A deep dive in the food system of Kibera and its environment

A spatial environmental analysis for a better understanding of environmental and socio-economic drivers

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The development of sustainable food system in urban area requires a good understanding of place specific spatial and functional relationships among food system activities, and the environmental and socio-economic factors. In the full belief a multiscale spatial analysis will help in further understanding potential linkages and priorities in food system interventions and strategies, this report dives into food system activities of Kibera (Nairobi -Kenya) and the environmental and spatial relations at different scales. Available households surveys serve as starting point. The objective of this research is to bring in suggestions for further extending the household surveys to challenge a deeper understanding of crucial environmental and spatial relations between the food system activities, environmental drivers and socio-economic drivers. Most of all, it is an experimentation in supportive strategic spatial analysis for common understanding, prioritization and strategy development.

Keywords: food systems, spatial analysis, environment, climate

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Photo cover: Kibera -Katrine Soma, 2019 (Wageningen University & Research)

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Summary

The development of sustainable food systems in urban areas requires a good understanding of place specific spatial and functional relationships among food system activities, and the environmental and socio-economic factors. This report dives into food system activities of Kibera (Nairobi -Kenya) and the environmental and spatial relations at different scales. It is a follow up to the initial exploration in 2020. The multiscale spatial analysis based on iterations is in the full belief it will help in further understanding potential linkages and priorities in food system interventions and strategies, The available households surveys carried out by Wageningen Economic Research in cooperation with Egerton University form a solid starting point. The objective of this research is to bring in a deeper understanding of crucial environmental and spatial relations between the food system activities, environmental drivers and socio-economic drivers. Secondly, it is an experimentation on the methodology of strategic spatial analysis to support common understanding, prioritization and strategy development. This research is subsidized by the Dutch Ministry of Agriculture, Nature and Food Quality as part of the motif 'Feeding cities and migration', within the KB program Food Security and Valuing Water (KB-35-002-001).

The focus in our research is on the linkage between food security and the water-energy-food nexus in the background of climate change. Along the topics of climate, water and energy (spatial) information at different spatial scales has been gathered and brought together in clear narratives. As a starter, the results of the existing household survey have been transferred into tables, figures and maps. In addition, relevant maps were collected and analyzed to indicate the past, current and upcoming future issues. A comparison has been made and dependencies considered.

The report introduces the main outcomes of the household surveys with an emphasis on the outcomes with (potential) environmental and spatial information and issues. Next, it brings together available data about climate change in the light of food security and natural resources. More specifically it analyses the crucial resources of water and energy in relation to the food system activities, starting from the local level and comparing and linking it to the regional and national perspective.

The main outcomes of this research show:

- The overall food security in Kenya is and will be faced with large scale challenges in the changing climates. In Nairobi the food security relies more on interventions across the value chain. A value chain consists of all the different, consecutive steps, activities and added value while going from production to consumption. Thus, multilevel arrangement is the key to a sustainable food system.
- Most of the urban population in Kenya relies on vendors for drinking water even though the water quality is not certain. Due to pollution and limited water availability, drinking water in Nairobi does not come from the nearby Athi River but from water reservoirs in the north via pipes. Food waste in Kibera is mostly discarded in the river, which set further pressure on the water quality. Enhancing environmental awareness and common sensemaking should be a first step.
- Liquefied petroleum gas (LPG), paraffin and charcoal are most commonly used for cooking in Nairobi. Comparatively, Kibera has a higher usage on less clean energy. The usage on paraffin is gradually replaced by that on LPG since 2020. While the dependency on charcoal stays the same. It should be encouraged to use more renewable and cleaner alternatives, i.e. via pricing and again common sensemaking.

Hence, many specific questions come up to extend the household surveys. More specific knowledge gaps have been addressed for further explorative research and to improve understanding. The outcomes the multi scale (spatial) data analysis and projected on the food system framework in Kibera are transferred into an initial causal chain. This shows the potential pressures, positive and negative feedback loops in the current food system in relation to climate, water and energy, and could serve as a preliminary guidance in prioritization and strategizing food system interventions.

1 Introduction

Problem statement
There is still limited understanding of the exact and (place) specific spatial and functional relationships among food system activities, and the (changing) environmental and socio-economic factors. This hampers the development of sustainable, just and effective solutions for food system challenges. There are many interdependencies and impacts within the food system, often also of the direct scope of a project or program. If these relations aren't in sight unforeseen risks and impacts could occur or an intervention could be less effective than expected or even soon at risk already. Additionally, we observe a limited understanding and uptake of spatialization and spatial analysis in food system analysis and assessments. However, this could play a role in uncovering these relations and in specifying and localizing areas of attention but requires new ways of practice.

Objective
The objective of this research is to a deeper understanding of crucial environmental and spatial relations between the food system activities, environmental drivers and socio-economic drivers. It will also bring in suggestion for extending current household surveys.

The first focus for extension is water and energy related information at a local level since they are two important resources for food related activities. Linkages between food security and the water-energy-food nexus in the background of climate change at different scales will be further and more specifically be explored. In doing so it will reveal and address potential knowledge and data gaps in the current household surveys.

In this research we focus primarily on Kibera. Based on the research outcomes the suggestions for other related research projects can be outlined.

The Food Systems Approach (FSA)
The Food Systems Approach (FSA) is a useful interdisciplinary conceptual framework for research and policy aimed at sustainable solutions for the sufficient supply of healthy food. The Food Systems approach sets the relationships between the different parts of the food system and the outcomes of activities within the system in socio-economic and environmental/climate terms to the forefront. Feedback loops are a distinguishing factor in systems thinking: they occur between parts of the food chain (production, processing, distribution and consumption) and from the socio-economic and environmental outcomes of food production and consumption (such as food security and soil depletion) back to that production and consumption (Berkum et al., 2018). This connectiveness is illustrated in the Food Systems Framework, that serves as a guiding tool in this study (Figure 1).

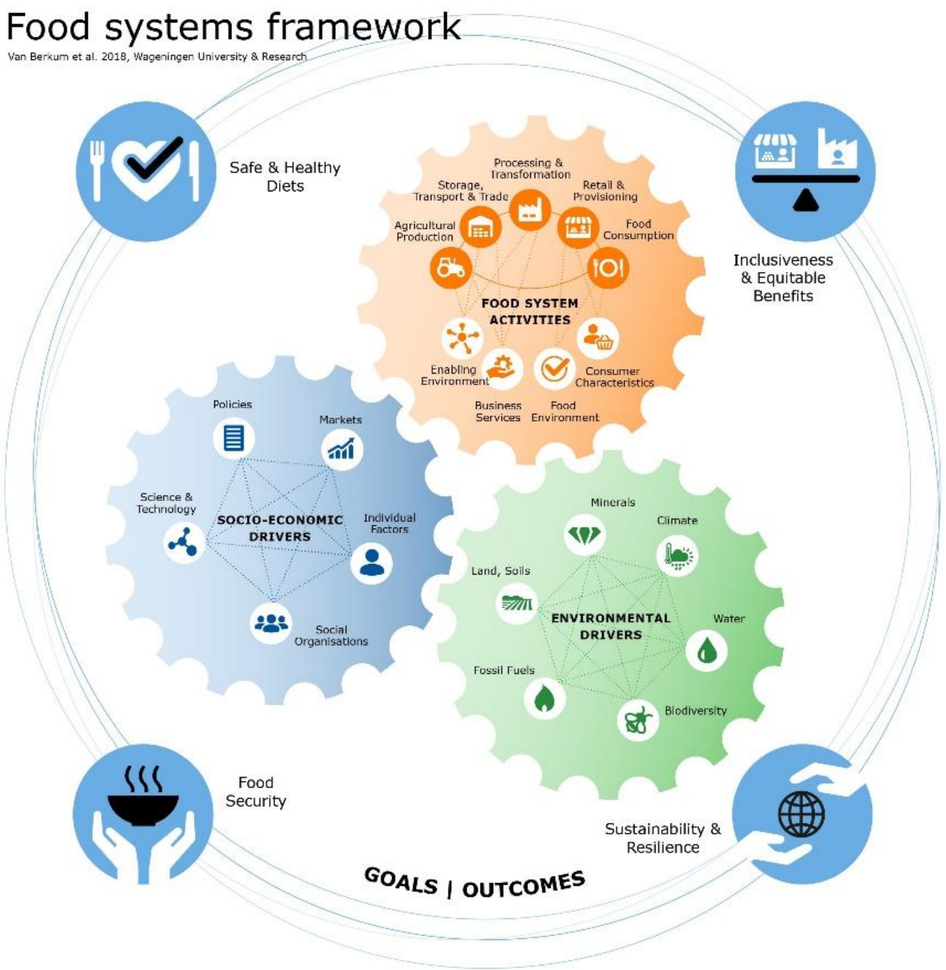


Figure 1 *Food systems framework (WUR, 2022).*

Household surveys
Wageningen University & Research, in close cooperation with Egerton University, has carried out two household surveys. The first was carried out in August 2020 and was repeated in August 2021. The household surveys were conducted at the local level. The household surveys provide good insights of local food system activities and related conditions and challenges. With these knowledges the active participation with the local communities and other stakeholders involved in the food system approach will contribute to profound solutions for a sustainable food system. The outcomes of the household surveys can also be combined with and compared with other local, regional and national data to link and deepen insights. Insights that serve a better understanding and helps in assessing potential interventions and strategies, linked to (inter)dependencies at different geographical and governance levels.

Contribution of multi scalar spatial analysis
The food system is complex, multifaceted, and multi-scaled. Already in 2012, Greiner concluded in a critical review of literature on rural-urban migration (Greiner & Sakdapolrak, 2013) that "overly generalizing assumptions about the distinct relations (between migration, agricultural change and the environment) fail to grasp their complexity". In the same review it is mentioned that "the impact of rural-urban migration on environmental resources is largely unaccounted for and constitutes a critical research gap". The study addresses the importance of the "ever-increasing rural urban interdependencies and their effects on the environment" and "the urgent need for future research on the migration-environment nexus in Kenya more systemically". Through this research we try to contribute to make this more specific.

Due to the complex nature of food systems, multi scale spatial analysis helps in understanding potential pressures and positive and negative feedback loops outside the direct area of interest. As such, spatial analysis in multiple scales can illustrate how food system activities across space and sectors impact food security and should be taken into account for in specific interventions and the development of a sustainable and resilient food system. Spatial analysis also makes results and insights more specific and tangible. It is not only on what and how, but especially also where. However, spatial analysis is not yet standardly used in food system analysis and often comes with challenges in complexity and available data.

How is the report organized?

In chapter 2 the case of Kibera will be introduced. It will outline the characteristics of Kibera and the current general insights on the main demographics, food activities, environmental drivers and socio-economic aspects. Chapter 3 provides an overview of the changing environment due to climate change. This chapter will place the expected changes and effects in a multiscale perspective, from Kibera, to Nairobi and Kenya as a whole. This forms the starting point for chapter 4 and 5 in which a deep dive will be made in two selected key issues: water and energy. Water and energy will be set in the framework of the Food System Approach. Both deepening chapters start with a description of the current situation and issues, followed by the effects of environmental and socio – economic drivers at the different scales in order to find the interrelationships. Finally, chapter 6 brings together the new insights, opportunities and limitations. A causal chain indicates how the elements in the Food System Framework connect to each other in Kibera. Recommendations will be given for further research.

Kibera and its food system.
(Photo credits: Katrine Soma (Wageningen Economic Research)).

2 Kibera and its food system

The African continent is urbanizing faster than other continents, with the expectation that more than half of the sub-Saharan Africa (SSA) population will live in urban areas by 2030. In Kenya about 60-80% of the population lives in informal settlements (Gallaher, Kerr, Njenga, Karanja, & WinklerPrins, 2013). In the capital city Nairobi, about half of the people lives in at least 100 slums and squatter settlements (Achungo, 2014).

Kibera is the largest informal settlement in Nairobi, Kenya, and one of the largest urban slums in Africa. Kibera is described as a densely populated informal settlement area, where residents face a range of challenges including to high levels of poverty and food insecurity, insecure land tenure, lack of adequate housing, poor infrastructure and drainage, frequent threats of violence, high crime rates, poor environmental conditions, and inadequate access to basic goods and services that include sanitation, health care and education and frequent outbreaks of water borne diseases (Achungo, 2014; Gallaher, WinklerPrins, Njenga, & Karanja, 2015). Kibera is located 5-7 km south-west of downtown Nairobi, within the legal city limits at an altitude of 1670m and about 140km South of the Equator (Gallaher et al., 2013; Gitahi, Gathura, Gicheru, Githinji, & Nordin, 2018).

There is a lack of understanding of the complexities of Kibera livelihood including food nutrition security and welfare measures, which has birthed lots of misconceptions and misinformation on its name, the size and the location, its exact population, the villages in the settlement and the poverty status, land and property ownership etc. Often rough guesses about Kibera are based on total population in Nairobi, or research is conducted in one of the 12-14 villages of Kibera, assumed to be representative to all. The true population size is obviously a disputed issue (Desgroppes & Taupin, 2011; Kibere, 2016). The total population of residents in Kibera in 2019 according to the national census is only 185.777 people (Statistics, 2019).

In informal settlements such as Kibera, food insecurity is a daily reality. Slum household spend around 40-50% of their income of food, but mostly rely in irregular sources of income. A household survey carried out by the project found 64% of the households say their income is not sufficient to cover food costs. Quality and quantity of food is limited and results in chronic food insecurity and malnutrition (Katrine Soma, Obwanga, & Kanyuguto, 2021). The Household Surveys that were carried out give a good sight on the different food system activities and related socio-economic and environmental drivers. In the following paragraphs we will successively outline the main insights.

Food system activities

The main focus of the household survey regarding food system activities is on consumption, with special attention to fish consumption(Ayuya, Soma, & Obwanga, 2021). Besides, the household surveys give a view on local production, both urban farming and remote farming, land rental or land ownership. Other food system activities, like food storage, transport and trade, food processing, food retail and provisioning have not been part of the household survey and currently require other sources of information.

Currently, people in Kibera eat *ugali* (a maize porridge) and vegetables (in small amount) in all meals. Small pieces of meat and fish are added to the meal only when income allows it. In lunch, next to vegetables and ugali, cereals are most common food. For suppers the households in Kibera consume more fish and meat than in lunch time. Porridge is the most popular food for snacks. It is followed by meat and fish. Dairy product such as milk is consumed with tea. Its consumption rate is currently low. The same low consumption is found in bread and fruits.

In this paragraph we will highlight the fish consumption and its value chain, urban farming and remote farming/land ownership. The fish value chain is key topic in ongoing research and participatory activities in Kibera and is an example how to improve current systems across regions.

Urban farming and remote farming/land ownership can provide first insights in both self-sustainability in relation to the area itself and surrounding areas. This sets the necessity of developing broader and additional chains on the one hand, and on the other hand a glimpse towards dependencies on natural resources in relation to agricultural practices.

Fish consumption and the value chain

In Kibera fish is an important source of proteins (Ayuya et al., 2021; Obwanga, Mbauni, Mwangi, & Soma, 2020; Katrine Soma et al., 2021). The main sources for this fish are the lakes Victoria and Naivasha. In 2020 a new chain from Nyeri is developed, by making a connection between fish producers in Nyeri with fish vendors in Kibera. Fish is transported in refrigerator tracks. From this fish part of the food chain, it is clear that part of it occurs in Kibera: more than 70% of the households buys fish from vendors in their own neighbourhood; 60% of household buys fish from vendors outside their neighbourhood. But only 10% buys it elsewhere in Nairobi. The processing demands of Kibera consumers are cleaning, gutting and removing scales, sun drying and smoking, but the main demand is deep frying, which is done by the fish vendors (Ayuya et al., 2021).

Urban farming

Urban farming is not very common in Kibera: only 7,5% of the households is involved in some kind of urban farming. Most frequent type is poultry keeping, which is done by 5% of the households. The most popular type of urban farming is sack farming in Kibera: big sacks with some holes are used to put soil and seeds. Sack farming is done by 2%, and other types by 1% (gardens and duck), and only 1 household with goats. Pigs and rooftop farming are not found in our research population. The most western villages like Kianda, Soweto West and Raila are leading in poultry farming.

