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Ecological and Hydrological Indicators of Climate Change Observed by Dryland Communities of Malipati in Chiredzi, Zimbabwe

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Abstract: Existing evidence about climate change in Zimbabwe has tended to focus more on elements and events of the climate system, marginalizing changes in the hydrological and ecological system. To contribute to the improved understanding of climate change, this study captured the observations of climate change in Malipati, a remote agrarian dryland area in the Chiredzi District, Zimbabwe. The aim of the study was to gather detailed insights about perceived environmental changes using the evidence drawn from local and indigenous populations who have close interactions with their natural environment. A household questionnaire-based survey with randomly chosen farmers (n = 116) revealed that participants' observations of changes in hydrological and ecological system were consistent with available evidence of increasing temperatures and little rainfall recorded in the district. Results also showed high sensitivity of the area to climate change that manifest in various indicators: hydrological changes in rivers, streams, swamps, and ground water; and ecological changes through the behaviour of trees, insects, birds, and wild animals. Sex and age of the participants did not influence the way they perceived most of these changes ($p > 0.05$). However, education and the period of stay in the area were related to the respondents' perceived changes in river flows and siltation, and the conditions of swamps ($p < 0.05$). Our study also revealed deeper insights about the human-biodiversity interactions in the face of climate change in unique areas where communities live alongside wildlife. The evidence drawn from local and indigenous populations can be used to inform local-based solutions to the growing problems of climate change and biodiversity loss. Future studies would need to further examine such areas to understand the mitigation and adaptation practices that would promote the sustainable co-existence of humans and wildlife.

Keywords: biodiversity; ecological changes; hydrological changes; local-based solutions; perceptions of climate change; wildlife

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1. Introduction

Zimbabwe is projected to become an increasingly warmer and drier climate because of climate change [1–3]. This knowledge is largely based on records from a few weather stations that are interpolated on coarse resolution grids and from downscaled global climate models (GCMs). These methods require ground-truthing to validate their capabilities to reflect changes that occur at finer local scales. Concerns about the generalizations associated with such methods continue to characterize debate within the climate change research community [4,5]. Beyond the challenge of available weather recording stations not being dense enough to capture spatial variabilities in climate data, the quality of readings given by the instrumentation used is also being queried [1,6]. Accordingly, there are considerable gaps in data records. In Zimbabwe, for instance, weather instruments are said to be poorly maintained, making the climate data questionable [7,8]. Furthermore, only about 48 weather stations out of the available 66 are said to be functional [8]. The situation has not been fully abated by the installation of automated weather stations (AWS) by non-governmental organisations. Out of the 18 AWS, only half are operational owing to maintenance and data inputting challenges emanating from budgetary constraints and limited skills and staff [8]. As part of the solutions towards addressing these challenges, a growing size of scholarship is now advocating for integrating perceptions from local people who, because of their climate-sensitive livelihoods, are believed to have a keen interest in observing environmental changes within their communities [4,5,9–14], and in seeking solutions to climate change and biodiversity loss [9,11,13,14]. Thus, local-based observations of climate change made by communities experiencing climatic phenomena can strengthen knowledge of climate change and help to inform local-based solutions to the problem of climate change and biodiversity loss.

Existing studies show that local observations of climate change impacts can improve our understanding of the localized responses of physical and biological systems to climate change [5,15]. This knowledge can also give useful pointers on how to design appropriate climate adaptation and mitigation strategies that are suitable to local socio-ecological systems [16–18]. Documenting the local observations of climate change and comparing them with existing knowledge in the traditional climate science domain can strengthen and enrich climate impact assessment studies [15]. Other scholars express that gathering the climate change experiences with users of climate information services, such as farmers, can also increase the uptake of and trust in such services [19–21]. Such place-specific insights are also capable of validating instrument data and ground-truthing data from GCMs [15,22]. This is particularly important in remote locations such as the south-eastern Zimbabwe that are still under-researched and not adequately covered by instrument weather data. It is thought that many of such places that are experiencing rapid and disruptive climate shifts are found in the developing world [4,23].

