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Vulnerability Assessment in African Villages under Conditions of Land Use and Climate Change: Case Studies from Mkomazi and Keiskamma

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Abstract: While most climate change vulnerability assessments focus on regional or city-levels, this paper studies villages and their different forms of vulnerability vis-à-vis climate change. In the African context, the village level proves to be central for land-use related decision-making given the traditional role of village communities. The paper analyses two different regions, namely the Mkomazi Water Basin in Tanzania and the Keiskamma River Catchment in South Africa. Due to the differing roles of agriculture, income sources and village structures, we developed and applied specific vulnerability indicators in the different regions. In both regions, we harness the Socio-Ecological Systems Framework to study explanatory factors for the variation in vulnerability between villages. In doing so, vulnerability has been found to be determined by an aggregate of ecological factors including water availability and soil depletion and social determinants including conflicts, strength of institutions and leadership as well as knowledge. Climate-change related factors play a role with regard to rainfall frequency and quantities, but need to be analysed together with other drivers of change, including population dynamics and migration. Our comparative conclusions focus on the need for explicit and clear institutional structures, legitimized leadership and good knowledge about land use options and their consequences.

Keywords: vulnerability assessment; climate change adaptation; agricultural production; communities; governance; socio-ecological systems

1. Introduction

For more than 50 years, vulnerability assessments (VA) have been in use in a number of fields, including famine and food security, ecology, business, security, disaster management and systems analysis. Mounting evidence for climate change led to a large number of climate change vulnerability assessments that specifically consider climate as the driving agent of change. While the reports of the Intergovernmental Panel on Climate Change contributed to establish an understanding of exposure, sensitivity and adaptive capacity as three key determinants of climate change related vulnerability [1] (p. 995), debates continue about methods and implementations of vulnerability assessments (e.g., [2–7]).

Although there is a "shift from estimating expected damages to attempting to reduce them" [8] (p. 301), researchers have expressed concerns that vulnerability research on climate change stays behind its potential to adequately inform and prepare decision makers for the challenges of adaptation to climate change [9]. To date, scientific assessments of climate change impacts, vulnerability and adaptation options have focused more on specific impacts than on adaptation options [10]. Vulnerability assessments often neglect adaptive capacities in social systems [11] and thus are often of little use for decision makers given the lack of information on how to reduce the vulnerabilities.

One particular field of interest in the context of climate change vulnerabilities relates to agriculture, food production and food security in contexts of developing countries. High levels of vulnerability are detected in particular for African agricultural systems [12]. Only selected studies in this field use the concepts exposure, sensitivity and adaptive capacity to assess vulnerabilities (e.g., [7,13–16]). Much of the work in this field struggles with this threefold definition of vulnerability since its categories are theoretically vague and require further specification to render them accessible for empirical research.

Therefore, many studies on climate change, agriculture and food security in developing contexts integrate other conceptual frameworks to analyse vulnerability. Three research traditions are most relevant in this respect. First, research on climate change and food security [17] provides a sound understanding of important climatic stressors for food production and food security (e.g., changes in rainfall). Second, livelihood and poverty research [18] focuses more on the economic and social drivers of vulnerability mainly at the household level. In climate change literature, poverty and poverty reduction research has often applied an economic lens by focusing on income per capita [18], reflecting various growth and development discourses [19,20]. But studies in this research field (mainly in livelihood research) increasingly address inequalities between different social groups, uneven power structures and ineffective governance institutions (e.g., [21–23]). Third, research on vulnerability of social-ecological systems (SES) focuses on social institutions such as governance systems even stronger and tries to address social and ecological determinants of vulnerability equally [4,24,25].

Acknowledging the co-existence and interaction of multiple vulnerability determinants at the level of rural communities in Africa, our objective in this paper is to learn from all three approaches but focus on a vulnerability analysis within a SES framework [24,26–28]. We adopt an assessment approach suited for rural agricultural and developing contexts with a particular focus on African villages. The research questions of the paper therefore are: (i) How can vulnerability of African villages be described and analysed using a SES framework? (ii) Which factors determine the vulnerability of African villages and what are the specific contributions from climate change impacts and land use change? (iii) How can these vulnerability determinants be addressed to reduce vulnerabilities?

We first explicate the SES framework approach we chose and its application to villages in two African regions (Section 2). By analysing two very different case study regions with the same SES framework we can show which concepts are applicable and which factors are influential in different SES and which concepts or factors are specific to a SES. In the subsequent sections, we analyse the case of the Mkomazi River Basin in Tanzania (Section 3) and the Keiskamma River Catchment in South Africa (Section 4) with regard to their vulnerability and potential social and ecological causes. Due to the differences between the social-ecological systems in Mkomazi and Keiskamma and different data availabilities case specific methods for assessing vulnerability and identifying vulnerability determinants had to be applied in the two cases. Section 5 provides a comparative discussion of the findings in the two cases, before Section 6 draws conclusions, also for future research.

2. Conceptual Framework

Of the available SES frameworks [29], we selected the *General Framework for Analysing Sustainability of Social-Ecological Systems* by Ostrom [27] (see Figure 1) because it provides "a common language for case comparison for organizing the many variables relevant in the analysis of SES into a multitier hierarchy" [29]. It integrates well natural and social science perspectives and allows developing a set of determinants of vulnerability that can be addressed in strategies for vulnerability reduction.

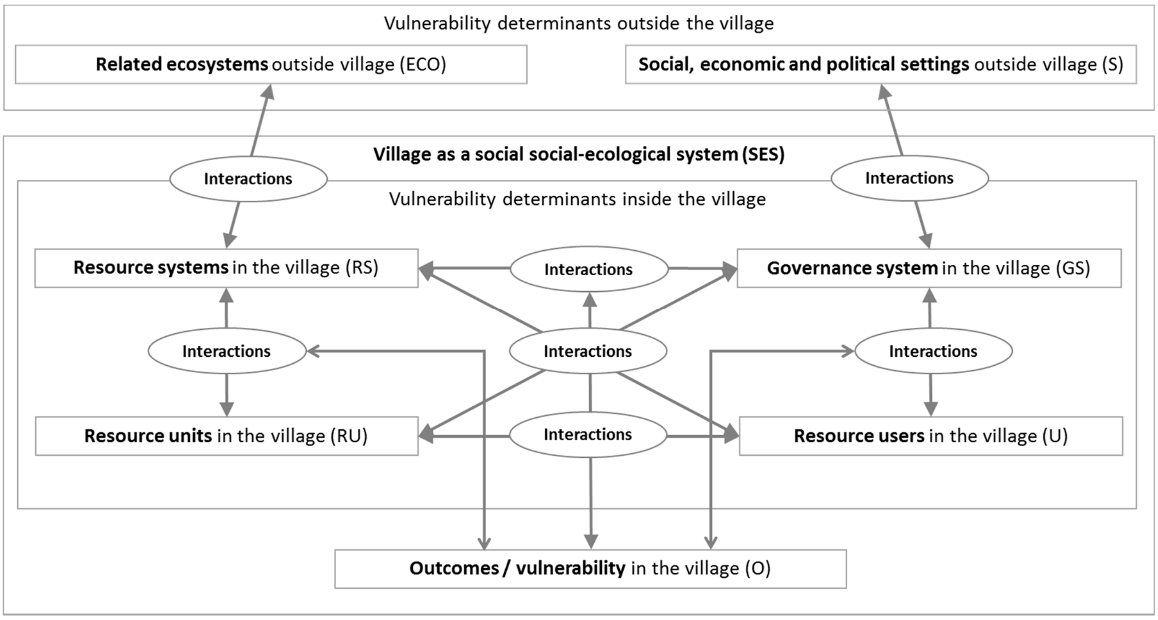

Figure 1. Application of the Ostrom framework to vulnerability assessments in villages. There are two types of vulnerability determinants: components of Ostrom's subsystems (boxes) and interactions between these components (ellipsoids) (adapted from [27] p. 420). ECO relates for example to water basins that provide ecosystem services to a village. S relates for example to national or regional regulations that apply to a village.

Nevertheless, SES frameworks—including the one by Ostrom—are abstract and only provide some rough guidance for selecting potential indicating variables for the social and bio-physical subsystems of the SES but not for aggregating them [5]. To address the specific contexts and purposes of our vulnerability study of villages in Africa we adapted the framework in the following directions:

1. *Semi-quantitative assessments of village vulnerabilities* as measures of possible harm for the villages mainly in terms of (potential for) agricultural production allowed comparisons of vulnerability levels between villages *within* each analysed water basin and gives regional decision makers useful information in which villages measures of vulnerability reduction are mostly needed. As described before, due to the differences between the social-ecological systems in Mkomazi (Tanzania) and Keiskamma (South Africa) and different data availabilities case specific methods for assessing village vulnerability had to be applied in the two case study regions. Therefore, the vulnerability indexes are not comparable *between* the two case study regions. This is not a major disadvantage since most decisions for vulnerability reduction are taken at national or subnational levels so that most decision makers have no need for international vulnerability comparisons. As noted before, *within* the regions, the vulnerability indexes are comparable and very useful for focusing policy interventions on the most vulnerable villages. In the SES framework, assessments of village vulnerability can be seen as indicators of *outcome* (*O*, see Figure 1).
2. *Analyses of relevant social and ecological vulnerability determinants* explain the differences in vulnerability measures and give decision makers useful information *how to* reduce vulnerability. The aim was to find the most relevant determinants for vulnerability in the local contexts. In the SES framework, these potential vulnerability determinants are to be found in the *resource system* (*RS*), *resource units* (*RU*), the *governance system* within the village (*GS*), the *users* of the resources in the village (*U*), the *social, economic and political setting* (*S*), the *related ecosystems* (*ECO*), and the *interactions* between these factors (Figure 1). Several of these factors proved difficult to quantify so that we focused on qualitative analyses of these determinants.

3. Mkomazi—Assessing and Understanding Village Vulnerability in Tanzania

3.1. Research Area

The central Mkomazi Water Basin in North-East Tanzania (4°30′ S, 38°05′ E) was chosen due to its immense variety of land cover types. It covers about 1000 km^2 comprising the South Pare Mountains to the West, the West Usambara Mountains to the East and the valley of Mkomazi River between these two mountain ridges (Figure 2). The water balance in the central Mkomazi River Basin strongly depends on four tributaries which emerge from the South Pare Mountains, namely Saseni, Yongoma, Hingilili and Nakombo [30]. Influenced by long environmental gradients ranging from semi-arid conditions in the valley to semi-humid conditions on the mountain ridges, the research area is characterized by a high diversity of land cover types and land uses. The latter comprise mainly small-scale rain-fed and irrigation farming, pasturing, logging, charcoal production and fisheries.

