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LETTER

Climate change perceptions, expectations, observations, and projections at Lake Victoria

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Abstract

Understanding people's perceptions of climate change and associated environmental risks is paramount in assessing how individuals respond to climate change. Awareness of the consequences of climate change determines the present and future behaviours and expectations, as well as the actions taken to mitigate the likely impacts. We surveyed the perceived and expected climate change consequences of experts and community members in the Lake Victoria basin in East Africa, compared them with hydro-meteorological observations and projections, and established that some perceived trends, such as increasing temperature or rainfall intensity, correspond with meteorological observations. However, the perceived increase in drought occurrence (believed to be a recent consequence), was not substantiated by the meteorological data. It was only in the northwestern region that drought frequency increased since the year 2000, while the rest of the basin did not experience such a trend. Community members were concerned about the already noticeable consequences of climate change on their livelihoods through agriculture or fishing, while experts were mainly focused on the amplification of hazards such as floods and droughts. This divergence may imply that experts underestimate the consequences that society is already facing. Nevertheless, both groups expect that climate change will undoubtedly lead to the deterioration of human well-being by affecting food security, increasing poverty, and increasing the incidence of disease. This is a serious concern that requires immediate attention. Such insights into people's climate change perceptions can help policy-makers, researchers, and community members to better tailor adaptation solutions acceptable to the local context. Effective governance is essential to enable people to adapt to climate change and other challenges, including those resulting from the impacts of globalisation, demographic trends, and the degradation and scarcity of resources.

1. Introduction

The need to address the growing impacts of climate change is increasingly becoming critical worldwide. According to Mulenga *et al* (2017) [1], an awareness of change is a prerequisite for both the emergence of adaptation strategies and their adoption. Public perceptions about climate change can be strong drivers of pro-environmental behaviour [2–4] and can either facilitate or hinder the implementation of climate policies [5].

The way people perceive environmental risks and climate change varies greatly, depending on their cultural context and worldviews, socio-political, socio-cultural, and demographic values and variables [6–9].

Understanding differences in climate change perceptions between actors is critical. Research has shown that there are discrepancies between the perceptions of climate change held by the general public and those of climate change experts [10–13]. Such discrepancies are likely due to the different ways in which the individuals learned about climate change—be it through formal education or daily activities [14]. Such differences in perceptions between actors may form a barrier to collaboration [15]. Prior research at Lake Victoria has identified differences between different groups of actors in their perceptions of the socio-ecological challenges in the region [16]. Identifying such differences in perceptions between experts and the general public can pave the way for bridging the gaps between actors that otherwise hinder transitions.

A more comprehensive understanding of the different perceptions between actor groups can be achieved by including environmental data in the analysis. The trends and patterns derived from this data provide an additional perspective with which to compare and contrast the perceptions of the different actor groups. It is important to acknowledge that both social and natural sciences have their own limitations in methods and approaches. The integration of these two fields can help to fill some of these gaps, as they have the potential to complement each other [17–19].

The objective of utilising past observational data can be to establish a benchmark for perceived changes. This is not necessarily to determine whether one group or the other rated hydro-meteorological trends more or less effectively, but to enhance understanding and potentially elucidate why one group may have been aware or unaware of a changing environmental phenomenon. This could be due to different levels of exposure [14, 20].

Comparing expectations of future climate change with simulations of its likely 21st-century impacts can either confirm or reinforce those expectations, reveal divergences between expectations and projections, or highlight unawareness of potential future risks. These findings can provide valuable insights into the accuracy of public perceptions and the scale of future dangers.

However, it is not yet fully understood how people will respond to climate change, when some will begin to act, and why others may never do so. Given that the communities within which climate change mitigation and adaptation strategies have to be anchored are complex, there is a need to examine climate change perceptions in regard to cultural, geographic, and political contexts, with a particular focus on regions where knowledge of climate change risk perceptions is limited [2, 7].

This study makes a contribution to the incomplete knowledge base by comparing the perceptions of climate change held by experts and community members in the Lake Victoria Basin (LVB) in East Africa. Furthermore, it relates these two perspectives not only to hydro-meteorological observations, but also to model projections of future climate change, a relatively novel area of research. This interaction between social sciences (climate change perceptions) and natural sciences (observations and projections) helps to identify gaps between scientific understanding and public perceptions of climate change, promotes mutual learning, and is crucial to gaining a more holistic picture.

Two surveys were conducted to examine how community members as well as experts perceive climate change and its consequences and which consequences they expect in future. These human perceptions were compared with hydro-meteorological data to determine how the perceived and expected consequences of climate change, for example, flooding and drought, match or diverge from observations and future projections. The study aimed at (a) investigating the views of experts and non-experts on climate change, (b) interpreting how people's perceptions about the present and future consequences of climate change relate with hydro-meteorological observations and projections, and (c) drawing lessons from the convergence and divergence in people's perceptions versus observations and projections.

This article includes an extensive appendix to which frequent reference is made. It should be noted that the material in the appendix is not a prerequisite for understanding the main text; rather, it provides supplementary information for readers who are interested in more details on the subject matter.

2. Materials and methods

2.1. Study area

The Lake Victoria Basin (LVB) is located at the equator in East Africa and is home to about 30 million people. It covers an area of approximately 264,000 km^2, with Lake Victoria being itself the largest of the African Great

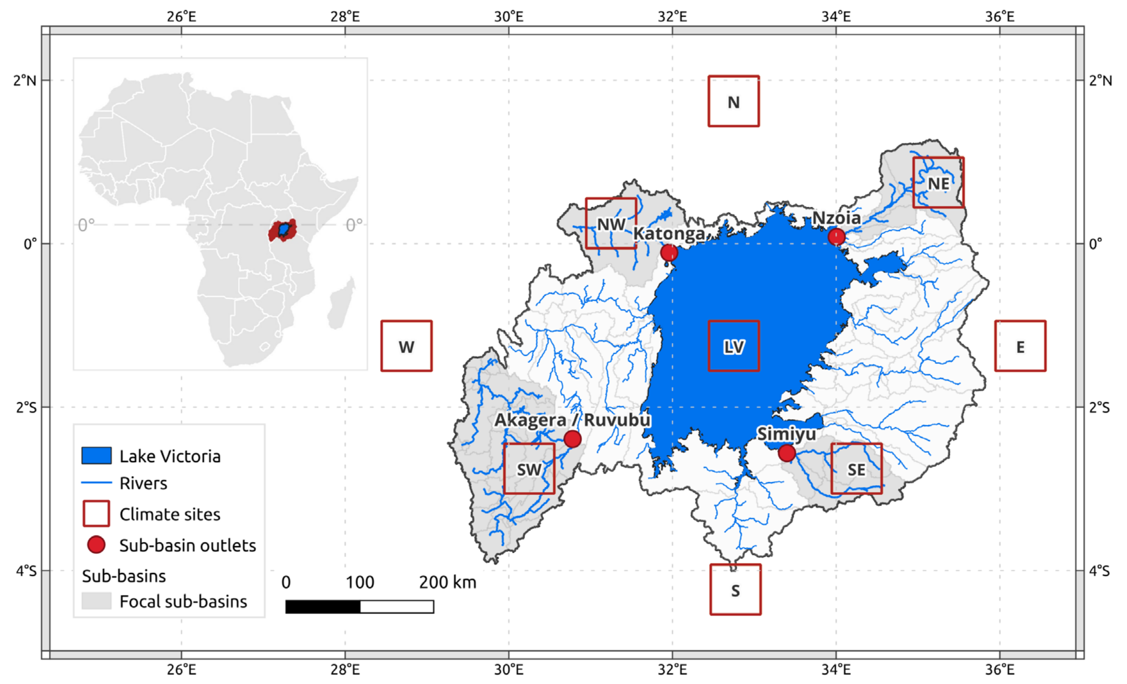


Figure 1. Lake Victoria basin, four focal sub-basins, and nine locations (grid cells) for rainfall analysis.

Lakes at 68,800 km^2. The climate is moderated by the high altitude, resulting in comparatively cooler temperatures and higher rainfall than, for example, at the Horn of East Africa, where severe droughts are more common. Climate change materialised over the period 1979–2019 in increasing air temperature (0.19 °C per decade, about the global average) and changed rainfall patterns.

The climate in the LVB is not homogeneous. For example, a bimodal rainfall regime prevails in the north and a unimodal one in the south. To address the spatial differences in climate at the survey locations along the lake's shore, we analyzed changes in rainfall patterns at nine sites (grid cells) and runoff patterns in four sub-basins of Lake Victoria's tributaries located in the northwest (NW), northeast (NE), southwest (SW), and southeast (SE), (figure 1).

2.2. Survey

By means of two surveys, one conducted among community members and the other among experts, we explored the views of these two actor groups on three topics: a) the causes of climate change, b) its recent consequences, and c) its future consequences. Details about the survey methodology are provided in Appendix A.1. The survey among experts was conducted as an online survey with 21 respondents who had a professional background in climate change. The survey among community members was conducted as face-to-face interviews with 146 respondents who are engaged in fishing, farming, livestock keeping, trading, and other occupations on the shores of Lake Victoria in Kenya, Tanzania, and Uganda. The aggregated survey data are provided in the Supplementary Material: *survey_data.xlsx*.

In the first step, we pre-processed both surveys by deriving 119 codes (e.g., rainfall, drought, cultivation practices) from the free-text responses [21, 22]. These 119 codes were grouped into 22 categories (e.g., climate and weather, hazards, agriculture), and these, in turn, into four domains (Societal, Human Activities, Governance & Policy, Environmental), see Appendix A.1.2. In the second step, we counted the code frequency per domain and topic as an indicator of the importance that respondents attached to the domains across topics. Corresponding data are shown in Appendix A.1.3. We then compared the experts' and community members' views on each topic by analyzing the categories and codes more closely. Focusing on codes with the highest frequencies that cumulatively explained at least half of the coded answers ($\geqslant$50%) facilitated the interpretation of similarities and differences between the two groups.

The survey design and evaluation, detailed in Appendix A.1, present some uncertainties, primarily stemming from the relatively small sample size of the expert survey and incomplete responses from all participants. This may introduce potential bias in the results. However, recruiting experts for such surveys is inherently challenging, and our sample size aligns with or exceeds that of many similar expert studies. Despite

Table 1. Hydro-climatic indicators.

Abbreviation	Variable	Unit
Pr_{basin}	Annual basin mean rainfall	mm^{-a}
T_{basin}	Annual basin mean air temperature	°C
Q_{mean}	Annual mean river discharge	m^3s^{-1}
$AMAX_{pr}$	Annual maximum rainfall event	mm^{-d}
$AMAX_{fp}$	Annual maximum flood peak	m^3s^{-1}
RP_{pr}	Pr for return periods of $AMAX_{pr}$	mm^{-d}
RP_Q	Q for return periods of $AMAX_{fp}$	m^3s^{-1}
SPI	Standardized Precipitation Index	*dimensionless*
WL	Water level of Lake Victoria	*m. a. s. l.*

these limitations, the insights gained from the expert responses offer valuable perspectives and serve as a meaningful comparison to the broader community survey, enhancing the depth of our findings.

2.3. Climate change: Perceptions and expectations versus observations and projections

To assess whether the perceptions of climate change and its consequences, such as flooding, droughts, changed rainfall patterns, align with meteorological observations and projections, we analysed daily weather data (WFDE5 [23]) from 1979 to 2019 along with ensemble climate simulations for 1979 to 2100. The climate simulations were provided by ISIMIP3b [24, 25], consisting of ten downscaled and bias-adjusted CMIP6 Global Climate Models (GCMs) for two scenarios: a low radiative forcing scenario (ssp126) and a medium-high radiative forcing scenario ssp370, see Appendix A.2. The meteorological data were also used to force the simulations of hydrological processes in the LVB, for example, river discharge and water levels in Lake Victoria, using the SWIM eco-hydrological and water management model [26] (see Appendix A.3).

To assess the projected effects of climate change, the following periods were established:

- P0: 1984–2014, reference (around 2000)
- P1: 2035–2065, near to mid-future (around 2050)
- P2: 2065–2095, distant future (around 2080)

In some cases, we also compared the differences between the earlier past (1980–1999) and the recent past (2000–2019). The methods used to assess changes in rainfall patterns and flood and drought occurrence are described in Appendix A.4.

The analysis was limited to variables directly related to hydro-climatic processes, such as changes in air temperature and rainfall patterns, extreme events such as heavy rains, river floods, droughts, and fluctuations in the water levels of Lake Victoria. Corresponding hydro-climatic indicators are shown in table 1. Affected variables, such as livelihoods, diseases, and agricultural productivity were not included in this study.

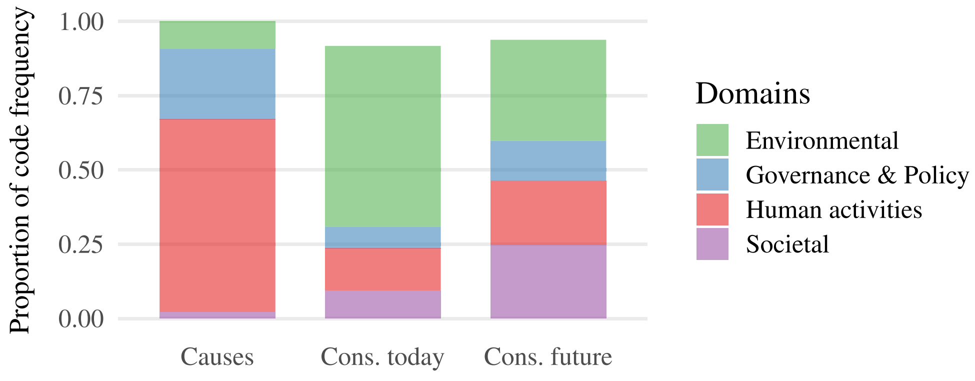
3. Results and discussion

3.1. Causes of climate change

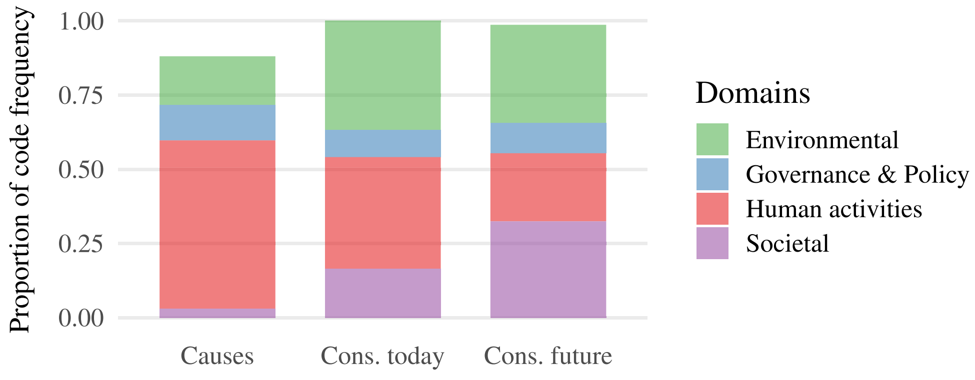
Experts and community members agree that climate change is mainly caused by human activities aiming at satisfying the food, water, and energy demands of growing populations (figure 2, topic: *Causes* and figure B1). The most frequent codes associated with domain Human Activities were: Greenhouse Gas (GHG) emissions, Deforestation, Fuel burning, Land degradation, and Industrialisation. The domain Governance & Policy was mainly represented by the codes Economic activities and Urban development.

