African Mountains in a Changing Climate: Trends, Impacts, and Adaptation Solutions

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Source: Mountain Research and Development, 39(2)

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-19-00062.1

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

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ARCOS NETWORK

African mountains are home to millions of people and provide a diversity of ecosystem services. Coupled with factors such as population growth and land-use change, climate change is putting more pressure on these mountains, with potential impacts on mountain ecosystems and ecosystem services and, therefore, on mountain people's wellbeing and livelihoods. However, there is limited information on how climate change is affecting African mountains, mountain people, and ecosystems. In this paper, the Albertine Rift Conservation Society uses published work and case studies provided by experts to compile the latest knowledge on climate change trends, impacts, and existing adaptation initiatives in African mountains to provide recommendations on how best to address the impacts of climate change.

Background

The African continent has 11% of the world's mountains, and 20% of Africa's total surface area is made up of mountains. They are home to more than 202 million people (FAO 2015). African mountains are characterized by high levels of biodiversity and provide ecosystem services to millions of people (Alweny et al 2014; Capitani et al 2018). Due to higher rainfall and high-quality agricultural land, these mountains are often centers of food production and serve as water reserves for the surrounding lowlands (FAO 2015; Cuni-Sanchez et al 2016). These pristine landscapes also attract millions of visitors annually, producing billions of dollars in tourist revenue that is vital to national economies (Marchant et al 2018).

Despite this importance, African mountains are facing socioeconomic changes driven by local and global factors, such as population growth (FAO 2015) and land-use changes (Brink et al 2014; Jung et al 2016). Population growth together with socioeconomic development has led to competition over resources for agriculture and pastoralism, water provision, and biodiversity conservation (Marchant et al 2018). Climate change compounds these effects, putting more pressure on African mountains, with potential impacts on mountain ecosystems and ecosystem services and, therefore, mountain people's wellbeing and livelihoods.

However, information on how climate change is affecting African mountains and its impact on mountain people and ecosystems is limited. In 2014, the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) compiled the available knowledge on climate change trends, its impact, adaptation efforts, and emerging risks in Africa (Niang et al 2014).

Although the IPCC report (2014a) provides a few insights into climate change and its impact on African mountains, it does not explicitly focus on the continent's highly diverse mountain regions and does not consider changes according to geographic locations, climate zones, and socioeconomic settings. Moreover, literature on the impacts of climate change and adaptation in African mountains is very limited. A recent analysis of peer-reviewed literature on adaptive capacity revealed that of the 276 papers analyzed only 33 focused on Africa. The analysis does not show how many of these papers address the situation in African mountains (Siders 2019). Another review looking at the linkages between climate change and landslides identified only one paper focusing on Africa out of 103 papers (Gariano and Guzzetti 2016).

Recognizing this knowledge gap and being aware of the increasing number of initiatives to strengthen resilience to climate change and enhance the adaptive capacities of people living in African mountain regions, the Albertine Rift Conservation Society (ARCOS) attempted to compile recent relevant information. In doing so, ARCOS aims to inform decision making on climate change in African mountains.

Relevant peer-reviewed literature published between May 2013 and June 2019 was identified using the Web of Science and Scopus databases. The titles, abstracts, and keywords were searched for the following terms: Africa, climate change, mountains or highlands or rift. The results were refined by adding search terms, such as livelihoods, food, livestock, and hazards (droughts, landslides, etc). In some instances, where no recent information was available, we referred to older publications. In addition, we considered case studies of specific mountains, such as the Drakensberg (South Africa), Mt Maroti (Lesotho), and Chimanimani Mountains (Zimbawe) in southern Africa, the Highlands of Kenya, Mount Elgon (Uganda) in East Africa, and Mount Cameroon (Cameroon) and the Atlas region (Morocco) in Central and North Africa, respectively. Insights from the case studies were provided by mountain researchers and practitioners in Africa. The case studies contained relevant published and gray literature. We present preliminary insights into available knowledge on climate change and its impacts on mountain ecosystems (including fauna), people's livelihoods, and their adaptation approach to climate change.

The activity was part of a broader global program to promote

https://doi.org/10.1659/MRD-JOURNAL-D-19-00062.1

TABLE 1 Changes in temperature in some African mountains.

