REPORT

Water, Peace and Security

Agent-Based Modelling of Conflict Risk in the Inner Niger Delta

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Agent-Based Modelling of Conflict Risk in the Inner Niger Delta

ABSTRACT

The Inner Niger Delta in Mali is a large wetland that supports the livelihoods of around 2 million cattle breeders, farmers, and fishers. These people depend on the annual inundation of the wetland to provide them with resources that support their livelihoods. Population growth and changes in flooding extent of the wetland increase the pressure on the natural resources in the Delta, which contributes to conflicts between herders, farmers, and fishers.

This Water, Peace and Security Partnership report aims to gain understanding of the interaction between the availability of water and water-related ecosystem services on the one hand and community-level conflict in the Inner Niger Delta on the other hand. In this context, Deltares in collaboration with the Wetlands International Sahel Office and International Alert Mali Office developed an agent-based model of the Mopti region, which is used to simulate three climate scenarios, three demographic scenarios, and two interventions. The tested interventions are a generally accepted natural resource and conflict management system, and increased production efficiency.

Model results show that with less inundation and population growth, conflict risk increases as compared to the base scenario, whilst a wetter scenario decreases the conflict risk. Furthermore, the effect of changes in inundation on conflict risk take place in the successive year, indicating that there is a one-year time lag in how the water system affects the conflict risk. Of the two tested interventions, the accepted natural resource management and conflict resolution system had the largest influence on the decrease of the conflict. This suggests that the management of natural resources and the manner of interaction between the competing agents has a larger influence on the conflict risk than the availability of those natural resources.

Apart from less inundation, the population density is positively correlated with conflict risk. Seasonal changes in the inundation pattern cause households to move to locations with sufficient resources, leading locally to higher population densities and increased conflict risk. The accepted resource management system decreases the seasonality and conflict risk, however, an upwards trend in conflict is still present. A possible explanation for this is that the accepted resource management system only affects a part of the pathway leading to conflict risk.

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1. Introduction

Engagement of the WPS Partnership in the Inner Niger Delta, Mali

The Inner Niger Delta (IND) in Mali is a large wetland that supports the livelihoods of around 2 million people (see Figure 1.1). The population depends on the annual inundation of the wetland to provide them with resources that support livelihoods based on cattle breeding, farming and fishing. Population growth and changes in flooding extent of the wetland affect the natural resources (i.e., land and water for agriculture, pastoralism, and fisheries) in the Delta, increasing the pressure on these resources. Moreover, the Delta has been the theatre of an increasing number of violent conflicts in the past decade, both within and between different communities. Research in the IND has shown that a decline in flooding resulted in overfishing, overgrazing and reduced cooperation between different ethnic groups (Wetlands International, 2017). As an example, Morand (2016) indicates that conflicts can occur when water scarcity pushes farmers to cultivate crops in the lower flood plains, which are also used as grazing fields by herders. The competition over this land is one of the contributing factors that contribute to conflicts between herders and farmers. Other factors include amongst others violation of rules and regulations and grievances (indirectly) related to high population density (Basedau et. al., 2021; International Alert, 2022). In turn,

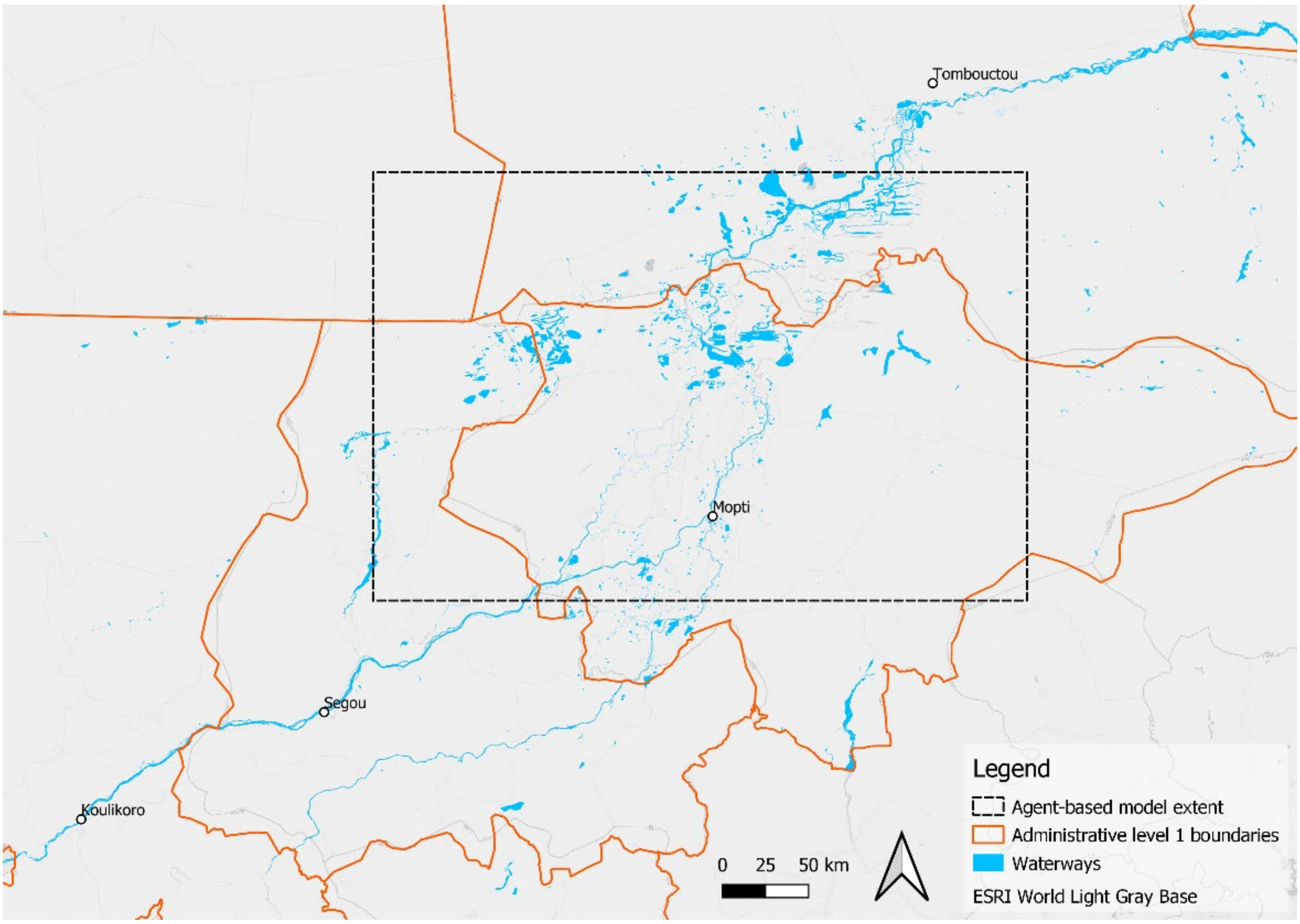

Figure 1.1 The IND in Mali and the agent-based model extent, mainly within the Mopti region.

these anti-government sentiments provide an opportunity for jihadist groups to gain support from the population (Benjaminsen & Boubacar, 2018). These sentiments can facilitate the support of jihadist groups in the region. The extent to which pressure on natural resources contributes to intra- and inter-community conflicts needs to be better understood to identify possible ways to reduce conflict risks over natural resources or prevent further escalation. Of course, it is recognized that conflicts are multi-dimensional and that other factors than water and resource availability and governance play an important role.

The Water, Peace and Security (WPS) partnership was created in 2018 to help identify water-related security risks and to improve the responses to them through the development and application of innovative tools and services as well as the facilitation of dialogue between the conflicting parties. Information gained from the research and modelling facilitates awareness-raising and capacity development to support evidence-based action the resolution and prevention of water-related conflicts. The IND is one of the regions in which the WPS Partnership engages. The cooperation with the local stakeholders and experts was done through the Wetlands International Sahel Office (WISO) and the International Alert (IA) Mali office that have a long-standing presence and engagement in the IND.

Through a participatory process, the WPS Partnership developed an approach with local stakeholders to work together on a better understanding of the relation between water and conflicts (Water, Peace and Security, 2023). This was done in collaboration with GIZ through the FREXUS project, who took the lead in engaging and training the relevant stakeholders in this approach. This resulted amongst others in a better understanding of the system through a Causal Loop Diagram identifying the relations between resource availability, governance and conflict. The WPS Partnership identified the local stakeholders' need to go from the system level to the behaviour of actor groups. Therefore, Deltares created an agent-based model (ABM) of the Mopti region in the IND in Mali, which was used to gain a mutual understanding of the extent to which changes in environmental factors can contribute to intra- and inter-community conflicts. The model has also been used to explore how demographic changes and governance interventions influence conflict risk. It must be noted that this model only represents a small and simplified part of the reality in the IND. It does not encompass all the contours of the complex reality. In this sense, it can only be used for investigating possible (future) scenarios rather than for predicting the future.

Agent-based modelling to better understand water-related conflicts

To understand what triggers actors to resort to violence in response to conflict requires for an understanding of the environment, characteristics, behaviour, actions, and inter-actions of these different actors. By simulating the individual actors over time, emerging patterns, like an increase or decrease in conflict risk (see the "conflict risk" box), can be identified and assessed.

> ### *Conflict risk*
>
> *In this report, "conflict risk" considers a broad definition of conflict, including non-violent and violent conflict. When households experience risk of conflict they have a heightened chance of being involved in a non-violent or violent conflict.*

models where local actions of agents and interactions between agents and their environment generate emergent patterns that can be studied using a bottom-up approach (Nikolic & Kasmire, 2013). They are typically used in scientific domains like ecology, biology and social science. ABMs allow for the modelling of decisions of actors in response to changes in their environment and to (changes in) the behaviour of others. ABMs are spatially distributed, and therefore very suitable to explore human actions in response to variations in the spatial environment. An ABM can simulate various actor groups as a heterogenous population; within each actor group, agents can have different characteristics. One of the main advantages of an ABM above other simulation techniques is that it allows for non-rational behaviour in modelling the agent-agent and agent-environment interactions. In addition to structuring one's understanding of current interactions; an ABM allows the exploration of different scenarios and interventions.

The main inputs to the model are the different agent groups, their decision rules, and information on (changes in) their environment. Decision rules describe the response of actor groups, based on their characteristics. For example, actors owning land are likely to respond differently to drought than actors without land.
Limitations for using agent-based modelling include that results of the simulations might be perceived as accurate and reliable predictions, while this is not realistic for complex human behaviour in conflict situations. Furthermore, the method requires a lot of data that is usually only available through surveys. This model handles those data gaps by working closely with local experts. Lastly, an ABM can be incomprehensible for those that did not make the model, which could be a pitfall if the (results of the) model are not communicated clearly.

Agent-based modelling of the Inner Niger Delta

The purpose of the agent-based model for the IND, Mopti region, was to understand patterns over time. It concerned the following pattern:

The increase in intra- and inter-community level conflict in the IND.

Related to this pattern, we aimed to answer the following questions:
- How can the interaction of changed inundation patterns on the one hand, and conflicts in the IND, on the other hand, be explained?
- Through what mechanisms do changed inundation patterns influence these conflicts and what mechanisms are likely to be most dominant?

The purpose of the modelling activity was two-fold. The first was to collaboratively, within the WPS partnership but also together with local experts, come to a better understanding of the above-mentioned research questions during the participatory development of the model. The second was to use the model results to gain a better understanding of the stated research questions.

The model has been developed in three phases and this report reflects the final phase. In the first phase, a preliminary ABM was developed to show the ability of such a model and to start the development of a full ABM. In the second phase, the first version of the current ABM was developed. During the third phase, the model was evaluated, updated and used to simulate scenarios.

The model is extensively described in Appendix A. The method is discussed in Chapter 2 and the model results of the simulated scenarios are described in Chapter 3. In Chapter 4, an expert reflection is given on the model and its results. A discussion is presented in Chapter 5, the recommended use of the model and results is explained in Chapter 6, and Chapter 7 gives recommendations for future work. Finally, Chapter 8 gives insights into the interaction of changing inundation patterns and community conflicts.

2. Method

Participatory process

The conceptual model has been prepared based on a literature review and input sessions with a team of local experts from Wetlands International Sahel Office, International Alert Mali office, GIZ Mali office, and two individual local experts, Aïda Zare and Ousmane Kornio. Instead of gathering information only from literature and theory, a participatory process has been developed for the development of this model to gain a better understanding of the mechanisms that influence conflict.

The process of developing the ABM is depicted in Figure 2.1. Multiple workshops were held with the above-mentioned team, after which written feedback was requested from the participants to validate the interpretation of the input from the workshops. The workshops aimed at gathering information on the appropriate agents and validating the conceptual ABM by 1) getting feedback on the agents, their characteristics, and how that influences their decisions, and 2) getting feedback on the decision rules. The workshops were also meant to lay the ground for literature and experience backing by the IND experts. The program and list of participants of the workshops can be found in Appendix B.

As part of the WPS efforts in Mali and collaboration with GIZ for the FREXUS project, the development of a policy dashboard took place in parallel to the development of the ABM (Water, Peace and Security & FREXUS, 2022). The partners and external stakeholders with which the dashboard was developed, wished for the dashboard to visualize of the impact of several (hydrological) scenarios and interventions to facilitate the dialogue on the links between water and conflict. Results of the ABM have successfully been integrated into this policy dashboard. The results are therefore easier to use for the WPS partners in Mali and local stakeholders. This influenced some of the design choices for the model, like the geographical extent and the simulated time

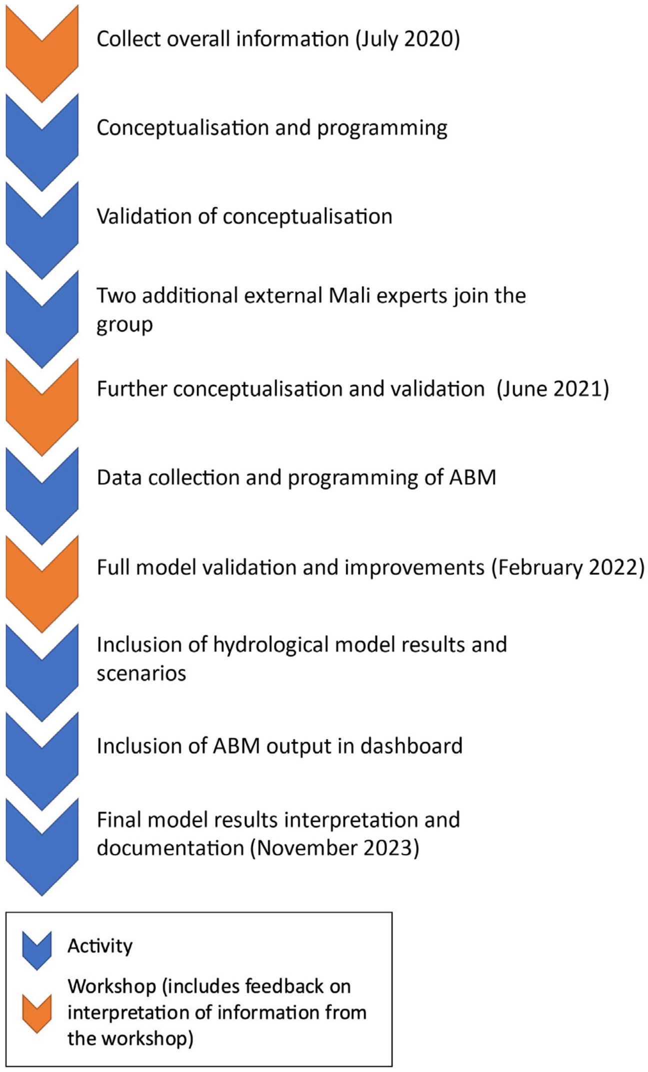

Figure 2.1 Process of developing the ABM.

period. The simulated scenarios are explained in Section 2.4.

Software

The agent-based model is programmed in the agent-based modelling software Netlogo (Wilensky, n.d.). This software is widely used by researchers and in academia. The advantage of Netlogo over other ABM software is the easy-to-program graphical user interface. The modelled 'world' in the interface shows the agents at their locations in the IND, Mopti region (Figure 2.2). The interface can be used to validate the model and to experiment with scenarios by tracking the agent's characteristics and observing the movements of the agents over time.

Model

An extensive model description is given in Appendix A. To enable the reader to understand the results and conclusions without reading the appendix, a brief model explanation is provided below.

The model simulates the period from June 1979 to June 1985, and one time step represents one month. This time period has been selected to include one of the driest years in the Delta, represented by the hydrological year of June 1984 – June 1985. The model starts five years before this year because the ABM required initialization time and to gain a better understanding of the longer-term trend of conflict. The monthly time step has been chosen because it allowed an appropriate representation of the agent's activities (see Appendix A.3.2). The spatial extent and resolution (see Figure 1.1) are chosen to align with the pre-existing hydrological model results that provide input to the model.

The ABM contains three agent types: farmers, herders and fishers, of which each agent represents 10 households (see Figure 2.3). The model assumes that the agents only practice their main source of livelihood. Non-state armed groups are not included in the model as they only became present in the Delta since 2016 (International Alert, 2022). These agents

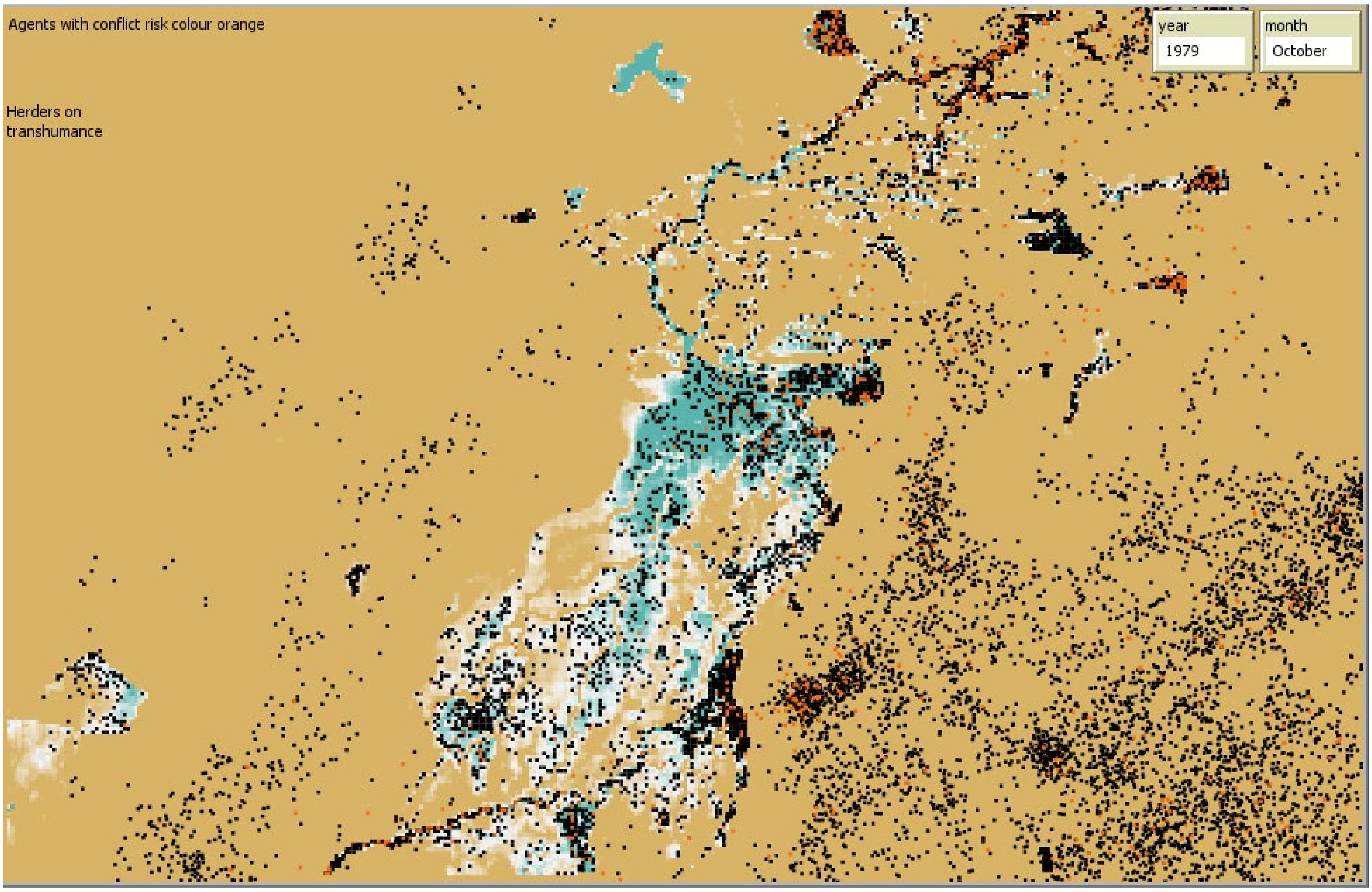

Figure 2.2 Snapshot of the modelled 'world'. The black dots are the agents. Agents with a risk of conflict colour orange. The water depth of the IND is visualized with green-blue-white colours. The darker the colour, the deeper the water. The year and month are displayed in the top-right.

are placed in a spatial representation of the household's environment, including the water system and water-related ecosystem services. The main characteristics of the agents are the timing of their activities for farming, herding or fishing, their preference for a certain natural resource management and conflict resolution system, the resentment that they might build up inter- or intra-community, and their livelihoods. The main characteristic of the environment is the flood inundation depth, which was derived from a study by ISL et. al. (2020). This study used the Delft-3D Flexible Mesh suite[1], an open-source software from Deltares, for the hydrodynamic modelling and to create inundation maps for different scenarios.