Table 1 *Frequency and types of urban farming in Kibera 2020.*

	Frequency	Percent
No	356	92,5
1 sack farming	4	1
1 3	1	0,3
3 poultry keeping	18	4,7
3 1	2	0,5
5 6 1	1	0,3
6 other, specify	2	0,5
6 1	1	0,3
Total	**385**	**100**

Kibera Household survey 2020, all 385 answers were valid, 356 households answered No and 29 Yes, from which some had more types; type 5 is goats.

Table 2 *Urban farming percentage per type per village in Kibera 2020.*

Village	Urban farming type					
	1 sack	2 rooftop	3 poultry	4 pigs	5 goats	6 other
1 Makina	0%	0%	0%	0%	0%	0%
2 Lindi	3%	0%	0%	0%	3%	3%
3 Mashimoni	0%	0%	0%	0%	0%	0%
4 Laini Saba	0%	0%	6%	0%	0%	0%
5 Kianda	6%	0%	17%	0%	0%	0%
6 Kisumu Ndogo	3%	0%	7%	0%	0%	0%
8 Soweto West	0%	0%	14%	0%	0%	0%
9 Gatwekera	3%	0%	3%	0%	0%	0%
10 Raila	6%	0%	9%	0%	0%	0%
11 Kambi Muru	0%	0%	0%	0%	0%	0%
12 Olympic	7%	0%	3%	0%	0%	3%
13 Karanja	0%	0%	3%	0%	0%	7%

Kibera Household survey 2020, all 385 answers were valid; villages 7 Soweto East and 14 Silanga were not visited in the HH survey 2020.

Remote farming, land rent and land ownership

From the household survey it appears that land rent is not very common in Kibera: only 4% of household rent land, with an average of 1 acre/household. Land ownership is more common: nearly 50% of the households' own land, with an average of 1.4 acre /household. Especially in the villages of Lindi, Gatwekera, Karanja and Kambi Muru land ownership is above 1.7 acre /household. But actual farming is done by only 21% of the households in Kibera. This is a yes-or-no question in the household survey. The size of the farming activities has not been asked. So, what about the ca. 30% of households that own land, but are not involved in farming? Is the land rented to other households, or is this land abandoned? Often the farms are family owned and are run by family members or rented out to other farmers.

Table 3 *Land size, land rent and remote farming in Kibera 2020.*

	Households	Minimum	Maximum	Mean
Landsize owning (acres)	192	0.06	15.00	1.42
Landsize rent (acres)	15	0.25	3.00	0.97
Farming in rural area? (yes=1)	82	0	1	0.21

Kibera Household survey 2020, all 385 answers were valid.

In some villages one third of households are involved in farming: Kambi Muru, Gatwekera, Mashimoni and Lindi. These villages have a relative high land size too, where in Lindi the average is double compared to the other villages. If you take a look on the aerial map of Kibera, it is clear that the agricultural land use is not located in the slum of Kibera. Urban rural linkages are interesting to further explore, especially in terms of strategies and opportunities relating to the food system.

		m7:landsize		m7:landsizerent		m7:farming	
		Valid N	Mean	Valid N	Mean	Valid N	Mean
m4:village	1 Makina	11	,83	0	.	30	,10
	2 Lindi	9	3,33	2	,75	30	,27
	3 Mashimoni	19	1,27	1	,25	30	,30
	4 Laini Saba	11	1,31	2	1,25	35	,17
	5 Kianda	24	1,10	3	,75	35	,17
	6 Kisumu Ndogo	15	1,03	0	.	30	,20
	8 Soweto West	18	,78	1	1,00	35	,20
	9 Gatwekera	22	1,97	0	.	35	,29
	10 Raila	18	1,11	2	,75	35	,11
	11 Kambi Muru	20	1,74	1	3,00	30	,37
	12 Olympic	15	1,43	2	,75	30	,23
	13 Karanja	10	1,85	1	1,00	30	,17

Figure 2 *Aerial map of Kibera.*

Environmental drivers

Important environmental drivers of a food system (Berkum et al., 2018)are:

- The availability of **land** for arable and livestock farming.
- The use of **energy** (in most cases fossil fuels) for agricultural machinery, transport, storage and processing the food.
- The use of **minerals** like NPK and lime to enrich soils for optimal production, together with additional micronutrients.
- **Biodiversity**, both in agricultural system itself as in the surrounding environment: more diverse breeds and plants in agriculture will result in a more resilient system in case of possible losses by climate change or diseases. More biodiversity in the soil and agricultural environment can also have positive effects on agricultural production.
- **Water** availability is an indispensable source of life, not only for agricultural production, but also needed for the people directly as drinking water, water for cooking and cleaning. Not only the amount but also water quality is important in this context.

In Kibera the households survey gives some information about the water availability for drinking and cooking. Since nearly all agricultural production occurs outside Kibera, specific additional information about the environmental drivers of the food system of Kibera is scarce. We will have to fall back on general information about food production in Kenia and possible additional food imports, in relation to the availability of land, energy, minerals, biodiversity and water. In terms of food security, Kibera is highly dependent on (in)formal value chains. Increasing food security also implies strategies along these chains and to a wider extent. It’s not only important to specify this more precisely in geographical extends, but also in facing a changing environment due to climate change and adverse effects. This changing environment will be elaborated in the next chapter.

Socio economic drivers

Important socio-economic drivers of a food system are:

- **Markets**: the system of prices and trade relations, in which supply and demand of food can come together, including incomes and availability of labour, etc.
- **Policy** in a broad sense: land rights, food security, environment, trade, food safety; policy can aim for certain food system outcomes e.g., food security, which can possible not match with the private interest of actors in the food system.
- **Science and Technology**: research and development of innovations can lead to a growth in productivity, and also in a better food quality and nutritional value.

- **Social organisations**: for example, households, organisations of farmers or vendors which could improve the functioning of the food system, of course depending on if and how they are organized. Also, media, education and health care are important in this social context.
- **Individual factors**: lifestyle and norms, (e.g., about animal welfare), attitudes and cultures (e.g., kosher of halal), can influence the demand of individual actors in the food system.

In Kibera the household survey gives a lot of information about the socio-economic drivers and livelihood welfare factors of the food system: size, age, gender, village, tribe, connection to rural area, education, occupation, income, income sources, and also about savings, loans and spending.

Besides, individual factors about food consumption in relation to culture or religion, preferences for breakfast, lunch, supper, snacks are asked.

A lot of attention is given to the choices of fish and the prices as part of the consumption pattern. Also, food security index questions are part of the survey, as well as trust in several social organisations, like government, local policies, communities, NGO's, traders, family and church.

The differences in livelihood factors across the villages in Kibera were analysed. It shows and explains some of the discrepancies in food security levels among its population, like current trust levels, cultural aspects (dominant tribes) and income factors. The large differences across villages in Kibera can be linked with the dominant tribe in the specific village. For instance, two villages (Laini Saba and Karanja) are dominated by tribes with less connectivity to rural areas in Western Kenya, with Laini Saba having a majority of Kamba and Kikuyu tribes who relate to the region of Mount Kenya and Eastern Kenya, and Karanja having most of the Nubians, who are not originally from Kenya, but were World War I veterans given temporary residence permits by the British colonial government between 1912 and 1934. The Luos and Luhyas are tribes from Western Kenya who in varying degrees dominate the other villages. Notably, also within these villages a series of welfare factors differ significantly, for instance, connection with Western Kenya, owning land in rural areas, access to steady electricity and trust in county government. Moreover, the selected income factors differ across the villages, with Laini Saba having the lowest, and Olympic having the highest average income levels. The variability in owning land in rural areas is high, ranging from a total of 69% owning land in Kianda, to only 33% owning land in Laini Saba. In addition, access to electricity varied highly across the villages, for which Makina ranged the highest, with 77% having access, to only 17% having access in Laini Saba. Further, food insecurity showed high variability, with Laini Saba ranging the highest and Karanja, Makina and Lindi lowest, confirming higher food security in these three villages than average.

To achieve real impact, the informal economy must be better understood and recognized as an equal partner. Research and implementation should go hand in hand (K. Soma, Janssen, Ayuya, & Obwanga, 2022).

An opening for a deep dive
The household surveys already gained a lot of information on the different elements of the food system. However, this information also motivates a deep dive. A deep dive that tries to find the mechanisms and linkages behind the numbers. There are many entry points to make this deep dive, nonetheless in this research we have chosen to start with climate, water and energy. Water and energy are intricately connected and crucial to food -from production to consumption. Climate puts the current food system also in the light of a changing world and changing conditions. In this deep dive available information on these topics at different scales and from different sources have been gathered and brought together. Linkages between food security and the water-energy-food nexus in the background of climate change are specifically explored. Aim is to unravel what the available data already shows us and what crucial information is still missing to really understand the mechanisms and linkages. Mechanisms and linkages that are essential to assess potential strategies and interventions. Crucial information that could be gathered by extending the household survey with more specific questions.

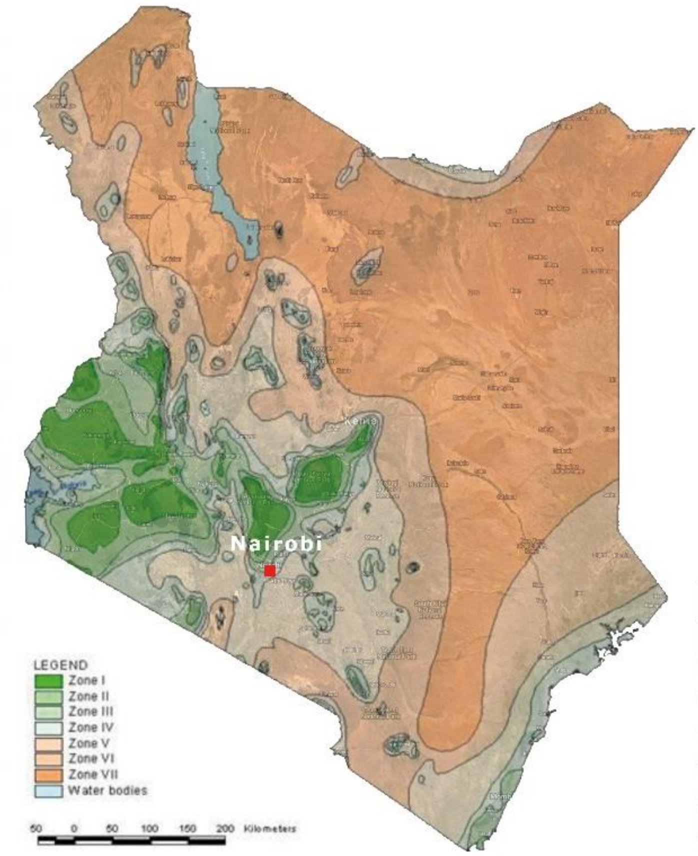
The Copernicus Sentinel-2 mission takes us over Nairobi.
Kibera, which can be seen as a light-coloured patch at the south-western edge of the city.
(Photo credits: ESA, 2019 via Flickr).

3 Climate change

Climate change leads to the altering in environmental conditions. Food system is highly dependent on the environmental conditions. Therefore, food security is very vulnerable to climate change. In this chapter, the current climate trends and projections in the scopes of Kenya and Nairobi are illustrated. Their potential impacts on the food system and, as such, the local resilience and food security in Kibera are discussed. The adverse impacts of climate change on water and energy are thereafter more specifically elaborated in chapter 4 and 5.

According to the historical climate disaster data and current projected climate change schemes, Kenya is and will be very vulnerable to climate change (Netherlands, 2018) (USAID, 2019) (Kogo, Kumar, & Koech, 2020). Rising temperatures, heat waves, extreme rainfalls and drought events have occurred and will even more frequently challenge the country in the future. This has resulted in and will lead to more food insecurity and regional food price fluctuations, especially in the northeastern Arid and Semi-Arid Lands (ASALs) (USAID, 2019) (see Figure 3).

ASALs (orange) cover the majority of Kenya. The medium to high potential agriculture land (green) looks like a peninsula, stretching from the western national boundary to central Kenya. Nairobi stands currently in the medium potential area on the green peninsula. However, Nairobi is influence by the impacts of food insecurity and regional food price fluctuations in its adjacent ASALs.



Zone	
I. Agro-Alpine	
II. High Potential	
III-IV. Medium Potential	
V. Semi-Arid	ASALs
VI. Arid	
VII. Very arid	

Figure 3 *Agro-ecological zones of Kenya and location of Nairobi (based on the map of Agro-ecological zones of Kenya (Netherlands, 2018)): 7 zones are classified based on a moisture index. Zones V, VI and VII have a moisture index of less than 50% where barely dry land crops can be produced. Zones I, II, III and IV have a moisture index of more than 50% as well as high rainfall and fertile soils, where there is a high potential for production of varied crops (Kogo et al., 2020).*

3.1 Current climate trends

Kenya has overall a tropical climate. It has very dry north and north eastern areas, and temperate inland. Its precipitation pattern results in 4 periods of seasonal rainfall (Kogo et al., 2020; Netherlands, 2018):

- long wet season: April – June;
- cool dry season: July – September;
- short wet season: October – December;
- warm dry season: January – March.

According to the last 50 years weather reports, the average numbers of rainy days in the short-wet season have reduced by 50%. The precipitation has become more irregular and variable over most regions of Kenya. A decline of precipitation for long wet season and an increase in rainfall for short wet season are being observed. In the same time, mean annual temperatures have dramatically increased by 1.02 ºC. (Netherlands, 2018) Extreme events such as droughts and floods happen more frequently due to these climate trends.

Floods have caused the great loss of human lives. From 2008-2012, the flood affected areas in Kenya have been enlarged dramatically (see Figure 4). In 2012, 100,000 people were displaced and 65 were killed by the floods (Netherlands, 2018). The northern bed of Athi River, where Nairobi sits, was mostly affected. The flood in 2012 has also led to a reduction in national agricultural growth by 4% (Kogo et al., 2020). Nearly 300 million dollars loss in crop production is estimated (D'Alessandro, 2015). Eight years later, Kenya and surrounding countries have faced with another heavy rainfall and widespread flooding. Many weather stations have reached their highest rainfall in the last 40 years. The death toll has risen to 237, and 211,000 persons were displaced in the whole country (News, 2020) (ECHO, 2020).

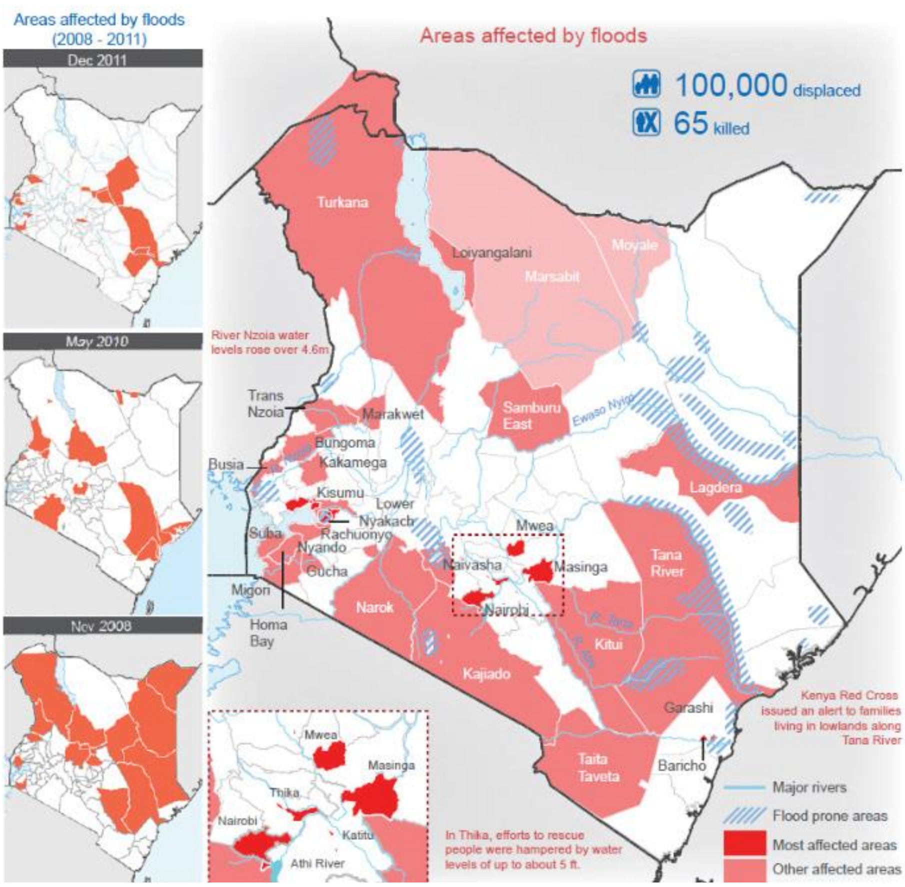


Figure 4 *Flood-affected areas 2008 - 2012 (ECHO, 2020) The maps on left show the situations in 2008-2011. The map on right indicates the flood-affected areas in 2012.*

In fact, major droughts occur even more frequently than floods in the recent years. They have affected more people then floods with greatest economic impact by 8% of GDP in every five years (Netherlands, 2018). The frequent drought events result in the decline of dam water levels and shortage of freshwater supply in overall Kenya (Faith Mulwa, 2021). Besides, the crop production loss due to droughts is up to 12% (Kogo et al., 2020). Based on the calculation of data from 1960 to 2014 by World Resources Institute, the drought risks in Kenya are medium to high level (see Figure 5). Nairobi sits on the medium to high drought risk area, where fresh water supply shortage and crop production loss are not avoidable.

