Aalto University
School of Business

THE SOCIAL-ECOLOGICAL SYSTEM FRAMEWORK IN THE GLOBAL SOUTH

An illustrative case: River basin pollution in Nairobi, Kenya

Master's Thesis
Mona Fritz
Aalto University School of Business
MSc in Creative Sustainability
Spring 2021

Aalto University
School of Business

Aalto University, P.O. BOX 11000, 00076 AALTO
www.aalto.fi

Abstract of master's thesis

Author Mona Fritz

Title of thesis The Social-Ecological System Framework in the Global South - An illustrative case: River basin pollution in Nairobi, Kenya

Degree M.Sc. in Economics and Business Administration

Degree programme Creative Sustainability

Thesis advisor(s) Minna Halme

Year of approval 2021 **Number of pages** 116 **Language** English

Abstract

Since the industrial revolution, humanity's impact on the biosphere – the foundation of our well-being - has increased magnificently. This impact is caused primarily by the Global North and results in numerous social-ecological challenges that are felt around the globe. Countries of the Global South are particularly vulnerable and less prepared to build resilience to these emerging challenges. One such challenge is the pollution of the Nairobi river basin by a broad range of pollutants, including faecal matter, consumer waste, industrial waste, and chemicals. The basin has been polluted for decades and multiple regeneration attempts have failed. The successful regeneration of Kenya's surface waters is key to ensure the availability of safe water in the water-scarce country. To enable an in-depth analysis of social-ecological system challenges such as the pollution of the Nairobi river basin, tools tailored to the context of the Global South are needed. This thesis contributes towards the development of such a tool, based on Elinor Ostrom's Social-Ecological System Framework.

The theoretical part of this thesis is concerned with the following research question: How applicable is the Social-Ecological System Framework to social-ecological phenomena in the Global South? I review Ostrom's framework and the various amendments proposed by different scholars to allow for the application of the framework in the broader area of sustainability, going beyond the original focus on collective action. Furthermore, I argue that the concept of well-being must be integrated in the framework to be applicable to the context of the Global South.

In the second part of the thesis, I illustrate the framework developed in the theoretical section by applying it to the Nairobi river basin pollution. I tend here to my second research question: How can these insights be used to analyse river basin pollution in Nairobi? Due to the ongoing COVID-19 pandemic, I rely predominantly on secondary data complemented by expert interviews.

I conclude that the proposed framework allows for a thorough and systematic analysis of sustainability questions of social-ecological systems. It enables its users to analyse both the processes and dynamics producing an emergent social-ecological system phenomenon, as well as the human and non-human ecological actors that participate in it. Thus, it enables an analysis of reciprocal interactions between the actors and the consideration of micro- and macro-levels. Moreover, the proposed framework is a first step away from the predominant use of language which re-enforces an anthropocentric view on social-ecological systems.

The integration of well-being has proven useful for the illustrative case, allowing for a consideration of the motives and realities of the participating human actors. Based on the application of the proposed frameworks, ten leverage points to regenerate the river basin were identified. They refer to the role of governmental authorities, NGOs, the media, and communities.

Keywords Social-Ecological System Framework; Nairobi; Surface water pollution

Für meine Eltern,

die mir die Welt eröffnet haben.

Table of Contents

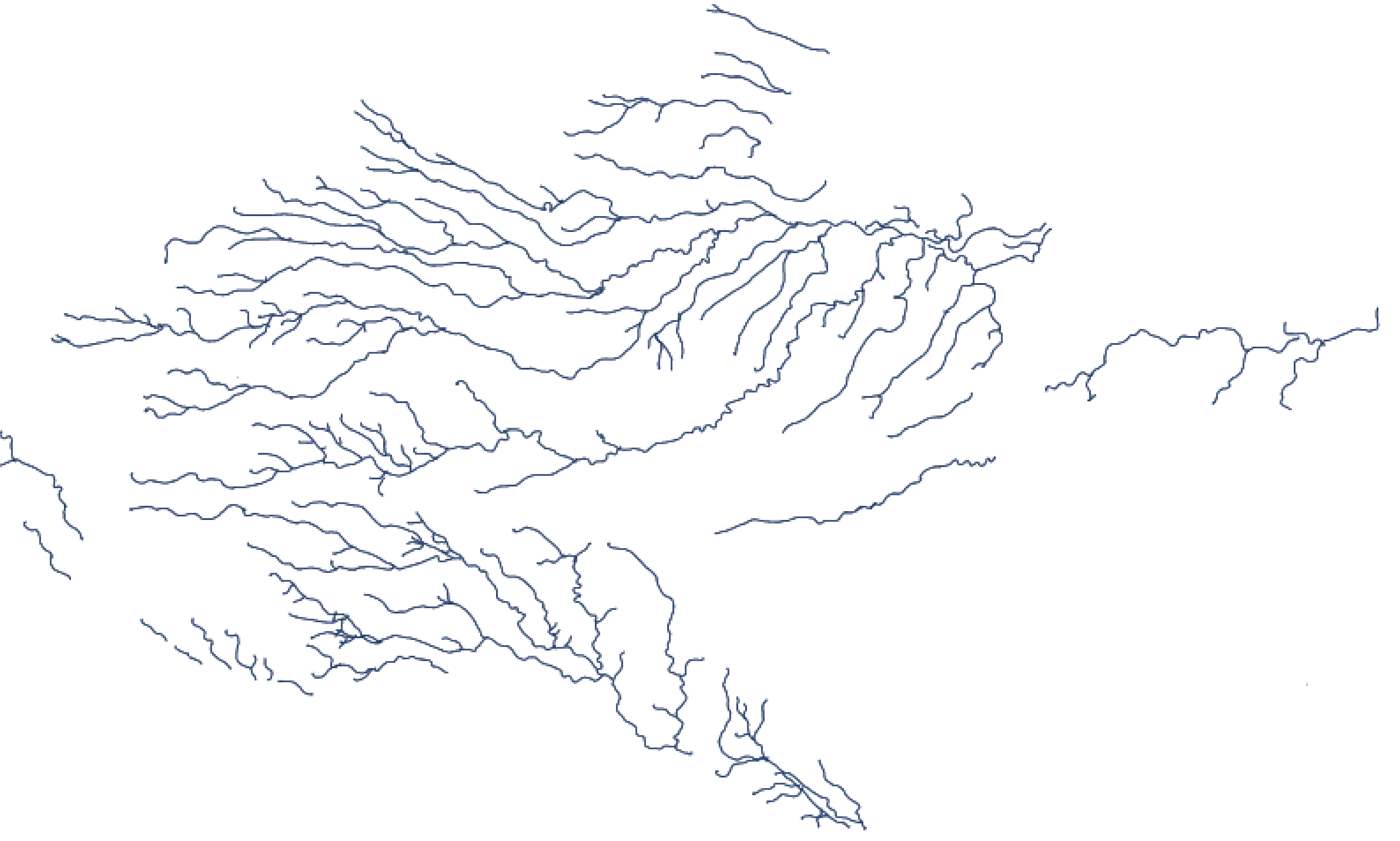
Table of Figures

Table of Tables

1. Introduction

"We may rule the planet in many respects,
but we still remain dependent on it."

- Folke et al. (2016)



1.1. Background

When we think of nature, we might think of our last trip to the forest, vacations at the sea, our garden, pets, or plants. We might look around and recognise the wooden desk we sit at or the air we breathe. We might think of challenges, such as biodiversity loss and climate change, or opportunities such as the profits to be made by extracting natural resources. Nature seems to be overtly present, but also 'domesticated'. It seems increasingly hard to think of 'pure nature'– a place entirely unaffected by human activity.

Humanity affects nature and is affected by nature. Our connections to nature can be conceptualised from various perspectives. We can, for example, think of our material relations with nature, and look at nature as a provider of goods and services (e.g. Fischer and Eastwood, 2016). We can also think of more intangible aspects. Connecting with nature is, for example, found to have positive effects regarding child development and learning (Wells, 2000), physical and mental wellbeing (Keniger *et al.,* 2013), and sustainable behaviour (Geng *et al.,* 2015). We can even think of humanity as a part of nature (e.g. Cooke *et al.,* 2016) (see chapter 3.1 for an overview of human-nature connections).

Since the industrial revolution, particularly our material interactions with nature have intensified and gained scope. Our relationship with nature has taken, what one could describe as, a fateful turn. Humanity has been simplifying and homogenising land- and seascapes (Liu *et al.,* 2007b). We have overfished coastal waters (Jackson *et al.,* 2001), deforested large areas, mobilised immense amounts of nitrogen and phosphorus, and are changing the earth's climate (Stockholm Resilience Centre, n.d.). The enormous force humans are to the Earth has been coined as a new geological epoch: the **Anthropocene**, describing an epoch in which humanity plays a central role in ecology and geology (Crutzen and Stroemer, 2000).

According to Steffen *et al.* (2007), the Anthropocene started between 1800-1850, i.e., during the industrial revolution. The industrial era (1800/50-1945) was characterised by an expansive use of fossil fuels and, particularly in the northern hemisphere, a conversion of forests to agricultural land. The concentration of atmospheric CO_2 rose to a level above "the upper limit of natural variation through the Holocene and thus provide the first indisputable evidence that human activities were affecting the environment at the global scale" [sic.] (Steffen *et al.,* 2007, p. 616).

1.1.1. The Social-Ecological System Framework

Our interactions with nature can be conceptualised as systems, so-called social-ecological systems (SES) (e.g. Fischer *et al.,* 2015; Kramer *et al.,* 2017; Liu *et al.,* 2007a; Liu *et al.,* 2007b). The idea of social-ecological systems is one of human beings and their activities (e.g. economic activities) being embedded in (Folke *et al.,* 2016), dependent on, and shaped by the biosphere which they in turn inhabit, shape, and co-evolve with (Folke *et al.,* 2011).

In light of increasing human impacts on the natural environment (Liu *et al.,* 2007b) as described above, the need to look beyond single disciplines has resulted in the development of frameworks to analyse social-ecological systems (Binder *et al.,* 2013). These include, for example, the Human-Environment Systems Framework (Scholz, 2011) and the Social-Ecological System Framework (SESF) (Ostrom, 2009; 2010). These frameworks are diverse in their views on social-ecological interactions. They consider either the impacts of human actions on the ecological system; the impacts of the ecological system on humans; or reciprocal interactions between human and other ecological components. The levels of interactions considered also differ between frameworks. Some consider just the macro, i.e., societal level; others the impact of the macro on the micro, i.e., individual level; or reciprocal interactions. Furthermore, the frameworks differ regarding their focus on either human or ecological systems, and whether they take an anthropocentric or an ecocentric perspective. Anthropocentric frameworks conceptualise ecological systems regarding their use for humans, while an ecocentric perspective conceptualises ecological systems regardless of their use for humans. Moreover, the frameworks were designed with different purposes in mind, such as either an analysis of social-ecological systems or acting upon them (Binder *et al.,* 2013).

In this thesis, I work with Ostrom's SESF. This framework was chosen because it is the only one of its kind that allows for an analysis of human and natural aspects of social-ecological systems in equal depth. The SESF is an analysis-oriented framework (Binder *et al.,* 2013) that provides variables and links (not causal relationships), that could be relevant for studies concerned with the sustainability of the institutions, via which social-ecological systems are managed (McGinnis and Ostrom, 2014; Partelow, 2018). It can be applied, for example, to the question of why some communities are able to manage their fishing resources sustainably, while others overexploit their fishing resources until a point of extinction. Moreover, it provides a specific language to organise research on social-ecological systems (McGinnis and Ostrom, 2014) and enables researchers to share and cumulate knowledge (Ostrom, 2009).

1.1.2. The Global South

As described above, the term *Anthropocene* is meant to capture the immense impact humanity has on the planet; the environmental effects of a continued strive for *more:* more consumption, more economic growth, more well-being (Coulthard *et al.,* 2011). At least that is the dominant narrative. However, one needs to differentiate who is referred to as *humanity* here. It would be misleading to think about humanity as a homogenous group of people equally contributing to environmental degradation around the globe (Coulthard *et al.,* 2018) and equally profiting from "our resource intensive global development" (Coulthard *et al.,* 2011, p. 453). While some countries have certainly achieved high standards of living via this path, "others struggle to achieve a basic standard of life" (Coulthard *et al.,* 2011, p. 453; United Nations Development Programme, n.d.a).

In 2017, high-income countries had a per capital material footprint of more than 13 times that of low-income countries; and more than five times that of lower middle-income countries. 37 percent of the material consumption of high-income countries was, furthermore, extracted in countries outside their category (United Nations, n.d.). In terms of carbon-dioxide emissions, in 2014, high-income countries emitted 35 times as much as low-income countries (The World Bank Group, n.d.b). Nevertheless, adverse environmental effects, for example due to climate change, will particularly impact low-income populations (Kreijci, 2017; The World Bank Group, 2016). Therefore, countries of the Global South are particularly vulnerable but also less prepared to build resilience to emerging global challenges, such as climate change (University of Notre Dame Global Adaption Initiative, 2018).

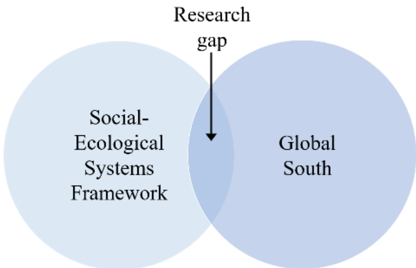
Before we dive deeper into the research gap and its relevance, a clarification of the term *Global South* is required. Three meanings of the term can be identified: (1) Global South refers to countries in Africa, Asia, the Caribbean, Latin America, and Oceania that fall into the low- or middle-income category. The term can be understood as a successor of terms such as *developing*, *third world,* or *periphery*. However, for the majority of scholars, the meaning of Global South goes beyond these predecessors (Clarke, 2018). It "references an entire history of colonialism, neo-imperialism, and differential economic and social change through which large inequalities in living standards, life expectancy, and access to resources are maintained" (Dados and Connell, 2012, p. 13); (2) Global South refers to "spaces and peoples negatively impacted by globalisation", including those located in wealthy countries, acknowledging that “there are Souths in the geographic North and Norths in the geographic South” (Mahler, 2018, p. 32); (3) Global South is a term used to “identify the social agency of dominated groups“ (Clarke, 2018).

In this thesis, the use of the term Global South is closest to the meaning described under (1). However, I concentrate on one specific characteristic which countries of the Global South share, and that requires specific attention in the context of this thesis: low levels of well-being of those countries’ populations.

1.2. Research gap, scope, and relevance of the topic

The previously described Social-Ecological System Framework has been further developed by various scholars (e.g. Epstein *et al.,* 2013; Hinkel *et al.,* 2015; McGinnis and Ostrom, 2014; Schlüter *et al.,* 2019; Vogt *et al.,* 2015). These developments have allowed for an application of the SESF outside its original context of collective action theory, to broader questions of the sustainability of social-ecological systems. However, it has not been specified whether and how the framework could be amended to be applicable to SES in the Global South (Figure 1). In this thesis, I respond to this **research gap** by drawing on the literature of well-being in the Global South conservation context. I present arguments for integrating the concept of well-being in the SESF and propose how this might be done. Therefore, I amend the original SESF and illustrate its application on the case of river basin pollution in Nairobi, Kenya.

Figure 1 Research gap



The river basin of Nairobi has been polluted for decades by multiple origins, such as industrial, urban, and agricultural pollution (Mbui *et al.,* 2016). The rivers contain, for example, faecal matter, consumer waste, industrial waste, medical waste, chemicals, metal parts, and even bodies (Toxic flow, 2019). Multiple initiatives have been undertaken to regenerate Nairobi’s rivers, but so far success has failed to appear (Leapfrog Projects, 2020). The regeneration of surface waters in an already water-scarce country, such as Kenya, is key to ensure the availability of safe water, especially for the low-income population which might lack alternative access to water (Kreijci, 2017).

This thesis is conducted in partnership with Leapfrog Projects, who provide the case of a SES-challenge for the thesis. The illustrative case is primarily based on sources from Leapfrog Projects and materials acquired via desk research. The secondary data acquired was complemented by two expert interviews to close data gaps. Due to the Covid-19 pandemic, the collection of primary data on-site was not possible.

Beside the **relevance** of the illustrative case itself, the outlined concept of the *Anthropocene* and our dependence on the biosphere and its capacity to sustain us (Folke *et al.,* 2016), make clear: we need tools to deal with the challenges of SES. While we have always been dependent on the biosphere, our impact on the earth has increased and the foundation of our well-being has been increasingly degraded (Liu *et al.,* 2007b; Millennium Ecosystem Assessment, 2005). Considering that countries of the Global South are particularly vulnerable and less prepared to build resilience to emerging social-ecological challenges, such as climate change (University of Notre Dame Global Adaption Initiative, 2018), there is an urgent need for tailored frameworks which allow for an analysis of these complex challenges in the Global South. Such frameworks are required to ensure that any proposed solutions to social-ecological challenges are grounded in a systematic and thorough analysis of the focal SES and enable (long-term) success in combating these challenges.

The **scope** of this study is limited in the following regards: (1) I draw on one particular definition of the term *Global South* for this thesis (see previous sub-chapter); (2) While I acknowledge that the *Global South* may be described with various attributes, I focus on one particular characteristic: low levels of well-being; (3) Finally, the study is limited by the context of its case. The case is concerned with one particular resource, i.e., water and located in an urban environment in East Africa. While I suggest in this thesis that the topic of well-being in environmental efforts is key in countries of the Global South in general, one should keep in mind that the Global South is nevertheless a diverse group of countries, and people and the focal study has a focus on rivers in Nairobi.

1.3. Research questions and objectives

Based on the literature gap and the importance of the topic elaborated in the previous chapter, the **academic objective** of this thesis is to determine how applicable the Social-Ecological System Framework is to challenges of social-ecological systems in the Global South, and to propose amendments if necessary. On a more **practical** level, the results of the literature study are illustrated on the empirical case of river basin pollution in Nairobi, Kenya. The objective here is to illustrate the application of the developed, amended SESF, and to gain knowledge usable for the industry partner Leapfrog Projects in working towards the regeneration of the Nairobi river basin.

On a **personal** level, the prevalence of the misconception of the human being as the conqueror of nature and the failure of so-called *developed* countries to embrace sustainability deeply concerns me. With this thesis, I hope to gain a deeper understanding of possibilities to approach social-ecological challenges in the Global South in an ethical manner; contribute towards the development of tools to analyse, and subsequently mitigate these challenges; and overall, prevent countries from following the Global North into unsustainability.

Based on the research gap and the objectives outlined above, I distil the following two research questions:

> **RQ1**: How applicable is the Social-Ecological System Framework to social-ecological phenomena in the Global South?
>
> **RQ2**: How can these insights be used to analyse river basin pollution in Nairobi?

RQ1 contains two elements: Firstly, the applicability of the Social-Ecological System Framework to social ecological phenomena in general, as the original purpose of the framework is more narrowly situated in the field of collective action theory. Hence, I investigate the original SESF and the various revisions which have been proposed. Secondly, the specificity of the Global South, and whether and how the SESF could or should be amended to account for this context. Here, I draw on conservation and well-being literature.

RQ2 is concerned with the investigation of the Nairobi river basin pollution to gain further knowledge on this SES-phenomena, as well as to illustrate the application of the results of the literature review.

With this thesis, I contribute to the literature on the SESF. After more than a decade in which various proposals have been made to amend the SESF, the time seems right for a review. In this thesis, I elaborate and connect the developments and proposals which have been made by various scholars. I explicitly discuss the context of the Global South and bring in literature on conservation and well-being to enhance the fit of the SESF to SES challenges in the

Global South. Moreover, I illustrate the value of the proposed amendments of the framework by applying it to the case of river basin pollution in Nairobi. On a more practical level, I contribute to the analysis of the Nairobi river basin pollution and provide Leapfrog projects with valuable knowledge for the further progress of the regeneration project.

1.4. Structure of the thesis

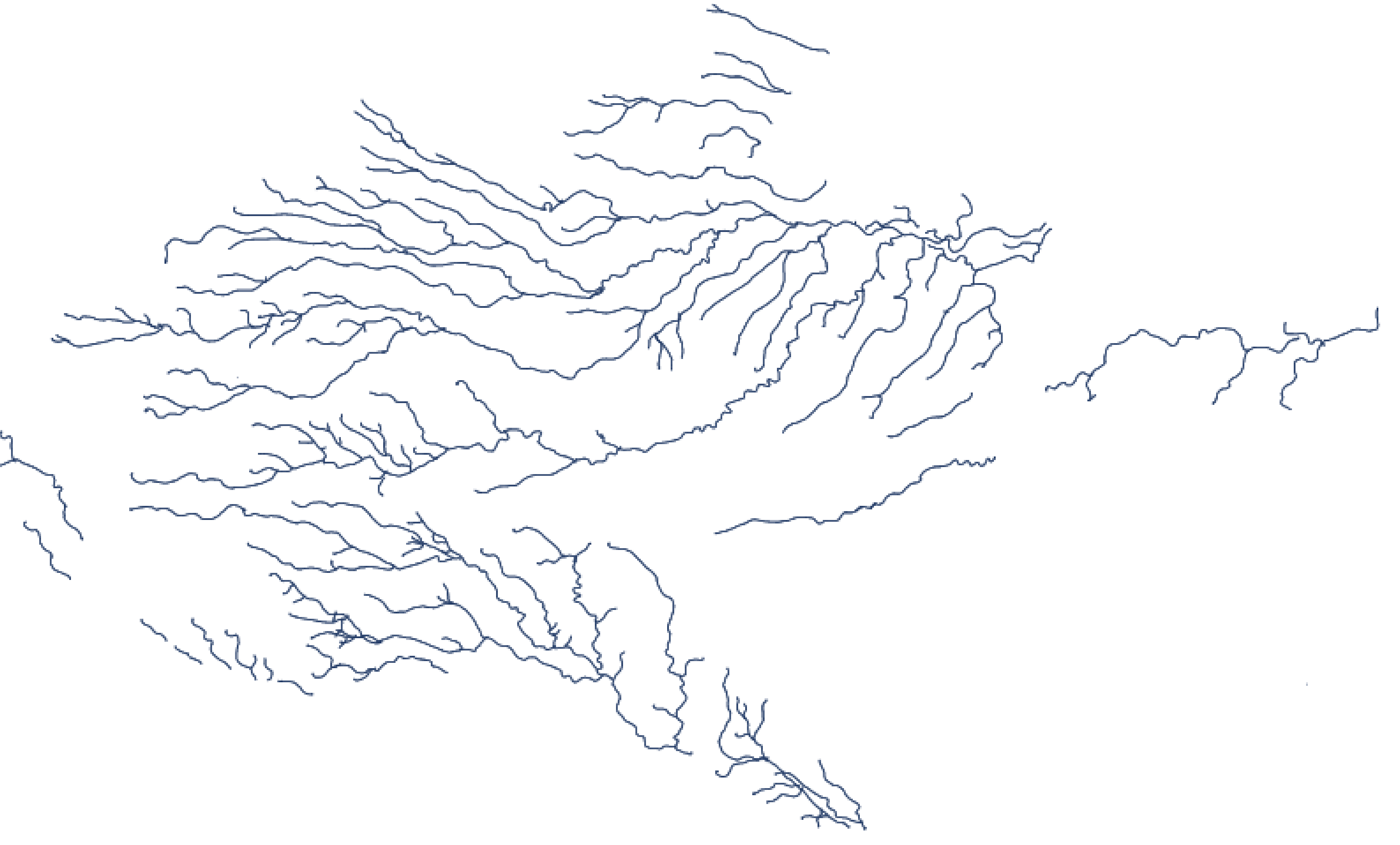
This thesis is structured as presented in Figure 2 and described in the following. Subsequently to this introduction, I outline the methodology applied in this thesis (chapter 1). I start off by describing the qualitative research design of the thesis and the onto-epistemological starting point (chapter 2.1). A description of how data was collected and analysed (chapters 2.3 and 2.4), as well as a discussion of the trustworthiness of the thesis follow (chapter 2.5). In chapter 1, I present an extensive literature review divided into four main topics. To set the scene, I outline diverse views on human-nature connections (chapter 3.1). I introduce social-ecological systems with their main characteristics, such as their relation to space and time, and resilience (chapter 3.2). In chapter 3.3, I elaborate on the Social-Ecological System Framework: its origin and initial form, as well as diverse revisions. Based on the outlined literature, I continue by describing the version of the SESF I use for this thesis (chapter 3.3.5). Finally, I propose and argue for further amendments to make the SESF more applicable to the context of the Global South (chapter 3.4). The literature review is followed by an illustrative case: the Nairobi river basin pollution (chapter 1). In chapter 5, I discuss and conclude the results of this thesis.

Figure 2 Thesis structure

2. Methodology

"As we say, you can only judge a society
by the way it treats its rivers,
and the way it treats its natural resources."

- LE2 (16.04.21)



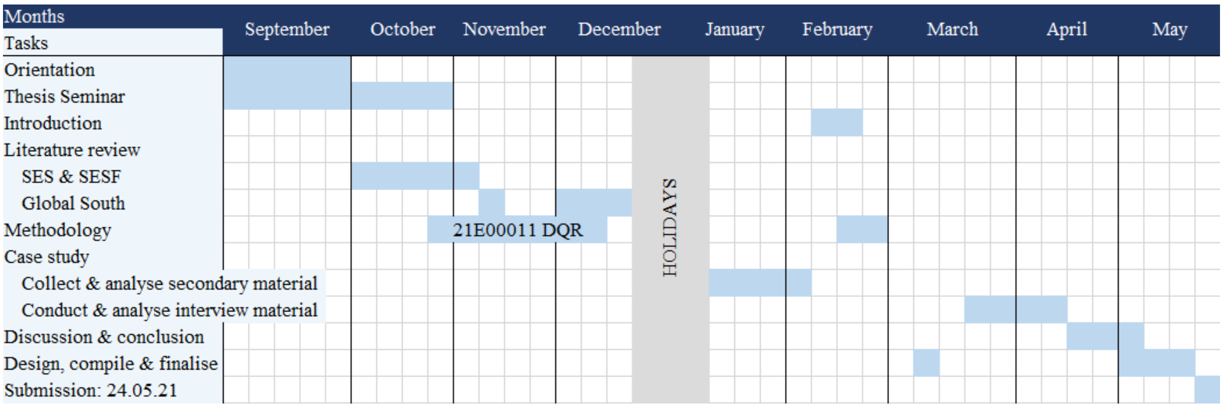
In this chapter, I elaborate the methodology applied in this thesis. I begin with a description of the design and process of the study and my onto-epistemological starting point (chapter 2.1). I continue by introducing the context of the illustrative case studied in this thesis, including the geographical context (chapter 2.2.1), the thematic context (chapter 2.2.2), and a description of the case itself (chapter 2.2.3). Subsequently, I elaborate on the data collection and analysis (chapters 2.3 & 2.4). In the final sub-chapter, I address ethical concerns and the trustworthiness of this thesis (chapter 2.5).

2.1. Study design, process, and onto-epistemological starting point

In this chapter, I introduce the **design** and process of the thesis, as well as my onto-epistemological starting point. Based on the outlined research questions (chapter 1.3), the thesis can be divided into two thematical parts: (1) a literature review; and (2) an illustrative case. The first part is mainly concerned with a review of the SESF, and the various suggestions that have been made for its further development. In addition, I bring in well-being literature that has been drawn on in the context of conservation, arguing that this enhances the applicability of the SESF for the Global South. In the second part, I utilise the version of the SESF that has been developed from the literature review to analyse the Nairobi river basin pollution. Therefore, I generate knowledge relevant to the regeneration of the Nairobi river basin. Finally, I use the river basin pollution as a typical social-ecological phenomenon in the Global South: surface water pollution, to illustrate and further explore the SESF in this context.

The **process** of the thesis started in May 2020, when I contacted Sara Lindeman from Leapfrog Projects to inquire about a possible thesis collaboration. Over the summer, Sara Lindeman, Sara Gottschalk, and myself started discussing which of their projects would best suit my interests. With the beginning of the semester in September, and the Master's Thesis Seminar (26E99905), we then distilled the topic. Throughout October, November, and December of 2020, I conducted a literature review on SES, the SESF, and the role of the well-being literature in environmental projects in the Global South. During roughly the same period, I also conducted a course on qualitative research and started drafting the methodology chapter for this thesis. With the beginning of 2021, I started collecting and analysing secondary material on the river basin pollution in Nairobi. Due to scheduling difficulties, I then wrote the introduction and finalised the methodology chapter in February. Subsequently, I resumed working on the illustrative case by collecting and analysing interview data in March. The thesis was finalised during April and May. An overview of the process is displayed in Figure 3.

Figure 3 Thesis process



To determine the **onto-epistemological starting point** of this thesis, I need to outline the broader field of the topic briefly. The topic is concerned with social-ecological systems and therefore, draws on the field of systems thinking. According to Hammond (2017, p. 12), two ontological questions need to be answered to investigate systems, namely: “What is a system?” and “What is the nature of reality from a systems orientation?” Concerning the first question, systems are processes rather than things, characterized by interactions, relations, and feedbacks. Systems are nested and produce emergent phenomena, i.e. a system is “more than the sum of its parts” and hence, must be considered in its whole (Hammond, 2017, p. 13). Researchers must define system boundaries when they study systems. However, systems are influenced by their environment and clear-cut boundaries do not exist in the real world. Thus, it is important to make explicit how boundaries have been determined for the research (Hammond, 2017). This becomes apparent in the illustrative case used in this thesis. The geographical boundaries of the focal SES are defined as the borders of Nairobi, even though the rivers of the basin originate outside of these borders and continue their journey beyond them.

According to Preiser *et al.* (2018), the nature of systems, particularly that they are not chaotic but complex, is an argument against constructivism. For this thesis, I draw on an objectivist view of **ontology**. Therefore, I acknowledge that the system I observe, the Nairobi river basin, is constructed collaboratively by its human and non-human entities, but exists objectively outside of me as a researcher.

Epistemologically, the systems perspective has further implications. As mentioned already, systems are nested and impacted by their environment (Hammond, 2017). They are adaptive and have a memory (Preiser *et al.,* 2018), and thus knowledge plays an important role (Hammond, 2017). How a system and the observed reality look like depends on how the boundaries of the system are defined, and on the observer's position. This makes it key to clarify the researcher's position regarding the system (Hammond, 2017). Considering geographical and personal variables, I position myself outside of the system I study. Nevertheless, the knowledge produced in this thesis may enter the focal system, and thereby, indirectly connect me to the system. I am also indirectly connected to the system in terms of data collection.

To conclude, I draw on the perspective of **critical realism** in this thesis. I see reality as existing objectively outside of me as a researcher, but the knowledge I produce in this thesis is mediated through my own interpretations of reality (Eriksson and Kovalainen, 2008). Therefore, I acknowledge that I carry "assumptions, biases, and motivations that influence the process of observation" (Hammond, 2017, p. 14) and interpretation. Consequently, it will be of utmost importance to reflect on my own assumptions and beliefs while conducting research on the focal SES.

2.2. Research context

The illustrative case I study in this thesis is provided by Leapfrog Projects. "Leapfrog Projects is a mission-driven enterprise based on research and innovation from Aalto University, New Global". The organisation works challenge-based, focuses on people and communities, and aims at restoring and stabilising ecosystems, as well as mainstreaming sustainable lifestyles (Leapfrog Projects, 2020). In this chapter, I describe the context of the illustrative case and briefly outline the case.

2.2.1. Geographical context: Kenya

The geographical context of the case is Nairobi, the capital of the Sub-Saharan country **Kenya**. Kenya, formally the Republic of Kenya or Jamhuri ya Kenya, is a presidential republic which gained independence from the United Kingdom in 1963. Its current head of state and government is Uhuru Kenyatta, the son of Kenya's first president Jomo Kenyatta. The country is located in East Africa at the Indian Ocean, bordering Somalia, Ethiopia, South Sudan, Uganda, and Tanzania (Central Intelligence Agency, 2021b). With an area of 580,367 km², it is between the size of France (643,801 km²) and Spain (505,370 km²)

(Central Intelligence Agency, 2021a). Kenya has an estimated population of 53,527,936 (July 2020 est.) – slightly more than Spain (50,015,792; July 2020 est.) and almost ten times the population of Finland (5,571,665; July 2020 est.) (Central Intelligence Agency, 2021c). Kenya's population is predominantly young: 38.71 percent of its population is below 15 years old and 59.16 percent is below 25 years old (Central Intelligence Agency, 2021b). According to the Central Intelligence Agency (2021b), reasons for this demographic distribution are "high fertility, early marriage and childbearing, and an unmet need for family planning". Kenya's annual population growth rate has been slightly decreasing over the last decade reaching an all-time low of 2.3 percent in 2019 (World: 1.1 percent; Sub-Saharan Africa (SSA): 2.7 percent) (The World Bank Group, n.d.e). Geographically, Kenya's population is concentrated along Lake Victoria in the West, the capital Nairobi, and the coast of the Indian Ocean in the East. 28 percent of the country's population live in urban areas, of which 4.735 million live in Nairobi and 1.296 million in Mombasa (2020). Kenya's population is ethnically diverse and mainly Christian (85.5 percent; 10.9 percent Muslim; 2019 est.) (Central Intelligence Agency, 2021b).

In the UN Human Development Index, Kenya ranks 147th. Life expectancy is 66.3 years, literacy 11.1 years, and Gross National Income (2011 PPP) is $ 3,052 (United Nations Development Programme, n.d.b). According to the United Nations Development Programme (n.d.b), 38.7 percent of Kenya's population is affected by multi-dimensional poverty. 68 percent of the country's population have access to improved drinking water sources (urban: 89 percent; rural: 60.4 percent), and 51.2 percent have access to improved sanitation facilities (urban: 78.8 percent; rural: 41.2 percent) (Central Intelligence Agency, 2021b). The lack of access to sanitation and safe water highly contributes to disease and mortality (World Resources Institute *et al.,* 2007). Furthermore, an estimate of 4.8 percent of Kenya's adult population, i.e. 1.5 million adults, live with HIV (2019) (Central Intelligence Agency, 2021b).

Pressing environmental challenges that the country faces are water shortage and pollution; floods; "water hyacinth infestation in Lake Victoria; deforestation; soil erosion; desertification; [and] poaching". Another natural hazard beside floods are recurring droughts (Central Intelligence Agency, 2021b).

Economically, Kenya falls into the World Bank category *low middle-income country* (Central Intelligence Agency, 2021b). Annual economic growth has been between 4 and

8 percent over the last decade (5.366 percent in 2019; SSA: 2.287 percent in 2019) (The World Bank Group, n.d.c). Corruption, weak governance, and infrastructure deficits are impediments to the country's economic development. Kenya has been described as the "economic, financial, and transport hub of East Africa", while its backbone remains agriculture, contributing one third of the country's GDP (Central Intelligence Agency, 2021b) (agriculture: 34.51 percent; industry: 16.15 percent; services: 43.22 percent; 2019; (The World Bank Group, n.d.a; n.d.d; n.d.f)). Agricultural production stems to over three quarters "from small-scale, rain-fed farming or livestock production". Another important sector for the country is tourism (Central Intelligence Agency, 2021b). Finally, the informal economy plays an important role in the Kenyan economy. 95 percent of Kenya's enterprises and entrepreneurs, and 80 percent of the country's employed people belong to the informal sector (Financial Sector Deepening Kenya, 2017; Leapfrog Projects, 2020). While the Central Intelligence Agency (2021b) sees Kenya well-placed to continue its trajectory on economic growth, un- and underemployment are estimated at up to 40 percent.

Nairobi

Nairobi, whose name was derived from the Maasai phrase 'Enkare Nyrobi' (cool water) (Encyclopaedia Britannica, n.d.), has its beginnings in the colonial area, when in 1899 the uninhabited swamp was selected as a location for the Uganda Railway (Nairobi City Council, n.d.; Sarkar, 2020). The location was chosen because it linked Mombasa and Kampala; its network of rivers was able to supply water; and the climate was cool enough for British settlers (Nairobi City Council, n.d.). Later, Nairobi became the railway's headquarters and the capital of the British East Africa Protectorate. Kenyans migrated from rural areas to Nairobi, and in 1954, Nairobi gained the status of a city. After Kenya became independent from the UK, Nairobi remained capital, now of the Republic of Kenya (Encyclopaedia Britannica, n.d.). At independence, Nairobi was a city of 267,000 people (Rodriguez-Torres, 2010) – one 18th of today's size of 4.735 million.

Today, most of the city's residents are migrants (Hendriks, 2011), and Nairobi is mainly seen as a place of transition (Béguy *et al.,* 2009). The constant growth of the city's population contributes to a shortage of economic opportunities and services (Hendriks, 2011). Income is distributed unevenly: the highest-earning 10 percent of Nairobi's households earn 42 percent of total income, while the lowest-earning 10 percent earn less than 1 percent of the total income (Society for International Development, 2004). This inequality is also reflected geographically. Informal settlements emerged in Nairobi already in colonial times, when the British wanted to discourage rural Kenyans from moving to the city "by prohibiting the provision of housing and basic services to these migrants" (Nilsson & Nyanchaga, 2008 cited in Winter *et al.,* 2019, p. 3). When the European settlers left Nairobi, the emerging upper and middle classes occupied their settlements, while the poorer population resided in areas with inadequate infrastructure (Sarkar, 2020). Today, Nairobi continues to be characterised by "the social and spatial segregation established during the colonial area", and discrimination between black and white people was succeeded by "differentiation within the black population itself" (Rodriguez-Torres, 2010, p. 121).

The SSA is the world's area with the highest proportion of people living in informal urban settlements (61 percent; 199.5 million in 2012) (United Nations Human Settlements Programme, 2012). In Nairobi, the percentage of people living in informal settlements is estimated between 60 and 70 percent, while 50 years ago, only a third of the city's population lived in informal settlements. In these settlements, housing and access to water and sanitation are inadequate. To give an example: In one of Nairobi's oldest informal settlements, Mathare, five people live on average in a 12 m² dwelling (Kamau and Njiru, 2018). Nearly 5 percent of the households in Mathare do not have access to sanitation facilities, and existing sanitation facilities "were pour flush toilets (72%) connected to a sewer line, septic tank or draining into a river" (Kamau and Njiru, 2018, p. 323). The inhabitants of informal settlements are furthermore severely disadvantaged, for example regarding morbidity, access to health services (Taffa *et al.,* 2005), and mortality (Kyobutungi *et al.,* 2008; Ziraba *et al.,* 2009; Zulu *et al.,* 2011). While Kenya's government neglected its urban areas in its early days (Metcalfe *et al.,* 2011), the needs of urban areas have been recognised in current policy documents such as the Vision 2030 development programme (Beyer *et al.,* 2016).

2.2.2. Thematic context: Climate change and water scarcity

As most countries, Kenya has to take on the challenge of balancing economic growth with social and environmental concerns to build a sustainable future (Leapfrog Projects, 2020). One major challenge of our time is climate change, which will make rainfall more volatile and less predictable; increase the severity of droughts and floods, as well as water scarcities (The World Bank Group, 2016). Kenya is already one of the most water-scarce countries of Africa, and particularly those areas with large populations, such as Nairobi, have drawn on distant water sources for decades due to a shortage of local water resources (World Resources Institute *et al.,* 2007). While the supply of water will become "more erratic and uncertain", demand is expected to rise as a result of population and income growth, and the expansion of cities (The World Bank Group, 2016, p. 6).

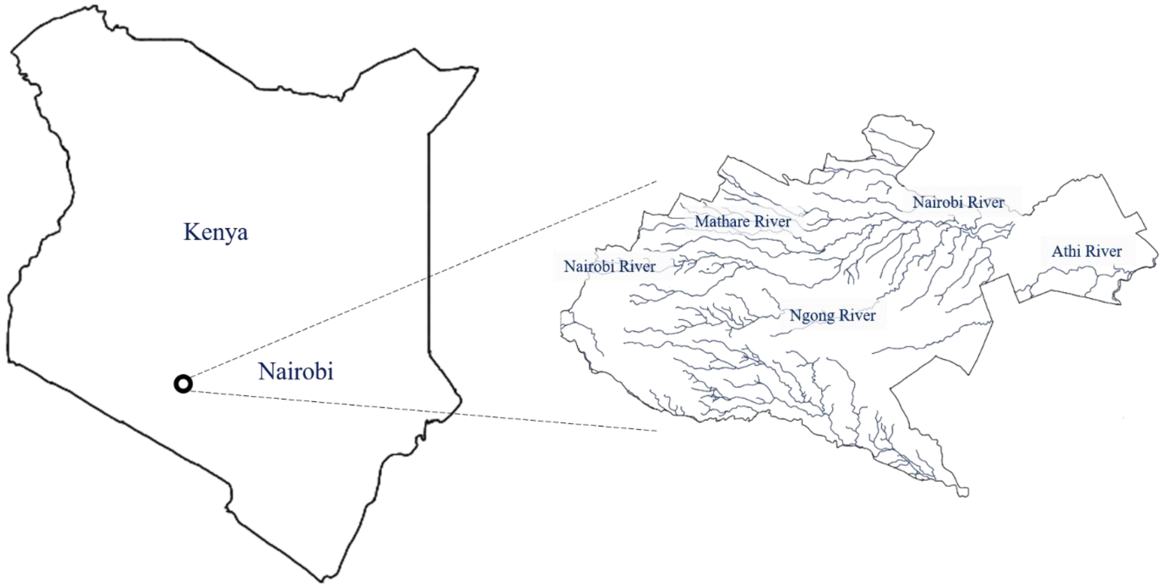
A lack of water would impact Kenya's economy, whose sectors, such as agriculture, energy (hydropower), and tourism, are sensitive to the climate (Leapfrog Projects, 2020; World Resources Institute *et al.,* 2007). According to Swiss Re Management Ltd (2020), Kenya is the country with the greatest GDP dependence on biodiversity and ecosystem services, which will certainly be affected by a change of the country's climate. In addition, scarcity of water means that developments in health, income, properties, and agriculture could not be sustained, further exacerbating an economic downturn. Due to climate change impacts, food prices are expected to increase by 77 percent in the following 60 years in SSA (World: 17 percent). Overall, low-income populations are the most vulnerable to such developments (Kreijci, 2017) and water scarcity could "prevent millions of people worldwide from escaping poverty" (The World Bank Group, 2016, p. 15). Water scarcity further worsens problems related to insufficient access to sanitation and safe drinking water, and thereby especially endangers the health of those at the margins (Kreijci, 2017). Disease and child mortality in Kenya are, for example, mainly caused by exposure to unsafe water (World Resources Institute *et al.,* 2007). The available water sources must therefore be used as efficiently as possible (The World Bank Group, 2016), and pollution must be stopped (Kreijci, 2017). This clearly relates to the illustrative case of this thesis.