All agents follow a monthly schedule of activities. The schedule is the same for each agent in the same group, farmer, herder, or fisher, but differs per group. Agents with an activity might try to find a better suitable location to farm, fish, or herd. When this is the case, agents check if this location is accessible and whether it has enough natural resources available.

Depending on the outcome of those two checks, they decide if they will use that part of land or water. In this process, an agent might develop resentment towards another agent because of disputes about land or water use. After the decision to use or not to use the land or water has been made, and if agents feel resentment towards any socio-economic group (including their own group), they might experience conflict risk.

The relevant indicators, like the fraction of agents with conflict risk, are tracked by the model per time step. These are further elaborated on in Chapter 3.

Stochasticity is an important concept within agent-based models. It describes the lack of any predictable order or plan, or randomness of phenomena. In multiple areas of the model, stochasticity plays a role (see Appendix A.5.1). Because of this, two model runs with the same input settings will not produce the same output.

Preference for a certain type of natural resource and conflict resolution management

Each agent has a random preference for one of the three (traditional, formal, or mixed) management systems. The natural resource management and conflict resolution management are assumed to be in the same institution.

Livelihood

The livelihood of the agents in the model is either sufficient or insufficient. An agents' livelihood is sufficient when the flood depth at its location is above their suitability threshold.

Resentment

The feeling of being treated unfairly; agents in the model can feel resentment towards their own or towards another socio-economic group. Herders and fishers build up resentment against farmers when they want to access land/water that was recently transformed into agricultural land. All agents build up resentment towards their own or another socio-economic group when others do not allow them to access land that the other group is also (partially) using.

1 https://www.deltares.nl/en/software/delft3d-flexible-mesh-suite/

Simulated scenarios

Different scenarios and interventions are simulated to see how these influence the conflict risk over time. We ran and analysed three hydrologic and three demographic scenarios, a resource and conflict resolution management system intervention, and a productivity efficiency intervention, which lead to a total of 36 simulated scenarios (see Figure 2.4). An additional wetter

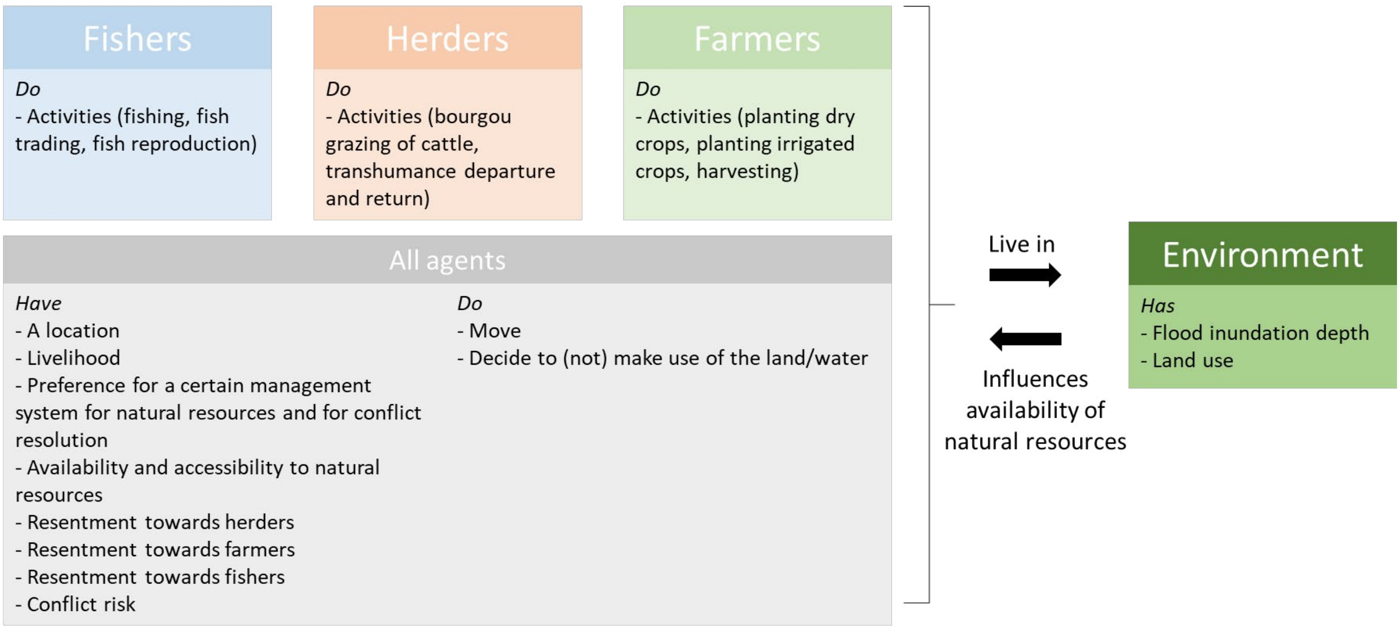

Figure 2.3 Overview of the agents' characteristics, activities, the environment characteristics, and their relation.

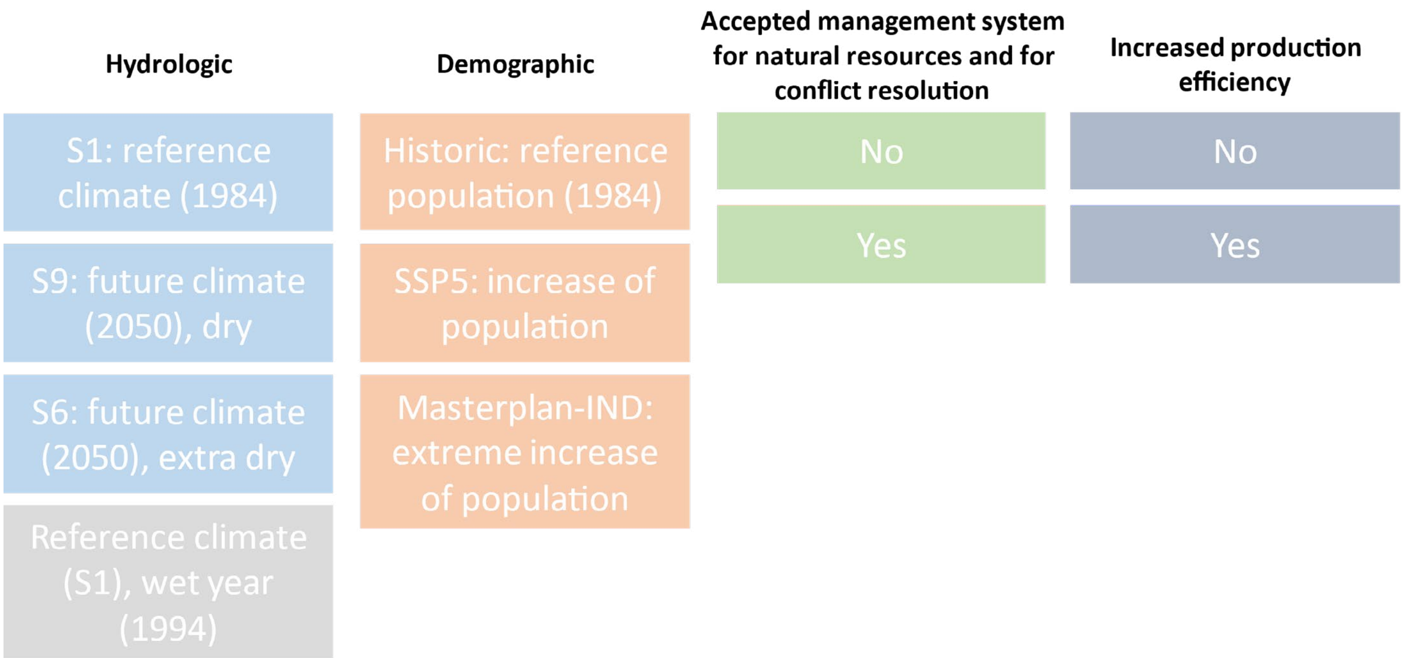

Figure 2.4 Simulated scenarios.

scenario is included by simulating the period from June 1979 to June 1996, including the remarkable wet year of 1994. With the accepted resource and conflict resolution management system intervention implemented, all agents prefer the same management system. Without this intervention, the agents have a random preference for one of the three (traditional, formal, or mixed) management systems. The increased production efficiency intervention decreases the need for natural resources to obtain sufficient livelihood for all agent groups. Both interventions are simplistic implementations of interventions that are complex in reality but can provide insights into which parameters have the greatest influence on conflict risk.

Each scenario is run 200 times, to capture the stochastic variability of the model (see Section 2.3). We observed that the variance of the range of the output variables is small, therefore we chose to show the outcomes as an average of the value over the different runs of the same scenario. The scenarios are explained in more detail in Appendix A.

Calibration and validation

Agent-based models are generally calibrated and validated with historic data. When this data is not available, or only available for a different time period, the model can be calibrated and validated with expert elicitation. For the modelled time period (1979-1985), no conflict data is available for the IND. Conflict databases like ACLED (ACLED, n.d.) and UCDP (UCDP, n.d.) contain data on conflicts from respectively 2004 and 1989 onwards. Furthermore, the conflict databases do not fully represent the non-violent part of the conflict risk that is represented in the model, as in some cases a dispute between for example farmers and herders might not be large enough to be recorded. Because of this lack of data, the ABM is calibrated by aiming to represent the conflict risk trend that is expected by the IND expert group and validated by expert elicitation.

During the workshop in June 2021 (see Appendix B), it was elaborated by the participants that the expected conflict risk trend has seasonal, yearly, and scenario-dependent variabilities. Seasonally, a higher conflict risk is expected in the months of January, February, March, June, July, and August. In January-March, the risk is high because it is the period of decline in flood extent, with a superposition of activities which often interfere with each other namely harvesting, fishing and the return of herders to the IND. In June-July, the risk is high because there is the preparation of agricultural fields, while the herder's cattle are still in the delta and the fishing activities are also still carried out in the same locations. In August, with the gradual rise of water levels, the herders begin to leave the delta. A lower conflict risk is expected in the months of September, October and November because there are fewer overlapping activities and the water levels are high. Annually, a higher conflict risk is expected in the dryer years compared to the wetter years, because of the fewer natural resources available with a smaller flood extent. Scenario-wise, a higher conflict risk is expected in the dryer hydrological scenarios and the scenarios with more population. Like the expected trend of a higher conflict risk with dryer years, we assume that dryer hydrological scenarios and a larger population both implicate that there are fewer natural resources available per household and that there is a higher risk of conflict. A lower conflict risk is expected with an accepted resource management system and increased production efficiency.

The conflict risk output of the model was calibrated with these trends in mind. The calibrated input variables are amongst others the weights of the factors that increase the risk of conflict: resentment, preference for a certain type of natural resource and conflict resolution management, and livelihood (see Appendix A). The values of the calibrated variables are reflected on in Chapter 4.

3. Results

The results of the simulated scenarios have been assessed with three types of indicators related to conflict risk and resentment:

- **Conflict risk** (see Section 3.1): the percentage of households that experience risk of conflict. "Conflict risk" in the ABM considers a broad definition of conflict, including non-violent and violent conflict (see explanation box in Section 1.2). The exact non-violent or violent conflict action is not modelled, because of the broader (system) scope of the model. In the model, a household experiences a higher chance of conflict risk when (1) their resentment towards the socio-economic group of the other household in dispute is higher than a certain threshold, (2) when their livelihood is insufficient and (3) when they prefer a different type of resource and conflict resolution management system. When households experience risk of conflict they have a heightened chance of being involved in a non-violent or violent conflict;
- **Population density** (see Section 3.2) was identified as an indicator that can partially explain the levels of conflict risk over time. The population density indicator is measured as the average population density over the cells in the ABM that contain population; and
- **Resentment to** (see Section 3.3) a certain socio-economic group: the percentage of households from a socio-economic group that experience resentment towards another, or their own, socio-economic group. For example, 20% of the farmers feel resentment towards herders. "Resentment" in the ABM is considered as households feeling mistreated after the actions of others.

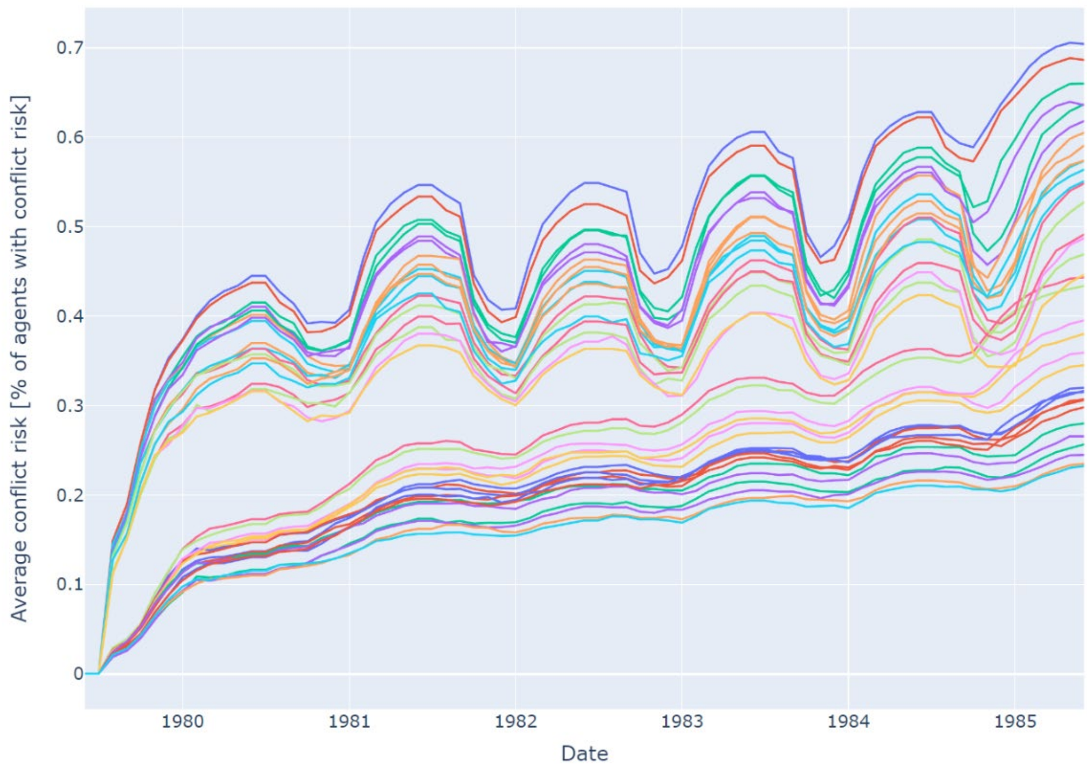

Figure 3.1 Fraction of agents with risk of conflict over time, for all 36 simulated scenarios. The figure does not have a legend because of the many scenarios displayed, and it would be hard to distinguish the different scenarios. It is meant to show the conflict risk pattern that occurs similarly in each scenario.

5. Conflict risk

This section focuses on the variance in conflict risk over time per scenario and the differences between the scenarios (see Section 2.4). First, the results of all scenarios without distinguishing the different scenarios are discussed, and then, the results for different combinations of scenarios are discussed.

All scenarios

The conflict risk over time follows a similar pattern for all scenarios (see Figure 3.1), although for some scenarios this pattern is stronger, i.e., with more variance, than for others. The difference between the patterns with a larger variance is discussed in Section 3.1.3. In January-March, the conflict risk increases; in June-August, the conflict risk is at its peak and starts to decrease; and in September-November there is a decrease in conflict risk. This is in line with the expected conflict risk patterns (see Section 2.5).

Climate and population scenarios without interventions

Without the resource management system intervention and the productivity efficiency intervention, the conflict risk is higher with a dryer climate and more population (see Figure 3.2). The colours of the lines in the graph represent the different climate scenarios, and the dash types of the lines in the graph represent

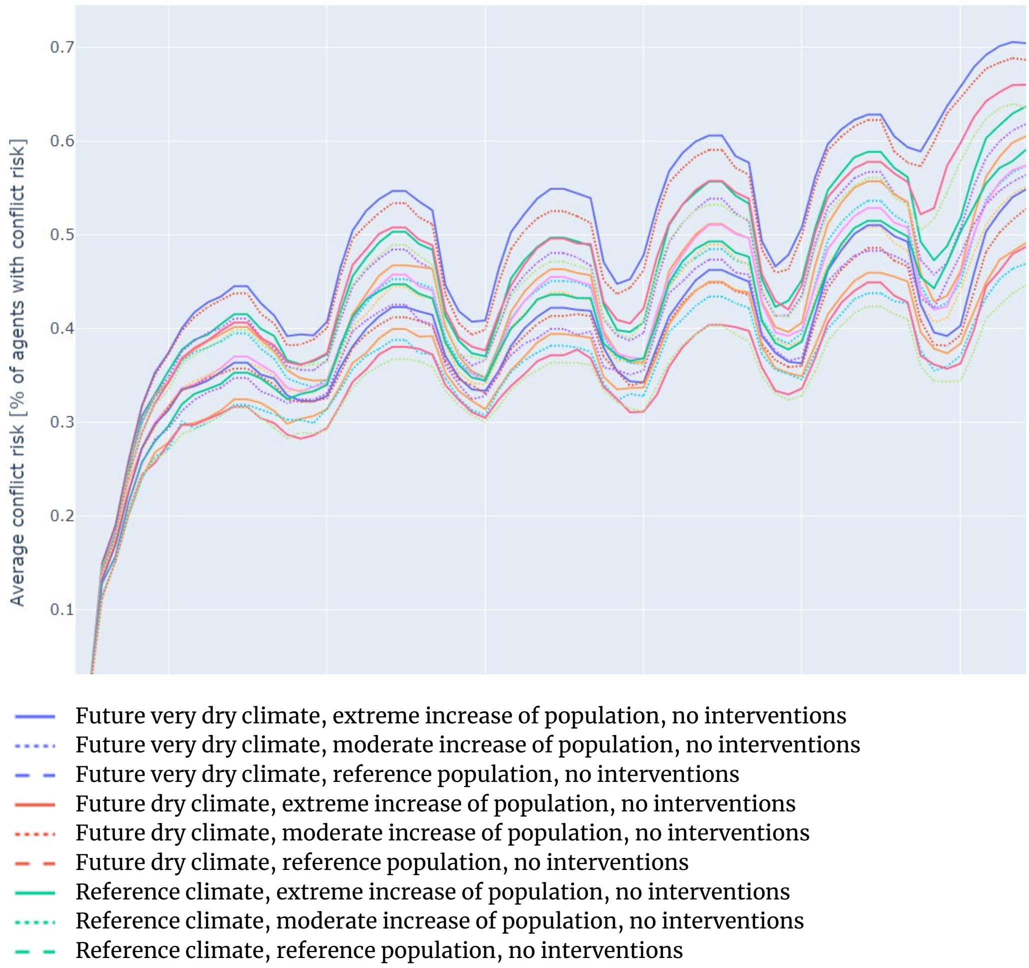

Figure 3.2 Fraction of agents with risk of conflict over time, for the three climate and population scenarios, without interventions.

the different population scenarios. The relative difference between the scenario with the reference climate and reference population and the scenario with the future extra dry climate and extreme population increase is on average 50% (e.g. from 40% to 60% conflict risk in August 1983). The difference in conflict risk varies over time for the different climate scenarios (i.e. with the reference population, comparing the different coloured large dashed lines), the difference in conflict risk is similar over time for the different population scenarios (i.e. with the reference climate, comparing the different dashed green coloured lines).