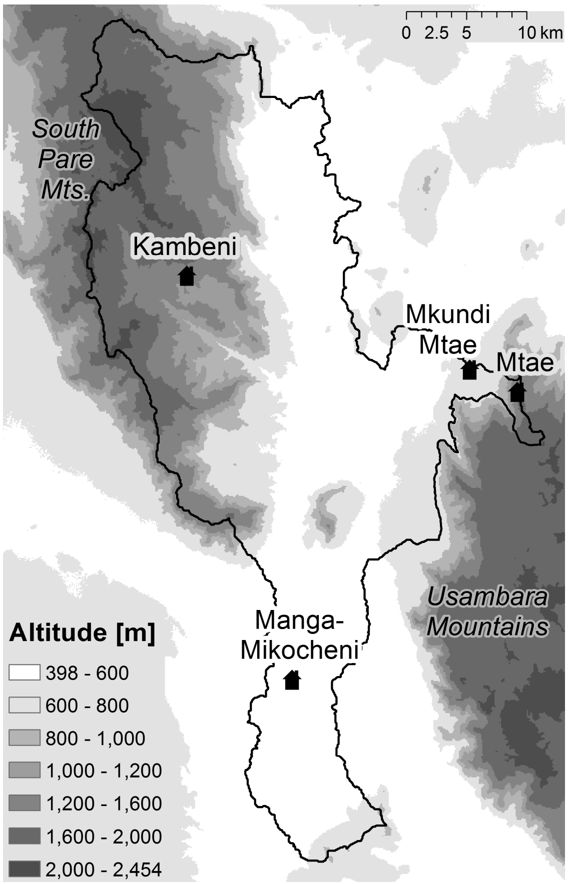

Figure 2. Map of central Mkomazi Water Basin and the four sample villages.

3.2. Materials and Methods

3.2.1. Study Structure and Selection of Sample Villages

This paper is based on results from two related studies in the central Mkomazi Water Basin, one with an ecological and the other with a socio-economic focus. In the ecological study [31] data from vegetation, soil and land use surveys, complemented by information from field observations and non-standardized interviews with local land users, were applied in logistic regression models to explore factors which influence the distribution of land cover types in the basin. Furthermore, land cover tolerance to different environmental factors and disturbances was assessed. The socio-economic study [32] focused on changes in the local climates and factors motivating changes in the farming practices. 189 questionnaires were collected from heads of smallholder farmer households followed by 17 expert interviews with village government leaders, selected elders from villages and representatives of district councils as well as the Pangani Basin Water Board (PBWB). In addition, four focus group discussions involving 25 smallholder farmers were conducted. Rainfall records for three weather stations and temperature records for one station were also analysed. The socio-economic study focused on four sample villages that were selected based on the following criteria. Villages had to

- be covered by the ecological study [31];
- differ in water accessibility in order to identify the impact of water accessibility on vulnerability;
- differ in climatic conditions in order to identify the impacts of climatic conditions on agricultural production and how climatic differences relate to changes in the farming practices by the smallholder farmers;
- represent different ecological zones (e.g., highlands vs. lowlands); and
- be accessible to make sure that data collection was possible.

In this article, which integrates the results of the two studies, we focus on the same four villages that were selected for the socio-economic study. Information regarding location and size of these villages are provided in Figure 2 and Table 1.

Table 1. Sampled villages, their locations and population.

Village	Location	No. of Households	Inhabitants
Mkundi	Foothills of West Usambara Mountains	348	1753
Manga-Mikocheni	Southern part of the central Mkomazi valley near Lake Manga	540	2694
Mtae	North-western ridge of Usambara Mountains	768	2552
Kambeni	Central South Pare Mountains	765	3827

3.2.2. Assessment of Vulnerability

Several ecological and socio-economic features can be considered as indicators of village vulnerability, i.e., *Outcomes* in the SES framework (e.g., biodiversity, functional diversity, process rates in ecological cycles, economic productivity, diversity of economic activities, and level of social inequality). However, the features which suit to display different levels of vulnerability between communities differ from one SES to another, depending on the specific predominant livelihood determinants (cf. [5]).

In Mkomazi Water Basin the major livelihood activities are small-scale farming and livestock keeping [33,34]. On account of the high dependency of all four studied villages on agriculture, we used the amount of agricultural production (AP) as a first vulnerability indicator. In order to cope with temporary events which cause considerable decreases of AP, like severe droughts, rural communities in the region often switch to a variety of alternative income sources (AIS) [35]. Therefore, we studied the availability of different AIS in each of the four villages as a second vulnerability indicator. Through the assessment of AP and AIS all major livelihood sources in the study region were covered and vulnerability of the four villages could be rated at sufficient detail. Low values of AP and AIS indicated high vulnerability. The calculation of both indices was based on the gathered socio-economic and environmental data.

Commonly the performance of agricultural systems is measured as agricultural productivity, which is the ratio of agricultural outputs to inputs [36–38]. Here we assessed only agricultural outputs in terms of AP, due to a lack of reliable monitoring of inputs on household level. Four measures were used to calculate an AP index that ranged from −2 (very low AP with food aid dependency) to 10 (very high AP) (see Table 2). Based on the village-specific average values of the four measures, valuation points were assigned to each of them in accordance to Table 2. Because farming is the most important agricultural activity in the region [34], farming outputs in terms of crop diversity and harvest frequency were given the highest weight; they could reach a maximum of 6 points. Livestock production was limited to a maximum of 4 valuation points. Livestock production was not regarded as an Alternative Income Source (see Table 3) because in the Mkomazi Water Basin small-scale farming *and* livestock keeping are major livelihood activities [33]. Furthermore, we wanted to develop a vulnerability index for 'agricultural production', which has to include livestock keeping. Dependency on food aid indicates failure of agricultural production, hence we assigned negative valuation points when food aid was supplied to the villages during the last five years. The final AP index for each village was calculated as the sum of all valuation points in accordance to Table 2 for each of the four measures (Table A1 in the Appendix A).

Table 2. Composition of the index for agricultural production (AP). The index comprises four measures. Based on our field data ("Input Data") valuation points are assigned to each measure. Values of input data represent village averages. The sum of all valuation points provides the AP index for each village.

Indicator	Input Data	Valuation Points						
		−2	−1	0	1	2	3	4
Crop diversity	Number of regularly cultivated crops	-	-	1 to 2	3 to 4	5 to 6	>6	-
Harvest frequency	Mean number of harvests per year	-	-	<1	1 to <2	2 to <3	3 and more	-
Livestock	Mean livestock number per household	-	-	<2	2 to 4	5 to 9	10 to 14	15 and more
Food aid	Number of times that food aid was received during the last 5 years	>1	1	0	-	-	-	-

Alternative income sources were measured by the AIS index on a scale from 0 (no AIS available) to 10 (many available AIS with large contribution to village income). The index comprised the number of available AIS and the degree to which they contributed to the village income (Table 3). Both measures were assessed for every village (Table A2 in the Appendix A), valuation points were assigned in accordance to Table 3 and finally the valuation points of both measures were summed to gain the AIS index for each village.

Table 3. Composition of the index for alternative income sources (AIS). The index consists of two measures. Based on our field data (input data) valuation points are assigned to each measure. The sum of all valuation points provides the AIS index for each village.

Indicator	Input Data	Valuation Points					
		0	1	2	3	4	5
Diversity	Number of AIS	0	1	2 to 3	4 to 5	6 to 7	>7
Contribution	Contribution of AIS to village income [%]	0 to 5	>5 to 10	>10 to 20	>20 to 35	>35 to 50	>50

3.2.3. Identification of Vulnerability Determinants

According to the SES framework, land cover types are regarded as *Resource Systems*, products from natural and cultivated land are seen as *Resource Units*. Government authorities and resource user groups are conceptualized as the *Governance System*, whereas *Users* refer to farmers, pastoralists and other resource users (Figure 3).

Land cover data from the ecological study [31] was used to identify land cover types in every village. Based on the sensitivity assessment of the ecological study we estimated in how far these land cover types contributed to vulnerability. Data on vegetation structure and plant functional traits from the same study was used to determine the availability of different products in the respective land cover types/villages. Finally disturbance data provided information regarding the consumption and use of the products by local residents.

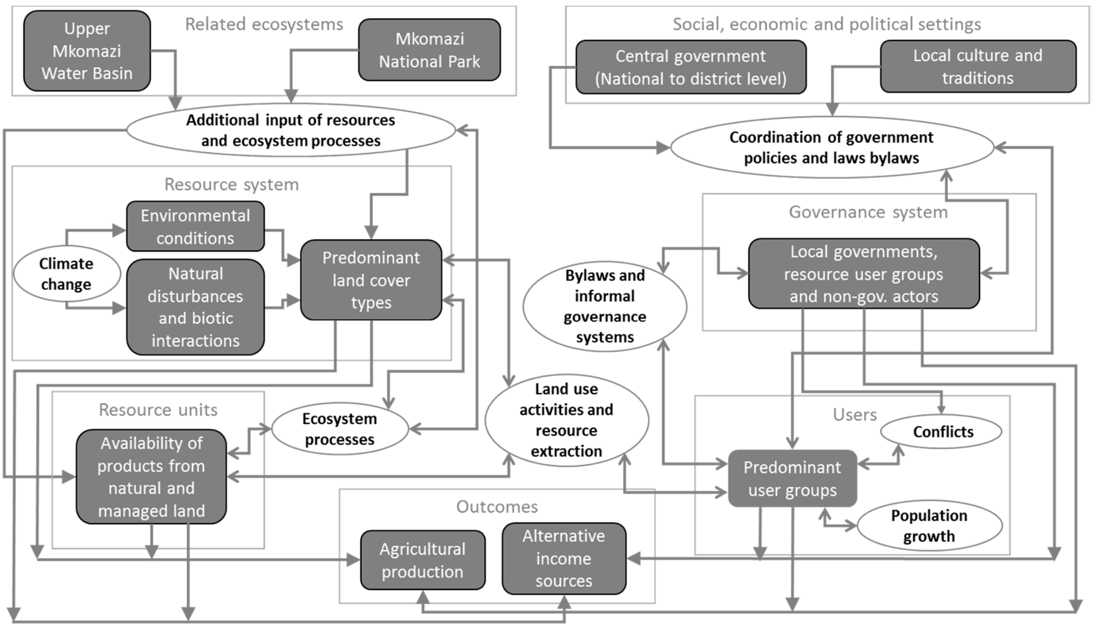

Figure 3. Application of the Ostrom framework [27] to the central Mkomazi Water Basin to explain different levels of vulnerability in villages by various vulnerability determinants. There are two types of vulnerability determinants: components of Ostrom's subsystems (e.g., predominant land cover types in Resource System) (boxes) and interactions between these components (ellipsoids) (We have chosen to define climate change as part of the resource system and not of the related ecosystems because we primarily refer to local climate change here).