Country	Place	Changes	Period	Data	Source
Uganda	Mount Rwenzori	Increase of 0.5°C per decade	Since mid-1960s	Observed	Taylor et al (2006)
Tanzania	Mount Kilimanjaro,	Increase of 0.27°C per decade	1976–2000	Observed	Buytaert et al (2011)
Ethiopia	Ethiopian Highlands	Increase of 0.72°C min. temperature and 0.36°C max. temperature per decade	1954–2008	Observed	Gebrehiwot and van der Veen (2013)
All of Africa	Ethiopian Highlands (zoom)	Between 2°C and 3°C	2040–2070	Projected (RCP4.5 and RCP8.5)	Platts et al (2015)
Maghreb	Atlas	Between 1.4°C and 2.6°C	2049–2065	Projected	Marchane et al (2017)

"Sustainable Mountain Development for Global Change" (Wehrli 2014) and to enhance the visibility of mountain communities in global development debates. The 5-year program (2014–2018) was funded by the Swiss Agency for Development and Cooperation.

African mountains and climate change

The Fifth Assessment of the IPCC (2014a) did not specifically highlight climate trends in African mountains. Instead, it presented climate trends for the whole Africa and highlighted an increase in surface temperature of 0.5°C or more during the last 50–100 years, a trend that is likely to continue during the 21st century under both low- and high-emission scenarios.

The low coverage of African mountains in the IPCC report could be explained by an existing gap in climate data. Our literature review revealed that few climate data are available for African mountains, and these data are unevenly distributed. The East African mountains are most represented. This can possibly be explained by the uniqueness of those mountains. They contain the only remaining glaciers in Africa (Klein and Kincaid 2007), a key indicator of climate change (UNEP 2008). Another reason may be that the East African mountains accommodate the largest proportion of the mountain population, up to 60% of African mountain people (FAO 2015). Climate data gaps can be more easily explained for other African mountains. For instance, in South Africa, where part of the Drakensberg is located, reliable records on climate data do not exist for much of the mountain areas because of their inaccessibility (Mukwada and Munatsa 2018). The next section summarizes information on changes in observed and projected temperature and rainfall in African mountains.

Changes in temperatures in African mountains

The observed changes in temperature (see Table 1) align with the IPCC report findings. Historical meteorological data, both observed and projected, show an increase in temperature over the past few decades, especially during the 21st century. In the East African mountains, historical data on the 2 highest mountains, Rwenzori and Kilimanjaro, show an increase of up to 0.5°C per decade in the average air temperatures since the mid-1960s (Taylor et al 2006; Buytaert et al 2011). In the Ethiopian Highlands, the increase over time was detected by measuring changes in the minimum and maximum temperature (Gebrehiwot and van der Veen 2013). Other factors were used for other mountains. For example, by comparing climate zonation between the periods 1961–1985 and 1986–2005 in the Maghreb region, the increase in temperature was translated from the reduction in humid and subhumid bioclimate zones and their replacement by semiarid and arid climate zones (Balaghi 2016).

Furthermore, researchers have considered community perception to trace changes in temperature. Cuni-Sanchez and colleagues (2018) discussed experiences of temperature changes with local communities in a study of 3 mountains in northern Kenya, Mt Kulal, Mt Marsabit, and Mt Nyiro. Communities reported a general increase in temperatures at Mt Kulal and Mt Marsabit but no change at Mt Nyiro. This increase in temperature was confirmed by historical data from the meteorological station in Masabiti town. Projections of future trends indicate that the current warming will continue throughout the 21st century. For example, at Jima, Thaita, and Kilimanjaro, the temperature is projected to increase between 2 and 3°C by the 2070s (Platts et al 2015). In the Rheraya catchment of the Atlas Mountains, climate models from the Med-CORDEX initiative with 2 emissions scenarios—RCP4.5, which leads to high greenhouse gas concentration levels, and RCP8.5, in which total radiative forcing is stabilized shortly after 2100 (Riahi et al 2011)—indicate temperature increases of +1.4 to +2.6°C for the period 2049–2065 (Marchane et al 2017).

