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Community perceptions of climate change and ecosystem-based adaptation in the mangrove ecosystem of the Rufiji Delta, Tanzania

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ABSTRACT

Mangroves are increasingly recognized for their role in supporting adaptation to climate change and variability. However, knowledge about how climate change and variability affect mangrove ecosystem services (MES) and their role in supporting coastal communities to adaption is limited in Tanzania. We used participatory rural appraisal methods and field observations to explore local communities' perceptions of climate change and variability, and ecosystem-based adaptation (EbA) strategies in the mangroves of the Rufiji Delta, Tanzania. Decrease in rainfall, increased temperatures, coastal flooding, and the incidence of sea level rise were identified as key variables associated with a changing climate in the delta. Perceived climatic stresses included damaged fish breeding sites, altered climate regulation and a decrease in coastal protection and flood control. Decline in crop, fish and honey production were perceived as the main impacts on community livelihoods, although there were significant differences across occupational groups. Dependence on MES in times of shocks, such as when agriculture production fails, switching of occupation, crop diversification, fishing in deep waters and migration to other areas provided potential adaptation options. Although the reported perceptions related to climate change or variability are not explicit, they both have negative consequences to mangrove dependent communities' livelihoods.

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Climate change; mangroves; ecosystem services; ecosystem-based adaptation; Rufiji Delta; Tanzania

1. Introduction

Climate change and variability are increasingly affecting the health of mangrove ecosystems, with impacts that are often experienced at local to regional scales (Mafi-Gholam & Zenner, 2018; Ward et al., 2016). Climatic variables, particularly increased temperature, reduced rainfall (or drier conditions) and sea level rise, have adversely impacted mangroves and continue to jeopardize their species composition, geomorphologic settings and biodiversity (Ellison, 2015; Gilman et al., 2008; Punwong, 2013). Human pressures, including uncontrolled exploitation and land conversions, have also, together with climate change, accelerated the loss of mangroves in many regions globally (Goldberg et al., 2020), and in developing countries in particular (Godoy & De Lacerda, 2015), which in turn adversely impact the livelihoods of coastal communities, who directly or indirectly rely on these ecosystems for their wellbeing (DasGupta & Shaw, 2013; Hochard et al., 2019). Empirical evidence of these impacts includes increased vulnerability of coastal communities to flooding, diminished fisheries and salt water intrusion (Malik et al., 2017; Singh et al., 2019; Uddin et al., 2013). However, climate-related vulnerabilities are often specific to a given place (van der Geest et al., 2019), and varies over time even within relatively small geographic regions (Thomas et al., 2019), depending on the adaptation strategies undertaken by different stakeholders to confront the impacts (Sahoo et al., 2018).

Healthy mangrove ecosystems are increasingly recognized and appreciated as nature-based solutions to adapt to the impacts of climate change and variability through ecosystem-based adaptation (Locatelli, 2016; Nalau et al., 2018). Ecosystem-based adaptation (EbA) is a nature-based approach that reduces the detrimental impacts of climate change to communities through the delivery of multiple benefits that are appreciated as ecosystems services (Munang et al., 2013; Scarano, 2017). For example, promoting mangrove restoration as an EbA approach is not only important for storage of atmospheric carbon and to protect the coastline against erosion (Saroar et al., 2019; Sierra-Correa & Cantera Kintz, 2015) but also to form the basis for livelihood options through provision of vital ecosystem services such as habitat for local fisheries and timber for building (Jones et al., 2020). Empowering local communities and adopting their traditional knowledge also provides an important opportunity for understanding changes in ecosystems and how to adapt to these changes (Reid, 2016). From this perspective, exploring how communities perceive and act in relation to climate variability and change, as well as their aspiration within specified geographical settings, is critical in identifying and confronting

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risks associated with a changing climate (Kupika et al., 2019; Sahoo et al., 2018).

In Tanzania, people in different parts of the country, including those in coastal areas, such as the Rufiji Delta, are increasingly becoming conscious about climate change and have witnessed various risks associated with changes in climate parameters (Ndesanjo et al., 2018; Yanda et al., 2019). However, statistical analysis from empirical evidence indicates that most of these changes, such as increasing or decreasing rainfall patterns that occur in the Rufiji basin region, are due to natural decadal variability in climate variables rather than climate change (Conway et al., 2017; Siderius et al., 2021). For instance, while the annual average temperature in the entire country has risen by almost 1.0°C since 1960 (Kimaro et al., 2018; Magita & Sangeda, 2017) and is expected to rise with 0.8–1.8°C by the 2040s (Conway et al., 2017) and 2–4°C by 2100 (Luhunga et al., 2018), the trends for rainfall in the Rufiji basin is heterogeneous, with dry spells alternating with periods of seasonal extreme precipitation (Conway et al., 2017; Luhunga et al., 2018; Rohli et al., 2019). Still, whether the observed changes in this region are due to a high level of seasonal/decadal variations in climate or climate change, their impact on people's livelihoods and ecosystems remains a matter of concern in the face of changing environmental conditions to which people need to adapt. For example, a recent period of bad years in this region (extreme seasonal droughts and floods) have impacted and will continue to have an adverse impact on farming systems, resulting in stunted growth and reduced yields, which affect peoples' livelihood and wellbeing (Duvail & Hamerlynck, 2007; Tumbo et al., 2015).

The Rufiji Delta is also confronted by a number of non-climatic stressors, including inadequate enforcements of management measures (Mshale et al., 2017), conversion of mangrove areas to other land uses such as rice farming and salt pans (Japhet et al., 2019; Monga et al., 2018), and extensive poverty and illegal exploitation of natural resources (Nyangoko et al., 2021). Thus, mangroves and the ecosystem services they provide are becoming increasingly vulnerable because of increased threats from both climate change and variability and human interventions (Rohli et al., 2019; Wagner & Sallema-Mtui, 2016). Specifically, fisheries in some areas within the delta have declined due to increased degradation of breeding sites, which has been linked to seasonal sea level rise (Ndesanjo et al., 2018; Yanda et al., 2019). Clearing of mangrove areas for rice farming upstream the delta is likely to increase due to the availability of nutrients in mangrove soils (Yanda et al., 2019), and the existence of freshwater flowing towards the northern part of the delta that favour rice farming in mangroves (Mwansasu, 2016). Consequently, the livelihoods of different local resource users, including fishermen, farmers and mangroves cutters, who rely on these resources for their survival (Nyangoko et al., 2021), are affected negatively by the impacts of climate change and variability. In this regard, detailed information about adaptation strategies that could enhance the livelihoods of coastal communities, while sustaining the health of mangrove ecosystems, are warranted for decision making (Wagner & Sallema-Mtui, 2016). Some research on the perceptions of climate change and variability as well as adaptation options have been carried out in coastal areas of Tanzania (e.g. Ndesanjo et al., 2018; Silas et al., 2020; Yanda et al., 2019; Yangaza & Nyomora, 2017), but little is known about the role of mangrove ecosystem services (MES) in helping communities to adapt to the threats of climate change, and how changes in climate variables affect MES. Therefore, this study aimed to explore local communities' perceptions of climate change and variability, and ecosystem-based adaptation (EbA) strategies in the mangrove ecosystem of the Rufiji Delta. Specifically, the study was set to answer the following questions: (i) How do mangrove dependent communities perceive climate change? (ii) Which MES are at risk to the effects of climate change, and how do these impact people's livelihoods? (iii) How do local communities perceive the importance of MES for ecosystem-based adaptation strategies to deal with the impacts of climate change and variability? and (iv) What other community-based measures are employed by the local communities as climate change adaptation strategies?