Zimbabwe has a semi-arid climate system that is divided into five natural regions (NRs) based largely on mean annual precipitation and temperature. Precipitation declines from NR I to NR V, whereas temperature increases from NR I to NR V (Table 1) [3,24]. Past studies show that the climate change trend in the country tends to be associated with these natural ecological regions [3,24]. The Chiredzi District falls in NR V, which covers 26.7% of the country but is reported to have expanded to 38.2% owing to climate change [24]. The decline in size of productive areas and expansion of unproductive ones is evident in Table 1. A recent study by Manatsa et al. [3] has reclassified this region (NR V) into NR Va and NR Vb after observing significant changes in rainfall patterns. They found out that NR Vb is becoming drier and hotter than NR Va, with a decline of up to 10 days in the length of the rainfall season separating these zones. This study focused on the Malipati area in Ward 15, which occupies the NR Vb according to the latest zoning suggested by Manatsa et al. [3].

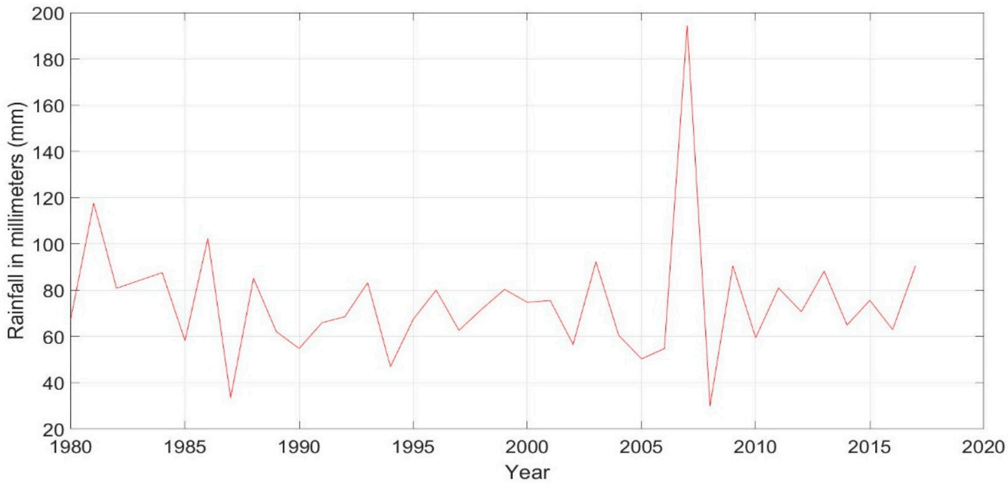
Table 1. Climatological description of natural regions in Zimbabwe.

Natural Region	Characteristics	Total Area, Original Classification(%)	Total Area, after 2020 Revisions (%)
I	Annual rainfall more than 1000 mm, length of rainfall season more than 130 days and maximum temperature between 21 and 25 °C	1.8	1.5
II	Annual rainfall between 750 and 1000 mm, length of rainfall season between 120 and 130 days and maximum temperature between 23 and 28 °C	15.0	15.0
III	Annual rainfall between 650 and 800 mm, length of rainfall season between 110 and 120 days and maximum temperature between 25 and 28 °C	18.7	16.2
IV	Annual rainfall between 450 and 650 mm, length of rainfall season between 105 and 120 days and maximum temperature between 27 and 29 °C	37.8	29.1
V	Annual rainfall below 600 mm, length of rainfall season less than 110 days and maximum temperature between 28 and 32 °C	26.7	38.2

