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Historicizing Natural Hazards and Human-Induced Landscape Transformation in a Tropical Mountainous Environment in Africa: Narratives from Elderly Citizens

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Abstract: Studying natural hazards in the context of human-induced landscape transformation is complex, especially in regions with limited information. The narratives of the elderly can play a role in filling these knowledge gaps at the multi-decadal timescale. Here, we build upon a citizen-based elderly approach to understanding natural hazard patterns and landscape transformation in a tropical mountainous environment, the Kigezi Highlands (SW Uganda). We engaged 98 elderly citizens (>70 years old) living in eight small watersheds with different characteristics. Through interviews and focus group discussions, we reconstructed historical timelines and used participatory mapping to facilitate the interview process. We cross-checked the information of the elderly citizens with historical aerial photographs, archives, and field visits. Our results show that major land use/cover changes are associated with a high population increase over the last 80 years. We also evidence an increase in reported natural hazard events such as landslides and flash floods from the 1940s until the 1980s. Then, we notice a stabilization in the number of hazard events per decade, although the two most impacted decades (1980s and 2000s) stand out. Despite this new information, an increase in natural hazard frequency due to land use/cover change cannot yet be quantitatively validated, especially when the probable modulator effect of climate variability is considered. Nevertheless, the increase in the exposure of a vulnerable population to natural hazards is clear, and population growth together with poor landscape management practices are the key culprits that explain this evolution. This study demonstrates the added value of historical narratives in terms of understanding natural hazards in the context of environmental changes. This insight is essential for governments and non-governmental organizations for the development of policies and measures for disaster risk reduction that are grounded in the path dependence of local realities.

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1. Introduction

The use of historical (multi-decadal) records of natural hazard events, including their types, mechanisms, causal factors, and incidence, is important for constraining the driving factors behind the evolution of risk in a region and devising appropriate disaster risk reduction measures [1–5]. For example, the scars of hazards, such as flash floods and landslides, are not permanent in a landscape, disappearing sometimes over short, month-to-year periods of time [6,7]. In other words, that a landscape currently does not show any recent evidence of a hazard does not mean that it cannot pose dangerous problems.

Although climate change is deemed to play a role in natural hazard occurrence [8], human-induced landscape transformations have been linked to an increase in the incidence of natural hazards [9–11]. For example, deforestation, urbanization, and road construction change the spatiotemporal distribution patterns of the occurrence of landslide and flood events [5,12–15]. These human disturbances of the landscape are particularly pronounced in the tropics, and are frequently associated with population growth, land needs, and agricultural expansion, e.g., [12,16,17]. In addition, an increase in settlements frequently pushes populations into hazard-prone areas, thereby increasing their exposure to natural hazards [18–20]. This exposure is expected to rise, especially in the tropical regions of the Global South, due to the projected population increases and weak management policies [14,21].

Understanding multi-decadal natural hazard patterns and landscape transformation is challenging, especially in data-scarce environments [22,23]. In such regions, data collection is impeded by inadequate resources, insufficient monitoring systems, and a lack of technical expertise for effective collection and analysis, often combined with difficult-to-access terrain [24,25]. Such hindrances preclude the proper trend analysis of natural hazards and understanding the environmental processes driving them [23,26]. Addressing the challenge of data collection requires multi-facetted approaches, involving participatory processes and remote sensing products to gain information on the historical patterns of natural hazard occurrences and the evolution of the landscape, e.g., [27–30].

Most studies of multi-decadal natural hazard occurrences and landscape transformation have been based on the analysis of historical aerial photographs, e.g., [31,32]. Historical aerial photographs are valuable sources of information as they provide some of the earliest records of land use/cover at a high spatial resolution of around 1 m [33]. For example, Luino et al. [34] analyzed historical maps to understand the impact of past natural hazards on various features, whereas Requelme et al. [33] analyzed historical archived photographs to understand past landforms. However, due to the limited number of photograph acquisition periods in many regions, historical aerial photographs often miss subtle details about the dynamics of the landscape [1]. Additionally, for the inventory of natural hazards, only relatively large-scale features such as large landslides can be identified in a reliable manner with these photographs [35].

Historical narratives about the evolution of the local environment reported by elderly citizens provide an opportunity to mitigate these historical data gaps in environments with limited information [36,37]. Because of their long interactions with the environment, elderly citizens have a rich knowledge of past hazards, and their understanding of historical landscape transformation is recognized as highly valuable. As Richardson et al. [38]

and Moezzi et al. [39] argue, narratives constructed from reliable participants such as elderly citizens are based on non-fictional events and thus provide credible insights in research. For instance, Nyssen et al. [27] applied the elderly citizen approach to reconstruct gully evolution in northern Ethiopia over several decades. Despite their importance in contributing to knowledge, the added value of the elderly citizens in understanding landscapes and past natural hazards has hitherto been overlooked [29].

Engaging elderly citizens through participatory approaches, such as participatory mapping, facilitates the structured narration of historical events, ensuring that their knowledge is shared in a coherent and systematic manner [40,41]. Participatory mapping is a collaborative process where community members actively engage in creating maps that reflect their local knowledge, experiences, and perceptions of their environment [28,41]. Researchers have used this approach to facilitate the understanding of environmental changes through the integration of local knowledge with scientific methods [42,43]. These methods allow for the visualization and spatial contextualization of historical events, enhancing the accuracy and depth of the narratives. Moreover, timelines have been shown to effectively aid in the reconstruction of historical events, particularly in overcoming the challenges associated with memory decay when recalling past occurrences [44]. Timelines, defined as visual representations of chronological events, have been successfully applied to reconstruct historical information across various domains. For instance, Hoffman et al. [45] applied timelines to examine historical environmental changes in the river systems of South Africa, while Bwambale et al. [46] used them to analyze the processes that shape indigenous knowledge regarding understanding flood risk in the Rwenzori region in Uganda. Moreover, Ben-Malek et al. [44] demonstrated that the temporal recall of past events heavily relies on reconstructive and inferential processes, where individuals draw upon their general knowledge of notable periods in their lives to place events in time.

The aim of our research is to document historical natural hazard patterns in relation to the human-induced transformation of the landscape in a data-scarce environment of Africa through the narratives of elderly citizens. More specifically, we focus on the Kigezi Highlands (southwestern Uganda), a mountainous region where problems associated with the occurrence of natural hazards are a growing concern [22,47,48]. This research also aims to assess the relevance of the elderly citizens' knowledge and experiences in terms of enriching the understanding of natural hazards and landscape characteristics. First, we focus on the implementation of the elderly citizen approach that is at the heart of this research. Then, we compile data on natural hazards and land transformation from the narratives of the elderly, complemented by secondary data sources and the interpretation of aerial photographs. We then analyze these patterns and discuss results with respect to disaster risk reduction, land management, and population dynamics.

2. Study Area

The Kigezi Highlands are part of the southwestern highlands of Uganda, bordering Rwanda to the south and the Democratic Republic of Congo to the west. More specifically, the study was conducted in eight relatively small watersheds (see Section 4) distributed throughout the three districts of Kabale, Rubanda, and Kisoro (Figure 1). The Kigezi Highlands experience rainfall during two wet seasons, March to May and September to November. The region received an average annual rainfall of 2500 mm between 2014 and 2020, as measured by the Kabale weather station [49]. The study area is one of the most densely populated regions in Uganda, with an average of 370 to 600 inhabitants per km^2 [50]. For many decades, the Kigezi Highlands have had an 'overpopulated' status, which is frequently cited as a primary cause of environmental degradation in the region [51]. The population consists mainly of smallholder farmers, dependent on subsistence agriculture and livestock production. The vegetation cover, which was largely composed of montane forests many years ago [52], has been greatly modified due to human activities arising from an increasing population [52–54]. According to Nseka et al. [48], subsistence agricultural land has been increasing, at the expense of forests and woodlands. Recent research in the region shows an increase in reported impactful landslide and flood hazard occurrences [47,55] that have caused the loss of lives, displacement of people, and severe damage to property [56]. Anthropogenic processes most likely play preparatory roles in the occurrence of landslides and floods [12,47,57]. According to OPM [56], Kigezi is the most exposed region to natural hazards in Uganda, highlighting the urgent need for disaster risk reduction interventions. The study area consists of eight small watersheds (Figure 1) of rather similar sizes (3–8 m^2). The watersheds, however, possess different natural and human-related characteristics (Figure 2) such as land use/cover (e.g., the proportion of forest vs. agricultural land), lithology, topography, land management practices, and population density (see Section 4, Results).

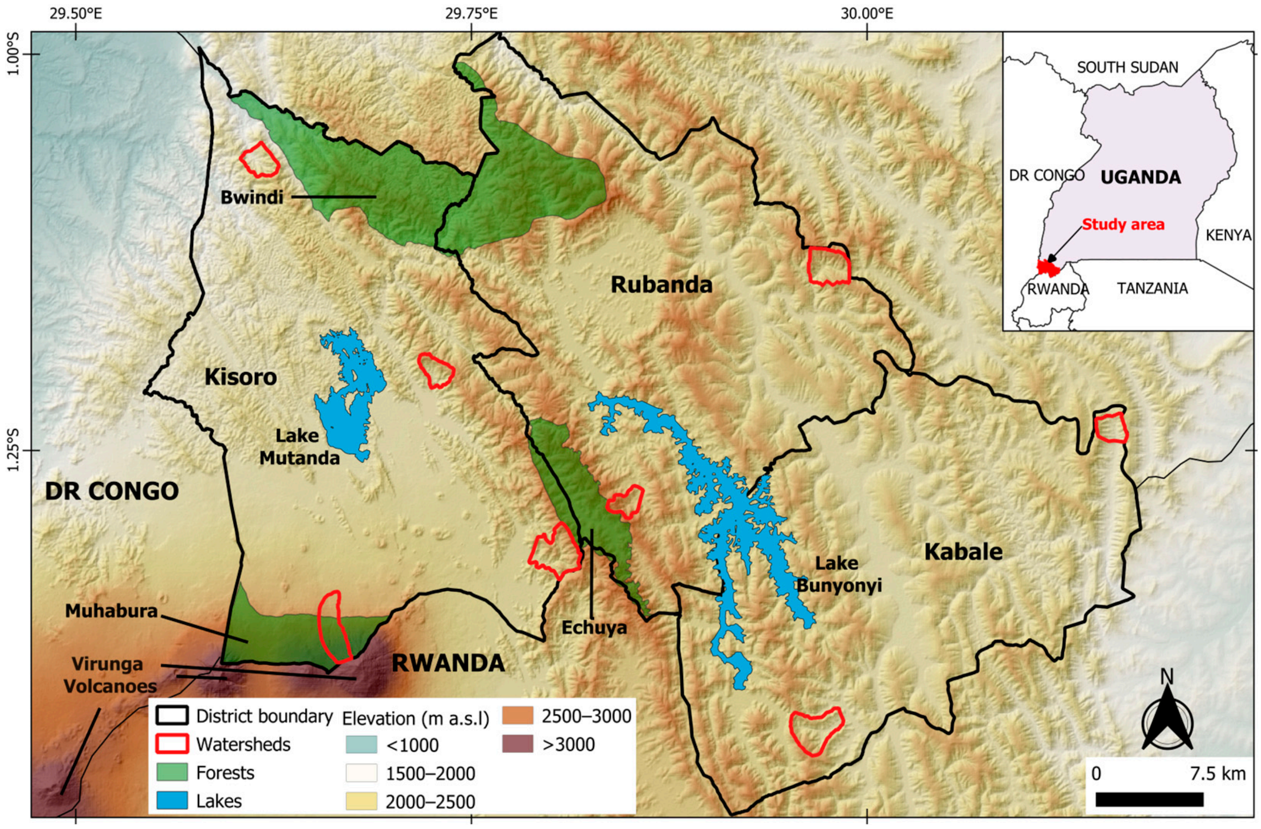

Figure 1. The location of the Kigezi Highlands comprising the Kabale, Rubanda, and Kisoro districts and the eight studied watersheds (W1 to W8). The forest cover data are from Google Earth imagery 2021. The map background is a shaded relief with elevation in color extracted from 1 arc sec SRTM DEM (https//lpdaac.usgs.gov/products/astgtmv003/, last access: 22 January 2022).

