

# Hydrology II: Hydrology, Society of Regions Surrounding Mount Kenya



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View of the leeward side of Mount Kenya from the Timau region. Mount Kenya is considered as a sacred mountain by the communities inhabiting the surrounding regions. The white snow-capped summit is regarded as the divine resting place of the Agikuyu God, “Ngai.” The glaciers are the source of water and serve as the lifeline of the society

**Abstract** This study evaluated whether the local communities residing in the leeward side of Mount Kenya in East Africa are aware of the on-going glacier changes, and its implications on domestic water supply and livelihoods. The spatial analysis of the glacial changes in Mount Kenya was conducted using medium resolution

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(30 m × 30 m) Landsat imageries and ArcGIS and ENVI software. The local perception survey on glacial changes, river flow, and livelihood impacts was undertaken through face-to-face interviews with 90 riparian residents along the Naromoru and Likii rivers, which included farmers, pastoralists, and urban residents. The findings demonstrated that Mount Kenya has continuously experienced progressive glacial retreat in the last four decades (1976–2016). The level of public perception on the glacial retreat was similar to the actual trend documented through scientific research. Based on this study, we recommend that both the national and county governments should integrate glacial retreat and its hydrological implications in policy and relevant development and natural resources management plans.

**Keywords** Climate change · Glacial recession · Water resources · Local perceptions

## 1 Introduction

### 1.1 Mount Kenya

Mountains in Kenya, as those in other parts of the world, represent an important natural heritage because they ensure water supply for the development of society and the economy. Mount Kenya (~2000 km<sup>2</sup>) is the largest and tallest (5199 m) mountain in Kenya, and the second highest summit in Africa. In terms of regional geography, the mountain is the source of the two largest rivers in Kenya, namely, River Tana that flows 1000 km southeastwards into the Indian Ocean (Omengo et al. 2016) and River Ewaso Ngiro that flows 700 km northeastwards toward the Kenya Somalia border (Fig. 1).

It is estimated that approximately 50% of Kenyans rely on the water resources which originate from Mount Kenya. In addition, the mountain also provides approximately 70% of the country's hydroelectric power. The mountain is surrounded by six different counties, namely Kirinyaga, Nyeri, Embu, Tharaka-Nithi, and Meru on the windward side and Laikipia on the leeward side (Fig. 2). These six counties are heavily dependent on the mountain, which sustains a wide range of economic sectors including agriculture, livestock husbandry, fisheries, forestry, tourism, and hydropower generation.

Geologically, Mount Kenya is a young volcanic cone which formed during the tertiary period (i.e., it originated 3.1–2.6 million years ago) with a base diameter of 80–100 km (Winkler et al. 2010). The mountain is characterized by a wide range of spectacular landscapes including volcanic ridges, deep valleys, moorland plains,