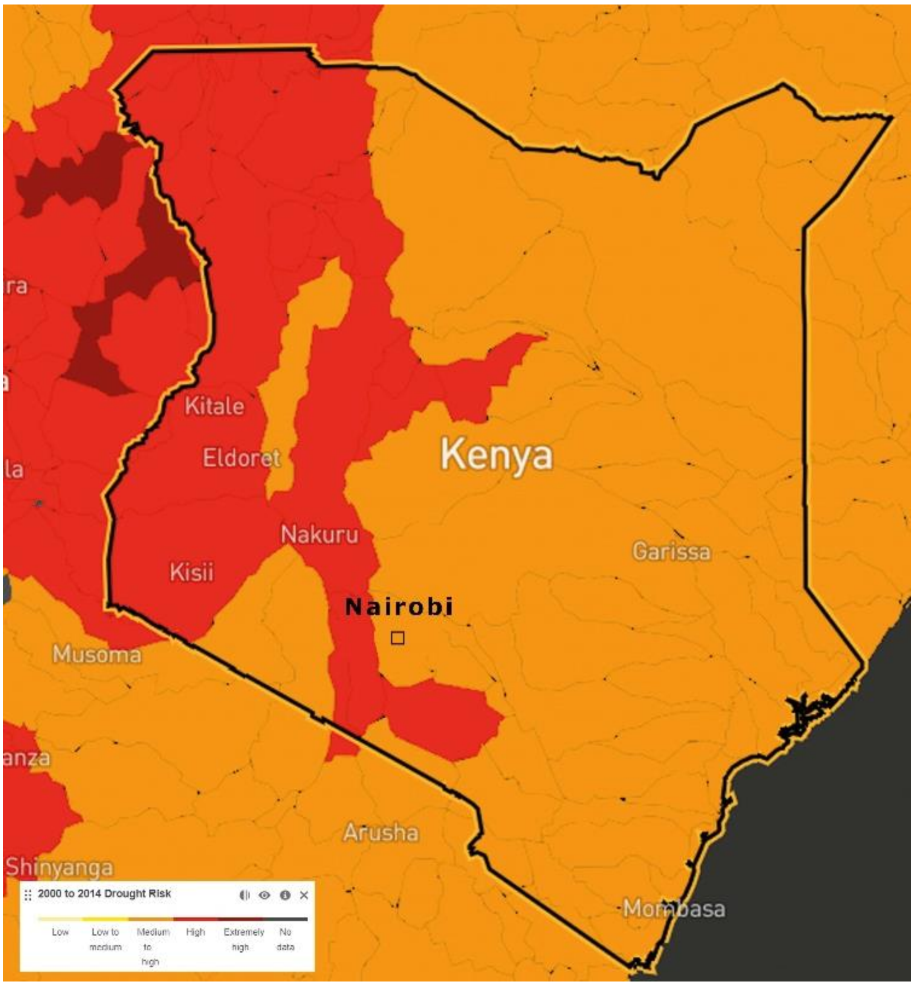


Figure 5 *Drought risk 2000-2014 (Hofste, 2019).*

3.2 Climate change projection

In Kenya, the current temperature and precipitation trends with the increasing frequency of extreme weathers are most likely expected to continue. For 2100 an increase in annual total rainfall as well as a slight decrease in dry spells are likely. It defers according to location and season (Netherlands, 2018):

- The highest rises of precipitation are expected for the northern part of Kenya;
- 100 mm decline of rainfall is expected for the long – wet season;
- For the short – wet season it is predicted with an increase in rainfall.

Meanwhile, increasing rainfall intensities are expected. It will result in more frequent floods with landslides and longer period of drought (Netherlands, 2018).

Temperature will continue to increase according to varied climate change models. Between 2000 and 2050 an average increase of 1-2ºC is most likely range. Higher rises are expected in the far northeast of the country than in the southeast. (Kogo et al., 2020; Netherlands, 2018).

Figure 6 shows the precipitation and temperature forecast in the coming 50 years. In Nairobi there will be a drop of 6.7% average yearly precipitation up to 2050. Afterwards the slight climbing of 1.3% will take place between 2050 and 2070. In contrast, the temperature in Nairobi will keep on increasing. In 2050 it will be 1.7 ºC warmer than in 1990. In 2070 extra 0.2 ºC will be added.

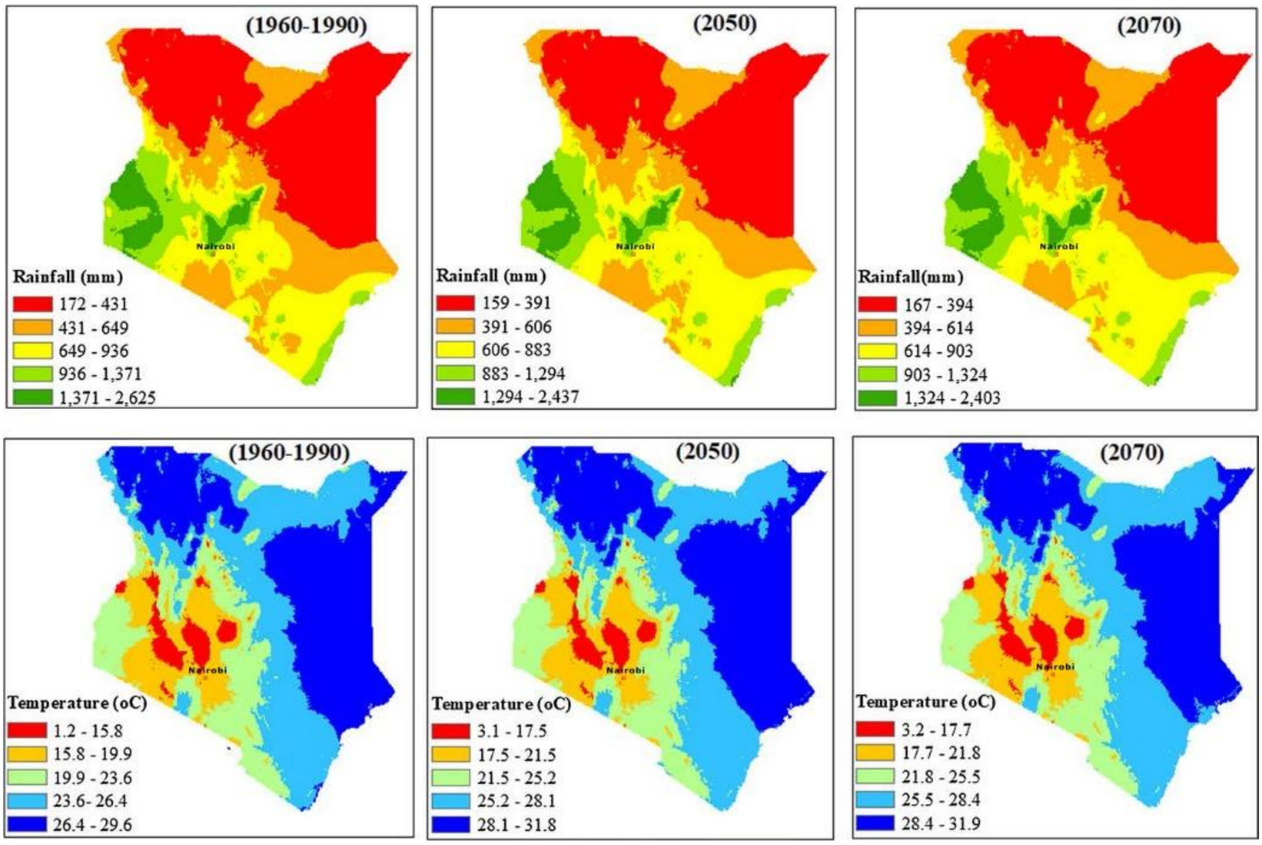


Figure 6 *The trend and projections on rainfall and temperature over time in Kenya (Kogo et al., 2020).*

3.3 Climate change impacts on food system

Food security in Kenya is under great pressure from the current and future climate change effects (Nganga, 2006) (Netherlands, 2018). The food security has been directly and indirectly influenced by the yields of crops (Kogo et al., 2020). The major peaks and falls in the productivity of different crops match perfectly with the extreme climate events (Figure 7).

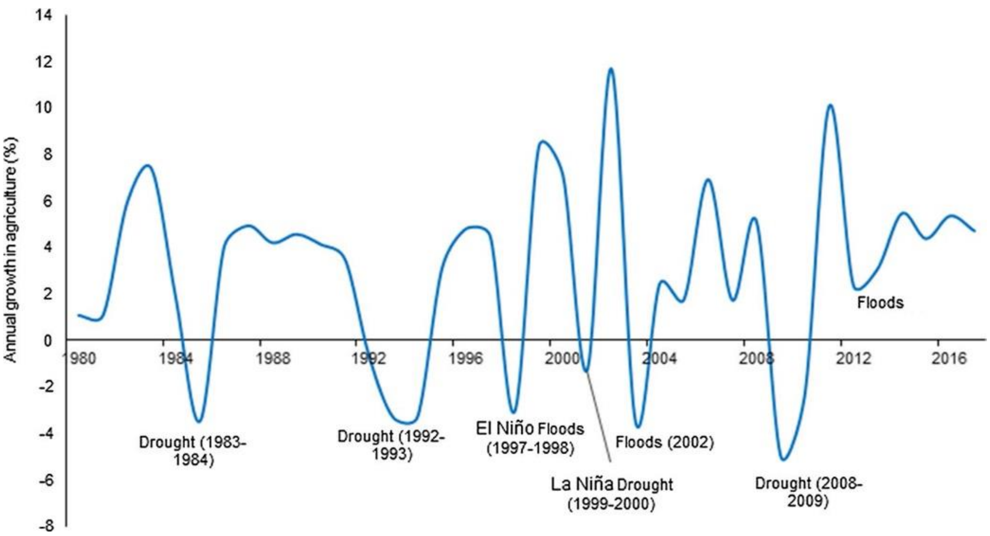


Figure 7 *Crop growth and extreme climate events in Kenya (Kogo et al., 2020).*

As shown in Figure 8 the productive crop area in Kenya has decreased since 1960. It is expected to decline in size up to 2039. The productivity in medium and low agriculture potential areas (Figure 3) including Nairobi will decrease by 21.5%. While that in high-potential areas will slightly fluctuate if the increase of temperature is under 3.5ºC (Netherlands, 2018). Therefore, the food supply for Nairobi will become more difficult in the future. Food security in Nairobi is and will be at more risks, especially in areas depending on (local) food chains.

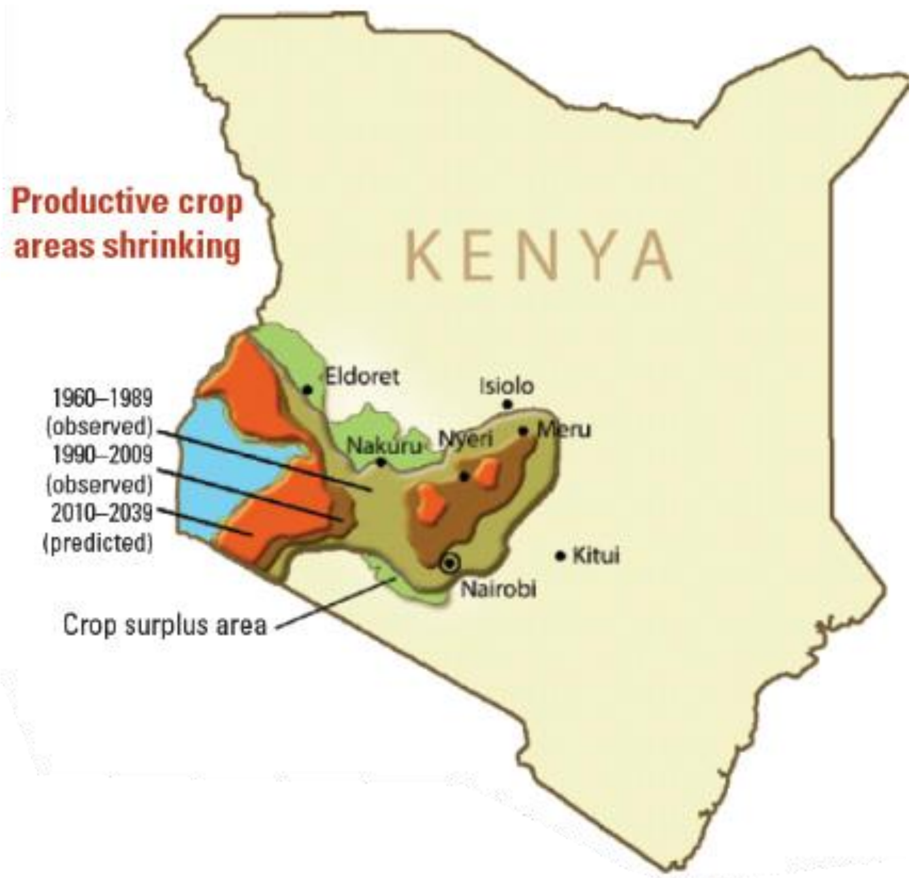


Figure 8 *Reduction of crop production areas due to climate change (Netherlands, 2018).*

Not only the productive crop areas face decline, but also all major areas in Kenya are under pressure of climate risks for food security (see Figure 9). In the south-east coastal area food security is challenged because of the high risk of flooding. The rest of the country the main risk for food security is the shortage of water. Nairobi lies in drought prone area, where is also sensitive to crop and livestock diseases. A self-sustaining food system in Nairobi seems difficult to realize and, as such, the dependency on food supply from other areas is high.