3.2. Perceived consequences (today)

According to the concept map created from the experts' responses (figure 3), climate change was perceived as temperature increase, heat waves, and changing rainfall patterns, for example, as more erratic rainfall, more extreme weather events, and change in seasonality. Increased flooding and drought associated with damage to infrastructure were perceived as the main consequences of climate change. The changes in rainfall patterns were held responsible for changes in the water levels of Lake Victoria, where some experts noted an increase, others a decrease or fluctuations. Increasing temperatures were related to an increase in human health problems in general and specifically to water-borne diseases, such as Malaria, as well as to the increased occurrence of plant



(a) Experts (based on data in table A3)



(b) Community (based on data in table A4)

Figure 2. Frequency of domains by topic. Standardized by the code frequency of the topic with the highest code frequency, setting the latter to the 100% baseline level. *Cons.* = Consequences. (*top panel = experts, bottom panel = communities*).

diseases and pests. Both changes in temperature and rainfall patterns are seen as directly and indirectly impacting the ecology of Lake Victoria and its basin, for example, higher water temperature, lake water levels and inundation, fish production and stock changes, biodiversity, eutrophication, and change in primary production. To some extent, this view was shared by members of the community.

3.2.1. Comparison between experts and communities

With regard to the perceived consequences of climate change, there was a clear difference between the frequency in which the various domains were referenced by experts compared to community members (figure 2, topic: *Cons. today* and figure B2). Experts predominantly considered those concepts important that are attached to the domain Environmental. The codes Rainfall, Flooding, and Drought alone made up 34% of the code frequency (table 2). Community members considered the domains Human Activities and Environmental almost equally impacted. The three codes Agricultural productivity, Land degradation and Fish production from domain Human Activities add up to about 25%, indicating a clearly perceived impairment of livelihood generation (opportunities).

Differentiating between experts and community members in terms of their background provides an understanding of why community members may rate the impact on concepts related to the domain Human Activities higher than experts do. On the one hand, many community members are themselves directly exposed to weather and other environmental conditions during their livelihood generation activities. On the other hand, environmental conditions directly affect the quality and quantity of their fishery, livestock, and agricultural products. Experts, by contrast, are more likely to work in an office and their income-generating activities are presumably less exposed to environmental conditions. Another difference is certainly related to the information channels used by the two groups [14].

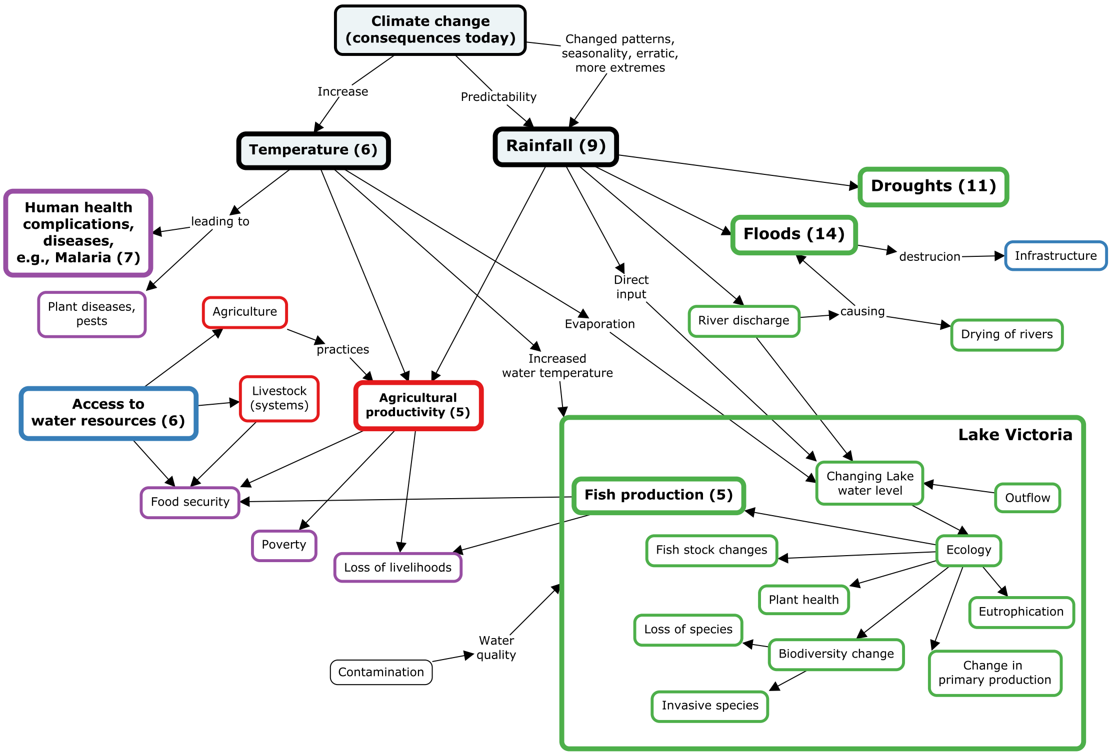


Figure 3. Concept map of perceived climate change consequences derived from the expert survey. Numbers in parentheses indicate the relative code frequency.

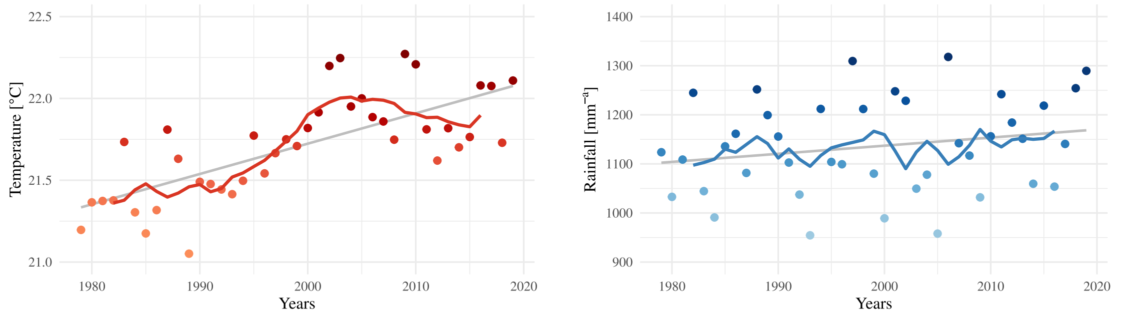
Table 2. Relative code frequency cumulatively explaining ⩾50% (consequences today).

Experts	[%]	Communities	[%]
Flooding (Env)	13.5	Agricultural productivity (HuA)	11.5
increased frequency and magnitude			
Droughts (Env)	11.2	Land degradation (HuA)	6.7
increased, frequent, prolonged			
Rainfall (Env)	9.0	Fish production (HuA)	6.3
increase, intense, heavy rains, unreliable, erratic, changed patterns, rainy season			
Disease (human) (Soc)	6.7	Droughts (Env)	6.1
		Dried up springs, extreme	
Access to water resources (Env)	5.6	Disease (human) (Soc)	5.8
Temperature change (Env)	5.6	Availability pasture (G&P)	5.4
increase, high, hot			
		Flooding (Env)	5.2
		Rising water level, inundation	
		Food security (Soc)	5.0
Sum	51.6		52.0

Attributes attached to codes analysed here in *italics*.
Domains: Env = Environmental; HuA = Human Activities;
Gov = Governance & Policy; Soc = Societal.

Interestingly, community members mentioned less frequently the codes Flooding and Drought than the experts (11% versus 25%) although one would expect the former to be more exposed to environmental conditions and respective hazards. It appears that community members focused more on the consequences of the hazards than the hazard itself. For farmers, De Longueville *et al* (2020) [20] interpret that they 'do not perceive climate in meteorological terms but rather as it affects agricultural activities'.

The experts on the contrary, assigned about two-thirds of their responses to the Environmental domain, of which about 40% included the codes Flooding and Drought and the domain Human Activities received only 15%. In responding to the survey questions, the experts may have initially focused on the immediate natural



(a) Temperature (b) Rainfall

Figure 4. Annual mean temperature and rainfall from 1979–2019 averaged over the LVB using W5E5. Points represent annual values and lines the 7-year moving average. The grey line indicates the linear trend, 0.019° C/a for temperature and 1.6 mm/a for rainfall.

consequences of climate change, such as floods and droughts, rather than on the social consequences of those hazards. Consequently, they may have undervalued or overlooked the already noticeable social consequences of climate change or alternatively, considered them to be a consequence of a consequence.

An interesting question worth pursuing in future research is to what extent the experts' perceptions are subject to (e.g., confirmation) bias, and whether such a bias may be grounded in media reporting [11] that tends to pay more attention to climate change where floods and droughts are omnipresent in general, which does not necessarily apply to the area in question, the LVB in this case.

3.2.2. Perceptions versus observations

To determine the extent to which experts' and community members' perceptions of climate change and its consequences are consistent with hydro-meteorological observations, we compared these perceptions with observed temperature and rainfall trends from 1979 to 2019. The comparison between perceptions and observations remained at a qualitative level, describing the most relevant results of the hydro-meteorological analysis in context. More specific results are discussed in Appendix B.2. The analysis of rainfall-related variables, which vary depending on the region within the LVB, is constrained by the inability to allocate all responses to the respective regions.

In alignment with a review article of studies examining perceptions and observations related to climate change [20], we also found that perceptions were consistent with some observed trends, while others were not. The perceptions corresponded quite well with the following observed trends: increase in temperature, increase in rainfall and intensity, changed seasonality, and the increased frequency and magnitude of flooding. In the case of droughts, however, the correlation between drought indicators and perceptions of increased drought is lower or more difficult to determine.

Not surprisingly, perceptions regarding increased temperatures were confirmed by observations showing an increase of about 0.8° C in the LVB from 1979 to 2019 (figure 4 (a)).

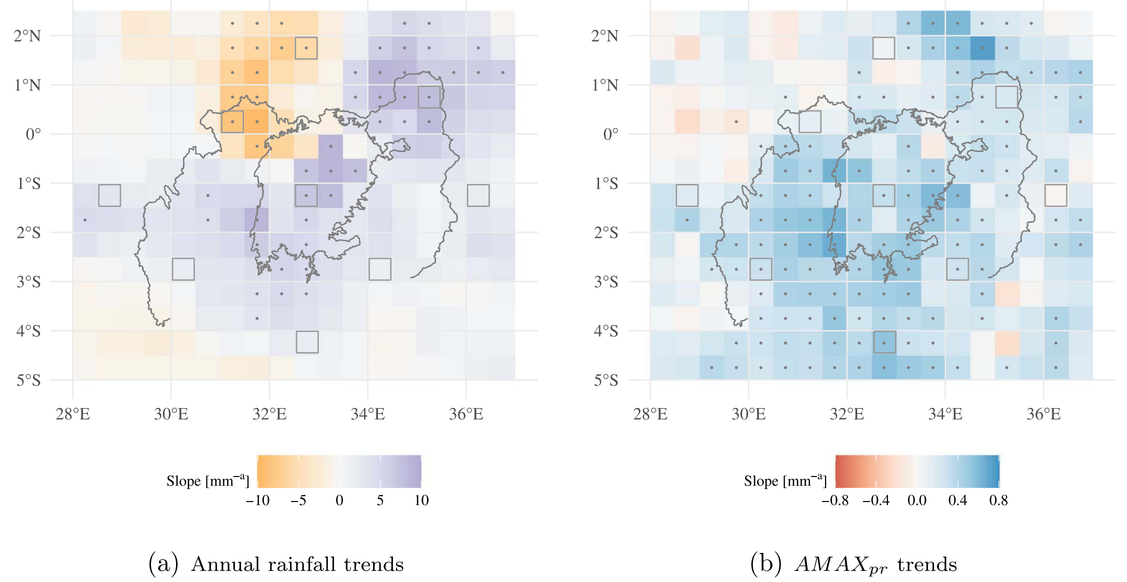
Generally, the perceived increase in annual rainfall, rainfall intensity, and a changed seasonality was confirmed by the observations, also reported by [27–31] using different data sources. This general agreement between perceived and observed rainfall-related variables is noteworthy, as many studies have found inconsistencies, particularly for rainfall, but not for temperature [20]. However, this is also a result of the survey design, which deliberately did not ask about specific changes in rainfall. Therefore, the fact that changes in rainfall patterns were mentioned at all was a result of the survey itself.

Our analysis confirms that annual rainfall averaged over the LVB showed a slightly increasing but statistically insignificant trend (figure 4 (b)). The map in figure 5(a) and figure B5 illustrate how annual rainfall trends varied in the LVB. Where the northwestern region, specifically the Katonga sub-basin in Uganda, experienced a drying trend, the rest of the basin area received more rainfall in the recent past.

Rainfall intensity in terms of annual maximum rainfall events ($AMAX_{pr}$) has increased in most areas significantly (figures 5 (b) and B6), confirming the perceived increase in extreme rainfall events.

Rainfall seasonality showed a tendency in the recent past for rainfall to decrease in the first half of the year, coinciding with the MAM (March, April, May) rainy season, and for it to increase in the second half, covering the OND (October, November, December) rainy season (figures B7, B8, and B9), also confirmed by [27, 28].

Shifts in rainfall patterns and seasonality, have the potential to negatively impact crop yields and may require adaptation of agricultural practices. It is conceivable that farmers may perceive or experience such changes as a drought, even if these changes would not necessarily be visible in a time series of mean annual rainfall. Farmers



(a) Annual rainfall trends (b) $AMAX_{pr}$ trends

Figure 5. Slope of linear rainfall trends from 1979 to 2019 based on W5E5. Dots indicate significant trends at 95% significance level.

may think about rainfall as a process rather than a quantity [32, 33], probably experienced differently by farmers cultivating different crops [34].

