Climate Change Vulnerability of Socio-Ecological Systems in Coastal Areas of River Basins in Mexico and South Africa – from Assessment to Management

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Summary

Climate change vulnerability of socio-ecological systems in coastal areas of river basins in Mexico and South Africa – from assessment to management is the ambitious plan with which the journey started. The aim is to reach a generally applicable vulnerability assessment framework, offering a realistic structure to similar assessments of coastal river basins and producing regional results to be directly implemented in local decision making in Mexico and South Africa. In other words, this work supports finding an answer to the question: "how can effects of climate change on socio-ecological systems be grasped?"

A geographical focus is set to two coastal riverine areas in Mexico and South Africa, offering the possibility of testing conceptual ideas in application. Further, a specific look was taken on rural livelihoods, suspecting a close interaction between the human and natural environmental sphere. Semi-structured, qualitative interviews were applied using a participatory modelling approach. This choice was based on the assumption that understanding the components determining rural livelihoods will on the one hand help define the socio-ecological system itself and on the other hand include local values forming behaviour. Participatory modelling combines capturing local perceptions and ad hoc modelling simultaneously in one interview.

Information on what resources are used to maintain people's daily lives, which major threats and changes are experienced and how they react to it, were obtained. These are used in a first step to define the central components and processes of the respective local socio-ecological system. In a second step this model of a socio-ecological system can be used as a basis for further analysis and interpretation, suggestions on potential future adverse effects due to climate change as well as possibilities for human reactions. Recognizing the complexity of processes in socio-ecological systems and the limited causal understanding of them, it immediately becomes clear that there is still a long way to go until climate change vulnerability can be assessed realistically. However, already a structuring framework and a first estimate of the situation in each case study region, as has been achieved here, offer a good basis for further steps. Motives of human behaviour are seen as key, both to understand current climate change vulnerability as well as to estimate potential future adaptation pathways.

Further steps to add to this work are identified mainly in evaluating the correctness and robustness of the established models, adding weighting factors and applying combined future scenarios. Beyond this work the suggested framework can be applied to similar case studies to verify and adapt the structure. On the conceptual side this work attempts to encourage everyone engaging in the field of vulnerability assessments to thoroughly define the core problem and necessary preconditions to achieve an appropriate result.

Zusammenfassung

Klimawandel Verwundbarkeit von sozio-ökologischen Systemen in küstennahen Regionen von Flusseinzugsgebieten in Mexiko und Südafrika – von der Beurteilung bis zum Management ist der anspruchsvolle Plan mit welchem diese Reise begann. Das Ziel ist es einen allgemein anwendbaren Rahmen für eine Verletzbarkeitsbeurteilung zu erreichen, welche eine realistische Struktur für ähnliche Beurteilungen von küstennahen Flussgebieten bietet und direkt anwendbare regionale Ergebnisse für lokale Entscheidungsträger in Mexiko und Südafrika hervorbringt. In anderen Worten unterstützt diese Arbeit das Finden einer Antwort auf die Frage: „wie können Klimawandelauswirkungen auf sozio-ökologische Systeme begriffen und erfasst werden?"

Ein geografischer Schwerpunkt liegt auf zwei küstennahen Flussregionen in Mexiko und Südafrika und ermöglicht so konzeptionelle Ideen in der Anwendung auszuprobieren. Weiterhin wurde ein konkreter Blick auf ländliche Lebensgrundlagen geworfen, mit der Annahme, dass dort ein enger Austausch zwischen dem menschlichen und dem natürlichen Umweltbereich stattfindet. Semi-strukturierte, qualitative Interviews wurden unter Verwendung eines partizipativen Modellierungsansatzes verwendet. Diese Wahl basierte auf der Annahme, dass das Verständnis der Komponenten welche ländliche Lebensgrundlagen bestimmen einerseits die Definition des sozio-ökologischen Systems selbst unterstützen und andererseits verhaltensformende lokale Werte mit einbeziehen wird. Partizipative Modellierung kombiniert in einem Interview das Erfassen lokaler Wahrnehmung und die gleichzeitige Modellierung.

Informationen über die zur Erhaltung des täglichen Lebens der Bevölkerung benötigten Rohstoffe, bedeutende, erlebte Bedrohungen und Veränderungen sowie die Reaktionen darauf wurden eingeholt. Diese werden in einem ersten Schritt verwendet um zentrale Komponenten und Prozesse der entsprechenden sozio-ökologischen Systeme zu definieren. In einem zweiten Schritt kann dieses Modell eines sozio-ökologischen Systems als eine Grundlage für weitere Analysen und Interpretationen, Vorschläge zu möglichen, zukünftigen, nachteiligen Auswirkungen des Klimawandels sowie Möglichkeiten für menschliche Reaktionen genutzt werden. Betrachtet man die Komplexität der Prozesse in sozio-ökologischen Systemen und das begrenzte Verständnis der kausalen Zusammenhänge, wird klar, dass es noch ein weiter Weg ist Verwundbarkeiten infolge des Klimawandels realistisch zu beurteilen. Allerdings konnte mit dem strukturierenden Rahmen und einer ersten Einschätzung der Situation in den Beispielregionen bereits eine gute Grundlage für weitere Schritte erreicht werden. Beweggründe menschlichen Verhaltens werden als Schlüssel, sowohl um die aktuelle Klimawandelverletzbarkeit zu verstehen als auch um mögliche Anpassungspfade einzuschätzen, angesehen.

Als weitere, diese Arbeit ergänzende, Schritte werden hauptsächlich die Evaluierung der Korrektheit und Belastbarkeit der entwickelten Modelle, die Ergänzung von Gewichtungsfaktoren und die Anwendung kombinierter Zukunftsszenarien bezeichnet. Über diese Arbeit hinaus kann der vorgeschlagene Rahmen auf ähnliche Beispielstudien angewendet werden um die Struktur zu überprüfen und anzupassen. Auf der konzeptionellen Seite möchte diese Arbeit jeden in diesem Feld der Verletzbarkeitsbeurteilung Beschäftigten dazu ermutigen das Kernproblem und notwendige Voraussetzungen sorgfältig zu definieren um ein angemessenes Ergebnis zu erreichen.

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Next to content related input the surrounding logistics played a central role. In this context I'm truly grateful to Prof. Dr. Daniela Jacob and the Helmholtz-Zentrum Geesthacht for providing me with the spatial and financial means to work at the Climate Service Center Germany (GERICS) in Hamburg. Related to the field work in Mexico I thank Dr. Rocío Rodiles and El Colegio de la Frontera Sur (ECOSUR) for hosting me as well as supporting the travels financially and organisationally. The field work in South Africa was made possible thanks to the EU-project KnowHow, with Dr. Louis Celliers at the hosting institution Council of Scientific and Industrial Research (CSIR).

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Table of content

Figures

Tables

"…we know a lot but understand very little."

(Max-Neef, 1991, p.94)

1. Introduction

In the context of climate change more and more people around the world will be and already are adversely affected in their livelihoods. In order to prevent severe damages, effective adaptation measures need to be planned and implemented well in advance. For this a thorough knowledge of the environment, central human and natural components, as well as processes surrounding and defining respective livelihoods is needed. Based on that, current weaknesses and projected future changes can be assessed. In a next step an estimate of potential adverse effects allows for planning necessary and suitable adaptation measures. Along this chain, from defining the frame of an assessment to ultimately fulfil requirements of management planning, several challenging obstacles as well as promising conceptual and methodological highlights are encountered.

Assessing climate change vulnerability is the attempt of framing a complex problem in a graspable form. Similarly to the vagueness of this first sentence the concept of vulnerability also offers a multitude of applications. They range from mostly conceptual discourses relating various theoretical approaches to vulnerability, e.g. resilience (see Gallopín, 2006; Janssen and Ostrom, 2006; Malone, 2009; Miller et al., 2010; Gitz and Meybeck, 2012; Oliver-Smith et al., 2012), risk (see Brooks, 2003; Cardona, 2003; Hoogeveen et al., 2004; Wisner, 2004; Birkmann, 2007; Welle et al., 2014;), sustainability (see Turner et al., 2003; Veisi et al., 2014) and adaptation (see Brooks et al., 2005; Vogel et al., 2007; O'Brien and Wolf, 2010; IPCC, 2014), up to specific case studies at various spatial scales, e.g. city of Toronto (see Rinner et al., 2010), coastal fishery ecosystems (see Mamauag et al., 2013) or Pakistan (see Khan and Salman, 2012). This variety is complemented by a similar multitude of methodologies and respective data including spatial analysis via GIS or remote sensing (see Taubenböck et al., 2008; Sheik Mujabar and Chandrasekar, 2011; Friedrich and Kretzinger, 2012; Reyes and Blanco, 2012), mainly quantitative (see Moss et al., 2001; Kaly et al., 2004; Holand et al., 2011; Simelton et al., 2012) or combined with qualitative assessments (see Haase, 2013; Harrison et al., 2013), as well as simulations via various model set-ups (see Hinkel, 2005; Kane et al., 2015). Resulting is a broad variety of interesting studies and publications which can only be compared and further used to a limited extent. The question why there are so many different understandings and applications of vulnerability concepts arises. In this work some light is shed into the mist of scientific concepts and terminology gathering around the common core of interest: analysing an unfavourable state and, possibilities to improve it.

The larger context of this work could also be classified as political ecology, trying to address climate change vulnerability in a way it can actually improve current livelihoods (Gebhardt et al., 2011). The topic can also be seen in a geographical context, looking at the interactions between human and natural spheres in coastal river basins, including effects relating to scale. Last but not least it should be viewed in a socio-psychological context, looking into the motivation behind specific behaviour, aiming to understand how resource use and other livelihood decisions are made. Despite the quite specific frame of this work, vulnerability as a concept has been broadly applied to various disciplines, ranging from neurosciences, to environmental sciences and computer sciences. This is illustrated when observing the Top 20 categories of the literature record generated by a Web of Science search on "vulnerability" (see Figure 1).

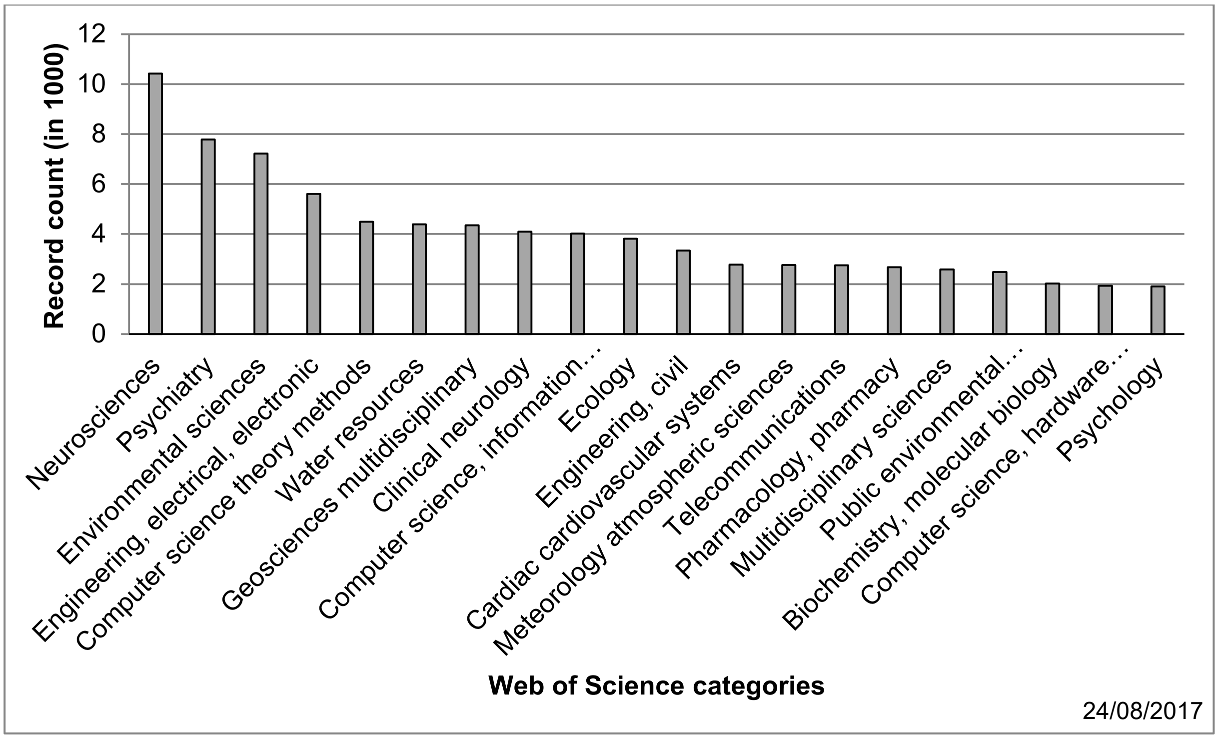


Figure 1: Search record for "vulnerability" in thousands sorted in Web of Science Categories; own visualization, search date: 24/08/2017

Originating from the hazard-risk context, vulnerability developed into a central geographical concept (Füssel, 2010). Especially with the increasing urgency of climate change and how it will affect different regions and people in the world, the number of climate change vulnerability assessments has increased and spread throughout the scientific community. This is shown by the publication numbers based on a Web of Science search for "climate change vulnerability assessment" (see Figure 2). Aims for vulnerability assessments differ between merely understanding a situation and specifically preparing the implementation of adaptation measures (Preston et al., 2011). The assessment can be focused on an ecosystem, a population group, an economic sector, or a whole region according to the focus of interest. This focus of interest is generally referred to as a system (Füssel, 2007), and in this case further refined to socio-ecological system. Applying an integrated understanding of vulnerability, resulting effects are both related to the preconditions of the system (starting-point vulnerability) and the external changes of climate related variables (end-point vulnerability) (Soares et al., 2012).

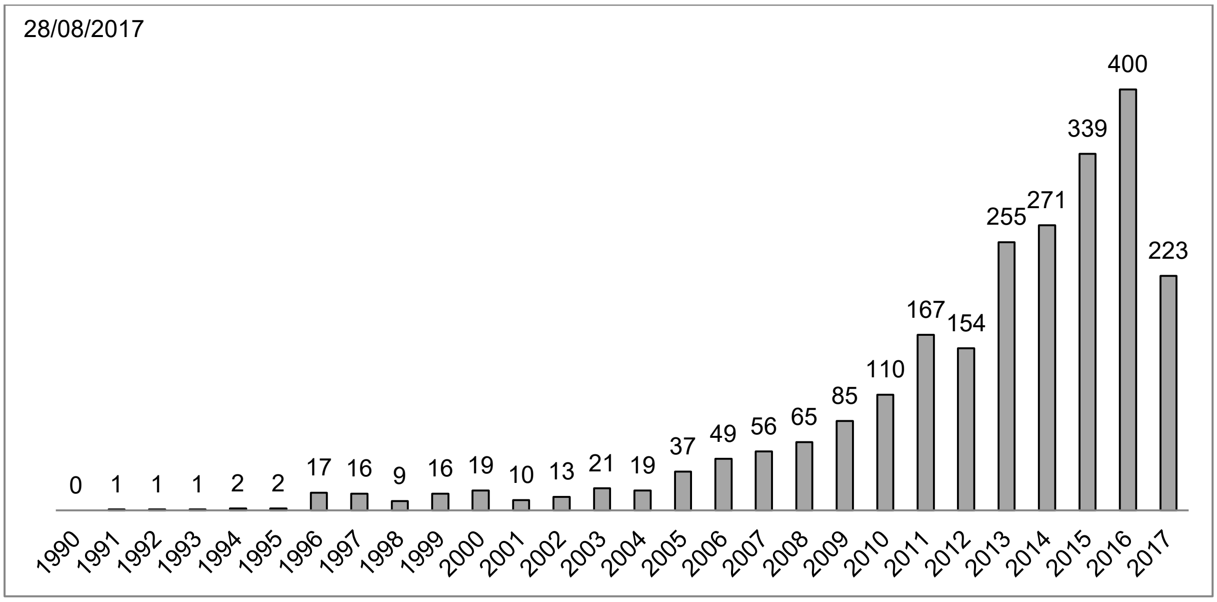


Figure 2: Search record for "climate change vulnerability assessment" per year, Web of Science; own visualization search date: 28/08/2017

In order to define the effects of climate change it is central to understand the system, its key components, interlinkages and dynamics ensuring its functionality. It is especially important to find the causes of weaknesses allowing damage to evolve, and to identify available sources for preventing damages. Talking about vulnerability always includes the notion of something being weak or insufficient and exposed to adverse effects. Even though vulnerability is a dynamic concept explicitly involving changes over time (Adger, 2006), it is commonly a current situation, perceived as unfavourable, that triggers an assessment. A vulnerable situation implicitly requests improvement. Already the literal meaning of the term vulnerable, namely to potentially get hurt or damaged, implies a necessity to change something. The broad variety of literature available on climate change vulnerability assessments also includes various reviews summarizing most important findings and highlighting remaining gaps.

Three reviews highlight the importance and remaining challenges of clear purpose and problem formulation (Füssel, 2010; Preston et al., 2011), an adequate treatment of uncertainty (Preston et al., 2011; Soares et al., 2012), and closing the gap between theory and practice (Preston et al., 2011). The communication with and involvement of stakeholders during the assessment is highly important (Wolters and Kuenzer, 2015) and helps in applying assessment results in practice (Reed, 2008). A recent review on risk and vulnerability assessments concludes that more emphasis is on the biophysical dynamics, whereas considering socio-economic dynamics are a continuing challenge (Jurgilevich et al., 2017). Similarly, in the context of coastal river deltas, a dominance of natural process analysis can be found in comparison to anthropogenic processes. This can be explained with the complexity of the latter and a lack of respective data (Wolters and Kuenzer, 2015). But even though many approaches have been undertaken and many important ideas and results are available, some confusion still remains: how do these different concepts fit together? Is there a common interest beyond terminology? And how can assessment results be compared and their quality and usefulness be ensured? It is impossible to answer all remaining questions in the context of climate change vulnerability assessments. This work aims at adding some new perspectives on how to approach such a complex task of linking theoretical concepts with the requirements of “real life”.

Assessments are often based on a scientific view point framed by a theoretical concept, and therefore there is the danger of shaping the problem for the respective scientific question (Vennix, 1996). The frame of an assessment is further influenced by resource limitations (time, financials and expertise) as well as the availability of data (Lemieux et al., 2014; Zhou et al., 2014). On the other hand management is planned and applied directly in the “real world”. This can cause a gap between scientifically framed conditions and the practical requirements, which is difficult to bridge. Considering and relating to each other can however lead to improvements for all parties. The key to bridge this gap is to involve both sides in the assessment process, which is why a participatory approach has been applied in the field work.

In this work a focus on socio-ecological systems in coastal areas of river basins limits the scope for the assessment of climate change vulnerability. The reason for writing about socio-ecological systems is first and foremost that humans and their natural environment cannot be looked at independently (Berkes et al., 1998). Especially in rural livelihoods the two are closely interlinked. However, social and ecological aspects are not equally weighted because the focus of this assessment lies on human livelihoods and which factors play a role in them. Coastal areas of river basins are both favourable due to the often rich availability of resources and are also subject to many stressors both from land- and seaside (Wolters and Kuenzer, 2015).

Linking these different aspects, the main objective is to define how to assess climate change vulnerability in socio-ecological systems, specifically rural communities in coastal riverine areas in order for posterior management options to maintain or increase the current living standard to be identified. This objective can be subdivided into a set of research questions:

1. What are the key components in each socio-ecological system ensuring the current living standard of people in rural communities?
2. Which inherent and external factors threaten or endanger the underlying functioning of the system? What climate related effects have already been experienced and how can future climate change affect the current system?
3. Which are the countermeasures to these changes and threats already implemented?

Another objective is to evaluate the possibilities and limitations of participatory modelling as a method for gathering data and assessing climate change vulnerability.

In the following chapters the context will first be set by highlighting some of the most relevant theoretical frameworks. The concept of vulnerability as the main focus of this work is compared to those of risk, resilience and sustainability (see chapter 2.1). Next, based on the focus on rural livelihoods, the sustainable livelihood framework will be described, together with the related capital theory (see chapter 2.2). In addition, capabilities, human needs and motivation for behaviour will be looked at (see chapter 2.3). To complete the theoretical frame of this work, systems theory and the socio-ecological systems approach (see chapter 2.4) will be briefly introduced before highlighting the importance of scale (see chapter 2.5) and summarizing the applied conceptual approach (see chapter 2.6). In the following chapter both case studies are presented in their general geographical context and the specificities of the visited communities (see chapter 3.1 for Mexican and chapter 3.2 for South African case regions). Chapter 4 combines the methodological context with the different analytical steps and respective results. At the beginning some theoretical input on the methodology of participatory modelling and group-model building is presented (see chapter 4.1). Based on the literature context the in here applied framework is described in detail (see chapter 4.2). Afterwards the resulting mental models are explained and summarized for each case study region (see chapter 4.3). In chapter 4.4 mental models are further analysed. First the information is structured into three tables and a current vulnerability rating is derived from them (see chapter 4.4.1). Second an emphasis is set on linkages and feedback loops (see chapter 4.4.2). A third analysis is based on two future climate change scenarios and their influence on the current systems (see chapter 4.4.3). Finally in chapter 4.4.4 the main components and linkages for both specific case regions are generalized and the derived hypotheses are summarized. All previous chapters including different conceptual viewpoints, a critical reflection on the possibilities and limitations of the methodological framework, the resulting vulnerability assessment and the specifics of the two case studies, are thoroughly discussed in chapter 5. In the conclusion and outlook some recommendations for further use of the results are given with respect to interesting additional perspectives, focus topics and methodological developments.

Added value to the broad already available scientific knowledge is given along the following three lines. First, by implementing a participatory approach, the gap between theoretical scientific perspective and practical application in “on the ground” measures is tackled. Second, the socio-ecological systems of two important rivers for each region are analysed in detail, adding local field knowledge which has not been available so far. Third, by highlighting and discussing various related conceptual ideas, an attempt is made to understand the diversity of interpretations and the core underlying interest.

2. Theoretical frame and conceptual thoughts

In this chapter a broad overview of relevant conceptual thoughts and theoretical frameworks surrounding the topic of climate change vulnerability is given. Concepts and theories are generally used in science to simplify the complexity of reality to a graspable form. However, the more complex a problem, the harder it is to agree on one specific approach to tackle it. Therefore often several different conceptual approaches exist for a similar problem. Climate change affectedness and reaction of interrelated human and natural environments is one example of a highly complex topic. In this context the main ideas of the concepts vulnerability, risk, resilience, adaptation and sustainability are introduced (see chapter 2.1). Central to the topic is also the understanding of the interrelated human and natural environments, here defined as socio-ecological systems, as well as of decision making factors motivating human behaviour and the resulting interaction with their natural environment (see chapter 2.2). Another part of the conceptual framing is the basic understanding of the structure of the topic, here looked at from the systems theory perspective (see chapter 2.3). This system dynamics thinking leads to the application of a respectively fitting methodological framework of participatory modelling (further defined in chapter 4.1 and 4.2). Last but not least scale plays a central role in most geographic issues and is therefore briefly mentioned in this context as well (see chapter 2.4). Finally this broad overview of relevant, related concepts is summarized and concluded to the applied framework in this work (see chapter 2.5).

2.1 Vulnerability, risk, resilience, adaptation and sustainability

The concept of **vulnerability** is broadly described and applied among various disciplines. In climate change related contexts vulnerability is most frequently understood as the "[…] propensity […] to be adversely affected" (IPCC, 2014, p. 1775). Independently from the conceptual components included in the understanding of vulnerability, different approaches are applied. The biophysical or physical vulnerability focuses mainly on the natural environmental components of and impacts on a system, e.g. ecosystem and climatic variables (Adger, 1996). This approach is also referred to as the end-point of an analysis. Having included the occurred impacts as well as the ability to react and recover diminishing these adverse effects, vulnerability is measured based on the remaining damages (Kelly and Adger, 2000). The social perspective includes different sources of disruptions besides climate change e.g. war, economic crises, cultural changes, affecting human individuals and groups (Adger, 1996). Often this perspective defines vulnerability as a prerequisite of adverse effects and is therefore also called starting-point analysis (Kelly and Adger, 2000). Both perspectives are combined in the integrated approach which highlights the dynamic character of each system by including interacting human and natural environmental spheres (O'Brien et al., 2004).

Despite the number of approaches and understandings of vulnerability it is rare to find an explicitly declared vulnerability theory. One of those is from a disaster perspective and relates to different effects of comparable disturbing events, such as earthquakes (Zakour and Gillespie, 2013). It relates to the socio-economic and environmental conditions leading to disastrous situations after a disturbance, including injuries and deaths, economic damages and environmental losses (Kelman, 2007; Zakour and Gillespie, 2013). In disaster vulnerability, or often also disaster risk, an estimation of future probability for the occurrence of a disturbing event, its magnitude and respectively potential damages is calculated (Zakour and Gillespie, 2013). This vulnerability definition shows the close interlinkage of the concepts vulnerability and risk. In the latest assessment report (AR) of the Intergovernmental Panel on Climate Change (IPCC) risk and vulnerability are also closely interlinked. Vulnerability is generally divided into exposure, sensitivity and adaptive capacity (IPCC, 2007) (see Figure 3, left) or only to the latter two. The core vulnerability of sensitivity and adaptive capacity is complemented to climate risk with exposure and hazards (IPCC, 2014) (see Figure 3, right). The example of the IPCC ARs shows how dynamically the concept of vulnerability is still evolving in the scientific community.

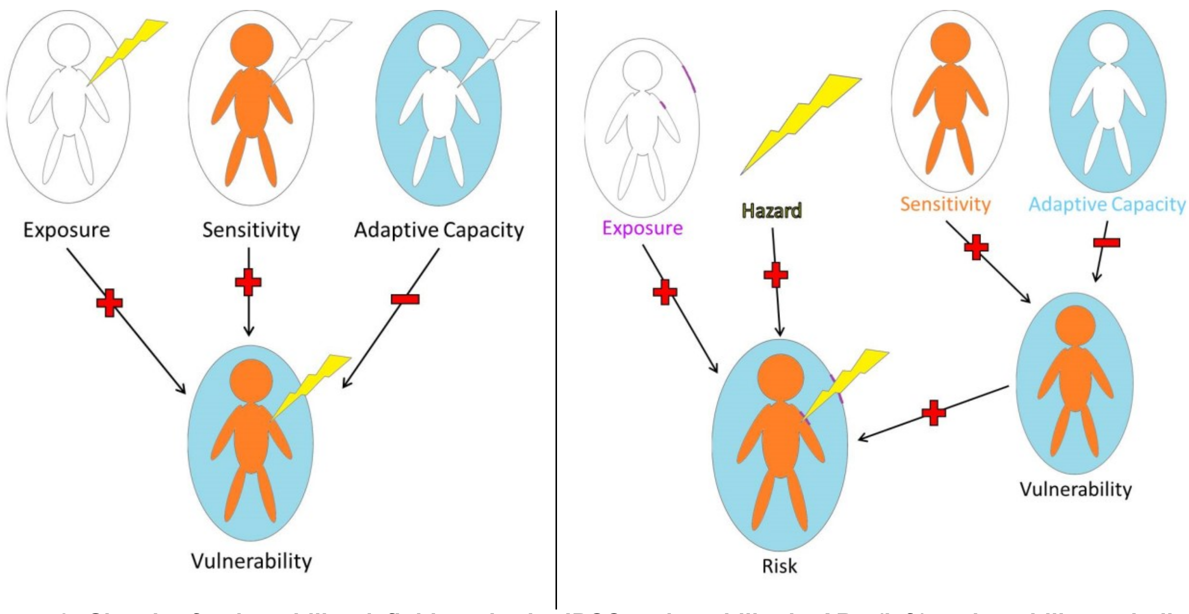


Figure 3: Sketch of vulnerability definitions in the IPCC, vulnerability in AR4 (left), vulnerability and climate risk in AR5 (right), own source

Exposure is the presence of people in affected places or in the more literal sense, any component or characteristic which allows an incoming disturbance to hit. Often exposure is directly related to a specific hazard and thus links to the theory of disaster vulnerability. Hazards are natural or human-made fast- or slow-onset changes potentially causing harm. Sensitivity or susceptibility stands for the magnitude of damage an incoming disturbance can have based on the conditions a system is in. In some concepts this is used equally to vulnerability or risk (Zakour and Gillespie, 2013). Susceptibility can further be divided into liabilities on the one side and capabilities on the other. Liabilities summarize all system components and processes increasing the effects of disturbances. Capabilities describe capitals allowing the system to mitigate, react and prepare (Zakour and Gillespie, 2013). Capabilities are also closely related to adaptive capacity, which defines how well the affected system can react, cope and adapt to the adverse effects of incoming disturbances (Smit and Wandel, 2006). This definition of susceptibility divided into liability and capability is reminiscent of the understanding of vulnerability divided into sensitivity and adaptive capacity. Similarities between components and overall concepts show the difficulties encountered when trying to clearly distinguish between them.

Varying time and perspective, sensitivity and adaptive capacity can also be seen as two sides of the same coin: one is high, when the other is low. This is especially the case, when the source for both is the same. Thinking about the effect of a flood on a low lying built-up area close to the river, one can argue that the sensitivity is high, because the houses are built of weak material, which ultimately leads back to the potential source of no financial means being available to use more robust material or building techniques. These lacking financial means, on the other hand, can also be the source of low adaptive capacity in the sense of not being able to rebuild houses quickly or even to build dams to decrease potential future damages (see Figure 4). Of course, this example presents only one component, and many more could also be distinct from each other when looking at sensitivity and adaptive capacity. Still, this shows how difficult it is to separate the influences on vulnerability within the conceptual subcomponents.

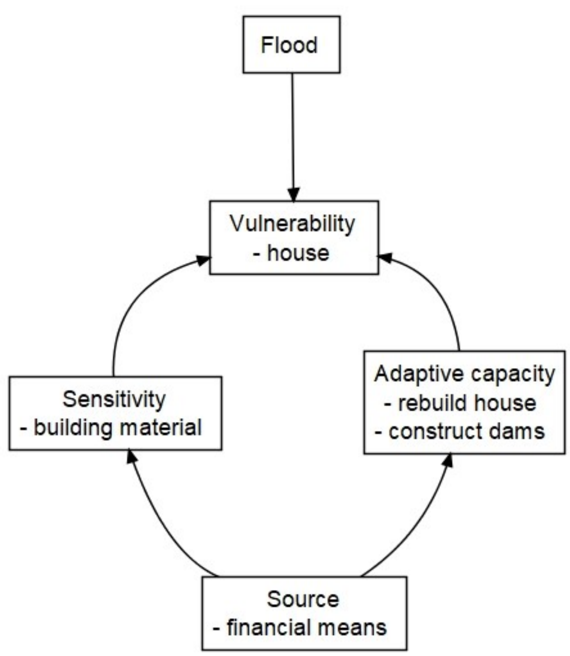


Figure 4: Flow chart showing an example classification of sensitivity and adaptive capacity for a fictional flood event, own source

Another example shows how at first sight exposure, sensitivity and adaptive capacity seem to relate to the same origin. However, when examining the common origin more closely, several related factors are revealed. When we imagine an old woman who has a high vulnerability to getting ill, this can be related to a multitude of factors. Is she more exposed to a threat, such as an illness, because she has to go to the hospital more often, and being surrounded with other ill people increases the risk of getting ill herself? Is she more sensitive to a threat such as an illness because her immune system is weakened by age, or is she less able to adapt to a threat such as an illness, because pensions are not high enough to cover additional health costs? All of these factors link to age and health, although when looking at the whole issue more closely, they can be further specified. While being surrounded by ill people adds to the exposure of the old person, it can be lead back to the external characteristic of the health infrastructure, not offering a high enough standard to avoid the risk of getting ill. The probability for her to get ill due to her weak immune system represents a part of her sensitivity to viruses and bacteria surrounding her. Last but not least, her financial situation possibly already contributed to her weakened state and further limits the possibility to pay for better health services as well as to adapt to her weakened state (see Figure 5).

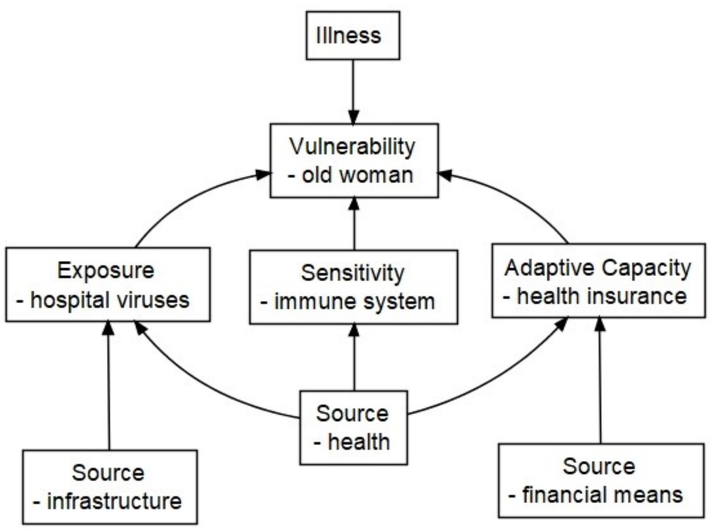


Figure 5: Flow chart showing an example classification of exposure, sensitivity and adaptive capacity for a fictional age-related health vulnerability case, own source

Beyond the conceptual components of exposure, sensitivity and adaptive capacity, the core of every attempt to frame vulnerability lies in the desire to assess vulnerability, to define where vulnerability starts and where it ends, what it means to be vulnerable and what needs to be done to improve this unfavourable situation. If we take the mathematical approach we can argue that when vulnerability (V) increases with exposure (E) and sensitivity (S), but decreases with adaptive capacity (AC), then: $V = E + S - AC$ (Monterroso et al., 2012). To answer the question of when vulnerability starts and when it ends, one could say it starts when $V > 0$, and ends when $V \leq 0$. Expressed in terms of the three components, this means when $E + S > AC$ a system is vulnerable, and when $AC \geq E + S$ it isn't. But this still can only be applied when numbers are available for each component. Another related approach is to define thresholds. For example, when one categorizes exposure and sensitivity as being below critical and adaptive capacity as being above necessary, the system is not vulnerable. But then again the question arises of who defines and how these thresholds are defined. Suddenly the problem turns from being purely scientific to highly political, philosophical and ethical. The thoughts also return to the beginning of this chapter and whether vulnerability can really be simplified in exposure, sensitivity and adaptive capacity? Or the other way round, what does vulnerability need the subcomponents for, other than explaining what is meant with the term? All in all vulnerability can be summarized as describing the potential of being adversely affected, due to some internal and external circumstances.

The concept of **risk** focusses mainly on the physical level of calculable damages (Cardona, 2003). It interacts with the understanding of vulnerability, by including several similar components such as exposure and sensitivity, as mentioned above. The definition of risk is based on hazard and vulnerability (UNISDR, 2004), and is applied to estimate damages related to the frequency and strength of potentially damaging events as well as the conditions of the affected components, e.g. the sensitivity of the building material. It is argued that risk and vulnerability are inseparably linked, because without vulnerable features, there is no risk for damage and without the risk for a hazardous event to occur, vulnerability is not present (Cardona, 2003). However, vulnerability can reveal itself in many different ways and physical damages after a disrupting event is only one of the appearances. Another possibility is the degradation of livelihoods based on gradual changes of natural environmental components, which cannot clearly be linked to an estimable temporal and spatial frame. Thirdly, vulnerability can be seen as a passive weakness, which might not yet have caused any adverse effects, but might lead to some unknown challenges. The latter is hard to define, as there is no current hint about possible reasons and causes for future challenges.

With **resilience theory** another theoretical concept which defines the ability of a system to withstand or absorb disturbances without changing its structure (Gunderson, 2000; Turner et al., 2003) is introduced. On the one hand, resilience is used as a measure for stability and the time a system needs to return to a desirable steady state. On the other hand, when a system has several desirable states, resilience is used as the magnitude of disturbance needed for the system to change states. The first definition is also called engineering resilience (Gunderson, 2000) or resistance, describing for example buildings and infrastructure (Zakour and Gillespie, 2013), whereas the latter is called ecological resilience and mainly refers to ecology, ecosystems and their functional biodiversity (Gunderson, 2000). Both of these definitions can be connected to vulnerability concepts. The resistance of buildings and infrastructure is central in the hazard-risk perspective of vulnerability, defining the damage which will occur when a certain event strikes. Having several desirable states available based on the central functions of the system links to the assumption that rural communities are vulnerable when a life ensuring functioning is threatened. More general resilience can also be linked to adaptive capacity, describing the ability to alter the conditions of maintaining the desired state as well as the thresholds of switching to another state (Gunderson, 2000). Some scientists relate vulnerability and resilience either as being opposite to and precluding each other (see Luers et al., 2003; Mamauag et al., 2013), or as being part of each other (Turner et al., 2003). Both concepts are linked to each other by looking at a system and how it deals with disturbances (Miller et al., 2010).

Adaptation is generally understood as the actual process and result of a system adapting to slow- and fast-onset changes. While adaptive capacity merely stands for potential adaptation (Smit and Wandel, 2006), such as available financial means, knowledge and interest in improving, actual adaptation measures can still be far from implemented. The latter is not only based on what is theoretically available, but what is mobilized under the respective, political, institutional and cultural conditions, just to name a few (Luers, 2005; Smit and Wandel, 2006). Adaptive capacity is used in both concepts leading to either increased resilience (Gunderson, 2000) or decreased vulnerability (IPCC, 2014), which again supports the argument that they are not only related but connected to each other. A core development and adaptation strategy fulfilling the needs of present societies, whilst at the same time ensuring the needs of future generations to be met, is **sustainability** (Brundtland, 1987). The sustainability concept is often applied in land use and resource management, looking at the environmental, social and economic spheres (Hansmann et al., 2012). Thereby the concept of sustainability supports development strategies to cover the needs of the poorest on the one side and to implement limitations through technology to secure environments resources on the other side (Berkes et al., 1998).

All of the described concepts are related to each other in some way. Here the commonalities and differences between these concepts are briefly emphasised. These overlaps are presented in a generalized way and vary strongly based on the respective interpretation and application of the concepts in different cases. All concepts are concerned with an actually or potentially unfavourable situation, as well as the necessities and possibilities to improve it. While vulnerability mostly focussed on the causes of the unfavourable situation, risk often looks at the outcome and calculable damage of this situation. Resilience defines the limits to the unfavourable situation and indirectly highlights the potential for improvement. Adaptation and sustainability describe pathways out of the unfavourable situation. From the conceptual viewpoint, vulnerability and risk share the components of exposure, sensitivity and adaptive capacity. Risk incorporates vulnerability and also shares the component of hazard or disturbance with resilience. A considerable resource and/ or knowledge stock can be interpreted as adaptive capacity in vulnerability, as a basis for renewal in resilience, and as provision for future generations in sustainability. In the assumption of decreased vulnerability via a sustainable lifestyle and resource use another linkage is considered between vulnerability and sustainability (see Figure 6).

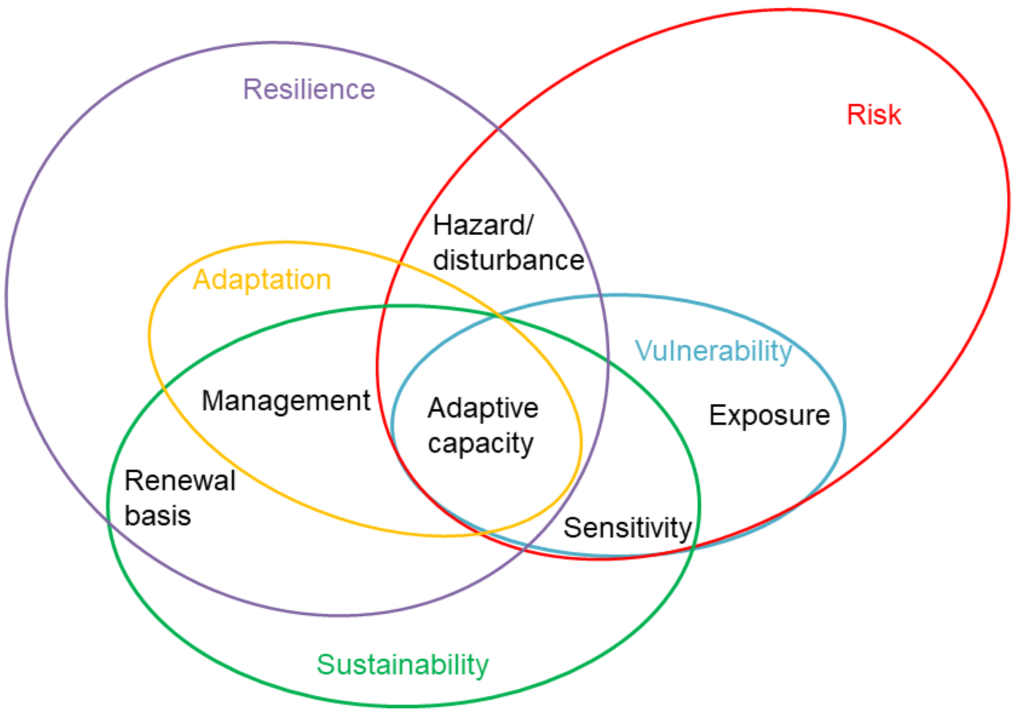


Figure 6: Conceptual framework of linkages and overlaps between vulnerability, risk, resilience, adaptation, sustainability and its main components; own source

All of these concepts are relevant when looking at climate change vulnerability of rural communities in coastal river systems. To understand the main processes in these interacting human and natural environmental systems human behaviour plays a central role. Therefore in the following chapter an insight into concepts related to human behaviour is given.

2.2 Human behaviour, sustainable livelihoods and socio-ecological systems

Understanding **motives of behaviour** of individuals and groups is important to estimate the adaptation potential for future long term changes as well as the current flexibility in case of fast-onset variabilities and extreme events. Every human has individual motives for behaviour. Still, some general assumptions can be made. First and foremost there are basic needs to be fulfilled. These include for example hunger and bodily health (Maslow, 1943; Max-Neef, 1991) and are comparable for all people. Additional motives are wishes and wants, which go beyond survival relevant needs (Scheffran and Remling, 2013) and vary highly based on the individual and cultural setting. These central motives are referred to as livelihood aims in this work. Structuring components in behaviour are individual as well as societal norms, values and rules. Through interaction and communication between actors, norms and values are established and can turn into a culture, which again controls and forms norms and values to act upon (Morel et al., 2001). These steering components can act as both motivating and restricting to individual behaviour. Furthermore, the abilities of people are determined by their available knowledge and resource means, and influence which needs, wants and wishes are transformed into actions. These abilities are referred to as capabilities (Sen, 1997; Nussbaum, 2003) or capital in the case of producing an economic turnover (Berkes et al., 1998). The set of capitals vary by applications, and can be categorized into a choice of human, social, cultural, political, natural, environmental, produced, physical and financial capital (see Berkes et al., 1998; Scoones, 1998; Bebbington, 1999; Department for International Development, 1999; Máñez et al., 2014; Lienert and Burger, 2015). Alongside the societal and cultural context, all other current framing factors, such as the economic, political or environmental situation, play a role in the capabilities and behaviours of people.

A livelihood is generally defined by the person or group of people in focus, their knowledge, abilities and resources available for living (Chambers and Conway, 1991). **Sustainable livelihoods** cover all capabilities, assets and activities necessary for living, while still being able to cope and recover from disturbances and at the same time ensuring the natural resource base (Scoones, 1998). Combining sustainability and fulfilling livelihood goals do not necessarily work together. Strict sustainability criteria can constrain well-being, in the same way that increasing welfare can lead to unsustainable resource use (Stern, 1997). In the sustainable livelihoods framework (SLF) these main components of the livelihoods are set into context with the surrounding system, available resources, livelihood strategies, aiming at specific development outcomes and supporting institutional processes (Scoones, 1998). **Socio-ecological systems** (SES) represent the close interaction between humans and nature (Berkes et al., 1998). The approach to analyse all components involved in the socio-ecological system and how they interact with each other is based on the systems theory which is introduced in the following chapter.