In the socio-economic study, primary and secondary data were collected. Primary data were collected using questionnaires filled in by farmers (resource users), interviews mainly with representatives from government authorities, focus group discussions with smallholder farmers, a two-day stakeholders' validation workshop and a field excursion in the research area. Because these research instruments were part of a broader PhD project [32] they also included questions and aspects that did not relate to the vulnerability study presented here. Secondary data, mostly long term rainfall and temperature records, were obtained from the Tanzania Meteorological Agency (Daily rainfall records were collected from three stations namely Suji Mission (code number 9437004, elevation 1560 m.a.s.l.), Buiko Hydromet (code number 9438009, elevation 536 m.a.s.l.), and Same Meteorological Station (code number 9437003, elevation 860 m.a.s.l.)).

The questionnaire (see Appendix B) having both close-ended questions and open-ended questions was administered to 189 farming households to obtain information on, among others, demographic and socio-economic information, perceptions on the local climate, changes in farming practices, and explanation of those changes. Other questions addressed socio-economic implications of changes at household level and community level as well as long-term policy and strategic interventions for enhanced resilience, which farmers believed they could support them to not only adapt but also enhance their resilience to withstand changes in future.

To obtain additional and technical information on all issues raised by the farmers in the questionnaires, and compare their information with a technical and experts' view, semi-structured and non-structured interviews were used. A checklist of broader questions (see Appendix B) was used to undertake 17 interviews. The interviewees were district agricultural and livestock development officers for Lushoto and Same districts, the representative of the Pangani Basin Water Board (responsible for management and regulation of water resources use in the basin), village chairpersons for all four villages, ward councillors for three wards, selected elders from the villages, and ward agricultural and livestock extension officers.

Four focus group discussions were conducted; one for each village, involving 25 individual smallholder farmers from randomly selected households. They discussed issues related to historical background of the villages and changes that have taken place over time in the villages, climate related events and local perceptions of climate change. Other aspects included decision-making to change farming practices, timing and reasons for such decisions as well as projections of future climate impacts and adaptation interventions (for more detail see Appendix B). The responses were directly recorded and later on transcribed.

Finally, a stakeholders' validation workshop and a field excursion were organized in Lushoto involving stakeholders from Same District Council, Lushoto District Council, Pangani Water Basin Office and the Mamba Myamba Ginger Cooperative Society alongside researchers from the Clim-A-Net project team (see Acknowledgments). The workshop was important in allowing stakeholders to validate the data collected from smallholder farmers, local leaders, elders and government authorities.

Together these data from the socio-economic study provided an understanding of changes in the local climate, changes in the farming practices, factors motivating these changes—including a sound understanding of the local governance systems and their relation to higher governmental levels.

3.3. Results

3.3.1. Levels of Vulnerability

Our assessment of the vulnerability indicators revealed large differences between the four villages in terms of AP but a rather balanced availability of AIS (Table 4, for more detail see Tables A1 and A2 in the Appendix A). Mkundi was the most vulnerable village as it gained a very low score for AP. Moderate levels of vulnerability were observed in Manga-Mikocheni. The least vulnerable villages were Kambeni and Mtae, where Kambeni had an advantage in AP and Mtae had more available AIS.

Table 4. Village-specific ratings for agricultural production (AP) and alternative income sources (AIS) indices and their components.

Indicator	Village			
	Mkundi	**Manga-Mikocheni**	**Mtae**	**Kambeni**
Crop diversity	1	2	3	3
Harvest frequency	0	1	2	3
Livestock	0	2	1	1
Food aid	−2	−2	0	0
AP index	**−1**	**3**	**6**	**7**
AIS diversity	2	3	3	2
AIS contribution	4	3	3	3
AIS index	**6**	**6**	**6**	**5**

Although the AIS index scores were almost equal among the four villages, the influence of AIS diversity and income contribution respectively showed relevant differences (Table 4). In villages like Mkundi where rather few AIS had a large contribution to the village income, the availability of AIS was less reliable than in villages like Mtae where the diversity of AIS was higher. The reason is that many AIS are socio-economically or ecologically unsustainable (e.g., the flow of remittances relies on the insecure economic situation of benefactors, charcoal production relies on exhaustible natural resources) and dependency on only a few of them is not very reliable.

3.3.2. Vulnerability Determinants

The key socio-economic vulnerability determinants that were effective with regard to the differences in AP include poor governance and coordination contributing to conflicts between resource users; ineffective implementation of development plans for smallholder farming; and low levels of access to information and education for farmers (cf. Figures 3 and A1 in Appendix A).

According to the interviewed villagers, conflicts between different resource users in the study villages were fuelled by poor governance and coordination at both, local and district levels, the lack of land use plans and the lack of reliable water sources for irrigation, cattle and other uses. These conflicts affected AP, threatened peace and security and contributed to varying levels of vulnerability between villages, particularly Mkundi and Manga-Mikocheni as compared to Kambeni and Mtae. The most notable conflicts in the past had occurred between pastoralists and smallholder farmers in both Mkundi and Manga-Mikocheni, whereas such conflicts were much less in Kambeni and Mtae. For example, at the time of undertaking this research, two smallholder farmers were reported to have been killed in Mkundi as a result of clashes between farmers and pastoralists. While changes in the climate and population increase exacerbated the lack of water and pasture, the lack of land use plans, weak law enforcement, poor development plans and untimely as well as ineffective conflict resolution interventions constituting major causes of low AP levels in Mkundi and Manga-Mikocheni.

Ineffective implementation of plans to develop and improve smallholder farming (especially with regard to water availability) was another major determinant of vulnerability in the area. While Kambeni used a traditional irrigation system, in Mtae only a few farmers depended on tap water to irrigate their vegetables. Contrary to that, in Mkundi farmers entirely depended on rainfall which was reported to be unreliable and decreasing [32]. Also Manga-Mikocheni had no reliable water source for irrigation but mostly depended on the flow of water from upstream. This means that there was no functioning irrigation system which could foster efficient use of the increasingly dwindling water resource and thereby promote higher AP, which would also allow farmers to produce for more than just subsistence. Our results [32] show that on average 54% of the farmers in the four villages within the Mkomazi basin produced for subsistence while 42% produced for both, subsistence and cash, depending on the level of production of a specific year. Only 4% stated that they produce for cash only.

Smallholder farmers especially in villages with low AP (Mkundi and Manga-Mikocheni) expressed the need for agricultural inputs and better access to extension services (educational, advisory and technical services provided to farmers in order to improve AP). These services include advice and education on better use of fertilisers, appropriate seeds, appropriate crop varieties amidst changing climatic conditions, issues of marketing etc. The extension officers are currently based at the ward level providing services to both crop producers and pastoralists for several villages. At the time the research was conducted, only Mamba Myamba Ward (in which Kambeni is located) had an extension officer. Agricultural inputs and better access to extension services both contributed to higher AP. Farmers especially in Mkundi and Manga-Mikocheni complained about poor access to agricultural inputs such as fertilizers, seeds as well as farm implements. The national government initiated a programme for distributing subsidised fertilizers to farmers through selected agents at district level but poor governance and coordination at district level made it difficult for the targeted farmers to have access to the fertilizers. A lack of a credit system for farmers hindered many from buying the subsidized fertilizers. This contributed to poor harvests. Furthermore, extension services were unreliable as the three villages with the lower AP values (Manga-Mikocheni, Mkundi and Mtae) had no extension staff, thus limiting access to information and education for farmers.

The different vulnerability levels of the four villages (Table 4) were caused by the following major ecological vulnerability determinants: climatic conditions which drive the distribution of the land cover types; upstream abstraction of water resources; and the availability of products from natural and cultivated land (cf. Figures 3 and A1). Semi-arid climate strongly limited the variety of potential land uses which was a major determinant of the low AP scores (and also caused low AIS diversity) for Mkundi (see Table 4). Deciduous *Commiphora*-Woodland was the main land cover type in this area. When transformed to farms, only few crops could be cultivated and harvest losses were frequent (Table 4: low crop diversity and harvest frequency in Mkundi). Likewise, *Commiphora*-Woodland supported only moderate numbers of livestock, in particular during dry seasons when fodder is rare.

Villagers exploited *Commiphora*-Woodland for charcoal production, which is an important but rather unsustainable AIS. Although the environment of Manga-Mikocheni is influenced by similar climatic conditions as Mkundi, it has the advantage of vicinity to the Mkomazi River and its floodplains, allowing to use seasonally flooded grasslands and reeds, irrigated paddy farms and even a lake (see Figure A1). Consequently, livestock keeping and farming were significantly more productive and diverse than in Mkundi (Table 4), and fish catches brought an additional AIS. However, the supply of irrigation water to Manga-Mikocheni strongly depended on upstream water abstraction. Occasionally, irrigation water became seriously scarce leading to harvest loss and soil salinization.

Conversely, the semi-humid climate at the Usambara and South Pare mountain ridges allowed high land cover diversity in Mtae and Kambeni (Table 4) leading to relatively high AP and AIS scores. Indigenous evergreen forest (accessible for Kambeni's inhabitants) played a crucial role by providing timber, fuelwood, traditional medicines and vegetables. The forest also discharged perennial water streams which were of substantial importance for the water balance of the entire basin. In contrast to Kambeni, Mtae did not have access to evergreen forest and its water discharges. Nevertheless, rainfall was sufficient to support productive agriculture so that AP differences in both highland villages were only marginal (Table 4). Different farming systems including agroforestry and irrigated terraced farms facilitated a high diversity of crops and reliable harvests. In Mtae, the lack of forest products was compensated by other AIS such as tourism.