2. Materials and methods

2.1. Study area

This study was conducted in six villages, of which five are located in the Kibiti District and one (Mohoro) in the Rufiji District, Tanzania (Figure 1). The villages were grouped into two groups. The first group comprised villages distant from the mangroves (DM), which included Mohoro, Mtunda A and Ruaruke Magharibi. The second group comprised villages in close proximity to mangroves (CM), which included Ruma, Mbwera Magharibi and Mbuchi (Nyangoko et al., 2021). The selection of local communities in these villages were based on different reasons. First, there are recent reports (e.g. Ndesanjo et al., 2018; Yanda et al., 2019) which perceived that climate change has begun to affect mangroves and livelihood activities in some places within and around the delta, and it is thus a possibility that these villages may be among those that have experienced impacts of climate change and variability. Second, the local communities display miscellaneous socioeconomic groups, which include farmers, fishers, small business-like food vendors and mangrove cutters, who all rely on mangroves for their livelihoods and thus potentially exhibit different adaptation strategies. The DM villages are characterized by a variety of livelihoods, including farming, small business-like food vending and utilization of both terrestrial/inland forests and mangroves. On the contrary, the CM villages are more connected to rural settings and dominated by mangrove-based livelihoods, which include fishing and collection of poles, firewood and honey (Nyangoko et al., 2021). The delta has the largest mangrove area in Tanzania (Wang et al., 2003), and about 75% of the livelihoods within and around the delta are rooted around MES (Mshale et al., 2017), where people rely on and exploit these services in different ways (Nyangoko et al., 2021). The area experiences temperatures from 25°C to 45°C and rainfalls of 750–1250 mm throughout the year (Mwansasu, 2016). The rainfall pattern in the delta is bimodal, with long rains occurring from February to May and short rains

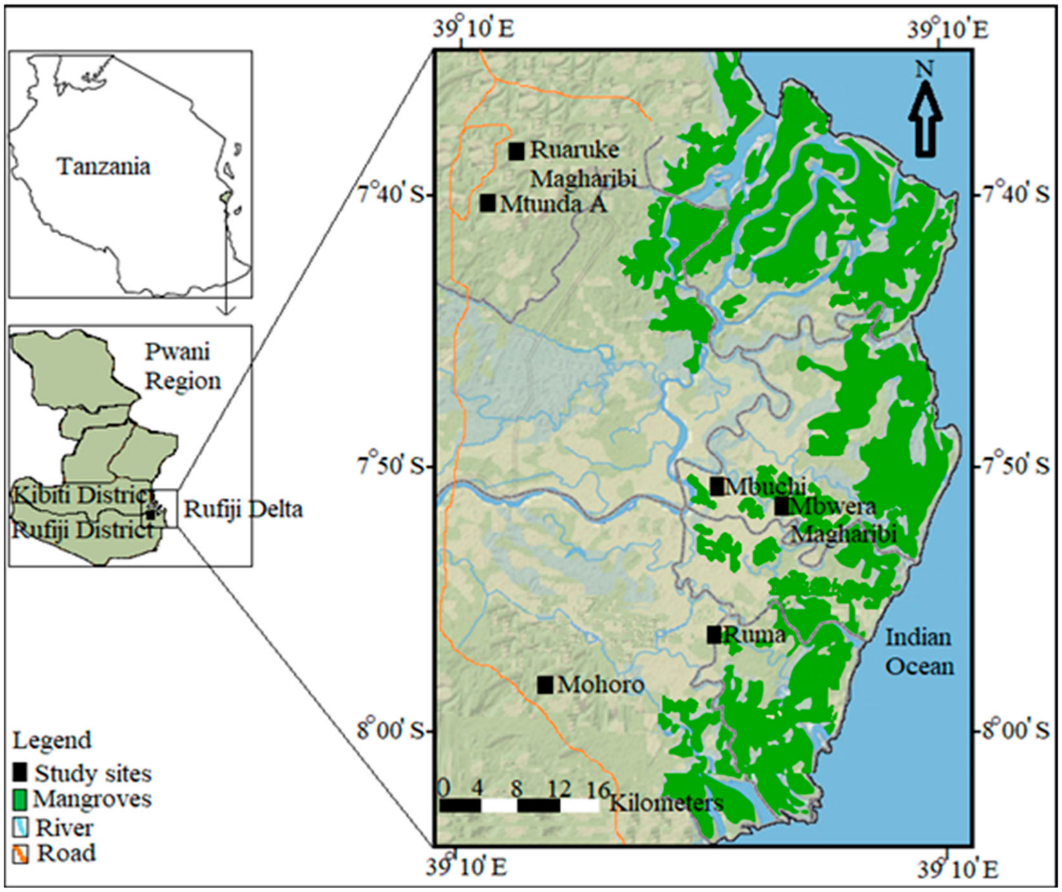

Figure 1. Map of the Rufiji Delta showing the study area and the location of the studied villages (Source: Nyangoko et al., 2021).

from October to December (Japhet et al., 2019). However, the intensity of the typical rainfall pattern is currently inconsistent and unpredictable across the delta (Village leaders, personal communication, 2019). The study area also experiences a hot, dry season, which occurs from June to August (Yanda et al., 2019).

2.2. Research design and data collection

The field work was conducted from early to late December 2019. Prior to the data collection, respondents involved in this study were informed about the purpose of the study and requested for their consent to participate. A 10 years-time frame was adopted, similar to that used by Ameztegui et al. (2018), and a research design of both qualitative and quantitative nature (Ajuang et al., 2016; Nyangoko et al., 2021) was used to collect information on local communities' perceptions of climate change and variability, their impacts on MES and people's wellbeing and adaptation strategies to these changes in mangrove ecosystems of the Rufiji Delta during the last decade (2009–2019). The time frame was selected because between 2009 and 2019, previous studies (e.g. Ellison, 2015; Wagner & Sallema-Mtui, 2016; Yanda et al., 2019) suggested that a perceived change in climate, through sea level rise and irregularity in rainfall patterns together with non-climatic stressors, may have threatened mangrove forests in the delta. During this time, a lot of changes may have happened, which could, in turn, have had influences on local people's perspective about the availability of MES in the face of a changing climate.