Figure 2. Field pictures of the eight watersheds (W1 to W8) illustrating dissimilar topographic and land use/cover characteristics. Photos taken by Violet Kanyiginya during fieldwork in September and October 2021.

3. Materials and Methods

3.1. Data Collection

3.1.1. Selection of the Study Participants

In this study, we engaged elderly citizens to gather their insightful narratives about past natural hazard events and landscape changes (Figure 3). This approach addresses the challenge of historical data scarcity, as elderly individuals often possess extensive knowledge and insights about historical landscape transformation due to their long-term interaction with the environment [36–38]. The elderly approach enables combining local knowledge with scientific knowledge, which is essential for the reliable and accurate monitoring of the environment [58].

To ensure the narratives provided a sufficient historical scope, participants were required to be at least 70 years old in order to enable coverage of periods corresponding to the acquisition of historical aerial photographs (see Section 4.3). Additional eligibility criteria included being a native of the watershed and possessing the ability to provide clear and detailed historical accounts of landscape events. We worked with community leaders who knew the community members well and were therefore our mobilisers and field guides. These included local chiefs, community-based officers, and geo-observers; the latter being a network of citizens trained in reporting natural hazard events and the associated impacts occurring in their communities [47]. To identify suitable elderly citizens, we integrated a snowball approach—a sampling technique suited for hard-to-reach or hidden populations [58]. The snowball sampling process begins with identifying a few participants who are part of the target population. These participants are then asked to refer other individuals they know who meet the study's criteria [58]. This approach was advantageous in finding the targeted population given the difficulty of finding eloquent elderly citizens who could recall and ably narrate the historical aspects of their environment.

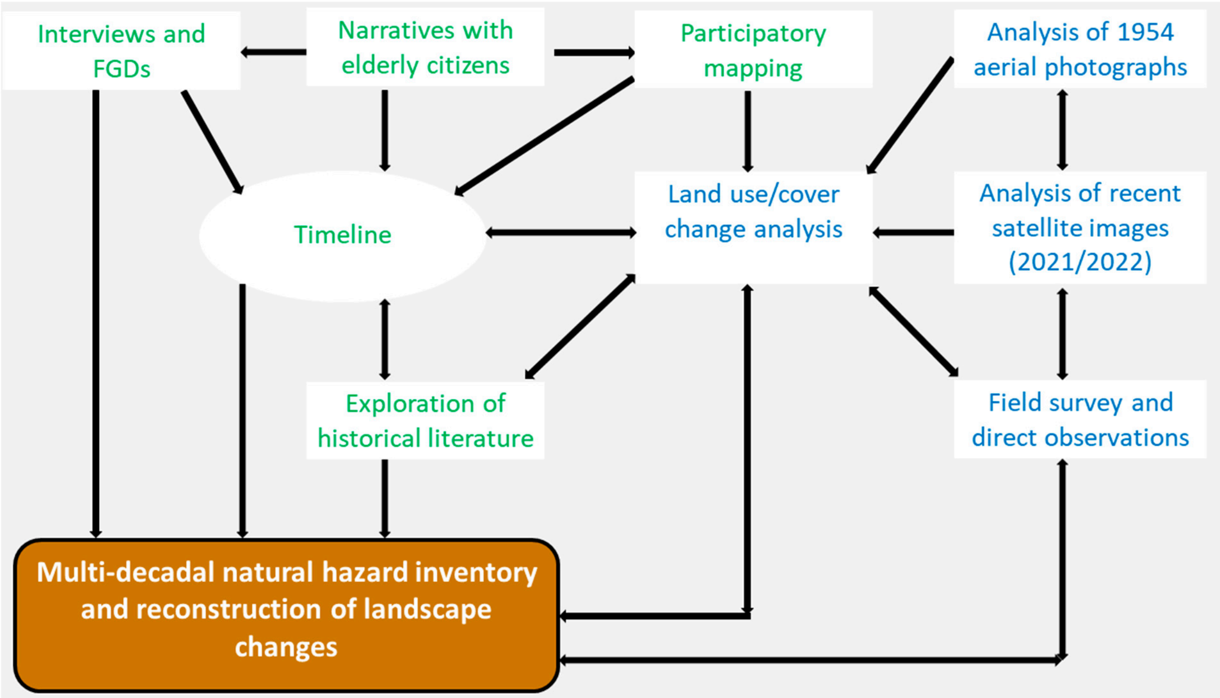

Figure 3. The methodological framework of the study illustrating how the multi-decadal inventory of natural hazards and landscape changes was achieved through a combination of historical narratives/approaches (in green text) and empirical methods (in blue text).

3.1.2. Historical Narratives with the Elderly Citizens

We conducted interviews and focus group discussions (FGDs) with a total of 98 elderly citizens, of which 37% were women. Guiding questions (see Appendix A) were prepared and administered during the interviews and FGDs. We interviewed 24 elderly citizens in their homes, while 74 participants were engaged through FGDs. The house-to-house interviews allowed us to reach elderly citizens (mostly >80 years old) who were unable to move to the designated centers for FGDs. In addition to enabling triangulation [59], the FGDs allowed for the validation of information provided in individual interviews, thereby enhancing the reliability of the findings. As compared to individual interviews, FGDs offer the advantage that respondents complemented one another to remember and clearly describe past events. Further validation of the narratives of the elderly was carried out during field visits, where we observed features related to past hazard events. For example, boulders associated with flash flood or landslide events were examined in the field, and their age and time of appearance were confirmed with residents. All the interviews and FGDs were carried out in November 2021.

3.1.3. Reconstructing of Key Events with a Timeline

To complement the interviews and FGDs, we constructed historical timelines and incorporated them into these discussions. This approach helped establish the actual years when natural hazards and key landscape changes took place, as narrated by elderly citizens (Appendix A.1). Using key political and social events as references in the timeline (e.g., presidential regimes: Elizabeth II (British colonial rule), Edward Mutesa II (first Ugandan president), Obote I, Obote II, Idi Amin, and Museveni), we asked the elderly what the landscape looked like in different past periods, i.e., the type of vegetation/tree cover, housing characteristics, roads, the types of crops grown, land management practices, and the associated policies that existed as well as any natural hazards that occurred. The narratives provided by the elderly highlighted key changes occurring between the colonial (pre-1962) and post-colonial (post-1962, i.e., 1962–2021) eras. Therefore, the timing of key events was analyzed in relation to these two distinct periods to better contextualize the transformations. The interview and FGD sessions were recorded and transcribed with the consent of the participants, and key thematic areas were extracted for further exploration and analysis.

3.1.4. Participatory Mapping and Spatial Reference of Events

For the eight FGDs, we applied the participatory mapping technique, where the elderly drew on manila papers the past (i.e., from the 1940s) and current (2021) land use/cover of their land (Figure 4). The mapping was guided by providing the exact delineation of the watershed boundaries as background information. The elderly citizens indicated (1) the locations and numbers of buildings and roads, and (2) the extent of croplands, tree cover, wetlands, and water bodies. Colored markers were used to distinguish between past and present land use/cover (Figure 4).

Figure 4. Interviews and participatory mapping with the elderly citizens. (**a**) One of the maps drawn by the elderly citizens during an FGD in W6, showing past (blue marker) and current (red marker) land use and cover. (**b**,**c**) Participatory mapping during FGDs with elderly citizens in W2 and W5, respectively. (**d**) An individual interview session with an elderly citizen in W8. Photos taken by David Mubiru in September 2022.

3.1.5. Field Assessment of the Extent of Human Activities

To better understand the extent of land transformation by human activities, we conducted a rapid assessment of the level of human disturbance in each watershed through direct observations in the field. Based on the methodology by [60], we assessed parameters including:

- Vegetation characteristics: the density and type of vegetation, such as native species versus invasive plants;
- Land use: the size and distribution of agricultural fields, settlements, commercial areas, and road infrastructure;
- Signs of soil erosion: evidence of erosion along riverbanks or hillsides and sediment deposits in lower areas;
- Water quality: water clarity and the presence of debris or foam in rivers.

We employed a scoring system ranging from 0 to 5 to evaluate the parameters of human disturbance, where 0 = no disturbance; 1 = very low disturbance; 2 = low disturbance; 3 = moderate disturbance; 4 = high disturbance, and 5 = very high disturbance. This systematic approach enabled us to classify the overall level of human disturbance within each watershed into three categories: low, moderate, or high (see Section 4).

3.2. Secondary Data Sources

Historical data sources include documentary archives and literature with information of considerable value in terms of establishing the characteristics of landscape processes [61]. These historical records also played a crucial role in validating the narratives provided by elderly citizens. We used keywords such as 'history', 'land use', 'colonial policies', and 'disasters', which we combined with 'Kigezi' to search the scientific literature in the Web of Science and Google Scholar. We also explored historical books and the other past literature and archives such as 'Old Maps online'. Some of this literature was obtained during our interactions with the elderly interview participants. Of relevance was the 'Kigezi n'Abantu Baamwo' (Kigezi and its people) book by [62], which details the historical evolution of the people of Kigezi, including land use and management practices, economic activities, population trends, and migration dynamics. Additionally, other historical research publications about Kigezi, such as [51,63,64], provided valuable insights.