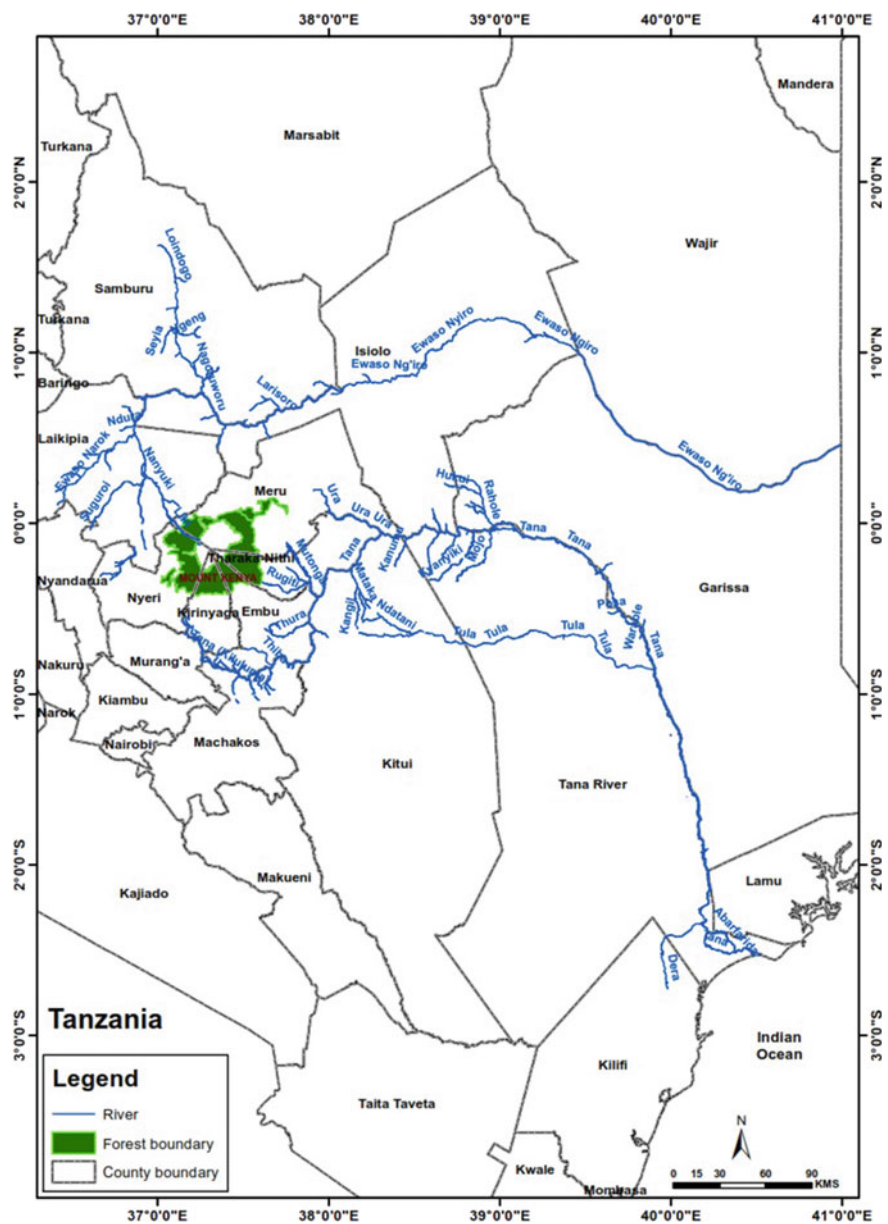


Fig. 1 Regional map of Mount Kenya and its key rivers

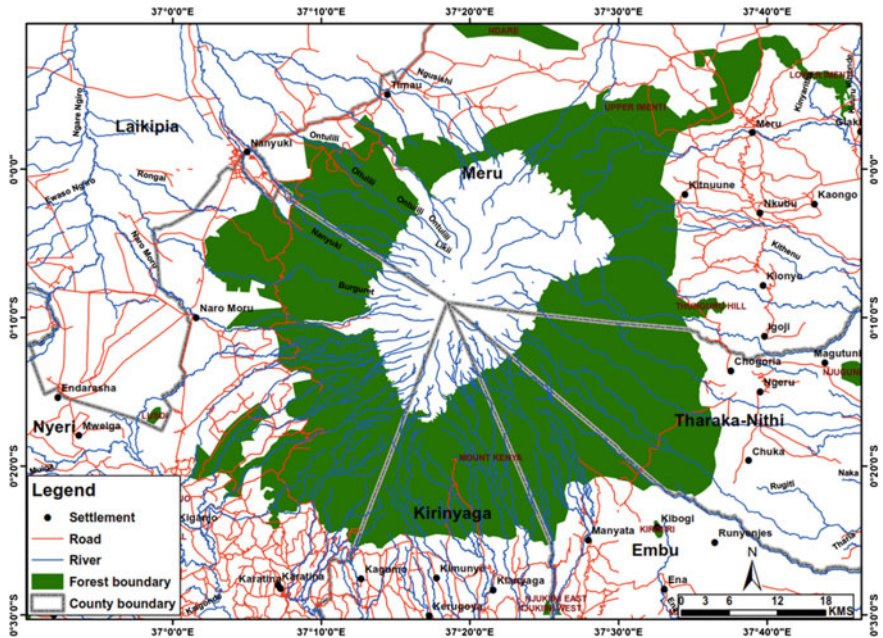


Fig. 2 Map of the six counties bordering Mount Kenya

rugged cliffs, alpine rivers, and lakes. The current summit is the remnant of a volcanic plug which remained after the progressive glacial erosion of softer rocks (Tanui 2009).

The high-altitude afro-alpine zone of the mountain, situated at an elevation higher than 4500 m, is predominantly characterized by low mean temperatures of up to 2 °C, especially during the cold rainy season (March–June), which leads to regular snowfall and glacier formation (Hastenrath 2005). The glaciers are known to enhance the hydrological stability of the mountain ecosystem by storing water in the form of ice, whose gradual release through glacial meltdown in the dry season ensures continuous flow of rivers and uninterrupted water supply to inhabitants in downstream areas (McDowell and Koppes 2017).

Mount Kenya is an important biodiversity area of Kenya with approximately 880 plant species including 11 endemic species in the lower elevation upto 3200 m (Winiger 1990; Mizuno and Fujita 2013). The mountain is characterized by distinct vegetation zones along the altitudinal gradient from dry forest in the low-lying areas (<3000 m), bamboo zone (<3200 m), montane rain forests (3700 m), ericaceous bush (4000 m), high-altitude moorland (>4000 m), and rugged afro-alpine zone at the top (Pellikka et al. 2004; Mizuno and Fujita 2013). The ecosystem supports a wide range of wildlife species including elephants, buffaloes, leopard, bongo, suni, black fronted duiker, bushbucks, water buck, elands, white tailed mongoose, tree hyrax, and giant forest hog (Nyaligu and Weeks 2013).

The mountain is a key asset of Kenya because it sustains a wide range of economic sectors both locally and regionally, namely, water supply, agriculture, forestry, fishing, wildlife conservation, tourism, and hydroelectricity generation. Based on this, Emerton (1996) estimated that the total annual economic value of the mountain ecosystem was more than \$100 million per year. Consequently, the Government of Kenya and the international community have made concerted efforts toward its conservation. In 1932, during the colonial times, a national forest reserve was established. Thereafter, a 715 km<sup>2</sup> national park was gazetted in 1949 while 718 km<sup>2</sup> of the mountain was listed as a biosphere reserve in 1978 under the United Nations Educational, Scientific and Cultural Organization-Man and the Biosphere Programme (UNESCO-MAB). Subsequently in 1997, a total mountainous area of 2023 km<sup>2</sup> was designated as a UNESCO World Heritage Site (UNESCO 2013).

Mount Kenya is regarded as a sacred holy mountain by the communities of the region, which includes the Gikuyu, Ndia, Gichugu, Meru and Embu communities. The snow-white cap on the mountain summit is considered divine, sacred, and the holy resting place of the Gikuyu God, “*Ngai*”, *Mũrungu*, or *Mwene-Nyaga* (Kenyatta 1965). Consequently, the mountain contains a wide range of sacred natural sites in the form of hills (e.g. Karima, Kamwangi, Gakina, and Kirimiri), lakes (e.g. Thaa, Nkunga and Mbutututia), caves (e.g. M’mwenda, Naromoru, Mau, and Old Moses), sacred groves (e.g. Igandegi, Kiamonko, Kionyo), and sacred tree species such as the *Ficus natalensis* (fig tree or *Mũgumo*). The local communities use these sacred sites for various traditional rituals including worship. Some communities in Kenya usually worship while facing Mount Kenya because of its sacred nature (Kenyatta 1965).

## 1.2 Mountain Glaciers and Hydrology

A large number of high-altitude cold mountain summits of the world are characterized by glaciers whose meltwater is usually discharged downstream into the surrounding landscapes. Consequently, one-sixth of the world population depends on rivers flowing downstream from mountain glaciers to meet their water supply demand (Veetil and Kamp 2019). However, this benefit is less significant in Africa due to the reduced glacial coverage. Several studies have shown that the widespread incidents of climate change associated with glacial recession are expected to generate increased meltwater discharge until a peak discharge point beyond which the river flow might decline substantially as the glaciers no longer serve as water sources (Huss and Hock 2018). Consequently, shrinkage of mountain glaciers is likely to generate less discharge of melt water with negative implications on freshwater availability to the downstream consumers.

In Africa, high-altitude glaciers are common solely in three mountains located in the eastern region, namely Kilimanjaro in Tanzania (5895 m), Mount Kenya in Kenya (5199 m), and the transboundary Ruwenzori Mountain in Uganda and the Democratic Republic of the Congo (5109 m). However, the number of glaciers is quite

small compared to those of other mountains in the world. For example, compared to the Himalayas with more than 54,000 glaciers spanning approximately 6,100 km<sup>2</sup> (Bajracharya and Shrestha 2011), Mount Kenya is currently characterized by only 10 glaciers with a total area of less than 1 km<sup>2</sup> (Chen et al. 2018) compared to the 18 glaciers which previously covered the mountain summit.

According to UNESCO, most mountain glaciers in the world, especially the ones in the tropics, have been retreating since the beginning of the eighteenth century due to the on-going climate change and associated precipitation reduction (Schoolmeester et al. 2018; Veettil and Kamp 2019). Rapid glacial retreat has been reported in South America including Venezuela, Argentina, Ecuador, Chile, and Colombia. According to Molg et al. (2008), tropical glaciers including those in Africa are highly sensitive to climate change and can serve as visible indicators of this phenomenon.

Mountain glaciers are known to have a strong link to both local and regional hydrology because they capture and store significant quantities of precipitation through ice formation. Thereafter, glacial runoff associated with the melting of ice due to increased temperature in the dry season (periods of low precipitation) ensures discharge modulation of downstream rivers through the glacier compensation effect. The glacial runoff is usually generated from a mix of both surface and subterranean meltwater, which flows downstream and is discharged in springs that feed into streams and subsequently into the rivers. In the wet seasons, the discharge can be accelerated by non-ice melt surface runoff.