2.2.1. Focus group discussions and key informant interviews

In each village, focus group discussions (FGDs), as a qualitative approach, were conducted at the community level, which included a small active group of 5–10 participants of heterogeneous gender and age for convenient discussions as suggested by Hennink (2014). The selected participants comprised of different occupational groups, including farmers, fishers, food vendors, mangrove cutters and livestock keepers, who generally rely on mangroves for their livelihoods. Participants were supposed to have lived in the area for more than 10 years, which is consistent with the suggestion by Mattah et al. (2018) that people interacting with their immediate environment for many years gain experience to identify the changes that occur in their environment and the causes of such changes. Prior to the discussions with the participants, a specific theme on climate change was introduced to the participants by the facilitators to differentiate climate-related stressors from non-climatic stressors. In this study, perceptions of climate change were defined as people's perspectives on local-scale changes in the state of weather-related factors, such as increased temperature, prolonged droughts, sea level rise, changes in precipitation patterns and large floods in a given area over the last decade (Makame & Shackleton, 2020), which if they persist over long periods of time become indications of climate change (Pachauri et al., 2014). After initial introductions, detailed discussions with participants were carried out using a pre-constructed checklist adopted from studies by Ofoegbu et al. (2016) and Sahoo et al. (2018), and modified to meet the objectives of our study. The participants were asked to mention the observed changes in climatic conditions during the last 10 years and narrate the extent of the noticed changes. Observed changes in climatic conditions that occurred over shorter time frames (seasons or a year), when compared to long-term periods (10 years) for the same calendar period, were described as climate variability rather than climate change (Murphy et al., 2010). Participants were also asked to indicate if the observed changes in climatic conditions had an impact on the availability of key MES in their area, and if such impacts had affected their livelihoods. Moreover, they were asked to narrate if MES were important for them to adapt to the impacts of the observed climate change and variability, and what other measures they had applied to deal with the impacts of the observed climate change and variability. As suggested by Nguyen et al. (2013), participants' narratives were also used to identify occupational groups that were more susceptible to risks of climate change and variability. Information from FGDs were supplemented with key informant interviews (KIIs) with 25 people who were: (i) one forest officer in the Kibiti District, (ii) two village elders in each village, (iii) one village leader per village and (iv) one member of existing local management committees in each village.

2.2.2. Household questionnaire survey

Before starting the actual survey with the households, a pilot survey was carried out with a few households to test the relevance and clarity of the questionnaire (Kupika et al., 2019). During the actual survey, the pretested and corrected semi-structured questionnaire was administered to 120 household heads, 20 in each village, and in their absence, any available adult member of the household was interviewed. Household heads were selected because they are primarily responsible for the decision making and socioeconomic well-being of their family (Nyangoko et al., 2021). The questionnaire was adopted from studies of Sahoo et al. (2018) and Kupika et al. (2019), and modified to meet the intended objectives. The perceived change in climatic conditions were assessed using a grading scale, where 1 = no change, 2 = decreasing and 3 = increasing, and the extent of change was examined based on a Likert scale, where 1 = low change, 2 = medium change, 3 = high change and 4 = very high change. Respondents were also asked to compare the effects of climate change and variability on mangrove ecosystems versus other human-caused disturbances, and rate their responses as either negligible, minor, moderate or major. To avoid duplications, the main causes of mangrove degradation and loss in these villages, were taken from a complementary study carried out in 2018, which aimed to explore changes in MES and associated drivers of change in MES from 2008 to 2018 (manuscript submitted to Ocean and Coastal Management for publication). Perceived impact of climate change and variability on MES was determined by 'yes' or 'no' responses, and the extent of the impact was measured on a grading scale, where 1 = low impact, 2 = medium impact, 3 = high impact and 4 = very high impact. Respondents were also asked to rate the impact of climate change and variability on their mangrove-based livelihoods by a grading scale, where 1 = low impact, 2 = medium impact, 3 = high impact and 4 = very high impact. Perceptions of how MES help respondents to adapt to difficult times of climatic stress as a nature-based solution were determined based on predefined statements about potential benefits of mangroves for climate change adaptation, which were identified during a pilot survey. In this regard, respondents were asked to select a statement and rank their responses as either 1 = strongly disagree, 2 = disagree, 3 = agree or 4 = strongly agree per given statement. Furthermore, respondents were given statements that included questions on community-based adaptations strategies, and they were asked to select a statement and rank their responses as strongly disagree, disagree, agree or strongly agree. With the aid from two native residents, particularly in the CM villages, physical visits to mangrove areas and other parts of the studied villages were also carried to gain a better understanding of the real situation on the ground and to verify collected information from the FGDs, KIIs and household surveys.

2.3. Data analysis

Content analysis was used to analyze qualitative information from the FGDs, KIIs and field observations, where the observed themes were translated into the smallest unit of meaningful information, which included issues expressed by respondents in relation to climate change and variability, its impacts and strategies. Information gathered from household surveys were analyzed using SPSS statistical software v. 23. Since there were insignificant differences within both the CM villages and the DM villages, the data of the studied villages were pooled into two groups, including villages distant from mangrove forests (DM) and villages close to mangroves (CM), each with 60 households, to increase statistical strength for an appropriate comparison. One-way ANOVA was used to compare the respondent's perceptions on the extent of climate change and variability, impacts and adaptation strategies.

3. Results

3.1. Household characteristics

Figure 2 summarizes the main characteristics of respondents in the studied communities. The majority of the household respondents (67% in DM and 70% in CM) were male. The study area is endowed with different livelihood sources, where farming was the main economic activity for most respondents in both DM and CM, accounting for 33% of the overall responses. There were also more fishermen and mangrove cutters in the CM villages than in the DM villages. The majority of respondents (43%) had lived in the area for more than 20 years, while only 30% had lived there for less than 20 years (10–15 years).

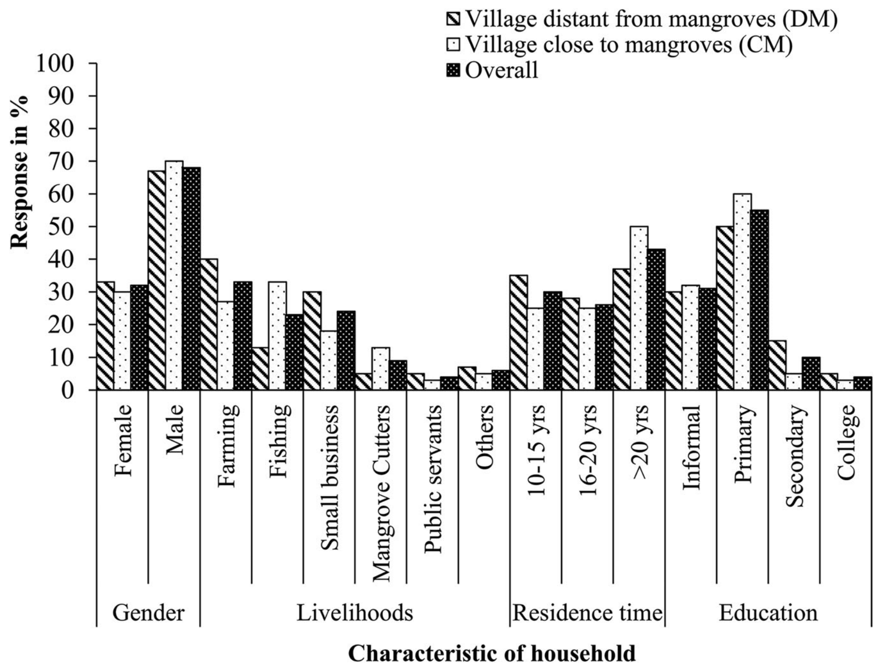

Figure 2. Key socioeconomic and demographic characteristics of households in the study area ($n = 60$ per grouped village).