4. Keiskamma—Assessing and Understanding Village Vulnerability in South Africa

4.1. Research Area

The Keiskamma is one of the largest catchments in the Eastern Cape Province, South Africa. It represents a particularly interesting case due to the very diverse levels of land degradation within the region. Keiskamma, the main river in the catchment has headwaters in the Amatole Mountains at an elevation of 1500 m. It flows eastwards for 263 km and drains into the Indian Ocean at Hamburg resort (33°17′ S 27°29′ E). The catchment comprises three main topographic regions, namely the escarpment zone, the coastal plateau and the coastal zone. The coastal plateau, which covers the central Keiskamma catchment is the focus of this study (32°51′19.36″ S, 26°53′38.14″ E and 32°58′03.11″ S, 27°12′09.51″ E, Figure 4). It constitutes most of the catchment at an altitude range of 600 to 900 m above mean sea level. The semi-arid area has an annual rainfall, received mainly in summer, ranging from 400 mm to 600 mm closer to the wet escarpment zone. The vegetation of the central Keiskamma consists of savanna (thornveld), while the river valleys are mostly characterized by the valley thicket (dense woody shrubs). The valley thicket has been extensively degraded due to overgrazing and clearance for wood fuel, which have resulted in the invasion of unpalatable patchy dwarf shrubs, particularly *Pteronia incana*, which is indigenous to the dry Karoo region of South Africa. The invasion is associated with numerous ecological and economic impacts, such as soil crusting, aridification and erosion and loss of grazing land [39,40].

Land in the central Keiskamma catchment is largely communally owned and is predominantly utilised for livestock grazing. Large portions of land which were previously cultivated lie abandoned, eroded and converted to grazing. However, uncontrolled grazing in some of the villages in the study area has caused severe land degradation.

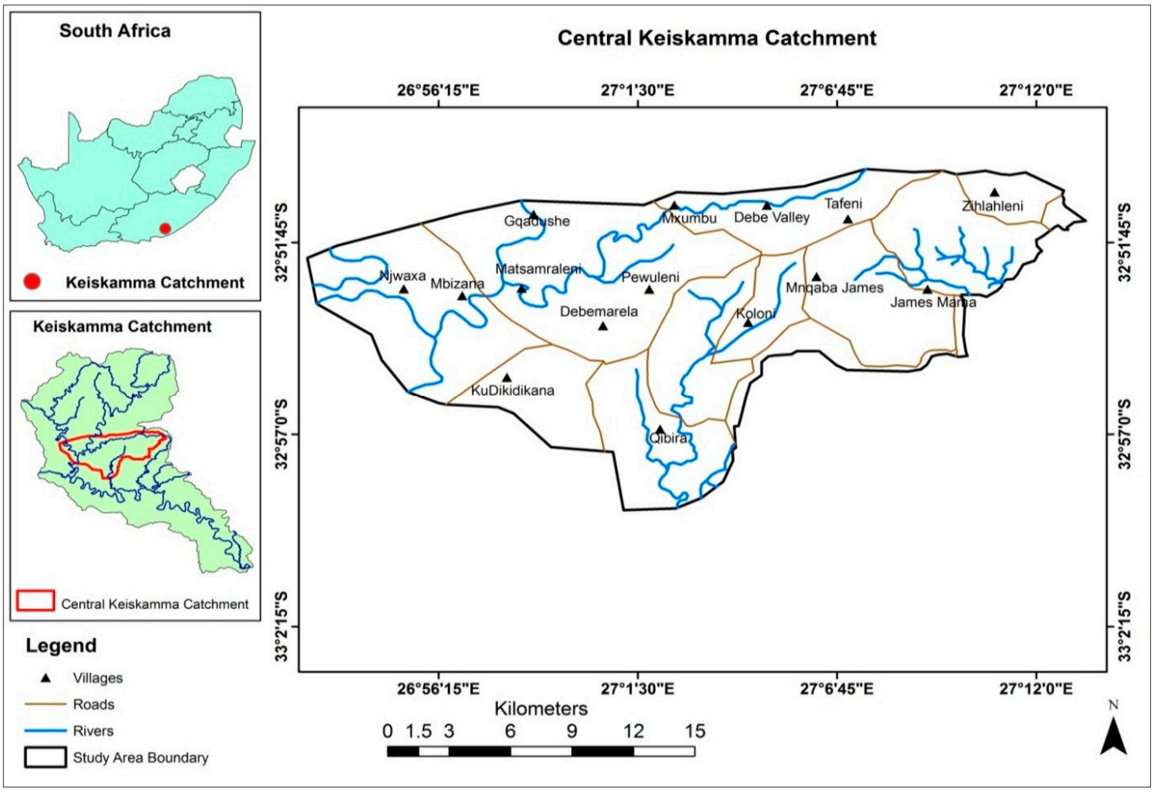

Figure 4. Villages of the Keiskamma study area.

4.2. Materials and Methods

4.2.1. Study Structure, Selection of Sample Villages and Data Collection

The study area comprises 15 communal villages (Figures 4 and 5), selected on the basis of the homogeneity of their topographic characteristics despite the marked differences in the quality of governance systems in the villages. A Chi-squared test confirmed that topography does not vary significantly across the villages of the study area ($p < 0.005$). Topographic homogeneity therefore provided the benchmark against which the differences in land quality were assessed. Notable among the land quality indicators were vegetation condition, current land use and land degradation status. Assessments of spatial and temporal variations in land condition across the study area were made using sequential satellite images, taken in 1984, 1999 and 2011 and by field observations in the selected villages. Sites representing land cover classes namely intact thicket, grass vegetation, transformed and degraded thicket, bare and eroded areas were classified from the imagery and observed in the field in order to verify the present land use and cover, and degradation conditions in the respective villages.

Our main hypothesis was that the quality and functionality of the local governance systems in the villages was a central determinant of the differences in land quality. Hence, semi-structured interviews were conducted during meetings with headmen and committee members of the 15 local committees to determine the existence and functionality of local level governance structures responsible for implementing grazing management and general land use strategies within the respective villages. The implementation or lack of land use strategies such as rotational grazing, fencing, herding, kraaling and farmer training in grazing and general land stewardship techniques constituted the functionality assessment of the governance structures.

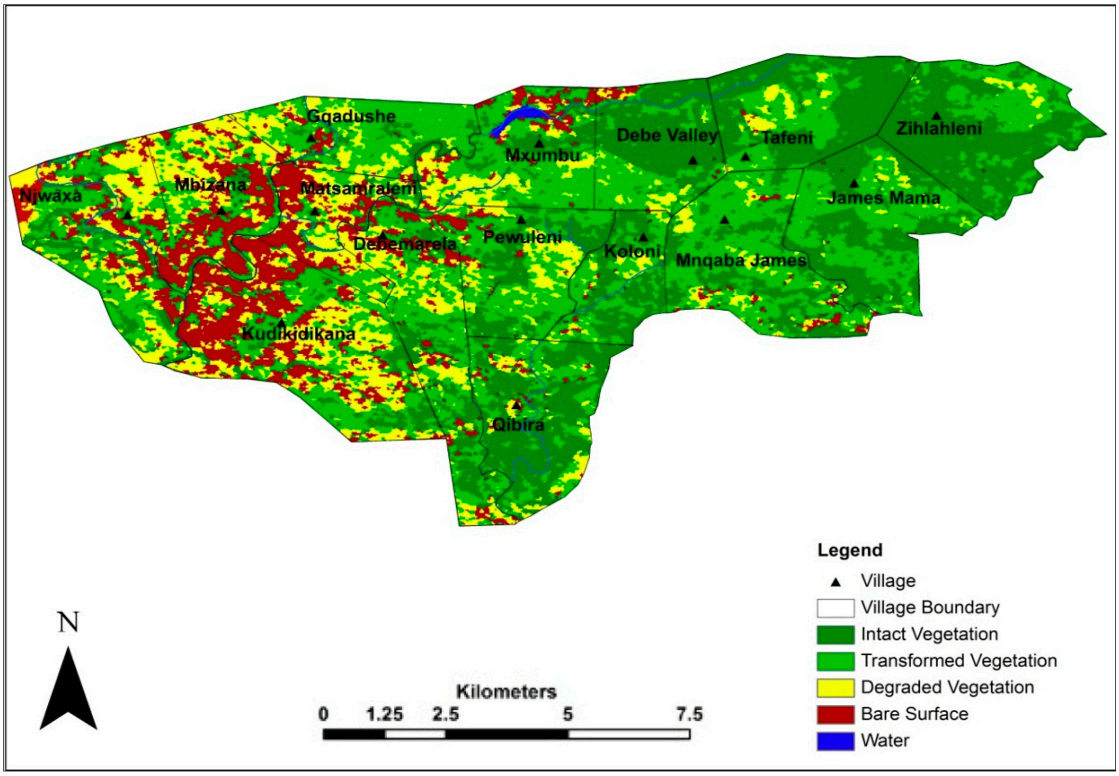

Figure 5. Land cover conditions of the Keiskamma study area villages based on 2011 imagery.

4.2.2. Assessment of Vulnerability

On the basis of the distinct variations in terms of the ecological status (land cover condition, degradation status), the state of governance related to grazing (existence of effective fencing, rotational grazing and farmer training) and the current agricultural activities (crop cultivation, livestock herding and kraaling) in the selected villages, the Potential for Agricultural Production (PAP) was developed as the main index of vulnerability. Due to the huge differences between the social-ecological systems in Mkomazi and Keiskamma specific vulnerability indexes had to be developed for Mkomazi (AP) and for Keiskamma (PAP). Whereas the Mkomazi index indicates the availability of agricultural products in the region, the Keiskamma index merely indicates the *potential* for agricultural production. It had to be chosen in contrast to the AIS of the first study due to the fact that in the Keiskamma area agriculture is not the main source of income for most local communities and that land cover change and degradation has progressed also due to a lack of agricultural activity. Whereas in the Mkomazi, all villages under consideration comprised of mostly used land, in Keiskamma large areas are no longer in use for agricultural purposes.

The PAP index for Keiskamma comprises 8 indicator values, according to which a village specific value of PAP was estimated, as a sum of the values (cf. Table 5). These values were based on field observations of the land cover and degradation conditions, and responses to the semi-structured interviews regarding the functionality of local village committees, such that 0 and 1 reflect either poor or good ecological condition, and absence or presence of a grazing governance practice and current agricultural activity. The PAP index can take values from 0 (lowest PAP) to 8 (highest PAP). Low PAP levels indicate high vulnerability.