2.2.3. Case description

While the focal case: river basin pollution in Nairobi, is analysed in-depth in chapter 1, a brief description is provided here. Leapfrog Projects established together with the Kenya Association of Manufacturers, Inclusive Business Sweden, the Quercus group, and the Confederation of Danish Industry, the Kenya-Nordic Green Hub. The different partners of the platform started to look into different pressing challenges in Kenya, including organic waste, industrial waste, and mobility and traffic. Leapfrog Projects has been concerned with industrial waste and found that industrial wastewater is polluting Nairobi's rivers. Consequently, the people at Leapfrog Projects started thinking about these rivers, realising that they were not only polluted by industrial wastewater, but that the problem was more systemic.

Nairobi does not have a big river like many other large cities, but a net of smaller ones, which are commonly known as the Nairobi river basin (Figure 4). The city's rivers include the Mathare River and Ngong River, which join the Nairobi River in the East. Even further East, the Nairobi River joins the Athi River (Askumo, 2015). The state of these rivers has been deteriorating for decades (Kithiia, 2007; Leapfrog Projects, 2020) due to industrial, urban, and agricultural pollution (Mbui *et al.,* 2016). The pollution of the river basin is complex, involving a large number of diverse stakeholders including the public, the private, the civic, and the informal sector (see Figure 5 for an overview of human stakeholders) (Leapfrog Projects, 2020). Contributing to the pollution of Nairobi's rivers are various informal settlements located along the rivers (Askumo, 2015) and their lack of adequate sanitation facilities and waste collection (Leapfrog Projects, 2020). These informal settlements include the Mathare and Korochogo informal settlements at the Mathare River, Kibera and Mukuru at the Ngong River, and Kiambiu at the Nairobi River (Askumo, 2015).

Figure 4 Map of the Nairobi river basin

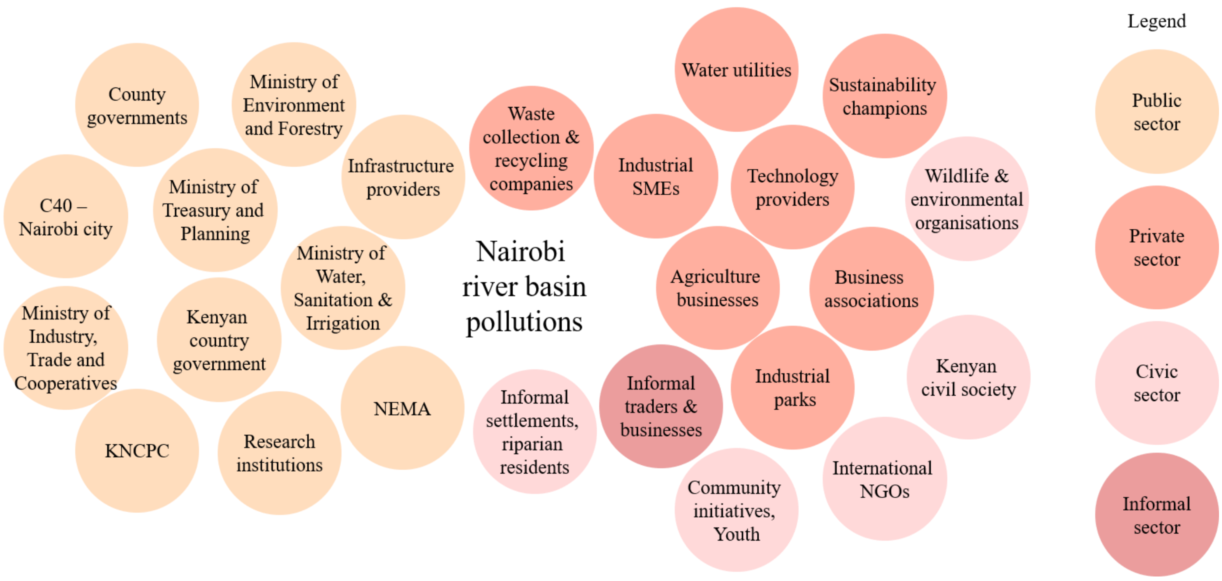


The river basin contamination and deterioration of the respective ecosystems is a node for many of Nairobi's challenges, such as the management of solid waste and industrial wastewater, "sanitation in informal settlements, water supply, equality and corruption" (Leapfrog Projects, 2020). Furthermore, the regeneration of surface waters in an already water-scarce country, such as Kenya, is key to ensure the availability of safe water, especially for the low-income population, which might lack alternative access to water (Kreijci, 2017).

Multiple attempts have been made in re-generating the rivers in the last two decades, but little success has been noticed. Initiatives have come from various actors, including the government, communities, and international NGOs. Unfortunately, the various initiatives have tended to work in silos and fail to effectively communicate. Personal political agendas and corruption complicate the problem. "A deep rooted distrust in authorities, political tensions and a public debate characterized by blaming others is further deepening the sense of hopelessness in solving the urban river challenge" (Leapfrog Projects, 2020).

The pollution of the river basin consists of various parts which are connected and may interact in unpredictable and surprising ways. One could describe the problem as a complex adaptive system (see chapter 3.2). To regenerate the rivers, harmony between the natural and the human components involved must be reached. Leapfrog Projects (2020) suggests that to regenerate Nairobi's rivers, the environment must be understood as "a precondition for human existence, well-being, and prosperity". To be able to regenerate the rivers, a deep understanding of "the behaviour of systems and people, their needs and obstacles to keeping the rivers clean" is needed (Leapfrog Projects, 2020). This is what this thesis contributes towards.

Figure 5 Nairobi river basin pollution - stakeholder map

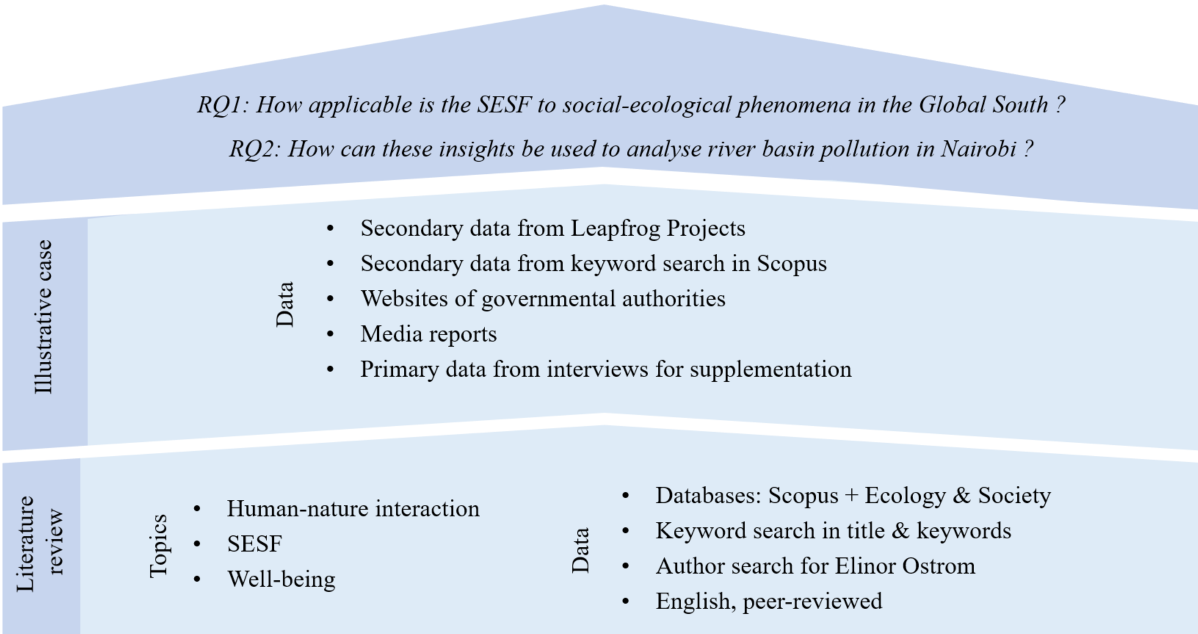


Based on Leapfrog Projects (2020).

2.3. Data collection

The data collection, described in the following, mirrors the structure of the thesis and is displayed in Figure 6. Its first (bottom) part is concerned with **literature research** on human-nature interactions, the Social-Ecological System Framework, and well-being. To collect literature on these topics, the following search strategies were applied. The Journal *Ecology and Society* has been identified as publishing articles particularly relevant for this thesis, and past issues available on their website were screened for relevant articles. The citations of identified key articles were used to determine additional relevant literature. Relevant literature on the SESF was also identified by sifting Elinor Ostrom's publications. To ensure no relevant articles were missed using this method, a search in Scopus was deployed using the following keywords and combinations thereof (in titles and keywords): Human-nature interaction; human-environment interaction; human-nature relationship; human-environment relationship; social-ecological systems; coupled human and nature systems; human-environment systems; social-ecological system framework; well-being; conservation; Global South; and good life. I considered the most cited, English, and peer-reviewed articles of the search results, as well as the newest articles which might be missed by the citation count.

Figure 6 Data collection



In the second part, data on the **illustrative case** was collected. Data in the form of documents (secondary data) was provided by Leapfrog Projects, who have accumulated a large amount of data on the Nairobi river basin pollution. This data was supplemented by a search for documents online. The online search started with a search in Scopus, using the search term *Nairobi AND river AND pollution,* focusing on the most recent publications, and excluding those published before 2010 to ensure relevance. Based on the acquired data, further search terms were applied to dig deeper into specific sub-topics, such as the role of informal settlements, or the industry. Media reports on the state of the rivers and the activities of various authorities in relation to the rivers were collected. To determine the official roles of various governmental authorities regarding the river basin, websites of key governmental authorities were also used.

Due to the COVID-19 pandemic, primary data could not be collected on-site. Consequently, the focus of this thesis was on the compilation and analysis of secondary data (see previous paragraph). In order to close data gaps that were difficult to close with secondary data and to include at least a bit of a local perspective, two expert interviews were conducted. The first data gap was on the ecological processes of the river basin. Given my own background in social sciences, I wanted to validate my research on the ecological processes of the river basin to ensure that all relevant ecological processes and factors important to the pollution and regeneration of the Nairobi basis were adequately captured. The local expert (LE1) consulted for this purpose is a Kenyan environmental scientist. LE1 was suggested as a suitable expert by Prof. Minna Halme and contacted via e-mail. The second data gap was on the role of the government. While I was able to determine responsibilities regarding Nairobi's rivers of various governmental authorities, it was not entirely clear how well these responsibilities were carried out. Moreover, the media has reported on increased governmental activities in the past years, bringing up the question of whether there was a significant shift in the activities of the government. The local expert who supported me in filling this data gap (LE2) is a member of a Kenyan organisation working on environmental conservation. LE2 has been working on regenerating aquatic environments within this organisation for five years. I discovered the organisation online and contacted them via an e-mail address presented on their website.

The interviews were semi-structured, and the questions were developed based on the data gaps that had appeared during the analysis of secondary data and according to the amended SESF (see chapters 3.3.5 & 3.4). To aid myself in conducting the interviews, the developed interview guides (Appendix I) were very detailed and included many sub-questions. The interviewees received simplified versions of these guides beforehand. The interviews were conducted between the 22nd of March and the 16th of April via Zoom and lasted between 45 and 60 minutes. They were recorded and subsequently transcribed. Briefing, de-briefing, and interruptions of the interviews were not transcribed but marked in the transcripts. The sentence form was kept even if syntactical mistakes occurred. Word repetitions were only described when they were used to emphasise something. Comprehension signals of the person not speaking were not transcribed.

2.4. Data analysis

The thesis can be divided into four major parts: (1) A review of SESF literature including the original framework and subsequent developments; (2) The exploration of the fit between the SESF and the Global South, and a subsequent alteration of the framework drawing on well-being literature in the context of conversation; (3) Data collection and analysis of the illustrative case; (4) Discussing and concluding the results based on the outlined research questions. Due to the nature of part one and two (literature review), I elaborate here only the analysis of the data collected on the illustrative case (part three).

The data on the **illustrative case** was analysed using the qualitative data analysis program Atlas.ti. In a first round of coding, data provided by Leapfrog Projects, collected from Scopus, the media, and websites from governmental authorities, was coded based on the altered Social-Ecological System Framework developed during the literature review. I here draw on Schlüter *et al.* (2019)(see Appendix II), who suggest that after the SES-phenomenon to be investigated has been established (here: Nairobi river basin pollution), one should determine the action situations and their outcomes. Therefore, the codes that were used for the first round of coding are the second-tier components of *interactions (I)* and *outcomes (O)* (see page 57; and Appendix III). From the analysis of the coded data, action situations of the Nairobi river basin pollution were established. These action situations where then used in a second round of coding (see Appendix III). In this second round, I focused on the factors that might drive the individual human and non-human ecological actors in the different action situations. I then analysed the codes using the amended SESF developed during the literature review. Finally, the material was also coded and analysed for external factors, i.e., the second-tier components of *Social, Economic, and Political Settings* and *Related Ecosystems* (see page 57; and Appendix III). The transcripts of the interviews were coded based on the data gaps that arose from the analysis of the secondary data, and thus the questions posed to the interviewees. Consequently, codes mostly resembled the second-tier components of the amended SESF. To showcase an example regarding the ecological processes of the river basins, codes included RS5- Productivity of the system; RS10 – Ecosystem history; RU4 – Economic value; ECO1 – Climate patters; and ECO3 – Flows into and out of focal SES. For the second interview, the codes used included GS4 – Regime type; GS6 – Rules in use; A6 – Norms; A7 – Knowledge of SES/mental models; and S2 – Demographic trends.

2.5. Trustworthiness of the thesis

In this section, I firstly elaborate on how I intend to ensure the **quality** of the focal study, and secondly on ethical concerns. As outlined, one major part of this study is concerned with a literature review. I intend to provide an unbiased view of the literature, reflect upon the literature and present relevant limitations. Nevertheless, any reader shall be aware that I am not free of assumptions, biases, and influences, such as my own background and experiences.

To ensure the quality of the illustrative case, I draw in parts from case study literature. I see recommendations to ensure the quality of case studies applicable regarding data collection. Eriksson and Kovalainen (2008) point out that a high-quality case study comes to an end when all, or at least sufficient relevant supporting and contradicting evidence, has been gathered and analysed, rather than due to limitations in time or money. While I do attempt to gather as much evidence as possible, this study is limited in time. Data collection is also restricted by geographical distance and the COVID-19 pandemic not allowing for on-site ethnography. Furthermore, I want to point out that what is *relevant* evidence is a matter of judgement and, therefore, carries the danger of biases. One technique to ensure that all the relevant evidence is collected, is the use of various perspectives (Eriksson and Kovalainen, 2008). This ties back to the nature of systems and the need to use multiple perspectives to study them. Supporting and critical evidence is both presented to allow the reader to evaluate the quality of the study, and the analysis and interpretations presented. Finally, I attempt to present the illustrative case clearly and “in an engaging manner” (Eriksson and Kovalainen, 2008, p. 113).

According to Lincoln and Guba (1985), four criteria can be used to ensure the trustworthiness of qualitative research: credibility, dependability, transferability, and confirmability. To ensure credibility, I use a triangulation of data (Lincoln and Guba, 1985) to include multiple perspectives and sources, such as reports and articles (secondary data) substituted by few interviews (primary data). However, it must be noted that the triangulation of data, as mentioned before, is somehow limited due to a lack of access to most of the stakeholders, caused by the pandemic and the subsequent focus on secondary sources. Secondly, the criteria of dependability replaces the classical criteria of reliability (Lincoln and Guba, 1985). I use dependability instead of reliability because the latter one pertains to the ability to carry out the same study again arriving at the same results (Eriksson and Kovalainen, 2008; Yin, 2009). While this is possible for the literature review part of the thesis to a certain extent, the illustrative case is concerned with a SES which is under constant change. A researcher using the same procedures as I do at any other point in time is likely to study an alternate state of the Nairobi river basin pollution, and might arrive at different results. Therefore, dependability seems more appropriate. I ensure dependability and credibility, i.e. an unbiased interpretation of the data, by clearly presenting the steps of the research, the data, interpretations, and conclusions openly to allow for those interested in this thesis to draw their own conclusions on its trustworthiness (Lincoln and Guba, 1985). It shall also be pointed out that an analysis using the SESF does not claim to determine causal relationships, but rather is a tool to determine one possible hypothesis to explain an emergent phenomenon (Schlüter *et al.,* 2019). Thus, while attempting to determine a hypothesis that is as close to the reality of the SES at hand as possible, I do not claim that the hypothesis presented is reality. In line with the perspective of critical realism, I acknowledge that the built hypothesis is a version of reality which is mediated through me as a researcher. Finally, to allow for transferability, the context in which the results of this thesis were determined will be presented (Lincoln and Guba, 1985). I follow Lincoln and Guba (1985), who describe the responsibility of the original researcher as allowing those who want to use and transfer the research results to evaluate the transferability to their own research context.

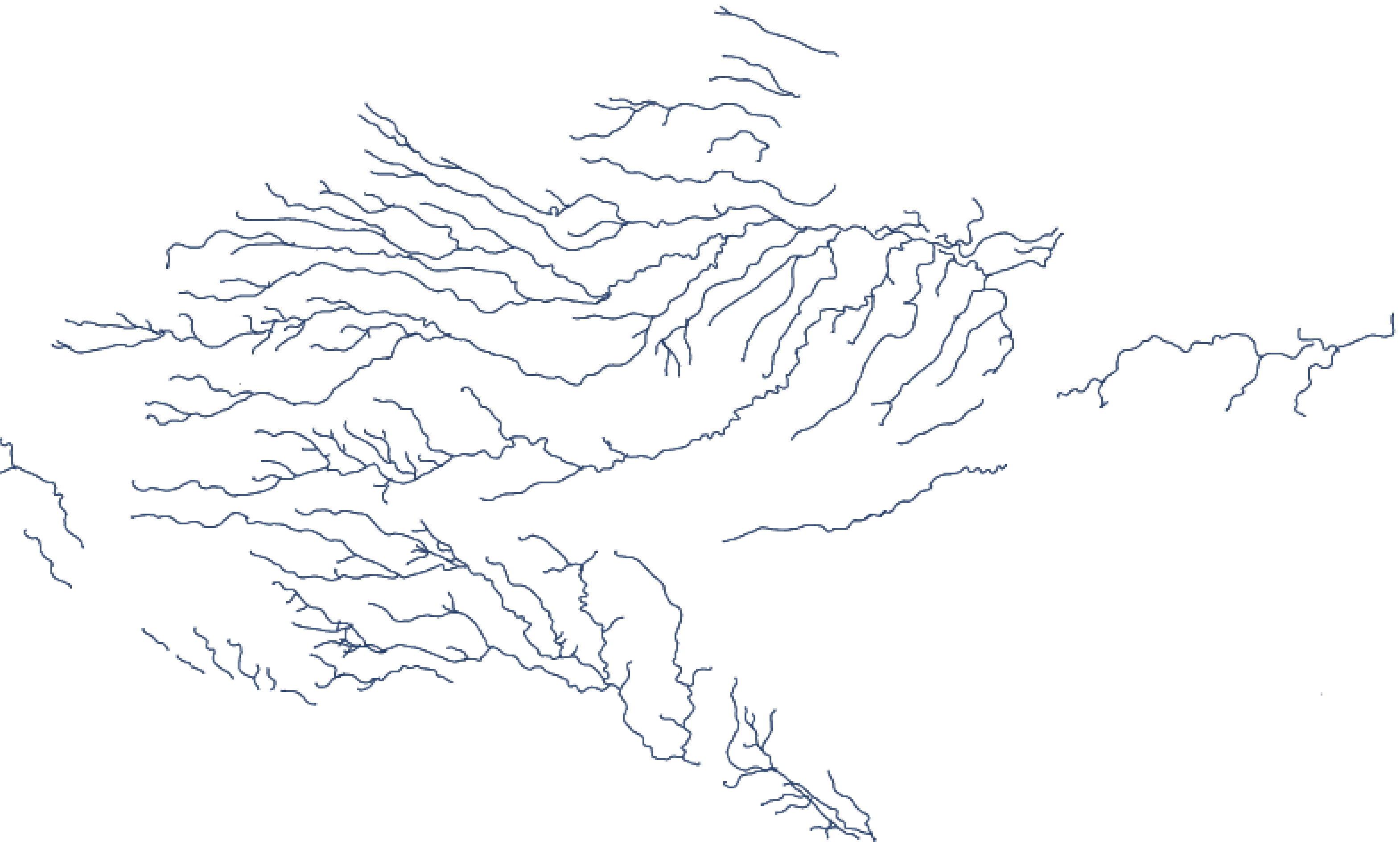
Various **ethical concerns** need to be considered for the focal study. One central topic of qualitative research is the collection of data (Eriksson and Kovalainen, 2008). As a researcher, I am responsible to ensure that the participants of my study, i.e., the interviewees are participating voluntary and that they are aware that they can withdraw from the study at any point (Eriksson and Kovalainen, 2008; European Parliament and Council of the European Union, 2018, Art. 7). Furthermore, I need to adequately inform the research participants about the purpose of the study and its basic procedures, my role as a student at Aalto University as well as the affiliation with Leapfrog Projects. As a researcher, I have a responsibility towards the participants of the study also in terms of data protection (Eriksson and Kovalainen, 2008). The rights of the participants in terms of personal data are guided by the General Data Protection Regulation. In order to comply with the principle of data minimisation (GDPR Art 5 (1)(c)) (European Parliament and Council of the European Union, 2018), any data collected via interviews is presented and stored pseudonymised to ensure that the interviewees cannot be identified. Personal data such as interview recordings are stored only on the Aalto network drive in Otaniemi, Finland, and will be deleted after the conclusion of this thesis.

Moreover, it is my responsibility to protect the study participants (human and non-human) from any direct or indirect harm caused by the study (Eriksson and Kovalainen, 2008; Hammond, 2017). Considering the possible impacts of the study is particularly important for research on SES (Hammond, 2017). However, this is also a complicated issue because SES are complex. I carry this research out with the intention to cause no harm to any of the human- or non-human entities that are part of the Nairobi river basin system. I try to ensure this by explicitly considering the complex adaptive nature of SES; by considering possible implications of my research and its outputs; and by emphasising that the outputs of this research are hypothesis rather than objective truths. According to Hammond (2017), it is key to outline the purpose of the research (as done above) and to consider in whose interests the research is conducted. This research aims primarily at the interests of the inhabitants of the Nairobi river basin, particularly those of informal settlements, the river ecosystem, but also Leapfrog Projects and the broader research community.

3. Literature Review

"Nature is inside us
as much as we are inside nature."

- Folke et al. (2016)



3.1. Humans and nature

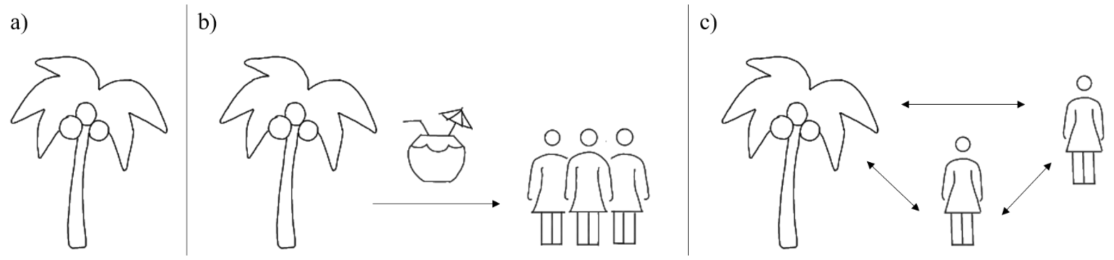
In this chapter, I introduce different conceptualisations of valuing nature (chapter 3.1.1); different types of connections between humans and nature, and the concept of *reconnection with nature* (chapter 3.1.2). Finally, the perspective taken in this thesis regarding human-nature connections is outlined (chapter 3.1.3).

3.1.1. Intrinsic, instrumental, and relational values

The discussion of how to look at nature has been primarily formed around intrinsic versus instrumental (Chan *et al.,* 2016). An intrinsic valuation of nature acknowledges nature as having a value by itself, outside any human activity or existence (Diaz *et al.,* 2014) (see Figure 7a). In contrast, an instrumental perspective attaches value to nature by humans deriving value from it (Diaz *et al.,* 2014), for example a tree is valuable because humans consume its fruit (see Figure 7b). A widely used concept focusing on the instrumental value is that of Ecosystem Services (ES), defined as any function or product beneficial to humans or societal welfare (Millennium Ecosystem Assessment, 2005).

Chan *et al.* (2016) suggest moving beyond the binary of intrinsic versus instrumental values, towards including relational values, because people consider more than intrinsic and instrumental values in decision-making (see Figure 7c). People also derive value from their relationships and consider how appropriate their choices are regarding these relationships. One example of value that is not captured by the intrinsic-instrumental binary, is that of a sacred tree whose value arises from the relationship people have with it. Relational values can be found in diverse well-being approaches, for example Ubuntu and Buen Vivir (Chan *et al.,* 2016). We may also connect relational values to kincentric ecology. Kincentric ecology is an indigenous understanding of ecology, where human and non-human entities belong to one ecological family, sharing the same origins. “It is an awareness that life in any environment is viable only when humans view the life surrounding them as kin” (Salmón, 2000, p. 1327).

Figure 7 Intrinsic, instrumental, and relational valuation of nature



Acknowledging relational values helps us to overcome the risk of conceptualising nature as something that is replaceable or can be commodified, while still motivating conservation. A relational perspective allows for conservation to be collectively negotiated, and to utilise different types of knowledge for conservation, including local, traditional, and scientific knowledge. Nature's relational values might not only foster stewardship of people's own places, but also of other people's places (Chan *et al.,* 2016).

3.1.2. Connecting with nature

Humans are connected to nature in various ways. Ives *et al.* (2017) classify these connections into five categories: material (e.g., consumption of a fish), experiential (directly interacting with nature, e.g., hiking), cognitive (knowing/being aware of nature, including values and attitudes), emotional (feeling attached or empathetic towards nature), and philosophical (mental model on nature, its significance, and how our interactions with it ought to be). These types of connections differ from each other regarding the level on which they occur (individual vs societal), and range from internal to external connections (Ives *et al.,* 2017). The different types of connections might overlap and influence each other (Ives *et al.,* 2018). For example, direct experience of nature can influence cognitive connections (Collado *et al.,* 2013), and cognitive and emotional connections to nature may result in more direct interaction with it (Lin *et al.,* 2014).

Calls to **reconnect with nature** have emerged and gained volume in light of pressing sustainability challenges (Cooke *et al.,* 2016; Folke *et al.,* 2011; Folke *et al.,* 2016), and the identification of the disconnect between society and nature as fundamental cause (Folke *et al.,* 2011). The term reconnecting to nature has been used for various similar, but not identical concepts (Ives *et al.,* 2018). These concepts refer, for example, to the intrinsic wish (biophilia-hypothesis; Wilson, 1984) or psychological need (Hurly and Walker, 2019) of humans to connect to nature; affective and cognitive connections to nature (connectedness to nature in environmental psychology; Restall and Conrad, 2015); geographical connections (telecoupling; (Liu *et al.,* 2013); and connections between child development and nature (Wells, 2000).

Ives *et al.* (2018) point out the possibility to use human-nature connections to treat environmental and social challenges. They introduce **leverage points** as a tool to reconnect humans with nature. Interventions at the leverage points of complex systems can result in rather small (shallow leverage point) or large (deep leverage point) changes of the system.

Shallow leverage points, such as material and experiential connections, relate to the parameters and feedback loops of the system. An example could be implementing a fishing quota or shortening supply chains. The latter one may even have effects on cognitive connections. Deeper leverage points influence the design or goals of the system. These include emotional and philosophical connections, whereas cognitive connections are positioned in between the two extremes. On a systemic level, reconnecting with nature may therefore require changes, for example, in education and urban planning policies. A sustainable transformation depends on internal rather than external connections between humans and nature, and a concert of interconnected rather than isolated interventions (Ives *et al.,* 2018).

Folke *et al.* (2011) focus on the **cognitive disconnection** from the biosphere, which is framed as the cause of environmental challenges. This disconnect is described as the failure to recognise our dependence on the biosphere. The approach has been criticised for embracing an interactional worldview, in which the human and its environment are independent entities which act upon and react to each other, rather than coevolve (Cooke *et al.,* 2016). Berkes (2003, cited in Cooke *et al.*, 2016) suggest that this division of mind and matter further drives the separation of humans and nature.

‘‘[T]he deepest cause of the present devastation is found in the mode of consciousness that has established a radical discontinuity between the humans and other modes of being and the bestowal of all rights on the humans’’
- Berry, T. cited in Escobar (2015, p. 453)

In response to this critique, Cooke *et al.* (2016) draw on relational values and a dwelling perspective to overcome the disconnect to the biosphere as a merely mental phenomenon. They propose an **embodied human-environment perspective** which positions humans as a tangible part of the biosphere they inhabit and co-produce with many other living beings. This perspective depicts humans as “organisms among organisms” (Adams, 2015, p. 55), which together make up the biosphere. Humans are part of the biosphere not as a result of the human mind, but through “engagement of mind-in-body” (Cooke *et al.,* 2016, p. 833).

Based on an understanding of humans being part of the ecosystems (Enqvist *et al.,* 2018) and through the engagement with our local surrounding (Cooke and Lane, 2015), and partly as a result of being involved and experiencing the lifeworld, the concept of **stewardship** emerges (Cooke *et al.,* 2016). Stewardship refers to managing something one is responsible for in a careful manner (Folke *et al.,* 2016). It is based on the desire to care/look after something resulting, for example, from emotions or values. Stewardship is normative and subjective as it is based on a specific understanding of care, as well as what is desired for the object which is taken care of (West *et al.,* 2018). Ecosystem stewardship is a process of continuous learning about, managing and governing SES among and by people across scales to find pathways that are sustainably based on the biosphere (Folke *et al.,* 2016).

3.1.3. The way forward

In the previous sub-chapters, I have outlined some of the perspectives that can be taken towards human-nature relationships. They differ greatly: on one extreme of the spectrum we have ecosystem services looking at nature as something we extract value from. On the other extreme of the spectrum, the human being is depicted as mentally and physically embedded in nature which s/he co-produces and embodies (Diaz *et al.,* 2014). Value emerges neither only instrumentally, nor only intrinsically, but also from the relations between the human and the non-human natural entities.

Human well-being is dependent on and grounded in the biosphere (Millennium Ecosystem Assessment, 2005), which is in turn impacted by humans (Crutzen and Stroemer, 2000). In this thesis, I take the stand that the humane and the natural are deeply intertwined and shall only be separated for analytical reasons, such as when analysing social-ecological challenges.

Taking our dependence and influence on the biosphere as a starting point, it seems clear that the human and the non-human are deeply intertwined, co-evolving and determining each other over time, space, and scales (Liu *et al.,* 2007a; Liu *et al.,* 2007b). Phenomena produced by such a system produce feedbacks, which typically do not emerge immediately or directly (Levin *et al.,* 2012). We therefore shape the biosphere and the options available to us and future human beings, regardless whether it is directly or indirectly, consciously or unconsciously (Folke *et al.,* 2016). The complex adaptive systems emerging from these interactions are known as social-ecological systems, and are the topic of the following chapter.

3.2. Social-ecological systems

In this chapter, I introduce social-ecological systems and some of their key features: couplings over space and time (chapter 3.2.1) and resilience (chapter 3.2.2). I then lay out what we need to consider based on the complex adaptive nature of SES (chapter 3.2.3).

Various terms are used to conceptualise the relations and interactions between human and non-human entities, including coupled human and natural systems, human-environment systems, and social-ecological systems (Liu *et al.,* 2007a). Twenty years after the field emerged, a clear and broadly accepted definition of social-ecological systems is still missing (Colding and Barthel, 2019). In the following, I describe how I understand the concept and the views I draw on in this thesis.

The terms *coupled human and natural system* and *human-environment systems* refer to the two categories of entities they are made up of: human and non-human natural entities. While this indicates a clear distinction between the *human* and the *natural,* such a distinction is inherently flawed. What we refer to as nature, the biosphere, comprises all living things and their connections and interactions with each other, as well as the "atmosphere, water cycle, biochemical cycles, and the dynamics of the earth system as a whole" (Folke *et al.,* 2016). In fact, the biosphere includes human beings (Folke *et al.,* 2016), resulting in an overlap between the terms 'human' and 'nature'/'environment.' In this thesis, I primarily use the term social-ecological systems to refrain from any implication of a separation of the human and the natural. I do not wish to imply that only the human is social and only the non-human natural world is ecological, but use this term to refer to systems which have social, as well as ecological aspects, both of which can be either human or non-human. The idea of social-ecological systems is one of human beings and their activities (e.g. economic activities) being embedded in (Folke *et al.,* 2016), dependent on, and shaped by the biosphere, which they, in turn inhabit, shape, and co-evolve with (Folke *et al.,* 2011).

"[T]he delineation between social and natural systems is artificial and arbitrary."
- Berkes et al. (1998, p. 4)

In a SES, **interactions** can occur between non-human entities, human entities, or both (Schlüter *et al.,* 2019). Non-human interaction occurs, for example, between a crop and the soil. A farmer harvesting a crop is an interaction between a human and a non-human entity, and the interaction between farmers is purely human. Interactions can be direct or indirect, for example, via the consumption of man-made products. Indirect links may result in the perception of a weaker interdependence with nature than actually given (Liu *et al.,* 2007b). Indirect relations can also describe secondary effects, i.e. what is happening due to the direct result of human intervention (Liu *et al.,* 2007b), such as ecosystem effects due to over-harvesting of a specific species.

Networks of interactions generate patterns (Schlüter *et al.,* 2019) and emergent properties/phenomena, i.e. novel properties which do not belong to one of the analytical subsystems (human-/non-human), and are more than the sum of their parts - they result from the interaction (Liu *et al.,* 2007b). For example, the quality of a habitat is likely to depend on human activities and ecological mechanisms (Liu *et al.,* 2001). SES are shaped by variables emerging on different organisational (Schlüter *et al.,* 2019) and geographical levels, and respond to internal and external changes (Liu *et al.,* 2007a). Interactions within the social-ecological system are adaptive, rarely planned or predictable (Folke *et al.,* 2016). The created patterns and emergent phenomena change the frame in which future interactions happen and feed back to the actors and interactions, which consequently adapt and evolve over time (Schlüter *et al.,* 2019). Feedbacks can increase or decrease the speed of change of interactions and the entities of a system (Liu *et al.,* 2007a). Therefore, the different levels of a SES interact. To explain the outcomes and dynamics of such systems, macro- and micro-levels need to be considered (Schlüter *et al.,* 2019). In addition, causation does not need to be linear, systems can be chaotic and, more than one basin of attraction may exist, and transformation may be irreversible (Folke *et al.,* 2016).

SES can also be described as **complex adaptive systems** (CAS) (Preiser *et al.,* 2018). CAS are characterised by six principles: (1) They are "constituted relationally" (Preiser *et al.,* 2018), i.e. they are characterized by their relations and interactions, rather than their components (Biggs *et al.,* 2010) and are more of a "process than a thing" (Hammond, 2017); (2) They are able to adapt to external context and internal interactions, build a memory and learn (Preiser *et al.,* 2018) ; (3) Their processes are dynamic, allowing for non-linearity and more than one basin of attraction and thresholds, resulting in uncertain and unpredictable behaviours (Gallopin *et al.,* 2001); (4) CAS are "radically open" allowing for interaction with their broader environment (Preiser *et al.,* 2018); (5) In line with this, CAS depend on and are partly a result of their context (Preiser *et al.,* 2018); (6) And finally, "novel qualities emerge through complex causality" (Preiser *et al.,* 2018). This refers to what Schlüter *et al.* (2019) and Liu *et al.* (2007b) describe as emergent phenomena or properties, i.e., a system being more than the sum of its parts.

3.2.1. Space and time

SES are not independent of time and place (Liu *et al.,* 2007a), they are coupled across space and time. On a **geographical** level, local processes are influenced by those on larger, even global scales, while those on the global scales are influenced and partly the result of interactions on lower levels. These regional and global couplings are the result of long-distance human activities and natural processes/phenomena affecting large regions. Particularly developed countries show indirect and long-distance couplings, due to high urbanisation and high amounts of raw materials being imported from developing countries (Liu *et al.,* 2007b).

SES are not only coupled over space but also over **time**. Past interactions of SES cumulate and evolve to legacy effects, impacting present and future conditions (Liu *et al.,* 2007b). Economic development, for example, can infringe ecosystem capacities not only for the present, but also for the future. Another example are land tenure systems which have been introduced centuries ago, but still determine land use, settlement, and various activities of the present (Liu *et al.,* 2007a). The magnitude of legacy effects and their duration varies (Liu *et al.,* 2007b).

Effects of SES might unfold slowly and hidden, occur after long time lags or immediately, making it challenging to uncover and manage them (Liu *et al.,* 2007b). Different effects of a single cause may become apparent at different times (Figure 8, equation (1)); and several causes occurring at different points in time may all result in a single effect (Figure 8;equation (2)). Increased birth rates and electricity prices, for example, both tend to increase fuelwood consumption, but their appearance takes different periods of time (Liu *et al.,* 2007a).

Figure 8 Coupling over time

$$cause_{t_0} \rightarrow effect_{t_x}^{n}\ ; n \geq 1; x \geq 0 \tag{1}$$

$$cause_{t_x}^{m} \rightarrow effect_{t_p}\ ;\ m \geq 1; 0 \leq x \leq p; t_p\ denotes\ the\ time\ at\ which\ the\ effect\ becomes\ present \tag{2}$$

3.2.2. Resilience

SES are vulnerable and resilient. Internal and external changes caused by human or non-human entities on any level can cause harm to the system (Liu *et al.,* 2007b), depending on the system's ability to respond. A system's susceptibility to such harm is called vulnerability (Adger, 2006). This implies that changes do not necessarily cause harm.

General resilience is the capacity of the system to respond to unexpected and novel changes or shocks by adaption or transformation (Folke *et al.,* 2016), while maintaining similar structures and functions (Walker *et al.,* 2004). Adaption refers to the ability of a system to maintain the current pathway/ basin of attraction[1] in the light of change (Folke *et al.,* 2010). Transformation goes beyond adaption. It is described as the ability of a system to respond to changes that make the existing system unaffordable and require reorganisation towards a novel system. Transformation refers to the shift to a new basin of attraction (Walker *et al.,* 2004). General resilience can be distinguished from specific resilience, i.e., the resilience to accomplish a specific goal (Walker *et al.,* 2009), which might even result in decreased general resilience (Carpenter *et al.,* 2015). In this thesis, the term resilience is used to denote general resilience.

Relationships of SES do not need to be linear, and spatial and temporal thresholds are common (Liu *et al.,* 2007a). Thresholds are those points at which a system moves from one state to another (Walker and Meyers, 2004). SES can experience traps, i.e., situations in which feedbacks result in an undesirable state. Common traps are situations where socioeconomic factors, such as economic deprivation, result in the depletion of key resources beyond certain thresholds, driving people deeper into poverty (Eckert *et al.,* 2018). Reversion of such a state may be difficult or impossible (Cinner, 2011).

3.2.3. The way forward

At this point, it has become rather clear that SES are complex – and they do not seem to become less complex. Interactions of SES increasingly occur on a larger scale (e.g. environmental impacts of urbanisation), at a faster pace (e.g. spread of diseases), and more indirect due to urbanisation and long-distance links (Liu *et al.,* 2007b). Understanding SES as CAS supports the position that the human is not a conqueror of nature (Preiser *et al.,* 2018), but embedded in and co-producing the biosphere (Folke *et al.,* 2011; Folke *et al.,* 2016). Human and nature are "inseparable ontological entities" (Preiser *et al.,* 2018). According to Preiser *et al.* (2018), this is the understanding on which any operation in the Anthropocene should be based. It provides "an ethical imperative to create novel forms of collaborative agency and alternative moral constructs" (Preiser *et al.,* 2018).

Several **management implications** follow from the outlined understanding of SES. These include, but are not limited to the following (Preiser *et al.,* 2018): (1) Focusing on emergent phenomena and relations, rather than system components (Capra and Luisi, 2014 cited in

[1] SES move about basins of attraction, i.e., "region[s] in state space in which the system tends to remain.“ (Walker *et al.,* 2004).