Changes in precipitation

The IPCC report (2014a) states that the past decades were marked by changes in rainfall pattern and that these changes will continue to affect many parts of Africa, including the mountains. As for temperature data, precipitation information for African mountains is patchy. The few available examples show different trends according to region. For instance, data from meteorological stations on Mt Marsabit in Kenya indicate an important decrease in rainfall during the first rainy season of each year since 1980 (Cuni-Sanchez et al 2018). On the other hand, data from the Bamenda meteorological station indicate an increase in extreme events (very wet and very dry years) in the Bamenda Highlands of Cameroon, especially during the past 15 years (Mbue et al 2016). Local communities in both Marsabit and Bamenda reported changes in rainfall quantity and distribution. They observed that the rainy season is now shorter with more spells of drought than in past years.

Communities further commented that the rainfall has become unpredictable. One respondent commented "that before you could tell when the rains would come and how long they would last, now sometimes the rains skip [non-occurrence of rains], and even when it rains you cannot tell if they will be the long rains, the short rains" (Cuni-Sanchez et al 2018). However, in some other areas, such as the Maloti Mountains in Lesotho and parts of Drakensberg, the precipitation did not significantly decline; instead the pattern has changed (Taylor et al 2016; Mukwada and Munatsa 2018).

Similarly, predictions for future precipitation show changes according to the region. In some cases, predictions have been made specifically for mountains. For instance, projections for 3 mountains of East Africa (Taita Hills, Kilimandjaro, and Jimma) show that in the Taita Hills and Kilimanjaro, rainfall will increase with increased variability of seasonal patterns. In the Jimma Highlands of the same region, there is a risk of prolonged and more intense dry seasons. This translates into a hotter future with wetter rainy seasons and drier months for the Taita Hills, a hotter future with similar rainy seasons and variable dry months for the Mt. Kilimanjaro area, and a hotter future with more extreme dry and wet seasons in the Jimma Highlands. Predictions have also been made for larger regions that include mountains. Downscaling of precipitation, predicted in northern Morocco, shows rainfall increases in December/January of up to about 60 mm in the period 2071–2100 compared to the period 1990–2019 (Schilling et al 2012). In the East African region, however, there has been less success in predicting rainfall variability using climate models. This is mainly because rainfall is influenced by a range of large- and local-scale drivers and feedbacks. Much of the variability that occurs during the short rainy season is linked to large-scale climate systems, such as the El Niño Southern Oscillation (Marchant et al 2018).

Climate change impacts in African mountains

Climate change impacts on mountain biodiversity and ecosystem services

Climate change constitutes a potential threat to montane biodiversity (Taylor et al 2015). One of the main effects is the shift in distribution, biomass, and species richness in mountain ecosystems (Hiltner et al 2016; Ponce-Reyes et al 2017). In the Albertine Rift, a mountainous hotspot, containing more endemic vertebrates than anywhere else in Africa, the projected distribution of ecosystems under a changing climate by 2070 found that areas with suitable conditions for most ecosystems will contract rapidly in extent and shift up in altitude. This will pose an immediate risk to high-altitude ecosystems and endemic species (Ponce-Reyes et al 2017). This is the case for mountain gorillas; according to climate change models, their current habitats in the Virunga Massif could become completely unsuitable by 2090 (AWF, IGCP, and EcoAdapt 2010). Climate suitability is also projected to influence routes for the movement of 12 bird species endemic to the Albertine Rift (extending through Uganda, the Democratic Republic of Congo, Rwanda, Burundi, and Tanzania); Bagchi et al 2018). This trend is not unique to the Albertine Rift. In South Africa, comparison of historical (from 90 years ago) and current occurrence data from a zone of sympatry in the tropical Soutpansberg Mountains (at 1250 masl) showed complete replacement of the grassland-adapted rodent species (*Otomys auratus*) by the savanna-adapted species (*Otomys angoniensis*) because of changes from a grassland-dominated to thicket-dominated landscape (Taylor et al 2015).