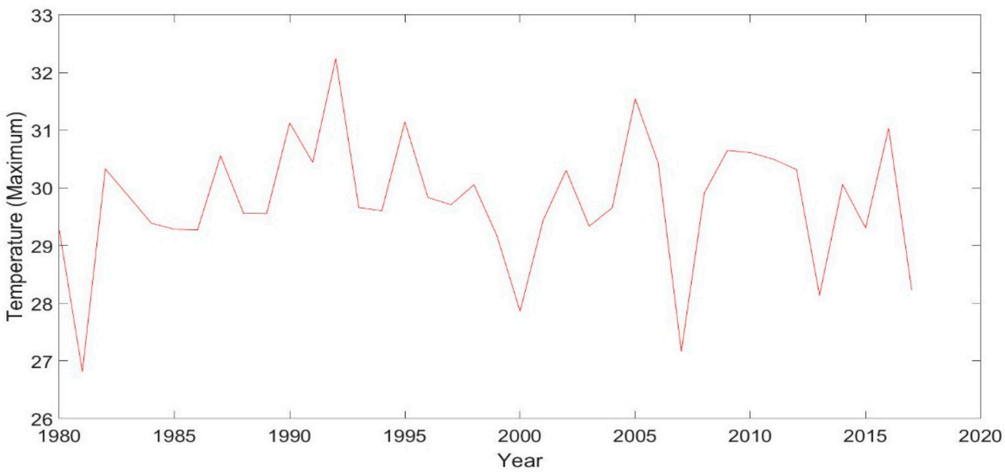
Source [3,24].

Aside from being isolated from the coverage of available meteorological stations, Malipati is also located in a wildlife zone where the combined influence of climate change, landscape changes and human and wildlife pressure imposes unique challenges to the subsistence communities [25,26]. The closest weather stations at Beitbridge and Buffalo Range are located more than 100 km away, beyond the World Meteorological Organisation's (WMO) standards that weather stations should be within a radius of 50 km from each other [8]. These characteristics make the area suitable for using the observations of local people to validate climate change information obtained from downscaled and interpolated patchy meteorological stations.

The purpose of this study was to determine if the local communities would corroborate the noticeable shifts towards a drier and hotter climate from their own subsistence-oriented experiences in this region (Figure 1). Most studies conducted in Zimbabwe have used climate data records to understand changes in temperature, precipitation and seasons [3,24], hydrological records and remote sensing data to understand hydrological changes [1,27,28] and climate models to predict species distribution under different climatic scenarios [29]. However, climate change perceptions and interpretations by communities experiencing environmental changes, and how these observations can be used to complement climate change evidence, have not been given adequate treatment.



(**a**) Rainfall



(**b**) Temperature

Figure 1. Climate variability in Chiredzi District from 1980 to 2017, (**a**) rainfall and (**b**) maximum temperature.

The focus of this study was on changes in hydrological and ecological indicators that are observed by local agrarian communities who live alongside wildlife protected areas. The study presumed that such zones exhibit unique climate change experiences owing to the complex interactions between humans and wildlife under harsh climatic conditions. The article begins by reviewing studies on climate change assessment in Zimbabwe, showing that much of the information has largely relied on physical climatic assessments with limited citizen science. It then describes the methods used to collect data after giving details about the geography of the study area. A discussion of the results is later presented. The article concludes by highlighting areas for future attention to fully utilize the capabilities of local people towards enhancing knowledge of local environmental changes in an increasingly changing climate system and degradation of landscapes.