Preiser *et al.,* 2018); (2) Considering fuzzy and permeable boundaries, and thus the effects of external variables (Capra and Luisi, 2014 cited in Preiser *et al.,* 2018). This also includes taking the various couplings and interactions over space, time, levels, and between system entities into account (Liu *et al.,* 2007b); (3) Anticipating adaptation and change while (4) keeping in mind uncertainty, unpredictability, and (5) characteristics such as feedback loops, thresholds, non-linearity, and the multiple functions of system components in various contexts (Preiser *et al.,* 2018); (6) In considering any intervention, one needs to keep in mind that SES challenges "cannot be definitively solved" (Preiser *et al.,* 2018), interventions might have disproportionate effects, have unforeseen consequences, and even result in novel challenges (Poli, 2013).

We may draw on the resilience literature to get some more concrete advice. Seven principles have been proposed to build resilience: (1) Diverse and redundant elements need to be maintained; (2) Connectivity, (3) slow variables and feedbacks need to be managed, while (4) complex adaptive systems thinking and (5) learning need to be supported; (6) Participation needs to be broad and (7) governance should be polycentric [2](Folke *et al.,* 2016).

In response to our inability to perfectly foresee and the inherent uncertainty of social-ecological systems, three strategies can be employed to minimise negative consequences of surprises: (1) Use safety margins, for example when determining a fishing quota; (2) Factor in insurance, for example add a buffer zone when determining a natural reserve; and (3) Ensure that mechanisms are adaptive (Liu *et al.,* 2007b). To conclude, social-ecological systems need to be managed with humility and an understanding of the need to continuously learn (Gunderson and Holling, 2001 cited in Liu *et al.,* 2007b).

3.3. The Social-Ecological System Framework

In this thesis, I utilise the Social-Ecological System Framework (SESF) developed by Elinor Ostrom (2007; 2009; 2010). Ostrom's Social-Ecological System Framework was chosen for this thesis for several reasons. Firstly, according to Binder *et al.* (2013), the SESF is the only of its kind that allows for the treatment of human and non-human components in equal depth

---

[2] In short, polycentric governance is "a complex form of governance with multiple centers of semiautonomous decision making. If the decision-making centers take each other into account in competitive and cooperative relationships and have recourse to conflict resolution mechanisms, they may be regarded as a polycentric governance system" (Carlisle and Gruby, 2019, p. 927).

(but see chapter 3.3.3: *Adding ecology*). Secondly, it considers reciprocal interactions between humans and nature. The framework considers macro and micro dimensions, and therefore overcomes a major shortage of many frameworks originating from natural science, which conceptualise systems only on an aggregate level (Binder *et al.,* 2013). It has been widely used; its ability to explain the sustainable management of forests, water, and fishery has been demonstrated (McGinnis and Ostrom, 2014; Ostrom, 2007; Ostrom, 2009); and it has been developed further by various scholars (e.g. Anderies *et al.,* 2004; Hinkel *et al.,* 2015; McGinnis and Ostrom, 2014).

In the following chapter 3.3.1, I describe the origination of the SESF including two concepts it builds on: The *Institutional Analysis and Development (IAD) framework* and *design principles for robustness*. In chapter 3.3.2, I provide a deep dive on the SESF and in chapter 3.3.3, I outline further developments of the framework proposed by different scholars. The Social-Ecological Action Situation (SE-AS) framework is introduced in chapter 3.3.4. In the final sub-chapter 3.3.5, an amended framework based on the outlined revisions is proposed.

3.3.1. Beginnings

The Social-Ecological System Framework was developed by Elinor Ostrom based on extensive collaboration with other scholars (Ostrom, 2007; Ostrom, 2009). It is grounded in numerous case studies (Binder *et al.,* 2013). The framework was developed as a result of three observations: (1) The presence and absence of *tragedies of commons*[3] (Evans, 2004); (2) The lack of knowledge on how to sustain increasingly more complex social-ecological systems, while ecological sciences and social sciences were developing isolated from each other (Ostrom, 2009; Ostrom and Cox, 2010); and (3) The prevalence of narrow models and panaceas, while social-ecological challenges tend to be complex, dynamic and diverse in their causes (Ostrom, 2007; Ostrom, 2009; Ostrom and Cox, 2010).

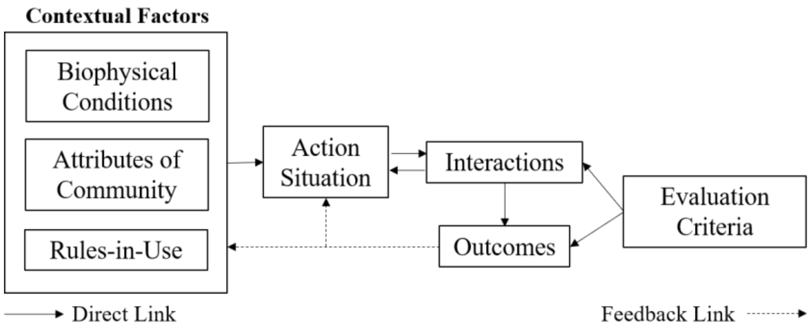
Institutional Analysis and Development framework

A predecessor of the SESF is the Institutional Analysis and Development framework (Figure 9), which was developed to provide the elements relevant for an analysis of “institutional settings including human interactions within markets, private firms, families, community organizations, legislatures, and government agencies“ (Ostrom, 2010, p. 646). At the centre of the IAD framework is the action situation in which people interact, and thereby produce

[3] A tragedy of commons is a situation in which the self-interested behaviour of individuals is contradictory to the benefit of the whole community/society.

outcomes (McGinnis and Ostrom, 2014; Ostrom, 2010). The framework assumes bounded rationality of actors, i.e., the actors chose among available options using information regarding what other actors might choose, and the costs and benefits associated with possible outcomes (McGinnis and Ostrom, 2014). Actors have certain goals, and their interactions are influenced by external factors. The framework provides the highest level of these external factors: biophysical conditions, community attributes, and rules in use. These variables are themselves composed of lower-level variables that might be used in an analysis (Ostrom, 2010).

Figure 9 Institutional Analysis and Development Framework



Based on Ostrom (2010, p. 646).

The essence of the IAD framework is that individuals make decisions influenced by external (contextual) factors (McGinnis and Ostrom, 2014; Ostrom, 2010). These individual decisions result in interactions and outcomes, which the participants of the focal action situation observe and assess. The interactions and outcomes themselves generate feedbacks to the action situation and the external variables (Ostrom, 2010).

Design principles

Ostrom (1990) and Anderies *et al.* (2004) have identified design principles, i.e., principles that characterize common-pool resource institutions that are robust. A system is "robust if it prevents the ecological systems upon which it relies from moving into a new domain of attraction that cannot support a human population, or that will induce a transition that causes long-term human suffering" [4] (Anderies *et al.,* 2004).

[4] Compared to resilience, robustness is a narrower concept which clearly defines system boundaries and deals with defined performance measures. It is closer to what has been described as specific resilience. Robustness is concerned with designing systems that do not fail, while resilience focuses on properties such as self-organisation, learning, adaption and transformation (Anderies *et al.,* 2013).

I now turn to these design principles and how they foster the robustness of SES. Principle 1: Robust systems have boundaries which are clearly defined regarding the resource system and the actors that are allowed to be resource users (Ostrom, 1990). A lack of clear boundaries might reduce the potential for trust among resource users, and between users and public infrastructure providers (Anderies *et al.,* 2004). Principle 2: Robust systems show proportionally equivalent costs to benefits (Ostrom, 1990), and thereby allow for a perception of fairness (Isaac et al., 1991 cited in Anderies *et al.,* 2004). Principle 3: Robust systems have collective-choice arrangements, which allow those to modify operational rules who are affected by them (Ostrom, 1990). Thereby, the ones who possess the most information and the highest stakes have a strong voice. This principle also fosters knowledge, understanding, and legitimacy of the established rules (Anderies *et al.,* 2004). Robust systems have monitoring mechanisms, which are, at least to a certain extent, accountable to the users (Principle 4), graduated sanctions (Principle 5), and mechanisms to resolve conflicts locally and inexpensively (Principle 6) (Ostrom, 1990). Sanctions should be graduate to foster the perception of fairness, and quick and inexpensive conflict resolution ensures that the common understanding of the meaning of rules is not lost in the light of conflicts (Anderies *et al.,* 2004). Design principles 1-3 are the response to challenges, such as deductibility and freeriding, and principles 4-6 transform them into action, monitor and enforce them. Principle 7: Robust systems have users who possess at least minimal rights to organise (Ostrom, 1990). This provides some security against evaders claiming that the system lacks legitimacy (Anderies *et al.,* 2004). Finally, enterprises are nested in large systems in their "[a]ppropriation, provision, monitoring, enforcement, conflict resolution, and governance activities" (Principle 8) (Ostrom, 1990, p. 90). Nesting ensures that challenges arising on different levels are addressed (Anderies *et al.,* 2004).

The design principles have not been spared by criticism. The lack to explicitly consider ecological dynamics has been pointed out (Brown, 2003). They also have been criticised for not including all the factors relevant for sustainability, and indeed the list of principles is not exhaustive (Anderies *et al.,* 2004). Theoretical criticism claims that the principles generalise too much and themselves represent the panacea problem (e.g. Blaikie, 2006). Indeed, Ostrom and Cox (2010) admit that they could be more precise, however, they also point out that they are useful as a diagnostic tool.

The way forward

To conclude this subchapter, I outline some of the most important points to keep in mind for the following chapter. The SESF borrows from the IAD several things: first and foremost, might be the action situation. In addition, bounded rationality, composability, and the idea that external factors determine the action situation re-occur in the SESF. The external factors themselves, the different elements of the robustness concept and the idea of different levels (operation, collective and constitutional) reoccur too, but in different places. As in the IAD, feedback links are an important element of the SESF, and some of the links between the elements of the robustness concept re-occur too. Finally, the design principles can be found in different forms in the SESF as well.

The design principles have been found moderately well supported (Cox et al., 2010 cited in Ostrom and Cox, 2010) and the IAD framework has been useful in areas such as "urban governance, groundwater, irrigation systems, forestry resources, and development policy"(McGinnis and Ostrom, 2014). Nevertheless, a more biophysically sophisticated framework has been demanded (e.g. Berkes *et al.,* 1998). The SESF can be seen as an attempt to follow suit.

3.3.2. Deep dive

After a brief introduction of the origin of the SESF, I elaborate on the SESF itself in more detail. Subsequent to an in-depth explanation of the framework, I elaborate on the topic of collective action, and finally outline the way forward from this chapter.

Originally, the SESF was designed to analyse one specific human-environment situation in which one group of users extracts resource units from a common-pool resource[5] (Hinkel *et al.,* 2015; McGinnis and Ostrom, 2014). Meanwhile, the SESF has also been applied to human-environment systems in which the users obtain more than one good/service from a resource system, and the category of goods the SESF is applicable to has been broadened to collective goods[6] (Hinkel *et al.,* 2015). An application of the framework to social-technical systems has also been proposed. As the IAD, the SESF attempts to be theory neutral. However, as the IAD, it assumes that individuals have a "meaningful degree of agency" and

[5] Common-pool resources are resources for which there is rivalry and a lack of excludability.
[6] Collective goods are those with "nontrivial costs of exclusion, irrespective of institutional arrangements". This excludes only pure public goods, and thus includes congestible public goods (Hinkel *et al.,* 2015).

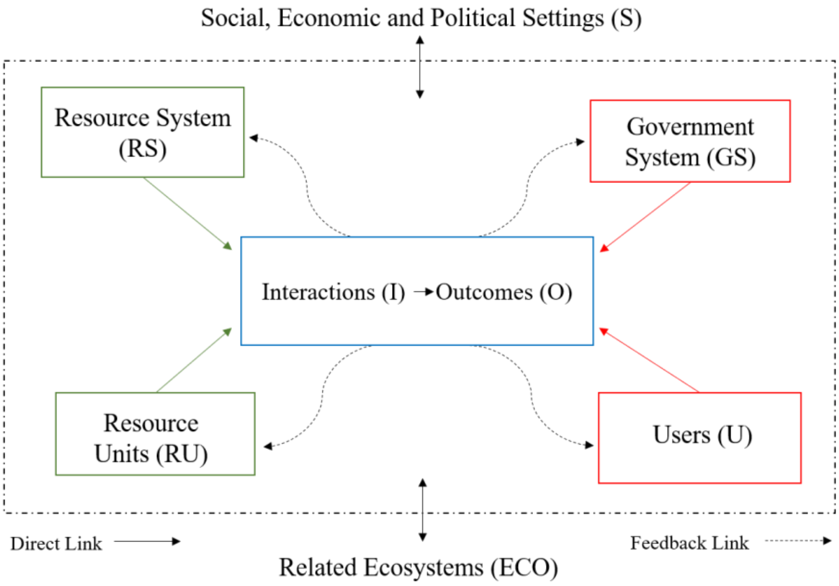
make boundedly rational decisions which have the potential to result in a change of outcomes (McGinnis and Ostrom, 2014).

The SESF understands social-ecological systems as **decomposable** (Ostrom, 2007). A decomposable system is one that comprises several levels, and the subsystems of one level are composed of the elements and sub-systems of the lower level (Simon, 2000). Decomposable systems possess the following three characteristics: (1) Variables can be organised in “classes and subclasses”; (2) The performance of a subsystem is relatively independent in some regards, but also affected by other subsystems; and (3) Synergetic effects exist (Ostrom, 2007).

In accordance with this understanding of SES as decomposable, the SESF (Figure 10) shows the highest level subsystems of a SES: resource system (RS), resource units (RU), governance system (GS), users (U), related ecosystems (ECO), social, economic and political settings (S), interactions (I), and outcomes (O) (Ostrom, 2007; 2009). These subsystems are called *first-level core subsystems*, *highest-tier variables*, or *first-tier variables/ components* (McGinnis and Ostrom, 2014; Ostrom, 2007; Ostrom, 2009). In the following, I will preferably use the terms first-, second-, and third-tier components. The individual tiers are the result of numerous case studies (McGinnis and Ostrom, 2014), which have shown their relevance for collective action and the sustainability of the use of a common-pool resource (Schlüter *et al.,* 2019).

The SESF builds on the concept of the **action situation**, developed in the IAD framework (Ostrom, 2007). Interactions and outcomes at a specific time and place are determined by RS, RU, GS, and U (Ostrom, 2010). The interactions and outcomes feed back to the RS, RU, GS, and U (Ostrom, 2007) (see Figure 10). More precisely, the first-tier components at a point in time (t) determine the interactions and outcomes, and feedback effects may result in altered first-tier components at the next point in time (t+1) (McGinnis and Ostrom, 2014). Later on, direct links between U and GS; and RS and RU have been introduced (see Figure 11) (Ostrom, 2009; 2010). The first-tier components I, O, RS, RU, GS, and U are embedded in S and ECO which they impact and are impacted by (Ostrom, 2010). To understand complex social-ecological systems, the different sub-systems, and horizontal and vertical interactions and effects need to be studied considering spatial and temporal dimensions (Ostrom, 2007; 2009).

Figure 10 The original Social-Ecological System Framework



Based on Ostrom (2007, p. 15182).

The distinction between resource system and the resource units has tended to be rather difficult, and Hinkel *et al.* (2015) attempt to clarify these concepts. The resource system is defined as "biophysical and technological processes that create, maintain and improve stocks of RU". A resource system may thus include more than one kind of resource units. The main difference between the two is that the RU is a stock, for example a stock of fish, and the RS is "a set of processes (or flows) relating the stocks", for example a water body (Hinkel *et al.,* 2015).

As a decomposable system, each tier component is composed of multiple lower-tier components, which themselves are composed of lower-tier components (see Table 1[7]) (Ostrom, 2007; 2009). For example, the first-tier component *resource system* has sub-divisions, such as mobility (RU1) and growth/replacement rate (RU2) (Ostrom, 2007). Ostrom (2007; 2009) does not suggest to take all possible second and lower-tier components into account, but rather provides a selection of variables from which one can choose depending on the focal case and question.

[7] The version found in Ostrom (2009) shows some changes to Ostrom (2007). The label of RU5 was changed from size to number of units; U8 was changed from dependence to importance of resource and two additional second-tier variables have been included for the first-tier interactions: I7: self-organisation activities and I8: network activities.

Table 1 Second-tier components

Resource System (RS)	Governance System (GS)
RS1 - Sector (e.g., water, forests, pasture)	GS1 - Government organisations
RS2 - Clarity of system boundaries	GS2 - Non-government organisations
RS3 - Size of resource system	GS3 - Network structure
RS4 - Human-constructed facilities	GS4 - Property-rights systems
RS5 - Productivity of system	GS5 - Operational rules
RS6 - Equilibrium properties	GS6 - Collective-choice rules
RS7 - Predictability of system dynamics	GS7 - Constitutional rules
RS8 - Storage characteristics	GS8 - Monitoring & sanctioning processes
RS9 - Location	
Resource Units (RU)	**Users (U)**
RU1 - Resource unit mobility	U1 - Number of users
RU2 - Growth or replacement rate	U2 - Socioeconomic attributes of users
RU3 - Interaction among resource units	U3 - History of use
RU4 - Economic value	U4 - Location
RU5 - Number of Units	U5 - Leadership/entrepreneurship
RU6 - Distinctive markings	U6 - Norms/social capital
RU7 - Spatial & temporal distribution	U7 - Knowledge of SES/mental models
	U8 - Importance of resource
	U9 - Technology used
Interactions (I) -> Outcomes (O)	
I1 - Harvesting levels of diverse users	O1- Social performance measures (e.g., efficiency, equity, accountability)
I2 - Information sharing among users	O2- Ecological performance measures (e.g., overharvested, resilience, diversity)
I3 - Deliberation processes	O3- Externalities to other SES
I4 - Conflicts among users	
I5 - Investment activities	
I6 - Lobbying activities	
I7 - Self-organising activities	
I8 - Networking activities	
Social, Economic, and Political Settings (S)	**Related Ecosystems (ECO)**
S1 - Economic development	ECO1 - Climate patterns
S2 - Demographic trends	ECO2 - Pollution patterns
S3 - Political stability.	ECO3 - Flows into and out of focal SES
S4 - Government resource policies	
S5 - Market incentives	
S6 - Media organisation	

Based on Ostrom (2009).

Collective action

As mentioned before, the SESF has been developed particularly for common-pool resources, with the tragedies of commons in mind. Ostrom (e.g. 2009) wanted to investigate under which circumstances resource users would invest in averting a tragedy of commons[8]. To

[8] This is a very similar question to what Anderies *et al.* (2004) termed as design principles for robustness in chapter 3.3.1. While they use the term robustness, they in fact have studied institutions that have governed resources over a long time (Anderies *et al.,* 2004).

answer this question, the effects of various variables on sustainability, self-organisation, and more immediately, on the perception of benefits and costs of collective action have been determined (Ostrom, 2009). These variables are described in this section. For an example of how the original SESF has been used, see Appendix IV.

Several of the second-tier components of the resource system impact self-organisation. The size of the resource system (RS3) influences the costs of defining boundaries, monitoring costs and costs of gaining ecological expertise, as well as benefits, i.e. the RUs which can be obtained from the RS (Ostrom, 2007; 2009). The productivity of the system (RS5) influences the RUs generated and therefore the perceived benefits, but also the perceived necessity of implementing some kind of management. The predictability of system dynamics (RS7) influences whether or not the users see any benefits of self-organising (Ostrom, 2009). Resource units also influence self-organisation, because the mobility of resource units (RU1) influences management and observation costs (Ostrom, 2007; 2009). The economic value of RUs (RU4) also affects self-organisation, as does the existence or possibility to introduce distinctive markings (RU6), and hence effective property rights (Ostrom, 2007). Furthermore, governance and users affect self-organisation. The presence of leadership/entrepreneurship skills (U5) among the users has a positive impact on self-organisation. Norms/social capital (U6), such as trust or norms of reciprocity, knowledge of the resource system (U7), the importance of/dependence on the resource (U8), and collective choice rules (GS6) positively influence self-organisation. The number of users (U1) also has an effect, which however depends on other variables. (Ostrom, 2009).

The way forward

Here, a more general reflection on collective action and the SESF is provided. On **collective action**, some of the attributes identified as significant for collective action, can be clearly related to the earlier developed design principles. The first design principle, regarding boundaries, relates to the size of the resource system. The second could be indirectly related to economic value, and therefore to RU4 and RS5. Collective choice rules (GS6) directly correspond to the third design principle. The mobility of RU (RU1), distinctive markings (RU6) and the number of users (U1) could be related to monitoring abilities (design principle 4). Here, GS8 (monitoring and sanctioning processes) has not been identified as an influencing factor for collective action but can be found as design principles. A reason here could be the slightly differing questions: While the idea was to determine factors important for collective action to emerge, the design principles are characteristics found in SES that are particularly robust. The latter includes outcomes of collective action, such as having established monitoring systems (principle 4), graduated sanctioning (principle 5), mechanisms to resolve conflicts (principle 6), and nested enterprises (principle 8). Design principle 7 on minimal recognition of rights to organise could be expected to be included in (GS7) constitutional rights but was not identified as significant in this case. It also seems surprising to me that GS4 on property rights systems were not found to be significant for collective action, particularly because distinctive markings were identified to be significant, due to their effect on the possibility to establish property rights.

To conclude, the rules used to govern a resource system need to be tailored to the specific RS, RU and U (Ostrom, 2007). Ostrom's (2010, p. 665) final note on self-organisation is a critique to the attempt of public policy to make "entirely self-interested individuals" strive for more sustainable outcomes. Based on her research, she suggests that public policy should instead create conditions (institutions) under which humans have the chance to become their *best versions.*

Now I turn to the SESF and the **critique** it faces in general. As already mentioned, the SESF has been widely used (McGinnis and Ostrom, 2014). However, its users are predominantly scholars connected to the framework‘s origin, and it has not received broad support in the wider research community (Partelow and Winkler, 2016). Publications about the SESF are dominated by single case studies and further developments of the framework. A lack of guidance on how to use the framework to design and collect empirical data, as well as the need for multi-disciplinary knowledge using the SESF, seems to have resulted in a domination of the use of secondary data (in mix with primary data) (Partelow, 2018).

While Binder *et al.* (2013) point to the possibility of an equal in-depth analysis of human and non-human elements of SES using the SESF, the framework is nevertheless anthropocentric. This is displayed, for example, in the terms used: Resource units, Resource systems, and Users (later changed to actors). Again, this can be attributed to the economic/ institutional lens of the developers of the framework and should be acknowledged (Partelow, 2018).

As it may have become apparent, various terms have been used to refer to the components of the tiers of the SESF, including variables, indicators, attributes, components and more. This may result in confusion, particularly regarding the interpretation of findings and regarding the use of the terms variables and indicators. According to Partelow (2018), this may be related to the lack of clear definitions for some of the second-tier components (*variable definition gap)*. The lack of unique and clear definitions allows for tailoring the SESF to the focal SES, but also trades off generalisability (Partelow, 2018). Generalisability is also infringed by human alteration of RU and RS, and in that context Hinkel *et al.* (2015) point out that it would be helpful to have before and after data. Furthermore, Partelow (2018) identifies a *variable indicator gap*. He uses the term to refer to broad variables that need context to be understood or separate indicators to be measured. These indicators consequently may differ between cases. Finally, even if a variable is clearly defined and an indicator selected, a *measurement gap* may occur, i.e., different methods may be used to measure one indicator. Once all data is collected, there are different options to transform it "into usable or presentable data in an analysis, graphic or written text form" and to use published data for further analysis. The transformation of data can allow for comparability across cases, but bears the risk of compromising "meaning and context" (*transformation gap*) (Partelow, 2018). In the end, all these *gaps* are obstacles in operationalising the framework, as well as comparing data and results between cases.

Furthermore, Hinkel *et al.* (2015) criticise that the SESF is unable to consider situations in which more than one type of actor may carry out several activities, which impact or are impacted by more than one RU and RS. In my understanding, this issue has been addressed by McGinnis and Ostrom (2014) (see chapter 3.3.3: Graphical amendments and labels).

Hinkel *et al.* (2015) also criticise the framework's inadequacy to consider the dynamic nature of SES, and overlaps of the components relating to these dynamics, resulting in interpretation difficulties. Components relating to these dynamics are the growth or replacement rate (RU2), equilibrium properties (RS6), predictability of system dynamics (RS7), and storage characteristics (RS8) (Hinkel *et al.,* 2015). The composability of social-ecological systems (Hinkel *et al.,* 2014), non-linearities, and thresholds make it rather challenging to operationalise these components (Hinkel *et al.,* 2015). These are valid points in my opinion and the complexity of SES is certainly a huge challenge. Epstein *et al.* (2013), Vogt *et al.* (2015), and Schlüter *et al.* (2019) have made amendments to capture ecological dynamics better (see chapter 3.3.3 and chapter 3.3.4).

Elinor Ostrom set out to develop a diagnostic framework that is general but adaptable, enables communication and comparison. One might ask whether she succeeded in doing so. The framework is general and has been adapted to various contexts, however, that has infringed comparability across cases (Partelow, 2018). While the SESF attempts to be theory neutral (McGinnis and Ostrom, 2014), Partelow (2018) argues that it is not, as its development draws on collective action theory and common pool resource systems. Nevertheless, the components are general and allow various applications of the framework. Various studies (e.g. Cox *et al.,* 2016; Epstein *et al.,* 2013) have used it beyond collective action theory to "generally characterise SES or to develop other closely related theory on natural resource governance" (Partelow, 2018).

3.3.3. Revisions

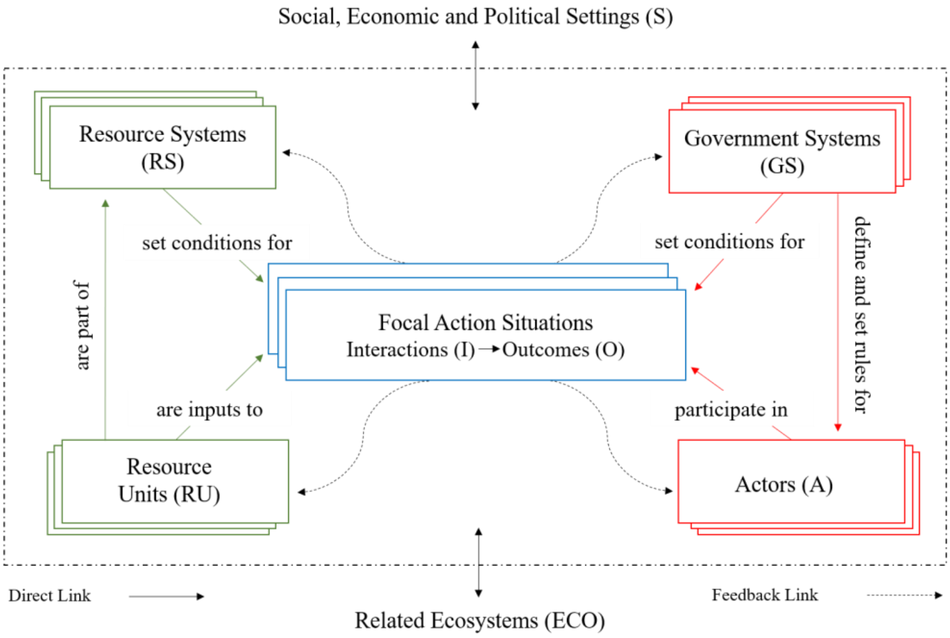
Various scholars have taken up the task to continue the development of the SESF. In this chapter, I elaborate on the changes proposed by McGinnis and Ostrom (2014), Epstein *et al.* (2013) and Vogt *et al.* (2015). The hereafter presented developments of the SESF are not exhaustive (e.g. see Hinkel *et al.,* 2015; Partelow, 2018; van Riper *et al.,* 2018), but I have chosen those which seemed most relevant to this work. I begin with the amendments of mainly graphical nature and continue with a closer look at the governance component, the action situation, and the ecological components of the framework. The chapter is concluded with reflections on critique on the SESF.

Graphical amendments and labels

The graphical representation of the SESF has been updated in so far that it now uses the label *focal action situation,* and thereby explicitly links the SESF to the IAD framework. The first-tier components of the focal social-ecological system are now each depicted by multiple boxes to show that several instances of the same component might co-exist. These different instances of one component might interact with each other (and with other components) in the focal action situation. Moreover, labels have been added for the links between the components (see Figure 11) (McGinnis and Ostrom, 2014).

Some labels of components have been amended as well. The component *user* has been relabelled as *actor* to enable an analysis of situations in which third parties, which are not users, play a role. Consequently, the *history of use* (U3) has been changed to *history of experience* (A3), and *technology used* (U9) has been changed to *technologies available* (A9). The list of interactions has been supplemented by *monitoring activities* (I9) and *evaluative activities* (I10), and the need for further additions is suggested. I1 has been renamed from harvesting levels, to harvesting to ensure a focus on interactions rather than results. To broaden the category, RU6 *distinctive markings* becomes *distinctive characteristics* to allow the inclusion of characteristics, such as time and place for breeding. Finally, *technology* (S7) has been added as an exogenous component; *market incentives* have been broadened to *markets* (S5); and *government resource policies* to other *governance systems* (S4) (McGinnis and Ostrom, 2014).

Figure 11 Updated Social-Ecological System Framework



Based on McGinnis and Ostrom (2014).

Governance

McGinnis and Ostrom (2014) discuss options to re-develop the governance component[9]. The list of second-tiers components they suggest still includes the original components, but attempts to structure them according to the logic used for the other components. Analogous to RS1: *sector*, GS1 is labelled *policy area*. The scale of the governance system is defined in *geographical dimensions* (GS2) and *population* (GS3). Regime type (GS4) determines whether the *regime* is democratic or autocratic; monocentric or polycentric (Ostrom et al. 1961 cited in McGinnis and Ostrom, 2014). GS5 refers to the types of *rule-making organisations,* and GS6 to the *rules in use*. Apart from rules, *property-rights systems* defining duties and obligations between people regarding objects are to be considered (GS7). Norms and strategies (GS8) available to the actors depict a channel through which culture

[9] While this chapter outlines the developments made by McGinnis and Ostrom (2014), it shall be mentioned that other papers have made similar attempts regarding the governance tier (e.g. Basurto *et al.,* 2013).

affects the action situation. The *network structure* component (GS9) describes the relations between organisations making rules and those subject to these rules. Lastly, the component *historical continuity* (GS10) has been added to distinguish between governance systems that have been in place for different durations and those that tend to be more static or more flexible (McGinnis and Ostrom, 2014).

Table 2 List of alternative governance second-tier components

Second-tier components	Third-tier components
GS1 - Policy area	
GS2 - Geographic scale of governance	
GS3 - Population	
GS4 - Regime type	
GS5 - Rule-making organisations	Public sector organisations Private sector for-profit organisations Non-governmental, non-profit organisations Community-based organisations Hybrid organisations
GS6 - Rules-in-use	Operational-choice rules Collective-choice rules Constitutional-choice rules
GS7 - Property-rights systems	
GS8 - Repertoire of norms and strategies	
GS9 - Network structure	
GS10 - Historical continuity	

Based on McGinnis and Ostrom (2014).

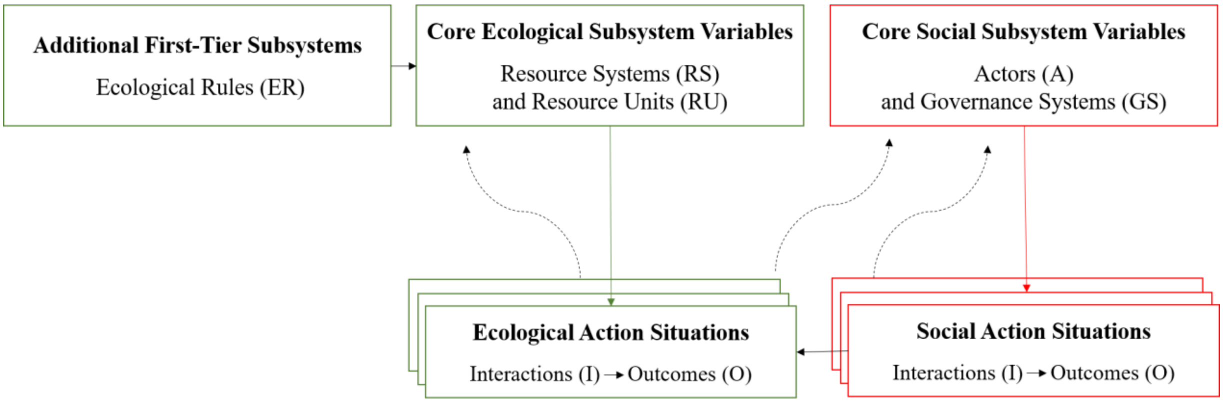
Adding ecology

While Binder *et al.* (2013) claim that the SESF allows an in-depth treatment of both human and non-human entities of SES, Epstein *et al.* (2013) and Vogt *et al.* (2015) lament the general absence of ecology in the SESF. This *lack of ecology* is unfortunate, considering the increasing interconnectedness of the human and non-human world (Crutzen and Stroemer, 2000; Liu *et al.,* 2007b). Particularly problematic is the central placing of the action situation, implying that SES can be explained by human interactions, i.e. non-human entities matter only to the extent that they relate to the human interaction (Vogt *et al.,* 2015). The limited attention towards ecological, non-human determinants, becomes also apparent in an analysis of the components used in various SESF studies, showing a domination of the use of the components *actors* and *governance systems* (Epstein *et al.,* 2013; Partelow, 2018).

To start a meaningful dialogue between social and natural sciences, and enable users of the SESF to take into account knowledge of natural sciences in studying SES, Epstein *et al.*

(2013) propose an additional component: **ecological rules** of physics, chemistry, and biology[10] (see Figure 12). This suggestion is based on an understanding of both human and non-human beings "as agents whose actions (or properties) are governed by rules" (Epstein *et al.,* 2013, p. 441). This component encourages the users of the SESF to actively think about the physical, chemical, and biological assumptions behind their understanding of a particular SES. Including ecological rules in the SESF allows for a more in-depth analysis of the non-human elements of SES, and avoids an over-reliance on human attributes, thereby equating cases with important ecological differences (Epstein *et al.,* 2013).

Figure 12 Adding ecology to the Social-Ecological System Framework



Based on Vogt *et al.* (2015).

In addition to the ecological rules proposed by Epstein *et al.* (2013), Vogt *et al.* (2015) propose an additional second-tier component ecosystem history, analogous to the actor component A9: history of use/experience. They also **unpack the second-tier components of RU and RS** further to make the operationalisation of the SESF easier (see Appendix V). The non-exhaustive third-tiers components shall serve as a starting point, and were derived by the authors with the help of ecological experts, textbooks and course syllabi (Vogt *et al.,* 2015). As already pointed out by Epstein *et al.* (2013), non-human beings can be actors (Vogt *et al.,* 2015). By considering this, Vogt *et al.* (2015) allow for interaction between humans, but also non-human ecological entities. Hence, they distinguish between social and ecological action situations (Vogt *et al.,* 2015) (see Figure 12), but fail to describe these different action situations or how they relate to each other (see chapter 3.3.4 for a description

[10] Note that these are not clear cut categories but might overlap (Epstein *et al.,* 2013).

of the different types of actions situations and their interaction based on Schlüter *et al.* (2019)).

The way forward

In chapter 3.3.5, I outline how the developments elaborated in the past chapter will be further considered for this thesis. Here, I briefly discuss the amendments of components that have been proposed so far.

Particularly the components proposed by Epstein *et al.* (2013) and Vogt *et al.* (2015) follow a different logic than the original development of the SESF (Partelow, 2018). The original components included in the SESF were found to be decisive for collective action during empirical research (Partelow, 2018). In contrast, Epstein *et al.,* 2013 and Vogt *et al.,* 2015 focus more generally on SES and their sustainability, for example "the modified framework presented in this paper should be seen as a tool explicitly designed to confront questions of sustainability that are rooted in biophysical processes and their interaction with the choices that emerge from social processes" (Epstein *et al.,* 2013, pp. 447–448). Literature does indicate that the SESF is useful beyond collective action theory, for a more general diagnosis of the sustainability of SES. Nevertheless, it is important to clearly state the underlying logic and purpose of adding and amending components. Thereby, the framework can be tailored to different uses (Partelow, 2018).

Furthermore, the origination of the SESF in collective action theory implies that the sustainability of a SES, referred to in the original work of Ostrom, is in fact institutional sustainability, i.e. "the development and maintenance of contextually appropriate institutions that can enable actors to cooperate and use resources in a way that allows for the long-term and equitable availability of those common resources" (Partelow, 2018). An addition of ecological components, such as proposed by Epstein *et al.* (2013) and Vogt *et al.* (2015), may however refer to a broader concept of sustainability. These differences are important to keep in mind.

3.3.4. The Social-Ecological Action Situation Framework

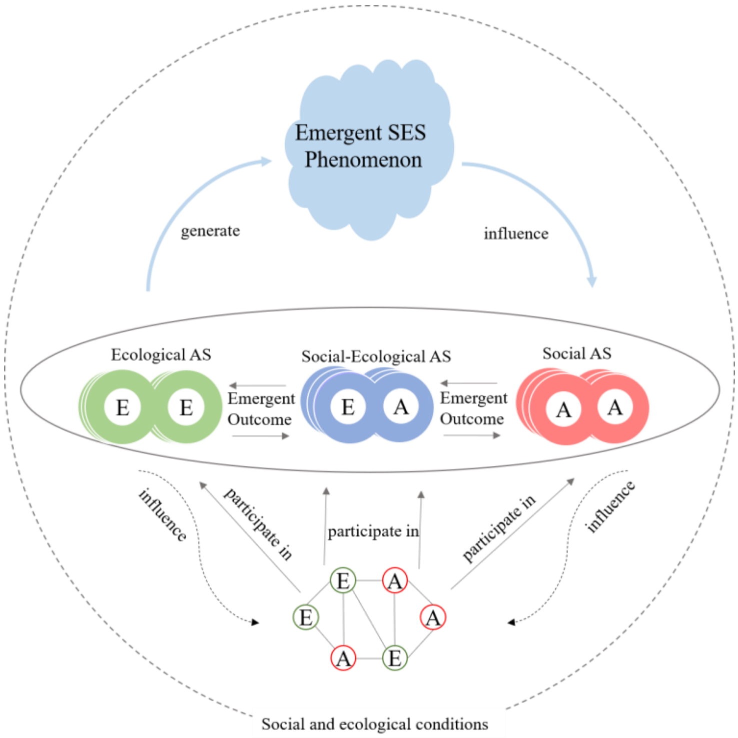
The SESF is not the only framework using the action situation to analyse SES. Schlüter *et al.* (2019) recently developed the Social-Ecological Action-Situation (SE-AS) framework (see Figure 13). The focal point of this framework is the analysis of the interaction between human and non-human entities at the micro-level and how they generate emergent outcomes. It tries to capture interactions between structures on multiple levels and the processes which determine the behaviour of social-ecological systems (Schlüter *et al.,* 2019). This focus on interactions is in line with the recommendation of Capra and Luisi (2014, cited in Preiser *et al.,* 2018) to focus on emergent phenomena and relations of systems rather than the components (see page 33). In the following, I outline the SE-AS framework. For an example of how this framework might be applied, see Appendix VI.

The SE-AS framework does not prescribe any specific theory on human behaviour, human-non-human interactions, the causes for the observed outcomes “or the role of agency versus structure”. They also reject the prescription of the boundedly rational actor, pointing out that actors have diverse “interests, motivations, and beliefs, interact within social or social-ecological networks, and can deliberately choose to change or not comply with the rules that structure interactions”. When using the SE-AS, researchers are encouraged to be critical towards their own assumptions on human behaviour (Schlüter *et al.,* 2019).

For analytical reasons, the SE-AS framework defines three different types of action situations: a social, an ecological, and a social-ecological action situation capturing interactions between humans, non-human entities, and both respectively. The ecological and social-ecological action situations allow for a dynamic representation going beyond understanding ecological components as “static constraints to social interactions”. By introducing the ecological and the social-ecological action situation, non-human entities can interact and become actors (Schlüter *et al.,* 2019) possessing acting capacity, i.e. agency (Stanford Encyclopedia of Philosophy, 2019). Agency can be interpreted as something that is carried out with or without conscious intentions. Which actors possess what kind of agency is not predetermined, but those using the framework are encouraged to disclose their position (Schlüter *et al.,* 2019).

The **social-ecological action situation** encompasses human and non-human entities, “their capacities, and the social and biophysical rules and structures that govern their interactions”. The participating human actors can be individuals or groups of people interacting with an ecosystem. Participating non-human entities can be individuals (e.g. one fish), groups (e.g. an entire fish population), or more aggregate entities (e.g. a water body or soil in a given location) - generally any ecosystem component (Schlüter *et al.,* 2019). The rules and structures, described above as governing interactions, comprise of human attributes, such as “needs, interests, values, knowledge, beliefs, skills, access, and opportunity sets, etc.” (Boons 2013 cited in Schlüter *et al.,* 2019); human-made rules, such as for harvesting or monitoring; and attributes/rules of non-human entities "such as spatial distribution, growth rates, quality", climatic conditions, food webs, and abiotic conditions. The interactions between human and non-human entities can take diverse (non-) material shapes. Humans can, for example harvest, pollute, nurture, enjoy, manage, or attach value to resources, while non-human entities can provide food for humans, flood or protect them (see Appendix VII for more action situations). Interactions can be conceptualised in more than one way, for example fishing can be seen as extracting a fish from a lake, or as the fisher's experience of fishing (Schlüter *et al.,* 2019). (Non-) material outcomes resulting from these interactions can be a harvest or gained knowledge (Masterson *et al.,* 2017; Schlüter *et al.,* 2019).