3.2. Local perception on climate change

Respondents were asked to indicate if they had noticed any unusual changes in climatic conditions, and the extent of observed climate change and variability as perceived by occupation in the study area during the last 10 years is presented in Table 1. There were significant differences in the responses from respondents with different occupations in relation to the perceived extent of change in temperature, amount of rainfall and sea level rise. Farmers and fishermen indicated that they had observed stronger change in many climate variables compared to other occupational groups (Table 1).

3.3. Impacts of climate change on mangrove ecosystem services and livelihoods

The main causes of mangrove degradation and loss in the study area that were identified by respondents during the household questionnaire survey are summarized in Table 2. Illegal harvesting of mangrove poles/timber, rice farming, climate change and inadequate management were cited as the most important causes of mangrove degradation and loss. Respondents were also asked to rate the effects of climate change and variability on mangrove ecosystems versus other human-induced disruptions, where most of the respondents (36%) in the study area indicated that climate change had a moderate impact on the health of mangroves compared to other disturbances from human activities (Figure 3). More MES were felt to be affected by climate change and variability in the CM villages than in the DM villages (Table 3). Habitats for fish (breeding sites), low honey production, climate

Table 2. Causes of mangrove degradation during the last 10 years as perceived by respondents at household level in the study area.

Driver of mangrove degradation	Village distance to mangroves (DM, n = 30)	Village close to mangroves (CM, n = 30)	Overall
	Mean score ± Standard deviation		
Illegal harvesting	3.4^{a} ± 0.7	3.6^{a} ± 0.7	3.5 ± 0.7
Rice farming	3.7^{a} ± 0.5	3.0^{b} ± 1.2	3.3 ± 0.9
Climate change	2.5^{a} ± 0.9	3.2^{b} ± 0.7	2.8 ± 0.8
Inadequate management	2.4^{a} ± 0.5	2.6^{a} ± 0.6	2.5 ± 0.5
Population increase	2.2^{a} ± 0.4	2.4^{a} ± 0.5	2.3 ± 0.4
Pastoralists	2.1^{a} ± 0.5	2.3^{a} ± 0.5	2.2 ± 0.5
Siltation	1.7^{a} ± 0.5	2.4^{b} ± 0.9	2.1 ± 0.7
Invasive species	1.2^{a} ± 0.4	1.8^{a} ± 0.4	1.5 ± 0.4

Note: Means with different superscript letters within rows are significantly different at $P < .05$. Likert score scale: 1 = low importance, 2 = medium importance, 3 = high importance and 4 = very high importance.

Table 1. Perceived extent of climate change and variability during the last 10 years (2009–2019) by occupation in the study area.

Observed change	Farmers (n = 40)	Fishers (n = 28)	Mangrove cutters (n = 11)	Small business (n = 29)	Public servants (n = 5)	Others (n = 7)	Total (n = 120)
	Mean ± Standard deviation						
Increase in temperature	3.5^{a} ± 0.6	3.4^{a} ± 0.7	3.0^{a} ± 0.6	2.1^{b} ± 0.3	1.4^{b} ± 0.4	2.7^{a} ± 0.7	2.7 ± 0.5
Decrease in amount of rains	2.9^{a} ± 0.8	2.6^{a} ± 0.9	2.2^{b} ± 0.5	2.1^{b} ± 0.6	1.8^{b} ± 0.4	2.0^{b} ± 0.5	2.3 ± 0.6
Increase in rainfall intensity	2.3^{a} ± 0.6	2.1^{a} ± 0.5	2.1^{a} ± 0.7	2.0^{a} ± 0.5	2.4^{a} ± 0.6	1.9^{a} ± 0.5	2.1 ± 0.6
Increase in coastal flooding	1.5^{a} ± 0.7	1.6^{a} ± 0.7	1.6^{a} ± 0.8	1.3^{a} ± 0.6	1.6^{a} ± 0.8	1.7^{a} ± 0.8	1.5 ± 0.7
Sea level rise	1.4^{a} ± 0.4	1.9^{b} ± 0.9	1.5^{a} ± 0.5	1.1^{a} ± 0.3	1.0^{a} ± 0.1	1.3^{a} ± 0.1	1.4 ± 0.4
Overall	2.3^{a} ± 0.6	2.3^{a} ± 0.7	2.1^{a} ± 0.7	1.8^{b} ± 0.4	1.7^{b} ± 0.4	1.9^{a} ± 0.6	2.0 ± 0.5

Note: Means with different superscript letters within rows are significantly different at $P < .05$. Likert scale: 1 = low change, 2 = medium change, 3 = high change and 4 = very high change.

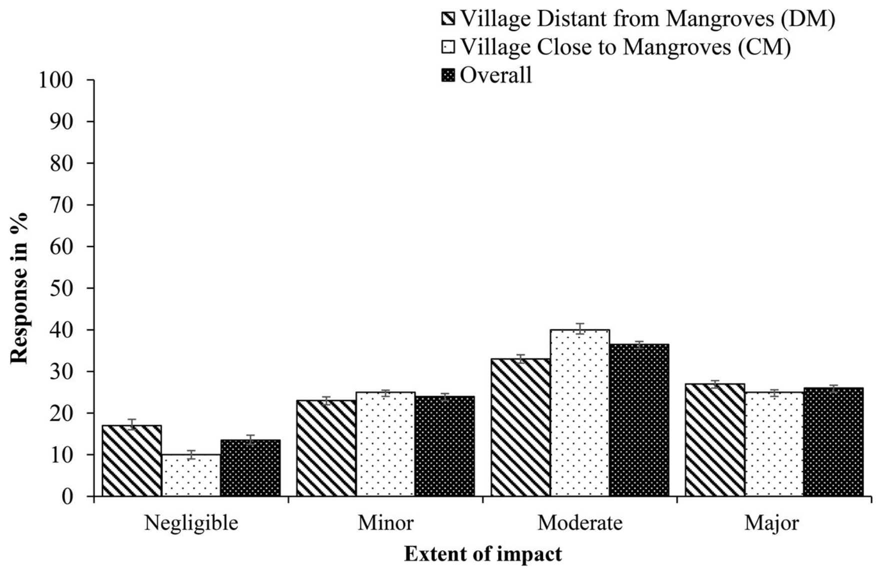

Figure 3. Respondents' perceptions on the extent of mangroves change as a consequence of climate change and variability compared to human interventions during the last 10 years (2009–2019) in the study area ($n = 60$ per grouped village). Error bars represent standard error.

regulation (high temperature and insufficient shading for air cooling) and coastal protection and flood control were perceived to be the most affected MES by climate change and variability (Table 3). Perceived impacts of climate change and variability on mangroves and livelihoods were also supported by narratives from the FGDs and KIIs as expressed in the following testimonies: One of the farmers (women) in DM villages (Mtunda A) said that

> We used to harvest enough rice and maize crops in our farms, but recent drought has resulted in loss of crops, inconsistency in quantity of crop harvested, salt intrusion in traditional wells that supply drinking water, and loss of livestock compared to previous years.