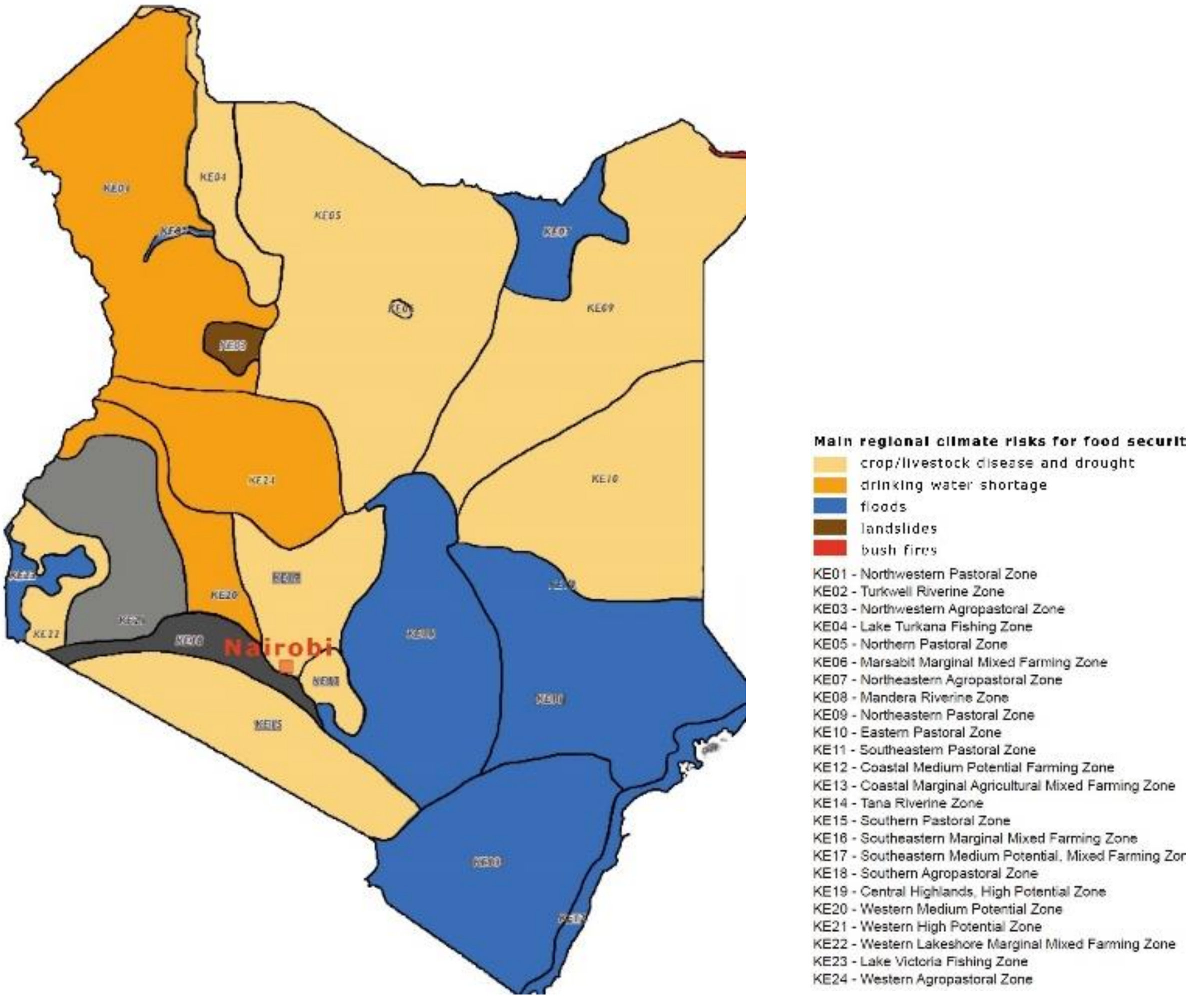


Figure 9 *Climate risks for food security (based on the map of climate risks for food security 2011 (Netherlands, 2018)).*

Overall food insecurity will lead to high global food prices, which will be no langer affordable by general Kenya households. In fact, the biggest deficit at the moment is the shortage of the most important staple food. For the poor residents in Kenya, climate change has definitely worsen their livelihood conditions (Kogo et al., 2020).

To conclude, climate projections show large scale challenges on the overall food security in Kenya. Due to the dependency of urban centres, like Nairobi, food security is not only a local challenge, but relies on interventions across the value chain. Multilevel arrangements and interventions should be the key to sustainable food system for Nairobi.

Women and children wait in line to collect water from a communal tap in Kibera.
(Photo credits: IMF, 2022 via Flickr).

4 Water

Water is of core an essential of life. Also, for food security it is a valuable resource. Nonetheless, the water challenges are as divers, ranging from water quality to water quantity and from too much to too little. Each deserves and values a thorough analysis in terms of current conditions, present pressure and forward looking. Nonetheless, in the light of local food security and livelihood, and keep closely connected to the household surveys at this point, this research focuses on the availability of drinking and cooking water on the one hand, and water quality issues due to local food system activities (food waste).

Current primary challenges determined for this exploration related to water, are on the hand, high prices and poor quality of drinking water, and on the other hand, contamination of water, open spaces, trenches, and roads.

The availability of drinking water at a reasonable price is a very important part of the food system. In Kibera the household survey gives a good overview of sources of drinking water. In this chapter we will try to explore the bigger picture of the water supply of Kibera. On what points is it different compared to Nairobi, or Kenya? Where does the water come from? Which problems the people of Kibera are faced with? What will be the impact of climate change on the water supply in Kibera? Which developments are visible? What is the role of the government? What specific elements or solutions come across by a spatial approach?

Chapter 4.1 describes the current situation of the water supply of Kibera. In the following chapter 4.2 environmental and socio-economic drivers in a wider geographical scope are discussed.

4.1 Current water supply chain and waste 'chain' of Kibera

4.1.1 Water supply chain

The water supply chain includes water sources, ways of purification, packaging, transport, and usage. The data from household survey provides insights from which sources people get their water.

Table 4 *Frequency and percentages of used water sources in Kibera 2020.*

	Frequency	Percentage
1 Purchased from vendor	299	77.7%
2 Piped water	78	20.3%
3 Fetched from a river or spring	0	0.0%
4 Fetched/bought from a CBO	2	0.5%
5 Fetched/bought from a FBO	1	0.3%
6 Fetched/bought from a NGO project	1	0.3%
7 Other, specify	4	1.0%
Total	**385**	**100%**

Kibera Household survey 2020, all 385 answers were valid.

In the household survey in Kibera of 2020 it appeared that with 78%, water purchased from a vendor is the most important water source; only 20% of the households have access to piped water. Other sources, like buying from a CBO, FBO, NGO, individuals, NMS occur together for only 1,5% of the households; one household reported water from a bore hole. Option 3 – fetched from a river or spring doesn't occur. Piped water seems to be available in all villages of Kibera, except for Kianda (see Figure 10); in some of them on a specific location.

Table 5 *Usage of water sources per village in Kibera 2020.*

Village	1 Purchased from vendor	2 Piped water	4 Fetched/bought from a CBO	5 Fetched/bought from a FBO	6 Fetched/bought from a NGO project	7 Other, specify
1 Makina	24	5				1
2 Lindi	23	7				
3 Mashimoni	24	6				
4 Laini Saba	28	7				
5 Kianda	27	7				1
6 Kisumu Ndogo	21	9				
8 Soweto West	27	7			1	
9 Gatwekera	28	7				
10 Raila	27	8				
11 Kambi Muru	23	7				
12 Olympic	23	4	2	1		
13 Karanja	24	4				2
Total	299	78	2	1	1	4

Kibera Household survey 2020, all 385 answers were valid; villages 7 Soweto East and 14 Silanga were not visited in the HH survey 2020.

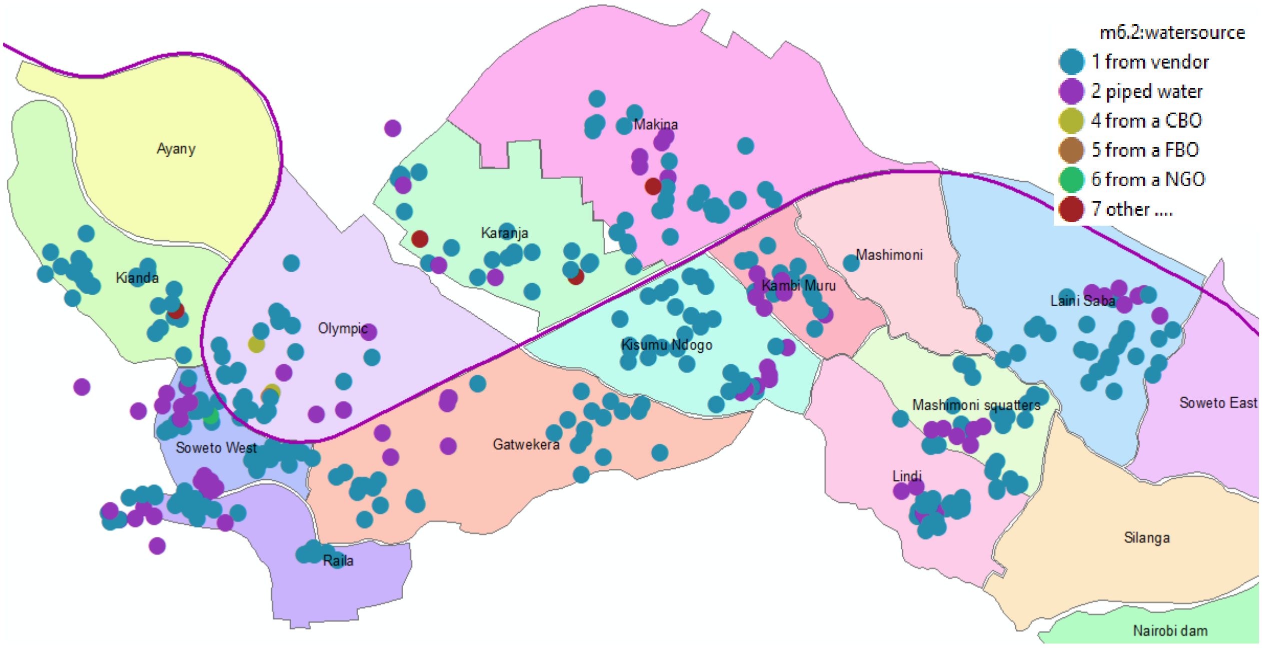


Figure 10 *Map of water source in Kibera 2020.*

More than half of the households in Kenya do not have the access to safe water. Access rates vary along ecological, economic and rural-urban gradients. Almost all the households in rural areas use untreated open surface water as their major source of drinking water. While the residents in urban areas mostly rely on vendors for their drinking water (Said M., 2007). According to the census 2009 the most dominant source of safe water is piped water, followed by boreholes and protected springs. Streams and rivers are the most important unsafe water sources. This is followed by unprotected wells and springs, and by water bought from vendors (Wiesmann, 2016). The present water supply situation of Kibera as it appears from the household survey, does not seem to be improved since 2007 (Said M., 2007).

Map Kibera Trust has built a map of water and sanitation points in Kibera by means of citizen mapping (https://www.mapkibera.org/about/). This resulted in over 400 public water points, and over 200 public toilets, 40 dumping sites and some rare other types (see Figure 11). So, the first impression is that a lot of public water points are available. But a lot of questions can be raised. How long and safe is the walking distance? What is the quality of this water? And what about availability over time and the level of the price? This goes the same for public toilets: at a first glance they well spread over Kibera, but taking a closer look, we find only four of them in Lindi, and only three in Mashimoni Squatters. Have the people of these villages to walk this distance to the toilet every day? Are private toilets available in some houses, or other sanitation solutions? In the past two household surveys questions about sanitation are missing. A future survey could be extended on this point.

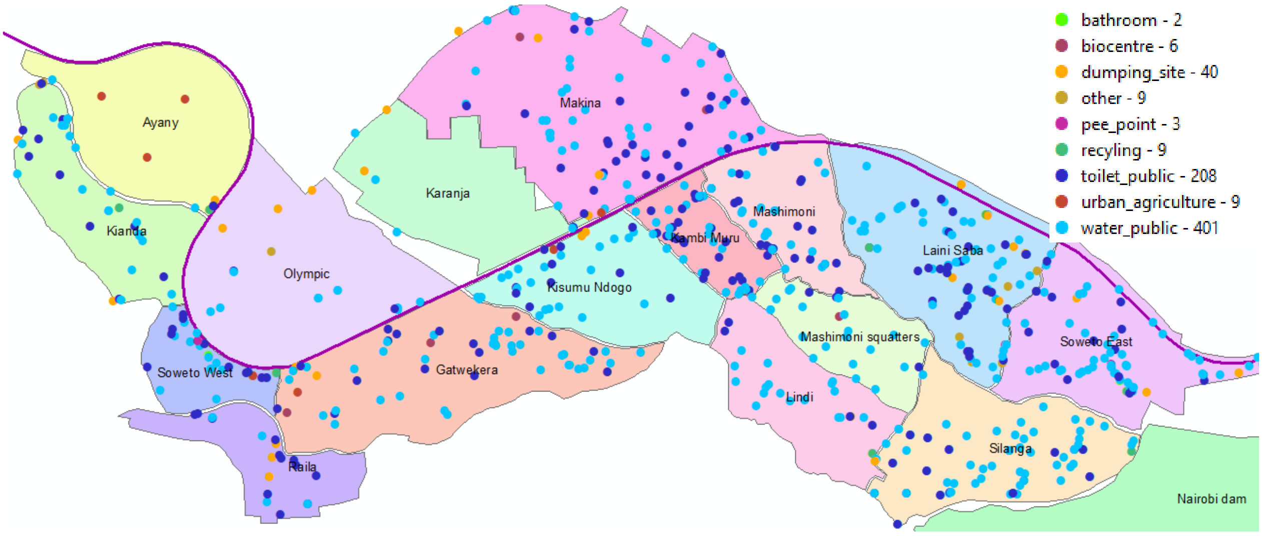


Figure 11 *Map of water and sanitation points in Kibera (https://www.mapkibera.org/about/).*

4.1.2 Food waste and water

The household survey includes questions about food waste, not about other waste sources. Three questions were asked:

- Reason of food waste;
- Storage of food waste;
- Waste disposal.

Most households (43%) tell that poor storage is the main reason for food waste, contamination is a problem in 11% of the households and 8% notice that food was bad or expired after buying. The second option, contamination by dirty water, doesn't seem a reason for food waste. Other reasons are often related to high temperatures during storage. Villages with a low score on storage have a higher score on other reasons, where warmth is the main reason: so, storage of food in combination with high temperatures seems the biggest reason for food waste in most villages.

Table 6 *Food waste and food waste reasons in Kibera 2020.*

	Frequency	Percentage
Not applicable	136	35,3%
1 Noticing that food was bad or expired after buying	10	2,6%
1 3	10	2,6%
1 4	2	0,5%
3 Food going stale due to poor storage	123	31,9%
3 1	5	1,3%
3 2	1	0,3%
3 4	7	1,8%
3 5	7	1,8%
4 Considered contaminated by foreign organisms	19	4,9%
4 1	3	0,8%
4 3	5	1,3%
4 3 5	2	0,5%
4 5	2	0,5%
5 Other, specify	40	10,4%
5 1	1	0,3%
5 3	6	1,6%
5 3 4	1	0,3%
5 4	3	0,8%
Total	**383**	**100%**

Kibera Household survey 2020, 383 of 385 answers were valid; HH could give more than one reason. Not good after buying was a reason for 9% of HH, poor storage for 43%, dirty water for 0.3%, contamination for 11% and other reasons 16%.

Table 7 *Food storage per village in Kibera 2020 (percentage of HH).*

Village	refrigerator	salting	open places	food container	other
1 Makina	23%	7%	23%	80%	0%
2 Lindi	0%	0%	17%	83%	7%
3 Mashimoni	3%	3%	17%	90%	3%
4 Laini Saba	3%	0%	31%	89%	6%
5 Kianda	3%	0%	37%	94%	0%
6 Kisumu Ndogo	3%	3%	20%	80%	10%
8 Soweto West	3%	0%	34%	97%	0%
9 Gatwekera	3%	0%	31%	91%	9%
10 Raila	3%	3%	40%	89%	0%
11 Kambi Muru	0%	0%	27%	90%	3%
12 Olympic	10%	0%	37%	77%	3%
13 Karanja	20%	0%	37%	77%	0%

Kibera Household survey 2020, all 385 answers were valid; villages 7 Soweto East and 14 Silanga were not visited in the HH survey 2020.

Food leftover storage in Kibera is for 85% of the households in food containers; 30% use open places too. The refrigerator is used by 6% for leftover, and 1% use salting. Four percent has other places, see Figure 12. The large use of food containers for storage of food leftover occurs in all villages.