4.2.3. Identification of Vulnerability Determinants

The SES framework was applied to the central Keiskamma catchment to understand the vulnerability determinants causing the vulnerability levels as reflected by the PAP index. Each village was designated as a Social-Ecological System (SES), comprising *Resource Systems* (*RS*), *Resource Units* (*RU*), *Governance Systems* (*GS*) and *Resource Users* (*U*) in the village (Figures 1 and 6). The RS include thicket vegetation, grassland, the riparian zone and stream water. Livestock, cultivated crops and other products from the land were defined as RU. GS in the respective villages include local institutions, particularly the village traditional committees headed by a headman and municipal ward councillors. Resource Users (U) are communal farmers whose level of organisation in village committees was assessed by means of the semi-structured interviews. Municipal councils, who are further important governance actors in addition to the traditional councils, are seen as part of the *Social*, *Economic* and *Political Settings* (*S*). The *related ecosystem* (*ECO*) outside the villages is the upper Keiskamma catchment. According to [40,41], water impoundments of the upper Keiskamma catchment in the form of Sandile and Binfield dams have had a considerable impact on the downstream ecological functioning (see also Figure 6). In general, the potential ecological vulnerability determinants (RS, RU, ECO) were identified and assessed mainly based on observational data (satellite data and field observations), whereas the potential social vulnerability determinants (GS, U, S) were mainly identified and assessed based on data from the interviews.

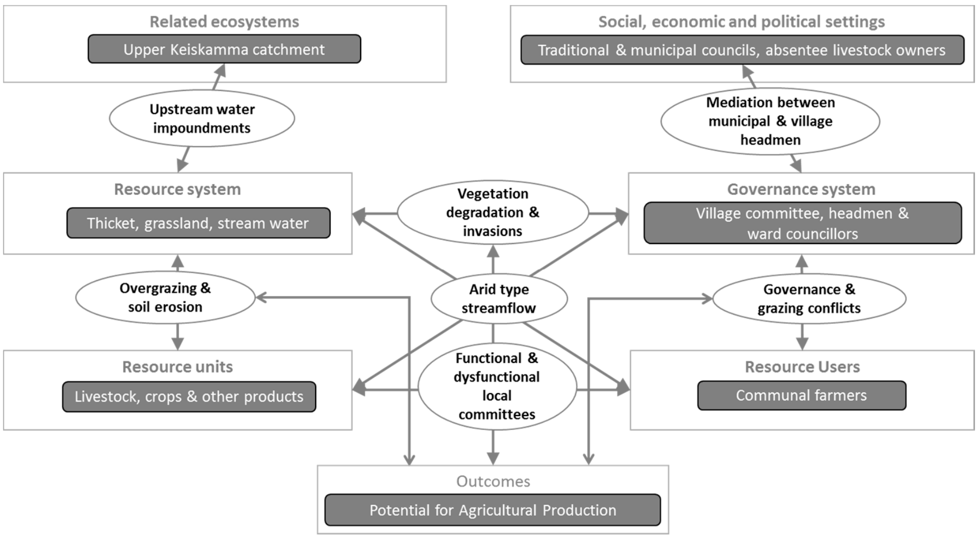

Figure 6. Social-ecological systems (SES) framework: an application to the central Keiskamma catchment.

4.3. Results

4.3.1. Levels of Vulnerability

As Table 5 indicates, there is great variance in PAP values between the 15 villages. While seven villages have a PAP value of 5 or more, eight villages got a PAP index of 4 or lower.

Vegetation in the villages with higher PAP values was mainly intact thicket and grassland, as opposed to the transformed and degraded thicket, as well as bare surfaces and eroded land that characterised villages with lower PAP values. Figure 5 conveys the vegetation condition related to this contrast. The image seems to indicate topographic determinants (such as slopes, altitude) of the differences in soil degradation due to the proximity of the degraded areas but the Chi-squared test showed that topography does not vary significantly across the villages of the study area ($p < 0.005$). The villages with low PAP values are also characterised by the lack of or inconsistent rotational grazing, and lack of effective fencing, herding and kraaling practices, and farmer training arrangements. Land abandonment, invasion of dwarf patchy unpalatable shrubs, severe erosion forms, loss of grazing and cultivated land are hallmarks of this category of villages. Degraded vegetation conditions, eroded bare lands (see Figure 5) and lack of sound grazing management systems in these villages have rendered the villages highly vulnerable.

Table 5. Indicator ratings for the selected Keiskamma villages. The sum of indicator values assigned to each village provides the potential for agricultural production (PAP) index.

Indicators		**Villages ***														
		JM	**KL**	**TN**	**QR**	**DV**	**ZH**	**MB**	**NX**	**MX**	**MZ**	**KD**	**MN**	**GD**	**PW**	**DM**
Ecological status	Original vegetation	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0
	Undegraded land	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
Grazing governance practices	Effective fencing	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0
	Rotational grazing	0	0	1	0	1	1	0	0	1	0	0	0	0	0	0
	Farmer training	1	1	1	1	1	1	1	0	1	0	0	0	1	1	0
Current agricultural activities	Crop cultivation	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
	Livestock herding	0	1	1	1	1	1	1	0	1	0	0	0	1	1	0
	Livestock kraaling	1	1	1	1	1	1	1	0	1	0	0	0	1	1	0
PAP index		**6**	**6**	**7**	**4**	**6**	**8**	**5**	**0**	**4**	**0**	**0**	**0**	**3**	**3**	**0**

* JM = James Mama; KL = Koloni; TN = Tafeni; QR = Qibira; DV = Debe Valley; ZH = Zihlahleni; MB = Mnqaba James; NX = Njwaxa; MX = Mxumbu; MZ = Mbizana; KD = Kudikidikana; MN = Matsamraleni; GD = Gqadushe; PW = Pewuleni; DM = Debemarela.

4.3.2. Vulnerability Determinants

Our main hypothesis was confirmed that the quality and functionality of the local governance systems in the villages was the main determinant of the differences in PAP values. While local institutional committees existed in each village, not all these structures were functional (Table 6) and the villages without functional local committees were the ones with low PAP values.

Table 6. Keiskamma villages with and without functional local committees.

Villages *with* Functional Local Committees	**Villages *without* Functional Local Committees**
James Mama	Njwaxa
Koloni	Mxumbu
Tafeni	Mbizana
Qibira	Kudikidikana
Debe Valley	Matsamraleni
Zihlahleni	Gqadushe
Mnqaba James	Pewuleni
	Debemarela

Whereas villages with functional local institutional committees were noted as implementing grazing management practices, the opposite was true where local committees were dysfunctional. A dichotomous variation in PAP values between villages with functional and dysfunctional local governance structures is noticeable in Table 5. While the villages where local committees are functional have high PAP values, the opposite is true for the villages whose local structures are dysfunctional.

Applying the SES framework to the 15 villages Figure 6 illustrates further determinants of vulnerability assessed by the PAP index.

In the analysed villages, municipal ward councillors ran parallel with traditional village headmen. The former believed they have greater powers, since they were democratically elected. However, village headmen, who were at the helm of the local committees claim more power than the municipal ward councillors based on tradition. This created power conflicts between the two governance levels, perhaps contributing to the dysfunctionality of some of the local committees.

Grazing conflicts had arisen between villages having effective local governance structures and fenced grazing land and those that did not. Fences were broken by livestock owners from the latter villages in order to access better grazing land. Other conflicts also arose between often absent livestock owners and communal land dwellers. The former did not respect grazing boundaries and their livestock sneaked into neighbouring villages' grazing land, especially at night.

The interaction between land users and RSs has been characterised by among other things overgrazing and abandonment of cultivated land. Much of the overgrazed and abandoned land had been invaded by unpalatable dwarf shrubs, leading to the loss of grazing land.

The main outcomes of this interaction, assessed in the PAP index, have entailed severe rill and gully soil erosion on invaded abandoned lands. This led to the conversion of many RSs to dysfunctional landscapes. The resultant hydrological impacts included constraints on precipitation water pathways on hillslopes and the alteration of stream flow to semi-arid type. The affected landscapes were inevitably highly vulnerable to climate change impacts, particularly on water for ecosystem functioning. The affected communities had become highly vulnerable, owing to their dysfunctional local village structures and exposures to vegetation and hydrological impacts, as explained above.

5. Comparative Discussion

Our analysis of vulnerability levels in villages of Tanzania and South Africa follow a case-specific and context-related approach integrating natural and social science methods. Addressing the question of how to assess local vulnerabilities best, the Mkomazi case indexes of agricultural production (AP) and alternative income sources (AIS) were developed, while for the Keiskamma case an index of potential for agricultural production (PAP) was calculated. All indexes and indicators had discriminatory power; especially the AP and the PAP indexes showed a high variance of vulnerability levels for the villages. Both use different indicators to operationalize vulnerability given the socio-ecological differences in the two regions.

In line with recent literature [2,6,11], these indexes also illustrate how strongly vulnerability assessments depend on social data, which in many cases cannot be drawn from available statistics, but have to be produced by data collection in the local communities. In the Mkomazi case study, social data are mainly drawn from questionnaires, interviews and focus group discussions, while in the Keiskamma case study the social data mainly originate from semi-structured interviews with village headmen. Here, the index of potential for agricultural production (PAP) acknowledges the fact that much of the area experiences soil degradation making agriculture impossible. By this index some villages appear highly vulnerable although they would probably appear less vulnerable if alternative income sources were taken into account. Many of the people living in the villages in the Keiskamma river catchment do not generate an income from agriculture but from remittances from relatives working in the cities or from governmental welfare aid. Due to lack of secondary social data regarding the income sources of the people in the villages, which were analysed in the Keiskamma case, and due to a lack of resources in our project for collecting these data by household questionnaires (as in the Mkomazi case study) these income sources could not be quantified in Keiskamma. Hence, they could not be included in the vulnerability index for Keiskamma.

The approaches for identifying vulnerability determinants developed for the Mkomazi and the Keiskamma case reflect that the seven broad categories of the SES framework (*RS*, *RU*, *GS*, *U*, *S*, *ECO* and their *interactions*) need to be specified to a great extent to be informative in terms of potential entry points for actions to reduce vulnerabilities. For example, *resource users* (*U*) as a general category had to be differentiated in more specific actor groups such as farmers and pastoralists. Nevertheless, the SES framework supported close interdisciplinary cooperation between the participating natural and social scientists in analysing interactions between ecological and social determinants of vulnerability. Furthermore the SES framework proved to be comprehensive as we did not identify any specific vulnerability determinant that could not be placed in one of the seven broad categories introduced by Ostrom [27].

