IHE DELFT Institute for Water Education under the auspices of UNESCO

ESCUELA COLOMBIANA DE INGENIERÍA JULIO GARAVITO

Agent-based Modelling for Assessing Potential Water-Related Conflicts

Case study of Lake Turkana, Kenya

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MSc Thesis Identifier WSE-HI.23-17

April 2023

Updated version, April 2023

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Master of Science Thesis
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This research is done for the partial fulfilment of requirements for the Master of Science degree at the
IHE Delft Institute for Water Education, Delft, the Netherlands.

Delft
04/04/2023

Abstract

The study of conflicts within a society is a complex topic that has been explored for years. However, due to the intricate nature of human beings, it is difficult to define this concept precisely. Similarly, the relationship between water availability and conflict generation is not entirely clear, despite being a crucial trigger in some cases.

In Kenya, this issue has been a persistent problem that government entities have attempted to solve by implementing changes in resource management and distribution. However, an effective model has yet to be established to accurately characterize this issue.

This research conducted an extensive investigation into the factors that most influence communities in the northern part of Turkana county and the surrounding lake area. The aim was to contribute to the general objectives of the Water, Peace, and Security partnership and to gain a better understanding of the conflicts that can arise due to water problems. The research also introduced a concept to represent the conflict potential in a given community, based on assessed stress and difficulties of its members regarding access to key resources, such as water and pasture.

As a final result, a model based on agents was developed, where the agents represent different communities embedded in the natural environment. The model enables modifying characteristics of the agents and the environment and obtain results in terms of conflict potential under different scenarios for a given simulation period. The primary outcome of this model is generation of a series of behavioral patterns of the communities in the area under different hypothetical (but realistic) climatic conditions and their sensitivity to the availability of water sources in the region.

The main conclusion drawn from this study is that communities are at a higher risk of conflicts during periods of drought. However, this risk decreases with the increase of water points in the area. This finding highlights the importance of implementing effective water management strategies to mitigate the risk of conflicts in the region.

Keywords: Agent-Based Models, Water Related Conflicts, Drought, Social Interaction, NetLogo

Acknowledgments

Having the opportunity to complete my Master's studies, started at the Escuela Colombiana de Ingeniería in Colombia, in an institution such as IHE Delft and in a country that has welcomed me in a great way such as the Netherlands is a great blessing and I want to express my gratitude to these two institutions that made it possible for this to happen.

In the same way, I would like to thank all the professors that were part of this process and especially my mentor Dr. Andreja Jonoski who guided me and advised me during the development of this thesis, motivating me to finish in the best way. Also, I would like to express my greeting to my supervisors Dr. Gerald Corzo and Dr. German Santos, who have been in charge of this cooperation between the two institutions and were always available to me with advice or a word of support.

My sincere thanks to the Water, Peace and Security partnership who supported me during this time of research and through which I had the opportunity to gain valuable knowledge and support from the team working both at IHE and in Kenya.

I would also like to express my gratitude to all the people who shared this process with me and all those friends I met along the way who enriched my experience of studying away from home. In the same way, I thank life for allowing me to meet Alejandra my girlfriend who supported me at all times and accompanied me during all this time.

Finally, this would not have been possible without the unconditional support of my family and especially my parents Rosana and Jose Luis who always give me their support and love and are an inspiration for my life and to whom I owe everything I have achieved.

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Abbreviation

ABM .... *Agent Based Modelling*
ASALs .... *Arid and Semi-Arid Lands*
BDI .... *Beliefs, Desires and Intentions*
DS .... *Dry Season*
ESA .... *European Space Agency*
HoF .... *Horn of Africa*
IDP .... *Internally Displaced Person*
IND .... *Inner Niger Delta*
KWS .... *Kenya Wildlife Services*
LR .... *Long Rains*
NDVI .... *Normalized Difference Vegetation Index*
PAGE .... *Perception, Actions, Goals and Environment*
PECS .... *Physical, Emotional, Cognitive and Social Factors*
SR .... *Short Rains*
SWC .... *Soil and Water Conservation*
WPS .... *Water, Peace and Security*
WRA .... *Water Resources Authority*

Chapter 1 Introduction

Since climate change has been increasing and the alerts around the world have been turned on over the recent years, there is a rising tension over water resources, tending to lead to local conflicts over natural resources (including water), sometimes escalating to violence, terrorism, and even civil wars in some countries (CAN, 2017). According to the World Bank Technical Contribution (2017), the increase on the global warming is on the rise and according to recent estimations, more than twenty million people are going back into poverty every year due to these extreme changes.

The Water, Peace and Security Partnership (WPS) is a partnership that was created with the aim of use the advances in technology and innovation into the development of new tools and services to help local communities to address and understand water-related risks. Since 2018 they have been working with local stakeholders in regions like Mali, Iraq, Ethiopia and Kenya and have developed an approach to fulfill their objectives based on four intervention areas such as Understand, Mobilise, Learn and Dialogue.

Kenya is no stranger to this phenomenon, with a significant impact on its territory. The socioeconomic conditions in the country are becoming more and more critical, which in turn increases the vulnerability of the population. The occurrence of more extreme events in recent years has made people more adaptable (Ratemo, et al., 2020), however, this level of flexibility is already close to a breaking point that will make the situation worse (County Government of Turkana, 2020).

This research was carried out in the north-western area of Lake Turkana, in the county of Turkana and mainly in the Sub-county of Turkana North. This area is close to the borders with Ethiopia and South Sudan on the north, Uganda on the west and the Marsabit county on the east.

Among the areas of the country, Turkana county is one of the most vulnerable regions, being part of the land known as Arid and Semi-arid Lands (ASALs). The weather in the county is mainly warm and hot, with temperatures between 20° and 41° C. Throughout the year, there are three well-identified periods, the long rains (akiporo) between April and June, the short rains between October and November and the dry period (akamu) in the months of January, February, and September (Turkana County Government, 2020).

According to the Water Peace and Security partnership (WPS, 2022), there are various degrees of conflict in the study area. The various ethnic groups residing in the region, have been engaged in conflicts over the exploitation of natural resources. Additionally, the political climate and the privatization of resources exacerbate these frictions. The border between South Sudan, Ethiopia, and Kenya is a source of ongoing transboundary conflict, fueled in part by the Ilemi triangle, an area in dispute among these countries and the zone known as the Karamoja Cluster.

Several studies have addressed the link between water and the conflicts that arise in a community over its use. (Bruin, et al., 2018) explores this relationship and indicates that there are several pathways that could link the water threats to conflict in the countries, with a general conclusion that one of the biggest drivers to conflict risk is the absence of an effective government. It also establishes the role that water plays in a community, with significant importance in the development and cooperation processes in a region.

The county's main water sources depend on the groundwater, via dug wells, streams and boreholes. It is usual that most of the population does not have access to these sources, sometimes because they are located in places far away from their villages or are simply located in private zones, which leads to the conditions that specific agents gain control over the accessibility of this resource.

Contrary to popular belief, however, there is not a very clear connection between conflict and water. According to the results of numerous researches, water scarcity and climate are negatively influencing global security. Others claim that while there is no direct correlation between water and conflict, the amount of conflict rises when combined with other influencing factors. According to a third group of studies, water is not a genuine cause of conflict, but it is a tool that could be very useful when collaboration and conflict-solving processes are underway (Bruin, et al. 2018).

This type of conflict is not a simple concept, as it can be inferred from above. A tool that will enable a better contextualization, representation, and analysis of water-conflicts in this area was created as a result of this study, which will involve a thorough examination of the many aspects of conflicts in the Lake Turkana region as a potential contribution to a better understanding of this problem.

1.1 General objective

The purpose of this research is to investigate the interactions between the various stakeholders that reside in the northwest region of Lake Turkana as well as the water-related conflicts in the region and generate tools that will make it easier to recognize the connection among the stakeholders and these conflicts, considering the hydro-climatic factors and harsh conditions of the region.

1.2 Specific Objectives

1. Determine which are agents/stakeholders that are present in the area, including what is the impact they have on the water resources, how they interact with each other, and what are their needs and their demands, among other aspects.

2. Identify, assess and characterize the main water-related conflicts between the various stakeholders in the northwestern area of Lake Turkana, making casual relationships that lead to conflicts more transparent.

3. Analyze the impacts of external aspects such as extreme dry and rainy conditions, that could affect the conditions of the area and how this affectation may disturb the communities.

4. Propose new strategies based on the picture of the conflict in the Lake Turkana region, that will contribute to conflict resolution management.

5. Learn how to apply modelling practices to address the interaction between different stakeholders in a given environment.

1.3 Research Questions

- What are the main advantages and disadvantages of an ABM and how it could help in the assessment of the water-related conflict in the Lake Turkana area?

- What are the main reasons that lead to conflicts on the Lake Turkana area and what role does water play in both domestic and transboundary conflicts within the region?

- What is the behavior of the different agents that are located in the county and how the extreme weather conditions affect them?

- What are the main components that could lead to a development of a strategies to prevent or solve the conflict?

1.4 Innovation and Practical Value

As a result of their inherent vulnerability to change, areas with the highest rates of poverty also have a higher likelihood of (potentially violent) conflicts. Numerous factors contribute to conflict, including ethnic divisions, resource privatization, and land occupation. Communities are directly impacted by water issues, yet it is not always clear how this impacts the disputes that result. The goal of this research is to develop tools that will make it easier to recognize this connection and to get a clearer picture of any potential conflicts in the region.

As mentioned in the definition of the objectives given above, the main outcome of this research is a model that allows us to carry out this characterization, and, additionally, we will propose a series of actions that will allow us to anticipate conflicts and take the necessary actions to reduce their impact. As part of the WPS partnership, these results will be of great help to achieve the particular objectives and support the stakeholders by including the four intervention areas defined by the partnership, Understand, Mobilize, Learn and Dialogue.

Agent-based modeling is a powerful tool that enables researchers to simulate complex systems and analyze their behavior. By incorporating various factors from different disciplines, we can obtain a more holistic view of the problems we are studying. This approach is particularly useful when dealing with intricate systems that involve multiple variables and interactions.

Moreover, agent-based models allow us to combine micro and macro perspectives of community components. This integration provides a more comprehensive understanding of the behavior and influences that govern them. By simulating the behavior of individual agents and their interactions, we can gain insights into the emergent properties of the system as a whole.

1.5 Thesis Outline

This research started with an extensive literature review with the main goal to identify the composition of the area, how people and resources are distributed along the space and recognize some of the water-related problems in the area, ant the relation with the community's interaction with the environment. In the following steps, a conceptualization of the information obtained was carried out to identify which are the principal agents in the zone, what are their characteristics, and how they interact among them and with the environment, thus generating a conceptual model that defines the main rules that will drive the ABM. The next phase was the implementation of these conceptual algorithms into the NetLogo software and setting up the whole environment to run the simulation. To do so, we define 9 scenarios that vary due to climate conditions (Normal conditions, dry conditions or rainy conditions) and water availability. Finally, the outcomes were analyzed and compared to other setups to produce a series of findings that help to better understand the conflicts in various situations.

To properly compare the various conditions that may arise in the area, we defined a division based on the physical basis of each proposed scenario. This division allowed us to analyze the results and provide recommendations for strategies that can aid in the prevention and resolution of conflicts.

In the discussion section, we delve into the variation of the monitored variables in the different scenarios. We provide insights into the implications of these variations and offer recommendations for addressing potential conflicts.

The research culminates in a section of conclusions and recommendations. Here, we highlight the most significant aspects of our study and their relationship with our objectives. We also provide recommendations for future research to improve the model, based on feedback from the community.

Chapter 2 Literature Review

As a first step, this chapter will summarize the key findings of the continuous literature review that was conducted throughout the period of development of this research, considering the local context, the conceptualization and previous work made in the field of ABM, as well as the background of research related to conflict in communities.

2.1 Local Context

2.1.1 Migratory Routes in Kenya

Since recent times, there are multiple studies that have been doing research in order to understand the migratory behavior of the habitants in this area and in the neighboring countries. The Kenyan Government have included into the most recent census the report on migration (Kenya National Bureau of Statistics, 2019a) where they analyze the internal and international migration, including the recent and historic trends, characteristics of migrants, and providing some recommendations for further studies in this field. A general conclusion of the internal migration status in the country is that the trend is that majority of migrants move towards the regions of Nairobi and the Rift Valley, while the areas from which the most migrants depart are located in the regions of Nyanza and the Western side of the country. On the other hand, it should be noted that the migration activity in north-eastern part of the country is way lower compared to the rest of it, however, it still has an overall net migration in negative terms, which means that there are more people departing the area than incoming.

Additionally, Marchand, et al. (2018) studied the dynamics of migration along the Horn of Africa (HoF), and the migration routes, both national and international between the countries in the area. This study focused on understanding the drivers of migration of each country and to collect the information about the usual routes that are used by the migrants. In the case of Kenya, it was found that the main reasons that make the people leave the country is because of economic reasons and lack of opportunities for skilled workers, who leave the country to develop professionally abroad. Then, following Marchand report's recommendation, Deutsche Gesellschaft für Internationale Zusammenarbeit (2022) expanded the report and focused on the regular routes that the people of this area follow in case of migration, analyzing which are the countries that the people leave the most, which of them are mainly temporal hosts while the migrants follow the route, and which ones are the final destination (Figure 1). In this way, Kenya has been found to be a destination for migrants from Burundi, Eritrea, Ethiopia, Somalia, Uganda and Tanzania; whereas the preferred destination for the migrants coming from Kenya are Saudi Arabia, Somalia, Tanzania and Uganda.

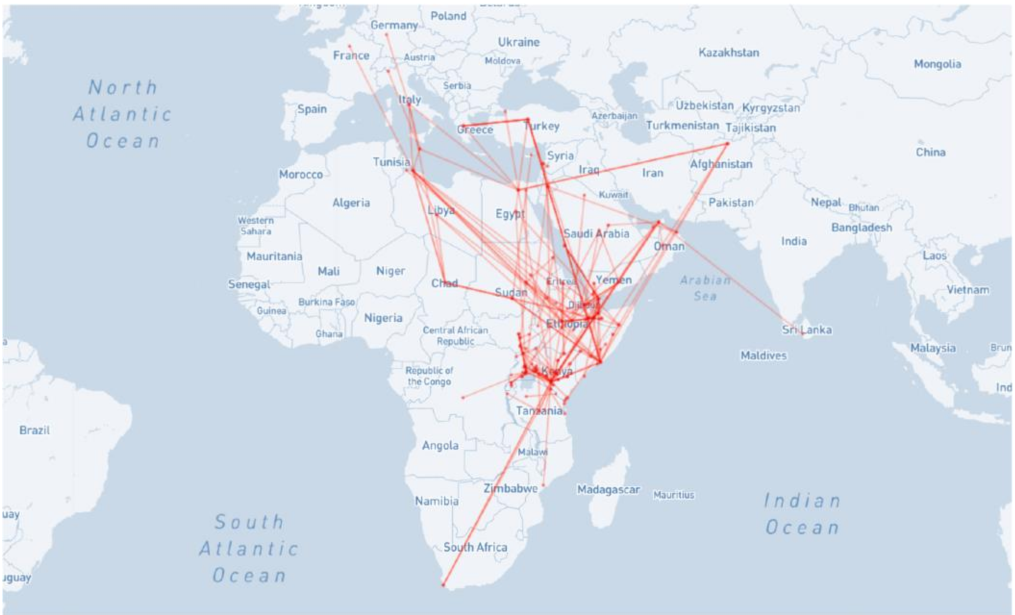

Figure 1: Cross-border Routes in the HoF
Source: GIZ (2022)

As for the internal migration, it was found that there are many common routes that the migrants used, mostly in the southern part of the country, with the most common destination in Nairobi city followed by Mombasa, Busia and Nakuru, as can be seen in the Figure 2.

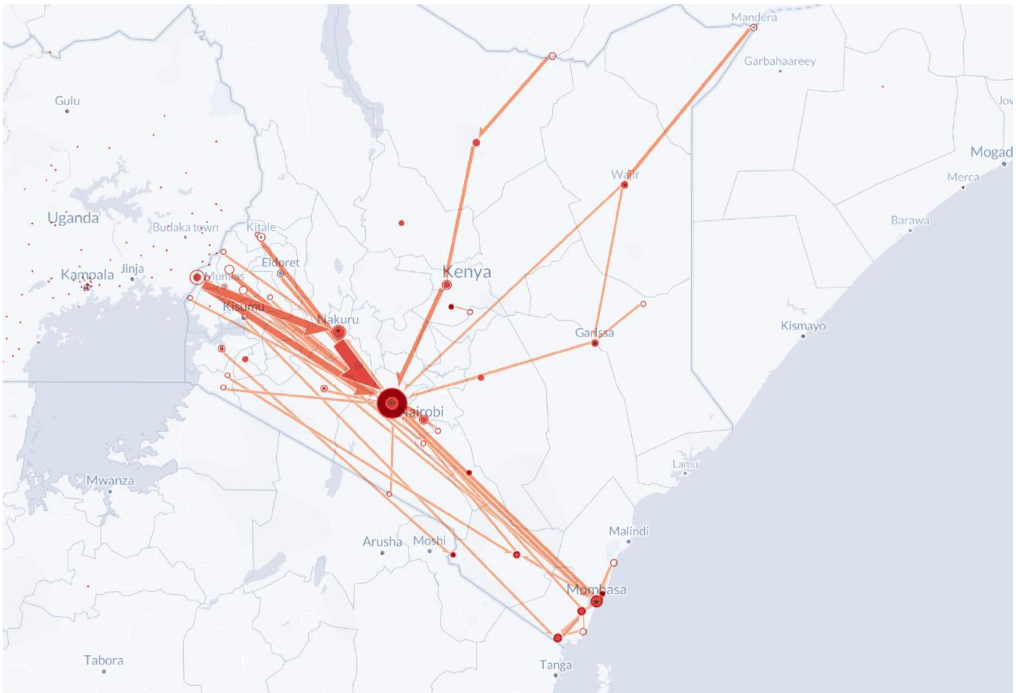

Figure 2: Internal Migration Routes in Kenya
Source: GIZ (2022)

Nevertheless, all of the mentioned reports lack a specific research to assess internal migration brought on by seasonal behavior, in which inhabitants generally remain the whole life within a specific area following regular internal migration routes.

2.1.2 Water Resource Management

The way in which resources are managed, particularly water, has been one of the major issues that has arisen throughout the nation's history. It is common knowledge that regulations ensuring the bare minimum required for the communities to exist are fragile in the Horn of Africa. Another emerging problem in the region is corruption. Together, these two factors have resulted in inefficient management of the allocation of water resources, which has in turn led to conflicts over access to these resources (Krampe, et al., 2020).

The Kenyan government, in order to establish better management in the country, released in 2016 The Water Act, through which it distributes the responsibilities that each of the regulatory entities must attend to and which are those that must watch over the correct compliance with the guidelines given in the said act. The act established a series of authorities with different responsibility levels, of which one of the most relevant is the Water Resources Authority (WRA), whose main aim is to regulate the management and use of water resources, reinforcing at the county level what is regulated through the mentioned act (Govenrment of Kenya, 2016). Subsequently, in 2019 the local government of Turkana County established the general standard for the distribution of drinking water and the standards for water supply and sewerage, following the provisions of the Water Act generated by the national government and prioritizing the different water uses in the zone. Within this prioritization, it was established that the first priority as the domestic use, followed by the livestock and support of pastoralism and agriculture in the area (Turkana County Government, 2019).

2.2 Agent–Based Modelling

Agent-Based Modelling (ABM) is a powerful tool to evaluate and assess the social behavior in communities. As a first statement, an ABM could be defined as a model system that is composed of several independent agents that have the capacity to interact with the environment as well with the other agents, and are able to take decisions to solve their own problems based on a series of rules defined by each one (Cardoso, et al., 2011). The nature of the agents is variable according to the objectives of the modeler, representing entities that can vary from atoms up to organizations and entities in a certain environment. Each one of the agents included into the model that is going to be developed have their own characteristics that let them have some level of knowledge and abilities that could vary through the simulation according to their own experiences.

The main advantage of this kind of models is that they enable the modeler to represent the individuality of each one of the agents, while taking into consideration the levels of Autonomy, Heterogeneity and Activeness among others (Crooks, 2015). The human behavior is not something easy to understand, and even more difficult when it is needed to model it. Over the years, different authors have been implementing several approaches to simulate social interaction based on certain agents' characteristics. According to Kennedy (2012), the approaches could be divided between mathematical, conceptual frameworks and cognitive target for the models.

The first approach is based on simplifications of the agents' characteristics, usually regarding the day to day decisions for which people evaluate different factors that could influence their choices. The mathematical simplification could reduce these factors to just those that are relevant for the study.

In the second approach, the main focus is to involve different concepts that are inherent to each agent, which are more abstract than the earlier mentioned mathematical simplifications and influence the behavior of the population. As an example of these, Kennedy (2012) list a couple of frameworks, including BDI (apply the concepts of beliefs, desires and intentions to describe the behavior), the PECS (uses the physical, emotional, cognitive and social factors, expanding the BDI framework). This framework can also incorporate the idea of PAGE, which establishes the attributes of the agents based on their own Perceptions, Actions that they will take, the Goals the will try to accomplish through the development of those actions and the Environment in which they will interact.

These past two frameworks were thought mainly to model social simulation with the ABM, for the case of the third framework the focus is to understand human cognition via the research of abstract cognition. This is made by the application of several architectures that are based on the idea that the basic statements do not change during the simulation while some abstract cognitive models are implemented to control the agents' behavior

Overall, the ABM kind of modelling is also applicable to several disciplines, including economics, finance, political science, geography, social psychology, biology, and hydraulics, among others (Manzo, 2014). As is possible to deduce, the utility of the ABM is very high, and different examples of water-related topics have been addressed over the years.

Dubbelboer, et al. (2017) made a research to produce an ABM that links the flood risk and insurance policies. During this research, they compiled a series of ABMs that are related to these topics, including models like the following: an ABM that relates the coastal flooding in North Germany with the social vulnerability (Sobiech, 2012); a link between shoreline model and market behavior to analyze how the dynamics of the markets and people act in cases where the sea level rises in US East Coast (McNamara and Keeler, 2013); a model that evaluates the consequences of the absence of flood insurance in the housing market in North Carolina, USA (Filatova, 2015, Filatova, et al., 2009, Filatova, et al., 2011). On the other hand, different authors have documented applications of ABM in different fields, as in the case of Gulden, et al. (2011) who conducted the research of an agent-based spatial interaction model of the Internally Displaced Person (IDP) dynamics in East Africa, or Assefa, et al. (2021) who evaluate different scenarios of land cover or quality of Soil and Water Conservation (SWC) via ABM in three villages in Ethiopia. The above show the wide applicability of this kind of models.

Schasfoort, et al. (2022) developed an ABM in the Inner Niger Delta (IND) as part of the WPS initiative to evaluate the conflict in the region between the cohabitants who have been impacted by changes in the availability of water and resources. This serves as an illustration and a useful point of comparison for this research. To achieve this, the authors establish a comprehensively characterized area that includes the population's primary means of subsistence and the key principles that will define the interaction between agents, generating a conflict map that makes it possible to identify the regions that are more prone to conflict and their primary causes. This model's main output is a distinct conflict horizon in the IND region, with sensitivity analysis based on various flood scenarios that could occur there.

2.3 Conflict

According to the literature, there are several definitions for conflict. One of those definitions was given by Mason and Rychard (2005) and is cited as follows: *“A conflict can be understood as an incompatible interaction between at least two actors, whereby one of the actors experiences damage, and the other actor causes this damage intentionally, or ignores it”*.

As would be expected, the definition shown is very general, since, due to the diversity of types of conflicts that can occur in a society, this could be slightly different. During the research for the Master thesis, Koirala (2006) listed some of the types of conflicts that could happen in a community, including the following: Intrapersonal conflict, interpersonal conflict, family conflicts, organizational conflicts, intergroups conflicts, public policy conflicts, international conflicts, intractable conflicts, justice conflicts and data conflicts. These listed types are not all that could be considered, however, by understanding these, it is possible to establish a connection with the problems related to water and conflict.

Several studies have been elaborated with the purpose of gaining more profound comprehension of the relationship between water-related problems and community conflicts. One of the most noteworthy discoveries is that insufficient governance, combined with water scarcity, can significantly contribute to the emergence of conflicts (de Bruin, et al., 2018).

Water scarcity is a critical issue that affects many communities worldwide. When there is a lack of water, people may become desperate and resort to extreme measures to obtain it. This can lead to conflicts between individuals, communities, and even nations.

Moreover, inadequate governance exacerbates the problem. When there is no clear framework for managing water resources, it can lead to disputes over access and usage. This can create tension and conflict between different groups, which can escalate into violence if left unchecked.

There are numerous ways to analyze and understand conflicts. Mason and Rychard (2005) describe a series of mechanisms that can be used to analyze conflicts and gain better understanding of the underlying the causes, the needs of each party involved, the current status of the conflict and possible mechanisms for resolving such conflicts. Table 1 offers a comprehensive overview of these tools.

TOOL	DESCRIPTION	AIM
Conflict Wheel (Mason and Rychard, 2005)	It is a tool used as an introductory approach to the conflict, as it includes an overview of the other 6 tools, taking into account the Actors/Relations, Issues, Dynamics, Context/Structures, Causation and Options/Strategies. With this tool, it is possible to choose which one of the considered aspects you want to inspect in more depth	Organize the other conflict analysis tools Serve as an overview when first approaching a conflict

TOOL	DESCRIPTION	AIM
Conflict Tree (Fisher, et al., 2000)	This tool offers manly visual support to understand the relation between three concepts, known as Dynamic Factors, Manifest Issues and Structural Factors. These concepts are located along the tree, with the structural or statics factor on the roots, the manifest issues along the trunk and the dynamics factors representing the branches and leaves.	To initiate reflections on the links between root causes, issues and dynamic factors To differentiate the time horizon of various conflict transformation approaches
Conflict Mapping (Fisher, et al., 2000)	It’s a tool that serves to summarize different conflict aspects in one map, including each one of the actors that are involved on the conflict, how is the relation between each other, how are their influences and what are the issues of the conflict that is wanted to analyze	Clarify relationships between actors Visualize the 'power' of various actors Represent the conflict on paper to overview it
Glasl's Escalation Model (Glasl, 1997)	This tool introduces 9 levels of escalation of a conflict, starting with a low level of hardening and increasing until reaching a total confrontation without any possibility of solving the conflict. This mechanism also includes the different forms of intervention that could be included according to the level of escalation.	To evaluate how escalated the conflict is To decide how to transform conflicts
INMEDIO's Conflict Perspective analysis (CPA) (Wüstenhube, 2004)	This is a tool special to make the actors have a complete view of the conflict, analyzing also the other parties’ motivations and point of view. It is mainly performed by a third actor who is not involved in the conflict and can give an outside and new point of view.	To separate facts from interpretations, people from problems, positions from interests/needs/fears To enable a change of perspective, “make motivation of all actors possible” Elaborate hypothesis on new options, or find solutions of the conflict away from the involved parties

TOOL	DESCRIPTION	AIM
Needs-Fears Mapping (Mason and Rychard, 2005)	The needs-fears mapping is a mechanism to clarify the conflict with a holistic view of it. It lists the characteristics of the actors including the issues, needs, fears, means and options. This tool could be used to analyze the conflict each actor at a time and is possible to be used by a third actor to have a broader view of the situation and be able to give an objective opinion. It is also applicable during conciliation stages and to perform a conflict perspective change exercise.	To clarify in a comparable format the various actors' attributes To focus on needs, fears and options to deal with these. To help people understand each other's perception To stimulate discussion
Multi-Causal Role Model (Mason and Rychard, 2005)	It is a tool to identify the causes of the conflict by analyzing the reasons for the conflict, the reasons that the different actors say they're fighting for, influences over the actors that are external from the root cause, but could affect the conflict, actions that could change the dynamics of the conflict and catalysts that could affect the dynamics and content of a conflict. Over the last years, this tool have been evolving into a different tool called Causal Loop Diagrams, which include also concepts of balancing and reinforcing loops, that help to understand in a better way how the factors affect the conflicts.	To trace causal mechanisms, patterns, to distinguish between the different quality and role of the various factors that lead to conflicts To analyze both the content as well as the dynamics of a specific conflict To facilitate the location of entry points for conflict transformation, to differentiate between short term and long-term commitment needs

Table 1: Summary of conflict analysis tools

By utilizing these mechanisms, individuals can gain a deeper understanding of the complexities of conflicts and develop effective strategies for resolving them. These tools can be particularly useful in situations where emotions are running high, and communication has broken down.