2. Existing Evidence of Climate Change in Zimbabwe

Studies examining the impacts of climate change in Zimbabwe are quite broad and multisectoral. Early research by Unganai [30], which used historical instrument records to understand past temperature and rainfall trends, and GCMs to project the future climate scenario, became a key reference point to understand climate change trend in the country. The study showed that the country had warmed by up to 0.8 °C between 1933 and 1993 while precipitation declined by about 10% from 1900 to 1994. Subsequent studies have corroborated this warming and drier trend [3,24,31], with some scholars adding that many places are experiencing disruptive climatic events in the form of temperature and precipitation extremes [32–34]. The water sector has been shown to be highly sensitive to climate change [28,35,36], with catchments found in dry natural regions showing evidence of water stress and decline in water levels of reservoirs [1,37]. Excessive evapotranspiration from high temperatures and decline in precipitation have also been blamed for contributing to the decline in both aquatic and terrestrial biodiversity [29]. Chapungu et al. [38] attribute the loss in plant species to decreasing precipitation and increasing temperatures whereas Mpakairi et al. [29] predicted shrinking habitats of the African elephant (*Loxodonta africana*) under a worst-case climate change scenario in Hwange National Park. Vegetation productivity is expected to decline consistently with the projections of 1.5 °C and 2 °C warming scenarios in Southern Africa [39]. Hartmann et al. [40] documented the health impacts of climate change on humans, revealing high possibilities of malaria transmission under different climatic scenarios.

The observed climatic changes have severely impacted on agricultural performance [41–44]. Subsistence farming communities, such as those found in Malipati, are more affected by climate change mostly because of the magnitude of drought, limited coping options, remoteness and other socio-economic stressors [6,31]. Although still limited, some vulnerability assessment studies in Zimbabwe have adopted a participatory analysis with the farmers themselves to understand their perceptions of climate change. A study by Rurinda et al. [31] in Makoni and Hwedza districts revealed that farmers' observations of changes in their local climate characteristics corresponded with the recorded data. Similarly, Makuvaro et al. [43] observed that interactions with smallholder farmers in Lower Gweru District revealed that the locals' perceptions of increasing temperatures were consistent with recorded historical temperature data, but their perceptions on rainfall were inconsistent with historical climatic trends. Mugambiwa and Rukema [45] qualitatively assessed perceptions of climate change among community members and smallholder farmers in the Mutoko District as the basis for understanding their adaptive capacities. The scholars observed that knowledge of climate change among the communities existed in the form of temperature changes, irregular rainfall patterns and early drying up of rivers.

Previous studies have mainly focused on regions in the country that have a wetter climate. The climate change situation in Malipati, an area which occupies the driest parts of the country has not been validated. Furthermore, most studies on climate change impacts have not included perceptions of local communities experiencing changes in climatic and environmental processes. Garcia-del-Amo et al. [5] complained that climate change impacts observed by indigenous and local people are not yet sufficiently included in climate change research. This study validates the generalised understanding of a warmer and drier climate system by gathering the observations of local people who have been witnessing rapid environmental changes believed to be triggered by climate change from the perspective of their agrarian-based livelihoods.

3. Research Methods

3.1. Study Area

Chiredzi is a dryland district located on the south-eastern side of Zimbabwe. Malipati, the area of interest, is found in Ward 15 in the Sengwe communal area, which borders Gonarezhou National Park (GNP) to the north and east (Figure 2). The GNP is part of the Great Limpopo Transfrontier Park, a protected area covering the Zimbabwean side, Kruger National Park in South Africa and Limpopo National Park in Mozambique. As such, the communities co-exist with wildlife, and human-wildlife conflict is a common phenomenon [25]. Ward 15 has a population of 8391 people and 1714 households as of 2012 [46]. The area has a mix of various ethnic groups dominated by the Tsonga people and complemented by minor groups of the Ndebele, Karanga, Venda and Shona. These groups have largely withstood the history of displacement following the establishment of the GNP [25].