Generally speaking, ecological factors such as water availability and temperature played a role in determining vulnerability. Villages in the Mkomazi with little water are far more vulnerable than the others. In the Keiskamma, climate impacts such as decreasing precipitation and increasing temperatures were generally not (yet) of high relevance as compared to social factors of land use change and local governance. Nevertheless, in managing social-ecological systems—or more specifically: in reducing vulnerabilities of (people in) social-ecological systems—both, social as well as ecological factors should be addressed [42].

Among the social factors, *local governance* stood out in particular in the Keiskamma case where the quality and functionality of the local governance systems in the villages was the main determinant of the differences in potential for agricultural production (PAP). This is an important finding because peer-reviewed literature on adaptation to climate change focuses on adaptation governance at national levels and tends to neglect the importance of supranational levels of governance [43]. In research on managing common-pool resources such as forests or fisheries local governance arrangements have been analysed since the 1990s and proven to be very influential [44,45], especially since the publication of Ostrom's institutional design principles for governing the commons [46].

Apart from the prominent relevance of the quality of local governance, in both case studies *conflicts* stood out as major vulnerability determinants. This result is consistent with several other studies that identify a close link between conflict and vulnerability [47–49]. In the Mkomazi water basin conflicts between different resource users, particularly between pastoralists and smallholder farmers but also between different villages that claim access to the limited water resources, are the main issue. Conflicts between different resource users, mainly between villages for grazing land, but also between governance levels, particularly between village headmen and municipal ward councillors, are major vulnerability determinants also in the Keiskamma river catchment. Apparently, the topic of conflict relates back to the importance of governance factors since good governance can avoid and solve conflicts, despite existing power differences and clashes of interests between the different actor groups. Therefore, the existence and functionality of conflict-resolution mechanisms is one of the institutional design principles by Ostrom [46] and has been shown to be essential for managing common-pool resources in several studies [44,45]. Furthermore, it may need to co-occur with the realization of other institutional design principles to be fully functional [45]. In other words, the ability to avoid and solve conflicts constitutes an essential dimension of adaptive capacity. The identification of conflicts as major vulnerability determinants in both cases also relates to the question of transferability of results to socio-ecological systems beyond the regions analysed in the two case studies. Although we analysed village vulnerabilities in only two regions, the identification of conflicts as major vulnerability determinants in both studies indicates that analysing existing and potential future conflicts might also be important for understanding vulnerabilities elsewhere [50].

Another social factor with explanatory power was *access to information* that differed between villagers in the two study regions. Access to resources such as information and knowledge is related to governance and equity, as has been shown in research on vulnerability to climate change [2]. Also in the larger literature on social learning access to information has been identified as an important factor in various fields of action, including agriculture [51]. In the Mkomazi region, better access of farmers to information and education (e.g., on drought resilient crops and cultivation methods) could increase their agricultural production and decrease vulnerability. For instance, the knowledge about more drought resistant crops helped farmers in highly marginal land in the Mkomazi area to generate agricultural produce. In their role as providers and disseminators of agriculturally relevant information, extension officers are crucial. However, the availability of their services and the reliability of their presence in the villages differ and are often uncertain to the villagers. In the Keiskamma, regional authorities engage little in extension services also given the low demand for agriculturally relevant knowledge. However, better land management practices promise also here better results and the potential to halt soil degradation.

While the SES framework has frequently been applied to larger systems determined by ecosystem boundaries such as nature conservation zones [52] or water basins [53], in the context of our study, we chose to apply it to a *village level*. This focus proved to be powerful with regard to the explanatory and decision support goals of our research in several ways. First, although our research started off with the aim of understanding regional vulnerabilities of large water basins in rural Tanzania and South Africa we adjusted our focus on vulnerabilities at village levels. This research focus related to our aim to produce more decision relevant scientific vulnerability assessments for actors at the village level. Second, our empirical research showed that vulnerability levels strongly differed between the various villages within the water basins—depending on the specific ecological and social conditions in the villages. Hence, an overall vulnerability statement for the whole water basin would be misleading because average values would underestimate the vulnerability of the highly vulnerable villages and overestimate the vulnerability of other villages. Third, vulnerabilities also emerge from the intersection of different inequalities, and uneven power structures, and hence is socially-differentiated [18]. We sought to provide a better understanding of the social differentiation of vulnerabilities by looking at the differences in vulnerabilities between villages that differ in our case studies—among other factors—in terms of access to water and good governance.

Furthermore, climate change vulnerability assessments at village levels are as yet conducted primarily by aid organizations such as USAID, also in Africa, using for example participatory rapid appraisal methods [54]. Peer-reviewed publications on assessments of vulnerability to climate change at village levels that combine sound natural and social science methods are as yet rare, particularly for the topic of vulnerability to food insecurity [43].

While the previous arguments outlined explanations for *current* vulnerabilities in terms of AP and AIS, a remaining and yet unanswered question relates to the potential *future* vulnerabilities. Results from [31] show that in particular indigenous evergreen forest is vulnerable to expected climatic changes and increasing land use intensity in Mkomazi Water Basin. Considerable forest degradation is likely to disturb the water balance of the basin and make irrigation farming increasingly difficult. In Kambeni this might not lead to serious problems as the relatively high availability of rainfall would still facilitate productive farming. This situation is comparable to Mtae where surface water is already rare, but farming would probably still be productive. However, in the valley a considerable reduction of available ground and surface water would have serious implications. Most of it would be noticeable in downstream areas like Manga-Mikocheni where stream flow is unreliable already today. There is high probability that the perennial character of Mkomazi River changes into an intermittent character and that seasonal swamps dry up completely. Since these swamps are the basis for livelihood in Manga-Mikocheni (rice production), the situation in this village would drastically deteriorate.

These potential future vulnerabilities point to a major challenge for sustainable land use and resource management in Mkomazi Water Basin: Increasing vulnerability of livelihoods in the lowlands is mainly caused by land use and land cover changes in the highlands. But willingness and motivation of the highland communities to stop unsustainable forest exploitation and to reduce water consumption seems to be very limited.

By contrast, future vulnerabilities in the case of the Keiskamma probably lie more in the social and institutional domain than in the ecological. Even though climate impacts are also expected to hit the region by even less and severely fluctuating water availability in most water systems, the analysis has shown that the socio-economic and institutional challenges lie at the core of the villages' vulnerability. Thus lack of good governance and potential ongoing political and societal destabilisation will also exacerbate the vulnerability of the villages at hand with severe impacts on increasing soil degradation. It is not unlikely that substantial parts of the Keiskamma region become inhabitable due to a lack of agricultural production capacity and a lack of available water.

6. Conclusions

With our case studies and the development of approaches for assessing vulnerability levels and understanding vulnerability determinants in villages of Tanzania and South Africa we addressed a research need to develop "tools to enable policy and other decisions based on the complexity of the world under climate change, taking into consideration [...] the potential contribution of local communities" [12] (p. 1243). To this end, we conceptualized villages as SES in which various social and ecological factors interact to produce high or low vulnerabilities in terms of (potential for) agricultural production and income. Villages are also social entities with scope for autonomous decision making to varying degrees. In doing so, villages prove to be central actors of local governance.

One of the challenges in this endeavour was to find a balance between the comprehensiveness of the vulnerability indexes and their understandability to local decision makers. In addition to conveying an understanding of the complexity of the social and ecological determinants of vulnerability it was a further aim of the development of our SES-based methodology to point to practical solutions for vulnerability reduction and adaptation to climate change. On first sight, social determinants related to governance systems, resource users and their interactions qualify as obvious starting points to be tackled by local decision makers. For example, transforming the dysfunctional local committees in the Keiskamma villages into functional ones would most likely reduce much of the vulnerabilities. Nevertheless, also the ecological vulnerability determinants can be addressed. For example, changing water intensive farm products (*resource units*) in the Mkomazi case to less water intensive products would be a promising option for vulnerability reduction.

More generally speaking, the Mkomazi case demonstrates that promoting sustainable and climate resilient alternative income sources would be an important policy intervention to reduce vulnerability. At the same time, agricultural production remains essential to stabilizing the villages and can be promoted through clear village land use plans, construction of dams and education for both pastoralists and farmers coupled with effective law enforcement to address conflicts as well as maintain peace and security. Furthermore, quick interventions by village leaders can help to resolve conflicts and thereby avoid any serious escalation, like it has already been achieved in Manga-Mikocheni. Having in place a sustainable irrigation system also helps farmers substantially to produce more using the little available water sustainably. In addition, promotion of water harvesting could be an opportunity for farmers to obtain water for irrigation, particularly in dry low-lying areas that showed a temporal dependency on food aid.

Nevertheless, more comparative research is needed on local levels to identify vulnerabilities and to point to effective practical solutions for vulnerability reduction and adaptation to climate change. The development of typologies of villages, which are similar in their vulnerability determinants and in the potentially effective solutions for reducing vulnerabilities, might be a useful next research step. More specifically, research that helps to identify win-win-solutions that can simultaneously increase agricultural production and alternative income sources is needed. Also more research and assessment methods regarding the potential effects and interactions of promising practical solutions for vulnerability reduction (e.g., the implementation of Ostrom's institutional design principles [46]) appear promising so that unwanted side effects (like the generation of new vulnerabilities) can be avoided.

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Author Contributions: Torsten Grothmann, Maximilian Petzold, Patrick Ndaki, Vincent Kakembo, Bernd Siebenhüner, Michael Kleyer and Pius Yanda developed the conceptual SES framework for vulnerability assessments in villages and wrote the paper. Maximilian Petzold, Patrick Ndaki, Michael Kleyer and Bernd Siebenhüner designed and conducted the case study in the Mkomazi Water Basin (including method design and data analysis). Naledzani Ndou and Vincent Kakembo designed and conducted the case study in the Keiskamma river catchment (including method design and data analysis).

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

Appendix A

Table A1. Agricultural production in the four villages.