Figure 13 Social-Ecological Action Situation Framework



Based on Schlüter *et al.* (2019).

In the **ecological action situation**, non-human ecological entities interact with each other, for example by competing for space or food, predation, facilitation, or "ecological, geological, or biophysical[11] processes". Possible outcomes of these interactions are erosion or the extinction or growth of a species. By adding the ecological action situation, Schlüter *et al.* (2019) want to allow a more explicit consideration of ecological process and outcomes

[11] "[B]iophysical processes such as water or nutrient flows" can be represented as interactions between stocks (Schlüter *et al.,* 2019).

which determine the rules of human-nature interactions, as well as objectives and motives of the agents beyond the components proposed by Ostrom's SESF (Schlüter *et al.,* 2019).

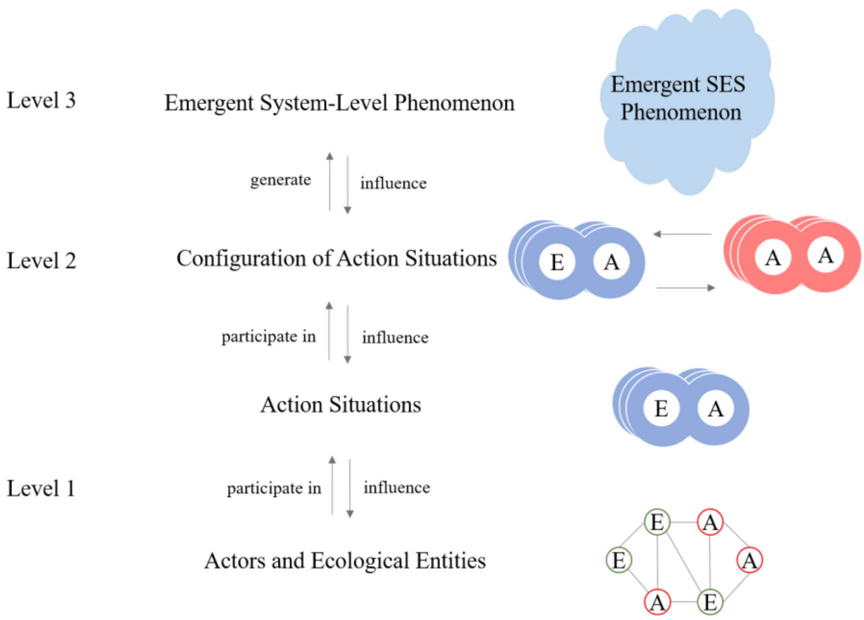
In the **social action situation**, human entities interact with each other based on existing rules, their interests, goals, and agency. Actors occupy positions in action situations, possess some level of control, and certain information. Schlüter *et al.* (2019) broaden the action situation of the IAD framework (see chapter 3.3.1) by emphasising that humans do not act necessarily as determined by external rules, such as positioning rules. Humans also have their own motivations and goals, and this influences their agency. The human interactions in the social action situation result in outcomes such as novel or amended rules, for example for harvesting (Schlüter *et al.,* 2019).

The action situations comprise of only those interactions deemed relevant for the focal SES phenomenon. Other (non-) human entities and attributes which influence the SES phenomenon, but are stable over the space and time under investigation, are considered as external drivers, i.e., social-ecological conditions. These conditions are important in so far that "processes in SES are highly context dependent and the hypothesised interactions may only generate the phenomenon of interest under specific social and ecological conditions" (Schlüter *et al.,* 2019).

In all the three action situations, outcomes can (in-)directly feed back to the participating human and non-human entities, and the structure and rules of the action situation in the short- or long-run (Schlüter *et al.,* 2019). The human (Boons, 2013 cited in Schlüter *et al.,* 2019) and non-human actors may adapt their behaviour and functioning to these outcomes (Schlüter *et al.,* 2019). The adaption of human behaviour is, however, also dependent on "intentionality and political processes" (Manuel-Navarrete, 2015 cited in Schlüter *et al.,* 2019).

The SE-AS framework considers interactions and feedbacks on **different analytical levels** (Figure 14). On the first level, the different entities participate and are influenced by an action situation. On the second level the social action situation and the ecological action situation influence each other indirectly, via the social-ecological action situation. More precisely, the outcome of an action situation can change rules and attributes of another action situation, such as the beliefs of an actor or the growth of an animal population. The resulting network of action situations is called configuration, which in turn feeds back to the individual action situations. The configuration represents a hypothesis of the interactions happening and the focal SES phenomenon. To be clear, this is only a hypothesis and causality for the determined relationships is not claimed. The hypothesis could rely on the macro-level structural features or put more emphasis on the agency of the actors. Schlüter *et al.* (2019) claim that outcomes of complex adaptive systems tend to be the result of "the interplay between bottom-up self-organised processes with emergent top-down structural constraints". The emergent phenomenon is on the third level, and may also influence the lower levels possibly with a considerable time lag (Levin *et al.,* 2012). Finally, Schlüter *et al.* (2019) emphasise that these levels were introduced solely for analytical reasons, and that the existence of more meso-levels between the macro- (level 3) and the micro-level (level 1) is possible (Schlüter *et al.,* 2019).

Figure 14 Analytical levels of action situations



Based on Schlüter *et al.* (2019).

3.3.5. The way forward

Following the elaboration of the original SESF, its further developments and the SE-AS framework, this chapter outlines the framework that will be used for the proceeding of this thesis.

A version of the SESF is used that includes the latest amendments made concerning graphics and labels. The proposed changes of the governance component will also be applied here. While McGinnis and Ostrom (2014) emphasise that these are just suggestions, they seem logically conclusive and better suited than the previous version. The additional component and amendments proposed by Epstein *et al.* (2013) and Vogt *et al.* (2015) are also integrated.

The SESF and the SE-AS framework may appear to be quite different in their foci. The SESF's focus is rather on the structural factors determining the action situation, whereas the focal point of the SE-AS framework is rather on the dynamics of the action situation itself. To me, it seems that these frameworks are complementary. Whereas the SE-AS framework focuses on interactions on different levels, the SESF displays different attributes influencing the participating actors and interactions. The SESF provides us with a list of attributes that influence the different entities. These attributes are also mentioned in the SE-AS framework, for example growth rates for non-human ecological entities and values for human entities, but they are not extensively specified. I believe a list to start off with is helpful to operationalise the framework, particularly for novice researchers like me. The SE-AS framework, on the other hand, allows an analysis of action situations on different levels, how they influence each other and co-produce an emergent phenomenon. The framework used in this thesis is the SE-AS framework depicted in Figure 13, describing how different kinds of action situations interact and produce an emergent phenomenon. When zooming in on the different types of action situations, the understanding follows Figure 15-Figure 17 integrating knowledge from Epstein *et al.* (2013), McGinnis and Ostrom (2014), and Vogt *et al.* (2015). The respective second-tier components are presented in Table 3. The *interactions* second-tier components have been amended to ensure congruence with the SE-AS framework. Interactions are therefore divided into interactions between human actors (I1: human interactions); interactions between ecological non-human actors (I2:non-human ecological interactions); and interactions between human and ecological, non-human actors (I3: social-ecological interactions). A list of what the interactions of these different second-tier components could be, can be derived from the list of action situations provided by Schlüter *et al.* (2019) (see Appendix VII).

The analytical framework presented here requires us to distinguish between human and non-human ecological actors. It allows us to analyse how human and non-human ecological entities interact within and across their domains, and produce macro-level phenomena, and to use an idea of Folke *et al.* (2011; 2016): how they co-produce the biosphere. While the framework distinguishes between human and non-human actors for analytical reasons, it also makes clear that the two groups do not exist in isolation, but are influenced by each other, and are embedded in the broader SES system. The dotted circle in Figure 13 depicts what Capra and Luisi (2014 cited in Preiser *et al.,* 2018) describe as fuzzy and permeable boundary.

To display the understanding of both human and non-human entities having social and ecological characteristics (see chapter 3.2), as well as possessing agency, labels have been amended. The actors participating in the various action situations are now labelled as EA, i.e., non-human ecological actor and HA, i.e., human actor. Action situations are now labelled as human action situation and non-human ecological action situation. These terms make clear who is participating in the different types of action situations. Moreover, to ensure clarity I have re-labelled the first-tier (and the respective second-tier) component *actors* as *human actors; resource systems* as *ecological systems;* and *resource units* as *non-human ecological actors.* This is more in line with the labels used for the action situations and shifts us a bit further from the very anthropocentric focus of the original SESF.

Referring to the management implications described in chapter 3.2.3., the framework described here aligns with the first implication to focus on phenomena and relations (or what is termed as *connectivity* in the resilience literature), and acknowledges that boundaries are permeable. Schlüter *et al.* (2019) also emphasise that the aim of the framework is the development of a hypothesis and not causality. This aligns with Preiser *et al.*'s (2018) recommendation to keep in mind uncertainties. Furthermore, any hypothesis is a snapshot based on the obtained data of a SES at a particular point in time. When developing and implementing interventions based on an analysis using the proposed framework, it seems advisable to follow the remaining recommendations outlined in chapter 3.2.3, such as anticipating adaption and change (Preiser *et al.,* 2018), expecting unforeseen consequences (Poli, 2013), and the principles developed in the resilience literature, such as fostering learning and broad participation (Folke *et al.,* 2016).

Figure 15 Non-human ecological action situation

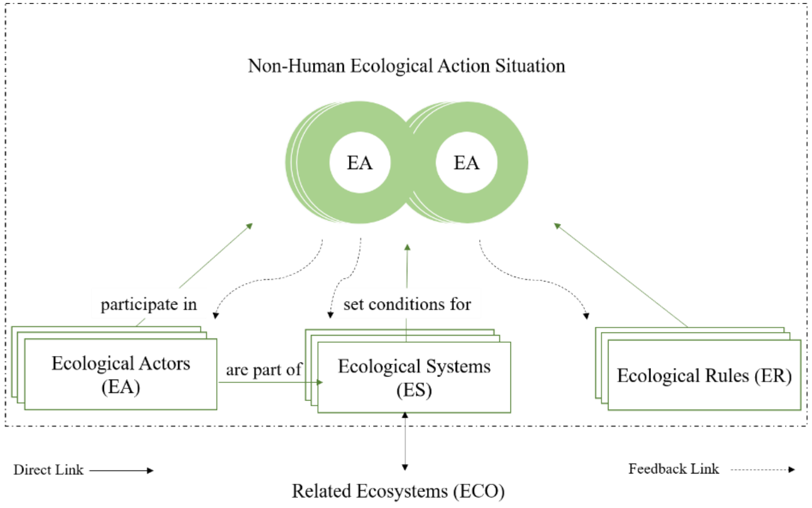


Figure 16 Social-ecological action situation

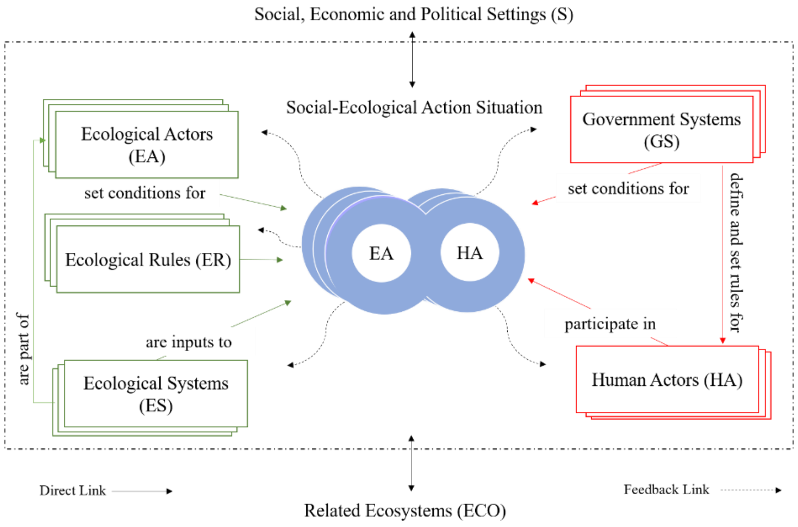


Figure 17 Human action situation

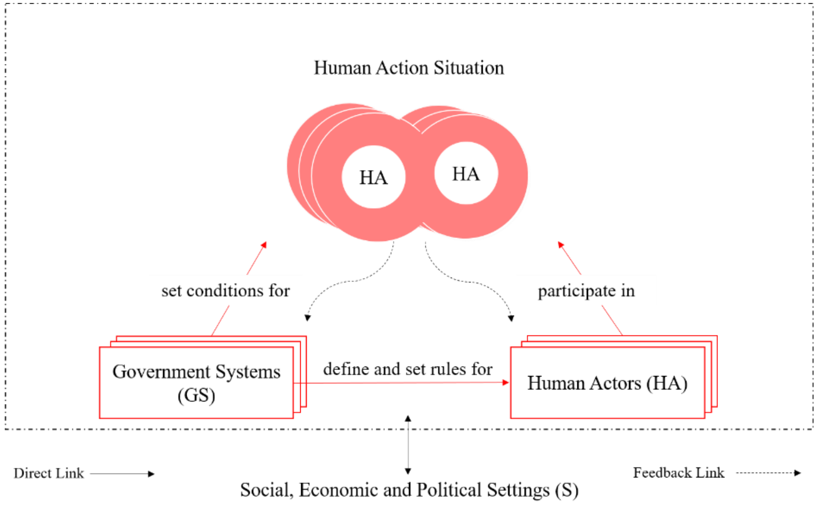


Table 3 Amended second-tier components

Ecological System (ES)

ES1 - Sector (e.g., water, forests, pasture)
ES2 - Clarity of system boundaries
ES3 - Size of ecological system
ES4 - Human-constructed facilities
ES5 - Productivity of system
ES6 - Equilibrium properties
ES7 - Predictability of system dynamics
ES8 - Storage characteristics
ES9 - Location
ES10 - Ecosystem history

Governance System (GS)

GS1 - Policy area
GS2 - Geographic scale of governance
GS3 - Population
GS4 - Regime type
GS5 - Rule-making organisations
GS6 - Rules-in-use
GS7 - Property-rights systems
GS8 - Repertoire of norms and strategies
GS9 - Network structure
GS10 - Historical continuity

Non-human Ecological Actors (EA)

EA1 – Ecological actor mobility
EA2 - Growth or replacement rate
EA3 - Interaction among resource units
EA4 - Economic value
EA5 - Number of units
EA6 - Distinctive markings
EA7 - Spatial and temporal distribution

Human actors (HA)

HA1 - Number of relevant actors
HA2 - Socioeconomic attributes
HA3 - History or past experiences
HA4 - Location
HA5 - Leadership/entrepreneurship
HA6 - Norms (trust-reciprocity)/social capital
HA7 - Knowledge of SES/mental models
HA8 - Importance of resource
HA9 - Technologies available

Ecological Rules (ER)

ER1 - Physical rules
ER2 - Chemical rules
ER3 - Biological rules

Interactions (I) -> Outcomes (O)

I1 – Human interactions
I2 – Non-human ecological interactions
I3 – Social-ecological interactions

O1- Human performance measures
(e.g., efficiency, equity, accountability)
O2- Non-human ecological performance measures
(e.g., overharvested, resilience, diversity)
O3- Externalities to other SES

Social, Economic, and Political Settings (S)

S1 - Economic development
S2 - Demographic trends
S3 - Political stability
S4 - Other governance systems
S5 - Market incentives
S6 - Media organisation

Related Ecosystems (ECO)

ECO1 - Climate patterns
ECO2 - Pollution patterns
ECO3 - Flows into and out of focal SES

3.4. The Social-Ecological System Framework in the Global South

As already mentioned, the Social-Ecological System Framework was originally developed to investigate collective action regarding SES: when and why it emerges in some cases, but not in others, as well as the decisive variables (Evans, 2004; Ostrom, 2009; Ostrom and Cox, 2010; Partelow, 2018). Thus, the components included in the original SESF were tailored to these questions (Partelow, 2018). Later on, Epstein *et al.* (2013) and Vogt *et al.* (2015) proposed to include further components that make the framework applicable to a more general investigation of SES, not just collective action. Schlüter *et al.* (2019) also contributed to this development.

The proposed SESF of chapter 3.3.5 is therefore tailored to investigate SES. It is not a development framework and does not make any suggestions regarding people's well-being or aspirations. The only well-being component it includes is the second-tier component *HA2 – Socioeconomic attributes.* The component is not further unpacked, but typically the term refers to income, education, and occupation. In this chapter, I argue for the integration of a broader well-being concept in the SESF. As Coulthard *et al.* (2018, p. 253) put it, we need to end thinking about people and ecosystems separately, and "conceive of people as agents who are part of these ecosystems and who are making decisions at all levels based on their wellbeing aspirations and motivations." Considering the links between environmental and human well-being seems especially important in the Global South, because countries of the Global South are particularly vulnerable and less prepared to build resilience to emerging global challenges, such as climate change (University of Notre Dame Global Adaption Initiative, 2018) and their inhabitants tend to experience lower levels of well-being compared to inhabitants of the Global North (e.g., United Nations Development Programme (2020)). In this chapter I draw on conservation literature to argue for an integration of a broader concept of well-being in the SESF, to make it more applicable to countries of the Global South.

Traditionally, **conservation** was about establishing zones within which natural resources were protected. This usually meant that people of lower societal status could no longer live in these protected zones nor engage in traditional uses of the zones (Brockington, 2004). While the establishment of protected zones may promise societal benefits, it may nevertheless adversely affect the well-being of those whose livelihoods and rights are infringed (Brockington and Wilkie, 2015); who would prefer a continuation of traditional use; and who reject a dualistic view on human and non-human nature (Biedenweg and Gross-Camp, 2018). In the beginning of the 1980s, the dominance of conservation as protectionism started to fade (Campbell *et al.,* 2010), and the idea that environmental protection should be integrated with poverty reduction, particularly in the Global South, emerged (Adams, 2003).

This ties to the debate on the **environmental dimension of development**. In the 20th century, it was assumed that economic progress needs to be prioritised to allow environmental challenges to be dealt with later (Adams *et al.,* 2004) – or would even be automatically solved (Environmental Kuznets Curve, see for example Mäler (2001)). Subsequently, this view was contested as a result of the record economic development turned out to have on environmental issues (Adams, 2003). In conservation, a pro-poor approach emerged (Roe *et al.,* 2003). The reconciliation of human well-being and conservation is the result of several developments: the recognition that human societies are part of (Breslow *et al.,* 2016; Mace *et al.,* 2014) and depend on ecosystems (Millennium Ecosystem Assessment, 2005); the emergence of the ecosystem service concept (Breslow *et al.,* 2016; Diaz *et al.,* 2014); efforts to enhance biodiversity (Beauchamp *et al.,* 2018); a shift away from solely economic measures of development (Breslow *et al.,* 2016; Gough and McGregor, 2007); observations that conservation may impact local people negatively (Coad *et al.,* 2008); and related ethical concerns (International Union for Conservation of Nature (IUCN), 2003).

As described in chapter 3.1, humans are inextricably connected to their natural environment in many ways. How they lead their lives is determined by their use of natural resources, as well as what they understand as a good life (Coulthard *et al.,* 2011). Social and ecological outcomes of conservation efforts can be mutually beneficial (Loring *et al.,* 2016) or constitute trade-offs (Daw *et al.,* 2015), for example when they result in conflicts between people and wildlife (Woodroffe *et al.,* 2005) or displacement (Brockington and Igoe, 2006). Conservation has been depicted as a mean to tackle poverty, as well as an impediment to economic progress (Turner *et al.,* 2012).

Adams *et al.* (2004) present **four views on the connection between poverty reduction and conservation**. One way to look at poverty and conservation is to recognise them as **separate policy realms**. Poverty and conservation are individual, legitimate goals to be pursued independently. While win-win scenarios are possible and conservation may indirectly contribute to a reduction of poverty via ecosystem services, resources are used deliberately to achieve conservation, not poverty reduction (Adams *et al.,* 2004).

A second position is that **poverty is a conservation constraint**, i.e. conservation cannot succeed if poverty is not eliminated (Adams *et al.,* 2004) and human well-being is not considered (Biedenweg and Gross-Camp, 2018). This position sees conservation as dependent on its fit with human needs and support by people (Biedenweg and Gross-Camp, 2018). In line with this position, Milner-Gulland *et al.* (2014) state that actions to conserve the natural environment affect the relationships communities have with their natural environment, and thus conservationists need to consider what people aspire in terms of well-being to be able to succeed with conservation. Conservationists need to understand the perception of the locals regarding conservation and its effects on their lives, because these variables determine if and how they engage and participate in conservation efforts (Beauchamp *et al.,* 2018). Not only do ecosystem services influence human well-being, but the link also works in the opposite direction: human well-being also affects ecosystems (Butler and Oluoch-Kosura, 2006). Butler and Oluoch-Kosura (2006) provide an example: "populations that experience poverty and ill-health, in part because of under-nutrition and material lack from soil exhaustion, are also likely to be relatively deficient in the human capability needed to improve local soil quality". Furthermore, incorporating well-being might affect legitimacy and funding positively (Woodhouse *et al.,* 2015). The position that conservation depends on human-wellbeing is however not uncontested. Brockington (2004) has for example shown that conservation can be successful even if it severely affects human well-being.

A third position is that **poverty reduction should not be infringed by conservation**, i.e., conservation is a legitimate goal on its own, but should not negatively affect poverty. This position differs from the previous one in that it does not claim that conservation is not possible without poverty elimination, but that there are "moral and political obligations" to not increase poverty by pursuing conservation (Adams *et al.,* 2004). Considering the effects conservation has on well-being is therefore described as an ethical necessity (Woodhouse *et al.,* 2015), and the minimal ethical standard of conservation is not to do any harm to people (International Union for Conservation of Nature (IUCN), 2003).

The final position presented is that **poverty reduction is dependent on conservation.** According to this view, the livelihoods of people described as poor depend on biodiverse ecosystems, and can be improved by conservation (Adams, 2003). Hence, conservation is perceived as a poverty reduction strategy (Adams *et al.,* 2004). According to Butler and

Oluoch-Kosura (2006), environmental conditions impact the material dimension of well-being, as well as psychological aspects. The degradation of the natural environment can impact health negatively (Millennium Ecosystem Assessment, 2005), and a feeling of insecurity and unhealthy social relations may for example result from a lack of adequate ecosystem services (Butler and Oluoch-Kosura, 2006). Furthermore, conflicts may connect to struggles over ecosystem services (Butler and Oluoch-Kosura, 2006).

Concluding, several arguments can be made to include well-being in environmental projects: (1) to adhere to moral obligations (e.g. Adams *et al.,* 2004; Woodhouse *et al.,* 2015); (2) to gain legitimacy, political support, and funding (Woodhouse *et al.,* 2015); (3) to determine outcomes for nature and people (Milner-Gulland *et al.,* 2014) and manage potential trade-offs (Daw *et al.,* 2015); and (4) to improve or facilitate conservation (Adams *et al.,* 2004).

Based on the presented literature, I propose that successful governance and restoration of SES also depends on the well-being of people, which should therefore be better integrated into the SESF. Moreover, to allow for successful interventions to tackle social-ecological phenomena, such as pollution, it might be helpful to identify where people are heading in terms of their own lives. In their case study of an irrigation system in Mexico, Ostrom and Cox (2010) mention, for example, that the functioning of the SES has been infringed by the emigration of young people. This could be interpreted as a change of people's concept of well-being and aspirations in life. According to Partelow (2018), the underlying logic and purpose of adding and amending components of the SESF must be stated, and I have done so in the previous paragraphs.

Looking at the framework proposed in chapter 3.3.5, well-being could be included in the actor component and replace the second-tier component *HA2 – Socioeconomic attributes* (see Table 4). Well-being would thereby be conceptualised as having effects on the interactions of human actors with other (non-) human actors, and via the interaction influence the emergent phenomenon. Both the emergent phenomenon and the interaction could then result in feedback affecting human well-being. An example could be aspirations to move from rural to urban areas, resulting in an uncontrolled influx of people to cities. This contributes to a lack of proper sanitation in informal settlements, and consequently surface water pollution. Economic deprivation may then result in people using polluted water, and adversely affecting their health and well-being.

Once it is established that well-being should be considered in environmental projects in general, and the SESF in particular, it needs to be determined what is meant by **well-being**. After all, how we look at the links between the environment and well-being depends greatly on the underlying understanding of well-being (Agarwala *et al.,* 2014; Biedenweg and Gross-Camp, 2018). When well-being was first considered in the field of conservation, it was used as a unidimensional concept focusing on monetary indicators (Biedenweg and Gross-Camp, 2018). While income and livelihoods are often highlighted as means to compensate people for conservation costs and to reduce pressure on resources, Woodhouse and McCabe (2018) emphasise that livelihoods entail more than material dimensions, such as cultural and social elements. They thus suggest moving away from the predominant measurement of material well-being in conservation (Woodhouse and McCabe, 2018).

Five different foci have emerged among the various conceptualisations of well-being: (1) the satisfaction of preferences (wants and desires); (2) the fulfilment of a list of exogenous identified material, social, and psychological needs; (3) the fulfilment of one's potential; (4) the domination of positive feelings and moods; and (5) self-evaluation (Dolan et al., 2006 cited in MacKerron, 2011). These approaches differ in their views on whether well-being is objective or subjective; an individual or collective experience; should be assessed from within or outside; and whether they rely on qualitative or quantitative data (Agarwala *et al.,* 2014). Each of these approaches is valuable, and well-being concepts may draw on several of them (Agarwala *et al.,* 2014).

Despite this diversity, there is an increasing consensus on several aspects of human well-being (Boarini *et al.,* 2014; Milner-Gulland *et al.,* 2014). Firstly, well-being is multi-dimensional (Boarini *et al.,* 2014; Milner-Gulland *et al.,* 2014) and contains more than economic well-being or money (Coulthard *et al.,* 2018). The shift towards multi-dimensional definitions of poverty, and subsequently well-being, stems from the recognition that poor people are more than *just poor*. A focus on multi-dimensional well-being, instead of just economic poverty, avoids stigmatisation and allows for "a holistic, person-centred analysis incorporating social and subjective assessments of life"(Coulthard *et al.,* 2018, p. 246). This is also a shift away from focussing on what people lack towards what they have and their well-being strategies, which is particularly important regarding links with ecosystems (Coulthard *et al.,* 2018), and aligns in this aspect with post-development thinking (Esteva, 1992). Nussbaum and Sen (1993) pioneered in the field of multi-dimensional well-being approaches with the *capabilities approach,* shifting the focus from people's material possessions to what they can achieve with these. Other multi-dimensional approaches include, for example the OECD's (2011) *How's life?; Voices of the Poor* (Narayan *et al.,* 2000); *Sustainable Livelihoods* (Scoones, 1998); the *Theory of Human Needs* (Doyal and Gough, 1991); and *the Good Life* (Skidelsky and Skidelsky, 2012) (for short descriptions, see e.g. Boarini *et al.* (2014)).

Secondly, to assess well-being, objective and subjective dimensions must be measured (Milner-Gulland *et al.,* 2014). The Voices of the Poor study (Narayan *et al.,* 2000) was significant not only in fostering a multi-dimensional view on well-being, but also in shifting the debate on poverty and well-being from a focus on objectivity towards subjective perceptions (Coulthard *et al.,* 2018). In addition, a relational dimension of wellbeing is increasingly considered when describing how social relationships determine one's participation in society (White, 2017 cited in Coulthard *et al.,* 2018). All of these perspectives are linked to ecosystems and their health (Loring *et al.,* 2016). The productivity of an ecosystem can impact, for example, access to food (objective dimension) (Millennium Ecosystem Assessment, 2005). Ecosystems can impact the "nature and quality of people's relationship with each other" and non-human ecological entities (relational dimension) (Loring *et al.,* 2016, p. 151). Furthermore, people's subjective well-being can be impacted, for example by drawing on ecological resilience. In the case of ecosystem interventions, people's participation and support depends on their subjective perception of well-being impacts (Woodhouse *et al.,* 2015). While human well-being is therefore clearly linked to ecosystems, one cannot help but notice that while well-being has increased on the global scale over the past decades, so has ecosystem degradation (Millennium Ecosystem Assessment, 2005). In addition, psychologists have discovered that people are adaptive and able to experience well-being in various environmental conditions (Diener and Ryan, 2009).

Thirdly, to measure well-being we need some kind of agreement on the concept, while allowing tailoring for the local cultural and social context. From an ethical viewpoint, any assessment of well-being must rest on a definition of well-being by those whose well-being is to be assessed (Milner-Gulland *et al.,* 2014). In determining well-being concepts, local perspectives are key because a lack thereof may result in a concept that does not mean something to the local people, and therefore "will not account for locally significant impacts of interventions" (Woodhouse *et al.,* 2015, p. 2). According to Milner-Gulland *et al.* (2014,

p. 1165), measuring the outcomes of conservation interventions also in terms of well-being allows us to "listen to local voices and empower marginalized groups of people to contribute to solutions that enable them to live sustainably alongside nature."

The well-being framework I draw on in this thesis emerged from the **Voices of the Poor** study, commissioned by the World Bank Group, during which "views, experiences, and aspirations of more than 60,000 poor men and women from 60 countries" were gathered (Narayan *et al.,* 2000, p. xv). The well-being framework developed by Narayan *et al.* (2000) draws on the views of 20,000 people in 23 countries, gathered during fieldwork in 1999. The views on well-being expressed during the study by "women and men, young and old, children and adults" were surprisingly similar "across continents, countries, in cities, towns and rural areas alike" (Narayan *et al.,* 2000, p. 22). Five dimensions of well-being were uncovered in the study: material well-being; bodily wellbeing; social well-being; security; and freedom of choice and action (Narayan *et al.,* 2000). These dimensions could function as third-tier components in the SESF (see Table 4).

Table 4 List of amended second and third-tier human actor components

Second-tier components	Third-tier components
HA1 - Number of relevant actors	
HA2* - Well-being	Material well-being Bodily well-being Social well-being Security Freedom of choice and action
HA3 - History or past experiences	
HA4 - Location	
HA5 - Leadership/entrepreneurship	
HA6 - Norms (trust-reciprocity)/social capital	
HA7 - Knowledge of SES/mental models	
HA8 - Importance of resource	
HA9 - Technologies available	

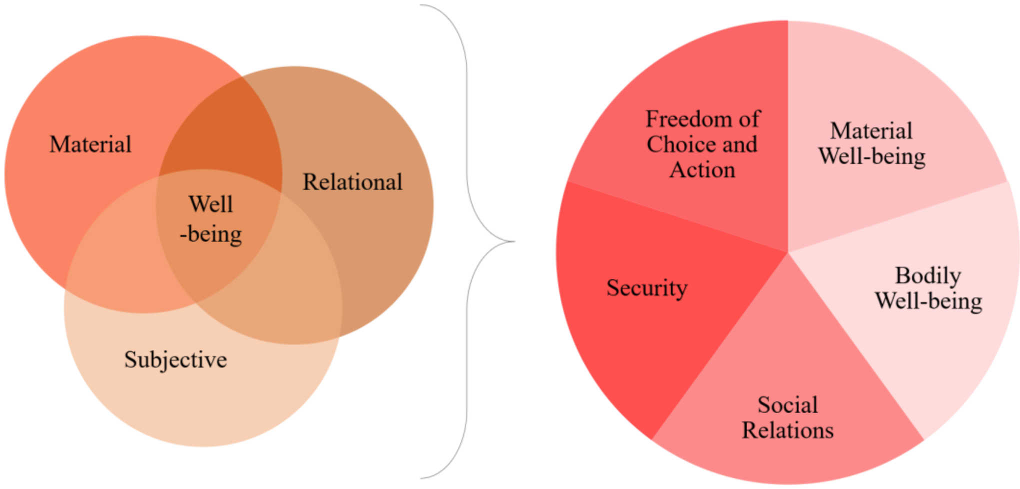
* amended tier

Based on Ostrom (2009) and the presented literature of this chapter, especially Narayan *et al.* (2000).

Material well-being includes food, assets, and work. Food refers to having "enough to eat every day" (Narayan *et al.,* 2000, p. 25), as well as food security (Woodhouse *et al.,* 2015). Assets include secure tenure (e.g. of land) and ownership of livestock (especially in rural areas), as well as accessible goods of consumption, savings, capital, housing, natural resources, and tools (Narayan *et al.,* 2000; Woodhouse *et al.,* 2015). Work is considered as key to gain a livelihood. Bodily well-being includes both health, accessible health services and appearance. Good health was also conceived as important to allow one to work (Narayan *et al.,* 2000). A healthy physical and mental environment was also conceived as important (Beauchamp *et al.,* 2018). Social well-being includes "peace, harmony and good relations in the family and the community"; dignity and self-respect, i.e., not being a burden to other people and being able to bury passed members of one's family in decency (Narayan *et al.,* 2000, p. 27). Social well-being also includes the ability to help each other out, and fulfil social obligations (Woodhouse *et al.,* 2015); and to raise, care for, marry, and settle one's children. Security includes civil peace, an environment that is physically safe and secure (i.e., not prone to physical disasters etc.); personal physical security; rule of law and access to justice; as well as security as one ages; and confidence into the future. The freedom of choice and action dimension covers a wide range, including being able to help others and being a good person. It also covers gaining education and skills, mobility and travels, and time to rest, recreate, and socialise (Narayan *et al.,* 2000). Furthermore, it includes a "sense of control and power" and the "ability to pursue what you value doing and being, and meet aspirations" (Woodhouse *et al.,* 2015, p. 4), and making choices and decisions (Narayan *et al.,* 2000). This last dimension is important for conservation interventions, as they could infringe the freedom of behaviour regarding one's environment (Abunge *et al.,* 2013). While the Voices of the Poor study has uncovered commonalities, it has also uncovered differences across gender and countries. Interestingly, the participants of the study clearly differentiated between economic wealth and well-being (Narayan *et al.,* 2000).

Both Beauchamp *et al.* (2018) and Woodhouse *et al.* (2015) use the Voices of the Poor concept not in isolation, but additionally draw on another perspective: The **Wellbeing in Developing Countries** (WeD) concept. The WeD concept looks at well-being through three lenses, by asking the following questions: (1) What does a person have? (material lens); (2) What can a person do with what s/he has? (relational lens); and (3) How does a person feel about what s/he has and what s/he can do? (subjective lens) (McGregor and Sumner, 2010 cited in Beauchamp *et al.,* 2018). Beauchamp *et al.* (2018) and Woodhouse *et al.* (2015) use these lenses to inform the different dimensions of the Voices of the Poor concept (see Figure 18). While this goes beyond the frame of this thesis, it shall be kept in mind for an application of the proposed amended version of the SESF to other cases.

Figure 18 Well-being



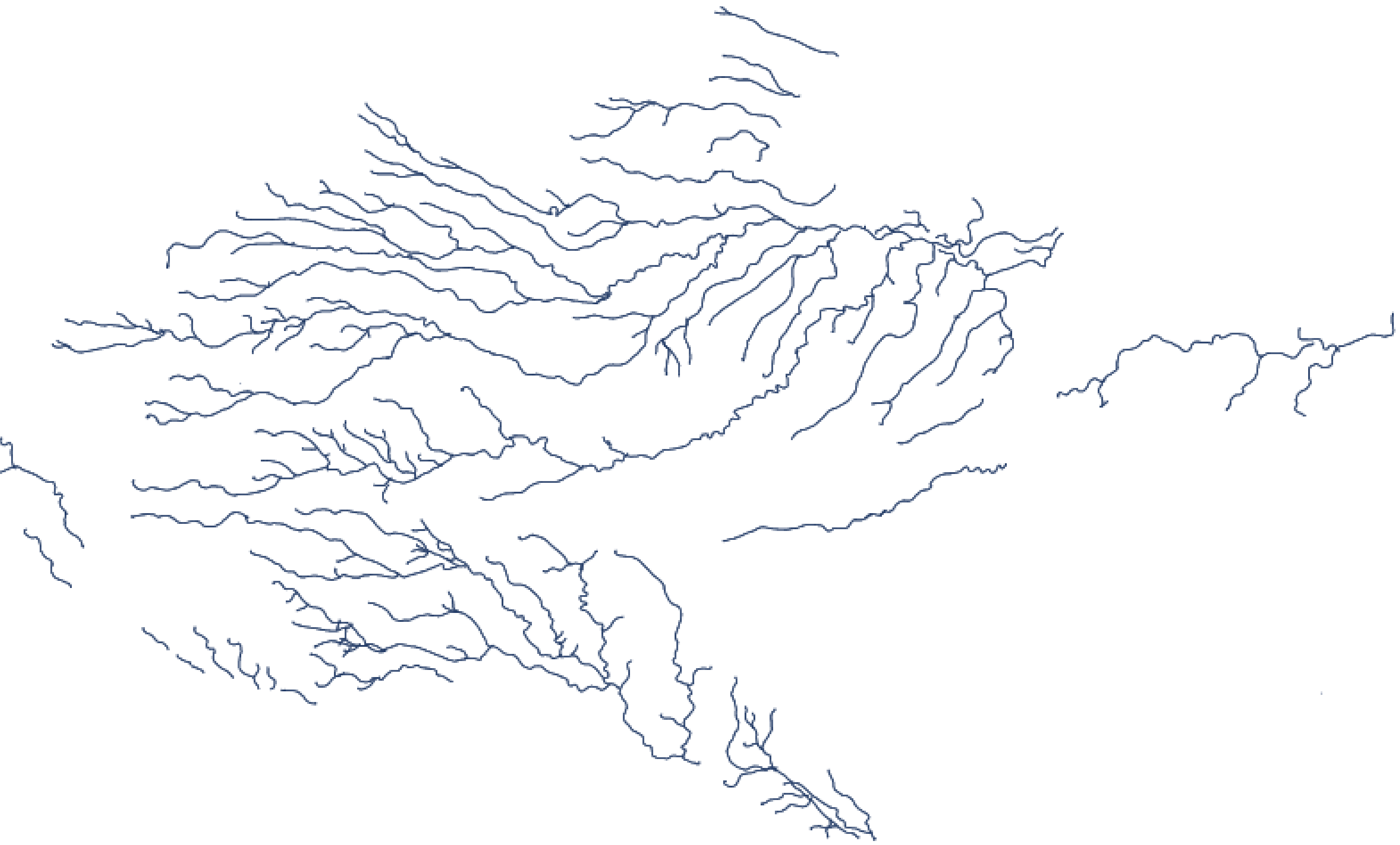
Based on Beauchamp *et al.* (2018).

Assessing well-being in practice comes with several **challenges**. First of all, different stakeholders: individuals, communities, conservation experts, and governmental organisations may have different understandings of well-being, as well as its measurement. As described above, it is not recommendable to enforce externally defined well-being concepts on people from an ethical viewpoint (Milner-Gulland *et al.,* 2014). Even within groups, well-being differences exist, for example between people of different economic status, gender, religion, etc. They may also differ in their valuation of ecosystem services, and perceive their contribution to their well-being differently. Averages therefore tend to hide winners and losers of interventions. Power relations and politics need to be understood (Coulthard *et al.,* 2018). Finally, Coulthard *et al.* (2018) emphasise that the relationship between the environment and human well-being is the result of multiple drivers at various time scales and levels ranging from “microsocial processes” to “global economic change”. As outlined in the previous chapters, the SESF allows us to consider various levels.

4. Empirical Case

"And I can tell you that one day
I'll invite you to Kenya
and you will swim on Nairobi River."

- LE2 (16.04.21)



4.1. Identification of the SES-phenomenon

In this chapter, I analyse the introduced case. The chapter is organised as follows. First, I present the configuration of action situations key for the identified SES phenomenon (chapter 4.2). Subsequently, I analyse the actors involved in the identified action situations (chapter 4.3), and the external factors influencing the focal SES-phenomenon (chapter 4.4). The chapter ends with a summary of the case findings (chapter 4.5).

In this analysis, I partly draw on steps and guidelines developed by McGinnis and Ostrom (2014) and Schlüter *et al.* (2019). However, as the used framework (see chapters 3.3.5 & 3.4) is a hybrid of various different developments, I do not strictly follow one specific guideline, but elaborate on the specific steps I have taken in the analysis. According to McGinnis and Ostrom (2014), the first phase of using the framework is to define the phenomenon, and to identify the components to be studied. Similarly, Schlüter *et al.*'s (2019) first step is to determine the SES-phenomenon one wants to explain. In this case, the phenomenon to be explained is the pollution of the Nairobi River Basin. The geographical boundaries are therefore those of Nairobi (see Map of the Nairobi river basin on page 17). A statement from the *toxic flow* report sets the scene:

*"Somewhere deep inside its rotten belly, it also carries dead people,
some victims of the immorality and impunity annihilating the stream. The latest clean-up discovered 14 bodies, most of them foetuses and babies wrapped in polythene bags. It is a convenient place to dump unplanned, unwanted foetuses and stillborns.
Just how many have been disposed of this way? No one knows."
- Toxic Flow (2019)*

According to Schlüter *et al.* (2019), the second step is to identify the action situations at the core of the phenomenon. The action situations and actors presented in the following chapter do not represent an exclusive list, and particularly regarding the governmental actors, more authorities are involved. To get an overview of further human stakeholders, please see the Nairobi river basin pollution - stakeholder map on page 18. I follow the recommendation of Schlüter *et al.* (2019), and focus on the most important action situations and actors.