Accordingly, one of the informants (village elder) in the CM villages (Mbwera Magharibi) mentioned that

> increased wave action due to sea level rise has destroyed fish breeding sites in mangroves near river banks, and has resulted in lower fish catch, which is also linked to destructive fishing gear and overfishing along the mangrove swamp and in the Indian Ocean.

Moreover, some of the residents in Mohoro (DM) and CM villages, which are situated close to the Rufiji river, reported seasonal floods that occurred during heavy rains, where one discussant (a fisherman) mentioned that "seasonal coastal flooding, which is directly linked to increased rainfall intensity during the rainy seasons, and river run-off from highlands into

Table 3. Respondents' perceptions on the extent of the impacts of climate change and variability on specific mangrove ecosystem services over the last 10 years (2009-2019) based on household surveys in the study area.

Mangrove ecosystem services	Village distant from mangroves (DM, $n = 60$)	Village close to mangroves (CM, $n = 60$)	Overall
	Mean ± Standard deviation		
Provisioning services			
Low production of honey due to prolonged droughts, which distress wild bees for pollination	3.0 ± 0. 4	3.2 ± 0.3	3.1 ± 0.3
Reduced access to firewood due to mangrove die-off by droughts and illegal harvesting.	2.2 ± 0.7	2.4 ± 0.7	2.3 ± 0.7
Decrease in quality poles due to mangrove die-off by illegal cutting, and drier conditions	2.3 ± 0. 6	2.2 ± 0.5	2.2 ± 0.5
Fodder depletion as a result of mangrove dieback caused by a general change in climate (drier conditions)	1.6 ± 0.2	1.8 ± 0.3	1.7 ± 0.2
Less suitable traditional medicines a result of the declined rain and overuse of mangrove species (*Avicennia marina*)	1.2 ± 0.5	1.4 ± 0.4	1.3 ± 0.4
Regulating services			
Climate regulation (decreased cooling of the air due to mangrove degradation)	2.7 ± 0.3	3.3 ± 0.3	3.0 ± 0.3
Decrease in coastal protection and flood control due to mangrove degradation, and increased wave activity	2.4^a ± 0.8	3.3^b ±0.5	2.8 ± 0.6
Cultural services			
Damage to natural beauty due to overharvesting of mangroves and drier conditions	2.2 ± 0.6	2.5 ± 0.6	2.3 ± 0.6
Decline in spiritual belief due to destruction of mangroves by both climatic and non-climatic stress	1.3 ± 0.2	1.5 ± 0.3	1.3 ± 0.2
Supporting services			
Damage to fish breading sites due to sea levels rise and wave activity, and other non-climatic stressors	3.2^a ± 0.1	3.8^b ± 0. 4	3.5 ± 0.2

Note: Means with different superscript letters within rows are significantly different at $P < .05$. Likert scale: 1 = low impacted 2 = medium impacted 3 = high impacted and 4 = very high impacted.

Table 4. Perceived impact of climate change and variability on mangrove-based livelihoods during the last 10 years (2009–2019) by occupations in the study area.

Observed impacts	Farmers ($n = 40$)	Fishers ($n = 28$)	Mangrove cutters ($n = 11$)	Small business ($n = 29$)	Public servants ($n = 5$)	Others ($n = 7$)	Total ($n = 120$)
	Mean ± Standard deviation						
Decline in rice yields due to decreased rains	$3.8^{a} \pm 0.6$	$3.6^{a} \pm 0.6$	$3.5^{a} \pm 0.5$	$2.3^{b} \pm 0.3$	$2.6^{b} \pm 0.4$	$3.0^{b} \pm 0.3$	3.1 ± 0.4
Reduced fish yields due to destruction of habitats for fish by sea level rise, and other non-climatic stressors	$3.5^{a} \pm 0.\ 3$	$3.8^{a} \pm 0.4$	$2.8^{b} \pm 0.7$	$2.2^{b} \pm 0.6$	$2.2^{b} \pm 0.6$	$2.6^{b} \pm 0.7$	2.8 ± 0.5
Low production of honey due to prolonged droughts, which distress wild bees for pollination	2.4 ± 0.9	2.2 ± 0.8	2.5 ± 0.8	2.4 ± 0.8	2.2 ± 0.7	2.0 ± 0.7	2.3 ± 0.8
Depletion of firewood for cooking due to mangrove die-off by both climate change (dry spell), illegal harvesting and population growth.	$2.4^{a} \pm 0.5$	$2.6^{a} \pm 0.4$	$2.2^{a} \pm 0.4$	$1.9^{b} \pm 0.2$	$1.0^{c} \pm 0.0$	$2.3^{ab} \pm 0.3$	2.1 ± 0.3
Damage of house and property due to flooding	$2.3^{a} \pm 0.6$	$2.4^{a} \pm 0.6$	$1.9^{a} \pm 0.5$	$1.8^{b} \pm 0.1$	$1.0^{c} \pm 0.0$	$1.6^{b} \pm 0.2$	1.8 ± 0.3
Overall	2.8 ± 0.6	2.9 ± 0.6	2.5 ± 0.6	2.1 ± 0.4	1.8 ± 0.3	2.4 ± 0.4	2.4 ± 0.5

Note: Means with different superscript letters within rows are significantly different at $P < .05$. Likert scale: 1 = low impact, 2 = medium impact, 3 = high impact and 4 = very high impact.

the delta have damaged our house and resulted in loss of some property including livestock (chicken)". The impacts of climate change and variability on mangrove-based livelihoods by occupation in the study area are summarized in Table 4. Farming and fishing were perceived to be the most impacted livelihood occupations.