3.3. Land Use/Cover Change Analysis with Historical Panchromatic Aerial Photographs and Satellite Images

To examine historical changes in land use/cover, we analyzed panchromatic aerial photographs from 1954 at a scale of ~1/40,000 and recent (2021/2022) satellite imagery available on Google Earth for a comparative understanding of landscape transformations over time. The historical aerial photos were acquired from the Department of survey and mapping of Uganda in Entebbe in digital format, scanned by a Ricoh MP500 at a 600 dpi resolution. The photographs were empirically analyzed in stereoscopy, then the georeferenced images were used to manually digitize land use/cover classes including forest/tree cover, settlements, agricultural terraces, wetlands, and roads. We focused on mapping agricultural terraces, as this represents an important land use practice that is easily identifiable in aerial photographs. In contrast, cropland and grassland often lack distinct visual markers, making them challenging to differentiate with certainty. The same classes were digitized from Google Earth satellite imagery. This analysis not only highlighted land use/cover changes over time but also served to validate the narratives provided by the elderly citizens. The general methodological framework is shown in Figure 3.

4. Results

From the elderly citizens' narratives, we generated a record of natural hazards that occurred since the 1940s. We recorded 73 natural hazard occurrences (landslides and flash floods) for the period between 1940 and 2021. We also analyzed landscape change dynamics for the same period using historical narratives from the elderly citizens, aerial photographs from 1954, and the available historical literature about the Kigezi region.

4.1. Watershed Characteristics

The eight watersheds exhibit diverse characteristics that highlight the distinct variations in their environmental profiles (Table 1). The variations include differences in size, reflecting the spatial extent of each watershed; land use/cover, which provide insights into the dominant vegetation, agricultural activities, and urban development within the watersheds; and topography. Additionally, the watersheds differ in terms of lithology, the level of human disturbance, and the type of frequent natural hazards experienced in each watershed.

Table 1. The characteristics of the eight watersheds. Lithology information is from the geological map of Uganda [65]. Information on frequent natural hazards is from the elderly citizens.

Watershed	**Size (km^2)**	**Land Use/Cover**	**Average Slope (%)**	**Lithology**	**Level of Human Disturbance**	**Frequent Natural Hazards**
W1	3.5	Forest, shrubs, crops (millet, tea, sweet potatoes, beans). Settlements on hilltops and upper slopes	48	Mudstone, shale, slate, phyllite	Low	Landslides
W2	4.5	Eucalyptus, crops (maize, potatoes, beans), agricultural terraces, drained wetland	42	Mudstone, shale, slate, phyllite, sandstone, quartzite, grit	Moderate	Landslides, flash floods
W3	7.2	Eucalyptus, crops (beans, maize, sweet potatoes), agricultural terraces, drained wetland	49	Mudstone, shale, slate, phyllite	Moderate	Landslides, flash floods
W4	6.7	Forest, eucalyptus, crops (potatoes, climbing beans, maize), ridges	34	Leucite, basanite	Moderate	Flash floods
W5	8.2	Eucalyptus, crops (potatoes, climbing beans), rock outcrops on upper slopes, wetland under cultivation	47	Mudstone, shale, slate, phyllite, sandstone, quartzite, grit	High	Flash floods
W6	3.2	Eucalyptus, crops (climbing beans, potatoes, maize), agricultural terraces, gullies	40	Mudstone, shale, slate, phyllite, sandstone, quartzite, grit	High	Floods
W7	3.5	Eucalyptus, pine, grassland on hilltops. Settlements mainly in the valley, crops (banana, sorghum, peas)	39	Mudstone, shale, slate, phyllite, sandstone, quartzite, grit	Low	Landslides, flash floods
W8	7.2	Eucalyptus, crops (sorghum, beans, maize), agricultural terraces, gullies, numerous gravel roads, drained wetland	39	Mudstone, shale, slate, phyllite	High	Landslides, flash floods

4.2. The Characterization of Watersheds During the Colonial Era (1940–1962)

From the narrations of the elderly citizens, we obtained historical information from as early as 1940. In a few cases, the elderly narrated events that they were told by their parents, thus delving into the 1930s. However, such narrations from before the 1940s were considered to be less reliable and were therefore not considered in our analysis. The information obtained since the 1940s comprised themes on land use/cover; management practices; land management laws and policies enforced; population and housing characteristics; road development; degradation activities, such as deforestation and wetland drainage; restoration programs; and natural hazard occurrences. Examples of quotes from the elderly narratives are provided in Appendix A.2.

4.2.1. Land Use/Cover

When referring to their childhood (1940–1950s), the elderly citizens described the landscape as hills covered with different natural tree species such as Ficus, shrubs, and short grass, especially Hyperemia ruffa (emburara in the Runyankole–Rukiga dialect), which were inhabited by wild animals such as wild pigs, foxes, and leopards. In watersheds adjacent to national parks, elephants and buffaloes were also regularly present. Our analysis of the 1954 aerial photographs and participatory mapping with the elderly citizens shows that settlements were in the mid-lower slopes of the hills since most valleys were covered with large papyrus swamps and the hill tops were forested. In some watersheds, such as W5, W6, W7, the upper slopes and hilltops were used for cultivation and grazing, and much livestock was kept since grazing land was widely available.

4.2.2. Land Use and Management Practices

Reports from the elderly show that, during the colonial period, land was freely acquired and the boundaries for land ownership were dependent on the family labor force and strength, i.e., as far as one could cultivate determined the boundary of their land. The elderly citizens reported that the main crops grown in the area included sorghum, maize, beans, millet, peas, sweet potatoes, and indigenous potatoes. These crops were notably resilient and could therefore be cultivated throughout the year. The elderly citizens also shared that farming was minimal due to the abundance of land, with cultivation primarily focused on subsistence food production. At that time, money was not a concept familiar to the community, and there were no markets for buying or selling food involving money. The elderly vividly recalled that barter trade was the sole method of exchange, where people traded food for other goods or services, as required.

Despite the low-intensity farming practices, the elderly indicated that food was abundant for the relatively small population, and there were established regulations regarding food storage. Regarding land management, the elderly recounted that the colonial administrators enforced strict fallowing practices, known locally as Hinga raza, along with the use of contours or strip cropping stabilized by elephant grass (locally known as katikankingo in the Runyankole–Rukiga dialect). Fallowing required farmers to divide their land into three plots, with one plot always left under fallow in rotation each season. The elderly citizens also emphasized that colonial administrators, through local chiefs, enforced laws to protect the vegetation cover. For instance, bush burning and tree cutting were strictly prohibited and punishable by law. It was also mandatory for every household to plant 18 black wattle trees on hilltops. Other tree species such as eucalyptus and pine were not allowed on the land. According to the elderly respondents, the black wattle tree species helped to prevent soil erosion, landslides, and flash floods. The elderly citizens believe that these regulations played a crucial role in protecting the land from soil erosion, preventing natural hazards, and enhancing soil fertility.

4.2.3. Hydrology

According to the elderly citizens, the lowlands in some watersheds, such as W3, W7 and W8, were covered by wetlands, and no permanent river existed. In W3 and W8, the wetlands in the valley were drained through a channel to create the river during road construction in 1971 (post-colonial period). The river in W7 was formed in 1959 but the elderly residents have different beliefs on how it happened. Some believe that an aquifer was compromised during borehole construction which produced the river, others believe it emerged from the drainage of a wetland in the valley. In all aspects, the residents are happy with the river today as it helps to provide water for animals and domestic use. According to the elderly in W6, a narrow river existed in the 1950s and traversed through the watershed, but it has recently widened and silted because of flash floods.

4.2.4. Natural Hazards

According to the elderly citizens, natural hazards were experienced in some watersheds as early as 1945 (Figure 5). However, they noted that these events did not cause severe damage, and their frequency was low at the time. For example, in W8 a large event involving the co-occurrence of landslides and flash floods happened in April 1945, but it did not cause human or property losses since it affected locations that were not inhabited. Despite the low population in the past, the elderly citizens reported that landslides frequently occurred in W8 during the colonial period. One village in W8, for instance, was named after landslides: Nyamutenguzi (literally meaning 'the sliding land' in the Runyankole–Rukiga dialect) a name that has remained to date. According to the elderly citizens, residents always relocated from Nyamutenguzi during the rainy season for fear of landslides. Similarly, the elderly in W5 reported the occurrence of landslides in the 1950s, which led people to avoid living on steep slopes for fear of these hazards. However, the elderly confirmed that flooding never existed before 1962, when the wetland was still in existence in W5. In addition, the elderly in W5 indicated that there were natural waterways which effectively drained the watershed during periods of excess water. They asserted that a desilting schedule existed in the community to maintain the channels, which prevented floods. The desilting practice was, however, abandoned after colonial rule in 1962, leading to the channels becoming silted and flooding starting to occur, as reported by the elderly citizens. The elderly acknowledged that the frequency of flooding worsened in the 1980s when the wetland was completely drained for cultivation and settlements. Today, the watershed experiences severe flooding every rainy season. In contrast, other watersheds like W1, W2, and W3 did not experience natural hazards during the colonial period (Figure 5).

As reported by the elderly, watersheds did not have gullies, which are associated with flash floods, until the 1980s when the first gully formed in W6. Gullies that were large enough to create a hazard began to appear in other watersheds during the 1990s and early 2000s.

4.2.5. The Temporal Trend in Reported Natural Hazards in Relation to the Ages of the Elderly

According to the elderly citizens, the number of natural hazards increased significantly from the 1940s to the 1980s, and quite high frequencies continued to be observed in the following decades (Figure 6). The elderly citizens attribute the increase in the natural hazard occurrences to various factors. For instance, W4 suffered from severe flash floods, including fatalities, which the elderly believe were caused by the deforestation of the Muhabura forest before the 1960s. Similarly, they attribute the landslides experienced in W1 after the colonial period to the deforestation that took place between 1960 and 1980. During our field observations, we noted large boulders scattered throughout the watershed, reportedly carried by flash floods more than 20 years ago (as recounted by the elderly).

These boulders vividly demonstrate the intensity of the past flash floods. As attested by the elderly residents, protecting the forest from further human activities not only saved it from extinction but also reduced the frequency of severe fatal disasters.