2.3 Systems theory and system dynamics modelling

To tackle the complexity of the topic, **systems theory** is applied as an overarching theoretical part of the framework. A system is generally understood as individual components interacting with each other for a common purpose. Components can be humans or many other things, e.g. plant or animal organisms. Systems theory strives to describe principles underlying all types of systems, e.g. physical, biological, social (Forrester, 1972). Independently from an apparent simplicity of a system, its behaviour can be highly complicated, exacerbating the understanding and analysis of it (Wolfram, 1988). The interactions between components can remain within the system itself or connect to the external environment (Fieguth, 2017). Generally it is assumed that complex systems have closed boundaries, meaning components inside act and react without essential influence from outside (Vennix, 1996). Closed connections form feedback cycles with an enhancing or diminishing (positive) as well as with a stabilizing (negative) effect on the system (Forrester, 1972). The behaviour of system components is driven by decisions which are based on the state of the system or how the state is perceived (see Figure 7). In case of complete information perceived and actual state are equal. However, in most cases, perceptions differ between persons and the objective reality. Perceived and actual state diverge with increasing complexity of the system (Forrester, 1972). Actions are generally based on the perceived state of the system (Vennix, 1996), which explains why it is of major importance to involve local perceptions in any attempt to manage or improve the respective local situation.

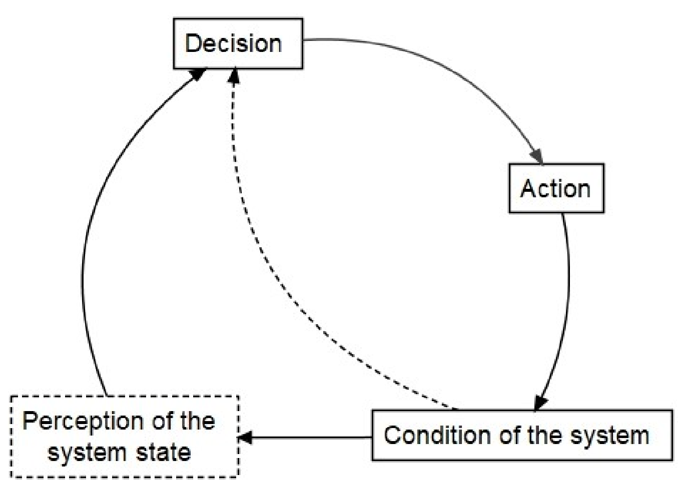


Figure 7: Schematic flow chart visualizing the mechanism of feedback cycles; own source adapted from Forrester (1972)

The systems theory is the basis for understanding and modelling the socio-ecological system, its relevant components and interactions. One central assumption before creating a model is that the current situation is problematic. However, this problem needs to be further specified according to the specific case. To understand complex problems, such as vulnerability of socio-ecological systems, a holistic view and multidisciplinary analysis is both necessary and desirable (Carruthers and Chambers, 1981). An approach to complex problems is group model-building (Rouwette, 2003) resulting in a system dynamics model. This approach is applied in this work and is described in detail in chapter 4.1.

Developing a **system dynamics model** can be subdivided into the qualitative stages of identifying the problem and conceptualizing the system, as well as the ensuing quantitative steps of formulating and calibrating the model, analysing its behaviour, analysing policy, evaluating and finally implementing the model, e.g. to support local decision-making processes. Independently from qualitative and quantitative modelling, the aim of system dynamics modelling stays the same: identifying the causes and feedback processes of the identified problematic situation. Even though quantitative modelling offers more insights into the specifics of the underlying dynamics, a qualitative model already supports mutual understanding and problem solving (Vennix, 1996). Ultimately, a system dynamics modelling approach is successful when its results can be applied in practice and improve the situation (Rouwette, 2003). System dynamics modelling is used to solve or at least increase the understanding of complex problems (Morrison-Saunders et al., 2015). However, next to the complex structure of the underlying system, limited processing capacity, employed biases and ignored feedback processes of individuals and groups (Vennix, 1999) can exacerbate the finding of solutions and decisions (Bérard, 2010).

When starting the modelling process with the models built during the group model-building exercises, influences between components can be derived. In a next step this influence map is transformed into levels and rates forming impact chains and feedback loops. Complex systems can be defined along the number of involved elements as well as linkages and functions connecting them (Bérard, 2010). The challenge is to decrease the complexity of the socio-ecological system in focus to a manageable level without missing any significant causal links (Tuler et al., 2009). The dynamic in system dynamics modelling is related to a systems' time dependency, actor interactions, feedback structures and counterintuitive behavioural reactions (Bérard, 2010). System dynamics models can be built at various scales. However, for the application of vulnerability assessment results, the chosen scale is especially critical. Therefore in the following chapter the importance of an appropriate scale in vulnerability assessments is briefly introduced.

2.4 Necessity of appropriate scale

There are three viewpoints on the scale requirements for vulnerability assessments: firstly from the conceptual side of vulnerability and system understanding, secondly from the implementation and decision making side and finally from the data availability side (Fekete et al., 2009; Kienberger et al., 2013). To bring these sometimes diverging framings together, up- and downscaling can help to transfer information between different scales. However, losing valuable information on system processes (Kienberger et al., 2013), or lack of comparability and generalizability, have to be considered as limitations of the process (Fekete et al., 2009). The choice of a spatial scale is relevant in terms of extent and resolution of the assessment (Gibson et al., 2000). Will the assessment cover a single village or the whole world, should it aggregate the units up to country level or does it only need to consider individual persons? The temporal scale also plays a role both in the data collection and the assessment. On the one hand the data availability influences whether the assessment is static or dynamic. The conceptual context of climate change vulnerability is dynamic (Birkmann, 2006).

Absolute and relative scales are used with different aims (Gibson et al., 2000). On the one hand, absolute spatial scales describe structures along a fixed hierarchical scale, e.g. a single tree or a lake is descriptive of local landscape structures, ecozones like the tropics are descriptive of the regional structures and ocean circulation stands for the global structures. Another possibility of absolute scales is based on the political-organizational level, differentiating between cities, counties, countries, unions and international forums. On the other hand, relative scale is focussed on processes and can be applied at each level of the absolute scale, describing the system at focus as internal and its surrounding environment as external.

2.5 Specific framework – compared and summarized theoretical context

All in all, this work is based on a holistic understanding of vulnerability: the complete socio-ecological system with all natural and human components as well as interactions relevant for ensuring current rural livelihoods, needs to be considered. Missing resources, insufficient structures, lacking knowledge and increased frequency of damaging events are possible reasons for an unfavourable situation. Existing deficiencies in the system have caused, or are expected to cause, adverse effects, like physical damage, and may lead to endangering current livelihoods. This possibility is a motivation not only for understanding and assessing the system and its vulnerability, but also to ultimately contribute to the improvement of it. The improvement, development or adaptation is therefore included as the inherent aim to assess vulnerability. Exposure, sensitivity and adaptive capacity as conceptual subcomponents of vulnerability are not further used in the applied assessment structure, because they are seen as mainly valuable to conceptually explain the framing. As highlighted in the previous chapters, also vulnerability itself represents a set of problems which can easily be framed in other terms as well. To avoid unnecessary confusion, here vulnerability is often circumscribed in more direct terms, e.g. how many livelihood aims depend on certain resources and which threats affect these resources (see chapter 4.3 for further explanation).

From the concept of resilience this work transfers the understanding, that disturbances and occurring damages are not necessarily bad for the whole system. It is further assumed that a vulnerable system can be resilient and a resilient system can be vulnerable. Likewise a vulnerable system doesn't have to be resilient or the other way round. Vulnerability and resilience are used as two perspectives giving different information about the condition of a system. An implicit aim of development and adaptation within the rural livelihoods is to maintain the current livelihoods, even under future climatic changes, and if this is not possible, to achieve another form of livelihood which allows people to live in at least similar conditions like today. This can also be linked to resilience thinking.

A prerequisite for maintaining current livelihoods is seen in sustainability thinking. By using available resources considerately today, future livelihoods can still depend on the same resources. The availability of resources secures resource dependent components of life, e.g. nutrition or income, and therefore contributes to a lower vulnerability. Furthermore a considerate natural resource use supports a healthy ecosystem, which is less prone to disturbances. By focusing on the resource use of the rural communities and their strategies to overcome disturbances and cope with changes, central ideas of the sustainable livelihood framework (SLF) are taken up (see Scoones, 1998). For the definition of rural livelihoods, both the SLF and the socio-ecological system understanding are combined. Figure 8 shows the here applied understanding of a typical rural livelihood, where household individuals are at the centre, interacting with and shaping their close surrounding consisting of natural and anthropogenic land- and water-based environment, indicated by the thin orange arrows. The thick arrows visualize the direct (solid line) and indirect (dashed line) influences from the more distant environment. While the main components are connected by thin arrows and symbolize the internal system, external influences (bold arrows) also have an unneglectable influence.

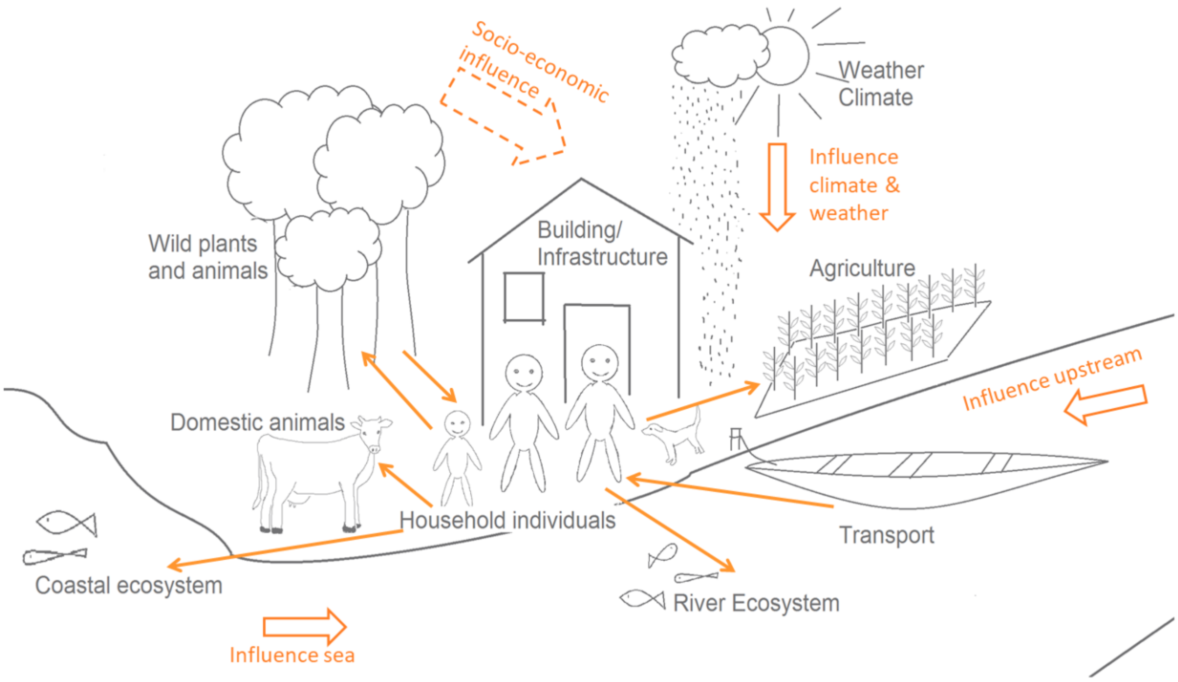


Figure 8: Sketch of a typical rural livelihood, interactions and resource use indicated in orange, thin arrows visualizing internal interactions and bold arrows external influences; own source

Another layer needs to be added to the understanding of a socio-ecological system: human behaviour. Especially behaviour motivation is seen as a central component driving activities and ultimately the security of livelihood aims, or in other words current vulnerability. Furthermore current human behaviour indicates the possibility or willingness to change patterns and successfully adapt to future changes. This conceptual thought has to remain conceptual throughout this work, because the needed data as well as psychological knowledge is not available. Therefore a combined assessment of livelihood aims allows only for a first estimate of potentially behaviour motivating factors in this work.

For complex and problematic situations, like the one at hand, system dynamics modelling is one approach to capture the complexity. In the present work the problem is generally assumed to be vulnerability towards climate change impacts. The complexity is given by the different human, socio-economic and natural environmental components relevant and interlinked in the rural livelihoods in coastal riverine areas. This automatically sets the scale for the assessment: local. Even though climate change is a global phenomenon, the local scale is seen as most relevant as implementation of adaptation measures takes place locally. Additionally, changes manifest themselves at the local scale and become most tangible for peoples livelihoods and behaviour. Therefore the extent is subnational, summarizing several villages in one region, while the resolution is based on the household level. The temporal basis of analysis is a one-time data collection via interviews due to lacking information on the needed spatial resolution (for further details see chapter 4.2). However, by taking into account potential future changes related to climate change some dynamics are applied. Furthermore, the application of a system dynamics model implicitly sets the frame for involving further dynamics through impact chains and feedback cycles.

In whichever scale context an assessment is set, it always needs to be taken into account that processes and components from different levels are interconnected. While the focus of the assessment may be at the local scale of human-environmental interactions in coastal riverine areas, influences go up to the global scale, where ocean circulation patterns influence local weather and climate along the coast as well as down to psychological and neurological processes defining decision making and human behaviour (see Figure 9). These interlinked scales complicate the understanding and modelling of socio-ecological systems. Although the consideration of the full range of scales exceeds the scope of what is possible in this work, the awareness of its relevance forms the larger context.

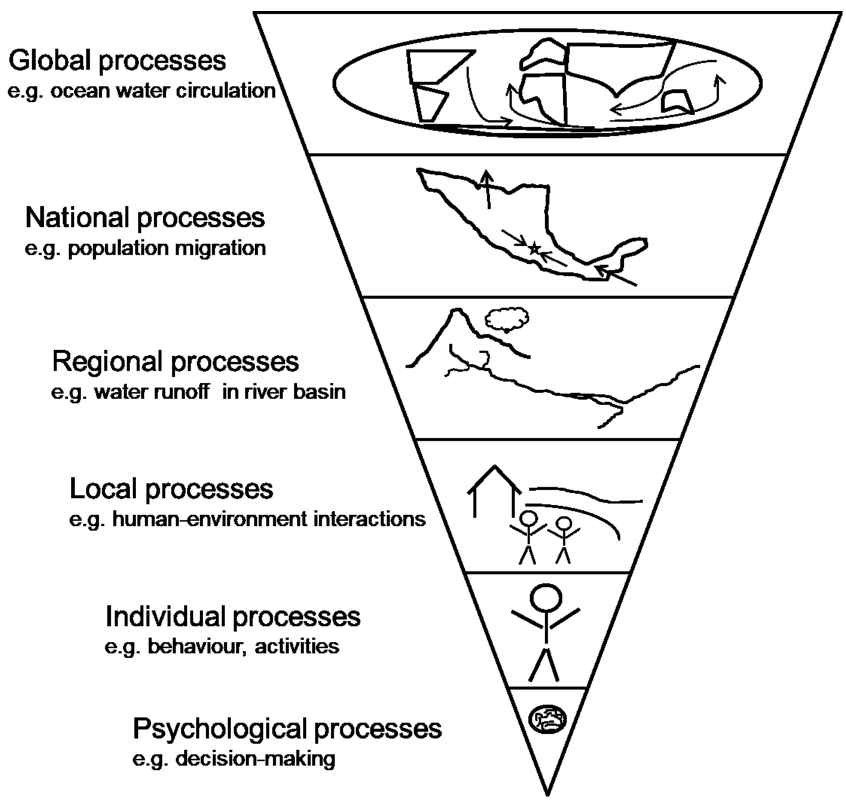


Figure 9: Sketch of different spatial levels influencing and defining each other; own source

These summarized conceptual ideas and theoretical approaches defining the analytical framework of this piece of work, are based on the digestive thoughts inspired by an extensive literature review and by experiences during field work. Before proceeding to the methodological framework and results (see chapter 4) the field study regions are introduced in the following chapter.

3 Case study regions

The introduced research questions, with the theoretical context of vulnerability and related concepts are applied in two case study regions. Both are situated in the coastal proximity of regionally important river basins. The Usumacinta River in Mexico and the Mkhomazi River in South Africa were visited with the aim of assessing local resource and land use behaviour. In the following, the two regions are introduced in a general geographic manner, highlighting river, climate, natural and societal characteristics, as well as looking at the main threats and experienced changes in conditions and processes of the socio-ecological system (see chapters 3.1.1 and 3.2.1). Additionally, a brief insight on the specific rural communities visited is given (see chapters 3.1.2 and 3.2.2).

3.1 Usumacinta River, Mexico

The Mexican case study region is situated in the states of Tabasco and Campeche in the South East of Mexico at the Southern Coast of the Gulf of Mexico (see Figure 10). This coastal region of the Usumacinta River basin is defined by an especially high biodiversity (Yáñez-Arancibia et al., 1999; Reyes et al., 2005; Gandin, 2012; Muñoz-Salinas and Castillo, 2015; Tapia-Silva et al., 2015), protected in the Laguna de Términos Protected Area and Reserva de la Biosfera Pantanos de Centla. Together they encompass an area of about 10.000 km² (Parks Watch, 2003; Montalvo-Urgel et al., 2010), and include the visited communities of Boca Chica, Palizada, Quintín Aráuz and Tembladeras. The fluvio-estuarine ecosystem is formed by the bifurcating rivers Grijalva and Usumacinta, as well as their distributaries, e.g. Palizada River (Álvarez-Pliego et al., 2015).

Figure 10: Overview of the case study region in Mexico; adapted from Google, Data SIO, NOAA, U.S. Navy, NGA, GEBCO (2016)

3.1.1 General geographical description of the larger region

The **Usumacinta River** originates in the Sierra de los Cuchumatanes in Guatemala and traverses parts of the Mexican States Chiapas, Tabasco, Campeche, Veracruz and Oaxaca before entering the Gulf of Mexico (López, 2009; Gandin, 2012; Muñoz-Salinas and Castillo, 2015; Kemp et al., 2016). In the lower basin, the Usumacinta and the Grijalva River combine and bifurcate frequently. Therefore, different definitions of river length, catchment size and annual discharge can be found in the literature. With a length of more than 1000 km (Lorenzo-Márquez et al., 2016) the Usumacinta is the longest river in Mexico (Muñoz-Salinas and Castillo, 2015; Tapia-Silva et al., 2015). It also encompasses the largest catchment in Central America with about 100,000 km² (Gandin, 2012). The total discharge lies between 85,000 (Muñoz-Salinas and Castillo, 2015) and 140,000 million m³ per year (Kemp et al., 2016), forming the second largest freshwater input into the Gulf of Mexico (Kauffman et al., 2016; Kemp et al., 2016).

Compared to Grijalva, Usumacinta has a higher **sediment** yield. Seasonal variations in sediment load are clearly linked to water discharge and could also potentially be dependent on cyclonic activity. Another correlation can be found between the sediment load and the maintenance of dams (Muñoz-Salinas and Castillo, 2015). Sediments transported by the river accumulate in the wetlands and lagoons inland, as well as directly along the coastline of the Gulf of Mexico (Kemp et al., 2016).

The hot and humid **climate** (Solís-Castillo et al., 2014) in the Usumacinta-Grijalva river catchment is defined by a dry season in spring and early summer, followed by two rainy seasons in late summer and winter (Jensen et al., 1989; Wakida-Kusunoki and Amador-Del Ángel, 2011; Kemp et al., 2016). About 1700 mm annual rainfall and a mean annual temperature of 27 °C determine the climate in the delta region (Solís-Castillo et al., 2014; Kauffman et al., 2016). The weather in the coastal region of the basin is generally characterized by easterly trade winds with an average speed of 4 m/s (Jensen et al., 1989).

About two thirds of the known national **biodiversity** can be found in the ecosystems of Usumacinta and Grijalva (Álvarez-Pliego et al., 2015). The natural diversity of plant and animal species also offers a broad variety of ecosystem services and resources available for human use (Gandin, 2012; Tapia-Silva et al., 2015). The vegetation in the flood plains, river deltas and lagoons contains mangrove forests (Yáñez-Arancibia et al., 1999; Muñoz-Salinas and Castillo, 2015; Kemp et al., 2016), marshes (Muñoz-Salinas and Castillo, 2015), submerged seagrasses (Yáñez-Arancibia et al., 1999; Kemp et al., 2016;) and pasture (Solís-Castillo et al., 2014).

Laguna de Términos serves many **fish**, shrimp and other fauna species as a shelter, nursery and feeding location. With fish production rates of 7 - 8.5 g/m², the region is more productive than many other coastal areas (Carvalho et al., 2009). Alongside the large variety of fish, shrimps, molluscs and other aquatic fauna, the invasive species of catfish (*Loricariidae, Pterygoplichthys spp.*) is of major appearance in the Usumacinta River and linked aquatic entities (Wakida-Kusunoki and Amador-Del Ángel, 2011). Even though mainly living in freshwater conditions, it tolerates brackish water and therefore easily disperses to different rivers through connecting lagoons, such as the Laguna de Términos (Álvarez-Pliego et al., 2015).

More than 5 million **people** depend on the water provided by the Grijalva-Usumacinta river basin (López, 2009). Currently about 1,383,000 people live in the delta region and the population is projected to increase by about 250,000 until 2025. This growth will mainly take place in the urban areas of Ciudad del Carmen and Villahermosa (Sánchez-Gil et al., 2005). Despite the richness of natural resources, the local population is highly marginalized and poor (Gandin, 2012).

Agricultural use consumes about one third of the watershed (López, 2009). Other primary **economic activities** are forestry and, most importantly, fishing (Yáñez-Arancibia and Day, 2004; Sánchez-Gil et al., 2005). Deforestation rates have increased since the 19^{th} century, using the river as a transport pathway for harvested woods (Muñoz-Salinas and Castillo, 2015). Even though a large proportion of the population, especially in rural areas, contributes to these activities, the strongest economic contribution in both Campeche and Tabasco is formed by oil production and transport through ports along the coast (Yáñez-Arancibia et al., 1999; Sánchez-Gil et al., 2005). Local fisheries depend on the high productivity of the lagoon, which is threatened by the effects of oil and petrol production (Jensen et al., 1989). Furthermore, commercial fishers based in Ciudad del Carmen intensify the pressure on fish resources in the lagoon (Carvalho et al., 2009). Dams built at the Grijalva River since 1964 are used for electricity production (López, 2009; Muñoz-Salinas and Castillo, 2015). The Usumacinta is still free of dams, but construction plans exist (Gandin, 2012; Muñoz-Salinas and Castillo, 2015).

Some natural extremes, such as **strong winds**, occur on a regular basis in the region. During so called “Norte” conditions, a cold front system (Kemp et al., 2016), wind speeds can exceed 8 m/s (Jensen et al., 1989). Extreme winds and weather are also caused by hurricanes, mostly occurring during the rainy season between August and September (Kemp et al., 2016). **Heavy rainfall** events can lead to flooding and landslides, and cause damages on a regular basis. In general, crop systems and settlement infrastructure are the most affected sectors by extreme weather events, like hurricanes, cyclones, and river flooding. The severity of damages from floods and heavy rain can be explained by the lack of preparation, emphasizing the importance of long-term planning for potential increases in intensity and frequency of such events (López, 2009).

In future, the region is projected to be a **climate change** hot spot with a significant temperature increase and a tendency for less annual precipitation, as well as longer and more frequent dry seasons (Kemp et al., 2016). However, no clear trend is visible for future heavy precipitation events or wind related changes (GERICS, 2015a). Therefore, a certain projection of future changes in frequency and intensity of related extremes, like floods and hurricanes, cannot be made. The projected drying trend will probably alter habitats and endanger the productivity of fisheries (Kemp et al., 2016). In the past, **sea levels** rose by about 2 mm per year off the Atlantic coast of Mexico. Projections based on a high emission scenario suggest further increases in sea level of up to 1 m by the end of the century (GERICS, 2015a). However, it is unclear how this will combine with river processes and effects in the delta. While López (2009) rated the vulnerability towards sea level rise in the delta region as high, Kemp et al. (2016) argue that, based on the high sediment transportation to the Usumacinta-Grijalva delta and the low subsidence rate, relative sea level rise effects are low.

Several threats and changes are based on human behaviour in the region and potentially amplify the effects of natural threats. **Deforestation** and degradation of natural vegetation based on agricultural land use in the upper part of the basin change the surface characteristic and soil stability and therefore alter the hydrological cycle, increasing the flood risk in the lower basin (López, 2009). Natural biodiversity and habitats are lost through an increase of the area being used for crops and pasture, urban expansion and general population growth (Yáñez-Arancibia et al., 1999; Sánchez-Gil et al., 2005; Gandin, 2012; Tapia-Silva et al., 2015; Kemp et al., 2016). Furthermore, **pollution** is a problem in the regions. One pollution source is the use of pesticides in agriculture and in various campaigns against vector-borne diseases (Carvalho et al., 2009), leading to an accumulation of chemicals in the soil, water and vegetation. Another major pollution source is related to oil and petrol production along the coastline of the Gulf of Mexico (Jensen et al., 1989). Alongside pollution, **overexploitation** of fish resources and commercial fishing threaten local fisheries (Jensen et al., 1989; Yáñez-Arancibia et al., 1999; Carvalho et al., 2009).

Two large **protected areas**, Centla Wetlands and Laguna de Términos, were established to preserve the biodiversity of flora and fauna while still allowing for sustainable development (Kemp et al., 2016). However, various activities, like dam building, increasing road infrastructure, logging and smuggling of timber, and fossil fuel extraction, influence the whole ecosystem and endanger an effective management of the region (Gandin, 2012; Kemp et al., 2016).

3.1.2 Visited communities Boca Chica, Palizada, Quintín Aráuz and Tembladeras

In the coastal proximity of the Usumacinta River basin, four villages were visited to conduct interviews. All are located along distributaries and natural channels connected to the Usumacinta River. Boca Chica and Palizada belong to the state of Campeche while Quintín

Aráuz and Tembladeras are situated in the east of Tabasco (see Figure 11). Based on a population census in 2010, population numbers range from 28 in Boca Chica to 3089 in Palizada. The average number of inhabitants per household is a minimum of 2.5 in Boca Chica and reaches a maximum of 4.6 persons in Quintín Aráuz. The large majority (71 - 97 %) of the population older than 15 years has attended school in some way. However, only 9 - 18 % of the general population finished their secondary education. Between 28 % (Quintín Aráuz) and 43 % (Boca Chica) of the inhabitants are employed. In Boca Chica, people own neither mobile phones nor refrigerators in their households. With 74 % and 87 % respectively, the highest share of the population in Palizada has access to mentioned assets. Strangely, in Quintín Aráuz and Tembladeras, the population share owning either of them diverges in almost opposite directions. While only 2 % possess a mobile phone in Quintín Aráuz, 22 % have one in Tembladeras. The other way round, 74 % of households in Quintín Aráuz and only 3 % in Tembladeras own a refrigerator (INEGI, 2010) (see Table 1).

Figure 11: Overview of visited communities in Mexico (Boca Chica, Palizada, Quintín Aráuz and Tembladeras); adapted from Google, INEGI (2016)

Table 1: Summary of selected census data for Boca Chica, Palizada, Quintín Aráuz and Tembladeras; adapted from INEGI (2010)

	Boca Chica	Palizada	Quintín Aráuz	Tembladeras
Total number of inhabitants	28	3089	1505	122
Total number of households	11	867	329	32
Average number of inhabitants per household	2.5	3.6	4.6	3.8
School attendance (% of population >15 years)	71.4	95.6	97.6	91.8
Secondary education completed (% of population >15 years)	14.3	18.3	9.4	17.2
% of employed persons of total population	42.9	38.8	28.4	36.9
Mobile phone (% of households)	0	73.8	2.4	21.9
Refrigerator (% of households)	0	86.6	73.6	3.1

Boca Chica is a small village situated at the Palizada River, just before it enters the Laguna de Términos. The river is already broadening to a small lagoon where the majority of the houses are located (see Figure 12). The only way to reach the villagers is via boat. People live in simple houses, which are located directly on the bank of the river.

Figure 12: Community centre of Boca Chica; own source, April 2015

Palizada is a small urban area situated at the Palizada River, further upstream of Boca Chica. The communities are neighbouring each other, however the centres are relatively far away. The houses spread along the river and further inland along smaller channels. Compared to all other visited communities, the standard of housing and infrastructure is much higher. Most houses are built with bricks and cement. Streets are also generally paved, offering the possibility of car transportation (see Figure 13).

Figure 13: Typical road in Palizada centre; own source, April 2015

Quintín Aráuz is located on a channel connecting Grijalva and Usumacinta River, within the Pantanos de Centla, close to the river junction called "tres brazos". It is the second largest village visited for interviews. The buildings are distributed along the bank of the river and land inwards along two main roads. The quality of houses varies between solid brick-cement construction and simple wood construction with dirt floor. Roads are negotiable by car although they are mostly enhanced dirt roads (see Figure 14).

Figure 14: One of the main roads in Quintín Aráuz; own source, October 2014

Tembladeras is a small village situated in the Pantanos de Centla, and surrounded by mangrove forest. It can only be reached by boat through small natural channels connected to the Usumacinta River. Most households are located directly along the main road. The low-lying village is easily flooded during the rainy season (see Figure 15) which leads to some houses being reachable only by boat, even from within the village itself.

Figure 15: Main road in Tembladeras; own source, October 2014

3.2 Mkhomazi River, South Africa

The Mkhomazi (also uMkhomazi or Mkomazi) River is located in the South of the province of KwaZulu-Natal, which is in the East of South Africa (Oyebode et al., 2015) (see Figure 16). KwaZulu-Natal province is the easternmost province of South Africa. Mkhomazi catchment encompasses parts of eThekwini, Ugu, uMgungundlovu and Harry Gwala/ Sisonke District Municipality. Untypical for this region, the river mouth or estuary is almost permanently open, while most other river mouths close during the dry season (Forbes and Demetriades, 2008).

Figure 16: Overview of the case study region in South Africa; adapted from Google, Data SIO, NOAA, U.S. Navy, GEBCO (2016)

3.2.1 General geographical description of the larger region

Mkhomazi River has its source in the Drakensberg Mountains and crosses 160-170 km linear distance (Taylor et al., 2003; Oyebode et al., 2015), with a total river length of about 300 km (Forbes and Demetriades, 2008), as well as 3300 m altitude difference in south-eastern direction before reaching the Indian Ocean in the town of Umkomaas (Taylor et al., 2003; Oyebode et al., 2015), about 50 km South of Durban (Forbes and Demetriades, 2008). The river basin covers about 4,400 km² (Taylor et al., 2003; Forbes and Demetriades, 2008; Oyebode et al., 2015) with a mean annual runoff of about 1,000 million m³. Mkhomazi is the second largest river in the KwaZulu-Natal region with a seasonally variable flow of 10-12.5 m³ per second in winter, and 42-48 m³ per second in summer (Taylor et al., 2003; Forbes and Demetriades, 2008).

High amounts of **sediments** (about 900,000 tons per year) are transported to and accumulate in the estuary, based on the steep course and the related strong stream flows of the river. Accordingly, the river depth in the estuary decreased over time from more than 6 m in 1920 to a little over 2 m in 1980. The sediment composition is mainly sandy, influenced also by marine input, pollution through the cellulose plant Sappi Saiccor, as well as the Umkomaas Waste Water Treatment and outtake through local sand miners. In low river flow season, salt water from the ocean enters into the estuary while, on the other hand high, river flows add freshwater to the coastal zone of the ocean (Forbes and Demetriades, 2008).

The south-eastern coast of South Africa, bordering the Indian Ocean and including the Mkhomazi river basin, is classified as sub-tropical **climate** (GERICS, 2015b). The climate in this region is further characterised by wet summers (November-March) and dry winters (June-September) (GERICS, 2015b; Oyebode et al., 2015). The mean precipitation in the catchment ranges between about 700 and 1200 mm per year (Taylor et al., 2003; Oyebode et al., 2015). This is relatively high in comparison with the country-wide average of 450 mm per year (CSIR, 2010). The whole country therefore struggles to cover the water needs of the population.

The **natural vegetation** alongside the river is strongly altered through anthropogenic use, such as sugar cane farming, sand mining and infrastructure for Sappi Saiccor, as well as for coastal tourism. A natural cliff on parts of the northern river bank allows for some coastal forest to grow. While both the different species, and the total individual density are decreasing, the fish community is still rated as good (Forbes and Demetriades, 2008).

A total **population** of a little more than 200,000 people (Umgeni Water, 2015) lives in dispersed rural communities with increasing density towards the coast. So far, no water reservoirs exist in the catchment. To supply rural communities, and the nearby cities of Durban and Pietermaritzburg, with piped water, six dams are planned (Taylor et al., 2003). The two cities so far obtain their water from the Mngeni River (Umgeni Water, 2015). Its catchment is comparable to Mkhomazi in size, though with a 30 % smaller annual runoff (Forbes and Demetriades, 2008) and 6 million more people to supply (Umgeni Water, 2015). Therefore, Mkhomazi River and the planned dams and pipelines are of major importance to meet the water demand of the mentioned metropolitan areas (Oyebode et al., 2015; Umgeni Water, 2015). Main land uses in the Mkhomazi catchment are commercial afforestation, tourism, intensive and extensive agriculture. Sappi Saiccor is the only larger industry situated along the river, and there are no further cities in the catchment apart from Umkomaas (Taylor et al., 2003).

Only about 10 % of the population in the Mkhomazi catchment has access to piped water within their houses (Umgeni Water, 2015), even though the policy of providing 9000 litres per household for free within the eThekwini Municipality is being followed (Friedrich and Kretzinger, 2012). For the lack of piped water, especially in rural regions, the Municipality brings water with trucks and stores it at a central place in large tanks. The free provision of clean water aims at decreasing water-borne diseases, like diarrhoea (Singh et al., 2013). Most households use pit toilets and live in traditional buildings (Umgeni Water, 2015). According to (Singh et al., 2013), the provision of potable water and sanitation in South Africa is not sufficient for, and is further exacerbated by a rapid population growth. About 20 % of the working age population is employed, leaving a large share dependent on the income of others or on different sources of income. With a poverty line of R400 per month or R4800 per year, about 20 % of the population lives in poverty (Umgeni Water, 2015).

Alongside droughts, **natural threats** in the region further include floods. In 1856, 1868, 1917, 1924, 1925, 1959 and 1987, major flood events occurred in the estuary (Forbes and Demetriades, 2008). **Climate change** scenarios suggest a mean temperature increase of up to 5 °C, a decrease in mean precipitation, an increase in the duration of dry spells, and a sea level rise of up to 1 m by 2085 (GERICS, 2015b). The waste water treatment plant at Umkomaas has been rated as highly vulnerable to sea level rise. However, due to its comparably low importance in the eThekwini Municipality, and plans for replacing it, actions are not seen as urgent (Friedrich and Kretzinger, 2012). From an ecological perspective, Sappi Saiccor poses a **human threat**. Through the extraction of water for cellulose production, and pumping the effluent directly into the sea, the company affects the stream flow and water quality of the estuary and the coastal zone of the ocean (Forbes and Demetriades, 2008). Another threat to river water quality is pollution related to a lack of sanitation and waste management in the communities along the river (CSIR, 2010), as well as insufficient waste water treatment. Contributing to the problem of bad river water quality is the insufficient provision and quality of domestic water (Singh et al., 2013), leading to several illnesses affecting human health (CSIR, 2010). Further disturbances of the river course, bank substrate and vegetation are caused by sand mining. These impacts are continuously worsening the situation and countermeasures taken by the government to improve the situation have so far been insufficient (Forbes and Demetriades, 2008).

3.2.2 Visited communities Ndaya and Emgangeni

Two rural communities, located in the coastal area close to the Mkhomazi River, were visited and interviewed. Following a road running parallel to the river, the village of Emgangeni is reached first, before arriving at Ndaya (see Figure 17). They are situated in the Vulamehlo Local Municipality which belongs to Ugu District Municipality. The settlements in this region are mostly organised in tribal structures and the main language is IsiZulu. Provision of infrastructure is aggravated by the low-density of the settlement pattern. Additionally, unemployment levels are high, poverty is a problem, and the overall economy is in recession. Among the total population of 77,403 almost 25 % above 20 years have not been able to obtain any form of schooling, and more than half are unemployed (Stats SA, 2011). In each Emgangeni and Ndaya, about 1300 inhabitants live in 223 to 249 households. While up to 80 % of the population obtained some form of schooling, only a share of 16 - 23 % completed their matric. Matric represents the graduation from high school and therefore covers the requirements to attend university. No numbers on village-based unemployment are available, though statistics indicate that 13 % of people are without income. The large majority of households have access to a mobile phone (84 - 90 %). Almost 70 % of households in Emgangeni, but only 39 % in Ndaya, own a fridge (SA Stats, 2011) (see Table 2).

Table 2: Summary of selected census data for Emgangeni and Ndaya; adapted from SA Stats (2011)

	Emgangeni	Ndaya
Total number of inhabitants	1210	1358
Total number of households	223	249
Average number of inhabitants per household	5,4	5,5
School attendance (% of population >20 years)	80,3	73,9
Matric completed (% of population >20 years)	22,7	15,9
% of population without income	13,0	13,0
Mobile phone (% of households)	90,1	83,5
Refrigerator (% of households)	68,9	39,0

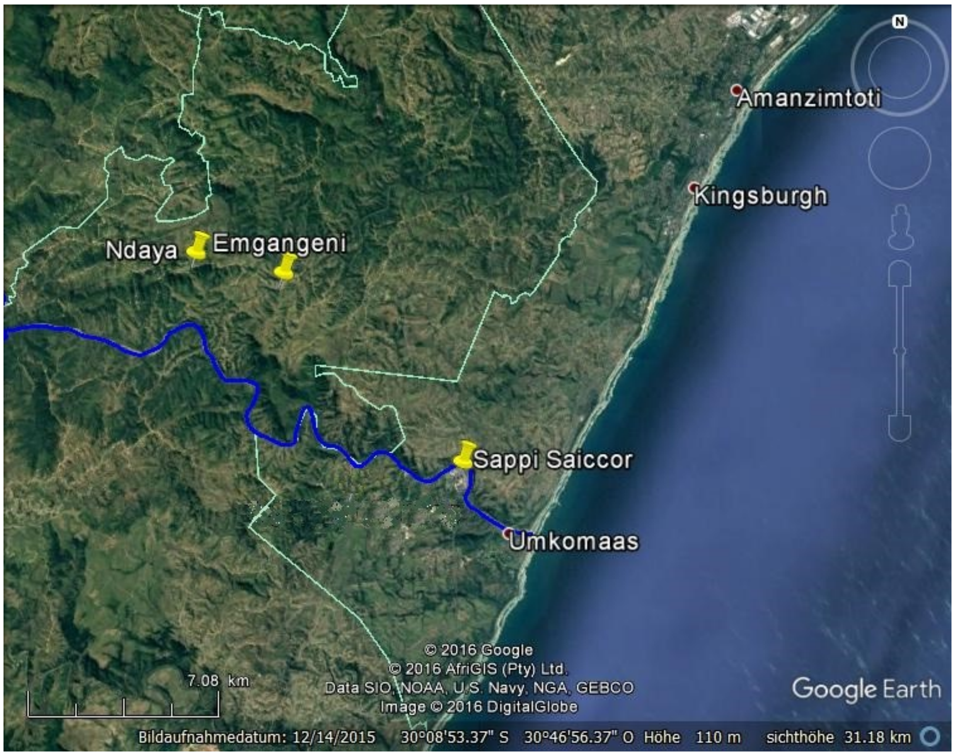


Figure 17: Overview of visited communities in South Africa (Emgangeni, Ndaya); adapted from Google, AfriGIS (Pty) Ltd., Data SIO, NOAA, U.S. Navy, NGA, GEBCO, DigitalGlobe (2016)

Generally, Emgangeni and Ndaya are quite similar in building structure, however some differences exist. The main road to Emgangeni is already paved following the road construction works from the coast inland. Most other roads, including those leading to the dispersed houses, as well as to Ndaya, are still unpaved (see Figure 18). The density of buildings is slightly higher than in Ndaya. Furthermore, many households have access to electricity, and some central taps provide water to the villagers. In comparison to Emgangeni, central places in Ndaya provide water mainly through water tanks.

Figure 18: Typical dwellings in Emgangeni and Ndaya; own source, October 2015

4. Methodological steps, respective results and analyses

This chapter explains the main methodological approach, intermediate results and further analysis in chronological order (see Figure 19). In that way steps building on each other can be tracked more easily. The chapter starts off by giving an overview on the contextual framing of participatory modelling, highlighting the importance of selecting stakeholders, specifics of group-model-building and the concept of mental models (see chapter 4.1). Based on the explained context the applied participatory modelling approach is categorized in chapter 4.2. Following the actual participatory modelling sessions in the case study regions, respective resulting mental models are described in chapter 4.3. The different interviews are summarized for the Mexican (see chapter 4.3.1.1) and South African (see chapter 4.3.2.1) region respectively, however considering main differences between the communities separately (see chapters 4.3.1.2 and 4.3.2.2).

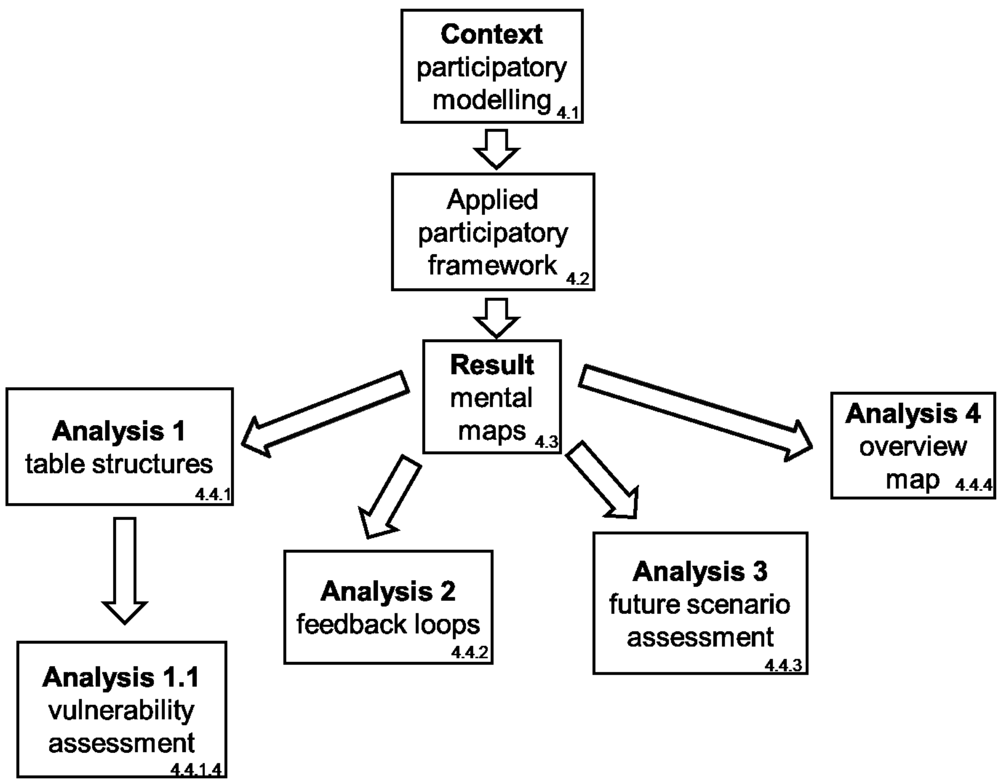


Figure 19: Analysis structure with indicated numbers of respective chapters; own source

Chapter 4.4 deals with further analysing the resulting mental models. First, the broad information offered by the models is structured in several tables following guiding questions on resources (see chapter 4.4.1.1), resource use and livelihood aims (see chapter 4.4.1.2) as well as threats (see chapter 4.4.1.3). This information structured and summarized along the components of the mental models are further analysed in chapter 4.4.1.4 to assess current climate change vulnerability. Another analysis step focuses on the linkages and especially available feedback loops derived from mental models of both Mexican and South African case studies (see chapter

4.4.2). Again based on the regional models two example future scenarios are analysed in chapter 4.4.3. For the Mexican case sea level rise and related increasing salt water intrusion are anticipated (see chapter 4.4.3.1). South African communities are looked at in the context of more frequent droughts (see chapter 4.4.3.2). Finally a common structure of coastal riverine socio-ecological systems is derived, which can be applied to similar case studies (see chapter 4.4.4).