3.4. The importance of MES for ecosystem-based adaptation strategies to climatic impacts

The use of MES were reported by the respondents as a way of adapting to the perceived impacts associated with climate change and variability in the study area during the last 10 years (Table 5). Among the identified uses of MES, food security, local climate regulation and coastal protection were scored as the most important roles of mangroves in facilitating communities to adapt to the impact of climatic change and variability (Table 5). Some respondents mentioned that they engaged in rice farming in mangrove areas during prolonged dry spells, as the conditions were more favourable in the mangrove areas than in upland areas during these times (Table 5). Moreover, some respondents in the study area mentioned that mangrove stores carbon and thereby reduce adverse effects of climate variability, a service that was not identified in Nyangoko et al. (2021). The reason for this could be due to recent awareness raised by a non-government organization (Wetland International) in partnership with researchers from the Institute of Marine Sciences (University of Dar es Salaam) about the value of mangrove blue carbon sequestration. However, the majority of respondents during the FGDs and KIIs reported that government-led conservation efforts to protect and restore degraded mangroves and their associated services for EbA in the study area are not efficiently implemented and often do not conform to the community's preferences for species to be planted and restoration sites. Narratives from participants in the DM (Mohoro) during FGDs elucidated that

> the existing management committees in the delta such as Village Natural Resources Committees (VNRCs) and Beach Management Units (BMUs) are still incapable of effectively enforcing management measures that could reduce persistent mangrove degradation, partly due to social ties, inadequate management and conflict resolution skills.

3.5. Community-based measures to climate variability

The identified community-based measures to deal with impacts associated with climate change and variability as perceived by the communities in the study area are presented in Table 6. Switching of occupations and crop diversification were the most preferred human-made adaptation measures for the majority of the respondents in the study area, although the perceptions differed between occupations and households (Table 6). These adaptation measures were also highlighted during the FGDs and KIIs in the study area, where one of the participants (farmer) in the DM villages (Mohoro) said that "despite farming being my primary source of income, I have been engaged in fishing for some years (2009-2019), as a response to the recent loss of rice and maize crops caused by drought, which was

Table 5. Perceived importance of MES for EbA to impacts from climate change and variability during the last 10 years in the study area.

Perceived benefits	Village distant from mangroves (DM, $n = 60$)	Village close to mangroves (CM, $n = 60$)	Overall
	Mean ± Standard deviation		
Mangroves provide food security (fish and honey) that are used for subsistence and income source during decreased crops yield.	$3.4^{a} \pm 0.8$	$3.7^{b} \pm 0.5$	3.5 ± 0.6
Mangroves provide shade, influence rainfall and cool temperature (climate regulation).	$3.2^{a} \pm 0.4$	$3.5^{a} \pm 0.3$	3.3 ± 0.3
Mangroves provide coastal protection and protect lives from flooding caused by intense rains.	$2.4^{a} \pm 0.\ 6$	$2.9^{b} \pm 0.2$	2.6 ± 0.4
Flooded alluvial soils in mangrove areas provide suitable site for rice farming in case of increased temperature and drought in upland areas.	$2.6^{a} \pm 0.\ 5$	$2.2^{b} \pm 0.3$	2.4 ± 0.4
Mangrove store carbon to reduce climate change	$2.3^{a} \pm 0.6$	$2.5^{a} \pm 0.6$	2.4 ± 0.6
Mangrove poles and firewood are used as source of additional income in times of difficulty, such as when agriculture production fails.	$1.2^{a} \pm 0.9$	$2.4^{b} \pm 0.5$	1.8 ± 0.7

Note: Means with different superscript letters within rows are significantly different at $P < .05$. Likert scale: 1 = strongly disagree, 2 = disagree, 3 = agree and 4 = strongly agree

Table 6. Respondents' perceptions on community-based adaptation measures to climate change and variability by different occupations in the study area during the last 10 years according to household surveys.

Strategies	Farmers (n = 40)	Fishers (n = 28)	Mangrove cutters (n = 11)	Small business (n = 29)	Public servants (n = 5)	Others (n = 7)	Total (n = 120)
	Mean ± Standard deviation						
Switching occupations	$3.5^{a} \pm 0.7$	$3.7^{a} \pm 0.6$	$3.2^{a} \pm 0.6$	$2.9^{a} \pm 0.7$	$1.8^{b} \pm 0.3$	$3.2^{a} \pm 0.7$	3.1 ± 0.6
Crop diversification	$3.9^{a} \pm 0.2$	$3.4^{b} \pm 0.8$	$3.1^{b} \pm 0.7$	$3.1^{b} \pm 0.6$	$2.0^{c} \pm 0.5$	$3.0^{c} \pm 0.4$	2.9 ± 0.6
Migration to other areas	$2.8^{a} \pm 0.3$	$3.5^{b} \pm 0.5$	$1.7^{c} \pm 0.6$	$2.4^{a} \pm 0.4$	$1.0^{c} \pm 0.7$	$2.2^{b} \pm 0.6$	2.3 ± 0.6
Farming in other regions outside the delta	$3.4^{a} \pm 0.4$	$3.0^{a} \pm 0.3$	$2.0^{b} \pm 0.6$	$2.0^{b} \pm 0.8$	$1.0^{b} \pm 0.7$	$2.0^{b} \pm 0.6$	2.2 ± 0.5
Fishing in the deep sea	$2.3^{a} \pm 0.6$	$2.6^{b} \pm 0.3$	$2.0^{c} \pm 0.7$	$2.0^{c} \pm 0.8$	$1.0^{c} \pm 0.8$	$2.0^{c} \pm 0.8$	2.0 ± 0.7
Remittance from relative in other towns	$2.3^{a} \pm 0.4$	$2.5^{a} \pm 0.5$	$2.4^{a} \pm 0.4$	$2.3^{a} \pm 0.5$	$1.2^{b} \pm 0.7$	$1.4^{b} \pm 0.6$	2.0 ± 0.5

Note: Means with different superscript letters within rows are significantly different at $P < .05$. Likert scale: 1 = strongly disagree, 2 = disagree, 3 = agree and 4 = strongly agree.

rare in previous years". Another discussant (fisher) in the CM villages (Mbwera Magharibi) commented that

> increased habitat degradation had caused changes in the delta's ecology, which has resulted in reduced fish catches and the migration of large fish into the Indian Ocean, and some of us have switched from fishing in mangrove swamps to deep sea fishing as a means of dealing with the dwindling fish stocks caused by climate change despite lack of fishing facilities.

One of the women in the CM villages (Ruma) during the KIIs said that

> We are now harvesting less than half of the yield we were harvesting from the same piece of land a few years ago, and because most of us are poor and cannot afford to buy maize floor, farming in other places where we have relatives (e.g. Utete, Katavi, and Mtwara) provided us with food security during hard times of unfavorable dry spell in the delta.

Moreover, she went on to say that "due to recent unpredictable rainfall for farming, our men migrate to nearby towns (Kibiti or Utete) or even a distant big city, like Dar es Salaam, to look for jobs and when they succeed, they send us money to buy food and other needs for the family".