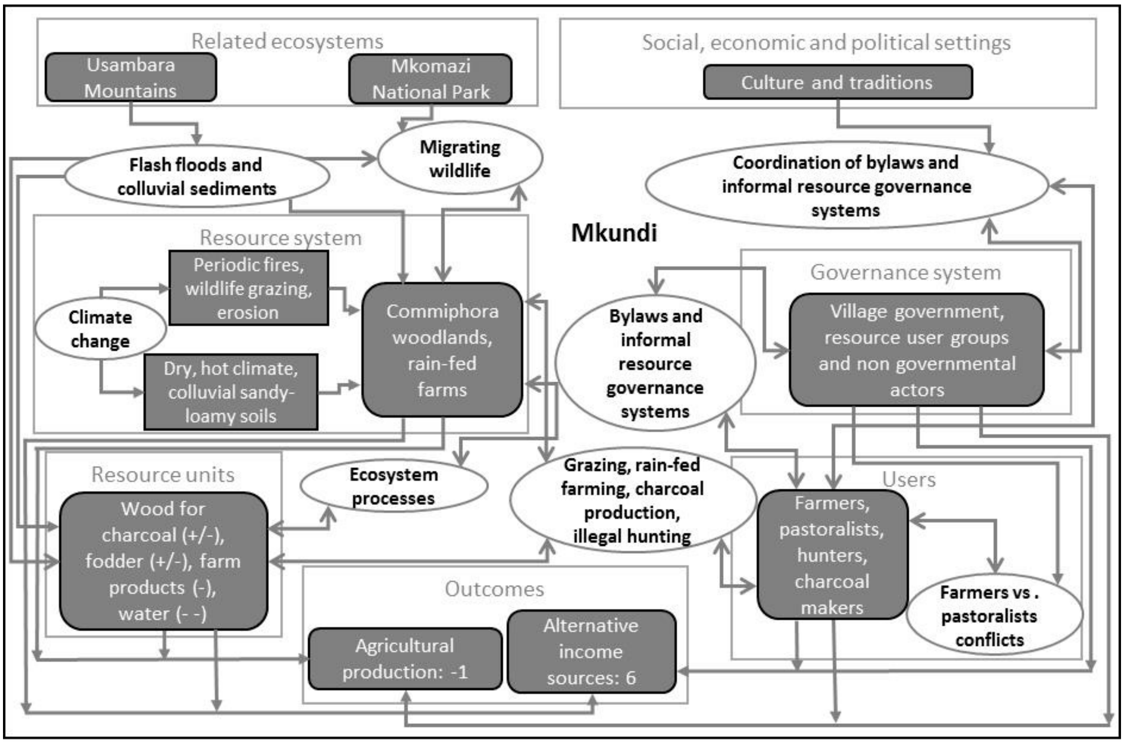
Input Data	Mkundi	Manga-Mikocheni	Mtae	Kambeni
Number of regularly cultivated crops *,†	3 (maize, cassava, lablab)	6 (maize, beans, tomatoes, rice, okra, green vegetables)	8 (maize, beans, cassava, potatoes, cabbage, green vegetables, onions, tomatoes)	9 (maize, beans, cassava, ginger, banana, tannia, onions, tomatoes, sugar cane)
Mean number of harvests per year †	0.67	1.5	2.5	3
Mean livestock number per household *	1	5	2	3
Number of times food aid was supplied during the last 5 years *	5	2	0	0

* Data from questionnaires, interviews and focus group discussions (socio-economic study); † Data from field observations and non-standardized interviews (ecological study).

Table A2. Availability and features of alternative income sources (AIS) in the four villages.

Input Data	Mkundi	Manga-Mikocheni	Mtae	Kambeni
Number of AIS *,†	3 (Charcoal, selling labour, hunting)	4 (Selling labour, fishing, remittance, hunting)	4 (Tourism, small business, remittance, timber and firewood)	3 (Small business, remittance, timber and firewood)
Contribution of AIS to village income [%] *	40	30	35	35

* Estimates based on data collected using interviews and focus group discussions (socio-economic study); † Data based on records of vegetation structure, plant traits and disturbance (ecological study).



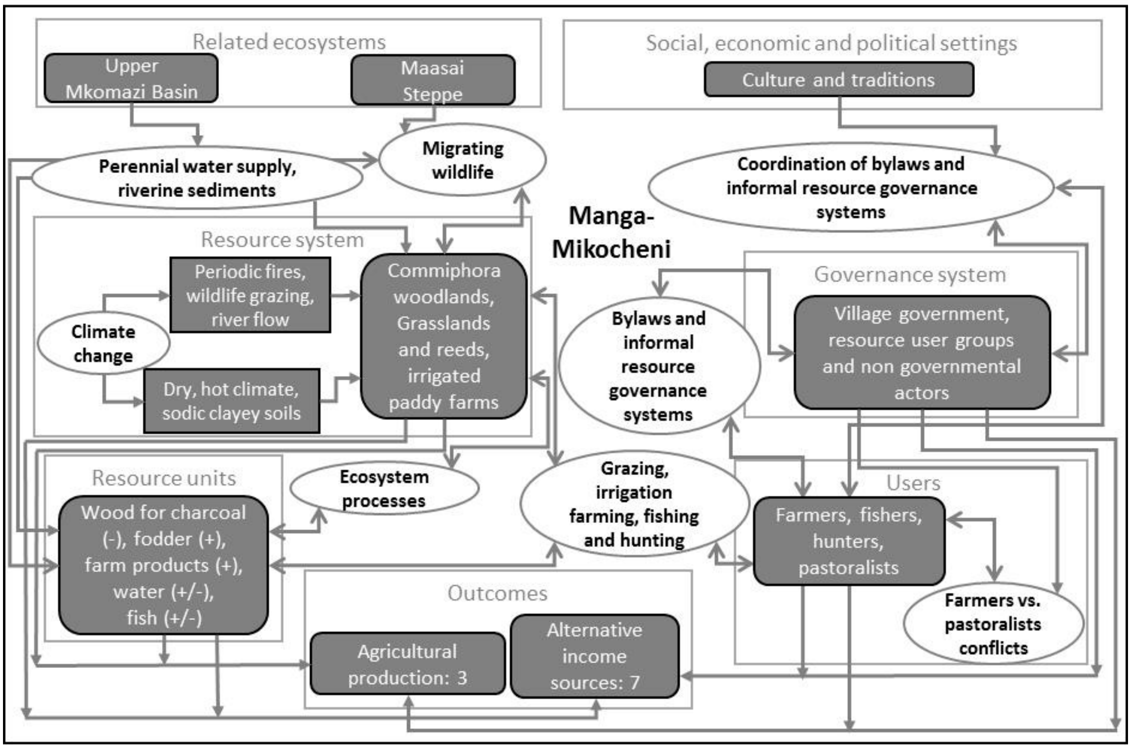


Figure A1. *Cont.*

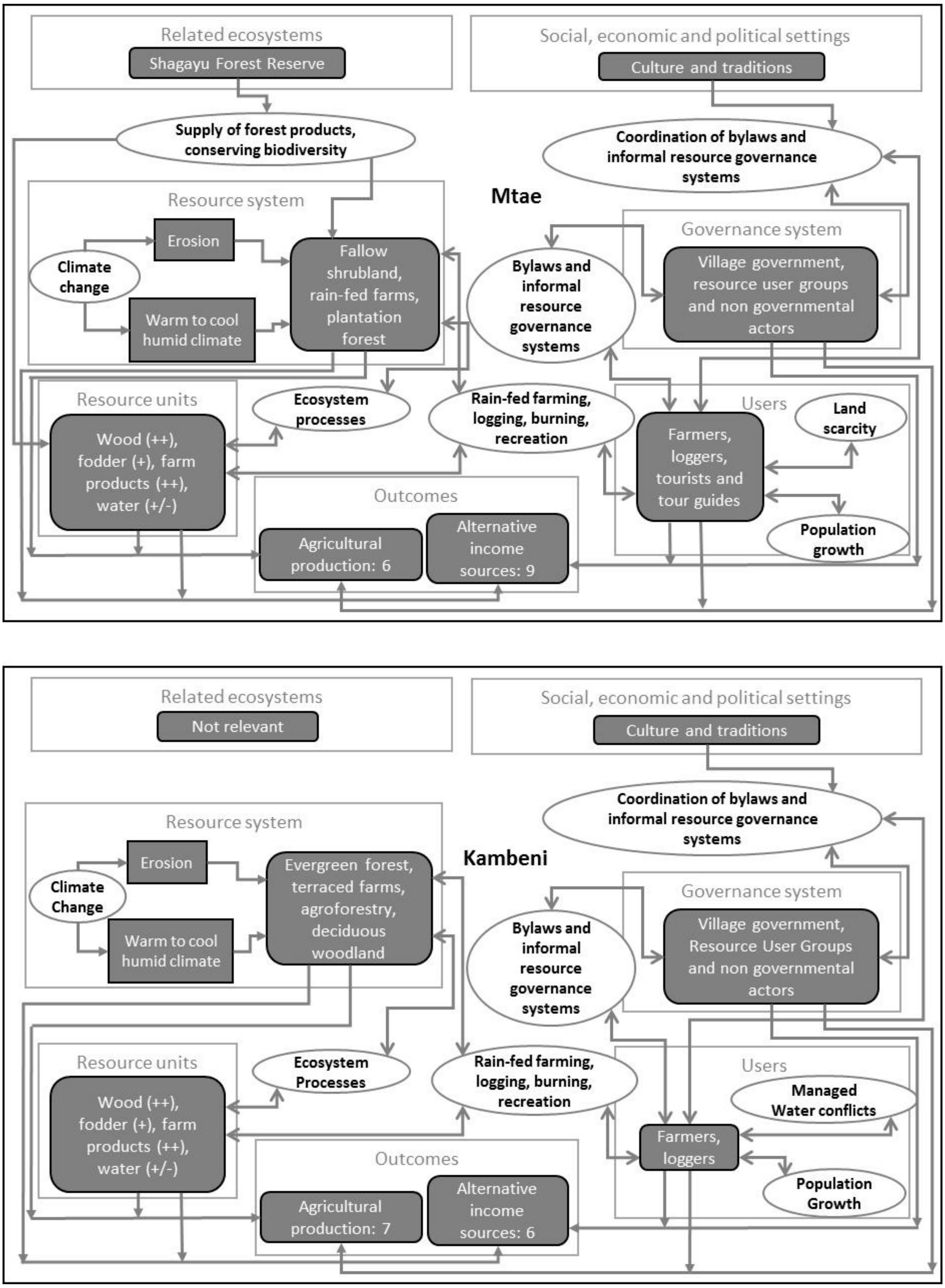


Figure A1. Village-specific application of the Ostrom framework [27] to explain different levels of vulnerability by various vulnerability determinants in four villages of Mkomazi Water Basin.