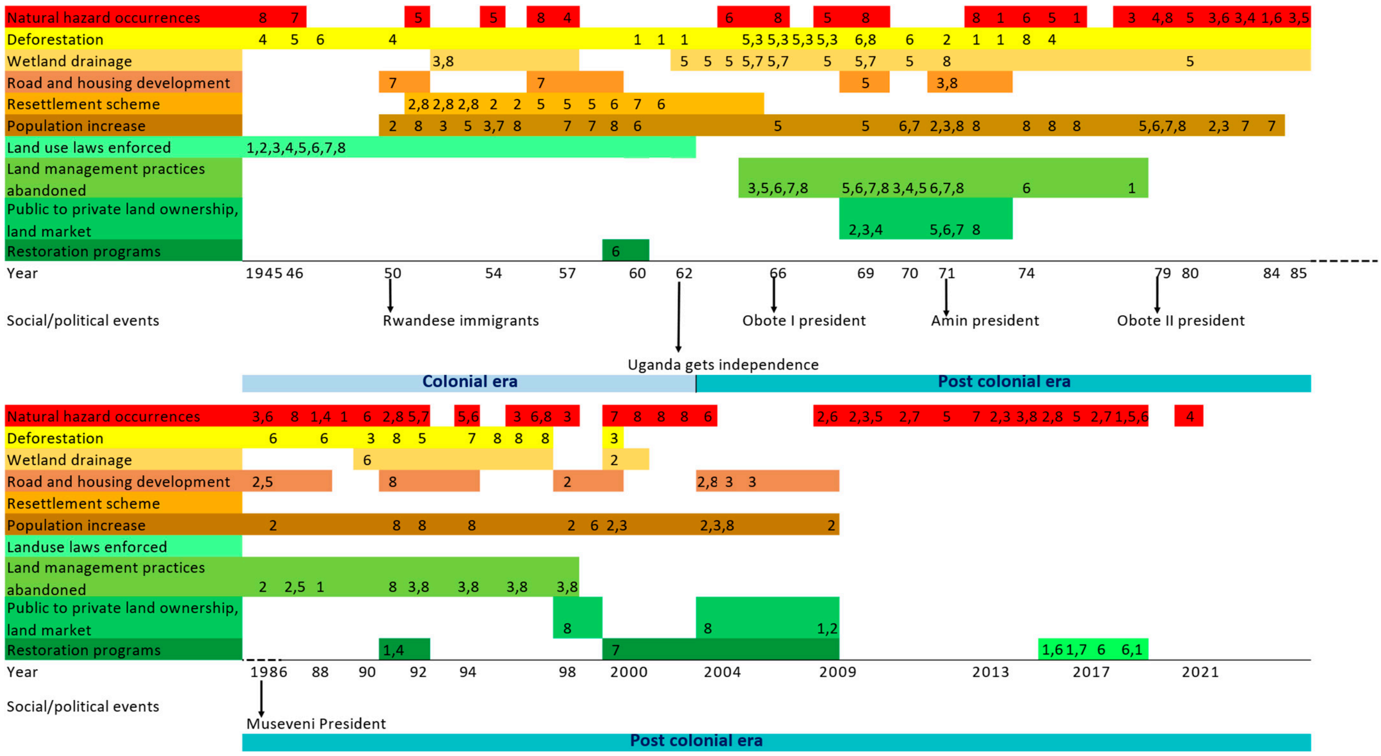

Figure 5. Timeline of events constructed from elderly interviews. The numbers represent watersheds where a particular event happened. “Natural hazard occurrences” includes landslides, floods, and gullies associated with flash flood events. “Deforestation” includes natural tree species that were cut down. “Wetland drainage” refers to the reclamation of wetlands for agricultural and construction purposes. “Road and housing development” includes the roads that were constructed and a change from grass-thatched to iron-roofed houses. “Resettlement schemes” are the measures implemented to depopulate the region. “Population increase” includes the increase in the numbers of both people and livestock, land shortages, and overcultivation. “Land laws enforced” includes the land management regulations that were followed during the colonial period. “Land management practices abandoned” includes the end of practices such as fallowing, the planting of native tree species, contour strip cropping, the avoidance of bush burning, and stabilizing contours with elephant grass. “Public land to private land ownership” refers to the time when land titling began to be given to individual owners and the rights of buying and selling land were established. “Restoration programmes” includes initiatives that have been implemented to rehabilitate the degraded landscapes like afforestation, diversion channels, and the creation of forest buffer zones.

Our analysis of the trend in reported hazards in relation to participant ages (Figure 6), shows that few or no hazards were reported for periods when the participants were younger (e.g., the 1940s). In contrast, more hazard reports concentrate in periods when the participants were middle-aged or older (typically 30 years and above). Notably, the 1980s show a high number of events and this coincides with a period when the median age of the elderly participants was 39, an age where they likely recall significant environmental changes [66].

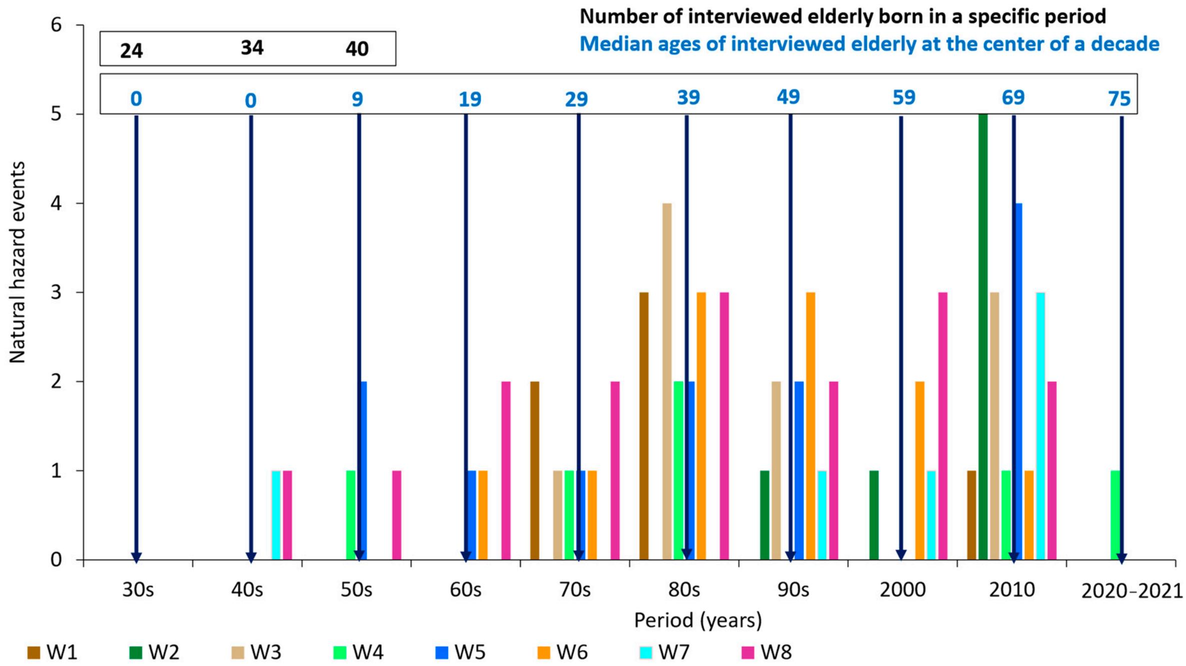

Figure 6. The temporal trend in natural hazard events recorded for each decade as per the elderly citizens between 1940 and 2010 and the corresponding median ages of the participants calculated for the middle of each decade. Note that the column for 2020 corresponds to only 2020 and 2021.

4.3. Catchment Characteristics in the Post-Colonial Era (1962–2021)

Narrations from the elderly citizens indicate that major changes took place in policies, land management, and farming systems after independence in 1962 (Figure 5 and Appendix A.3). For instance, land ownership changed from public to private ownership and people were free to use their land in the way they wished. This period also saw a rise in the buying and selling of land, a practice that was uncommon before independence. The elderly reported that the land management practices and laws, which had been strictly enforced by the colonial government, were gradually abandoned, as shown in the timeline (Figure 5). These changes led to poor management practices on the land, according to the elderly citizens. For instance, there was an increase in the removal of vegetation cover through tree cutting and bush burning, including the cutting of natural tree species and black wattle for charcoal and timber. This deforestation intensified in 1971 during Idi Amin's regime. According to the elderly, this is the period when markets were opened and the trading of different commodities such as food, livestock, construction materials, and charcoal increased. Moreover, the population had increased and therefore the demand for construction materials and fuel energy was high. The elderly also reported that, after 1980, eucalyptus trees increasingly replaced native tree species, and by 2000, most landscapes had been planted with eucalyptus, leaving no traces of black wattle or other native species. The elderly further narrate that after independence, traditional practices such as fallowing and contour plowing were abandoned (Figure 5). Instead, people began cultivating land up and down the hills without contouring, and this was carried out year round. They also observed that, starting from the 1970s, both the human population and livestock numbers increased significantly (Figure 5). This led to overcultivation, characterized by excessive tillage, a reduction in grazing areas, and the draining of wetlands for farming and settlements. Additionally, the elderly pointed out that after the 1970s, with the emergence of a growing market economy, people began to recognize the value of money and began growing food for sale. This practice further contributed to overcultivation.

The elderly citizens also recall that after independence, new crop varieties were introduced to increase productivity. For example, a potato variety more suitable for growing in lowlands was introduced, which led to the further drainage of wetlands to accommodate its cultivation. Unlike the indigenous potato, this new variety required the extensive use of chemicals. From the 1980s through the 1990s, the construction of new roads accelerated, often cutting through hills and draining wetlands to improve access for the growing population. The elderly also noted changes in housing during this period, with traditional grass-thatched houses gradually being replaced by iron-roofed structures in the 1980s.

4.4. Land Use/Cover Change Analysis with the 1954 Aerial Panchromatic Photographs

Major changes in land use/cover occurred between 1954 and 2021 (Figures 7c, 8 and 9). As explained by the elderly, forests existed on hilltops and the upper slopes of most watersheds in 1954. However, this is no longer the case for most of the watersheds in 2021. For W3, W7, and W8, forests existed in 1954 mainly along steep ridges on slopes, whereas the hilltops were covered with short grass. Generally, watersheds adjacent to large, forested areas like W1, W4, W5, and W6 experienced extensive deforestation before 1990. This occurred because there were no boundaries separating the forest from the community, and these areas had not yet been designated as National Parks with restricted access (Figures 7c and 8) [53]. The analysis further shows that W2 and W3 experienced deforestation as well. However, W8 did not show major changes in forest cover (Figures 7c and 8). Whereas deforestation in W1 commenced from 1954, the results suggest that the deforestation in W4, W5, and W6 was conducted well before 1954 (Appendix B). This is confirmed by [67] who showed that the heavy exploitation of Muhabura forest (adjacent to W4) for cultivation and grazing took place in the 1940s. The exploitation of the forest in W4 is also confirmed in the analysis of the 1954 landcover map, where terraces and cultivated fields are shown extending into the forest (Figure 9).

The land use and cover change analysis reveals a significant increase in the area covered by settlements across all watersheds (Figures 8 and 9). The most notable increase occurred in W5, where the area covered by settlements grew from 0.5% in 1954 to 22% in 2021. The analysis also shows that, with the exception of W7, settlements in most watersheds have extended to upper slopes, a shift from 1954 when settlements were primarily located on lower slopes or in valleys. The elderly citizens recall that in the past housing consisted of scattered grass-thatched huts locally known as kateteyi (dress-shaped). These huts were progressively replaced by iron-sheet roofs during the 1970s and 1980s as the population expanded.

