat islands cut off from the adjacent plains. Changes in environmental conditions pose a particular hazard to endemic species that only exist in a few locations, such as mountain tops (Spehn, 2011).

1.4 Mount Kilimanjaro's flora

Mount Kilimanjaro features a diverse environment, particularly in terms of flora kinds, due to the mountain's wide variety of altitude and rainfall. Mt. Kilimanjaro is especially important because of the diversity of its ecosystems. According to Schuler et al (2012), the dominant species of the submontane forest between 1,300- 1,600m in the west and 1,600-2,000m in the north are *Croton megalocarpus* and *Calodendron capense.* Dominant in the lower to middle montane forest between 1,600-2,200m in the west and 2,000-*2,*400m in the north is *Cassipourea malosana.* However, on the southern and southeastern slopes from 1,600 to 2,100m the dominant lower montane forest species is the commercially valuable camphorwood *Ocotea usambarensis;* from 2,100 to 2,400m the dominant middle montane forest species are camphorwood *Ocotea usambarensis* with yellowwood *Podocarpus latifolius,* a large evergreen, with the tree fern *Cyathea manniana*, sometimes growing to 7m high. From 2,400 to 2,800m the dominant upper montane forest species are *Podocarpus latifolius* with *Ocotea usambarensis.* The subalpine southern and southeastern slopes between 2,800-3,100m have forest of *Hagenia abyssinica* with *Podocarpus latifolius* and *Prunus Africana*; and on the north slopes *Juniperus procera - Podocarpus latifolius forest* with *Hagenia abyssinica*. Above 2,800m to the edge of the tundra at 3,500m is *Erica excelsa forest* (Pepin et al,2014).

The occurrence of non-anthropogenic forest fires on Mount Kilimanjaro has risen with climate change. The structure and composition of the subalpine vegetation on this mountain is strongly influenced by recurrent fires. At elevations above 3200 meters above sea level *Erica excelsa* forest has presently been replaced by *Erica trimera* and *Erica arborea* bush in most areas. Erica vegetation is largely influenced and controlled by fire. According to Pepin (2014), the growing influence of fire pushed down the forest line replacing Erica forests with Erica bush. Fire has also shifted the upper frontier of Erica trimera bush and replaced it with a vegetation of Helichrysum cushion. This cushion is not threatened by fire since its limited biomass provides little fuel. The distances between patches of vegetation and cushions are too large to permit the spreading of fire too. On reaching this vegetation zone the spread of fire stops. In 1976, the Erica trimera bush, which today is presently depressed in the northern and western portions of the mountain below 3400 m above sea level, reached higher elevations up to 4100m a continuous belt (Zawierucha et al,2019**.**

1.5 Mount Kilimanjaro's fauna

The entire mountain along with the montane wooded area belt, a part of which extends into the National Park, is inhabited by myriads of fauna species. They include, one hundred and forty mammals, such as, 7 primates, 25 carnivores, 25 antelopes and 24 species of bat. Above the tree line at least seven of the larger mammal species were recorded. Some of them may, however, be residents of the montane wooded area habitat.

The eastern tree hyrax (*Dendrohyrax Validus*) (VU), grey duiker (*Sylvicapra Grimmia*), and eland (*Tragalaphus Oryx*), which occur in the moorland, are the most frequently encountered mammals above the treelined, with bushbuck T. scriptus and red forest duiker (*Cephalophus Natalensis*) occasionally moving out of the forest into the moorland and grassland, and central African savanna buffalo (*Syncerus caffer*) Between the Namwai and Tarakia Rivers, an estimated 220 elephants (*Loxodonta Africana*) (VU)) are found, with some on the upper slopes. Although golden moles
(Chrysochloridae) are missing, insectivores and rodents can be found above the tree line, especially during times of population expansion.

The montane woods are home to three primate species: the blue monkey, the eastern black-and-white colobus monkey, and the eastern black-and-white colobus monkey. Leopards (*Panthera pardus*) and some of the species listed above are among the mammals found, as are Colobus guereza caudatus and bushbaby Galago species. Abbot's duiker (Cephalophus spadix) (EN) is only found on Mount Kilimanjaro and a few nearby ranges. Chanler's mountain reedbuck (*Redunca fulvorufula chanleri*) (VU) is probably gone, while eastern black rhinoceros (*Diceros bicornis*) (CR) is now extinct in the area. The changing weather patterns have impacted animal distributions as well as terrain characteristics (Altmann et. al. 2002). Changes in migration behavior and population dynamics of large animals has been observed in the forests of Mt. Kilimanjaro.