After each peak of inundated area in October, there is a peak in conflict risk in July-August in the dry period thereafter (see Figure 3.3, top figure). When the flood extent in the peak is smaller compared to the reference scenario, the conflict risk in the dry period thereafter is higher, compared to the reference scenario. The differences in the values of the inundated area and conflict risk peaks of the reference

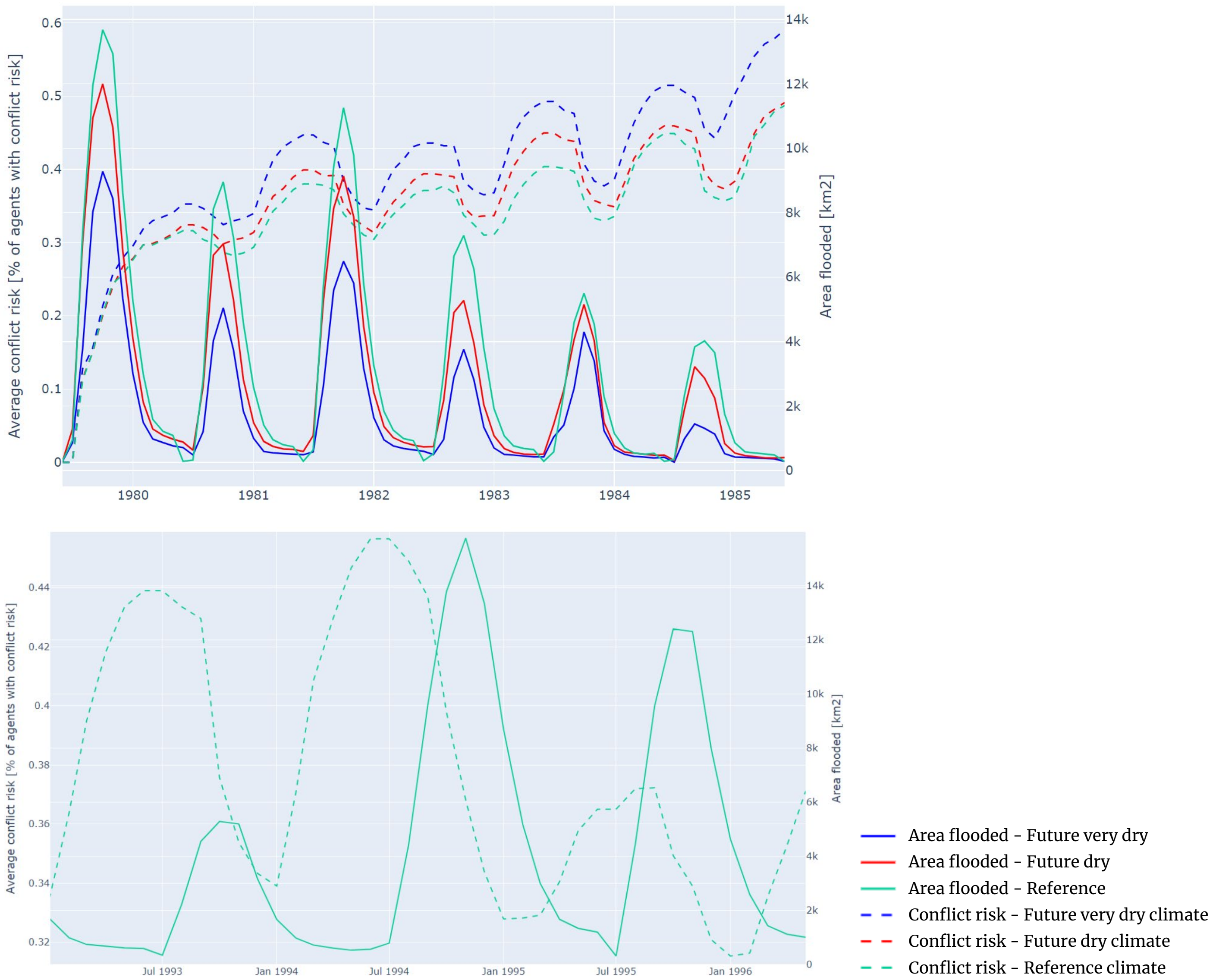

Figure 3.3 Conflict risk and inundated area with a reference population and no interventions for the three climate scenarios (top figure) and the additional wet scenario (bottom figure).

climate were compared with those of drier climate scenarios. The average difference of the inundated area between the reference and future very dry scenario is approximately twice as large as the average difference of the inundated area between the reference and future dry scenario. The conflict risk, however, increases by two-thirds when comparing the average difference for the future very dry scenario and the future dry scenario with the reference climate scenario.

The wetter scenario is presented with the reference climate, around the wet year 1994 (see Figure 3.3, bottom figure). The difference between the peaks of inundated area of 1993 and 1994 is relatively similar to the difference between the peaks of conflict risk of 1994 and 1995. The inundated area is increasing, and the conflict risk is decreasing, both with around 70%. This suggests that there is a one-year delay in the impact of the water system on the risk of conflict. One explanation for this could be because of the process of rice production and fish catch; the peak water level in the last quarter of a year determines the crop yield in the following year and the fish is often caught in the retreat of the flood (ISL et. al., 2020).

For the reference scenario, i.e. reference climate and population, and no interventions, the most occurring factor leading to a higher chance of conflict risk was recorded per socio-economic group. This differs over time but in total the most occurring factors were, in order of most occurring to least occurring:

- **For farmers**: natural resource and conflict resolution management system preference, livelihood, resentment farmers, resentment fishers, resentment herders;
- **For fishers**: resentment fishers, natural resource and conflict resolution management system preference, livelihood/resentment herders, resentment farmers; and
- **For herders:** livelihood, natural resource and conflict resolution management system preference, resentment herders/fishers, resentment farmers.

The order of the most occurring factors leading to conflict risk differs per socio-economic group. Farmers, herders, and fishers undertake activities in different locations in the IND and at different times, requiring different resources. Fishers require more water than farmers or herders and have a smaller area to navigate in. This could explain why resentment from fishers toward other fishers is the main contributing factor to a larger conflict likelihood. Farmers have a low resentment throughout the season (see Section 3.3) and when their resentment 'level' does not pass the set threshold (see Section A.5.2), it will not be included in the factors leading to conflict likelihood. Herders have natural resource requirements that are overlapping with the farmers. However, farmers are more stationary in the model, giving them the 'power' to (not) grant access to, for example, herders, leading to decreased livelihoods for the herders.

The regulation preference is for all socio-economic groups an important, but not dominating factor leading to conflict risk. There is a 67% chance that the regulation preference of two households in dispute differs, as there are three natural resource and conflict resolution management system preference options which are randomly assigned to all households. Interesting to see is that the other factors, resentment and livelihood, can be more frequently-occurring factors leading to conflict risk than this deterministic factor.

Climate and population scenarios with interventions

The intervention of having a generally accepted natural resource management and conflict resolution mechanism is assessed first. There is a difference (on average 20%) in conflict risk between the climate and population scenarios with and without this intervention (see Figure 3.3). This difference is the same as the weighting of the natural resource management preference leading to conflict risk (20%) (see Appendix A, Section A.5.2). However, the natural resource and conflict resolution management system preference also influences the (in)accessibility

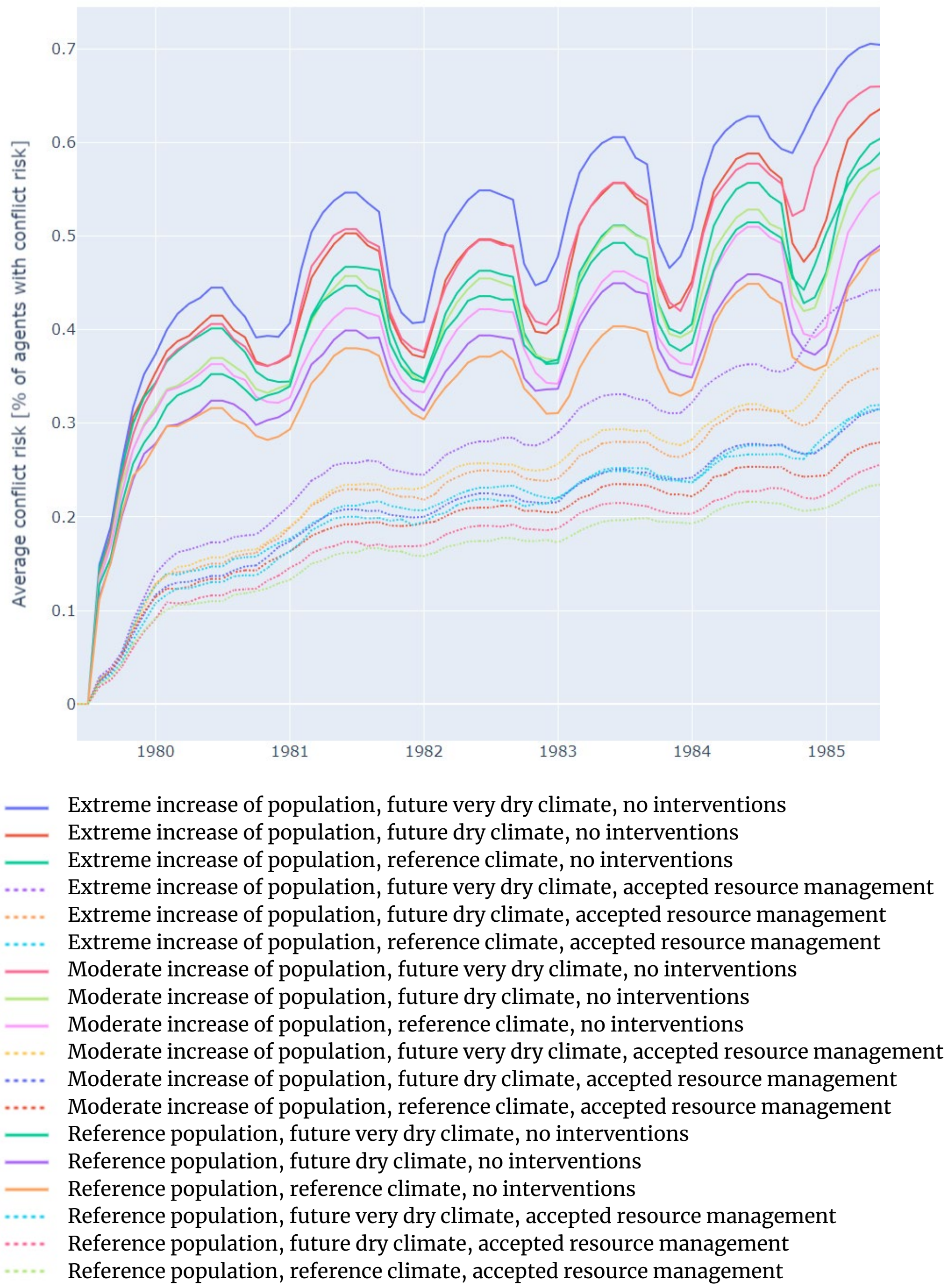

Figure 3.4 Fraction of agents with risk of conflict over time, for the three climate and population scenarios, with no interventions (full lines) and the accepted resource management intervention (dashed lines).

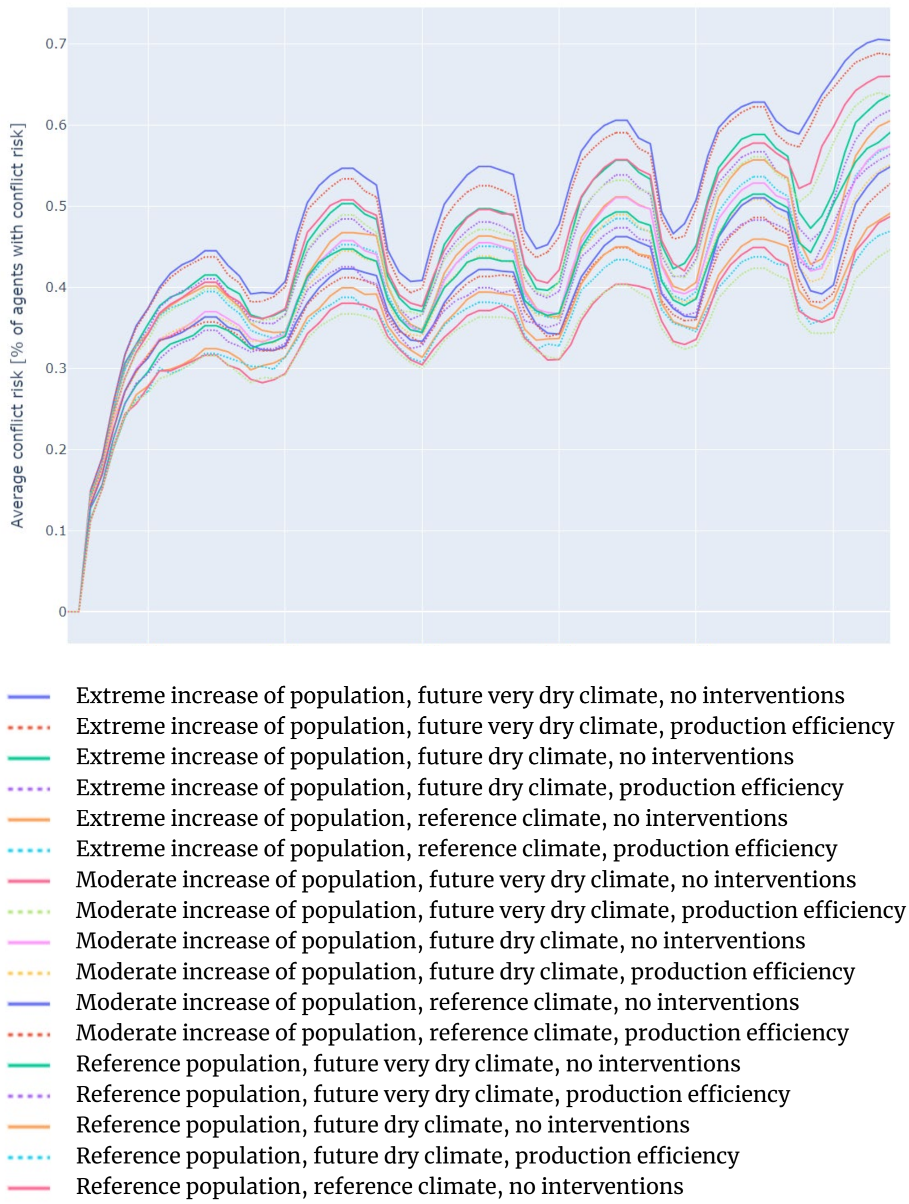

Figure 3.5 Fraction of agents with risk of conflict over time, for the three climate and population scenarios, with no interventions and the production efficiency intervention.

and resentment of the agents (see Appendix A, Section A.3.3), which are drivers for conflict risk, suggesting that the decrease of 20% conflict risk is not a direct effect of the 20% weighting for the natural resource management preference. It should be noted that the pattern of conflict risk with the accepted management system for natural resource and for conflict resolution intervention is still present but is flattened.

This intervention will have the largest effect on the farmers, as the natural resource and conflict resolution management system preference is the most occurring factor that causes conflict risk (see Section 3.1.2). However, as it is the second-most occurring factor that causes conflict risk for the fishers and herders, it also has a large effect on these socio-economic groups.

With the accepted natural resource management intervention, the climate and population scenarios have the same effect on the conflict risk as without this intervention. The drier the climate and the increased population, the more conflict, although the differences between the conflict risk for the scenario with the lowest and highest conflict risk are smaller with the intervention.
The effect of the increased production efficiency intervention on the conflict risk is smaller than the effect of the accepted natural resource management intervention (see Figure 3.5). On average over all population and climate scenarios, there is 1% less risk of conflict with this intervention which is almost a neglectable difference. The increase in efficiency influences the livelihood of the agents, which in turn influences the chance of conflict risk. In the ABM, agents without sufficient livelihood have a 5% higher chance of risk of conflict (see Appendix A, Section A.5.2). More research must be done to study the possible effects of an increased production efficiency intervention in relation to conflict risk.

With both interventions and without intervention, the order of the conflict risk patterns over the climate and population scenarios is the same. From lowest to highest conflict risk, this is (1) reference population and reference climate, (2) reference population and future dry climate, (3) moderate population increase and reference climate, (4) reference population and future very dry climate, (5) moderate population increase and future dry climate, (6) extreme population increase and reference climate, (7) extreme population increase and future dry climate, (8), moderate population increase and future very dry climate, and (9) extreme population increase and future very dry climate.

Conflict risk and population density

The relation between conflict risk and population density over time is investigated with cross-correlation, a statistical measure of the similarity the two variables have increasing or decreasing over time. The maximum cross-correlation values and correlation coefficients for all scenarios

Table 3.1 Average cross-correlation values for all combinations of scenarios, ordered from high to low.

Climate scenario	Demographic scenario	Intervention	Max. cross-correlation[2]	Correlation coefficient[3]
Future very dry climate	Extreme increase of population	No intervention	208.3	0.87
Future very dry climate	Extreme increase of population	Production efficiency	203.9	0.86
Future dry climate	Extreme increase of population	No intervention	172.4	0.84
Future very dry climate	Moderate increase of population	No intervention	169.3	0.86
Future dry climate	Extreme increase of population	Production efficiency	167.2	0.83
Future very dry climate	Moderate increase of population	Production efficiency	163.3	0.85
Reference climate	Extreme increase of population	No intervention	153.7	0.82

2 Discrete cross-correlation, calculated with the NumPy “correlate” function (https://numpy.org/doc/stable/reference/generated/numpy.correlate.html).
3 Pearson product-moment correlation coefficients, calculated with the NumPy “corrcoef” function (https://numpy.org/doc/stable/reference/generated/numpy.corrcoef.html).