4.1 Participatory modelling – a tool to capture local perspectives

In participatory modelling, local information and perceptions of the environment are captured by involving stakeholders in a common model-building process (Hare, 2011). Why is it important to capture local perceptions? Mainly due to the perspectives of those people creating and affected by the problem (Ison and Ampt, 1992), also called stakeholders. They and their perspectives are central to the solution of the problem. The importance of capturing perspectives is also supported by several theories, like the systems theory (see Forrester, 1972) and the theory of human needs (see Maslow, 1943; Max-Neef, 1991), emphasizing the influence of subjective values on individual behaviour (see chapter 2.2 and 2.3). In other words, if person A perceives a situation to be perfectly fulfilling his needs, he won't feel motivated to change his behaviour. However, the same situation can be perceived as unsatisfying by person B, who will then act accordingly. Therefore including all perspectives is necessary to understand the whole conglomerate of perceived realities. With the help of a qualitative, semi-structured interview guideline the experiences and observations of people are captured in their local environment.

Prior to capturing local information through participation it is crucial to **define all stakeholders** who should be involved in the process. A stakeholder can generally be defined as anyone who can influence or be influenced by the system in focus, e.g. persons, groups, communities, organizations, institutions and natural environment itself (Mitchell et al., 1997). This interest or stake can further be specified in describing under which conditions it is of importance for the system (Mitchell et al., 1997). So the question is not only who the stakeholders are, but also how they influence the system (Laplume et al., 2008). One aim of participatory modelling is to define the exact way of influence and the resulting impacts. Due to the high labour intensity of this interview technique selecting a representative sample, based on the stakeholder analysis is inevitable. Stakeholder involvement can generally take place before, during and after the modelling process (Hare, 2011), supporting problem definition, model creation as well as evaluation and dissemination of results (Scherhaufer, 2013).

A subtype of participatory modelling specializing on groups is called **group model-building**. The aim of a group model-building process is to describe a system in the perspective of local stakeholders (Vennix, 1996). By addressing a group of different opinions at once, individual biases are weakened by testing them in the group model (Vennix, 1999). Potential difficulties can be created by a) selective memory which simplifies problems and strengthens own beliefs

(Vennix, 1996), b) contextual influences, such as the persons' position in the system and c) defending accustomed perceptions (Vennix, 1999). These biases cannot be avoided completely, but through being aware of these biases, information can be interpreted accordingly. In a common process modellers and facilitators as well as experts and stakeholders combine their technical skills and system content knowledge to develop a model (Bérard, 2010). The developed model is the means to learn about the problem, reach an agreement, and increase acceptance in the group (Vennix, 1996). In general, there is no standard procedure and ending point of a modelling process. Structural flexibility is of key importance to each group model-building project. Working with a group on a problem solution requires an open minded, reflective and supportive facilitator knowing until when a process is productive (Vennix, 1999), reacting sensitively to group dynamics and being aware of their own influence on the process.

A **mental model** visualizes perspectives, memories and values and is therefore the result of a participatory modelling process. Mental models form the basis for each system dynamics analysis and further modelling efforts. They represent the perceived system, which can differ from the real system. Even though this difference can be limiting for the use of the models, the perceived "reality" is important in order to understand people's behaviour (Rouwette, 2003).

4.2 Categorizing the applied participatory process

Based on the introduced existing literature, the experience of supervising scientists and the specifics encountered during field work in the case study regions, a participatory modelling approach has been developed and was continuously updated. In this work the focus was set on rural livelihoods, their interactions with the natural environment, and effects of climate change. Therefore stakeholders are defined as everyone who bases his or her life in the coastal river basins of Mexico and South Africa (see chapter 4 for detail description). The emphasis lies on people living in the area because it is assumed that in this case the socio-ecological system can be described more fully. In contrast specified actors possibly focus on one aim, e.g. economic turnover. In this work the influence between rural stakeholders and the surrounding natural system is considered from two sides. On the one hand, the environment influences the human population, including resource provision as well as natural hazards. On the other hand, the local population has a direct impact on the environment through land use, waste disposal and other activities. To cover the whole variety of stakeholders, a regional authority was approached to identify central profiles. I.e. when the local chief mentions mainly farmers and fishers live in the region, a gender and age mix of farmers and fishers was contacted to give a representative perspective of the area. Even though stakeholders can and sometimes also should be involved at various points of time during the assessment process, here the focus is put on the beginning. Defining the problem and system at hand relying on stakeholder perspectives is seen as most important in this case, basing all further analysis steps on this local knowledge.

Local perspectives were captured in individual and group model-building sessions. The original setup intended to cover individual opinions in the first round and summarizing, comparing and adding experiences in a second round involving the whole group of individual interviewees. However, the applicability of this interview structure was highly dependent on the cultural setting of each case study region. In the Mexican region, this structure was developed and was successfully followed, while in South African villages individual interviews had to be turned into group sessions spontaneously (see discussion in chapter 5).

The whole participatory modelling process can be summarized and structured into a framework of preparation, personnel, session scope, logistics and post processing, adapted from (Bérard, 2010) (see Table 3). The modelling process has been initiated externally, from the scientist's side. The focus of the sessions lied on estimating the climate change affectedness via understanding the interactions between natural environment and rural livelihoods in the region. To start the process a brief introduction to the aim of the session and auxiliary materials was given. Two to three persons facilitated the process. One was leading through the session with the support of predefined topics and guiding questions but flexibly reacting to the story lines of participants. The second person was building the model in parallel to the discussion, reassuring the correctness with the participants every once in a while. If available a third person assists flexibly wherever necessary. Supporting material for the modeller includes a big sheet of paper, coloured stickers, a pencil, a black and a red pen to build the model from scratch. Coloured stickers and pens represent different categories of components and linkages respectively. To avoid additional stress through an unknown environment, the sessions were located at the individual homes of participants or at a central place, like a school, in the respective village. The aim was to lead individual interviews to avoid biases from more dominant persons in a group. Depending on the situational setting smaller groups were interviewed at once. Participants were selected based on their main occupation, age and gender, striving for representativity of the diversity of each community. Each session lasted approximately 2 hours. The almost 50 models on paper were transferred into Vensim®, a system dynamics modelling tool on the computer, completed with missing links and combined to one model per community (see Table 3).

Table 3: Summary of participatory process framework, own source adapted from Berard, 2010

Category	*Topic*	*Specifics of application*
Preparation	Initiator	Modeller
	Problem focus on	Climate change affectedness, interactions between natural environment and rural livelihoods
	Introduction	Very rough contextual introduction, to simplify process and avoid biases
Personnel	Facilitation	2-3 persons: 1 facilitator leading the process, 1 modeller, 1 support
	Number of participants per session	1-10 persons
	Varying participants characteristics	Occupation, age, gender
Session scope	Format	Individual and group interviews
	Structure	Guiding topics and questions
	Model	No preliminary model, starting from scratch
	Flow	Mainly guided by the facilitator, following the inputs from participants
	Number of sessions	40 in Mexico, 8 in South Africa
	Average duration per session	2 hours
Logistics	Place of interview	At participants homes, or at a central place in their known surrounding
	Layout	All participants and facilitators surrounding a big table
	Material	Big sheet of paper, coloured stickers, pencil, red and black pens
Post processing	Transfer	Transferring paper models into Vensim®
	Clarification	Adding missing components and links, correcting modelling mistakes
	Combination	Combining individual models into one overarching model per community

Each interview started with the question of “what does the river mean to you”. This on the one hand directly introduces the geographical focus of the interview on the local river and its importance in rural livelihoods. On the other hand it is an easy and open question allowing the interviewee to respond in any way for him or her feeling comfortable. Following that entry question, topics representing the natural side of the system, like water, soil, natural vegetation, wild animals and weather were covered. To connect the natural to the human sphere, questions were asked concerning how these natural components are actively used or how they influence their daily lives. Completing the system on the human side, topics like hydration, nutrition, financial means, health, housing, transport, education and social networks were covered. Last but not least perceived threats and changes affecting these core livelihood components were added to the picture. Mentioned topics were attempted to be covered in each interview. However, the flexibility to follow each interviewee’s story and avoiding any unnecessary imprinting of topics was valued more important than absolute completeness. The full set of guiding questions can be found in the Appendix A1.

The respective topics and linkages were visualized on a sheet of paper in parallel to the interview. At first natural components are represented with green, activities with blue, socio-economic/ human components with orange and threats with purple stickers in the paper model.

After each interview the paper model was transferred into a computer model. Here the original colours are translated into different shapes:

- Natural – green – box
- Activity – blue – hexagon
- Human – orange – circle
- Threat – purple – triangle

This translation of colours into shapes allows adding a layer in the post processed model. For both natural and human components a different shade of the original colour indicates whether it is a specific resource/ service (light shade of green and orange) or a condition, source or aim pre- or succeeding the respective resource/ service (medium shade of green and orange). An example for natural components is “river” in medium green representing the providing source or subsystem for the natural resource “water” in light green. A human or socio-economic example is “nutrition” in medium orange showing a livelihood aim being covered by bought resources, like “rice” in light orange. Furthermore, the dark shade of both green and orange allows for a differentiation of the sources of threats, e.g. “heavy rain” in dark green and “pollution” in dark orange/ brown, between natural and human respectively. Activities are the only components which kept the original colour, because it always refers to humans. A new shape was added with the upside down triangle to highlight experienced environmental changes, e.g. delayed rainfall, over time. The colour is applied similarly to the threats (see Figure 20). The model components are connected through differently coloured arrows signifying proportional and counter-proportional linkages. A black arrow shows the enhancing effect of the originating component on the ensuing component. If one component increases or decreases the subsequent increases or decreases respectively. A red arrow always relates to an opposite effect, which means if one is increasing the other is decreasing and vice versa (see Figure 20). The legend in the figure below shows some usual connections, e.g. a threat of both natural and human source usually has a reverse effect on natural and human resources.

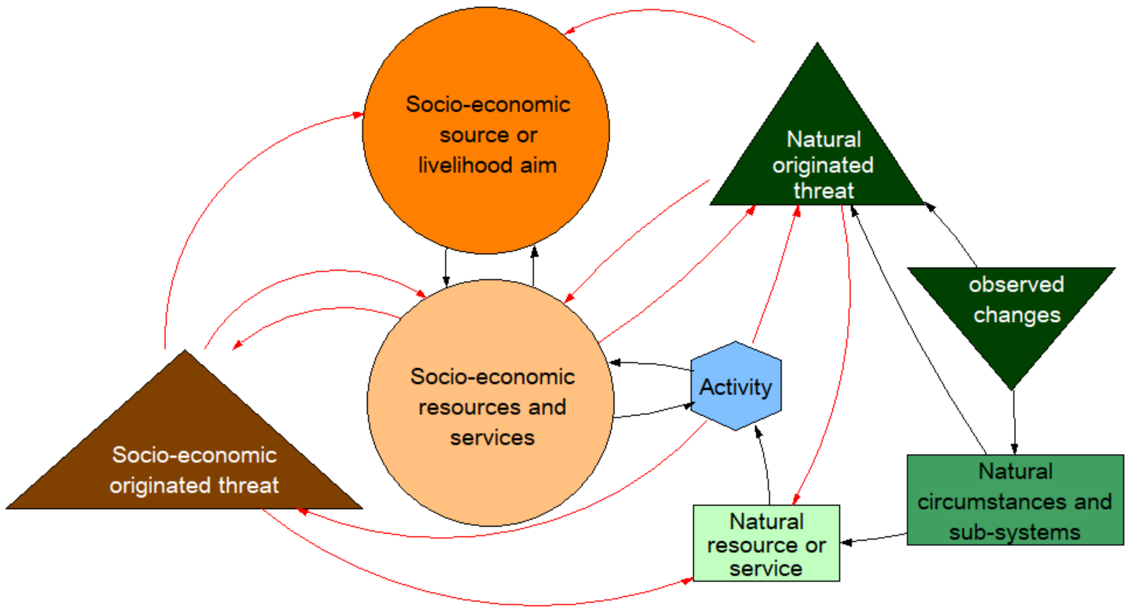


Figure 20: Legend of post processed mental models, showing natural components in green shades, human components in orange shades, activities in blue and linkages in red and black; own source

4.3 Description of local mental models – results from participatory modelling process

The broader geographical context of both case study regions has been introduced in chapter 3. The information described here is based completely and solely on local perspectives of interviewed people in the rural areas of Mexico and South Africa. Several mental models resulted from the participatory modelling sessions. In each individual or group interview one model was developed on paper. Here the summaries of 40 individual models in the Mexican case region and of 8 group models in the South African case are described respectively. Due to the close proximity of the villages to each other the similarities between them were large. Hence, for both regions, Mexico and South Africa, one common description is made, highlighting specifics of single communities and mentioning main differences between communities wherever relevant. The common description is structured into main topics, following the interview structure and highlighted in bold font in the text. For each of the topics an excerpt of the combined regional model is shown. The complete community mental models can be found in the Appendix A2.

4.3.1 Mexican case studies

In the Mexican case study region the four communities Boca Chica, Palizada, Quintín Aráuz and Tembladeras were visited and interviewed. The four complete community mental models can be found in the Appendix (see A2.1 - A2.4).

4.3.1.1 Regionally summarized components and processes – Mexico

Many of the interviewees live close to the **river, channel or lagoon**, which provides water and fish. The water level regularly rises based on increased rainfall during the rainy season. This high water level has been mentioned as good flood, enriching the soil with nutrients. However, flood based on salt water intrusion has a negative effect on the river ecosystem, decreasing the water quality. Also various pollutants or contaminants affect the water quality. An additional connection between the river and the groundwater has been added posterior to the interviews by the modeller. Especially based on the negligible altitude difference between river and shoreline in the case study region, an influence of both river water quantity and quality on the surrounding ground water is expected (see Figure 21).

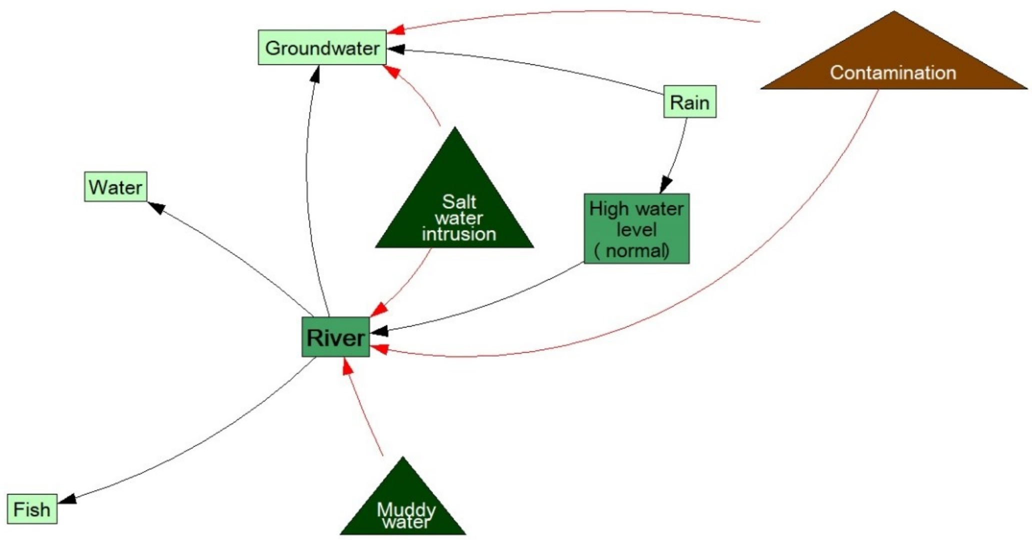


Figure 21: River focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Water gathered from the river is mainly used for washing and cleaning. Some people also drink it after boiling. Another source of water is water gallons, which provide a reliable however expensive alternative to river water. Furthermore, people fetch groundwater from wells or collect rain water. Some households additionally have access to tap water. However, water treatment is not yet reliable. The water quality and resultantly the usability of the water from the river and wells are limited by various factors. First and foremost, waste pollution both from within the community and from further upstream is mentioned. Especially for villages close to the coastline contaminated water originating from oil and petrol production is a problem. The petroleum contamination affects the whole environment, also including air and soil quality. Further, salinity, low water levels and intruding salt water prevent drinking river and well water directly. Last but not least pesticides and other chemicals pollute the river. Clean water and sufficient hydration is recognized as an important basis for maintaining health (see Figure 22).

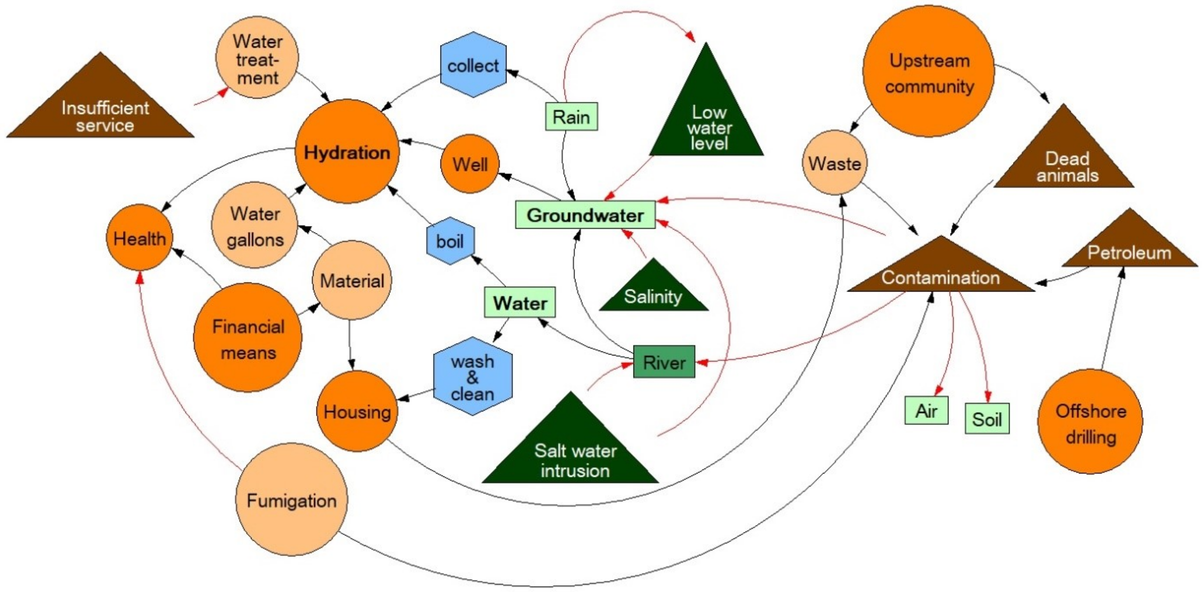


Figure 22: Hydration focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Fish resources play a central role for most of the interviewees. Depending on the water composition in the river close by, channel or lagoon either only sweet or also salt water fish are relevant for fishing. Additionally, some households get subsidies to maintain separate ponds for aquaculture. In that way inhabitants can influence the fish available by protecting them from river influences, e.g. contaminated water and by feeding and breeding them. Fishing products are the main component for both income and nutrition. A part from the income is again needed to buy material for fishing, feeding and conserving fish, e.g. nets, fodder, salt and ice. An invasive catfish species, called “Pez diablo” is one major threat killing or dispersing other fish (see Figure 23 for a juvenile example).

Figure 23: A juvenile individual of the invasive catfish species; own source

Other major threats include overexploitation and bad fishing techniques decreasing the fish stock. These threats are partly based on and partly amplified by too many local and external fishermen as well as lacking awareness of the problematic behaviour and its effects on the ecosystem. Through flood and heavy rain the water quality can be worsened, the fish are dispersed, ultimately leading to less available catch (see Figure 24).

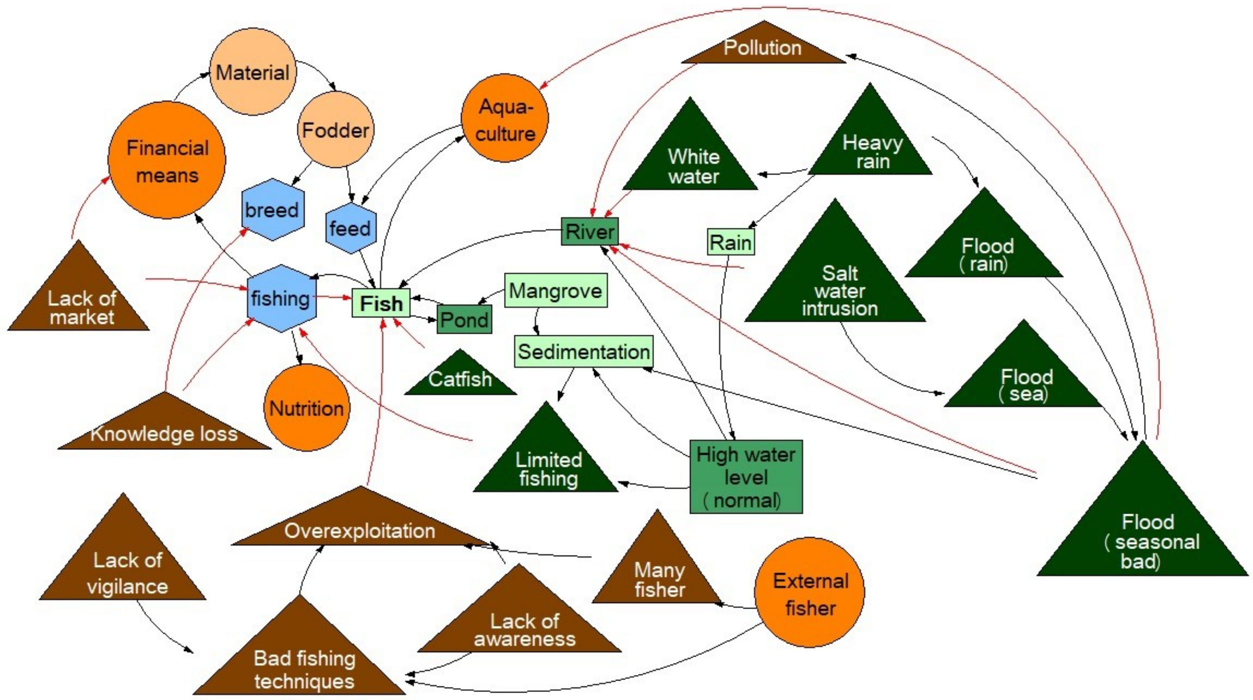


Figure 24: Fish focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Natural vegetation is mentioned as forest containing various tree species, e.g. mangroves, and **wild animals**. Both vegetation and animals are protected by the government. Before that people went logging and hunting in the forest. When possible, especially for unprotected species, these activities are still proceeded today and contribute to income and nutrition. Current and past deforestation are counteracted against with government supported reforestation initiatives. Another threat to natural vegetation and fauna is fire. Again through government support fire breaches are installed and maintained (see Figure 25).

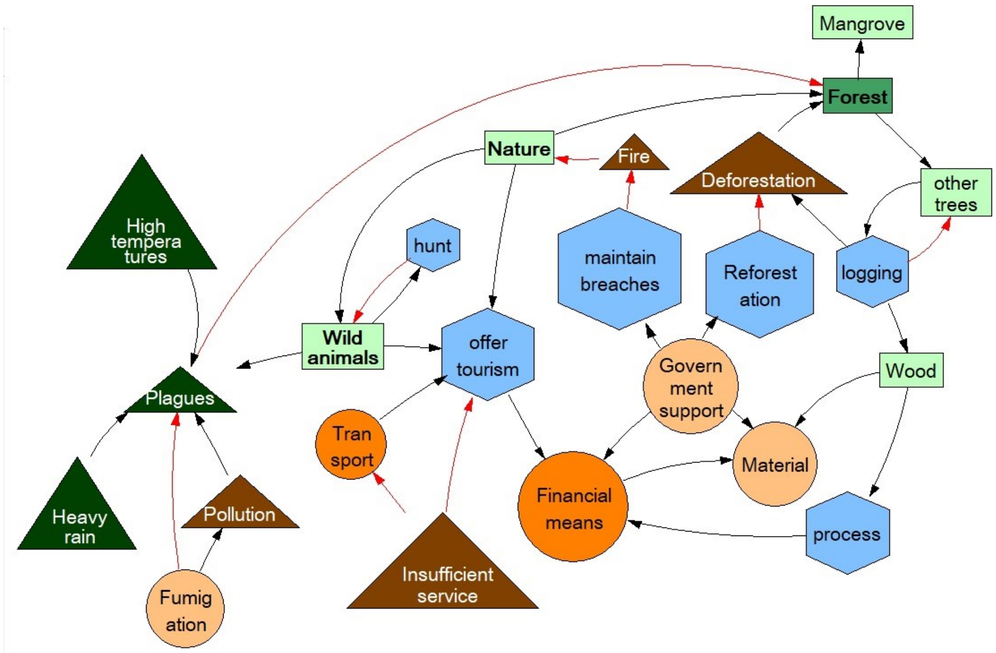


Figure 25: Nature focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Another central part of the livelihoods in the region is **cattle farming**. The animals feed on pasture, which is dependent on rain and the quality of soil, and drink water from the river (see Figure 26). Material needed for cattle farming is partly bought and partly produced from wood gathered from the logging of unprotected tree species. Cattle are in danger of getting infected by mosquito, of suffering under high temperatures, and in the worst case of getting hurt or even drowning when there is a flood. Even though the "good" seasonal flooding is good for the soil quality, it still damages the current pasture.

Figure 26: Examples of domestic animals: Cows and horses at the river (left), chicken (right); own source

Good soil quality is not only important for pasture, but also a major component for **growing crops** (see Figure 27). Like crops, small domestic animals (see Figure 26) also need water, which they get from the river in all four communities. The so called “animalitos” are fed with bought fodder or with grown crops. Additionally to growing crops, some people have fruit trees (see Figure 27) in their backyards.


Figure 27: Examples for crops and fruit trees: Chili (left), Coconut (right); own source

This gardening and agriculture activity contributes to nutrition and income of rural households. Flooding is the biggest threat for crops, fruit trees and small domestic animals. Contaminated air and soil pose further negative effects on crops (see water paragraph above). Plagues are a problem impacting crops and domestic animals. Furthermore, crops are damaged by bad water quality and by wild animals. Similarly to cattle, other domestic animals also suffer from heat (see Figure 28).

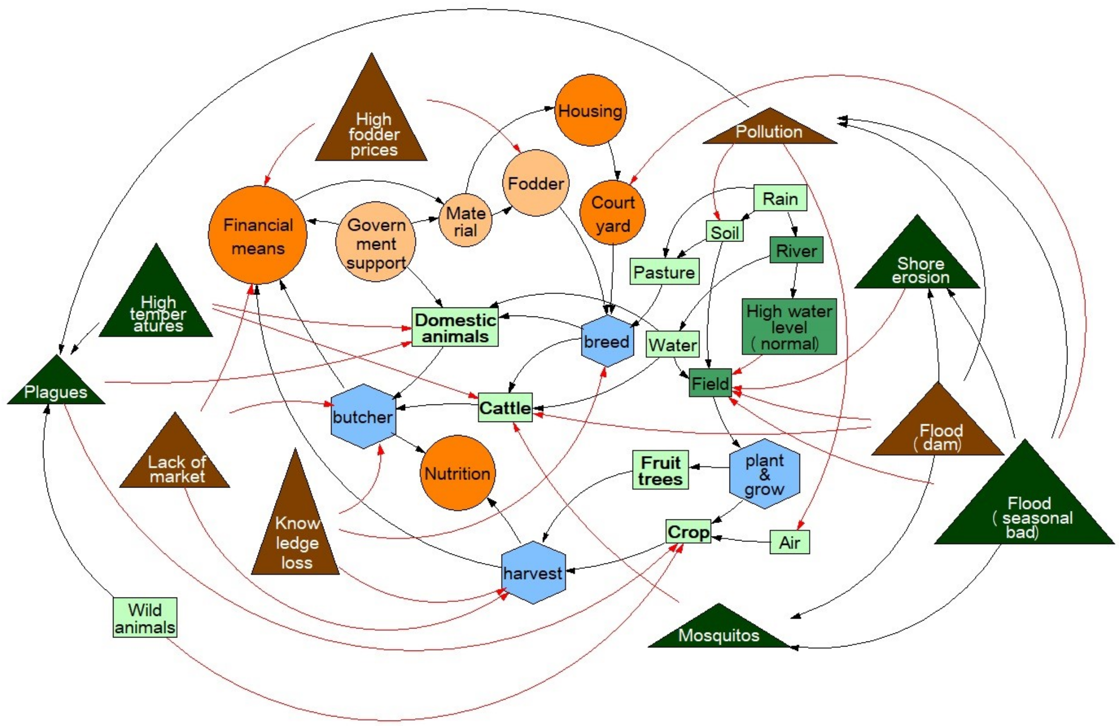


Figure 28: Human land use focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

As mentioned above, the main **food sources** are dependent on natural resources obtained from the direct environment through fishing, agriculture, cattle farming and gardening. Additional products are bought (see Figure 29).

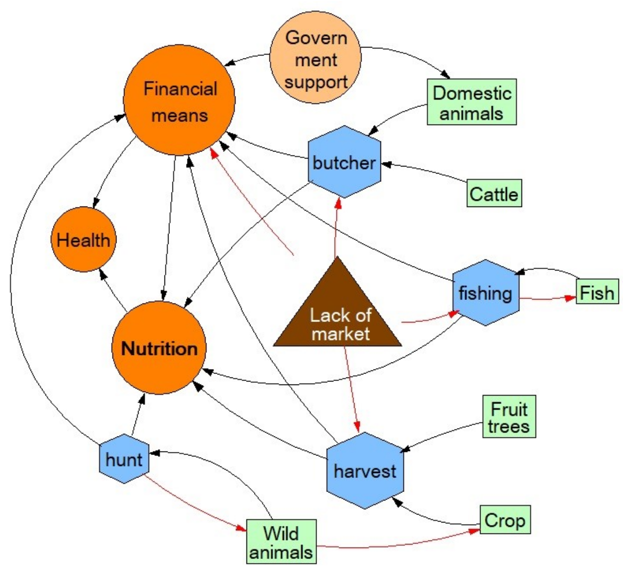


Figure 29: Nutrition focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. from human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Exactly like providing the basis of nutrition, natural resources also form a large share of **income**. Another income source comes from the government, mostly related to natural protection initiatives, such as reforestation, wild life protection, maintenance of fire breaches and waste recycling. Furthermore, government initiatives also compensate for the lack of work and the lack of housing. If the lack of work cannot be compensated, people migrate to find other sources of income. In any case having no work decreases the available money. Tourism, related to the beauty of nature and the available wild life provided by the Usumacinta and its environment, has been identified as a potential income source. In some households further income is provided by running a small shop, leasing land, producing wooden products, transferring money from migrated family members and other economic activities. Income and potential savings are mainly needed for paying water gallons, health services, housing, food, material for fishing and farming, but also for paying higher education for their kids and a house keeper or a merchant to participate in regional market activities. The latter can also be covered by neighbours or family members if available (see Figure 30).

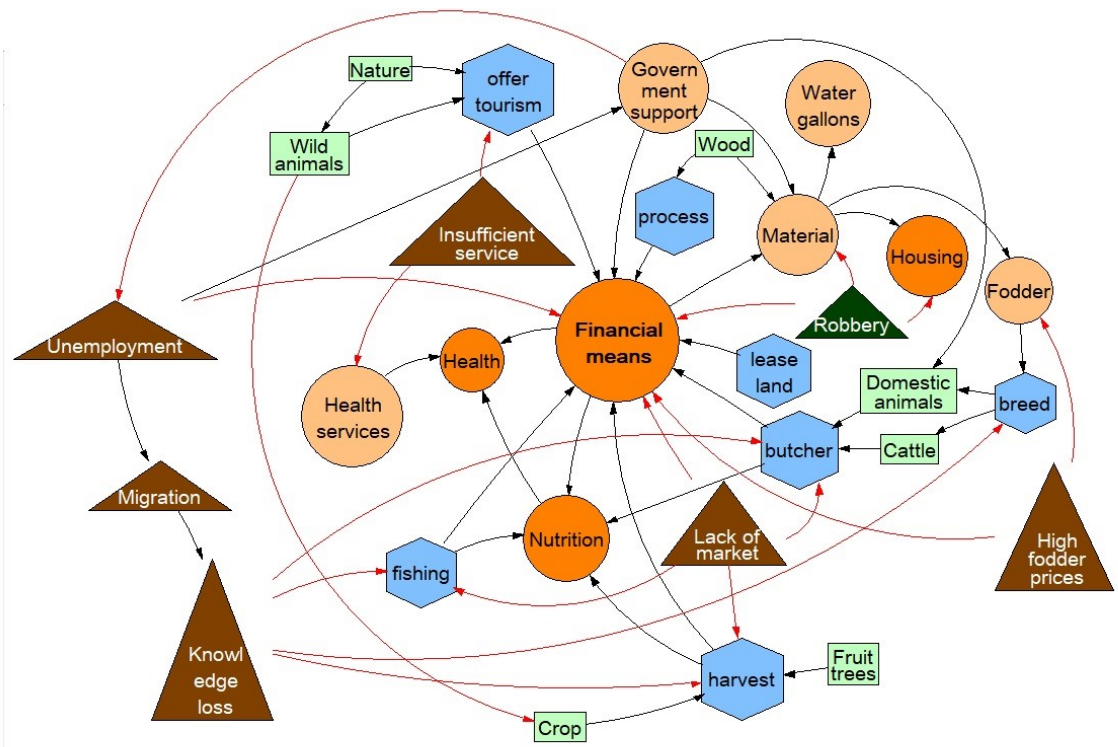


Figure 30: Financial means focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

In order of maintaining good **health** nutrition, hydration and housing are seen as central components. In case of problems all communities consult a doctor, a health centre, or other comparable health services, although the amount of the available services is partly criticized as insufficient. An alternative to health services are medicinal plants which are gathered in the natural surrounding or even planted in own gardens. As already mentioned in the context of fishing, health is a prerequisite to engage in any livelihood activities and therefore is both directly (paying for health services in terms of illness) and indirectly (being able to create income only when healthy) connected to income. Mosquito are mentioned as the major threat to health. Some interviewees specified this threat as the illness dengue transported by mosquito. The fumigation implemented to fight mosquito poses another health risk itself. Further health problems originate from pollution and contamination of the environment, especially the river (see Figure 31).

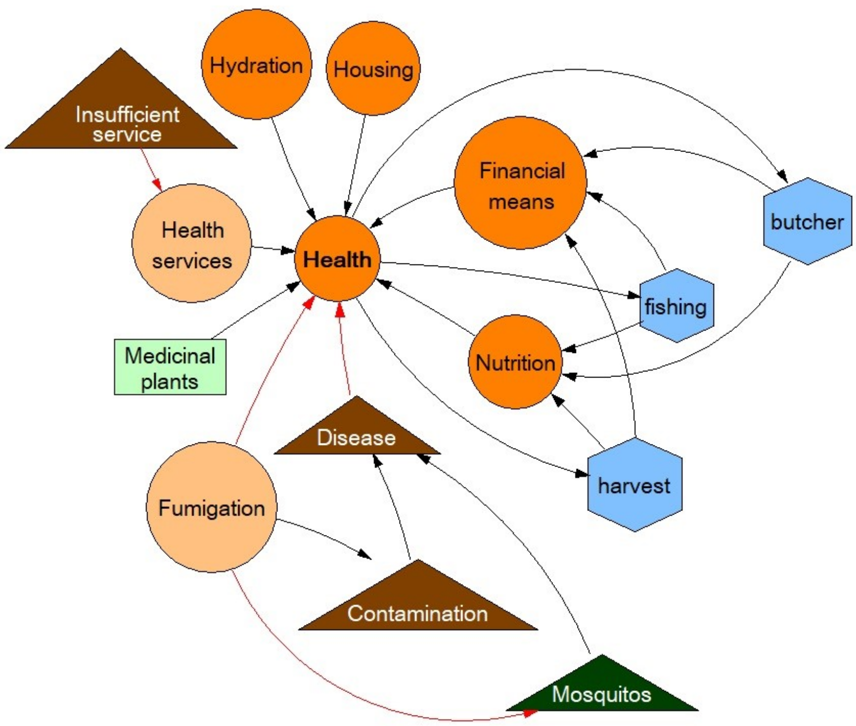


Figure 31: Health focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Living also always produces waste. When badly managed this leads to various problems, first and foremost through contaminating the river, the environment, and existing wells. Only in some parts of the region waste management through government supported recycling is implemented. Most people live in very simple houses built of wood and corrugated iron (see Figure 32).

Figure 32: A typical simple house in Boca Chica; own source

House building is based on bought material, logged wood from the forest and is partly supported by the government. Some households produce own energy with subsidized solar panels. Other households have temporal access to electricity through a small generator. Damages to their homes are caused by flood, strong winds, shore erosion, bad water quality, and robbery during absence of household members. The latter can be avoided by having a house keeper or otherwise never leaving the building unattended (see Figure 33).

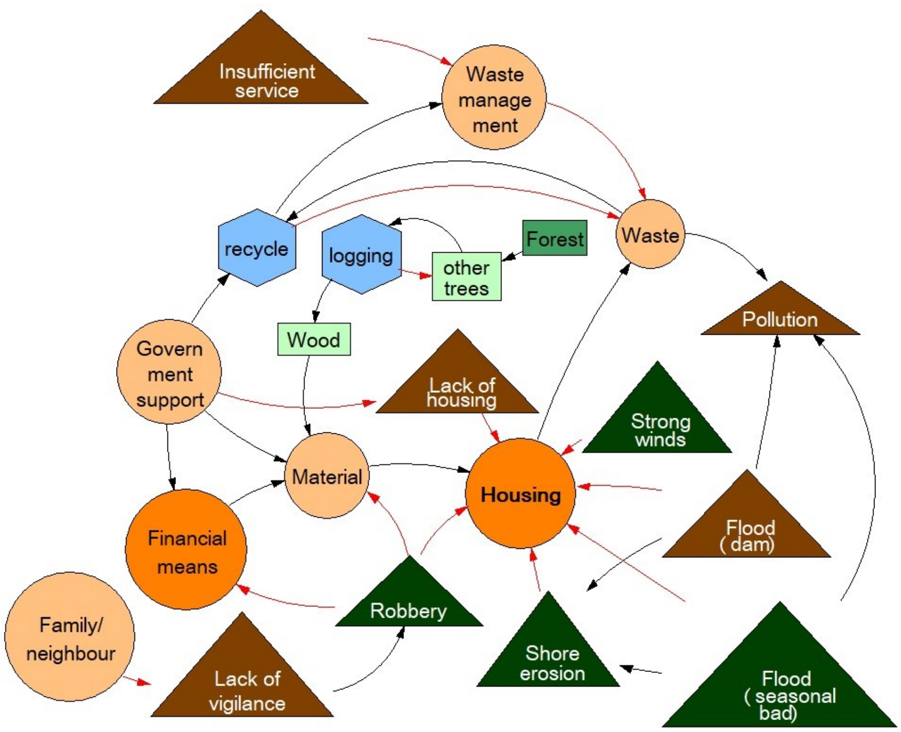


Figure 33: Housing focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

During the interviews three different **seasons and weather conditions** have been described. First of all, during the dry season less rain, higher temperatures and intruding salt water define the river in the region close to the coast. In the same communities salt water intrusion is also experienced during the cold front, the so called “Norte”, season. This season has further been connected to heavy rainfalls, similar to hurricanes. Three weather related possibilities of flooding were mentioned: 1) intruding salt water, 2) increasing river flow from upstream (based on rain) and 3) both conditions together, leading to a peak in water levels. Only once delayed rainy seasons were mentioned as potentially linkable to climate change (see Figure 34).

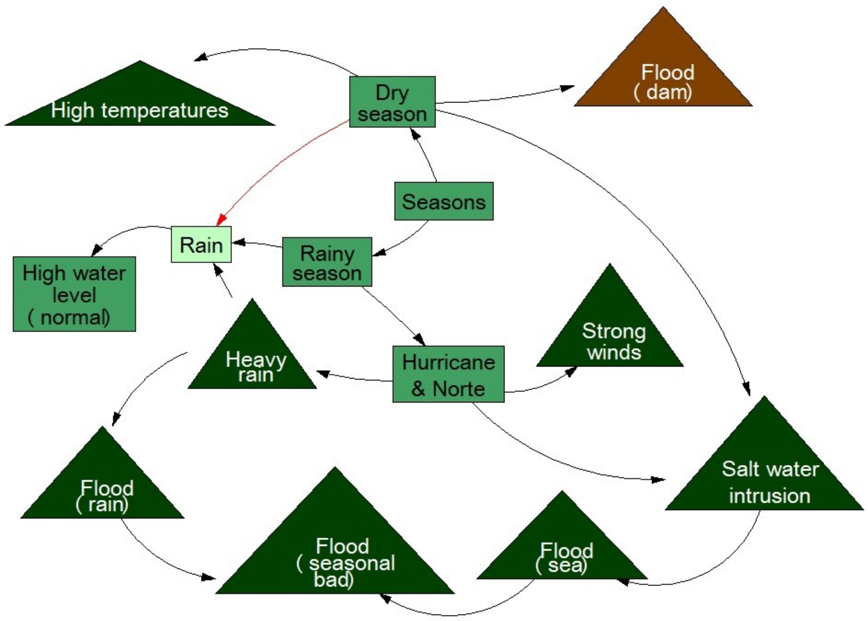


Figure 34: Weather focussed excerpt from Mexican mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

4.3.1.2 Differences between visited communities – Mexico

All four communities share many commonalities, however some remarkable differences remain. Interviewees in Quintín Aráuz possess quite an extensive **knowledge on the river** and related processes. For example, the relevance of regular “good” floods for enriching the soil with nutrients, the spread of the invasive catfish species from Grijalva, related to dam openings and most different pollution sources were mentioned there.

While all communities cover **hydration** with water gallons, Palizada and Quintín Aráuz obtain water also from wells and the tap, Tembladeras gathers water from wells and rain collection and Boca Chica relies on boiled river water and collected rain.

Boca Chica and Tembladeras are situated relatively closer to the coast line than Palizada and Quintín Aráuz. Thus, salt water **fish** as a fishing resource and salt water intrusion as a threat are relevant there. Generally, in these communities fishing plays a more important role than in Palizada and Quintín Aráuz. The latter additionally engages in cattle farming.

All four communities are situated within **nature** protection zones. This leads to less logging and in Quintín Aráuz and Tembladeras also to governmentally subsidized reforestation projects. Also wild animals are largely included in the protection, prohibiting hunting. However, in Palizada hunting is still common and adds to nutrition and income of some households. In Palizada and Tembladeras people mentioned fire as a threat to the natural ecosystem. Only in the latter village a government programme supporting maintenance of fire breaches in the local mangrove forest is implemented.

Some minor differences have been mentioned in the context of **agriculture, gardening and domestic animals**. For example, only in Boca Chica growing fruits has been mentioned explicitly as contributing to nutrition and income. People in Palizada mentioned the effect of heat on domestic animals, while other communities didn't recognize this threat. Interviewees in Quintín Aráuz feed their animals with grown fodder compared to all other communities feeding mainly bought fodder. Additionally to the common threats of flood and plagues in Quintín Aráuz, also air and soil contaminated by petroleum as well as wild animals are mentioned. Similarly, petroleum and generally bad water quality is problematic in Tembladeras.

Fish is the most common **income** source throughout all four case study communities. Most diverse income sources are mentioned in Quintín Aráuz, adding crops, government programmes, wood products and money transfer from family members to the list. Government programmes also play an important role for incomes in Boca Chica and Tembladeras. In Palizada next to fish, crops, wild animals and tourism are sources for income. The income is mainly needed for nutrition, health and various materials, while paying a house keeper in Boca Chica, paying for education in Quintín Aráuz and other individual needs are covered as well. Furthermore, people living in the relatively bigger settlements of Palizada and Quintín Aráuz consider **migration** as a possibility to avoid damage through unemployment, while for people in Tembladeras and Boca Chica this possibility was not so present.