1.5 Impacts of climate change

A study by Minja (2014) found that increased drought due to CC&V fostered forest fires, melting of the glacier and decreased hydrology. Studies suggest that the Kibo glacier will diminish by the mid-21st century. Despite the permanently harsh conditions of Mount Kilimanjaro's glacier/snow habitats, they have always supported a remarkable diversity of life ranging from bacteria to animals (Zawierucha., & Shain, 2019). Sadly, according to many studies, the existence of equatorial glaciers is almost over, which may likely lead to mass extinctions of species. Glaciers are very important since they support the existence of cold streams, which are natural habitats to unique pools of plants and animals. Furthermore, the glaciers themselves are habitats to plants and animals (Zawierucha, & Shain, 2019).

As climate changes over time, the disappearance of Mount Kilimanjaro's unique flora and fauna has been observed due to forest fires. Significant fires were found to have been initiated naturally (Minja, 2014). Among the impacts of climate change is the frequency of sightings of black and white colobus monkeys. They presently have reduced in number and are only sighted occasionally. Species whose numbers have also fallen include the grey duiker and eland. These are presently categorized as endangered species. The once common black rhinoceros (*Diceros bicornis*) is now extinct.

The occurrence of fires mainly natural because of climate change was found to have destroyed attractive flowers such as red-hot poker which used to be seen on all climbing routes especially the Marangu route. Climate change was shown to have also influenced population changes in wild dogs, elephants, mountain reedbuck, leopard. The shrinking of glaciers on Mount Kilimanjaro was found to have favored the thriving of some microorganism species. Periglacial soils and ice on Mount Kilimanjaro were shown to contain significant diverse and rich populations and communities of Bacteria and Eukarya implying that there could have been high rates of dispersal to the top of the mountain. It is possible that this habitat was more conducive to microbial life than was previously thought (Vimercati, et.al. 2019).

2. Methodology

This study was carried out by reviewing studies carried out on Mount Kilimanjaro that have been published in over 20 peer papers reviewed. Information related to the stud topic was extracted and used to model the change of the ice top with respect to the number of years, and hence, predict elevation in 2040. The results are presented in this document. Model of lateral cliff retreat versus years on Mount Kilimanjaro (2002-2008).

Data analysis here involved synthesis of information in the publications downloaded that was related to Mount Kilimanjaro's flora and fauna. After synthesis of information, the information's were linked to convey messages on the subject being studied in this paper. Microsoft excel statistical tool was used to model data of lateral cliff retreat with respect to years.

3. Results and Discussion

Among the impacts of climate change is the change in the size of ice on Mount Kilimanjaro. This is a manifestation of change in climate on the mountain *vis-à-vis* years. In September 2004, January 2006, and August 2008, terrestrial laser-scanning studies of the south-facing cliff of the northern Ice Field atop Kilimanjaro's summit crater were conducted by Pepin et.al. (2014). The rates of lateral cliff retreat and surface lowering can be calculated by comparison of the three scans. The average annual lateral retreat from 2004 to 2006 was 1.39 m. For the time 2006 to 2008 it dropped to 0.89. The rates are like those determined in prior studies which utilized ablation stakes. However, the rate of surface decreasing is substantially slower, at 0.65 m per year and 0.25 m per year, respectively. Most of the lateral decreases takes place during the austral summer, when seasonal forcing (radiation on a south-facing cliff, radiation on a flat surface, surface vapor pressure, and relative humidity) are highest.

Table 1. Lateral cliff retreat for 2004-2008 on Mount Kilimanjaro (Pepin et al., 2014)

Year	Average (m)
2004	5789.39
2006	5788.52
2008	5787.88

Using Microsoft Excel's statistical tool kit, a prediction model of average elevation at the ice top on the cliff versus years was plotted. The model is presented in Figure 1, and has an R square greater than 95%, suggesting that it is a strong model.