Another effect of climate change will be the reduced availability of ecosystem services to both mountain and lowland communities in Africa. Water, for instance, which is one of the main ecosystem services, is critical for direct domestic use and for agriculture and livestock activities. Both activities are strongly dependent on seasons; seasonal changes may affect agricultural and livestock productivity (Cuni-Sanchez et al 2018).

Another impact is the receding glaciers in African mountains, which have lost up to 80% of their surface area since 1990 (IPCC 2007). This, however, is of little concern for future water supply according to several studies (Mölg et al 2008;

https://doi.org/10.1659/MRD-JOURNAL-D-19-00062.1

Taylor et al 2009; Hardy 2011). For example, a study by Taylor et al (2009) notes that water from glaciers contributes relatively little to total river flows in the East African region. The same study found that meltwater from the glaciers on the Rwenzori Mountains contributes less than 2% of the discharge of the main river downstream.

Additionally, climate change will impact the provision of ecosystem services. One specific example is found in Mt Cameroon, where the changes in rainfall patterns are affecting honey production. Local famers known for their "white honey" from beehives placed at high altitudes report that honey production is reduced in drier or wetter years (Cuni-Sanchez et al 2018).

Climate change impacts on mountain people's livelihoods and health

Like other communities in Africa, mountain people are directly dependent on natural resources and ecosystem services for their livelihoods. Agricultural activities and livestock serve for both food security and income generation (Alweny et al 2014). Therefore, any change in the availability of water services, for example, will reduce agricultural and livestock productivity, thereby affecting their income. The Middle Drâa valley in Morocco is one of many semiarid to arid mountainous areas struggling with increasing water scarcity that threatens self-sufficient husbandry and irrigation agriculture.

While the climate scenario shows a significant decrease in available water resources up to 2029, all socioeconomic scenarios show an increase in water demand (Johannsen et al 2016). These impacts are not limited to mountain people; lowland communities are also affected. For the Kilombero catchment in Tanzania, an East African floodplain surrounded by mountainous areas, modeling results indicate that increased temperatures will intensify the distinctive features of the dry and rainy season. This will aggravate hydrological extremes, such as decreasing low flow. Consequently, agricultural intensification is shifting from upland cultivation into the wetlands, which have year-round water availability combined with fertile soils (Näschen et al 2019).

Moreover, climate change in mountain areas is linked with the incidence of vector-bone diseases, such as malaria (Hay et al 2002). In the highlands of West Uganda, researchers found that extreme flooding resulted in an increase of approximately 30% in the risk of an individual having a positive diagnosis of malaria in the postflood period in villages bordering a flood-affected river, compared with villages farther from the river. There was also a larger relative impact on upstream versus downstream villages (Boyce et al 2016).

Furthermore, climate change combined with other factors, such as land degradation on mountain slopes, may result in a number of hazards. On Mt Elgon, one of the highest and most populated mountains in eastern Uganda, heavy rains on unstable settlements result in the deaths of tens of people every year and destroy crops and properties (Gorokhovich et al 2013). Another, albeit uncommon, hazard in Africa is cryospheric hazard (Haeberli and Whiteman 2015). The Lesotho Highlands are one of the few places in Africa affected by this. In these mountains, prolonged snow cover sometimes results in human and livestock deaths from isolation and exposure (Grab and Linde 2014).

Climate change adaptation solutions

The IPCC (2014b) defines adaptation as the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm and exploit opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate changes.

Climate change adaptation in African mountains is not a stand-alone process. Our review did not find any climate change plan that specifically focused on African mountains. An assessment done in 2014 of sustainable mountain development in East Africa in a changing climate highlighted a lack of public investment in mountain-specific programs, which marginalizes mountain ecosystems and communities. The assessment further argues that "policymakers do not always consider users of mountain ecosystems as key partners when designing adaptation strategies" (EAC et al 2016). However, mountains are considered to some extent in national climate change plans and strategies, especially in countries that have the main mountain ranges in Africa, including Uganda, Ethiopia, Morocco, Lesotho, and South Africa.

Nevertheless, we found a few scattered adaptation initiatives and case studies that specifically focused on African mountains. They include climate-smart agriculture, ecosystem-based adaptation, and diversification of livelihood incomes. The EAC report further mentioned the importance of implementing specific adaptation measures to manage and reduce the risks of changing rainfall on productive systems, such as agriculture and forestry, and to build resilience.