4.2. Action situations

Subsequently, I outline the determined action situation(s) and their outcome(s). Outcomes and interactions were determined based on the coding of secondary material. Interactions were determined directly from secondary material and by deriving them from outcomes, e.g., if industrial pollutants are found in the river basin, there is necessarily an interaction of pollution between the industry and the river. In the following, I outline the action situations involved in the pollution of the Nairobi river basin, starting with those interactions between numerous human actors and the rivers of Nairobi, i.e., the **social-ecological action situations,** and then continue with the ecological and social action situations involved. I also outline the (intermediate) outcomes of the focal phenomenon for Nairobi's population.

The actors that most often occurred in the context of the river basin pollution were the **riparian residents**. These include the residents of informal settlements, as well as residents of lavish estates (Toxic flow, 2019). Riparian residents pollute the rivers with (a) solid waste (Leapfrog Projects, 2020; LE2, 16.04.21); (b) human waste (Bauza *et al.,* 2019; Kamau and Njiru, 2018; Leapfrog Projects, 2020; Mbui *et al.,* 2016; Mugo, 2006; Toxic flow, 2019); and (c) various other domestic substances (Mbui *et al.,* 2016). The residents of informal settlements mainly pollute the rivers with human waste, while those of lavish estates also pollute with large amounts of domestic garbage (LE2, 16.04.21). In general, pollution by riparian residents can enter the rivers directly; form "stagnant pools of water" and therefore "breeding grounds for mosquitoes and flies outside people's houses" (Bickel et al., 2000 cited in Gallaher *et al.,* 2013, p. 11); or the waste, wastewater, and faecal matter that is disposed of in drainage ditches is washed into the rivers via precipitation (Gallaher *et al.,* 2013; Kamau and Njiru, 2018).

Human waste pollutes the rivers due to open defecation (Kamau and Njiru, 2018; Mbui *et al.,* 2016); leaks (Bauza *et al.,* 2019; Leapfrog Projects, 2020); poor maintenance of pit latrines resulting in overflows; sanitation facilities which are directly connected to rivers (Kamau and Njiru, 2018; Mugo, 2006); improper disposal of the faecal matter of children especially (Bauza *et al.,* 2019; Kamau and Njiru, 2018; Sarkar, 2020); and flying toilets, i.e., the use of plastic bags for defecation, which are then disposed on the road, roofs or in a river (Sarkar, 2020).

Other polluting substances include organic waste (Mbui *et al.,* 2016), general domestic wastewater, waste from markets (Toxic flow, 2019), detergents, bleaching agents, and disinfectants (Mbui *et al.,* 2016). Domestic effluents have several effects on the river. They result in an increased electrical conductivity of the rivers (Mbui *et al.,* 2016); an increased biochemical and chemical oxygen demand (K'oreje *et al.,* 2016); contamination with enteric pathogens (Bauza *et al.,* 2019); locational increased sulphate levels (e.g. due to detergents) (Mbui *et al.,* 2016); high concentrations of manganese (Toxic flow, 2019), especially during the dry season (e.g. due to bleaching agents, disinfectants, and from natural sources) (Njuguna *et al.,* 2017); locational, high chromium levels during the dry season (e.g. due to detergents); and high levels of phosphates (e.g. due to detergents, fertilisers, surface water runoff, and decomposition of organic matter) (Mbui *et al.,* 2016). Furthermore, heavy metals enter the rivers via the surface run-off at the neighbouring dumpsite (Toxic flow, 2019). The management of solid waste also plays an important role in terms of collection: Garbage collection has been licenced to private operators, whose operations are not monitored and of which some will “dump it somewhere that nobody is seeing them dump” (LE2, 16.04.21). Informal settlements (as well as the pharmaceutical industry, the dumpsite, and agriculture) contribute to the contamination of the rivers with pharmaceuticals (Bagnis *et al.,* 2013; K'oreje *et al.,* 2016; Ngumba *et al.,* 2016).

The second main actor directly contributing to the pollution of the rivers in Nairobi is the **industry**. The polluting matter contains both solid industrial waste, as well as (toxic) industrial wastewater from various industries, including the cement industry (LE2, 16.04.21; Toxic flow, 2019), the leather industry, breweries, and electroplating industries (Leapfrog Projects, 2020). The industries of the city use the rivers as a dumpsite, contaminating them with pollutants, such as hazardous industrial chemicals on a daily basis (Toxic flow, 2019). Not only formally established businesses, but also commercial activities of the residents of informal settlements tend to be highly polluting (Toxic flow, 2019). Garages along the rivers pollute them with oil, paint, chemicals, and vehicle parts (LE2, 16.04.21; Mbui *et al.,* 2016; Toxic flow, 2019). The rivers are contaminated with iron which originates from industries (Mbui *et al.,* 2016) (e.g. tanneries, which also pollute the rivers with chromium (Njuguna *et al.,* 2017)), manganese-based pesticides, and the burning of fuel (Part two, 2019). Another metal found in dangerous concentration in the rivers is lead (Mbui *et al.,* 2016; Part two, 2019), which might enter via effluents from car wash facilities, painting activities (Mbui *et al.,* 2016), and the dumpsite (Njuguna *et al.,* 2017). Industries that mine metals, produce organic chemicals, and iron and steel plants pollute the rivers with cyanide. In addition, cyanide comes from the burning of waste and the exhaust of vehicles (Part two, 2019). The burning of waste, as well as industrial effluents, the light industry, car washes, and garages may contribute to the pollution with polychlorinated biphenyls (Ndunda and Wandiga, 2020). Selenium is found in dangerous quantities in the rivers as well. The element is used, for example, “to make batteries, solar cells, alloys and glass” (Part two, 2019). Industrial effluents also contaminate the rivers with zinc and arsenic (Njuguna *et al.,* 2017). In addition, high levels of copper[12] and ammonia were discovered, but no specific cause has been identified (Part two, 2019).

The rivers are also polluted by **agricultural activities** (Leapfrog Projects, 2020; Mbui *et al.,* 2016; Toxic flow, 2019) – upstream e.g., through greenhouse farming (Toxic flow, 2019), urban agriculture, and livestock (Mbui *et al.,* 2016). However, based on the sighted secondary data and the interview with LE2 (16.04.21), I have concluded that farming activities primarily take place up- and downstream, and not so much in Nairobi itself. Thus, farmers will not be investigated further in this thesis.

Besides the polluting activities elaborated, various actors have tried to clean and regenerate the rivers of Nairobi. These actors included international NGOs, the government, and communities themselves (Leapfrog Projects, 2020). Below you can find a summary of all key social-ecological interactions that have been described so far.

Interactions: Social-ecological interactions (I3)

- Riparian residents polluting the rivers with solid waste.
- Private waste collectors polluting the rivers with solid waste.
- Riparian residents polluting the rivers with human waste.
- Riparian residents polluting the rivers with various other domestic substances.
- Private waste collectors disposing their waste at the official dumpsite.
- (In)formal commercial activities (industry) polluting the rivers with solid industrial waste.
- (In)formal commercial activities (industry) polluting the rivers with industrial wastewater.
- Farmers polluting the rivers via farming activities and livestock.[13]
- Various actors regenerating the rivers.

"From a river full of life to a sewer, it is now a mass of death-filled sludge."
– Toxic Flow (2019)

To sum up the **ecological state** of the Nairobi river basin: it is polluted by domestic activities of households of diverse socio-economic status, agricultural, and industrial activities, including formal and informal activities. The rivers contain plastics, consumer waste, oil, cement, paint, medical waste and drugs, human and animal waste, domestic and industrial waste and wastewater, metal, vehicle parts, chemicals, and human bodies (Leapfrog Projects, 2020). They are furthermore polluted with ammonia, phosphates, fluorides, chlorides, sulphates, chromium, cyanide, lead, selenium, copper, manganese, zinc, and iron (Mbui *et al.,* 2016; Njuguna *et al.,* 2017; Part two, 2019). The rivers show dangerous levels of

[12] While Mbui et al. (2016) describes copper levels below WHO standards, they are described as crossing recommended guidelines of 0.05ppm in Part two (2019).
[13] Mainly up- and downstream of Nairobi – is not investigated further in this thesis.

phenolic compounds and very high concentrations of bacteria (total coliforms, total faecal streptococcus, and Escherichia coli) (Part two, 2019). Moreover, the pollution of the rivers' waters also results in a contamination of sediments and the rivers inhabitants (Part two, 2019). Both sediment and fish "were found to contain chromium, arsenic, cadmium, lead, selenium, copper, aluminium, manganese, barium and iron" (Part two, 2019). A list of the key ecological, non-human outcomes is shown below.

Outcomes: Non-human ecological performance measures (O2)

- River water contains various pollutants, such as: plastics, consumer waste, oil, cement, paint, medical waste and drugs, human and animal waste, domestic and industrial waste and wastewater, metal, vehicle parts, chemicals, human bodies, ammonia, phosphates, fluorides, chlorides, sulphates, chromium, cyanide, lead, selenium, copper, manganese, zinc, and iron, phenolic compounds, and bacteria.
- Sediments and inhabitants of the river, such as fish are contaminated with various pollutants.
- The plants and animals of the river basin "have lost the fight a long time ago" (Leapfrog Projects, 2020).

This pollution poses threats to Nairobi's population and its wellbeing (Leapfrog Projects, 2020). The water of the Nairobi river basin is not safe to use for domestic purposes, let alone for drinking (Mbui *et al.,* 2016). The river water is used for bathing, washing (Sarkar, 2020), and irrigation (Leapfrog Projects, 2020). Some sources say that the river water is used for drinking (Leapfrog Projects, 2020), and that water vendors and kiosks obtain water from the rivers (Kamau and Njiru, 2018) – others have not identified the rivers as a source of drinking water (Sarkar, 2020; Winter *et al.,* 2019). The water of the rivers used to be drinkable, and their fish edible. Kids used to play in the rivers, and they were a source of recreation. These things seem impossible today (Leapfrog Projects, 2020).

Consumption of the polluted river water poses various **health risks**, elaborated in the following and summarised in a list below. High chloride and TDS[14] concentrations in the water result in a change of taste (and colour). High TSS[15] values of the water and high sulphate levels may lead to gastrointestinal irritations. High levels of fluoride can lead to dental and skeletal fluorosis (Mbui *et al.,* 2016). Especially lead, manganese, and chromium found in the river are concerning, due to their toxicity (Mbui *et al.,* 2016; Njuguna *et al.,*

[14] Total dissolved solids refer to "inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions" (World Health Organization, 2003, p. 1).
[15] "Total suspended solids (TSS) are defined as solids in water that can be trapped by a filter" (Ismail *et al.,* 2018).

2017). Manganese damages the liver and respiratory system, is a neurotoxin, causes birth defects, aggressive behaviour, forgetfulness, hallucinations, and respiratory inflammations (Mbui *et al.,* 2016; Part two, 2019). Lead, on the other hand, is carcinogenic (Njuguna *et al.,* 2017), damages most body systems, and causes “anaemia, weakness, kidney and brain damage”, or even death (Part two, 2019). Chromium is carcinogenic as well (Njuguna *et al.,* 2017). Furthermore, the various metals found in the rivers have contributed to an increase of diseases, such as cancer (Leapfrog Projects, 2020; Toxic flow, 2019). Selenium can accumulate in the body and can damage nerves and cause fatigue (Part two, 2019). Copper also damages nerves and particularly the liver. Nausea, diabetes, and vomiting are symptoms of an overconsumption of iron (Part two, 2019).

Not only the final result: river pollution, but also the intermediate outcomes of the SES phenomenon impact the health of the residents (Part two, 2019). The lack of a proper waste management system and adequate sanitation facilities result not only in river pollution, but also causes diarrheal diseases and contributes to “malnutrition, malaria, and acute respiratory infections” (Kamau and Njiru, 2018, p. 322). These diseases particularly contribute to child mortality (Kamau and Njiru, 2018; World Resources Institute *et al.,* 2007; Zulu *et al.,* 2011). Communicable diseases are common in informal settlements, and cholera outbreaks occur (Sarkar, 2020). The contamination of rivers with antibiotics may result in further antibiotic resistances (Ngigi *et al.,* 2020). The human right to clean water can hardly be fulfilled “as long as the rivers and lakes of Kenya continue to be polluted and poisoned” (Leapfrog Projects, 2020).

Outcomes: Human performance measures (O1)

- Infringement of the human right to clean water for Nairobi’s population.
- Gastrointestinal irritations, diarrheal diseases, and malnutrition.
- Damage of various organs, increased danger of cancer, and multiple other health effects from metal pollution.
- Malaria and respiratory infections.
- High prevalence of communicable diseases.
- Antibiotic resistances.

Non-humane, ecological interactions (see also list below) are, for example, the flow of water, dilution, and surface runoff. The **flow** of water in a river means that water constantly travels down the stream, carrying its pollutants with it. The speed by which it flows, i.e., the flow velocity, thereby affects the pollution at a specific location (here: in Nairobi) because the faster the river flows, the faster the pollutants are carried away. This flow velocity is affected by the feed-in rate of the river/ the amount of water coming from upstream, as well as precipitation. Furthermore, precipitation dilutes pollution by increasing the water volume. A lack of precipitation (diminishing rains) therefore magnifies the concentration of pollutants (LE1, 24.03.21). In Nairobi, dilution during the wet season has, for example, been found to result in lower levels of manganese, chromium, chemical, and biochemical oxygen demand, compared to the dry season (Mbui *et al.,* 2016). However, precipitation does not only have a diluting effect, but can also increase the concentration of certain pollutants via surface runoff. This effect of precipitation depends on the characteristics of the surface the precipitation meets. Soils may naturally contain geological pollutants that can be washed into rivers, or have accumulated pollutants via human activities (LE1, 24.03.21). In Nairobi, higher concentrations of phosphates, sulphates, and chloride were found during the wet than the dry season. This was attributed to surface runoff from phosphate and sulphate rich soils. Additionally, phosphate increasingly enters the rivers during the wet season due to a higher decomposition of organic matter. Soils can also be contaminated by chlorides, e.g., due to human waste, livestock, or fertilisers, and hence increasingly enter the rivers during the wet season (Mbui *et al.,* 2016). The interviewed local ecologist also mentioned the effect of roads near rivers whose surface runoff collects pollutants from the exhausts of fumes (LE1, 24.03.21). Plants such as water hyacinths can induce natural attenuation, reducing, for example, the pollution with pharmaceuticals, as well as decreasing biochemical and chemical oxygen demand, turbidity, and TSS (K'oreje *et al.,* 2016), and macrophytes can remove heavy metals from water (Njuguna *et al.,* 2017). Vegetation near the rivers stabilises the soil, reduces soil erosion, and therefore the count of TDS in the rivers (Mbui *et al.,* 2016). However, riverbank vegetation has suffered from clearings for farming activities (City Council of Nairobi, 2013 cited in Njuguna *et al.,* 2017).

Interactions: Non-human ecological interactions (I2)

- Flow of water.
- Precipitation and feed-in from upstream diluting the concentration of pollutants.
- Surface runoff collecting pollutants and increasing the river pollution.
- Plants attenuating pollution.
- Vegetation stabilising the riverbanks, inhibiting further pollution.

Purely **human interactions** to consider, include the interactions between the various human actors that have been working on the regeneration of the Nairobi river basin, such as international NGOs, communities, and the government (Leapfrog Projects, 2020). I refer to the actors working on the regeneration of the river basin as *regenerators*. Important action situations to be considered between these actors, in working towards the common goal of the regeneration of the basin, are information sharing and deliberation, defined as “[s]haring information or knowledge between actors” and “[c]ommunicating, exchanging observations and views, reflections, assessing outcomes, [and] persuading each other” (Schlüter *et al.,* 2019). Unfortunately, these very action situations seem to be lacking, as projects are developed in isolation and actors miss out on sharing information and supporting each other (Leapfrog Projects, 2020). Similar challenges occur regarding the evaluation of projects, as the results are not (sufficiently) documented (Leapfrog Projects, 2020). Social monitoring is practically not happening: everyone is contributing to the pollution of the rivers and no-one is opposing it (Toxic flow, 2019).

“They are doing it day and night, with gay abandon”
- Toxic Flow (2019)

Further human action situations are happening within the government, as it sets up and enforces rules (or: fails to do so) regarding the treatment of solid waste, industrial waste, and faecal matter, as well as pollution of rivers and land use in general. Interactions contributing to cleaner rivers also include efforts to improve the management of waste and faecal matter, such as providing infrastructure including sanitation facilities and access to water, implementing a waste collection system, or raising awareness and distributing knowledge on the importance of a healthy river ecosystem. Here, diverse actors are involved, such as authorities, international institutions, and NGOs. On the governmental side, the Ministry of Water and Sanitation and Irrigation is responsible for “[i]mproving the provision of water and sewerage services” (Ministry of Water and Sanitation, n.d.), and the sub-ordinate Water Sector Trust Fund is assisting “in financing the development of and management of water and sanitation services in the marginalised and underserved areas” [sic.] (Water Sector Trust Fund, n.d.). For Nairobi itself, the Nairobi City County has a sub-department to improve the provision of water and sanitation (Nairobi City County, n.d.). In addition, there are water utilities, such as the Nairobi City Water & Sewerage Company (NCWSC) involved to provide water and sanitation services (Leapfrog Projects, 2020). Importantly, in 2019 NEMA wanted to arrest the managing director of the company for discharging untreated sewage into the Nairobi River (Kihiu, 2019). The Nairobi City County is responsible for waste management (Nairobi City County, n.d.), and several waste and recycling companies exist (Leapfrog Projects, 2020). Private actors involved in the provision of water and sanitation services and waste management are elaborated under the heading *Regenerators*. For a better overview, key human interactions are listed below:

Interactions: Human interactions (I1)

- Regenerators not sufficiently sharing information.
- Regenerators not sufficiently engaging in deliberation.
- Regenerators not sufficiently evaluating and documenting projects.
- Government setting up policies and laws on solid waste, industrial waste, faecal matter, environmental protection, and land use.
- Government not sufficiently implementing policies and enforcing rules.
- Various actors not sufficiently providing infrastructure, such as sanitation facilities and water access.
- Private operators providing waste management services.
- Riparian residents not engaging in social monitoring.

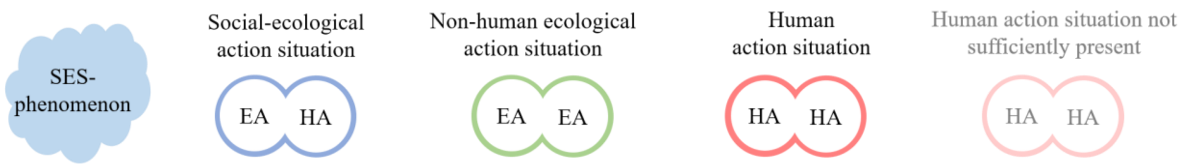
As described above, the pollution of the Nairobi river basin is not the result of a single action situation, but of a configuration of action situations and their diverse actors (see Figure 20); and while the boundaries of the SES to be studied here have been identified geographically as the area of Nairobi, the effects of the pollution are unfortunately not bound to this area and pose **externalities to SES** downstream. The rivers of the basin join first the Nairobi River and then the Athi River. The Athi River then flows further towards the east until it reaches the Indian Ocean. The pollutants, such as heavy metals, that enter the rivers of the Nairobi basin therefore take up a long journey throughout the country (Toxic flow, 2019). Pharmaceuticals entering the rivers in Nairobi were, for example, still found 75 km downstream (Bagnis *et al.,* 2013). While the pollutants that entered the rivers in Nairobi get diluted on the way (K'oreje *et al.,* 2016), the Athi River also picks up more pollutants downstream (Toxic flow, 2019). On its journey, the water of the Athi River is used to irrigate flowers and crops, such as pineapples and maize (Toxic flow, 2019), for livestock and domestic purposes, including drinking (Wafula, 2019). According to Njuguna *et al.* (2017), especially the high levels of manganese, iron, lead, and chromium found in the Nairobi river basin, which exceed WHO standards, are concerning regarding the downstream use of the water for domestic purposes and crop irrigation. Produce of the farms along the Athi River gets exported or sold in Kenya (Part four, 2019). According to a member of the Nairobi Irrigation Bord (cited in Part four, 2019), "[i]f we do not take punitive actions today to deal with pollution, the impact of the heavy metals will be felt 20 to 50 years from now and this will be too late". It is safe to say that the pollution of Nairobi's rivers affects large parts of Kenya's population, and in the light of climate change, plays a key role for Kenya's resilience. It threatens public health and the human right to clean water beyond Nairobi (Leapfrog Projects, 2020). These effects fall under the second-tier component *externalities to other SES (O3)*, as shown in the list below.

Outcomes: Externalities to other SES (O3)

- Pollution of the rivers downstream.
- Pollution of flowers and crops downstream.
- Negative health effects beyond Nairobi.
- Infringement of the human right to clean water for Kenya's population.
- Infringement of Kenya's resilience.

Based on the previously presented references, Figure 20 on page 79 displays the configuration of action situations identified in this chapter. Social-ecological action situations are shown in blue, non-human ecological action situations in green, and human action situations in red (see Figure 19). The slightly faded, red action situations display those human action situations that are not sufficiently present, and whose absence is of importance for the focal SES-phenomenon. Connections between individual action situations are displayed as arrows. For simplicity, the arrows have not been labelled and only the most important connections are presented.

Figure 19 Legend for figure 20



On the bottom half of Figure 20, mainly polluting activities are displayed. While waste is collected by various private operators, these services are not used by all residents and industry actors some of which may prefer to dump the waste illegally in/at the river. Furthermore, waste collectors may not transport the waste to the official dumpsite but instead dump it somewhere in the environment. Even if the waste is disposed of at the official dumpsite in Nairobi, leakages continue to pollute the river basin. A lack of water and sanitation services results furthermore in the improper disposal of wastewater, domestic effluents, and human waste in the riparian environment.

Human action situations include governmental activities of making and enforcing rules – or the lack thereof. Social monitoring of polluting activities could impact the pollution, but seems to be absent. The polluting activities mean that pollutants enter the river basin either directly, for example, when a sewer is connected to the river, or indirectly. The latter could be, for example, the dumping of waste and sewage in drainage channels. These pollutants are then washed into the rivers via precipitation. Indirect pollution also includes a contamination of soil via farming[16], which then enters the rivers via surface runoff, or an improperly managed dumpsite via precipitation.

The top half of the figure depicts action situations that counteract the pollution of the river basin. Non-human ecological action situations include the flow of water, dilution, attenuation, and stabilisation. The effectiveness of dilution and attenuation depends on how polluted the water is, as well as the substances that pollute it. Attenuation further depends on the existence of specific plants. The stabilisation of riverbanks is dependent on the existence of riverbank vegetation, which has been described as diminished by increasing farming activities along the riverbanks. Dilution and surface run-off are further connected. An increase in precipitation increases dilution, but at the same time may increase the pollution by substances that enter the river basin, via surface run-off.

In terms of human action situations, regeneration activities, such as clean-ups and infrastructure provision, affect the state of the river basin. Regeneration activities are influenced by emergent outcomes of human action situations such as deliberation, information sharing, and evaluation.

[16] Farming is displayed in light grey in Figure 20, as it is only of minor importance within Nairobi.

Figure 20 Configuration of action situations of the Nairobi river basin pollution

4.3. Actors

In the next step of the analysis, the individual action situations are further investigated. To do so, I look at the individual actors participating in the various action situations. I draw on the second- and third-tier components outlined in chapters 3.3.5 and 3.4. I look for these in the literature relating to the river pollution in Nairobi, to determine whether these components are of importance in generating the emergent phenomenon. To analyse the river basin and its water, I draw on the *ecological system-* and *non-human ecological actors*-tiers. Flow, dilution, surface-runoff, stabilisation, and attenuation are captured es ecological action situations using the *ecological rules*-tier (chapter 4.3.1). I draw on the *human actors*-tier to analyse the (riparian) residents, the industry, and the regenerators, and the *governance*-tier to look at the involvement of the government and its authorities (chapter 4.3.2).

4.3.1. Non-human ecological actors

The focal **ecological system** is the river basin of Nairobi (Table 5). The sector (ES1) of the river basin is *water*. The boundaries of the system (ES2) are rather unclear because the rivers are not confined by the boundaries of the city (Leapfrog Projects, 2020), and therefore the parts of the rivers flowing through the city are affected by what happens upstream, and themselves affect what happens downstream. This also implies, that the incentive to stop pollution and regenerate the rivers is affected by the activities upstream: if the river water that enters Nairobi is polluted anyways, why should the people of Nairobi not pollute as well? In addition, the basin includes many small rivers, rather than just one big river (Askumo, 2015), which further contributes to the unclarity of the system boundaries. The size (ES3) of the individual rivers is small, but the basin includes many rivers (Askumo, 2015). Thus, the size could be described as fragmented. The fragmentation and the lack of clear boundaries contribute to the pollution as such that it might be easier to clean up one big river, compared to many small ones, as well as to monitor activities and enforce rules. In addition, the rivers do not follow the political division of Kenya, meaning its different parts fall under different administrations which would need to co-operate on the issue (Leapfrog Projects, 2020). Human constructed facilities (ES4) influencing the ecological system include both informal settlements, as well as expensive housing and commercial buildings that encroach on the rivers (LE1, 24.03.21; LE2, 16.04.21; Toxic flow, 2019). From these facilities, waste enters the rivers, and pit latrines and sewage outflows are connected to the rivers (Kamau and Njiru, 2018; LE1, 24.03.21; Toxic flow, 2019). In relation to the pollution of the river basin, the productivity of the river system (ES5) can be described as the speed by which the polluted river water is cleaned by natural, ecological processes. According to the consulted ecologist, this depends on the volume of the water, the flow velocity, as well as the presence of certain plants (and of course, the level and type of pollution present). The water volume affects the state of the rivers in so far that a higher volume of water means a comparatively lower concentration of pollutants. A higher flow velocity of the river means pollutants are transported downstream quicker, meaning that a certain area is *cleaned* faster compared to a lower flow velocity. Flow velocity and water volume are affected by human activities, such as extraction of water, the feed-in rate, as well as precipitation (LE1, 24.03.21). Furthermore, pollutants can get filtered out of the water by plants through a process known as attenuation (K'oreje *et al.,* 2016; Njuguna *et al.,* 2017). The relevant processes (non-human ecological action situations): attenuation and dilution were outlined in chapter 4.2. The role of the feed-in is further taken up in chapter 4.4. So are the external factors that affect flow velocity and water volume, such as seasons and climate change. As described by Ostrom (2009), it is easier to organise collective action upon a system that is predictable i.e., when people can be rather certain that an action will yield benefits. According to the interviewed ecologist, river systems are predictable (ES7) from an ecological point of view: “Rivers wait and react” (LE1, 24.03.21). The interviewee mentioned here that the challenge does not lie with the predictability of the system, but rather the growth of the human population, economic growth, and the increasing shortage of water resources, as well as the execution of regeneration activities in practice (LE1, 24.03.21). The location (ES9) of the rivers is key as such that if they were not located in Nairobi, the anthropocentric factors polluting them would not be present. Particularly, their location at informal settlements, but also commercial activities and expensive housing determine their state of pollution. Their existence is, as described before, a reason why people settle there. The rivers flow through informal settlements because riverbanks are flood-prone areas where nobody else would settle (Winter *et al.,* 2019). At other locations, land next to the rivers has a higher value – which is why expensive houses and commercial buildings are located there (LE1, 24.03.21). The history of the rivers (ES10) is relevant as such that they have been polluted for decades (Kithiia, 2007; Leapfrog Projects, 2020). According to LE2 (16.04.21), the basin used to be clean, but human activity has polluted it severely particularly since independence. Therefore, pollutants have had time to embed themselves into the ecosystem (LE1, 24.03.21): not only the water of the rivers is polluted, but so are its sediments, plants, and animals (Part two, 2019), making the regeneration more challenging (LE1, 24.03.21). From a human perspective, the long history of pollution might mean that change is hard to imagine, particularly because so many initiatives have resulted in little change (Leapfrog Projects, 2020). Consequently, changing this narrative and getting people motivated to make yet another attempt to regenerate the rivers might be challenging.

Table 5 Ecological system

Water	
ES1	Water
ES2	Unclear system boundaries
ES3	Fragmented: many small rivers
ES4	Informal settlements, expensive housing, and commercial estates Pit latrines and sewage outflows connected to the rivers
ES5	Water volume; flow velocity; vegetation
ES7	Predictable
ES9	Nairobi; informal settlements; expensive housing, commercial activities
ES10	History of pollution; little success of regeneration initiatives

The **non-human ecological actors** of the river, that are of interest in this case, is the water that flows through it (Table 6). The water of the rivers is mobile in a sense that it just *flows away,* but also highly constrained by the path of the rivers (EA1). Its replacement rate (EA2) depends on the season, and is higher during the wet season (LE1, 24.03.21). The river water interacts (EA3) with other ecological units of the system, such as surface run-off and the water up- and downstream; vegetation stabilising river basins and filtering the water; the animals living in the rivers; and the rivers' sediments (Mbui *et al.,* 2016). Some of these interactions (flow, dilution, pollution by surface run-off, stabilisation, and attenuation) are displayed as individual action situations in Figure 20. The contamination of plants, sedimentation and animals are not explicitly displayed in Figure 20, but are included in the overall phenomenon of river pollution. The question of the (economic) value (EA4) of the rivers is a tricky one in so far that it depends on the actor considered (see sub-chapter: *Riparian residents*). Nevertheless, if the water of the rivers was clean, the (economic) value of the rivers could possibly increase by becoming drinking water, suitable for irrigation, and a place of recreational activities. The number of ecological units (EA5), i.e., the water volume of the rivers, is seasonally dependent (LE1, 24.03.21; Mbui *et al.,* 2016), but never enough to satisfy Nairobi's demand for water (World Resources Institute *et al.,* 2007). There are no distinctive markings (EA6) relevant here, and the water of the rivers can be described as a congestible, public good that is expected to become increasingly rival in the light of climate change and during the dry season. The spatial distribution of the water (EA7) follows the path of the rivers and is seasonally dependent (Mbui *et al.,* 2016). This is important as far as described above for the ecological system.

Table 6 Non-human ecological actors

Water	
EA1	Mobile, but path dependent
EA2	Feed-in rate and precipitation, dependent on the season
EA3	Interactions with surface runoff, and up- and downstream water; inhabitants of the river; vegetation; and river sediment
EA4	*See riparian residents – A8*
EA5	Seasonally dependent, not enough to satisfy Nairobi's needs
EA7	Seasonal; path-dependent

Ecological Rules to be considered (Table 7) are, for example, the flow and dilution of river pollutants and the increased surface run-off during the wet season (Mbui *et al.,* 2016). These have been presented as non-human ecological action situations above. Other ecological rules to consider are the contamination of sediment and the rivers inhabitants (LE1, 24.03.21; Part two, 2019), attenuation, and soil stabilisation (K'oreje *et al.,* 2016; Mbui *et al.,* 2016; Njuguna *et al.,* 2017). The latter two are presented as ecological action situations, while the contamination of sediment and river life is included in the SES-phenomenon of pollution.

Table 7 Ecological rules

Physical, chemical, and biological rules	
ER	Flow – dependent on the season Dilution –dependent on the seasons Surface runoff – dependent on the seasons Stabilisation of soil Attenuation of water Contamination of sediment and river inhabitants

4.3.2. Human actors

Riparian residents

Subsequently, I analyse the riparian residents and those of their attributes that impact the action situations they are involved in. As elaborated before, there are three action situations in which the riparian residents are directly involved with the river: pollution by solid waste; pollution by human waste; and pollution by other substances (Table 8). These are investigated here together, and differences between them are pointed out as necessary.

The riparian residents include those of informal settlements located along the rivers, but also inhabitants of more formal housing who direct their sewage into the river. The number of riparian residents (HA1) involved can be described as high, considering the population of

Nairobi and the numerous small rivers running through Nairobi. As outlined in the demographic trends in chapter 4.4, Nairobi's population is expected to rise further. This makes the regeneration complicated in a sense that a case of only one or two big polluting sources could probably be easier and more efficiently tackled, compared to many small sources.

The well-being (HA2) of the riparian residents is key, particularly considering those that live in informal settlements. About 60-70 percent of Nairobi's population live in informal settlements on very little space. Their material well-being is low, considering that they live in inadequate housing and do not have access to proper sanitation facilities and clean water (Kamau and Njiru, 2018). The unreliable supply of water (Sarkar, 2020); the high economic burden of buying water and paying fees for using sanitation facilities; the distance; and the lack of female only facilities mean that, at times, residents may have to resort to open defecation or flying toilets (Kamau and Njiru, 2018; Sarkar, 2020; Winter *et al.,* 2019). Exposure to environmental hazards affects the residents' bodily well-being negatively through "a high prevalence of communicable disease and a lack of access to essential services such as sanitation, solid waste management, water and electricity" (Sarkar, 2020, p. 217). Therefore, factors that contribute to the pollution of the rivers, such as the lack of appropriate sanitation and solid waste management, also negatively affect the residents' health. The lack of sanitation, for example contributes to diarrhoea, "malnutrition, malaria, and acute respiratory infections" (Kamau and Njiru, 2018, p. 322). Children particularly suffer from the lack of adequate housing, sanitation, and health services (Zulu *et al.,* 2011). The pollution of the river basin itself can also affect the bodily well-being of the residents, depending on what the river water is used for (Part two, 2019). In terms of security, the residents of informal settlements face tenure insecurity because they do not have a title of deeds (Kamau and Njiru, 2018; Sarkar, 2020), as well as violence and crime (Sarkar, 2020). The lack of security becomes particularly problematic during the night, when women and children cannot use sanitation facilities (Amnesty International, 2010; Kamau and Njiru, 2018). Finally, it shall be considered that the residents of informal settlements are not a *homogenous mass* but a diverse, heterogeneous group of people in terms of income, "mobility, livelihood opportunities, nutritional status, food security, and health outcomes"(Zulu *et al.,* 2011, S194).

"Some families that cannot afford to buy water from the vendors search for alternative sources during times of shortage. These alternative sources include the Gitaturu and Mathare rivers. A few families, especially those whose houses are located near the river, use the river water when taps run dry. Since the river water is dirty, it is used mostly for bathing, washing clothes and utensils, and for flushing toilets."
- Sarkar (2020, p. 225)

The history or past experience (HA3) of Nairobi's residents can be described as such that the river basin has been polluted for decades, and that regeneration projects have had very limited success (Kithiia, 2007; Leapfrog Projects, 2020). The location (HA4) of residents along the rivers makes it convenient for them to use the rivers as a place for disposing all unwanted. The location also carries dangers such as flooding (Winter *et al.,* 2019). It must not be forgotten that the informal settlements emerged along the rivers exactly because these are not particularly safe places (Winter *et al.,* 2019). The norms (HA6) present are as such that it is normal to dispose all kinds of waste in the rivers, and there is no social monitoring of polluting activities (Toxic flow, 2019). Nevertheless, the responsibility for the dire situation is blamed on the industry (Leapfrog Projects, 2020). Therefore, environmental norms asking to take responsibility for one's environment seem to be lacking, as well as respect for the laws protecting the environment (LE2, 16.04.21). There is also a lack of knowledge and awareness (HA7) about "the importance of healthy river ecosystems and water management" (Leapfrog Projects, 2020).

"Everybody cares about what gains they are getting from... it is like a river that passes near my house instead of connecting to the server, the existing sewer line, I prefer doing it through the river so that I don't pay some levy to the government. […]
If I have some garbage, domestic garbage, I want to throw it in the river when nobody is watching that I don't pay collectors to do it.
So that is the attitude that has really messed up our river."
- LE2 (16.04.21)

However, some things seem to be changing. Recently more and more youth and women groups have started speaking out about the river pollution and engage in cleaning it up (HA5): "Urban communities right now are starting being more vigilant and more proactive on matters of cleaning of the rivers". According to LE2, an increased exposure of young people to the outside world has increased awareness and knowledge on the issue. The high youth unemployment has also contributed, requiring young people to think "without the box", for example on the fact that only healthy rivers carry fish allowing for economic activity (LE2, 16.04.21).

The importance (HA8) of the river (water) to the riparian residents depends on the type of residents. One main value of the rivers, for both informal settlements, as well as residents of expensive houses along the river, is the disposal of waste and sewage (LE2, 16.04.21). For some, the river basin has value as a place to relax and enjoying its beauty (LE1, 24.03.21). For the residents of informal settlements, the water has also value for domestic purposes, such as bathing and washing (LE1, 24.03.21; Sarkar, 2020). For many purposes, the rivers are too polluted. Even to irrigate plants, Nairobi's residents seldomly use the river water (Gallaher *et al.,* 2013). For those who are better off, the rivers have value in terms of location and "the value of land next to water is normally higher" (LE1, 24.03.21). In the face of climate change and if the water was clean, the rivers' value for the different actors could change. Another interesting role to be at least mentioned here is that of insurance companies. As people have been encroaching on the rivers and in case of floods tried to claim insurance money, insurance companies have started to react. If insurance companies no longer insure facilities encroaching on rivers, this will affect the value of the land along the rivers and the overall pollution situation (LE1, 24.03.21).

"So, the value changes [...] If they are actually working with the United Nations is totally different from the person who is using the river as a source of water to wash every day. They are both values - but totally different."
- LE1 (24.03.21)

A major contributing factor to the focal SES-phenomenon is the lack of sanitation facilities and waste management in the informal settlements (HA9) (Gallaher *et al.,* 2013; Kamau and Njiru, 2018; Sarkar, 2020). For example, in Kibera, only one percent of the households are served by a public garbage collection system (Gallaher *et al.,* 2013). The amount of sanitation facilities is not sufficient either. For example, in Mathare there are 16 times less sanitary facilities than the minimum standard for a humanitarian crisis. Even if sanitation facilities are available, as described before, they may overflow and thereby pollute the rivers, or even be directly connected to them (Kamau and Njiru, 2018). Regarding facilities for the disposal of wastewater, the channels are open, small, and poorly maintained (Gallaher *et al.,* 2013). This infringes the residents of informal settlements in their freedom of choice, as they do not have many other options than disposing their waste, human waste, and wastewater in Nairobi's rivers.

"In other words, refugees living in a refugee camp are likely to have more sanitation facilities per population than residents of Mathare slums."
- Kamau and Njiru (2018, p. 331)

Table 8 Actor (1)

Riparian residents	
HA1	High number of riparian residents
HA2	Residents of informal settlements: poor material well-being; poor bodily well-being; lack of security; lack of freedom of choice and action
HA3	Used to the pollution of the river basin and failure of regeneration projects
HA4	Location along the rivers
HA6	Normalisation of river pollution; blaming of the industry; potential lack of environmental norms
HA7	Lack of knowledge and importance of a healthy (river) ecosystem
HA8	Waste disposal; domestic use; location
HA9	Lack of sanitation facilities, access to water, waste management

Industry

The role of the industry in polluting the rivers has been displayed in two action situations of pollution: river pollution with solid waste, and river pollution with industrial wastewater (Table 9). Here, they are treated together, but we shall consider that the two problems might be driven by different attributes, such as a lack of different infrastructures. It shall also be considered that the industry can not only directly pollute the rivers, by directing its solid waste and waste waters into the rivers, but also by polluting surfaces, and pollutants entering the rivers via precipitation. Nairobi has numerous (HA1) (in)formal businesses/ commercial activities (Financial Sector Deepening Kenya, 2017; Leapfrog Projects, 2020). The high number of commercial activities complicates the situation as such that it might be easier to ensure that a few businesses treat their waste(water) correctly, compared to many very small businesses– in terms of logistics but also economically. In general, Nairobi's businesses lack waste(water) treatment plants, some of the waste "going directly to the river" (LE2, 16.04.21). The industry has been polluting the rivers for decades and the consequences have been very limited (Leapfrog Projects, 2020), making the incentive to change something quite small (HA3)[17]. Particularly for those located along a river (A4), the river is the simplest way to dispose industrial waste. As for residents, it is also normal for the industry to dispose waste in the rivers - everyone does it and no one hides it (Toxic flow, 2019). It therefore seems that there is a lack of norms (HA6) that pertain to one's responsibility for the

[17] Recently, the government has increased enforcement of laws protecting the rivers – see *Government*.

environment, and a priority of profit over the environment. Nevertheless, there are good practice examples of companies that take up responsibility towards the environment (LE2, 16.04.21). In terms of knowledge on SES (HA7), there clearly seems to be a lack of knowledge and awareness about "the importance of healthy river ecosystems and water management" (Leapfrog Projects, 2020). The river basin seems to be important (HA8) to the industry primarily as a mean of disposing waste and wastewater.

Table 9 Actor (2)

Industrial actors	
HA1	Numerous
HA2	Formal and informal businesses/commercial activities
HA3	History of pollution and limited consequences
HA4	Proximity to the rivers
HA6	Normalisation of river pollution; blaming of the riparian residents; potential lack of environmental norms; exceptions exist
HA7	Lack of knowledge and importance of a healthy (river) ecosystem
HA8	Primarily as waste and wastewater disposal method

Government

The government is an important actor when it comes to the making of rules and their enforcement (Table 10). Policy areas (GS1) that touch upon the SES phenomenon are related to a protected, safe environment, as well as to the provision of sanitation facilities, clean water, and waste management (for residents and the industry), agricultural policy, land use policy, and the development of informal settlements. A recent change to consider was mentioned by one of the interviewees. Accordingly, Kenya is re-mapping its wetlands which will result in making certain areas "off limits to physical infrastructure", which can be interpreted as a sign of change on the side of the government (LE1, 24.03.21).