Mosquito and related illnesses are limiting **health** in all case study villages. Pollution is mentioned as affecting health in Quintín Aráuz, Boca Chica and Palizada. In the latter two furthermore insufficient health services have been criticized. However, only in Boca Chica medicinal plants are applied on a regular basis to support health in an alternative way.

Housing is supported by the government through subsidized building material in Quintín Aráuz and Tembladeras, as well as through solar panels in Boca Chica. Even though in all communities waste pollution of the river and its environment is recognized as a problem, only Tembladeras actively contributes to waste management through recycling. Similarly all also experience damages to their houses from floods. Additionally, housing and other household assets are damaged through robbery in Boca Chica, by shore erosion in Quintín Aráuz and strong winds in Tembladeras.

During dry **seasons** Boca Chica and Tembladeras are mostly affected by salt water intrusion, while Palizada and Quintín Aráuz suffer from high temperatures. Heavy rain is experienced in Boca Chica and Quintín Aráuz during hurricane events, in Palizada during the “Norte” season. Three different types of resulting floods are defined by an interviewee in Boca Chica as salt water flooding, rain water flooding, and both combined. Only in Tembladeras a delay of seasonal rainfall patterns was observed over the past years.

4.3.2 South African case studies

In South Africa the villages of Emgangeni and Ndaya were visited to gather the local knowledge of people. The two complete community mental models can be found in the Appendix (see A2.5 - A2.6).

4.3.2.1 Regionally summarized components and processes – South Africa

For both communities the **Mkhomazi River** first of all is connected to people’s origin. Most mention their ancestors having lived in this area as one of the most important reasons for living there as well. Except for the indirect connection to the river by the heritage of the land, not many linkages exist to the livelihoods. It serves as a water source, even though not the preferred one. Also people occasionally go there for fishing, swimming or washing. In this context the river has often been mentioned merely as danger for life. Due to its strong currents, and presumably the limited ability to swim, people are drowning occasionally. Both strong currents and the lack of certificates and material make fishing a rare activity (see Figure 35).

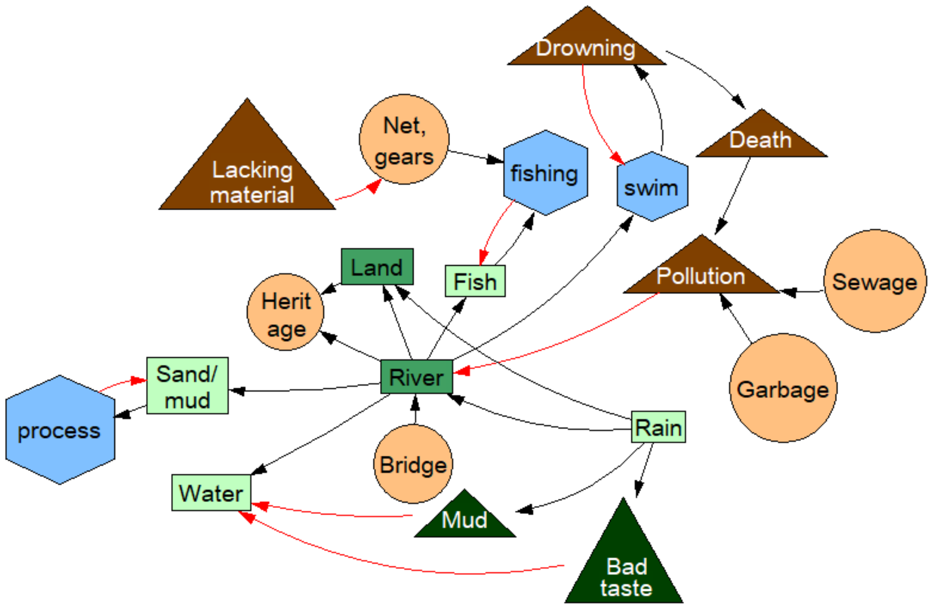


Figure 35: River focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Additionally to the river, water tanks, tap water and rain water collection are available **water** sources (see Figure 36). People don't like the river water, because it is far away and collecting is strenuous due to the steep hills. Also it has been said that the taste is not especially good, and the inhabitants of the villages are not sure about the water quality. So far no health related disadvantages have been observed, and therefore boiling river water before using it is being practiced, but rather unusually. No one mentioned having piped water available in their houses. Tap water and water tanks are located at central places in both villages to provide clean water (see Figure 37). Both water sources are only erratically usable because of limited amount of water available through taps and an unreliable frequency of visits by the water truck. Tap water being used on a first come first serve basis can lead to internal conflicts between the inhabitants of the community. Based on the unreliable situation of regional water provision, people tend to save water and draw on river water and rain water, collected in buckets, to satisfy their water need. Water is being used for hydration and washing.

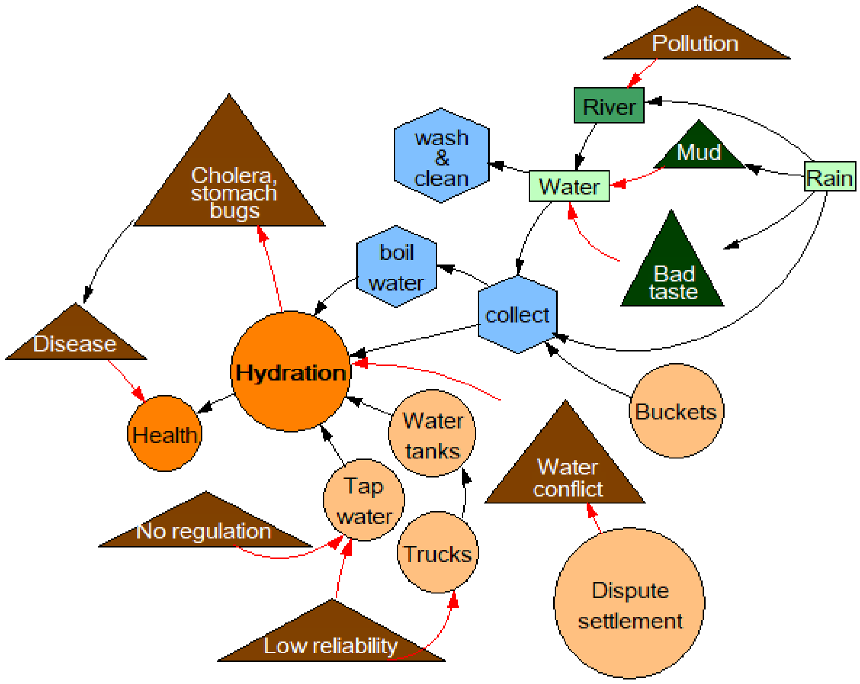


Figure 36: Hydration focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Figure 37: Water supply at the Mkhomazi (SA): Water tank and river (left), water tap (right); own source

From the **natural vegetation** mainly wood is used as building, cooking and heating material. Only few know of the use of medicinal plants. No further use of natural vegetation has been mentioned. The land is used for **gardening/ small scale vegetable farming** to feed the household members, to sell in small amounts or to support neighbours in difficult times (see Figure 38).

Figure 38: Small fields growing vegetables; own source

However, in recent years farming has become increasingly difficult and is being surrendered more and more because of increasing heat and drought as well as the destruction of fields by bush pigs. To limit the destruction by wild animals as well as domestic animals some start building fences. Furthermore, inhabitants decrease the numbers of wild animals by hunting. Both measures have proven to be insufficient to keep farming worthwhile (see Figure 39).

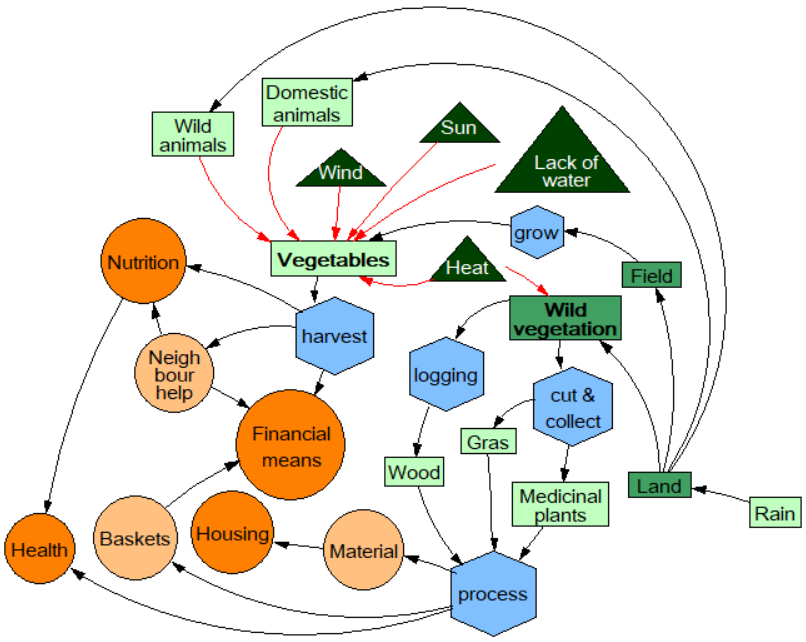


Figure 39: Vegetation focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Wild animals such as springboks, monkeys and bush pigs are being hunted and contribute to peoples' nutrition. As there is no large hunting community, both numbers of wild animals cannot be kept sufficiently low to avoid damage of crops, and their contribution to nutrition is comparably small. Alongside wild animals, **domestic animals**, especially goats, sheep and chicken, are also held for nutrition (see Figure 40). Generally, domestic animals have a high value in the livelihoods of these two rural communities. Cows are used for traditional ceremonies and are an alternative saving, together with all other domestic animals, which can be traded if needed. Cows and goats are affected by insects, causing udder illnesses. Furthermore, theft of domestic animals can lead to conflict between community members. Dead animals are a source of pollution of the river.

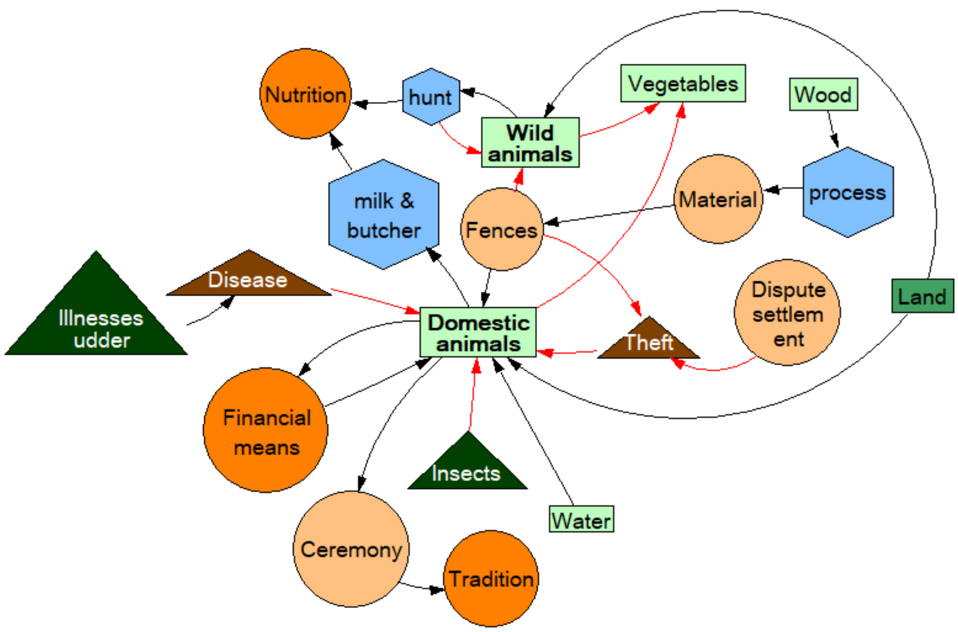


Figure 40: Animal focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Natural sources only make up a comparably small share of **food sources**. Most is purchased in shops and markets in the close-by city of Isipingo (about 40 km distance). The mainly purchased products for basic nutrition are rice, "mielie" (maize flour) and potatoes. To reach the markets most people are dependent on public transportation. A limiting factor is often money, which is needed in large shares for transport and purchase. Some mentioned hunger to be a problem. An additional limitation for the variety of food is the ability to store. The lack of fridges or continuous electricity in many households hinders the consumption of perishable food, such as meat and dairy products (see Figure 41).

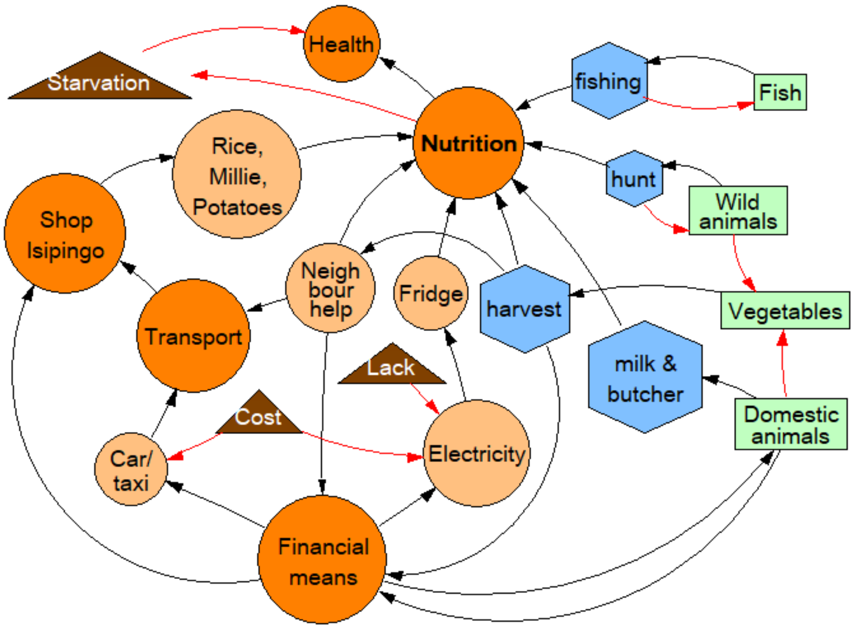


Figure 41: Nutrition focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. from human sources in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Income sources of local people are various. Many mentioned being unemployed or working only temporarily. They mostly base their income on government funding, such as sick grant, child grant, pension fund or household head funding. Other jobs are indirectly linked to the local government or public work, like teacher, administrative work, local representative of traditional leadership, community work, or community security. Furthermore, temporal income sources are selling old steel, part time jobs in close by cities, or grass cutting. Based on the high unemployment rate poverty was also mentioned as a problem in the region. Many young people go to school, some even until matric. Those currently still attending school have high hopes, such as becoming a social worker, a policeman or similar, while those having recently graduated are mostly unemployed and disillusioned. In contrast to this group of young people who went or still go to school, the lack of education in general and of good education in specific has been mentioned throughout different interviews. Distance and cost are further complicating education (see Figure 42).

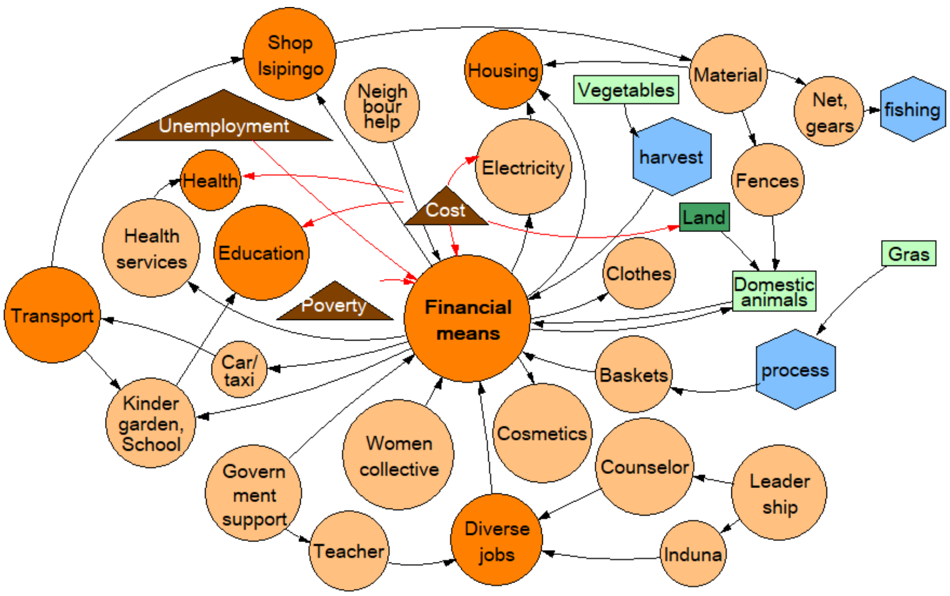


Figure 42: Financial means focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. from human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Another major cost in addition to transport, nutrition and education is **health**. Similarly to education also health care is hindered by long distance, therefore connected to the need of transportation, and extra costs. Opinions on the health services are diverging. Some mention them as insufficient in terms of quality and accessibility, while others mention the clinic as a major source of information. Next to conventional medicine people trust in alternative medicine, like medicinal plants and holy water from the church to alleviate pain and diseases. A range of occurring diseases, such as stomach bug, flu, asthma, tuberculosis, HIV, cholera, cough, high blood pressure, weak legs and body have been described. An additional threat to health in its most ultimate way is death through drowning in the river or being struck by lightning. The latter has explicitly been mentioned in the context of housing (see Figure 43).

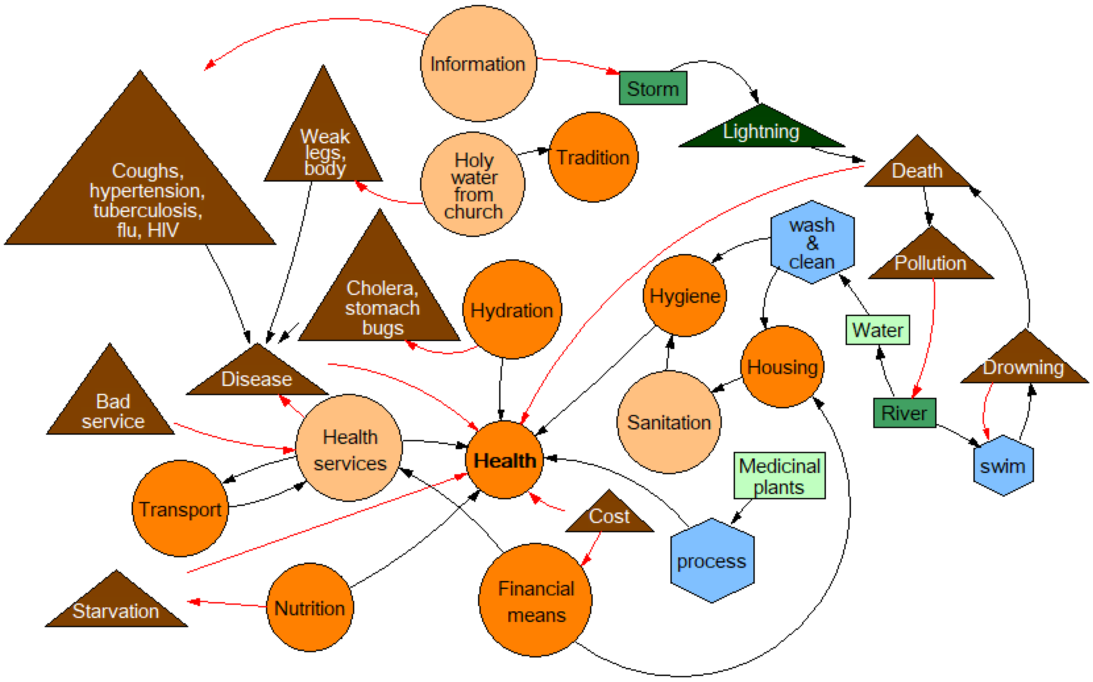


Figure 43: Health focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

The simple **houses** are built on hill tops and are made of mud blocks, wood and metal roofs (see Figure 45). They are both sensitive to lightning and heavy rain. Components such as wood, mud blocks and cement are regionally collected and produced out of natural resources. In terms of basic **infrastructure**, some buildings are equipped with electricity. However, people still report high costs and outages. It serves as a source for lighting, television, radio and fridge, as well as for activities such as boiling water and ironing clothes. Garbage and sewage are being recycled on an individual basis, but mostly dumped into a garbage hole prior or after burning (see Figure 44). Inhabitants report on garbage pollution of the river, which also leads to their mistrust in the quality of river water. Roadways in the region are mostly unpaved and the only public transportation available is taxis, small buses which commute between the villages, schools and shops in Isipingo. Some own private cars which can be borrowed from others, or in case of illness the ambulance picks patients up. Distance is the major issue to reach various facilities, like schools, clinics, shops and police stations.

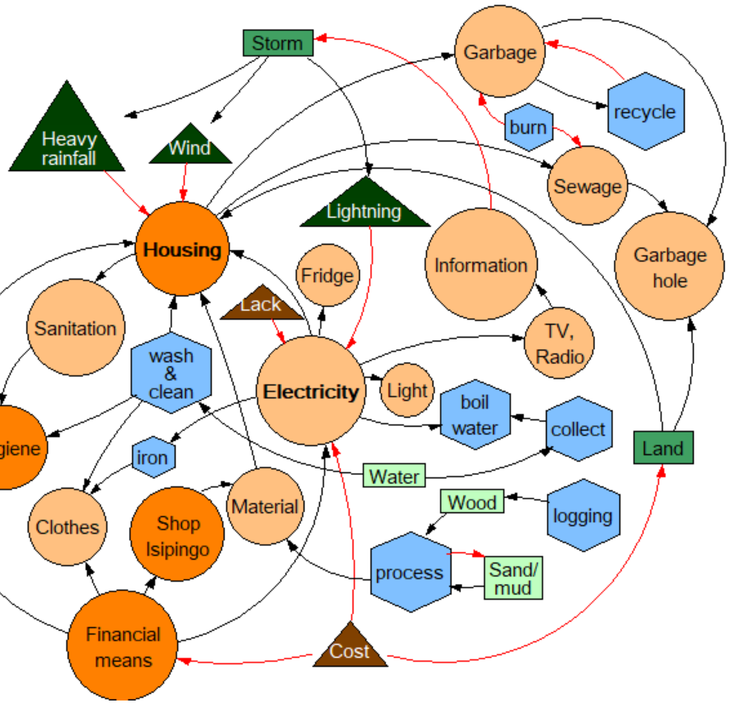


Figure 44: Housing and infrastructure focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. naturally caused in dark green and with human source in dark orange/brown. Blue hexagons stand for human activities. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

Figure 45: Housing and building material: Traditional house (left) and metal roof (right); own source

Both communities are in tribal territory and therefore **traditional leadership structures** are important. The Mkosi is deciding on land use, solving conflicts and overseeing the traditional council on a regional basis, while the Indunas are representing his duties on the community level. The officially elected representative of each community in the region is the counsellor. The traditional roles of the chief Mkosi and Induna are informally selected by family heritage and community members. These roles are mostly filled by men. Women expressed themselves reluctantly on the possibility or even wish to fulfil one of these positions. Never the less in our sample women showed themselves in very active roles both within and beyond their households. For example, one mentioned to be involved in a women collective managing their savings, while others contributed in **neighbourhood help**. Neighbourhood help is not usual everywhere as some persons see themselves not supported, even when in need (see Figure 46).

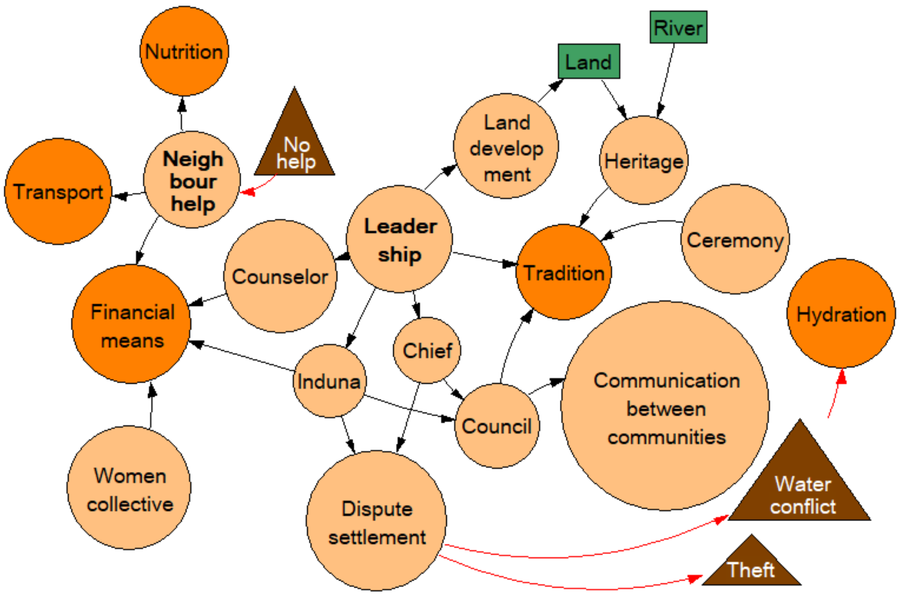


Figure 46: Social structures focussed excerpt from South African mental model. Boxes represent natural components, i.e. subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange and a source or livelihood aim in medium orange. Triangles visualize threats, i.e. from human source in dark orange/brown. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

The whole socio-ecological conglomerate is externally affected by **weather events and climate**. Especially in land use rain plays a crucial role in the natural rain and dry season cycle. Inhabitants observed an increase in droughts and heat, leading to lower productivity in small scale vegetable farming. Drought furthermore facilitates the occurrence of wild fires, causing damage on vegetation. Another set of severe impacts is caused by frequent storms where strong winds affect housing and vegetables as well as heavy rain and lightning damaging buildings and threatening human life. Even though most have access to radio or cell phones, weather information to prepare is valued inadequate. From the interviewers perspective we also see an additional challenge by a lack of knowledge on how to prepare, even if weather information is sufficient (see Figure 47).

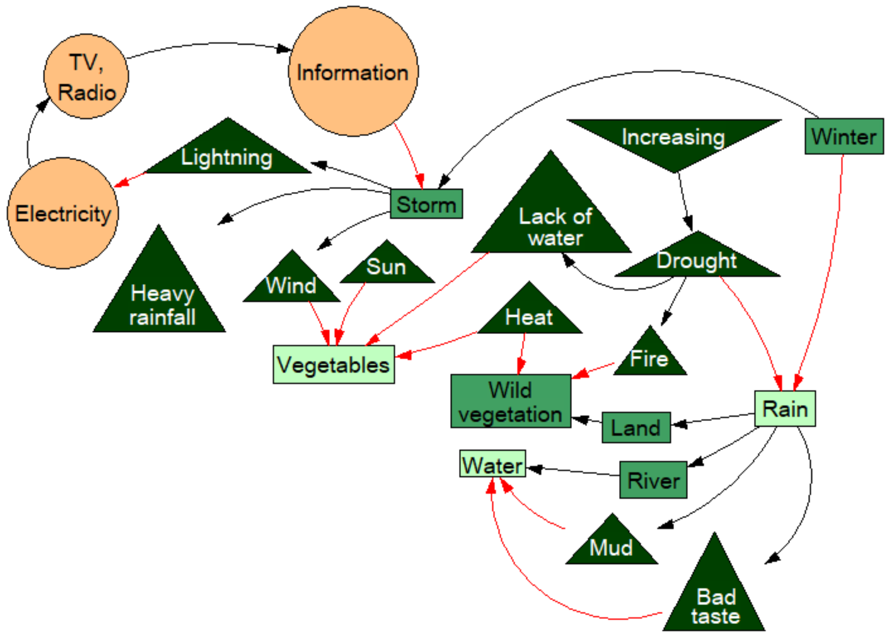


Figure 47: Weather focussed excerpt from South African mental model. Boxes represent natural components, i.e. resources and services in light green and conditions or subsystems in medium green. Circles show socio-economic components, i.e. products and resources in light orange. Triangles visualize threats, i.e. naturally caused in dark green. Black arrows represent an enhancing linkage, while red arrows lead to an opposite effect. Own source based on empirical data

4.3.2.2 Differences between visited communities – South Africa

In the two South African communities some differences also have to be remarked at this point. Emgangeni is reported to be much better equipped with basic infrastructure than Ndaya. While most people in Emgangeni mentioned retrieving their water solely from central taps or tanks, in Ndaya many constantly save water and use rain and river water for backup. This leads to the assumption, that water supply is more frequently available in the first case. Similar observations are made in terms of electricity. In Emgangeni people mainly complain about the cost of it, while many households in Ndaya do not have electricity at all. However, overall there are more similarities between the South African case communities than between the Mexican communities.

4.4 Analyses of results: interpretation of mental models

There are different possibilities to further proceed with the mental models derived from the participatory modelling sessions. At this point they show qualitative information, such as impact chains and feedback loops, which are essential for understanding the system's composition and behaviour (Vennix, 1999). A next step could be to add quantitative numbers and formulas to the model. Quantitative models tend to be more convincing to people applying their results (Rouwette et al., 2002). But due to the need for causal understanding, respective data, available financial and time resources, this is often only feasible for comparatively simple problems (Rouwette et al., 2002) and cannot be pursued here. Qualitative models have the additional advantage to potentially have a higher relevance for a broad group of people (Vennix, 1999). Also there are various possibilities to gather qualitative information from the models.

4.4.1 Central components and current local vulnerability

In a first step the rather complex models are structured in three different tables, to allow for a quick overview of components. All tables are structured along a set of questions. These questions are answered for each of the six communities and summarized for each case study region in Mexico and South Africa. Colour codes indicate whether the listed information on resources, livelihood aims and threats have been mentioned during the interviews in either Mexico (turquoise), South Africa (purple) or in both regions (blue). Therefore one can easily distinguish overlaps and differences between the regions. Independently from the frequency each piece of information has been mentioned, all is included in the table, equally as in the mental models. Single components can thus be based on one individual's perspective or also on a narrative of the majority of the interviewees.

4.4.1.1 Natural and semi-natural resources

One table focusses on natural and semi-natural resources being obtained from the local people (see Table 4). In this case, semi-natural resources are provided by the human altered natural system, e.g. crops. These agricultural yields are mostly based on the natural environment setting the preconditions, like nutrient rich soils, available water and others to maintain a productive field. However, the initiation is carried out by humans, planting and growing crops. Based on the assumption that, the higher the dependency on natural environment and resources, the more affected people will be by environmental changes, it is important to gather the information on which natural resources are used and what for.

The table structure is adapted from Hinkel et al. (2015) following this set of questions:

1. What provides the respective resource? How is it generated?
2. Is it dependent on additional factors?
3. For what is it used? What is the value it provides to the local population?
4. How is it used by humans?
5. Is it threatened by something? What is the danger?

Comparing the main resources in use, wild plants and animals as well as agricultural and farming products play a role in both Mexican and South African case studies. Also water gathered from the river or collected from rain is central to hydration, washing and cleaning. About the same number of resources or services obtained from the respective natural environment has been mentioned in the Mexican and South African communities.

Table 4: Natural and semi-natural resources in use in socio-ecological systems of case studies in Mexico, South Africa and both, no information available is marked with NK (not known), numbers of columns indicate to which question it refers; table structure is an own source adapted from (Hinkel et al., 2015), information in the table are mostly derived from the case study mental models with some minor additions from the author

Natural/semi-natural resources	1. generated/ provided by	2. dependent on	3. used for	4. used how	5. threatened by
Crop/ vegetables	Fields	Water availability, soil, air, land	Nutrition, financial means	Plant, grow, harvest, eat, feed, sell	Flood (dam release, seasonal good and bad flood), plagues, wild animals, pollution (water, soil, air), salt water, bad water, sun, lack of water, wind, domestic animals
Domestic animals	Garden, courtyard, river ecosystem	Water availability, fodder, crops, pasture, governmental support, plants, land	Nutrition, financial means, tradition	Buy, breed, feed, collect, milk, butcher, cook, eat, sell	Flood, plagues, high temperatures, high fodder prices, polluted water, salt water, insects, theft
Fish	Aquaculture, pond	Fodder, young fish, material, mangrove forest	Nutrition, financial means	Breed, feed, fish, cook, eat, sell	Flood
	River	Rain, water level (good flood)	Nutrition, financial means	Fish, cook, eat, sell	Bad fishing techniques, overexploitation, catfish, white water, sea water, pollution, suspended material, fire
Fruit	Fruit trees	Water availability	Nutrition	Plant, grow, harvest, eat	Flood
Grass	Plants	Land, water	Financial means	Collect, process	NK
Medicinal plants	River ecosystem	Land, water	Health	Collect, process	Salt water intrusion
Nature	River ecosystem	Wild animals, plants, transportation	Financial means	Offering tourism	Fire
Sand/ mud	River	NK	Housing	Collect, process	NK
Water	River	Rain, water level	Hydration, hygiene, watering animals, irrigation	Collect, boil, drink, wash, clean, water	Pollution, muddy water, sea water intrusion, bad taste
	Rain	Weather, seasonal variability	Hydration, hygiene	Collect, drink, wash, clean	Dry season, drought
	Well	Groundwater	Hydration, cleaning	Collect, drink, wash, clean	Low ground water level, pollution, salt water intrusion/ salinity
Wild animals	River ecosystem	Water, plants, animals, land	Nutrition, Financial means	Hunt, cook, eat, sell	Fire
Wood	Forest, plants	River ecosystem, other trees, land, water	Fuel, housing, financial means, material, fences	Collect, log, process, sell, fuel	Deforestation

4.4.1.2 Resource use and livelihood aims

A second table follows up on the third question of 4.4.1.1 about the use of respective resources. These uses are sorted into livelihood aims (see Table 5). Even though livelihood in the literal sense of the word, refers to the basis of existence, here livelihood aims refer to all explicit and implicit objectives of life. These are derived from what people describe as their daily routines and what value they obtain from them and the resources they use. Livelihood aims are seen as central to the use of resources, the fulfilment of needs and wishes of people as well as ultimately defining the motivation of their behaviour. They are interrelated and can hardly be separated from each other or be put in a hierarchical order. Still, hydration, nutrition and financial means are defined as most basic and central livelihood aims. Subsequently health, housing, education and transport are important. Health is here described as subsequent to hydration, nutrition and financial means, not because it is less important to people's livelihoods, but for being largely based on the latter three.

For each livelihood aim the following questions are answered with the information of the mental models:

1. What provides and fulfils the respective livelihood aim?
2. Which components support the provision of the aim?
3. What events and conditions threaten either providing or supporting components?

Question 1 is largely covered by the resources listed in Table 4. Still, many livelihood aims can alternatively be provided by socio-economic resources. This adds another perspective and allows identifying how dependent one livelihood aim is on single resources. Additionally, the variety of threats potentially affecting the provision of the livelihood aim gives information on how dependable each source is.

Both visited Mexican and South African communities rely on four sources of water to cover their hydration needs each. As mentioned in the context of Table 4 water needed is mainly provided by the natural sources of river, rain and wells. However, partly due to the increasingly polluted rivers in both regions and an unreliable frequency of rainfall in South Africa, water gallons, tap water and water tanks form alternative sources of water. In both regions products from fish, domestic animals and plants, whether planted or growing wild, contribute to nutrition. In the Mexican villages additional sources are fruit trees and wild animals. Based on the higher number of natural food sources, the assumption is made that in the Mexican case study area nutrition is based on natural resources to a larger proportion than in the South African case. This assumption is backed up by the qualitative observation, that in the visited South African region natural resources only supplement nutrition to a minor share. The majority seems to be obtained from shops and markets. Similarly, financial means in the visited Mexican region are gained from eleven different sources, out of which at least seven rely on natural resources and environmental services. In the South African case though, only three out of seven are based on the natural environment. Health is indirectly related to hygiene, nutrition, hydration and housing. In case of an unfavourable health state, health services, medicinal plants and the church are consulted and relied on. Housing and energy are in both regions mostly covered by socio-economic structures, like building material and electricity either bought and paid for individually, or supported by the government, while additional resources, like wood, are taken from the natural environment. Education and transport have frequently been mentioned as important to livelihoods in South Africa. Neither of the latter three (housing, education, transport) has been a specific focus in the interviews and are therefore expectedly incomplete (see Table 5 and A3.1 for complete table).

Table 5: Livelihood aims of people of case studies in Mexico, South Africa and both; table structure developed by the author, information in the table derived from the case study mental models

Livelihood aim	**1. provided by**
Hydration	River water Rain water Well Water gallons (shop) Water tanks Tap water
Nutrition	Fish Domestic animals Plants/ vegetables/ crops Fruits Wild animals Shop
Financial means	Fish Domestic animals Crops/vegetables Processed wood Grass baskets Wild animals Lease land Shop Tourism Diverse jobs (external) Government grants/ support Neighbour help Family money transfer Women collective
Health	Health services Medicinal plants Church Hygiene Nutrition Hydration Housing
Housing	Building material Energy Government support
Education	Kindergarten, school Voluntary work with kids
Transport	Ambulance Taxi Private car

4.4.1.3 Threats, their sources and countermeasures

Last but not least, experienced threats are specified along the following questions:

1. What is the cause or the source of the threat?
2. What does the threat impact on?
3. Are the sources and affected components natural, semi-natural or human?
4. What factors have an additional affect, increasing the impact of the threat?
5. Are countermeasures in place? If yes, what kind of measures?

Information on the source of the threat allows for interpretations on the influenceability and adaptability to future events. Looking at the impact one can estimate how broad the effects of one threat are on the system, in terms of how many components are affected. Both threat sources and affected components are further categorized into natural (N), semi-natural (N/H) and human (H). This categorization was added by the author posterior to the interview in order to further structure the broad variety of threats. All categories can refer to a single component or the combination of several. Therefore semi-natural doesn't only stand for semi-natural components such as domestic animals, but also for a mixture of natural and human components. The combination of source and impact gives insights into the most common threat-impact relation. For example, if natural threats mainly affect natural components or equally influence semi-natural and human components of the socio-ecological system. Additional influence factors are an interpretation added by the author. In the mental models some components affect each other, however including the available background knowledge, it can be distinguished whether this component is really the source or only an additional influence on the respective other component.

With the information on countermeasures, an additional estimate of the possibility to manage a threat is given. Existing countermeasures can act as a starting point for further developments, independent of the current efficiency of the respective measures. Furthermore, the threats listed differ in terms of impact, ranging from directly affecting and potentially inhibiting, like drought to rain water, via deteriorating the quality, like mud and suspended material in river water, to indirectly influencing, like robbery and unemployment diminishing financial means needed to buy fishing material every now and then.

More threats affect natural components of the river ecosystem, such as fish, river water and mangrove forest in the Mexican compared to the South African region. This observation is potentially related to the closer proximity of Mexican communities to the river than South Africans. In the latter case more drastic threats, like death through lightning, drowning or starvation were mentioned, while an observer in local Mexico got the impression of a diversity of threats, however none of them life threatening. In Table 6 a selection of the complete table A3.2 in the Appendix is shown.

Table 6: Selection of threats and their characteristics; including cause(s), affected components, additional influence(s) and potential countermeasures in place in Mexico, South Africa and both, no information given marked with NK (not known), numbers of columns indicate to which question it refers; table structure developed by the author, information in the table are mainly derived from the case study mental models with some minor additions from the author

Threat	1. cause/ source	2. impact on	4. additional influence	5. countermeasures
Catfish	NK	Fish, shore erosion	Grijalva upstream, intruding through opened dams	NK
Dry season/ Drought	NK/ Seasonality	Rain, temperatures, salt water intrusion	NK	NK
Flood (seasonal bad)	Hurricane, Norte, sea water intrusion, heavy rain, rain, high water level	River ecosystem, housing, domestic animals, fruit trees, crops, pond/aquaculture, transportation, sediments, mosquitos, dengue, pollution, shore erosion	Suspended material, pollution	NK
Knowledge loss	Migration	Agriculture, gardening, fishing, cattle farming	Unemployment	NK
Low reliability	Irregular arrival of water trucks, irregular availability of tap water	Hydration	NK	NK
Overexploitation	Many & external fishermen	Fish	Lack of awareness	NK
Pollution/ contamination	Dead animals and humans, fumigation, petroleum, waste (garbage, sewage), pesticides, chemicals, bad waste management	Air, rain, soil, river ecosystem, water, fish, crops, domestic animals, health, plagues, well, diarrhoea	Upstream communities, offshore drilling, flood (dam & seasonal)	Water treatment, recycling initiative supported by the government, burning garbage
Robbery/ Theft	NK	Financial means, housing, material, domestic animals	Lack of vigilance	Carer, trader, family, neighbour help, fences, induna settles disputes
Salt water intrusion	Hurricane, dry season, Norte, high tides at sea	Fish (+/-), river ecosystem, water, flood, well, domestic animals, crops, medicinal plants, health	NK/ geomorphology of the region (very flat)	NK
Storm	Winter season	Wind, rain, lightning, electricity, housing, health	NK	Weather forecast via radio
Unemployment	NK	Financial means, migration, need for governmental support	NK	Government support to increase available work, fishing, agriculture, gardening, cattle farming

Based on the N-H categorization of threat sources and impacted components into natural (N), semi-natural (N/H) and human (H), some meta-analysis is added. Almost half of all 56 mentioned threats are caused by humans. More than a third not only have a human source but also affect only human components and structures. In the broad majority this category describes structures functioning insufficiently, e.g. bad health services, or lack of education. These conditions can be threatening to important livelihood components although they are not necessarily related to recent changes or fast-onset disturbing events like the majority of natural threats. Almost 40 % of threats are based on a fully natural source, like weather related events or seasonal conditions in weather and river ecosystem (see Figure 48). The colour scale in Figure 48 is adapted from the colour scale in the mental models: green represents natural and orange human components. To clearly separate natural and semi-natural with brown another colour is added. Because here a matching of two natural and human categories is applied, the colour scale first refers to the threat source in the selection of the main colour. Secondly, the shade of the main colour is adapted based on the category of the affected components. Finally, affected natural components link to the darkest shade, semi-natural to the medium shade and human to the lightest shade of the respective colour. For example, a natural threat is assigned the colour green and combined with the affected semi-natural components the category results in medium green (see Figure 48).

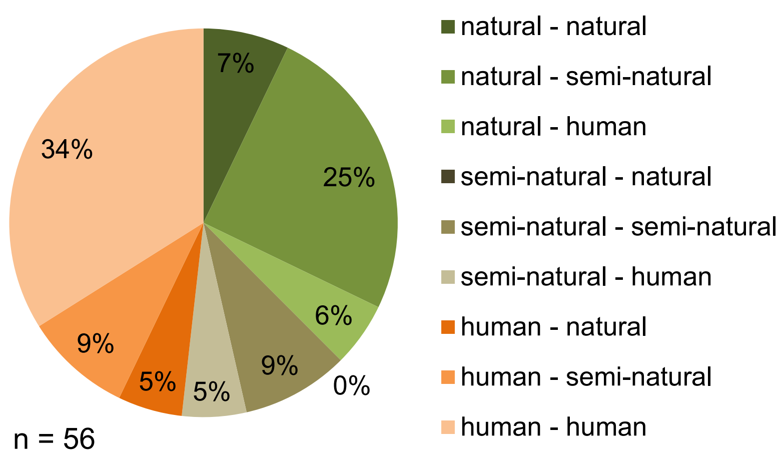


Figure 48: Categorization of threat source and impact, differentiating between natural (N), semi-natural (N/H) and human (H) for all 56 threats mentioned, the assigned colours are based on the source of the threat, with natural, semi-natural and human, varying the shade according to the impact from dark to light for natural to human; own source

Combining the different information from the table and the observations during the interviews one major difference is the higher overall importance of the natural environment in terms of resource use and affectedness by threats in the Mexican case study area compared to the South African case study. For example, in both regions fish are used as a natural resource.

While South African interviewees mentioned fish only as an additional source of food, for the Mexican interviewees, it plays a central role for both nutrition and income.