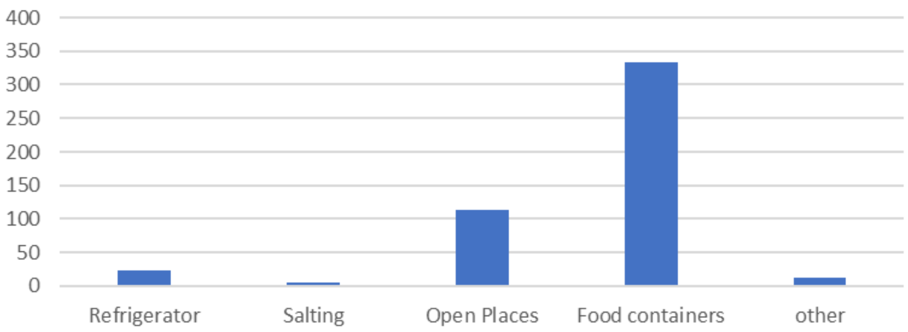


Figure 12 *Food leftover storage in Kibera 2020.*

The main disposal place for waste in Kibera is throwing it in the water of springs and streams: 40% of the household. 29% also pay persons for getting rid of waste. A formal designated waste area is used by 23% of the household, and 9% uses the open spaces for waste disposal. Pets or livestock counts for less than 1%. Other destinations are used by 12% of the household: mainly trenches and water drainage, some household uses the forest. If the formal designated areas for waste and paid waste collectors can count for a responsible waste disposal, more than 50% of the household realize this; but more than 60% use the local environment too.

Table 8 *Waste disposal per village in Kibera 2020 (percentage of HH).*

Village	open spaces	springs/streams	formal waste area	pay persons	pet or livestock	other
1 Makina	7%	30%	20%	50%	0%	7%
2 Lindi	13%	43%	0%	23%	3%	30%
3 Mashimoni	0%	63%	10%	10%	3%	20%
4 Laini Saba	9%	49%	20%	23%	0%	11%
5 Kianda	0%	29%	23%	57%	0%	3%
6 Kisumu Ndogo	10%	43%	23%	13%	0%	30%
8 Soweto West	9%	34%	54%	14%	0%	3%
9 Gatwekera	9%	49%	14%	20%	0%	20%
10 Raila	20%	80%	6%	3%	0%	11%
11 Kambi Muru	10%	37%	33%	37%	3%	3%
12 Olympic	17%	3%	47%	37%	0%	3%
13 Karanja	7%	20%	20%	63%	0%	3%

Kibera Household survey 2020, all 385 answers were valid; villages 7 Soweto East and 14 Silanga were not visited in the HH survey 2020.

Good examples of responsible waste disposal are the villages Olympic, Karanja, Kianda, Makina, Soweto West and Kambi Muru.

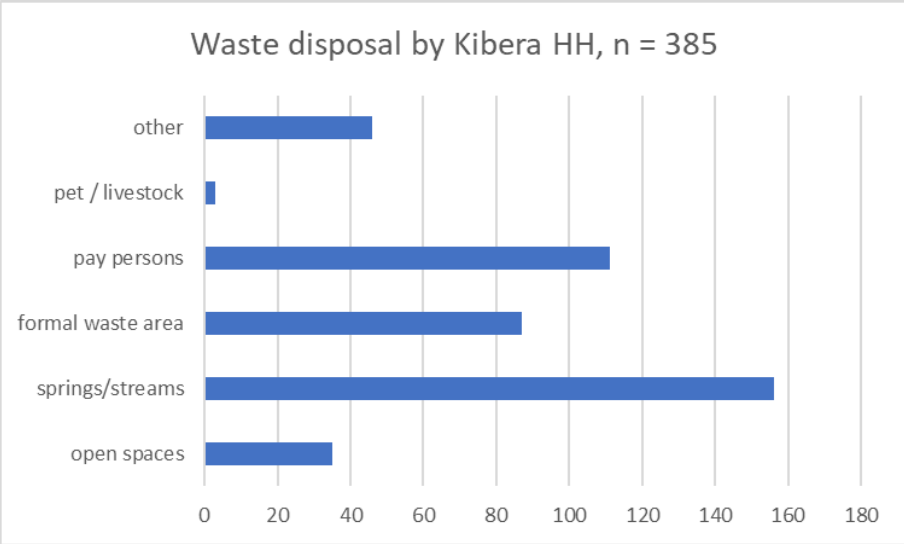


Figure 13 *Waste disposal in Kibera 2020.*

If we look to the reported answers about food waste in Kibera we can conclude that for many households this seems not a problem: when it is hard to buy enough food, it seems to result in little or no waste. But everyone is confronted with food contamination or food turned bad after storage at for instance warm places. This bad food is mostly stored in food containers; sometimes put on open places. Finally, half of the household's report throwing it on a designated place or pay some person to take it away, but 60% also reports throwing it springs, streams or open places. Question is: does this also mean that half of the food waste is put in a proper place? Or is it more about 10% formal and 90% in the environment? Many households of Kibera seem not to worry about the environment: the water in springs and streams is only used as a sewage stream, not as water which can be used to realize a green city and maybe food production next to city. In fact, the polluted water in Kibera has a larger environmental impact: It changes the water quality in Nairobi dam (Mandela, 2020).

Besides, the surface water in Kibera is not used for food production. Urban farming is not very common: only 7,5% of the households is involved in some kind of urban farming. Most frequent type is poultry keeping, which is done by 5% of the households. Sack farming is done by 2%, and other types by 1% (gardens and duck), and only 1 household with goats. Pigs and rooftop farming are not found in our research population. The most western villages like Kianda, Soweto West and Raila are leading in poultry keeping. Any form of arable farming or horticulture cannot be found in Kibera.

To conclude, households in Kibera mostly purchase drinking water from vendors. The daily lives of locals seem limited connected to their surrounding physical environment. Building environmental awareness, including common understanding of the crucial linkages with livelihood conditions, could probably help to reduce the environmental pressure from food activities such as food waste disposals.

4.2 Food Systems Framework for water

From a food system perspective, it is crucial to look at the linkages between water and food at different scales. So besides analysing and interpreting the data from the household survey we zoom out to the bigger picture and linkages also to a changing environment.

4.2.1 Effects of environmental drivers

Water availability in Kenya
More than 30% of the households in Kenya do not have the access to safe water (V. Nyakundi, 2020). Access rates vary along ecological, economic and rural-urban gradients. According to the census 2009 the

most dominant source of safe water is piped water, followed by boreholes and protected springs. Streams and rivers are the most important unsafe water source. This is followed by unprotected wells and springs, and by water bought from vendors (Wiesmann, 2016). Almost all the households in rural areas use untreated open surface water as their major source of drinking water. While the residents in urban areas mostly rely on vendors for their drinking water (V. Nyakundi, 2020). However, the main source of the drinking water sold by vendors are not clear.

Water availability in Nairobi

In the aspect of natural surface water in Kenya, there are five drainage basins established by the Government of Kenya to coordinate upstream-downstream water use for sustainability. Nairobi sits in the Athi River Basin where a single watershed drains to a single outlet (Wiesmann, 2016). The Athi River runs from the northern mountain range of Aberdares to the Indian Ocean. It bypasses Nairobi in the upstream. The surface water quality in the downstream of Athi is directly influenced by Nairobi. Athi River is already in brown coloured due to the industrial pollutants' residuals arising from industrial activities in Nairobi City (Group, 2013). Due to the limited water amount and varied pollutants, the Athi River is not used for the drinking water in Nairobi. Instead, the drinking water, as Figure 14 shows, is transported mostly through pipes connected to the water reservoirs in the north. The rest of the drinking water comes from the intake points in the Tana River Basin (Said M., 2007).

Figure 15 reveals in 2009 the various households water sources in Nairobi. The city relays mostly on water pipes for safe water. Most areas in the centre have higher than 75% households with access to safe water. While the suburban areas and Kibera have lower accessibility. Major source of unsafe water comes from vendors. But where do vendors fetch the drinking water is not yet found out.

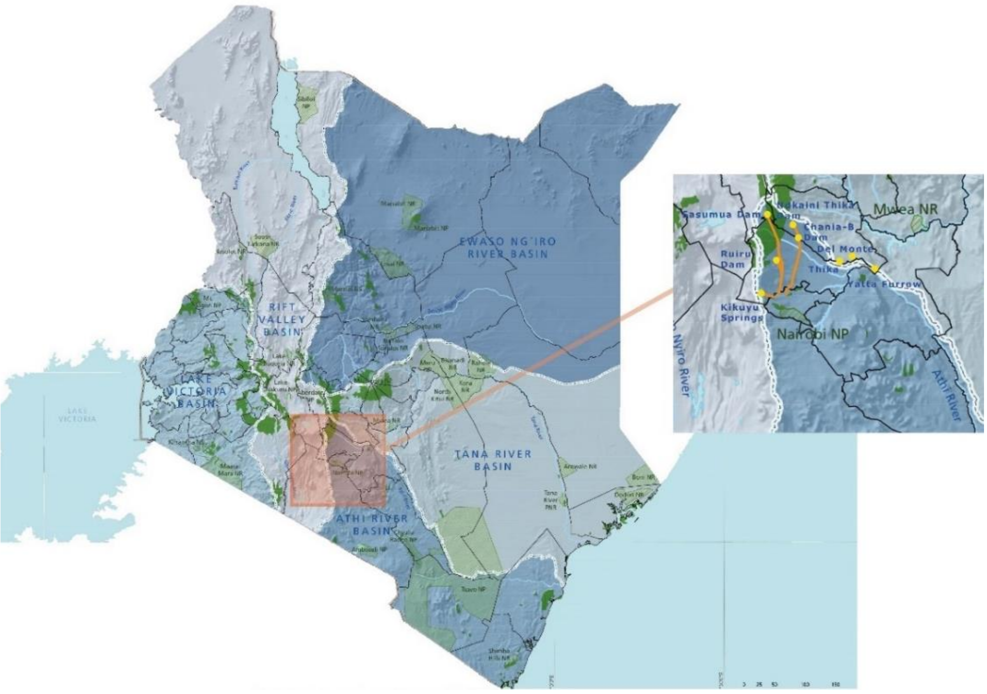


Figure 14 *Hydrologic map in Kenya and water supply map in Nairobi 2003 (based on (Said M., 2007; Wiesmann, 2016)): In the area surrounding Nairobi there are 5 existing water supply sites in the north and 3 important water withdrawal sites in the east.*

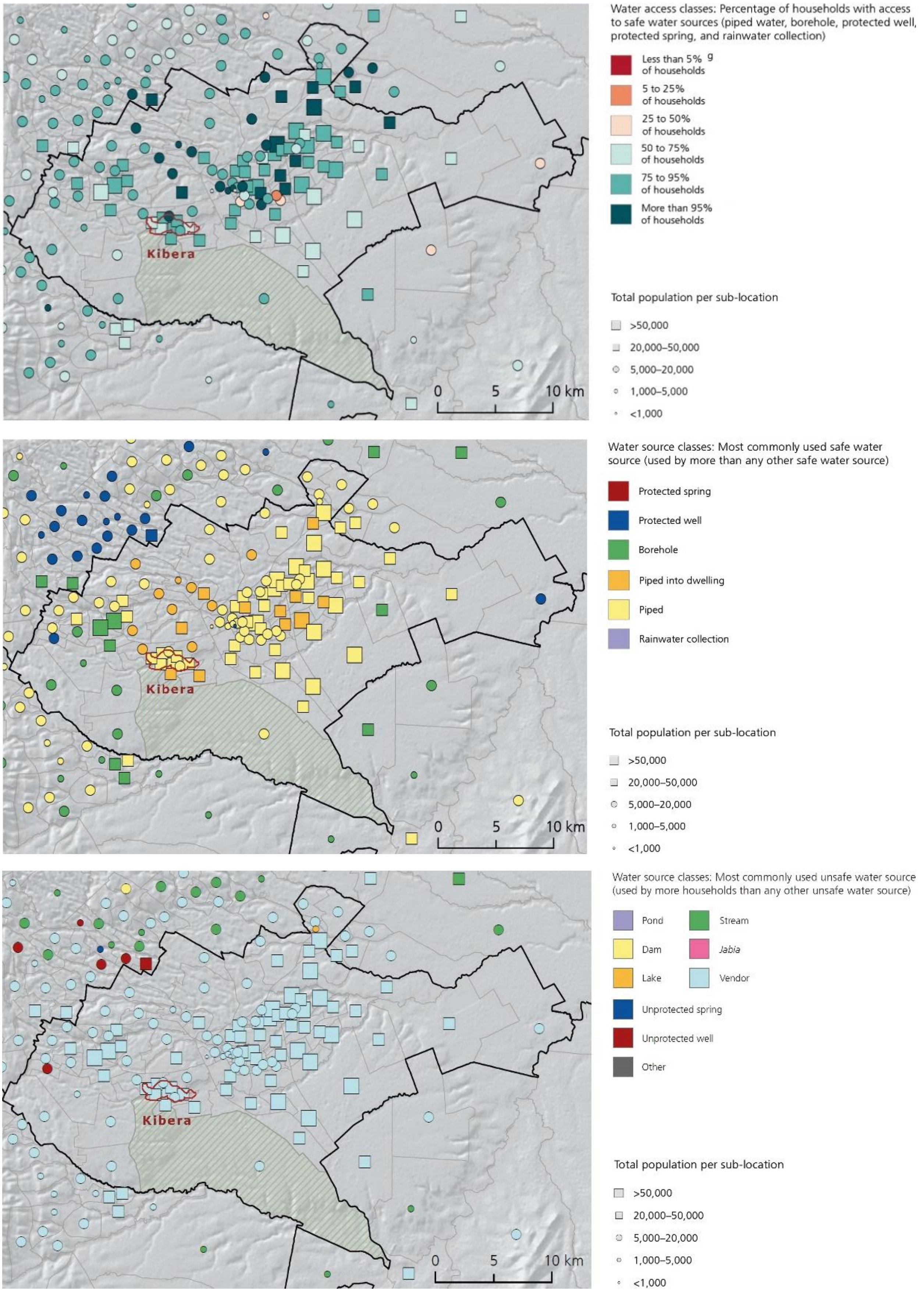


Figure 15 *Water source in Nairobi 2009 (top: access to safe water source; middle: most commonly used safe water source; down: access to unsafe water source, based on (Wiesmann, 2016)).*

According to the census data from 2008 to 2019 of drinking water source (see Figure 16), more than 60% of households have access to safe water source in Kenya. In the last 12 years the number of households that use safe water source has increased by around 8%. However, bottled water with uncertain water quality - potentially unsafe- has become more popular than before, especially in urban areas. As shown in the data from household survey, it is very common in Kibera that households rely on water vendors for drinking water.

Other profound findings are listed as follows:

- When the data from household survey in Kibera is compared to census 2019 we noticed the proportion of water vendors in the census data is much lower. The possible reasons for the big difference in the popularity of vendors could lie in different spatial boundaries. It seems that the census 2019 covers a larger area than household survey. However other reasons for the data difference shall be found out later.
- From census data in urban areas, it is obvious that the proportion of safe water sources has decreased. This trend goes in line with the decreasing usages on the piped water in household survey Kibera. However, the reason why this trend has happened shall be explored in the future.