Improving farming practices: Agriculture is a main livelihood activity in African mountains but is also highly vulnerable to climate change impacts. It is therefore important to develop practices that can tolerate climate change impacts while improving production. A case study provided by Dr Philip Talu from Zimbabwe observes that sustainable farming in the Chimanimani Mountains involved shifting from the rainfed agriculture to irrigation, which has more flexible planting times.

https://doi.org/10.1659/MRD-JOURNAL-D-19-00062.1

Talu observed that sustainable farming practices are already practiced in one village in Chimanimani, and work is under way to extend these practices to other villages in the vicinity. Villagers rely on farming and conservation agriculture: they plant drought-resistant and early-maturity crops. The major adaptation techniques they practice are dry planting, crop diversification, and varied planting dates, in addition to developing irrigation infrastructure. According to Mutekwa (2009), crop diversification in villages in Zimbabwe improves household food security, since different crops respond differently to the same climatic conditions. Drought-resistant crop varieties, such as sorghum (*Sorghum bicolor*) and *rapoko* or finger millet (*Eleusine coracana*), as opposed to the traditional staple maize, are much more common in view of the high frequency of midseason dry spells and shortening of the rainy season. Also, mixed farming and organic crop rotations are protecting the fragile soil surface and may even counteract climate change by restoring organic matter content.

In the East African mountains, coffee is an important cash crop. However, using a mechanistic crop model, Rahn et al (2018) predicted that coffee plants will be severely impacted (coffee yield reductions ranging from 18% to 32%) by increased temperature and water scarcity. Indeed, both the coffee plants and shade trees need water, and therefore careful selection of appropriate shade tree species is required, as well as adoption of other technologies, such as conservation measures or irrigation.

Diversification of livelihood incomes: It is important to diversify income-generating activities to respond to climate change pressures. Farmers in west Cameroon are investing in a sheep or goat (under zero grazing), or a few chickens, which they can sell if crops fail (Mbue et al 2016). Pastoralists in the highlands of Kenya are encouraged to adopt agriculture as a livelihood diversification strategy (Cuni-Sanchez et al 2018). Another option is adopting nonfarming activities. For example, communities in west Cameroon are producing honey and woodcarvings in addition to agriculture. In Zimbabwe, the Chimanimani communities are increasing their income by bottling water and collecting and selling fruit (Semente and Dangare 2015).

Ecosystem-based adaptation: Ecosystem-based adaptation (EBA) is defined as a “nature-based solution that harnesses biodiversity and ecosystem services to reduce vulnerability and build resilience to climate change.” This approach involves interventions such as conservation, sustainable management, and restoration of ecosystems to help people adapt to the impacts of climate change (Jiménez Hernández 2016). EBA restores and maintains ecosystem health, reduces social and environmental vulnerabilities, and generates societal benefits in the context of climate change adaptation (FEBA 2017).

Ecosystem restoration involves a wide range of activities at different levels. In Morocco, forest restoration in the Atlas Mountains involved country-level programs, including the establishment of forest-health-monitoring systems, rehabilitation of degraded ecosystems by increasing the pace of forest replenishment, and fighting forest fires through prevention and risk management systems (Taleb 2016). In Kenya and Ethiopia, a community-based approach called “Farmer Managed Natural Regeneration” (FMNR) is being successfully used to restore forests, especially on agricultural lands. FMNR is the systematic regrowth and management of trees and shrubs from felled tree stumps, sprouting root systems or seeds, or woody thickets. Forest restoration also rehabilitates degraded natural forests so that they can again provide sound ecosystem services. In addition to managing natural forests by establishing protected areas, Ethiopian Highland communities are encouraged to recognize the value of sacred forests for conservation ecology, as areas of high biological diversity, and as shelters for endemic and threatened species (Daye and Healey 2015).

Another EBA approach is to conserve soil and water (FEBA 2017). Such an approach has been applied in the highlands of southwest Uganda targeting farmlands prone to degradation by erosion, resulting in reduced soil erosion and increased water retention (Harari et al 2017).