Climate scenario	Demographic scenario	Intervention	Max. cross-correlation[2]	Correlation coefficient[3]
Reference climate	Extreme increase of population	Production efficiency	148.3	0.81
Future dry climate	Moderate increase of population	No intervention	136.8	0.83
Future dry climate	Moderate increase of population	Production efficiency	132.3	0.82
Future very dry climate	Reference population	No intervention	126.6	0.84
Reference climate	Moderate increase of population	No intervention	123.2	0.80
Future very dry climate	Extreme increase of population	Accepted resource management system	121.7	0.83
Future very dry climate	Reference population	Production efficiency	120.0	0.78
Reference climate	Moderate increase of population	Production efficiency	119.3	0.85
Future dry climate	Reference population	No intervention	100.7	0.80
Future very dry climate	Moderate increase of population	Accepted resource management system	97.5	0.78
Future dry climate	Reference population	Production efficiency	95.6	0.83
Future dry climate	Extreme increase of population	Accepted resource management system	93.5	0.82
Reference climate	Reference population	No intervention	91.6	0.76
Reference climate	Reference population	Production efficiency	89.1	0.75
Reference climate	Extreme increase of population	Accepted resource management system	82.4	0.79
Future dry climate	Moderate increase of population	Accepted resource management system	74.6	0.79
Future very dry climate	Reference population	Accepted resource management system	67.7	0.81
Reference climate	Moderate increase of population	Accepted resource management system	66.7	0.76
Future dry climate	Reference population	Accepted resource management system	51.9	0.75
Reference climate	Reference population	Accepted resource management system	47.6	0.71

are shown in Table 3.1, ordered from high to low cross-correlation. The conflict risk and population density are plotted for the scenarios with the highest and lowest cross-correlated values, to illustrate this statistical metric (see Figure 3.6). The scenario with the most overlap in time of a relatively high conflict risk with a relatively high population density is the future very dry climate with an extreme population increase scenario, without interventions. The scenario with the least overlap in time of a relatively high conflict risk with a relatively high population density is the reference climate with reference population scenario, with the accepted resource management system intervention.

The dryer the climate and the more population, the higher the cross-correlation of conflict risk and population density. The scenarios with an increase in population have slightly larger cross-correlation values than the dryer climate scenarios. Without interventions, the similarity of the movement of the conflict risk and population density over time is the most similar, followed by the scenarios with production efficiency implemented. The conflict risk and population density are the least cross-correlated with the accepted resource management system intervention because that intervention causes a flattening of the seasonality in conflict risk (see Figure 3.6).

Besides the maximum cross-correlation, the correlation coefficients are also computed per scenario. The closer this value is to 1, the stronger the positive association between conflict risk and population density for a scenario. The correlation coefficients follow a similar trend as the cross-correlation, that is, increasing in value with a dryer climate and more population, representing a stronger (linear) association between conflict risk and population density. However, the scenarios with a dryer climate and with an accepted resource management

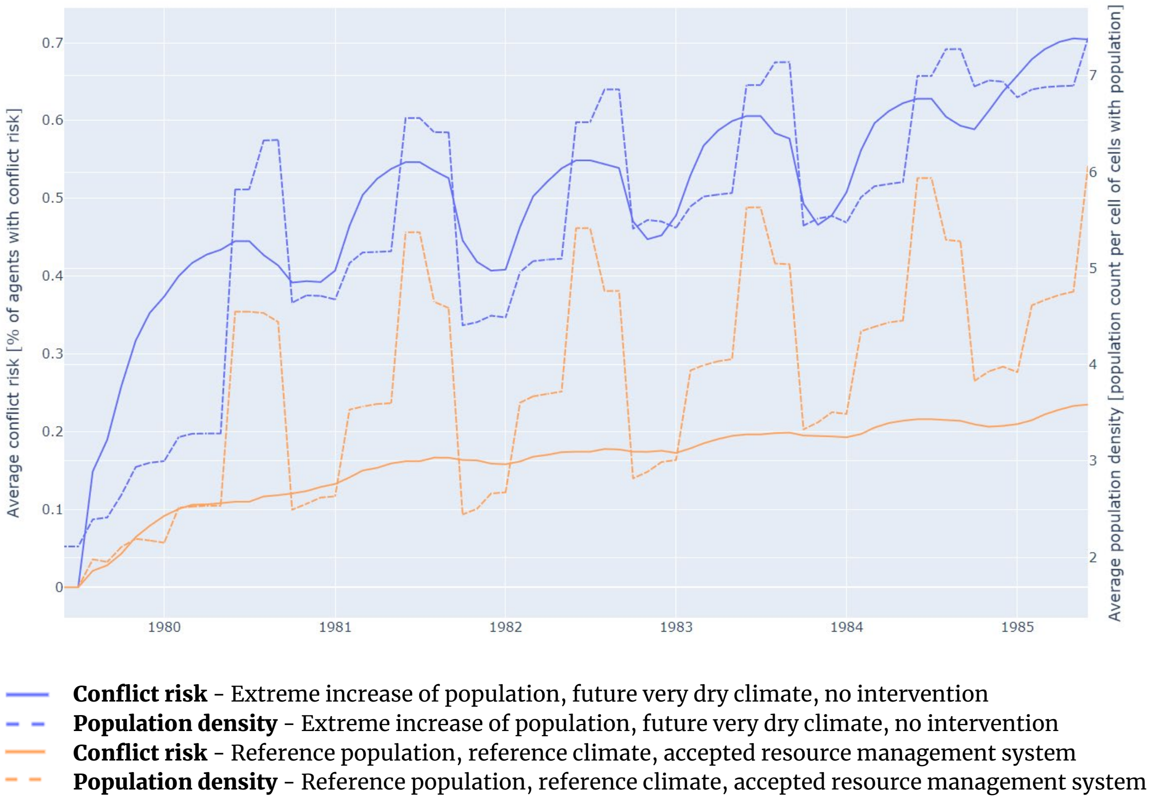

Figure 3.6 Conflict risk and population density for the highest and lowest cross-correlated scenarios.

system are more strongly correlated than cross-correlated, indicating that for these scenarios there is a stronger linear tendency than that there is (relative between the scenarios) an overlap between the time when the conflict risk and population density are high.

The above observations could imply that firstly population growth and secondly a dryer climate are large drivers of seasonal conflict on the one hand, and on the other hand, that firstly a dryer climate and secondly population growth are large drivers of a longer-term conflict risk trend. Furthermore, the accepted resource management intervention has a large effect on reducing the seasonal trend of conflict, but, the long-term trend of increasing conflict, also in relation to population density, is still present.

Resentment

One of the factors in the ABM that leads to the agents having conflict risk is resentment. This is the factor with the highest weight in the model setup that has been used for simulating the scenarios. The other factors are an agent's natural resource management preference, with the second highest weight, and livelihood, with the lowest weight. However, resentment is only the most occurring factor for conflict risk for fishers (resentment to other fishers), for farmers and herders it is the third-most occurring factor for conflict risk (see Section 3.1.2).

It is still interesting to track the levels of resentment per socio-economic group because even if the resentment does not (directly) lead to conflict risk, it is related (see Chapter 4).The levels of resentment differ over time per socio-economic group, and for each scenario, it has been recorded from which group and to which group (inter- or intracommunity) resentment occurs. This results in a lot of data and for the purpose of this report, too much to show here. Therefore, we chose to only present the resentment pattern per socio-economic group for the reference climate and reference population scenario, without interventions:

- **Herders** have high peaks of resentment when they are in the IND, mainly directed to other herders and farmers;
- **Fishers'** resentment peaks from August to March, mainly directed to other fishers, herders and over time increasingly towards farmers;
- **Farmers** have a low resentment throughout the season, mainly directed toward other farmers and herders.

Farmers with a low resentment seems contradictory to the statements made in the expert reflection (see Section 4.1) but it can be explained with the modelled rules of behaviour. In the model, when two households want to make use of the same piece of land, the household that was there first has the 'power' to (not) grant access to the other. In the model, farmers are more stationary than herders, which more often leads to a farmer declining a herder land-access than vice versa. Only being declined increases resentment. This overall pattern of farmers with low levels of resentment might not be the best representation of the reality in the IND, as can be perceived from Section 4.1. This can be a point of improvement for future work.

Expert reflection on the model and results

The model (calibration) and model results are interpreted and reflected on with the help of one of the individual local experts who is an environment, water, and societies specialist with working experience in the IND (Zare, 2022, see C).

Model calibration

The calibration of the weights of the factors determining conflict risk was required to output the expected conflict risk pattern. The expert elicitation however might result in different weightings for resentment, preference for a certain type of natural resource and conflict resolution management, and livelihood, in relation to conflict risk. It brought forward a similar weight value for resentment (25%), a lower value for preference for a certain type of natural resource and conflict resolution management (from 20 to 15%), and a higher value for the influence of livelihood (from 5 to 10-15%) (see 1).

The risk of conflicts is indeed predominantly determined by resentment, without neglecting climatic factors. This is illustrated by Kone (2007), who made an inventory of the frequency of occurrence and causes of conflicts in the region of Mopti. Most conflicts are between farmers and herders (43.5%), caused by for example, refusal of a farmer or herder to leave land, an early return of herders to the IND, damage to fields, and transformation of a pasture into agricultural land. The conflict between farmers (25%), is the second-largest part of conflict, followed by conflict between herders (17.5%), between fishermen (7.29%), and between fishermen and herders (6.61%).

For the groups that make up the largest part of the conflict, the farmers and the herders, the causes of these conflicts are often linked to resentment on the side of the farmers because of damage incurred by herders and their animals, and on the side of the herders because of the occupation of the pastures and non-respect for the herders' calendar by the farmer (Moseley et. al., 2002). The risk of conflict between farmers and herders is higher in November-December due to the risk of crop damage (farmer resentment) (Moseley et. al., 2002). The ABM results show in this period a decline in overall conflict risk, but the resentment from farmers toward herders is at its peak in November-January. The conflict is moderate in June-July, corresponding to the exit of the herders from the delta and the sowing period (risk of destruction of the seedlings, farmer resentment) (Moseley et. al., 2002). The overall risk of conflict from the ABM results is in this period going to and at its peak. The resentment of herders against farmers is at its peak in May-June and then declines because they are practising transhumance in July in the model. The resentment from farmers against herders is lower than in November-January.

A weighting exercise based on expert judgement by a local expert was executed to relate the actions to the three causes that can lead to a risk of conflict, as is modelled in the ABM (see Table 4.2). The weighting ranges from 1 to 5, with 1 being the lowest cause that leads to risk for a certain activity, and 5 being the highest. By taking the sum of all weights per conflict reason category and dividing it with the maximum score per category, we arrive at a weighted average per category (percentage of the total per factor).

Furthermore, by taking the sum of all weights per conflict reason category and dividing it with the maximum score of all categories (15), we arrive at a weighted average over the categories (percentage of the total over all factors). The percentage of the total per factor is 84% for resentment, for regulation preference or rather, the implemented regulation mechanism, 63%, and for livelihood 36%. The percentage of the

Table 4.1 Weights of the factors leading to conflict risk, from calibration (see Section A.5.2) and from expert elicitation (see Appendix C).

Factors leading to conflict risk	Weights from calibration [%]	Weights from expert elicitation [%]	Weights from specific actions leading to conflict causes [%]*
Resentment	25	25	28
Regulation preference	20	15	21
Livelihood	5	10-15	12

*% of total over all factors of Table 4.2

total over all factors, is 28% for resentment, for regulation preference, 21%, and for livelihood 12%.

The weighting exercise provides insight into the effect of certain actions on the three factors leading to conflict risk in the ABM. However, these actions are not specifically modelled in the ABM. Therefore, the overall percentages instead of the per-action weights from the weighting exercise were compared to the calibrated weighting factors. The percentage of the total over all factors (the last row in Table 4.2) was most relevant for a comparison with the calibrated weights in the ABM, because the calibrated weights represent an increase in the chance of conflict risk. Summed-up, this cannot be higher than a 100%. For example, the calibrated weight of regulation preference (20%) implies that there is a 20% higher chance of conflict risk when the regulation preference of the households in dispute are different. To illustrate this further, when the household also has, for example, insufficient livelihood the chance of conflict risk increases further with 5%.

In terms of order of the factor that most influences the risk of conflict, this is the same as is implemented in the ABM. The weights from calibration and the weights from the specific actions leading to conflict causes are also similar, with the largest difference (7%) for the livelihood factor (see Table 4.1). We recommend doing a sensitivity analysis on the weights in future research.

Results interpretation

The 1980s were marked by drought in the IND, resulting in a drop in flood elevation and a decline of the flooded areas. The reference year (1984) is one of the driest years in the Delta with few flooded areas. Figure 3.4 shows that the smaller the flooded area, the greater the risk of conflict. The complexity and particularity of the delta is that the same space is at the same time agricultural, pastoral and a fishing zone following the rhythm imposed by the flood and the flood decline. The smaller the flooded area, the more they are subject to competitive uses, especially between herders and farmers.

Moreover, according to Zare et. al. (2017), the moment when the flood extent is at its maximum is earlier in a dry year. This impacts the schedule of activities in the Delta because

Table 4.2 Weighting exercise that relates actions to causes that can lead to a risk of conflict (Zare, 2022, see C).

Actions	Resentment	Regulation preference[4]	Livelihood
Increasingly incompatible calendars of activities	5	2	4
Nationalization of land and water and modern administration	5	4	1
Early return of animals to the IND and straying of animals	5	4	2
Non-respect of tracks by farmers and breeders	5	2	1
Transformation of a pasture into a field	5	2	3
Denial of animal right of way	4	3	2
Insufficient cropland	4	2	3

Actions	Resentment	Regulation preference[4]	Livelihood
Increasingly incompatible calendars of activities	5	2	4
Nationalization of land and water and modern administration	5	4	1
Early return of animals to the IND and straying of animals	5	4	2
Non-respect of tracks by farmers and breeders	5	2	1
Transformation of a pasture into a field	5	2	3
Denial of animal right of way	4	3	2
Insufficient cropland	4	2	3
Refusal to evict a farmer or breeder	4	4	2
Exceeding cultural limits	4	2	2
Unauthorized occupation of land	4	3	2
Refusal to pay a fee	3	4	1
Attempt to transform pre-trial detention into final detention	5	2	1
Claiming dioro[5] or grazing title	2	4	2
Crossing order violation	4	3	2
Non-payment of royalties to the dioro	4	3	1
Ignorance of stopover lodges	3	4	2
Non-compliance with traditional rules on prohibitions and fishing periods	4	4	2
Damage to fishing structures	5	1	2
Damage to fishing gear	5	1	2
Claiming customary properties	4	5	1
Non-respect of traditional rules	4	5	1
Traditional and modern ruler overlay	4	5	1
% of the total per factor	84%	63%	36%
% of the total over all factors	28%	21%	12%

4 This is rather the implemented regulation mechanism than the regulation preference.
5 Claiming access to grazing pastures and water

the passage of the maximum flood indicates the start of the flood decline (décrue in French) and therefore, the return of herd animals to the IND. The earlier this date, the greater the risk of conflict between farmers and herders because of potential damage from animals in the fields.

As activities are linked with the timing of the flood and the flood decline, the risks of conflicts are also dependent on this rhythm. During the high-water period (September-October), the risk of conflicts decreases because agricultural activity is predominant and corresponds to the period when the herd animals are stationary in the villages or are outside the Delta. Fishing operations are reduced, and fishermen take advantage of this period to repair their gear.

The risk of conflict increases according to the rate of decline of the water levels (November-February) and reaches its peak during low water (March-June). This is explained by the superposition of activities in the same space. As soon as the flood begins, the herd animals enter the delta to take advantage of the bourgou pasture (bourgoutière in French) and this can often cause damage to the fields if the harvests are late. Fishing also begins when the floods recede with the risk of conflicts between fishermen (access to a dwindling resource) and with herders (destruction of gear by animals).

5. Discussion

The development of the ABM has brought us a systemic method of gathering knowledge and information from local experts on the topic of water and conflict in the IND in Mali. During the development process, we have learned how best to gather specific inputs and validate whether our interpretation of the given information was correct. We have learned that at the beginning of the development, a workshop with some open questions about the agents, their characteristics, the environment, and their (inter)actions, works well for understanding better the context and creating an initial conceptualization. Later in the process, when more specific input is required, it is important to ask more specific questions and to let the participants of the workshop take turns in providing input. In this phase, it also works better to show an initial conceptualization of the agents and for example decision flowcharts than to request information without showing how the information will look when conceptualized. Finally, after conceptualizations have been explained to the local experts it is important to request their written feedback on the conceptualizations. The concepts can be hard to grasp in the quick setting of a workshop, so it is required to give them time to think.

The limitations of the participatory process include that the IND experts and stakeholders are already working in the peace-building domain, have an environmental background and/or want to be included in the participatory process. This might have resulted in a view of the complex relation between natural resources and conflict as a more one-dimensional causal relation, while other factors (e.g., politics, institutions, non-state armed groups, legitimacy of the state) are very relevant and could have been more detailed in the model.

During the development process, literature research was done in parallel. The added benefits of developing an ABM, besides only doing a literature review and general stakeholder engagement, are two-fold. On the one hand, the model enables investigating future conflict trends with population and climate projections and test potential measures like an accepted resource and conflict resolution management system and a productivity efficiency intervention. On the other hand, the conceptual model and its outcomes give information on the micro- and macro-scale. Micro in terms of behaviour and the different pathways to conflict, and macro in terms of relations between climate, population counts, population density, measures, and finally the overall risk of conflict. An unexpected insight of the ABM is that the measure of an accepted resource and conflict resolution management system decreases the seasonality in overall conflict risk but does not significantly decrease the correlation between population density and conflict risk and an upwards trend in conflict risk is still present.

Furthermore, some design choices have greatly influenced the ABM and therefore it's results. The decision to model the chosen time period with the most severe drought resulted in that we could not compare the results to conflict databases and there were no non-state armed groups present at that time, which are extremely influential in present-day. The inclusion of the latter as an agent group would have increased the conflict risk in all scenarios. The decision to model agents as having one profession, either farmer, fisher, or herder, has influenced the mechanics leading to conflict risk. When agents would be able to diversify their livelihood, the conflict risk might be positively (e.g., the agents will have a higher chance of successfully providing in their livelihoods) or negatively (e.g., more agents want to switch to the same other source of livelihood) affected. The institutions, like the natural resource and conflict resolution management systems, were not modelled as agents. This could have expanded the knowledge of the mechanisms that could help in peace-building, like the accepted natural resource and conflict resolution management system intervention.

6. Recommendations on the use of the model and results

We recommend that the ABM and results are used to better understand the relation between changing inundation patterns and conflict risk. The "pathways", or "mechanisms", to conflict exist of multiple actions and interactions between the farmers, fishers, herders, and their environment in the IND, over time. The conceptualization of the ABM, namely the characteristics of the agents, the decision rules, the actions and interactions (see Appendix A), helps in understanding these mechanisms. A better and more integral understanding of the mechanisms hopefully helps to view the behaviours and actions from different points of view and to find a more integral and holistic solution to the identified issues. Furthermore, the results of the model help to understand the implications of scenarios and interventions on the mechanisms and conflict risk. This can help to steer the users of the results in directions for considering certain interventions. The results point more towards interventions leading to a general societal accepted system to manage natural resources and conflict resolution than increasing the production efficiency.

The agent-based model and results should not be interpreted as the truth or method to predict the locations and frequency of future conflict, but they should be used to explore the impact of a range of possible scenarios. Furthermore, the results should be used in the comparison between the scenarios, instead of using the absolute output metrics per scenario.

7. Recommendations for future work

During the development of the ABM, many ideas for improvements and additions were formed. We recommend considering these for any future work on this model.