4.4.1.4 Current local vulnerability

In the previous three chapters (see 4.4.1.1-3) major components and processes defining rural socio-ecological systems in coastal river areas of the Mexican and South African case studies have been identified related to the mental models. Based on these, an assessment of existing pressures on available resources and therefore livelihood aims is derived. By looking at the number of uses relying on one resource and including the number of threats affecting the respective resource, a calculation of the resulting double pressure is made. This pressure serves as an estimate of relative current vulnerability. In other words, it is expected that a resource on which an above average number of human uses relies, is especially important to the socio-ecological system. Depending on the frequency and intensity of uses as well as the renewal rate of the respective resource, the latter is not only important but also at risk of depletion. In turn, if a resource of high importance (in terms of uses relying on it) is not available anymore, it will most probably severely disturb the socio-ecological system and related livelihoods. Adding here the number of threats currently affecting the respective resource, an estimate of the probability of the unavailability of the resource, due to other reasons than use, complements the evaluation (see Figure 49).

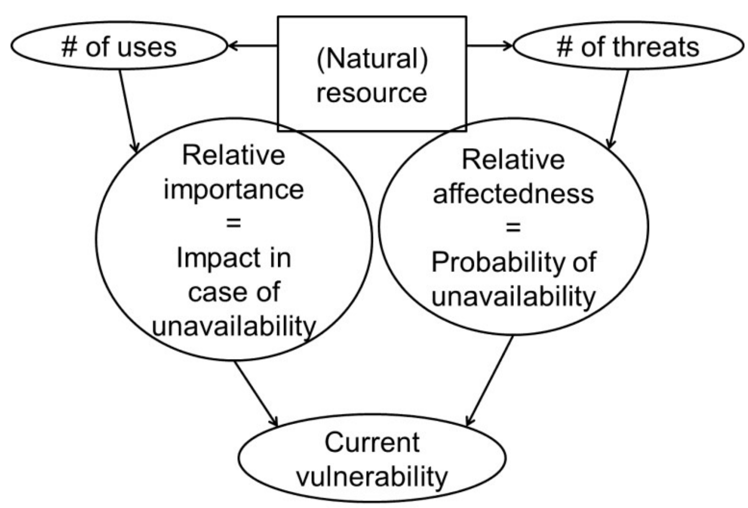


Figure 49: Central thought concept behind definition and calculation of current vulnerability; own source

This central thought concept of relying the vulnerability of the whole rural socio-ecological system on relative importance and affectedness of its resources is complemented by two further steps. First, before looking at the resource, an estimate of each threat, based on the number of sources and countermeasures, is added. E.g. pollution in Mexico has been mentioned related to waste, petroleum production and pesticides use. Therefore the summarized threat pollution should be valued higher than another threat like deforestation which is only caused by logging.

Several causes for a similar threat potentially lead to a higher variety of potential appearances in the context of frequency, spatial extent and impact. Countermeasures can lower the effect of a threat through mitigating, coping and adapting to it. E.g. waste management lowers the waste related pollution. Therefore it leads to a lower value for the threat in this approach. The consideration of sources and countermeasures doesn't include the actual effect each threat has, but shows the possibilities to differentiate threats by their potential impact in various ways in the assessment. In a second step, after looking at uses and threats affecting each resource individually, a summary of all resources serving the fulfilment of a livelihood aim is derived. This last step allows for an estimate of which livelihood aim is probably most vulnerable to not being fulfilled in the future.

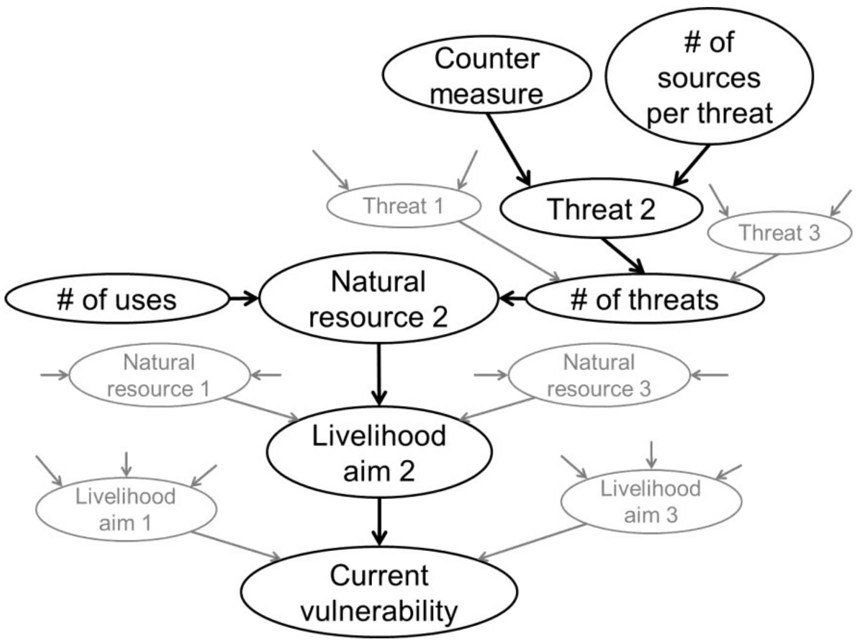


Figure 50: Complete pathway to define current vulnerability; own source

To compare different threats, resources and livelihood aims with each other, a rating based on a simple traffic light colour code is used. Red indicates the highest or severest category which is either based on a specific weighting, e.g. a threat based on several sources, or on a relative comparison amongst the group of components, e.g. number of uses based on one resource is higher than the average (Median) number throughout the group of resources. Yellow generally marks the average itself. Green signifies an improved or uncritical situation by having active countermeasures or less than average effect. The colour codes are applied whenever new measures are added. At the end of the calculation the resulting values are again transformed into colours for each resource and each livelihood aim. To simplify the calculation in between the original colours are transferred to the values 2 for red, 1 for yellow and 0 for green. This simple categorization allows to cross calculate averages, e.g. between the number of uses and the number of threats affecting a specific resource (see Table 7).

Table 7: Local vulnerability calculation criteria, colour and value assignment; own source

Criteria	Colour code	Value for calculation
> 1 source per threat, > Median # of uses, > Median # of threats		= 2
1 source per threat, no countermeasure, Median # of uses, Median # of threats		= 1
counterm.(s) available, < Median # of uses, < Median # of threats		= 0

The local vulnerability rating starts with the mentioned threats. Those which result of different causes are valued as more severe than those which are observed to be based on one trigger and are therefore categorized red. Each threat-source combination has by default the same severity. So for example pollution due to waste doesn't differ in the severity of the impact compared to drought. Countermeasures are interpreted as having identified and tackled a problem in a certain way and therefore add a green category. These two pieces of information give an extra value for each threat. By default a threat has one source and no countermeasure and hence is rated yellow twice in the traffic light rating.

Out of 41 mentioned threats in the Mexican example region 29 originate each from only one source and have no countermeasure in place. Against eight threats the communities already have countermeasures implemented and five threats are caused by more than one trigger. Only the above described example of pollution has both more than one source and active countermeasures. Similarly also in the South African case pollution is the only threat emerging from several causes and acted against via waste management. Five of the remaining threats are also caused by more than one trigger and against a total of six threats counteracting structures are implemented. 21 out of 32 mentioned threats are related to each one source and have no countermeasures in place (see Appendix A3.2 for complete threats table).

Based on the threats affecting a resource, an average over all additional threat values (considering source and countermeasure) is calculated. This average additional threat value over all threats per resource combines together with the number based threat rating to an average threat value per resource. Each resource is then evaluated based on the pressures from threats on the one side and human uses on the other side. This double pressure results in a vulnerability value for each resource. An example calculation is: an additional threat value of 1 for pollution (several sources = red (2), countermeasures = green (0)) combines in the resource water from river together with the additional threat values of four more threats to 1.25 for the average source-countermeasure value for threats on river water. This 1.25 is combined with a 2 (red) based on the Median number of one threat per resource in the Mexican region to a total 1.63 for the overall threat pressure. On the other hand river water is directly used for hydration and hygiene, as well as it indirectly contributes to nutrition and financial means via irrigation of crops and offering a water source to domestic animals which is rated again as 2 (red) based on the Median number of 2 uses per resource in the Mexican case studies. This results in a total average value of 1.81 and therefore a red rating for the resource river water. See Appendix A4.1 and A4.2 for complete calculation tables.

Following this approach for all resources, in the Mexican example only river water is rated as critical (red) and only nature as uncritical (green). All other natural and semi-natural resources are pressured but still within an intermediate range (yellow), relative to the maximum. In the South African communities on the other hand domestic animals, river water and wood result in a critical rating. With fish, grass, sand/mud and wild animals also more resources are in an uncritical state. Comparing both regions with each other crops, medicinal plants and rain water are pressured at a similar relative level. While domestic animals and wood are more pressured in the South African than in the Mexican region, fish and wild animals are less pressured (see Table 8). This rating is to be valued as one facet of a broad conglomerate of influence factors on the local vulnerability.

Table 8: Comparison regional natural and semi-natural resource rating, background colour red = critical, yellow = pressured, green = uncritical; font colours in "threatened by" column red = more than one source/ no countermeasures, brown/yellow = one source/ no counter-measure or several sources/countermeasures, green = one source/ countermeasures or not known (NK); own source based on empirical data

Mexican case study				South African case study		
Natural/semi-natural resources	**Used for** (Median=2)	**Threatened by** (Median=1)		**Natural/semi-natural resources**	**Used for** (Median 1.5, rounded 2)	**Threatened by** (Median 1.5, rounded 2)
Crop	Nutrition, financial means	Flood, high water level, plagues, wild animals, pollution, salt water		Crops (vegetables)	Nutrition, financial means	Sun, lack of water, wind, wild animals, domestic animals
Domestic animals	Nutrition, financial means	Flood, mosquitos, plagues, high temperatures, high fodder prices, pollution, salt water		Domestic animals	Tradition, nutrition, financial means	Insects, theft, disease (illness udder)
Fish-Aquaculture	Nutrition, financial means	Flood				
Fish-River	Nutrition, financial means	Bad fishing techniques, overexploitation, catfish, white water, salt water, pollution, suspended material, fire		Fish	Nutrition	NK
Fruit	Nutrition	Flood				
				Grass	Financial means	NK
Land	Financial means	Flood, high water level				
Medicinal plants	Health	Salt water		Medicinal plants	Health	Fire, heat
Nature	Financial means	Fire				
				Sand/ mud	Housing	NK
Water-River	Hydration, hygiene, crops, domestic animals	Pollution, muddy water, salt water, suspended material		Water-River	Hydration, hygiene, domestic animals	Pollution, mud, bad taste
Water-Rain	Hydration, hygiene	Dry season		Water-Rain	Hydration, hygiene	Drought
Water-Well	Hydration, hygiene	Low ground water level, pollution, salinity				
Wild animals	Nutrition, financial means	Fire		Wild animals	Nutrition	NK
Wood	Fuel, housing, financial means, material for cattle	Deforestation		Wood	Housing, fuel, domestic animals/crops	Fire, heat

All resource values, equally calculated for natural, semi-natural and socio-economic resources are transferred to the livelihood aims they contribute to. Each livelihood aim depends on a set of resources and can therefore be evaluated by the average pressures of threats and uses on each resource and respectively the overall average of resources per livelihood aim (see Figure 51).

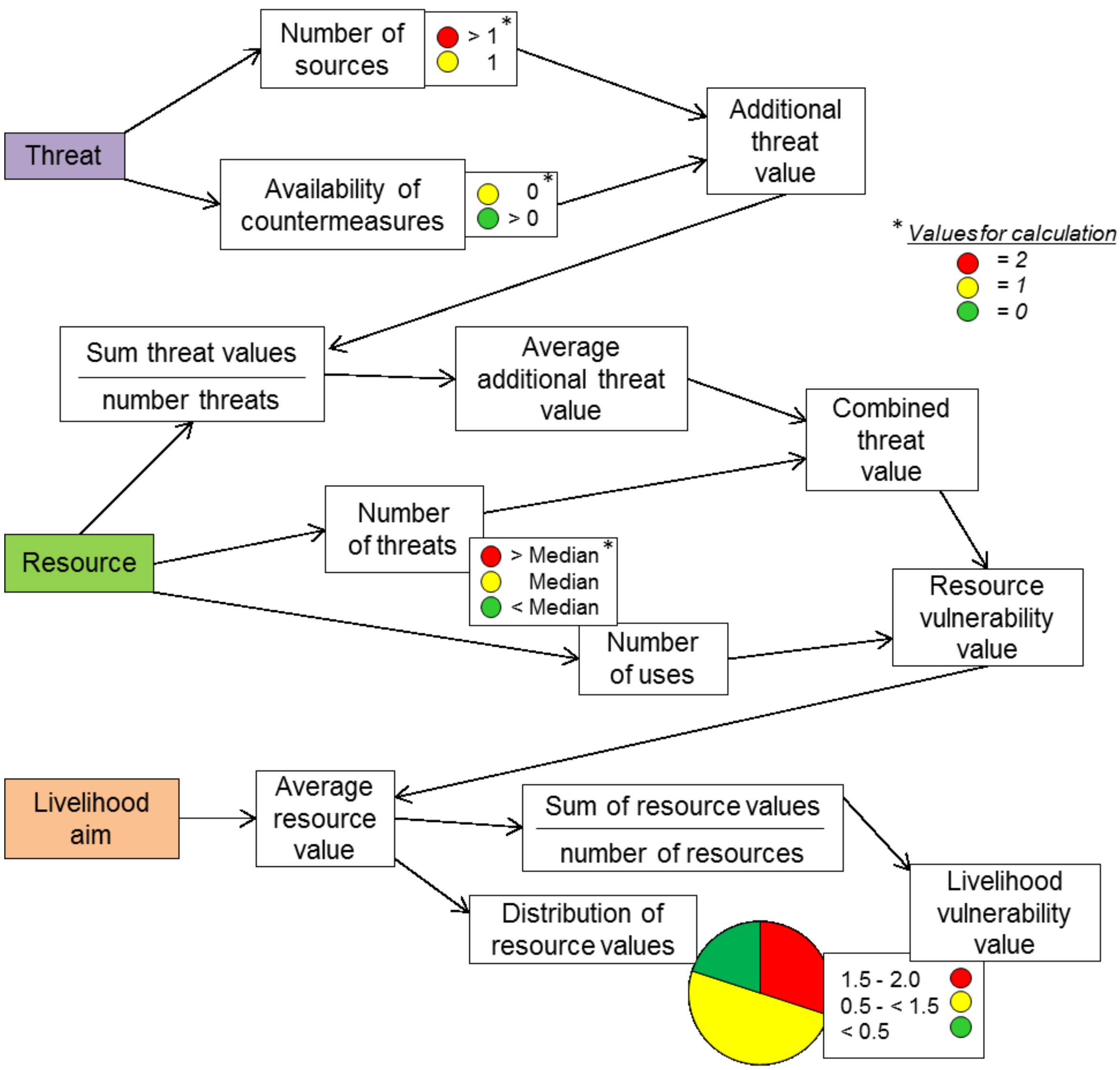


Figure 51: Complete calculation scheme for local vulnerability, based on the three steps of categorizing 1) threats based on the number of sources and countermeasures, 2) resources based on the number of threats and uses, and 3) livelihood aims based on the average of included resources. Own source

As a result of several steps of averaging, like described in the previous paragraphs, all livelihood aims for both case studies are expectedly rated with yellow, pressured. Therefore a look at the distribution of the resources ratings per livelihood aim gives further interesting insights. In the Mexican region hydration and hygiene include one critical resource, namely river water, while all other livelihood aims are overall only pressured with occasional uncritical shares. In relation to the total number of resources included per livelihood aim, the uncritical share is largest for financial means. For the latter also the resource diversity is highest (see Figure 52).

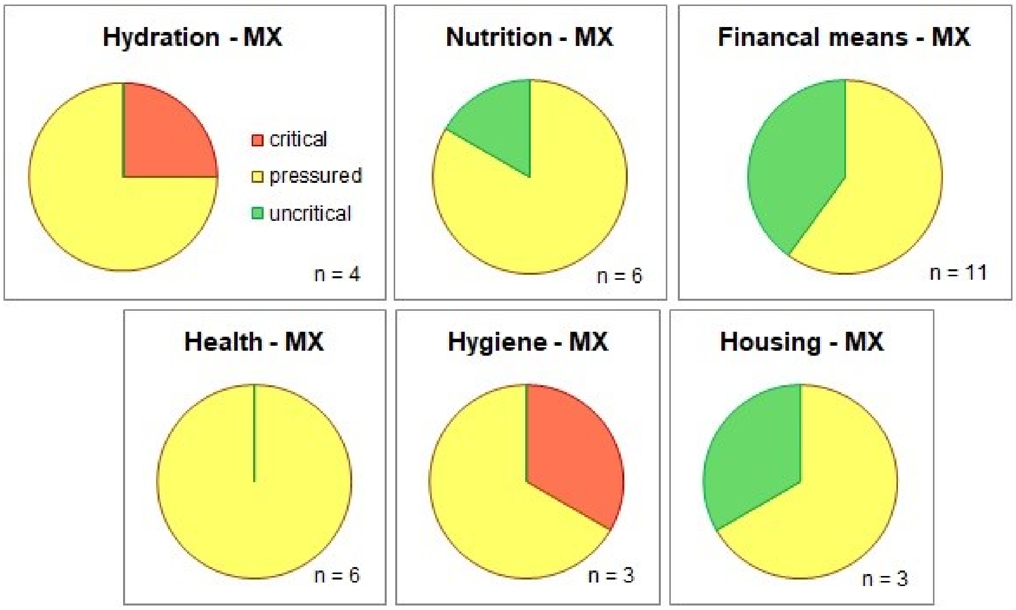


Figure 52: Distribution of resource values for each livelihood aim in the Mexican region, total number of resources is indicated with n; own source, analysis results based on empirical data

In the South African case hydration, hygiene, nutrition and financial means all include one critically rated resource, which is river water for the first two and domestic animals for the latter two. Remaining resources in hydration and hygiene are in a pressured state. Nutrition and financial means are otherwise ensured by uncritical and one more pressured resource. All other livelihood aims are partially pressured and uncritical. Similar to the Mexican example also in the South African communities financial means is the aim ensured by the highest diversity of resources and mainly rated uncritical. Based on this approach transport is fully uncritical (see Figure 53).

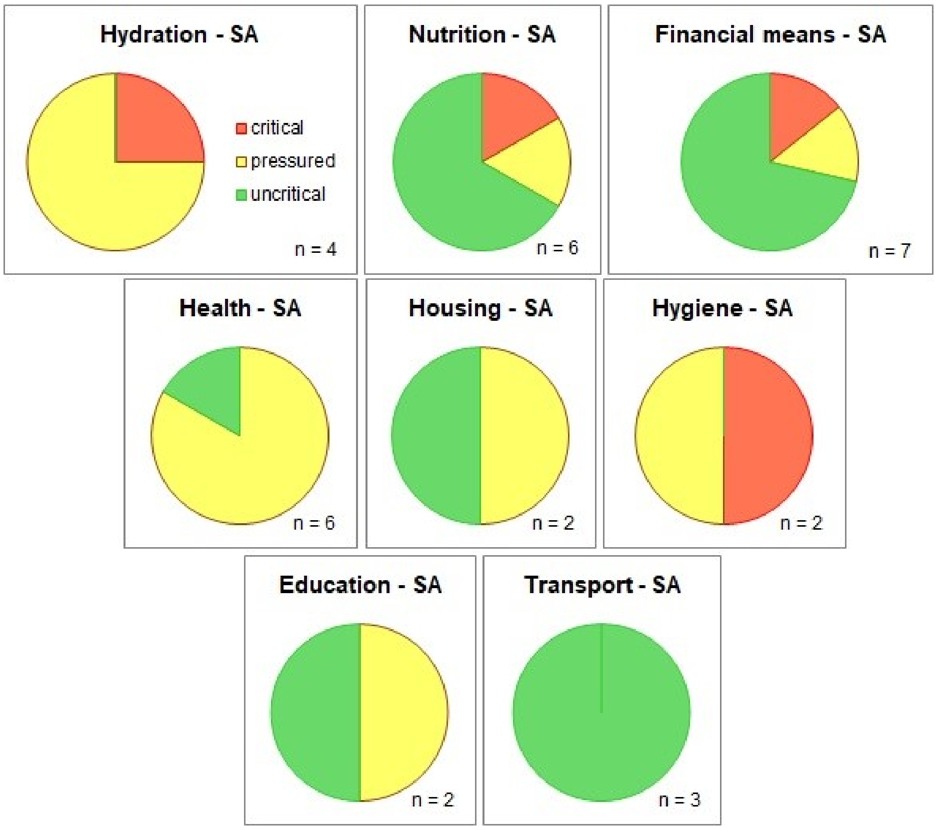


Figure 53: Distribution of resource values for each livelihood aim in South Africa, total number of resources is indicated with n; own source, analysis results based on empirical data

Based on this rating both case studies are vulnerable at an intermediate level. However taking into account the vulnerability of individual resources, especially river water is highly vulnerable to additional stressors in both regions. This vulnerability assessment is based on a one-time appraisal and therefore only represents a snapshot of current conditions. Because vulnerability is mostly viewed as a dynamical concept in the next chapter potential future developments of the described socio-ecological systems under climate change are explored.

4.4.2 Linkages and dynamics

In another step the completed models are analysed in their dynamics. Referring to chapter 2.2 and 4.1.2 the arrows in the mental models showing the linkages between the components are the focus here. Two types of information can be derived from the arrows. First, the arrowhead points to the influenced component A, while the end of the arrow originates from the component B, the one A is dependent on or otherwise related to. This influence can simply be a material inflow, e.g. rain providing water to the vegetation. It can be an indirect influence e.g. in terms of quality, the fish population depends on the water quality of the river. Further it can be a structuring influence, e.g. the government setting an environmental protection plan for the region. Second, the colour of the arrow symbolizes the sign of the linkage. As described in chapter 4.2, components connected by a black arrow keep the sign of the previous component, e.g. when one increases the other does too. Components linked by a red arrow switch the sign, e.g. when one increases the other decreases. This colouring helps to identify the effect and feedback of a chain of linked components (see Figure 54). E.g. two components which are linked by a black arrow but feedback with a red arrow, like in the case of fish and fishing, are stabilizing each other (see loop 2 description). However, two black arrows reinforce the cycle, independently whether the original input is strengthening or weakening. This also applies for larger feedback cycles with more than two components. Generally with an even number of red arrows the starting and end component keeps the sign, meaning it reinforces the process. With an uneven number of red arrows the sign switches from starting to end point, stabilizing the component. Similar effects result from an unclosed chain of components, here called impact chain. In this case an uneven number of red arrows leads to a switching effect, meaning if the starting component increases the end component decreases and vice versa.

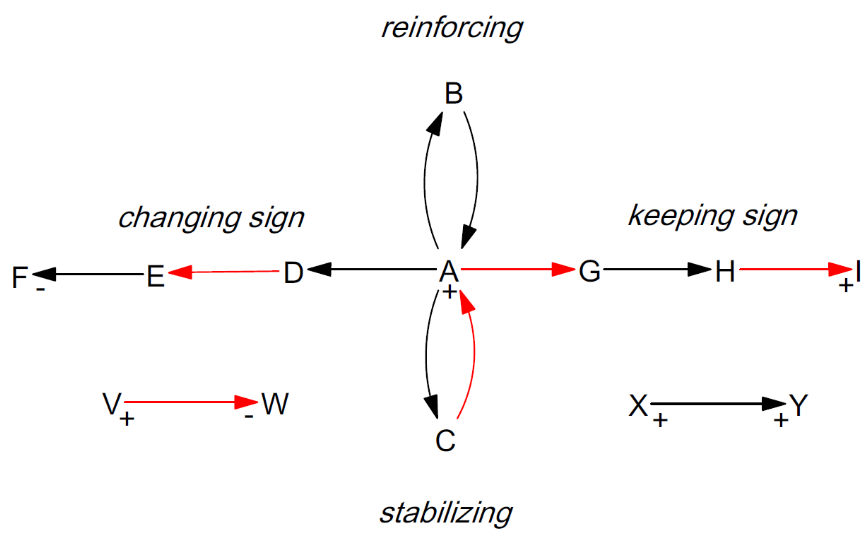


Figure 54: Sketch to explain linkage effects and their visualization, letters A, B, C, etc. symbolize fictional components, indicated signs show the effect of the linkage of respective colour: red arrow switching sign and black arrow keeping sign; own source

With this analysis of dynamics, the model can easily be distinguished into key motors, reinforcing the system, brakes, stabilizing the system, and further impact chains. These give information on the status of the system, whether it is stable or developing in a certain direction. Several feedback cycles have been identified in the mental models (see Figure 55) and are further analysed here.

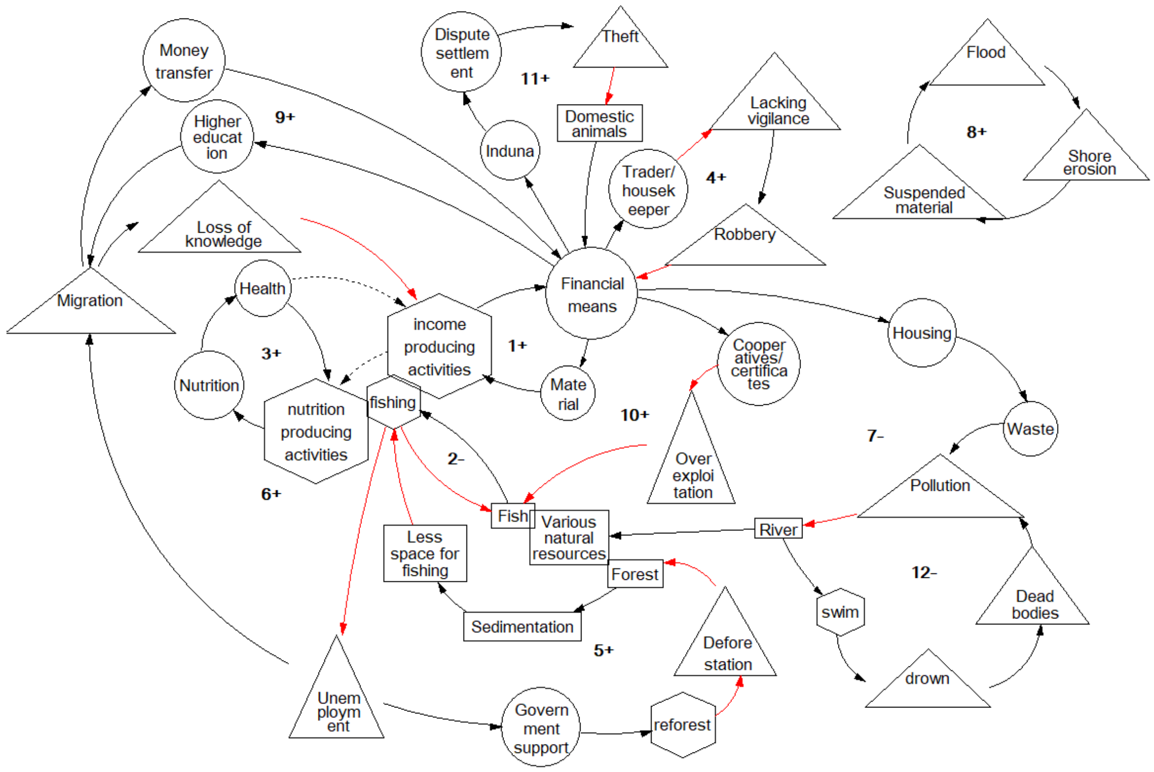


Figure 55: Overview of existing loops in both case studies. Boxes visualize natural and circles socio-economic components. Human activities are represented by hexagons and threats by triangles. Black arrows indicate reinforcing linkages and red arrows stand for stabilizing processes. All loops are consistently numbered according to the description below. Signs show the overall feedback of the closed loop; own source based on empirical data

1) Financial means – investment – income producing activity – financial means

With a starting capital people can invest in various needed material to follow income producing activities, which again increases their income. These materials can for example be fishing nets, boats and certificates to be able and allowed to fish. Another example is buying animals and fodder to produce eggs and meat. This feedback cycle is self-enhancing without further influence.

2) Fish – fishing – fish

The availability of fish enables people to fish. By extracting fish from the system the fish population is decreased and therefore limits future fishing activities. This relation depends on the ratio between fish reproduction and fishing amount. In case the fish reproduction is much larger than the amount of fish caught, the regulating effect of diminished fish population on fishing activity is small to negligible. On the other hand a fishing rate higher than natural reproduction, can easily lead to a degradation of the fish population. This latter case depends on the reactivity rate of fishing endeavours (BenDor et al., 2009). In the optimal case this feedback cycle has a stabilizing effect.

3) Nutrition – health – food producing activity – nutrition

Sufficient nutrition is one major precondition for good health. Good health in turn determines the capability to actively produce food and therefore supports nutrition. This cycle is generally applicable to all food producing systems and has been identified in other scientific work, e.g. (Joffe, 2007). Even beyond that, also socio-ecological systems not directly producing own food show this feedback, by exchanging food producing activity with income producing activity, which again allows to purchase necessary nutrition to maintain health.

4) Lacking vigilance – robbery – financial means – trader/ housekeeper – lacking vigilance

Lacking vigilance amongst neighbours exposes households to robbery during absence of the residents. Robbery directly and indirectly affects financial means by stealing money and material. Financial means are in turn deployed to assign either a merchant to represent oneself at the market or a housekeeper to never leave the house unattended. Similarly like in the feedback cycle between fish and fishing, also here the impact of the cycle on the system depends on the ratio between costs for employing an additional person and the benefit of avoided robbery losses.

5) Unemployment – government support – reforestation – deforestation – mangrove forest – sedimentation – less space for fishing – fishing – unemployment

In case of unemployment many states offer possibilities to request financial support from the government. In the Mexican region there is a specific initiative financing local people to actively reforest the protected mangrove forest to counteract deforestation. Mangrove forests are observed to influence sedimentation through their roots. Therefore by increasing the coverage of mangrove forests also the passable waterways are limited. This in turn limits the access to the fish population. Fishing as a source of both food and income again can counteract unemployment. Interestingly here evolves a potentially unemployment increasing cycle, even though the direct measure to substitute lacking jobs with reforestation activities seems to bring a double benefit for both the natural environment and the human population. However, looking at the complete picture, reforestation is not the only initiative supported by the government and fishing is not the only income producing activity counteracting unemployment. Furthermore fishing is not actively decreasing unemployment, but only in case the possibility exists to fish, a person doesn’t need to be unemployed.

6) Migration – loss of knowledge – income producing activity – unemployment – migration

Through migration of people to other regions local knowledge is lost. Especially when this knowledge loss is related to an income producing activity, such as fishing or cattle farming, it can ultimately threaten the activity as a whole and lead to increased unemployment. During our interviews in Mexico, unemployment was mentioned as one of the main reasons to migrate. Therefore migration can enhance further migration.

7) ***River – natural resources – income producing activity – financial means – housing – waste – pollution – river***

Various natural resources are directly produced or influenced by the river. In case these resources are the basis for an income producing activity, like fish in fishing, financial means are equally based on these resources. Financial means are central to build and maintain housing. Housing as a basis for various daily activities, such as sanitation, is producing waste, which due to an insufficient or lacking waste management leads to pollution of the surrounding environment, including the river. In turn the decreased quality of the river, water and fish will affect the quality of living. Although there might be no feedback on the amount of pollution by decreased river quality, it definitely leads to changes in the use of the river. In both case studies pollution was mentioned as a reason to shift the focus of drinking water collection from the river to alternative sources such as water gallons or water tanks.

8) ***Flood – shore erosion – suspended material – flood***

High water level leads to increased shore erosion. This again raises the suspended material in the river. The higher the amount of suspended material in the water, the worse are the impacts of the flood, was stated by the interviewees. Although there is a reinforcing of the impact of the flood on the environment, suspended material doesn't increase the strength of the flood and in turn the shore erosion, which would close the cycle and cause a direct enhancing effect.

9) ***Financial means – higher education – migration – money transfer – financial means***

Those who can afford, spend money to enable higher education for their kids. This higher education leads to migration away from the region, combined with loss of knowledge (see above) and loss of family members. However, in some cases migration paves the way for higher income and money transfer back to the families, which again supports available financial means. It is not clear whether financial costs or benefits of education are higher. Anyhow, this is not merely a financial decision but mostly emotional and cultural. It is assumed, that parents tend to try and provide the best possible future for their kids, of which good education in many culture seems to have a high value. Migration of higher educated people is a well-known phenomenon called brain drain, leading to an extraction of educated people from rural or generally less developed regions.

10) Fish – fishing – financial means – cooperative/ fishing certificate – overexploitation – fish

Fishing as the main income producing activity in the visited villages in Mexico relies on the availability of fish. A share of the financial means resulting from fishing is used to buy certificates from cooperatives organizing and controlling all fishing efforts. This measure also helps to control overexploitation and therefore keeps fishing rates at a level for fish to reproduce and maintain a stable population. External fisher and fisher not participating in the cooperative limit the efficiency of this control mechanism. Otherwise this would be an enhancing feedback cycle.

11) Theft – domestic animals – financial means – dispute settlement – theft

Stealing domestic animals leads to a decrease of financial means, because domestic animals, especially cows are of high value in rural South Africa. These financial means are also needed and used to engage the local leader, Induna, to solve the dispute following the theft. The effects of the theft can then again be returned. Interesting would be to know, if the involvement of the Induna also prevents future theft attempts.

12) River – swimming – drowning – dead bodies – pollution – river

In South Africa the river is used for leisure activities such as swimming. Based on strong currents and limited swimming skills it tends to be dangerous and life threatening. From time to time people are drowning and their remaining bodies are mentioned as a pollution source. It is not clear if the worsened quality of the river water through pollution is keeping people from future swimming activities or whether alone the danger of drowning limits the attractiveness.

4.4.3 Potential future developments and changes

Even though the mental models in this work are defined by the current perspective of local people, it can serve as a basis for future scenario analysis. Including potential future changes in the model, allows for a first estimate of effects on system components. Knowing what might change in the future obviously supports the identification and planning of necessary adaptation measures. The focus of this work is climate change. The aim of this analysis step is therefore to estimate which parts of the current socio-ecological system will be affected by climate change and optimally also in what way. This step allows testing the analysis possibilities offered by the chosen participatory modelling approach and deriving some first qualitative trends. Here two example climate change scenarios are developed based on recent climate projections. One example is sea level rise in the Gulf of Mexico and the other example considers increasing dry spells in East South Africa. It is assumed that only the main component related to the scenario (Mexico: salt water intrusion, South Africa: drought) changes and the rest of the systems stays the same like in the current versions.

The starting point of the analysis lies in the overlapping component of the future scenario and mentioned threats in the mental model. Following the linkages in the mental models shows 1) which other components will be influenced by the respective change, 2) if it in- or decreases and 3) whether the impact results from the direct pathway or through feedbacks within the system. To get a clearer overview, the combined regional models are visualized in a reduced form, only showing the affected parts (see Figure 57 and Figure 58). Based on the direct pathway originating from the change itself, affected components are sorted into levels of steps after the original change. So on top of the figure is the change itself. In the line below are the directly impacted components. In the third line are the components which are directly linked to the prior ones of the second line and so on. This type of direct connection is symbolized by a solid line character. Additional influences on the same level are visualized by a long dashed line. Last but not least there are also feedbacks originating from a later level of direct impact and a previous level. These are represented by short dashed lines (see Figure 56).

To analyse the total effect of the scenario all connections are counted once. Therefore a feedback cycle doesn't repeat here. Based on the effect of each connection (symbolized by red and black) a summary of all three pathways results in the number of increasing and decreasing changes listed per component in Table 9 and Table 10. Each arrow signifies an incoming linkage. Upwards directed arrows (↑) refer to an increase which can be based on an increased preceding component and a positive (black) link or a decreased preceding component and a negative (red) link. Likewise downward directed arrows (↓) result. To avoid counting one linkage several times the total number of changes is calculated in a three step approach (see Figure 56). First, the direct pathway is counted from top down (1a and 1b). This first step also selects all affected components. All components not reached on this pathway are excluded from further steps. Second, the long dashed lines are added to the first count (2). And third, from bottom up the summarized count from step one and two is added along the short dashed line (3a and 3b). In this last step always the previous count is combined through all three steps before continuing one level further up. The resulting summary of up- and downward arrows cannot be set against each other to calculate an effective change in the respective component. Therefore the total change is indicated by a sum of upward arrows next to a sum of downward arrows. This also highlights the diverse effects one changed components can have on the whole system.

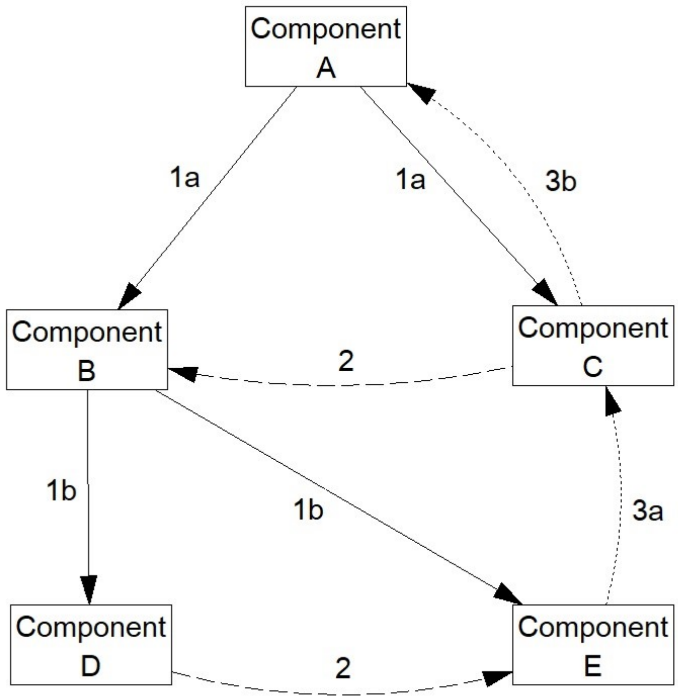


Figure 56: Sketch explaining future scenario calculation scheme, components A-E are fictional, numbers 1-3 represent the different steps of analysis, a and b indicate the order of counting and summarizing resulting effects; own source

4.4.3.1 Sea level rise scenario – Mexican case study

During the last decades sea level was rising at the coast of **Mexico**. Also future projections indicate continued sea level rise up to 1 m until end of the century for the RCP 8.5 emission scenario (GERICS, 2015a). In the interviews people mentioned several occasions when intruding salt water is affecting their livelihood. If in the future salt water intrusion is increasing due to sea level rise this first affects the groundwater and the river ecosystem but also the severity of the seasonal flooding. Especially by the latter many components of the daily life, such as transport, housing, aquaculture and the courtyard are affected. Also the natural resources river water, fish and medicinal plants are decreased, while the natural process of sedimentation is generally increased by flood. Following down the direct impact pathway, ultimately wood extracted from the forest is affected by salt water intrusion (see Figure 57).

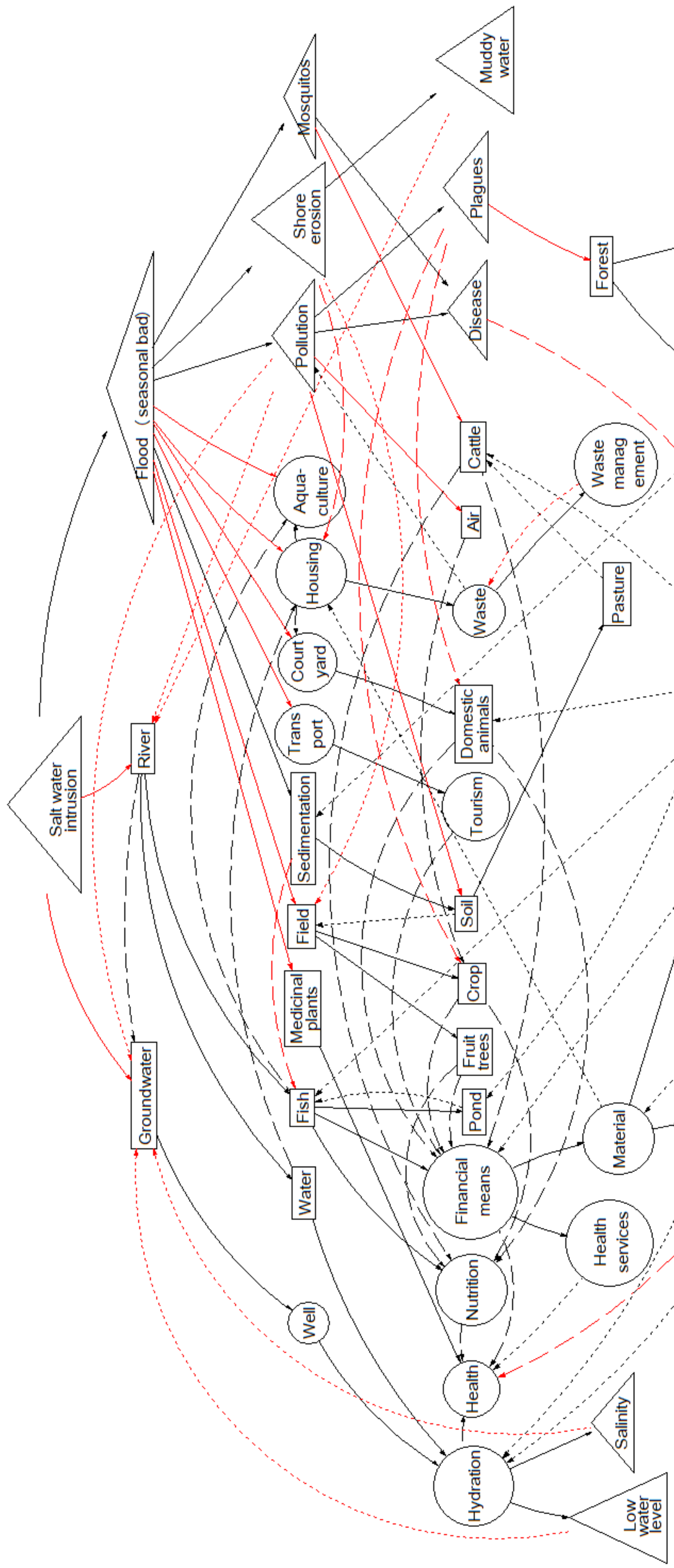


Figure 57: Mexican socio-ecological system affected by sea level rise scenario. Boxes represent natural, circles socio-economic components, and triangles visualize threats. Black arrows stand for enhancing and red arrows for opposite connections. Sorting along the first direct impact pathway (solid line) and indicating further linkages on the same level (long dashed) and from subsequent components (short dashed). Based on empirical results from case studies and own interpretations

An increase in salt water intrusion leads to an overall negative effect on the system (see Table 9). The majority of components decreases in quality or quantity. Most affected are health and financial means as well as fish, housing and nutrition. Interestingly even though the first direct effect of salt water on groundwater is negative (decreasing quality) with indirect feedback effects such as decreasing pollution and less low water level lead to an increase.

Table 9: Affected components in the Mexican case sorted by the highest number of changes; own source, based on empirical data

	Component	*Total change*	
Scenario	Salt water intrusion	↑	
	Health		↓↓↓↓↓↓↓↓
	Financial means		↓↓↓↓↓↓↓
	Groundwater	↑↑↑↑	↓↓
	River	↑	↓↓↓↓
	Fish		↓↓↓↓↓
	Housing		↓↓↓↓↓
	Nutrition		↓↓↓↓↓
	Hydration		↓↓↓↓
	Pollution	↑↑	↓
	Cattle	↑	↓↓
	Aquaculture		↓↓↓
	Crop		↓↓↓
	Domestic animals		↓↓↓
	Disease	↑↑	
	Field	↑	↓
	Sedimentation	↑	↓
	Waste	↑	↓
	other trees	↑	↓
	Courtyard		↓↓
	Pond		↓↓
	Low water level		↓↓
	Salinity		↓↓
	Material		↓↓
	Flood (seasonal bad)	↑	
	Shore erosion	↑	
	Mosquito	↑	
	Soil	↑	
	Plagues	↑	
	Muddy water	↑	
	Pasture	↑	
	Well		↓
	Water		↓
	Medicinal plants		↓
	Transport		↓
	Fruit trees		↓
	Tourism		↓
	Air		↓
	Health services		↓
	Waste management		↓
	Forest		↓
	Water gallons		↓
	Fodder		↓
	Mangrove		↓
	Wood		↓

4.4.3.2 Drought scenario – South African case study

In the past no clear precipitation trend was observable for **South Africa**. However future projections suggest a decreasing amount of precipitation per year. Also an increase in duration of dry spells is possible (GERICS, 2015b). Local people reported longer lasting droughts during the past years as well. Increasing dry periods would impact directly the lack of water and the amount of rainfall, but also vegetables growth, the land and the river as a whole, mud in and bad taste of the river water and the overall hydration of people. This again affects the usability of fields for vegetable growth and the thriving of wild vegetation and animals. Following also transport, nutrition and housing are affected. Ultimately the change reaches the threats of exposure to weather and various diseases whose effects on the system are altered (see Figure 58).