For example, in Asia, glacial meltwater from the Himalayas, which has the largest coverage of ice outside the polar regions, is a key source of major rivers in the region such as the Indus, Ganges, and Brahmaputra in India as well as the Saptakoshi, Narayani, and Karnali in Nepal (Hasnain 2002; Gautam et al. 2013). On the overall, the Himalayan glaciers are estimated to provide water to 1.4 billion people (Bolch et al. 2012). Consequently, the United Nations Environment Program (UNEP) has previously indicated that the continued reduction of tropical glaciers is likely to affect domestic and urban water supply, agriculture, fishing, and livestock husbandry in villages and cities far away from the glacier mountains (Roer et al. 2008).

Studies have shown that the magnitude of hydrological impact of high-altitude glaciers in East Africa is significantly lower due to the smaller-sized glaciers in the region compared to the Asian glaciers (McKenzie et al. 2010). Several hydrological studies have concluded that water recharge from the dense forest zones in the high mountains of Eastern Africa constitutes the hydrological powerhouse of those ecosystems, and represents the most critical sources of water for the downstream consumers (McKenzie et al. 2010). The dense forest canopy usually intercepts rainfall and serves as a natural hub for water recharge, through which spring and river discharge is maintained. The thick forest canopy enhances rainwater interception and infiltration under the ground by creating numerous macro-pores through tree roots, which enables water seepage into the soil matrix. This process eventually facilitates the natural recharge of groundwater aquifers and subsequent discharge through springs, streams, and rivers (Mwaura et al. 2016).

Previous studies have revealed that in Mount Kenya, up to 90% of the dry season discharge in the Ewaso Ng'iro River originates from the high-altitude glaciers in

the alpine zone (>4000 m), mid-altitude moorland (3000–4000 m), and discharge from the dense montane forest canopy (>2400 m). Significant changes in the glacial surface area are therefore likely to have implications on regional hydrology and the livelihoods of downstream communities.

A recent detailed study by Prinz et al. (2018) showed that the total glacier cover of Mount Kenya decreased by  $121.0 \times 103 \text{ m}^2$  in 2004–2016, which was equivalent to 44% glacial cover reduction. According to the study, Lewis, the largest glacier, lost approximately  $62.8 \times 103 \text{ m}^2$  (46%) of its area and  $1.35 \times 103 \text{ m}^3$  (57%) of its volume. An earlier study by Hastenrath (2005) demonstrated that the total area of 18 glaciers decreased from  $1.64 \text{ km}^2$  to approximately  $0.27 \text{ km}^2$  in 1899–2004, which was equivalent to an 84% reduction. This trend has been also reported by Mizuno (2005a, b) and Mizuno and Fujita (2013). Currently, only 10 out of the initial 18 glaciers are believed to be active in Mount Kenya, which implies that only less than one-third of the previous ice cover is remaining. The key question is whether the continued glacial recession due to climate change can negatively affect the downstream water consumers. In the Ruwenzori Mountain, a recent study has shown that glacial recession had marginal impact on the flow of the Mubuku River (Uganda) because glacial meltwater contributes to less than 2% of the river discharge (Taylor et al. 2009).

Empirical studies on the hydrological implications of climate-change-glacial recession have been undertaken in different parts of the tropical regions such as the Mount Everest glaciers (Wood et al. 2020), Bolivian Cordillera Real (Frans et al. 2015), Peruvian Cordillera Blanca (Baraer et al. 2012), Bolivian Cordillera Oriental (Soruco et al. 2015), Ruwenzori glaciers (Taylor et al. 2009), Andean glaciers (Coudrain 2005), and Nepalese Langtang Himalayan glaciers (Chaulagain 1970). Most of the empirical studies have indicated that the peak point of glacial recession has already been reached; hence, the strong likelihood of diminishing water supply on the long-term due to the depletion of glacier-related discharge.

The rapid retreat of glaciers around the world, especially in the tropics, requires knowledge of its impacts on local communities, especially in terms of water supply and related livelihoods. Despite the importance of glacial hydrology studies on this subject, there is a need for society-oriented studies to assess the perception of local communities on the shrinking glaciers. Such studies can assess the implications of glacial recession on water supply, livelihood impacts, and also probe on the intended adaptation and coping strategies especially in relation to water supply and water dependent livelihoods. Such studies are rare, especially in Africa hence the need for that focus in this chapter.

### ***1.3 Climate Change, Glacier Recession, and Water Supply for Downstream Societies in Mount Kenya***

Water is a critical physiological requirement for all societies in the world regardless of their race or economic status. According to Thomas et al. (2020), the World Health Organization (WHO) recommends the provision of a minimum of 20 L/person/day for human consumption (drinking, cooking, sanitation, and basic hygiene). For this reason, water supply was identified as one of the key issues for the global 2030 agenda, in which sustainable development goal 6 (SDG-6) on water and sanitation was established. Target 6–1 of SDG-6 aims at ensuring universal and equitable access to safe and affordable drinking water for all by 2030 (Ortigara et al. 2018). Recently, the issue of water supply has been in the headlines during the COVID-19 global pandemic because WHO has recommended handwashing as one of the most effective measures to reduce the spread of the virus.

Mount Kenya is one of the largest water towers in Kenya, which provides water to over 9 million people in six counties located directly around the mountain ecosystem (Kirinyaga, Nyeri, Laikipia, Meru, Tharaka-Nithi, and Embu) and other distant counties that are hydrologically connected to the mountain through rivers originating from the ecosystem. These include the arid counties of Northern Kenya (Isiolo, Samburu, and Garissa) and some coastal counties (Tana River, Kilifi, and Lamu). These countries are connected to Mount Kenya by the Tana River on the humid windward side, and by the Ewaso Ngiro River on the leeward side (Figs. 1 and 2). Approximately 90% of the water requirements for people in the Ewaso Ng'iro Basin (15,000 km<sup>2</sup>) are fulfilled almost entirely from the water originating from Mount Kenya. On the other hand, the Tana River is the largest and longest river in Kenya (1000 km), which drains to the Indian Ocean and has been the source of most of the hydroelectric power (HEP) in the country since a long time.

The Mount Kenya water tower is a key player in the realization of SDG-6 in Kenya. The Constitution of Kenya (2010) considers access to clean and safe water in adequate quantities as a fundamental human right. However, its realization is likely to be affected by the impacts of climate change and global warming. Climate change studies have shown that Africa is among the regions of the world which are likely to be seriously affected by climate change. Global climatic models predict that by the year 2100, climate change in Kenya will lead to increased temperatures by approximately 4 °C, and cause rainfall variability by up to 20% (IPCC 2007). Climate change has already caused glacial recession in Mount Kenya. If the current rate of glacial retreat persists, the glaciers of Mount Kenya's are expected to be depleted before 2030 (Prinz et al. 2018). Despite this, very few studies have been undertaken to assess the perception of the local communities on glacial recession as one of the conspicuous indicators of climate change and the hydrological implications of deglaciation, especially with regard to water supply and livelihood adaptations.