Improvements to the model. In addition to increasing resentment due to the non-accessibility of natural resources, resentment also increases when ethnic polarization increases. Polarization can be estimated with the ethnic polarization index (Chakravarty & Maharaj, 2010), which indicates the ethnic diversity in a population. Inequality further increases resentment, which could be estimated at a later stage, based on differences in livelihood between ethnic and socio-economic groups.

Besides resentment, livelihood, and natural resource regulation preference, another factor that influences conflict risks linked to natural resources is the presence of armed groups. According to Pflaum (2021) communal violence tends to increase when armed groups are present, as they exploit local grievances. This factor has not been included in the model because, in the simulated years (1979-1985), these armed groups were not yet present. However, this factor should be added in future work as in the time after 2012 one cannot understand the violence and conflicts related to natural resources without looking into jihadist, self-defence groups as well as Malian and international troops in the zone.

The low resentment levels of farmers could be further investigated. One way to better estimate the resentment of farmers is to explicitly include land ownership, which is a central issue in the IND (International Alert, 2022). Nevertheless, one must weigh the time it takes to include this and the order of magnitude of better understanding the system.

Expansion of the model. In stakeholder discussions held for the parallel dashboard development, the stakeholders expressed that the model would gain in quality if the forestry livelihood group would be explicitly modelled rather than implicitly within the farmer group. We recommend looking into adding this agent group to the model.

Validation with conflict data. The ABM is calibrated and validated by expert elicitation, however, the model results could be interpreted with more confidence if it would be validated with actual conflict data, e.g. from ACLED. Because this data is only available from 2004, we recommend running the model with flood maps from 2004 to the most recent available year and comparing the results to the ACLED database.

Sensitivity analysis. The development of the ABM and its results give insights that are validated and reflected on by IND experts. However, the model sensitivity to its input parameters is not assessed. Therefore, we recommend doing a sensitivity analysis on, at least, the calibrated variables, and preferably also on the variables that are used for the initialization of the agents.

8. Insights into the interaction of changing inundation patterns and community conflicts

With the results and the expert reflection on the results, we answered the research questions from Section 1.3.

How can the interaction of changed inundation patterns on the one hand, and conflicts in the IND, on the other hand, be explained?

The path from changed inundation patterns to conflict is represented in the agent-based model via the accessibility and availability of natural resources, that influence the resentment and livelihood of farmers, herders and fishers. The required natural resources per socio-economic group are defined by (the schedule of) their activities, hence the different groups need land or water suitable for their activities at different times of the year. The household's resentment, livelihood and preference for a certain natural resource management and conflict resolution mechanism, determine the household's risk of conflict.

The ABM has shown that with drier inundation patterns, i.e. comparing the reference climate with a future dry or very dry climate, an overall higher risk of conflict occurs. A wetter year subsequently results in lower levels of conflict risk. However, the changed inundation pattern is not the only factor influencing the conflicts in the IND. A moderate or extreme increase in population also increases the risk of conflict, compared to the reference population scenario. The moderate and extreme population scenarios in combination with the reference climate scenario even result in more conflict risk than respectively the future dry and very dry climate scenarios in combination with the reference population scenario. This could suggest that natural resource availability might have a smaller influence on conflict risk than accessibility and population density. However, no sensitivity analysis has been done to verify that the population scenarios influence the conflict risk more than the climate scenarios.

The activities that the farmers, herders and fishers undertake to sustain in their livelihoods are statically modelled in the ABM; the households do not change the timing of their activities according to the changes in inundation pattern. However, the households do change location over time, depending on more or less successful activities, like crop planting for a farmer. If the environment does not provide the required resources for the household, they are more likely to move to a location that does provide these resources. Therefore, the relation between population density and conflict risk was assessed. These two factors are indeed correlated, with a higher correlation for a dryer climate and a larger population. The correlation shows the longer-term trend of changes in inundation patterns and households moving to locations with sufficient resources, leading locally to higher population densities and more conflict. Furthermore, the seasonal conflict is increasing and decreasing in the same pattern as the seasonal population density. Only the accepted resource management system intervention changes this, by decreasing the seasonality in overall conflict risk. However, this intervention does not significantly decrease the correlation between population density and conflict risk.

Through what mechanisms do changed inundation patterns influence these conflicts and what mechanisms are likely to be most dominant?

A decrease in inundated area decreases the area of land and water that is suitable for fishers, farmers and herders to provide for their livelihood. Similarly, an increase in population in the same area decreases the suitable area for the three socio-economic groups. Accessibility can be an issue for those that cannot find an unused piece of land or water. For households that request access, the main factor that determines whether they get access is if they have recognized and adopted the same natural resource and conflict resolution management. The unavailability of suitable land or water can make fishers, farmers and herders unable to provide for their livelihood and stimulate the illegal use of others' land or water and the damaging of others' properties. For example, a farmer that transforms a pasture into agricultural land and a herder's cattle damaging others' fishing structures and/or gear. Illegal use of land and damage to one's properties increases resentment between households in dispute, which can lead to risk of conflict.

Each socio-economic group in the agent-based model has a different main driver for conflict risk. For farmers, the main driver is their preference for a certain natural resource and conflict resolution management system, for fishers it is their resentment towards other fishers, and for herders it is their insufficient livelihood. Over time, these factors vary in their contribution to the risk of conflict.

The tested interventions, implementing an accepted natural resource management and conflict resolution system and improving production efficiency, show the influence of the regulation and livelihood mechanisms on the conflict risk.

The accepted natural resource management and conflict resolution system has the largest influence, decreasing the conflict risk by 20% on average. This intervention also decreases the seasonal pattern of conflict risk, which could be interpreted as the interaction between households being more peaceful throughout the year. The contribution of natural resource management preference was calibrated to account for a 20% larger chance of risk of conflict if the preference was different between the two parties in dispute. This is however not only a direct relation in the model, because the intervention also solves reasons for resentment for non-accessibility of land and enables households to peacefully share parts of land and water, that in turn can lead to a decrease in conflict.

The effect of the increased production efficiency intervention is much smaller, it decreases the conflict risk by 1% on average. This intervention makes it possible for the farmers, herders and fishers to have a stable livelihood with fewer natural resources. The livelihood however has a smaller influence on the mechanisms that lead to conflict. Before obtaining livelihood, households need to have access to land or water, which is largely determined by their natural resource preference and that of the owner of the resource. Also, we calibrated the agent-based model to resemble the expected conflict risk patterns as such, that insufficient livelihood contributes to a 5% larger chance of conflict risk.

Changes in inundation patterns influence conflicts in the IND through multiple mechanisms, namely availability, accessibility, livelihood, and the implemented or preferred natural resource management and conflict resolution system. The direct influence of changes in inundation patterns influences natural resource availability and the livelihood of households. These are also influenced by the number of households that need to make use of those resources and the population density. A more indirect influence of changes in inundation pattern on conflict is through the implemented or preferred natural resource management and conflict resolution system. The way that the resources from inundation are managed and how households competing over natural resources interact with each other, has a much larger influence on the resentment and conflict risk than the availability of those natural resources.

How natural resources are managed and how households competing over natural resources interact with each other, appears to have a much larger influence on the conflict risk than the availability of those natural resources. The pressure of a drier climate and population growth on existing natural resources seem to be an underlying continuous driver for the increase of conflict risk, whereas the seasonality of the conflict risk seems to be caused by the conflicting ways of management of natural resources and of conflict resolution. A wetter climate does relieve some of the pressure, decreasing the conflict risk in the successive year, however, an accepted system to manage natural resources and conflict resolution decreases the conflict risk more.

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Appendix A. Model description

The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al. 2006), as updated by Grimm et al. (2020) (see Figure A.1). We use the ODD protocol to make the model description as complete and transparent as possible so that results can easily be traced back to modelling decisions and/or assumptions.

Purpose and patterns

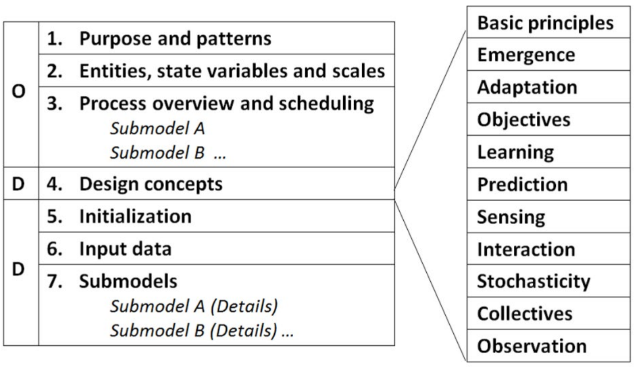

Figure A.1 ODD protocol overview from Grimm et. al. (2020).

The purpose of this model is to better understand the interaction between the availability of water and water-related ecosystem services on the one hand and intra- and inter-community conflict in the IND on the other hand. To better explain the purpose of this model, the context in which it is developed must be described. The model is developed within the Water, Peace, and Security[6] (WPS) partnership that had multiple activities ongoing in Mali at the time of development. One of those activities was the development of a policy dashboard[7] as a local analytical tool, which was developed in a combined effort between WPS and FREXUS[8]. The partners and external stakeholders with which the dashboard was developed, wished for it to give insight into the effect of different hydrological scenarios and possible interventions on conflict. It was decided to use the agent-based modelling results in the dashboard to quantify this relationship. This influenced some of the design choices for the model, like the geographical extent and the simulated time period.

We evaluate the model's suitability for application in the dashboard by its ability to reproduce the seasonal and yearly patterns of conflict risk amongst households in the IND. The patterns are defined by expert elicitation, in this case through a workshop in which conversations were held about the expected conflict risk during different seasons. Different conflict risk intensities are expected for different hydrological and demographic scenarios and for different interventions regarding governance.

Entities, state variables and scales

This section explains the entities, state variables and scales of the agent-based model.

Entities

The participatory development process (see Section 2 of the main report) of the agent-based model identified three main socio-economic groups in the IND: farmers, herders and fishers. For the most part the socio-economic groups are aligned along the lines of ethnic groups.

Farmers are mainly Bambara, Marka and Dogon, of which the Bambara represent the largest ethnic group in the country (33%[9]). Most farmers (approximately 95%) are small subsistence farmers, growing millet, sorghum or cowpea. Although approximately 87% of agricultural farmers claim to own a field or agricultural area, only 12% hold a land title (Bodian et al, 2020).
Herding is mainly practiced by the Fulani (International Alert, 2022). Historically the

6 https://waterpeacesecurity.org/
7 https://app.powerbi.com/view?r=eyJrIjoiMTMzYjkzNjktMDczNC00YThkL-WFhNTktYzRjM2RlN2RkNmZhIiwidCI6IjE1ZjNmZTBlLWQ3MTItNDk4M-S1iYzdjLWZlOTQ5YWYyMTViYiIsImMiOjh9&pageName=ReportSectiond-4103a4b98981952e180&pageName=ReportSection9cbb0fb9530b10b055b9
8 https://www.water-energy-food.org/frexus-improving-security-and-cli-mate-resilience-in-a-fragile-context-through-the-water-ener-gy-food-nexus
9 We found three different sources, world population review, the OECD and the CIA World Factbook, that all give a different percentage. The 33% of the CIA World Factbook (CIA, 2022) was chosen as it is the median of the three.

herders follow a nomadic lifestyle, migrating according to long-standing seasonal migration schemes, following a strict calendar, in search for feed for their cattle (Morand et al, 2016). Herds of livestock are mainly owned by the head of the household, the shepherds in charge are mostly the children or fellow villagers of the head (Bodian et al, 2020). Slowly the nomadic lifestyle starts to change, with more herders settling down.

Fishers, mainly consisting of Bozos and Somonos, and have authority over the different waters of the IND (International Alert, 2022).

The different groups tend to diversify their livelihood according to the environmental opportunities. This means that a Bozo fisherman can convert (part of the season) into a farmer and a Fulani herder into a farmer or fisher. Table A.1 presents the percentage of households that practise a certain activity and illustrates the diversification of livelihoods.

Table A.1 Percentage of households that practise a certain activity (Bodian et al, 2020).

Livelihood activity	% Households
Agriculture	77%
Animal husbandry	74%
Fishing	13%

The following paragraphs explain how these groups are implemented in the model.

The entities that are included in the model are agents representing farmer households, agents representing fisher households, agents representing herder households, and spatial environment, i.e. the spatial representation of the household's environment including the water system and water-related ecosystem services.

Each agent, farmer, herder, or fisher, represents 10 farmer, herder, or fisher households in the IND. The spatial environment is built up by grid cells representing the IND. Each grid cell represents 1x1km of land or water, some grid cells also contain settlement locations.

The agent entities were chosen by the workshop participants and Deltares during a workshop in July 2020 (see Appendix B) as they were perceived the most relevant socio-economic groups to the increase of conflict risk in the IND. The focus of this research is on the relation between changes in the water system and water-related ecosystem services on the one hand and conflict on the other hand. Therefore, the spatial component has been included as grid cells. Another reason to make the model spatially explicit is that within the socio-economic groups, some or all households are nomadic and that causes different (inter)actions than those for stationary households.

State variables

State variables, or attributes, of the entities characterize its current state. A state variable distinguishes an entity from other entities of the same kind (e.g., distinguishes a farmer from other farmers) and traces the changes in state over time (e.g., how a farmer's livelihood develops over the seasons and years). To understand why and in what context these state variables are used, a very brief explanation of the agent's activities and decision rules is provided below. A more detailed description of the activities can be found in Section A.3.2 and of the decision rules in Section A.3.3.

All agents follow a monthly schedule of activities, of which some months do not have any activity. The schedule is the same for each agent in the same group, farmer, herder, or fisher, but differs per group. Agents with an activity might try to find another location, the move-option (see Table A.2). When this is the case, agents check if the option to move to is accessible and whether it has natural resources available. Depending on the outcome of those two checks, they decide if they will use that part of land/water. In this process, an agent might feel resentment towards another agent because of disputes on land or water use. After the decision to use or not to use the land/water has been made, and if agents feel resentment towards any socio-economic group (including their own group), they might experience conflict risk.

The state variables of the agents are described in Table A.2[10]. First, the state variables that apply to all agent groups (i.e., farmers, fishers and herders) are described, and lower in the table the state variable that only applies to the herder agent is described.

Table A.2 State variables of all agents together and agent-specific state variables.

Name	Dynamic/ static*	Type	Range	Description
All agent groups				
my-suitability-threshold	Static	Float	Any positive numeric value	When the current grid cell where the agent is located has a water depth [m] above this threshold, that grid cell is a suitable land or water for the agent
regulation-preference	Static	Text string	“Traditional”, “formal”, or “mixed”	The natural resource and conflict resolution regulation mechanism preference of the agent.
my-land-use	Static	Text string	“Pasture”, “farmland”, or “fishing ground”	The land use of the agent, this is used to indicate if land is recently transformed to farmland.
my-activities	Static	List of text strings	A list of activities per month (see Section A.3.2)	The monthly activities per agent group.
activity	Dynamic	Text string	For possible values per agent group, see Section A.3.2.	The activity of that agent of that month.
accessibility	Dynamic	Boolean	True/False	This indicates that the agent has or does not have accessibility to the preferred land/water. Accessibility is defined by following the “accessibility” decision rule (see Section A.3.3).
availability	Dynamic	Boolean	True/False	This indicates that the land/water an agent is located on is suitable, or has enough natural resources, for the agent’s profession. This suitability is determined with the agents my-suitability-threshold by following the “availability” decision rule (see Section A.3.3).
other-party	Dynamic	Other agent(s)	One or multiple other agents	The agent(s) that is/are on the same piece of land/ water.

move-option	Dynamic	Grid cell locations	List of potential suitable land/water	When an agent wants to move to a different location it searches in radius search-r-land for farmers and herders or search-r-water for fishers for a suitable location. The result is this list of possible options.
move?	Dynamic	Boolean	True/False	This indicates that the agent will move to a different location or will stay in the same location
use-land?	Dynamic	Boolean	True/False	This indicates that the agent will or will not use the land/water at its current location.
locations	Dynamic	List of grid cell locations	List of locations where the agent has been	A list of the locations where the agent has been each month, monthly updated.
current-water-depth	Dynamic	Float	Any numeric value	The water depth at the location of the agent at that time.
resentment-herders	Dynamic	Integer	Any positive numeric value	The number of times resentment towards herders is experienced.
resentment-farmers	Dynamic	Integer	Any positive numeric value	The number of times resentment towards farmers is experienced.
resentment-fishers	Dynamic	Integer	Any positive numeric value	The number of times resentment towards fishers is experienced.
total-resentment	Dynamic	Integer	Any positive numeric value	The total number of times resentment is experienced towards any group.
livelihood	Dynamic	Boolean	True/False	This indicates whether the agent could obtain sufficient livelihood from its profession (farming, herding or fishing).
factors-conflict	Dynamic	List of text strings	"resentment-fishers", “resentment-herders”, resentment-farmers”, “regulation-preference”, and/or “livelihood”	The factors that contributed to potential conflict risk.
conflict-risk	Dynamic	Boolean	True/False	True or false
Herders				
transhumance?	Dynamic	Boolean	True/False	This indicates whether the herder agent is practicing transhumance and is outside of the model extent (True) or is not practicing transhumance and is within the model extent (False).

*Dynamic is that the state variable is changing over time and static is that the state variable is never changing.

The state variables of the spatial environment are explained in Table A.3.

Table A.3 State variables of the spatial environment

Name	Dynamic/ static*	Type	Range	Description
water-depth	Dynamic	Float	Any positive numeric value	The water depth from the hydrological model output (see Section 0)
max-annual-water-depth	Dynamic	Float	Any positive numeric value	The maximum annual water depth from the hydrological model output (see Section 0
land-use	Dynamic	Text string	"Pasture", "farmland", or "fishing ground"	The land use in the current time-step
land-use-last-season	Dynamic	Text string	"Pasture", "farmland", or "fishing ground"	The land use in the time-step before the current
recently-transformed-to-farmland	Dynamic	Boolean	True/False	The state variables land-use and land-use-last-season are used to determine this state variable that indicates whether the grid cell has recently transformed from pasture or fishing ground to farmland
population	Static	Integer	Any numeric value	The number of agents per group that needs to be created per grid cell. The same number applies to all agent groups because the groups are equally divided (see Section A.5)
dire-station?	Static	Boolean	True/False	To indicate the location of the Diré station, to check the consistency of the water levels in the agent-based model with the hydrograph (see Section 0)

The state variables of the global environment are explained in Table A.4.