However, in order to apply these tools, it is necessary to know the different components that make up a conflict, such as the number of parties involved in the conflict, the influence and power of the potential opponents, the environment in which the conflict is taking place, among others. Through this characterization it is possible to determine, among other things, whether it is short, medium or long-term conflict as well as the stages through which it has passed or is expected to pass.

In the case of the stages, conflicts can escalate quickly and become more complex as they progress. Therefore, it is important to be aware of those stages through which a conflict can go through, going from the initial disagreement and beginning of the conflict, hottest points during the confrontation, and, in some cases, eventually reaching stages of conflict resolution and cooling.

By understanding these stages, it is possible to identify the appropriate conflict resolution strategy to use at each stage. This will help to effectively manage the conflict and prevent it from escalating further. Allwood and Ahlsén (2015) compile different approaches that classify these stages based mainly in the escalation of the conflicts, which in the majority of the cases finished with a violent resolution and even elimination of one of the parties. Table 2 presents the different conflict stages, as considered by different authors.

CONFLICT ESCALATION STAGES				
AUTHOR				
Glasl	**Noll**	**Cornelius et al.**	**Hocker and Wilmos**	**Brahm**
0. Dialogue 1. Discussion—hardening positions 2. Debate—polarization 3. Running over the other—own goals 4. Harassment—scurrilous images 5. Loss of face 6. Strategical threats 7. Painful attacks—cause damage 8. Elimination—attacking “nerve center” 9. Together down the abyss—annihilation	1. Part of normal, everyday life. Even good relationships have moments of conflict 2. The parties fluctuate between cooperation and competition 3. Concrete action—no common solution 4. Cognitive function regresses—know but do not consider each other’s perspectives 5. Progressive regression	1. Uncomfortableness. an inner, intuitive feeling that something is going wrong 2. Incidents. irritation 3. Misunderstanding. communication is deficient 4. Tension negative attitudes. Consciously or unconsciously people hurt each other 5. Crisis. repressed emotions release. Violence can appear	1. A problem to be solved 2. A difference 3. Confrontation 4. Fight and/or flight 5. Deadly combat	1. No conflict 2. Latent conflict 3. Emergence 4. Escalation 5. (Hurting) Stalemate 6. De-escalation 7. Settlement/ resolution 8. Post-conflict 9. Peace and reconciliation

Table 2: Conflict Escalation Stages
Source: (Allwood and Ahlsén, 2015)

2.4 ABM and Conflict

One of the key benefits of using ABM in community conflicts is that it allows researchers to simulate complex social systems and observe how different variables interact with each other. In this context, this tool enables researchers to test different scenarios and interventions without having to conduct expensive and time-consuming experiments in the real world. By modifying various parameters in the model, researchers can explore how changes in policy or environmental changes might affect the outcome of a conflict.

Overall, the use of ABM in community conflicts has opened up new avenues for understanding human behavior and improving conflict resolution strategies. As technology continues to advance, we have been seeing even more sophisticated models that capture the nuances of social interactions, leading to an improvement of the decision-making process for both community leaders and individuals in the same way.

As an example of this type of model, two cases in which ABM has been implemented for the identification of conflicts in different communities are shown below.

The first model involves the use of ABM in a community to determine the behavior of people under an established type of governance and personal conditions that are given to each of the agents. These behaviors can culminate in rebellion against the government, generating a response from some defenses forces from them as authority.

In the article, Epstein (2002) contemplates two concepts: on one hand the perceived hardship and on the other hand the legitimacy towards the government. By combining these two, it was possible to simulate how the individuals decide whether to rebel or remain inactive. Perceived hardship (H) refers to how challenging an individual perceives their own means, either physical or economic, while legitimacy (L) refers to the extent to which the government is seen, which is equal for every agent in the model.

Due to the complexity of aspects that are considered at the moment of making a decision that involves an individual risk, it is not correct to rely on individual concepts, so a combination of the above is made, thus arriving at a level of grievance which is compared with the risk that each person has, of being caught by government agents. This combination is shown in the equation below.

$$Grievance\ (G) = H * (1 - L)$$

Equation 1: Epstein's Grievance

The number obtained in the above expression is used in conjunction with the net risk of the agents, which is determined as the product of the internal risk of each one and the probability of being arrested by the police. This comparison is made against a threshold that is defined by the modeler and determines the turning point between inaction and action.

With this model it was possible to achieve the representation of two behaviors of society in the face of a regime. At the beginning it was observed that the agents did not show rebellious behavior when they were close to the authority, however, when they moved away from it, they began to rebel; at that point, a state of equilibrium was observed in which there were no violent outbursts, while with some changes in the parameters it was possible to achieve a violent outburst, which varied in size according to the modifications made.

The second case involves the use of ABM to identify conflicts in a rural community in Africa. The model was designed by Kennedy (2012), with the aim to simulate the interactions between different groups within the community, such as farmers and herders, and to predict potential conflicts that could arise due to competition for resources like water and grazing land. This model was with the aim of building a model that could include in a proper way GIS data and characterize spatially those agents and the cycles in the climate.

This case was studied in the border area between Somalia, Ethiopia, and Kenya and was based on previous studies conducted on the behavior of pastoral communities and how this variation and competition for scarce resources occurs with the inclusion of new communities such as the farming community. The model was created using the MASON tool. It primarily evaluates the interaction of livestock farmers with the environment. Conflict arises from physical aspects that are measured in the hunger and thirst levels of the animals that each agent has and their needs, establishing a stress threshold through which these agents will evaluate options for the survival of their animals and ensure the well-being of their community.

The model tracks population growth, the impact of community size, the generation of conflicts, and cooperation between communities, by manipulating the amount of water available in the area. The results reveal that as the amount of water increases, so does the number of pastoral populations. Conversely, the less water available, the more conflicts arise, leading one of the communities to dispossess the resources of the other, culminating in their elimination. and increasing the cooperation among members of the surviving community. This study sheds light on the intricate interplay between environmental factors, community size, and competition for resources in pastoral communities.

Chapter 3 Case Study Description

The purpose of this chapter is to present a thorough and detailed overview of the case study that was the central focus of this research. It is through this case study that the crucial information necessary for the development of the model was extracted. The first part includes a geographic description of the area, while the subsequent parts present the state of the conflict, mainly that which occurs internally.

Kenya is a country located near the equator, in the East Africa area. It's composed of 47 counties with their own dynamics and challenges that are identified and managed by each of the local governments. Lake Turkana is located between the counties of Turkana and Marsabit, which are the biggest overall, reaching almost 24% of the total area of the country (Kenya National Bureau of Statistics, 2019b). Nevertheless, despite its size, this territory has a relatively low population density.

Lake Turkana is located between the counties of Turkana and Marsabit, which together make up almost a quarter of Kenya's total area (Kenya National Bureau of Statistics, 2019b). Nevertheless, despite its size, this territory has a relatively low population density.

The lake is primarily fed by the Omo river and serves as a vital source of livelihood for the communities living in the area and the cities established there. As shown in Figure 3, Lake Turkana is surrounded by neighboring countries of Ethiopia, South Sudan and Uganda, as well as the mentioned local counties.

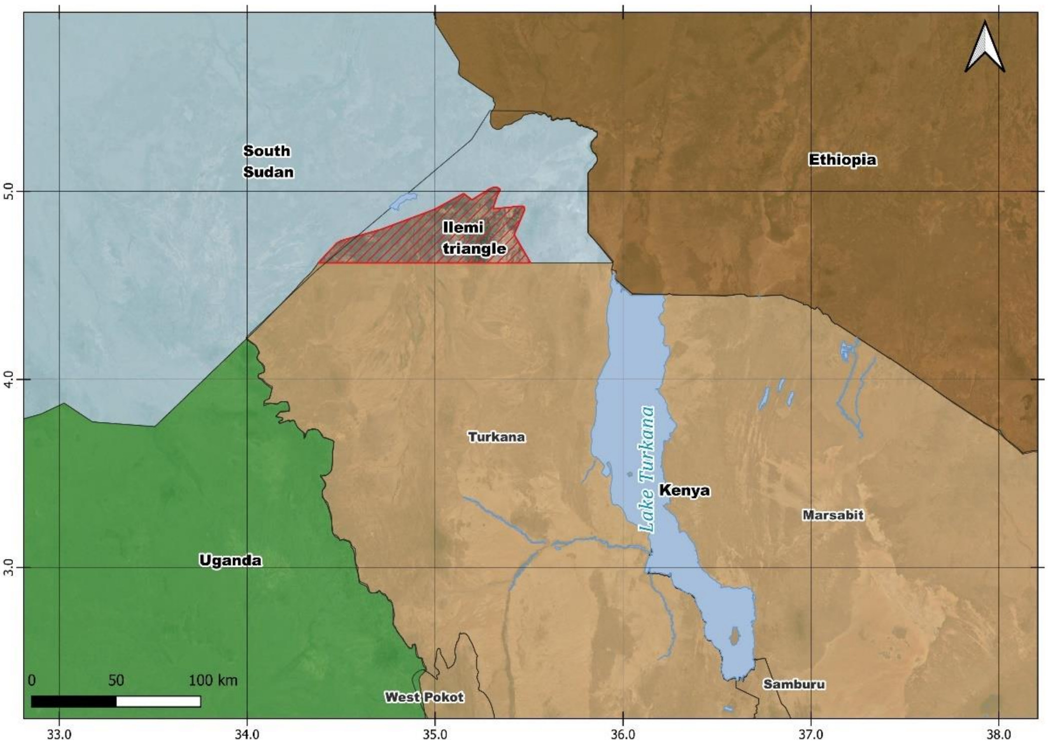

Figure 3: Lake Turkana Location

However, this study was primarily focused on the area of Turkana, more specifically in the Turkana North Sub-county, taking into account potential Marsabit agents and those who reside in the border regions with Ethiopia and South Sudan.

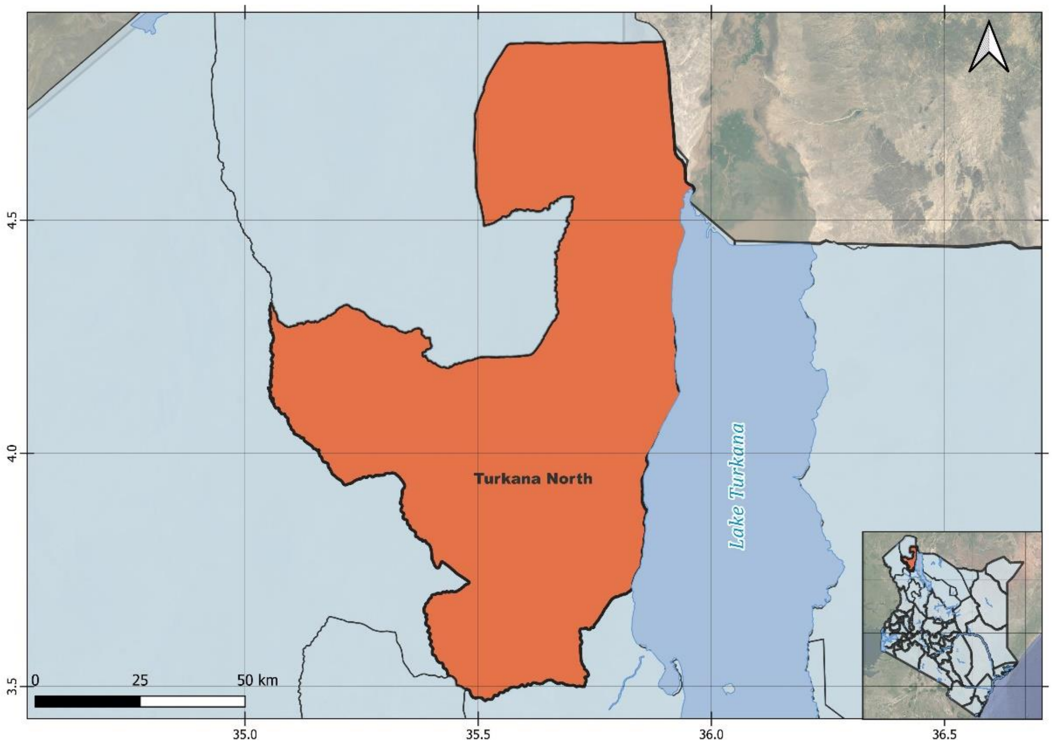

Figure 4: Turkana North Sub-county location

The climate in Kenya is very variable county by county, with 23 out 47 of them included in the ASALs, including Turkana and Marsabit (Govenrment of Kenya, 2018). As the size of the counties is large, they have an internal distribution of micro-climate with approximate percentages of 24% as arid, 19% as semi-arid, or 38% as very arid (Turkana County Government and UN Resident Coordinator Office, 2015).

Indigenous people make up the majority of the local communities and they depend on farming, raising livestock, fishing, and other related activities for their primary means of subsistence. Turkana county is divided up into 7 sub-counties, each with its own set of practices depending on where it is located. Almost 37% of the county's land is classified as a farming area, and as a result, roughly 67% of the population works in an industry related to agriculture. In addition to this, the majority of households that have their main livelihood as farming, also engage in other activities including raising livestock, growing crops, fishing, or irrigation. (Ministry of Agriculture Livestock Fisheries and Co-operatives (MoALFC), 2021).

Pastoralism in the region is a practice that is not properly appreciated, especially considering that it provides income for about 62% of the local population, (Akall, 2021). Turkana County's herders supply significant quantities of meat and dairy products to both domestic and foreign markets. According to Nyariki and Amwata (2019), pastoralism in Kenya is not just a source of income but also a cultural identity, a way of measuring status and wealth, and a major factor in family dispute resolution.

Every year, people confront many difficulties that lead them to change their way of life, especially during times of drought, when getting access to water is considerably more difficult than it usually is (Ministry of Agriculture Livestock Fisheries and Co-operatives (MoALFC),

2021) When there are not enough resources to raise livestock successfully, households will frequently start different activities such as fishing or agro-pastoralism. Primitive indigenous people with their capacity of examine the environment, create their own Traditional Ecological Knowledge (TEK) by which they develop strategies that include early mobility, information sharing among communities, quick reactions to the changes in vegetation, regulation of movement of livestock and trade them (Akall, 2021, Ratemo, et al., 2020, Western, et al., 2020). Conflicts are more likely to occur during drought times. Due to the fact that Kenya is not the only country affected by this phenomenon, nomad communities from South Sudan and Ethiopia relocate into some sections of the Turkana county, causing unease among the local communities.

As part of the project that WPS has been carrying out for several years, a study was conducted in the area of interest mentioned above, to understand the nature of the conflict in the area, determine the causes of the conflict and the link to water in the communities. This exploration was the starting point for the present research, thus making it possible to identify the main agents who are most vulnerable to the occurrence of conflicts and the conditions in which they usually live. In the Analysis of stakeholder interests and concerns report (WPS, 2022), a comprehensive examination of the country's overall situation was elaborated, including an in-depth analysis of the water governance mechanisms that have been implemented over the years. It also explores the key agents involved in water-related conflicts in the areas surrounding Lake Turkana and the potential causes of these conflicts. Based on the above, the following information can be highlighted:

There are four main areas in the Turkana County that could be the base to understanding a proper way how the conflicts are generated, and what are the main issues in the zone (Figure 5). These areas are the Lodwar township, Kalokol ward and urban center, the Todonyang area bordering with Ethiopia and the Kibish zone which is a conflict prone area due to the proximity with South Sudan and is the area occupied by the Toposa.

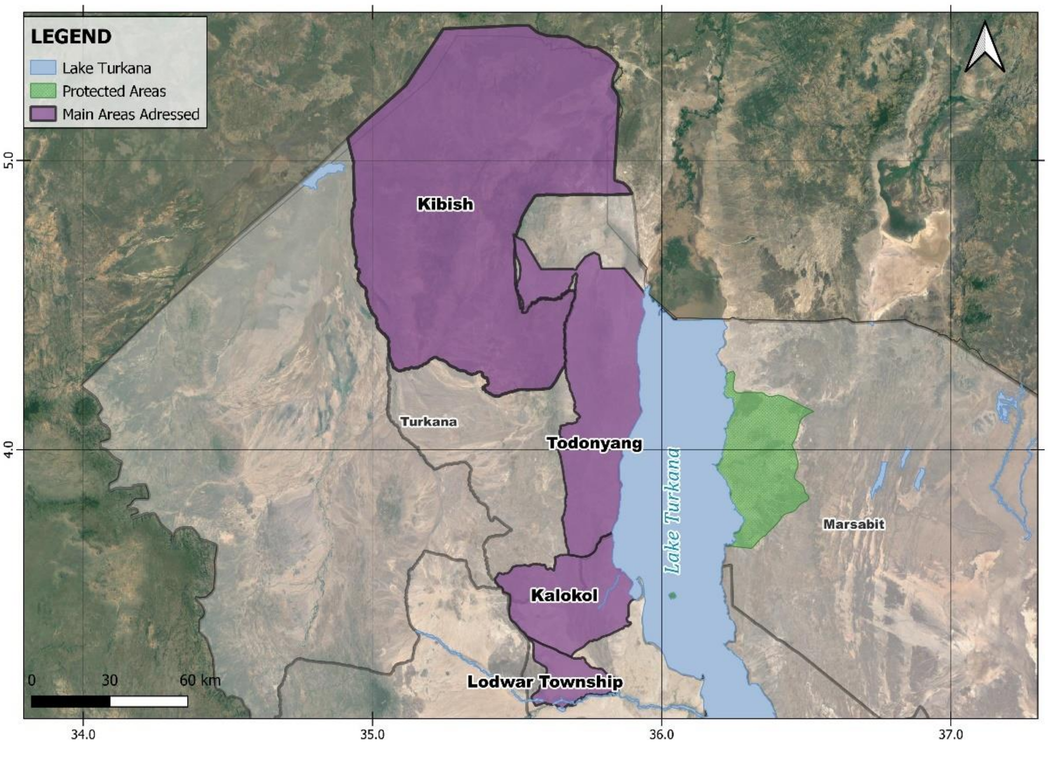

Figure 5: Main Areas Addressed

Overall, for the pastoralist communities that reside in more rural areas as is the case of the Kibish and Todonyang zones, the main issues that may lead into conflict are the cross-border problems, which lead people from Ethiopia and South Sudan to occupy areas that are part of Kenya’s territory and increase the pressure over resources, which become less available in periods of drought. These confrontations have generated a general feeling of insecurity, which has led to a state of prevention on part of the communities, restricting a correct resolution of conflicts.

Following, all along this area there is a poor governance that leads to bad control of water resources and lack of accessibility to the water sources, leading people to arise grievance against this management. More specifically, in the main cities over the county, which are Lodwar and Kalokol, this management has been appropriated by a series of organizations that increase prices for the community and control the main water points, thus avoiding any kind of competition and adequate management of the resources.

Moreover, there are some communities that have been in conflict because of competition over the fisher areas and resources in the area surrounding the Lake in Kalokol Sub-county. Local communities there have been in conflict with Marsabit people. Additionally, several disputes have been reported involving the fishermen and the Kenya Wildlife Services (KWS). Fishermen often seek to carry out their activities in areas that are designated as protected, such as the central island and northeastern border of the lake (see protected areas in Figure 5). However, this can pose a threat to the delicate ecosystem and wildlife that inhabit these areas, which are monitored by the KWS officers.

Chapter 4 Research Methodology

The methodology depicted in the Figure 6 below was applied during this research. It also visualizes how different phases of the methodology are related to the research objectives. This methodology was based on common procedure used to create an ABM, starting with the desk work, followed by the conceptualization and actual implementation of the model. In addition, new phases have been included to analyze simulations with different scenarios and identify possible conflict resolution strategies. In order to leave the results section of this report exclusively to the model results, in this chapter the main information for building the related model is included, following in the same order the stages shown below.

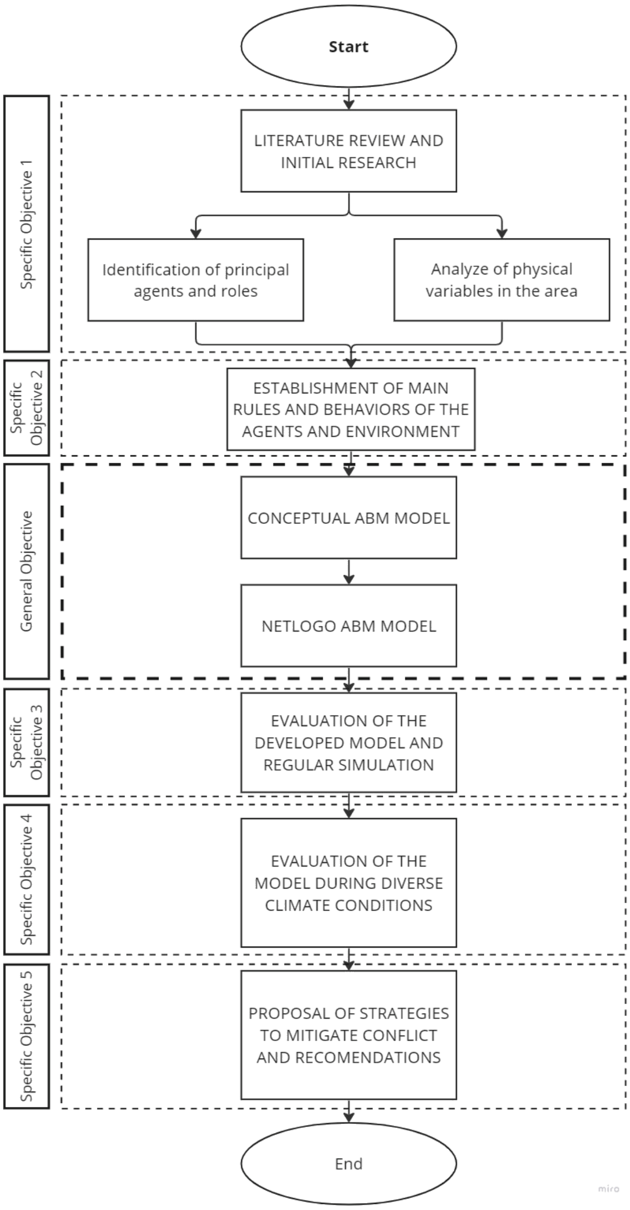

Figure 6: Methodology Flowchart

4.1 Phase 1 – Research regarding Agents and the Environment

The first stage for this research was the investigation for identification of the agents to be included in the model, together with their characteristics, based on the PAGE concept. On the other hand, we searched for relevant information about the environment in which they will interact and behave in the model. Even though that this is a methodology chapter, it includes the main information that will feed the model, whose results are those that compose the next chapter.

4.1.1 Agents Research

As a first step, it is necessary to be clear about the population size found in the study area, for which we resorted to the results obtained by the Kenyan government in 2019, when it conducted the most recent population census. During this study a discretization of this population was carried out, differentiating between the population of each of the counties and their respective sub-counties, as well as differentiating with respect to gender and the size of the households that make up the communities. The population density in the country was also reported. Table 3 below shows the overall population of Turkana County and the distribution in each of the sub-counties, with Turkana North County highlighted.

Subcounty	Sex			Household	Land area	Densisy
	Total	Male	Female	Total	sq km	persons per sq km
TURKANA	**926,976**	**478,087**	**448,868**	**164,519**	**68,233**	**14**
Kibish	36,769	18,651	18,117	5,805	10,466	4
Turkana North	**65,218**	**32,810**	**32,408**	**13,119**	**7,012**	**9**
Turkana West	239,627	123,867	115,758	45,451	16,779	14
Turkana Central	185,305	93,145	92,160	38,173	6,415	29
Loima	107,795	54,341	53,453	19,438	9,120	12
Turkana South	153,736	78,402	75,329	24,552	7,045	22
Turkana East	138,526	76,871	61,643	17,981	11,396	12

Table 3: Population in Turkana County

As mentioned in the previous chapter, the focus area for this research is the Sub-county of Turkana North, with population of about 65.000 people, divided proportionally between male and female. The household size is approximately five people per household for a total of almost 13.000 households (Kenya National Bureau of Statistics, 2019b). In this sub-county there are four main areas namely Kaaleng, Kataboi, Lapur and Lokitaung and within them there are several villages. Figure 7 indicates the locations of the villages in the study area, considering the surrounding sub-counties, as well as population located on the borders with neighboring countries.

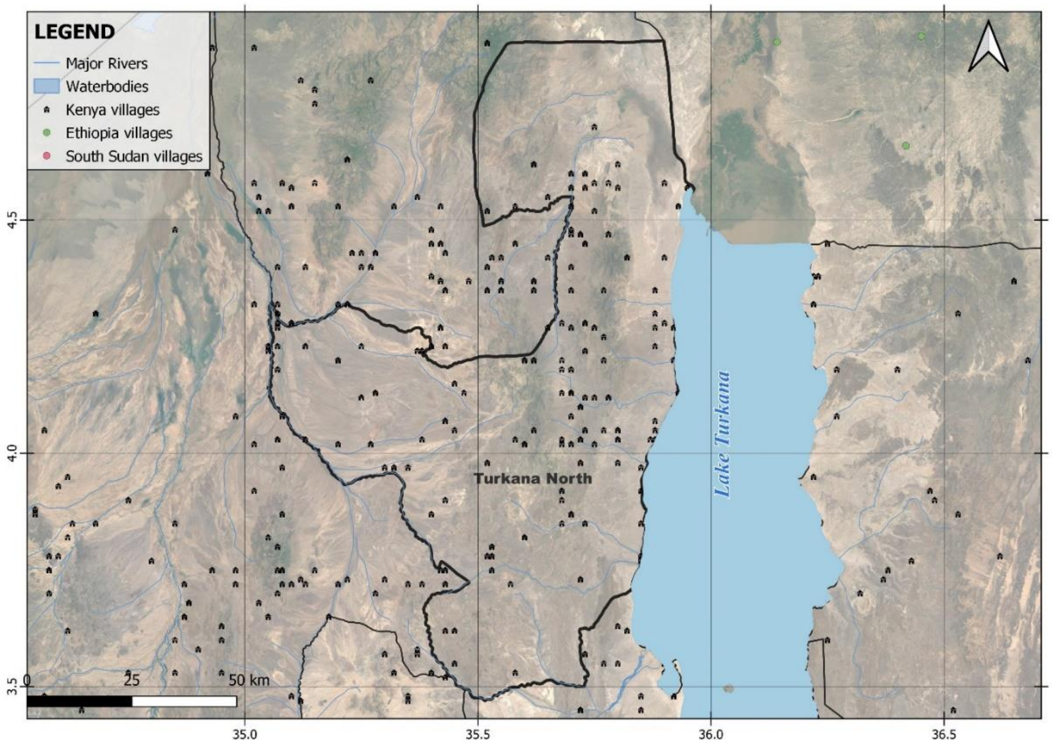

Figure 7: Villages within the study area

Now, it is important to know the means of subsistence and the main activities of the people living in the study area. For this task, we consulted different investigations that have reported the daily life of the population and their ability to adapt to each of the seasons over the year. In addition, the time periods in which the climatic conditions were not favorable were identified.

Both the research conducted by WPS and the results obtained by the Ministry of Agriculture Livestock Fisheries and Co-operatives (MoALFC) (2021) and the Japan International Cooperation Agency (2015), have found that the main source of work and subsistence for the population is the care of livestock of different types (sheep, goats, camels, cows, etc.). However, agricultural activities are also carried out but to a lesser extent, thanks to the nature of the soils of the region. As for fishing activities, they are limited to the areas surrounding the lake, with the point of greatest trade is the city of Kalokol. In the Figure 8 there is a summary of the overall distribution of the livelihoods and the geographical distribution.