In regard to the perceptions of an increasing frequency and magnitude of flooding, it was not always evident which type of flooding (pluvial, fluvial, or inundation) the responses were referring to. We will provide a brief overview of the developments of all three types over the period 1979 to 2019.

Given the substantial rise in the maximum annual rainfall events ($AMAX_{pr}$) in the LVB in some regions over recent decades, it would be reasonable to anticipate an increase in the intensity of pluvial flood events.

Concerning rising river flood peaks $AMAX_{fp}$ and associated return periods RP_Q, perceptions of increase are consistent with the simulated trends only in the northeastern and southwestern sub-basins (figure B12). The other sub-basins in the northwest and southeast did not experience increasing trends in flood peaks.

The flooding associated with high water levels in Lake Victoria displayed a cyclical pattern, with periods of high and low water levels between 1979 and 2019. However, an upward trend was observed since 2005 (figure B13), which may explain the general perception of increased flooding due to inundation among respondents. Additionally, in 2020, a flooding event occurred at Lake Victoria that exceeded the historic high recorded in 1964.

There is less agreement between the perceived increase in drought occurrence and the observations, which only show more relative drought events in the recent than in the early past in the northwestern and northern sites of the LVB in Uganda (figure B10). It is plausible that the focus on droughts, particularly among experts, may be attributed to the fact that the Horn of Africa was experiencing its most severe drought in decades at the time the survey was conducted. Around 22 million people were acutely food insecure and about 1.7 million people have been internally displaced, seeking food, water, and relief [35]. It is therefore reasonable to assume that this issue was covered extensively in the media throughout East Africa, influencing the respondents' perceptions of drought, even though the LVB area was not directly affected. This is another example of how current extreme events in close proximity, or recently experienced events, such as the flooding of Lake Victoria in 2020, may influence the awareness and perceptions, at least for a period of time. This phenomenon has been observed in western Kenya, for example in relation to flood risk perception [36], but is neither unique to Kenya nor flood risk [37–39].

3.3. Expected consequences (future)

It was anticipated by experts and community members that the immediate consequences of climate change would be an increase in temperatures, an intensification of heat waves, alterations to rainfall patterns, and an elevated frequency of droughts and floods. However, there was a greater focus on the indirect consequences of climate change, which concern not the hazards themselves, but rather their consequences for the population and their well-being.

Table 3. Relative code frequency cumulatively explaining ⩾50% (consequences future).

Experts	[%]	Communities	[%]
Food security (Soc)	8.8	Food security (Soc)	13.2
Disease (human) (Soc)	7.7	Droughts (Env)	7.7
Changing lake water level (Env)	6.6	Agricultural productivity (HuA)	5.9
Fish production (HuA)	5.5	Flooding (Env)	5.5
Deforestation (HuA)	4.4	Poverty (Soc)	5.3
Poverty (Soc)	4.4	Disease (human) (Soc)	4.8
Access to water resources (Env)	4.4	Fish stock changes (Env)	3.9
Temperature change (Env)	4.4	Death (Soc)	3.3
Droughts (Env)	4.4	Availability pasture (G&P)	3.1
Sum	50.6		52.7

Compared to the perceived consequences today, where both groups showed little agreement at the domain level, the agreement regarding the expected consequences in the future is much higher (figure 2, topic: *Cons. future* and figure B3).

3.3.1. Comparison between experts and communities

One commonality between both groups was the high importance attributed to the category Human well-being of the Societal domain. The category includes the codes Food security, Poverty, and Disease and was the most frequently reported by both groups. Community members gave this category a relatively higher priority (table 3).

Experts paid less attention to future hazards than to present ones. Droughts received only 4.4% and river floods only 1%, but changes in lake water levels and associated inundation received 6.6% (cf tables 2 and 3). Conversely, community members rated future hazards as relatively more important than they perceived today.

The shift in emphasis from the perceptions of current consequences to potential future threats to human well-being has therefore essentially been at the expense of hazards among experts and livelihood-generating activities among community members. It may be assumed that this shift towards societal aspects can be interpreted as a concern for the future. The consequences of climate change may be perceived to be more personal in the future and therefore less focused on the outside world.

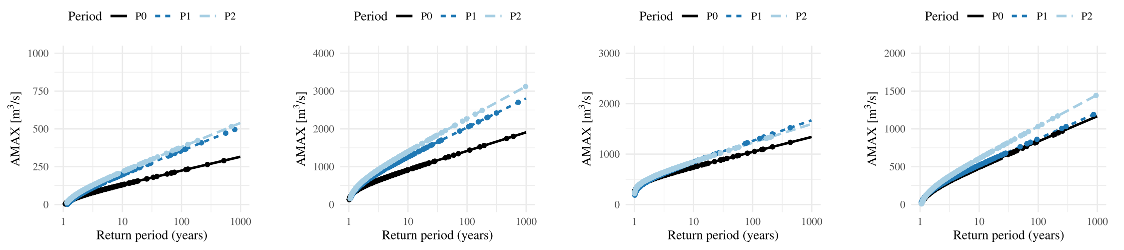
3.3.2. Expectations versus projections

To determine the extent to which experts' and community members' expectations about future climate change consequences are aligned with hydro-meteorological projections, we compared the expectations with temperature, rainfall, and discharge trends projected over the 21st century. The comparison remained at a qualitative level focusing on the most relevant results. We will see that the discrepancies between expectations and projections are more pronounced than those between perceptions and observations. This is particularly true for rainfall-related variables.

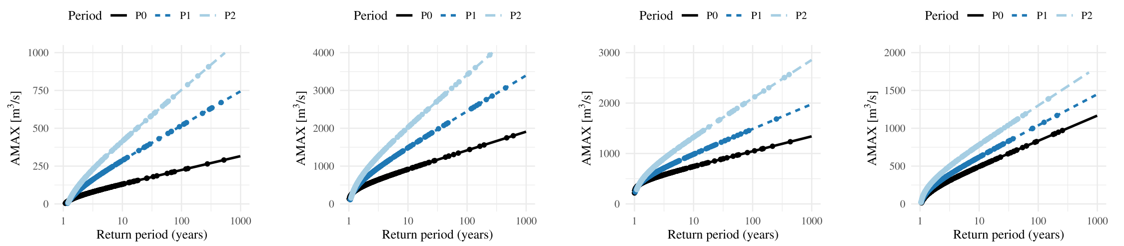
The survey participants' assumptions regarding future temperature increase were found to align with the projections, which indicate an increase of 1.5°C in the near future, around 2050, and a further increase to 1.4°C and 2.8°C in the distant future around 2080 under ssp126 and ssp370, respectively, and compared to the reference period P0 (figure B14).

Both groups paid relatively little attention to changes in future rainfall patterns, but Lake Victoria and its catchment is projected to experience an increase in mean annual rainfall of 2-8% and 8-11% in the near and distant future, respectively (figure B14). This increase is more pronounced under the medium-high scenario ssp370. Comparable results report Akurut *et al* (2014) [40]. Excluding three very wet outliers, a robust statement is that the majority of the models projects an increase in mean annual rainfall up to 10%. Roughly 10-30% of the models indicate a possible decrease, but only under the moderate scenario ssp126. We take this also as a rough estimate for future drought occurrence. To examine droughts in more detail, context-specific drought indicators need to be elicited and taken into consideration [34], but this was not the subject of the survey.

Regarding future rainfall extremes, given low attention by both groups, the GCM ensemble projected that future maximum daily rainfall events would exceed those simulated in the reference period, with significance varying by scenario, time period, and GCM. The future change in the number of rainy days over specific thresholds shows a clear tendency to increase. More details provides Appendix B3.



(a) Katonga (b) Nzoia (c) Akagera / Ruvubu (d) Simiyu



(e) Katonga (f) Nzoia (g) Akagera / Ruvubu (h) Simiyu

Figure 6. Return periods of annual maximal flood peaks $AMAX_{fp}$; ssp126 (top), ssp370 (bottom), ISIMIP3b. P0 = 1984–2014; P1 = 2035–2065; P2 = 2065–2095.

The projected changes in rainfall translate to changes in simulated river discharge, flood peaks and return periods, and changes in the water levels of Lake Victoria. Higher mean annual rainfall in the LVB resulted in higher mean annual inflows into the lake by 8% under ssp126 around 2050 to a maximal 36% under ssp370 around 2080 (figure B15).

River flood peaks $AMAX_{fp}$ were generally projected to increase and were simulated to be stronger in the two northern sub-basins and stronger under ssp370 (figure 6). In terms of return periods, a 100-year event in the past may become a 10-year event in the future in the extreme case and a flood peak RP_Q associated with a 100-year event in the past may double in the future, causing an increase in the overall river flood risk. In light of the projected risk of future river flooding and the low level of attention given to the issue by both groups, it can be concluded that the future river flood risk is underestimated.

The type of flooding of greatest concern was associated with flooding of land areas by rising lake water levels. Basically due to the increase in rainfall over Lake Victoria (from which it receives about 80% of water, depending on inter-annual variability [41, 42]), but also due to increased inflows from its tributaries, the majority of the simulations projected that water levels would rise. An increase from 20 cm to 70 cm was projected under ssp126 around 2050 and ssp370 in the distant future, respectively and with 70% to 90% model agreement (figure B16). Associated losses due to inundation in terms of land area, homes, livelihoods, property, and habitats, are not known, but the concern addressed by both groups is certainly justified.

4. Conclusions

Our investigation into the perceptions of climate change from people around Lake Victoria has revealed an overall agreement but also a disparity between the responses of experts and members of communities in Kenya, Tanzania, and Uganda. The general agreement between both groups speaks for good 'climate literacy' at the community level, is consistent with scientific assessment, and is specifically noteworthy because of the different backgrounds and realities of the two actor groups in terms of education, information sources, and livelihood-generating activities, which differ substantially. Disparity in responses was only observed for the question about climate change consequences perceived today. Where experts gave the greatest weight to changes in rainfall, flooding and droughts, basically hazards, community members rated their livelihood-generating activities as the most impacted by climate change. This may suggest that experts underestimate the severity of the consequences that the wider population is already facing. Alternatively, it could indicate that their attention was primarily directed towards a more theoretical or immediate understanding of the consequences, focusing on the hazard phenomenon itself. Nevertheless, it accentuates the need for experts and decision-makers to further engage with the public, in order to give local communities a stronger platform from which to voice their demands for climate action.

Uncovering disparities in the perceptions of climate change, or better, of change in its entirety—as this often cannot be differentiated—can therefore contribute to a more holistic and transdisciplinary understanding of societal perspectives. The incorporation of hydro-meteorological observations and projections enhances this process by providing a benchmark and an additional and broader perspective.

If people's perceptions of climate change and its consequences are consistent with observed hydro-meteorological trends, it may imply that the information regarding climate change is being effectively communicated. Disagreement may indicate that climate change is felt either more strongly or more weakly than it materializes in the data or that the reality is not sufficiently captured by the data and methods used. Disagreement could also mean that existing science communication and education strategies should be re-evaluated and implemented where appropriate. From this survey, we conclude that the people at Lake Victoria show a well-calibrated understanding of climate change and are concerned about their future—which should be taken seriously.

Regarding the consequences of climate change expected in the future, both actor groups agree that a deterioration of human well-being (food security, poverty, diseases) is a major concern. The fact that the concepts behind this concern are not only affected by climate change underlines the urgent need for people to adapt not only to climate change, but to change in general, caused for example by globalisation trends, demographic developments, and resource degradation and scarcity.

While there was general agreement on perceived and observed trends in temperature, rainfall, and extreme events over the past four decades, experts and community members gave hydro-meteorological extreme events in the future less weight compared to other concepts. Changes in rainfall patterns and related hazards were given relatively low importance. However, the climate model ensemble indicates an increase in future extremes (rainfall, river floods, lake water level). This may be indicative of a lack of awareness regarding future "wet" extremes, an underestimation of future impacts, or, while contemplating the future, a shift in focus towards concerns about future human well-being.

In contrast, droughts were mentioned as a future consequence. Yet, a generally drier future in the LVB is projected by only a minority of the climate models, which does not exclude the possibility of a drier future in some regions or extended drought periods. To understand the potential risk posed by extreme events, it is essential to consider the exposure and adaptive capacity of people who may be affected.

There is an extensive literature on climate change. However, this research has so far primarily focused on studying WEIRD (Western, Educated, Industrialized, Rich, and Democratic) populations. Studies investigating highly vulnerable regions in the Global South are crucially needed. This study contributes a piece of the puzzle—a perspective from East Africa.

Acknowledgments

We would like to acknowledge the people who participated in the two surveys and the research assistants conducting the interviews with community members. This research was funded in the frame of the AXIS MECCA project (https://mecca.sites.uu.nl/) by ERA-NET co-fund action initiated by JPI Climate, funded by BMBF (Germany, Grant 01LS1909A), NWO (The Netherlands, Grant 7934), and RCN (Norway, Grant 300227) with co-funding by the European Union's Horizon 2020 Framework Program (Grant 776608).

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Appendix A. Materials and methods

A.1. Surveys

A.1.1. Survey design and implementation. We conducted two surveys, one with experts and one with community members.

The expert group consisted of 21 people who were professionally involved in the topic of climate change, either as researchers or as decision-makers. They were recruited through the networks of the authors and research assistants, or identified through scientific publications on climate change in the LVB. The expert survey was an online survey to which individuals were invited by email. This was a consequence of the COVID-19 pandemic. Originally, the MECCA[12] project planned to conduct a larger survey in person during workshops.

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[12] https://mecca.sites.uu.nl/

The community group consisted of 146 community members, engaged in fishing, farming, livestock tending, trading, and other occupations on the shores of Lake Victoria in Kenya, Tanzania, and Uganda. The community survey was conducted face-to-face in the manner of a structured interview. Data were collected between the 19*th* of November 2020 and the 11*th* of June 2021 in Kenya, Uganda, and Tanzania by a team of local researchers. In each country, three villages on the shore of Lake Victoria were randomly selected from a list of villages. In collaboration with local village leaders, local fishers, farmers, livestock keepers and urban community members were contacted to participate in the study.

In each country, data were collected by a team of two research assistants and one lead researcher. Questionnaires were translated into native languages of the target samples by two research assistants independently. Differences in translation were resolved in collaboration with the lead researcher of each team. Participants had the option to fill in the paper-based questionnaire themselves or have the research assistant fill in the questionnaire for them. After informed consent was obtained, a list of open-response questions about climate change followed. First, participants were asked to characterize climate change, as well as the causes of climate change. Next, their perceptions of climate change in the local area were assessed including the current and future consequences, local factors contributing to these consequences, and mitigation and adaptation strategies. The survey closed with demographic questions including age, gender, occupation and education. Participants were debriefed, thanked for their participation and financially compensated for their time according to local standards. Information about gender, education, and occupation provides table A1.