The total road length increased from 29 km in 1954 to 66 km in 2021 (Figures 8 and 9). Increases in areas covered by agricultural terraces are noted in W2 and W5, by 75% and 61%, respectively, while a reduction was experienced in W4 and W8 (Figures 8 and 9). The other watersheds did not show major changes in terraced land coverage (Figures 8 and 9). Our field observations also revealed that many of the existing terraces were established during the colonial period and have not been maintained since then, leading to their collapse over time.

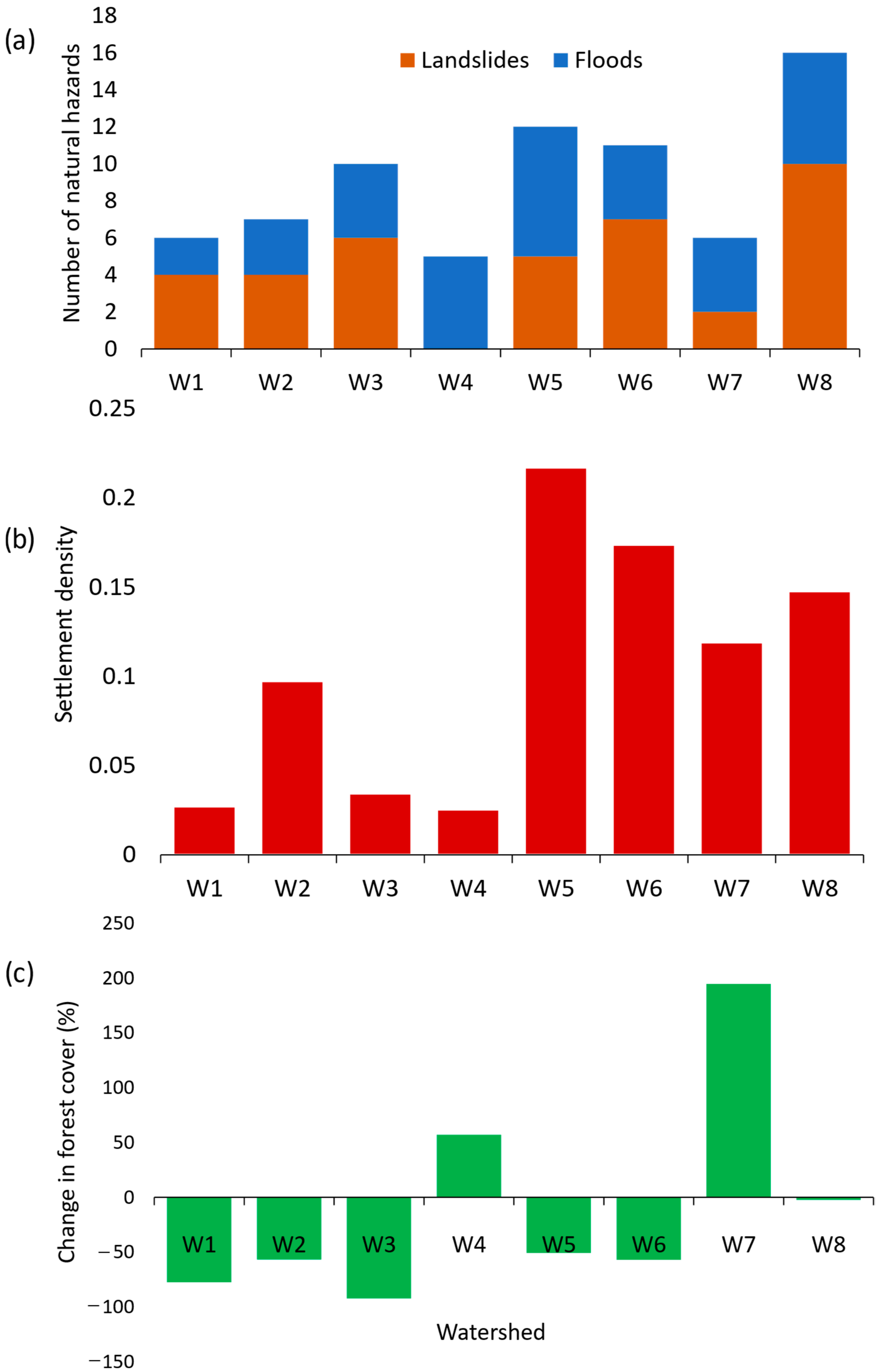

Figure 7. (**a**) Landslide and flash flood events recorded as per the elderly respondents from 1940 to 2021. (**b**) The watershed settlement density for 2021 expressed as a ratio of the total area covered by settlements and the total area of the watershed (the settlement area was manually extracted from Google Earth imagery 2021). (**c**) The percentage forest cover change between 1954 (historical aerial photographs) and 2021 (Google Earth). Positive values indicate an increase in forest cover since 1954, while negative values represent a decline in forest cover between 1954 and 2021.

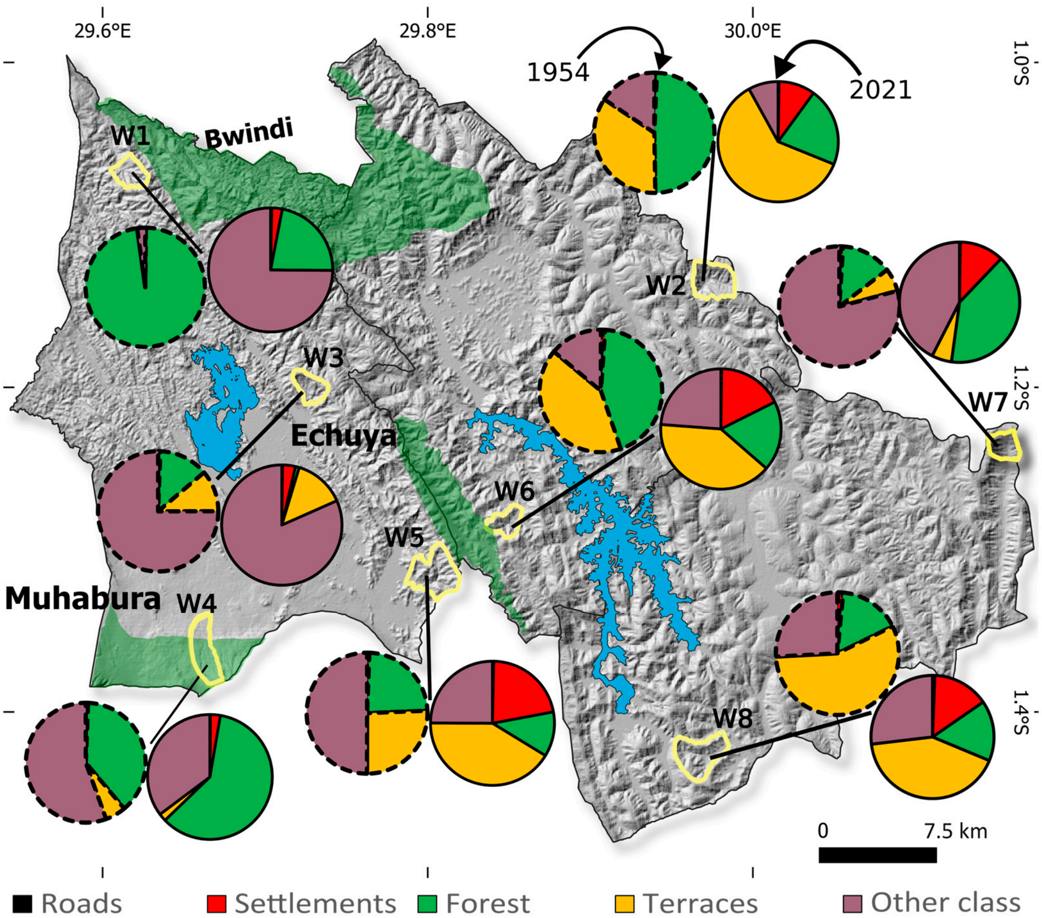

Figure 8. The proportions of different land use/cover classes for 1954 (circles with a black stippled line) and 2021 (circles with a black contour) in each watershed (yellow polygons) as mapped manually on the 1954 aerial photographs and 2021 Google Earth imagery. The 'other' class represents unterraced croplands, wetlands, and other mixed land uses. The map background is a shaded relief with elevations in color extracted from 1 arc sec SRTM DEM (USGS, 2021).

4.5. Population Dynamics

The overall national population of Uganda has grown from two million people in 1911 to 46 million people in 2024, with an average population density of 224 people per square kilometer [50]. For the Kigezi region, based on the delineation of the areas covered by settlements on Google Earth imagery, we see that the highest settlement density is in W5, followed by W6 and W8, with settlement proportions of 22%, 17%, and 15%, respectively (Figure 7b). According to the elderly citizens, the population in all the watersheds was low and sparsely distributed in the 40s, ranging between 6 and 15 households in each watershed. This is confirmed from the 1954 historical land use/cover analysis (Figures 8 and 9). Early researchers reported a rapidly increasing population density in the 50s which put pressure on the land. In his book, 'Kigezi and its people' [62], Ngologoza describes the dilemma of the increasing population density in Kigezi with associated effects of conflicts and competition over land, which necessitated the colonial administrators to establish a resettlement scheme to relocate people to other regions in Uganda. The first resettlement was executed in 1957 where people were resettled from Kigezi to other districts in Uganda. According to the elderly, the resettlement scheme continued in Kigezi in the 60s and after the colonial period.