Changes in mountain glaciers are considered an excellent indicator of global climate change (Winkler et al. 2010; Prinz et al. 2018). Consequently, global glacier monitoring is implemented through the Global Climate/Terrestrial Observing System



(GCOS/GTOS) according to the Global Hierarchical Observing Strategy (GHOST). Glacial changes are usually analyzed by monitoring glacial morphometrics such as length, width, surface area, and volume as indicators of trends in climate change. Although such glacial changes are usually monitored using sophisticated scientific techniques including remote sensing and GIS, the change is also visible through the naked eyes of the non-scientific society. However, very few studies have been undertaken in Africa to determine how different societies perceive such glacial change, especially in relation to climate change and its implications to their water demands and livelihood needs. The analysis and documentation of such local perceptions can enrich policy making because such studies will reflect local concerns, including peoples' fears and worries (Byg and Salick 2009). The analysis of public perception has the potential to highlight the most critical impacts of climate change on people's livelihoods. Such studies can direct the attention of scientists towards the ignored aspects of peoples' lives. Unfortunately, this line of investigation has not been popular among the scientific communities that study global climate change.

In Mount Kenya, the following research questions on the relationship between climate change and glacial retreat are withstanding from the point of view of the local people's perception: (a) how do the people perceive trends in glacier change? (b) what are their views regarding the impacts of visualized glacier change on river flows? (c) what are the likely implications of deglaciation on long-term water demands? It also interesting to determine how the local awareness on these issues varies in the society according to age, gender, and the level of education.

The overall purpose of this study was to establish whether the different local communities residing in the dry and water-scarce leeward side of Mount Kenya are aware of the on-going glacier changes and their implications on their livelihoods. The aim was to determine whether the people are accurately aware of the impacts of the on-going climate-change-driven deglaciation and their likely implications on water supply and livelihood activities (especially irrigation, urban water use, and pastoralism). The specific objectives were to determine the following:

- (a) actual trend of glacier reduction in Mount Kenya from 1970s to 2000s.
- (b) perceived changes of glaciers in Mount Kenya in relation to the trend in river flow and its implications on people's livelihood with emphasis on irrigation, urban water use, and pastoralism.
- (c) variability in the perception patterns according to age, gender, and level of education.

## 2 Study Sites

Mount Kenya represents a hydrologically influential ecosystem, whose impact stretches all the way to the Indian Ocean in the humid south-eastern side (windward side) through the Tana River, and to the Kenya-Somali border in the dry north-eastern side through the Ewaso Ngiro River (leeward side). The hydrological impact is more prominent in the six counties bordering Mount Kenya, namely

Nyeri, Kirinyaga, Embu, Tharaka-Nithi, and Meru on the southern and eastern side and Laikipia on the leeward side to the north (Fig. 2). The on-going deglaciation is likely to have more serious implications on the leeward side due to the persistent water scarcity, increasing water demand, and occasional tension and conflicts related to water availability.

In this study, we conducted a public perception survey among the communities along the Naromoru River, which is located on the western side of Mount Kenya in Nyeri County (Naromoru Ward, Kieni East Sub-County), and along the Likii River, which is located on the northern side of Mount Kenya in Laikipia County (Nanyuki and Segera Wards, Laikipia East Sub-County). Figure 3 shows the location of the study area.

Naromoru River is the western-most tributary of the Ewaso Ng'iro River, whose tributaries drain water from Mount Kenya, especially Lewis, Tyndall, and Darwin glaciers (Fig. 4). The river is also sustained by water flow from several glacial lakes such as Lewis, Tyndall, Teleki, and Hut tarns, all of which lie above 4500 m (Aeschbacher et al. 2005; Nussbaumer 2015). The river flows westwards, down the mountain through Nyeri County, and forms the south-western tributary of the Ewaso Ng'iro River. The Naromoru catchment (173.4 km<sup>2</sup>), which accounts for only 1.1% of the Ewaso Ng'iro Basin, represents a water-scarce area on the leeward side of Mount Kenya. A water abstraction assessment undertaken in the area during the early 2000s revealed that up to 80% of the river flow is abstracted through furrows, gravity pipes,

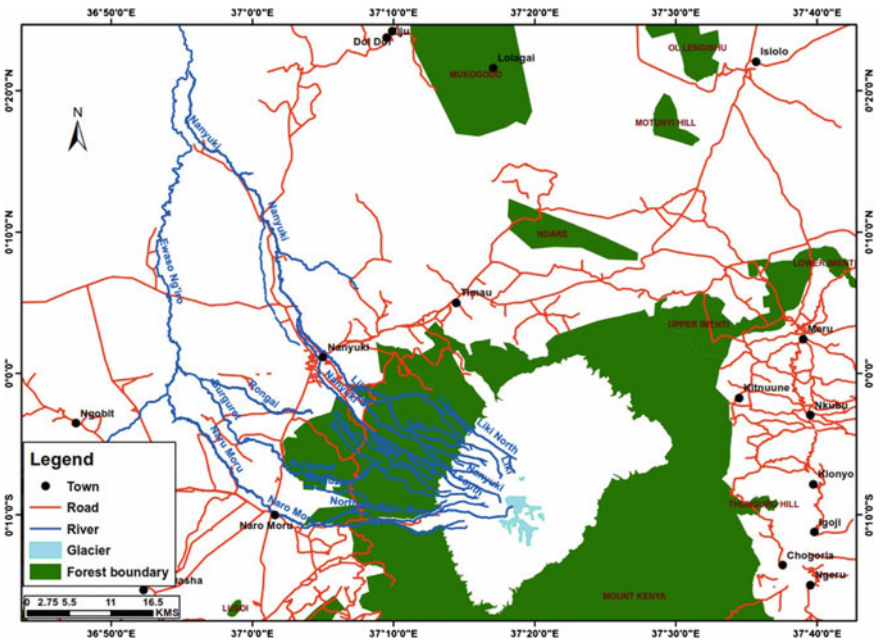
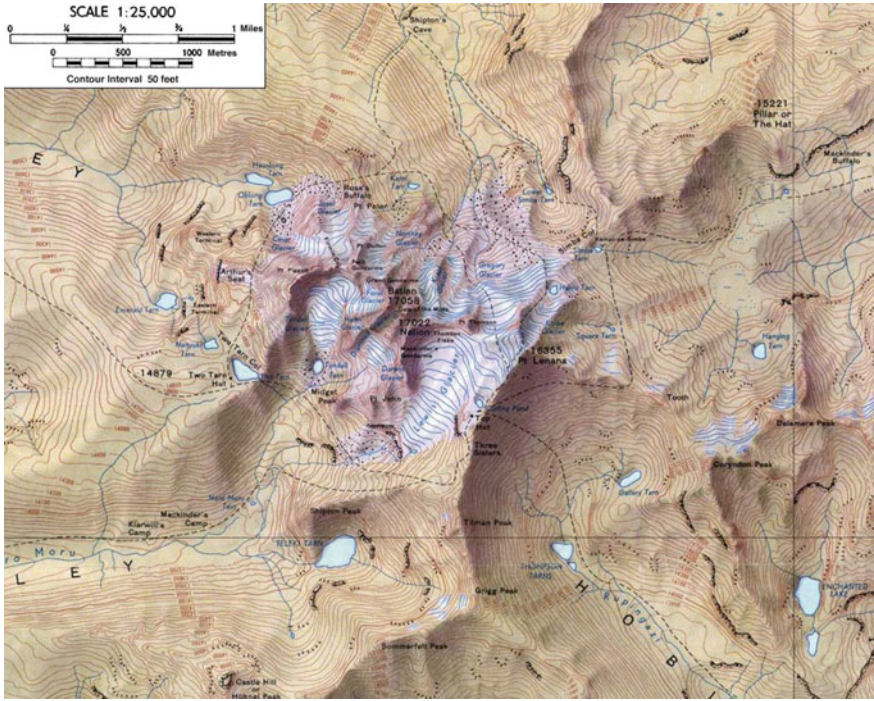