The geographic scale (GS2) of the government is contributing to the problem in so far that it does not align with the paths of the rivers. Thus, the authorities of different counties would need to collaborate to ensure a clean river basin (Leapfrog Projects, 2020). At 4.735 million (Central Intelligence Agency, 2021b), the population (GS3) the authorities of Nairobi have to manage is quite big, and constantly increasing (see chapter 4.4.). The informal character of the city (Leapfrog Projects, 2020) and the mobility of riparian residents of informal settlements (Beyer *et al.,* 2016; Zulu *et al.,* 2011) may add to the challenge.

Regarding Kenya's regime type (GS4), three characteristics have been mentioned. The devolved system, i.e., that the national government gives responsibilities, such as waste management to the regional governments, is important. Secondly, LE2 (16.04.21) expressed a positive attitude towards the handing of responsibilities of some government departments to the army: “we have started seeing good progress, because now the army is able to do a lot of good work”. Thirdly, the importance of the election cycles and the uncertainty that comes with them has been pointed out (LE2, 16.04.21), affecting the priorities of politicians (Leapfrog Projects, 2020).

A key rule-making organisation (GS5) is the Ministry of Environment and Forestry. It is responsible for environmental protection, and the corresponding policies and regulations (Leapfrog Projects, 2020; Ministry of Environment and Forestry, n.d.). Under the ministry, the National Environment Management Authority (NEMA) safeguards the environment (National Environment Management Authority, n.d.a). NEMA is “the principal instrument of the Government of Kenya in the implementation of all policies relating to the environment”, and advises, supervises, and coordinates everything that relates to the environment (Leapfrog Projects, 2020; National Environment Management Authority, n.d.b).

Regarding the rules in use (GS6), the lack of enforcement of laws on environmental protection has been criticised. According to Toxic flow (2019): “[a]uthorities that should be keeping the environment safe either are overwhelmed or have stopped caring”. This is in line with the experience of LE2 (16.04.21), who points out that the problem is not “the absence of laws, there have been laws in place, there have been policies in place”, but the lack of implementation – the government fails to “follow up on the laws”. However, from 2018, on the media has repeatedly reported inspections of informal settlements, as well as expensive houses, malls, and businesses by the NEMA with regards to river pollution (Ambani, 2018; LE1, 24.03.21; Wabala, 2020) “because they were designed and utterly built on the river system” (LE1, 24.03.21). In 2018, the media reported that 4000 buildings would be demolished along the riverbanks to combat pollution (Charo, 2018), and in the following years similar reports kept coming (Mabonga, 2019; Omondi, 2018; Onyango, 2019a; Onyango, 2019b).

“The Nema operation will specifically target riparian encroachment by both formal and informal settlements, industrial set-ups, and other activities such as garages, farming, food kiosks, latrines, solid waste transfer stations, waste recycling and car wash.“
- Wabala (2020)

NEMA has been carrying out these activities in collaboration with the Nairobi City County (Charo, 2018; Omondi, 2018), which also has a mandate to rehabilitate Nairobi's rivers (Nairobi City County, n.d.). Polluters, such as landlords and business owners who have failed to adjust to the regulations, have been arrested (Kihiu, 2019; Mumo, 2020). In 2020, NEMA has also announced the increase of their staff to ensure the enforcement of regulations (Wabala, 2020). According to an interviewee, this recent change at the government comes from the realisation that "the water systems are drying up. They are affecting people not only upstream, downstream, everywhere". The interviewee disclosed confidence in the fact that the government really does want to change things, but also mentioned that "the majority of the land that was sort of misallocated to such infrastructure, was by the same politicians, it belongs to the same politicians. So there's a bit of a challenge there" (LE1, 24.03.21). LE2 (16.04.21) who has been working more directly with the pollution of the basin seems less optimistic than LE1, stating that: "But now the government I think the government has not done... even on a scale of one to 10 I can't even give them three, you know? I can't. I can't." LE2 (16.04.21) also points out that the enforcement of laws is based on political conveniences.

Another factor contributing to the river pollution is the property rights system (GS7), or rather the lack of property rights of residents of informal settlements. Without formal land titles, residents struggle to get access to water and sanitation facilities (Kamau and Njiru, 2018), and in the past projects have been "'hijacked' by slum lords, who 'own' the land, and have formidable economic and political influence over their majority tenants" (Mugo, 2006, p. 154). Furthermore, "[u]rban communities are very capitalistic and lack basic social structures", meaning that it is rather difficult to mobilise communities (GS8) (Mugo, 2006, p. 155). Those belonging to the government tend to have *personal political agendas* which may collide with the river regeneration, and prefer projects with quick results and a minimal danger of public failure to ensure re-election (Leapfrog Projects, 2020). In addition, corruption is a widespread phenomenon hindering resources from being spent on what they are supposed to (Charo, 2018; Leapfrog Projects, 2020). Nevertheless, according to the increased activity of the NEMA, the re-mapping of the wetlands, and projects such as the

Michuki Park[18] can be interpreted as positive changes regarding the norms and values present in the government.

Table 10 Governance system

Government	
GS1	Protected, safe environment; provision of sanitation facilities, clean water, and waste management; agricultural policy; land use policy, urban development
GS2	Geographical scale of governance does not align with the paths of the rivers, i.e., would require inter-county collaboration
GS3	Increasing population; mobility of informal settlement residents; going beyond the geographical scale of Nairobi
GS4	Devolved system; involvement of the army; importance of election cycles
GS5	Ministry of Environment and Forestry; National Environment Management Authority (NEMA); Nairobi City County
GS6	Lack of enforcement on rules of environmental protection; recent improvements
GS7	Residents of informal settlements lack land titles
GS8	Lack of community norms; personal agendas and corruption are the norm – possible change towards environmental norms

Regenerators

Numerous human actors (HA1) have attempted to regenerate the Nairobi river basin, ranging from NGOs, over the government to communities themselves (Table 11) (Leapfrog Projects, 2020). Regenerators include, for example, the African Development Bank in the Nairobi Rivers Basin Rehabilitation and Restoration Program (African Development Bank Group, 2018), and the Ministry of Environment and Mineral Resources in the Nairobi River Basin Rehabilitation Program (Ministry of Environment and Mineral Resources, n.d.). Attempts to regenerate the Nairobi river basin may also include the provision of water and sanitation facilities, and waste management infrastructure. Regarding the provision of water and sanitation infrastructure, international organisations, such as the World Bank (The World Bank Group, 2020), USAID (USAID, n.d.), and NGOs, such as The Water Project (The Water Project, n.d.) are involved. The civil society is present, for example, via KEWASNET (KEWASNET, n.d.; Leapfrog Projects, 2020). Regarding the waste management of the industry, the Kenya National Cleaner Production Centre is key (Leapfrog Projects, 2020). Furthermore, mainly private operators with licences are involved in garbage collection. According to LE2 (16.04.21), this is a result of the devolved system of governance: the

[18] According to LE1 (24.03.21) the regeneration of Michuki Memorial Park is a good example of where the river has been reclaimed and the ecosystem regenerated. The former dumping side is now a park where people can relax (LE1, 24.03.21). The Kenyan Forest authority and the NEMA were involved in the regeneration of the area. According to the media, the regeneration started when President Uhuru recognised the terrible state of the area and instructed the Ministry of Environment to take action (Star Reporter, 2020).

government gave the responsibility of garbage collection to the regional authorities, and some of the regions are now “doing very badly”.

Problems that have been faced in the attempts to regenerate the rivers are, for example, budgetary constraints (HA2). The past experiences (HA3) of these actors are related to multiple attempts and failures to regenerate the river. The actors are located (HA4) within the communities, at various governmental levels, or internationally. One major problem is related to leadership (HA5). The various initiatives have been working in isolation, and there is no leadership or integration between them (Leapfrog Projects, 2020). With regards to sanitation, there is not only a lack of integration, but even competition between foreign led organisations in areas such as Kibera. They compete for space, clients, and brand visibility in Nairobi, which has been described as the “Silicon Valley of shit” (De Lima, 2020, p. 99). While interactions between actors providing sanitation are “usually friendly […] social entrepreneurs and NGO employees were often heard to gossip and criticize each other’s organizations, questioning their motivations and effectiveness and undermining each other’s initiatives” (p. 100). The overlapping in service provision is also caused by local authorities who, motivated by the rewards of bringing more organisations into the area, fail to provide information on existing activities (De Lima, 2020). The norm (HA6) seems to be that everyone works for themselves and transparency is lacking. This has effects on the knowledge available on the SES (HA7), as this mode of work does not allow for exchanging learnings, let alone failures. There also seems to be a lack of understanding on the importance of integrating all the relevant direct and indirect stakeholders of the SES to regenerate the river basin (Leapfrog Projects, 2020).

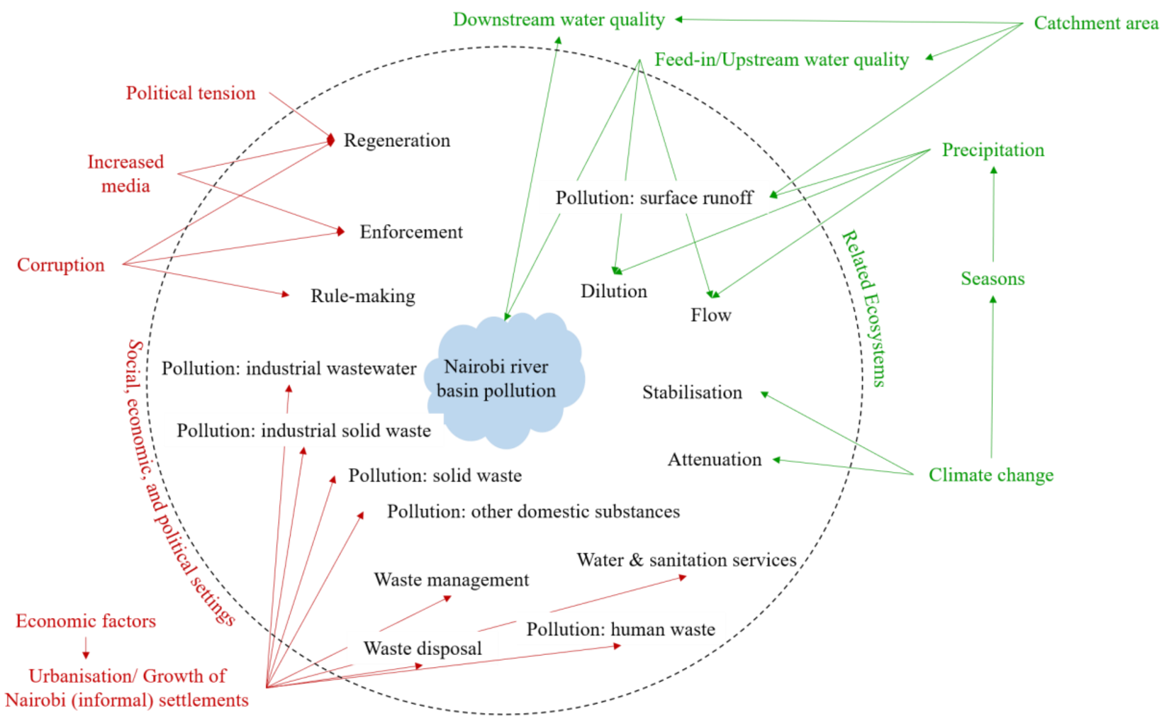
Table 11 Actor (3)

Regenerators	
HA1	Several
HA2	Budgetary constraints
HA3	Multiple failures to regenerate the rivers
HA4	Community; government; international
HA5	Lack of integration of initiatives/ leadership
HA6	Lack of norms of sharing and transparency; norm of isolated work and competition
HA7	Lack of sharing knowledge and understanding the importance of integrating stakeholders

4.4. Related ecosystems and social, economic, and political settings

Besides action situations, the focal SES phenomenon is also influenced by external factors. I consider as external factors those that are stable within the space and time under investigation (Schlüter *et al.,* 2019), or happen outside of the SES boundaries, as defined for the task at hand. The external factors identified below are displayed in Figure 21, outside of the circle. External factors of the tier *related ecosystems* are coloured in green, and those of the tier *social, economic, and political settings* are displayed in red. Arrows indicate which action situations (in the circle) are affected by which external factor. These relations are described in the following, but for reasons of simplicity, the arrows are not labelled in the figure itself.

Figure 21 Nairobi river basin pollution - external factors



One external, macro-level factor that falls under the category of **related ecosystems** (Table 12) is climate change (ECO1). As previously described, climate change will increase water scarcity, as well as the severity of floods and droughts (The World Bank Group, 2016). Looking at the Nairobi river basin pollution, the alteration in precipitation will affect the dilution of pollutants in the river water, as well as surface runoff. Climate change has already affected the seasons, making the timing of their occurrence less predictable, and therefore affecting the in-flows of the river basin. Thus, climate change affects the volume of water the rivers carry and their flow velocity – and has an impact on the concentration of pollution (LE1, 24.03.21). The growth of plants could also be affected, and thus the action situations of attenuation and stabilisation. In addition, climate change will also have indirect effects, for example if rains fail to appear and more people draw on the water of rivers, then the remaining water volume will further decrease (LE1, 24.03.21). Floods will affect the state of the rivers as well. Increased water scarcity would drive crop prices up (Kreijci, 2017), and further affect the budget low-income residents have to buy clean water or use sanitation facilities. To sum up, climate change can be expected to affect those that already live at the margins the most (Kreijci, 2017); to prevent people from escaping poverty (The World Bank Group, 2016); and to result in a further deterioration of the state of the rivers – in times where its clean water would be highly needed.

Another external ecosystem factor is the *flows into and out of the focal SES* (ECO3). This is an important factor considering that the rivers of Nairobi are not confined by the city's boundaries, but originate and continue their journey outside of Nairobi (Askumo, 2015; Leapfrog Projects, 2020; Toxic flow, 2019). Therefore, it matters how much water (feed-in rate and upstream precipitation) and in what state the river water enters Nairobi. The upstream water quality is likewise affected by human activity and how the lands within the catchment area are operationalised. According to LE2 (16.04.21), the source of Nairobi River: Ondiri wetland, used to be polluted by farmers (chemical fertilisers, some containing metals), industrial activity, and solid waste disposal. However, according to the interviewee, a lot has changed since those days and today the wetland is regenerated.

"When you come to the wetland, where the source is,
you will even be tempted to drink water from the stream."
- LE2 (16.04.21)

Furthermore, the ecological characteristics of the catchment area of the rivers are decisive (LE1, 24.03.21). Once the river(s) leave Nairobi, its water and pollutants continue their journey towards the east (Bagnis *et al.,* 2013). Downstream of Nairobi, the water of the Athi River is used for irrigation, domestic purposes, including drinking, and livestock - posing health risks to the population along the river (Wafula, 2019). "The farmers, the pastoralist communities, they are forced to give their cattle and also to irrigate their crops with contaminated water because they have no other option". Along the river, the water has quite a different value than within Nairobi: for pastoralists, it is a place to water their cattle, for farmers to irrigate their crops (LE2, 16.04.21). Finally, the river reaches the Indian Ocean, polluting the coast of East Africa and its marine ecosystems (Toxic flow, 2019).

"It's a breathing in and breathing out, it depends on the ins and outs."
- LE1 (24.03.21)

Within the geographical borders of Nairobi, precipitation could be interpreted as flows into the focal SES. Precipitation (within and outside Nairobi) is dependent on the seasons (ECO1). During the dry season, water volume and speed velocity are decreased, affecting the concentration of pollution. During the wet season, precipitation increases the water volume and flow velocity, diluting pollutants and carrying them downstream quicker. In addition, increased turbulence of the water shakes up pollutants that have accumulated in the rivers' sediments, and surface runoff may carry pollutants to the rivers. This increases pollution, and results in elevated levels especially during the beginning of the wet season (LE1, 24.03.21). These inflows to the SES are, as described above, affected by climate change, via the seasons.

"Due to climate change our seasonality have also become quite something."
- LE1 (24.03.21)

Table 12 External factors (1)

Related ecosystems	
ECO1	Climate change; Seasonality
ECO3	Precipitation; Feed-in/Upstream water quality; Downstream water quality, Catchment area

The situation is further influenced by drivers belonging to the category of **social, economic, and political settings** (Table 13), such as *demographic* trends (S2). Nairobi's population has grown rapidly and, as a consequence, lost its reputation as the *green city in the sun* (Mbui *et al.,* 2016). According to UN-HABITAT (cited in Sarkar, 2020), the city will grow further to 5.87 million inhabitants by 2025. Even with the current population of 4.735 million, the city is not able to sufficiently provide services, such as sanitation and waste management (Hendriks, 2011; LE2, 16.04.21). As growth will continue to concentrate around informal and low-income settlements, the pressure on service delivery will grow (Sarkar, 2020), and along with it, the pressure on the city's ecosystems, including its rivers. More people without adequate sanitation facilities, access to clean water, and waste management will mean larger amounts of inadequately disposed waste of all kinds. More people may result in more commercial activities, and without adequate services, more pollution by industrial waste and wastewater. Even if the waste is collected, the improperly secured dumpsite continues to pollute the rivers of Nairobi.

Furthermore, it is important to consider the reasons due to which people live in informal settlements. *Economic factors* (S1) play a role, as the lack of economic opportunities is what drives people from rural areas to Nairobi (Zulu *et al.,* 2011). They migrate to informal settlements to be able to afford the rent, but also to "save some money for investment in their rural homes" (Zulu *et al.,* 2011, S190). People stay in these settlements because they have to, or in case of economic success, to take care of and acquire more property (Zulu *et al.,* 2011).

As described in the previous chapter, in the *political* sphere (S3) corruption is influencing the situation, as funds allocated, for example to clean the rivers, simply disappear. Beyond regeneration, corruption may affect the enforcement and making of rules. Political tensions make it difficult to collaborate across groups, and personal political agendas override goals such as river regeneration (Leapfrog Projects, 2020).

As mentioned before, the *media* (S6) has increasingly reported on investigations, company closures, demolishment of encroachments along the river, and arrests of polluters by the NEMA (Ambani, 2018; Charo, 2018; Kihiu, 2019; Mabonga, 2019; Mumo, 2020; Omondi, 2018; Onyango, 2019a; Onyango, 2019b; Wabala, 2020). In 2019, the Nation Media Group, one of the biggest private media houses in Africa, accompanied "a team of scientists and toxicology experts from the University of Nairobi, tracing Nairobi River from its source at Ondiri Swamp in Kiambu all the way down its 400-kilometre path to the Kenyan coast" for two months (Part two, 2019). The report that followed designated the Nairobi River as *toxic flow* and criticised the failure of the authorities to protect the rivers, and thus the health of Kenya's citizens (Toxic flow, 2019). Some media reports attributed the subsequently increasing activities of NEMA to the *toxic flow* report (Mabonga, 2019; Onyango, 2019a). Along these lines, the increase of media attention might have also influenced regeneration efforts.

Table 13 External factors (2)

Social, economic, and political settings	
S1	Lack of economic opportunities resulting in rural-urban migration
S2	Growth of Nairobi's population is expected, particularly in informal settlements
S3	Corruption; political tensions
S6	*Toxic flow* report; reports on NEMA's activities

4.5. Summary

As the previous ~30 pages made clear: a lot is happening at the Nairobi river basin. The configuration of action situations is displayed on page 79, and the contributing external factors can be found on page 93. To conclude this chapter, I briefly summarise some of the main characteristics that contribute to the destitute situation and need to be kept in mind for any regeneration attempt. To start off, a quote from LE1 (24.03.21):

> *"Rivers will attract people, they will attract animals, they'll attract everything. And because of their geographical location, they will attract runoff, they will attract dilution, they will have all these things."*

From the **ecological viewpoint**, the fragmentation and unclarity of the system boundaries of the river basin are key. This structure requires political collaboration across county borders (Leapfrog Projects, 2020) and complicates clean-up and monitoring activities. These observations are in line with Ostrom (1990) and Anderies *et al.* (2004), who emphasise the importance of clear system boundaries. The location of the rivers along human constructions makes it easy and convenient for people to dispose their waste in them. The rivers are located close to these human constructed facilities, not by chance, but as LE1 (24.03.21) points out: because it "attract[s] people". For all the polluters, one main value of the rivers seems to be that they can dispose their waste and sewage in them. For the informal residents, the water that the rivers carry has value, as it can be used for bathing and washing (LE1, 24.03.21; Sarkar, 2020). The legacy of pollution has allowed for pollutants to get embedded in the wider ecosystem of the river sediment, plants, and animals, contributing to the challenging character of regeneration (LE1, 24.03.21; Part two, 2019). In addition, the multiple un-successful regeneration attempts make the situation daunting and might diminish people's hope in further attempts. On the positive side, rivers are rather predictable ecological systems (LE1, 24.03.21).

The concentration of pollutants in the water depends on the water volume the rivers carry as well as the flow velocity. These are affected by external ecological factors, such as seasonality and climate change (LE1, 24.03.21). Other external factors to consider are precipitation and up- and downstream water quality. Ecological rules to be considered include surface runoff, dilution, attenuation, and soil stabilisation.

From the **human perspective**, the high number of polluters, both riparian residents and industrial polluters makes the situation challenging. In general, there seems to be a lack of knowledge and awareness of the river system, and the disposal of all kinds of waste seems to be seen as *normal* (LE2, 16.04.21; Toxic flow, 2019) – resulting in a lack of social monitoring. Regarding the informal residents, several dimensions of their well-being affect and are affected by the pollution of the river basin. Inadequate water, sanitation, and waste disposal infrastructure (*material well-being)* contribute to the pollution and infringe the residents' *freedom of choice*. A lack of *security*, particularly during the night for children and women, contributes to the pollution as well. The *bodily well-being* of riparian residents is affected as well. In this context, design principle 2 regarding the importance of proportionally equivalent costs to benefits (Ostrom, 1990) is particularly interesting, as in this case the costs of pollution fall disproportionately on the residents of informal settlements.

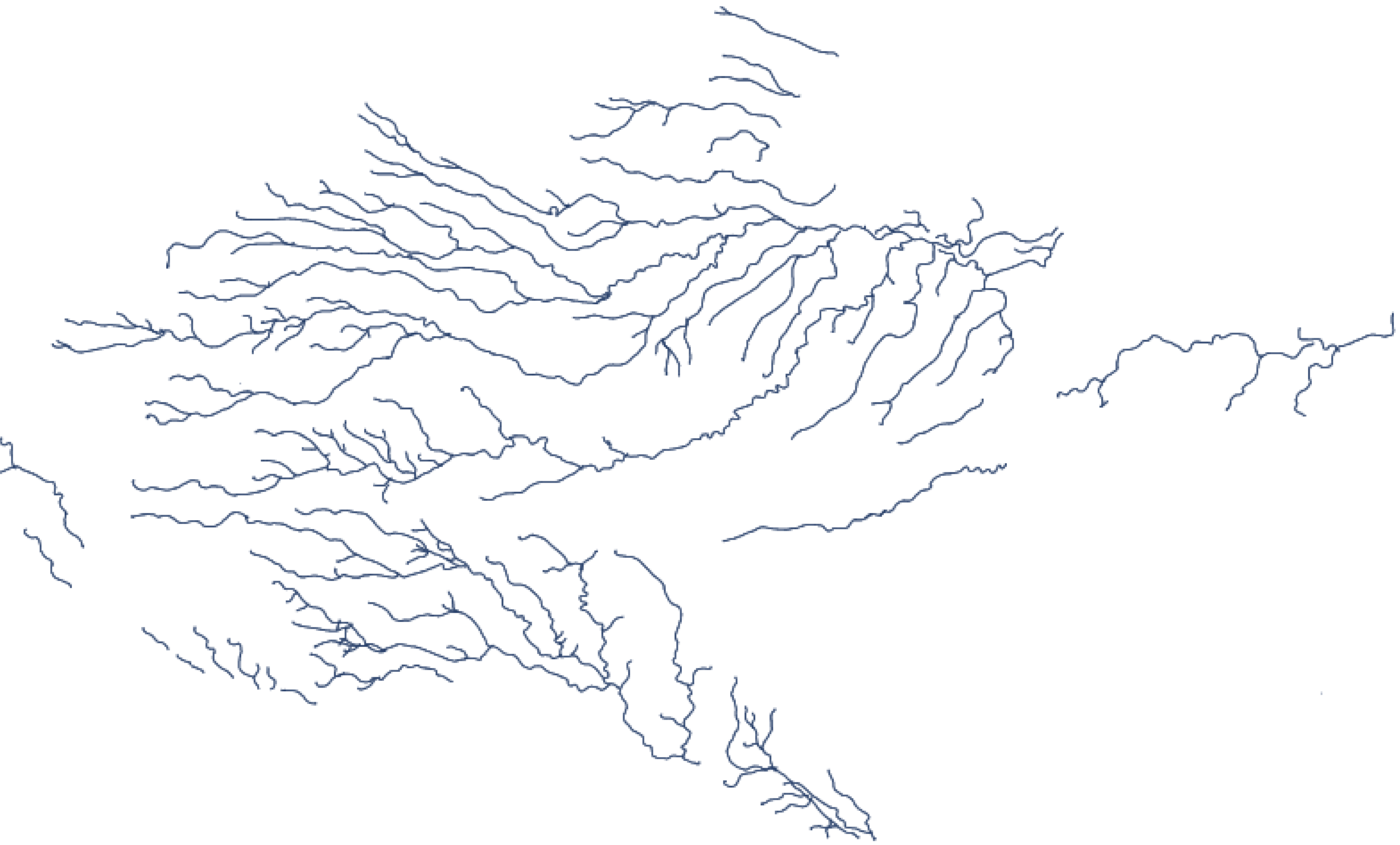
On the governmental level, as mentioned before, the geography of the rivers requires collaboration across county borders (Leapfrog Projects, 2020). Nairobi's big population and demographic trends showing a further increase especially in informal and low-income settlements, make governance and the provision of services further challenging (Hendriks, 2011; Mbui *et al.,* 2016; Sarkar, 2020). The insecurity of property rights in informal settlements is another contributing factor. In the past, the lack of governmental action on the dire situation has been especially criticised (Toxic flow, 2019). The media has reported more activity of the government in recent years, and some are hopeful that the government is motivated to tackle the pollution (LE1, 24.03.21; compare e.g. Ambani, 2018; Charo, 2018; Wabala, 2020). Nevertheless, issues of personal political agendas, corruption and personnel have been pointed out (Charo, 2018; Leapfrog Projects, 2020), and LE2 (16.04.21) seems to lack trust in a long-term change of governmental activity. Here, we can therefore draw a connection to Ostrom's (1990) design principles 4 and 5: accountable monitoring principles and graduate sanctions are lacking. External factors to consider are the economic situation in rural areas contributing to the demographic trend of urbanisation (Zulu *et al.,* 2011), and the impact of the media.

Finally, organisations working on the regeneration are multiple and originate from communities, various governmental levels, and the international field. They miss learnings because they lack coordination, transparency and leadership, and because they compete and work in isolation (Leapfrog Projects, 2020). This may be a result of their number and diversity, but also of the failure of local authorities to provide information to the entering organisations (De Lima, 2020).

5. Discussion and Conclusion

"[U]nderstanding what people mean by and aspire to for their well-being is crucial to the success of conservation measures."

- Milner-Gulland et al. (2014, p. 1161)



In this final chapter, I discuss and conclude the results of this thesis starting with the theoretical findings (chapter 5.1) and the findings of the illustrative case (chapter 5.2). Subsequently, I elaborate on the limitations the results of this study are subject to (chapter 5.3), and summarise, my answers to the research questions I set out to answer in this thesis (chapter 5.4). In the final chapter 5.5 I provide potential future research avenues.

This thesis is based on an understanding of a diversity of connections we can have with nature, ranging from material and experiential, over cognitive to emotional and physical connections (Ives *et al.,* 2017). Humans and nature are not only connected, but humanity is part of nature. We are embedded in nature (Folke *et al.,* 2016). We shape and are shaped by nature (Folke *et al.,* 2011). We co-produce and embody nature (Diaz *et al.,* 2014). We inhabit nature. We co-evolve with nature (Folke *et al.,* 2011). We depend on nature (Millennium Ecosystem Assessment, 2005). As French and Garderner (2012, p. 158 cited in Winter *et al.,* 2019) put it:

> *"[H]uman activity is not simply the product of abstract social norms and conventions, or an expression of inner, autonomous motives or drives: it is inextricably immersed in a physical, material environment that prompts, facilitates, constrains, and transmutes human action. The material world both configures, and is a product of, the everyday activity of humans."*

During the last decades, the *Anthropocene*, our impact on the biosphere has increased, degrading our very own foundation of well-being (Liu *et al.,* 2007b; Millennium Ecosystem Assessment, 2005). Interactions between human and non-human entities in SES are getting more and more complex: their scale and pace increases, they span wider distances and become increasingly indirect (Liu *et al.,* 2007b). This impact on the biosphere has not been caused to equal shares by people around the world. Instead, high income countries have degraded the earth's resources by a multiple of the impact of low- and middle-income countries (The World Bank Group, n.d.b; United Nations, n.d.). Unfortunately, in today's globalised world, and given the inter-connectedness of ecosystems, these impacts are seldomly contained within the borders of the perpetrators. Instead, challenges such as climate change affect people around the globe – whether or not they are contributing to the effect. Even more unfortunate: Countries of the Global South are particularly vulnerable to large-scale environmental challenges such as climate change (Kreijci, 2017; The World Bank Group, 2016; University of Notre Dame Global Adaption Initiative, 2018). Thus, tools tailored to the context of the Global South to deal with these challenges are urgently needed.

In response to this need, I set out in this thesis to review a prominent framework to analyse SES challenges: Elinor Ostrom's SESF; and to adapt this framework to the context of the Global South.

5.1. The SESF in the Global South

In the following, I summarise and discuss the amendments adapted to the original SESF based on suggestions by various scholars outlined in this thesis (chapter 5.1.1). I then turn to two specific topics: the wording used in the amended SESF (chapter 5.1.2) and the role of well-being (chapter 5.1.3).

5.1.1. Review of the SESF

Multiple amendments have been made to the original SESF, of which some have been adopted in this thesis. First of all, the amendments in terms of graphics and labels by McGinnis and Ostrom (2014) herself, have been adapted. Specifically, the re-labelling of the user-tier to (human) actor – tier has allowed me, in the illustrative case, to look beyond those consuming water, and include, for example, those involved in the regeneration of the rivers, as well as NGOs involved in providing water and sanitation infrastructure. This example makes clear, that we need to look beyond users, and include actors that have other relations to the focal ecological system as well. Moreover, the amendments made to include more than one group of actors by Hinkel *et al.* (2015) and McGinnis and Ostrom (2014), have been adapted and were necessary to look at multiple actors, such as regenerators, the industry, and riparian residents.

Furthermore, the proposed restructured governance tier by McGinnis and Ostrom (2014) was adopted. Overall, the structure of the governance tier was helpful to analyse the focal case. However, in some cases the second-tier components were interpreted rather loosely to tailor them to the case. For example, Ostrom *et al.* (1961 cited in McGinnis and Ostrom, 2014) describe the regime type as democratic or autocratic; monocentric or polycentric. Nevertheless, in this illustrative case, I included characteristics such as uncertainties caused by elections, the lead of certain authorities by the army, and the devolved system under the regime variable.

Further developments have been adopted deviating from the original focus of the framework. The framework originates from collective action theory, and therefore includes components that were found to be helpful to investigate the <u>institutional</u> sustainability of SES. Later on, Epstein *et al.* (2013) and Vogt *et al.* (2015) proposed amendments to broaden the framework in its scope towards sustainability in a broader sense. Their amendments are based on a critique of the lack of ecology in the framework.

Epstein *et al.* (2013) introduce an additional first-tier component: *ecological rules*, with the scope of encouraging those using the SESF to actively think about the physical, chemical, and biological assumptions they base their understanding of any SES on. Moreover, they want to allow for a more in-depth analysis of the non-human components of SES. Vogt *et al.* (2015) unpack the second-tier components of RU and RS further into third-tier components, and add the RS second-tier component: *ecosystem history*. These amendments have been very helpful in analysing the illustrative case. The third-tier components fostered my understanding of the different second-tier components, and gave guidance. In my experience, these third-tier components are therefore very useful, especially for those lacking experience of environmental sciences. The ecosystem history component has also turned out to be useful in the illustrative case. In Nairobi, the history of pollution has allowed pollutants to embed themselves in the river ecosystem, and this needs to be considered for any regeneration activities. Furthermore, the importance of this characteristic can be validated drawing on Preiser *et al.* (2018), who refer to the memory of complex adaptive systems as a decisive characteristic to be kept in mind.

Vogt *et al.* (2015) critique the central placing of the original action situation as implying that non-human entities only matter when they relate to the human interaction. Thus, they distinguish between social (human) and ecological (non-human) action situations (Vogt *et al.,* 2015). Schlüter *et al.* (2019) go even further and distinguish three types of action situations: social (human), ecological (non-human), and social-ecological action situations. Their Social-Ecological Action Situation Framework allows to look at interactions at the micro-level when looking at individual action situations, but also to capture interactions between the different action situations and how they co-produce an emergent SES-phenomena. Thus, the framework enables us to look at the relations and processes between the components of a SES. The SE-AS framework explicitly allows non-humane, ecological entities to take part in action situations, and thereby gives them agency. Moreover, Schlüter *et al.* (2019) consider not only material connections between humans and nature, but also interactions such as *enjoying.* Thus, they allow us to think about diverse connections between human and non-human entities. Nevertheless, in the focal case, only material connections are presented as SE-AS (see Limitations).

As summarised above, I have combined the original SESF with amendments by various scholars and the SE-AS framework for the amended SESF presented in this thesis. I argue that the SESF and the SE-AS framework are complementary. The tiers of the SESF are beneficial as they provide attributes that could influence the actors and action situations. While the tiers are not comprehensive lists and not all components are necessarily relevant for any SES phenomenon, they are a good starting point. The SE-AS framework allows for an analysis of the dynamics of a SES on different levels, and how its action situations co-produce an emergent phenomenon. This is key, considering that SES are characterised by relations and interactions (Biggs *et al.,* 2010; Hammond, 2017; Preiser *et al.,* 2018), and follows the recommendation of Capra and Luisi (2014 cited in Preiser *et al.,* 2018) to focus on emergent phenomena and relations.

Another strength of the amended framework is that while it distinguishes between human and non-human ecological actors for analytical reasons, it also allows us to see how these different entities co-produce macro-level phenomena. To use an idea of Folke *et al.* (2011; 2016): how they co-produce the biosphere. It insightfully shows how we depend on nature, influence each other, and belong to the same system. Moreover, the framework allows for external factors to be included. This is key as SES are "radically open" and are partly a result of their context (Preiser *et al.,* 2018). Further characteristics of SES, such as their adaptability and complexity, need to be considered in using the results of an analysis using the outlined framework (see chapter 5.3.2).

The combination of the two frameworks (SESF and SE-AS framework) has worked well for the illustrative case. However, the adaption of the different types of action situations and the ecological rules tier has turned out to be redundant in this case. What could have been captured as ecological rules, such as dilution or stabilisation, has also been captured as non-human ecological action situations, and hence the ecological rules tier did not add value. However, it must be pointed out that this could be caused by my lack of in-depth knowledge on environmental sciences – an ecologist might have applied the framework differently. Thus, no premature conclusions should be drawn.

5.1.2. Wording

As discussed in the previous sub-chapter, I have changed some of the labels used in the SESF and the SE-AS framework. The social action situation was re-named as human action situation, and the ecological action situation as non-human ecological action situation. This was done to refrain from assigning only humans the capacity to be *social,* and to remind us that the human is ecological as well. Humans are “organisms among organisms” (Adams, 2015, p. 55), and a part of nature. Interestingly, this was also pointed out by LE1 (24.03.21) who repeatedly used the term *human ecology.* The social-ecological action situation retains its name, as I have also used the term social-ecological system throughout this work (see chapter 3.2). Adjustments have also been made to second-tier components of the interaction tier. The actors and respective first (and second)-tier components are specified as *human actors* and *non-human ecological actors* to ensure that it is understood that both have acting capacity. The *resource system* was re-labelled as *ecological system.* These adjustments shift the wording of the framework away from the very anthropocentric focus of the original SESF. They may seem small, but as for example debates about gendered language in Germany have shown: language is power.

5.1.3. Well-being

In this thesis, I have argued that for the SESF to be applicable to the context of the Global South, it needs to be adapted even further. I postulate to integrate *well-being* as a component in the framework. This may not only be of use in the Global South, but especially important in this context.

Several arguments have been made for integrating well-being in environmental projects. Adams (2015) and Woodhouse *et al.* (2015) have described this as a moral obligation, and Woodhouse *et al.* (2015) have also pointed out the necessity to integrate well-being to gain legitimacy, political support, and funding (Woodhouse *et al.,* 2015). Furthermore, people “are part of these ecosystems” and act “based on their wellbeing aspirations and motivations” (Coulthard *et al.,* 2018, p. 253). Therefore, Biedenweg and Gross-Camp (2018) argue that well-being needs to be considered to succeed in conservation. For the focal case, this argument can easily be made: as long as poverty is not dealt with/ higher levels of well-being are not achieved in terms of security, freedom of choice, and material wellbeing (infrastructure), the pollution of the river basin will continue - simply because the residents of riparian informal settlements have no other choice than polluting. There is also an argument that the link works the other way round as well: that poverty reduction is dependent on conservation (Adams, 2003; Adams *et al.,* 2004). In the focal case, people’s health is affected negatively by the (bad) health of the ecosystem. The regeneration of the ecosystem and the well-being of people in the focal case are inextricably linked.

In the amended framework, well-being has been integrated as an actor-tier component using the five components developed by Narayan *et al.* (2000): material well-being, bodily well-being, social well-being; security; and freedom of choice. By integrating well-being as a second-tier component of the *human actor tier,* it functions as a factor which influences human actors, and thereby the action situations the respective human actors are part of. Via the action situations, well-being affects the SES phenomena which can feed back to the wellbeing of the actors. In the focal case, the lack of material well-being, security, and freedom of choice of the residents of informal riparian settlements results in the pollution of the river basin via various action situations. The pollution feeds back and affects the health of the riparian residents negatively.

Overall, integrating the well-being component in the framework was insightful for the focal case. The component was, however, more useful in the analysis of the residents of informal riparian settlements than, for example, NGOs (regenerators) and the industry. Thus, I suggest that the well-being component might be insightful for some of the actors of SES in the Global South, but potentially not for each of them. After all, not everyone's well-being influences or is influenced equally by challenges of SES.

While not all well-being dimensions have been used for the focal case, this is not a problem in a sense that the components of the framework are only suggestions of variables that could be helpful to look at. There are no claims made regarding the necessity to look at these variables or causal relationships. Nevertheless, the focal case also shows that it might be difficult to obtain data on well-being, particularly if one wants to go beyond the objective lens used in this work and integrate subjective and relational well-being lenses, as suggested by Beauchamp *et al.* (2018) and Woodhouse and McCabe (2018). Theoretically, integrating all three lenses of well-being (objective, subjective, and relational) is convincing, but in practice this might be challenging. Notwithstanding, no harm is done in suggesting this as part of the framework. Researchers and practitioners using the framework will then make decisions based on their study and recourses.

Finally, it shall be pointed out that the well-being component must be kept in mind not only for the initial analysis of a SES challenge, but also in proposing (and implementing) any interventions. For the focal case, for example, it might be obvious to suggest demolishing all estates on riparian land. However, especially in cases of informal settlements, this would affect the well-being of the residents tremendously.

5.2. Illustrative case

The deep intertwining of the human and non-human become inevitably clear looking at the Nairobi river basin pollution. The river basin can be understood as an indicator of human well-being: its detrimental state is a result of a lack of human-wellbeing, equality, collaboration, and care for each other and the environment. It puts a spotlight on many failures, such as the lack of water and sanitation infrastructure, corruption, political failures, and the lack of collaboration between NGOs. This study set out to generate a deeper understanding of the pollution of the Nairobi river basin as a SES phenomenon. The application of the amended SESF has uncovered a configuration of factors contributing to the pollution. Based on the findings of chapter 1, I discuss a few changes that are needed to move towards a healthy river ecosystem.

1. Implement existing legislation impartially, fairly, and empathetically

Legislation protecting aquatic environments has long been in place. Nevertheless, people have encroached on the rivers and wetland areas (LE2, 16.04.21). While the media has reported the demolishment of buildings encroaching on Nairobi's rivers in recent years, LE2 (16.04.21) points out that the demolishment of buildings has been highly politicised, and only those with a lack of political connections have had to fear consequences. LE2 (16.04.21) refers to the *Animal Farm* by George Orwell to emphasises the need for equal treatment of those encroaching on the rivers, independent of their socio-economic status and network.