EBA is helping mountain communities to use ecosystem services sustainably for their livelihoods. This is also the case in transhumance and rangeland rotation systems in the Atlas Mountains. These systems are characterized by the seasonal and recurring movement of livestock, whereby seasonal grazing areas and routes for livestock movement are fixed. They are therefore effective in reducing rangeland degradation. Also, in the Albertine Rift region, ARCOS is working with local communities through a program called “Nature Based Community Development.” The program supports community groups in forming cooperatives that care for and benefit from nature. Through this program, ARCOS has worked with over 32 cooperatives, promoting activities such as agroforestry, beekeeping, and handicrafts. At the same time, communities are encouraged to plant more trees, use energy-saving options (such as cooking stoves), and use organic manure, among other activities.

Conclusions and recommendations

Climate change in African mountains is already happening, and the impacts on mountain ecosystems and people are critical. Our literature review

https://doi.org/10.1659/MRD-JOURNAL-D-19-00062.1

revealed an increase in temperature in most African mountain regions over recent decades; this trend is projected to continue during the 21st century. Changes in precipitation are mainly observed as changing rainfall patterns, but these varied among mountain areas.

The changes are affecting livelihoods and health of mountain and lowland people, as well as ecosystems and ecosystem services. Changes in temperature and precipitation have affected biodiversity in terms of structure and distribution, ecosystem services such as water resources availability, and agriculture, which is fundamental to mountain people's livelihoods and food security. Climate change impacts also include increased incidence of vector-borne disease and disasters such as landslides and flooding. However, some of the effects observed are a result of the combination of climate change and other factors, such as population growth and land-use changes.

Several climate change adaptations have been identified. These include better farming practices, diversification of income-generating activities, and ecosystem-based adaptation.

Significant gaps in climate data can be identified for African mountains. Only a few meteorological stations exist in African mountain areas, and they are generally not well maintained over the long term. In addition, the data are not systematically analyzed, which makes it difficult to draw accurate conclusions to guide decision making. Much of the literature reviewed has used community perception to detect changes in temperature and precipitation.

This review has noted a low coverage of African mountains in global climate change reports, including by the IPCC. Further, the available information is incomplete and fragmented. East African mountains are better represented in terms of climate data in mountains. ARCOS recommends increasing efforts in climate data collection to improve data coverage and to accurately guide adaptation processes in African mountains.

There are no specific plans for climate change adaptation for African mountains. Instead, they are implicitly considered in the national adaptation plans of countries with main mountain ranges, including the East African mountains and the Atlas and Drakensberg. It is important to develop mountain-specific plans and investment and involve mountain people in their design and implementation.

Our main recommendations are that more research is urgently needed to reduce uncertainties in current and future climate change scenarios. Efforts in climate data collection are needed to improve coverage and to accurately guide adaptation processes in African mountains. Additionally, since some climate change impacts are specific to or more intense in mountains, mountain-specific adaptation plans are needed. Finally, since African mountains are rich in biodiversity and ecosystem services, nature-based solutions are an idea that should be promoted for climate change adaptation.

ACKNOWLEDGMENTS

The following contributors are gratefully acknowledged: Aida Cuní Sanchez, Researcher, Department of Environment and Geography, University of York, United Kingdom; Bob R. Nakileza, Senior Lecturer in the Department of Geography and Environmental Management, Makerere University, Uganda; Geofrey Mukwada, Senior Lecturer, Faculty Natural and Agricultural Sciences, University of Free State, South Africa; Jackson G. Majaliwa Mwanjalolo, Senior Lecturer in the Department of Geography and Environmental Management, Makerere University, Uganda; Mohammed Sghir Taleb, Senior Lecturer in the Department of Botany and Plant Ecology, Mohammed V University, Morocco; Philip Taru, Senior Lecturer in the School of Wildlife, Ecology and Conservation, Chinhoyi University of Technology, Zimbabwe; Sue Taylor, Director of AFroMont, Centre for Environmental Studies, University of Pretoria, South Africa. I also acknowledge Susanne Wymann von Dach for invaluable inputs to this manuscript, as well as Isabelle Providoli, Veruska Muccione, and the ARCOS team at large for insightful comments on earlier versions.

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