Fig. 3 Location of the study area



**Fig. 4** Glaciers in Mount Kenya, and their connection to Naromoru and Likii Rivers

and pumps for irrigation purposes (Aeschbacher et al. 2005; Nussbaumer 2015). According to Nussbaumer (2015), the population density in the Naromoru catchment increased from 198 to 243 persons/km<sup>2</sup> during 1999–2009, which is equivalent to an annual growth rate of 1.9%.

The Likii River catchment area (174 km<sup>2</sup>) stretches above 4000 m in Mount Kenya. It is associated with Tyndall, Josef, and Cesar glaciers. The river is also sustained by water flow from the Nanyuki, Emerald, Hausberg, and Oblong tarns (Fig. 4). It flows downstream through Nanyuki town before joining the Nanyuki River at an altitude of approximately 1850 m to form the south-eastern tributary of the Ewaso Ngiro River (Fig. 3). The river flows through diverse landscapes, and it supports a wide array of local communities in both the rural and urban zones. The upstream high-altitude section of the river is dominated by small-scale farmers, with land parcel size ranging between 1 and 4 acres. On the other hand, the downstream low altitude section crosses through the Nanyuki municipality within the low-income urban residential area of Likii next to the river. The lower part of the river below the Nanyuki town is dominated by Masai pastoralist activities, who rely on the river as the water source for their livestock.

### 3 Research Methods

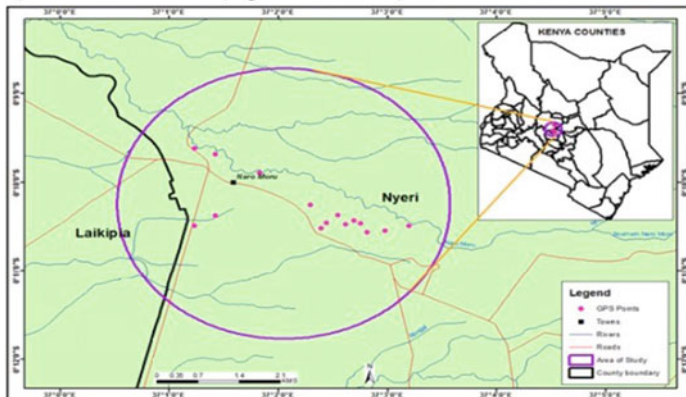
A simple spatial analysis of glacial changes in Mount Kenya was undertaken using medium resolution (30 m × 30 m) low-cloud cover Landsat imageries acquired from the Regional Centre for Mapping of Resources for Development (RCMRD) in Nairobi. The analysis was undertaken for the period 1976–2016 using imageries acquired in 1976, 1987, 1995, 2007, and 2016. The analysis was carried out using ArcGIS and ENVI software.

A local perception survey on glacial change, river flow trends, and livelihood impacts was conducted via face-to-face interviews with 90 riparian residents along the Naromoru and Likii rivers (Fig. 4). This included 30 irrigation farmers along the Naromoru River, 30 low-income urban residents along the Likii River in Nanyuki town, and 30 pastoralists along the same river situated below Nanyuki town. Systematic random sampling was used to select the respondents, whereby every third farm or household in Naromoru was considered. Every third urban water user along the Likii River in Nanyuki town and every third livestock herder were interviewed using a standard questionnaire. Figure 5 shows the specific locations, marked using GPS, where the interviews were undertaken. The interviews were conducted on August 2016, between the dry and wet seasons to avoid seasonal bias.

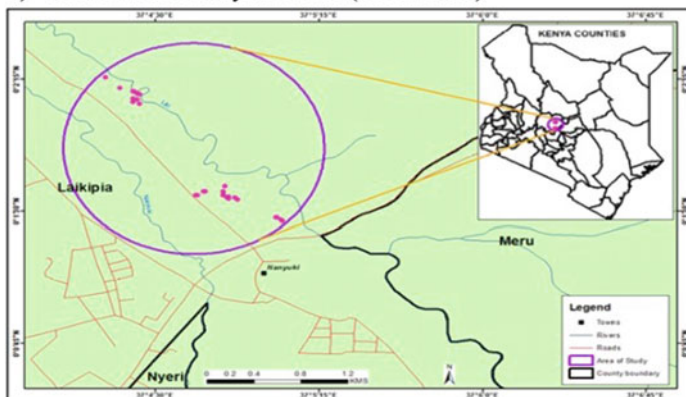
Among the three sites, the lower section of the Likii River (pastoralist zone) has the best visual view of the mountain glaciers due to un-obstructive terrain, location approximately at the middle of the leeward zone and the prevalence of cloudless weather almost throughout the year. The Naromoru River zone, on the other hand, has the most inconspicuous view of the mountain glaciers due to obstructive terrain, frequent cloudiness, and dense forest cover. This is due to its location in the transition zone between the windward and the leeward zones (Fig. 4). Figure 6 shows a general view of Mount Kenya from the Nanyuki and Naromoru sides.

The standard questionnaire for the local perception survey included a preliminary section to determine the respondents' profile such as gender, age, and level of education. The rest of the questionnaire was carefully configured to gauge the respondents' perception regarding glacial changes in Mount Kenya, localized trends of river flow changes in relation to the perceived glacial change, implication of the latter on the livelihoods of residents, and proposed adaptation strategies. The questionnaire was structured in accordance with the Likert Scale, whereby the respondents were offered a choice of five pre-coded responses with the neutral point being "neither agree nor disagree." The non-parametric Mann–Whitney U Test was used for data analysis as a tool for comparing the local perceptions according to gender, age, and level of education, with the level of significance evaluated at  $\alpha = 0.05$ .

a) Naromoru River (Agriculture zone)



b) Likii River in Nanyuki Town (Urban zone)



c) Likii River below Nanyuki Town (Pastoralist zone)

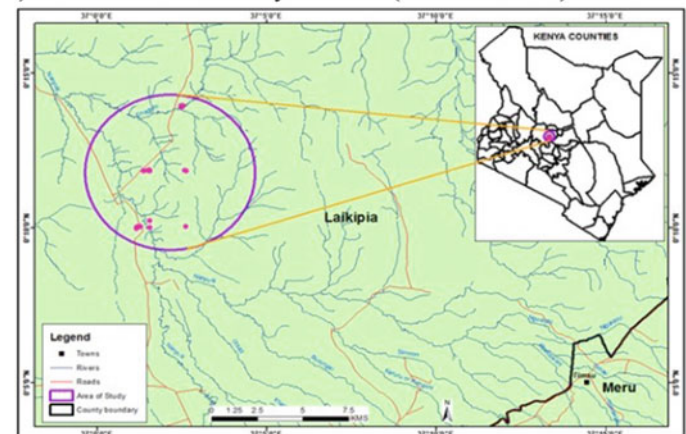


Fig. 5 Survey sites to evaluate the public perception of glacial changes



**Fig. 6** General view of Mount Kenya from the Nanyuki and Naromoru sides, respectively

## 4 Results

### 4.1 *Actual Changes in Glaciers*

Figure 7 shows the glacier coverage in Mount Kenya during 1976, 1987, 1995, 2007, and 2016. The analysis of the satellite imageries showed that the glaciers were concentrated on the windward side of the mountain. The spatial analysis showed that the glacial surface area has been declining consistently, from approximately 1.86 km<sup>2</sup> in 1976 to around 0.17 km<sup>2</sup> in 2016.