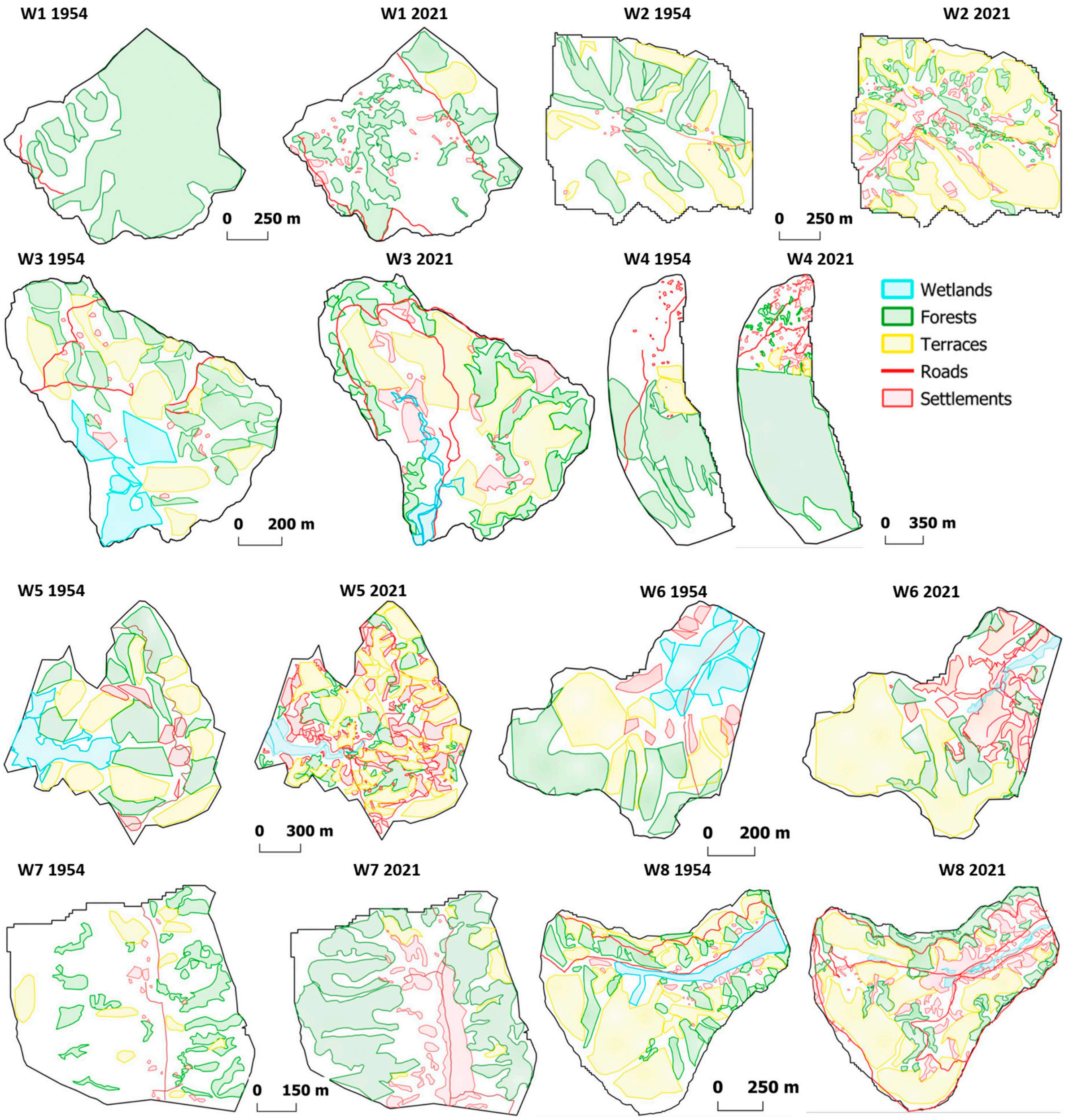

Figure 9. Land use/cover maps of the eight watersheds for 1954 and 2021. The empty spaces encompass other unmapped land uses such as unterraced croplands, grasslands, and all mixed land uses.

4.6. Restoration Programs and Natural Hazards

We note that there is a forest cover increase in some watersheds such as W4 and W7. According to the elderly narratives in W4, Muhabura forest was inhabited by the community residents who carried out their farming activities in the forest until 1991 when they were evicted by the government, and the forest designated as a protected area. The demarcation and establishment of buffer zones for the forests significantly restored the lost forest cover in W4, which is noted in our results, i.e., from 38% in 1954 to 60% in 2021 (Figures 7c and 8). This forest increase was noted within the forest park and surrounding communities (Appendix A). A forest cover increase was also shown in W7 from 14% in 1954 to 40% in 2021 (Figures 7c and 8). According to the elderly in W7, this increase is attributed to restoration programs introduced in the watershed by NGO programs from 2000, which is confirmed in the Google Earth imagery. The elderly reported that afforestation programs in W7 were carried out from 2000 on one side of the watershed where eucalyptus and pine trees were grown and resulted in increased tree cover. The elderly testimonies suggest that natural hazards have been controlled by the increased tree cover in this watershed. Our field observations indicate that restoration programs have been implemented in some watersheds, and they include afforestation and soil and water conservation programs. For instance, during our interactions with the elderly, we learnt that in W1 there are initiatives to plant indigenous tree species to replace those that were cut down long ago. In W6 and W7, NGOs and government programs installed soil and water conservation programs including water diversions; the planting of pine, eucalyptus, and grevilia trees; the implementation of mulching; and fanya chini trenches (trenches and earthen ridges facing downslope). According to the elderly, these practices, if adopted by all residents, could help in reducing incidences of natural hazards.

5. Discussion

5.1. The Added Value and Limitations of the Elderly Approach—Can the Information Be Trusted?

Analysis of the aerial photographs from 1954 for the region and the historical literature validate the elderly citizens' narratives, confirming the reliability of the information collected on the region's landscape dynamics. This shows that elderly citizen-based approaches relying on their lived experience can be a reliable way to retrieve historical information. A detailed inventory of natural hazards in the Kigezi region was compiled from global databases and archives by [47]. When comparing this inventory with the data we gathered from the elderly citizens for the same period and locations, i.e., the eight watersheds, we found only 12 events recorded in the existing global databases. This inconsistency clearly highlights the added value of using the elderly approach in documenting natural hazards. While other researchers have recognized the importance of documentary historical records and archives in recording natural hazards and reconstructing the historical landscapes [1], such records are often lacking in both quantity and quality, particularly in data-scarce regions [68,69].

Obtaining historical narratives of environmental changes offers several advantages, including increasing the understanding of the dynamic nature of landscapes [68]. Records of past natural hazards not mentioned in other inventories might also contribute to improved risk assessments and a better understanding of potential future hazard events [70]. However, most current databases do not provide records for events that occurred many decades ago. For instance, the DesInventar database, which has the largest quantity of data for the Kigezi region, contains records from 1989 at the earliest [71]. In addition, historical trends in land use and land cover were not easily available before the start of satellite missions [34,72]. These efforts become even more difficult when historical aerial photography is required because such records are not always easy to find [1,73]. Consequently, elderly citizens could help to fill in this information gap. Natural hazard records from the elderly are often accurate at a spatial scale, as they typically provide the exact locations where events occurred. This positive attribute has been recognized in various studies using the citizen science approach; e.g., [74–76]. When reconstructing past land use/cover, the elderly articulate much landscape-related information that cannot be found in satellite images or aerial photographs. For instance, we gathered information on the farming systems, land management practices, types of vegetation that existed, and the regulations that governed land use. As demonstrated by [46], this comprehensive information offers a deeper understanding of natural hazard processes and mechanisms, which is crucial for effective disaster risk reduction.

While the elderly approach was valuable in creating an account of natural hazards and the historical landscape, there are limitations associated with the approach. First, the recollections of the elderly are incomplete in terms of the exact timing of events. Even if the timeline assisted in memory recall, there were still challenges in obtaining the exact date of an event. In some cases, statements like 'the event happened during that regime' were experienced, leading to inaccuracy regarding the time of occurrence. In comparison, Jack et al. [77] demonstrated that children and adolescents tend to be less accurate in recalling past events compared to adults. In Friedman et al. [78], it was revealed that memory accuracy for past events improves with age, indicating that older adults often provide more precise accounts of historical events due to their broader life experience and more developed cognitive recall abilities. This suggests that elderly participants have clearer memories of hazards from the periods when they were most actively engaged with their environment or when their memory capacities were active, than when they were younger with limited early memories. However, research has also shown that information from the elderly is often limited by memory decay, as memories can fade or become distorted over time, leading to inaccuracies in recalled events [79]. The apparent trend of reported hazard events shown in Figure 6 may therefore be influenced by the age and memory capacity of elderly participants. Spatial biases also exist in the data collected because the elderly primarily recall events that occurred in their areas of residence [80]. Consequently, the information provided is highly context- and place-specific, necessitating caution when extrapolating these insights to broader scales. Such biases can lead to the underreporting of events in less populated or uninhabited areas, potentially skewing the data. As a result, it may seem that natural hazards are more frequent in densely populated areas, when in fact this could simply be due to higher rates of recollection and reporting in these regions. Regarding documenting natural hazards, biases exist in recording only large and impactful events [55,81,82]. The elderly tend to recall events that caused severe impacts or fatalities, while less impactful events are often overlooked. As noted by Flicker et al. [36], it is natural for people to remember events with a significant impact, while omitting or forgetting those of lower magnitude, which can result in incomplete historical records. The inventorying of low magnitude and frequent events is important in building a reliable hazard susceptibility assessment [83]. Similar biases in citizen science data have been reported by other authors, including Sekajugo et al. [76], Arazy et al. [81] and Foody et al. [84]. Another limitation is that the information provided by the elderly citizens is often limited in terms of the process understanding of the events, hence causal relationships are inferred from personal perceptions, cultural beliefs, and social contexts [36,85].

With such discrepancies and biases in mind, the information provided by the elderly, although valuable, must be carefully analyzed and complemented with other methods to ensure reliability. This complementarity between the narratives of the elderly and empirical methods has been effectively applied by researchers such as Nyssen et al. [27] and Solecka et al. [29]. In our study, apart from analyzing historical aerial photographs, field surveys were conducted to validate the reported land transformations in the landscape. Additionally, exploring the historical literature, including books and research publications, provided further insights and confirmed the plausibility of the accounts of the elderly. Some researchers, such as Kanyiginya et al. [47] and Sekajugo et al. [76], have utilized multiple methods for natural hazard inventorying to address spatial biases and the tendency to report only significant events. To mitigate inaccuracies arising from memory decay, our study employed a triangulation approach to cross-verify accounts from different elderly participants to ensure accuracy and reliability. This strategy, used by Bwambale et al. [46], for example, enhances the validity of findings from qualitative research.

5.2. Natural Hazards and Forest Cover Changes

Accounts from the elderly attribute the increase in the reports of natural hazards to land use changes, especially vegetation removal and changes in land management practices. According to Kizza et al. [86], the most significant and predominant land use change that took place in the Kigezi region from 1987 to 2014 was the conversion of tropical high forests to small-scale farmland and woodlots, and the decline in the wetland areas. Similar findings were reported by Twongyirwe et al. [53] and Barasa et al. [87], which highlighted important deforestation in the Bwindi Impenetrable Forest Reserve. This included the largescale clearance of forest cover from 1960 to the 80s before restrictions and boundaries separating the forest and community land were established. It is possible that landslides were favored by this deforestation. Forest conversion, especially to agricultural land, has been associated with increased landslide activity in similar regions just south of our study area [12,22,88], demonstrating that when deforestation occurs, an increase in landslides is experienced over a span of approximately 10–15 years.