Table A.4 State variables of the global environment

Name	Dynamic/ static*	Type	Range	Description
Scenarios				
flood-scenario	Static	Text string	"S1", "S6", or "S9"	The hydrologic scenario of which the water depth maps are used
demographic-scenario	Static	Text string	"historic", "masterplan-IND", or "SSP5"	The population scenario that determines the starting population in the model
accepted-management-system	Static	Text string	“Yes” or “No”	The scenario where there is or is no accepted natural resource and conflict management regulation system
increased-production	Static	Text string	“Yes” or “No”	The scenario where agents do or do not have a more efficient (increased) yield/catch
Calibration				
initial-%-successful-conflict-resolution	Static	Integer	0-100	The (initial) percentage chance an agent has to successfully resolve the dispute it is in. From this percentage, the w-resentment, w-regulation-preference, and w-livelihood are subtracted if they apply (see Figure A.7)
w-resentment	Static	Integer	0-100	The percentage (weight) that experiencing resentment contributes to the chance that a dispute will not be successfully resolved
threshold-resentment	Static	Integer	Any positive numeric value	The number of times an agent experiences resentment towards others, after which the percentage w-resentment is subtracted from the initial-%-successful-conflict-resolution
w-regulation-preference	Static	Integer	0-100	The percentage (weight) that having a different natural resource and conflict resolution preference contributes to the chance that a dispute will not be successfully resolved
w-livelihood	Static	Integer	0-100	The percentage (weight) that not having a sufficient livelihood contributes to the chance that a dispute will not be successfully resolved

Population				
factor-decrease-pop	Static	Integer	1-20	The number of households in reality represented by one agent in the model, the default value is 10
annual-pop-growth	Static	Float	1.62%	The annual population growth (see Section A.3.1 and A.6.4)
Output				
all-households	Dynamic	List		All agent households of all three socio-economic groups
total-conflict-risk	Dynamic	Integer	0 to the total number of agents in the model	The number of agents with a risk of conflict
perc_conflict_risk	Dynamic	Float	0-1	The fraction of agents with a risk of conflict
fr-livelihood-<group>	Dynamic	Float	0-1	The fraction of the socio-economic group (farmers, fishers, or herders) that have sufficient livelihood (see A.7.1)
resentment_<group1>_<group2>	Dynamic	Integer	Any positive numeric value	The number of agents from group1 with resentment towards group2. This can for example be the number of herders with resentment towards farmers but also the number of herders with resentment towards other herders
resentment_to_<group>	Dynamic	Float	0-1	The fraction of households that feel resentment towards a certain socio-economic group, like farmers
resentment_from_<group>	Dynamic	Float	0-1	The fraction of households from a certain group that feel resentment towards any other socio-economic group, including their own
<group>-factors-conflict	Dynamic	List	List of strings[11]	A list with factors that lead to households of a socio-economic group (farmers, fishers, or herders) having risk of conflict
sum-<group>-factors-conflict	Dynamic	List	List of integers	The number of occurrences of the factors that lead to households of a socio-economic group (farmers, fishers, or herders) having risk of conflict

11 The values of this list can be “resentment-fishers”, “resentment-herders”, “resentment-farmers”, “regulation-preference”, or “livelihood”.

Environment				
month	Dynamic	Integer	1-12	The month as a numeric value; 1 is January, 2 is February, and so on
year	Dynamic	Integer	Any positive numeric value	The year
total-km²-flooded*	Dynamic	Integer	0 to the total number of grid cells (95,589, see Section A.2.3)	The total square kilometre that is flooded in the current time-step
total-list-km²-flooded*	Dynamic	List	List of integers of total-km²-flooded	A list of total-km²-flooded per month
annual-max-km²-flooded*	Dynamic	Integer	0 to the total number of grid cells (95,589, see Section A.2.3)	The maximum area flooded in a time-step, per calendar year

* These values are implemented to validate a correct implementation of the hydrodynamic model results into the agent-based model (see Section A.6.2).

Scales

One time step represents one month and simulations were run from June 1979 to June 1985. A wetter scenario is represented by simulating a wetter year (1994, see Section A.5.1) and therefore was run with its associated scenarios from June 1979 to June 1996. Each square grid cell represents 1 km and the model landscape represents 387 x 247 km; i.e., 95,589 square kilometres. The temporal extent and resolution are chosen to align with the dashboard development. The stakeholder meetings for the dashboard development indicated that they prefer to display data from a typical dry hydrological year like that of June 1984 – June 1985. The dashboard displays the same monthly activities that are used as the activities for the agents (see Section A.3.2), and a monthly debit value. To also be able to show a monthly conflict risk value, we chose a monthly time step. The spatial extent (see Figure A.2) and resolution are chosen to align with the pre-existing hydrological model results that provide input to the spatial environment entity (see Section A.6.2).

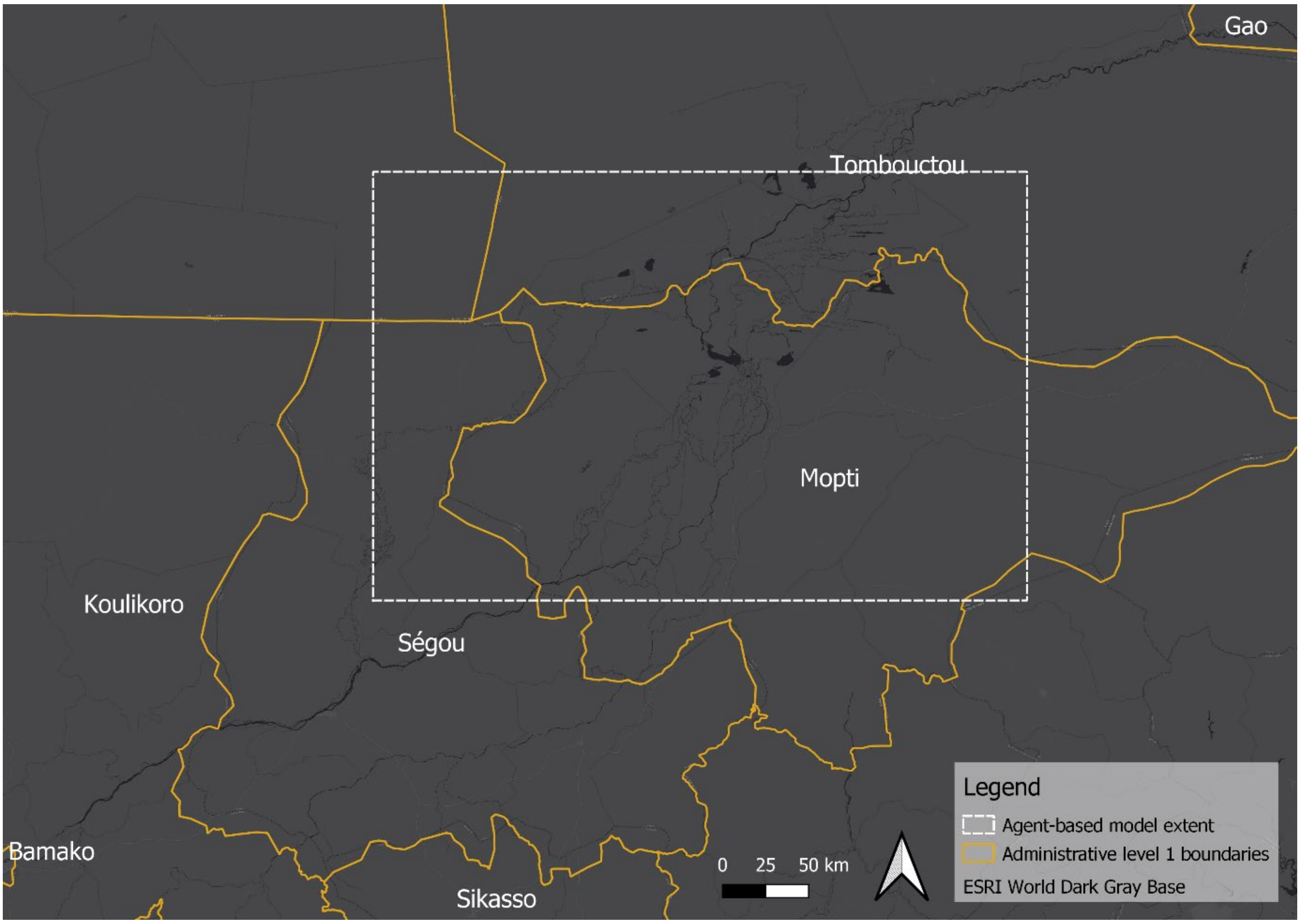

Figure A.2 Agent-based model extent.

Process overview and scheduling

This section describes what the model does as it is executed: which agents do what and in which order. Each timestep starts with an update of the global, environment and agent state variables (see Section A.3.1). Then, the agents with an activity in that month, will do that activity, otherwise they stay in the same location and will not actively do anything (see Section A.3.2). Agents with an activity in that timestep will follow the decision rule flowcharts (see Section A.3.3). Finally, one more global variable is updated (see Section A.3.1).

Updating global, environment and agent state variables

The state variables that are updated at the beginning of each timestep are described below, in the order in which they are executed in the model:

1. The global environment updates its state variables month and year with one month and when the month goes from December to January, with one year.
2. The global environment clears the state variable lists *farmers-factors-conflict, fishers-factors-conflict, and herders-factors-conflict.*

3. The spatial environment updates its state variable *water-depth* with the value from the flood map corresponding to the current time step. The flood map is input provided by the hydrological model (see Section A.6.2).
4. The spatial environment updates its state variable *max-annual-water-depth* if the *water-depth* of the grid cell is higher than the current *max-annual-water-depth*. When it is February, *the max-annual-water-depth* is set to 0 to allow the maximum annual water depth to be counted from February till February in the next year. In February, the water levels generally reach the bottom of the peak. With the timing of this update of *max-annual-water-depth*, it is assumed that agents to not consider those maximum water levels at a later stage in the year when it has been dryer for some months.
5. When it is January, the global environment increases the agent population with one-third of the *annual-pop-growth* for each agent group, to equally divide the number of new agents per group. This is an assumption that was also adopted for the initial setup of the agents (see Section A.5). Agents are created with the same state variable values as agents are created at the initialization of the model (see Section A.5).
6. The global environment updates the state variable *all-households* with all (potentially new) herder, farmer and fisher agents.
7. The global environment updates the state variable *total-conflict-risk* with the number of all-households (all herder, farmer and fisher agents) that experience conflict risk.
8. The agents update their state variable *current-water-depth* with the *water-depth* of the grid cell they are located on. The agents execute this action in an order that is randomized each time step.
9. The agents set their state variables *resentment-herders*, *resentment-farmers*, and *resentment-fishers* to zero, if the state variable livelihood of the agent is True. The agents execute this action in an order that is randomized each time step.
10. The global environment updates the state variable *total-km^2-flooded* with the count of the grid cells in the spatial environment with a *water-depth* larger than zero.
11. The global environment updates the state variable *total-list-km^2-flooded* by appending *total-km^2-flooded* to the list.
12. When it is December, the global environment updates the state variable *annual-max-km2-flooded with the maximum number of the list total-list-km^2-flooded* and clears the *list total-list-km^2-flooded*. This variable is updated in December to track the maximum annual inundated area per calendar year, to compare to the annual values from the study of ISL et. al. (2020) (see Section A.6.2).

The following state variables are updated in the end of each timestep:

1. The global environment updates the state variables *fr-livelihood-farmers*, *fr-livelihood-fishers*, and *fr-livelihood-herders* to the fraction of respectively farmers, fishers and herders with sufficient livelihood (*livelihood* = True).
2. The global environment updates the state variables *total-conflict-risk* to the total number of households with a risk of conflict and *perc_conflict_risk* to the fraction of the number of households with a risk of conflict.
3. The global environment updates the state variables *sum-<group>-factors-conflict* to the number of occurrences of factors that lead to conflict risk for the three socio-economic groups.

Activities

The agents follow the activities as depicted in Table A.5. The agents follow the same activity schedule each year. When an agent has an activity in the month of the current time step, they follow the decision rules as described in the flowcharts in Section A.3.3. Otherwise, they do not actively do anything besides responding to interaction started by other agents.

Table A.5 Activities per agent group, simplified from the activities schedule identified by International Alert (2022).

Month	Farmers	Herders	Fishers
January	Harvest		Fishing
February	-		
March	-	Bourgou grazing	Fish trading
April	-		-
May	-		-
June	Plant dry crops	Transhumance - departure	-
July	-	-	-
August	Plant irrigated crops	-	Fish reproduction
September	-	-	
October	-	Transhumance – return	
November	Harvest	Bourgou grazing	Fishing
December	Harvest		

In all activities, the agent determines whether it wants to stay in the same location or whether it wants to move to a different location. This can depend for example on the agent's expected livelihood at the location where it is at that moment, or on another factor, like the yearly transhumance. The state variable move-option is set in all activities to the chosen location.

Harvest: the farmer agents' livelihoods are calculated (sufficient or not sufficient) with the rice production from the location where the agent is at that moment (see Section A.7.1), and they will stay in the same location.

Plant dry / irrigated crops: the farmer agents will try to find a new suitable location for farming.

Bourgou grazing: if the water-depth of the current location of the herder agent is below its my-suitability-threshold, the agent tries to find a better suitable location for its cattle to graze. The herder agents' livelihoods are calculated for the best location found (see Section A.7.1).

Transhumance – departure: the herder agents move to a location outside of the IND model extent and their livelihood is set to be sufficient (livelihood = True), since it does not depend on the water system of the IND.

Transhumance – return: the herder agents move to any location in the IND model extent that has a sufficient max-annual-water-depth (max-annual-water-depth > my-suitability-threshold).

Fishing: if the water-depth of the current location of the fisher agent is below its my-suitability-threshold, the agent tries to find a better suitable location to fish.

Fish trading: the fisher agents' livelihoods are calculated (sufficient or not sufficient) with the fish trade from the location where the agent is at that moment (see Section A.7.1), and they will stay in the same location.

Fish reproduction: the fisher agents are letting the fish reproduce and will move to a parcel of land to farm.

Decision rules

The aforementioned socio-economic groups are the main agents in the model. They are all in need for land and water to fish, herd or farm. The main determinants in the decision to use land or water are accessibility of land/water and the availability of natural resources.

Communal conflicts or disagreements can arise during the search for or use of land or water. For example, conflicts over access to land and water, depletion of natural resources, violation of rules and regulations and grievances (indirectly) related to high population density (Basedau et. al., 2021).

The agents follow the decision rules in this section when they are doing an activity in that time step. The move-option is determined by the activity (see Section A.3.2). The main decision rule shows the order of sub-decision rules that are explained below (see Figure A.3). First, the agents check if the option to move to (move-option) is accessible (see Figure A.4), then they check the availability of natural resources (see Figure A.5) and decide depending on those two checks if they will use

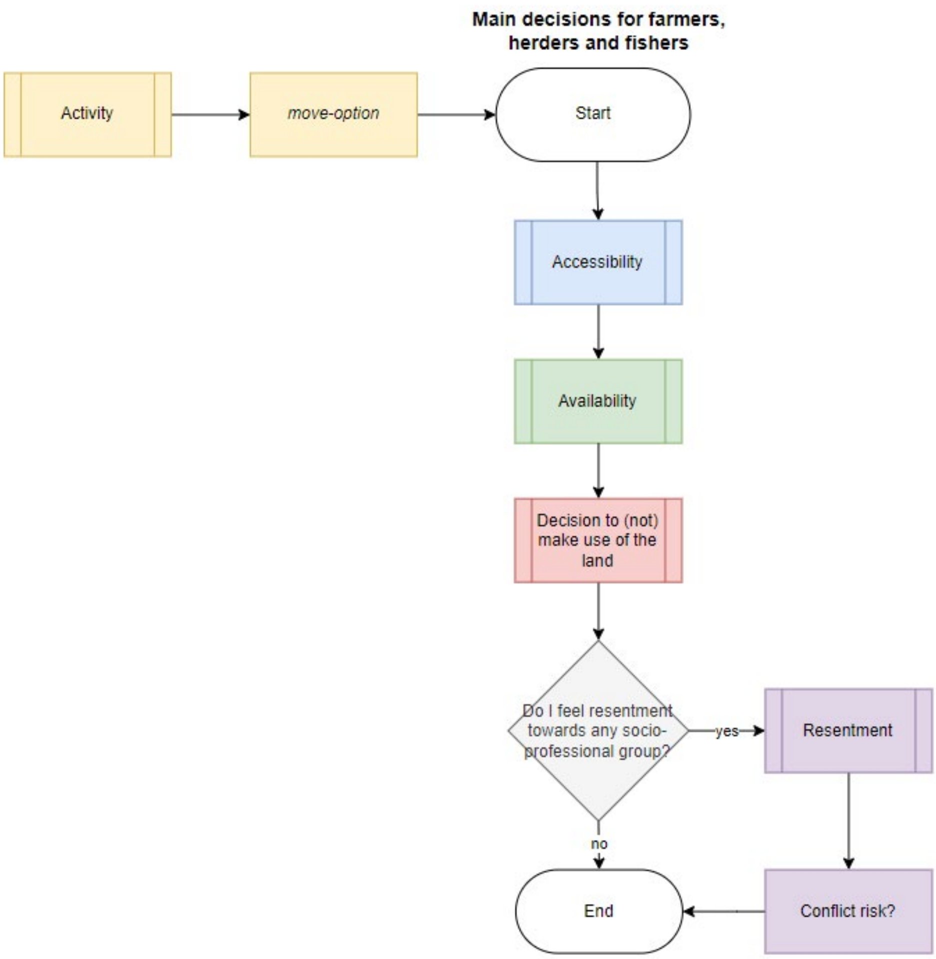

Figure A.3 Main decision rule. Only agents that are doing an activity follow this decision-rule flowchart.

that part of land/water (see Figure A.6) After this decision has been made, and if agents feel resentment towards any socio-economic group (including their own group), they go through the decision rule that determines whether they experience conflict risk (see Figure A.7).

When access to land and fishing waters is restricted, the assumption is that tension can build up and conflicts arise more easily (International Alert, 2022). For example, this is the case when pasture land was recently converted into agricultural land, and is not accessible anymore for herders and fishers (International Alert, 2022). If there are no claims on the land, the assumption is that the land is accessible and can be used. However, when the land is already in use or claimed there will be negotiations between the land owner or manager and the farmer or herder that wants to make use of the land. During this negotiation many small conflicts may arise. The chance on small conflicts is higher when there is disagreement about the rules of access. International Alert (2022) showed that when the traditional authorities that set the rules are respected, the system of access to land and natural resources is effective. (Dis-)agreement on the regulation is therefore an indication of resentment that can lead to conflict risk. The lack of legitimacy of the traditional authorities, amongst others induced by the focus on formal rules by the national government, and rules set by extremist groups, increases the frustration of the groups requesting land use, which may

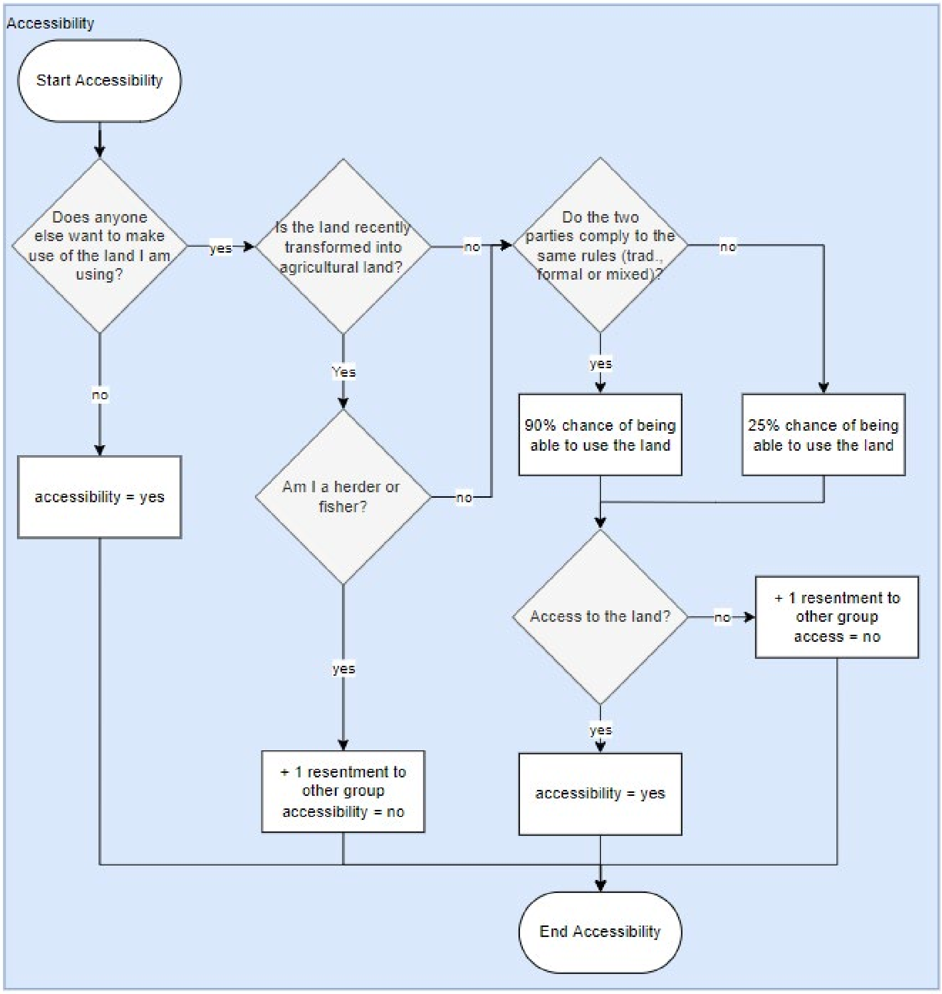

Figure A.4 Decision rule “accessibility”. Only agents that are doing an activity follow this decision-rule flowchart.