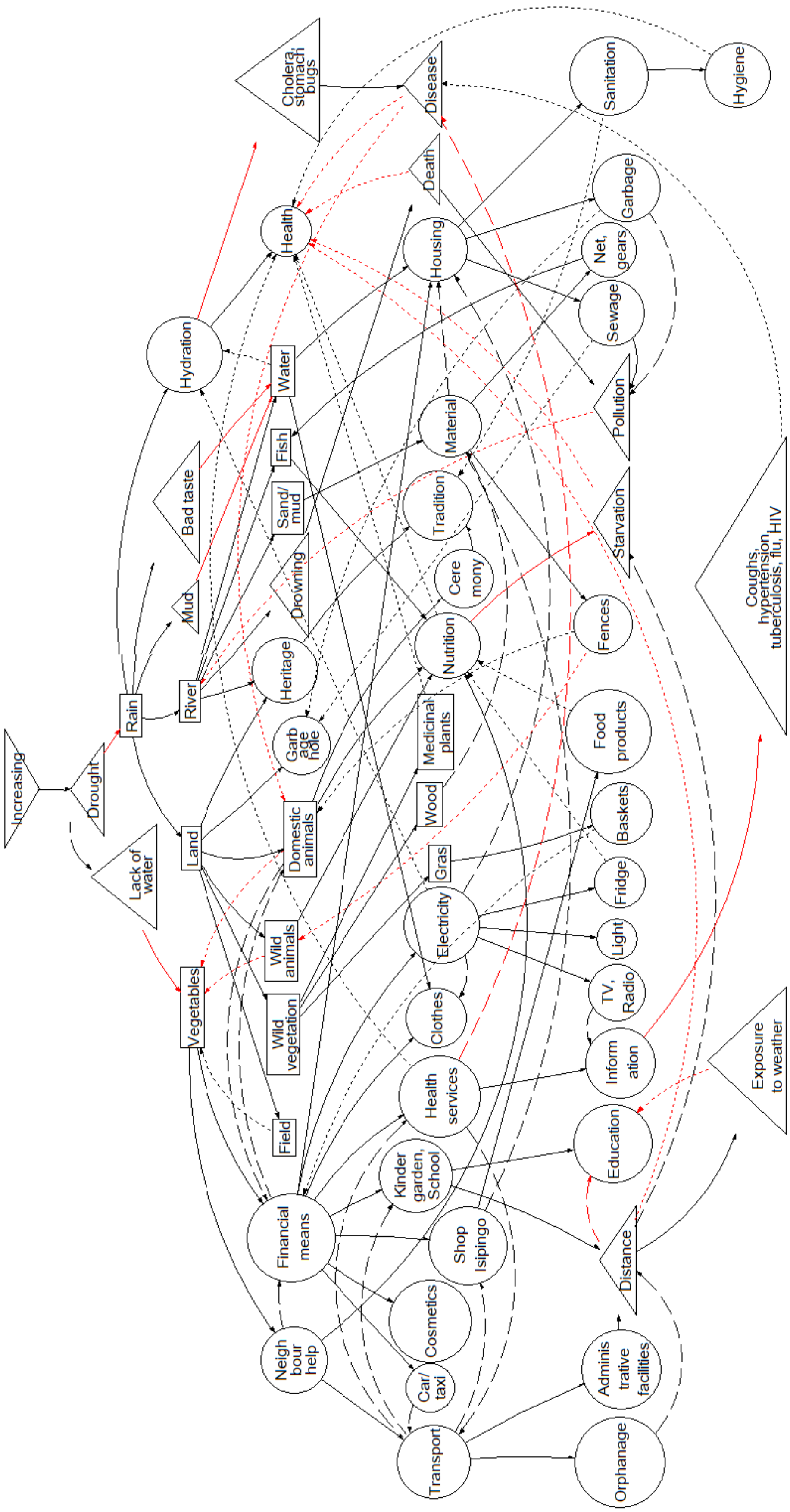


Figure 58: South African socio-ecological system affected by drought scenario. Boxes represent natural, circles socio-economic components, and triangles visualize threats. Black arrows stand for enhancing and red arrows for opposite connections. Sorting along the first direct impact pathway (solid line) and indicating further linkages on the same level (long dashed) and from subsequent components (short dashed). Based on empirical results from case studies and own interpretations.

Also in the case of prolonged drought phases the majority of components are affected negatively (see Table 10). By far most impacted is health based on its strong interlinkage with other components in the model. Similarly like in the Mexican case study also here one interesting feedback effect evolves. Vegetables suffer directly under the lack of water caused by drought conditions. However, the effect of several additional threats, like wild and domestic animals is diminished. Therefore several more upward than downward effects are counted.

Table 10: Affected components in South Africa sorted by the level after direct impact, own source based on empirical data

	Component	*Total change*	
Scenario	Drought	↑	
	Health	↑↑↑↑↑	↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓
	Vegetables	↑↑↑↑↑↑↑	↓↓↓↓
	Garbage hole	↑↑↑↑	↓↓↓↓↓
	Domestic animals	↑	↓↓↓↓↓↓
	River	↑↑↑	↓↓↓
	Tradition	↑↑	↓↓↓↓
	Hydration	↑↑	↓↓↓
	Housing	↑↑	↓↓↓
	Pollution	↑↑	↓↓↓
	Nutrition		↓↓↓↓↓
	Disease	↑↑↑	↓
	Starvation	↑↑↑	↓
	Sewage	↑↑	↓↓
	Garbage	↑↑	↓↓
	Sanitation	↑↑	↓↓
	Hygiene	↑↑	↓↓
	Financial means		↓↓↓↓
	Water	↑↑	↓
	Education	↑↑	↓
	Transport		↓↓↓
	Material		↓↓↓
	Distance		↓↓↓
	Wild animals	↑	↓
	Heritage		↓↓
	Shop Isipingo		↓↓
	Kindergarten, school		↓↓
	Health services		↓↓
	Clothes		↓↓
	Information		↓↓
	Lack of water	↑	
	Cholera, stomach bugs	↑	
	Coughs, hypertension, tuberculosis, flu, HIV	↑	
	Rain		↓
	Land		↓
	Mud		↓
	Bad taste		↓
	Neighbour help		↓
	Field		↓
	Wild vegetation		↓
	Drowning		↓
	Sand/ mud		↓
	Fish		↓
	Car/ taxi		↓

Cosmetics	↓
Electricity	↓
Gras	↓
Wood	↓
Medicinal plants	↓
Ceremony	↓
Death	↓
Orphanage	↓
Administrative facilities	↓
TV, radio	↓
Light	↓
Fridge	↓
Baskets	↓
Rice, mielie, potatoes	↓
Fences	↓
Net, gears	↓
Exposure to weather	↓

In both regions the change of one threat in intensity or frequency has a broad effect on the whole system. Several components are either directly or indirectly influenced by trickle down and feedback effects. Similarly like the two example climate change scenarios, scenarios for other changes in socio-economic or natural environmental conditions as well as adaptation measures can be tested. Limitations and improvements of this analysis approach are discussed in chapter 5.3.3.

4.4.4 Overall structure – presenting a generalized framework

Comparing the local perspectives of people interviewed in Mexico and South Africa some commonalities but also differences can be found. Simplifying and summarizing the community models of both case study regions leads to a first generalized framework defining major components of rural livelihoods in coastal riverine socio-ecological systems. Here components, of all types are summarized according to their topical setting. This allows a quick impression of the main components as well as their linkages with each other. The resulting overview structure is based on commonalities between the perspectives in the Mexican and South African case studies and can be used as a starting point for analyses of similar regions. Although the overall components are similar for both regions details are quite different, for example the type of crops planted or the threats experienced. So to derive specific conclusions, it is necessary to take the detailed version into account.

As previously defined, there are seven main livelihood aims: hydration, nutrition, financial means, health, housing, education and transport. These are supplemented with government support, external income and hygiene on the socio-economic side and the river ecosystem, with rain and water as well as plants and animals on the natural environmental side. Being the most central components defined during the analyses, they are visualized in Figure 59. For simplification reasons only the shapes of circles for socio-economic components and the squares for natural components are used here without colours. Diminishing impacts on a component are indicated with a minus directly next to the box or circle.

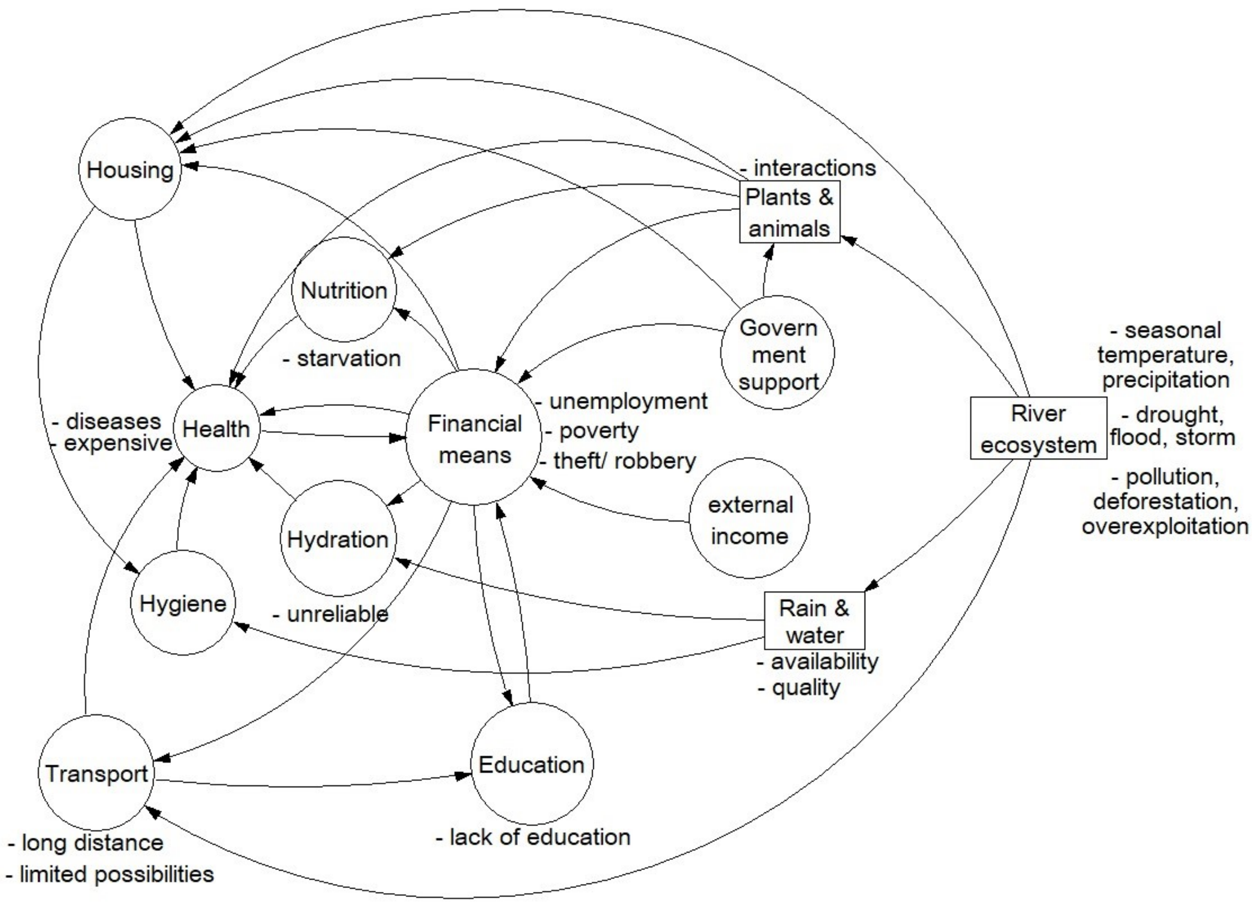


Figure 59: Central components and linkages in Mexican and South African case studies, boxes representing natural and circles socio-economic components, arrows show general linkages, with specific adverse effects indicated next to each respective component; own source interpreted from empirical data

Some remarkable detail commonalities are the central role of diverse income possibilities. Also the ability to cope with the natural environment, however struggling with recently changed components, e.g. the invasive species catfish (MX) and wild pigs (SA), is comparable in both regions. Waste pollution of the river and surrounding natural environment is another common problem of comparable importance in both case studies. In both regions, at least in some communities, alternative leadership structures and social networks structure the daily life of people.

Despite all commonalities also some major differences between the two case study regions have to be mentioned. First and foremost the surrounding terrain of the two rivers and the visited communities are quite different. While the Mexican case region is completely flat, the South African region is dominated by steep hills. This difference can be connected to differences in river use and in river related threats. Therefore, the Usumacinta River plays a central role for local people in terms of fishing, gathering water and transportation. Additionally, interviewed people in Mexico referred to regular floods affecting their houses, land and most activities. On the contrary, Mkhomazi River is only sporadically visited for fishing and gathering water. Furthermore, most threats mentioned by South African interviewees are independent from the river, e.g. drought, storm, lightning. A second major difference between the two case study regions is defined by the climate. In the Mexican case frequent heavy rainfalls and resulting floods are both common and adversely affecting rural livelihoods while in the South African region missing rain and following droughts were more problematic than strong rain. A third difference is related to the above mentioned diverse sources of income. On the one hand, in the Mexican case several sources of income are available for individuals. In the South African case, on the other hand, several sources of income may be generally available, while single persons or households usually depend only on one source. Connected to income another slight but interesting difference can be made in the context of governmental support. In the Mexican example these payments are usually either connected to direct employment in related jobs, e.g. community work, or to nature protection initiatives, e.g. reforestation. However, in the South African example payments are more related to substitute lacking income due to illness, age and children. A fourth difference can be found when looking closer at alternative leadership structures and social networks. Even though in both regions some structures exist, in South Africa they seem to be more dominantly involved in different parts of daily lives, e.g. in land disputes, water division, domestic animal theft and money saving initiatives. In Mexico only the regulation of fish catch was mentioned, which was not even attended by every inhabitant. Several more differences can most probably be found when zooming into local vegetation and animal species, as well as individual differences in local livelihoods.

Still, the overall structure presented in Figure 59 can provide a helpful starting point for in depth analysis of similar regions. Already the here indicated adverse effects are specific to either of the two case study regions. Similarly further regional variations can be added to the figure or an attached catalogue to constantly develop and further complete the framework.

5. Discussion

The main aim of this chapter is to highlight some controversies related to the conceptual ideas of vulnerability and how they are recognized in the application of assessment frameworks in the field. One important insight developed throughout the process of this work is that a problem, situation or topic can always be seen from different perspectives. Every observer may focus on a different aspect, scale or level of understanding. This exacerbates not only the comparability of different concepts and assessments, but also the chance to define a common core. Ultimately, the core of understanding a socio-ecological system and its future changes is seen in human behaviour and the question why people act the way they do. This does not mean that natural ecosystem processes are irrelevant. On the contrary, all components and processes shaping a socio-ecological system, including different scales and topics are important to consider. However, I argue that the individual, psychological mechanisms are still mostly neglected in these complex assessments. Therefore the following chapters are setting the basis for coming to a conclusion on how to tackle climate change vulnerability in the future.

Following the same structure like in the rest of this work, first conceptual ideas will be discussed. A major challenge is to apply conceptual ideas into an assessment framework and ultimately measure reality with it. In the first chapter 5.1 both conceptual and theoretical approaches introduced in chapter 2 are compared to each other as well as implications evolving when applying these. In chapter 5.2 the methodological approach of participatory modelling for data acquisition is discussed in respect to its main possibilities and limitations. In this context also the specificities of the applied interview guideline is taken into account. After that, in chapter 5.3, the vulnerability assessment framework is critically looked at in its different steps. Here the mental models resulting from the participatory modelling process are discussed in terms of completeness and credibility. The structured information as well as the derived rating of local vulnerability is analysed thoroughly. Some of the main limitations identified are lacking quantitative data and causal understanding. Also in the future scenario analysis and summarized overview structure of socio-ecological systems these limitations appear. All in all the applied analysis steps are seen as a structural suggestion, however needing further information to produce reliable results. Last but not least the gathered information is discussed content wise in the context of the two case study regions. Again the lacking literature available for the specific regions is a challenge when comparing and verifying the analysis results.

5.1 Conceptual ideas and how to apply them in the assessment

Considering the broad variety of conceptual and theoretical approaches surrounding vulnerability (see chapter 2) it is central to every scientific piece of work to clarify at the beginning which ideas underlie the research. Not only clearly formulating the problem at focus is important (Füssel, 2010; Preston et al., 2011), but increasingly also to clarify in what way specific terminology is applied. Broad concepts like vulnerability and resilience are used in most diverse contexts, which lead to the necessity of further specifying what exactly is meant by the terms of vulnerability or resilience. A suggestion following this work is not only to clarify how respective terms are used but also to check which concepts are necessary and of added value to the research aim. In some cases worrying about appropriate concepts and correct terminology might actually distract from finding and pursuing the core of the research problem.

Also in order to compare and relate different work on the same topic a clear and common language is important (Füssel, 2010). Misunderstandings can easily happen when the same problem is described with different terms (Wolf, 2012), e.g. because people come from different disciplines. Also the opposite, using the same terms for describing different issues, can lead to misunderstandings. Still, in a complex topic like assessing and managing climate change vulnerability of socio-ecological systems in coastal river areas applying various concepts shows the attempt to capture the core of the problem. Following different approaches is therefore seen as added value. However, it can lead to initial confusion. Vulnerability is only one of many concepts attempting to formulate central problems. But the number of different interpretations, definitions and applications of vulnerability indicates that a) there is no common concept, b) the problems approached with vulnerability are too diverse to fit into one concept, or c) vulnerability as a concept is not fit to frame the complex reality in a satisfying way.

Talking about climate change **vulnerability**, the first and foremost question is, whether vulnerability is the appropriate term to talk about. The general character of the term vulnerability allows for a high flexibility in choice of focus topics. This however links to an intangible side of vulnerability. Talking about vulnerability is never enough to explain what exactly the respective work is about. One could argue that it is more efficient to directly formulate the topic itself without taking a detour via vulnerability. E.g. in this work one could talk about climate change vulnerability of socio-ecological-systems or one could directly describe the effects of climate change on key natural and socio-economic resources and processes fulfilling rural livelihood aims. The first expression can be interpreted very differently out of which the latter is one possibility. Overall, the aim of any vulnerability assessment is to define the weaknesses of a situation and potentially also to improve it.

The concept of vulnerability has its limitations. It allows analysing weaknesses but hardly to categorize and compare an exact vulnerability value of one case to another. For this a deeper understanding of central natural environmental, social, economic processes as well as underlying influence factors is needed. Because vulnerability of socio-ecological systems cannot be measured directly (Kienberger et al., 2013), scholars tend to approach vulnerability with representative parameters, also called indicators. After having defined a set of appropriate indicators, they can be evaluated in different ways, e.g. indirectly by quantitative numbers, like assigning scores (see Kaly et al., 2004) or qualitatively with levels of low, medium and high (see Negi et al., 2015). This evaluation and compilation of different indicators into an index allows for a representative comparison of different vulnerability states. Examples of country level rankings are defining highest vulnerability on the basis of 15 indicators (see Butenop et al., 2013), climate risk based on experienced fatalities and economic damages (see Kreft and Eckstein, 2014) as well as combined food and climate vulnerability including 18 indicators (see Krishnamurthy et al., 2014). Such approaches are suitable when the aim is to compare the average situation in different countries, for example to assign global financial support. The generalized criteria used for this comparison however tend to neglect critical case specifics, like the political system or cultural groups. Also local characteristics can vary strongly within one country and need to be generalized in order to achieve an average national value. When the aim is to plan and implement specific adaptation measures it is crucial to adapt the scale of the assessment first.

So the question how vulnerability can be grasped remains. This ultimately leads to the underlying question of who is (defined) vulnerable and how to identify sources of vulnerability. Does being vulnerable require immediate action or can someone be vulnerable and still maintain a satisfied life? For each vulnerability assessment it is therefore also necessary to define where the threshold between "vulnerable" and "not vulnerable" or at least between different classes of vulnerability lies. It is generally difficult to define such a threshold, because perceptions can largely vary depending on who is making the judgement. Furthermore, causes for vulnerability can be manifold. When the underlying system is defined by complex processes the assessment is even further complicated.

Let's briefly highlight the different aspects of defining the beginning and the end of vulnerability by looking at a recent example like the flood in Texas after Hurricane Harvey. First of all, one can say everyone who lost property due to the flooding was vulnerable, while those who return to their undamaged homes after the flood dropped were not. Already here a distinction is made by defining the threshold between damage and no damage. An alternative definition of this threshold could be someone who had to leave his house due to the danger of flooding, while another was not threatened and stayed in the house. Another difference can be made in weighting different damages. While the loss of human life is probably highest, the loss of purchasable assets is annoying but mostly not critical. A third distinction can be seen on a temporal scale: can a person return to a normal state directly after the flood occurred, will it take some months to recover from all damages or will some damages even persist. These small but significant variations define a whole assessment and are highly subjective. People being affected by Harvey in any way would probably judge their situation as vulnerable. When comparing the whole event with another, such as the flooding following the monsoon in India at about the same time this year, an unaffected person might come to a different conclusion.

Ultimately, one cannot generally agree on common criteria to define a threshold for vulnerability (here damage), relative importance amongst different criteria or strength of impact (here loss of life vs. damaged physical assets) and temporal scale of recovery throughout different assessments. For each case these or similar parameters have to be defined in order to limit the framework.

As soon as having agreed on the framework distinguishing vulnerable from not vulnerable the next challenge is to define how vulnerability evolves. In the case of Harvey several reasons are possible for this outcome: first and foremost the strength of the hurricane, but also the preparedness of the region, including long term planning of infrastructure, housing and emergency rescue. Ultimately, the identification of vulnerability sources requires a thorough understanding of key components and processes in the respective system. Socio-ecological systems, like a city in Texas, are highly complex and, based on my blunt assertion, far from fully understood. The complexity can be approached in various ways. Vulnerability assessment is one of them. Vulnerability itself can be looked at from a starting point, or from an end point perspective, comparing whether a judgement made prior to a damage event based on the contextual setting is similar to a retrospective assessment based on experienced damages. This approach tests if existing weaknesses can be estimated without taking into account a specific damage scenario.

Similarly, also the differentiation into exposure, sensitivity and adaptive capacity mainly tackles the understanding of vulnerability as a multi-faceted concept instead of actually supporting the definition of vulnerability sources. This becomes obvious when attempting to assign these three subcomponents to factors of daily life (see Figure 4 and Figure 5 in chapter 2.1). In any way, when aiming to improve the current situation by alleviating weaknesses, the framing is less important than actually identifying the core of the problem. Key weaknesses can finally be identified in different ways. Important is that they are defined as correctly and realistically as possible. Two possibilities are comparing the current state to an optimal state or analysing past damage experiences. The latter case includes an explicit threat scenario the respective system is exposed to. Therefore conceptual approaches which exclude exposure from the definition of vulnerability need to either define weaknesses along an optimal state or include exposure implicitly in sensitivity. The optimal state can either refer to existing structures not optimally functioning or to missing structures compared to a similar better working system. For either of the possibilities at least an assumption about an optimal state or potential damages is needed.

The assumption made in chapter 2.1 that **resilience and vulnerability** can be features of a system at once can be further interpreted in different ways. On the one hand, it can be related to different levels of a system. While one component is vulnerable the whole system can still be resilient. Also, it can be related to different time scales. Regular disturbances are seen as normal in resilience thinking (Folke, 2006), but when focussing on one disturbance, it could also be interpreted as happening due to a vulnerable setting. Vulnerability is often related to adverse effects (IPCC, 2014), however it is not always specified what these are. Analogically to the resilience thinking, I assume that also socio-ecological systems can benefit from smaller variations and are inherently adaptive in the long term. With inherently adaptive here the continuous improvement and development of a system is meant. A severe disturbance occurs when the fast-onset event or the slow-onset change exceed this pace of adaptation. This disturbance, having the magnitude to alter the “normal” course of the system, can be based on the systems vulnerability. So everything is related to the framing, the scales and limits of the system and its components, what is interpreted as normal and last but not least the contextual setting of both the situation and the person evaluating the situation.

Within the concept of **sustainability** one central aspect remains unclear in the application. Sustainability thinking includes the overall aim to ensure the resource needs of future generations (Brundtland, 1987). However, these needs are rarely defined at all. Even though the underlying thought of a considerate resources use is very valuable, to apply it into actual guidelines the missing definition can be crucial. In the hypothetical case that future generations will need more than will be available an entitlement discussion between the needs of today’s and tomorrow’s population would be needed. With a growing world population and increasing development this hypothetical situation is realistic. How to evaluate whose needs are justified or even more important than the others? A similar challenge exists, when evaluating and comparing different vulnerability states. Who is most vulnerable and most in need for support? For both vulnerability and sustainability the remaining question is: Would it be legitimate to request people to relinquish from certain resources to ensure other lives to be fulfilled? This question is also central to the climate change mitigation discourse. In reality future generations’ needs are probably too abstract to be included in specific planning. However, already the hypothetical discussion is important to build awareness of people and consider it in the planning of development strategies. Additionally, needs are only one side of the coin in sustainability thinking. The available resources base both today and in the future are ultimately limiting which needs can be fulfilled. Furthermore, not only resources but also main global biogeochemical cycles as well as physical circulation systems are seen as potentially limiting a sustainable future of human kind (Rockström et al., 2009).

Underlying the **socio-ecological system** definition is the understanding that human and natural environmental sphere are closely interlinked (Berkes et al., 1998). Therefore they cannot be looked at independently. However, it is not clearly defined in literature, whether both human and natural sphere are equally weighted in the concept of socio-ecological systems. In a holistic perspective it would make sense to involve both equally because interactions are vice versa.

While changes in the ecosystem influence human livelihoods, also human livelihoods influence the ecosystem. Depending on the perspective on e.g. biodiversity or human resource use, the weighting can easily vary accordingly. Hence, in this work, with the focus on human livelihoods, the natural environmental part of the socio-ecological system is mainly looked at as the basis and resources providing context of livelihoods. The feedbacks from human actions on the environment and back to their livelihoods are not considered. However, the state of the ecosystem should be of central interest in further analysis. This is especially relevant in the case study of Mexico, where natural resources and therefore a healthy ecosystem form a central component of rural livelihoods.

The terms capitals, capabilities, needs, wellbeing and the respective concepts describe the core of human living, both from the necessity (what is needed) and the ability (what people can do) side. Both are highly subjective values which are the mentioned scientific concepts aim to capture. Necessity, or the motivator for behaviour, links to vulnerability through sensitivity, while the abilities define adaptive capacity and what can actually be achieved. While capitals and capabilities form a central part of preparing, reacting and coping with disturbance (Stern, 2006; Adger, 2012), fulfilled needs and high status of wellbeing potentially lower the severity of the effect. However, despite a high level of capitals, capabilities and wellbeing a situation can remain vulnerable, depending on the chosen frame of vulnerability. This means certain assumptions can be made, but need to be critically tested in each case. Still, an analysis of these components supports the definition of potential and needed improvements of the system. The potential is hereby based on the knowledge and skills of the people in the system.

Looking at motivation for behaviour the theory of human behaviour by Maslow (1943) suggests a hierarchical order of basic human needs to be fulfilled. It is questionable whether human needs as a central driver of behaviour can really be sorted hierarchically and how these basic needs compare in their dominance to other drivers. In the example of South Africa, where people stay on their ancestors land even though their bodily health is threatened by the lack of food, clean water and health services, Maslow’s theory doesn’t seem to fit completely. The impression arises, that living on their ancestors land is more important than fulfilling basic human needs, which could potentially be achieved more efficiently in another place. The assumption that people would first and foremost care for the fulfilment of their most basic physiological need still fits in so far that they relate on alternative sources instead of the natural ones. Therefore one can argue that the importance lies on the physiological needs being covered, not necessarily how they are covered or whether it is the most efficient way. However, the question is, when is a need fulfilled? Is it already fulfilled when a person survives, when she is healthy or when it is covered in a sustainable way by local resources?

Putting needs or generally motives for behaviour in a hierarchy was not of major importance here. More interesting was to find out what people value in their lives and what they are willing to do or change for it. These subjective perspectives define or at least motivate behaviour as well as behavioural changes. Why certain things are valued of high or low importance, e.g. due to personal reasons or cultural imprinting, would be of interest. However, to answer that, a whole set of different questions would have been needed. By asking what people do in their lives to cover food, water, health, income and other needed assets and the resulting storylines, an indirect qualitative judgement about the importance of individual sources can be derived. These sources as well as prioritized ways of covering needs and wishes are defined by cultural values and societal rules. Therefore, both intrinsic motivating factors and limiting or guiding structures influence behaviour (see Figure 60). This should however be double-checked with the local people in a next step. First hand biases of the emphasis on single components from the data collection methodology will be discussed in a later paragraph (see chapter 5.3). This work neither offers the space nor experience for further behavioural analysis. However, further psychological perspectives are assumed to add an interesting an important facet.

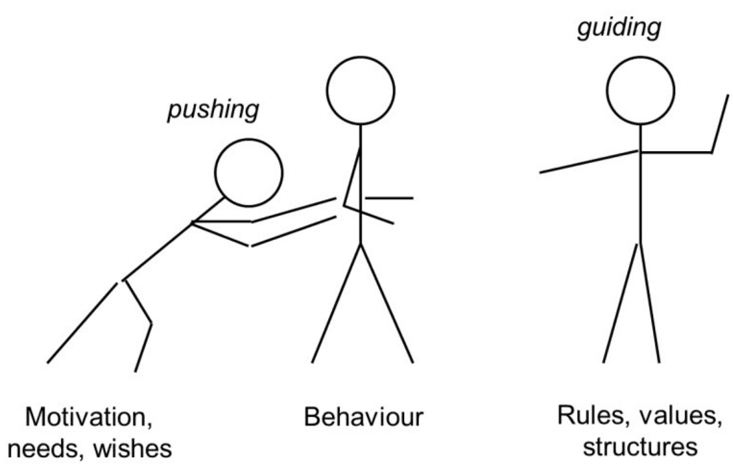


Figure 60: Conceptual ideas of factors motivating and guiding behaviour; own source

When the conceptual framing and aim of an assessment is clear also the organizational frame is important to be defined. Usually available time, personnel and financial resources are limited, and therefore a decision has to be made between a broad analysis of interlinked components and a narrow, in-depth analysis of a specific problem (Carruthers and Chambers, 1981). A clearly defined aim helps to identify the appropriate scale, system limitations and involved components and therefore allocate available resources most efficiently. In this work the aim is to reach a broad understanding of main components and processes defining rural livelihoods and ultimately allow assessing the current state of the socio-ecological system as well as potential future affectedness by climate change. A local assessment of vulnerability forms the basis to identify specific measures to maintain or improve the current living standard. Usually adaptation measures equally aim at improving the situation as vulnerability requires improvement. However, here maintaining livelihoods is defined as lower limit of measures based on the assumption that the current situation is still bearable. Otherwise people would have decided to change their livelihoods or even move to another more favourable place already.

Several scientific criteria have been defined in literature to ensure a high quality and usefulness of assessments. Generally, vulnerability analyses are recommended to be qualitative instead of quantitative, proportional instead of absolute and dynamic instead of static. Looking at vulnerability in a dynamic way allows analysing not only current vulnerability but also the roots of it, and its development over time. However, a dynamic assessment requires a large amount of data gathered on different points of time which makes it hard to comply. The human share in vulnerability, and therefore the responsibility and ability to change the current system, is important to consider in the assessment (Kelman, 2007). Again, this is difficult to achieve. Human structures linking socio-economic, political and cultural components with individual motivations for behaviour are highly complex to fully understand. Still, by applying the concept of livelihood aims the importance of human lifestyles in vulnerability is taken into account.

5.2 Participatory modelling – methodological discussion

Participatory approaches can be chosen due to many reasons. The motivation for applying participatory modelling was, to capture local perceptions for understanding a socio-ecological system which is dominantly influenced by human behaviour and at the same time to cover the lack of available local data. The aim was therefore to represent reality as perceived by local people in a model. Because it is generally impossible to capture a complex system completely realistically, the intention is to at least develop a useful model (Sterman, 2002).

5.2.1 General possibilities and limitations

Involving stakeholders has both normative and pragmatic benefits. On the one hand, it increases trust in decisions, empowers different perspectives, supports social learning and participants to use co-generated knowledge. On the other hand, it is a tool to gather local knowledge, improves decisions itself, enhances acceptance and therefore longer term support and implementation (Vennix, 1999; Reed, 2008). In this case, the focus lies on gathering local knowledge however including the possibility to exchange perspectives and support local decisions. Including the experiences made during the interviews and their analysis afterwards it became clear, that gathering information for scientific analysis includes different requirements than supporting local development.

Participation can also have potentially negative effects, like altering existing power structures in a destabilizing way, disappointment and fatigue of stakeholders through unsuccessful participatory processes and last but not least lacking expertise can make the whole approach questionable (Reed, 2008). Not only alteration but also lacking alteration can be a negative outcome of participation. If the chosen approach is not open enough, participation can reassure and even legitimate certain hypotheses and ideas without testing potentially necessary alternatives (Carruthers and Chambers, 1981). Furthermore, the process itself can be challenging, like finding appropriate contact and entry points, reacting to individual and group behaviour, e.g. dominant opinions in groups, people showing up in groups instead of individuals, as requested. Especially group model-building projects face a series of challenges, like following the predefined structure during the process and staying flexible but still achieve as precise and complete results as possible (Bérard, 2010).

Reed (2008) argues that participation in the research process adds quality and robustness. However, quality of participative input varies considerably. From field work experience in the Mexican and South African case studies, participation adds different perspectives, which can significantly differ from expert opinions. Also including local perspectives in the process is important for mutual understanding and uptake of results (Reed, 2008). Still, individual opinions are not necessarily correct and therefore their quality needs to be tested. For testing, respective information like expert knowledge or quantitative data is needed. The lack of this information led to the use of participative research results without thorough verification. This limitation has to be considered in the interpretation and further use of the results.

One major challenge is to capture subjective perspectives scientifically. This is difficult because perspectives differ between individuals and science strives to be fully objective (Schutz, 1962). Not only the captured impressions of local people are subjective, but also the capturing person, here the scientist, adds his or her subjectivity (see chapter 5.3.1) (Vennix, 1996). Even more important for the conducting scientists in every participatory approach is to keep this additional subjectivity small and personal filters open (Carruthers and Chambers, 1981). Also Vennix (1996) emphasises the importance of following scientific rules, like transparency and replicability, in the gathering of information. Standardized procedures have to be applied with care to still capture the problem at hand best possible. The model should always be built around the problem and not the over way round (Vennix, 1996).

There is a general danger with participative methods that the interviewer's or modeller's predefined understanding dominates the results of the appraisals. An open approach and respective mind-set is necessary to challenge potentially wrong assumptions and discover the true core of the problem (Carruthers and Chambers, 1981). Not only the problem formulation should be focussed on the input of stakeholders, but also the results should be evaluated by them. Even though such a participatory evaluation can be highly subjective and differ in opinions, generally a clearly structured and well communicated process enhances the success of participation (Reed, 2008).

Despite a replicable methodology results can still diverge due to the dynamic development of socio-ecological systems altering both human and natural conditions as well as the impact of a prior group-model-building exercise. It is questionable, that the same mental models would result in a second round of participatory modelling with the same interview partners in Mexico and South Africa. Being visited by foreigners and asked specific questions can easily change perceptions at least for a short time. Critical voices in system dynamics state that qualitative modeling can be dangerous or even misleading, based on the limited capability of human minds to capture complexity (Vennix, 1996).

5.2.2 Specific limitations of applied approach – internal critical evaluation

Despite mentioned benefits of applying a participatory modelling framework some critical points have to be discussed here. First, the stakeholder selection only partly fulfilled previously defined criteria of covering all available profiles, considering main occupation, gender and age in individual interviews. Partly due to limited access to the region it had to be relied on the help and preparatory work of local contact points. It was not possible to control the diversity of household profiles being equally represented in the interviewee selection. Also due to these externally influenced conditions individual interviews were only feasible in the Mexican case studies. In the South African interviews the structure of the interview had to be adapted spontaneously to a group setting. Posteriorly, more compliant conditions would potentially have been achievable, when investing more time and effort in preparations. The group setting led to the necessity of skipping a whole set of personal profile characteristics, which would have allowed for another level of analysis and comparison between case study regions.

A semi-structured qualitative interview guide, as applied here, has both benefits and limitations. The chosen structure is the attempt to balance objectivity of the interviewer, structure the content and ensure certain topics to be covered while still maintaining a highest possible flexibility to adapt to the individual storyline of each interviewee. However, the predefined topics guiding the interviews can already influence individual storylines. On the other hand, more open questions can increase the risk of an even less complete picture of rural livelihoods. Just asking "what is important in your life?" would most probably lead to neglecting all implicitly included components, such as drinking, eating etc. which are too obvious to actively think about it. Therefore the chosen approach is seen at the optimal compromise between predefining too much, like in a multiple choice, quantitative questionnaire, and missing focus, like with completely open questions. Furthermore some structure and comparability is still given by a semi-structured guide.

The interview guide includes a broad variety of topics and respective detail questions offering the interviewer a catalogue to roughly follow and complete so far missing topics during the interview (see Appendix A1 for complete interview guide). An initial version of the interview guide already set a certain emphasis on specific topics, especially related to natural resources and ecosystem services. However, throughout the analysis process it got apparent, that this predefined selection of topics doesn't necessarily cover all topics relevant for a vulnerability assessment. With the emphasis on natural components, socio-cultural, political and economic components were easily neglected in the interviews, due to both time and ethical constraints. Even though it is unquestionable that religious beliefs, personal and cultural values, local politics and social structures can be sensitive topics, the importance to include these components in the interview is similarly unquestionable. To approach these topics appropriately more specific preparation would have been needed. Some other biases remained in the interview guide based on the specific interest of involved scientists. This latter factor has to be considered, though it will return in any case depending on the respective author of the guiding questions. Another recommended shift in emphasis for future interviews in similar style is in the coverage of temporal scales. Although the interview guide includes specific questions about differences in the past and expectations for the future, this information was followed with low priority during interviews. The emphasis was set on the completeness of given components and linkages. Additionally, interviewees tended to get nervous after 1-1.5 hours of interview, which made it difficult to cover all topics to its fullest. However, these temporal developments would have been especially interesting to enable a dynamic vulnerability assessment. Last but not least, components and linkages were mainly captured in a qualitative way. Already adding relative weighting factors or even quantitative data would have increased to modelling possibilities in the analysis. Still, the qualitative system is seen as the cornerstone for all further analysis.

Not only including information on relative importance of different resources and other components in the system, but generally verifying the designed mental models with local interviewees, not interviewed control group and regional as well as topical experts can further improve the quality and reliability of mental models. The small number of interviewees per community, even though each was selected to be representative of a whole group, increases the risk of missing or wrong statements influencing the summarized picture of the region. In the Mexican region, community sizes range from 60 to 3000 people. Still, for each community only ten representative persons were interviewed. The method to summarize all ten individual models into one community model, including every mentioned component and linkage can additionally distort the picture. From a community model it cannot be derived, whether one component or linkage has been mentioned by just one person or by all interviewees. However, this weighting would give an estimate on the importance of the respective element or process in the system. Such a weighting of course would also be biased related to the selected interviewees, the set of questions and emphasis. Still, it would indicate that for example fishing is a more common income source in the Mexican case study region than leasing land. In the followed approach the emphasis lies on the variety of components and processes in the respective socio-ecological system, therefore including all details was chosen over including only overlapping information.

Despite the predefined topics in the interview guide (see Appendix A1), the emphasis of one topic over another can be influenced a lot by the interviewer. E.g. in Mexico the question for potential future incomes through tourism has explicitly been asked, leading to an often affirmative answer and was therefore included in many mental models, even though it wasn't mentioned independently before. On the other hand, topics such as politics and religion were not artificially brought up by the interviewer and therefore only appear in the mental model when an interviewee had the urge to involve it anyhow.

Apart from the structure and content of the interview guide the applied approach of visualizing the mental model in parallel to the dialogue poses further challenges to overcome: The method in general, dividing components into different categories and assigning further information to the linkages, is complex enough to induce discussions about the correct visualization of what has been said by interviewees. E.g. the interviewee explains that heavy rain leads to flooding in the area, but it is up to the modeller whether heavy rain is first connected to "rain" and then results in "flood" or whether it is connected directly. Leaving space for interpretation, such as does heavy rain occur in the normal rainy season, enhancing normal rainfall until it leads to a flood or do heavy rain events appear independently from normal rain events? Such differentiation might seem exaggerated and out of place, but when representing the perspectives of interviewees, the influence of the interviewer should be minimal. This shows also, that models drawn by different people during the same interview can be quite different, based on individual interpretations by the respective modeller.

Working with several models of comparable situations tempts the modeller to include easily comprehensible connections and components into other models, when appearing in one. E.g. in one case an interviewee mentions he cannot go fishing when he is ill. This leads to the expectation, that health is a prerequisite for all of the activities in all of the communities. But it could be the case, that it hasn't been mentioned by other interviewees because it simply usually is not the case. Potentially fishers can also follow their fishing activity in most cases of limited health, but only in the extreme case which the one interviewee had in mind this was impossible. These individual differences could help specify a threshold. In this case of health and fishing it would be interesting to know what health requirements need to be fulfilled to be able to go fishing. For this kind of details for each component and interaction, much more time and probably several iterations would be necessary, which was not feasible in this work. Especially in comparable situations small differences can be of importance. The aim to find exactly these differences to widen the mosaic should be followed very strictly, instead of following the urge for mainstreaming and finding communalities. On the other hand, this additional connections transferred through comparison between the communities can also cover gaps which might have simply been forgotten to be mentioned by the respective interviewees.

Underlying hypotheses or available background knowledge can additionally influence the understanding and translation of the modeller. Although the neutral position of involved researchers is an absolute prerequisite for the effectiveness and power of this methodology. On the other hand personal subjectivity is normal. The complexity of the methodology limits the possibility to involve the interviewee more in the actual model construction or even, what would be the best case, give the lead completely to him/ her. Based on (Rouwette et al., 2002) the best learning effect for interviewees or participants can be achieved when they are involved in the model building itself. While little specific case region knowledge can increase the neutrality of the interviewer, lacking background information can also lead to a misinterpretation of what interviewees said, e.g. the genesis of weather conditions and their impacts on the region.

5.3 Applied analysis framework and results

Generally many of the recommendations given in mentioned literature and discussed in the previous chapters 5.1 and 5.2.1 have been followed during the model-building process. Still some potential limitations also apply to this work. For example, the purpose of the conducted interviews to understand interactions in the local socio-ecological system has been clearly communicated in the preparation of the process. Also a common semi-structured qualitative interview guide was used to ensure a certain comparable structure. However, the set of questions as well as the flexible focus on specific topics was subject to the interpretation and situation dependent reaction of the interviewer (see chapter 5.2). Amongst others, these limitations challenge the credibility of resulting mental models. The credibility of the mental models is in turn central to all further analysis steps. Applied steps are therefore first and foremost methodological and structural ideas, highlighting the broad variety of ways to derive valuable information.