Our results further indicate that the natural vegetation as well as cultivable lands were or are quickly being converted to eucalyptus plantations. As mentioned by the elderly, black wattle trees which were enforced by the colonial government protected the land against soil degradation. This observation aligns with findings by De wit et al. [89] and Babur et al. [90] who highlighted that black wattle trees enhance soil aggregate stability and reduce soil erodibility, thereby preventing the risk of landslides and flash floods. According to the elderly citizens, the rising demand for wood products, their high economic value, and the fast maturing of eucalyptus are causing the rapid conversion of native tree species. Other countries in the region have recorded a rapid rate at which eucalyptus is replacing native tree species as well as crop land. In Ethiopia, for example, eucalyptus is perceived positively for its economic benefits and many small-holder farmers have engaged in the conversion of croplands to eucalyptus stands [91]. However, there is controversy from the elderly citizens surrounding the effectiveness of eucalyptus trees in controlling natural hazards. Some elderly citizens and local residents believe that eucalyptus has inflicted more harm than good regarding land management. Other elderly citizens have attached a positive role to eucalyptus in controlling natural hazards. For instance, the section of W7 where afforestation programs were implemented with eucalyptus has registered a reduction in landslides and flash floods according to the residents. In a recent fatal disaster that occurred in one of the watersheds (W4), a cascading event comprising landslides and flashfloods killed nine people and displaced about 300 households [92]. From our interactions with survivors, homes that had eucalyptus plantations around them were saved from being swept away by the flashfloods. Other controversies of eucalyptus in land management have been highlighted by some researchers such as Wang et al. [93] who noted that the successive planting of eucalyptus reduces soil aggregate stability and exposes the land to soil erosion and landslides. Moreover, eucalyptus landscapes were found with soil compaction problems, as well as poor aeration and water-holding capacity, which could be linked to flash flood occurrences. Another study in Ethiopia by Nyssen et al. [27] highlighted the role played by eucalyptus plantations in initiating gully formation and flash floods. Eucalyptus woodlots do not encourage undergrowth and limit water retention which in turn increases surface runoff and therefore contributes to flash flood occurrence [94].

5.3. Influence of Land Management Practices and Farming Systems on Natural Hazards

Historical researchers in the region such as Purseglove et al. [63] had previously warned of the disasters that the Kigezi region might face due to the increasing population pressure that was noted as early as the colonial era. According to the elderly and confirmed by Purseglove et al. [63], the increase in population was attributed to immigration from Rwanda that started in 1932 and continued to the 1950s. The elderly reported that the increase in population prompted the colonial administrators to set up laws and policies governing the use and management of land. These findings align with Turyahabwe et al. [40] and Purseglove et al. [63] who established that, in response to the increased population and shortage of land, the colonial administrators passed several policies including the planting of black wattle trees for every household, restrictions on the cutting down of trees and bush burning, fallowing, and terracing. These policies and practices to conserve the land, transformed and made Kigezi a model region as far as terracing is concerned [51,95]. The terraces still existing today are a heritage of the policies that were put in place to reduce the increasing land degradation. In W2 and W5, terraces increased at the expense of forest cover as forested land was converted into cropland land (Figures 8 and 9). On the other hand, the terraces in W8 reduced as the cropland land was turned into settlements as confirmed by the increase in the area covered by houses. The reduction in terraces in W4 can be explained by the restriction of cultivation in Muhabura forest. The terraces which were in the forest were concealed as the forest rejuvenated. With the abandonment of land management practices, the terraces have not been maintained and are therefore dilapidated.

According to the elderly, terracing and consistent fallowing practices prevented natural hazards from occurring; however, as the population grew and these practices were no longer practiced, the land became more susceptible to natural hazards. However, there is controversy on the effectiveness of terraces in terms of controlling natural hazards. For instance, Cornelis et al. [96] argues that terraces control floods by reducing the velocity of runoff. On the other hand, terraces create favorable conditions for landslides because of their capacity to increase water infiltration [97,98]. The problem is exacerbated by the unmaintained terraces which are a source of shallow landslides. Most shallow landslides we observed recently in the field have their scarp/head originating from an old terrace ridge. The role of terraces in initiating shallow landslides was demonstrated in a study by Schilirò et al. [99] in Italy. The same was also demonstrated in Eastern Uganda [100], and in a region of Rwanda close to our study area [101]. Furthermore, Rogger et al. [98] highlighted the risks associated with abandoned terraces in terms of causing gully initiation and flash floods. According to the elderly, the terraces in the past were stabilized with elephant grass, which prevented the terrace from collapsing and causing shallow landslides. The issue of terracing and landslides could therefore be linked to land management practices and the nature of the terraces, but we lack data from the current study to ascertain this. More studies are therefore required.

Another land management practice that has been abandoned was fallowing. Apart from keeping the soil covered, fallowing allows the soil to regenerate and therefore increase water infiltration, thereby reducing runoff and flash floods [102]. Previous research has shown the role played by fallows and elephant grass along contours in positively improving the soil's physical properties and preventing runoff and flash floods [103]. Our field observations discovered that W1 is making efforts to maintain the traditional crops; for instance, millet is still grown in this watershed, a crop which other watersheds abandoned after the colonial period. Millet promotes conservation agriculture by acting as a cover crop but also by improving the soil structure [104,105], which can be associated with reduced frequencies of natural hazards in W1.

5.4. Population Growth and Infrastructure Development in Relation to Natural Hazard Risks

Our analysis shows that the population in the watersheds has grown rapidly, increasing exposure to natural hazards. For example, in contrast to the 1940s and 1950s, many settlements are currently located on hillslopes, which exposes people and their property to landslides (Figure 9). Similarly, other new settlements were mapped in the drained wetlands, which puts the population at risk of floods. This trend is also highlighted by various authors who have reported the increasing impacts of natural hazards, exacerbated by population growth, which pushes people to live in more hazardous terrain [5,14,19,20,106]. Infrastructure has developed in the watersheds with more roads constructed, especially starting from 1980. With the hilly terrain of the region, roads had to be dissected through the hills, which probably reduced the stability of the slopes and increased the susceptibility of the landscape to landslides. The role played by road construction in causing landslides in mountainous environments is clearly demonstrated [107]. Furthermore, the type of roads constructed were of the sand and gravel type without embankments for the side cuts, which led to more slope instability. In our previous landslide inventory by Kanyiginya et al. [47], several landslides were mapped along newly constructed roads in W3 and W8. Moreover, in most cases the roads were crossing wetlands which necessitated drainage, a management action that can influence the occurrence of floods.

5.5. Natural Hazards and Climate Variability

Despite the potential role of human activities in the occurrence of natural hazards as highlighted in the preceding sections, and the evident increase in the population's exposure, the trends observed in the reported hazards must also be analyzed in the context of climatic variability. El Niño and the Southern Oscillation (ENSO) are examples of such a variability that has influenced rainfall patterns in the region [108]. For instance, the 1982-83 El Niño event was particularly intense and was linked to a noticeable rise in rainfall and hazard occurrences [109]. Beyond ENSO variability, anomalous periods of rainfall not only lead to more frequent hazard events but may also potentially result in more impactful events [110]. Such impactful events are more likely to be vividly recalled by the elderly participants [80]. Future studies could consider a deeper investigation of the interaction between climate variability, land use change, and natural hazards in this region. However, much more data and knowledge would be needed, not only on natural hazards and land use [12,16], but also on climate [111].

6. Conclusions

Our findings reveal that major land use/cover changes associated with a high population increase have occurred over the last 80 years. The changes, which include vegetation removal, conversion from natural to exotic tree species, the increased cultivation of hillslopes, road construction, wetland drainage, the abandonment of agricultural terraces, and fallowing practices, are all associated with an increase in population pressure, laxity in the land management laws and policies, and change from public to private land ownership. These changes are commonly reported to be associated with an increase in natural hazard frequency. However, despite an unprecedented amount of new information for the region, this association between natural hazard frequency and land use change cannot yet be quantitatively validated. Nevertheless, the increasing exposure of vulnerable populations to the dangers of natural hazards is evident, with population growth and poorly designed landscape management practices as the key drivers. Integrating the knowledge of elderly citizens into the analysis of natural hazards and land transformation has proven to be highly valuable. The rich knowledge of the past narrated by the elderly citizens underscores the effectiveness of this approach in generating unique and otherwise inaccessible knowledge that would be hard to obtain with other scientific or social research methods. This contribution enhances a comprehensive understanding of landscape transformation and natural hazard dynamics. The elderly approach can also be useful to pass on historical memory about natural hazards from older to younger generations by leveraging their lived experiences and long-term observations. Such information could be used in policy- and decision-making, for disaster risk reduction, and to bolster the resilience of local communities.

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Institutional Review Board Statement: This research in its entirety was approved by the Research Ethics Committee of Mbarara University of Science and Technology and the Uganda National Council of Science and Technology.

Data Availability Statement: Data are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Questionnaire A1: Questionnaire guide for the elderly interviews

Introduction

Hello. I am Violet Kanyiginya a PhD researcher attached to Mbarara University of Science and Technology. I will be having a discussion with you about how the landscape in your area has evolved and identify any natural hazards that have occurred in the past.

The purpose of the interview/discussions is to understand landscape change dynamics and how it is linked to natural hazard occurrences over the past decades. The information you provide is very important for this study to enable the understanding of the natural hazard processes, with a hope of contributing to disaster risk reduction

I will keep your name and your answers confidential. Your responses will be used only for the purpose of this research.

Name: ____

Sex: ____

Age (when were you born?) ___________________________________

Village: ____

Parish: ____

Sub-county: ____

District: ____

1. How long have you lived in this area?
2. From the time you started understanding, what do you remember about your village? How many were you in this village (household)? Show on the map where your houses were located.

3. How did your village look like generally? Or what was in the environment when you were young (structure of houses, roads, budlings, wetlands, forest, etc.) for FGDs use the map to show how the landscape looked like in the past and What it looks like currently.
4. What changes on the landscape do you remember happened? what has changed, what has not changed in your environment when did the change happen and where did it happen?—Use the timeline to re-member and the map to show where the changes occurred.
5. What about the river in your area, can you tell me about its history/evolution through time?
6. How were the land managed, what crops did you grow?
7. Any policies that existed?
8. Have you experienced landslides and floods in the past?
9. If yes, when did they happen—which years/months/seasons—use the timeline of historical political or social events to remember.

Appendix A.1

Table A1. Historical timeline guide used during interviews.

Year	Historical Event/Change			Visualization of Landscape Change
	Political and cultural changes (new laws, policies and practices, immigrants)	Socio-economic changes (livelihoods, farming practices, promotion of certain crops, population, infrastructure, building architecture)	Environmental/landscape changes (deforestation, afforestation, what natural hazards occurred)	Using the available map, show how the landscape looked like in this period? (forested, terraced or not, bare, bushy, uncultivated, wetland, grazing land, uninhabited, etc.)