The entire survey included eight questions on climate change, of which the following three were selected for this article:

- What do you think are the main causes of climate change?
- What do you think are the main consequences of climate change that are already experienced in your region?
- What do you think will be the main future consequences of climate change in your region?

Note that we did not suggest specific variables for survey participants to focus their perceptions on, such as rainfall amounts, heavy rainfall events, the onset and cessation of wet and dry seasons and so on. We aimed to tap into people's conceptions of climate change and therefore did not guide them by selecting variables for them. We asked in an open-response format, giving participants the opportunity to express what they considered relevant. We applied an inductive thematic analysis to the responses [43], by developing a coding scheme based on the data that was applied to all three open-ended questions about the causes of climate change, its consequences perceived today, and expected in the future.

We also did not ask the respondents of the online survey (experts) about the specific region in the LVB to which they were referring. As rainfall regimes and patterns are very heterogeneous in the different regions of the LVB (figure B7), we could not associate a particular statement with a specific region, for example, ‘heavier rainfall’. This put certain limits to the extent to which we could assess whether respondents’ perceptions were consistent with observations with respect to the spatial occurrence of the event. However, the results of the hydro-meteorological analysis were conducted at regional and local scales. These included four sub-basins representing river discharge into Lake Victoria from different climates in the northwest, northeast, southwest,

Table A1. Community survey participants.

	Female	Male	Total
Count (n)	38	108	146
%	26	74	100
Occupation %			
Fishing	0	34	25
Farmer	39	22	27
Cattle/Livestock	21	31	28
Urban dwellers	21	1	6
Business	8	3	4
Other	11	9	10
Education %			
No education	3	3	3
Primary	53	56	55
Secondary	29	26	27
College	8	11	10
University	8	5	5

and southeast of the LVB, and nine grid cells to differentiate climate data into northern, central, and southern, as well as western and eastern areas.

A.1.2. Codes, Categories, and Domains. Codes. The codes represent the lowest level of aggregation derived from the free-text answers. They can be composed of different attributes. For example, the code *Rainfall* aggregates the attributes: intense, heavy rains, extremes, erratic, increase, changed patterns, rainy season, unreliable. Some codes were held in a neutral form, for example, *Changing lake water level* when the direction of change (increasing or decreasing) was not clear or contradicting between respondents.

In some cases, it was necessary to take a closer look into the attributes attached to selected codes to better evaluate to what extent perceptions and observations or expectations and projections deviate from each other. The code *Rainfall*, for example, was too aggregated to understand which climatic phenomena were actually associated with it.

Altogether, 119 codes were derived from the free-text answers of the total number of questions in the entire survey.

Categories and Domains. The 119 codes were aggregated into 22 Categories and four Domains (table A2). Information on which codes were assigned to which categories can be found in the Supplementary Material: *survey_data.xlsx*.

Definition of domains. A critical step was the definition of the domains. They formed the main basis for the interpretation and visualization of the results. As there are naturally overlaps between the domains as well as the categories, the coding entailed a certain amount of subjective judgment, as any coding process does. Therefore, coding was independently done by four coders and their inter-rater reliability was determined (A.1.4).

On a superordinate level, we distinguished the environmental domain from the human sphere, neglecting the diffuse boundary or the fact that humans are an integral part of the environment. We call the domain Environmental, its associated categories are shown in table A2.

The human sphere was further differentiated into three domains: (a) Human Activities: activities associated with livelihood generation, energy consumption, and GHG emissions, (b) Governance & Policy: higher order activities that organize and govern, and (c) Societal: society-related.

Table A2. Categories and domains.

Category	Domain
Climate and weather	Environmental
Ecology	Environmental
Hazards	Environmental
Hydrology	Environmental
Natural phenomena	Environmental
Other	Environmental
Awareness	Governance & Policy
Economy	Governance & Policy
Governance and management	Governance & Policy
Infrastructure and urban development	Governance & Policy
Land use management	Governance & Policy
Technology	Governance & Policy
Waste management	Governance & Policy
Agriculture	Human Activities
Behaviour	Human Activities
Fishery	Human Activities
Industry and GHG emissions	Human Activities
Land use	Human Activities
Pollution	Human Activities
Beliefs	Societal
Supernatural Powers	Societal
Human well-being	Societal

Table A3. Code frequency per topic and domain (experts).

Domain	Causes	Cons. today	Cons. future
Societal	2	9	24
Human activities	63	14	21
Governance & policy	23	7	13
Environmental	9	59	33

Table A4. Code frequency per topic and domain (community).

Domain	Causes	Cons. today	Cons. future
Societal	14	76	150
Human activities	262	174	106
Governance & policy	55	42	47
Environmental	76	170	153

Table A5. Inter-rater reliability.

Survey	Agreement [%]	
	Category	Code
Communities	67	59
Experts	83	76

A.1.3. Survey analysis. Based on the tables in the Supplementary Material: *survey_data.xlsx*, the following tables (A3, A4) summarize the number of codes per domain and topic for both experts and communities. The data served as the basis for the stacked bar plots (figure 2).

A.1.4. Inter-rater reliability. Inter-rater or inter-coder reliability quantifies the degree of agreement among independent raters or coders in assessing the same phenomenon. In our case, it represents the reliability of the categorization of free-text responses of survey participants into a common system of Codes across four coders. A rater had the freedom to select more than one Code per response and therefore different raters are likely to end up with different numbers of Codes. To calculate the rater agreement, the common Codes assigned to the responses of a participant to a specific question were divided by the maximum number of assigned Codes. For instance, if rater 1 assigned four Codes and rater 2 assigned three Codes and two of the Codes are in common, the agreement for that specific question and respondent would be 50%.

The inter-rater agreement was calculated separately for both surveys by summing up the numbers of common Codes and dividing it by the sum of the maximum assigned Codes across all questions and respondents. The same was done with the Categories that are attached to a specific Code but describe the responses in a more general way. This strategy does not account for selecting specific Codes by chance. However, as there is a total of 119 Codes that could be selected from during coding, random chance is low and percentage agreement can be considered as an adequate metric to assess inter-rater reliability.

The results of the inter-rater reliability assessment show agreements between 67% and 83% for Categories and, as expected, a little lower values for the Codes ranging from 59% to 76% (table A5). Generally, values above 80% are considered as excellent, whereas values below 40% are considered as fair to unacceptable. According to [44], the agreement of the inter-rater reliability in this study was between substantial and nearly perfect for the analysis of Categories and substantial for Codes.

A.1.5. Survey interpretation. It should be noted that the expert survey has some limitations. First, one could argue that the survey is not representative enough, as it is based on only 21 respondents and not all of them have responded to each and every question. But then, experts are difficult to recruit and our sample size is not smaller than that of many expert studies. Second, these are people with demanding work lives who may not have had the opportunity to devote sufficient time to responding to the survey. Possibly, their attention and motivation to respond diminished throughout the survey. These limitations need to be taken into consideration when interpreting the results and assessing their reliability. Nevertheless, the answers are insightful and provide a worthwhile comparison to the more comprehensive community survey.

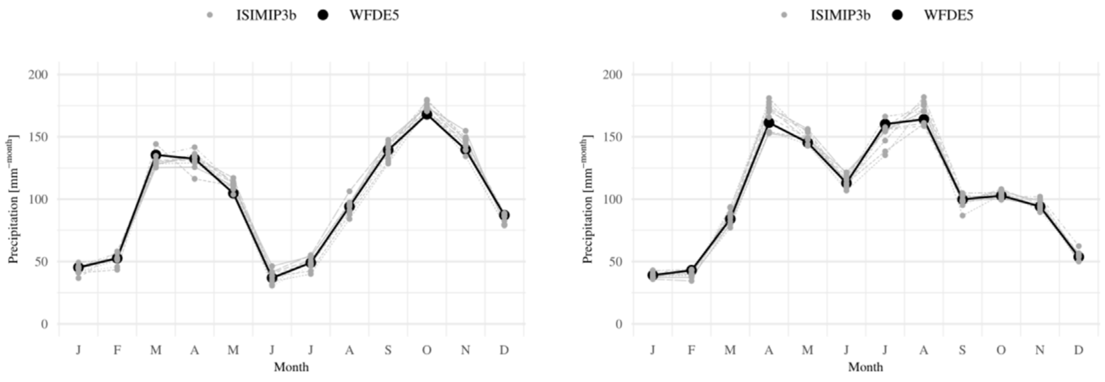
A.2. Climate: observations and projections

The gridded data set WFDE5 [23] with a spatial resolution of 0.5 degree provided the daily temperature, solar radiation, and precipitation data of the four decades between 1979 and 2019, covering the reference period P0 from 1984 to 2014. The dataset was considered as 'observed' weather data in this study. It was used to calibrate and validate the eco-hydrological model SWIM (A.3) and as reference climate to bias-adjust and downscale the ten GCMs used as climate forcing in this study [45, 46]. The two climate scenarios ssp126 (based on RCP 2.6, low radiative forcing) and ssp370 (based on RCP 7.0, medium-high radiative forcing) were selected to cover an extensive range of future projections from P0 until the year 2100. These projection data were provided by the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b) [24, 25] (https://www.isimip.org/).

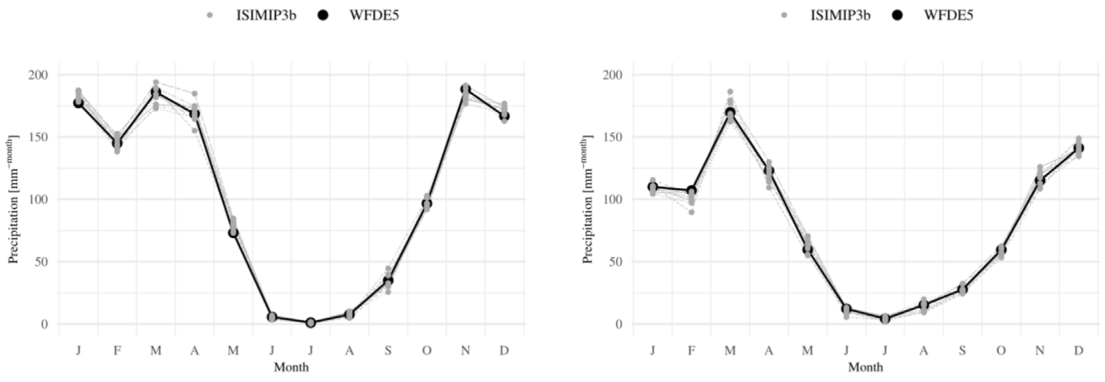
Measured by mean monthly rainfall in the four representative sub-basins, simulations of the ten bias-adjusted ISIMIP3b GCMs agree well with the reference dataset WFDE5 (P0: 1984–2014) (figure A1). All models reproduce the different rainfall regimes very well, but this does not reveal how strongly the individual GCMs were forced into the reference regime (WFDE5) during the bias adjustment or how far their uncorrected simulations deviated from the reference regime. However, the bias adjustment may affect future projections by transferring the original change signals to other (new) conditions, thus affecting their qualitative changes.

A.3. Hydrological modelling

To simulate the occurrence of floods, hydrological droughts, and the hydrology of Lake Victoria, especially the fluctuations of the water level, the Soil and Water Integrated Model (SWIM) was applied to the entire LVB. SWIM is a spatially semi-distributed, process-based, eco-hydrological, and water management model that operates at a daily time step. It was developed on the basis of the MATSALU [47] and SWAT [48] models and is continuously further developed and adapted to new or specific requirements [49]. Hydrological response units (HRU), considered areas with similar hydrological characteristics, are the smallest model units where all hydrological, nutrient, and vegetation processes are calculated. There is no lateral interaction between HRUs but



(a) Katonga (NW) (b) Nzoia (NE)



(c) Akagera / Ruvubu (SW) (d) Simiyu (SE)

Figure A1. Mean monthly rainfall of 10 bias-adjusted ISIMIP3b GCMs and WFDE5, P0 (1984–2014).

area-weighted daily fluxes are calculated and aggregated at the sub-basin scale and routed through the river network. SWIM distinguishes three flow components: surface runoff, subsurface runoff, and contributions of the shallow groundwater aquifer. Actual evapotranspiration is determined by soil evaporation and transpiration from the vegetation cover. Water percolating from the shallow groundwater aquifer into the deep groundwater aquifer is lost from the system but is considered in the water balance (figures A2 and A3). SWIM integrates water management, such as reservoirs [50] and irrigation [51].

The LVB was delineated into 1327 sub-basins and SWIM was calibrated at about 60 discharge and water level stations. The integrated reservoir module was used to simulate the effects of storage, evaporation, and release from Lake Victoria and 13 lakes. Although SWIM was applied to the entire LVB, for the flood risk analysis we selected the four focal sub-basins representing tributaries draining the NW (Katonga), NE (Nzoia), SW (Akagera / Ruvubu), and SE (Simiyu) regions, see figure 1.

Figure A4 shows the performance of the calibrated SWIM model to simulate inflows, outflows, and water levels of Lake Victoria.