### 4.2 *Local Perception on the Changes of Mountain Glacial Cover*

During the local perception survey, from the total of 90 respondents, 87 valid responses from 56 males (64%) to 31 females (36%) were obtained. 64% of the valid respondents were aged between 25 and 34 years, 9% were aged between 55 and 64 years, and the rest were in the middle age group (35–54 years) as shown in Fig. 8. All the age groups were considered to have a good grasp and personal internalization of the Mount Kenya glacial change trend for the 40-year duration. The level of education for the respondents was dominated by primary and secondary school education at 37.9% and 36.8%, respectively, with only 6.9% having attained tertiary education (college and university levels). Meanwhile, 18.4% of the respondents had only informal education (traditional indigenous knowledge) because they never went to school.

The sample residents included irrigation farmers along the Naromoru River, urban residents along the Likii River in Nanyuki town, and Masai pastoralists along the same river below the town. The irrigation farms in Naromoru had an average area of 1–10 acres, with approximately 1–3 acres being used for growing vegetables

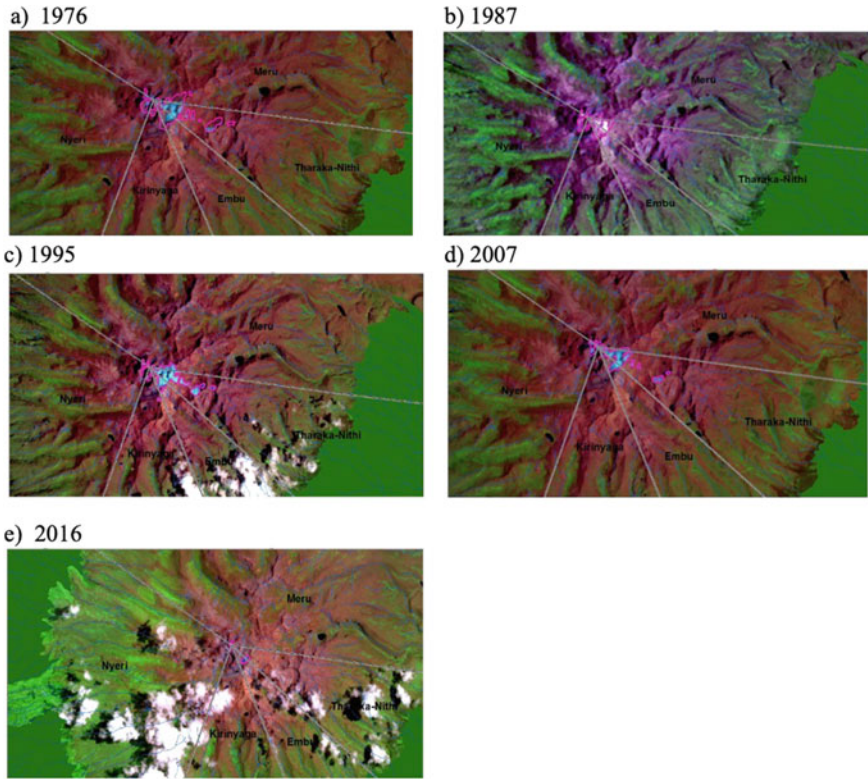


Fig. 7 Glacial coverage in Mount Kenya during 1976, 1987, 1995, 2007, and 2016

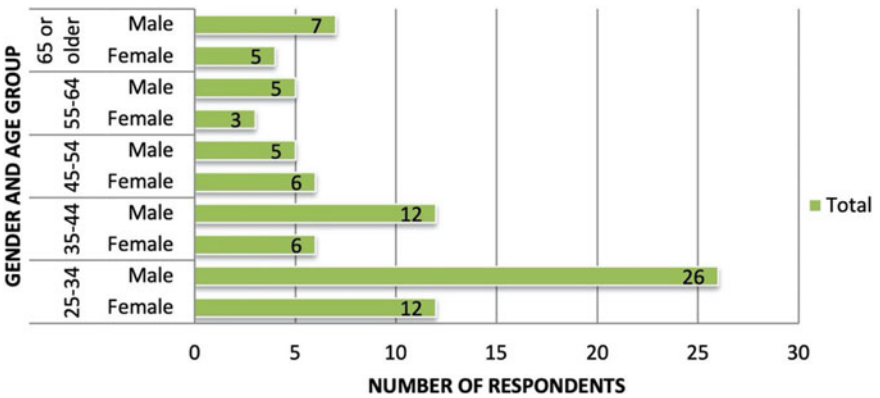


Fig. 8 Distribution of the respondents' gender and age

and maize. Most of the urban residents in Nanyuki town consisted of low-income residents, who depended on the river as a source of water for domestic use and small-scale business activities (including small-scale urban agriculture). The pastoralists along the Likii River below Nanyuki town mainly raise cattle, sheep, and goats with an average herd size ranging between 50 and 100 animals. The Likii River is the main source of water for livestock which are taken to the river almost on daily basis.

During the perception survey, 58 out of 87 respondents (67%) strongly agreed that the glaciers of Mt Kenya had reduced significantly during the 40-year period considered in the study (1976–2016). However, this view was not unanimous because 17 respondents (20%) were unsure and 1 respondent (1%) was in strong disagreement (Table 1). The survey showed that 36% of the respondents, who felt that the glaciers had significantly reduced, were from the Nanyuki region, which has an excellent view of the mountain. On the other hand, only 20% of the respondents from the Naromoru area had a similar perception (Fig. 6). The latter had a poorer view of the mountain glaciers due to more rugged terrain, frequent cloudy weather, and dense forest cover due to its location at the transition zone between the leeward and the windward sides.

Table 1 shows that there was no significant difference among the residents' perception regarding the occurrence of glacial reduction in Mt Kenya either by age ( $p = 0.712$ ), gender ( $p = 0.115$ ), or level of education ( $p = 0.077$ ). Majority of the respondents strongly attributed the deglaciation trend to the impacts of global warming due to climate change, which is in agreement with the findings of scientific studies around the world. However, there were significant differences in the perception between male and female respondents regarding the consistency of deglaciation trend in Mount Kenya, which is reflected in the Mann–Whitney U test results (Table 1).