While an impartial treatment of those encroaching on the rivers may seem like a good idea, I suggest that a blind enforcement of rules will hardly be enough. Instead, the protection of the river basin has to be implemented in a fair and empathetic manner, and acknowledge the motives and realities of those polluting the rivers. On the one hand, the better off population of Nairobi has built lavish estates and commercial buildings too close to the rivers by choice. They also dispose their waste and thus pollute the rivers by choice. They need to be held accountable and can be reasonably expected to change their behaviour independently without much support. On the other hand, the residents of informal settlements have encroached on the rivers out of necessity and a lack of alternatives. They pollute the rivers as a result of poor well-being and failures of the authorities in urban development. Here, the authorities have a responsibility to create real alternatives to polluting activities, such as building adequate water and sanitation infrastructure (see below). This ties in with Elinor Ostrom's (2010, p. 665) critique on public policy that tries to make "entirely self-interested individuals“ strive for more sustainable outcomes, instead of creating conditions under which humans have the chance to become their *best versions*.

2. Provide water, sewage, and sanitation infrastructure

In terms of water, sewage, and sanitation infrastructure, the government must live up to its responsibility and built adequate infrastructure, especially for informal settlements. All of Nairobi's residents must be able to access water and sanitation facilities around the clock, independently of their age, gender, and location of residence. Moreover, the industry must be able to adequately dispose their wastewater. While larger businesses might have the means to install treatment solutions themselves, this is hardly feasible for the countless small, informal businesses of Nairobi, and here the government needs to provide solutions.

3. Improve and monitor waste management

As suggested by LE2 (16.04.21), the management of both domestic and industrial solid waste is key. If Nairobi's authorities continue the licencing of garbage collection, they also need to effectively monitor collection, transportation, and disposal of these private operators. They need to ensure that licensed operators follow the regulations and that businesses adequately dispose their waste using these licenced operators. Effective solutions of waste management in informal settlements have to be found as well. Furthermore, amendments have to be made to the existing landfill to ensure leakage does not continue to pollute Nairobi's water sources.

4. Combat deeper institutional problems

In order to ensure the enforcement of (environmental) regulations for all, the deeper problems of corruption and the prevalence of personal political interests have to be tackled. While these issues are deeply rooted and difficult to eradicate, the Nairobi river basin has no time to spare, and hopeful examples, such as the study of Reinikka and Svensson (2005) in Uganda, do exist.

5. Update development policies

The problems which have resulted in the pollution of the basin are not new – the lack of access to water and sanitation infrastructure has persisted for much too long. Settlements that were meant to be *temporary* have long become permanent and require permanent solutions, not quick fixes. Development policies regarding Nairobi's informal settlements have to be reviewed, one example being the issues around property rights. Moreover, if the government wants to slow down the influx of people to Nairobi, it should also review its rural development policies and provide residents outside of Nairobi with alternatives to rural-urban migration.

6. Hold regional governments accountable

While the national government has delegated responsibilities, such as waste management to regional authorities, it would be well advised to not only delegate, but also hold these bodies accountable. Given the far-reaching consequences of a single black sheep, the national government must assume responsibility. Furthermore, it could facilitate the highly needed collaboration on the issue between the counties.

7. NGOs – become role models of transparency and collaboration

In light of the competitive behaviour of NGOs in Nairobi, the development community must ask themselves some tough questions. The number of NGOs involved in providing sanitation and water infrastructure has resulted in a true muddle. In the interest of their beneficiaries, the various actors must become transparent, communicate, and collaborate. They need to evaluate their efforts – whether they succeed or not - and share their learnings. To put it in the terms of the SESF, they need to engage in evaluation, information sharing, and deliberation.

Local authorities have mis-used NGOs to their own benefit, bringing more and more organisations in and not providing information on existing operations. As long as local authorities benefit from this muddle, change must come from the NGOs themselves: they need to communicate with each other and coordinate their activities. Considering the noble intentions they claim to have, as well as the amount of resources wasted by missed learnings, it seems counterintuitive that this has not happened yet. Moreover, LE2 (16.04.21) suggests that NGOs should take a more active role in lobbying the government to take action regarding sanitation, as well as river pollution in general.

8. Work with communities

LE2 (16.04.21) emphasised the need to work with communities, rather than just governments: "Because most of the governments rely on an election cycle that today they are here, tomorrow they are not here. […] But the communities […] The people are always there." Politicians may put their personal political interests, such as re-election, first and governments are always characterised by a certain level of temporarily. Hence, working closely with the communities themselves seems to be a fruitful approach. As LE2 (16.04.21) puts it: Building “a chain of likeminded people” along the river. This also includes another suggestion of LE2 (16.04.21): empowering youth and women groups; and thereby foster notions of stewardship. Communities themselves might also be much better able to identify what is needed to abate pollution.

9. Media – use what you have got

The recently increased activity of the government to regenerate the river basin has been attributed by some news reports to the *toxic flow* report. The media can therefore expose failures and successes related to the regeneration of the rivers and exercise pressure on the government.

10. Built knowledge and norms

Finally, the perhaps most effective leverage point to be discussed here, is to ensure knowledge on the importance of the river basin, and that norms and values of environmental conservation are present. As LE2 (16.04.21) puts it: “So I think we should have more women and youth participation and make sure that even the children in school are able to be taught about the importance of environmental conservation. […] Creating a society that is conscious about environmental conservation […].” We can also draw on Ives *et al.* (2017), who classify these connections as experiential, cognitive, emotional, and philosophical. It is easy to imagine how a society, which truly values nature and embraces the notion of stewardship, would pressure its government to provide adequate sanitation and waste management infrastructure, would engage in social monitoring, and collaborate for the greater good – however, the implementation of such a transformation is less easy. And again, environmental norms by themselves will not be able to turn things around single-handedly – even if the residents of riparian informal settlements understand the value of a healthy river ecosystem and possess strong environmental norms, they still need alternatives to pollution, such as an adequate sanitation infrastructure.

The regeneration of surface waters in Kenya is key to ensure the availability of safe water, especially for the low-income population (Kreijci, 2017). The pollution of the Nairobi river basin has far reaching effects beyond the counties borders and is a topic that “should be dealt with, like yesterday” (LE2, 16.04.21). To end on a positive note, here is what LE2 (16.04.21) said when I asked whether or not s/he feels hopeful about the situation:

"I've never been so hopeful. Because the five-year journey has taught me a lot. I have been able to interact with people who are serious and others who are jokers. And even if the serious ones are very few, their voices cannot be underestimated. So therefore, there is hope. And I can tell you that one day I'll invite you to Kenya and you will swim on Nairobi River."

5.3. Limitations

Here, I elaborate on the limitations this thesis is subject to. I start with the limitations that apply to the theoretical part of the thesis, i.e., the proposed framework, and continue with the limitations the illustrative case is subject to.

5.3.1. The SESF in the Global South

Firstly, while this work is titled "The Social-Ecological System Framework in the Global South", it draws on a specific definition of **Global South** as low- (and middle-) income countries in Africa, Asia, the Caribbean, Latin America, and Oceania, and focuses on one main characteristic: well-being. Clearly, the Global South can be defined by many more characteristics, such as a history of colonialism (see chapter 1.1.2). Moreover, I draw on one specific concept of **well-being.** Therefore, I need to acknowledge here, that while the arguments for this choice have been outlined in chapter 3.4, there might also be arguments to use other well-being frameworks or to amend the existing one based on the context the amended SESF is applied to.

Secondly, the amended framework presented in chapters 3.3.5 and 3.4 draws on amendments which are all based on Ostrom's framework, but which might carry contradicting **underlying assumptions**. While McGinnis and Ostrom (2014) point out that the framework is based on the assumption that actors are boundedly rational, Schlüter *et al.* (2019) reject this assumption and refrain from prescribing any specific theory on human behaviour.

Thirdly, I argue for including and relabelling framework tiers, and including ecological action situations based on the grounds of moving towards a less anthropocentric focus. Nevertheless, the framework is still **anthropocentric**, as it defines actors and action situations based on whether or not they are *human* (e.g., human action situation vs. non-human ecological action situation). This distinction is made for analytical reasons, in a sense that different variables need to be considered for human and non-human ecological actors. One could however argue, that given the diversity of non-human ecological actors, different categories could be set up. Whether or not this would be helpful or make the framework more complex, would need to be evaluated.

Forth, some of the **critique and limitations the SESF has received** is also valid for this amended version of it. The framework is rather general, and comparability across cases is limited. This also relates to the critique of variable definition gaps, variable indicator gaps, measurement gaps, and transformation gaps. However, in this thesis I have, compared to Elinor Ostrom, not set out to compare cases and find hypothesis valid across them. Instead, this amended version of the SESF is meant to aid researchers and practitioners to analyse individual cases of SES challenges they are concerned with. Opening the framework to more general sustainability questions, rather than institutional challenges, it seems to me that it is not advisable to look for *ultimate truths* valid for a great diversity of these challenges. Even if we would restrict the focus to the Global South, SES and their contexts are diverse, and such an *ultimate truth* could hardly do justice to these diversities.

Fifth, Hinkel *et al.*'s (2015) critique regarding the difficulties to operationalise the framework given the **complexity of SES** can also be pointed out. In this amended version of the SESF, the developments of Epstein *et al.* (2013), Schlüter *et al.* (2019), and Vogt *et al.* (2015) have been integrated to capture the ecological dynamics of SES better. Nevertheless, this remains a framework, and we should not forget that the usability of a framework, such as the one presented here, also lies in its ability to analyse complex real-world phenomena in a simple enough way for us to make sense of them.

Lastly, in amending the SESF, I draw on literature arguing for the inclusion of well-being in the context of conservation in general. However, in illustrating the use of the amended SESF, I present only **one case: river basin pollution in Nairobi, Kenya**. Therefore, I demonstrate the application in the context of one ecological system: a river basin; one country: Kenya, in East Africa; and a specific environment: an urban metropole. The outlined context must be kept in mind in transferring the results and conclusions drawn here to any other context.

5.3.2. Illustrative case

One clear limitation regarding the case is the **predominant use of secondary data**. This was due to the Covid-19 pandemic, meaning that the collection of primary data on site was not possible. Thus, the presented analysis depended on data collected prior to the pandemic and lacks the voices of the locals. While two Nairobians have been consulted via interviews, these were expert opinions rather than people directly affected or contributing to the river basin pollution. Furthermore, the predominant use of secondary data has resulted in a focus on scientific knowledge and instrumental values, neglecting local and traditional knowledge, as well as relational values locals might have towards the river basin. The lack of access to primary data has implications especially on the introduced component of **well-being,** where access to on-site data would have been decisive. This also means that the information obtained regarding the connections between well-being and the river pollution are from an objective lens, neglecting subjective and relational lenses.

The collection and triangulation of data has not only been limited by geographical constraints, but also by the **time and resources** available in the context of this thesis. In addition to the lack of primary data of those most affected and affecting the river pollution, the study also faces limitations regarding my own background in social sciences. While I have met these shortcomings by drawing on the ecological expertise of LE1 (24.03.21), it shall be kept in mind that this study was written by a student of social sciences, not an expert of river ecology. Moreover, specific data on some of the second-tier components of the framework could not be obtained. For example, I was able to determine that the concentration of pollutants in the basin depends on variables such as flow velocity and water volume, however I could not obtain exact numbers for the streams of the basin. Regarding the data on the pollutants, I only considered studies conducted within the last ten years to ensure some level of **temporality**. Nevertheless, more timely data will be required to design specific regeneration activities for the basin. The policies and laws decisive could have also been analysed further. However, the data suggested that the problems do not rely with the design of policies and laws, but rather the implementation. A deeper analysis of the various governmental bodies involved in environmental protection, sanitation, sewage, and waste management provision might have also uncovered useful information.

Further limitations arise from a **systems-thinking** point of view. First of all, in order to study the system of the Nairobi river basin, I had to draw artificial, clear-cut boundaries: I looked specifically at Nairobi, knowing very well that the rivers of the basin originate and continue outside of the county's boundaries. While the amended SESF does allow for external factors to be considered, what is external and what is internal is in the end a question of how the boundaries of the study, and therefore the system have been defined. Moreover, as pointed out by Hammond (2017): how a system and the observed reality look depends on how the boundaries of the system are defined and on the observer's position. The knowledge created in this study is mediated by me as a researcher and affected by any biases and assumptions I might carry, my experiences, background, and motivation. This applies, for example, to any judgements I have made during the research process regarding the relevance of studies and data.

Most importantly, we need to remember that any analysis using the SESF does not claim to determine causal relationships. In line with Schlüter *et al.* (2019), the amended SESF is a tool I have used to determine **one possible hypothesis**, which according to my best knowledge is as close to reality as possible, but I do not claim that this hypothesis *IS* reality. Rather, it is a version of reality mediated by me as a researcher, as well as countless other researchers whose studies I have drawn on in this thesis.

Finally, we also need to remind ourselves of Preiser *et al.* (2018): SES challenges "cannot be definitely solved", and the characteristics of complex adaptive systems set out in chapter 3.2. SES adapt and learn (Preiser *et al.,* 2018), are dynamic, are characterised by non-linearity, thresholds, and uncertain and unpredictable behaviours (Gallopin *et al.,* 2001). Consequently, any interventions in SES may have disproportionate effects, unforeseen consequences and even result in novel challenges (Poli, 2013). Thus, we need to manage them with humility and an understanding of the need to continuously learn (Gunderson and Holling, 2001 cited in Liu *et al.,* 2007b). Any of the recommendations made for the regeneration of the river basin, therefore, need to be constantly reviewed and rethought as the system changes and evolves.

5.4. Concluding thoughts

In this thesis, I make the case for tailored tools to analyse SES-challenges in the Global South. I base this need on the erosion of the biosphere, and thus the erosion of humanity's foundation of well-being (Liu *et al.,* 2007b; Millennium Ecosystem Assessment, 2005), as well as the vulnerability and lack of preparedness to build resilience to emerging social-ecological challenges in the Global South (University of Notre Dame Global Adaption Initiative, 2018). In the following, I conclude the findings of this thesis with regards to the original research questions posed. The first research question I set out to answer in this thesis is:

> **RQ1**: How applicable is the Social-Ecological System Framework to social-ecological phenomena in the Global South?

As described in chapter 1.3, RQ1 contains two elements: (1) the applicability to social-ecological phenomena; and (2) the context of the Global South. Regarding the first part, the

SESF originates from collective action theory, and hence, is applicable to questions of institutional sustainability, such as: Why are some irrigation systems in a certain country managed successfully by their users, while others are overstrained? Adapting the amendments proposed by various scholars, especially Epstein *et al.* (2013), Schlüter *et al.* (2019), and Vogt *et al.* (2015), the focus of the framework shifts away from institutional towards more general sustainability. A framework that takes these developments into account is therefore suitable for analysing social-ecological phenomena in general.

Regarding the context of the Global South, I have drawn on conservation and well-being literature to argue for the need to include well-being as a framework component. I present arguments to do so, such as ethical considerations and the interdependence of human and environmental well-being. Moreover, I propose to integrate the well-being framework developed by the *Voices of the Poor* study (Narayan *et al.,* 2000) and if feasible, use objective, subjective, and relational lenses. These amendments, I argue, make the SESF more applicable to the context of the Global South. They allow us to explicitly consider the motives and realities of human actors participating in the focal SES-phenomenon. The illustrative case has shown the necessity to do so, especially regarding the low-income population.

In the second part of the thesis the developed amended SESF was applied to the river basin pollution in Nairobi. The pollution has been reported for decades (Mbui *et al.,* 2016), and can be described as a node for many of Nairobi's challenges (Leapfrog Projects, 2020). Considering the water-scarcity present in Kenya, the regeneration of the river basin is of great importance (Kreijci, 2017). Thus, the second research question I set out to answer in this thesis is:

RQ2: How can these insights be used to analyse river basin pollution in Nairobi?

The aim here was to test and illustrate the application of the amended SESF, as well as to gain knowledge on the Nairobi river basin pollution. Overall, the application of the amended SESF was insightful. The framework allowed for an analysis of the configuration of action situations contributing to the pollution of the basin, and a deeper analysis of the individual human and non-human ecological actors, the ecological, and the governance system. Based on the analysis, I was furthermore able to identify ten leverage points which are key for the regeneration of the basin.

With this thesis, I contribute to the theoretical development of the SESF. I review and assess major developments of the SESF proposed by various scholars and connect them into an amended SESF. The proposed framework allows for an analysis of: human, and non-human ecological dimensions of a SES's micro-and macro-levels; both processes and system components; and reciprocal interactions of the actors on different levels. Moreover, I bring in the concept of well-being to enhance the applicability of the framework to the Global South. The amended SESF presented in this thesis is a contribution towards the development of tools for scholars and practitioners to analyse SES in the Global South thoroughly and systematically. It therefore contributes to providing the basis for (long-term) success in developing responses to SES-challenges in the Global South. Moreover, by amending the language used in the framework, I make a first step away from the anthropocentric focus with which the SESF has been originally developed. I illustrate the value of the proposed amended SESF with its application to the Nairobi river basin pollution. Regarding the river basin pollution in Nairobi, I provide an analysis of the actors and processes contributing to the phenomenon, as well as possible leverage points.

Finally, I demonstrate in this thesis how the SESF can be applied *remotely*. This was not by choice, but rather a result of the circumstances of the COVID-19 pandemic. As the pandemic is on-going at the time this thesis is submitted, and resources of those implementing a version of the SESF might be limited, this might be useful to other scholars. However, it must be stated that the success of an application of the framework using predominantly secondary sources greatly depends on the availability of data on the specific case. I also recommend that such a remote analysis should only be seen as a *first step,* and additional data collection is highly recommended before and during the undertaking of any interventions on the ground. A remote analysis may function as a first step and provide researchers and practitioners with some orientation and an initial picture of the SES-challenge on which further research can be based.

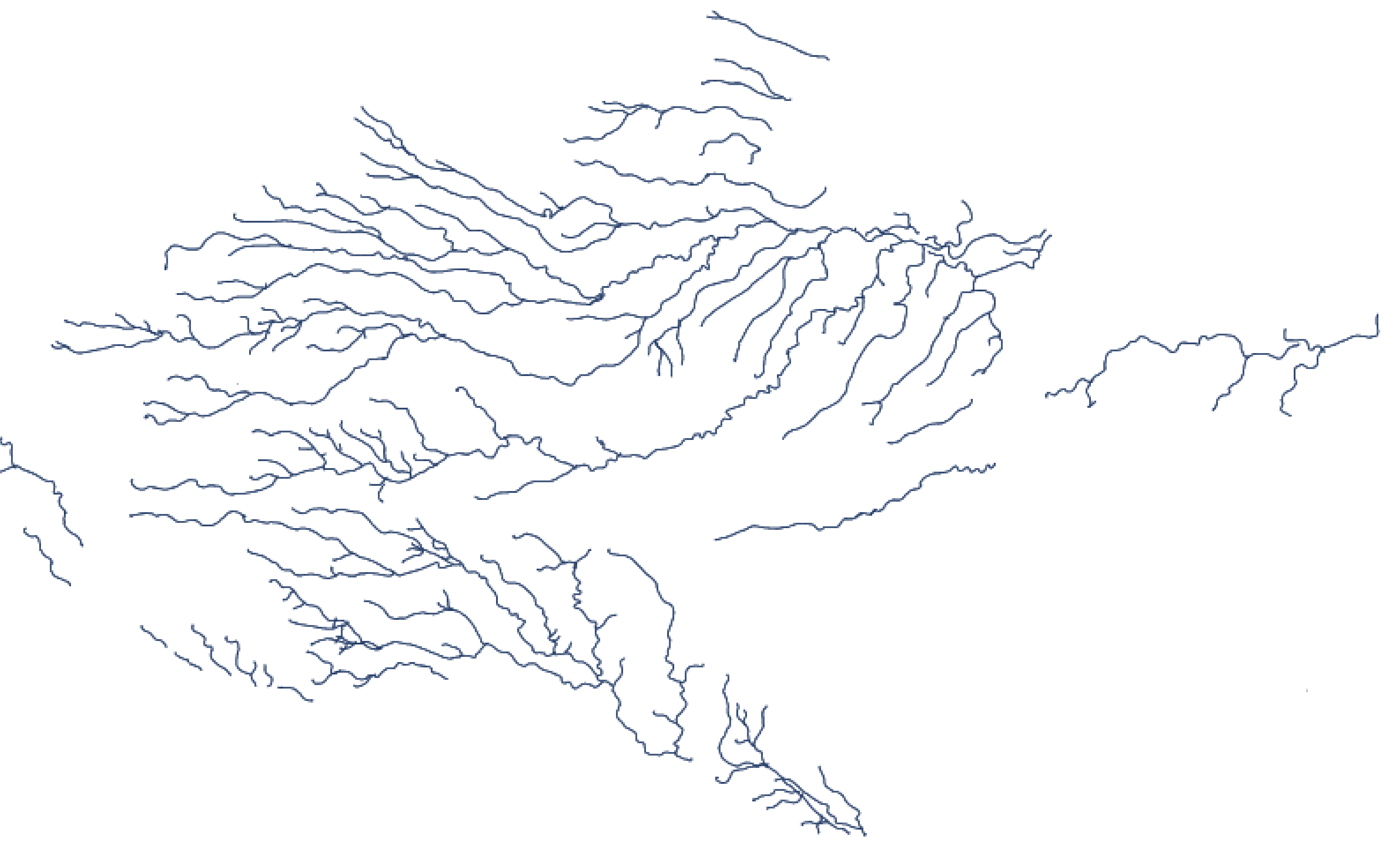
5.5. Outlook

Further research avenues can be determined from a theoretical viewpoint, and specific to the case. From a **theoretical viewpoint**, well-being concepts other than the one used in this thesis could be integrated into the framework. Well-being frameworks could be, for example, tailored to the context the framework is applied to and depend on who and for what the framework is used for, as well as the resources available. Secondly, well-being might not be the only component that should be added to make the SESF more applicable to SES-phenomena in the Global South. Research could explore further characteristics of the Global South that could be integrated in the framework. Moreover, the Global South refers to a large and diverse group of countries, and different contexts within the group might ask for different amendments to the framework. As described in the limitations, the amended SESF proposed in this thesis has been only applied to one specific case. To test the usefulness of the framework, it needs to be applied to more cases on other continents and countries, to other contexts (e.g., rural areas), and to other ecological systems. Further research avenues might be concerned with improving the ability of the framework to capture the complexity of SES better, for example by setting up more actor categories than just human, and non-human ecological actors.

Regarding the **illustrative case**, up-to-date information on the specific pollutants of the river basin will be required to design regeneration activities. Further knowledge on the various species which inhabit or used to inhabit the basin is also needed. Regarding the leverage points proposed in this thesis, their (political) feasibility shall be evaluated based on the position and resources of those involved in the regeneration of the basin. While the proposed leverage points refer to the *what question*, the *how* still has to be answered: How can an impartial, fair, and empathetic enforcement of existing legislation be fostered? How can we ensure NGOs change their mode of working? How can deeper institutional problems be combated?

In light of the focus of this thesis on secondary materials, on-site data will need to be collected to include local (and traditional) knowledge and gain access to relational values, as well as subjective and relational views of well-being. Finally, given that SES adapt and learn, this application of the proposed framework shall serve as a starting point. To allow for a successful regeneration, the system needs to be closely observed when planning and implementing any intervention, to capture changes and responses of the SES.

References



Abunge, C., Coulthard, S., and Daw, T.M., 2013. Connecting marine ecosystem services to human well-being. Insights from participatory well-being assessment in Kenya. *AMBIO,* 42 (8), pp. 1010–1021. doi: 10.1007/s13280-013-0456-9.

Adams, P.C., 2015. Placing the Anthropocene. A day in the life of an enviro-organism. *Transactions of the Institute of British Geographers,* 41 (1), pp. 54–65. doi: 10.1111/tran.12103.

Adams, W.M., 2003. *Green development. Environment and sustainability in the Third World*. London: Routledge.

Adams, W.M*., et al.,* 2004. Biodiversity conservation and the eradication of poverty. *Science,* 306 (5699), pp. 1146–1149. doi: 10.1126/science.1097920.

Adger, W.N., 2006. Vulnerability. *Global Environmental Change,* 16 (3), pp. 268–281. doi: 10.1016/j.gloenvcha.2006.02.006.

African Development Bank Group, 2018. *Nairobi river basin rehabilitation and restoration program* [online]. Available at: <https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/KENYA_-__AR__-_Nairobi_Rivers_Basin_Rehabilitation_and_restoration_Program.pdf> [Accessed on 3 February 2021].

Agarwala, M*., et al.,* 2014. Assessing the relationship between human well-being and ecosystem services. A review of frameworks. *Conservation and Society,* 12 (4), pp. 437–449. doi: 10.4103/0972-4923.155592.

Ambani, S., 2018. Nema commences clean-up of heavily polluted Nairobi River. *Nairobi News,* 19 August. Available at: <https://nairobinews.nation.co.ke/news/nema-clean-up-nairobi-river> [Accessed on 3 February 2021].

Amnesty International, 2010. *Insecurity and indignity. Women's experience in the slums of Nairobi, Kenya*. London: Amnesty International Publications.

Anderies, J.M*., et al.,* 2013. Aligning key concepts for global change policy. Robustness, resilience, and sustainability. *Ecology and Society,* 18 (2): 8. doi: 10.5751/ES-05178-180208.

Anderies, J.M., Janssen, M.A., and Ostrom, E., 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society,* 9 (1): 18. doi: 10.5751/ES-00610-090118.

Askumo, G., 2015. *A guide to Nairobi's rivers and streams* [online]. Available at: <http://askumo.com/a-guide-to-nairobi-rivers-and-streams/> [Accessed on 17 January 2021].

Bagnis, S*., et al.,* 2013. Characterization of the Nairobi River catchment impact zone and occurrence of pharmaceuticals. Implications for an impact zone inclusive environmental risk assessment. *Science of the Total Environment,* 703: 134925. doi: 10.1016/j.scitotenv.2019.134925.

Basurto, X., Gelcich, S., and Ostrom, E., 2013. The Social–Ecological System Framework as a knowledge classificatory system for benthic small-scale fisheries. *Global Environmental Change,* 23, pp. 1366–1380. doi: 10.1016/j.gloenvcha.2013.08.001.

Bauza, V*., et al.,* 2019. Enteric pathogens from water, hands, surface, soil, drainage ditch, and stream exposure points in a low-income neighborhood of Nairobi, Kenya. *Science of the Total Environment,* 709: 135344. doi: 10.1016/j.scitotenv.2019.135344.

Beauchamp, E*., et al.,* 2018. "Living a good life". Conceptualizations of well-being in a conservation context in Cambodia. *Ecology and Society,* 23 (2): 28. doi: 10.5751/ES-10049-230228.

Béguy, D., Bocquier, P., and Zulu, E., 2009. *Migration dynamics in Nairobi slums*. Detroit.

Berkes, F., Folke, C., and Colding, J., eds., 1998. *Linking social and ecological systems. Management practices and social mechanisms for building resilience*. New York: Cambridge University Press.

Beyer, L.I., Chaudhuri, J., and Kagima, B., 2016. Kenya's focus on urban vulnerability and resilience in the midst of urban transitions in Nairobi. *Development Southern Africa,* 33 (1), pp. 3–22. doi: 10.1080/0376835X.2015.1115739.

Biedenweg, K., and Gross-Camp, N., 2018. A brave new world. Integrating well-being and conservation. *Ecology and Society,* 23 (2): 32. doi: 10.5751/ES-09977-230232.

Biggs, R., Westley, F.R., and Carpenter, S.R., 2010. Navigating the back loop. Fostering social innovation and transformation in ecosystem management. *Ecology and Society,* 15 (2): 9. doi: 10.5751/es-03411-150209.

Binder, C.R., *et al.,* 2013. Comparison of frameworks for analyzing social-ecological systems. *Ecology and Society,* 18 (4): 26. doi: 10.5751/ES-05551-180426.

Blaikie, P., 2006. Is small really beautiful? Community-based natural resource management in Malawi and Botswana. *World Development,* 34 (11), pp. 1942–1957. doi: 10.1016/j.worlddev.2005.11.023.

Boarini, R., Kolev, A., and McGregor, J.A., 2014. *Measuring well-being and progress in countries at different stages of development. Towards a more universal conceptual framework*. Paris.

Breslow, S.J., *et al.,* 2016. Conceptualizing and operationalizing human wellbeing for ecosystem assessment and management. *Environmental Science & Policy,* 66, pp. 250–259. doi: 10.1016/j.envsci.2016.06.023.

Brockington, D., 2004. Community conservation, inequality and injustice. Myths of power in protected area management. *Conservation and Society,* 2 (2), pp. 411–432.

Brockington, D., and Igoe, J., 2006. Eviction for conservation. A global overview. *Conservation and Society,* 4 (3), pp. 424–470.

Brockington, D., and Wilkie, D., 2015. Protected areas and poverty. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 370 (1681), pp. 1–6. doi: 10.1098/rstb.2014.0271.

Brown, K., 2003. Integrating conservation and development. A case of institutional misfit. *Frontiers in Ecology and the Environment,* 1 (9), pp. 479–487. doi: 10.1890/1540-9295(2003)001[0479:ICADAC]2.0.CO;2.

Butler, C.D., and Oluoch-Kosura, W., 2006. Linking future ecosystem services and future human well-being. *Ecology and Society,* 11 (1): 30. doi: 10.5751/ES-01602-110130.

Campbell, B.M., Sayer, J.A., and Walker, B., 2010. Navigating trade-offs. Working for conservation and development outcomes. *Ecology and Society,* 15 (2): 16. doi: 10.5751/ES-03380-150216.

Carlisle, K., and Gruby, R.L., 2019. Polycentric systems of governance. A theoretical model for the commons. *Policy Studies Journal,* 47 (4), pp. 927–952. doi: 10.1111/psj.12212.

Carpenter, S.R*., et al.,* 2015. Allowing variance may enlarge the safe operating space for exploited ecosystems. *Proceedings of the National Academy of Sciences,* 112 (46), pp. 14384–14389. doi: 10.1073/pnas.1511804112.

Central Intelligence Agency, 2021a. *The World Factbook. Area* [online]. Available at: <https://www.cia.gov/the-world-factbook/field/area/country-comparison/> [Accessed on 16 January 2021].

Central Intelligence Agency, 2021b. *The World Factbook. Kenya* [online]. Available at: <https://www.cia.gov/the-world-factbook/countries/kenya/#people-and-society> [Accessed on 16 January 2021].

Central Intelligence Agency, 2021c. *The World Factbook. Population* [online]. Available at: <https://www.cia.gov/the-world-factbook/field/population/country-comparison> [Accessed on 16 January 2021].

Chan, K.M.A*., et al.,* 2016. Why protect nature? Rethinking values and the environment. *Proceedings of the National Academy of Sciences,* 113 (6), pp. 1462–1465. doi: 10.1073/pnas.1525002113.

Charo, G., 2018. Houses on or near Nairobi River banks demolished over pollution. *Bana Kenya,* 7 August. Available at: <https://www.bana.co.ke/2018/08/houses-on-or-near-nairobi-river-banks.html> [Accessed on 3 February 2021].

Cinner, J.E., 2011. Social-ecological traps in reef fisheries. *Global Environmental Change,* 21 (3), pp. 835–839. doi: 10.1016/j.gloenvcha.2011.04.012.

Clarke, M., 2018. *Global South. What does it mean and why use the term?* [online]. Available at: <https://onlineacademiccommunity.uvic.ca/globalsouthpolitics/2018/08/08/global-south-what-does-it-mean-and-why-use-the-term/> [Accessed on 10 February 2021].

Coad, L*., et al.,* 2008. *The costs and benefits of forest protected areas for local livelihoods. A review of the current literature*. Cambridge: UNEP World Conservation Monitoring Centre.

Colding, J., and Barthel, S., 2019. Exploring the social-ecological systems discourse 20 years later. *Ecology and Society,* 24 (1): 2. doi: 10.5751/ES-10598-240102.

Collado, S., Staats, H., and Corraliza, J.A., 2013. Experiencing nature in children's summer camps. Affective, cognitive and behavioural consequences. *Journal of Environmental Psychology,* 33, pp. 37–44. doi: 10.1016/j.jenvp.2012.08.002.

Cooke, B., and Lane, R., 2015. How do amenity migrants learn to be environmental stewards of rural landscapes? *Landscape and Urban Planning,* 134, pp. 43–52. doi: 10.1016/j.landurbplan.2014.10.006.

Cooke, B., West, S., and Boonstra, W.J., 2016. Dwelling in the biosphere. Exploring an embodied human-environment connection in resilience thinking. *Sustainability Science,* 11 (5), pp. 831–843. doi: 10.1007/s11625-016-0367-3.

Coulthard, S., Johnson, D., and McGregor, J.A., 2011. Poverty, sustainability and human wellbeing. A social wellbeing approach to the global fisheries crisis. *Global Environmental Change,* 21 (2), pp. 453–463. doi: 10.1016/j.gloenvcha.2011.01.003.

Coulthard, S., McGregor, J.A., and White, C., 2018. Multiple dimensions of wellbeing in practice. *In:* K. Schreckenberg, G. Mace, and M. Poudyal, eds. *Ecosystem services and poverty alleviation. Trade-offs and governance.* London: Routledge, pp. 243–256.

Cox, M., *et al.,* 2016. Synthesizing theories of natural resource management and governance. *Global Environmental Change,* 39, pp. 45–56. doi: 10.1016/j.gloenvcha.2016.04.011.

Crutzen, P.J., and Stroemer, E.F., 2000. The "Anthropocene". *Global Change Newsletter,* 2000, pp. 17–18.

Dados, N., and Connell, R., 2012. The Global South. *Contexts,* 11 (1), pp. 12–13. doi: 10.1177/1536504212436479.

Daw, T.M., *et al.,* 2015. Evaluating taboo trade-offs in ecosystems services and human well-being. *Proceedings of the National Academy of Sciences,* 112 (22), pp. 6949–6954. doi: 10.1073/pnas.1414900112.

De Lima, W., 2020. *Modern missionaries. An ethnography of social entrepreneurs and entrepreneurial legitimation in the humanitarian field:* Stockholm University.

Diaz, S., *et al.,* 2014. *Preliminary guide regarding diverse conceptualization of multiple values of nature and its benefits, including biodiversity and ecosystem functions and services*.

Diener, E., and Ryan, K., 2009. Subjective well-being. A general overview. *South African Journal of Psychology,* 39 (4), pp. 391–406. doi: 10.1177/008124630903900402.

Doyal, L., and Gough, I., 1991. *A theory of human need*. Basingstoke: Macmillan.

Eckert, L.E., *et al.,* 2018. Linking marine conservation and Indigenous cultural revitalization. First Nations free themselves from externally imposed social-ecological traps. *Ecology and Society,* 23 (4): 23. doi: 10.5751/ES-10417-230423.

Encyclopaedia Britannica, n.d. *Nairobi. National capital, Kenya* [online]. Available at: <https://www.britannica.com/place/Nairobi> [Accessed on 17 January 2021].

Enqvist, P.J., *et al.,* 2018. Stewardship as a boundary object for sustainability research. Linking care, knowledge and agency. *Landscape and Urban Planning,* 179, pp. 17–37. doi: 10.1016/j.landurbplan.2018.07.005.

Epstein, G., *et al.,* 2013. Missing ecology. Integrating ecological perspectives with the social-ecological system framework. *International Journal of the Commons,* 7 (2), pp. 432–453.

Eriksson, P., and Kovalainen, A., 2008. *Qualitative methods in business research*. London England: SAGE Publications Ltd.

Escobar, A., 2015. Degrowth, postdevelopment, and transitions. A preliminary conversation. *Sustainability Science,* 10, pp. 451–462. doi: 10.1007/s11625-015-0297-5.

Esteva, G., 1992. Development. *In:* W. Sachs, ed. *The development dictionary. A guide to knowledge as power.* London: Zed Books, pp. 6–25.

European Parliament, and Council of the European Union, 2018. *General Data Protection Regulation. GDPR*.

Evans, P., 2004. Development as institutional change. The pitfalls of monocropping and the potentials of deliberation. *Studies in Comparative International Development,* 38, pp. 30–52. doi: 10.1007/BF02686327.

Financial Sector Deepening Kenya, 2017. *Leveraging Kenya's informal sector for growth* [online]. Available at: <https://fsdkenya.org/blog/leveraging-kenyas-informal-sector-for-growth/> [Accessed on 18 January 2021].

Fischer, A., and Eastwood, A., 2016. Coproduction of ecosystem services as human–nature interactions. An analytical framework. *Land Use Policy,* 52, pp. 41–50. doi: 10.1016/j.landusepol.2015.12.004.

Fischer, J.*, et al.,* 2015. Advancing sustainability through mainstreaming a social–ecological systems perspective. *Current Opinion in Environmental Sustainability,* 14, pp. 144–149. doi: 10.1016/j.cosust.2015.06.002.

Folke, C.*, et al.,* 2010. Resilience thinking. Integrating resilience, adaptability and transformability. *Ecology and Society,* 15 (4): 20. doi: 10.5751/ES-03610-150420.

Folke, C.*, et al.,* 2011. Reconnecting to the biosphere. *AMBIO,* 40 (7), pp. 719–738. doi: 10.1007/s13280-011-0184-y.

Folke, C.*, et al.,* 2016. Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society,* 21 (3): 41. doi: 10.5751/ES-08748-210341.

Gallaher, C.M.*, et al.,* 2013. Real or perceived. The environmental health risks of urban sack gardening in Kibera slums of Nairobi, Kenya. *EcoHealth,* 10 (1), pp. 9–20. doi: 10.1007/s10393-013-0827-5.

Gallopin, G.C.*, et al.,* 2001. Science for the twenty-first century. From social contract to the scientific core. *International Social Science Journal,* 53 (2), pp. 219–229.

Geng, L.*, et al.,* 2015. Connections with nature and environmental behaviors. *PLOS ONE,* 10 (5), e0127247. doi: 10.1371/journal.pone.0127247.

Gough, I., and McGregor, J.A., eds., 2007. *Wellbeing in developing countries. From theory to research*. Cambridge: Cambridge University Press.

Hammond, D., 2017. Philosophical foundations of systems research. *In:* M.C. Edson, P. Buckle Henning, and S. Sankaran, eds. *A guide to systems research. Philosophy, processes and practice:* Springer, Singapore, pp. 1–19.

Hendriks, B., 2011. Urban livelihoods and institutions. Towards matching institutions for the poor in Nairobi's informal settlements. *International Development Planning Review,* 33 (2), pp. 111–146. doi: 10.3828/idpr.2011.9.

Hinkel, J*., et al.,* 2015. A diagnostic procedure for applying the social-ecological systems framework in diverse cases. *Ecology and Society,* 20 (1): 32. doi: 10.5751/ES-07023-200132.

Hinkel, J., Bots, P.W.G., and Schlüter, M., 2014. Enhancing the Ostrom Social-Ecological System Framework through formalization. *Ecology and Society,* 19 (3): 51. doi: 10.5751/ES-06475-190351.

Hurly, J., and Walker, G.J., 2019. Nature in our lives. Examining the human need for nature relatedness as a basic psychological need. *Journal of Leisure Research,* 50 (4), pp. 290–310. doi: 10.1080/00222216.2019.1578939.

International Union for Conservation of Nature (IUCN), 2003. *The Durban Accord* [online]. Available at: <https://www.iucn.org/sites/dev/files/import/downloads/durbanaccorden.pdf> [Accessed on 9 December 2020].

Ismail, A.F., Khulbe, K.C., and Matsuura, T., 2018. Chapter 8 - RO Membrane fouling. *In:* A.F. Ismail, K.C. Khulbe, and T. Matsuura, eds. *Reverse osmosis.* Amsterdam: Elsevier, pp. 189–220.

Ives, C.D*., et al.,* 2017. Human–nature connection. A multidisciplinary review. *Current Opinion in Environmental Sustainability,* 26-27, pp. 106–113. doi: 10.1016/j.cosust.2017.05.005.

Ives, C.D*., et al.,* 2018. Reconnecting with nature for sustainability. *Sustainability Science,* 13 (5), pp. 1389–1397. doi: 10.1007/s11625-018-0542-9.

Jackson, J.B*., et al.,* 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science,* 293 (5530), pp. 629–637. doi: 10.1126/science.1059199.

Kamau, N., and Njiru, H., 2018. Water, sanitation and hygiene situation in Kenya’s urban slums, 29, pp. 321–336.

Keniger, L.E*., et al.,* 2013. What are the benefits of interacting with nature? *International Journal of Environmental Research and Public Health,* 10 (3), pp. 913–935. doi: 10.3390/ijerph10030913.

KEWASNET, n.d. *About. Who we are* [online]. Available at: <https://kewasnet.co.ke/> [Accessed on 2 February 2021].

Kihiu, N., 2019. NEMA, water authority accuse Nairobi sewerage company of polluting Nairobi river. *Capital News,* 19 August. Available at: <https://www.capitalfm.co.ke/news/2019/08/nema-water-authority-accuse-nairobi-sewerage-company-of-polluting-nairobi-river/> [Accessed on 3 February 2021].

Kithiia, S.M., 2007. *An assessment of water quality changes within the Athi and Nairobi river basins during the last decade:* IAHS Press.

K'oreje, K.O*., et al.,* 2016. Occurrence patterns of pharmaceutical residues in wastewater, surface water and groundwater of Nairobi and Kisumu city, Kenya. *Chemosphere,* 149, pp. 238–244. doi: 10.1016/j.chemosphere.2016.01.095.

Kramer, D.B*., et al.,* 2017. Top 40 questions in coupled human and natural systems (CHANS) research. *Ecology and Society,* 22 (2), p. 44. doi: 10.5751/ES-09429-220244.