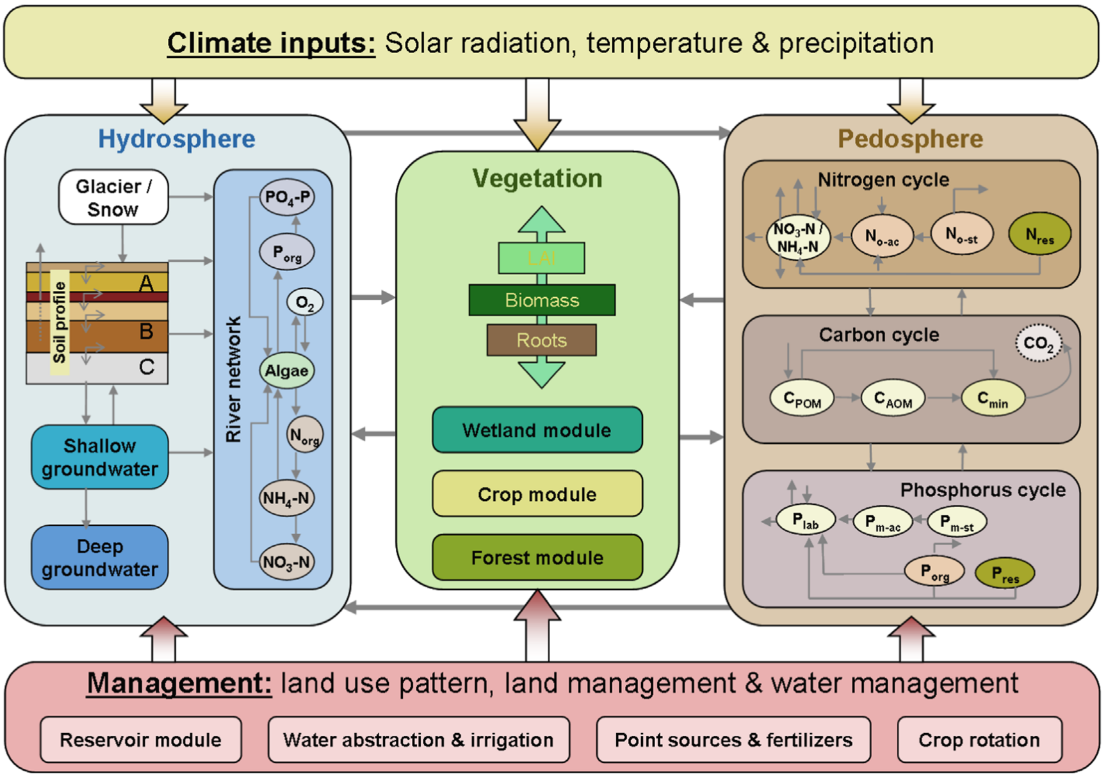


Figure A2. Structure of the SWIM model.

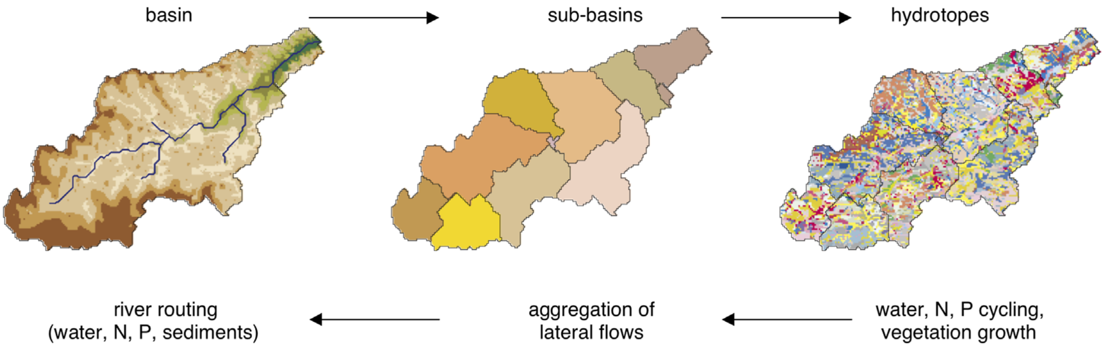
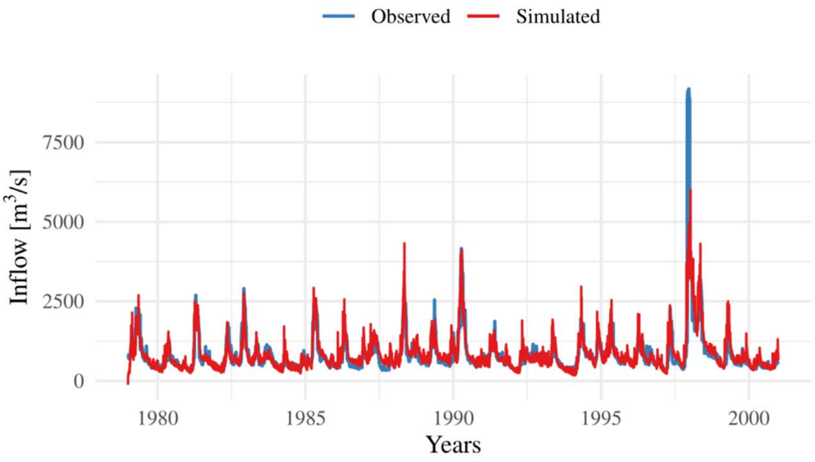
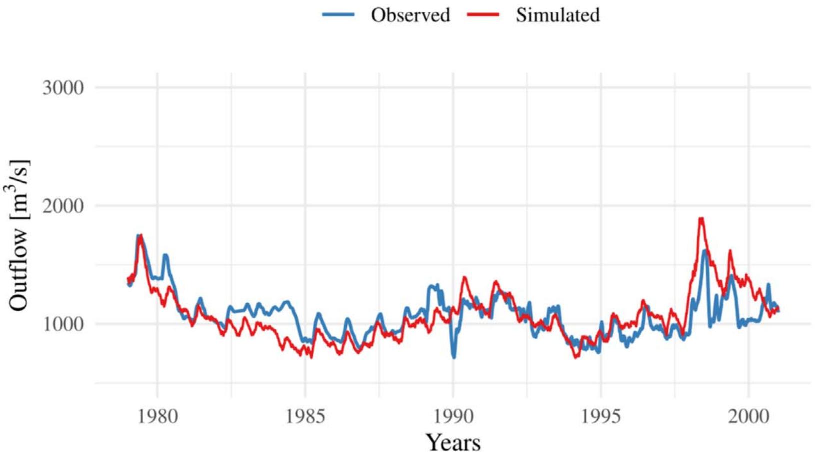


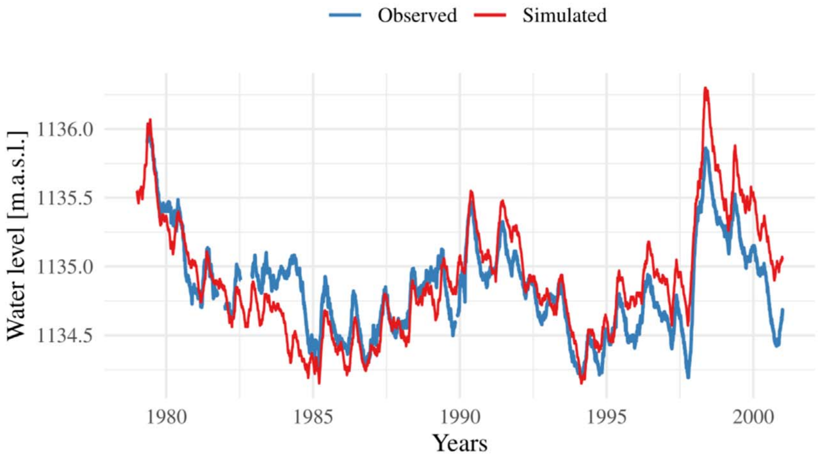
Figure A3. Spatial disaggregation.



(a) Inflow



(b) Outflow



(c) Water level

Figure A4. Lake Victoria observed and simulated daily inflow, outflow, water level. Water level was measured at Entebbe and outflow at Jinja, Uganda.

A.4. Hydro-meteorological analysis

The hydro-meteorological analysis was conducted at regional and local scales. These included the entire LVB, four focal sub-basins representing river discharge into Lake Victoria from different climates in the northwest, northeast, southwest, and southeast of the LVB, and nine grid cells to differentiate climate data into northern, central, and southern, as well as western and eastern areas.

A.4.1. Rainfall and temperature. We analyzed the following rainfall and temperature indicators using daily rainfall data from WFDE5 and the ten single ISIMIP3b GCMs:

- Annual rainfall [mm a^{-1}]
- Average annual rainfall over the three periods P0, P1, and P2 [mm a^{-1}]
- Daily rainfall maxima per year, AMAX [mm d^{-1}]
- Return periods RP_{pr} of daily precipitation maxima (AMAX), e.g., the AMAX value for a 10- or 50-year event in a given period. The Gumbel extreme value distribution type 1 was used to estimate the return periods of maximum rainfall events.
- Number of days per year with rainfall over certain thresholds
- Rainfall seasonality, by comparing the average monthly rainfall in two time periods
- Annual mean air temperature [° C]

The number of grid cells representing the study area was 18 rows and 15 columns = 270, as for example shown in figure 5. We deliberately used time series from single grid cells instead of computing the average over 9 adjacent cells, because averaging would smooth the rainfall maxima.

The trends in rainfall and temperature for the period 1979–2019 were estimated using the Mann-Kendall trend test.

A.4.2. River floods. The river flood analysis was carried out for the four main sub-basins in a similar way to the analysis of the rainfall time series. A series of annual maximum flood peaks $AMAX_{fp}$ was generated from the simulated daily discharge time series forced by WFDE5 and used to derive return periods RP_Q and associated discharge values that can be compared between different periods. The Gumbel extreme value distribution type 1 was used to estimate the return periods of annual maximum flood peaks.

To assess the changes in future flood peaks and return periods, one $AMAX_{fp}$ time series was created for each of the 31-year periods (P0, P1, P2). The daily simulations of each of the ten GCMs were considered and combined into one time series. Thus, each periodic time series consisted of 310 $AMAX_{fp}$ values from which return periods were estimated.

A.4.3. Inundation, lake water levels. Lake Victoria water level fluctuations were simulated using the SWIM model by simulating daily water inflow from rainfall over the lake and all tributaries, and daily water outflow from evaporation over the lake area, seepage from the lake bottom and regulated discharge at the outlet in Jinja. The simulated time series of mean annual water levels or averaged 30-year periods were compared for different future periods and scenarios.

A.4.4. Droughts. The Standardized Precipitation Index (SPI) was used to investigate the past development of drought occurrence over the period 1979–2019. The SPI was estimated based on monthly rainfall amounts using the R Package SPEI developed by [52]. The 12-months SPI (meteorological drought) was used to show a general trend over the observational period and the 3-months SPI (agricultural drought) was used to analyse changes in the two rainy seasons MAM and OND.

The analysis (SPI) revealed that meteorological droughts can be experienced over a longer period in one region of the LVB where other regions received normal or above-normal rainfall amounts. The SPI over the period 1979–2019 can show opposing trends for different locations in the LVB.

Appendix B. Results

B.1. Survey

B.1.1. Tree plots (experts). The size of the circles in the following tree plots indicates the code frequency per domain, so in a sense, it represents its relative importance compared to the other domains. While interpreting the figures, pay attention to the circle size a domain is represented by, to get an indication of how often (not how many) associated codes were mentioned. Some illustrations suggest visually that more importance can be given to a domain, which is represented by many different codes but which received only a low number of mentions.

The text size is not relative to the number an item was mentioned but whether it represents a domain, category, or code.

B.2. Perceptions versus observations

To answer the question whether the experts' and community members' perceptions of climate change consequences felt today match observations, we used the most important codes and their attributes associated with physical climate change impacts (table 2), primarily represented by domain Environmental. To address the changes over the observational period (1979–2019), we compared the differences between the earlier past (1980–1999) and the recent past (2000–2019) using the indicators in table 1.

Basin-wide. The perceptions of increased temperatures were in line with the observations that showed an increase of about 0.8 degrees from 1979 to 2019 (figure 4(a)). Annual rainfall averaged over the LVB also shows a slightly increasing but statistically insignificant trend (figure 4(b)). This general trend is also confirmed by [28–31]. figure B4 puts the recent trends into a long perspective since 1891. The map in figure 5(a) and B5 show that the annual rainfall trends have spatially different patterns. Where the northwestern region, specifically the Katonga sub-basin in Uganda, experienced a drying trend, the rest of the basin area received more rainfall in the recent past. However, significant trends dominate in the north and over the central and southwestern lake areas.

Code Rainfall. In terms of changed patterns and seasonality, there was a tendency in the recent past for rainfall to decrease in the first half of the year, coinciding with the MAM rainy season, and for it to increase in the second half, covering the OND rainy season (figures B7, B8, and B9), also confirmed by [27, 28]. Exceptions are the sites in the northwest and north, where rainfall was lower in the recent past in all months, except in September. A shift towards more and higher extreme events was observed, as confirmed by [30]. It is noticeable that the majority of grid cells in the LVB show statistically significant increasing trends of annual maximum rainfall event ($AMAX_{pr}$), up to about $40mm^{-d}$ over four decades, figure 5(b) and B6.

The number of rainy days (> 1 mm) has not significantly changed in most sites, except in the northwest, where it decreased from 182 to 164 days. The number of days with rainfall events above thresholds from 20 to 50 mm increased in almost all cases and almost doubled in many sites (table B1 and B2). However, the number of days with rainfall above 40 mm is insignificant (< 1). The rainfall values associated with return periods RP_{pr} indicate in most cases a statistically significant increase from the first to the second decades. An exception constitutes the eastern site. In the most extreme case in the southwest, the $AMAX_{pr}$ associated with a 10-years

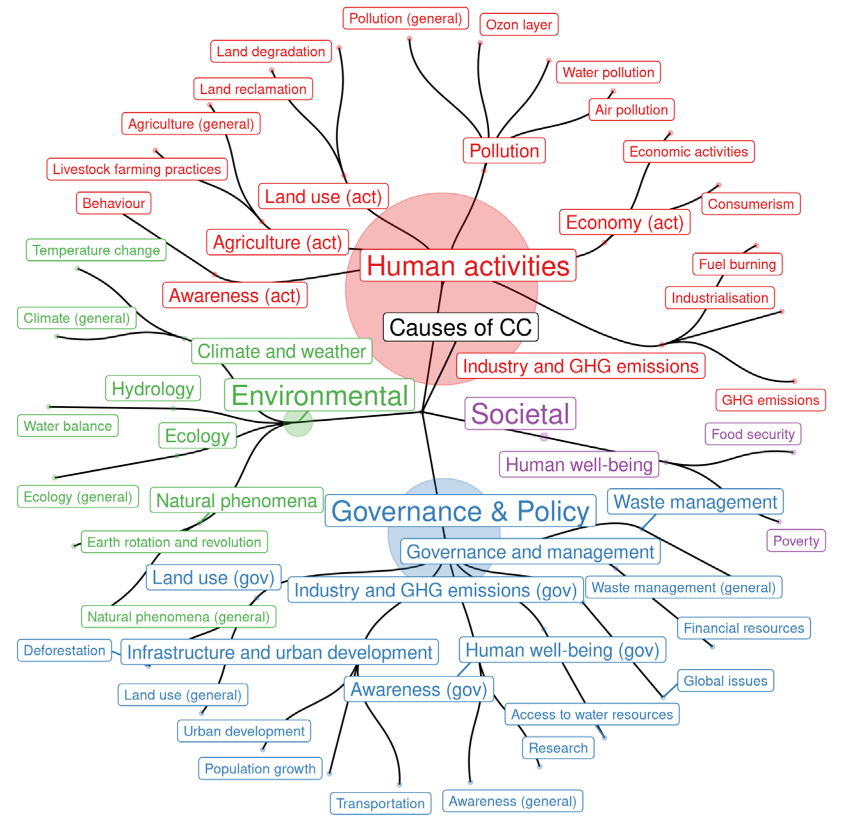


Figure B1. The *causes* of climate change (experts). Domains, categories, and codes.