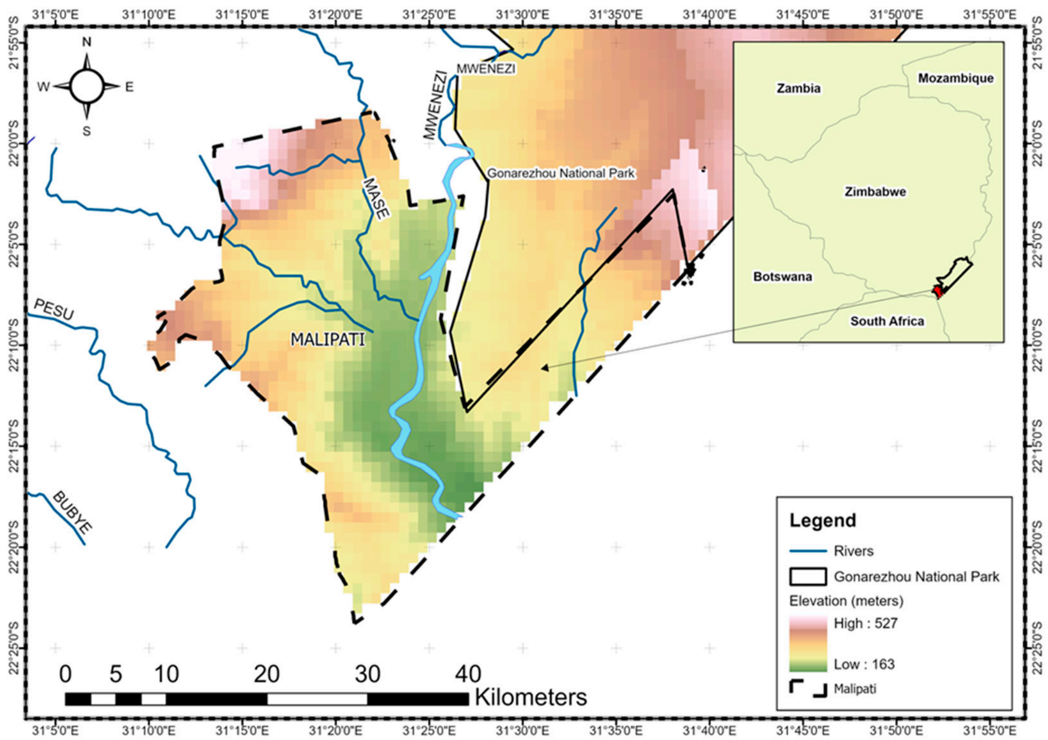


Figure 2. Location of Malipati, Ward 15 in Chiredzi District, Zimbabwe.

The area receives little amounts of rainfall ranging from 250 to 500 mm per annum, which is very poorly distributed. Mean maximum temperature ranges from 28 to 32 °C [24]. However, high temperatures of up to 39 °C that are recorded in summer are believed to cause high evapotranspiration [3,24]. The area sits in the Mwenezi sub-catchment, which is one of the watersheds that are highly sensitive to climate change in Zimbabwe [35]. Drought and dry spells always punctuate the rainfall season, which stretches from November to April. However, the rainfall season is said to be shortening owing to late onset and early cessation of rainfall because of climate change [3]. The harsh climatic conditions make it difficult for the agrarian-based communities to secure food and decent livelihoods. The predominant livelihoods activities involve a mix of crop and livestock farming. Rain-fed cereal crops of maize and traditional grains (mainly sorghum and pearl millet) are grown during the cropping season. However, these crops usually wilt before they mature owing to frequent and worsening drought. Pastoral livestock production is being hampered by drought, which leads to drying up of pastures and water during the dry season [26,47]. The low altitude of the area also exposes the community to seasonal flash and riverine floods [48]. This means that the people in Malipati are highly exposed to extreme weather and climatic risks.

3.2. Data Collection and Analysis

A cross-sectional survey was employed to gather the perceptions of climate change in subsistence communities in June 2021. The study administered 125 household questionnaires to participants who were drawn from selected villages in Malipati. However, data analysis focused on 116 questionnaires after filtering for respondents that did not meet the criterion of being directly involved in agrarian-based livelihoods. This was intended to draw data from people who had lived experiences of climate change which were primarily related to their farming activities. Purposive sampling was first used to choose villages that were remote from shopping centres and which had predominantly agrarian-based livelihoods. This approach was intended to ensure adequate coverage of the most remote areas. Random sampling was then adopted to choose households from the identified villages. Accordingly, the study focused on 25 villages out of a total of 55 villages available in Ward 15. Each village had an average of 25 households. The study randomly selected 5 households from each targeted village. Responses were sought from the head of the household or any other senior member of the household. There were 47 male and 69 female respondents, and about three quarters of the total participants were more than 36 years old. Only 22% had never been to school, whereas 66% of the households interviewed had stayed in the area for more than three decades (Table 2).