5.3.1 Credibility of mental models, its components, linkages and loops

The components mentioned in the models are always somehow summarizing and generalizing one or more specific characteristics behind. For example “river” represents water quality and quantity, but also the surrounding ecosystem, included processes and indirect influences like landscape formation. Therefore storylines behind each box always have to be looked at in context with the other linked components. In case of “river” being influenced by “petroleum” and “rain” suggests water quality and quantity being relevant. By influencing “fish” and “water” it is indicated, that “river” goes beyond simple water quality and quantity. It further also represents more complex processes such as providing a healthy habitat for fish and potentially several other resources adding to water. A more abstract connection is to “beauty of nature”, which can be interpreted as the landscape forming power of a river. The broad variety of information provided by such a mental model can easily be misunderstood, when simply looking at the model without including detail description. Also it has to be looked at considering the subjective stories that lie behind such a mental model. It can neither be comprehensive nor does it verify the objective correctness of all components and linkages. Still it gives a sensible insight into local livelihoods.

In terms of the categories of components especially the triangle shaped boxes offer space for discussion. Triangles represent generally unsatisfying conditions, e.g. lacking health services, slow-onset changes, e.g. increasing catfish population, and fast-onset events, e.g. floods. Summarizing clearly temporal defined events with persisting conditions, internal insufficiencies and externally caused impacts in one category can lead to confusion. This confusion could be alleviated by introducing subcategories of “active” and “passive”. Is something threatening, because it “allows” adverse effects to happen, e.g. lacking health services or rather because a damaging event causes adverse effects, e.g. flood? This connects to the influenceability of a threat and related impacts. While a bad health system can be improved with respective means, flood usually cannot be avoided. One can only implement measures to limit the adverse effects, e.g. build dams, construct houses on higher terrain, learn new fishing techniques, use better boats etc. However, what all these threats have in common is the adverse effect on rural livelihoods in the case study regions. For adaptation and management planning purposes it would be helpful to distinguish threats between regular and exceptional events, as well as between influenceable and superior originated.

This distinction of different threat types is independent from the severity of the respective effects. Anyhow, the term threat includes a subjective valuation which can differ individually. Similarly to the discussion on who is vulnerable and who isn’t also here one can ask what defines a threat. Is an unsatisfying situation like insufficient health services already threatening? In the most cases it is probably not life threatening, but still leading to aggravated and delayed help in case of illness and injury. From case to case it has to be differentiated between seriously threatening and simply uncomfortable. Kelman (2007) additionally highlights that changes can also have a valuable effect on the system. A slow-onset change or a fast-onset event only turn into disasters, threats or hazards due to the existing socio-economic conditions of a system.

Including activities as an extra category in the models can also be controversially discussed. On the one hand, activities offer additional information by emphasizing those interactions which are led actively by human actors in the system. In contrast, components linked without an activity box in between can be interpreted as happening without human intervention. On the other hand, activities as additional boxes in the models only complicate matters further, while the actual information, e.g. that wood from the forest is used for building houses, can also be derived from the respective components being connected directly. For simplification reasons activities were not always directly included during the interview and modelling process. They were added and completed afterwards. Therefore this information is not further analysed, because a certain bias towards the subjective interpretation of the interviewer could not be avoided. The respective column “Used how” in Table 2 shows the variety of activities involved in transferring resources into serving livelihood aims.

During the interview process and the model-building in parallel only four colours were used to indicate the respective component categories: green for natural environmental, orange for socio-economic components, blue for activities and purple for threats and changes. To maintain this original structure, the shapes of rectangular boxes, circles, hexagons and triangles were introduced afterwards. An additional change of colours distinguishes natural and socio-economic components into sources, structures and aims (darker shade of colour) as well as specific resource and service (lighter shade of colour). Also threats and changes were separated based on their natural or socio-economic origin into the respective colour of dark green or dark orange/ brown. This colour code allows for a better structure and overview of the mental models. However, this information is based only on the subjective interpretation of the modeller and was not evaluated with local people or experts. Therefore it is possible, that misinterpretations lead to some wrong colour assignments. Additionally, the several steps approach to the final set of colours and shapes can be confusing for the reader.

Alongside the components, linkages form a central part of the mental models. As long as specific correlations and causalities between components of a socio-ecological system are unknown, one can only make assumptions. More important is the rough understanding of how components link together. E.g. what is the causal relation between education and health? On the one hand, one can assume that people with higher education levels are healthier, because they pay more attention to themselves and are informed about healthy nutrition and potential health risks in daily behaviour, such as smoking. On the other hand, people with higher education might also be more prone to stress related health issues, because of time and energy intensive jobs. So in the end, it is not completely clear what the causal link between education and health is. Relating to such unknown but anticipated linkages it is inappropriate to assign indicators to it. Also in other cases where causality is clear, like the status of health affecting the ability to work, it can still be unclear which exact indicator represents the link correctly. E.g. does the number of HIV infected people correlate with the number of people not being able to work because of health issues? Each specific connection would need detail knowledge of various disciplines to be fully validated. Firstly, even though including the respective knowledge, there is the challenge to have the necessary data available to support it. Secondly, a correlation doesn’t necessarily proof causality, but can only be used as a region specific coincidence. Thirdly, it might be of minor importance which exact indicator is applied, since the highest relevance is related to this linkage being represented in a sensible way. Therefore it is suggested that the importance of indicators, lies in the representativeness of certain topics and appropriateness of scale.

Even more critical than the categorization of components is the evaluation of linkages between components as well as resulting impact chains and loops. The representation of different kinds of connections is limited by the only choice between enhancing (black) and opposite (red) as well as the direction of the arrow. However, arrows stand for several more types of connections. A linkage can represent a coinciding or a causal relationship. Additional to the qualitative information on enhancing or stabilizing the subsequent component specific quantitative information, for example on the preconditions as well as frequency and intensity of the linkage, could be provided. If this quantitative information is not available a relative weighting factor can give additional information on the share different linkages define in a component. Especially when different models are combined into one it would also be interesting to distinguish linkages and components being relevant in all previous models or only in some. For modelling endeavours another temporal component would be important. Do all processes in the model happen at the same time or is there a temporal delay? For all these possibilities additional information would be needed.

The following example shows the limitations of currently available linkages. Rain quantity is connected to the quantity of mud in the river water and the quality of taste of it. The latter feeds back in the amount of river water used for hydration. While this impact chain was developed for the case of more rainfall, leading to worse taste of the river water and therefore less use for drinking, it is questionable if it also works the other way round. This would mean in case of less rain, the river water tastes better and is more abundantly extracted for drinking. However, it is unclear how large the effect of rain on the taste of river water is. Potentially other factors influence the water taste and moreover the decision for the source of drinking water. Neither the weight of different influence factors nor every possible scenario has been inquired during the interviews. Therefore the importance and overall validity of linkages cannot be evaluated conclusively. The subjective perception of each person, household and peer group in the region adds another factor underlying the decision to use the river water, potentially also independent from the actual quality of it.

Furthermore, not all linkages truly build on the previous ones. E.g. agricultural products as a result from harvesting, form a contribution to neighbour help in the community. But the input to financial means from neighbour help is understandingly not related to this contribution. The first is support for others, an active contribution into a solidary system, while the second is support provided by others for one self. In- and output of this neighbour help structure are independent from each other. In the individual case it doesn’t matter whether one only gives or only takes. In summary however it has to equal up, otherwise the system won’t survive. Based on the example of this specific connection one can conclude, that for the individual the whole impact chain is not correct, but for the whole community the link does work eventually: one person is affected by weather variations, harvests less and can therefore give less to neighbours, which in the end influences their financial means or nutrition equally negatively. However, this thought already impacts financial means directly because the own harvest is also diminished.

In many cases of feedback loops similar difficulties like in the just described example of neighbour help appear. Even though connections exist and even form a loop, the interaction described by each link isn't necessarily triggered by the previous one. Therefore also the resulting loop is not truly closed and doesn't enhance or limit continuously. The example of enhanced shore erosion due to a flood event is another example for a circular, but actually unclosed, impact chain. While shore erosion contributes to the amount of suspended material in the river and this again is perceived as worsening the effects of flood, the strength of the flood is not influenced by suspended material and doesn't enhance shore erosion.

Even though other loops do actually feedback into the whole process another limitation appears in the analysis. The above mentioned lacking weighting of different influence factors also affects the weight of a closed loop on included components. Adding a factor for relative importance of certain connections compared to others, the quality of the loop analysis could be increased. E.g. income derived from natural resources does support housing to a certain amount, which again is responsible for a certain amount of waste being produced and potentially adding to the pollution of the ecosystem originally providing the resources. Income is also added from other sources and serves for different purposes than only housing. Income is not the only input defining housing, as well as housing is not the only source for waste, etc. These examples show that loops are part of a bigger picture and play only a limited role in the whole system, depending on the importance of involved components.

5.3.2 Analysis of mental models and rating of current vulnerability

Summarizing resources, livelihood aims and threats in tables allows for a better overview of mentioned components. However, characteristics such as whether a threat affects a resource directly or indirectly, via several feedback steps cannot be derived. It is possible, that indirect influences are less central to the affected component than direct ones. One can even suggest that they are not to be counted in the traffic light rating, or at least not fully. Although one might not be sure about the exact magnitude of influence, the fact that there is or can be an influence is already important to consider. Especially these indirect influences are easily overlooked and can form a crucial insight into the combinations forming vulnerability. Also a counterintuitive effect can happen, where direct impacts are actually less important than indirect trickle down effects. Due to the lacking information on the effective impact each process or threat has compared to others, the assumption was made that all are equally important.

Introducing the categories natural (N), semi-natural (N/H) and human (H) for the source of the threat and the component affected by it, adds some structure to the long list of threats. This classification is limited to obvious sources and mostly direct impacts. Further feedback mechanisms or unclear influences in the origin of the threat have not been included. Neglecting trickle down-effects decreases the amount of available information involved in the analysis. The classification gives an insight into the share of natural compared to human threats affecting both natural and human parts of the system. Even though an indirect focus was set on natural resources and climate related changes during the interviews, most of the threats perceived by local people are based on socio-economic events and conditions. From the naturally originated threats only a small share can directly be related to climate change. However, indirect effects of climate change are highly probable to influence the system on a much broader scale (see chapter 4.4.3).

Following the interest of understanding motivation for behaviour, livelihood aims of the rural case communities have been analysed. Although livelihood aims partly combine needs and wishes, they neglect the influence of surrounding environmental, socio-cultural, economic and political conditions (see also chapter 5.1). For example, traditional community structures have been mentioned during interviews in South Africa. Even though these structures play a central role in the daily lives of people, they can hardly be captured as livelihood aims. However, they are expected to influence motivation, limitation, and especially guidance for human activities (see Figure 60 in chapter 5.1). Additionally, many of these framing conditions like social networks, family structures, political engagement and religion are complex to understand. Therefore these components were not inquired directly (see chapter 5.2.2). These topics have also only scarcely been mentioned by interviewees. Still it is expected that a thorough understanding of local socio-cultural dynamics and psychological processes is necessary to correctly and sensitively cover these important topics in a vulnerability assessment. Livelihood aims are assumed to not only form the major motivations for behaviour, but indirectly include also individual valuation as well as other guiding conditions.

Based on the structured information of the Table 4-6 a vulnerability rating was derived. Using a colour code to visualize the state of resources and livelihood aims presents easy graspable information. The central part of the assessment is the double pressure of uses and threats per resource. On the one hand, the relative importance of the resource is estimated based on the number of uses or livelihood aims depending on it. On the other hand, the current probability for the resource to be unavailable is defined by the number of threats affecting it. This two-sided approach offers a frame for adding further information and weighting factors. However, the absolute number of uses and threats as only criteria to calculate vulnerability neglects the actual availability or renewal rate of the resources, as well as the frequency, intensity and extent of the threats. Therefore especially for socio-economic resources the rating can be significantly different when compared to reality. Multiple uses and growing demand would most probably not lead to higher pressure on a limited number of resources, but could easily be met by higher supply.

A first weighting has been added on the threat side, including different sources and available countermeasures in the calculation. However, simply a relatively high number of threats affecting one resource, does not allow for the judgement that the resource will actually be highly affected. One high impact event, like a severe flood killing a large share of the domestic animals, would probably be rated more critical than a series of smaller adverse effects like insects, diseases and theft affecting single animals temporally. Also the efficiency of the measures in place, as well as whether or not other threats could easily be counteracted against is not taken into account here. Furthermore, it has to be considered that having countermeasures in place can have a counterintuitive effect by soothing only the surface of a problem. When the implemented measure is ineffective, however the problem is expected to be solved, the necessity for improvements can actually be enhanced. One example of a still insufficiently functioning countermeasure in both case studies is waste management.

All in all, adding the relative importance of each use and threat on each resource, and the relevance of each resource for the respective livelihood aim, can give interesting information on the actual effect in case the resource can no longer be provided. The given framework can easily be complemented with respective information, potentially derived from expert judgments, follow-up interviews with local people or in other case studies also from available quantitative datasets.

The definition of rating classes and connected values for calculation is an example choice and can be challenged in various ways. While here the traffic light colours of red, yellow and green were implemented in decreasing order of criticality, one could also argue for more classes or different terms describing the classes. With “critical”, “pressured”, and “uncritical” a strong subjective valuation supports the intuitive colour scale rating. Based on the fact that these colours are assigned related to the Median of the number of uses, number of threats and respective sources as well as countermeasures the whole value set can be questioned. Setting aside the already discussed points (see previous paragraph) different variations of linking and transferring the three colours to the final rating are possible:

1) Basing colour rating on

a. Median
b. Average
c. Evenly distributed groups
d. Fixed number of maximum and minimum

2) Assigning colours based on Median (M) (red = > M, yellow = M, green = < M)
   a. Rounded to full numbers
   b. Unrounded (potentially skipping yellow class completely)
3) Calculating with numbers assigned to each colour
   a. red = 2, yellow = 1, green = 0
   b. values between 0 and 1
   c. any other different set of values
4) Calculating directly with the colour code
   a. Conservative (rounding up average, e.g. red + yellow / 2 = red)
   b. "Extreme wins" (e.g. yellow + green / 2 = green)
   c. Optimistic (rounding down average, e.g. red + yellow / 2 = yellow)

Applied in this work is each variation a. of steps 1) - 3). By applying the Median instead of a simple average, outliers are less dominant. This leads to the effect that, e.g. the threat rating of a resource is equally rated critical (red) with eight damaging events and changes (fish-river, MX) like with only 2 events (land, MX). Variation 1c, to distribute all resource-source combinations equally in the three groups of critical, pressured and uncritical, potentially leads to separating resources with a similar rating into two different classes. In the case of the visited Mexican communities, 13 combinations spread in the number of uses from four to one. Dividing them equally leads to 4-5 combinations per class. However, dividing a set of 4, 4, 2, 2, 2, 2, 2, 2, 2, 1, 1, 1, 1 number of uses would lead to some resources with 2 uses being classified "critical" and others only "pressured". This problem would be avoided by defining a maximum and a minimum threshold for each class. Freely deciding whether one, two, three or more uses lead to a pressured state of a resource would add subjectivity to the already questionable rating. Therefore the Median might not be the perfect measure to define the classes, but it is definitely a good starting point to highlight the possibilities and limitations of such a vulnerability rating.

Steps 2) and 3) differentiate details in calculating and assigning values and classes. Assigning classes based on the Median another challenge arises. The calculation of the Median in a group of an even number of components can result in a decimal number. This in turn doesn't allow allocating the middle class (yellow) to any of the components. The complete rating would therefore be based only on extreme states (red and green). To avoid an additional distortion, the Median has been rounded in this specific case. Another decision is whether to use only colours or transfer them into values for easier calculation. The effective difference is probably small.

However, calculating averages with numbers is easier than with colours. For example, the average of red, yellow and yellow is probably yellow while the average of 2, 1 and 1 is most definitely 1.33. Which number scale to use, is estimated as a minor detail variation in the calculation. In the end both with and without transfer are categorized as yellow, based on the assignment of the colours on the rounded values 0, 1 and 2. Therefore the effective difference between results based on numbers (3) or on colours (4) is probably small.

Linkages are included indirectly in the vulnerability rating. For example, the number of threats affecting a specific resource is calculated based on the number of incoming arrows to the resource box and their respective origins. This includes both direct effects, like catfish decreasing fish population, and indirect effects, like pollution decreasing the quality of the river ecosystem and therefore the habitat of fish populations. Similarly like for the components themselves also the linkages lack quantitative, relative or causal information. If this information was available, an additional weighting could be added to the vulnerability rating. Most importantly, more detail information on the linkages would enable system dynamics modelling and calculating outcomes of potential future scenarios.

In both regions financial means are covered by the broadest variety and the largest share of uncritical resources. Being more and more important in today's lifestyles it is not surprising to have the broadest variety ensuring this livelihood aim. Also having a large uncritical share can be a first result of the broad variety. With increasing variety less dependence and therefore less pressure lies on one resource. However, this is only correct in theory, when assuming that resources are equally efficient, reliable and used in producing financial means.

5.3.3 Future scenario analysis

To analyse impacts of future changes a methodology is used counting each link only once and following the pathways for a total count. However, feedback cycles can have an amplifying effect which is not considered like that.

A complete future scenario analysis is not possible with the available information. Still, the mental models derived from the interviews can be further developed into system dynamics models by adding respective quantitative and causal information. The here applied approach for future scenario analysis is a qualitative and visual assessment framework. It highlights the large potential impact already when only one component changes. Many natural and socio-economic components and other threats are affected by the two model scenarios on various trickle-down pathways. As already mentioned in the discussion of the current vulnerability assessment framework (see chapter 5.3.2), also here it has to be considered, that the pure number of linkages does not include the decisive information on the quality and relative effect of each connection. Also a large number of different influences can in total be smaller than one strong effect. Therefore summarizing the number of inputs with an increasing or a decreasing effect per component gives rather an impression on the interconnectedness of it, than a judgement of the overall impact of the respective change.

Behind each linkage are different kinds of processes, concerning various characteristics of the mentioned components. This makes it difficult to judge whether one arrow up neutralizes with one arrow down. Thus, one cannot come to a summarized conclusion, such as whether income will in- or decrease as an effect of more frequent floods altering the system. Further complicating is the unknown spatial and temporal context, as well as the magnitude and specific scenario behind each linkage (see chapter 5.3.1). For example, flood in general might increase sedimentation and bring nutrients, therefore having a positive effect on pasture and vegetation. But, in the case of salt water flooding, the positive influence of new nutrients might be partly or completely dissolved by the fact that salt water degrades the soil and vegetation. How a future scenario affects each component needs to be looked at in a diversified way, summarizing different effects on same components when comparable. For this a more detailed look on all processes and components is needed.

With sea level rise and resulting increasing floods in the Mexican case region as well as with increased droughts in the South African case region, two potential scenarios were selected. On the one hand, these scenarios are not fully realistic because they exclude any further changes of system components, including additionally planned countermeasures. On the other hand, these scenarios represent realistically climate change related projections (see GERICS, 2015a, 2015b). Despite the regional projections of Mexico and South Africa visited local case studies can still be affected differently. Still, the rough trends, consistent with the explanations of local people, can be assumed to be relevant.

5.3.4 Setting the overview structure into a larger context

Based on the parallels found during structuring and analysing the mental models of the Mexican and South African case studies an overarching framework of socio-ecological systems in coastal riverine areas is suggested. Even though similar components may be part of different systems, detail characteristics and linking processes are probably quite different. Hence, also the variables and measures describing the conditions of the components are rarely comparable. E.g. nutrition is central to every livelihood, but whether it is sufficiently covered and by what is dependent on local specificities. In the case of Mexican communities a comparatively large share of nutrition was obtained directly from their surrounding natural environment, containing fish, fruits, vegetables and animals. In the case of South African communities the major part of nutrition was covered by purchased food products. The set of components can also be different based on the subjective bias introduced by the interviewer and modeller (see chapter 5.2.2). For example, another interviewer might focus less on the basic needs of nutrition, hydration, etc. but more one the framing structures defined by politics, institutions, etc. Still, this overview structure gives a first hint on topics to consider in a socio-ecological system analysis and could be further enriched with other case study examples, growing to a catalogue of possible detail combinations of components. After having agreed on the components and comparable measures one can assess the condition of each component to identify most urgent fields of action. However, it has to be kept in mind, that components and linkages are not complete. Even though scientists, including me in this work, tend to focus on a specific set of topics on a specific scale the context of influences to consider is much broader and more complex. Further components to involve could be soil process, psychological triggers or the national political setting amongst many others. Some ideas are highlighted in the extended version of the overall structure of a socio-ecological system in Figure 61.

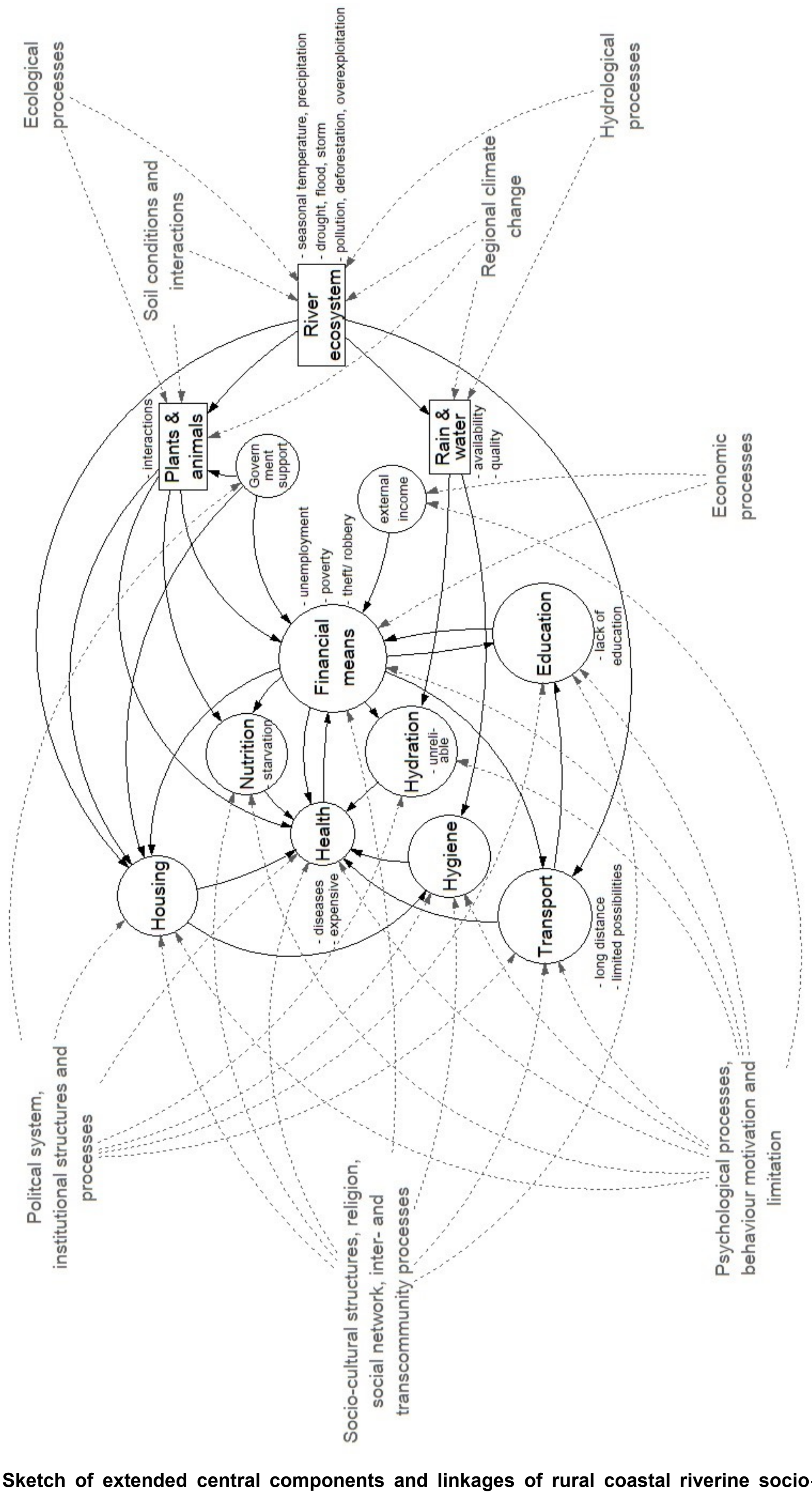


Figure 61: Sketch of extended central components and linkages of rural coastal riverine socio-ecological systems in black and solid lines, complemented by related subsystems in grey and dashed lines; own source

5.4 Case Studies

Apart from the methodological approach chosen to analyse the gathered information, the information and the results as such need to be discussed as well. In the context of the case studies in Mexico and South Africa a first challenge is to compare and possibly verify components and linkages in the mental models with existing literature. Secondly, observations underlying the definition of commonalities and differences amongst communities within and beyond one specific case study region are reflected.

5.4.1 Mexican case study specifics

Looking for literature on the Usumacinta River in Mexico one for example finds information on land use change in Chiapas (Christman et al., 2015), risk analysis of heavy metals in fish (Lorenzo-Márquez et al., 2016) and geomorphological characterization of fluvial processes in sediments (Solís-Castillo et al., 2014). Many publications either focus on a different region of the Usumacinta River basin or cover less relevant topics. Therefore the information given by the local population during the interviews can mostly not be verified by existing literature. However, in some cases relatable information is available. Most specific, the occurrence of the invasive catfish species, or “pez diablo” how local people call it, is also mentioned in literature. During interviews people stated the abundance and therefore adverse effects of the catfish. A sample catch resulting in 40 % of catfish coincides with this information (Wakida-Kusunoki and Amador-Del Ángel, 2011). Similarly, both local people and scientific literature see the upper Usumacinta-Grijalva River basin as the origin of the catfish plague (see Álvarez-Pliego et al., 2015). More general also the problems of overexploitation of fish resources and pollution by petroleum and pesticides are present in literature (see Carvalho et al., 2009; Jensen et al., 1989). Furthermore the general environmental setting during interviews is also confirmed by literature, including the nature protected areas (see Montalvo-Urgel et al., 2010) and the seasonal weather specifics like the “Norte” (see Kemp et al., 2016).

It was much harder to verify linkages between components in the mental models. In Badjeck et al. (2010) various influences of climate change on fish and fisheries are presented. E.g. environmental changes like sea level rise, variations in rainfall, temperature and storm frequency affect the ecology of the natural ecosystem hosting the fish population, fishing structures and techniques need to be altered, communities and livelihoods have to face new challenges, and finally also lead to changes in the wider society and economy. Generally, it can therefore be assumed, that fishing communities will face more challenges than opportunities under climate change. However, each specific case varies from others in its detail interactions. Therefore it is difficult to say how local fish species will react to changes in the coastal and river environment. It is additionally complicated to capture interactions and feedback mechanisms between different fish species, the environment and the human population in general.

5.4.2 South African case study specifics

For the Mkhomazi River in South Africa hardly any literature can be found. In South Africa in general the problem of lacking availability and quality of potable water, sanitation and the respective infrastructure is mentioned and discussed by Singh et al. (2013). Open water tanks, open defaecation and lacking hygiene are seen as key factors increasing diarrhoea, coliforms and other microbial diseases (Singh et al., 2013). During interviews in the region people mentioned disease appearing related to water. However, other than cholera no further water related illness was specified. Various publications approach the sanitation issue from a different perspective and highlight the potential of urine reuse in agriculture (see Okem et al., 2013; Tilley, 2016; Udert et al., 2016). Even though urine reuse can help in case of nutrient poor soils in the visited case studies soil quality was not mentioned as major concern by the people interviewed. More challenging factors identified by local people and ultimately leading to ceasing subsistence farming are heat, drought and wild animals. Sewage was only mentioned in the context of pollution.

5.4.3 Comparing localities and regions with each other

The focus for this analysis was rural communities. However, in both regions also other land uses interact with the natural environment. While in the Mexican region the main land use was dominated by rural communities in South Africa also commercial activities like a cellulose plant, sand mining and vegetable farming play a major role. In the larger region of the Usumacinta, further upstream coffee plantations and downstream offshore oil drilling should be mentioned as land and resource uses potentially influencing the case study regions. In a holistic analysis all other land uses should also be included. The interactions of these different land use types can evolve in some additional dynamics in the system to be taken into account. However, the structure of a purely economic activity is too different from the centre of living to be combined with each other easily. Most probably a different set of factors would be needed to capture key components and process of specified activities. Existing knowledge highlights beneficial and competing effects. For example, scientists see sand mining mostly as damaging the ecosystem (Forbes and Demetriades, 2008). Representatives from the cellulose plant and of the local population mentioned the benefit of sand mining for counteracting sedimentation and offering more space for fishing. It would be interesting to analyse where links between the different land uses already exist, can potentially be established and whether different interests rather cause conflicts, co-benefits, competition or other co-existence effects. Here further research would be needed.

During the case study description in chapter 3 and the description of the mental models in chapter 4.3 many similarities between communities in one region, but also between the overall Mexican and South African region were discovered. There are different possibilities to explain occurring similarities. Firstly, descriptions of communities and regions are based on incomplete knowledge. Incomplete knowledge can be related to generally not covered topics in research, simply unavailable publications or in this case specifically biased data collection. Secondly, similarities and distinctions found on the community level can be rooted on single individual perspectives. On the one hand, variations in specific activities, like employing a house keeper to prevent robberies, are valued more as individual storylines than a common community feature. On the other hand, differences in mentioned weather, season and climate information is valued as incomplete knowledge of individual interviewees and is combined together to achieve a complete picture. Still, due to these limitations, evaluations of similarities can only be subjective (see also chapter 5.2.2). A first impression is that South African communities are relatively more similar than Mexican communities. This can be related to the direct neighbouring of Emgangeni and Ndaya. However, also in the Mexican case, villages are located close to each other. Although only in the case of Palizada and Boca Chica they directly connect to each other. Still, in this case only some of the most distant households were next to each other, while the village centres are several kilometres apart. Similarities amongst the larger case study regions of Mexico and South Africa are already less pronounced than within a region. They have to be further relativized due to the same interview guide and therefore similar focus topics structuring the observations in both regions equally (see also chapter 5.3.4).

Comparing the two case study regions the impression arises that people in Mexico interact with the river ecosystem more closely than people in South Africa. Because Mexican interviewees are living much closer to the river than South Africans, the hypothesis is derived, that the distance of the centre of life, i.e. home, of people to the river is crucial for their interaction with it. As soon as they are not anymore directly affected by variations in the river flow (high and low flow, flood, etc.) their relation also in other parts of their lives is significantly smaller. For example, in the Mexican case, where people are directly affected by flooding, they also frequently use the river for fishing, hydration, hygiene, transport and tourism. In the South African case people have a strenuous hill to climb when returning from the river, so they merely use it for hygiene, only rarely for fishing and mostly see it as a danger as such. Therefore not only the distance but also other obstacles, e.g. the terrain, are decisive for the amount of interactions between human livelihoods and the river. Hypothetically, this close connection between human and nature leads to both a higher affectedness by environmental changes, e.g. climate change, as well as better adaptive capacity based on the knowledge of the system.

Furthermore, a better knowledge of the system does not necessarily mean people will actually adapt. In the specific Mexican case the impression came up, that people would rather migrate than adapt to major changes. The affectedness by adverse effects also can only be linked to the knowledge of the river ecosystem in a limited way. Especially climate change is happening independently from river dynamics. So only because someone knows the river, doesn't necessarily mean he or she is better prepared, because also other things than the river might change. Therefore the made assumption is possibly valid in a more general context of the whole natural environment. The more someone interacts with the natural environment, the better he or she knows it and the earlier changes are recognized and can be reacted or adapted to.

Another assumption is based on the spatial context defining where the coastal region of the river basin starts and ends. One of the criteria to select the case studies was based on the proximity to the coastline. However, the distance of active interaction between sea and river appears to be more appropriate to define the coastal river basin. In fact the assumption is made, that other than this interaction, the socio-ecological systems only differ slightly to other communities along the river further inland. The characterizing influence on the livelihoods is formed by the river, while the coast is an additional influence further specifying the region. For example, even though South African communities are situated much closer to the coastline, the effect of the sea on the river is already negligible (or not even existing at all). On the other hand, Mexican villages are much further inland in absolute distance, but based on the flat terrain the influence of the sea is still significant. Analysed South African villages are therefore probably more comparable to other villages along the river further upstream.

In the previous paragraph the assumption is made, that the coastal region of a river basin differs mainly from the rest of the river basin based on the water exchange between sea and river. This is possibly the most obvious difference, however there are other differences which can be used to draw a line between coastal and inland river basin. First and foremost, also weather and climate are influenced by sea or land respectively. Aquatic as well as terrestrial flora and fauna are subsequently related to regional weather and river water composition. Last but not least, coastal regions are often also more attractive to human settlements. Therefore a distinction between coast and inland could also be related to socio-economic factors. For example, in the case study region in South Africa local people mentioned the development of infrastructure, like roads, electricity and piped water, proceeding only gradually from the coastline inwards. However, it is not fully clear whether this incline is related to the coast or merely to the development as such. A similar effect can probably be observed in the proximity of cities.

A third important observation is seen in the cultural influence on livelihoods. This topic has not explicitly been covered during the interviews, because like politics it is seen as a sensitive topic in both regions. The hypothesis is made, that cultural imprinting superimposes all other influences. Even though culture is not a basic need to be fulfilled in life, it strongly forms the “how” in the “what do I need”. This point is linked to the discussion on behaviour motivation (see chapter 5.1) and the differentiation to guidance of behaviour. Based on Max-Neef (1991) culture covers the need for identity. In the Mexican case study both a traditional settlement structure, including specific fishing and agriculture techniques, as well as a migrating culture seems to exist. As already mentioned in the results (see chapter 4.4.4) local Mexican people tend to engage in a diversity of work to provide the necessary income. Compared to this, in the South African case no matter how harsh the living conditions, including droughts, wild animals, heat, lightning, existing traditions, like the value of ancestor land and building on hilltops, keeps them living the way they do. These two examples show the effect of cultural and individual values on habits, potentially adding to or even altering basic motivators such as human needs.

6 Conclusion and outlook

The main objective of this work is to define how to assess climate change vulnerability in socio-ecological systems, specifically rural communities in coastal riverine areas in order for posterior management options to maintain or increase the current living standard to be identified (see chapter 1). To achieve this objective, an assessment framework is suggested which starts off with capturing local perspectives on the composition of their livelihoods.

By translating rural livelihoods into natural and human resources, livelihood aims, and threats a socio-ecological system is derived. This step tackles the first research question on key components ensuring current living standard. Some of the main components and processes maintaining the current living standard can be summarized in the categories of hydration, nutrition, health, financial means, housing, transport and education. In the Mexican case study the key providing source is the river and its surrounding ecosystem. In the South African case study the institutional and governmental context providing finances, water, sanitation and other infrastructure is identified as central to rural livelihoods.

The second research question concerns threats endangering the main functioning of the system and focuses on experiences with climate related effects. A broad variety of both human and natural threats, including climate related ones, as well as their impacts on the current system have been identified in exchange with local people. Also a framework to analyse influences of future changes with estimates for one climate change scenario per case study region has been developed. In the South African region dry periods are most threatening to the socio-ecological system, potentially enhancing the dependence on governmental structures.

The third question on countermeasures in place to further develop and adapt from them can be answered from the local people's perspective. Several countermeasures, such as waste management, reforestation, weather forecast and governmental support, have been mentioned during the interviews. However, the number of mentioned threats still exceeds available countermeasures. It would therefore be interesting to add local expert's knowledge on available regional countermeasures and inquire ideas about additional measures to be implemented.

Returning to the main objective, one can conclude that several steps are suggested on how to assess climate change vulnerability. Whether these steps can suffice for a realistic assessment and resulting management options will have to be tested in future work. A second objective was to test and evaluate possibilities of participatory modelling as a tool to gather data. By thoroughly reviewing available literature, applying the participatory modelling approach in the case studies and discussing benefits and limitations the objective is covered.

Following the aim of supporting the better tangibility of climate change vulnerability this work adds on the conceptual, methodological and empirical levels to existing knowledge. Main conclusions of the whole process are

A) On the conceptual side: Different theoretical frameworks on vulnerability, risk, resilience, adaptation and sustainability approach a common core problem from different perspectives and therefore can enrich or confuse each other. The core problem can vary based on the setting. In this work it is how rural livelihoods are affected by climate change and how they can, should and will react.

B) On the methodological side: Participatory modelling is a challenging approach, requiring a clear aim, a well-structured frame and possibly an experienced team. However, it offers a good possibility to exchange perspectives, resulting in a broad diversity of information and respective further steps of analysis. The developed mental models capture main components and linkages defining the socio-ecological system in a dynamic way.

C) On the empirical side: Mexico and South Africa are very different countries, in terms of climate, natural environment, land use, culture and many more. The major climate change related challenge for rural communities in the coastal Usumacinta River basin is expected to be floods from heavy precipitation events and sea level rise. In the Mkhomazi River basin in South Africa the climate change challenge of rural households is seen in droughts, potentially enhancing the dependence on governmental structures. Despite all regional differences some commonalities can be identified leading to a comparability of the two case studies.

With these insights this work aims at motivating the field of science to invest a little on sorting the conceptual setting prior to each assessment, a little more on finding the core of the respective problem behind the sometimes distracting conceptual layers and most on understanding human behaviour. From a conceptual perspective an important next step in climate change vulnerability research is seen in including psychological understanding of individuals, groups and societies. Apart from the necessary contextual knowledge on the externally observable natural and human environmental processes, the internal valuation and decision mechanisms form the source of all human processes. Independently from the chosen theoretical frame, being risk, vulnerability, resilience, or else, assessments can only cover the symptoms as long as no underlying motivating factors are considered.

In regard to this work, specific next steps suggested to improve the current participatory modelling approach are to

1. Verify the correctness of mental models with
   a. Interviewees and other community members,
   b. Local experts, and
   c. Literature (on general causal relations)
2. Add information on
   a. Relative importance (weighting factors),
   b. Causal relationships, and
   c. Quantitative data
3. Model socio-ecological system and future scenarios with system dynamics
4. Update and combine current vulnerability rating with future scenario

The regional results can be used by local decision-makers in Mexico and South Africa. Adding the respective information, potential damages and costs to expect from climate change can be derived. Information needed for the local application is especially quantitative numbers and causal relationships. Already on the qualitative side the results show for Mexico and South Africa what components and linkages are central to rural livelihoods. This can give insights into what future adaptation measures are necessary, due to adverse effects, and possible, based on human interests and motivation.

All in all, this work has to be seen in the large and complex context of human life on earth. The resource use and rural livelihood aims approach defined, covers several key facets. In next steps these facets should be set into context with in depth knowledge from other disciplines, like climate modelling, hydrological, geomorphological and soil processes, as well as political, cultural and psychological dynamics, to mention only some. This will ultimately increase the understanding and ability to plan and project future changes effectively.

Appendix

In the following the complete interview guide, on which the applied participatory modelling approach (see chapter 4.2) is based on, is presented in A1. Adding to the topic specific excerpts from mental models in chapter 4.3, in A2 the underlying community models for the Mexican villages Boca Chica, Palizada, Quintín Aráuz and Tembladeras as well as the South African villages Emgangeni and Ndaya are fully visualized. A3 lists the complete tables of livelihood aims and threats as presented in chapter 4.4.1.2 and 4.4.1.3 respectively. Last but not least A4 shows the underlying calculation steps for the summarized local vulnerability assessment in chapter 4.4.1.4.

A1. Interview guide (shortened)

The complete interview guide originally developed in cooperation with colleagues from Mexico included an introductory part, describing the aim of the interview as well as needed materials and recommendations to consider during the process. Here only the translated and prior to the interview sessions in South Africa adapted set of questions is seen as relevant to follow the findings of this work.

Each interview took about 1-2 hours and started off with a brief introduction of the interviewing team, including a moderator, a modeller and if necessary a translator as well as the structure and procedure of the interview and posterior processing of gathered information. The original interview framework aimed at individual interview sessions, which would allow taking personal specificities into account. Information such as name and address where merely collected to be able to contact interviewees after the interviews again, when necessary, while all further analysis was kept anonymous. In Mexico section 1) could be followed strictly, however in South Africa it was not possible due to initial group interviews. Sections 3) to 7) were used as rough guidelines encouraging the interviewee to express his or her experiences on the respective topics, but not forcingly covering each specific question.

1) **About the interviewee (5 mins) (please fill the file for each interviewee)**
    1. Name
    2. Family name
    3. Address
    4. Graduation level, school visit until
    5. Gender
    6. Age
    7. Family members living in this household
    8. Are you married?
    9. Do you have children? How many?

10. Any grandchildren?
11. What is your main employment (only one)?
12. Other employments?
13. For how many years do you live in this community already?
14. Were your parents born in this community?
15. Were your grandparents born in this community?
16. Day and time when you would be available for the second interview:
17. Are you available to come to ……………….. to take part in a workshop for about 1.5 days in the beginning of November?
18. Are you available to come to ………………. to take part in a second workshop for about 1.5 days in the beginning of November?
19. Do you have any requirements which can help you to ensure your participation in the workshops (specific times for the schedule, transportation, etc.)?

2) "Ice-breaker" (5 mins)

- What does the river mean to you?

3) Identification of natural capitals (25 mins)

The underlying reason for the following questions is "what do you use?", "from where?", "what has changed during your life in this community?"

A) Nutrition

- What do you usually eat?
- Where do you get the mentioned food from? Are these secure food sources?
- Did this change? If yes how and why?

B) Income

- Where does your income come from? Are these income sources reliable? (in case of selling fish: How much do you get for a product?)
- Do you get help from the government to protect, maintain natural resources (e.g. forest, animals)? Which kind? For which activity or purpose? How much do you get? How often, frequency of payment?
- What are your daily expenditures?
- Did anything change? What and why?

C) Savings

- Which proportion of your income can you save?
- For what do you need your savings? Which type of emergencies?

- In case you don’t have any savings to pay for an emergency, what do you do?
- Did anything change?

D) Living

- Which materials do you use to build your house? Where do you get it from?
- Did anything change?

E) Health

- What do you do to recover from common and severe illnesses?
- What do you think are most important causes for health problems?
- If you collect plants/ animals, which ones do you use for which illness, and where do you find it?
- Did anything change?

F) Hydration

- Where do you obtain your water for drinking and for washing/cleaning from?
- Did anything change?

G) Combustible/ Fuel

- What combustible do you use for cooking, for heating and for transport? Where do you get it from?
- What changed?

H) Garbage management

- How do you get rid of your garbage and sewage from the house?
- Something changed?

I) Transport

- What means of transportation do you use?
- How frequently do you use the river for transportation?
- In times of flooding (if there are any) what happens to your transportation?
- What changed?

4) Identification of activities (25 mins)

Depending on the answers before, we can start with different questions on the activities. The underlying questions in this paragraph are “What do you do?”, “where?”, “for which purpose?”

A) Land Use

- How do you use the land surrounding you?
    a. Agriculture/ husbandry
- Do you own productive land? What do you cultivate there? Where is it? For which purpose?
- Do you have any other type of land? Where? How do you use it?
- Do you have animals? Which and how many? Where? For which purpose do you maintain them?
- Is there any risk for your animals? Which kind?
- Were there any changes?
    b. Hunting
- Do you hunt? What do you hunt most often? For which purpose? Where? Is there any permission needed?
- Did any changes occur? Why?
    c. Quality of the field
- How do you consider the quality of your soil? How did it change?

B) Water Use
- How do you use the water from the river?
    a. Fishing/ aquaculture
- Do you go fishing? Where? For which purpose? Did anything change?
    b. Transport or other?

C) Tourism
- Are you involved in tourism, how?
- Which tourism potential exists in your community?
- Which changes occurred? Why?

5) Identification of current and future threats (15 mins)

In general

- Which types of problems currently occurring or which could occur in the future worry you? How often do they occur? Why are you worried about the mentioned situations? What are the causes of the mentioned problems? Where do these causes come from? How bad are their consequences? *Intends that people focus on worries related to their activities and to the natural capital.*
- What do/did you or your community, local/regional/national authorities or governments do to reduce these threats and worries or their consequences? Is there an official paper/framework?