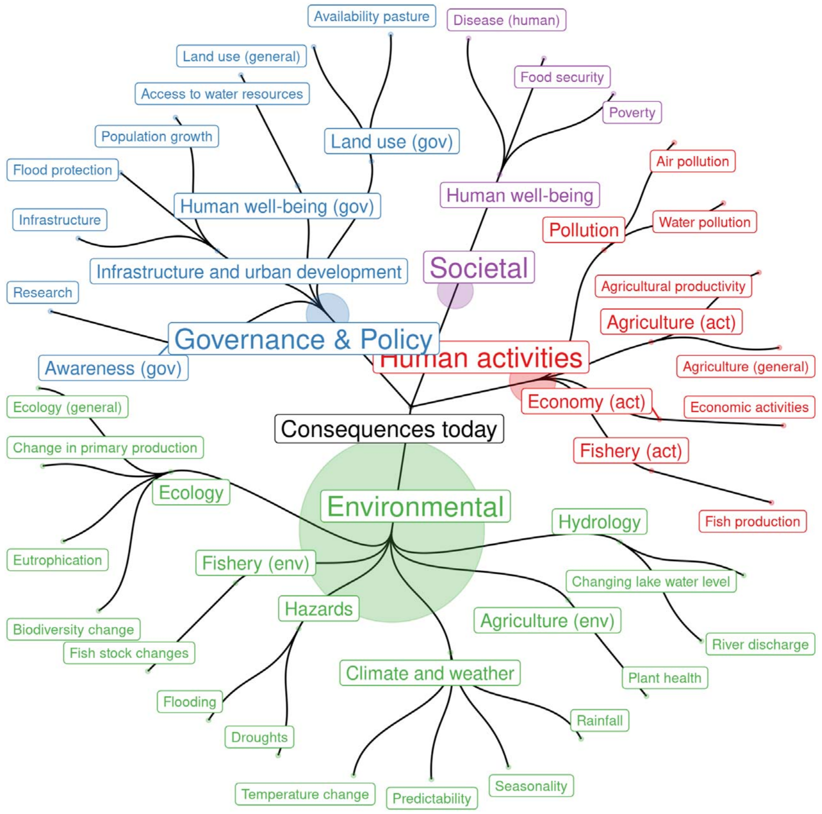


Figure B2. The *perceived consequences* of climate change (experts). Domains, categories, and codes.

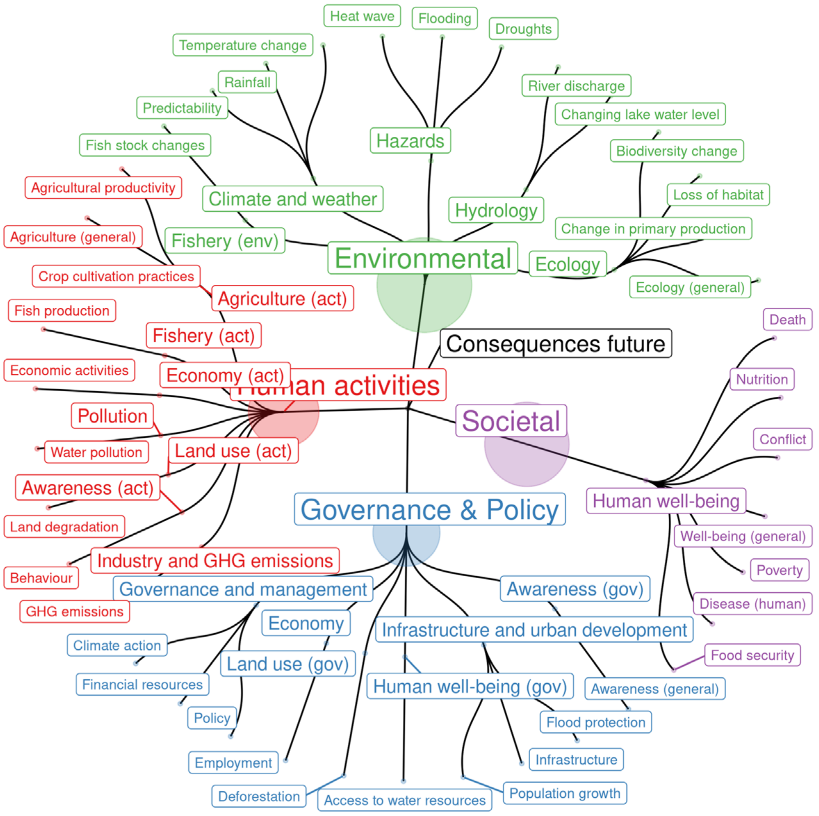


Figure B3. The *expected consequences* of climate change in future (experts). Domains, categories, and codes.

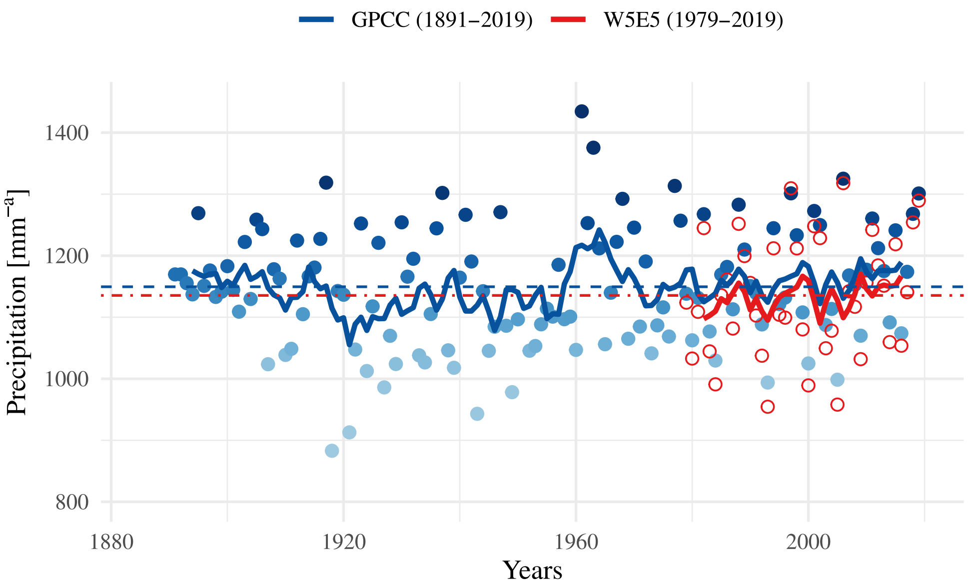
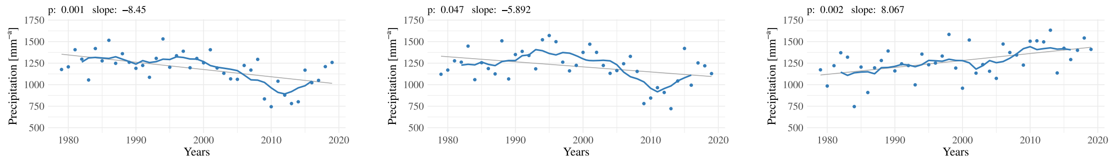
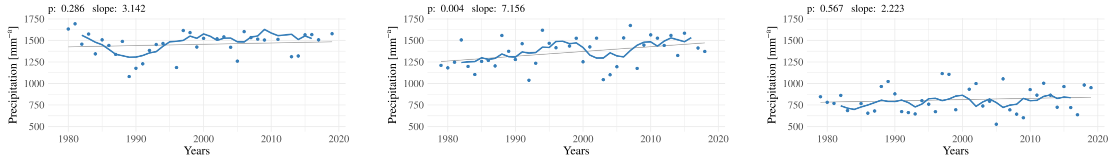


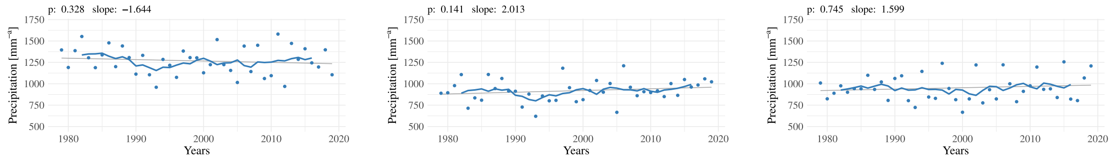
Figure B4. GPCC [53] and W5E5 annual rainfall averaged over the LVB. The upward and downward trends observed in various decades of the historical period since 1891 put the recent (1979–2019) upward trend into perspective. Compared to the long-term variations of wetter and drier periods since 1891, the recent maximum and minimum annual rainfall amounts are not outside the range of long-term observations.



(a) Northwest (b) North (c) Northeast



(d) West (e) Central (f) East



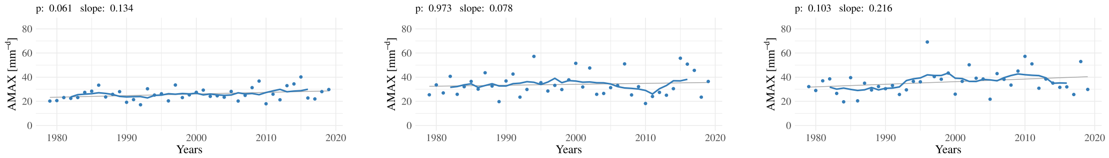
(g) Southwest (h) South (i) Southeast

Figure B5. Annual rainfall based on W5E5. p-value based on Mann-Kendall, slope = linear trend.

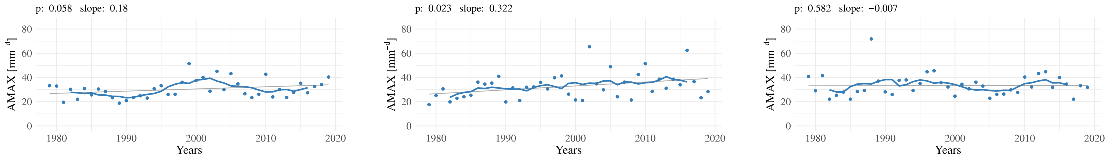
return period, for example, increased from about 28 mm^{-d} to 45 mm^{-d} (figure B11 (g)). Hence, the perceptions associated with changes in code Rainfall seem to match the observations.

Code Droughts. According to the 12-month SPI time series (figure B10), droughts did not occur more frequently in the recent past than in the earlier past. Exceptions were again the northwestern and northern sites that experienced extremely dry conditions in three to four years between 2009 and 2014 of a magnitude not observed since 1979.

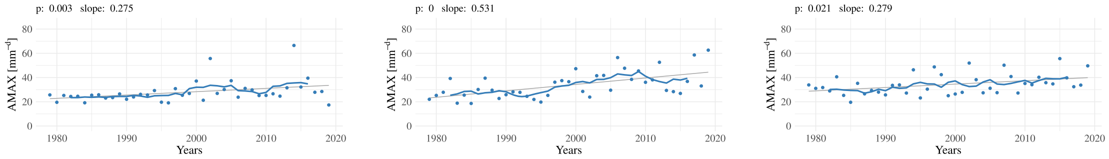
Code Flooding. Different types of flooding were counted under the code Flooding (pluvial, fluvial, inundation) because it was often not possible to clearly differentiate which one was meant. We consider (river)



(a) Northwest (b) North (c) Northeast

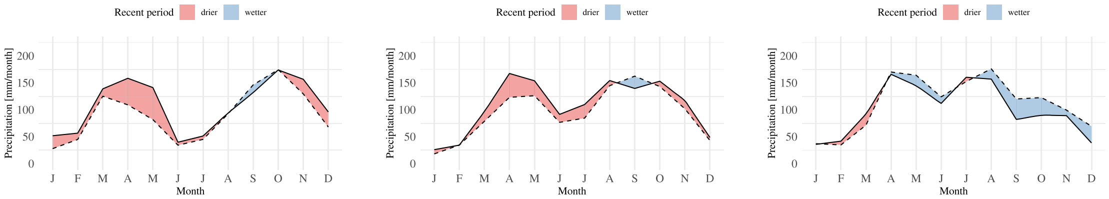


(d) West (e) Central (f) East

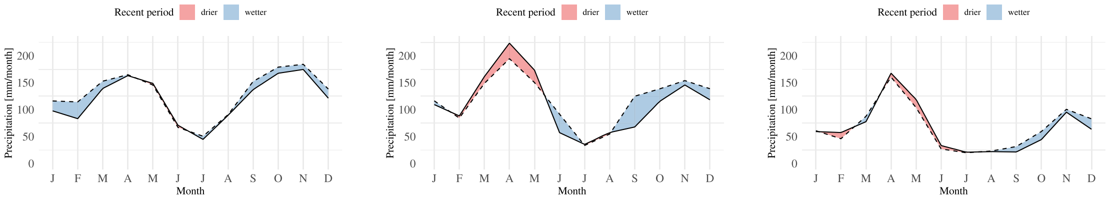


(g) Southwest (h) South (i) Southeast

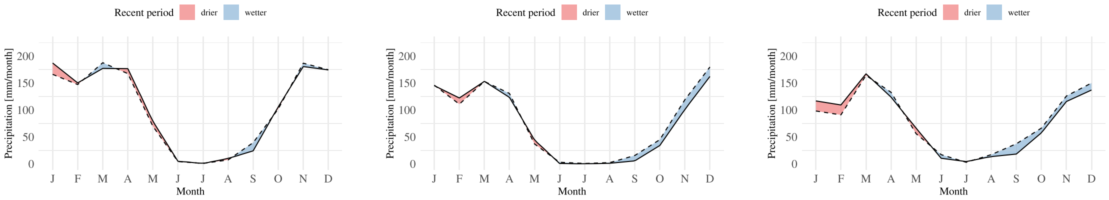
Figure B6. Annual maximum rainfall $AMAX_{pr}$ from 1979–2019 using W5E5, lines represent the 7-years moving average.