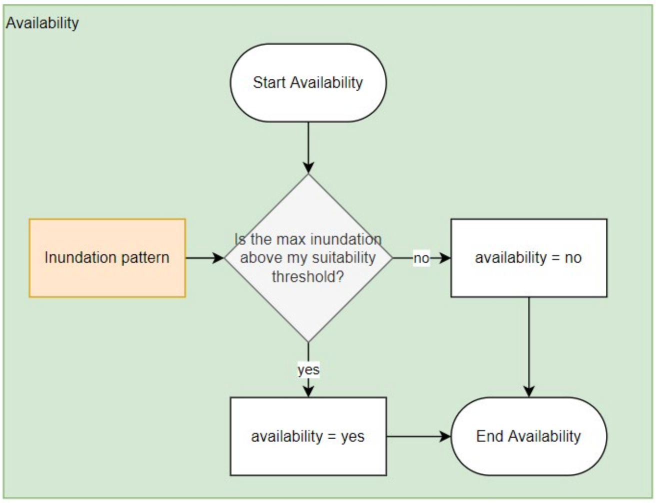

Figure A.5 Decision rule "availability". Only agents that are doing an activity follow this decision-rule flowchart.

increase conflict risk. This is also illustrated by International Alert (2018) and Tobie (2017) which describe that the gaps between traditional law and formal law, recognizing different concepts of land ownership, have led to questioning of both public and customary authorities legitimacy. They illustrate that this could create disputes over land management and the legitimacy of the historical agreements. For example, this could lead to disputes about access dates and fees (workshop June 2021). These processes are meant to be captured in the model with the "accessibility" decision rule (see Figure A.4).

Aside from access to land or water, the land or water should contain sufficient natural resources to sustain a livelihood. The assumption is that there should be sufficient bourgou and water points for cattle, fish stock for the fishers and water and fertile soil for the farmers. The inundation pattern affected by, amongst others, changes in meteorological conditions and large infrastructure, affects the availability of natural resources. Furthermore, a growing population might increase the pressure on natural resources. Depletion of natural resources can lead to expansion of farmers, fishers and herders to other land or grazing areas, which potentially increases tension (International Alert, 2022).

The availability of natural resources is captured in the model with land suitability thresholds (see Sections A.2.2 and A.6) and the ecosystem services submodel (see Section A.7.1). These processes are meant to be captured with the decision rule "availability" (see Figure A.5).

The accessibility of land together with the availability of natural resources determines the decision whether or not to make use of the land (Figure A.6). International Alert (2022) showed that conflicts can arise when herders and farmers violate access rules. As such, the conceptual model includes a chance that the requester still makes use of the land without official access. Furthermore, there is a small chance that the requester will make use of the land when there are insufficient natural resources to sustain its livelihood. This could increase resentment of the owner/manager due to depleted water resources, fish stocks or bourgou fields (International Alert, 2022). When the decision is made to not use the land, the agent stays in the same location.

Aside from conflicts directly related to accessibility or availability of land and natural resources, conflicts can arise related to high population densities and shared use of land. For example, livestock can cause damage to nets sets by fishers, and the other way round, livestock can fall or get stuck in fishing canals dug by fishers (International Alert, 2022). This has been indirectly implemented in the model with the demographic scenarios of population growth for the starting population and an annual population growth (see Sections A.2.2 and A.5). More agents in the model will indirectly lead to more resentment due to the scarcer resources and space per agent.

The last step of the model is the step regarding resentment and conflict risk. During the previously mentioned steps, resentment, frustration or tension could have been build up. Whether the resentment leads to violent conflict risk depends (amongst others) on the conflict resolution mechanisms in place (International Alert, 2022). All socio-economic groups start with a 90% chance of successful conflict resolution, except the fishers that are fishing in a water depth below 1 meter (see the "Fishers' conflict in low water" box).

Fishers' conflict in low water

In periods of low water (with depths less than 1 meter), some fishermen put their nets in pirogue passages. When these nets are damaged, there is a higher chance of conflict between the fishers and transporters (stakeholder consultation WPS Mali dashboard, 2023). Because the transporters are not included in the model, this hightened change of conflict is represented by a 10% decrease in successful conflict resolution for the fishers.

Besides this, successful conflict resolution depends on different factors. The first is the resentment that has been build up towards another group. When more resentment has been build up than the chosen threshold, there is a smaller chance that the conflict will be solved. The second is the livelihood of the agent. A relation has been found between climatic changes, food insecurity and conflict, however this relation is indirect and complex (Kangogo et. al., 2021). The model tries to capture this with the translation of water depth into livelihood (see Section A.7.1) and the availability and accessibility of natural resources (see Figure A.4 and Figure A.5), and finally by including this as a factor to assess the conflict risk. The third factor is related to support of a similar authority and rules. Conflicts are traditionally resolved by traditional authorities, such as traditional chiefs (Bodian et al, 2020). However, the groups in conflict might not support the same authority and resolution rules. When there is disagreement about the conflict resolving authority and rules, there is a higher chance that the conflict is not resolved (workshop June 2021). The different factors together determine the probability of successful conflict resolution and therefore also the risk on violent conflict. See Figure A.7 for the implementation of (some of) these factors in the model.

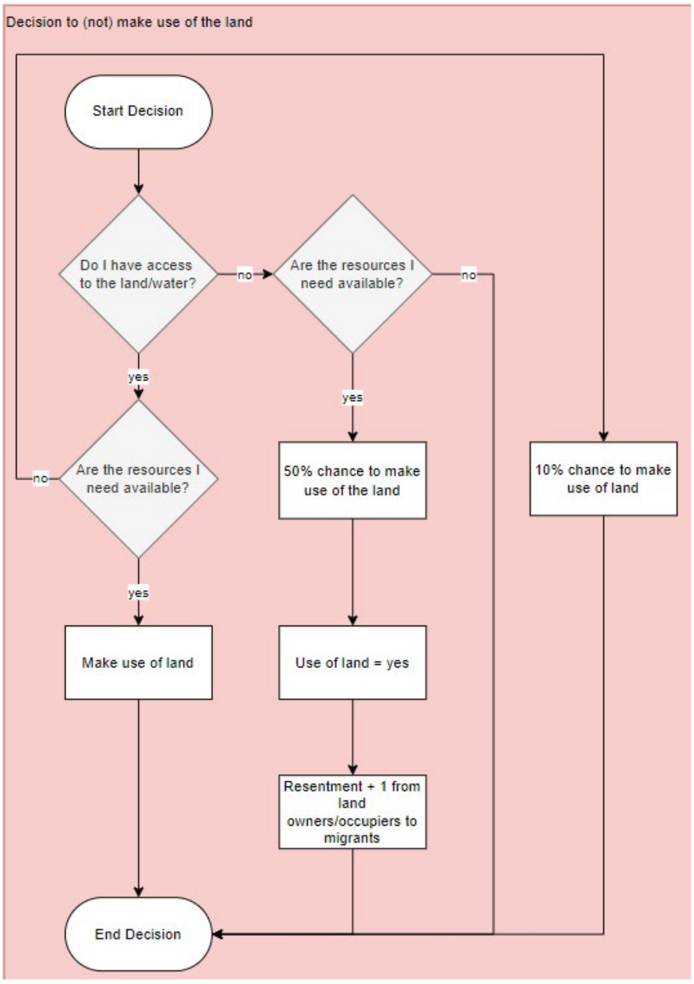

Figure A.6 Decision rule "Decision to (not) make use of the land". Only agents that are doing an activity follow this decision-rule flowchart.

The percentages (25, 5, and 20%) used to decrease the chance of successful conflict resolution (see Figure A.7), come from calibration of the model (see Section A.5.2).

The decision rules have been defined in close collaboration with IND experts, with many iterations between defining the flow charts and validating them with the experts (see Section 2 in the main report text and Appendix B). The actions and interactions that come from the activities and decision rules are perceived to be the most important factors leading to conflict risk.

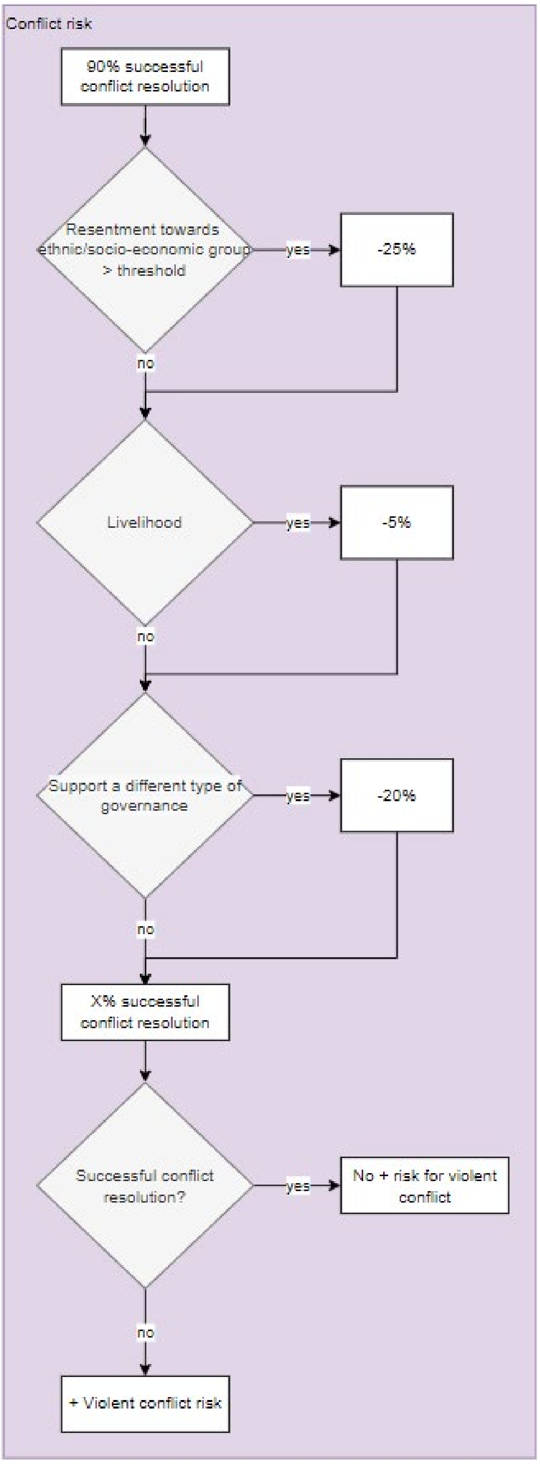

Figure A.7 Decision rule "conflict risk". Only agents that are doing an activity and feel resentment towards others follow this decision-rule flowchart.

DESIGN CONCEPTS

This section explains how emergence, interactions and stochasticity are implemented in the agent-based model.

Emergence

The main model result that emerges from the adaptive decisions and behavior of the agents is the conflict risk (global state variables total-conflict-risk and perc_conflict_risk). The agents' characteristics that directly influence their conflict risk are the agents state variables resentment-fishers, resentment-herders, resentment-farmers, the regulation-preference of one of the other-party (the agents that are in dispute), and livelihood (see Figure A.7).

The three resentment variables can increase in two decision rules, "accessibility" and "Decision to (not) make use of the land" (see Figure A.4 and Figure A.6), which leads to a higher chance of conflict risk. The migrating party experiences resentment towards the agent group of the agent that is already located on a part of land/water (grid cell), if they, the migrating party, are not allowed to access that land/water. The party that was the first to arrive on a part of land/water (grid cell) experiences resentment towards the agent group of the agent that uses that same part of land/water, even though they were not given access to the land/water. The resentment variables decrease (are set to 0) when an agent has sufficient livelihood (see Section A.3.1).

The difference in regulation preference (regulation-preference) influences the risk of conflict more directly. The regulation preference in the scenario when there is no accepted natural resource management system is randomly assigned to the agents. There are three possible options for regulation preference, traditional, formal, or mixed, resulting in a 33% chance that two agents have the same regulation preference. This affects the "accessibility" decision rule (see Figure A.4). Agents with the same regulation preference have a larger chance of getting permission to use someone else's land than agents that have a different regulation preference. Therefore, in the scenario when there is an accepted resource management system, more agents can use the same piece of land without getting into disputes. This leads to less resentment and more sufficient livelihoods. The difference in regulation preference is more directly influencing the risk of conflict, as there is a 67% chance that the regulation preference between two agents is different, which decreases the chance on a successful conflict resolution by 20% (see Figure A.7).

We chose for this very simple way of representing different natural resource and conflict resolution mechanisms and the preferences or implementation thereof, because of the complexity of the implementation and real-world situation of the different mechanisms. For example, some people would like to follow the traditional conflict resolution mechanism but are forced to go through a formal process, and the formal process might be led by people that have their own agenda (workshop June 2021). The data lacks on which people use and prefer which mechanism and where certain mechanisms are implemented properly and functioning well. However, for the understanding and conceptualization of this simple representation of the different natural resource and conflict resolution mechanisms we used the information in Box 1 below.

The last factor in the model that influences the chance of successful conflict resolution is the livelihood of the agents. This is a binary state variable that is influenced by the accessibility of agents to use a good piece of land or water, and the availability of natural resources. Again, we have chosen for a very simple representation. For the livelihood this is because the available study on translating water availability to livelihood in the context of the IND is done on a regional level, which could not be directly translated to a household level (see Section A.7.1).

Interaction

Agents interact in the model by (potentially) moving around in the space and meeting each other when they are on the same piece of land/water (on the same grid cell). The agent that is first at a location "claims" the land – the agents that come thereafter need to request permission to access the land (decision rule "accessibility", see Figure A.4) with that agent. This is the agent with which the "new" agent could have a dispute and to which the regulation preference is compared in the decision rules "accessibility" and "conflict risk" (see Figure A.4 and Figure A.7). Only when agents just moved because they were doing an

Box 1: Traditional/Formal natural resource and conflict resolution management systems

In the 19th century, the Fulani Massina Empire of Seku Amadu developed a Diina system. In this system the control of pastoral areas has been allocated to djowros who are selected from wealthy Fulani families (International Alert, 2018). For agricultural land the village chief is responsible for regulating the access over land. There is a customary succession right that the village chief considers in his/her decisions (Tobie, 2017). Water rights are traditionally regulated by the masters of water, which are (village chiefs of) the Bozos. They provide access and regulate fees.

A more recent development is that the formal state laws have been superimposed on the more traditional rules. The formal rules include that all land and water belong to the state. Land can be registered by people with customary succession right, following a challenging procedure. Fishers must buy a license when they fish for the market. Furthermore, all pasture land is open to use by pastoralists, sometimes with or without a fee. However, communities with costumery rights have priority rights (workshop June 2021).

Traditional management of natural resources

Resources	Types	Regulations	Managers
Pastures	Private	Symbolic fee for strangers No fee. Priority for members of the Dioro	Masters of the pastures (Dioro)
	Community	No fee. Only diary cows, forbidden to foreigners	Village chief
Water		Fee for strangers of the leydi Free for members of the leydi	Masters of water (Jii-tu)
Land	Community	Distribution by the village chief	Land chief
	Family	Use by people related to the first occupant	

Formal management of natural resources

Resources	Regulations	Access rules
Pastures	Law Number 01-004: Pastoral Charter	Open to all pastoralist (possible fee) Priority access to communities holding customary rights
Water	Law Number 95-032: Setting fishing conditions	Fish rights belong to the state Fishing license for a fee Rights of use: No fee in case of domestic consumption
Land	Law Number 10-028 : Agricultural law	All land belongs to the state Free of charge land registration by lineage owners

Figure A.8 Differences between traditional and formal management of natural resources in the IND (Source: workshop June 2021).

activity, they initiate this interaction. When agents are not undertaking an activity, the agent that is stationary will not initiate interaction but might receive a request for land/water access.
This is the only interaction in the model. We modelled this interaction to represent the competition over limited resources (see Section A.3.3).

Stochasticity

Stochasticity describes the lack of any predictable order or plan, or randomness of phenomena. In multiple areas of the model, stochasticity plays a role: the random order in which agents act, the probabilities that are used in the decision rules, the random location of the different agents and agent groups, and the type of regulation-preference that is randomly assigned to the agents in (see Section A.5.1). Because of this, two model runs with the same input settings will not produce the same output. To get the range of the output variables, the model is simulated 200 times per scenario. We observed that the variance of the range of the output variables is small, therefore we chose to show the outcomes as an average of the value over the different runs of the same scenario.

Initialization

In total, 22,056 household agents are created at initialization of the model. This number was derived by dividing the total population of 1,169,002 in Mopti in 1979[12] with an average household size of 5.3 (Mali Demographic and Health Survey, 2001), and dividing it with global state variable factor-decrease-pop set to 10 (see Figure A.8). It was necessary to decrease the household population with a factor of 10, to be able to run all model simulations in an appropriate time. We assumed that the population is equally divided over the three socio-economic groups, resulting in 7352 fisher, farmer, and herder households at initialization. This is an assumption that we expect to largely influence the model results. However, no data was available on the part of the population that belongs to these three socio-economic groups, and the division per group. The socio-economic groups do largely align with the ethnic groups (see Section A.2.1), but with regard to the diversification of livelihoods of the different groups (see Table A.1 in Section A.2.1), in some periods, the activities of the socio-economic groups can overlap. This is simplified by dividing the groups equally. For future work we recommend modelling the number of households per group more according to the division of ethnic groups and their primary source of livelihood.

The locations of the herder and farmer households is determined by a settlement map (see Section A.6.3). The herder and farmer households are placed randomly within a radius of 7 km from the settlement locations. The location of the fishers is on a random ‘wet’ cell, i.e. with a water depth larger than 0. This mainly random distribution of agents was done because of the lack of data of locations of farmer, herder, and fisher families.
Table A.6, Table A.7, and Table A.8 depict the state variables of respectively the agents, the spatial and the global environment that are set at initialization. Most of the agent state variables are set the same for all agent groups. It is specified in the table when a value applies to a specific agent group. The choices for the initialization values of the global state variables are explained in the sections below.

Scenarios

In total 36 different scenarios are simulated. The scenarios are combinations of the different values for flood-scenario, demographic-scenario, accepted-management-system, and increased-production (see Figure A.9). The implementation of the different scenarios and interventions is described below.

12 Source: interpolated census data from ISL et. al. (2020).

Hydrologic scenario *(flood-scenario)*
Three hydrologic scenarios are simulated with the agent-based model. The names of the scenarios, S1, S6, and S9, match with the names used in the study in which the hydrological model and water depth maps were created (ISL et. al., 2020). Scenario S1 uses the actual climate of the modelled time period and is the wettest of the three scenarios (see Figure A.9). An additional wetter hydrologic scenario was simulated with a wet year (1994) in the S1 reference climate scenario. The other two scenarios S6 and S9 use future (2050) climate projections. S6 uses the results of the global climate model HadGEMCC and is the driest scenario. S9 uses the results of the CNRM global climate model and is an intermediate scenario between S1 and S6. More information on the hydrologic scenarios can be found in the online report of ISL et. al. (2020).