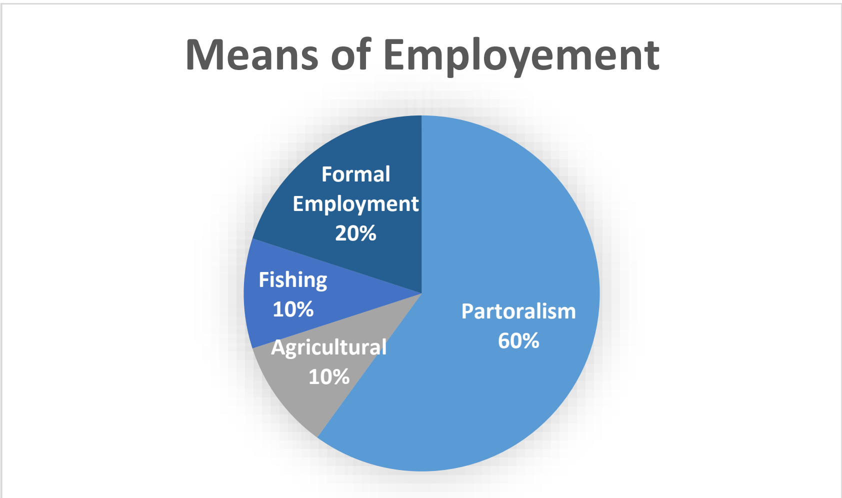

Figure 8: Distribution of Livelihoods in Turkana county

Understanding the general dynamics of how people live and behave is crucial for creating an accurate model, so that the agents can make decisions under different situations. Incorporating this information into the model could be challenging, as it requires to account for a wide range of factors that can influence human behavior. However, based on some of the previous research made in the area and in zones with similar conditions, it is possible to define some of these behaviors, which are drivers for the decisions that each agent takes. Two of the most important information maps for this simulation are the spatial location of each agent group (by type of work) and the sites designated for typical movement of the agents who have a nomadic lifestyle during different seasons.

The Figure 9 shows the location of the four main sources of labor in the territory of Turkana County, while the Figure 10 shows the zones to which the pastoral population commonly migrates during the typical seasons of the year.

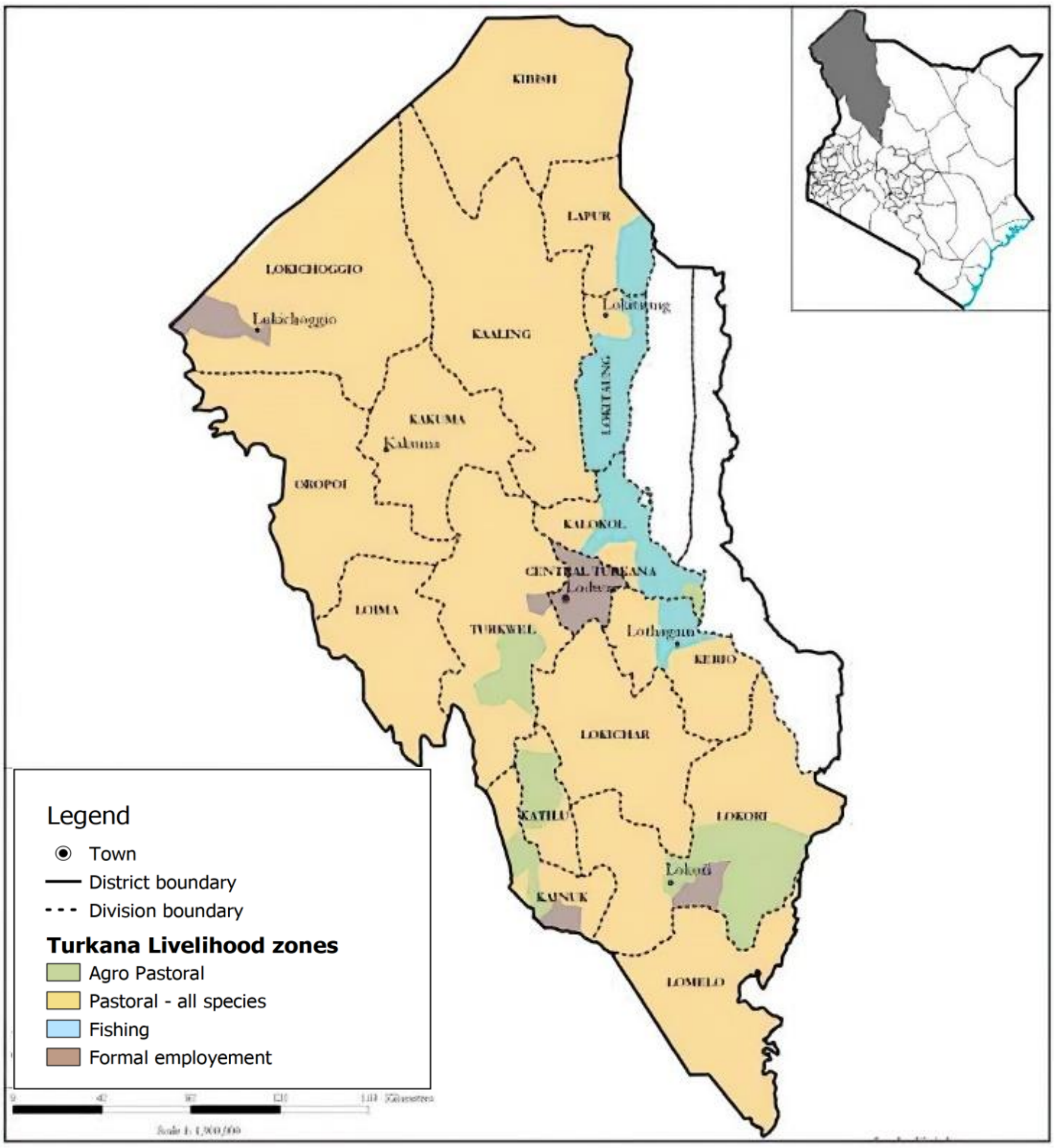

Figure 9: Spatial distribution of livelihoods

Source: (Kenya Food Security Steering Group and Turkana County Steering Group, 2022)

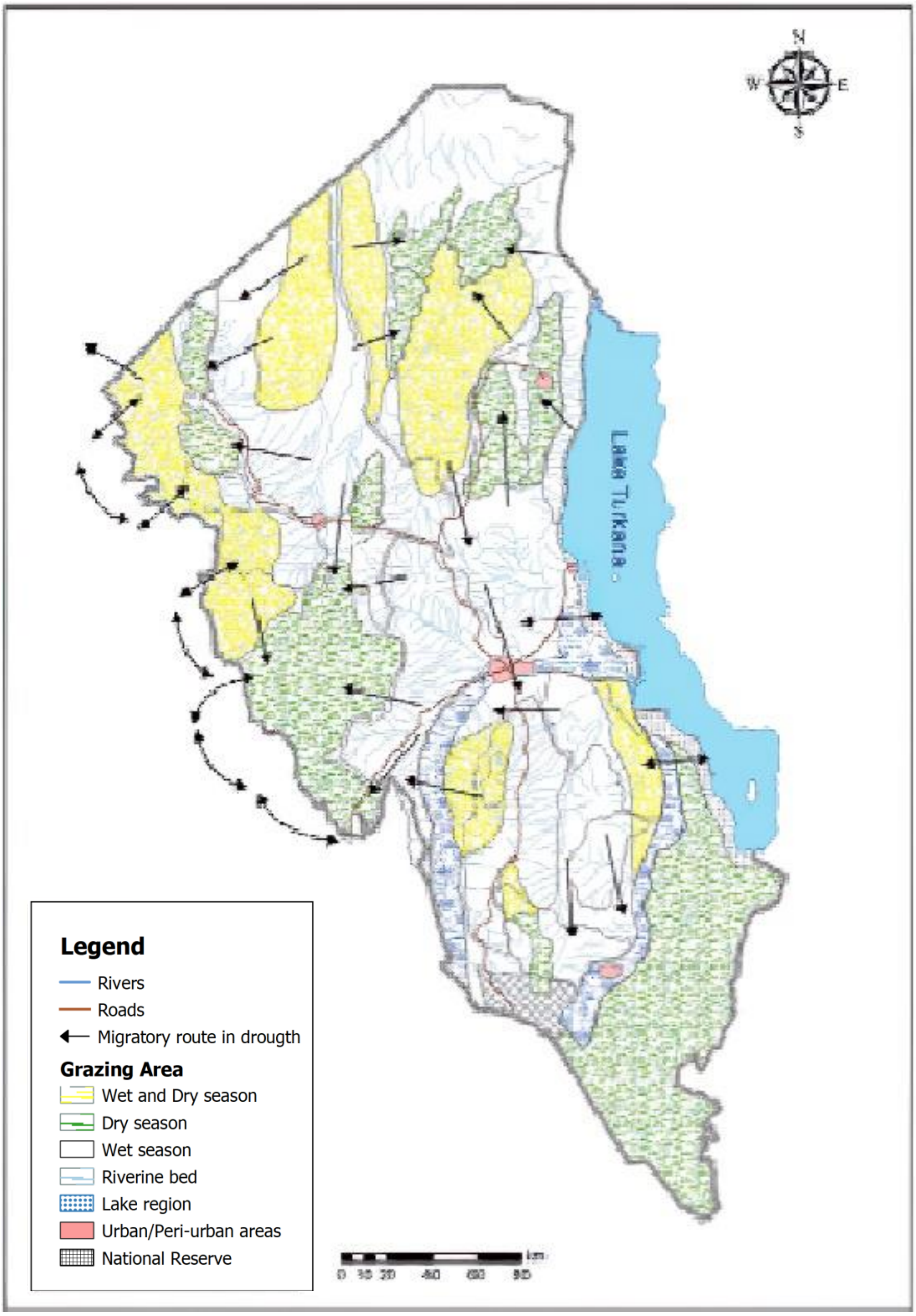

Figure 10: Grazing areas and migratory routes during season change

Source:(Japan International Cooperation Agency, 2015)

4.1.2 Environment Research

As a second step in this phase, it was needed to understand in a proper way the environment in which the activities and interactions among the various agents will take place throughout the simulation. For this purpose, the first source of information consulted was the landcover classification published by the European Space Agency (ESA)(Zanaga, et al., 2022) with the information collected during the year 2021, as shown in the map in Figure 11.

This information was crucial in determining the different types of land use that would be present in the simulation, such as the tree cover, shrubland, grassland, and cropland. Additionally, data on typically seasonal behavior in the area, specifying the dry and rainy season over a year was coupled.

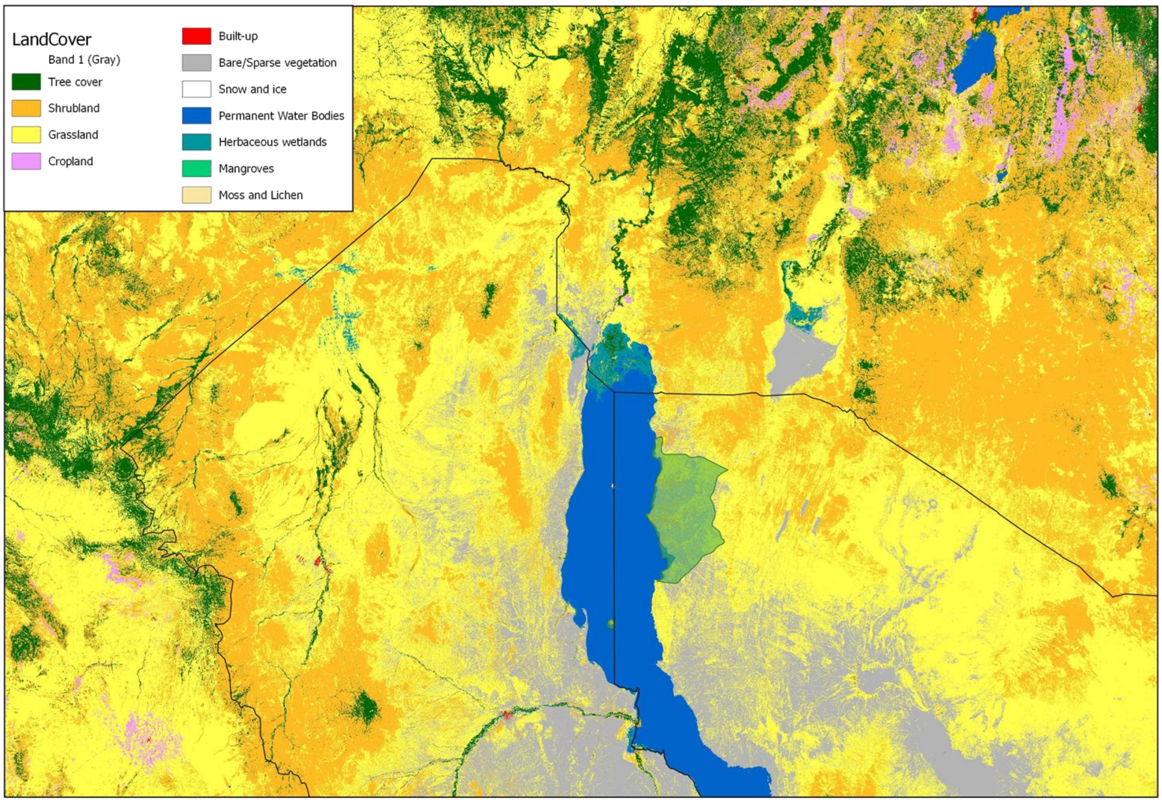

Figure 11: Landcover Classification
Source: ESA 2021

To ensure the precision and reliability of our data, we utilized the Copernicus SENTINEL 2 data to get the Normalized Difference Vegetation Index (NDVI), which is a widely used index to measure the vegetation cover and health of an area using satellite images. For this purpose, the Copernicus Open Access Hub was consulted by specifying the desired area, the use of information from the Sentinel 2 mission and a low cloud cover.

In total, 23 images were obtained between March and June 2022, which were processed individually to generate a multilayer raster file which was then combined into one file, followed by the estimation of the area's NDVI applying the Equation 2, generating as a result the map shown in the Figure 12.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Equation 2: NDVI Calculation

Where the terms 'NIR' and 'RED' refer to the Near infrared and Red bands in the generated raster.

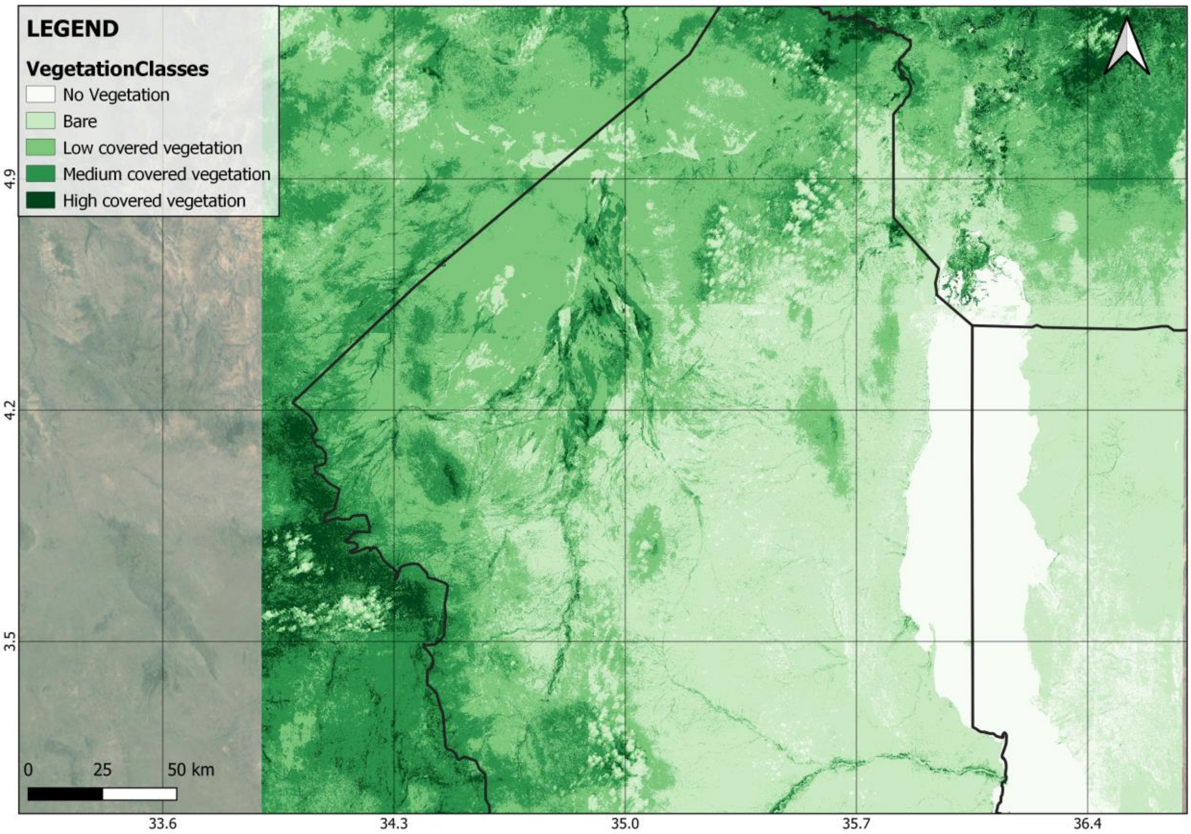

Figure 12: Vegetation Cover in the Area

It was now also necessary to gather data regarding the local river system. Despite the fact that many of these are only seasonal, it is essential to understand where each one is located and how it is defined. The areas near these rivers are with most frequent settlements for communities whose primary source of income is farming, even if there is not a large farming community in the area. This information is crucial to understanding how water moves through the landscape and understanding the behavior of vegetation. The location of rivers is shown in Figure 13.

As a final stage for this research regarding agents' environment, we used the information obtained from JiCAS's report, through which we identified the areas where pastoralism communities in the county move when there is not enough grassland, or during periods of dry seasons or rainy seasons. Figure 14 shows these zones, indicating which of them are suitable to be occupied during each of the periods and which of them are optimal during most of the year.

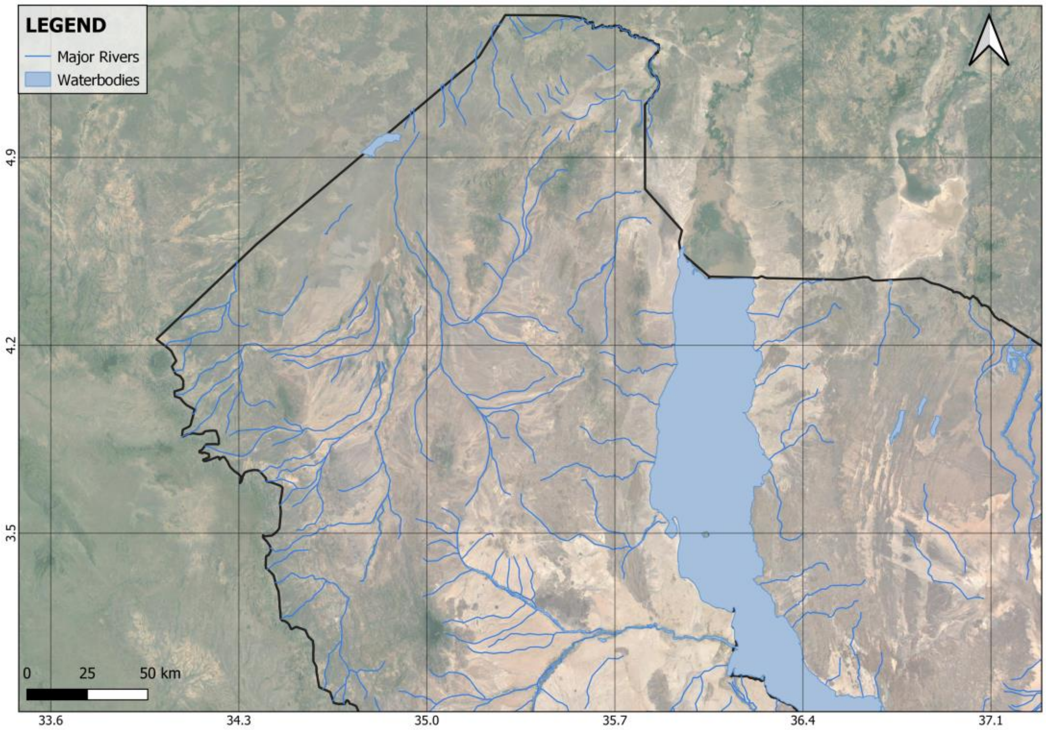

Figure 13: River Distribution in the Lake Turkana Area

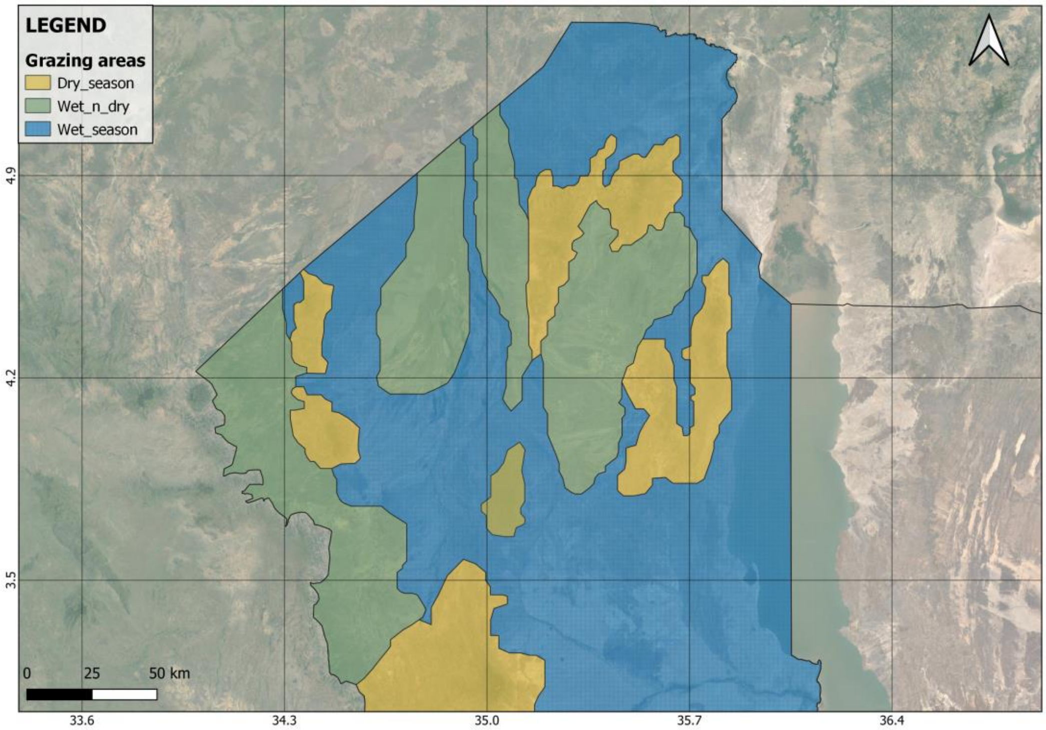

Figure 14: Common Grazing Areas During Periods of Migration

4.1.3 Conflict Conceptualization

It is of utmost importance to meticulously consider and define the factors that will impact the behavior and generation of conflict for each agent in the system. These factors are designed to capture not only the impact of the environment on each individual but also the influence that the presence of various agents has on one's actor environment. By doing so, we can ensure that the model faithfully represents the dynamics of the system and provides valuable insights into how different variables affect its overall performance. It is crucial to note that these factors are not static and may change over time, as new information becomes available or as external conditions shift.

As discussed in chapter 2.3 of this thesis, conflicts can take different forms and pass through various stages. However, these stages are typically defined for conflicts that have already begun and are mostly in the escalation and worsening stages of such confrontations. Nevertheless, the aim of this research is not to address ongoing conflict but to understand their initialization and the triggers that motivate an agent to start a conflict.

In order to do this, two factors were initially considered: difficulties and stress. Difficulties refer to the perception of agents regarding the lack of physical supplies that decrease their ability to perform tasks effectively. Additionally, lack of resources makes it even more challenging to achieve the desired goals. On the other hand, stress is the response of agents to the competition for resources and the presence of diverse agents (including different ethnic groups) in the same space.

This means that each agent in the simulation has a unique set of values for difficulty and stress that determine their risk level for initiating a conflict. These values are randomly generated at the beginning of the simulation and follow a normal distribution between 0 and 5. By multiplying these values, we can obtain a single figure that represents an agent's overall risk level (See Equation 3 below).

$$Conflict\ Risk = Difficulties * Stress$$

Equation 3: Conflict Risk Estimation

However, it is important to note that these properties are not fixed. As agents make decisions and interact with each other, their internal values may change over time. This means that an agent who was initially low-risk may increase the conflict risk if they perceive a threat or feel like they're being deprived of resources. In the following chapters, the dynamic way in which these changes take place is explained in more detail.

Overall, this approach allowed us to create a dynamic simulation where agents have different levels of risk \and respond differently to the changes in the environment. Below, in Table 4 we present the matrix that defines the point at which each of the conflict risk levels is located.

Stress \ Difficulties	0	1	2	3	4	5
0	Zero	Zero	Very Low	Very Low	Very Low	Very Low
1	Zero	Very Low	Very Low	Very Low	Very Low	Low
2	Very Low	Very Low	Very Low	Low	Low	Medium
3	Very Low	Very Low	Low	Low	Medium	High
4	Very Low	Very Low	Low	Medium	High	High
5	Very Low	Low	Medium	High	High	High

Table 4: Conflict Risk Stage Matrix

4.1.4 Work Session inTurkana County

During the development of the research, we had the opportunity to participate in a working session with the community of Turkana County in Kenya. Different stakeholders participated in this session, including officials from the Water Department of Turkana County, as well as agents of the national water authority WRA and Ministry of Peace. Also involved were wildlife management organizations and other international organizations working in the area, such as International Alert and Wetlands International.

In these working sessions, projects that were implemented in past years were discussed, which sought to clearly characterize the area and address various problems that occur there. This was divided into two phases, the first of which consisted of visiting the facilities of different authorities, thus obtaining valuable information for this research. As for the second phase, a technical training day was held in which progress was made in the ongoing projects, including the initial phases of the model developed in this thesis.

As main results of these sessions, it was identified that numerous projects have been carried out in the area, however the information produced by these investigations has not been properly shared with the interested parties there, nor has a baseline been developed based on the main findings. As a result, there is no clear database or adequate characterization of the state of groundwater in the area. This is why it is necessary to implement a project that allows the development of a platform to store this information and future projects that are developed in the area and also be easily accessible to those who require it.

During the technical training day, it was possible to identify and corroborate the problems that most concern the community in general. The first of these is the lack of accessibility to water, since in many cases the exact location of the water points is not known, nor the state in which they are located. This concern extends to the lack of characterization of the groundwater in the areas surrounding the lake and how saline intrusion influences the aquifer. Finally, it was possible to acquire a general idea of the way in which water-related conflicts are generated, which mainly occur in areas close to the borders where members of different communities avoid at all costs that other communities do not have access to water.

4.2 Phase 2 – Conceptual ABM

According to the main methodology shown at the beginning of this chapter, the next phase to be developed was the conceptual definition of the ABM that was implemented. The principal aim of this phase was to describe properly the behavior that each agent will perform, and the changing conditions of the environment. With this in mind, the rules to be followed during the simulation were defined, as well as the actions to be taken in the event of a given interaction, either with the environment or with any other agent. In order to describe this conceptual model, we will begin by describing the general concept and then move on to more specific rules as shown in the following paragraphs.

Starting with the flowchart shown in Figure 15, we first describe the general actions for the agents. At the beginning they are assigned by a series of characteristics depending on the livelihood, initial location and initial levels of Stress and Difficulties. Among the characteristics that are defined for each agent, the beginning of the simulation assigns the ethnic group to which they belong, the main means of subsistence, the type of area they prefer to occupy and the initial state of risk of conflict, given by the stress and difficulties which are adjusted to a normal distribution with a mean value of 2.5. The aforementioned location is determined in such a way that an agent occupies a patch of the virtual environment, which size is about 800 m^2.

Following, they start to analyzing that area, using their personal preferences and needs, to determine whether or not that location is suitable for them. This will be the starting decision that the agents perform at each step, which correspond to a period of ten days, and it is based on the availability of the land. Subsequent, the agents need to evaluate the accessibility of the land, which consists of evaluating whether there is another agent in the land using the resources available. Finally, they can occupy their land and start developing their activities.