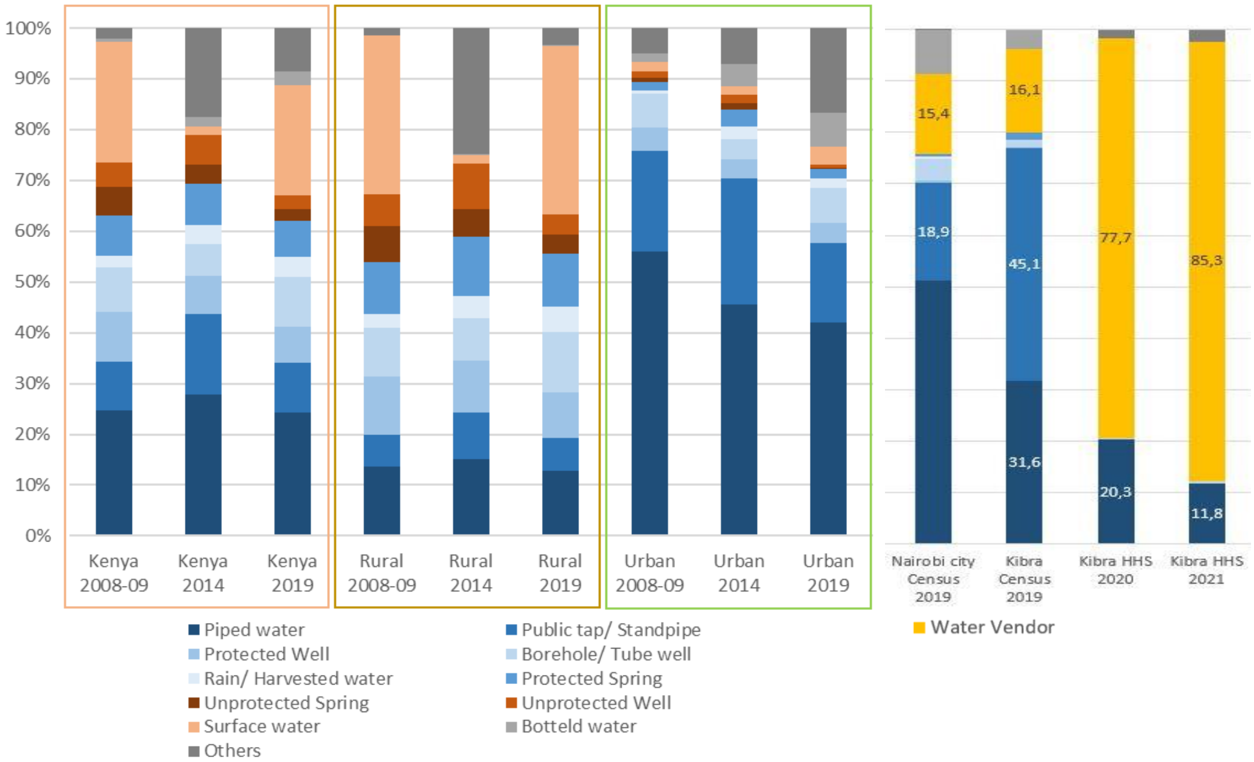


Figure 16 *Drinking water source data from 2008 to 2021 (Central Bureau of Statistics, 2004; Macro, 2010; Statistics, 2015, 2019).*

Water quality

Drinking water in Kenya is mostly contaminated due to the disability to maintain clean water (Marshall, 2011). In Nairobi, it is shown that drinking water leaving the treatment works is of good quality. The longer the water is kept in the network, the higher the contamination levels. The contaminates are caused by using non-corrosive and broken pipelines, leakage of sewage pipes for the safe delivery, and shallow boreholes close to septic tanks (V. Nyakundi, 2020).

In slums of Kenya, it is indicated that the severe contamination in drinking water is caused by the close distance between pit latrines and wells. The main source of contamination is total coliforms. The other contaminations come from dirty containers, domestic animals, and laundry activities (Kimani-Murage, 2007).

However, in Kibera it is not the case, the risk of pollution by pit latrines in drinking water is low due to the high reliability on water vendors. The drinking water they provide is with uncertain and unsafe water quality.

So further research is needed to know what is the quality of the water from vendors? What is the contamination in the water from vendors? What are the health risks?

Impacts of climate change on water
In Kenya safe water source is scares because of decades of recurrent drought, poor management of water supply, contamination of the available water, and high population growth (Marshall, 2011). The climate impacts on water resource are largest in the marginal rainfall areas in Kenya. Nairobi sits on the boundary of the impacted areas (see Figure 6). It is shown that precipitation variability and increased evaporation due to higher temperatures will decrease the water availability as well as the water quality (Nganga, 2006). Even though the original source of drinking water in Kibera is not yet clear, the general heavy impacts of climate change on safe water source is still profound and unavoidable.

4.2.2 Effects of social-economic drivers

The reasons for the popularity of vendor water could be further found out in the socio-economic drivers. For example, the questions can be asked as follows:

Policies: What role does government policy play in the availability of drinking water?

Science and technology: How is the drinking water sanitized and transported to Kibera (by vendors)? How are the technologies used in sanitizing and transporting influencing the water quality?

Individual factors: Can we link income and water expenses?

Market: Can we link different sources (piped vs vendor) to quality and prices of the water?
and how does this impact the consumer choices?
How do prices in Kibera compare to prices in Nairobi?

Social organizations: What are the roles of CBO, FBO, NGO in drinking water supply?

However, due to the limited research time the answers were not found. They remain as the knowledge gaps for further exploration.

4.3 Conclusions

Due to the limited water amount and various pollutants, the Athi River is not used for drinking water in Nairobi. Drinking water is mostly transported through pipes connected to the water reservoirs in the north. In Kibera, instead of getting water directly from pipes, most households buy drinking water from vendors. Actually, water vendors are the most used (unsafe) water source in urban areas of Kenya and are even becoming more popular.

In Kibera there are enough public water points. The census puts forward a share of 45%! Nonetheless, the use rate of the public drinking water facilities is low. The similar low use is found for food waste containers, which leads to water pollution in local and surrounding environment. People in Kibera do not seem to care about their living environment. The missing link between their daily lives and the local environment may probably the reason for environmental pollutions. Therefore, building up the environmental awareness of locals could mitigate the pressure of food waste on the local environment.

Knowledge gaps:
To get an overview on the entire water supply chain it is necessary to find out where the water comes from, where the water is purified and packaged, and how the water is transported to Kibera. Further questions in categories could be formulated:

- About water from vendors:
  - What are the water sources of vendors in Kibera?
  - How is the quality of water from vendors?
  - What is the contamination in the water from vendors?
  - What are the safety risks attached?
  - How do people deal with safety risks?
  - Do they avoid certain vendors with dubious quality water?
  - Do water prices influence in buying preference?
- About public water points:
  - How safe is the walking path from households to public water point in Kibera?
  - How safe is the water from public water points?
  - What is the availability over time and the level of the price?
- About the data difference between census and household survey:
  - Does the difference come from data source boundaries (e.g. used geographic borders)?
  - Does the difference come from the different answers given by households?

Charcoal for heating in Kibera.
(Photo credits: Ninara, 2015 via Flickr).

5 Energy

Energy is needed for everyone’s daily life. In food system activities cooking fuel is essential. Besides, energy is used for heating, cooling and lighting. Most energy consumption can lead to different issues such as bad air quality, emission of greenhouse gasses, risks of fire and high cost etc. Therefore, energy supply chain deserves a thorough analysis on current consumption, availability, and affordability. The household survey in Kibera gives an overview of current energy usage (chapter 5.1). Starting from this research in the local level, the further research is performed in broader scale of Nairobi and Kenya (chapter 5.2) to answer the following questions: What is the difference between the energy use in local scale and national scale? What is the impact of energy consumption? What are the changes in consumption on varied energy resources? Are they available and affordable? What is the impact of climate change in energy consumption?

5.1 Current energy supply chain of Kibera

Energy supply chain includes the energy resource, production, transport, and usage. The household surveys show the main energy source and usage.

5.1.1 Results of household survey

In Kibera 40% of the households use paraffin as energy source for heating and cooling; 19% use charcoal and only 5% use the electricity network for this. Firewood, LPG Gas or Solar energy (option 2 in Kibera Household survey 2020) are hardly used; but 36% use other sources, which are mostly not specified. According to the repeated census in 2021 this 36% other source in 2020 has to be LPG.

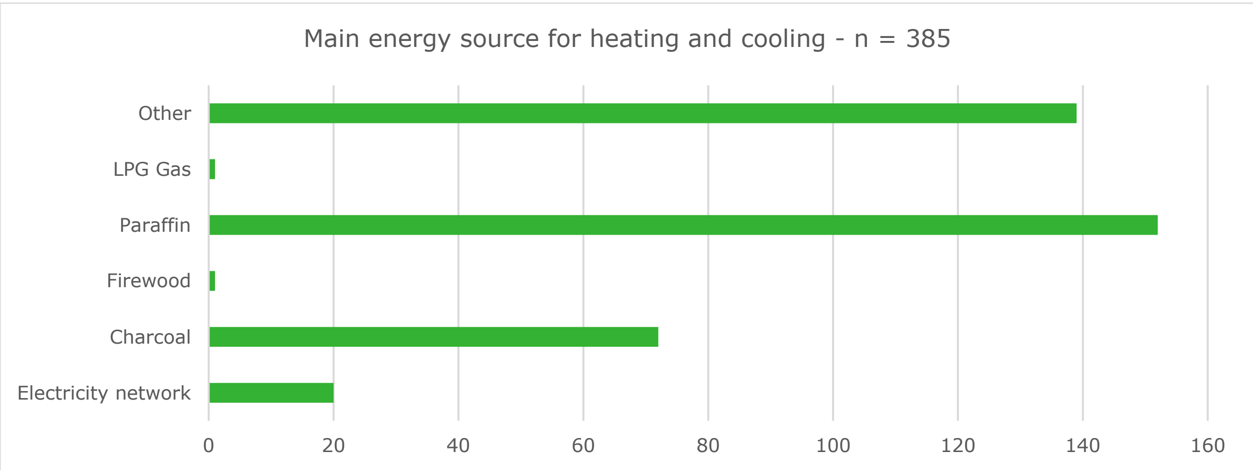


Figure 17 *Main energy source for heating and cooling in Kibera 2020.*

Table 9 *Number of HH with main energy source for heating and cooling per village in Kibera 2020.*

Village	1 Electricity network	3 Charcoal	4 Firewood	5 Paraffin	6 LPG gas	7 Other, specify
1 Makina	1	4		11		14
2 Lindi	2	6		11		11
3 Mashimoni	3	7	1	13	1	5
4 Laini Saba	4	1		19		11
5 Kianda		6		12		17
6 Kisumu Ndogo	2	6		12		10
8 Soweto West	2	9		12		12
9 Gatwekera	1	9		11		14
10 Raila	2	4		19		10
11 Kambi Muru		5		14		11
12 Olympic	3	10		7		10
13 Karanja		5		11		14

Kibera Household survey 2020, all 385 answers were valid; villages 7 Soweto East and 14 Silanga were not visited in the HH survey 2020. Option 2 Solar energy never occurred in 2020.

The main sources paraffin and charcoal are used in all villages, except for charcoal in Laini Saba. Use of the electricity network is rare but occurs in nearly all villages, so there should be some network available. This also appears from other questions about steady connections for electricity, (cell)phone, internet and mobile money transfers: nearly half of the households in Kibera in 2020 reports access to a steady electricity connection. Steady (cell)phone connections are reported by 90% of the households, steady internet connections by 80% and access to mobile money transfers for even 99% of the households. In the villages Mashimoni, Lindi and Laini Saba access to electricity is only available to 30% or less of the households.

After reading those results, it turns out that paraffin and charcoal are the most important energy resource in Kibera. The electricity usage is low due to less accessibility to a steady electricity connection. However, several questions remain unanswered. Which other energy sources are used for heating and cooling? And why is solar power not used by the households in Kibera? A good network for cell phone and internet seems to exist in Kibera, much better than the electricity network; who is taking care of that? And who is responsible for the lack of a steady electricity source for half of the households?

Table 10 *Number of HH with Energy access per village in Kibera in 2020.*

Village	House holds	Electricity	Phone	Internet	Mobile money
1 Makina	30	23	30	28	30
2 Lindi	30	11	25	23	30
3 Mashimoni	30	8	26	25	30
4 Laini Saba	35	6	27	25	34
5 Kianda	35	16	32	29	35
6 Kisumu Ndogo	30	17	27	22	30
8 Soweto West	35	19	32	21	34
9 Gatwekera	35	15	30	26	35
10 Raila	35	14	35	31	35
11 Kambi Muru	30	19	28	28	30
12 Olympic	30	17	28	23	30
13 Karanja	30	20	29	26	29

Kibera Household survey 2020, all 385 answers were valid; villages 7 Soweto East and 14 Silanga were not visited in the HH survey 2020.

5.2 Food Systems Framework for energy

As mentioned in the previous chapter, from a food system perspective we also zoom out to the bigger picture and potential linkages to a changing environment. As we did for water, we also carried out this analysis for energy.

5.2.1 Effects of environmental drivers

Energy use in Kenya
According to the 2009 census, Kenyans use energy mainly for cooking and lighting. Up to 82.5% of households rely on solid biofuels for cooking. Solid biofuels include biomass such as wood, grass and crop residues, dung, and charcoal. In Kenya charcoal is transformed from biomass in kilns particularly in the semi-arid lands. Firewood remains the main source for cooking for 64% of local households. Charcoal is used by 17% of households who reside in and around urban centres (Wiesmann, 2016). The following maps show that Nairobi has profoundly different energy usage than the rest of the country. In Nairobi, lower percentage of households use solid fuels for cooking. Besides, compared to the rest of the country, Nairobi uses less paraffin and more electricity on lighting. Compared to Nairobi, Kibera has relatively higher usage on paraffin and lower usage on electricity for lighting.

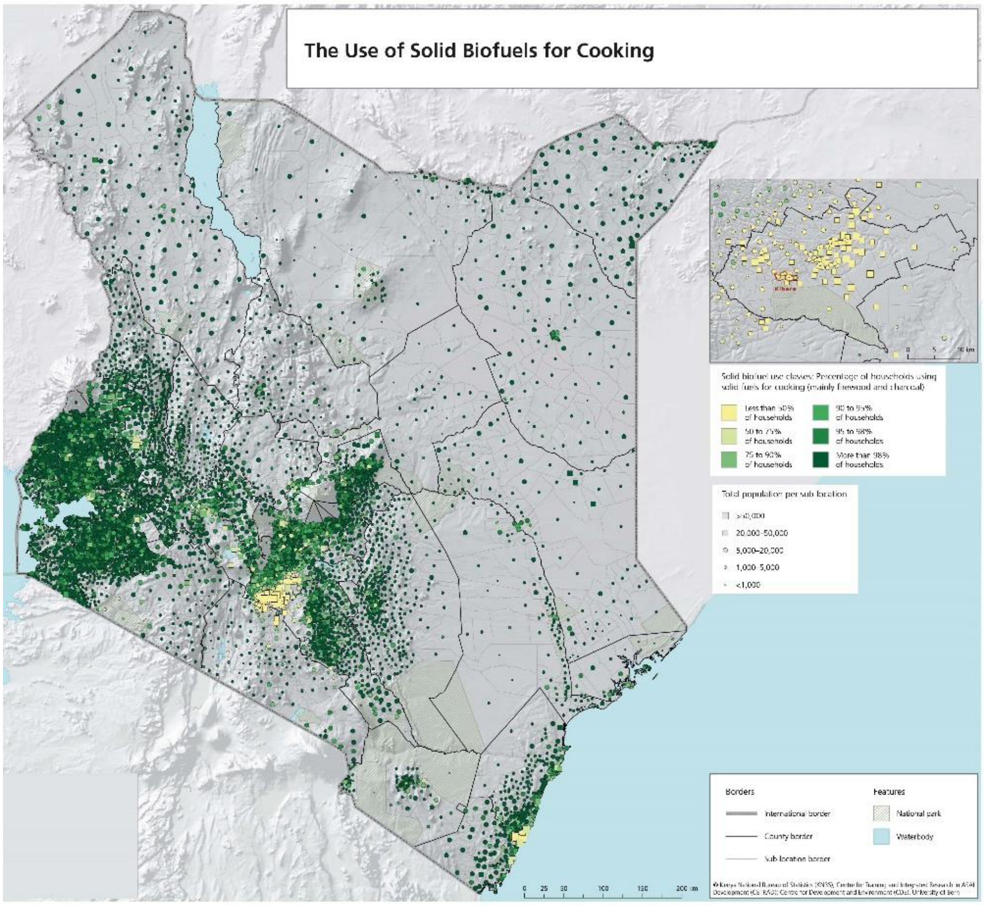


Figure 18 *The use of solid biofuels for cooking 2009 (based on (Wiesmann, 2016)).*