Table 2. Demographics of the respondents in Malapati, Chiredzi District.

Demographics	Description	Frequency/Proportion (%)
Sex	Male	47 (41)
	Female	69 (59)
Age (years)	18–35	30 (26)
	36–49	34 (29)
	50–64	33 (28)
	65 plus	19 (16)
Education	Never been to school	26 (22)
	Primary	47 (41)
	Secondary	37 (32)
	Tertiary	6 (5)
Period of residency (years)	Less 10	2 (2)
	10–20	15 (13)
	21–30	23 (20)
	30 plus	76 (66)

Participants were asked to indicate their perceptions of changes that they had noticed in the hydrological system (rivers, streams, swamps, ground water) and ecological system (wild fruit trees, woodlands, grasslands, insects, wildlife, diseases, pests, predation). They were asked to make inferences about these changes based on their lived experiences or observations over the whole period they had stayed in the area. The themes were generated based on indicators of climate change identified from previous studies [3,26,45]. The question responses were designed based on a Likert scale, which showed possible answers based on a sliding scale from highly significant observed changes to no change in variable indicators sought. The questionnaires were administered with the help of three local research assistants who had knowledge about location of the villages. These were first trained so that they could understand the research purpose and to get acquainted with the research protocol. This approach facilitated smooth identification of the desired households and the data collection process.

Data were entered into Statistical Package for the Social Sciences (SPSS) Version 23 (IBM Corp. New York, NY, USA) using pre-coded responses for analysis. Crosstabulations were computed to generate frequencies of the variables. Chi-Square (χ^2) tests were performed to determine the relationship between the categorical variables of demographics (age, sex, education and period of residency) and categories of observed hydrological and ecological changes. The Chi-Square statistic measures the relationship between categorical variables. The *p*-value of the Chi-Square is a statistical test that describes the probability of finding a particular set of observations if the null hypothesis holds. In this case, a *p*-value less than 0.05 indicates that there is a relationship between the categorical variables, whereas a *p*-value greater than 0.05 indicates that the variables are not related. The study observed the research ethical guidelines provided by the Faculty of Engineering and the Built Environment, University of Johannesburg.

4. Results and Discussion

4.1. Observed Hydrological Changes

The sensitivity of water resources to climate change is quite evident in Malipati. As Table 3 indicates, almost all the respondents (98%) agreed that they had experienced some changes in terms of either early drying up of rivers and streams (72%), or the rapid loss of water in them (27%). The effects of the perceived high temperatures and little rainfall were also largely felt as swamps were reportedly drying up earlier (79%), or some places becoming less swampy (8%) or desiccating completely (7%). The respondents also witnessed noticeable changes in ground water recharge where the water table is said to be very deep (48%), deeper (38%) and inaccessible in some places (6%). Associated with the degradation of water resources is the siltation of water bodies, a phenomenon that suggests the limits of natural systems to withstand the combined effects of climate change and human activities. The effects of observed livelihoods practices such as cultivation in riverbanks, livestock trampling in swamps and overgrazing probably combine with drought to cause erosion and siltation. A study by Musakwa et al. [25] revealed unsustainable agricultural practices involving encroachment of ecological sensitive areas as communities try to cope with landscape changes and climate change in the area.

Table 3. Observed changes in the hydrological system in Malipati, Chiredzi.