(a) Northwest (b) North (c) Northeast

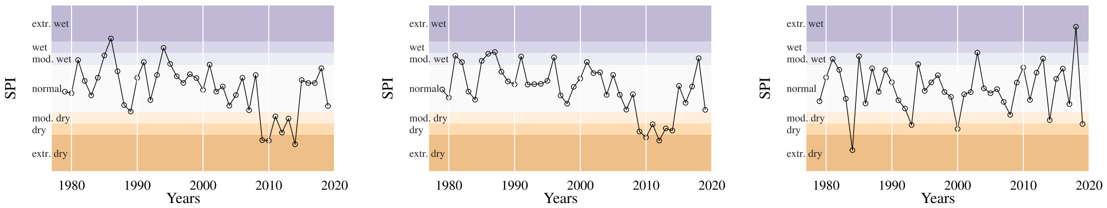


(d) West (e) Central (f) East

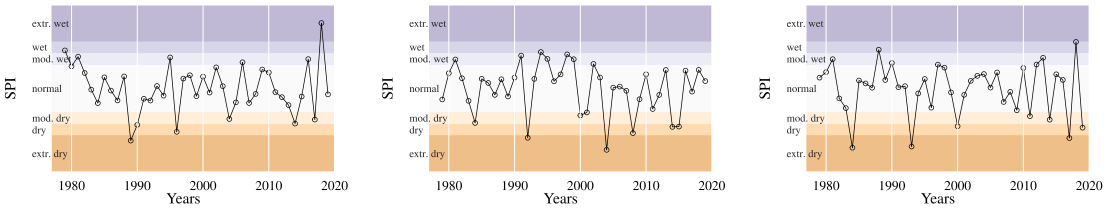


(g) Southwest (h) South (i) Southeast

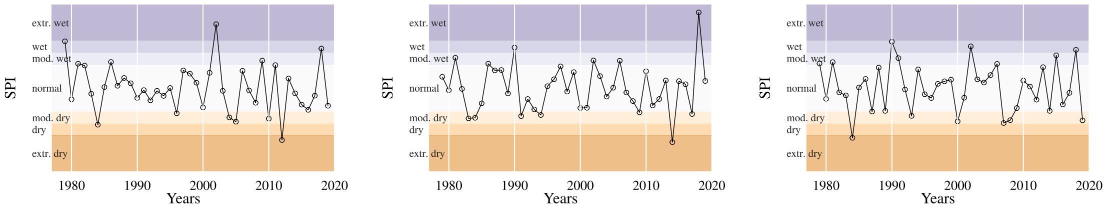
Figure B7. Average monthly rainfall in the two decades 1980–1999 (D1, solid line) and 2000–2019 (D2, dashed line) using W5E5. Differences are shown as coloured areas (reddish = D2 drier than D1, bluish = D2 wetter than D1.



(a) Northwest (b) North (c) Northeast

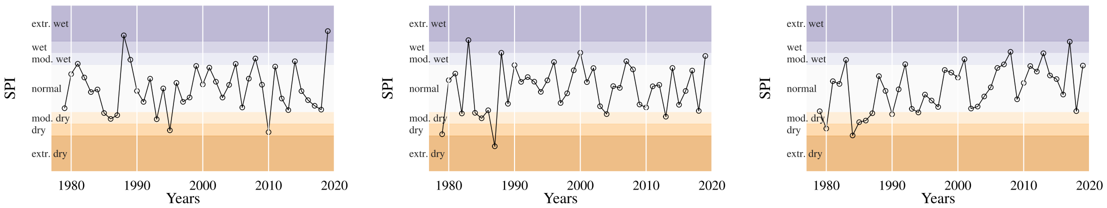


(d) West (e) Central (f) East

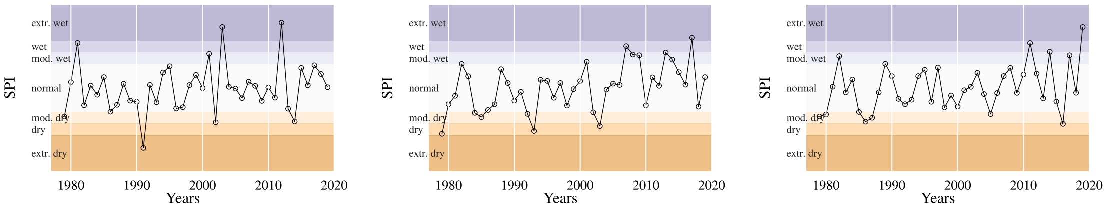


(g) Southwest (h) South (i) Southeast

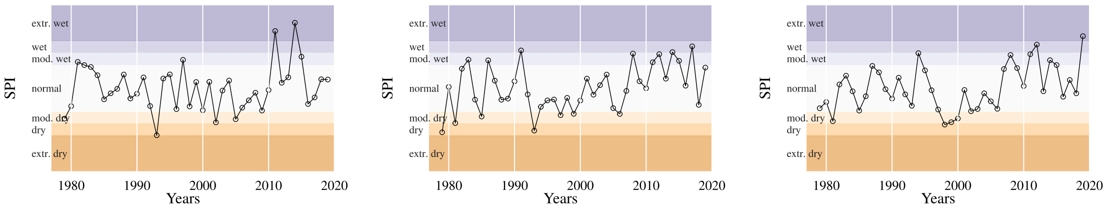
Figure B8. 3-month SPI at month May to cover the MAM rainy season using W5E5.



(a) Northwest (b) North (c) Northeast

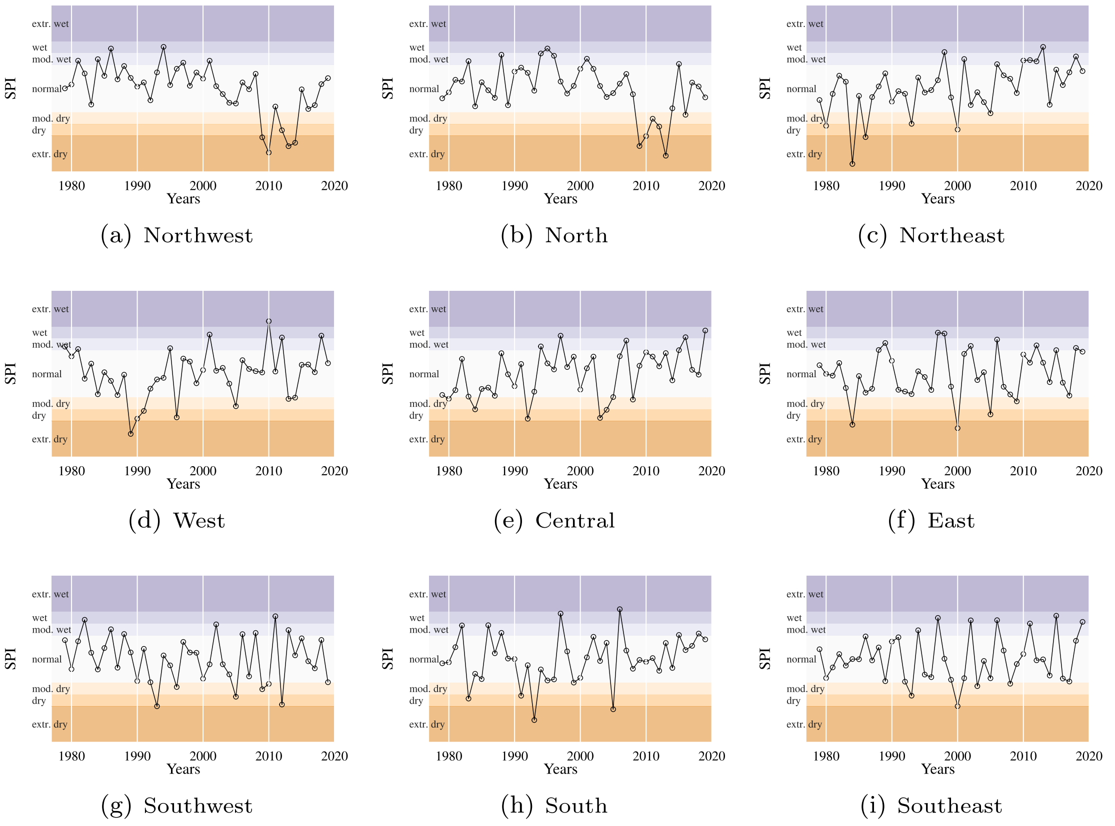


(d) West (e) Central (f) East



(g) Southwest (h) South (i) Southeast

Figure B9. 3-month SPI at month December to cover the OND rainy season using W5E5.



(a) Northwest (b) North (c) Northeast

(d) West (e) Central (f) East

(g) Southwest (h) South (i) Southeast

Figure B10. 12-month SPI at month December using W5E5.

Table B1. Number of days with rainfall over thresholds (N, S, W, E).

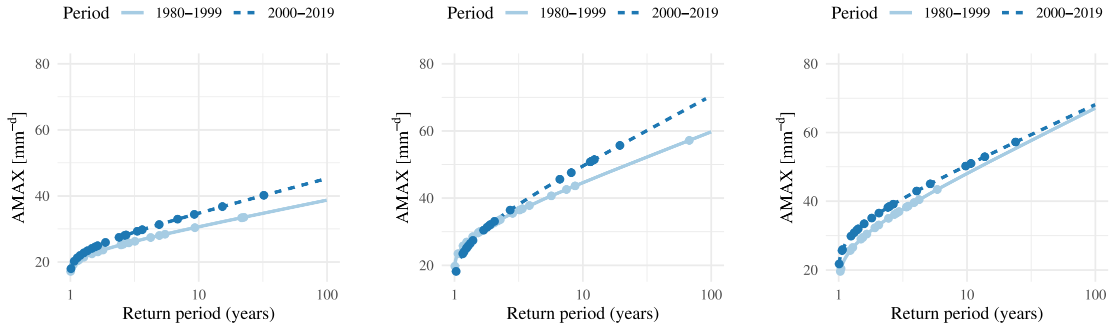
Threshold [*mm*/*day*]	North		East		South		West	
	HP1	HP2	HP1	HP2	HP1	HP2	HP1	HP2
1.0	149.4	145.6	112.3	109.8	120.8	118.9	171.7	174.8
10.0	46.9	38.0	23.7	26.2	32.1	35.4	43.4	51.0
20.0	5.8	6.1	4.5	6.0	3.4	6.7	3.0	5.9
30.0	1.0	1.15	0.9	1.3	0.6	1.6	0.6	1.2
40.0	0.3	0.5	0.2	0.2	0.1	0.5	0.1	0.2
50.0	0.1	0.3	0.1	0.0	0.1	0.1	0.1	0.0

HP1 = 1980–1999, HP2 = 2000–2019

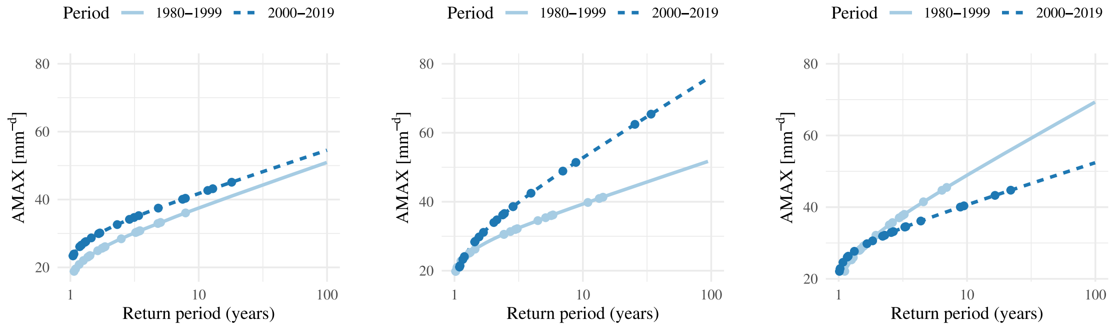
Table B2. Number of days with rainfall over thresholds in sub-basins and over the lake.

Threshold [*mm*/*day*]	NW		NE		SW		SE		Lake	
	HP1	HP2	HP1	HP2	HP1	HP2	HP1	HP2	HP1	HP2
1.0	182.1	164.2	158.6	164.6	154.4	152.7	118.8	117.0	162.8	166.7
10.0	36.8	31.1	38.7	45.0	43.4	44.9	31.9	33.1	41.2	46.3
20.0	2.5	3.4	5.3	9.9	2.6	5.2	5.3	6.4	3.1	5.5
30.0	0.1	0.3	1.1	1.6	0.1	0.7	1.1	1.8	0.7	1.4
40.0	0.0	0.1	0.1	0.3	0.0	0.2	0.2	0.5	0.1	0.2
50.0	0.0	0.0	0.1	0.2	0.0	0.1	0.0	0.2	0.0	0.1

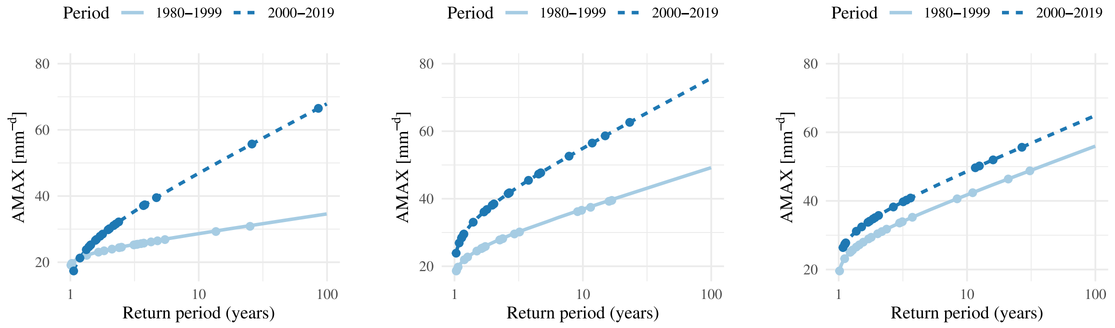
HP1 = 1980–1999, HP2 = 2000–2019



(a) Northwest (b) North (c) Northeast



(d) West (e) Central (f) East



(g) Southwest (h) South (i) Southeast

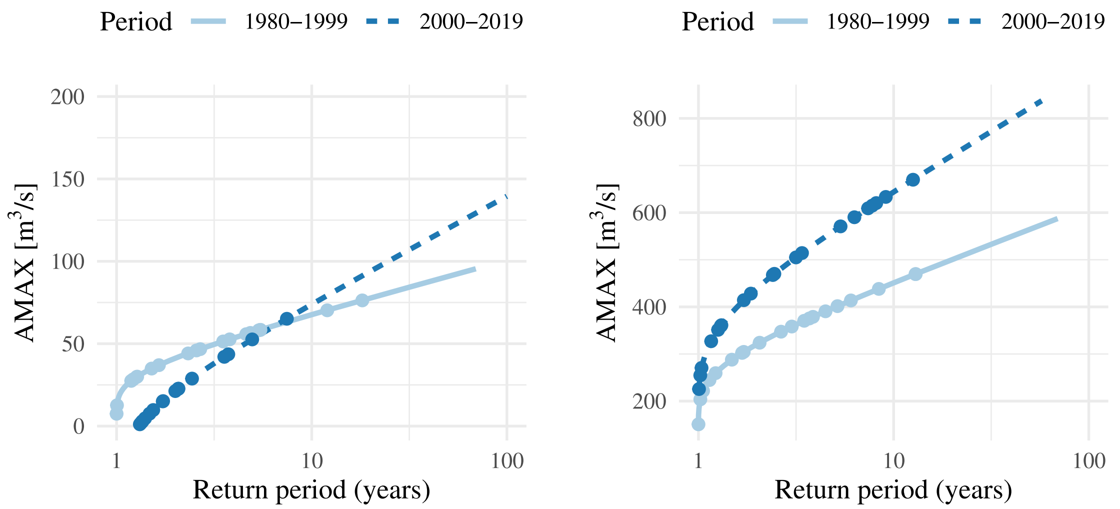
Figure B11. Return periods of $AMAX_{pr}$ using W5E5 (Gumbel extreme value Type 1 distribution).

fluvial floods as well as fluctuating water levels in Lake Victoria. The flood peaks $AMAX_{fp}$ associated with return periods RP_Q have increased significantly in the Nzoia (NE) and the Akagera/Ruvubu (SW) sub-basins in the recent past. Mixed patterns were observed in the Katonga (NW) and Simiyu (SE) sub-basins (figure B12).