More specific

- Do you perceive any differences in the weather, seasons, growing plants, animals etc. compared to the past? Which, why and how does it affect you?
- Do you perceive any differences in the quality/taste of the water compared to the past? Which type? Why?
- Are there differences in the quality/taste of water in the rainy or dry season? Which and why?
- What do you or your community do when mentioned changes in the water quality occur?
- Can you tell us anything about the turbidity of the water? Do you experience it often? When does turbid water occur? Why? How did the situation change? And how does it affect you?

  Did you detect any inland movement of the coastal line (coastal erosion)? If yes, since when and how much? What do you think why this phenomenon appears? Does it harm or benefit you? What measurements are taken to reduce the mentioned effects?
- Are there any plagues? What changes occurred? Why?
- Are there contaminations? Where do they come from? For how long?

Past threats (15 mins)

- Did you experience any kind of disaster or negative changes in the community, or something your parents or grandparents told you about? Which and when? Which impacts did it have? What were the causes?
- Do you know the measures which were adapted to recover from this disaster/change? Why were these actions taken?
- Do you know which measures are taken to avoid the mentioned disaster to occur in the future?

6) Identification of social, human, cultural and political capital

If the interviewee hasn’t mentioned anything about cooperatives or other types of social activities in relation to the uses of natural resources, ask for them for each activity

- Does there exist any collective or cooperative activity involved in maintaining the resources needed to sustain ”this” activity? Are you part of these groups?
- Are you interested/ involved in local politics?
- May we ask you about your cultural and religious background?
- Do your neighbours, people from your community support you (in case of emergency)? How?
- How do you receive information about local news, weather, and threats like hurricanes or flooding?

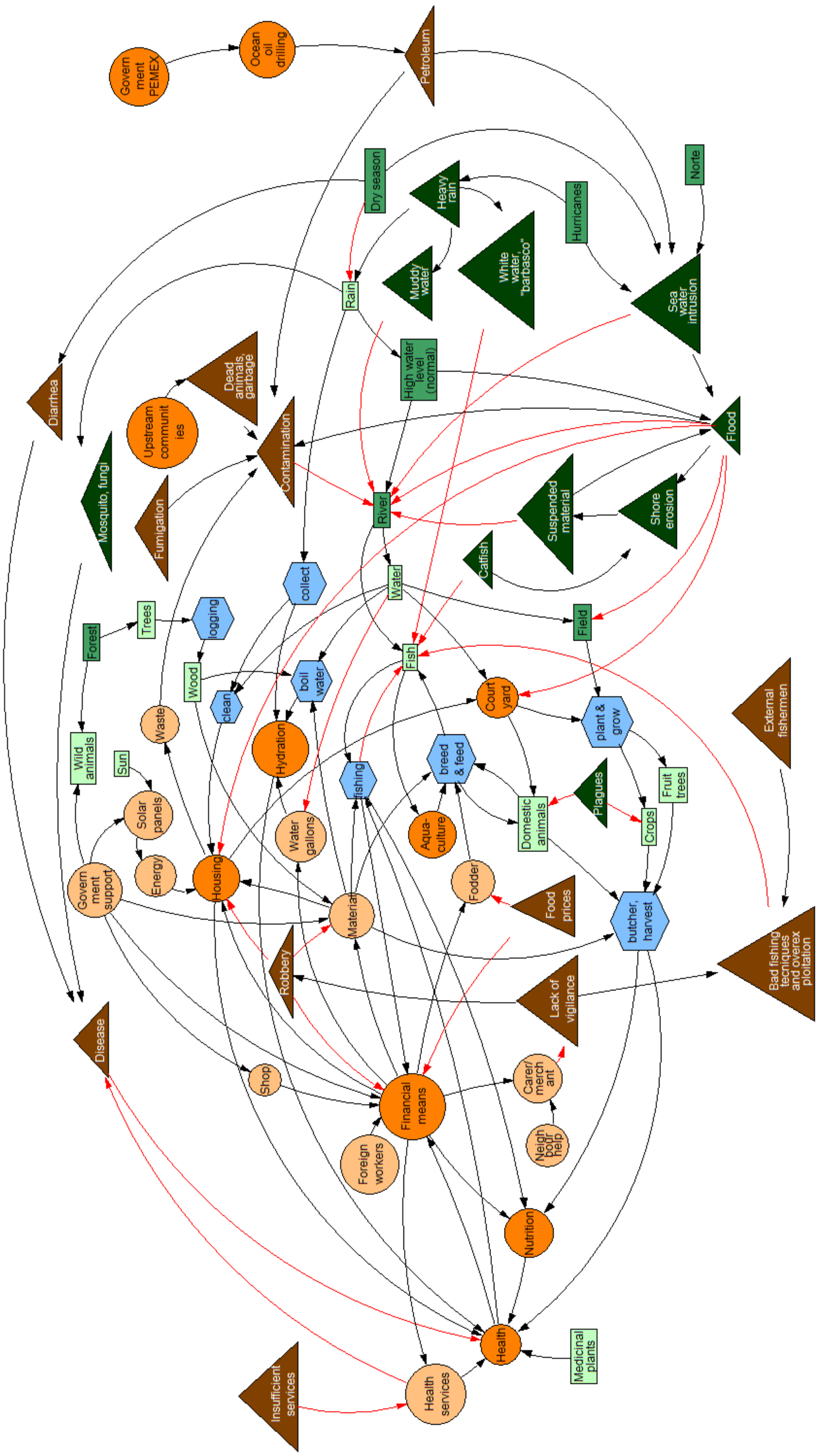
7) Willingness to stay/ future perspective

- Would you like your children or grandchildren to stay in this community? Do they want to?
- How do you see the future of your community/culture, or what changes did you experience in the past (growing shrinking population/income), how does this effect your personal livelihood?

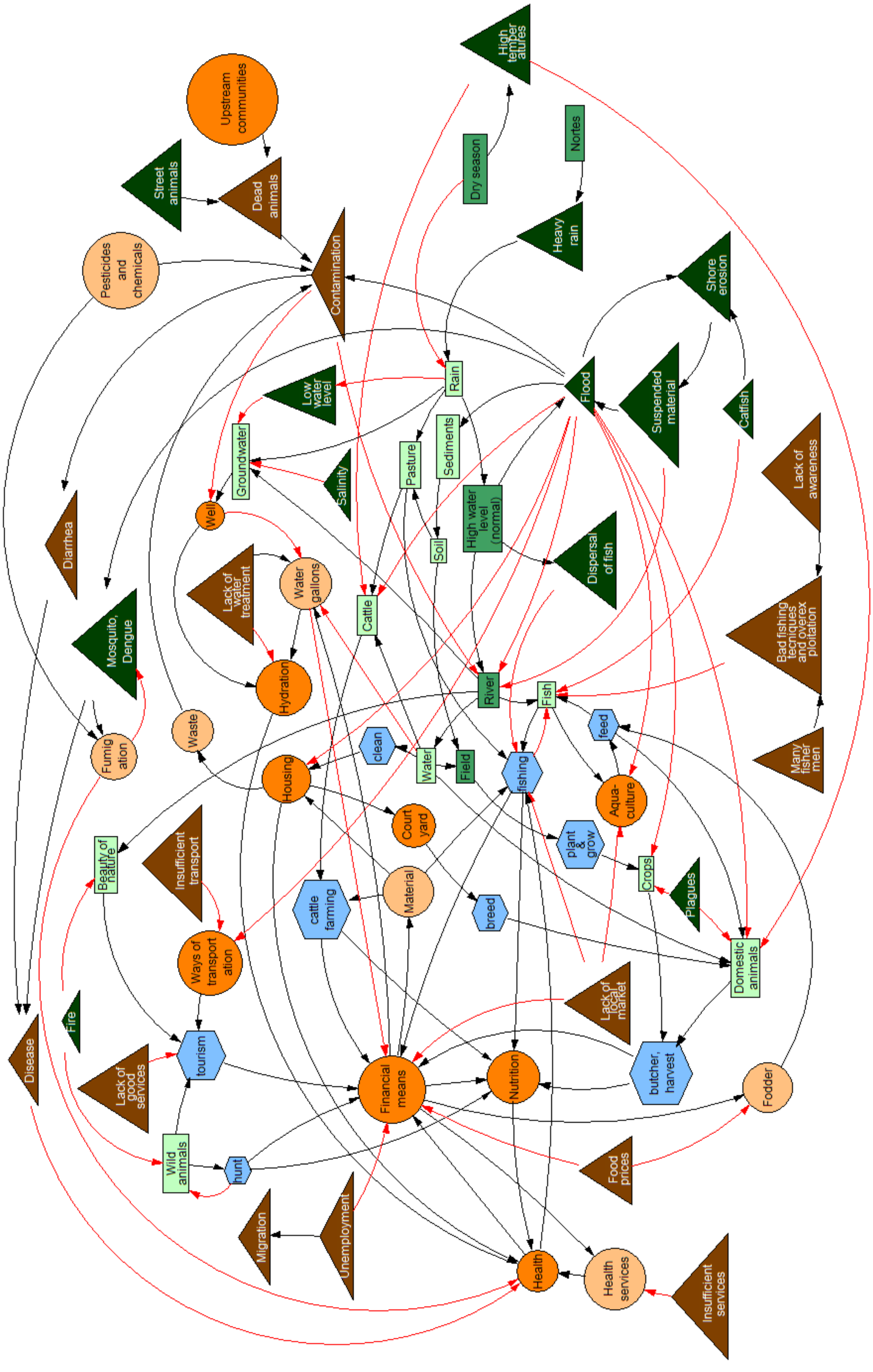
A2 Summary community mental models

Each of the mental models below represents the summarized group model of the respective community. The models consist of four types of boxes, representing components of the socio-ecological system: square = natural environment, round = socio-economic assets, hexagon, blue = activities, triangle = changes and threats. The green and orange colour shades further differentiate between natural or socio-economic respectively. The darkest shade visualizes the source of the threat, medium shade stands for a system subcomponent, condition or livelihood aim and the lightest shade represents a specific resource or service. All boxes are connected by different types of arrows, representing relations, interactions and processes within the system: black = enhancing relation, more at the start of the arrow results in more at the end of the arrow and vice versa, red = opposite relation, more means less and vice versa. Presented models are based completely on empirical data gathered during interviews in the respective communities. Some minor changes, like adapting the colours, are added in post-processing by the author.

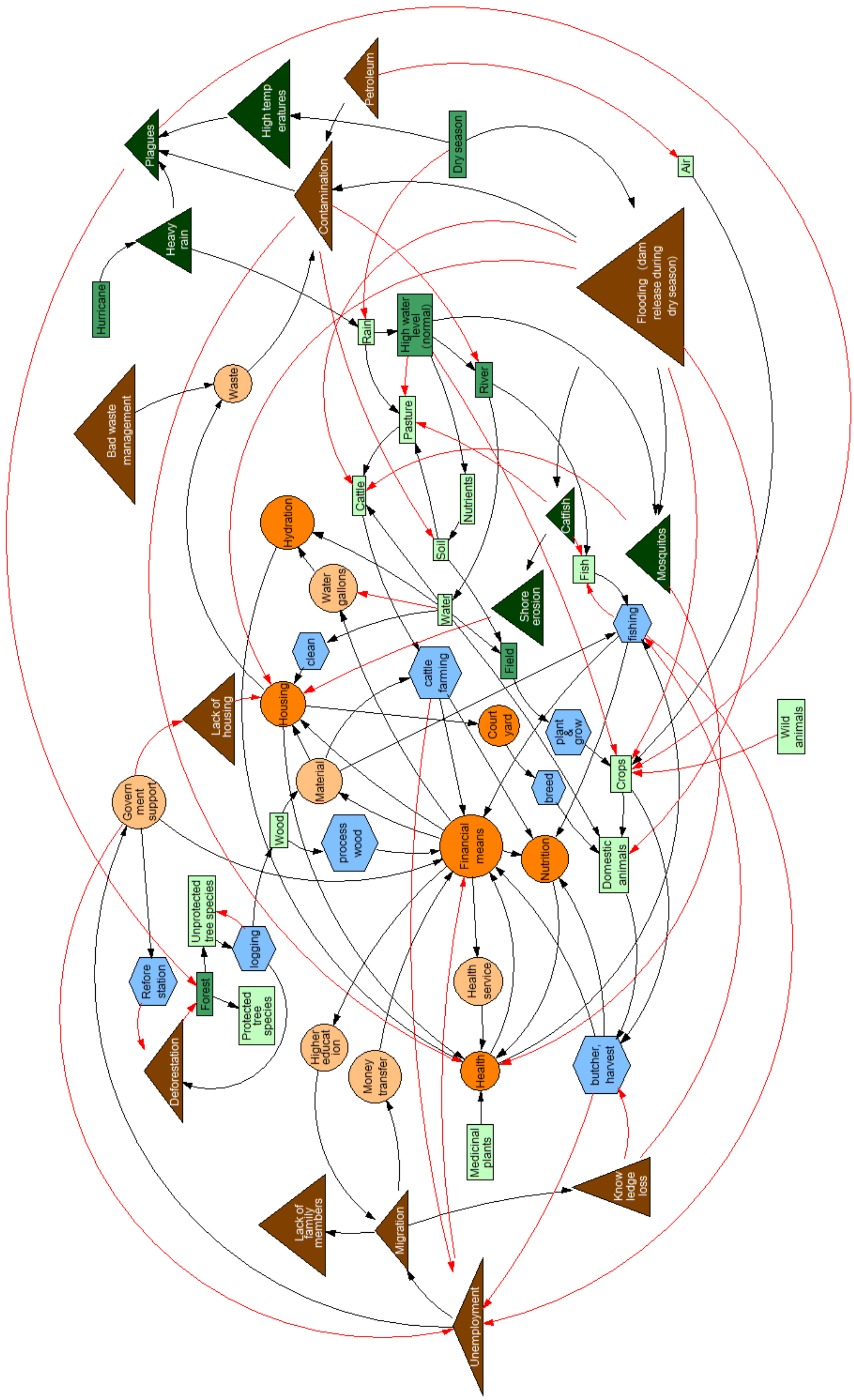
A2.1 Boca Chica (MX)



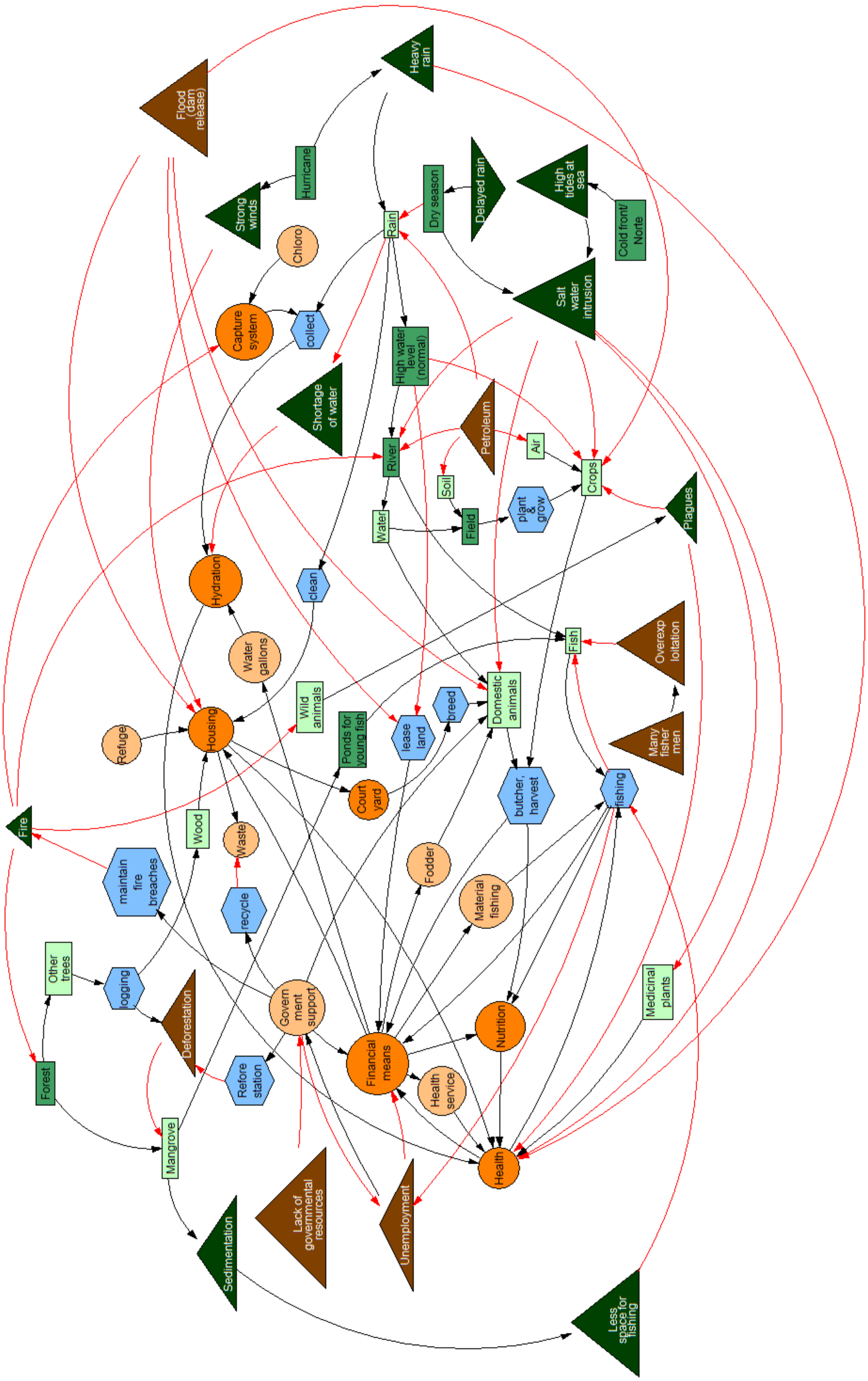
A2.2 Palizada (MX)



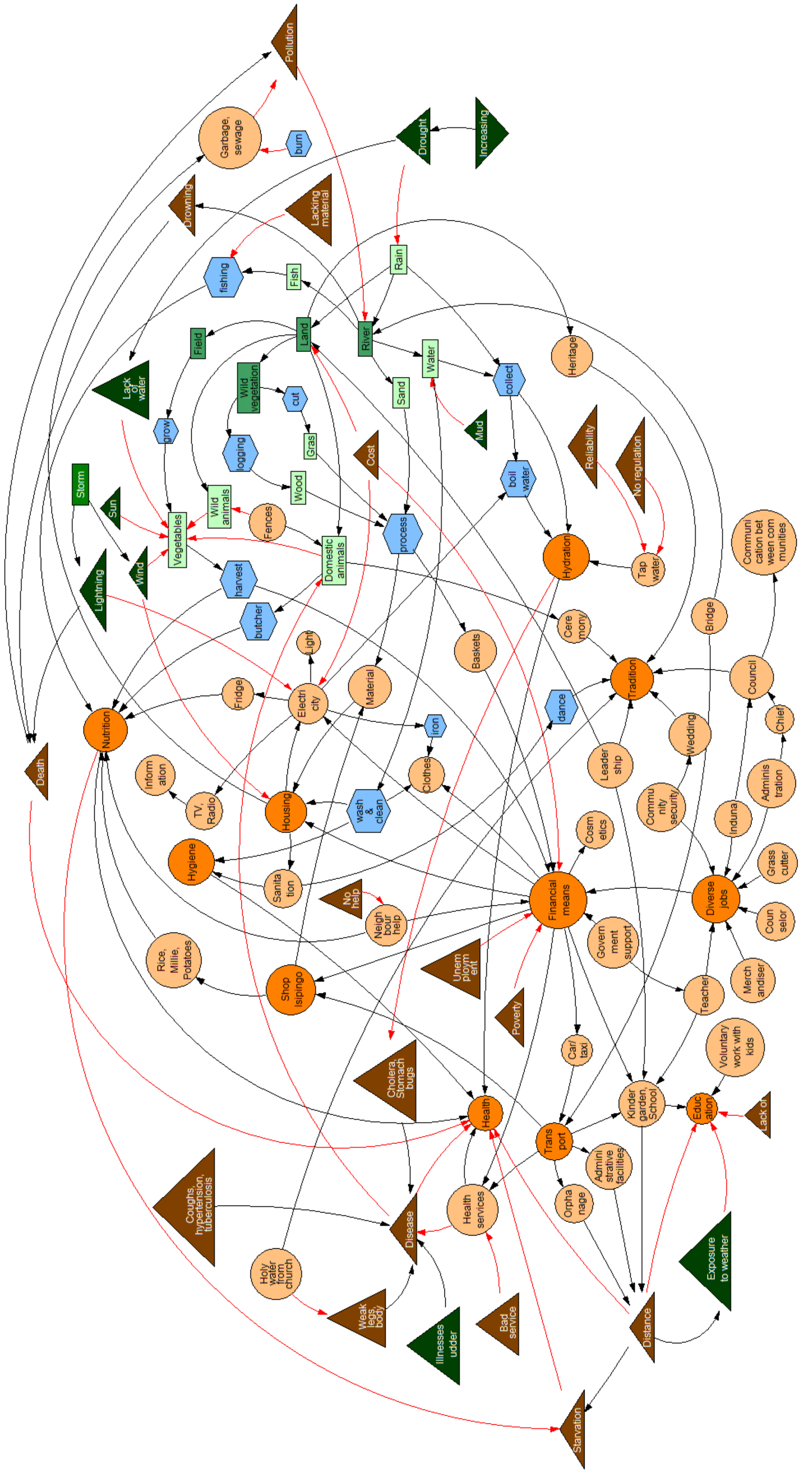
A2.3 Quintín Aráuz (MX)



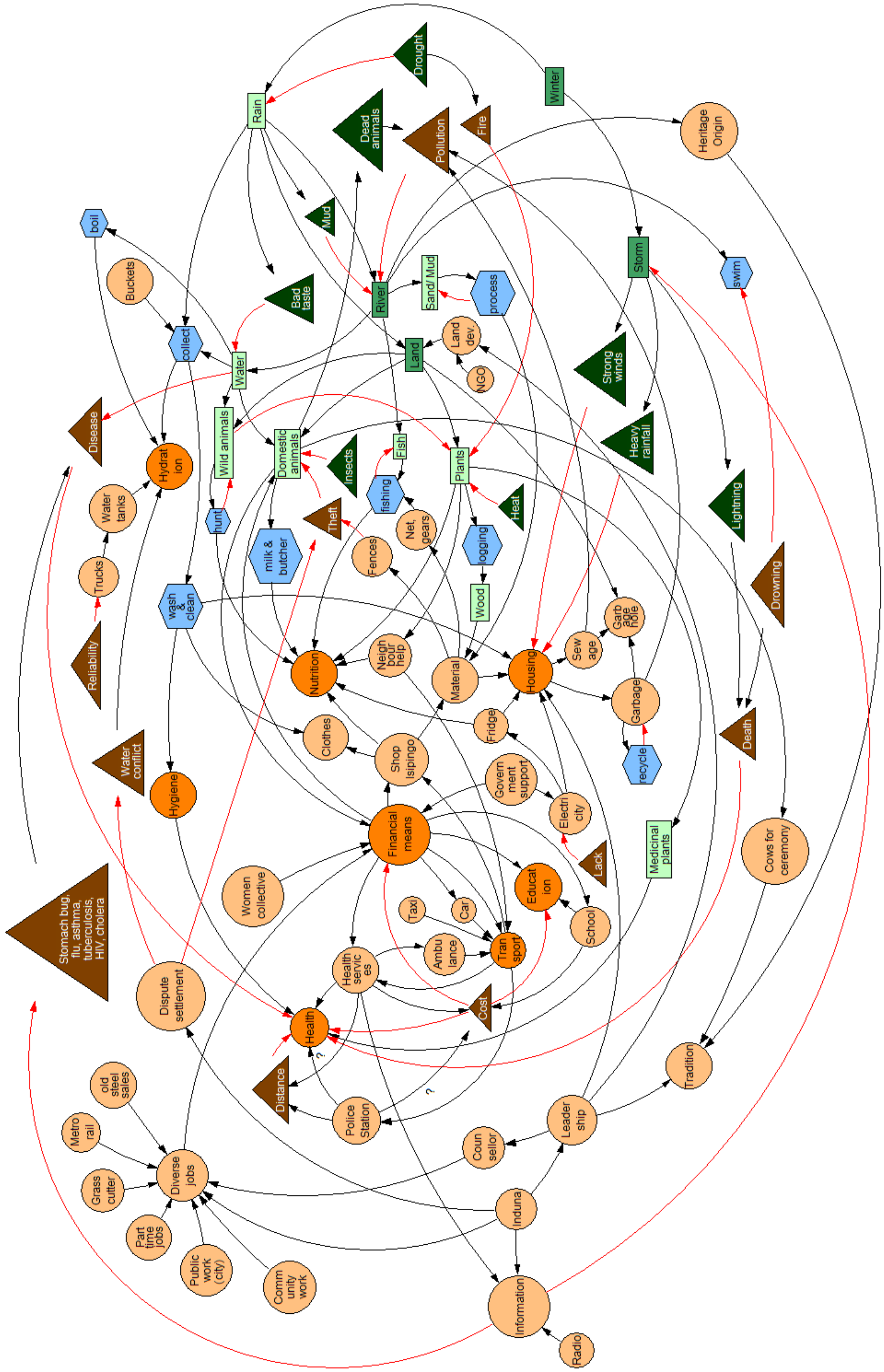
A2.4 Tembladeras (MX)



A2.5 Emgangeni (SA)



A2.6 Ndaya (SA)



Drought
Winter
Rain
Dead animals
Pollution
Fire
Heritage Origin
Mud
Bad taste
River
Sand/ Mud
process
Storm
swim
boil
Buckets
collect
Water
Land
Land dev.
NGO
Strong winds
Disease
Wild animals
Domestic animals
Insects
Fish
Plants
Heavy rainfall
Hydrat ion
Water tanks
hunt
fishing
Heat
Lightning
Theft
Net, gears
Fences
logging
milk & butcher
Trucks
wash & clean
Wood
Drowning
Reliability
Garb age hole
Neigh bour help
Sew age
Nutrition
Material
Housing
Garbage
Fridge
Death
Water conflict
Clothes
Shop Isipingo
Govern ment support
recycle
Hygiene
Electri city
Financial means
Medicinal plants
Cows for ceremony
Lack
Women collective
Stomach bug, flu, asthma, tuberculosis, HIV, cholera
Taxi
Car
Educat ion
School
Ambu lance
Tran sport
Health servic es
Dispute settlement
Cost
Health
Tradition
Distance
Police Station
old steel sales
Metro rail
Leader ship
Coun sellor
Grass cutter
Diverse jobs
Induna
Part time jobs
Public work (city)
Comm unity work
Information
Radio
?
?

A3 Complete tables summarizing components of mental models

Based on the guiding questions described in chapter 4.4.1 the information from the resulting mental models was structured into tables. However, the extent exceeds what is possible to present in a clear overview in the flow text. Therefore here the complete tables on livelihood aims (see chapter 4.4.1.2) in A3.1 and threats (see 4.4.1.3) in A3.2 are displayed.

A3.1 Livelihood aims, resources, supporting and threatening influences

Livelihood aims of people of case studies in Mexico, South Africa and both, no information available marked with NK (not known), numbers of columns indicate to which question it refers; table structure developed by the author, information in the table derived from the case study mental models

Livelihood aim	1. provided by	2. supporting	3. threatened by
Hydration	River water	River water quality, rain, water collection (buckets), fuel/energy (boil water)	Pollution, mud, drought (no rain), dry season (less rain), sea water intrusion, bad taste, heat, fire (destroying plants/wood for fuel), costs and lightening affecting electricity
	Rain water	Rain, water collection (buckets), fuel/energy (boil water)	Drought (no rain), dry season (less rain), fire (damaging the capture system)
	Well	Ground water quality, rain, material for water collection	Pollution (dead animals, pesticides, waste), salinity, low ground water level (dry season)
	Water gallons (shop)	Financial means, transport	Unemployment, food prices, lack of a local market, robbery (all decreasing available financial means)
	Water tanks	Water trucks	Irregular delivery
	Tap water	NK	Irregular availability, lacking regulation
Nutrition	Fish	River, water quality, fodder and fishing material (financial means), mangrove forest, aquaculture, government support	Pollution, flood, drought, suspended material, muddy water, dispersed fish, sedimentation, deforestation, salt water intrusion, catfish, overexploitation, bad fishing techniques, lack of local market, unemployment, robbery, food prices , knowledge loss, various costs, poverty, unemployment
	Domestic animals	Land, courtyard, water/rain, fodder/plants, pasture, fences, material for cattle farming, financial means (to buy animals)	Pollution, flood, suspended material, muddy water, dry season, drought, high temperatures, high water level (normal), salt water intrusion, fire, mosquitos and plagues, disease, lack of local market, unemployment, food prices, robbery, knowledge loss, limited governmental resources, various costs
	Plants/ vegetables/ crops	Land, soil, field, rain/water, material for agriculture (financial means)	Pollution, flood, suspended material, wind, sun, drought, dry season, high water level (normal), salt water intrusion, wild animals, domestic animals, plagues, fire, heat, lack of local market, unemployment, robbery, poverty, various costs, food prices, knowledge loss, limited governmental resources
	Fruits	Courtyard, water, material for gardening (financial means)	Pollution, flood, suspended material, robbery, food prices
	Wild animals	NK/ Forest, ecosystem, material for hunting (financial means)	Fire, lack of local market, unemployment, food prices

	Shop	Financial means, transport, neighbour help	Unemployment, poverty, no neighbour help, high costs for various assets, lack of local market, robbery
Financial means	Fish	River, water quality, fodder and fishing material (financial means), mangrove forest, aquaculture, government support	Pollution, flood, drought, suspended material, muddy water, dispersed fish, sedimentation, deforestation, salt water intrusion, catfish, overexploitation, bad fishing techniques, lack of local market, unemployment, robbery, food prices , knowledge loss, various costs, poverty, unemployment
	Domestic animals	Land, courtyard, water/rain, fodder/plants, pasture, fences, material for cattle farming, financial means (to buy animals)	Pollution, flood, suspended material, muddy water, dry season, drought, high temperatures, high water level (normal), salt water intrusion, fire, mosquitos and plagues, disease, lack of local market, unemployment, food prices, robbery, knowledge loss, limited governmental resources, various costs
	Crops/vegetables	Land, soil, field, rain/water, material for agriculture (financial means)	Pollution, flood, suspended material, wind, sun, drought, dry season, high water level (normal), salt water intrusion, wild animals, domestic animals, plagues, fire, heat, lack of local market, unemployment, robbery, poverty, various costs, food prices, knowledge loss, limited governmental resources
	Processed wood	Wood, forest	Deforestation, plagues
	Grass baskets	Land, rain, grass	Drought (no rain)
	Wild animals	NK/ Forest, ecosystem	Fire, lack of local market, unemployment, food prices
	Lease land	Land ownership	Flood (dam), high water level (normal)
	Shop	Financial means, government support	Robbery, food prices (decreasing financial means)
	Tourism	Beauty of nature, wild animals, transport	Lack of good services and transport, flood, fire
	Diverse jobs (external)	Job availability	Unemployment
	Government grants/ support	NK	Limited governmental resources
	Neighbour help	NK	No help
	Family money transfer	Migration, higher education, financial means	NK
	Women collective	NK	NK
Health	Health services	Financial means, transport	Bad health services, poverty, unemployment, high costs for health services, food prices, lack of local market
	Medicinal plants	Land, healthy ecosystem, rain	Drought (no rain), wild animals, fire, heat, salt water intrusion
	Church	NK	NK
	Hygiene	Sanitation, river and rain water	Pollution, mud, drought
	Nutrition	Financial means, fish, domestic animals, wild animals, crops/vegetables, fruits, shop	Pollution, flood, drought, high water level, wind, sun, suspended material, muddy water, dispersed fish, sedimentation, salt water intrusion, catfish, overexploitation, bad fishing techniques, high temperatures, dry season, wild and domestic animals, mosquitos and plagues, fire, unemployment, poverty, knowledge loss, lack of local market, robbery, various costs, food prices, limited

			governmental resources
	Hydration	River water, rain, well, water gallons, water tanks, tap water	Pollution, flood, suspended material, salinity, low ground water level, dry season, drought, fire, lightning, sea water intrusion, muddy water, unemployment, food prices, lack of local market, robbery, various costs, irregular availability, lacking regulation
	Housing	Building material	Unemployment, food prices, lack of a local market, fire, plagues, deforestation
Housing	Building material	Financial means, transport, river, land, rain, plants/forest, sand/ mud, processing material (financial means)	Unemployment, poverty, no neighbour help, food prices, lack of local market, pollution, drought, wild animals, fire, heat, plagues, deforestation
	Energy	Financial means, government support, solar panels	Costs for electricity, lightning, lack of electricity
	Government support	NK	Limited governmental resources
Education	Kindergarten, school	Teacher, government support, traditional leadership, transport, financial means	Long distance, lack of good schools, exposure to weather, poverty, unemployment, high costs for education and health
	Voluntary work with kids	NK	NK
Transport	Ambulance	NK	NK
	Taxi	Financial means	High costs, poverty, unemployment
	Private car	Financial means, neighbour help	High costs, poverty, unemployment

A3.2 Threats, their sources, impacts, additional influences and countermeasures

Threats and their characteristics; including cause(s), affected components, natural (N), semi-natural (N/H), human (H) categorization, additional influence(s) and potential countermeasures in place in Mexico, South Africa and both, no information available marked with NK (not known), numbers of columns indicate to which question it refers; table structure developed by the author, information in the table are mainly derived from the case study mental models with some minor additions from the author

Threat	1. cause/ source	2. impact on	3. N-H Source-Impact	4. additional influence	5. countermeasures
Bad fishing techniques	External fishermen, lack of awareness	Fish	H-N	Lack of vigilance	NK
Bad health services/ insufficient services	NK	Health	H-H	NK	NK
Bad water/ polluted water, bad taste	NK	Domestic animals, crops, land rent, hydration	N-N/H	Rain	NK
Catfish	NK	Fish, shore erosion	N-N	Grijalva upstream, intruding through opened dams	NK
Death	Lightning strike, drowning	Health	N/H-H	Storm	NK
Deforestation	Logging	Protected (e.g. mangrove) and unprotected trees	H-N	Use of wood in housing, cattle farming and processing for increasing value, fire	Reforestation initiative supported by the government
Diarrhoea/ Disease	River water, hydration, pollution	Health, domestic animals	N/H-N/H	NK	NK
Domestic animals	River ecosystem	Vegetables	N/H-N/H	NK	Fences
Dry season/ Drought	NK/ Seasonality	Rain, temperatures, salt water intrusion	N-N	NK	NK
Exposure to weather	NK	Education, health	N-H	Long distance to school	NK
Fire	NK	Forest/Plants, wild animals, river ecosystem, rainwater capture system	N/H-N/H	Drought	Fire breaches, government support for maintenance
Flood (dam release)	Dam release	Cattle, housing, pollution, mosquitos, crops, domestic animals	H-N/H	NK	NK
Flood (seasonal bad)	Hurricane, Norte, sea water intrusion, heavy rain, rain, high water level	River ecosystem, housing, domestic animals, fruit trees, crops, pond/aquaculture, transportation, sediments,	N-N/H	Suspended material, pollution	NK

		mosquitos, dengue, pollution, shore erosion			
Flood (seasonal good)	Rain	Crops, land rent, river ecosystem, mosquitos, nutrients, pasture	N-N/H	NK	NK
Fumigation	NK/ mosquitos	Health, mosquitos, dengue	H-N/H	NK	NK
Heavy rain	Hurricane, storm, seasonality	Rain, white water, health, housing	N-N/H	NK	Shelter against heavy rain
High cost	School fees, health services cost, police station	Electricity, financial means, education	H-H	NK	NK
High fodder prices	NK	Fodder, financial means	H-H	NK	NK
High temperatures/ Heat	dry season, seasonality	Cattle, domestic animals, plants	N-N/H	NK	NK
Knowledge loss	Migration	Agriculture, gardening, fishing, cattle farming	H-H	Unemployment	NK
Lack of education	NK	Education	H-H	NK	NK
Lack of electricity	NK	Electricity, fridge, light etc.	H-H	NK	Government support
Lack of fishing material	NK	Fishing	H-H	NK	NK
Lack of good tourism/ insufficient service services	NK	Tourism	H-H	NK	NK
Lack of housing	NK	Housing	H-H	NK	Government support in building houses
Lack of local market	NK	Fishing, aquaculture, agriculture, gardening, financial means	H-H	NK	NK
Lack of transportation/ insufficient service	NK	Transport, tourism	H-H	Flood	NK
Lack of water treatment/ lack of water treatment	NK	Hydration, water gallons	H-H	NK	NK
Limited governmental resources	NK	Government support, recycling, reforestation, fire breaches, financial means	H-N/H	NK	NK

Long distance	Kindergarten, school, administrative facilities, orphanage, police station and health services at far distance	Starvation, education, health	H-H	NK	NK
Low ground water level	Dry season, little rain	Well	N-N/H	NK/ intensive consumption	NK
Low reliability	Irregular arrival of water trucks, irregular availability of tap water	Hydration	H-H	NK	NK
Migration	Unemployment, higher education	Knowledge loss, money transfer, lack of family members	H-H	NK	NK
Mosquito, fungi, insects	Flood (seasonal, dam)	Health, domestic animals	N/H-N/H	Rain	NK
Mud(dy water)	Hurricane, heavy rain, shore erosion, rain	River (ecosystem/water), flood	N-N	NK	NK
No neighbourly help	NK	Neighbour help, financial means	H-H	NK	NK
No water regulation	NK	Tap water	H-H	NK	NK
Overexploitation	Many & external fishermen	Fish	H-N	Lack of awareness	NK
Plagues	Pollution, heavy rain, high temperatures, wild animals	Domestic animals, crops, trees, health	N/H-N/H	Dry season, hurricane	NK
Pollution/ contamination	Dead animals and humans, fumigation, petroleum, waste (garbage, sewage), pesticides, chemicals, bad waste management	Air, rain, soil, river ecosystem, water, fish, crops, domestic animals, health, plagues, well, diarrhoea	H-N/H	Upstream communities, offshore drilling, flood (dam & seasonal)	Water treatment, recycling initiative supported by the government, burning garbage
Poverty	NK	Financial means	H-H	NK	NK
Robbery/ Theft	NK	Financial means, housing, material, domestic animals	H-N/H	Lack of vigilance	Carer, trader, family, neighbour help, fences, induna settles disputes
Salinity	NK/ intruding salt water, dry season, overconsumption	Well	N-N/H	NK	NK

Salt water intrusion	Hurricane, dry season, Norte, high tides at sea	Fish (+/-), river ecosystem, water, flood, well, domestic animals, crops, medicinal plants, health	N-N/H	NK/ geomorphology of the region (very flat)	NK
Sedimentation	Mangrove forest	Fishing	N-H	NK/ Reforestation	NK
Shore erosion	Catfish	Housing, fields/ crops	N-N/H	NK	NK
Starvation	Lacking nutrition	Health	N/H-H	Long distance to supporting facilities	NK
Storm	Winter season	Wind, rain, lightning, electricity, housing, health	N-N/H	NK	Weather forecast via radio
Strong winds	Hurricane, Norte, storm	Housing	N-H	NK	NK
Sun	NK	Vegetables	N-N/H	NK	NK
Unemployment	NK	Financial means, migration, need for governmental support	H-H	NK	Government support to increase available work, fishing, agriculture, gardening, cattle farming
Water conflict	NK/ not enough water for everyone, selfish use	Hydration	N/H-H	NK	Induna settles dispute
Water shortage/ lack of water	Dry season, little rain, drought	Hydration, vegetables	N-N/H	NK	NK
White water	Hurricane, heavy rain	Fish	N-N	NK	NK
Wild animals	River ecosystem	Crops/ vegetables	N-N/H	NK	Hunting
Wind	NK	Vegetables	N-N/H	NK	NK

A4 Underlying calculations for current vulnerability assessment

The summarized results in chapter 4.4.1.4 are based on several steps of calculation which could only be described theoretically. Here the complete tables are added.

A4.1 Colour and value assignment to number of uses and threats per resource

	Resource-source	**# uses**	**colour based on Median**	**value based on colour**	**# threats**	**colour based on Median**	**value based on colour**
Mexican case study	Crop	2		1	5		2
	Domestic animals	2		1	7		2
	Fish-aquaculture	2		1	1		1
	Fish-river	2		1	8		2
	Fruit	1		0	1		1
	Medicinal plants	1		0	1		1
	Nature	1		0	1		1
	Water-river	3		2	4		2
	Water-rain	1		0	1		1
	Water-well	1		0	4		2
	Wild animals	2		1	1		1
	Wood	4		2	1		1
	Median	***2***			*1*		
South African case study	Crop	2		1	5		2
	Domestic animals	2		1	3		2
	Fish	1		0	0		0
	Gras	1		0	0		0
	Medicinal plants	1		0	2		1
	Sand/mud	1		0	0		0
	Water-river	3		2	3		2
	Water-rain	2		1	1		0
	Wild animals	1		0	0		0
	Wood	3		2	2		1
	Median	*1,5*			*1,5*		
	Median (rounded)	***2***			***2***		

A4.2 Complete resource value and colour assignment

	Resources-source	Sources of threats & countermeasures (SCM)				# threats value	SCM + # threats	# uses value	threats + uses	Overall resource color
		# red	# yellow	# green	average value		average value		average value	
Mexican case study										
Natural/ semi-natural	Crop	4	8	2	1,14	2	1,57	1	1,29	
	Domestic animals	4	10	1	1,20	2	1,60	1	1,30	
	Fish-aquaculture	1	5	0	1,17	1	1,08	1	1,04	
	Fish-river	3	7	1	1,18	2	1,59	1	1,30	
	Fruit	1	5	0	1,17	1	1,08	0	0,54	
	Land	0	2	0	1,00	2	1,50	0	0,75	
	Medicinal plants	1	1	0	1,50	1	1,25	0	0,63	
	Nature	0	1	0	1,00	1	1,00	0	0,50	
	Water-river	2	3	1	1,17	2	1,58	2	1,79	
	Water- rain	0	1	0	1,00	1	1,00	1	1,00	
	Water-well	2	3	1	1,17	2	1,58	1	1,29	
	Wild animals	0	1	0	1,00	1	1,00	1	1,00	
	Wood	0	1	0	1,00	1	1,00	2	1,50	
Socio-economic	Family money transfer	0	0	1	0,00	0	0,00	1	0,50	
	Government support	0	1	0	1,00	1	1,00	1	1,00	
	Other income	0	0	1	0,00	0	0,00	1	0,50	
	Shop (buy)	0	4	2	0,67	2	1,33	2	1,67	
	Shop (sell)	0	2	1	0,67	2	1,33	1	1,17	
South African case study										
Natural/ semi-natural	Crops (vegetables)	0	5	1	0,83	2	1,42	2	1,71	
	Domestic animals	1	3	1	1,00	2	1,50	2	1,75	
	Fish	0	0	1	0,00	0	0,00	0	0,00	
	Gras	0	0	1	0,00	0	0,00	0	0,00	
	Medicinal plants	0	2	0	1,00	2	1,50	0	0,75	
	Sand/ mud	0	0	1	0,00	0	0,00	0	0,00	
	Water-river	1	2	1	1,00	2	1,50	2	1,75	
	Water-rain	0	1	0	1,00	0	0,50	2	1,25	
	Wild animals	0	0	1	0,00	0	0,00	0	0,00	
	Wood	0	2	0	1,00	2	1,50	2	1,75	
Socio-economic	Water-tanks	1	1	0	1,50	1	1,25	1	1,13	
	Water-tap	1	2	0	1,33	2	1,67	1	1,33	
	Shop (buy)	1	4	0	1,20	2	1,60	1	1,30	
	Neighbour help	0	1	0	1,00	1	1,00	2	1,50	
	Other income	0	1	0	1,00	1	1,00	1	1,00	
	Government support	0	0	1	0,00	0	0,00	1	0,50	
	Women collective	0	0	1	0,00	0	0,00	1	0,50	

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Eidesstattliche Versicherung – Declaration on oath

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertationsschrift selbst verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.

I hereby declare, on oath, to have written this dissertation by my own and have not used no other than the acknowledged resources and aids

08.11.2017, Hamburg,