Indicator	Frequency/Proportion (%)
Observed changes in rivers/streams	
drying earlier	83 (71.6)
less water	31 (26.7)
no more water	0 (0)
no change	1 (0.9)
not sure	1 (0.9)
Observed changes in swamps	
drying earlier	92 (79.3)
less swampy	9 (7.8)
no more swamps	8 (6.9)
no change	0 (0)
not sure	7 (6.0)
Observed changes in ground water	
very deep water table	56 (48.3)
deeper water table	44 (37.9)
water inaccessible	7 (6.0)
no change	1 (0.9)
not sure	8 (6.9)
Observed changes in siltation of water bodies	
heavily silted	75 (64.7)
slightly slighted	28 (24.1)
no change	1 (0.9)
not sure	12 (10.3)

These observations validate the hydro-climatic and water loss challenges reported in the Runde catchment by Malanco et al. [35]. Likewise, perennial water pans such as the Tembwehata pan along the Runde River are now drying up. This suggests that water resources are a very useful indicator of climate change impacts in the area. Chanza and Gundu-Jakarasi [49] reported about the high sensitivity of the water sector to climate change. It was also noted that education and the period of stay in the area were related to the respondents' observations of changes in river flows and siltation, and the conditions of swamps ($p < 0.05$).

4.2. Observed Ecological Changes

Table 4 captures the respondents' perceptions of climate change in terms of observed changes in ecological processes. There is a trend towards loss of wild fruits, which the respondents perceived to be caused by climate change. This was revealed by 86.2% of the people interviewed, whereas very few indicated that they were not sure of such changes (7.8%), or there was no change at all (3.4%). Only 2.6% perceived that there were more fruits found in the area. The depletion of fruits as a result of climate change is a common phenomenon reported by Rurinda et al. [31] and Musakwa et al. [25]. Most of the respondents perceived increases in insects (78%), birds (58%) and predators (63%), whereas increases in wild animal herbivores were reported by 46%. The perceived increase in predators could be related to reported high incidences of predation on domestic animals (71%), aggressiveness of wildlife (53%) and crop raids by wild animals (55%). A significant proportion of the respondents thought that the decrease in woodlands and grasslands was related to climate change; 88% and 80%, respectively. However, other studies reveal that this decline is from the combined effects of climate change, livestock and wildlife [4,25,29,50]. These observations confirm existing findings on increased incidences of human-wildlife conflicts in communities living around protected areas, which could be aggravated by climate change [25]. The depletion of woodlands, grasslands, pastures and water resources could be widening the feeding and hunting range of wild animals, becoming more aggressive as they compete with humans and livestock over dwindling resources [4,50]. The suggestion by Mpakairi et al. [29] that a changing climate may influence elephant distribution is also confirmed by these results.

Table 4. Observed changes in the ecological system in Malipati, Chiredzi.

Indicator	Frequency/Proportion (%)
Observed changes in fruit trees	
more fruits	3 (2.6)
less fruits	100 (86.2)
no change	4 (3.4)
not sure	9 (7.8)
Observed changes in wild animal herbivores	
Increase	53 (45.7)
Decrease	25 (21.6)
no change	7 (6.0)
not sure	31 (26.7)
Observed changes in wild animal predators	
Increase	73 (62.9)
Decrease	20 (17.2)
no change	4 (3.4)
not sure	19 (16.4)
Observed changes in birds	
Increase	67 (57.8)
Decrease	25 (21.6)
no change	11 (9.4)
not sure	13 (11.2)