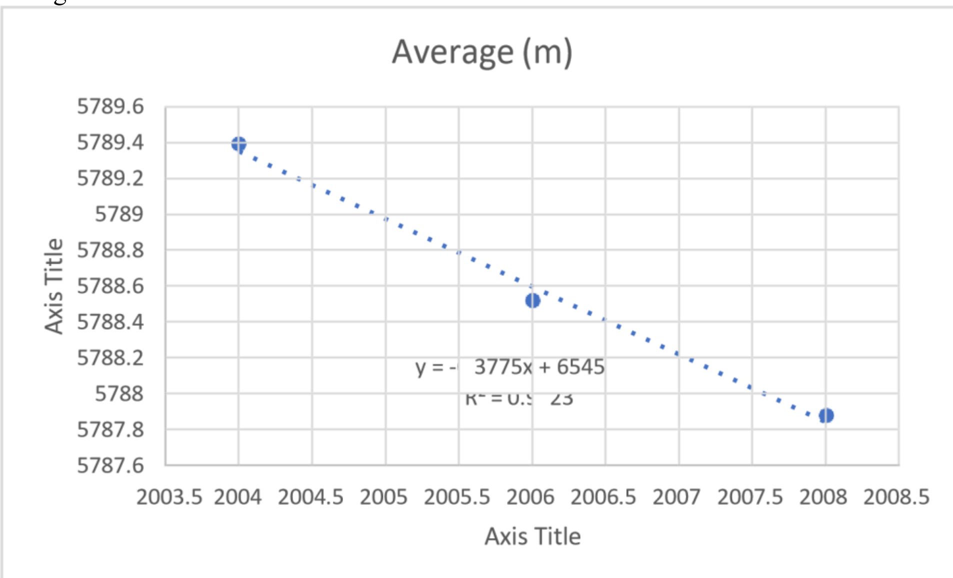

Figure 1. Model of lateral cliff retreat versus years on Mount Kilimanjaro. (2002-2008)

Linear extrapolation of the model displayed in Figure 1 was used to produce the predicted elevation for the year 2040. The results are presented in Figure 2. According to the model, in 2040 the cliff retreat is expected to be 5776 m.

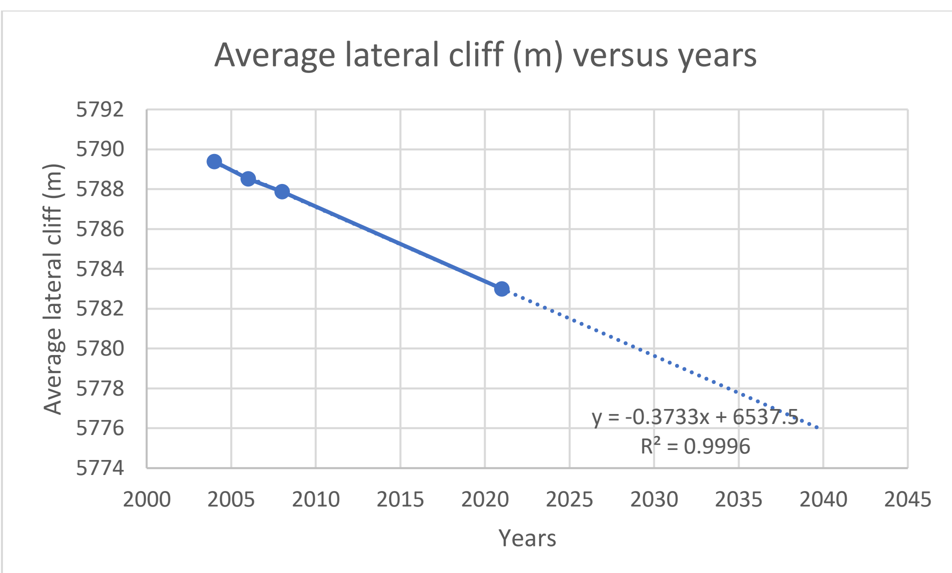

Figure 2. Model of lateral cliff retreat versus years on Mount Kilimanjaro (2002-2021)

To determine whether the relationships between the elevations with respect to years was statistically significant, regression analysis with the Microsoft Excel tool kit was carried out. It yielded Table 2. The p value presented in Table 3 is less than 0.05, the level of significant. Hence the relationship was statistically significant.

Table 3 Summary for the model for lateral cliff retreat versus years on Mount Kilimanjaro (2002- 2040)

Regression Statistics	
Multiple R	0.999958
R Square	0.999917
Adjusted R Square	0.999889
Standard Error	0.058798
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	124.9377	124.9377	36138.6	3.20974E-07
Residual	3	0.010372	0.003457		
Total	4	124.9481			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	6532.37	3.931734	1661.448	4.81E-10	6519.85744	6544.883	6519.857	6544.883
Year	-0.37078	0.00195	-190.102	3.21E-07	-0.376983938	-0.36457	-0.37698	-0.36457

4. Conclusion

Climate change has become one of the most pressing global issues of our time, and one of the area's most directly and dramatically affected by this global phenomenon is the flora and fauna of Mount Kilimanjaro in Tanzania. Presently, the effects of global climate change on the mountain's ecosystem and its non-human inhabitants are increasingly pronounced and concerning.