4. Discussions

4.1. Perceived climate change and variability

This study aimed to explore local communities' perceptions of climate change and variability, its impact on MES and people's wellbeing and ecosystem-based adaption strategies to deal with these impacts in the Rufiji Delta, Tanzania. Some of the changes perceived by local communities may have been more associated with climate variability than climate change, as the respondents revealed that most of the observed changes had occurred over shorter time periods (e.g. seasons or 1–2 years). Still, perceptions of decrease in rainfall and increase in temperature, as revealed in this study, are consistent with empirical evidence that coastal areas of Tanzania are experiencing higher temperatures and strong decadal variability of rainfall with a declining trend (Kabanda, 2018; Kashaigili et al., 2014; Makame & Shackleton, 2020), which although statistically insignificant (Borhara et al., 2020; Mahongo & Francis, 2012), could bring about long-term shifts in average weather conditions in the future. Thus, fluctuations in seasonal or annual rainfall, temperature and floods, which control many biogeochemical processes in the delta have led to inconsistency in crop production, with higher crop yields during periods of increased rain and lower crop yields and losses of crops during periods of decreased rain. This concurs with previous studies by Saronga et al. (2016) and Yanda et al. (2019), who reported declines in crop yields due to perceived decreases in rains. This implies that the studied communities' livelihoods are closely linked to local environmental conditions, and that even small climate variabilities rather than climate change, could have a negative impact on their livelihoods. This is felt stronger by farmers and fishers compared to small businessmen and public servants, whose livelihoods are less reliant on the weather. The observed decrease in flooding was linked to respondents' proximity to the river estuary, with some residents living near the river estuary (CM villages and Mohoro (DM)) feeling more vulnerable to increased flooding caused by seasonal variation in run-off from uplands compared to the majority of DM residents (Mtunda A and Ruaruke Magharibi) who live distant from the river. The perceived sea level rise, reported in this study, attributed to the respondents' local knowledge from working in coastal areas, including mangrove swamps, is consistent to empirical observations in some parts of the western Indian Ocean region (Ellison, 2015; Mahongo, 2009; Punwong, 2013). This observation, however, more likely reflects inter-annual and decadal fluctuations than long-term trends from climate change (Mahongo, 2009).

4.2. Impacts of change and climate variability on mangrove ecosystem services and livelihoods

Forest ecosystems and their associated services are becoming more widely recognized as an important way to adapt to climate change and variability, but they are also impacted by changing climatic conditions, which need to be accounted for when relying on MES for ecosystem-based adaptation strategies (Locatelli, 2016). Respondents perceived that climate change and variability had to some extent, impacted the availability of key MES (Table 5), which in turn had consequences for local people's livelihoods and options to adapt to changing environmental conditions. Habitats for fish was, for example, perceived to be at risk. This was seen as a serious threat by primarily fishermen, because fishing comprises a critical part of their income and livelihoods. This is in line with the finding of Akinbile et al. (2018), who noted that people often feel more vulnerable to the impact of climate change and variability when it impacts directly on their livelihoods, upon which they rely on for sustenance. A previous study in the Rufiji Delta found out that sea level fluctuations and changes, through wave action and erosion, destroy mangroves, which serve as important breeding and nursery grounds for fish and crabs, resulting in lower fish catches (Yanda et al., 2019). However, in the present study, surveyed communities in the CM villages also stated that fish catches had been declining not only as a result of climate variability but also due to an overexploitation of these resources, and climate change and variability is often adding an extra pressure on MES, which already are under high pressure. Moreover, seasonal decreases in rainfall and increases in temperature over an extended period of time affect water availability, and hence negatively impact natural resources and water-dependent economic activities such as agriculture (Misra, 2014).

The results of the FGDs showed that in the past years, mangrove forests were tall and dense and provided more shade that cooled the local environment, but due to recent prolonged dry spells, sea level rise and other non-climatic related stressors, mangroves are dying and are no longer as suitable to provide sufficient cool air as in the past. This supports the idea that well managed natural forests act as "air conditioners" and help to reduce the high temperature by providing cooler environments through shading (Lee et al., 2018). The impact of climate change and variability on honey production observed in this study is consistent with the findings of Schweitzer et al. (2013), who found that increased temperature impacts on the development of bee colonies and their life cycle, resulting into lower production of honey. As bees are important pollinators, it is possible that a declined pollination could lead to decreased crop yields. Ofoegbu et al. (2016) reported that the decline of building material and firewood are potential risks caused by climate change and variability, which is in line with the findings of this study. Respondents also felt that the high demand of mangrove resources such as poles, timber and firewood both within and outside the delta is also associated with recent population growth, which has resulted in overharvesting and a decrease in the availability of MES. However, Mwansasu (2016) found that population expansion cannot be blamed for mangrove deterioration in the delta, and that it is more linked to ineffective management practices that have led to illegal exploitation and overharvesting. The differences in the perceived impact of climate change and variability on MES revealed in this study seemed to be partly linked to the location of the studied communities and partly to the stakeholders' occupation, as discussed above. Communities living in close proximity to natural resources often have good local knowledge about environmental changes and impacts of such changes due to their reliance on natural resources for their livelihoods and well-being (Kamwi et al., 2015). For example, the majority of the local people in the CM villages, living close to the Rufiji River, reported the occurrence of coastal flooding, while only a few households in the DM (Mohoro), located further away from the river, reported such incidences. The CM villages also rated the impacts from climate variability on MES higher than those from the DM villages, probably because they were more dependent on these MES and thus more aware of their status and change.

4.3. Ecosystem-based adaptation and community's response to impacts of climate change

The study shows that communities rely on MES in dealing with climatic stress, such as when agricultural production is hampered by dry spells or during seasonal coastal flooding. Local communities indicated that they utilized mangrove resources for subsidence needs and to supplement their income, while still engaging in other economic activities. The use of MES for EbA was identified as more important by the respondents from the CM village than by the respondents from the DM villages, due to their close contact with mangroves. The majority of the communities in the CM and Mohoro village had experienced seasonal flooding due to the overflow of the Rufiji River (Nyangoko et al., 2021), and thus they acknowledged the importance of mangroves in protecting their homes and lives from seasonal flooding.

Generally, the use of MES as an EbA strategy to adapt to risks associated with climate change and variability revealed in this study aligns with Pramova et al. (2012) and Pearson et al. (2020), both of whom explored the role of forest ecosystems for community adaptation to climate change and variability. The result of the FGDs and KIIs, however, revealed that a high dependency on mangrove resources can also contribute to a decline of mangrove forests, thereby decreasing the capacity of mangroves to provide alternative livelihoods. One of the elders in the CM villages narrated that "illegal activities such as charcoal making and mangrove cutting that are practiced by few households to cope with difficult times of drought and fish decline are not sustainable and can lead to mangrove loss". Moreover, one of the women in the DM villages (Ruaruke Magharibi) revealed that rice farming in the delta could be sustainable if it is limited to mangrove areas that have already been cleared (i.e. old rice farms), but expanding new farms by clearing mangrove area, which was practiced by some farmers, causes mangrove degradation. It was surprising that, while the government recently imposed a ban on the use of mangrove resources, the majority of the communities, especially in the CM villages, felt that existing management measures were not adequately enforced due to close social ties between residents and members of local management committees, and the introduced ban was not fully working because mangroves are an important part of their livelihoods. Thus, some of the residents both within and outside the delta were still associated with the illegal exploitation of mangroves to enhance their household welfare. This implies that the threats to MES in the Rufiji Delta are associated with many factors apart from climate change and variability (Table 2), with illegal harvesting of mangrove resources and rice farming being the major driver of degradation. Rice farming in the Rufiji Delta is mainly linked with shifted patterns of freshwater flow from the southern Delta to the northern block (Mwansasu, 2016), and thus some residents in the northern block (Mtunda A and Ruaruke Magharibi) have taken advantage of freshwater and engaged in rice farming in mangrove areas, compared to some respondents in CM village (central and southern blocks).