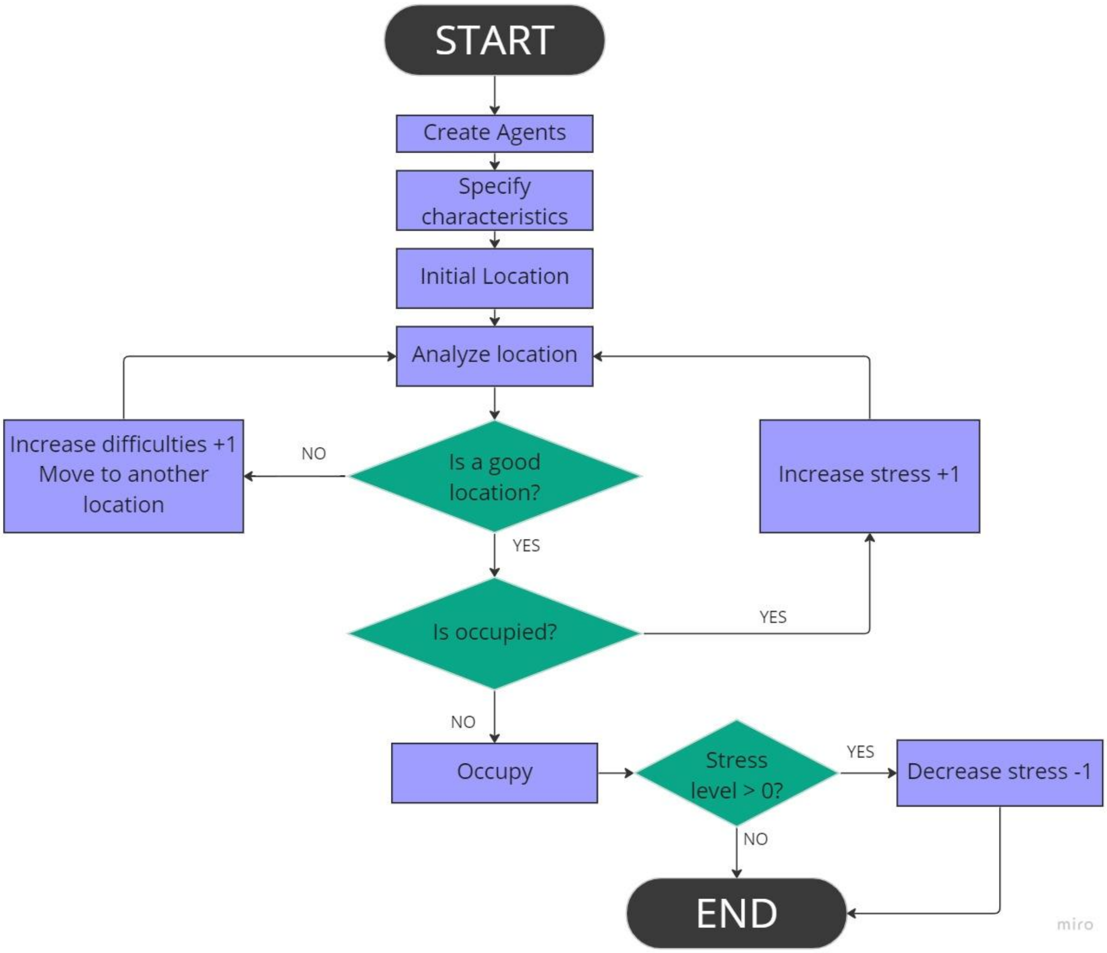

Figure 15: General rules for the agents

Now, starting with more specific rules, in the following charts we explained the overall behavior of the three kind of agents that are modelled. Figure 16 describes the activities of the pastoral community, starting with a general evaluation of the area in which they are located, specifically taking into account the quality of the vegetation cover that predominates in the area. This vegetation cover is divided in 5 classes, marked on a scale varying between zero and four (0-4), with zero indicating absence of vegetation and higher values indicating increasing quality of the vegetation. This classification was made by the use of the Equation 2, and comparing it with the landuse showed in the Figure 11. The agents evaluate whether this vegetation cover is higher than 1, to decide whether stay or look for another place that could suit their needs. If the condition is achieved, they will check again whether there is a patch nearby with an even higher value of vegetation cover and decide whether to stay and carry out their activities at this location, or to move to that new location which is more suitable. Another validation that the agents perform in these steps is the water availability, which consist of having a waterpoint at a distance of no more than 10 km from the area in which a favorable land was found.

During this whole evaluation of the land and water, the agents will change the values of their difficulties, increasing if they need to move, or decreasing if they can develop their activities in this location. As a final action, the model will estimate at each step the value for the conflict risk level for each agent, using the Equation 3 presented above.

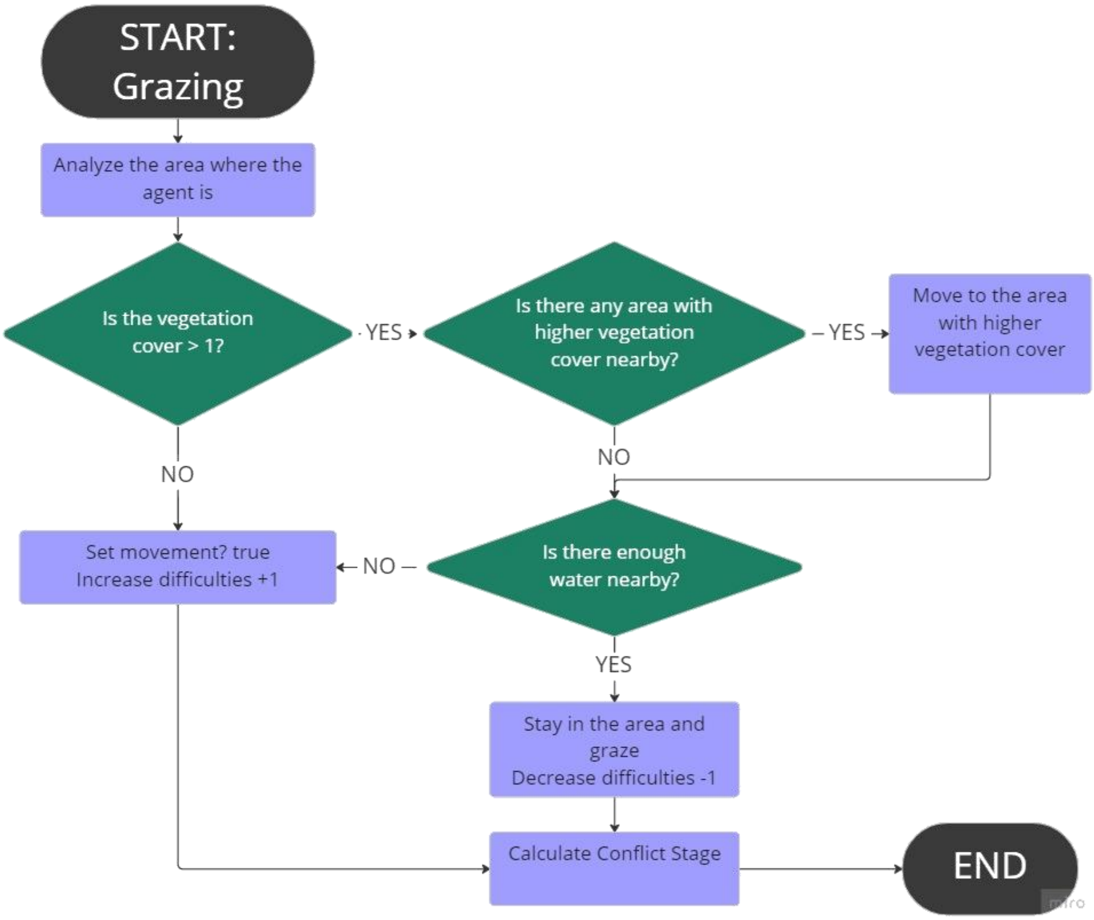

Figure 16: Rules for the Pastoralist Community

Similarly, Figure 17 shows the rules that describe the actions and behavior of the fishing community in the area. Due to the low number and the small influence they may have on conflicts in general, the complexity of this diagram is minor. At the beginning, each the ‘fisher’ agents will be assigned a “house” in which it will be located during the majority of the simulation. Along with this, each of them will have a radius of action of 30 km (defining their ‘influence area’), including as well the area among the Turkana Lake where they can perform their actions. At each timestep they will go to one of the patches that are over their influence area and will try to catch some fish. At each time step the agents have a probability of 50% to catch fish, and the outcome will be linked to the increase or decrease their difficulties accordingly. As with the pastoral agents, the actions will end with the recalculation of the conflict risk in which the agents find themselves.

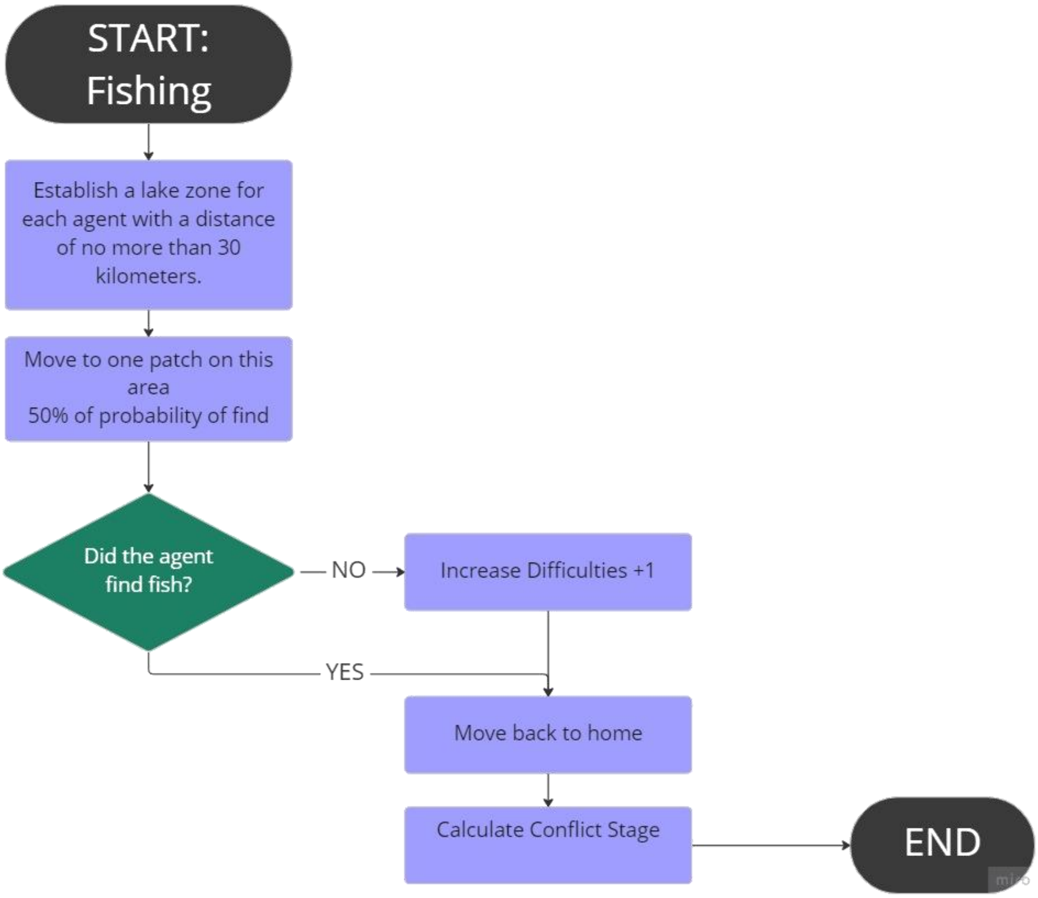

Figure 17: Rules for the Fishers Community

The farmers are the third type of agents that will be part of the simulation, and the definition of their activities is shown in Figure 18. In this case, each farmer will evaluate whether the land they occupy is designated to be used by them (suitable for farming), thus defining whether they need to move and find another location or stay in the area and start their actions. The suitability of land for farming is mainly defined by seasonality. If it is a rainy season, the agents will be able to seed, and if it is a dry season and they need to harvest. In the case that the 'farmer' agents are in a dry season, and it was not possible to seed in the previous season, they will increase their difficulty level, as well as when they need to move to find a more suitable land for them. Again, the final step is calculation of the conflict risk for each of the farmers.

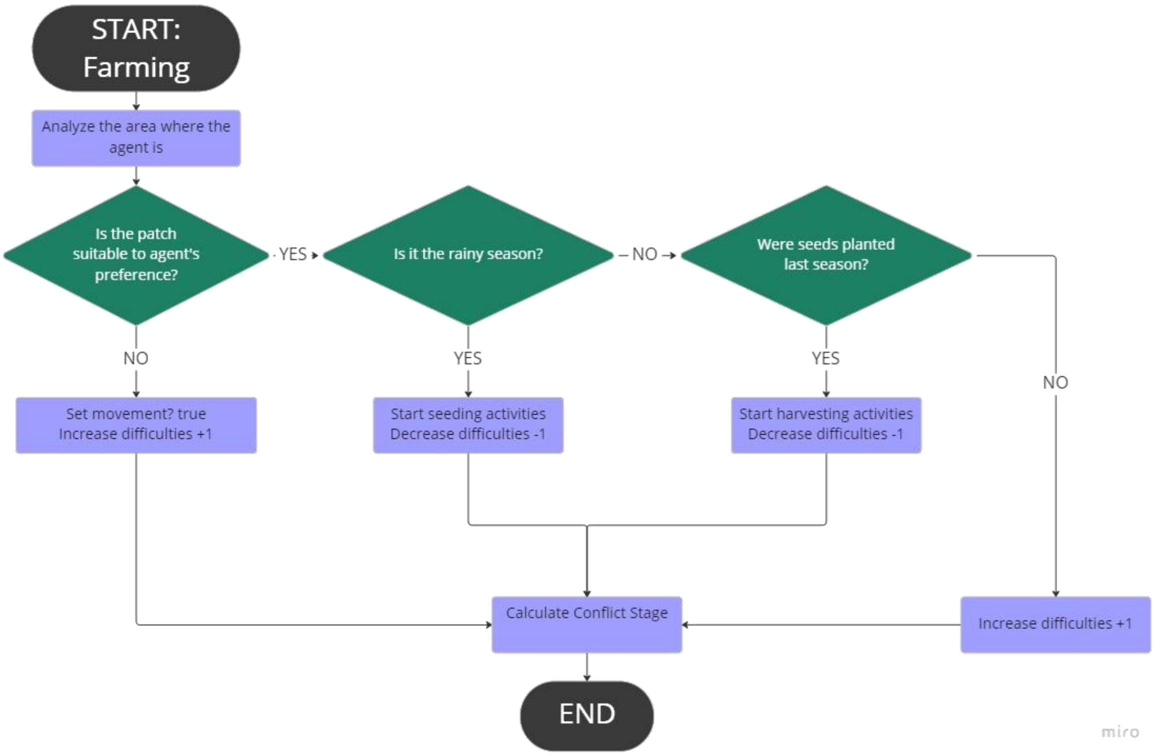

Figure 18: Rules for the Farmers Community

Now, the next important rule that should be defined is the movement rule, which is described in the Figure 19. When the movement property of an agent is turned to true, this rule will apply. As a first step, the agents will analyze the area where they can share knowledge among their community by a mouth-to-mouth and the distance they can travel without access to the resources in a period of 10 days. In a normal condition, the migration in a season could be about 150 km (Sheik-Mohamed and Velema, 1999). Said so, we defined a maximum movement during these 10 days in a radius of 30 km to determine if the agent is able to use it, comparing again with their own characteristics. If the agent is able to find a suitable land, it will analyze its accessibility in the same way as described in the flowchart presented on Figure 14. When the agents are able to find a suitable location, they will occupy it and start their own activities. In the event that the agents could not find a suitable area after the two validations, the stress will increase and they will be forced to move in some other direction in the hope that in the next time step it will be possible to find a place to settle.

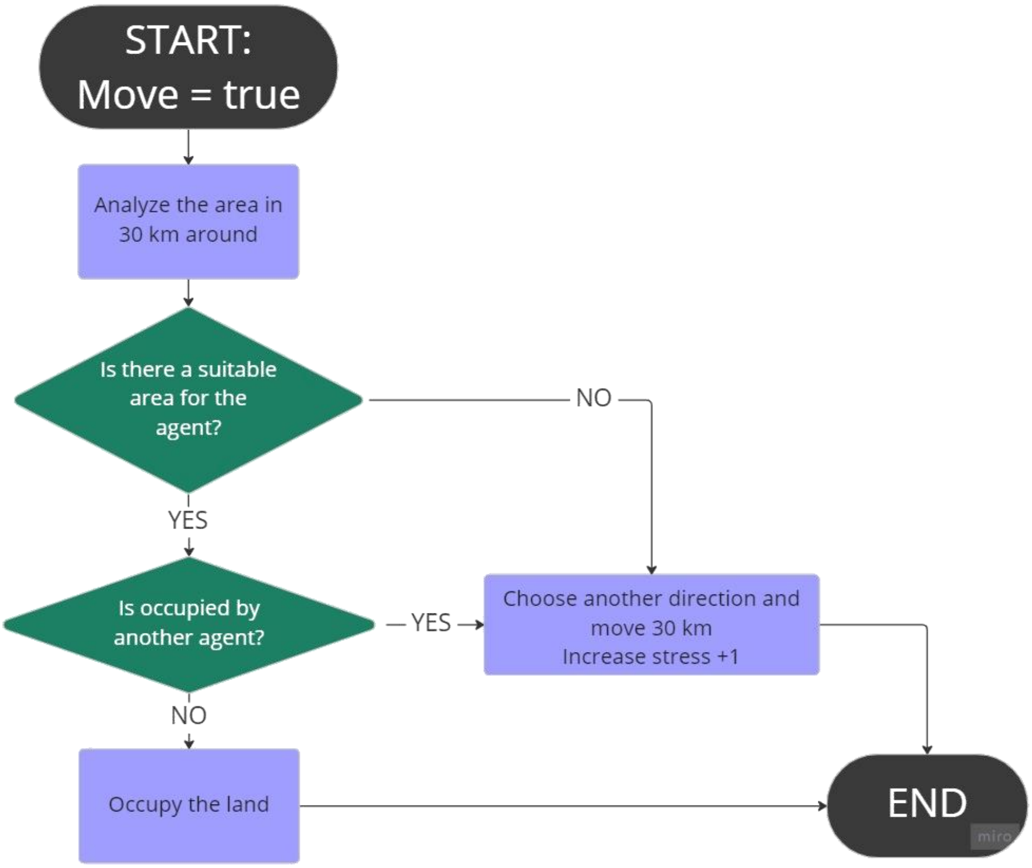

Figure 19: Rules for the Movement of the Agents

Additional to the previous movement rule, there is a specific rule, shown in the Figure 20, that describes the agents' movement when a new season comes within given year. This rule will only apply to the pastoralists community because they are those who are governed by a nomadic or semi-nomadic lifestyle. Starting again with evaluating the current land to know whether it is possible to use it during the current season. The Figure 14 shows which areas are available during the two main seasons, so the agents will check if they could access to one of these main two areas during the current season, leaving the third one (available throughout the year) for a further validation. In the case that the first condition is true, the agent will start analyzing whether it is occupied or it is available to be used. Otherwise, if the condition is not true, the agent will enter to analyze if the zone is available throughout the year and its accessibility.

If in any of these verifications it was not possible to be settled in a place, the agent will move to one of the zones that are available for the current season and will say there for the ongoing time step. Later in the following time step they will determine if it can be established there or it is necessary to continue in traditional movement. In this process, the values of perceived difficulties and stress will be involved, which will increase or decrease depending on the fulfillment of the given conditions.

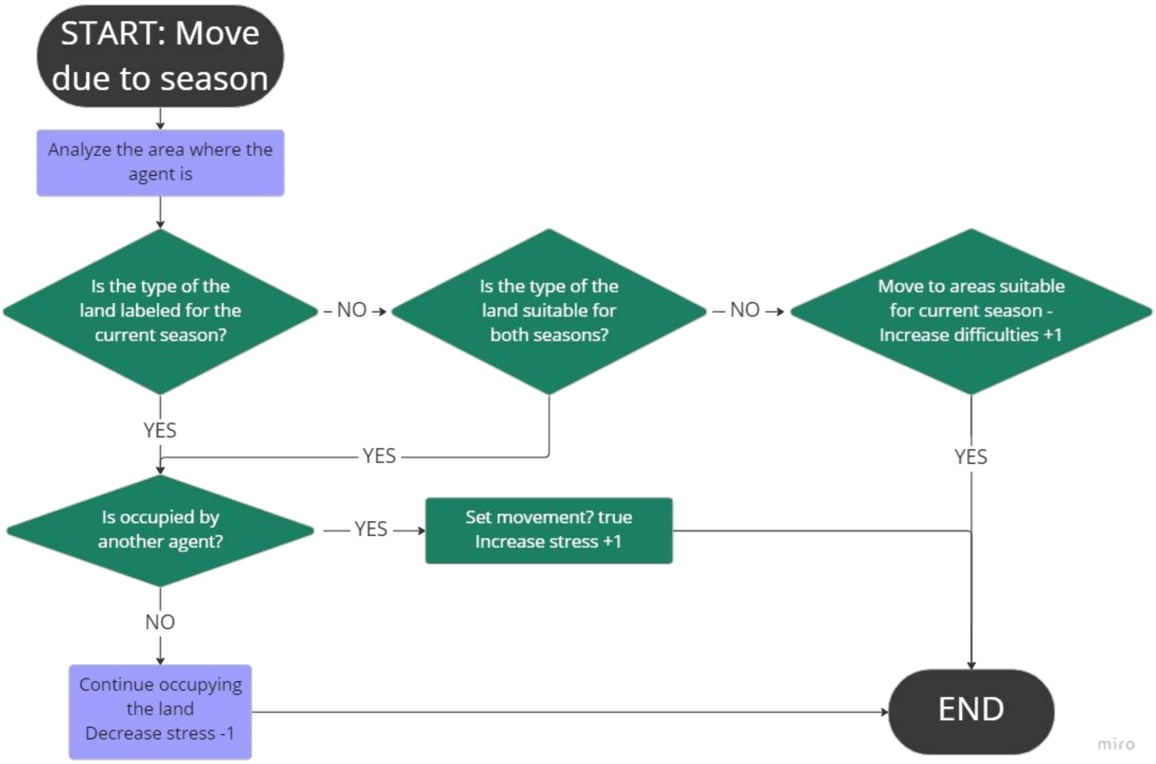

Figure 20: Rules for the Movement of the Pastoralism Community Due to Seasonality

Next, it is necessary to introduce the rules that drive the changes of certain aspects of the environment in which the interactions will take place. In the case of the water points, the information received from the Water Department of Turkana County mentions active and inactive water points. In order to run a more dynamic modeling, the inactive water points are introduced with the possibility to be emptied due to use by the agents. Figure 21 shows the process by which these water points are depleted. The process starts by checking whether the waterpoint is established as an active or inactive point. If one of this waterpoints is inactive it means that during the previous step it was emptied. Therefore, it should be necessary to validate whether it is possible that it can be refilled, based on the station in which the simulation is located and the number of time steps that have passed since it changed to the inactive state, since refilling requires two time steps during rainy water season. In the case where the water point is active, the model evaluates the number of agents using it in a time step. In order to represent a dynamic behavior of groundwater in the area, the assumption was made that a minimum of 10 pastoral communities are needed to empty the water point in a period of less than one month.

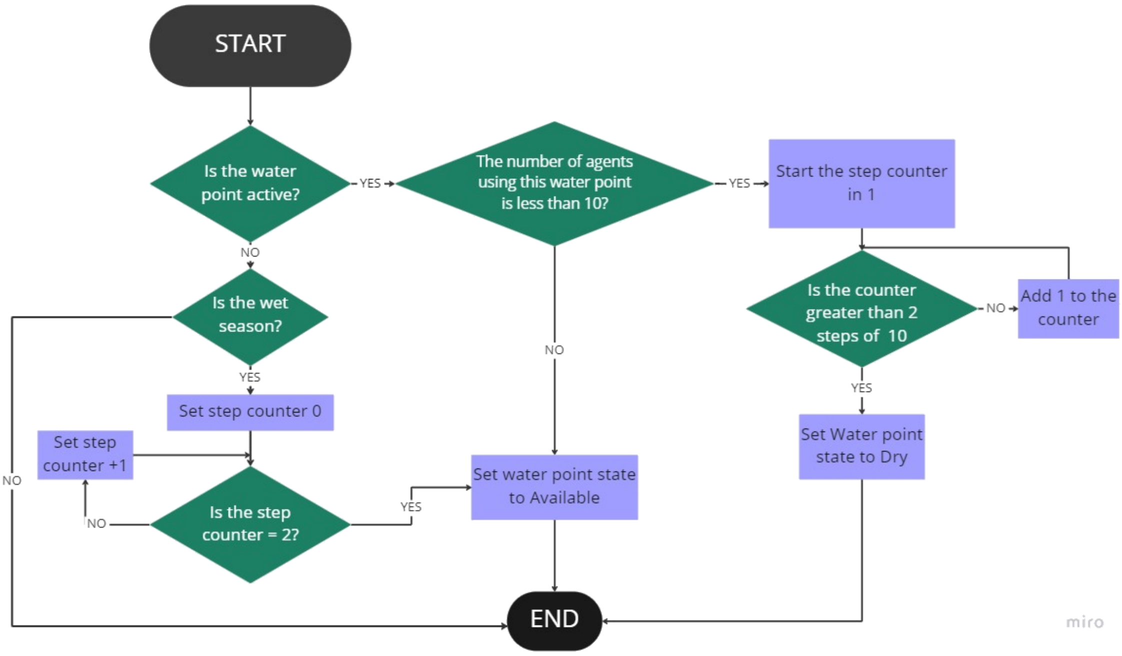

Figure 21: Rules for Behavior of Waterpoints

Finally, it is crucial to determine whether conflict is generated between two agents based on the level of their individual conflict risk. To do this, each agent, after completing the relevant actions in the current step, will determine firstly if its conflict risk is high, and, secondly it will check the patches adjacent to its own to determine if there is any agent located in any of these. The assumption here is that neighboring agents with high individual conflict risk result in occurrence of conflict. These conflicts will be recorded in a global variable that is used to track the number of events during a year. This process is shown in Figure 22.

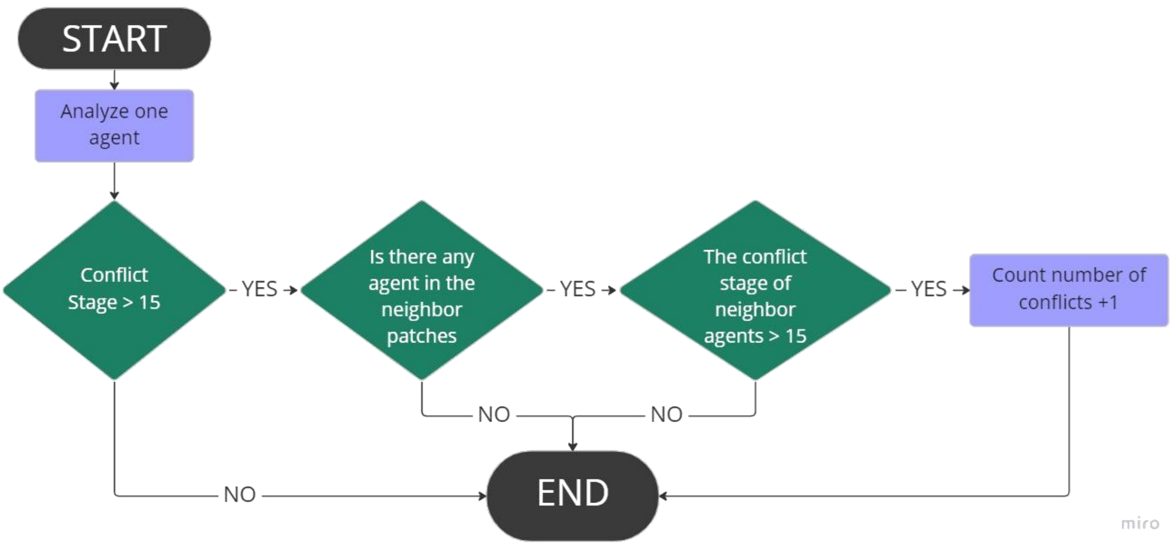

Figure 22: Rules to Decide on Conflict Occurrence

4.3 Phase 3 – NetLogo Software Implementation

4.3.1 Model Implementation

During the implementation of the conceptual model in the selected software for agent interaction simulations, it was crucial to explore the most effective approach to leverage NetLogo's capabilities. This required a thorough investigation of the most commonly used procedures to ensure optimal utilization of the software's features.

This investigation involved studying the documentation and tutorials provided by NetLogo, as well as consulting previous publications regarding usage of this software. It was important to understand how to properly define agents, create their behaviors and interactions, and set up the simulation environment. Additionally, it was necessary to consider factors such as computational efficiency and scalability, as the model would need to be able to handle large numbers of agents and complex interactions.