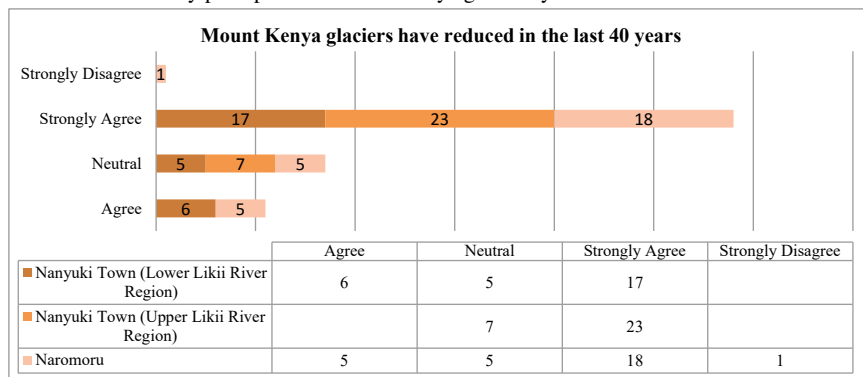
The difference was attributed to the distant location of the glaciers for all the respondents who lived in settlements at the base of the mountain and had rarely ventured up the mountain. It is likely that the findings of the perception survey could have differed if the assessment was done among regular mountain climbers such as tour guides and porters, who interact more closely with the glacial zone while escorting both local and international tourists.

### ***4.3 Local Perceptions on the Dynamics of Glacial Cover Changes, Water Resources, and Social Livelihoods***

Table 2 shows the findings of the local perception survey on the glacial cover change, and its impact on water resources and livelihood. Majority of the respondents in Naromoru and Nanyuki strongly considered that deglaciation in Mount Kenya had significantly reduced river flows and affected the availability of water and people's livelihoods, especially for farming and pastoralism. However, some pastoralists in the lower sections of the Likii River did not associate the reduction in the river flows to glacial retreat but rather to excessive abstraction by upstream people especially the



**Table 1** Community perception on Mount Kenya glacial dynamics



**Perception by age and gender**

|              | Disagree | Not sure | Agree | Strongly agree | Total |
|--------------|----------|----------|-------|----------------|-------|
| 25–34 years  | 1        | 3        | 3     | 29             | 36    |
| 35–44 years  | 0        | 1        | 0     | 18             | 19    |
| 45–54 years  | 0        | 0        | 3     | 11             | 14    |
| 55–64 years  | 0        | 0        | 1     | 5              | 6     |
| =/> 64 years | 1        | 0        | 2     | 9              | 12    |
| Female       | 2        | 1        | 5     | 23             | 31    |
| Male         | 0        | 3        | 4     | 49             | 56    |

**Mann–Whitney U test**

| Test variable 1                                   | Test variable 2  | N                  | Mean rank | Mann–Whitney U | Wilcoxon W | Z      | p-value |
|---|------------------|--------------------|-----------|----------------|------------|--------|---------|
| Significant glacier decrease in the last 40 years | 25–34 years      | 36                 | 24.81     | 205            | 283        | -3.69  | 0.712   |
|   | =/> 64 years     | 12                 | 23.58     |                |            |        |         |
|   | Female           | 31                 | 40.23     | 751            | 1247       | -1.578 | 0.115   |
|   | Male             | 56                 | 46.09     |                |            |        |         |
|   |                  | Informal education | 17        | 22.53          | 230        | 383    | -1.866  |
|   | Formal education | 34                 | 27.74     |                |            |        |         |
| Inconsistent deglaciation trend                   | Female           | 31                 | 52.74     | 597            | 2193       | -2.602 | 0.004   |
|   | Male             | 56                 | 39.16     |                |            |        |         |

**Table 2** Community perceptions on glacial dynamics, river flow, and the impact of deglaciation on livelihood

| <b>Mount Kenya deglaciation has reduced river flows, and water availability and uses (%)</b> |          |       |                |          |       |
|--|----------|-------|----------------|----------|-------|
|  | Not sure | Agree | Strongly agree | Disagree | Total |
| Naromoru (Irrigation zone)   | 13.4     | 31    | 65.5           | -        | 100   |
| Upper Likii (Urban zone)   | -        | 33.3  | 60.0           | 6.7      | 100   |
| Lower Likii (Pastoralism zone)   | 3.6      | 57.1  | 32.1           | 7.1      | 100   |

**Table 3** Community perception analysis on deglaciation, and its impact on livelihoods

|   | Not sure | Disagree | Agree | Strongly agree | Total |
|---|----------|----------|-------|----------------|-------|
| Deglaciation and reduced river flow have negatively affected irrigation along the Naromoru River              | 3.4      |          | 31.0  | 65.5           | 100   |
| Deglaciation and reduced river flow have increased water use tension along the Naromoru River                 | 24.1     | 6.8      | 24.1  | 44.8           | 100   |
| Deglaciation has escalated irrigation, urban, and pastoralism-related water use tension along the Likii River | 26.7     | 33.4     | 13.3  | 26.7           | 100   |
| Deglaciation and reduced river flow have negatively affected pastoralism along the Likii River                | 3.6      | 7.1      | 57.1  | 32.1           | 100   |

**Mann–Whitney U test**

| Test variable 1   | Test variable | N  | Mean rank | Mann–Whitney U | Wilcoxon W | Z      | p-value |
|---|---------------|----|-----------|----------------|------------|--------|---------|
| Deglaciation has increased irrigation water use tension                                 | 25–34 years   | 6  | 11.08     | 14.5           | 69.5       | -1.828 | 0.05    |
|   | 35–44 years   | 10 | 6.95      |                |            |        |         |
| Deglaciation has affected downstream irrigation   | Females       | 6  | 9.83      | 38             | 59         | -2.010 | 0.04    |
|   | Males         | 23 | 16.35     |                |            |        |         |
| Deglaciation has escalated irrigation, urban, and pastoralism-related water use tension | Females       | 5  | 18.40     | 38             | 314        | -1.375 | 0.05    |
|   | Males         | 23 | 13.65     |                |            |        |         |
| Deglaciation has affected the pastoralism sector  | Females       | 5  | 21.20     | 24             | 300        | -2.201 | 0.02    |
|   | Males         | 23 | 13.04     |                |            |        |         |

large scale irrigation farmers. This finding was a clear indication of the deep mistrust and potential water conflicts among the water users on the leeward side of Mount Kenya.

Sixty six percent of the respondents along the Naromoru River, who were mostly small-scale irrigation farmers, had the strong perception that Mount Kenya deglaciation was responsible for the reduced river flows and is likely to have serious negative impacts on irrigation (Table 3). However, only 45% respondents perceived that mountain deglaciation is likely to increase the water usage tension along the river. This view of residents was different from those in the Nanyuki area as explained above. The difference can be attributed to the mono-ethnic nature of the Naromoru area, which is mainly occupied by the Kikuyu people who are mostly farmers. The Nanyuki area, on the other hand, is more cosmopolitan. The Maasai pastoralists, who reside in the downstream area, have always considered themselves a disadvantaged group in terms of sharing natural resources, such as land, pasture and water resources. However, only 27% of the respondents in the Nanyuki area had serious fear that the continued glacier retreat in Mount Kenya was likely to escalate water usage tension and conflict between the downstream pastoralists and the upstream irrigation farmers and urban residents. Up to 32% of the respondents in the lower sections of the Likii River had a strong perception that continued deglaciation and reduced river flows could eventually have negative impacts on pastoralism through reduced stock sizes (Table 3).