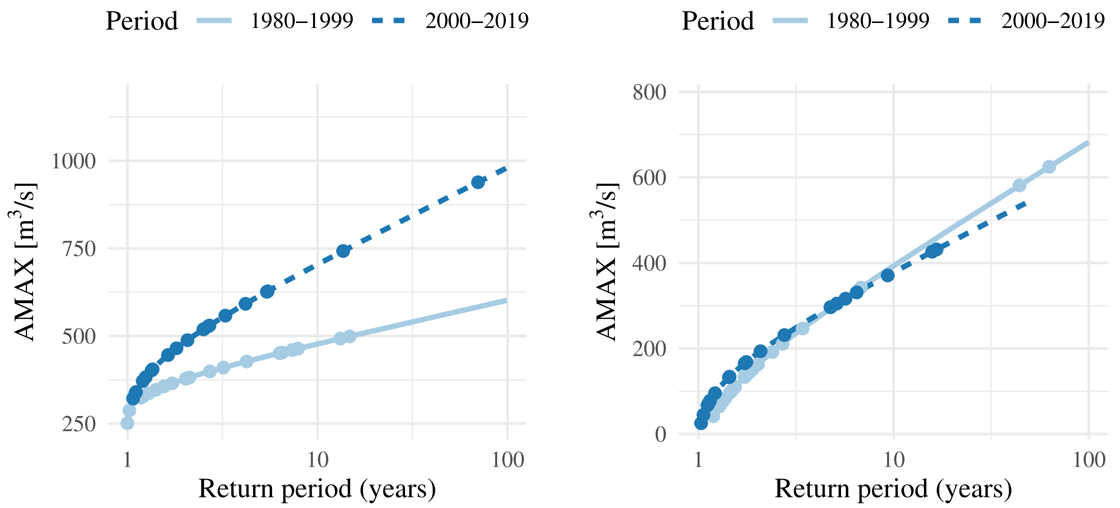
Changes in lake water levels showed a cyclic pattern between 1979 and 2019. Therefore, the increasing linear trend in the recent past is only a poor indicator. High water levels occurred in 1979, 1998, and 2019 and low levels in 1986 and 2005 (figure B13). Thus, the recent past was characterized by a rapid downward trend from 2000 to 2005 and a steep upward trend thereafter.

B.3. Projections

Future maximum daily rainfall events have the potential to be higher than those simulated in the reference period, although this was only significant in 20% to maximal 70% of the simulations across scenarios and periods. The future change in the number of rainy days over specific thresholds is inconclusive but shows a clear tendency to increase. The number of days with rainfall $\geqslant$ 30 mm is projected to increase significantly over the lake area, but those exceeding 50 mm show no significant trend. Uncertainty is high in projecting changes in extreme rainfall events; advanced regional climate models with nested convection-permitting models (CPMs) may help offset these uncertainties and improve extreme rainfall simulation. [54] conclude that both wet and dry extremes over Africa may be more severe using CPMs than without improved convection processes.

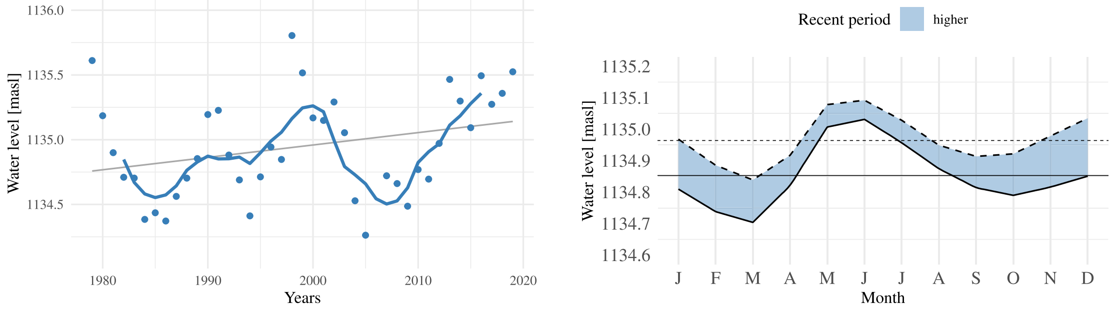


(a) Katonga (b) Nzoia



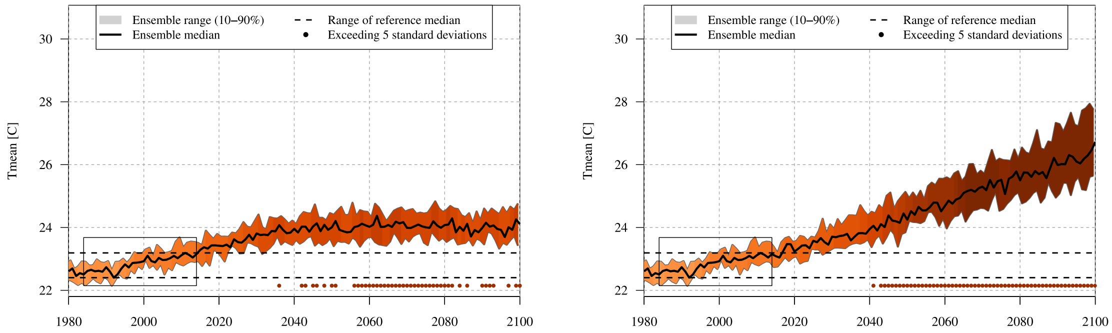
(c) Akagera / Ruvubu (d) Simiyu

Figure B12. Return periods of annual maximal flood peaks $AMAX_{fp}$ after Gumbel extreme value Type 1 distribution (estimated) using W5E5.

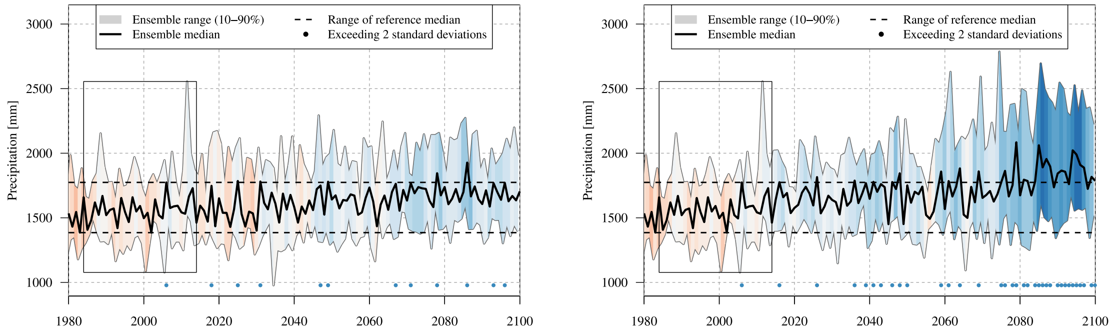


(a) Water level (mean annual) (b) Water level (seasonality)

Figure B13. Annual mean water levels *WL* (left) from 1979–2019 using W5E5. Mean monthly *WL* (right) averaged over the two decades 1980–1999 (D1, solid line) and 2000–2019 (D2, dashed line) using W5E5.

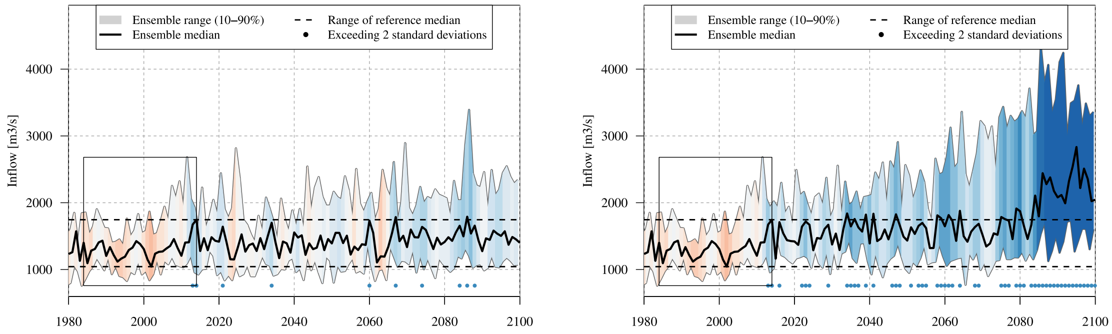


(a) ssp126 (b) ssp370

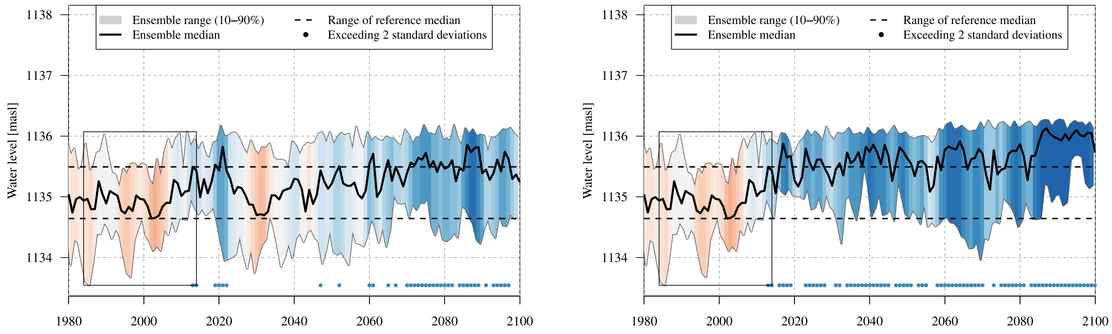


(c) ssp126 (d) ssp370

Figure B14. Annual projections of temperature (top) and rainfall (bottom), 10 ISIMIP3b GCMs.

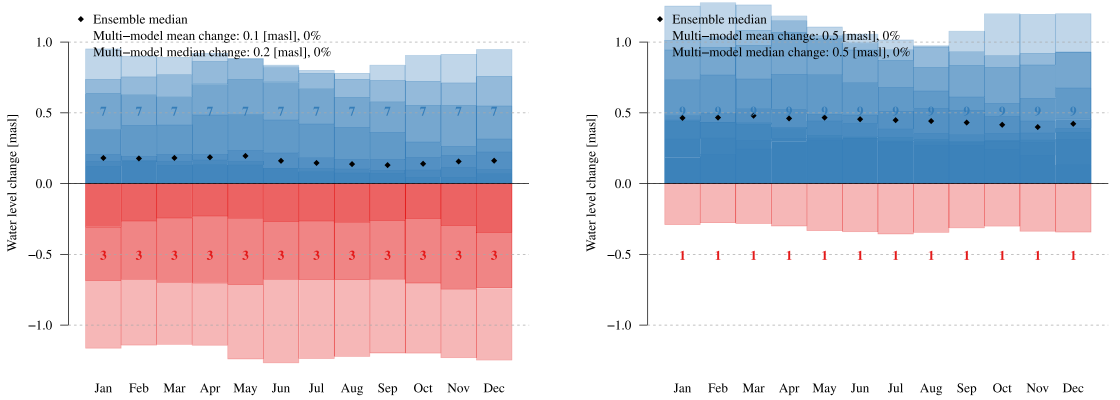


(a) ssp126 (b) ssp370

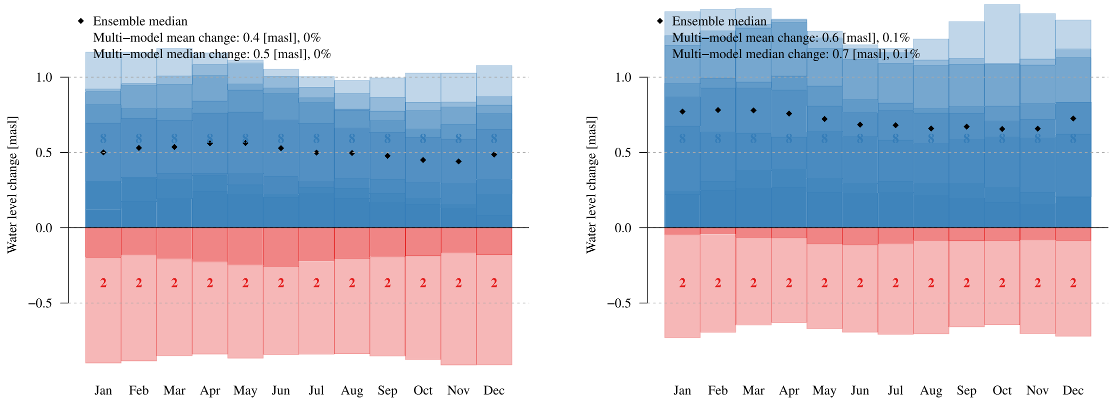


(c) ssp126 (d) ssp370

Figure B15. Annual projections of inflow (top) and water level (bottom), 10 ISIMIP3b GCMs.



(a) ssp126 (2035-2065) (b) ssp370 (2035-2065)



(c) ssp126 (2065-2095) (d) ssp370 (2065-2095)

Figure B16. Monthly projections of water levels, 10 ISIMIP3b GCMs. Blue and red numbers indicate the number of GCMs projecting an increasing or decreasing trend.

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