Once the optimal procedures were identified, they were implemented in the software using a combination of built-in functions and custom code. The model was then tested to ensure that it somehow represent the real-world system being studied and produced meaningful results. Overall, our efforts resulted in a successful implementation of the conceptual model in NetLogo, which enabled us to conduct accurate and reliable agent interaction simulations.

Considering the above, the construction of this model includes different established procedures starting with the "setup" action, by which the environment is created, and the agents are created, initialized and distributed in that environment. In order to adequately characterize the area in the model, we made use of the extension to combine it the GIS files, thus giving the possibility of applying the characteristics defined in different raster files. To simulate the grasslands, the NDVI information was used, and for the availability of areas, the layer with the available areas during the seasons was used. Similarly, information on the location of the villas and the areas destined for each type of agent was included as a raster. All this information is applied to the patches in the model. In the same way, each of the agents will be initially located in the villages that are in the area following the distribution of the maps presented in previous chapters.

Regarding the number of agents, the initial ideas and attempts have been to perform the simulations with the actual population in the sub-county, including an escalation factor to include agents that are located in nearby areas. However, a simulation with such large number of agents, interacting and making decisions over 186 steps of 10 days would be very complex, requiring a longer time for each simulation, demanding more computing processing. This is why, in order to implement the model in the software, the decision was made to reduce this number, defining each agent as a household.

By making this change, it was possible to reduce the computational requirements to carry out the experiments. Nevertheless, the duration of each of the time steps was still long, preventing a thorough analysis of the simulation process and the results it can give. To provide a better solution to this issue, we choose to set as an agent a small community, which are composed of 5 households per community, thus optimizing the time and computational use for the model.

Now, it should be noted that in order to capture and establish more clearly the behavior defined for the water points in the model, they were included as static ‘agents’ located according to their geolocation information. However, they do not have properties of movement or interaction with the actual agents.

Following the above definitions, the graphic sections of the NetLogo user interface were assembled, including controllers for the scenarios, the population size to be simulated, controllers to see the various characteristics in the world, and viewers to track the outcomes as the simulation moves forward.

These graphic sections have been designed to provide a user-friendly interface for models developed with this simulation software. The controllers allow users to customize the simulation according to their needs, such as adjusting the population size or changing environmental factors. The viewers provide real-time feedback on how the simulation is progressing, allowing users to make adjustments as necessary.

Figure 23 shows the graphical user interface of the model. This interface includes the buttons to perform the setup, the controllers to choose the type of simulation and to visualize the different layers of the model. In addition, it includes the boxes to monitor different aspects of the model.

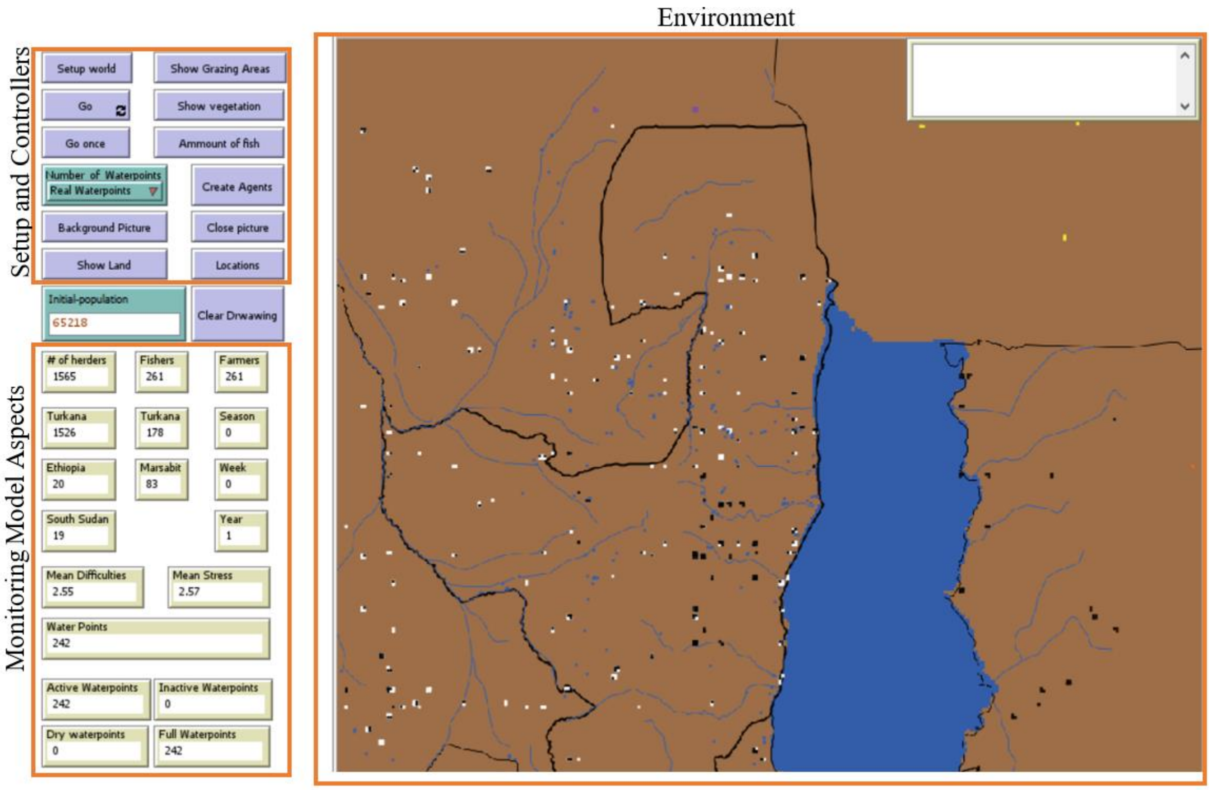

Figure 23: Simulation Setup

4.3.2 Scenarios

To fully assess the functionality of the model, it is necessary to examine the results it produces and determine how sensitive these results are to variations in simulation parameters. To achieve this, a series of scenarios were devised to evaluate the model's behavior under different climatic conditions throughout the year, as well as the number of waterpoints available in the area. This will allow for a comprehensive exploration of the model's operability and provide valuable insights into its potential applications. Table 5 summarizes those scenarios with the main variability to the parameters.

SCENARIO	BASIS	NUMBER OF WATERPOINTS	CLIMATIC CONDITION	NAME
1	Actual Waterpoints	242	Normal	Sc_ActWP_NormalCC
2			Dry	Sc_ActWP_DryCC
3			Rainy	Sc_ActWP_RainyCC
4	50% more	363	Normal	Sc_50%WP_NormalCC
5			Dry	Sc_50%WP_DryCC
6			Rainy	Sc_50%WP_RainyCC
7	100% more	484	Normal	Sc_100%WP_NormalCC
8			Dry	Sc_100%WP_DryCC
9			Rainy	Sc_100%WP_RainyCC

Table 5: Simulation Scenarios

Complementing the above, each of the conditions mentioned in the scenarios is based on the same annual seasonality pattern (four seasons in a year) over a 5-year time period, starting with a Dry season (DS), followed by a Long rainy season (LR), then a repeat of the DS and finally a Short rainy season (SR). For the normal condition, each of the five years has a pattern in which the seasons are interchanged as shown in the first part of Table 6. For the dry and rainfall conditions, between years 3 and 4, there is a shift in which conditions are adverse depending on the scenario.

YEAR 1				YEAR 2				YEAR 3				YEAR 4				YEAR 5			
NORMAL CONDITION																			
DS	LR	DS	SR	DS	LR	DS	SR	DS	LR	DS	SR	DS	LR	DS	SR	DS	LR	DS	SR
DROUGHT CONDITION																			
DS	LR	DS	SR	DS	LR	DS	SR	DS	DS	DS	DS	DS	DS	DS	DS	DS	LR	DS	SR
RAINY CONDITION																			
DS	LR	DS	SR	DS	LR	DS	SR	LR	LR	LR	LR	LR	LR	LR	LR	DS	LR	DS	SR

Table 6: Distribution of Seasons for Each Condition

Chapter 5 Results

After conducting the simulations outlined in the previous chapter, we have obtained results for four variables that were closely monitored throughout each run. These variables include: 1) the number of agents at high risk of conflict, 2) their movements, 3) the number of conflicts that occurred annually and cumulatively over the simulation period, and 4) the number of active water points at each time step. Additionally, we have generated maps that highlight the areas where most conflicts arose and the movements of the agents during the simulation. Despite apparently chaotic nature of the agents' movements, we were able to identify certain paths that were frequently transited.

Our findings shed light on the complex dynamics at play in this simulation and provide valuable insights into potential solutions for mitigating conflicts. By closely analyzing the data, we can identify patterns and trends that may have otherwise gone unnoticed. In order to present these results clearly, they are presented below classified by the number of waterpoints available in the environment, and compared for different climatic condition.

5.1 Simulations with the Actual Number of Waterpoints

The first scenarios to be analyzed are those that include the waterpoints that were shared by the Water Department of Turkana County in Kenya and includes the exact location of 242 waterpoints and their state (active or inactive). With this information we were able to represent what could be the current state of conflict generation in the area and its likelihood of occurrence.

Upon analyzing the first parameter, which is the number of agents in high conflict risk during each time period, it is evident that the initial years for all three conditions are relatively similar as can be observed in Figure 24, with minor variations in scenario 3. However, these variations are due to the individuality of the agents and their own interactions. When extreme conditions enter the environment, there is a considerable increase in the number of agents at high risk of being involved in a conflict during scenario 2, reaching the maximum number of agents at high risk of conflict during the beginning of the 5^{th} year. From this point, there was a decrease throughout the year, ending with a total of 885 agents at high risk of conflict.

As for scenarios 1 and 3, it is clear that during the first year, there is a gradual increase in risk, which reaches a peak in the second year, thus beginning a general decrease in risk. In scenario 3, from the third year onwards, there is a general decrease in risk compared to scenario 1, due to the fact that for most of the agents (herders), this scenario generates more favorable spaces for them.

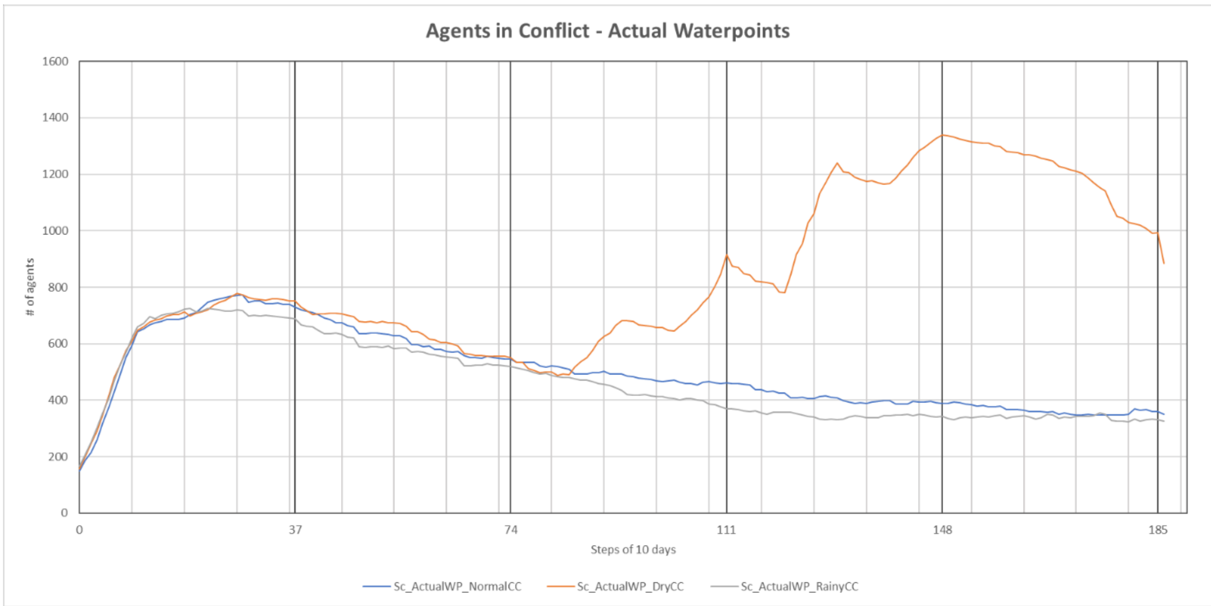

Figure 24: Agents in Conflict - Actual Waterpoints

Continuing with the results, Figure 25 displays the number of agents in motion throughout the simulation. It is evident that all scenarios exhibit a behavior that accurately responds to the seasonal changes of the modeled environment. However, the most significant difference in this parameter is observed during years three and four. Due to the scarcity of rainfall and limited space available for the agents during these periods, over 1500 agents are in constant motion. This outcome corresponds to the overall increase in the risk of conflicts.

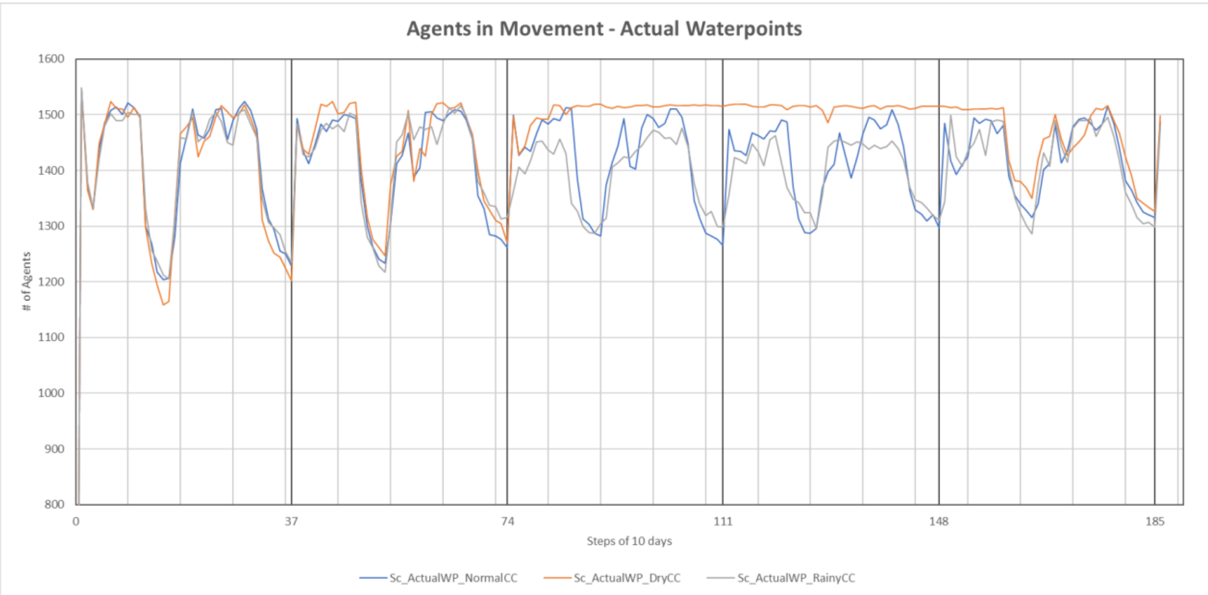

Figure 25: Agents Motion -Actual Waterpoints

The average conflict state was calculated as a third type of result. This was done in order to obtain a more general overview of the stages of agents' conflict risk in which they currently are. Figure 26 shows the change in this general state throughout the simulations. For scenarios 1 and 3, there is a similar behavior, starting with low conflict risk, reaching the maximum point in a medium state during the first year, and then decreasing from the second year, even ending in too low conflict risk.

In the case of scenario 2, since it is more sensitive to extreme cases, a gradual increase is observed from the third year, going from low conflict risk to high risk at the beginning of the 5th year, when it decreases to end in a medium conflict risk.

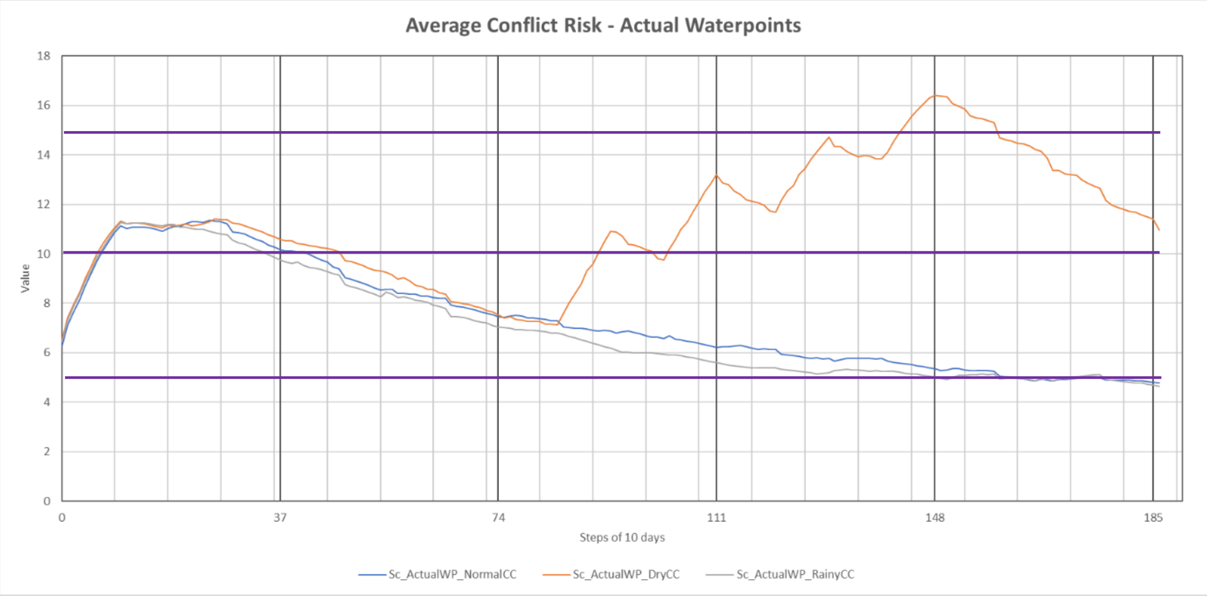

Figure 26: Average Conflict Risk - Actual Waterpoints

During the development of this research, we took into account a fundamental aspect - the number of conflicts that occurred throughout the year. For the purpose of this study, we defined the occurrence of conflict as the moment when two or more agents approached each other with a high risk of conflict.

In the Figure 27, we can observe the accumulated number of these conflicts for each scenario, indicating their trend. Similar to the previous results presented, we can see that the beginning of the three scenarios is similar. However, unlike the patterns identified previously, in this case, the differentiation of behavior in these scenarios occurs in the middle of the third year. We can see a notable growth in the drought scenario, while the decrease in the number of conflicts for the scenario with the highest amount of rainfall is less noticeable but still present.

Based on the information previously mentioned, we have conducted calculations to determine the number of conflicts that occurred annually, as depicted in the Figure 28. Our findings reveal a substantial increase in conflicts for scenario 2, reaching a peak of over 45,000 in the fifth year. In contrast, the simulation conducted under rainy conditions resulted in the lowest number of conflicts, with values remaining around 13,000 during the fifth year.

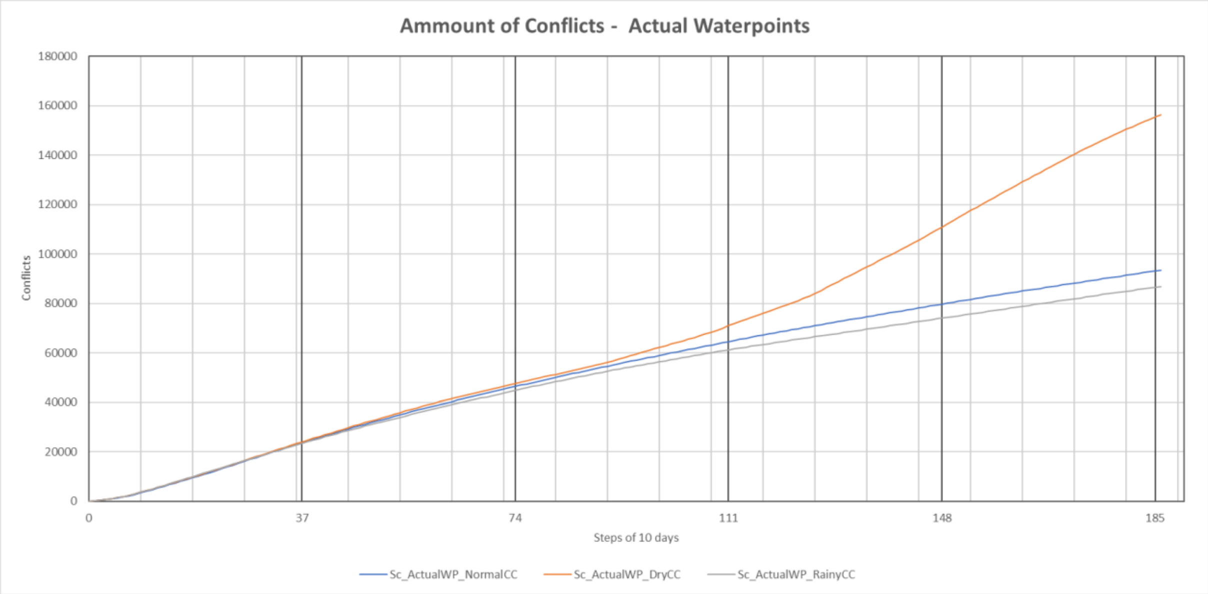

Figure 27: Accumulative Number of Conflicts - Actual Waterpoints

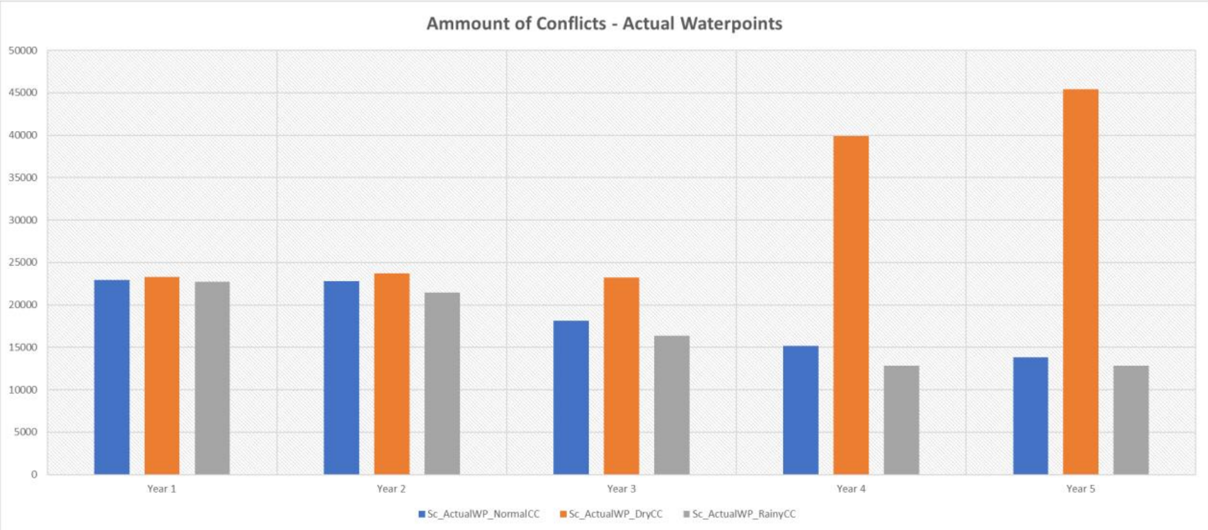

Figure 28: Conflicts per Year - Actual Waterpoints

The behavior of water points that were susceptible to being emptied by agents was analyzed using a similar approach. This behavior is a direct response to seasonal changes, with a consistent decrease during dry periods and a greater recharge during rainy periods. In the event of dry years, the number of active water points decreases until a certain point, after which it remains mostly constant until the fifth year, when it returns to its seasonal behavior. Figure 29 shows the behavior for the three starting scenarios.

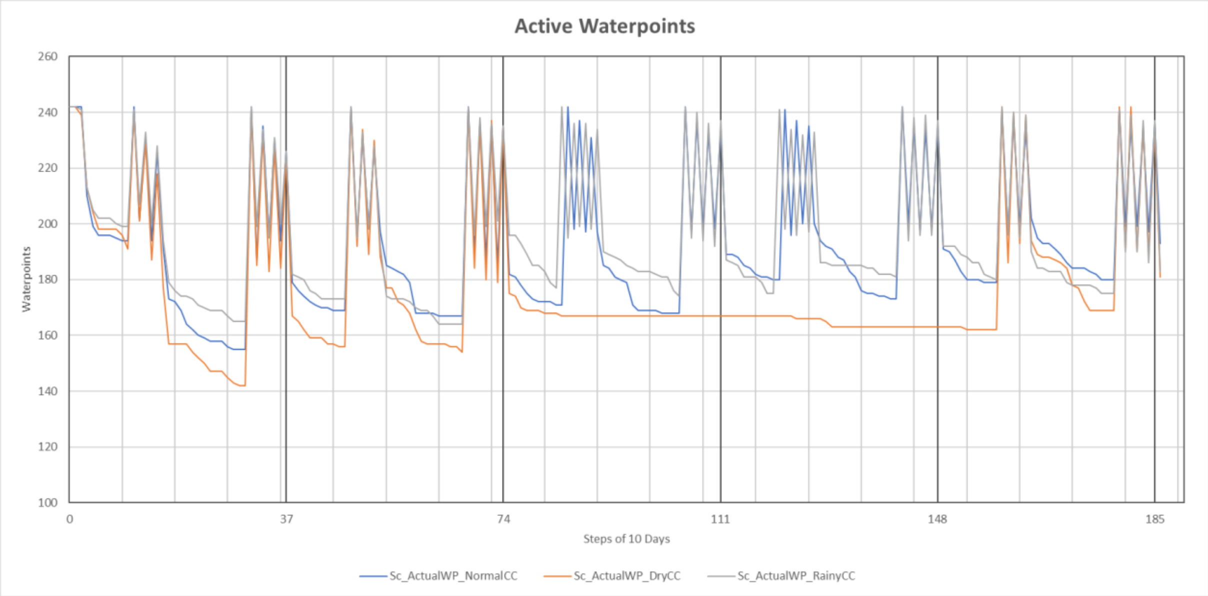

Figure 29: Active Waterpoints - Actual Waterpoints

Finally, the results in Figure 30, present final settlements of agents at the end of a simulation, together with zones of high conflict risk in maps a, b and c, corresponding to scenarios 1, 2 and 3. These maps show that the central area of the sub-county is an important point where the agents are located, being also a critical point for the generation of conflicts, as can be seen in scenario 2, where most of the agents located in this area have a high risk of conflicts. In the case of the simulation with rainy conditions, it is observed that the communities are slightly more dispersed than in the case that includes a similar climatic pattern, which confirms that in this case there is a greater number of areas that can be inhabited after the end of the simulation.

In the other hand, the Figure 31 shows the movement of the agents throughout the scenarios simulated. It can be observed that in general the movement of the agents is somewhat erratic, responding to the absence of previously established migratory routes. In any case, it can be observed in the three cases that the most transited zones are located mainly in the western zone to the center of the sub-county, with an increase in movement with a high risk of conflict during dry conditions.