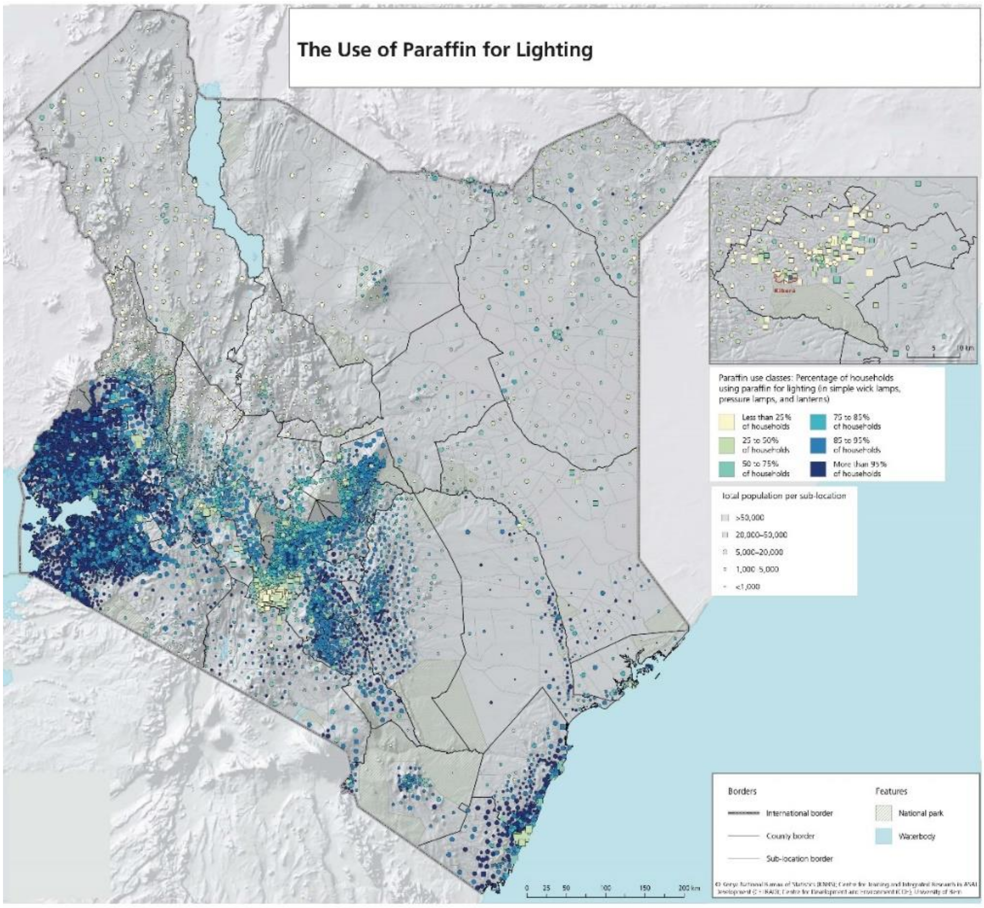


Figure 19 *The use of paraffin for lighting 2009 (based on (Wiesmann, 2016)).*

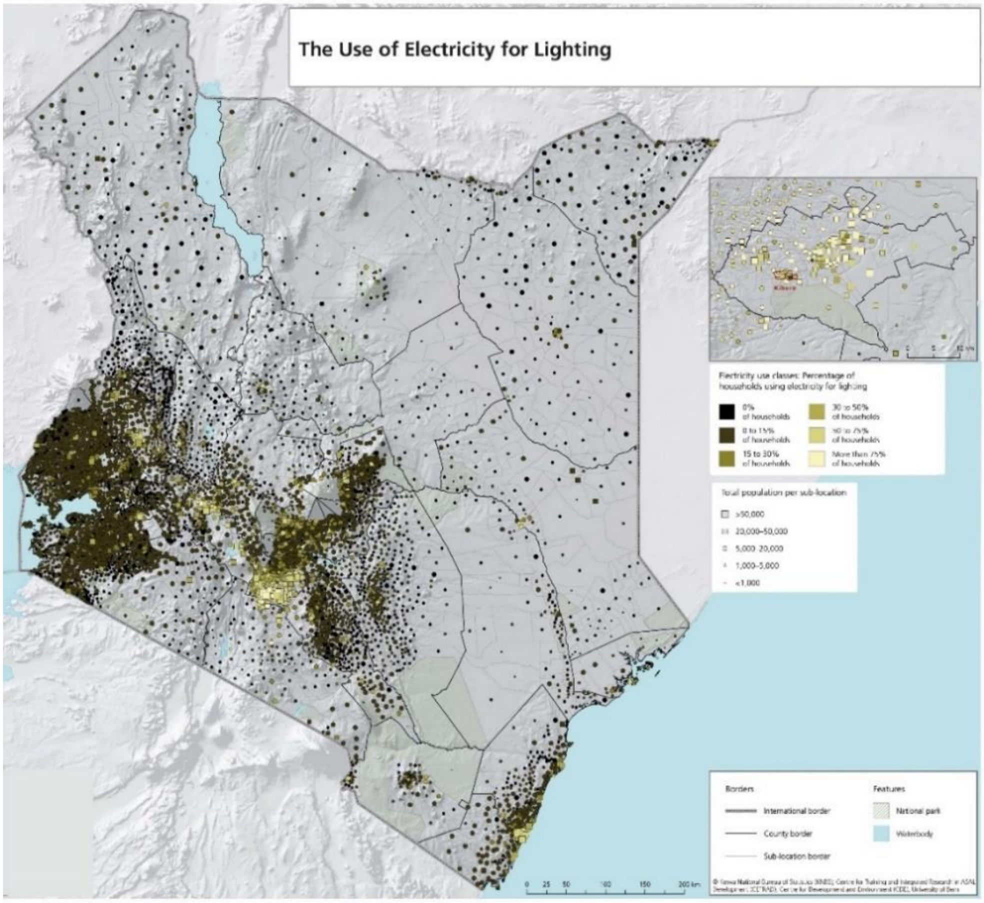


Figure 20 *The use of electricity for lighting 2009 (based on (Wiesmann, 2016)).*

In the 2019 Kenya population and housing census, it is shown that the national wide dependency on solid biofuels for cooking has decreased to 66.7% (firewood 55.1% and charcoal 11.6%). LPG has replaced most of the use on solid biofuels. The rest of energy source for cooking are paraffin 7.8%, electricity 0.9%, biogas 0.5%, and solar 0.2% (Statistics, 2019). In urban areas the use on paraffin, gas and charcoal is more than rural areas (see Figure 21). The difference in energy use in 2009 and 2019 shows a clear transition from paraffin to LPG. The main reason for this change is explained in the following chapter 5.2.2.

Besides, firewood is most used cooking fuel in Kenya especially in rural areas. But its popularity in the whole country has decreased since 2003 by 11.1%. The similar decrease can be found by charcoal and paraffin. In contrast, the portion of LPG/Biogas and electricity has increased by 21.4% in Kenya. In urban areas, the utilize rate on LPG/Biogas in 2019 is nearly five times the rate in 2003. However, the percentage of using on charcoal and firewood have slightly dropped with some fluctuations during the 17 years.

On the right side of Figure 21, the comparison chart of household survey in 2020 and 2021 is shown. It is obvious that the use of LPG in Kibera is less than that in Nairobi, but it has a slight climb in the recent two years. However, the use of paraffin in Kibera is more than that in Nairobi. Meanwhile it has a significant drop of more than 10% recently. In contrast the use of charcoal in Kibera is far more than that in Nairobi and it stays around 18%.

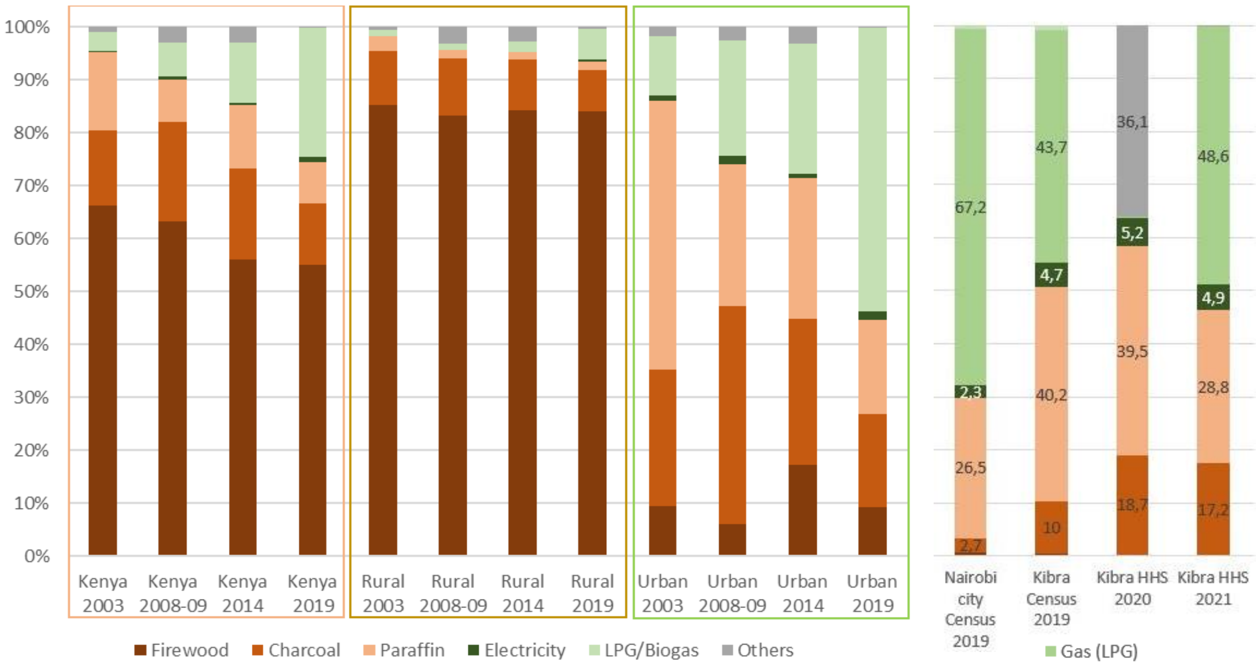


Figure 21 *Use of cooking fuel 2003-2019 in Kenya, rural, urban, Nairobi city, Kibera (% households) (Central Bureau of Statistics, 2004; Macro, 2010; Statistics, 2015, 2019).*

Energy consumption in Kenya
According to the recent data from CBS Kenya, in 2018, most energy demand in Kenya is fed by biomass 75.2%, electrical energy 13.5%, and imported petroleum 10% (see Table 11).

Table 11 *Production, trade and consumption of energy by primary sources, 2018(TJ) (Statistics, 2020).*

	2018
COAL AND COKE.....	**2,876.4**
LIQUID FUELS	
Imports of crude oil	
Imported Petroleum	25,582.7
Exports of Petroleum Fuels	116.0
Stock changes and balancing item	
ELECTRICAL ENERGY	
Total Local Energy Production..	**34,690.2**
Local production of hydro power	14,351.0
Local production of geothermal power	18,460.2
Local production of thermal power	
Local production of wind	1,352.1
Local production of Solar	49.2
Local production of Co-generation	8.9
Losses	8,800.2
Electricity Imports	468.9
BIOMASS	
Non-Renewable Feedstocks	**192,915.1**
Fuelwood	155,601.3
Wood Charcoal	11,434.6
Wastes or scraps	25,879.2
TOTAL Demand	**256,417.3**
LOCAL PRODUCTION AS PERCENTAGE OF TOTAL	**88.7**
PER CAPITA CONSUMPTION IN TERMS OF GIGA JOULES (GJ)	5.3

* Provisional.
[1]Terajoule (TJ) =10^12 Joules

Impacts of climate change on energy resource
The impact of climate change on biomass is illustrated by the Arabuko Sokoke forest, the largest and most intact coastal forest in East Africa (Service, 2022). Tree biomass in Arabuko Sokoke has significantly accumulated over time for certain vegetation types which leads to shift of forest species in the ecosystem (Kipkorir, 2017). In order to get easier access to fuelwoods for daily use the locals moved further into the forest. Due to diminishing supplies of preferred species, locals needed to collect different kind of woods with less diversity (Team, 2002). It is recommended that the local residents are advised to reduce their dependency on forests for their livelihoods in the event the predicted shift of species range sets in (Kipkorir, 2017). From the example of the Arabuko Sokoke forest we can see that climate change has major impacts on the communities relying on fuelwoods as their energy resource. Therefore less reliability on fuelwoods is highly recommended.

Being one of the most used electricity resource in Kenya (Nganga, 2006), hydropower is very vulnerable to the adverse effects of global average atmospheric temperature increase. The rising temperature and foreseen drought risks will reduce the productivity of hydropower plants dramatically. Therefore, a transform from hydropower to geothermal power has taken place. Since 2013, total power generation from thermal and geothermal energy has exceeded that from hydropower. In 2019 hydropower is even less than the half of the power from thermal and geothermal. It is obvious that the government of Kenya has done quite some effort to reduce its vulnerability to climate change in electrical energy (see Table 12).

Table 12 *Generation of electrical energy and imports in Kenya 2010-2019(KWh) (Statistics, 2020).*

Million KWh

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019*
Generated										
Type of power										
Hydro	3,224	3,217	3,977	4,386	3,411	3,463	3,960	2,777	3,986	3,205
Thermal	2,201	2,801	2,200	2,162	2,585	1,412	1,471	2,534	1,546	1,313
Geothermal	1,442	1,444	1,516	1,781	2,917	4,521	4,484	4,756	5,128	5,235
Cogeneration	92	81	105	56	50	-	-	2	3	0
Wind	17	18	14	15	17	60	56	61	376	1,563
Solar	-	-	-	-	-	-	-	-	14	92
Sub Total	**6,976**	**7,560**	**7,812**	**8,399**	**8,981**	**9,456**	**9,971**	**10,130**	**11,053**	**11,409**
Imported From Uganda and Tanzania	30	34	39	49	158	59	86	230	130	212
Total Generated and Imported	7,006	7,594	7,852	8,448	9,139	9,515	10,057	10,360	11,183	11,621

Source:Kenya Power and Lighting Co.Ltd and Kenya Electricity Generation Co. Ltd

* Provisional

Impacts of current energy consumption

Cooking with dirty fuels as paraffin, charcoal, and firewood cause significant damage to health at a household level and the environment at large (Dalberg, 2018). The ways of cooking with solid biofuels lead to high levels of smoke exposure. Several respiratory diseases are caused by the indoor air pollutions (Wiesmann, 2016). 8-10% of early deaths are attributable to indoor air pollution. Besides, overuse of solid biofuels can cause environmental degradation. Kenya loses more than 10 million m^3 of wood from its forests every year by firewood and charcoal consumption, which contributes to 0.3% annual deforestation rate (Dalberg, 2013). Biomass fuel use in households releases more than 22 million tons of CO_2 every year, which is equivalent to 30-40% of total GHG emissions (see Table 3). Deforestation exacerbates food insecurity and damage the agriculture sectors (Dalberg, 2018),since forests reserve most water source in the country. Less forests means less water. Hence the frequent drought caused by deforestation has heavily negative impacts on crop productions. Therefore, cooking with cleaner energy source is strongly recommended in Kenya.

Table 13 *Impacts of dirty fuels (Dalberg, 2018).*

IMPACT	Wood	Charcoal	Kerosene
Health (deaths and DALYs due to household air pollution from PM2.5)	~2k avoidable deaths 165k aDALYs	~3k avoidable deaths ~250k aDALYs	~2-3k avoidable deaths ~160k aDALYs
Environment & climate (GHG emissions)	2.5-4.4 tonne CO2eq / urban HH annually	3.6-5 tonne CO2eq / urban HH annually	1 tonne CO2eq / urban HH annually
Social opportunity costs (time opportunity costs to fuel collection, cooking and cleaning)	0.8-1.3 avoidable hrs per day per urban HH	0.3-0.4 avoidable hrs per day per urban HH	No time poverty impact
Household and macro- economics	• Foregone incomes for avoidable time spent cooking and cleaning • Tax revenue loss for government given informality of market	• Foregone incomes for avoidable time spent cooking and cleaning • Avoidable spending on expensive fuel • Tax revenue loss for government given informality of market	• Cost to economy of illicit mixing of kerosene with diesel • Negative balance of payments effects due to kerosene imports

5.2.2 Effects of socio – economic drivers

Energy source affordability and availability

According to the survey by Dalberg in 2018, paraffin and charcoal remain dominant in urban Kenya because of their affordability, availability, and accompanying stoves. Paraffin and charcoal in 40 kg bags have both very low prices. In Nairobi there are over 1500 paraffin dispersing points. Most people live within 50-150 m walking distance to a charcoal seller (Dalberg, 2018).