Appendix A.2

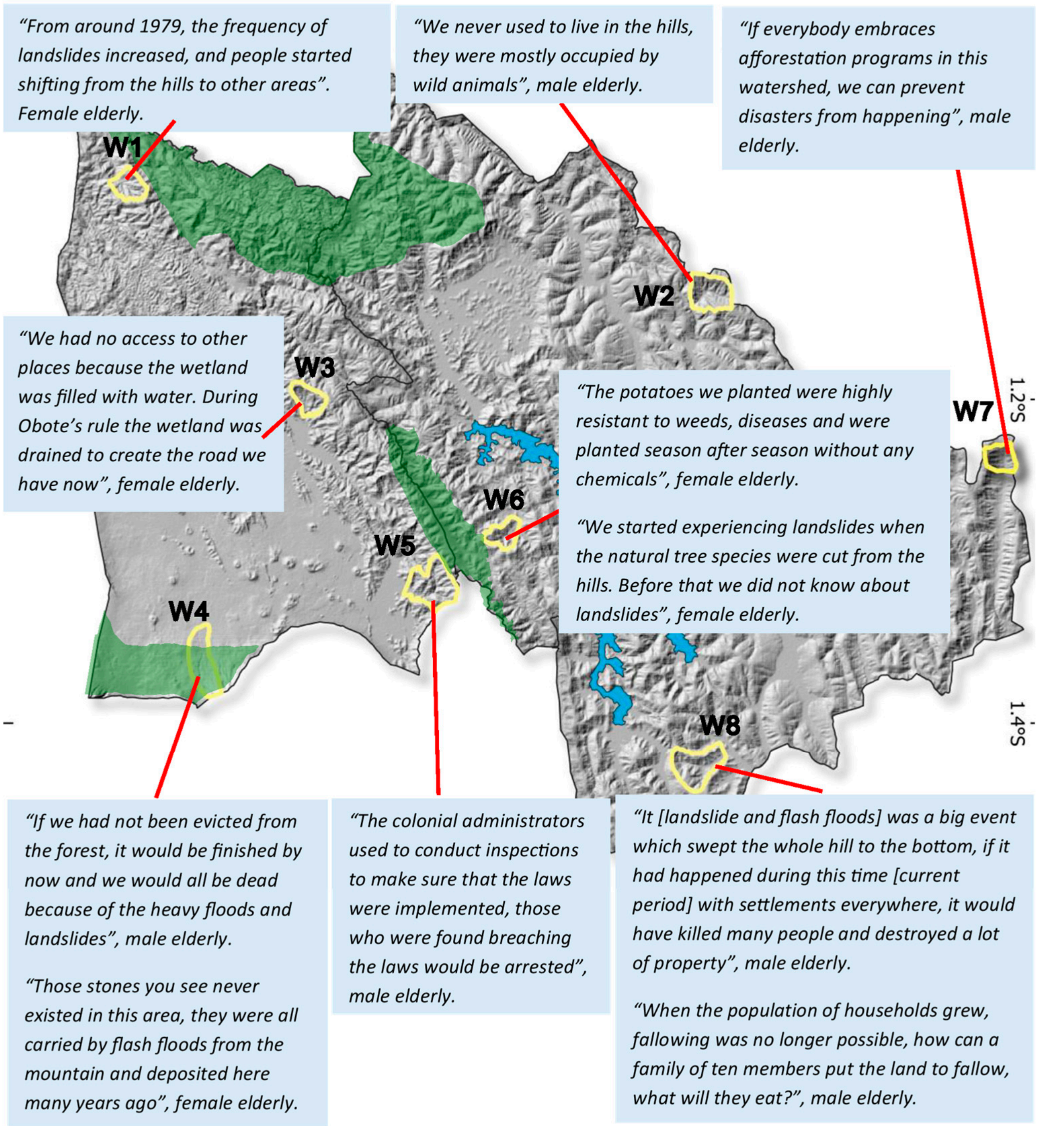

Figure A1. Examples of quotes from interactions with the elderly citizens.

Appendix A.3

Table A2. Detailed watershed timelines.

W1—Nteko		
Dates	**National/Regional Context**	**Local Events**
1932	Pre-colonial period	Park boundary was established separating Bwindi forest and communities
1960	Colonial period	Heavy deforestation in the catchment started
1979	Obote I president	Landslides experienced and people started shifting due to landslides
1991	Museveni's rule	Bwindi forest was designated a national park
2016	Museveni's rule	Restoration program by NGOs to plant indigenous trees
2019	Museveni's rule	Heavy landslides occurred

Table A2. *Cont.*

	W2—Kyokezo	
Dates	**National/regional context**	**Local events**
1950–60	Colonial period	Resettlement scheme took place as a depopulation strategy
1971	Obote I president	The natural forest started to decline, replaced with eucalyptus
1980	Obote II rule	Population grew, land fragmentation
1986	Museveni became president	Many iron sheet-roofed houses; fallowing competently ended
1998	Museveni's rule	The first road was constructed
2000	Museveni's rule	Swamp drainage
2009	Museveni's rule	The first serious landslides occurred killing 6 people and destroying several properties. Many large gulleys were formed
	Museveni's rule	Buying and selling of land increased; land fragmentation
April 2017	Museveni's rule	Deadly landslides
2004	Museveni's rule	Road constructed began
1980	Obote II rule	Over-population and cultivation
	W3—Nyundo	
Dates	**National/regional context**	**Local events**
1952	Colonial period	Mass wetland drainage for cultivation and road access
1966–70s	Obote I rule	Land management practices abandoned
1971	Obote I president	Construction of many roads cutting through the mountains
1980	Obote II rule	Population increase, over-cultivation overgrazing; disasters increased, happening in April and September every year
1990–98	Museveni's rule	Fallowing was no more
2000	Museveni's rule	Eucalyptus dominated the landscape, natural tree species cut down
2004	Museveni's rule	Road constructed began
	W4—Rukonji	
Dates	**National/regional context**	**Local events**
1950	Colonial period	Muhabura forest heavily cut down for cultivation
1957	Colonial period	Flash floods
April 1974	President Amin rule	Heavy flashfloods involving deaths occurred
March 1982	Obote II rule	Heavy flashfloods involving deaths occurred
April 1988	President Museveni's rule	Heavy flashfloods involving deaths occurred
1991	Museveni's rule	Forest designated a national park and the regrowth of the forest
	W5—Chibumba	
Dates	**National/regional context**	**Local events**
1950	Colonial period	Landslides occurred in the hills, people relocated to lowlands
1954	Colonial period	Fallowing, planting elephant grass along contours, black wattle trees enforced
1957	Colonial period	Depopulation plan, people were resettled

Table A2. *Cont.*

	W5—Chibumba	
Dates	**National/regional context**	**Local events**
1959	Colonial period	Rwandese war, immigrants
1960	Colonial period	Mining of tin
1966–70s	Obote I rule	Land management practices abandoned, natural trees cut down, cultivating in the swamp
1969	Obote I president	Iron-sheet houses
1980	Obote II rule	Wetland in the valley was reclaimed and finished
1981	Obote II rule	Natural hazards, especially floods increased in the catchment
1986	Museveni's rule	Road construction
	W6—Kacereere	
Dates	**National/regional context**	**Local events**
1936	Pre-colonial period	Echuya forest separated from community land
1959	Colonial period	Echuya forest gazetted a forest reserve
1955–66	Colonial period	Resettlement plan for depopulation happened
1960	Colonial period	Sinkholes experienced
1970	Obote I rule	Land management practices abandoned; natural trees cut down replaced with exotic ones
1974	President Amin rule	Elephants left the catchment
1979	President Amin rule	Over cultivation and shortage of land
1980–90	Obote II rule	Landslides and floods were experienced, and gulleys started to form
Apr-84	Obote II rule	Serious flashfloods happened and swept crops and houses
1990–98	Museveni's rule	Wetland lost completely because of siltation
Sep-94	Museveni's rule	Landslides occurred and destroyed 3 houses, bridges, animals, and crops
2016	Museveni's rule	Soil and water conservation programs introduced
	W7—Kahondo	
Dates	**National/regional context**	**Local events**
1946	Colonial period	Landslides occurred and killed livestock, destroyed crops
1950	Colonial period	First main road constructed
1954	Colonial period	Fallowing, planting elephant grass along contours, black wattle trees enforced
1956–1959	Colonial period	The first iron-sheet houses were built
1966–70s	Obote I rule	Land management practices abandoned, natural trees cut down, cultivating in the swamp
1971	Obote I president	Public land became private land with land titles. There was no source of water, the first borehole was constructed. A river was formed and continues to flow
1980	Obote II rule	Overpopulation of people and livestock, overgrazing and cattle trails all over the landscape, over cultivation
1984	Obote II rule	Buying and selling of food, food scarcity
1990–98	Museveni's rule	Gullies started forming in the catchment

Table A2. *Cont.*

	W7—Kahondo	
Dates	**National/regional context**	**Local events**
1992	Museveni's rule	Severe famine happened in 1992 due to drought, and pests and diseases
2000	Museveni's rule	Afforestation programs introduced, with Eucalyptus and pine dominating
2005–2009	Museveni's rule	Soil and water conservation programs introduced
April 2013		Serious landslides and floods occurred
	W8—Kibuga	
Dates	**National/regional context**	**Local events**
1945	Colonial period	Deadly landslides occurred
1952	Colonial period	Mass wetland drainage
1966–70s	Obote I rule	Land management practices abandoned
1971	Obote I president	Construction of many roads cutting through the mountains
1972	Immigration started	Population increase
1980	Obote II rule	Over-cultivation and overgrazing set in; landslides and floods increased
1990–98	Museveni's rule	The natural vegetation began to shrink, Eucalyptus dominated the land cover, iron-sheet houses replaced grass-thatched houses; fallowing was no more
	Museveni's rule	Buying and selling of land increased; land fragmentation
April 2017	Museveni's rule	Deadly landslides
2004	Museveni's rule	Road construction began, more landsides occurred
1980	Obote II rule	Over-population and -cultivation; landslides and flash floods

Appendix B

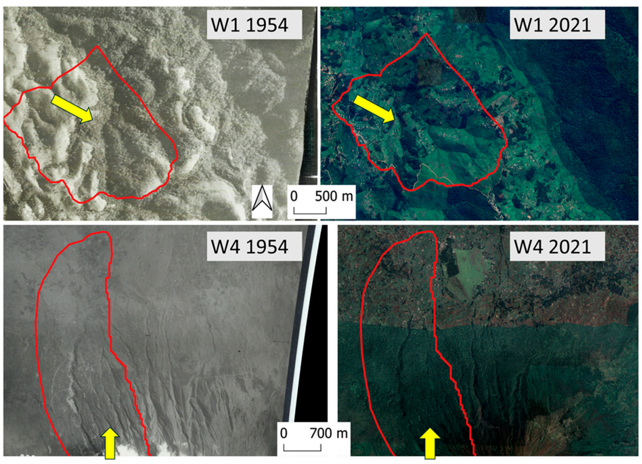

Figure A2. Examples of land use and land cover changes in the watersheds. W1 shows a reduction in forest cover, showing that deforestation took place after 1954, and W4 shows an increase in forest cover. The red polygons are the watershed boundaries. The yellow arrows indicate where forest cover change took place.

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