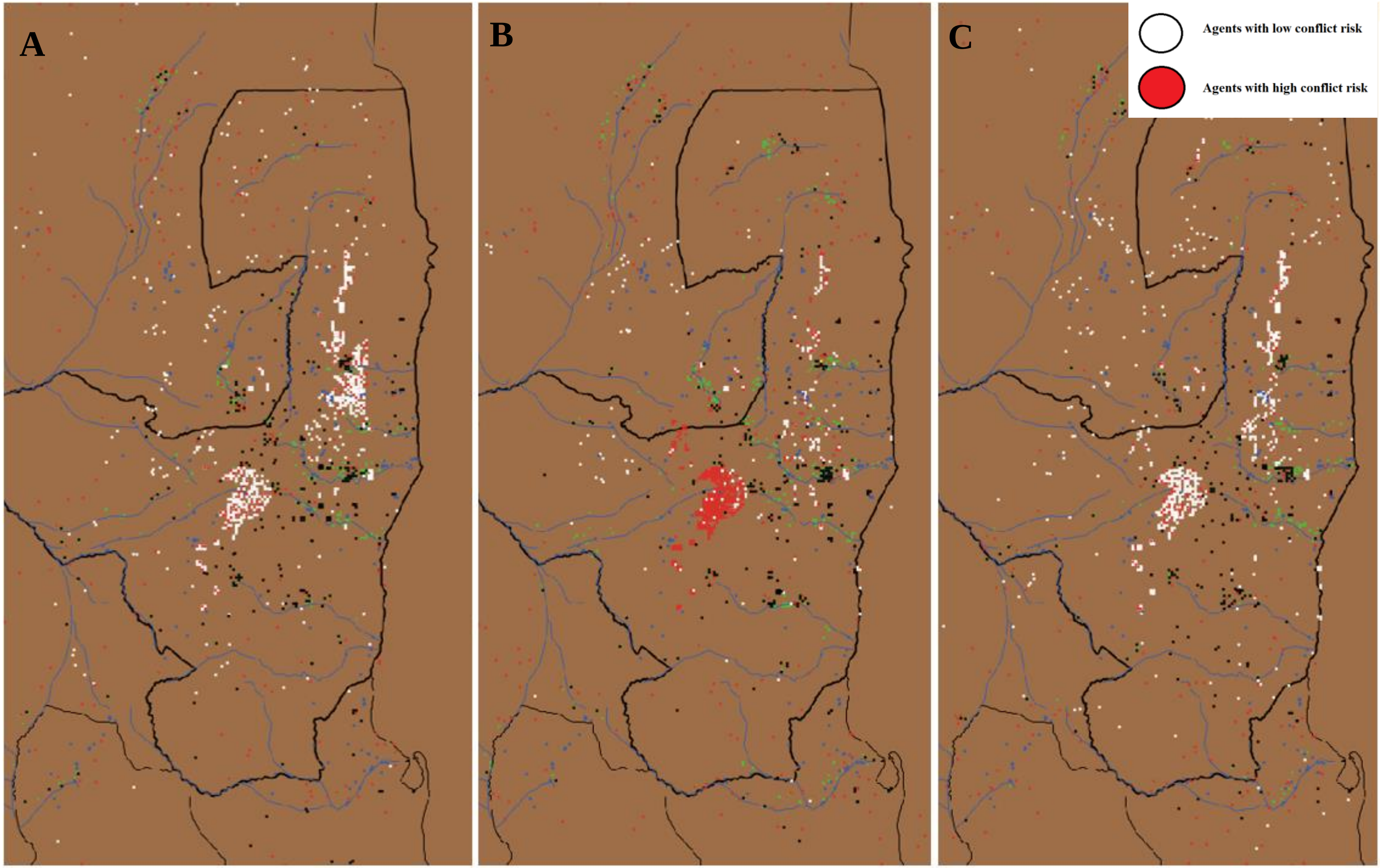

Figure 30: Final settlements and conflict risk - Actual Waterpoints

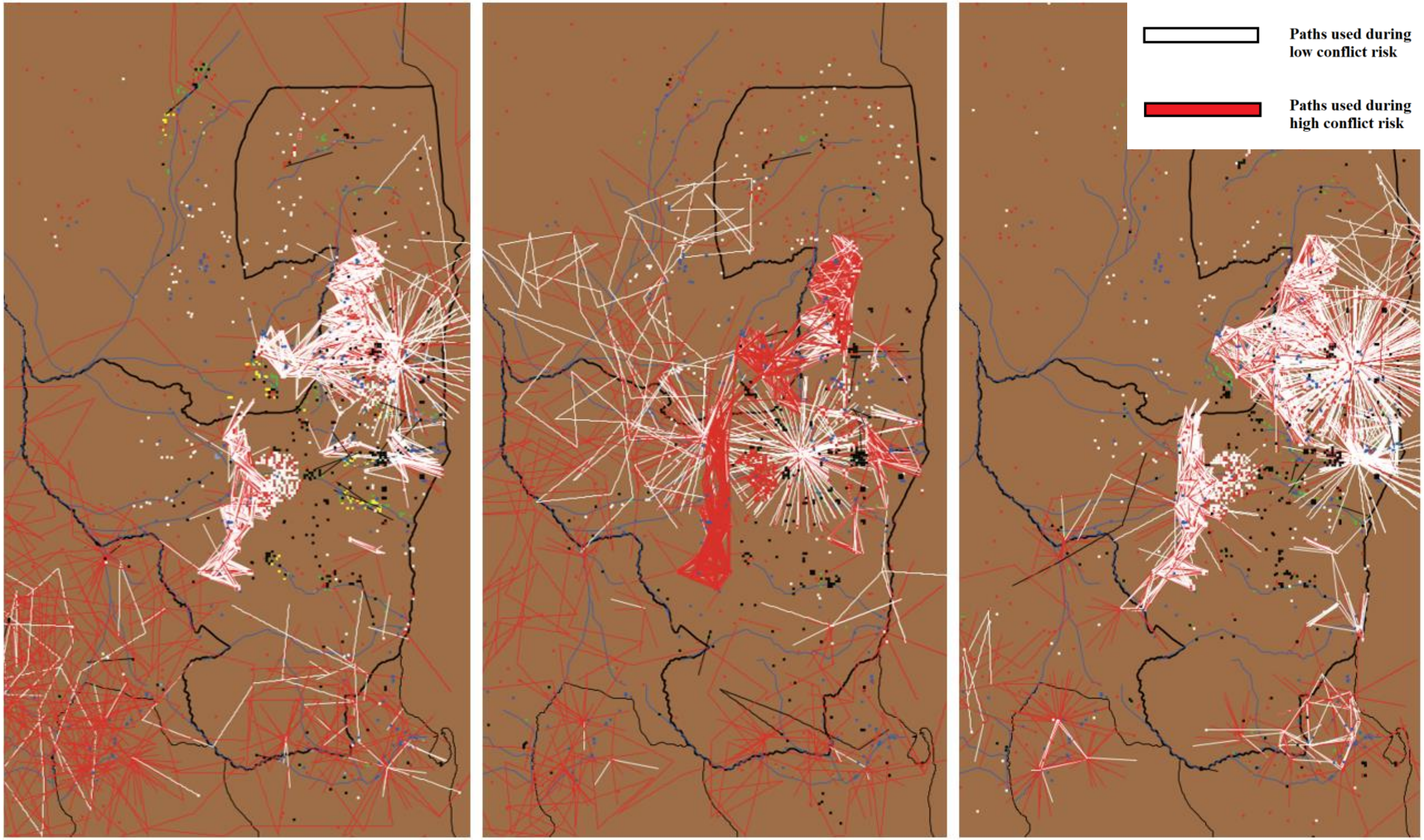

Figure 31: Common Migratory Routes - Actual Waterpoints

5.2 Simulations with 50% More Waterpoints

We have increased the number of water points by 50% for the upcoming scenarios, specifically scenarios 4, 5, and 6. This decision was made to evaluate the impact of improved accessibility to water for agents within the environment. By augmenting the water points, we aim to enhance the agents' ability to navigate and operate within the environment. This adjustment will allow us to gather more comprehensive data and insights into the agents' behavior and performance.

The initial years for all three conditions are evidently similar when the first result, the number of agents in high conflict risk during each time period, is analyzed, as shown in Figure 32. However, these differences result from the agents' uniqueness and relationships with one another. When extreme environmental factors are present, there is a noticeable increase in the number of agents who are at high risk of getting into a conflict during scenario 5, reaching its peak at the beginning of the fifth year. From this point on, there was a decrease throughout the year, with a final total of more than 1200 agents.

The graph shows a similar behavior of the three scenarios during the first two years, where the peak for scenario 4 is reached just before the beginning of the second year, while the peak for scenario 6 is reached at the beginning of the third year, at which point adverse conditions begin. In response to this, the number of agents at high risk increases during drought periods, reaching a maximum of almost 1500 agents, being higher than the scenario with the actual waterpoints. This strange behavior may be a response to the fact that the new water points are not located in areas close to the typical movement of the agents, and furthermore may not be located in areas suitable for the agents to carry out their activities. For the simulation with the rainfall condition, a very similar behavior to the base scenario is observed, with slight decreases during year 4, to later end with similar values.

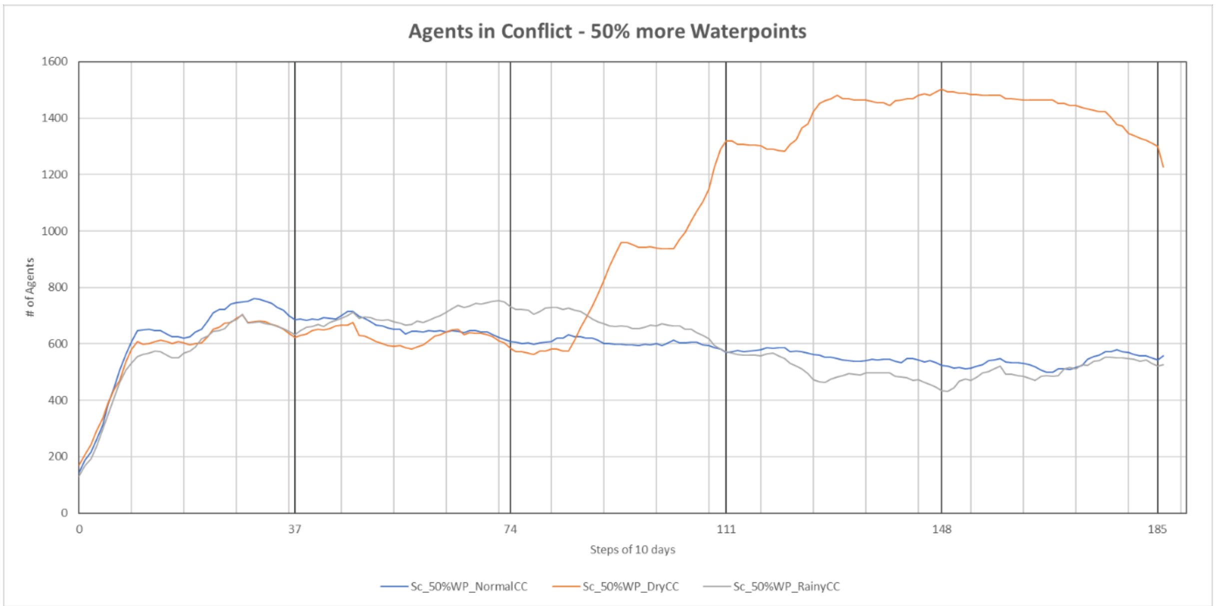

Figure 32: Agents in Conflict - 50% more Waterpoints

Moving on, Figure 33 illustrates the number of agents in motion during the simulation. It is clear that all scenarios accurately respond to the seasonal changes of the modeled environment. However, the most notable difference in this result is observed during years three and four. This is due to the scarcity of rainfall and limited space available for the agents during these times, resulting in over 1500 agents being in constant motion, with a possible explanation similar to what was mentioned in the previous. This outcome corresponds to an overall increase in the risk of conflicts. It has been observed that the inclusion of more water points has resulted in a significant difference between the high and low points in the graphs, which could mean that the agents were able to find new places that are suitable for them in a quicker way.

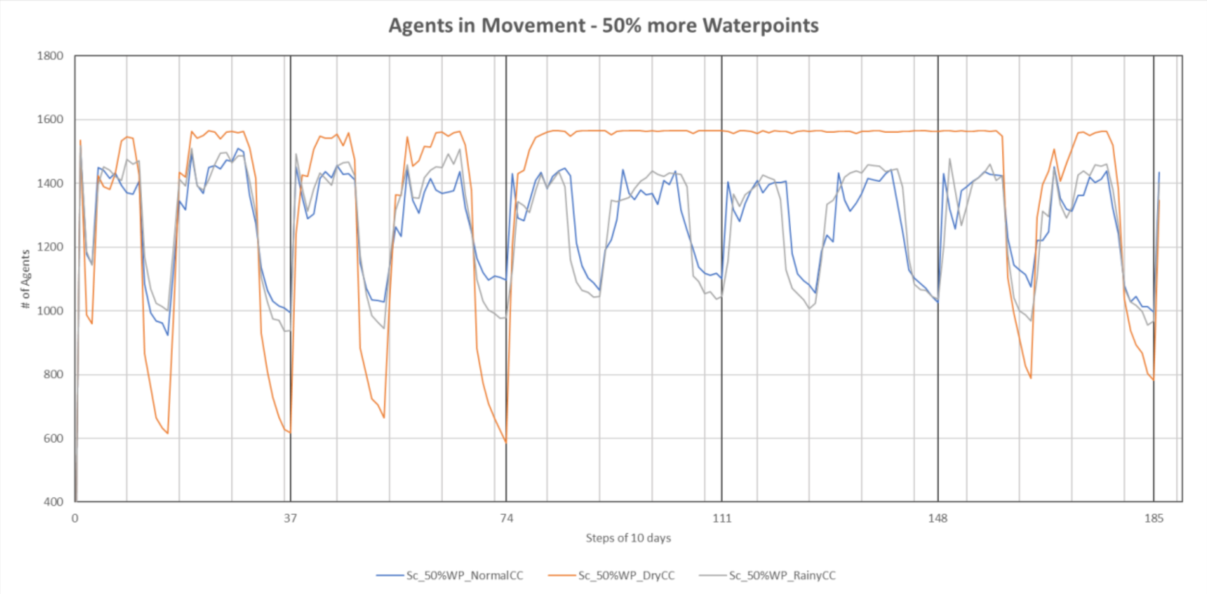

Figure 33: Agents Motion - 50% More Waterpoints

Moving on to the third parameter, we calculated the average agents' conflict risk state to gain a comprehensive understanding of the conflict risk stages in the current model. Figure 34 illustrates the fluctuation of this general state throughout the simulations. Scenarios 4 and 6 exhibit similar patterns, starting with low conflict risk and peaking at a medium state during the first year. From the second year onwards, the risk decreases and may even end up being too low.

The scenario under dry climate conditions, on the other hand, is more sensitive to extreme cases, resulting in a gradual increase in conflict risk from the third year. By the beginning of the fifth year, the risk reaches a high point before decreasing to a medium conflict risk level. In a similar way to the previous results, it is observed that in this case the risk of conflicts is higher than with a lower number of water points, meaning that in order to optimally avoid the generation of conflicts it is necessary to include a greater number of water points.

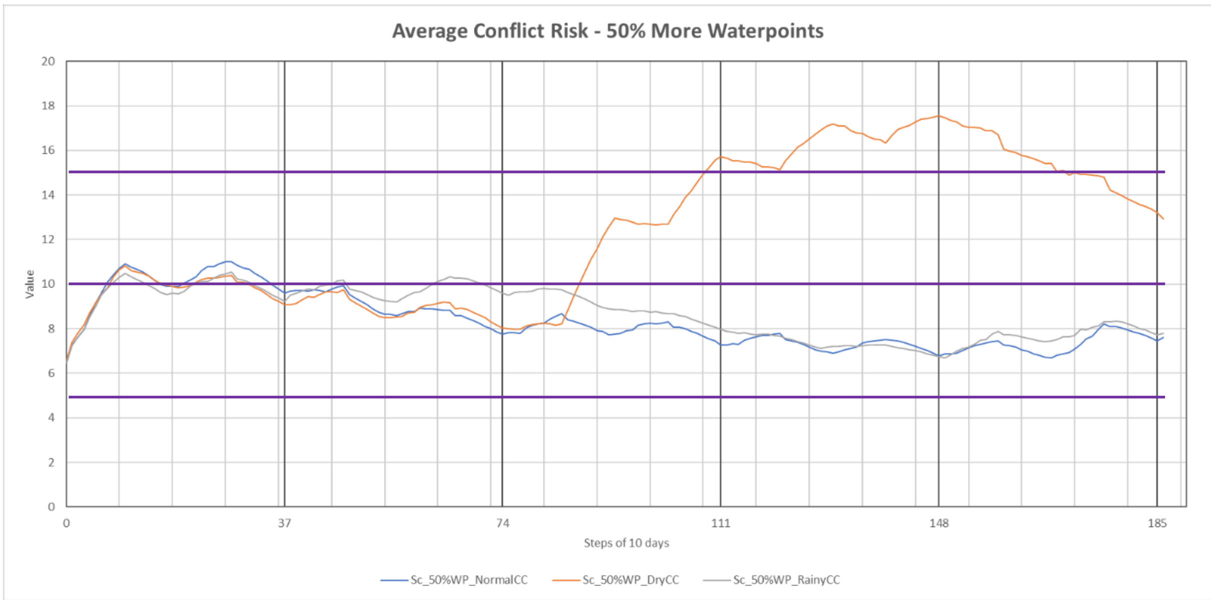

Figure 34: Average Conflict Risk - 50% More Waterpoints

In Figure 35, we can observe the cumulative number of these conflicts for each scenario, indicating their respective trends. Similar to the previous results presented, we can see that the beginning of the three scenarios is similar. However, unlike the patterns identified previously, in this case, the differentiation of behavior in these scenarios occurs in the middle of the third year. We can see a notable growth in the drought scenario.

Based on the aforementioned information, we conducted calculations to determine the annual number of conflicts that occurred, as depicted in Figure 36. Our findings reveal a substantial increase in conflicts for scenario 5, reaching a peak of over 50.000 in the fifth year, being this peak about 5.000 higher than the initial simulation. In contrast, the simulation conducted under rainy conditions resulted in the lowest number of conflicts, with values remaining around 19,000 during the fifth year.

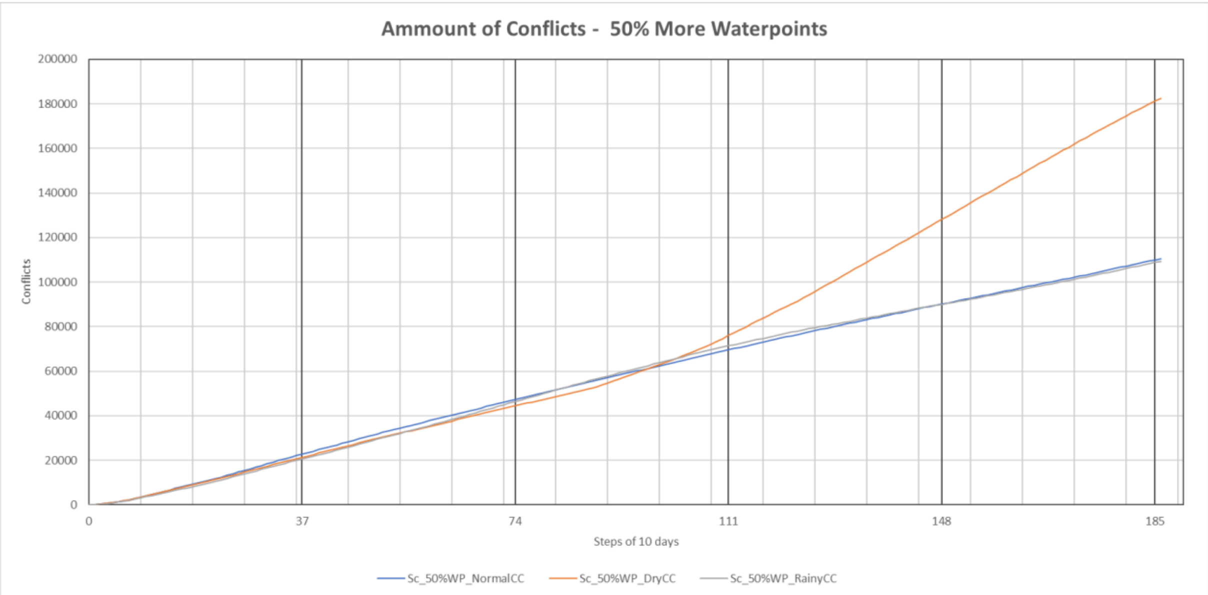

Figure 35: Accumulative number of Conflicts – 50% More Waterpoints

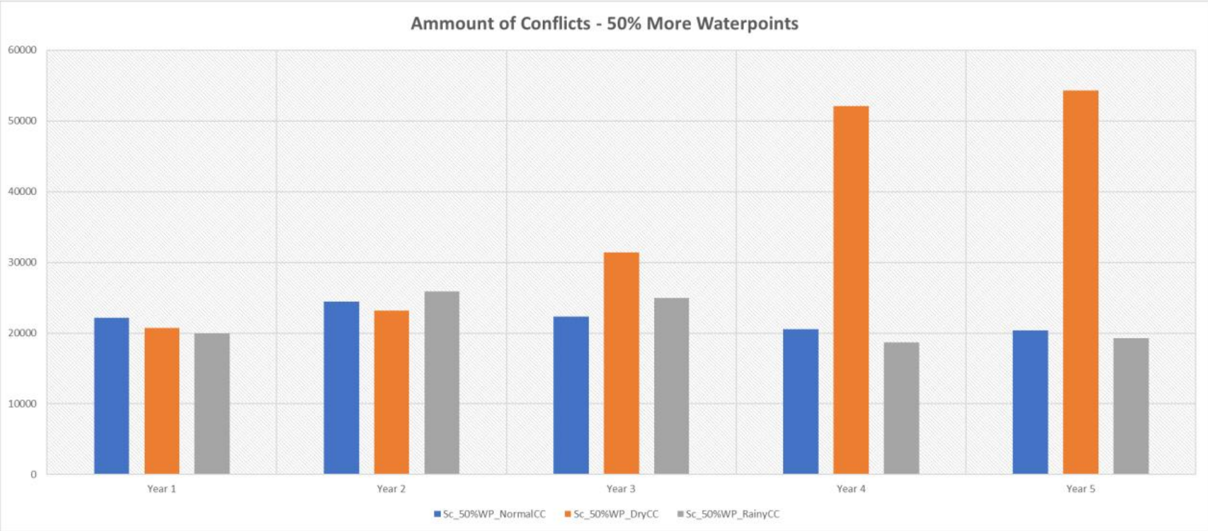

Figure 36: Conflicts per Year - 50% More Waterpoints

Using a comparable method, the behavior of water points that were vulnerable to agent emptying was examined. With a consistent decline during dry periods and a higher recharge during rainy periods, this behavior is a direct reaction to seasonal changes. The number of active water points declines during dry years up to a certain point, after which it largely stayed constant until the fifth year, when it resumed its seasonal pattern. A curious aspect of this result compared to its counterpart with the actual water points is that the normal and rainy condition scenarios swapped positions, with the rainy condition being the scenario in which these points are emptied most rapidly. This may indicate that indeed most of the additional points for this case were located in areas available during rainy seasons. The behavior for the three scenarios is depicted in Figure 37.

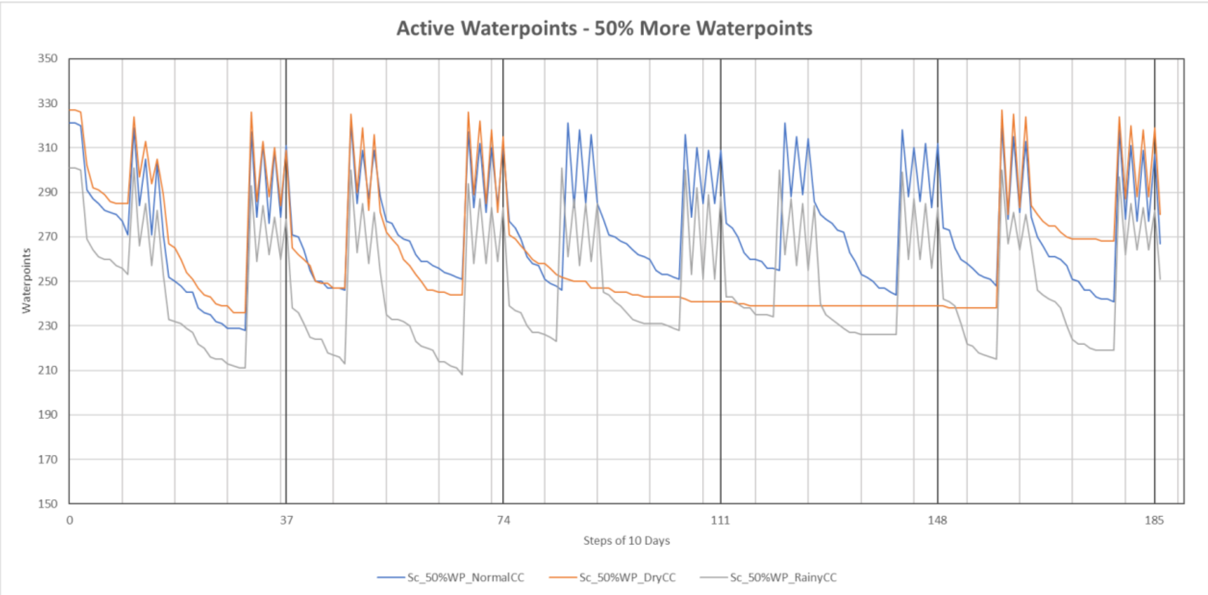

Figure 37: Active Waterpoints – 50% More Waterpoints

Now, the first part of the graphical results is shown in Figure 38, where it can be seen that the agents are considerably dispersed and in the case of scenario under normal conditions, it is a little more complicated to identify the key points to take into mind when including strategies to avoid conflict generation. There are two crucial locations in dry scenario that should be considered for the area. The first is near the sub-county's center, and the second is in the simulation's northwest corner. Last but not least, in the rainfall scenario, there are fewer agents engaged in conflict; however, there is an accumulation of agents with a lower risk of conflict towards the northeast side of the sub-county.

On the other hand, Figure 39 depicts the agents' movement across the simulated scenarios. It is noticeable that when there is an increase of the waterpoints in the Lake Turkana Area, the agents have more possibilities to move, which generate an even more unpredictable migration pattern. In all three instances, it can be seen that there are not clear routes, but it can be observed some hotspots where different small paths lead to. In the case of the rainy conditions, it can be observed that the movement was reduced considerably due to the low intensity of the paths drawn.