The most pressing issue facing Mt. Kilimanjaro's flora and fauna is the increasing number of temperatures on the mountain. Right now, the average temperature on Mt. Kilimanjaro is on the rise, which is resulting in a dramatic reduction of the mountain's snow cover. The decrease in snow cover, in turn, is having significant negative impacts on species of birds, mammals, plants and invertebrates native to the mountain's upper slopes. For example, the most prominent bird species of Mt. Kilimanjaro, the Lammergeier Vulture, is experiencing a downward population trend due to the melting of its heavily snow-dependent habitat.

The warming of the mountain's temperatures is also resulting in the increased prevalence of species that are non-native to the mountain's ecosystem. This is likely since these non-native species have a greater capacity to thrive in the warmer climate, placing an additional strain on the resources of the region's native species. This study found that climate change influenced changes in patterns of large animals' migration and changes in flora and fauna species' population and structure.

5. Recommendations

- Geo-engineering interventions such as cloud seeding and aerosol injections should be considered as possible approaches to control, reduce, and potentially reverse the trajectory of rising temperatures on Mt. Kilimanjaro.
- The implementation of sustainable, low-carbon energy policies in the nearby towns and cities to mitigate some of the increased pressure placed by greenhouse gas emissions on the mountain's fragile ecosystem.
- Introducing new and innovative conservation strategies that focus specifically on monitoring, controlling and eradicating non-native species from the mountain's ecosystem.
- The introduction of new species to the mountain's ecosystem could be considered if it is determined that these species are capable of co-existing successfully with other species found on the mountain.

Reference

Akinsemolu, A. A., & Akinsemolu, A. A. (2020). Effects of Everyday Activities on the E Butynski, T. M., & de Jong, Y. A. (2018). Geographic range, taxonomy, and conservation of the Mount Kilimanjaro guereza colobus monkey (Primates: Cercopithecidae: Colobus). *Hystrix*, *29*(1), 81. cosystem. *The Principles of Green and Sustainability Science*, 81-107.

Butynski, T. M., & de Jong, Y. A. (2018). Geographic range, taxonomy, and conservation of the Mount Kilimanjaro guereza colobus monkey (Primates: Cercopithecidae: Colobus). *Hystrix*, *29*(1), 81.

Hastenrath, S. (2017). Changes in African Glaciers since the 19th Century. In *Oxford Research Encyclopedia of Climate Science*.

Hemp, A. (2006). Continuum or zonation? Altitudinal gradients in the forest vegetation of Mt. Kilimanjaro. *Plant ecology*, *184*, 27-42.

Minja, G. (2014). Vulnerability of tourism in Kilimanjaro national park and the livelihoods of adjacent communities to the impacts of climate change and variability. *European Scientific Journal*, *10*(29).

Pepin, N. C., Duane, W. J., Schaefer, M., Pike, G., & Hardy, D. R. (2014). Measuring and modeling the retreat of the summit ice fields on Kilimanjaro, East Africa. *Arctic, Antarctic, and Alpine Research*, *46*(4), 905-917.

Schüler, L., Hemp, A., Zech, W., & Behling, H. (2012). Vegetation, climate, and fire-dynamics in East Africa inferred from the Maundi crater pollen record from Mt Kilimanjaro during the last glacial–interglacial cycle. *Quaternary Science Reviews*, *39*, 1-13.

Spehn, E. (2011). Mountain biodiversity: effects of climate change and how to manage them. *Mountain biodiversity: effects of climate change and how to manage them.*, (60), 40-43.

Vimercati, L., Darcy, J. L., & Schmidt, S. K. (2019). The disappearing periglacial ecosystem atop Mt. Kilimanjaro supports both cosmopolitan and endemic microbial communities. *Scientific Reports*, *9*(1), 10676.

Zawierucha, K., & Shain, D. H. (2019). Disappearing Kilimanjaro snow—Are we the last generation to explore equatorial glacier biodiversity? *Ecology and Evolution*, *9*(15), 8911-8918