The results of the Mann–Whitney U test indicated significant differences in local perceptions of glacial changes according to age and gender. The perception difference by gender could be attributed to the configuration of the sample size, which was dominated by males (64%). Male respondents were dominant, especially in the Naromoru River irrigation farms and in the livestock grazing fields along the lower sections of the Likii River.

The findings would probably have been different if the sample size was equally distributed across the gender spectrum. Overall, the findings showed that formal education was not a necessity in the mental internalization and personal awareness of mountain deglaciation and its implications on the livelihoods of downstream societies.

## 5 Discussion

The findings of the study showed that the local people on the dry leeward side of Mount Kenya were aware of the on-going glacial retreat and the changing trends of water availability in the downstream regions. This was similar to the findings of other studies, such as the study on local perceptions of glacial retreat in the Bashi Range (4800 m) of Tien Shan Mountains in Kyrgyzstan, Central Asia, where the perception of deglaciation among the respondents was not unanimous (Piersall and Halvorson 2014). The study also established that public perception on the trend of glacial retreat was largely inconsistent among the respondents. Other studies on glacial retreat, especially in South America such as that on the Peruvian Andes (Mark et al. 2010; Bury et al. 2011) and in Eastern Tibet (Byg and Salick 2009) have recorded consistent patterns between local perception and actual deglaciation trends. In South America, the findings of a local perception study on glacial recession in Cordillera Blanca mountain of the Peruvian Andes, which contains the largest proportion of tropical glaciers in the world, were concurrent with the actual trend of glacier recession determined through scientific research (Mark et al. 2010, 2017; Bury et al. 2011).

The highly accurate perception of the actual glacial retreat trend by the respondents from the Nanyuki side of Mount Kenya, which has a better visual perspective compared to the Naromoru side, is similar to the findings of other studies. For example, the studies by Byg and Salick (2009) in Eastern Tibet reported considerable differences in local perceptions on glacial retreat, which depended on topography and proximity of the village to the mountain glaciers that ultimately affect visual recognition.

Although Mount Kenya appears to have experienced a rapid glacial meltdown in recent years due to global warming and climate change, the local perception indicates that it is mostly associated with declining river flow in the downstream, and not increasing river flow. This can be considered to confirm the hypothesis that glacial recession generates increased meltwater discharge and high river flows only up to a peak point, beyond which the flow declines substantially because the glacier no longer serves as a significant source of water discharge. Furthermore,

this view could also confirm the marginal impact of African mountain glaciers on river flows, which has already been established for the case of the Ruwenzori Mountain, where Taylor et al. (2009) estimated a contribution of less than 2% of the discharge in the Mubuku River (Uganda). This might support the hydrological argument that the watershed powerhouse of the mountain is actually located within the forest zone, and not in the afro-alpine glacier zone. However, these findings could also be the outcomes of misconception in the minds of the local people as a result of the increasing water demand driven by population growth. Such misconception has been reported in other places. For instance, Mark et al. (2010) observed that although the on-going glacier melt in Peruvian Cordillera Blanca was accompanied by significant increase of discharge in rivers, the local people perceived that the river flow and available water were both decreasing. This suggests that actual hydrological studies need to be conducted to identify the disparities between scientific evidence and societal perceptions.

Significant variations in local perception by gender and age were noted for several dimensions associated with the glacial retreat in Mount Kenya. The local perception on the glacial retreat trend was significantly different between the youth and the elderly as well as between males and females. The perception difference according to age group was attributed to the duration of the visual impact. The older respondents (those above 64 years) had a longer visual memory of glacial changes compared to the younger group (25–34 years). The differences in perception between male and female respondents could also be attributed to the fact that unlike females, who are restricted to their homes, males are more mobile given their responsibility as household income earners. Due to their movements to different geographic locations in the area, the males are likely to internalize a more accurate visual impression of the glacial retreat. The insignificant differences in public perception pertaining to the changes of mountainous glaciers, based on the level of education can be attributed to the view that the uneducated respondents mostly remain in their home areas in Mount Kenya area throughout most their lives without migrating to other locations for formal education (especially secondary and college education), and are therefore likely to have a clearer picture of the actual trend in glacial retreat. In contrast, the educated respondents, despite their inconsistent view of the mountain glaciers, are more likely to learn about the impacts of climate change on glacial cover change in schools and colleges, and will hence share a common view with the less educated people.

As the white surface of the glaciated zone of Mount Kenya is considered holy, one of the unclear issues regarding the on-going glacial retreat in the mountain is how the total disappearance of the glacier will eventually affect the holy, divine, and sacred status of the mountain. It is likely that glacial retreat will create spiritual distress among individuals with a strong sacred attachment to the mountain because the affected societies cannot locally intervene with the ungodly changes associated with deglaciation. The social concerns on this matter can cause cultural and spiritual anxiety and psychological stress among the local residents, and therefore further research on this issue is necessary.

## 6 Conclusion and Recommendations

The spatial analysis of glacial changes demonstrated that Mount Kenya has continuously experienced progressive glacial retreat during four decades between 1976 and 2016. The analysis of the perception of local people regarding glacial retreat showed that the people were aware of the on-going deglaciation; however, their perception differed slightly according to gender and age, although the level of education had negligible influence on the perspective. The accuracy of public perception on the glacial retreat with respect to the actual trend (as documented through scientific research) is likely to be influenced by the nature of visual impression, especially in terms of proximity to the mountain, topographic orientation, weather conditions, and vegetation obstruction. Although community perception does not fully correspond to the actual trend due to distant visual inspection, all local people have noticed the glacial retreat.

The local people on the dry leeward side of Mount Kenya are aware, concerned, and worried about the hydrological implications of the glacial retreat, particularly in terms of changing river flows and increasing water scarcity, and also on its implications for livelihoods and social needs. The people in Naromoru were worried about the impacts of the on-going glacial retreat on irrigation and farming along the river, while those along the Likii River in Nanyuki were concerned about sharing of water resources in future between the upstream farmers and urban consumers with the downstream pastoralists. All the respondents were worried and concerned about future water related tensions and conflicts that would likely accompany the glacial retreat progress.

The following recommendations are based on the findings of this study:

- (a) The national and county governments should integrate the issue of glacial retreat and its hydrological implications in the future reviews for relevant development and natural resources management plans such as the County Integrated Development Plans and Laikipia Water Conservation Strategy.
- (b) Further research should be undertaken on the following aspects: (i) comparative assessment of local perceptions on glacier retreat between communities in the dry and water-scarce leeward side and humid and water-abundant windward side of the mountain ecosystem, and (ii) cultural, spiritual, and religious implications of glacier disappearance in Mount Kenya.

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