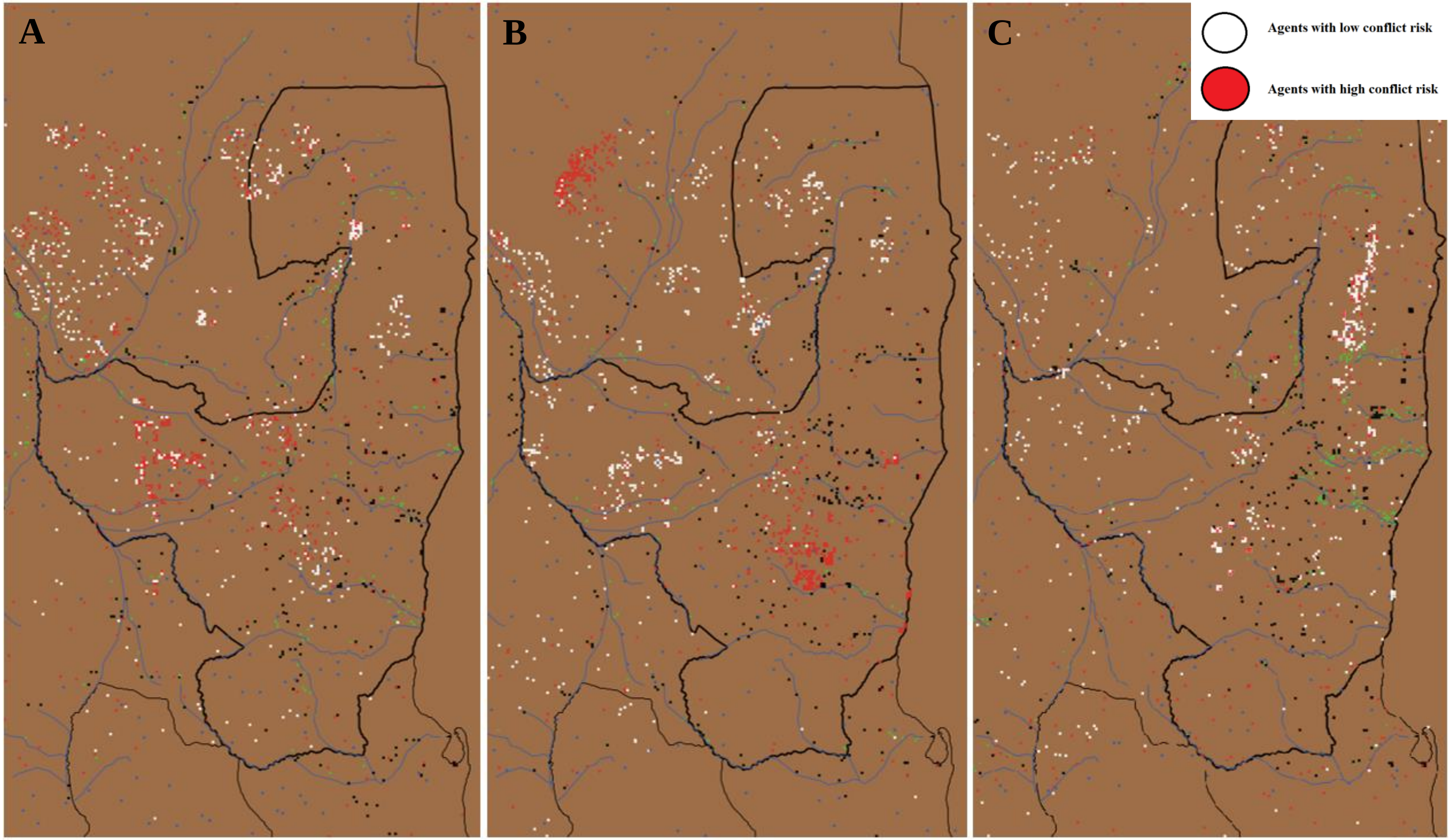

Figure 38: Final Settlements and Conflict Risk - 50% More Waterpoints

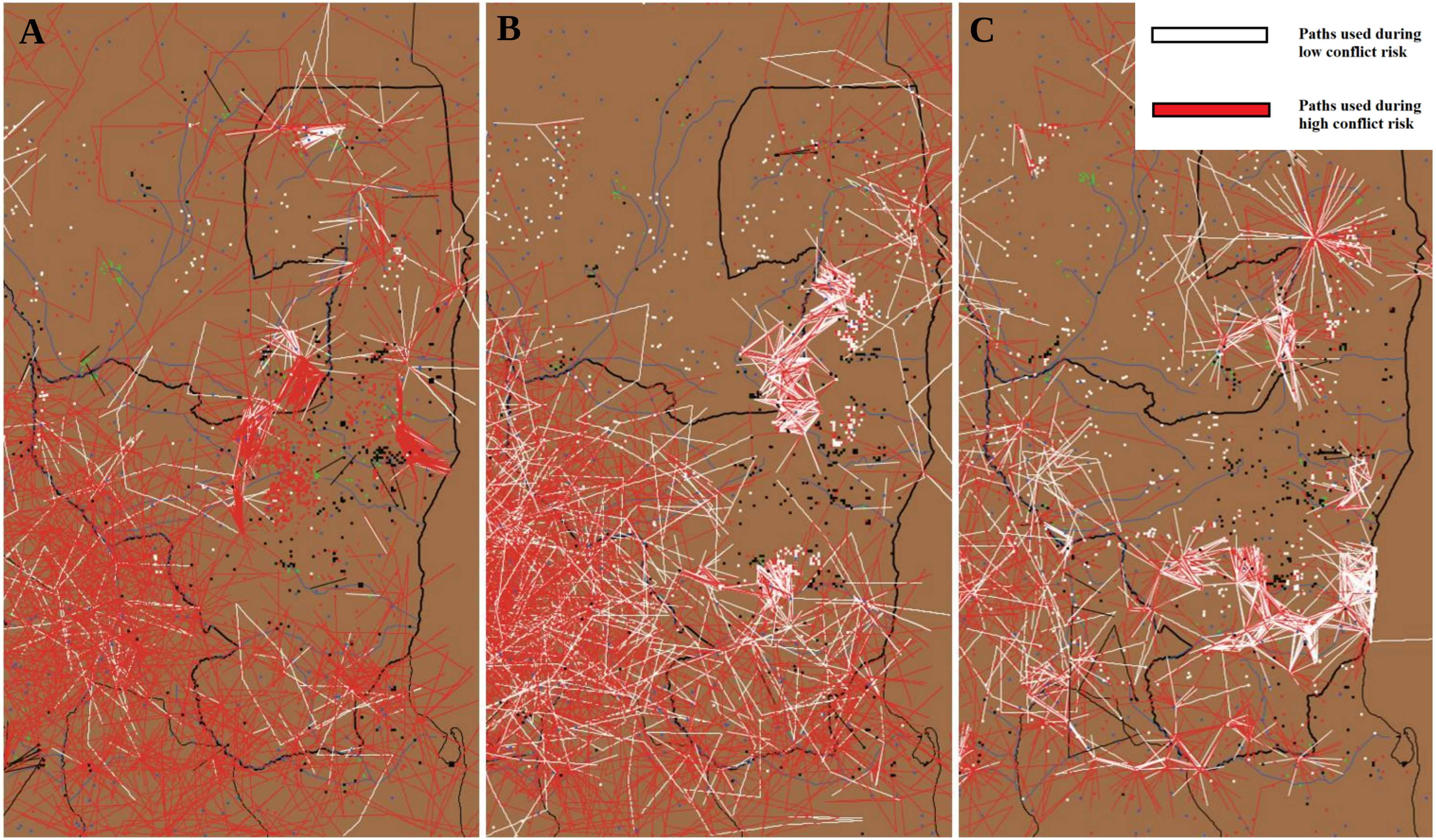

Figure 39: Common Migratory Routes- 50% More Waterpoints

5.3 Simulations with 100% More Waterpoints

For the final group of scenarios, the results of the different conditions were generated by increasing the number of available water points by a 100% and in that way the accessibility to them by the agents was significantly increased.

Throughout the previous chapters, we have noted a significant increase in the number of agents in conflict during the first year of the simulation, followed by a gradual decline from the beginning of the second year, and a similar pattern could be observed in the Figure 40. It is important to note that, in the normal conditions' scenario, the values are consistently higher than the other two scenarios until the onset of adverse conditions, where an increase occurs for the drought scenario.

Upon comparing scenarios under normal and rainy conditions, which had previously, in the scenarios with the actual number of waterpoints and with 50% more, exhibited similar behavior, we have identified a significant decrease in the case of rainy conditions. By At the end of the simulation, the number of agents in conflict under the rainy condition decreased by 25 to 50% respectively.

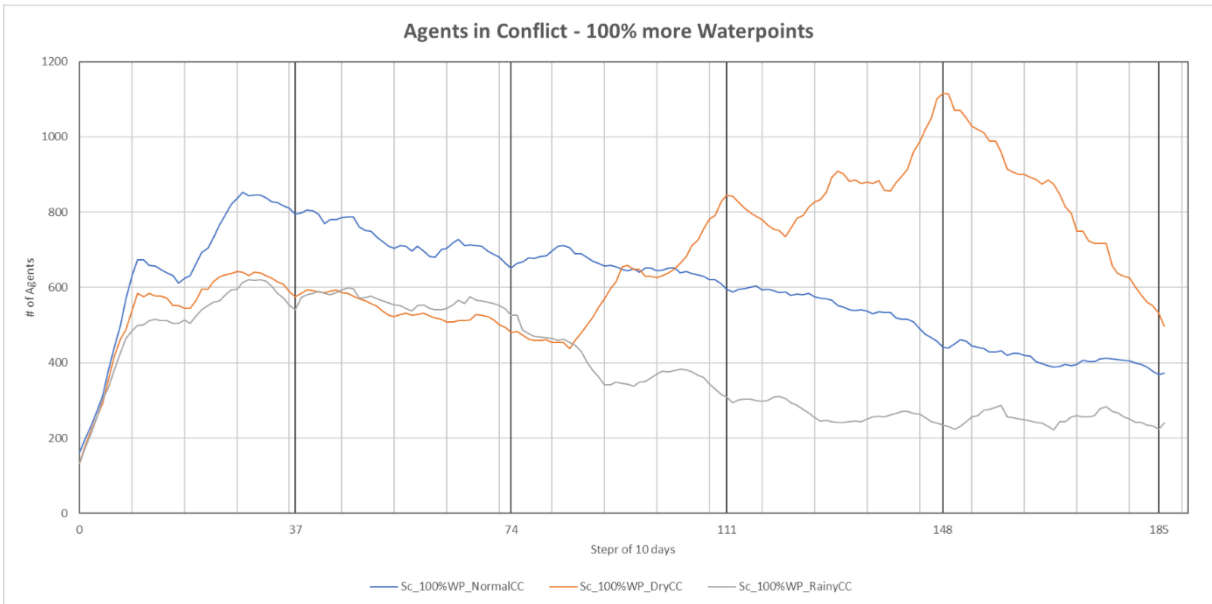

Figure 40: Agents in Conflict – 100% More Waterpoints

As we continue with the results, Figure 41 shows how many agents were active during the scenario. It is clear that every scenario displays behavior that appropriately adapts to the modeled environment's seasonal fluctuations. The three and four-year periods show the greatest change in this metric, though. Almost 1500 agents are constantly moving because there isn't much rain during these seasons and there isn't much area for the agents. This result is consistent with the overall rise in conflict risk. When compared with the results obtained with the two previous quantities of water points, it is observed that this result is similar among the three in terms of the highest peaks of moving agents. When reviewing the rest of the behavior of the graphs, it is observed that the conditions have a similar behavior to that which occurs when increasing the number of water points by 50%.

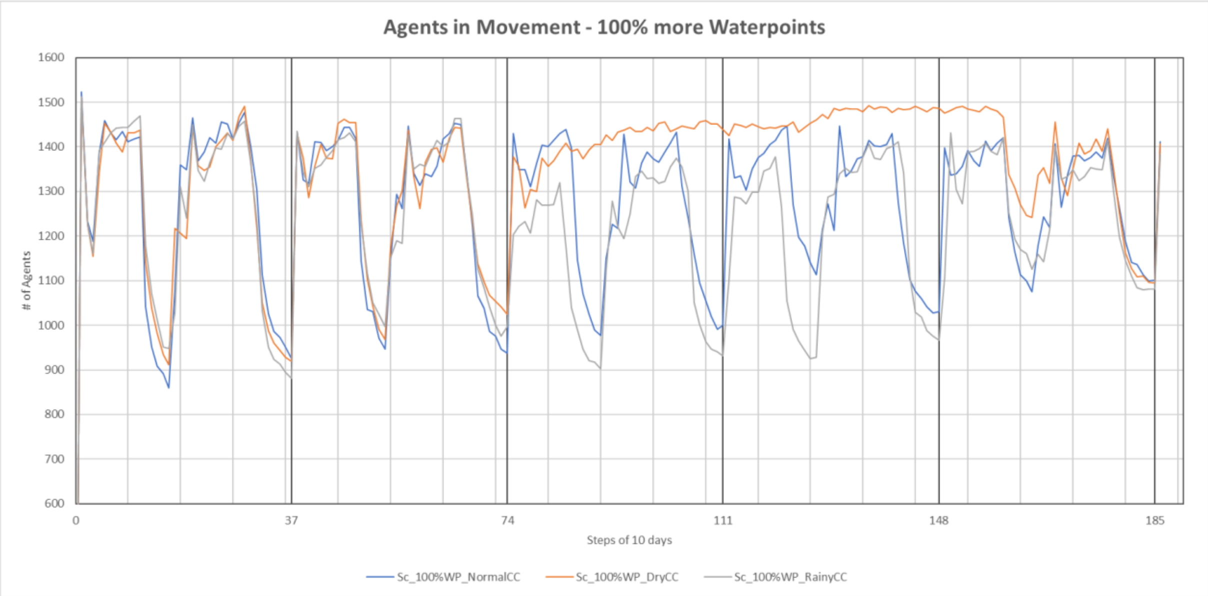

Figure 41: Agents Motion – 100% More Waterpoints

Next, the average agents' conflict risk state was determined using the aforementioned conceptualization. This was done in order to get a more comprehensive picture of the conflict risk stages that the agents are going through. The change in this overall state during the course of the simulations is depicted in Figure 42. Similar patterns can be seen during the beginning of the three simulations, where conflict risk begins low. During this first step, scenarios 8 and 9 remain in an overall medium risk, while in the simulation under normal conditions the conflict risk reaches a medium risk. From this point the scenarios under normal and rainy condition start decreasing, ending in low and too low conflict risk correspondingly.

Although scenario 8 is more sensitive to extreme occurrences, a progressive increase is shown starting in the third year, going from a low conflict risk to a medium conflict risk at the start of the fifth year, before decreasing to a low conflict risk at the end of the scenario.

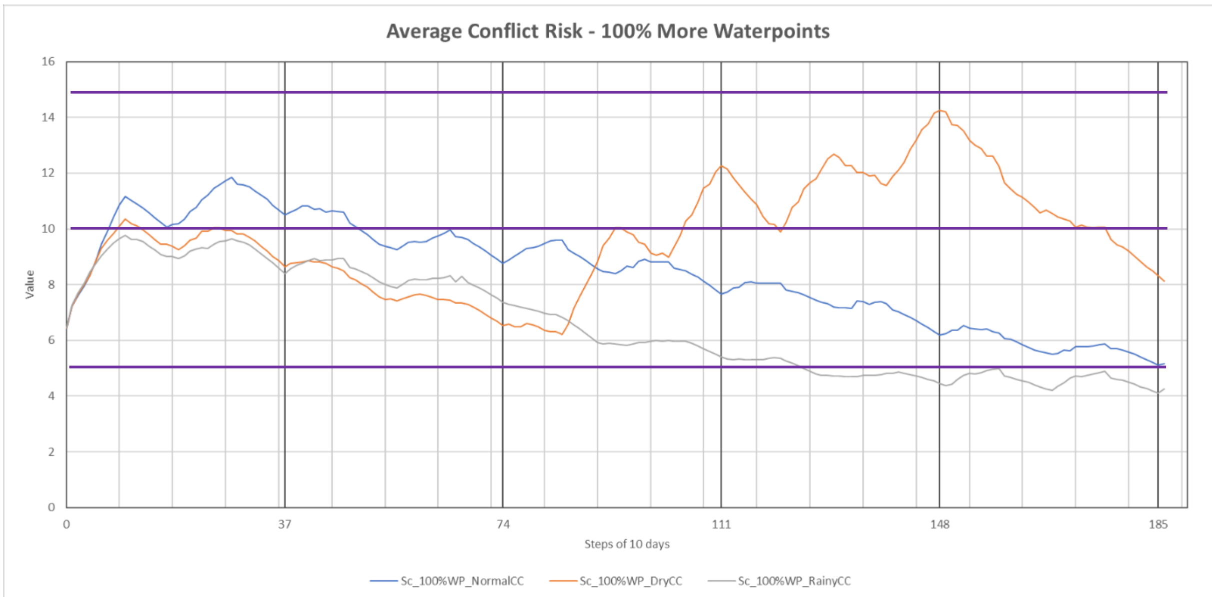

Figure 42: Average Conflict Risk – 100% More Waterpoints

Moving on to the number of conflicts caused by year, Figure 43 shows us the total number of conflicts caused by each scenario and their trend. We can observe that the commencement of the three scenarios is comparable to the results that were previously reported. Yet, it's noteworthy that accumulated number of conflicts in the scenario for normal conditions is higher to the other two scenarios. This behavior may be a similar reason to that discussed in previous sections, where additional water points are located in areas where there are no conditions necessary for the agents to settle and it persists until the start of the fifth year, at which point the scenario with drought circumstances surpasses it, with values exceeding 12,000 conflicts over the course of this time. The tendency is for fewer conflicts to be produced annually in scenarios 7 and 9, whereas there is an increase in scenario 8.

We calculated the annual number of conflicts that took place based on the data previously given, and the results are shown in Figure 44. Our data show that disputes significantly rise in scenario 8, reaching a peak of over 30,000 in the fourth year. Contrarily, the simulation performed in rainy conditions produced the fewest disputes, with levels remaining at or near 9,500 in the fifth year.

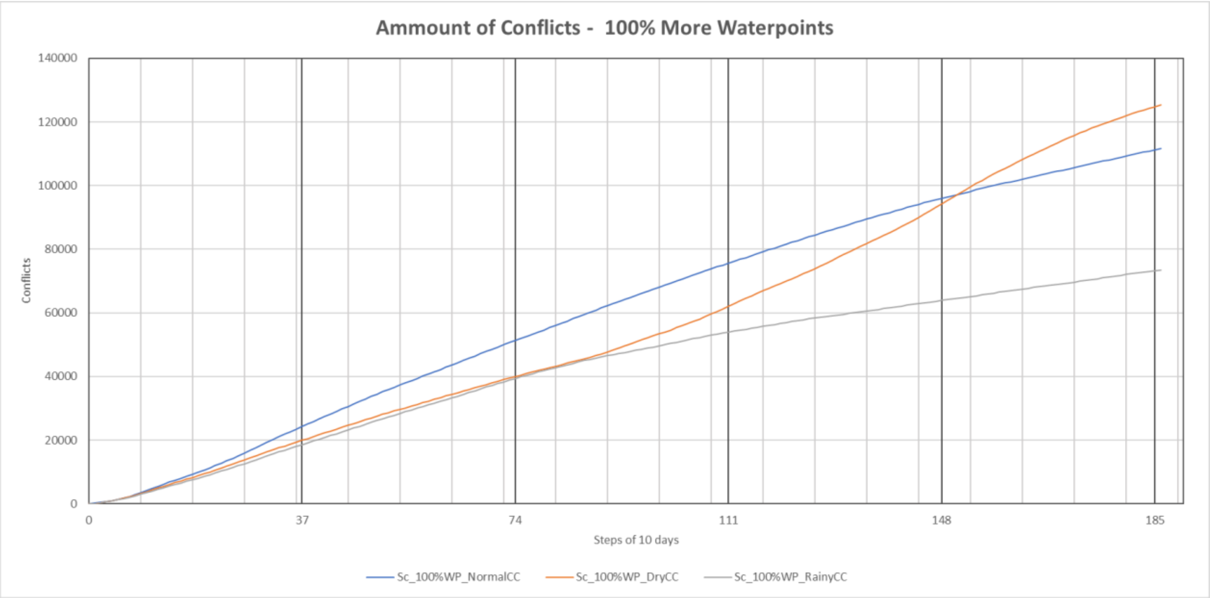

Figure 43: Accumulative Number of Conflicts – 100% More Waterpoints

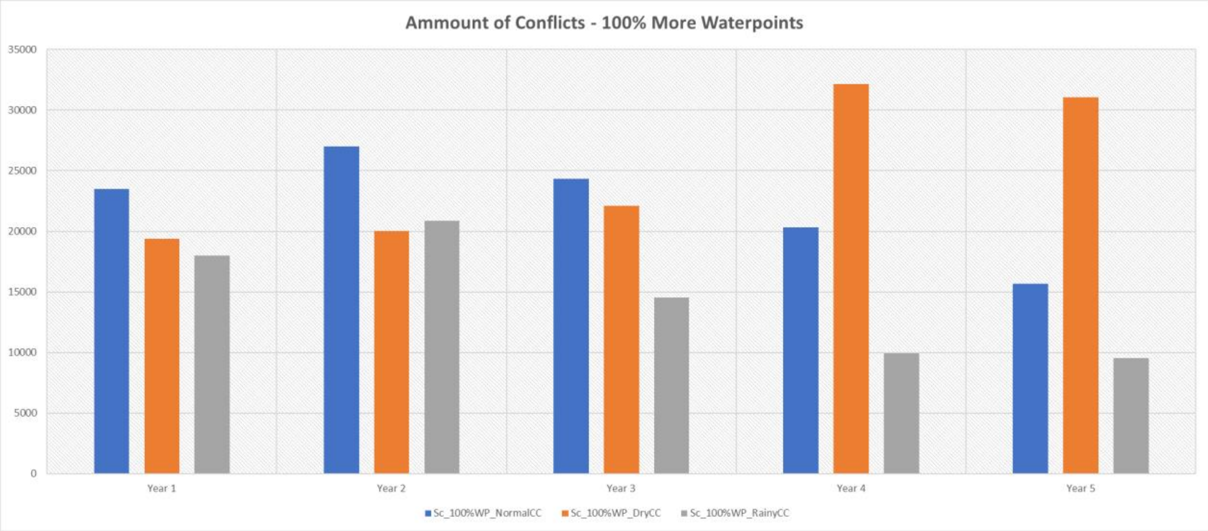

Figure 44: Conflicts per Year – 100% More Waterpoints

Using a similar methodology, a study was done on the behavior of water points that were susceptible to being emptied by agents. With a consistent decline during dry periods and a higher recharge during rainy periods, this behavior is a direct reaction to seasonal changes. The number of active water points declines during drought years up to a certain point, after which it largely stays constant until the fifth year, at which point it resumes its seasonal pattern. Figure 45 depicts the behavior for the three initial situations. In this case, the behavior of the number of active waterpoints is again similar to that occurring during the scenarios with the actual waterpoints, where the lowest points are reached during the dry conditions.

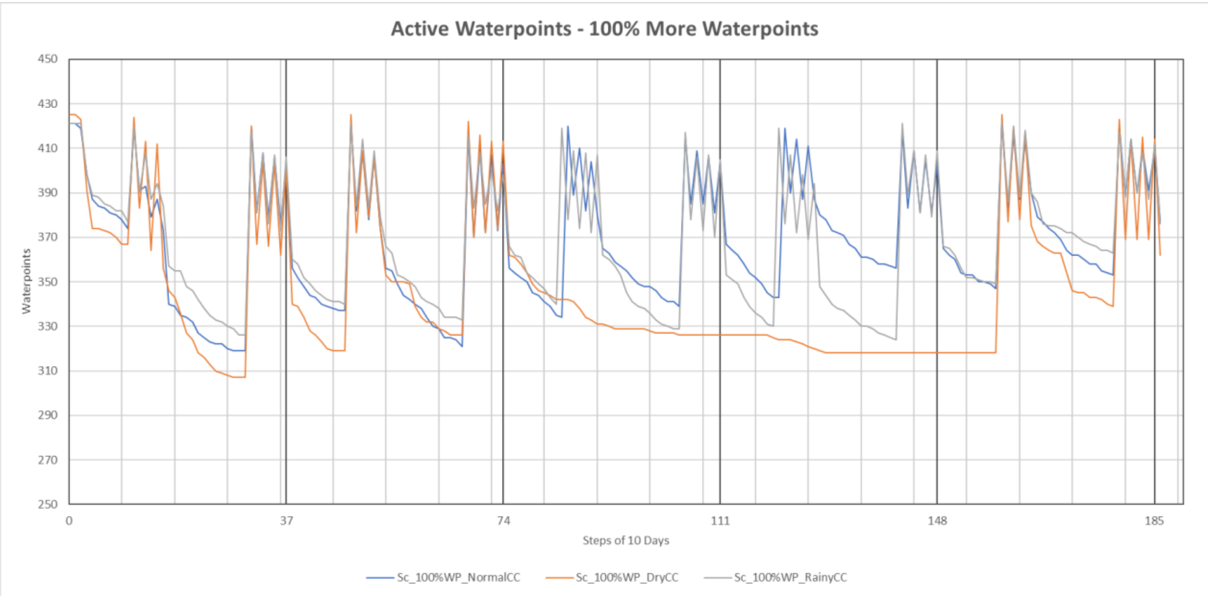

Figure 45: Active Waterpoints – 100% More Waterpoints

The graphic results of the study are presented in Figure 46, which includes the maps a, b, and c correspond to scenarios Sc_100%WP_NormalCC, Sc_100%WP_DryCC and Sc_100%WP_RainyCC respectively. These maps depict the final settlements of the agents, during the simulations. It is evident that the central area of the sub-county is a crucial point where the agents are located, and it is also a critical point for the generation of conflicts.

Sc_100%WP_DryCC shows that most of the agents located in this area have a high risk of conflicts as can be inferred from its red color.

Furthermore, the simulation with rainy conditions reveals that the communities are slightly more dispersed than in the case that includes a similar climatic pattern. This observation confirms that there are more areas that can be inhabited throughout the year.

The movement of the agents across the simulated scenarios is depicted in Figure 47. As a result of the lack of previously known migratory pathways, it can be seen that the agents generally migrate fairly erratically, especially during the dry and rainy scenarios. Whatever the case is, it is possible to note that in the southwestern side of the sub-county, there is an increase of the agents' movement, which could be a response of the lack of waterpoints in this area. Similar than the scenarios with less waterpoints, the areas that are prone to conflict are located mainly in the center of the Turkana North sub-county, being this a common point where the paths cross each other.

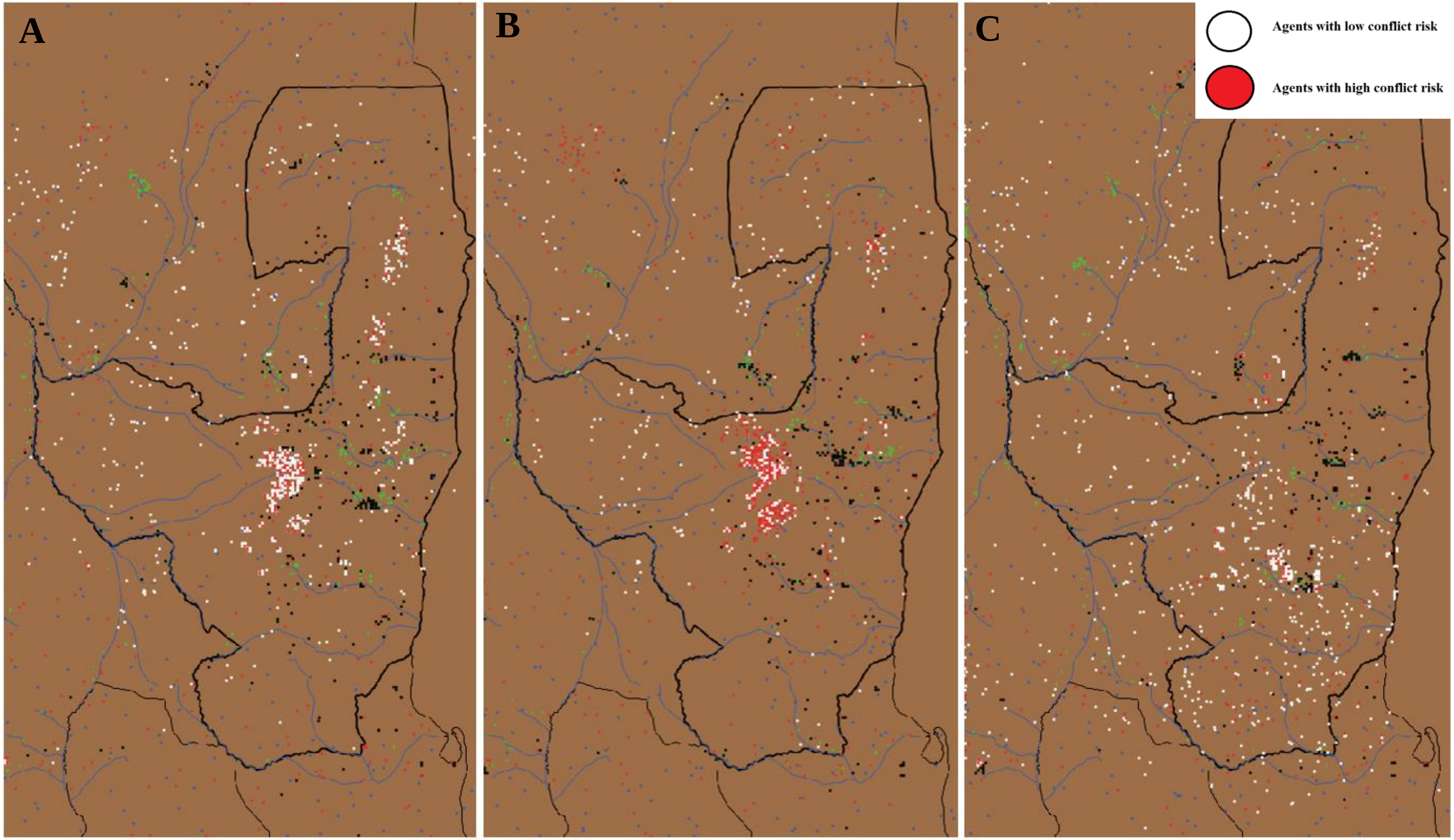

Figure 46: Final Settlements and Conflict risk – 100% More Waterpoints

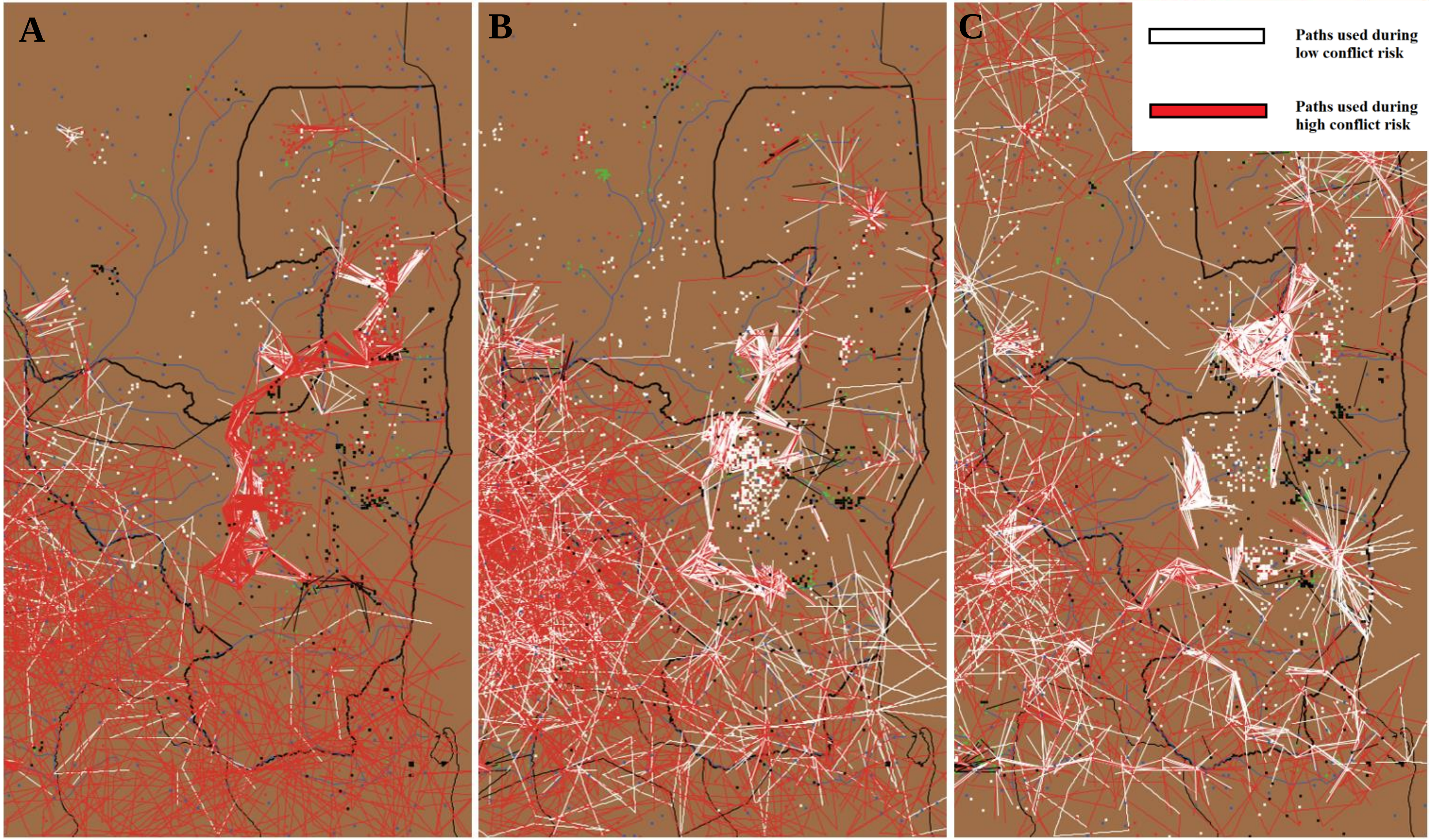

Figure 47: Common Migratory Routes- 100% More Waterpoints

5.4 Conflict per Agent Group

Now, as a final result, this section of the chapter presents a summary of the number of agents at high risk of conflict for each group of simulated agents, taking into account the scenarios mentioned above.