On the contrary, LPG has less popularity because of its higher price and limited availability outside Nairobi. Besides, the poor safety practices of illegal grey market have led to a weak perception of safety. Electricity is scarcely used for cooking due to the high price of efficient electric cookstoves (Dalberg, 2018).

Table 14 *Availability assessment on fuels 2018 (Dalberg, 2018).*

FUEL	Affordability & availability assessment
Wood	• Abundant and largely free in rural areas for collectors, though 20-30% of rural HHs buying at least some of their firewood[1] • Firewood is increasingly scarce and expensive in urban Kenya, particularly Nairobi (e.g., >$0.50 / kg), but still fairly low cost (e.g., $0.15 / kg in Kisumu, $0.10-0.15 / kg in most rural and peri-urban Kenya)[2] • Traditional and moderately improved firewood stoves are free or very low cost (<$10)
Charcoal	• Widely available in urban Kenya (e.g., charcoal available within 50 – 150m of most homes in Nairobi)[3] • Increasingly expensive as forests recede (prices rose from $0.10/kg to $0.35-0.50 / kg in Nairobi in past decade, doubling in just past 3-5 years)[4] • Major poverty premium – 20-30% higher cost from buying charcoal in 2kg tins vs. 40kg bags[5]
Kerosene	• Widely available throughout mass-market neighbourhoods at hyper-local distribution points (e.g., 1500+ points in Nairobi alone)[6] • Most affordable and lowest cost fuel in urban Kenya currently • Often only truly affordable option for poorest urban residents (e.g., kerosene is primary fuel for 70-80% of slum households in Nairobi)[7]
FUEL	**Affordability & availability assessment**
LPG	• Fuel availability is fairly widespread **in Nairobi** (>40% use LPG as primary fuel and >60% have LPG stove)[1]; **for urban Kenya as a whole**, availability is projected to increase – Kenya Pipeline Company (KPC) plan to more than double LPG storage capacity by 2020 • LPG is largely unaffordable as a primary fuel for bottom 50-70% **across urban Kenya** and prices have been unstable ($1.25 to 1.75 / kg over course of 2017)[2] • High upfront stove/cylinder costs (>$100 for 2-burner)[2]
Electricity	• Not widely available: residential grid provisioned for lighting only; major capex investment required • Electricity costs too high for mass-market electric cooking (uptake ~5% in Nairobi, ~2% in urban Kenya)[1] • Efficient electric stoves are priced uncompetitively (>$200) for stoves that bring costs of electric cooking within realm of other fuel alternatives[2]

Decreased use of paraffin

Because of its affordable price, paraffin is popular in informal settlements in the urban areas and rural parts of Kenya to power cookstoves and lanterns (Dalberg, 2018). Recently, paraffin is even illegally used to blend diesel by unscrupulous traders. Due to disturbances on the market and the negative impacts on environment and people's health of paraffin, the use of LPG has increased rapidly from 2013. In 2017, 28% of urban households use LPG for their cooking needs. Since 2017 Government of Kenya has thrown series of policy supports to enforce the energy transition to LPG. This includes removing import duty, VAT zero-rating and subsidize appliance (Dalberg, 2018). This has led to the fact that the consumption of paraffin has hit the lowest point in 13 years by 2019. The fall in paraffin coincided with the growth of LPG. This is because of the efforts from the state to replace paraffin with the cleaner gas (MUTUA, 2019). The census 2019 shows that nearly 60 percent of urban households use LPG which is more than triple the amount of the households who use paraffin.

5.3 Conclusions

Compared to the data of the national scale, Nairobi has lower percentage of households who use solid fuels for cooking. LPG, paraffin, and charcoal are mostly used to cook. In comparison with Nairobi, Kibera has low use on LPG, higher use on paraffin and charcoal. In the past two years the use on paraffin is gradually replaced by LPG because of its increasing affordability and government support. However, the use of charcoal stays more or less the same. To encourage cleaner energy (or the uptake of alternative energy sources) usage in Kibera policies and support schemes seem key, as availability, reliability and price count in individual decisions and opportunities.

Knowledge and data gaps
It is crucial to get a better overview on the whole current energy supply chain, as well as a better understanding of the governance of energy infrastructure along this chain. Current barriers for alternative sources and decisions at individual level could help in improving current systems or moving towards new systems.

6 Conclusion and discussion

Starting from the household surveys and activities carried out in Kibera, the exploration via a multi-scale spatial analysis provides interesting insights in the environmental and socio-economic drivers and the different linkages and dependencies within the food system. The outcomes of the analysis carried out on climate change, water and energy in relation to the food environment and food system activities can be mapped in the food system framework. This provides an initial causal chain and clearly shows the relations between the food system. It is just a starter, but helps in understanding crucial linkages and feedback loops and most of all in prioritization of actions. The causal chain in itself is supportive in constructing an understandable narrative to address to policy and society and for further common understanding.

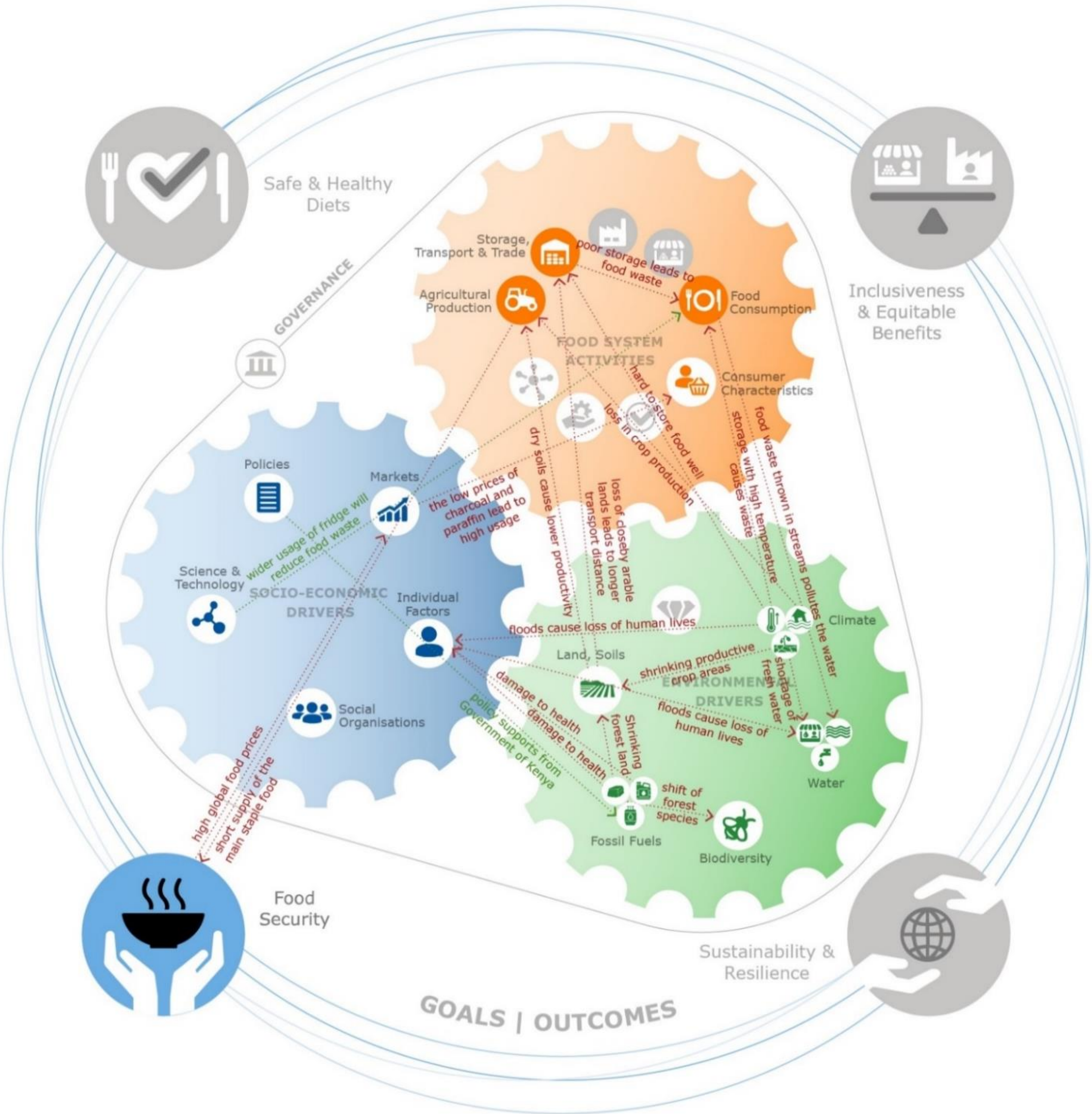


__Figure 22__ Initial causal chain of Kibera on food system framework based on the outcomes of this analysis.

6.1 Recommendations

The research has led to valuable insights, but also brings forward different recommendations to take into account for further consideration, respectively on data, policy and potential measures.

Data recommendations

- Once a good data set is available, which can answer the first questions, new questions will pop up, asking for new data sources. This is inevitable an iterative process. Awareness of this effect can help in planning data collection and research, by planning subsequent iterations beforehand.
- Monitoring as data source, for example quality of drinking water: monitoring of quality of piped water, public water points and water of vendors gives information about quality development of different water channels. Other examples are quality of river water, air quality and food quality.
- Accessibility of data is very important: broad access of data, makes broad use possible. It can help in making systems more transparent, thus helping consumers, vendors and policy in making better choices. The lack of data in informal settlements is definitely a crucial hurdle to take.
- The responsibility for data gathering, maintenance and most of all linking the data in an informative way should be placed at the right organisation, which can be trusted by all stakeholders. A more integral approach seems to have better possibilities for creating relevant linkages.

Policy recommendations

- Policy improvements often come from sectoral sources like a ministry of food, or water or energy. But the food system approach show a lot of connections between water, energy and food. Water, climate, energy and food actions should have bridges in each policy, to realise a more integrative policy.
- Tailored subsidies and instruments based on specific situation, should be assessed in a wider context in order to prevent undesired effects in changing or other situations.
- Capacity building and public awareness are important factors to work on. Narratives can be very helpful in making people aware of problems and solutions, and connections in the food system.

Potential measures recommendations

From the research the following measures seem to have potential for further research to implementation:

Water quality and availability improvement

- Water source information monitoring
  Data of varied water sources can be collected in hydro-metrological stations (Marshall, 2011; V. Nyakundi, 2020). Afterwards the data can be used for correct operational decisions on water management and engineering.
- Infrastructure maintenance
  The pipelines for drinking water should be maintained well: broken and rust pipes should be replaced and the leakages of sewage pipes need to be monitored.
- Forest rehabilitation and protection
  Forests not only produce wood but also regulate water flows. They have crucial function in water resource protection (Wiesmann, 2016) (Nganga, 2006). By promoting sustainable management of the forests surrounding water catchment areas the forests can be preserved and enlarged. It will offer more canopied area where evaporation will be decreased. In this way drink water reservoirs will be able to produce more amounts of water.

Energy resource availability improvement

- Power lines access to each household.
- Enhancing the exploitation of renewable energy resources such as wind, solar and geothermal energy (Nganga, 2006).
- Adoption of efficient stoves driven by solar power (Dalla Longa & van der Zwaan, 2017).
  Solar power is a clean and sustainable energy type. The use of solar powered kits for fishermen were increasing in 2018 when the prices of paraffin were too high to afford (OTUKI, 2018).
- For low-income populations like Kibera the low-carbon energy technologies such as decentralized solar energy driven electricity production could be beneficial on their potential contribution to poverty reduction and their affordability. For centralized energy production, wind and geothermal energy possess the highest

potential for offering low-cost electricity and a profitable return on investments (Dalla Longa & van der Zwaan, 2017).

- Transition to cleaner energy
  The energy transition from paraffin to LPG/Biogas is on the path since 2017 (see Figure 21). However, compare to the fast path of transition in Nairobi, the popularity of solid biofuels is still relatively high in Kibera and most rural areas. More government support and increasing affordability of LPG is the key to this energy transition.

Climate

- Stimulate climate adaptive farming. 1) crop management in diversified crop species especially drought resistant crops (Nganga, 2006) and staggering of planting dates to spread the risks of extreme climate events; 2) water conservation and rainwater harvesting; 3) mixed crop – livestock farming systems (Kogo et al., 2020) (Marshall, 2011).
- Stimulate food forests:
  Food forests utilize limited urban space for clusters of fruit trees which produce food for residents. In the same time the shaded areas are created by the tree canopies. They offer the cooling off effect on in the urbanized areas. Besides the planting and management activities can involve the local community to rise their awareness about the climate change as well as encourage them transform from food consumers into food producers(Forest, 2016).

Capacity building

- Public education and awareness raising can enable farmers to prepare for varied climate conditions as well as utilize the up to date techniques and inputs to maximize their crop production (Nganga, 2006).
- Adaptive capacity of low income groups is crucial. Often many day-to-day choices are also the result of lack of alternatives and the poverty trap. Making funds available for loans for low income groups could turn this.

6.2 Knowledge gaps and data needs

Next to the knowledge gaps encountered in the previous chapters, the household survey itself has also led to the new knowledge gaps. This kind of survey is a qualitative and quantitate survey about the behaviour of the residents in Kibera. However it is recommended to include more specific questions, i.e. how much water and energy in total is used and how people perceive the impact on their food security.

Household survey with clearer goals (place in process)
Before a household survey is conducted a thorough design process and preliminary analysis is crucial. It is advised to be more goal oriented and reach out more and give follow up to key players and data owners. For example, if people answer that they receive water from an organization, then the follow up question to this specific organization is to find out their water source. This provides more specific info and enables to translate the data to spatial impact on maps and specific locations. It seems impossible to foresee all relevant follow up questions; so the planning of an iteration approach seems a good solution.

Household survey with comparable spatial scope
The household surveys are carried out at a certain moment. As such, the data can only show the behaviour and preferences of interviewees in that certain year. In order to get the whole image of water and energy usage, it is helpful to compare the data from household surveys to the local statistic census data in the past years. However, in our research, due to the different research scopes of household survey and census, the comparability is rather low. Therefore, for further research the spatial boundaries for household survey should be carefully selected before operation.

Household survey prepare with key players
Which are the right questions? Aim of surveys is an inventory of the situation of people in a certain area. A good survey reveals the problems and gives leads to solutions. We have to keep in mind, that with a survey you find what you ask. In a more open discussion in groups with key players first pictures of problems in an

area can become clear. Such sessions can be of great help in preparing a relevant survey, which can help in making a next step in the assessment of problems and solutions.

6.3 Discussion and suggestions

This research was carried out as an experimentation: moving from household surveys to a multiscale analysis and trying to unravel the place based aspects of crucial resources and conditions in the food system.

How did this work out? What are the benefits? Which restrictions or barriers were encountered?
The maps with data reveal the specific information on specific locations. The unique situation of Nairobi and Kibera is obviously indicated in most of the maps. The spatial approach gives more concrete geo information than data of table and charts. It helps to get the clear view on the scale of its environmental impacts of each food related activity. Hence, it can help decision makers to make the proper interventions on the correspondent scale level in order to develop a better food system in the future.

In the different thematic fields (energy, water) that we analysed, it becomes clear that in day to day practices and interventions there seems limited notion or understanding of the reliance and the effects of the food system activities on the (broader) environment. Nonetheless, much of these activities rely on a safe and enabling environment, Is there a spiral movement to further mutually reinforced effects? What is needed to stop this movement? Can we really involve the local population more, not only building awareness but moving to different practices? A common understanding, a common narrative and common action are needed. This really builds towards an integrative strategy and sets the different interventions in the right order. Building a food community.

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