In relation to community-based measures as a way to adapt to climate change and variability, changing of occupation was commonly considered by households. Many of the respondents in the study area agreed that their experiences and observations of a changing climate had led them to switch occupation, such that fishers become bodaboda (motorcycle riders) to transport passengers as means of generating income, or farmers becoming mangrove cutters or tailors. Crop diversification through the planting of crops that are resistant to drought was also perceived to provide an opportunity for adaptation to the stress of decreased rain. This is consistent with the findings of Saalu et al. (2020), who found that forest-dependent communities cultivated drought-tolerant crops as a means of coping with the seasonal dry spells. However, during the FGDs, most of the participants revealed that they had inadequate knowledge about suitable crops that are drought-tolerant and economically viable, and also did not have good access to these crops or agricultural extension agents. Some farmers and fishers also said that they temporarily moved to other areas to search for alternative livelihoods, and some fishers travelled long distances to fish in the deep sea. These findings are in line with Yanda et al. (2019), who also found that dwindling near-shore fish stocks, as a result of climate variability and overfishing, enticed fishermen to pursue deep sea fishing, despite their insufficient fishing equipment. However, it should be noted that, most fishers misinterpreted the term “deep sea fishing” as they intended to mean fishing near-shore water away from the coastal areas but within the continental shelf (shallow water), using small-sized vessels and gears such as small boats, dhows, and canoes, and not fishing in the open deep ocean. Remittance transfer as a human response to various threats, including climate variability, was also reported by Maharjan et al. (2020), which is consistent with the findings of this study.

Although MES may provide local relevant means for ecosystem-based adaptation to climate change and variability, high reliance on mangrove resources can also lead to mangrove degradation if the use of mangrove is not well managed in close collaboration with local stakeholders. For example, despite a government ban on all mangrove forests in 1987, to allow for mangrove inventory and the preparation of a national mangrove management plan in Tanzania (Semesi, 1992), illegal harvesting persisted, and the ban measure failed due to ineffective enforcement and insensitivity of community rights to access mangrove resources (Mangora, 2011; Mshale et al., 2017; Von Mitzlaff, 1989). Likewise, the ban on mangrove harvesting, which was re-introduced in 2016, outraged a large portion of the delta’s households that are most reliant on MES for their well-being (Nyangoko et al., 2021). As a result, there is still some ongoing illegal harvesting of mangrove resources because many people in and around the delta depend on mangroves and their related activities for employment and income generation. This calls for the government to rethink its management measures and reduce the period of the ban. Promotion of feasible alternative livelihoods and appropriate interventions that could reduce threats to mangroves and help people to adapt to climate variability and non-climatic stressors are warranted. Since the majority of residents in the DM villages are rain-fed farmers and small business operators, improved technology for maize production through irrigation, provision of fertilizers and quality seed in the upland areas could provide potential options to improve livelihoods in these villages. In line with this, a study on comparisons of cost to income ratio between rice farming and farming of other crops should be conducted to see how farmers could switch to other crops that could guarantee them a better income while protecting mangroves. Moreover, despite the perceived decrease in honey production revealed in this study, the KIIs showed that the potential for beekeeping in the Rufiji Delta has not been fully utilized, and it has the potential to improve livelihoods, especially in villages near mangrove forests (CM). However, these kinds of alternative livelihoods need support in terms of modern hives, adequate capacity building and sufficient market for bee-products. Weak follow-up, unreliable markets and an over-reliance on local hives, were cited by one of the participants in Ruma village as failures for the past pilot study on beekeeping in the delta. Existing VICOBAs (Village Community Banks for Local Groups) in the CM villages should be strengthened by providing capital and raising awareness among group members. This could assist fishermen in the CM villages in purchasing deep sea fishing equipment and reduce their dependence on mangroves. Furthermore, since some of the women and men during the FGDs in the CM villages mentioned that they make mats and baskets, improvements in rural-to-urban infrastructure (roads) could increase their income by allowing them to take their products to the market (town), and hence reducing the pressure on mangroves.

5. Conclusions

This study explored local communities’ perceptions of climate change and variability, its impact on MES and people’s well-being, and means to adapt to these impacts in the Rufiji Delta. Local communities commonly perceived a decrease in rainfall and an increase in temperature during the last decade (2009–2019). Perceived influences of climate change on MES included damage to fish nursery and breeding sites, low honey production, local climate regulation (insufficient shading for air cooling) and a decrease in coastal protection and flood control. Decline in crop yields, reduced fish yields, and decline in honey production were generally perceived as the main impacts of climate change and variability on livelihoods by mangrove dependent communities, although the perceptions differed significantly across occupational groups. Reliance of local people on MES, switching of occupation, crop diversification, fishing in deep water and migration to other areas were cited as the most important adaptation strategies. Relying only on MES for ecosystem-based adaptation could lead to destructive exploitation of mangrove resources. Hence, ecosystem-based adaptation and human-made measures should not be promoted in isolation but in a complementary and sustainable way. We conclude that, although it is difficult to know if people’s perceptions are related to climate change or climate variability, both have negative consequences for local people’s livelihoods and wellbeing and healthy mangroves and their associated services are important for people to adapt to these and other environmental changes. Relocating farming areas from the delta to upstream floodplain areas through the promotion of small-scale modern irrigation farming methods is recommended as a potential option for reducing mangrove degradation and dealing with climate variability and an escalating future climate change. To accomplish this, further research on the farmers’ perspective on land relocation is needed, considering factors such as where to farm, land availability and access rights, farming style, willingness of other stakeholders (private sector, non-governmental organizations) to collaborate with the government in supporting farming initiatives and which farmers to relocate first and reasons for such consideration. Accordingly, provisions of soft loans to individual fishermen through regular monitoring could provide an opportunity for further offshore fishing and to reduce community vulnerability to risks of declining coastal fisheries. Further research on long-term climate modelling is also needed to analyze and verify the perceived impacts of climate change and variability on mangroves and associated services, as revealed in this study.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author, [BPN]. The data are not publicly available to respect the privacy of the responding communities.

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