Appendix B. Research Instruments for the Socio-Economic Study

Appendix B.1. Research Instrument 1: Households/Farmers Questionnaire

1. Demographic and Socio-economic Characteristics of Respondents

General Information

Village/District:	Ward:
Region:	Name (optional):

1.1. Do you own the following? (Tick the appropriate answer)

House(s)

☐ Yes
☐ No

Land

☐ Yes
☐ No

2. Respondent's agricultural activities details

2.1. Land holding details (Please fill in the boxes indicating the amount of land in acres)

Land Area Owned	Cultivated Area in Past 20 Years	Grazing Land	Cultivated Land This Year	Land under Irrigation	Cultivated Leased Land

2.2. Land use intensity details (please fill in the boxes the amount of land in acres)

Area Cropped Once in a Year	Area Cropped Twice in a Year	Area Cropped Three Times in a Year

2.3. Crops intensity details (Please list the types of crops in the boxes)

Crops Cultivated Once in a Year	Crops Cultivated Twice in a Year	Crops Cultivated Three Times in a Year

2.4. Can you please categorize the amount of production of your farm per acre per year per crop for the good and bad years?

Crop	Amount of Land Cultivated	Production per Year (Bugs)	
		Good year	Good year

2.5. Do you mainly produce for cash or subsistence?

☐ Subsistence ☐ Cash

2.6. If you produce various crops for both cash and for food, please list down the crops you produce for cash and those ones you produce for food.

Crop Name	Subsistence or Food (tick)	Cash (tick)

3. **Perception of changes in the climate variables**

3.1. How do you perceive climate change and variability through? (Tick as appropriate)

Code	Perceptions	Tick
A	Change in amount of rainfall during main rain season	
B	Increasing rainfall in amount during main rain season	
C	Decreasing rainfall in amount during main rain seasons	
D	Shift in the timing of the onset of rain in the main season	
E	Rain starting later than normal	
F	Rain starting earlier than normal	
G	Short rains than normal	
H	Long rains than normal	
I	Planting date change applying to most crops	
J	Temperature of the area decreasing	
K	Temperature of the area increasing	
L	Rainfall increasing	
M	Rainfall decreasing	
N	Rainfall fluctuating	
O	Increase in recurrences of floods	
P	Decrease in recurrence of floods	
Q	Increase in intensity of floods	
R	Increase in recurrence of droughts	
S	Increase in intensity of droughts	

4. What has been the trend of rainfall for the past 20 years to date according to your memory? (Please tick as appropriate)

A. ☐ Increasing
B. ☐ Decreasing
C. ☐ Fluctuating
D. ☐ Constant
E. ☐ unpredictable
F. ☐ Don't know

5. What has been the trend of temperature for the past 20 years to date according to your memory? (Please tick the appropriate answer)

A. ☐ Increasing
B. ☐ Decreasing
C. ☐ Fluctuating
D. ☐ Constant
E. ☐ Don't know

6. Information on existing adaptation strategies and motivating factors

6.1. Please tick in the appropriate box matching the factors that motivated you to change farming practices (listed in the first row) against the changes that you have made in response to changing climate (listed in the first column).

Adaptation Strategies	Possible Factors						
	Negative CC Effects	Financial Capital	Income	Good Markets	High Living Costs	Others Influence	Household Size
Shift to higher yielding crop varieties							
Introduce new crop varieties							
Shift to shorter cycle crop varieties							
Stop cultivating some crop varieties							
Shift to crops that command good market prices							
Shift to drought resistant crop varieties							
Intensify irrigation							
Diversify household income sources							

6.2. In the third column, please provide more details including examples regarding the adaptation strategies you have been using

Code	Adaptation Strategy	Details on the Responses (e.g., the New Crop Varieties, Other Economic Activities Opted for etc.)
A	Shift to higher yielding crop varieties	
B	Introduce new crop varieties	
C	Shift to shorter cycle crop varieties	
D	Stop cultivating some crop varieties	
E	Shift to crops that command good market prices	
F	Shift to drought resistant crop varieties	
G	Intensify irrigation	
H	Diversify household income sources	

7. Socio-economic implications of the impacts of the changes farmers have made in their farming practices as adaptation options

7.1. What are the socio-economic implications of the changes you have made (as your adaptation to the changes in the local climate that you have been experiencing) at your household as well as at the community level? Please fill in the two blank columns as appropriate.

Code	Implications	Details on the Implications	Level (H = Household or C = Community)
A	Average annual income has increased		
B	Average annual income has decreased		
C	Awareness on climate change has risen		
D	Water shortage for domestic and other uses		
E	Human health threats have increased		
F	Food insecurity threats have increased		
G	Quality of life deteriorated		
H	Migrations increased		
I	Social cohesion threatened		
J	Social conflicts over diminishing resources increased		
K	Family conflicts increased		

7.2. What do you think you can do in the future to be able to adapt to the changes if they persist?

Code	Future adaptation options	Tick
A	Abandon agriculture at the expense of other economic activities	
B	Abandon the current farms and move to wetter areas like river banks	
C	Emigrate from your village to other areas with better conditions	
D	Continue changing agricultural practices in line with the changes in the local climate	
E	Ask for food aid	
F	Ask for government support like introduction of new and modern adaptation options	
G	Seek to obtain more information, knowledge and education on adaptation to climate change	
H	Promote irrigation using underground water	
I	Promote conservation practices further	

8. Policy and strategic interventions for long term resilience

8.1. What do you propose to be done by policy makers and other relevant stakeholders to help you to adapt to the changes in the long term? (Please tick as appropriate)

Code	Intervention	Yes
A	Enhance your capacity through education and training	
B	Improve institutional capacity and efficiency	
C	Improve access to credits	
D	Enhance awareness and information provision	
E	More research and dissemination of research results to farmers	
F	Respect and disseminate local experience and knowledge	
G	Develop and introduce new crop varieties to increase the tolerance and suitability of plants to temperature, moisture and other relevant climatic conditions	
H	Introduce crop insurance	
I	Support to adopt improved crop varieties, modern irrigation and agricultural related better technologies	
J	Provide the needed infrastructure in the rural areas, post-harvest support and support for agro industries	
K	Develop and/or strengthen early warning systems that provide daily weather predictions and seasonal forecasts	
L	Strengthen timely dissemination of weather forecasting information to farmers	
M	Encourage participation of private sector in agriculture investment;	
N	Undertake research to quantify the magnitude of climate change for each agro-ecological zone and advise accordingly	
O	Develop and strengthen water management innovations to address the risk of moisture deficiencies and increasing frequency of droughts	
P	Introduce and/or improve subsidy and incentives provisions to support farmers to adapt	
Q	Develop and implement policies and programs to influence farm-level land and water resource use and management practices	
R	Support diversification of agriculture as an economic activity	

Appendix B.2. Research Instrument 2: Governance Interview Guide

Interview Questions			
Information Required	**General Question**	**Possible Guiding Questions**	**Interviewees**
The long term trend of changes in the key elements of climate (rainfall and temperature) at the local level with a minimum of the past 20 years	Are there any past, present and future changes in the local climate and how are they perceived and explained by the local communities?	Are there any changes in the state of the climate e.g., rainfall, temperature for the past 20–30 years?	PBWB, DALDOs-WAEO, VCPs, Ward Councillors and Village Elders
		Why do you perceive the changes?	PBWB, DALDOs-WAEO, VCPs, Ward Councillors and Village Elders
		What are the reasons for the changes?	PBWB, DALDOs-WAEO, VCPs, Ward Councillors and Village Elders
Changes in the farming practices as a result of climate change and variability and sustainability of such changes	Are there any changes in farming practices that have been or are being made in the area within past 20–30 years ago? Are these changes sustainable?	Have there been changes in the farming practices as an adaptation response to climate change and variability?	PBWB, DALDOs, WAEO, VCPs, Councillors, Village Elders
Motivating factors for decision to change farming practices	What are the motivating factors for the local communities to make decisions in certain times to change from one farming/land use practice to another?	Does availability of good market price particular crops and crop varieties play a role in the changes?	PBWB, WAEO, DALDOs, VCPs, Councillors, Village Elders
		How does the available infrastructures and communication system motivate changes farming?	PBWB, WAEO, DALDOs, VCPs, Councillors, Village Elders
		Did perceived changes in the local climate motivate changes in the farming practices?	PBWB, WAEO, DALDOs, VCPs, Councillors, Village Elders
		Does the availability of extension and other services motivate changes in the farming practices in the area?	WAEO, VCPs, Councillors, Village Elders
		Could the availability and access to agricultural and weather information services have played a role in the changes in the farming practices?	WAEO, VCPs, Councillors, Village Elders
		Any other possible factors which motivated changes in the farming practices in the area?	WAEO, VCPs, Councillors, Village Elders
The socio economic implications of the changes to the household and community	What are the socio-economic implications of the changes at community level in the study area?	What socio-economic changes do you experience at the household as well as community level as a result of changes in the local climate?	PBWB, DACO, WAEO, VCPs, Councillors, Village Elders
Policy and strategic interventions appropriate to support smallholder farmers in the area to adapt and enhance resilience to climate change	What are the appropriate policy and strategic interventions that can support smallholder farmers to adapt to the changes they perceive and why?	What can you propose as appropriate interventions to help you to adapt sustainably and enhance your resilience to climate change and variability?	PBWB, DALDOs, WAEO, VCPs, Councillors, Village Elders

Abbreviations: PBWB: Pangani Basin Water Board; DALDO: District Agricultural and Livestock Officer; WAEO: Ward Agricultural Extension Officer; VCPs: Village Chairpersons.

Appendix B.3. Research Instrument 3: Focus Group Discussions with Smallholder Farmers

Broad Guiding Topics

(1) State of the local climate

(a) The state of the local climate in the past 30 years to-date
(b) Any changes so far (good/bad ones)
(c) Why those changes (if any)?
(d) The state of the climate to change further in the future? Good or bad?

(2) Key changes in the farming practices and their sustainability

(a) What are these changes (specifically) e.g., type and characteristics of crops, soil management techniques, water harvesting and storage etc.
(b) Timing of the changes
(c) Alternative income sources and whether they are sustainable

(3) Motivating factors for changes in the farming practices and adoption of alternative income sources

(a) Climatic conditions
(b) Economic factors
(c) Policy changes
(d) Any other

(4) Socio-economic implications of the changes in the local climate

Identification of the effects of the changes, e.g.,

- Incomes
- Water availability
- Food production and security
- Social conflicts
- Health status
- Household conflicts etc.

(5) Policy and strategic interventions for enhanced adaptive capacity and long term resilience

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