In the initial overview, Figure 48 indicates the quantity of pastoral community members who are at a heightened risk of conflict during the simulation, based on their presence in the Lake Turkana region. This data aligns with the overall behavior of all agents, indicating that the actions of this community have a significant impact on the dynamics of the study area.

In the same way, it is possible to observe that during the scenarios in which there is more water, the number of agents at high risk of conflict is lower, as a response to the increase of available areas in the area.

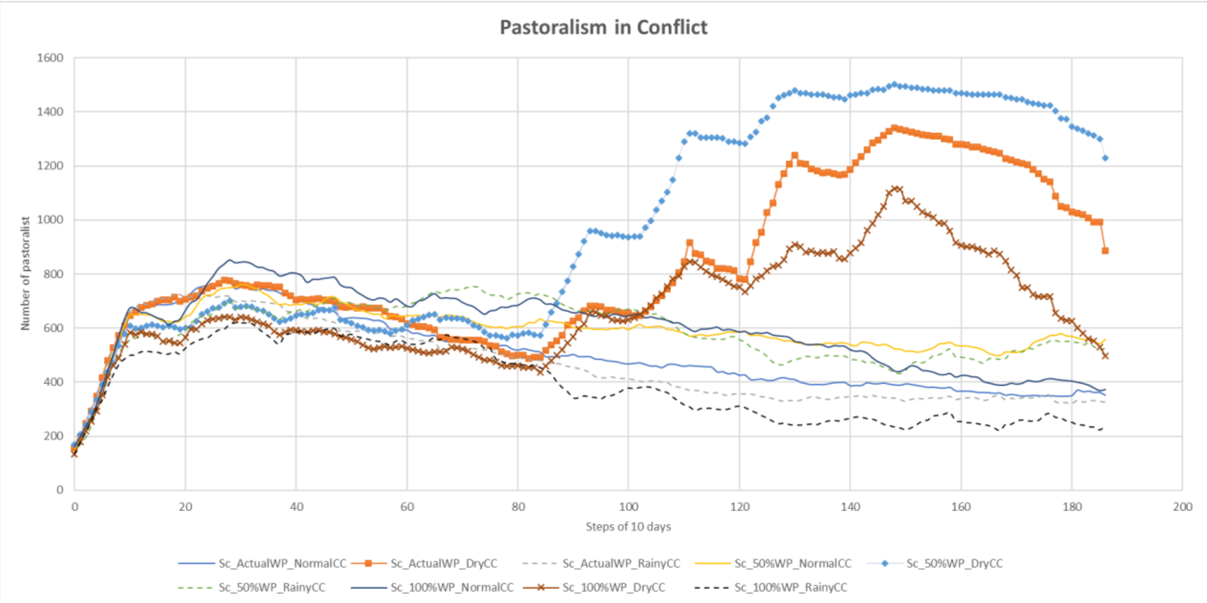

Figure 48: Pastoralist in Conflict

Moving on, the next group to be analyzed are those belonging to the farming community. The summary of the number of farmers at high risk of conflict during the simulation is presented in Figure 49 below.

It can be observed that in general, conflicts can be generated at the beginning of the simulation periods, reaching their peak in the middle of the first year, after which a constant decrease is observed, even reaching zero in some cases. As a particular result, it is clear that for this community an improvement is observed when a greater number of water points are included, since the results of the scenarios with 50 and 100% more water points show a number of agents at high risk of conflict close to zero.

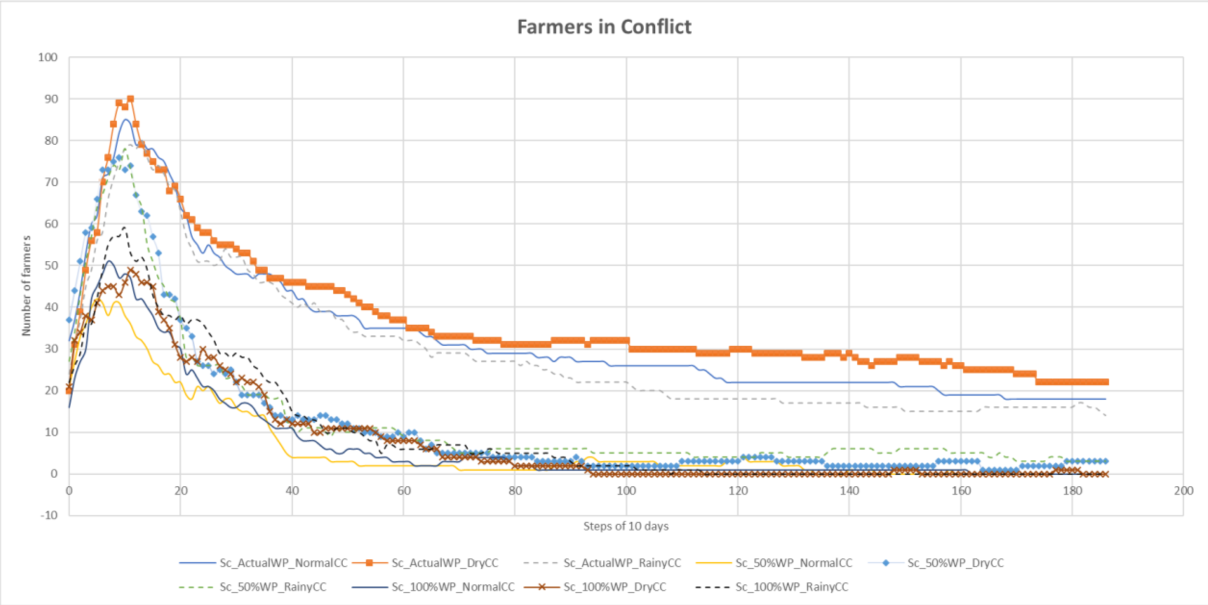

Figure 49: Farmers in Conflict

Finally, the last group is made up of fishermen from the Lake Turkana area, including Marsabit and Turkana counties. This communities are located in a focused area and their activities are very pointed and not interacting so much with the rest of the agents. For this reason, it is observed that there are no agents with a high risk of conflict during most of the simulations, only at the beginning of the simulation period. The aforementioned is stated in the Figure 50.

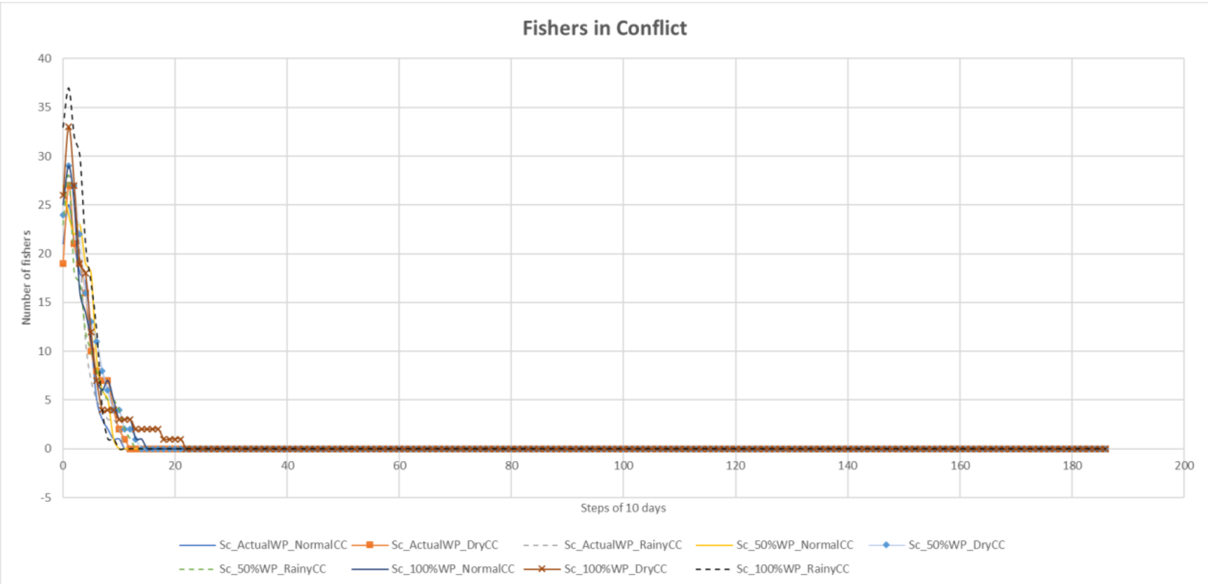

Figure 50: Fisher in Conflict

Chapter 6 Discussion

6.1 General Discussion

To begin the discussion of the results obtained from each of the simulations performed and their relevance to the study, it is pertinent to start with a general account of these results. First of all, it is clear that the general behavior of the simulated agents is mainly influenced by the pastoral community, as was expected due to the large size of its population. Secondly, general patterns were observed that respond to seasonality in each of the years and to the generation of conflicts, the latter being a primary factor in understanding these dynamics.

Now, we came back to the general objective of the Thesis, which established the search for a tool that would allow a general understanding of the way in which various communities located around Lake Turkana interact. With this we were able to address the way in which they make choices that allow them to clarify the general objectives associated with their main activity, through the implementation of ABM in this region. Also, we have been able to gather valuable behavioral data that can be analyzed based on specific circumstances. This information is a good start in the path to assist the decision-makers in mitigating the risk of conflict within and between communities. By gaining a deeper understanding of these patterns, authorities can take proactive measures to prevent conflicts from arising and promote peaceful coexistence among all communities.

The utilization of ABM has allowed us to collect data that is tailored to the unique needs of each community. This approach has enabled us to identify potential areas of conflict and develop targeted strategies to address them.

Overall, the results are consistent with the way in which the rules of interaction were indicated and established, with the greatest number of conflicts occurring during times of drought. A curious aspect that was observed is that during a period of continuous rainfall, the number of conflicts did not increase, nor did the number of agents at high risk of being involved in a conflict. This may be a response to the distribution of the agents, since while for farmers and fishermen this may not be a favorable condition, for herders, it is a period of time in which they have more areas available for settlement and a greater number of waterpoints available, thus reducing the overall risk of conflict.

These results require further analysis and discussion. It is important to note that the inputs used in this study are general and while they capture specific aspects of daily life, the complexity of human decision-making involves many more factors that were not meticulously considered. Nevertheless, the model enabled us to obtain results based on a rough sensitivity analysis of the available water points in the study area.

In the scenarios in which the actual water point information in the area provided by the Water Department of Turkana County is included, a large difference is observed when extreme conditions are included in the time period, with a difference of more than 900 agents at high conflict risk during the simulation under rainy conditions when compared with the normal conditions. Likewise, more than 30,000 conflicts generated during the dry years, which is the higher values obtained for the scenarios based on the actual number of waterpoints. This elevated number of conflicts generated throughout the simulations is a response from the agents to a sense of imminent conflict when encountering those who have a high overall risk of conflict and they are especially high because in this model, conflicts are automatically generated when the mentioned condition is met, without taking into account different factors that may intervene to avoid confrontations, such as ethnicity, season in which they are located or location on the map. However, it does not represent the reality in which conflicts arise from the combination of various factors such as resentment towards other communities or ethnicities.

When observing these results with the scenarios in which the number of water points were increased by a 100%, this difference decreases considerably, to the point where having twice as many waterpoints available in the model, the difference was reduced to a little more than 15,000 conflicts generated during the last year of simulation and a total reduction of 31,000 cases during the 5 years, corresponding to a reduction of approximately 20%.

An interesting observation when comparing the results with the actual number of water points and those obtained with the increment of the 50% more is that, contrary to what might be expected, the number of conflicts generated throughout the simulation and the number of agents in conflict increased by approximately 20% and 30%, respectively. This may be a response to the fact that agents have greater availability of water, which makes it easier for them to settle in one place more quickly. However, at the time of a change of season, many of them have to move against their will, which increases the perception of stress and difficulties at the same time. Another cause of this behavior may be due to the fact that the additional water points are being placed randomly throughout the territory, so some of them end up in areas that are not suitable for any of the agents to use at any time of the year. In order to verify these results, similar simulations were performed, obtaining similar results, reinforcing the reasons exposed before.

When the obtained results are compared to real reports on conflicts during a period of time, as is showed in the Figure 51, it possible to confirm that in cases when a strong drought came into the area, the number of conflicts increase considerably, as was the case of the year 2017. This was reported as one of the hardest drought cases over the last years in the area, with a return period of approximately 120 year (CDKN, 2017). In combination with the lack of implementation of the Water Act released just a year prior this event, over 900 conflicts were reported with an increase of more than 30% in comparison with the previous year.

Figure 51: Reported Conflicts in Kenya 1997-2021

Now, observing the maps generated by the simulation in each of its scenarios, we can see the critical points where it is necessary to prioritize intervention and implement some of the conflict resolution or prevention strategies that could help in solve or prevent them. In the case of the migration routes generated with each movement of the agents, it can be observed that in general this is a rather erratic behavior in which it is not possible to clearly observe a common route that they have traveled during the migration times, however, certain points can be observed where these routes cross and may indicate hotspots for the generation of conflicts in the territory.

6.2 Conflict Resolution Strategies

According to the results obtained, it is necessary to generate a series of strategies for the prevention of conflicts and, additionally, to establish plans in case of their occurrence in order to solve them in an optimal way so that they do not escalate to a point of no return.

These strategies should be based on a thorough analysis of the root causes of conflicts, as well as the dynamics and patterns that have led to their escalation in the past. In addition, a crucial matter to choose which strategy should be applied is a better understanding on which are the agents that are involved into the conflict as well as their own needs and the possible impact that an occurrence would have into their common lives.

Based on the principal results obtained from the model, it is evident that the agents respond positively to an increase in the number of waterpoints and their accessibility. Therefore, the most effective strategy to implement in the area would be to improve the accessibility of water by constructing more drilling wells and boreholes. These should be managed by government entities to ensure proper distribution and accessibility to the population.

Additionally, it is important to consider the sustainability of these waterpoints. The government should invest in maintenance and repair programs to ensure that the waterpoints remain functional and accessible in the long term. Community involvement and education programs can also be implemented to promote responsible use of the water resources and to encourage community members to take ownership of the waterpoints.

Furthermore, it is crucial to address any potential negative impacts on the environment and local communities that may arise from increased drilling activities. Environmental impact assessments should be conducted prior to construction, and measures should be taken to mitigate any negative effects on ecosystems and biodiversity.

One key aspect of conflict prevention is communication. Effective communication channels should be established to facilitate dialogue and understanding between different parties, and to address any misunderstandings or grievances before they escalate into full-blown conflicts.

Another important strategy is to promote collaboration and cooperation among different groups. This can be achieved through joint projects, shared resources, or other forms of mutual support that forge a sense of common purpose and reduce tensions. Historically, there have been some ongoing conflicts between different ethnic communities that compete for resources in a common area that have not been resolved yet and are very prone to conflict.

One of the best strategies to resolve conflicts like these was introduced in the literature review when a whole concept of conflict was exposed. It states that a third party could perform as a mediator which should analyze the motivations each actor has and what are they asking for, with the aim of make a selfish statement and find a medium point that will fulfill both demands.

The WPS partnership has helped to the authorities to introduce these strategies to some of the ongoing conflicts between the fisher communities on Turkana and Marsabit, as well as the communities located on surrounding areas of the border line between the northern side of the Turkana County and the southeast zones in Ethiopia with great outcome. These strategies that the authorities have been implementing have been reducing considerably the conflicts in the area and promoting the cooperation between the neighbors communities, even been able to retake the trade between borders and stop activities that produce resentment between tribes such as the stole of cattle or the overcontrol of the common resources (WPS, 2023).

Furthermore, this dialogue interventions could be included into some workshops that involve several stakeholders whose should try to understand the other stakeholders' motivations and what are the roots of the conflict. This could be achieved by the implementation of activities such as the elaboration of a conflict tree that could lead to understand why are conflict emerging and what could be the outcome of the ongoing conflict. Likewise, the causal loop diagram is a tool that allows the participants of a workgroup to understand what are the key aspects that drive the main problems in the area, how are the actions performed by the agents reinforcing the problems and find which are the leverage points that should be the main focuses of intervention and be able to reduce conflicts over time.

In addition to prevention strategies, it is also important to have contingency plans in place in case conflicts do occur. These plans should include clear protocols for managing crises, such as establishing lines of communication with relevant authorities or mobilizing resources to address urgent needs.

Chapter 7 Conclusions and Recommendation

7.1 Conclusions

To derive the conclusions from the research presented in this study in an organized manner and make it easier to understand, we will first outline briefly each objective and subsequently summarize the overall findings. This approach will enable us to provide a comprehensive and cohesive analysis of the results.

The general objective of this research was to generate a tool for the characterization of water-related conflicts, capturing the interaction between the agents in the area. During the development of this research it was possible to identify the main agent types, and in the same way to obtain their main actions that define their mutual interactions and with the environment. These were defined in the form of general rules that were included in the model developed in the NetLogo software. As an overall outcome, the results were able to identify how the conflicts were generated, the amount of conflicts happening per year of simulation and the variability over the conflict risk of the agents. All of these parameters were addressed by different scenarios and conditions. In total we analyze 9 scenarios, where the bases were the number of waterpoints in the area starting with the actual number of them and then increasing by 50% and 100%. Those were combined with the three climate conditions stated, such as a normal condition, dry condition and rainy condition. Using this classification, we were able to develop an analysis of the different options that may be arise.

As part of the specific objectives, the first one of them was to develop a stakeholder analysis. By doing so, we were able to established a baseline information that helped us to correctly identify the agent types and their environment for which the model will be implemented. Regarding this objective, mostly carried out as desk study, the main communities (agent types) were identified, the location of these communities, their main livelihoods and characteristics that lead to the development of the activities that they can perform in the media according to the livelihoods.

By conducting this stakeholder analysis, we were able to identify the key players who would be part of the model and those who could use it as an understanding tool for their own interests. This allowed us to correctly understand their actions and ensure that the needs and concerns of these stakeholders were correctly addressed. Additionally, during this stage of the research we were able to identify which were the main conflicts and concerns for the communities in the area, information that was then confirmed during the workshop made in the area. This allowed for the completion of the theoretical part of specific objective 2, which was later complemented with the results of the model.

Then, we have successfully developed a model that can incorporate various factors present in the area and can be easily modified to fin the influence of these external variables in the generation of conflicts and generate diverse outcomes that reflect the different conditions affecting the local population. By identifying this impact in the model, it was possible to complete the third specific objective and find sensitivity to different conditions.

Now, as part of the fourth specific objective, the recommendation of strategies for conflict reduction or resolution was established. The fulfillment of this objective was initially achieved through the search for those strategies that can be applied in an area such as Lake Turkana, and subsequently, based on the results obtained, determining which of them can be applied in the best way to the case study.

Finally, the ultimate goal was broadly determined to identify ways in which this type of model can handle problems related to social interaction in a given environment. The most relevant general conclusions of the present study are shown below.

- The implementation of agent-based models has demonstrated the flexibility that can be achieved through such research and development. These models can represent not only physical factors, which are typically studied in the field of hydroinformatics (regarding the physical / natural water conditions), but also social concepts that are important for generating results that contribute to develop better management actions for a community.

  By incorporating various characteristics into the development of these models, they can provide a comprehensive understanding of complex systems. This approach allows for a more faithful representation of real-world scenarios, which can lead to better decision-making and improved outcomes for communities.

- Despite the overall diversity of the country's population and their various means of supporting themselves, the specific area under analysis is primarily defined by the actions of the pastoral community. This conclusion was reached through multiple stages of research, including a literature review and modeling, and was further confirmed during the modelling stages and later on a work session with the community.

- The concept of conflicts in a society is a highly complex topic due to the unpredictable nature of the individuals that may be engaged in it. However, it was evidenced that different authors have managed to implement ways to understand it and even carry out complex simulations using such conceptualizations. In the development of this research, it was possible to establish a concept of conflict based on individual levels of Difficulties and Stress, obtaining a methodology that allows to evaluate different stages through which the community may go through before the generation of a conflict itself. In this way, the main water-related conflicts that can arise in this area were analyzed, which are mostly due to the lack of water and to accessibility to pasture areas, making the zone around the water points more crowded and conflict prone.

- For the correct development of an ABM to study this type of problems, it is necessary to adequately characterize the environment in which the agents develop and interact, so it is crucial to determine the physical aspects that influence most their behavior. In this case, the most influential aspects were the vegetation cover present in the area and its dynamics according to the seasonality of the place, in order to correctly capture the migratory behavior generated in the communities. Likewise, the next aspect that mostly influences the results is the quantity of water points, which showed high sensitivity even in the location of these water points, therefore it is concluded that for a correct improvement in this area, a detailed study is required to determine the most suitable areas to propose new ones.

- During all the simulation scenarios carried out, it was possible to confirm that the general behavior of the communities in this zone is defined by the herders, who are more vulnerable to any modification in the environment, either regarding type of vegetation cover of the zone or regarding its availability, while the farming and fishing communities have greater stability to develop their activities.

- At the beginning of the simulation period in each of the scenarios there is an increase in the number of agents who have a high risk of conflict, reaching a maximum point after which there is a drop in this risk. This may be a reason why agents can find an area that is suitable for them for most of the year and avoid those patches where agents are found, so they can develop their actions more freely, adapting to seasonality and generally reducing the risk of conflicts.

- A behavior that is directly related to the temporality of the simulations is the number of agents that are in motion in each of the steps of the simulations. Given the basic conditions regarding the number of waterpoints, it is observed that although the behavior is similar, the agents manage to find a suitable area much more quickly as the available water points increase, which in turn decreases their difficulties.

- Regarding the number of conflicts generated each year for each of the simulations, it is interesting that as the number of water points increased by 50%, the number of conflicts generated also increased. This may be due to the fact that there is not a substantial increase in the water availability, therefore the interaction of the agents is similar to a scenario with the real information of the water points. On the other hand, many of these points are accumulated in the central area of the sub-county, so by increasing water points randomly, the distances that agents have to travel to reach them can be increased, increasing their risk of conflict.

- In contrast, when the water points in the environment are doubled, a notable decrease in the number of agents at high risk of conflict is observed when drought conditions are incorporated during years 3 and 4, which corresponds to what is expected when simulating with more resources. When simulating with humid conditions, a similar overall decrease in the risk of conflicts was observed, deviating slightly from the simulation under normal conditions.

- It is noteworthy that the simulation accurately captures the impact of environmental factors on the behavior of the agents. The results provide valuable insights into the dynamics of the system and can inform decision-making processes.

- Finally, looking at the maps showing the agents after the simulations, it is concluded that the most conflict-prone areas are located towards the center of Turkana North sub-county, where majority of the waterpoints are located, becoming less crowded as the number of available water points increases.

- On the other hand, migratory routes are more identifiable in scenarios with few water points, while as these increases, a more chaotic behavior is observed as a direct response of the amount of areas available for the agents.

7.2 Recommendations

- The model elaborated during this research has captured the behaviors in a general way, conceptualizing the parameters such as the main activities or migration behavior in a simple manner, so the results obtained may represent trends but with values far from reality. In order to improve these outcomes, it is necessary to include more physical information that adjusts these values to reality. These could include real hydroclimatic data that represent the seasonality and the changes into de environment in a more representative way. In the same way, a more rigorous social study is required in which different methodologies are established to more accurately represent the behavior of agents in the given space

- In this model, the main resource that is being depleted by the agents is water. However, in real life, the use of resources is much higher and varies depending on what each resource is being used for. In addition to this, depending on the time of year, communities may have the need to consume more or less. A correct approach to capturing this usage is by analyzing in more detail how those activities are being developed, how much grass each animal will eat at all times, the productivity of the land, how much farmers could harvest in a season, and even the real dynamics of the fish in the lake and how their behavior changes during times when the water levels increase or decrease due to the climate. Therefore, it is recommended that in a future improvement of the model, the necessary consumption for the animals be specified first, given the importance of the pastoral community, and then include the modifications in the other communities.

- In order to fully understand the potential risks associated with different aspects such as the development of hydropower industry or irrigation projects along the Omo River in Ethiopia, it is necessary in future stages to include some parameters that could represent these threats. Additionally, it is crucial to take into account the impact of oil exploration and changes in landcover in the area, as these factors can greatly affect the dynamics of the agents' interactions and thus increasing the conflict risk for them.

- During the work session with the community during the research period, it was possible to confirm that the main concerns of the people are related to the accessibility to water and the state of the groundwater, which, due to the arid nature, is the main source for the area. For this reason, it is recommended that for further development of this model, the results of the groundwater modeling be included in order to better capture the dynamics of the environment, the state of the salinity intrusion into the aquifer and how is the groundwater dynamics and aquifer levels.

- Another concern observed during this session was the possible use of this model to predict future conflicts and act before they occur. It should be clarified that this is a tool that is intended to improve the understanding of conflicts, not to make predictions, however, a better approach can be reached by coupled modeling with physical and forecast information from different researches.

- Despite that the results shows an improvement in the conflict reduction of the agents when increasing the accessibility to waterpoints, it is important to note that this is not enough. It is also necessary to ensure that those points are maintained by the management authorities and that communities have the knowledge and resources to use them effectively.

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Appendix A. - Ethical Approval Letter

Appendix B. - Personal Ethics Declaration