Kreijci, C., 2017. *The drastic impacts of climate change and water scarcity* [online]. Available at: <https://borgenproject.org/climate-change-and-water-scarcity/> [Accessed on 23 September 2020].

Kyobutungi, C*., et al.,* 2008. The burden of disease profile of residents of Nairobi's slums. Results from a demographic surveillance system. *Population Health Metrics,* 6 (1). doi: 10.1186/1478-7954-6-1.

LE1, 24.03.21. *Non-humane, ecological factors of the Nairobi river basin pollution*. Online.

LE2, 16.04.21. *Human factors of the Nairobi river basin pollution*. Online.

Leapfrog Projects, 2020. *Accelerating urban river regeneration processes through Kenya-Nordic collaboration. Proposing an inclusive approach for regenerating Nairobi's urban rivers and thereby ensuring health and climate resilience for Kenyan citizens*. Helsinki, Finland.

Levin, S*., et al.,* 2012. Social-ecological systems as complex adaptive systems. Modeling and policy implications. *Environment and Development Economics,* 18 (2), pp. 111–132. doi: 10.1017/S1355770X12000460.

Lin, B.B., *et al.,* 2014. Opportunity or orientation? Who Uses Urban Parks and Why. *PLOS ONE,* 9 (1), e87422. doi: 10.1371/journal.pone.0087422.

Lincoln, Y.S., and Guba, E.G., 1985. *Naturalistic inquiry*. Beverly Hills, Calif.: SAGE Publications.

Liu, J., *et al.,* 2001. Ecological degradation in protected areas. The case of Wolong Nature Reserve for giant pandas. *Science,* 292 (5514), pp. 98–101. doi: 10.1126/science.1058104.

Liu, J., *et al.,* 2007a. Complexity of coupled human and natural systems. *Science,* 317 (5844), pp. 1513–1516. doi: 10.1126/science.1144004.

Liu, J., *et al.,* 2007b. Coupled human and natural systems. *AMBIO,* 36 (8), pp. 639–649. doi: 10.1579/0044-7447(2007)36[639:CHANS]2.0.CO;2.

Liu, J., *et al.,* 2013. Framing sustainability in a telecoupled world. *Ecology and Society,* 18 (2): 26. doi: 10.5751/ES-05873-180226.

Loring, P.A., Hinzman, M.S., and Neufeld, H., 2016. Can people be sentinels of sustainability? Identifying the linkages among ecosystem health and human well-being. *FACETS,* 1 (1), pp. 148–162. doi: 10.1139/facets-2016-0022.

Mabonga, M., 2019. NEMA shuts down Daima Dairy over environmental pollution. *Tuko,* 2019. Available at: <https://www.tuko.co.ke/313925-nema-shuts-daima-dairy-claims-polluting-environment.html> [Accessed on 3 February 2021].

Mace, G.M., *et al.,* 2014. Approaches to defining a planetary boundary for biodiversity. *Global Environmental Change,* 28, pp. 289–297. doi: 10.1016/j.gloenvcha.2014.07.009.

MacKerron, G., 2011. Happiness economics from 35 000 feet. *Journal of Economic Surveys,* 26 (4), pp. 705–735. doi: 10.1111/j.1467-6419.2010.00672.x.

Mahler, A.G., 2018. *From the Tricontinental to the Global South. Race, radicalism, and transnational solidarity*. Durham: Duke University Press.

Mäler, K.-G., 2001. Economic growth and the environment. *In:* S.A. Levin, ed. *Encyclopedia of biodiversity.* San Diego, Calif., London: Academic, pp. 277–284.

Masterson, V., *et al.,* 2017. The contribution of sense of place to social-ecological systems research. A review and research agenda. *Ecology and Society,* 22 (1): 49. doi: 10.5751/ES-08872-220149.

Mbui, D., *et al.,* 2016. The state of water quality in Nairobi river, Kenya. *Asian Journal of Research in Chemistry,* 9 (11), pp. 545–550. doi: 10.5958/0974-4150.2016.00078.X.

McGinnis, M.D., and Ostrom, E., 2014. Social-ecological system framework. Initial changes and continuing challenges. *Ecology and Society,* 19 (2): 30. doi: 10.5751/ES-06387-190230.

Metcalfe, V., Pavanello, S., and Mishra, P., 2011. *Sanctuary in the city? Urban displacement and vulnerability in Nairobi*. London, United Kingdom: Overseas Development Institute.

Millennium Ecosystem Assessment, 2005. *Ecosystems and human well-being. Synthesis*. Washington, DC: Island Press.

Milner-Gulland, E.J., *et al.,* 2014. Accounting for the impact of conservation on human well-being. *Conservation Biology,* 28 (5), pp. 1160–1166. doi: 10.1111/cobi.12277.

Ministry of Environment and Forestry, n.d. *Ministry overview* [online]. Available at: <http://www.environment.go.ke/?page_id=6250> [Accessed on 2 February 2021].

Ministry of Environment and Mineral Resources, n.d. *Nairobi River Basin Rehabilitation Program (NRBP)* [online]. Available at: <http://archive.basel.int/convention/XX%20Anniversary/Press%20kit/Kenya%20Project%20leaflet.pdf> [Accessed on 3 February 2021].

Ministry of Water and Sanitation, n.d. *About the ministry* [online]. Available at: <https://www.water.go.ke/about-the-ministry/> [Accessed on 3 February 2021].

Mugo, K., 2006. *Sustainable water and sanitation services for the urban poor in Nairobi*. Colombo, Sri Lanka.

Mumo, M., 2020. Landlord arrested for polluting Nairobi River. *The Star,* 24 July. Available at: <https://www.the-star.co.ke/news/2020-07-24-landlord-arrested-for-polluting-nairobi-river/> [Accessed on 3 February 2021].

Nairobi City Council, n.d. *History of Nairobi* [online]. Available at: <https://nairobi.go.ke/history/> [Accessed on 17 January 2021].

Nairobi City County, n.d. *Environment energy water and sanitation* [online]. Available at: <https://nairobi.go.ke/environment-energy-water-and-sanitation/> [Accessed on 3 February 2021].

Narayan, D., *et al.,* 2000. *Voices of the poor. Crying out for change*. New York: Oxford University Press.

National Environment Management Authority, n.d.a. *Departments* [online]. Available at: <http://www.nema.go.ke/index.php?option=com_content&view=article&id=6&Itemid=140> [Accessed on 2 February 2021].

National Environment Management Authority, n.d.b. *Functions* [online]. Available at: <http://www.nema.go.ke/index.php?option=com_content&view=article&id=2&Itemid=137#> [Accessed on 2 February 2021].

ND-GAIN Country Index, 2018 [online]. University of Notre Dame Global Adaption Initiative. Available at: <https://gain-new.crc.nd.edu/ranking> [Accessed on 9 November 2020].

Ndunda, E.N., and Wandiga, S.O., 2020. Spatial and temporal trends of polychlorinated biphenyls in water and sediment from Nairobi River, Kenya. *Environmental Monitoring and Assessment,* 192: 600. doi: 10.1007/s10661-020-08566-x.

Ngigi, A.N., Magu, M.M., and Muendo, B.M., 2020. Occurrence of antibiotics residues in hospital wastewater, wastewater treatment plant, and in surface water in Nairobi County, Kenya. *Environmental Monitoring and Assessment,* 192: 18. doi: 10.1007/s10661-019-7952-8.

Ngumba, E., Gachanja, A., and Tuhkanena, T., 2016. Occurrence of selected antibiotics and antiretroviral drugs in Nairobi River Basin, Kenya. *Science of the Total Environment,* 539, pp. 206–213. doi: 10.1016/j.scitotenv.2015.08.139.

Njuguna, S.M., *et al.,* 2017. Assessment of macrophyte, heavy metal, and nutrient concentrations in the water of the Nairobi River, Kenya. *Environmental Monitoring and Assessment,* 189: 454. doi: 10.1007/s10661-017-6159-0.

Nussbaum, M.C., and Sen, A., eds., 1993. *The Quality of life*. New York: Oxford University Press.

OECD, 2011. *How's life? Measuring well-being. Available at:* <https://www.oecd-ilibrary.org/economics/how-s-life_9789264121164-en. Paris: OECD Publishing.

Omondi, A., 2018. NEMA closes down 25 companies discharging toxic waste into Nairobi River. *Tuko,* 2018. Available at: <https://www.tuko.co.ke/305621-nema-closes-25-companies-discharging-toxic-waste-nairobi-river.html> [Accessed on 3 February 2018].

Onyango, L., 2019a. Kenya. Nema shuts down four firms for polluting Nairobi River. *AllAfrica,* 26 August. Available at: <https://allafrica.com/stories/201908270581.html> [Accessed on 3 February 2021].

Onyango, L., 2019b. Kenya. Govt. agency shuts down four firms for polluting Nairobi River & compromising access to clean water. *Business & Human Rights Resource Centre,* 28 August. Available at: <https://www.business-humanrights.org/en/latest-news/kenya-govt-agency-shuts-down-four-firms-for-polluting-nairobi-river-compromising-access-to-clean-water/> [Accessed on 3 February 2021].

Ostrom, E., 1990. *Governing the commons. The evolution of institutions for collective action*. Cambridge: Cambridge University Press.

Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences,* 104 (39), pp. 15181–15187. doi: 10.1073/pnas.0702288104.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. *Science,* 325 (5939), pp. 419–422. doi: 10.1126/science.1170749.

Ostrom, E., 2010. Beyond markets and states. Polycentric governance of complex economic systems. *The American Economic Review,* 100 (3), pp. 641–672.

Ostrom, E., and Cox, M., 2010. Moving beyond panaceas. A multi-tiered diagnostic approach for social-ecological analysis. *Environmental Conservation,* 37 (4), pp. 451–463. doi: 10.1017/S0376892910000834.

Part four, 2019 [online]. Available at: <https://beyondtheframe.shorthandstories.com/toxic_flow_four/index.html> [Accessed on 5 February 2021].

Part two, 2019 [online]. Available at: <https://beyondtheframe.shorthandstories.com/toxic_flow_two/index.html> [Accessed on 22 January 2021].

Partelow, S., 2018. A review of the Social-Ecological Systems Framework. Applications, methods, modifications, and challenges. *Ecology and Society,* 23 (4): 36. doi: 10.5751/ES-10594-230436.

Partelow, S., and Winkler, K.J., 2016. Interlinking ecosystem services and Ostrom's framework through orientation in sustainability research. *Ecology and Society,* 21 (3): 27. doi: 10.5751/ES-08524-210327.

Poli, R., 2013. A note on the difference between complicated and complex social systems. *Cadmus,* 2 (1), pp. 142–147.

Preiser, R.*, et al.,* 2018. Social-ecological systems as complex adaptive systems. Organizing principles for advancing research methods and approaches. *Ecology and Society,* 23 (4): 46. doi: 10.5751/ES-10558-230446.

Reinikka, R., and Svensson, J., 2005. Fighting corruption to improve schooling. Evidence from a newspaper campaign in Uganda. *Journal of the European Economic Association,* 3 (2-3), pp. 259–267. doi: 10.1162/jeea.2005.3.2-3.259.

Restall, B., and Conrad, E., 2015. A literature review of connectedness to nature and its potential for environmental management. *Journal of Environmental Management,* 159, pp. 264–278. doi: 10.1016/j.jenvman.2015.05.022.

Rodriguez-Torres, D., 2010. *Nairobi today. The paradox of a fragmented city*. Dar es Salam, Tanzania, Nairobi, Kenya: Mkuki na Nyota Publishers; French Institute for Research in Africa.

Roe, D.*, et al.,* 2003. In pursuit of pro-poor conservation—changing narratives… or more? *Policy Matters,* 12, pp. 87–91.

Salmón, E., 2000. Kincentric ecology. Indigenous perceptions of the human-nature relationship. *Ecological Applications,* 10 (5), pp. 1327–1332. doi: 10.1890/1051-0761(2000)010[1327:KEIPOT]2.0.CO;2.

Sarkar, A., 2020. Everyday practices of poor urban women to access water. Lived realities from a Nairobi slum. *African Studies,* 79 (2), pp. 212–231. doi: 10.1080/00020184.2020.1781594.

Schlüter, M*., et al.,* 2019. Capturing emergent phenomena in social-ecological systems. An analytical framework. *Ecology and Society,* 24 (3): 11. doi: 10.5751/ES-11012-240311.

Scholz, R.W., 2011. *Environmental literacy in science and society. From knowledge to decisions*. Cambridge: Cambridge University Press.

Scoones, I., 1998. *Sustainable rural livelihoods. A framework for analysis*. Brighton, UK: Institute of Development Studies, University of Sussex.

Simon, H.A., 2000. Public administration in today's world of organizations and markets. *Political Science and Politics,* 33 (4), pp. 749–756. doi: 10.2307/420911.

Skidelsky, E., and Skidelsky, R., 2012. *How much is enough? Money and the good life*. New York: Other Press.

Society for International Development, 2004. *Pulling apart. Facts and figures on inequality in Kenya*. Nairobi, Kenya.

Stanford Encyclopedia of Philosophy, 2019. *Agency* [online]. Available at: <https://plato.stanford.edu/entries/agency/> [Accessed on 15/12/20].

Star Reporter, 2020. Restoration of Michuki Memorial Park underway. *The Star,* 16 June. Available at: <https://www.the-star.co.ke/news/2020-06-16-restoration-of-michuki-memorial-park-underway/> [Accessed on 13/04/21].

Steffen, W., Crutzen, P.J., and McNeill, J.R., 2007. The Anthropocene. Are humans now overwhelming the great forces of nature? *AMBIO,* 36 (8), pp. 614–621. doi: 10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2.

Stockholm Resilience Centre, n.d. *The nine planetary boundaries* [online]. Available at: <https://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html> [Accessed on 8 February 2021].

Swiss Re Management Ltd, 2020. *Biodiversity and ecosystem services. A business case for re/insurance*.

Taffa, N., Chepngeno, G., and Amuyunzu-Nyamongo, M., 2005. Child morbidity and healthcare utilization in the slums of Nairobi, Kenya. *Journal of tropical pediatrics,* 51 (5), pp. 279–284. doi: 10.1093/tropej/fmi012.

The Water Project, n.d. *Mashimoni water and sanitation project - 2* [online]. Available at: <https://thewaterproject.org/community/projects/kenya/urban-water-project-in-kenya-4283> [Accessed on 3 February 2021].

The World Bank Group, n.d.a. *Agriculture, forestry, and fishing, value added (% of GDP) - Kenya, Uganda, Sub-Saharan Africa* [online]. Available at: <https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=KE-UG-ZG> [Accessed on 16 January 2021].

The World Bank Group, n.d.b. *CO2 emissions (metric tons per capita) - high income, low income, middle income, world* [online]. Available at: <https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?contextual=aggregate&end=2014&locations=XD-XM-XP-1W&name_desc=false&start=1960> [Accessed on 10 February 2021].

The World Bank Group, n.d.c. *GDP growth (annual %) - Kenya, Sub-Saharan Africa* [online]. Available at: <https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2019&locations=KE-ZG&start=1994> [Accessed on 16 January 2021].

The World Bank Group, n.d.d. *Industry (including construction), value added (% of GDP) - Kenya, Uganda, Sub-Saharan Africa* [online]. Available at: <https://data.worldbank.org/indicator/NV.IND.TOTL.ZS?locations=KE-UG-ZG> [Accessed on 16 January 2021].

The World Bank Group, n.d.e. *Population growth (annual %)* [online]. Available at: <https://data.worldbank.org/indicator/SP.POP.GROW> [Accessed on 16 January 2021].

The World Bank Group, n.d.f. *Services, value added (% of GDP) - Kenya, Uganda, Sub-Saharan Africa* [online]. Available at: <https://data.worldbank.org/indicator/NV.SRV.TOTL.ZS?locations=KE-UG-ZG> [Accessed on 16 January 2021].

The World Bank Group, 2016. *High and dry. Climate change, water, and the economy*. Washington, DC.

The World Bank Group, 2020. *Providing sustainable sanitation and water services to low-income communities in Nairobi* [online]. Available at: <https://www.worldbank.org/en/news/feature/2020/02/19/providing-sustainable-sanitation-and-water-services-to-low-income-communities-in-nairobi> [Accessed on 3 February 2021].

Toxic flow, 2019 [online]. Available at: <https://beyondtheframe.shorthandstories.com/toxic_flow/#group-THE-FLOW-oEIhrmNdyC> [Accessed on 22 January 2021].

Turner, W.R.*, et al.,* 2012. Global biodiversity conservation and the alleviation of poverty. *BioScience,* 62 (1), pp. 85–92. doi: 10.1525/bio.2012.62.1.13.

United Nations, n.d. *Ensure sustainable consumption and production patterns* [online]. Available at: <https://unstats.un.org/sdgs/report/2019/goal-12/> [Accessed on 10 February 2021].

United Nations Development Programme, n.d.a. *Human development reports. Global human development indicators* [online]. Available at: <http://hdr.undp.org/en/countries> [Accessed on 10 February 2021].

United Nations Development Programme, n.d.b. *Kenya. Human development indicators* [online]. Available at: <http://hdr.undp.org/en/countries/profiles/KEN> [Accessed on 16 January 2021].

United Nations Development Programme, 2020. *Human development report 2020. The next frontier - human development and the Anthropocene*. New York: United Nations Development Programme.

United Nations Human Settlements Programme, 2012. *State of the world's cities 2012/2013. Prosperity of cities*. Nairobi, Kenya.

USAID, n.d. *KIWASH* [online]. Available at: <https://www.kiwash.org/> [Accessed on 3 February 2021].

van Riper, C.J.*, et al.,* 2018. Incorporating multilevel values into the Social-Ecological Systems Framework. *Ecology and Society,* 23 (3): 25. doi: 10.5751/ES-10047-230325.

Vogt, J.M., *et al.,* 2015. Putting the "E" in SES. Unpacking the ecology in the Ostrom Social-Ecological System Framework. *Ecology and Society,* 20 (1): 55. doi: 10.5751/ES-07239-200155.

Wabala, D., 2020. Kenya. Nema to shut 140 firms for polluting city river. *AllAfrica,* 7 September. Available at: <https://allafrica.com/stories/202009080026.html> [Accessed on 3 February 2021].

Wafula, P., 2019. *Part five. Disease corridor* [online]. Available at: <https://beyondtheframe.shorthandstories.com/toxic_flow_five/index.html> [Accessed on 5 February 2021].

Walker, B., *et al.,* 2004. Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society,* 9 (2): 5.

Walker, B., and Meyers, J.A., 2004. Thresholds in ecological and social–ecological systems. A developing database. *Ecology and Society,* 9 (2): 3.

Walker, B.H., *et al.,* 2009. Resilience, adaptability, and transformability in the Goulburn-Broken Catchment, Australia. *Ecology and Society,* 14 (1): 12.

Water Sector Trust Fund, n.d. *Welcome to Water Sector Trust Fund* [online]. Available at: <https://www.waterfund.go.ke/> [Accessed on 3 February 2021].

Wells, N.M., 2000. At home with nature. Effects of "Greeness" on children's cognitive functioning. *Environment and Behavior,* 32 (6), pp. 775–795. doi: 10.1177/00139160021972793.

West, S., *et al.,* 2018. Stewardship, care and relational values. *Current Opinion in Environmental Sustainability,* 35, pp. 30–38. doi: 10.1016/j.cosust.2018.10.008.

Wilson, E.O., 1984. *Biophilia. The human bond with other species*. Cambridge: Harvard University Press.

Winter, S.C., Obara, L.M., and Barchi, F., 2019. Environmental correlates of health-related quality of life among women living in informal settlements in Kenya. *International Journal of Environmental Research and Public Health,* 16 (20): 3948. doi: 10.3390/ijerph16203948.

Woodhouse, E., *et al.,* 2015. Guiding principles for evaluating the impacts of conservation interventions on human well-being. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 370 (1681), pp. 1–11. doi: 10.1098/rstb.2015.0103.

Woodhouse, E., and McCabe, J.T., 2018. Well-being and conservation. Diversity and change in visions of a good life among the Maasai of northern Tanzania. *Ecology and Society,* 23 (1): 43. doi: 10.5751/ES-09986-230143.

Woodroffe, R., Thirgood, S., and Rabinowitz, A., eds., 2005. *People and wildlife. Conflict or co-existence?* Cambridge: Cambridge University Press.

World Health Organization, 2003. *Total dissolved solids in drinking-water. Background document for development of WHO guidelines for drinking-water quality* [online]. Available at: <https://www.who.int/water_sanitation_health/dwq/chemicals/tds.pdf> [Accessed on 13 April 2021].

World Resources Institute*, et al.,* 2007. *Nature's benefits in Kenya. An atlas of ecosystems and human well-being*. Washington, DC and Nairobi: World Resources Institute.

Yin, R.K., 2009. Case study research. Design and methods. *In:* L. Bickman and D.J. Rog, eds. *Applied social research methods series.* California: SAGE Publications.

Ziraba, A.K.*, et al.,* 2009. Maternal mortality in the informal settlements of Nairobi city. What do we know? *Reproductive Health,* 6 (1): 6. doi: 10.1186/1742-4755-6-6.

Zulu, E.M.*, et al.,* 2011. Overview of migration, poverty and health dynamics in Nairobi City's slum settlements. *Journal of Urban Health: Bulletin of the New York Academy of Medicine,* 88, Suppl. 2, S185–199. doi: 10.1007/s11524-011-9595-0.

Appendices

Appendix I: Interview guides

Interview Guide I: Non-humane, ecological factors of the Nairobi river basin pollution

Briefing

1. Productivity of the system

- = speed by which the polluted river gets clean again
- What does this productivity depend on?
  - Replacement of water
    - Dilution – water from upstream (flow velocity)(season)
    - Dilution - precipitation (season)
  - Attenuation by plants
  - Anything else?
- Does the flow velocity depend on the season? Or only the volume of water?
- If the human pollution would stop – would the river get clean by itself over time?
- Sediments and animals of the rivers such as fish are contaminated with various pollutants
  - is this something than needs to be taken care of, or can one just wait X years?
- Is the river basin a rather predictable system or are there a lot of uncertainties?
- Potential impact by climate change?

2. Interactions and biological, chemical, or physical rules

- What interactions need to be considered?
  e.g., dilution, attenuation, surface water runoff, animals, plants, and river sediments
- Storage characteristics
- Equilibrium properties

3. Human constructed facilities

- Which human constructed facilities need to be considered?
  e.g., pit latrines and sewers directly connected to the river

4. External ecological factors

- What external ecological factors are decisive? How?
    - Seasons (dilution; surface runoff)
    - Climate change
    - Up- and downstream water quality

5. Anything else?

- Are there any other ecological factors decisive for the pollution and/or regeneration of the river?
- Ecosystem history
- What is the (economic) value of the river for Nairobi's residents/ businesses/ …?
  – Is it just the transportation of waste?
- How have you experienced the role of the government?
  – Any changes in the last years?

Debriefing

Interview Guide II: Human factors of the Nairobi river basin pollution

Briefing

1. Government

- Are there any specific **policies or regulations** that contribute significantly to the problem?
  / Any specific policy or regulations that would need to be changed to stop pollution or enable regeneration?

- How well are the existing rules **enforced**? Why, or why not?
  Have there been changes?
  Are the existing rules 'enough'?

- What is the government's role in providing **infrastructure** for sanitation and/or waste collection?
  Is that mainly the role of NGOs?
  Who is taking up the responsibility here?

- How easy or difficult is it to **govern** the area of Nairobi given the constant increase in population?

- How does the **collaboration** with the authorities up- and downstream work?
  Is there any collaboration?

2. Industry/ Commercial activities

- Why does the industry pollute the river?
- What role does the industry play? Is there any kind of leadership from the industry?
  Is the industry trying to do something about the pollution?
  Are they trying to lobby against stronger regulation/ enforcement?

3. General

- What are the predominant **norms**?
  Is it just normal to use the river for waste disposal?
  Is there any shame, guilt, or sense of responsibility?
  Are there any environmental norms present?

- What is the **value** of the river?
  Does it have any value in itself?
  Is its value only in transporting waste?

4. Farmers

- How big is their role in river pollution within Nairobi?

Debriefing

Appendix II: Application of the SE-AS framework

Schlüter *et al.* (2019) provide instructions (a list of guiding questions) on how to operationalise their SE-AS framework. These were copied from APPENDIX 2 of their paper and are presented below.

List of guiding questions for framework application

1. What is the emergent phenomenon that should be explained?
2. What social-ecological action situation or situations are at the core of the phenomenon, e.g. harvesting, cultivating, conserving, polluting, recreation, etc.? Which outcomes do they give rise to (e.g. catch, information, mortality, change in landscape structure).
3. For social-ecological AS: which actors (individuals, groups or collectives) and which ecological components constitute the social-ecological AS? Which roles do actors take in this interaction context, which actions can they take (e.g. harvesting, conserving), which ecological processes take place through the interaction (e.g. decrease in population size)? Through which structures are actors or ecological components connected, e.g. networks, spatial settings, etc.? What attributes of actors and non-human entities, such as preferences, motivations, skills or growth rates are important for explaining the emergent behavior of this AS?
4. Which drivers, structures or processes such as climate, regulations or food-web interactions or other social-ecological interactions enable or constrain the social-ecological action situation?
5. Are these external to the social-ecological system of interest, i.e. they cannot be influenced by actors or ecological processes within the SES, and can be represented as external drivers?
6. Or are they internal and directly influencing the social-ecological interactions and thus need to be represented as social or ecological AS? What are their emergent outcomes and how do they affect the social-ecological or other social or ecological AS?
7. For social AS: which actors (individuals, groups or collectives) participate in the social AS? How do actors relate to each other? Which roles do actors take in this interaction context, which actions can they take, which attributes of the actors are important for explaining the emergent behavior of this AS? How do the outcomes of social-ecological AS enable or constrain the social interaction? How are the social interactions in the social AS influenced by the social-ecological interactions?
8. For ecological AS: which ecosystem components (organisms, populations, geophysical entities) interact in the ecological AS? How do they relate to each other? Which processes or structural changes do they result in that are important for explaining the emergent behavior of this AS (e.g. change in food web structure, change in soil quality)? How are the ecological interactions in the ecological AS influenced by the social-ecological interactions?

Appendix III: Codebook

Codes used for the 1st round of coding:

Interactions

- I1 - Human interactions
- I2 - Non-human ecological interactions
- I3 - Social-ecological interactions

Outcomes

- O1 - Social performance measures
- O2 - Ecological performance measures
- O3 - Externalities to other SESs

Codes used for the 2nd round of coding:

Interactions

- I1
  - Rule Making
  - Enforcement
  - Provision of sanitation
  - Provision of waste management
- I2
  - Contamination by surface runoff
  - Dilution
  - Stabilisation
- I3
  - Pollution by agricultural activities
  - Pollution by riparian residents
  - Pollution by the industry
  - Regeneration

Codes used for the 3rd round of coding:

External factors

- Related Ecosystems (ECO)
  - ECO1 - Climate patterns
  - ECO2 - Pollution patterns
  - ECO3 - Flows into and out of focal SES
- Social, Economic and Political Settings (S)
  - S1 - Economic development
  - S2 - Demographic trends
  - S3 - Political stability
  - S4 - Government resource policies
  - S5 - Market incentives
  - S6 - Media organisation

Appendix IV: Example of the application of the SESF

In the following, an example of the application of the SESF is presented. The case deals with water bodies in the urban area of Bangalore and the question of why some of them have been restored while others are heavily polluted, have dried up have been encroached. The following text and table were taken (copied) from Nagendra and Ostrom (2014):

We use a social-ecological system (SES) framework to investigate why some locations have been successful in negotiating changes in governance from community-based systems to state management following urbanization, whereas other lakes have deteriorated. We use seven second-tier SES variables that were associated with self-organization in previous research: size of resource system, number of actors, leadership, social capital, importance of resource, existence of operational-choice rules, and existence of informal mechanisms for monitoring. We also include three third-tier variables previously identified as important in urban lake commons in Bangalore: scale and type of pre-existing pollution, exclusion of socioeconomic groups from the planning process, and networking with government organizations. We use this subset of 10 variables to examine social outcomes of the lakes, which we define as the extent of collective action by residents working together for lake restoration and ecological outcomes based on the ecological condition of the lakes. Collective action was low in only one of seven lakes, which challenges the presumption that citizens will not organize efforts to cope with common-pool problems. However, only two of seven lakes were highly successful in regard to both the extent of collective action and the level of ecological performance. While one lake was small and the other moderate in size, these two cases shared similar ranking in all other variables. Both lakes were polluted at a relatively low level compared with the other lakes, and in both cases, the leaders of local groups were able to network with government officials to clean up the lakes. Unfortunately, the challenge of cleaning up urban lakes after many decades of pollution is very difficult without effective interaction with various governmental units. Our analysis illustrates the usefulness of the SES framework in examining the combination of variables that makes a collective difference in affecting the outcomes of collective action and ecological performance. Our findings illustrate the need for polycentric arrangements in urban areas, whereby local residents are able to organize in diverse ways that reflect their own problems and capabilities, but can also work jointly with larger-scale governments to solve technical problems requiring changes in major engineering works as well as acquiring good scientific information. Such arrangements can reduce transaction costs for city governments by actively engaging local communities in processes that include coordination of collective activities, design of inclusive and locally suited ecological and social restoration goals, and planning and enforcement of regulations limiting access and withdrawal. At a time when many city governments are facing financial and administrative challenges that limit their ability to regulate and maintain urban commons, models of public-community partnerships could provide more inclusive, equitable, and sustainable institutional alternatives. This is an aspect that needs significant further consideration because the attention of most urban planners and scholars has remained on privatization while studies of successful instances of cooperative action in the urban context remain few and far between.

Variable	**Lake**						
	Agara	Ambalipura	Bellandur	Kaikonda-nahalli	Mestripalya	Parappana Agrahara	Varthur
RS3: Size of resource system	Moderate	Small	Large	Moderate	Small	Small	Large
A1: Number of relevant actors	Moderate	Moderate	Large	Moderate	Small	Moderate	Large
A2: Socioeco. groups excluded	Yes	No	No	No	Yes	No	No
A5: Leadership	Lacking	Present	Present	Present	Present	Absent	Absent
A6: Norms of trust, social capital	Low	High	Moderate	High	Low	High	Moderate
A8: Importance of resource, dependence	Low	Moderate (+)	Moderate	Moderate (+)	Low	High	Moderate

GS5: Operational community rules	Absent	Present (+)	Absent	Present (+)	Present	Absent (-)	Absent
I8: Networking with government	Low	High (+)	Low	High (+)	Moderate	Low	Low
I9: Informal norms for monitoring	Absent	Present (+)	Absent	Present (+)	Absent	Absent (-)	Absent
O1: Social performance measures (collective action)	Moderate	High (+)	High	High (+)	High	Low (-)	Moderate
O2: Ecological performance measures (lake)	Low	High (+)	Low	High (+)	Low	Low (-)	Low

Note: (+) and (−) indicate recent changes from 2007 to 2012 in the direction indicated.

Appendix V: Unpacked Resource System and Resource Units

The following content was taken from Vogt *et al.* (2015).

Table 1 Resource system – second- and third-tier components

Second-tier components	**Third-tier components**
RS1 - Sector	
RS2 - Clarity of system boundaries	RS2a - Ecologically defined boundaries of the resource system (e.g., watershed, ecological zone boundaries, etc.) RS2b - User-defined boundaries of a resource system RS2c - Contiguity of resource system to adjacent ecosystems of the same type (e.g., type and quality of matrix ecosystems)
RS3 - Size of resource system	RS3a - Extent of resource system in geographic area RS3b - Resource system shape or configuration (e.g., edge to interior ratio) RS3c - Fragmentation dynamics RS3d - Size of different habitat or ecosystem types within the resource system (mosaic features)
RS4 - Human-constructed facilities	RS4a - Facilitation of ecological movement (e.g., sewage outflows, species corridors) RS4b - Impediments to ecological movement (e.g., dams, fences, roads)
RS5 - Productivity of system	RS5a - Resource dynamics (e.g., water, light, nutrient availability) RS5b - Community/species composition
RS6 - Equilibrium properties	RS6a - Successional stage/trajectory RS6b - Existence of alternative stable states and thresholds between states RS6c - Frequency/timing of disturbance(s) RS6d - Extent of disturbance(s) RS6e - Magnitude/intensity of disturbance(s)
RS7 - Predictability of system dynamic	RS7a - Stochasticity/uncertainty of driving forces (e.g., disturbances, populations dynamics) RS7b - Probability of driving forces leading to a given outcome (or intermediate outcome) RS7c - Variability (range of) of driving forces RS7d - Time period that may be predicted
RS8 - Storage characteristics	RS8a - Nutrient source-sink dynamics RS8b - Spatial and temporal patterns in storage
RS9 - Location	RS9a - Connectivity of resource system to nearby ecosystems of similar and different types
RS10 - Ecosystem history	RS10a - Relevant geologic history RS10b - Natural disaster history‡ RS10c - Human use and disturbance history

Table 2 Resource units – second- and third-tiers variables

Second-tier components	Third-tier components
RU1 - Resource unit mobility	RU1a - Mobile resource units RU1b - Stationary resource units
RU2 - Growth or replacement rate	RU2a - Length of time to reproductive maturity| RU2b - Source-sink population dynamics (incl. migration patterns)| RU2c - Effective population size and reproductive rate
RU3 - Interaction among resource units	RU3a - Competition within species (intraspecific competition) RU3b - Competition between species (interspecific competition)| RU3c - Predation (incl. herbivory, parasitism) RU3d - Mutualism| RU3e - Multilevel trophic interactions/cascades
RU4 - Economic value	RU4a - Subsistence value| RU4b - Absolute economic value| RU4c - Relative economic value|
RU5 - Number of units	RU5a - Population (and subpopulation) dynamics RU5b - Absolute size RU5c - Relative size (of the population or of individuals in the population)
RU6 - Distinctive markings	RU6a - Natural distinctive markings RU6b - Artificial distinctive markings
RU7 - Spatial and temporal distribution	RU7a - Spatial patchiness (heterogeneity of resource or habitat distribution over space) RU7b - Temporal patchiness (heterogeneity of resource or habitat distribution over time, i.e., phenology)

Appendix VI: Example of the application of the SE-AS Framework

In the following, an example of the application of the SE-AS framework is presented. The case deals with the collapse of the cod population of the Baltic sea and the text was taken (copied) from Schlüter *et al.* (2019):

We applied the SE-AS framework to develop a hypothesis about the social-ecological interactions that may have accelerated or prevented the collapse […]. The main social-ecological action situation is the harvesting of cod by fishers (fishing SE-AS). We hypothesized that fisher decision making in this social-ecological AS affected the stability of the fishery (compared to the ecosystem alone) and thereby its tendency to undergo a regime shift. Based on empirical evidence, we assumed that the decision of a fisher to spend time fishing was influenced by the perceived profitability of cod fishing, his previous catch experiences, and investments in his fishing fleet (sunk cost effect; Lade et al. 2015).

We could then decompose these decision-making factors by identifying the social and ecological interactions that influenced them. A fisher's perception of cod abundance is influenced by previous catch experiences, which are the result of past socialecological fishing interactions (perceiving AS). Fishers had a perception of high cod abundance because of a preceding cod boom. Cod abundance is influenced by food web interactions, such as the competition and predation between cod and sprat and cod and herring in ecological AS (competition, predation ASs). Because these ecological interactions have been well studied (Möllmann et al. 2009), we do not go into their details here. An actor's perception of profitability of cod fishing is influenced by the market price for cod. Market prices for cod, which were also affected by cod supply from other areas, and subsidies from the Swedish government are both considered critical factors for high fishing pressure in the 1980s. The market price emerged in a social AS from market transactions that were influenced by cod supply resulting from the fishing social-ecological AS (market transaction AS). Finally, a fisher's investments in his fleet were influenced by subsidies provided by the Swedish government. These subsidies were the result of a rule-making social AS that was influenced by information provided by the fishing AS (policymaking AS). The fishing pressure, as an outcome of the fishing interactions, was also influenced by an external driver, namely immigration of fishers from the west coast of Sweden, who were attracted by the prospect of high catches during the cod boom.

A model-based analysis of the role of these different interactions for explaining the cod collapse revealed that adaptation of fisher behavior to changing cod populations helped to delay the cod collapse until the nonlinear dynamics of the ecological interactions caused the collapse (Lade et al. 2015). Fishers responded to changing cod availability by changing their decisions with respect to time spent fishing, investment in their fleet, and in the case of the west-coast fishers whether to enter the Baltic Sea. Fishers' adaptability to changing conditions was, however, delayed by slow updating of perceptions of cod availability, sunk cost effects from investments in new fleet, and subsidies, which in interplay with the ecological dynamics, ultimately caused the collapse.

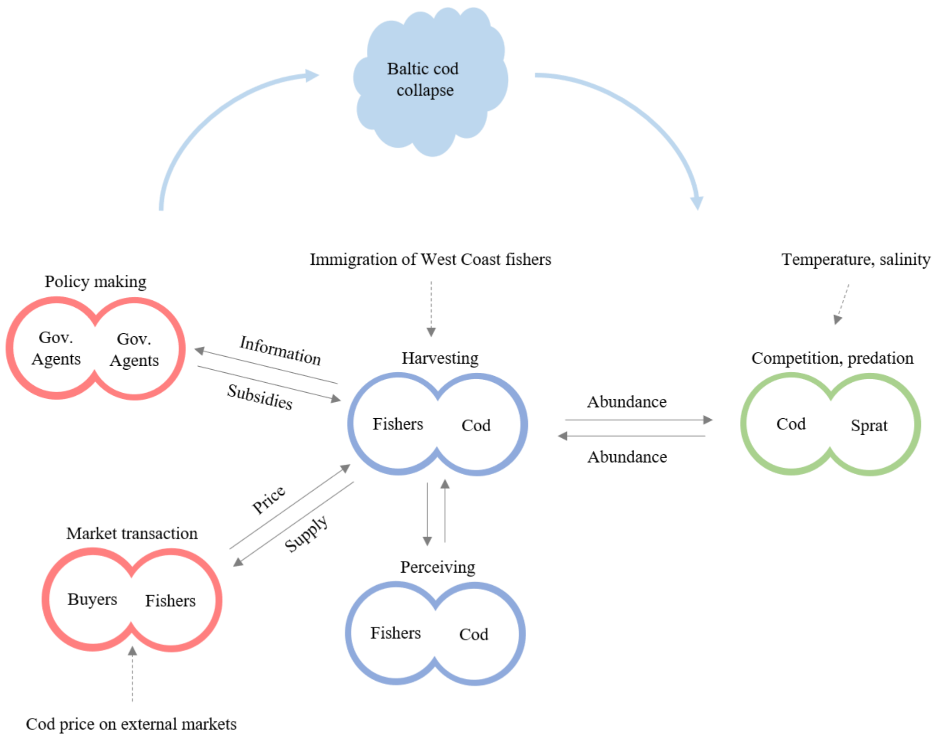


Figure is based on *Schlüter et al. (2019).*

References as presented by Schlüter *et al.* (2019)

Lade, S. J., S. Niiranen, J. Hentati-Sundberg, T. Blenckner, W. J. Boonstra, K. Orach, M. F. Quaas, H. Österblom, and M. Schlüter. 2015. An empirical model of the Baltic Sea reveals the importance of social dynamics for ecological regime shifts. Proceedings of the National Academy of Sciences 112(35):11120-11125. https://doi.org/10.1073/pnas.1504954112

Möllmann, C., R. Diekmann, B. Müller-Karulis, G. Kornilovs, M. Plikshs, and P. Axe. 2009. Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: a discontinuous regime shift in the Central Baltic Sea. Global Change Biology 15(6):1377-1393. https://doi.org/10.1111/j.1365-2486.2008.01814.x

Appendix VII: Social-ecological, social, and ecological action situations

The following content was taken from Schlüter *et al.* (2019).

SE-AS	Description
Cultivating/Harvesting	Cultivating crops, harvesting natural resources such as fish, timber, grass
Converting	Changing sea or landscapes through technology (e.g., building a dam) or by restoring or converting use to protect ecosystems (e.g., protected areas/reserves)
Recreating	Spending time in nature, enjoying (physically, psychologically)
Cultural activities	Performing cultural or spiritual activities in nature
Ecological monitoring	Observing or measuring ecological conditions
Polluting	Introducing substances into ecosystems

S-AS	Description
Rule making	Developing an operational rule, e.g., the level at which individuals can harvest a common pool resource; developing collective choice rules that determine who is involved in decision making
Information sharing	Sharing information or knowledge between actors
Deliberating	Communicating, exchanging observations and views, reflections, assessing outcomes, persuading each other
Conflicts	Engaging in actions that aim to harm other actors
Investing	Allocating financial resources to restore, conserve, or convert sea or landscapes
Lobbying	Influencing political actors to follow one's own interests
Networking	Creating and maintaining social ties
Social monitoring	Monitoring compliance of others
Evaluating	Evaluating outcomes of action situations
Competing	Aiming to do better than other actors, may involve interfering with their activities to reduce their performance
Trading	Exchanging goods or services between two or more actors, selling products at markets

E-AS	Description
Predation	Individuals of one species prey on another
Competition	Individuals of the same or different species compete for a limited food resource or space
Facilitation	Individuals of one species facilitate growth or reproduction of another species
Infection	One organism infects another organism with a disease
Species-habitat interaction	Generation of offspring, facilitated by suitable ecological environment
Vegetation-soil interaction	Vegetation growth stabilizes soil Soil quality affects vegetation growth and vice versa