Table 4. *Cont.*

Indicator	Frequency/Proportion (%)
Observed changes in insects	
Increase	90 (77.6)
Decrease	12 (10.3)
no change	1 (0.9)
not sure	13 (11.2)
Observed changes in grasslands	
Increase	4 (3.4)
Decrease	93 (80.2)
no change	0 (0)
not sure	19 (16.4)
Observed changes in woodlands	
Increase	0 (0)
Decrease	102 (87.9)
no change	2 (1.7)
not sure	12 (10.3)
Observed changes in aggressiveness of wildlife	
more aggressive	61 (52.6)
less aggressive	8 (6.9)
no change	24 (20.7)
not sure	23 (19.8)
Observed changes in crop raids	
more crop raids	64 (55.2)
less crop raids	19 (16.4)
no change	12 (10.3)
not sure	21 (18.1)
Observed changes in predating on domestic animals	
more predation	82 (70.7)
less predation	4 (3.4)
no change	1 (0.9)
not sure	29 (25.0)

A test of the independence of the variables discussed here revealed that residency period was related to the respondents' perceptions of changes in wild fruits ($\chi^2 = 28.16$, $p < 0.05$) and birds ($\chi^2 = 19.91$, $p < 0.05$), whereas age only influenced their perceptions on incidences of crop raids by wild animals ($\chi^2 = 17.51$, $p < 0.05$). The rest of the independent variables (gender, education) did not show any relationships with indicators in ecological and biological changes ($p > 0.05$).

The study only relied on knowledge from past studies to compare climate change evidence with that from the perceptions of the farmers interviewed. Similar studies have indicated that what makes local communities capable of observing climate change is mainly their subsistence-oriented livelihoods that are climate-dependent [16,43,51,52]. Being in a wildlife zone, climate change adds unique socio-ecological challenges which complicate the communities' livelihoods and generate much interest for the people to understand changes in their local environment. Overall, additional evidence derived from the perceptions of local communities resonates with existing scientific knowledge about climate change in Zimbabwe, and adds insights for further investigation. Marin [9] also observed that perceptions of nomadic herders in Mongolia added more evidence about the occurrence of drought and more frequent sandstorms as a result of climate change. These findings suggest that observations made by local people can be quite useful in enriching existing evidence of climate change that is mostly relevant for use towards strengthening evidence-based adaptations by communities experiencing climatic events.

5. Conclusions

This study gathered the evidence of climate change from agrarian communities who consistently observe changes in their environment. The evidence from climatological observations of a drier climate has been confirmed by the observations of changes in hydrological and ecological systems that are perceived by the locals of the Chiredzi District. Hydrological indicators exist in changes in river and stream flows, and the state of swamps and ground water, whereas ecological indicators range from changes in behaviour of trees, insects, birds and wild animals and changes in grasslands and woodlands. By virtue of their subsistence-oriented livelihoods which are primarily dependent on the climate situation, the communities are consistent observers of changes happening in their local environment. One of the areas not sufficiently explored in Zimbabwe is the response of the ecological system to the effects of climate change. Being in a wildlife zone, the locals in Malipati have keenly observed the ecological processes associated with changes in their local climate system. These insights have helped in enriching our knowledge about how ecological systems are responding to climate change at the boundary between humans and wildlife. These indicators range from the increased pestiferous nature of certain pests to high incidences of predation and crop raids by wild animals, which suggest the modified behaviour of insect and animal species as they try to adapt to a challenging climate.

Against a background of patchy studies and a generalised understanding of climate change in Zimbabwe, this study has contributed to the knowledge of climate change impacts by drawing on the ecosystem-based experiences of local and indigenous populations who live alongside wildlife-protected areas. Essentially, the study did not only validate existing climatological information about climate change reported in the drier parts of the country, but also managed to give deeper insights about the socio-ecological complexities experienced in regions where communities live alongside wildlife in the milieu of climate change. Overall, this is an opportunity to integrate local people with their unique ecosystem knowledge towards developing local-based solutions to climate change and biodiversity loss. Future studies would need to further examine such areas to understand the mitigation and adaptation practices that would promote the sustainable co-existence of humans and wildlife.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the Faculty of Engineering and the Built Environment of the UNIVERSITY OF JOHANNESBURG (protocol code UJ_FEBE_FEPC_00046 and date of approval 6 June 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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