Table A.6 State variable values of the agents at initialization. The state variable that are not included in this table are not set to any specific value at initialization.

State variable	Value
move?	False
my-suitability-threshold	Random selection from a normal distribution with average suitability-threshold-farmers/fishers/herders and standard deviation std-suitability threshold (see Section A.5.2 and Table A.8).
resentment-herders	
resentment-farmers	0
resentment-fishers	0
total-resentment	0
conflict-risk	0
my-land-use	False
regulation-preference	“pasture” for herders, “farmland” for farmers and “fishing ground” for fishers
locations	If there is an accepted resource management system in place (accepted-management-system = “Yes”), then each agent has the same regulation preference (whether that is traditional, formal or mixed does not matter for the model). If there is no accepted resource management system in place (accepted-management-system = “No”) Traditional, formal, or mixed
move-option	A list of locations as if the agent was in the same location the whole previous year
my-activities	The current location
current-water-depth	The water depth of the location the agent is at that moment
transhumance?	False for herders, the other agent groups do not have this state variable

Table A.7 State variables of the spatial environment (grid cells) at initialization. The state variable that are not included in this table are not set to any specific value at initialization.

Name	Value
water-depth	The water depth from the hydrological model output, at the location of the grid cell (see Section A.6.2).
land-use	The land use of the agent that is on that grid cell at initialization.
population	The number of agents per group that should be created at that grid cell at initialization.
dire-station?	The location of the Diré station from the hydrological model.
recently-transformed-to-farmland	For a random 70% of the land, this variable is set to False and for random 30% to True. These are arbitrary values to initialize this state variable, which are more accurately build up over time by the farmer agents.

Table A.8 State variables of the global environment at initialization.

Name	Options / setting	Description
Scenarios		
flood-scenario	"Reference climate (1984)", "Future climate (2050), dry", or "Future climate (2050), extra dry"	The three hydrological scenarios as described in Section A.5.1.
demographic-scenario	"Reference population (1984)", "Moderate population increase (SSP5)", or "Extreme population increase (Masterplan IND)"	The three demographic scenarios as described in Section A.5.1.
accepted-management-system	“Yes” or “No”	The two resource and conflict resolution management scenarios as described in Section A.5.1.
increased-production	“Yes” or “No”	The increase production scenario as described in Section A.5.1.
Calibration (see Section A.5.2)		
threshold-resentment	15	If the resentment of an agent, towards another or towards its own agent group, is higher than the *threshold-resentment*, the probability of successful conflict resolution decreases with *w-resentment*.

initial-%-successful-conflict-resolution	90	The initial probability that conflict between two parties is successfully resolved. The w-resentment, w-regulation-preference and w-livelihood percentages are subtracted from this probability if applicable.
w-resentment	25	The weight of how much probability resentment contributes to the decrease of successful conflict resolution.
w-regulation-preference	20	The weight of how much probability a different preference for natural resource and conflict resolution mechanism contributes to the decrease of successful conflict resolution.
w-livelihood	5	The weight of how much insufficient livelihood contributes to the decrease of successful conflict resolution.
suitability-threshold-farmers	0.5	The average water depth value that is used to pull a number from a normal distribution for my-suitability-threshold of the farmer agents
suitability-threshold-herders	0.5	The average water depth value that is used to pull a number from a normal distribution for my-suitability-threshold of the herder agents
suitability-threshold-fishers	2	The average water depth value that is used to pull a number from a normal distribution for my-suitability-threshold of the fisher agents
std-suitability-threshold	0.1	The standard deviation that is used to create a normal distribution for my-suitability-threshold of the agents
Population		
factor-decrease-pop	10	This factor is chosen to best represent the full population in the IND while being able to run the agent-based model simulations.

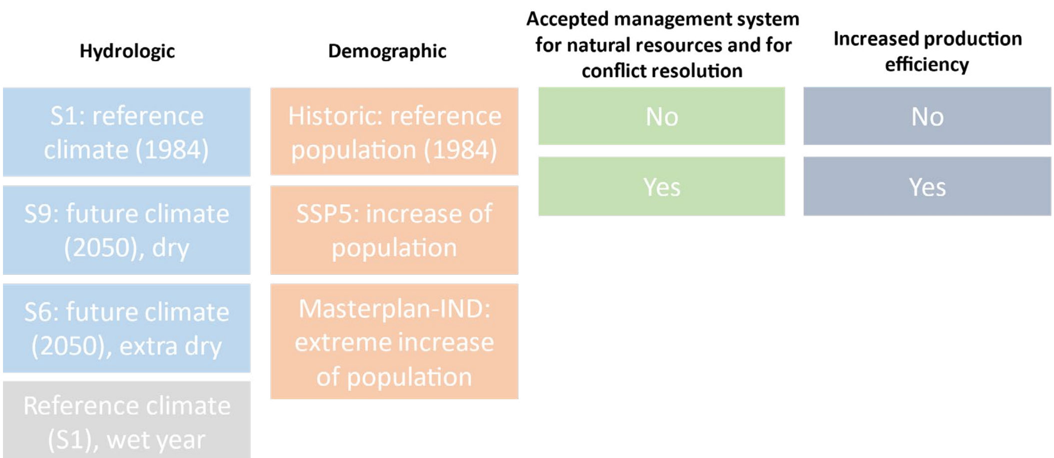

Figure A.9 Simulated scenarios.

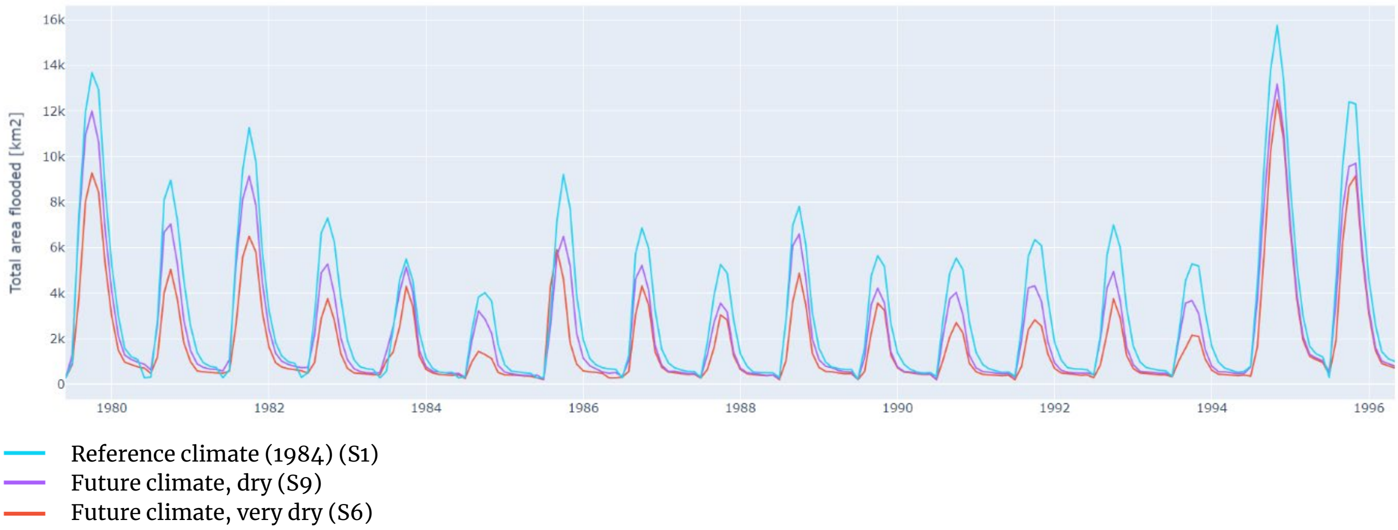

Figure A.10 Hydrological scenarios plotted as inundated area (km²) over time.

Demographic scenarios (demographic-scenario) The demographic or population scenarios determine the starting population of the model. Three scenarios are simulated: the reference, or historic population, an increase in population and an extreme increase in population, the latter two compared to the reference case (see Figure A.11). With the reference population scenario, 22,056 households are created at initialization (see Section A.6.4 for the data source). For the increased population scenario, the Shared Socioeconomic Pathways 5 (SSP5) scenario is used, which states an increase in population of 50.5%[13] resulting in 33,194 households created at initialization. For the extreme increase in population scenario, the population projection from the IND Masterplan (Ministere de l'environnement, de l'assainissement Republique du Mali et du developpement durable et. al., 2018) of a population increase of 107.3%[14] was used. This amounts to 45,722 households being created at initialization.

13 This is a country level projection considering population growth from 2020 to 2050.

14 The Master Plan of Inner Niger Delta provides a local population projection from 2020 up to 2037, which we extrapolated to 2050.

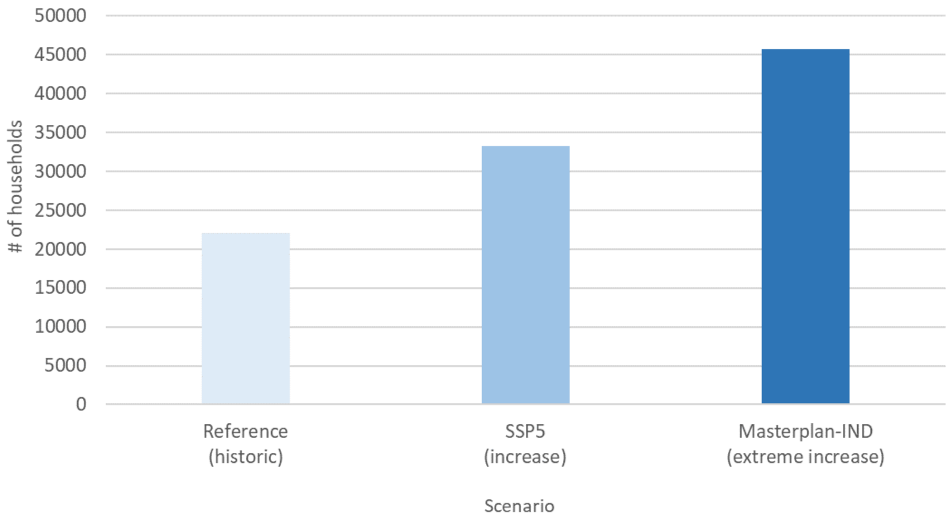

Figure A.11 Demographic scenarios.

We have two sources of population projection. The Master Plan of IND provides one local population projection up to 2037, which we extrapolate further to 2050. The Shared Socioeconomic Pathways (SSP) Database contains population projection for five socioeconomic scenarios at a country level.

Accepted natural resource management and conflict resolution mechanism intervention (accepted-management-system)
With this intervention, we tested a situation with a generally accepted natural resource management and conflict resolution mechanism, and one without. In the former, all agents have the same preference (regulation-preference). This can be seen as a governance improvement and general social acceptance of the implemented mechanism. In the latter, the agents have a (randomly assigned) preference for one of the three natural resource management mechanisms. This is the reference case.

Increased production efficiency intervention (increased-production)
With this intervention, we tested a situation with an increased production efficiency for all agent groups, and without, i.e. the reference case. In the former, the agents can obtain sufficient livelihood with less water than in the latter. The thresholds used in the calculation with sub-model 'ecosystem services and livelihood' are explained in Section A.7.1.

Calibration and validation

Agent-based model are generally calibrated and validated with historic data. When this data is not available, or only available for a different time period, the model can be calibrated and validated with expert elicitation. For the modelled time period (1979-1985), no conflict risk data is available for the IND. Conflict databases like ACLED (ACLED, n.d.) and UCDP (UCDP, n.d.) contain data on conflicts from respectively 2004 and 1989. Therefore, the ABM is calibrated and validated by trying to represent the conflict risk trend that is expected by the IND expert group.

The expected conflict risk trend has seasonal, yearly, and scenario-dependent variabilities. Seasonally, a higher conflict risk is expected in the months January, February, March, June, July, and August. In January-March, the risk is high because it is the period of decline in flood extent, with a superposition of activities which often interfere with each other namely harvesting, fishing and the return of herders to the IND. In June-July, the risk is high because there is the preparation of agricultural fields, while the herder's cattle are still in the delta and the fishing activities are also still carried out in the same locations. In August, with the gradual rise of water levels, the herders begin to leave the delta. A lower conflict risk is expected in the months September, October and November because there are fewer overlapping activities and the water levels are high. Annually, a higher conflict risk is expected in the dryer years compared to the wetter years, because of the fewer natural resources available with a smaller flood extent. Scenario-wise, a higher conflict risk is expected in the dryer hydrological scenarios and in the scenarios with more population. Like the expected trend of a higher conflict risk with dryer years, we assume that dryer hydrological scenarios and a larger population both implicate that there are fewer natural resources available per household, and that there is a higher risk of conflict. A lower conflict risk is expected with an accepted resource management system and an increased production efficiency.

The conflict risk output of the model was calibrated with these trends in mind. The calibrated input variables are set to the following:

- Farmers and herder search for better land in a **radius of 20 km**
- Fishers search for better water in a **radius of 14 km**
- Suitability threshold of herders = **0.5** (meter water depth)
- Suitability threshold of farmers = **0.5** (meter water depth)
- Suitability threshold of fishers = **2** (meter water depth)
- Standard deviation of the suitability thresholds = **0.1** (meter water depth)
- threshold-resentment = **15** (if the total resentment level is higher than this, the chance at conflict risk increases with w-resentment)
- w-resentment = **25** (percentage increase in risk of conflict if the resentment is higher than threshold-resentment)
- w-regulation-preference = **20** (percentage increase in risk of conflict if the agents in a dispute have a different resource regulation preference)
- w-livelihood = **5** (percentage increase in risk of conflict if the agent has no livelihood)

Input data

Conceptualization

Most of the input for and conceptualization of the model come from workshops and written feedback and input from IND experts. This is explained in the main text of this document (see Section 2) and in Appendix B. Literature review has been done additionally.

Hydrological model data

The results of a "Study on advanced modelling of ecosystem services in the Inner Niger Delta" (ISL et. al., 2020), were used to represent the water system in the agent-based model. This study used the Delft-3D Flexible Mesh suite[15] for the hydrodynamic modelling, an open source software from Deltares. A few pre-processing steps were required so that the agent-based model could read the water depth map per time step. The raw model results were filtered, cut to the agent-based model spatial extent (see Figure A.12), downscaled, and converted into the ASCII file format that is readable for the agent-based model software used.

To ensure that the hydrodynamic model results were modified and incorporated correctly in the agent-based model, the global state variable annual-max-km2-flooded was created, tracked, and compared with the annual model results from ISL et. al. (2020). The annual-max-km2-flooded was compared to the study results of Mopti, because the model extent is largely in Mopti, and those largely aligned. Small differences were observed because the model extent does not cover all of Mopti and it also includes some parts of Tombouctou and Ségou (see Figure A.12).

Settlement data

Mali settlement data from Direction Nationale de l'Administration Territoriales (DNAT) and l'Institut national de la statistique (INSTAT)[16]

15 https://www.deltares.nl/en/software/delft3d-flexible-mesh-suite/

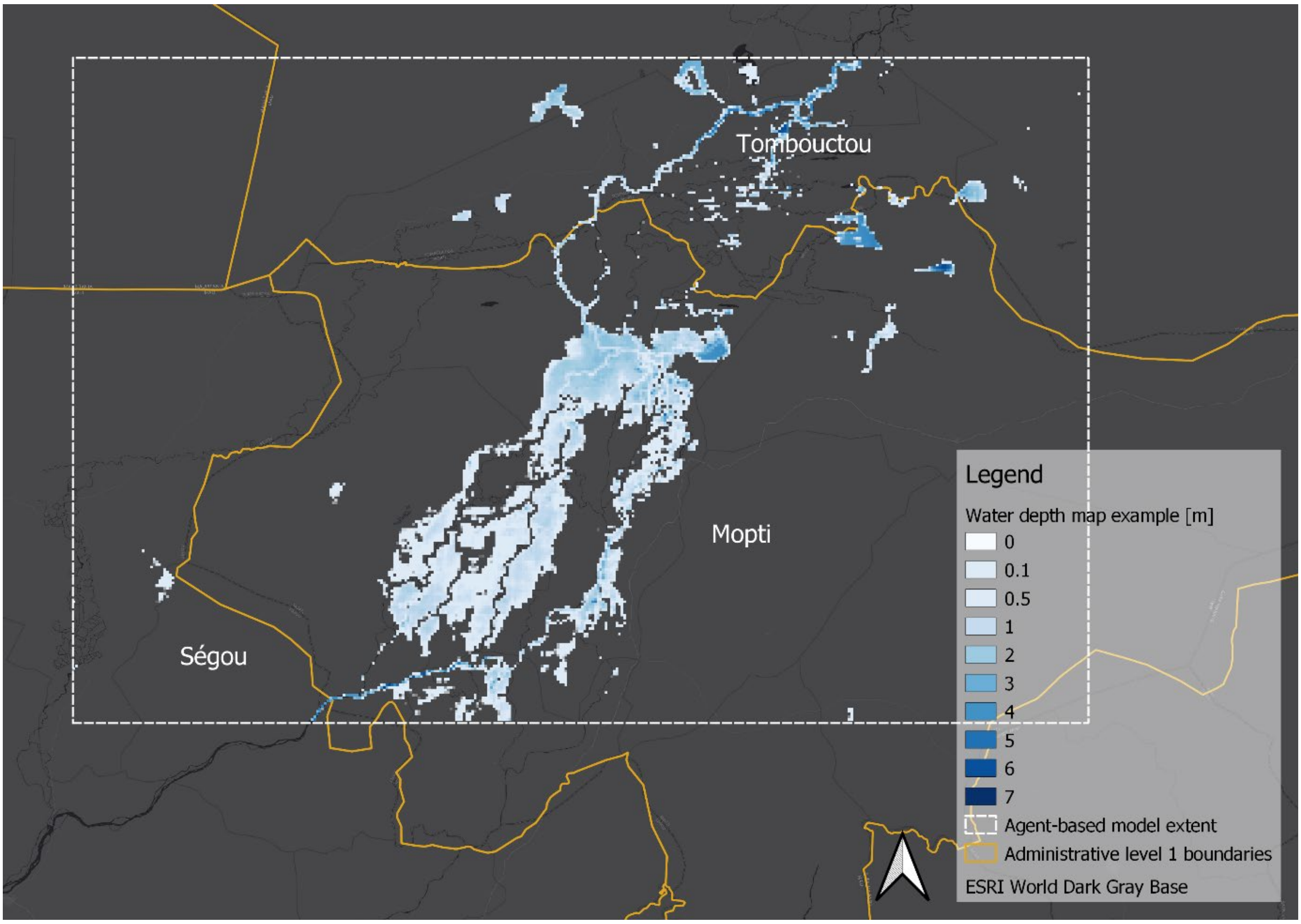

Figure A.12 Example of a flood map from the hydrological model study (ISL et. al., 2020).

is used to distribute the agents in the model at initialization. Because the settlement data is first developed in 2015, years after the starting date of the model (1979), the normalized population distribution is used from this dataset and not the population counts. The data source for the population count is explained in Section A.6.4 below.

Population data

The population count and population growth rate that were used in the "Study on advanced modelling of ecosystem services in the Inner Niger Delta" (ISL et. al., 2020) were also used for the agent-based model. They obtained the population count in 1979 by interpolating Census data. An annual population growth rate of 1.62% was used.

Submodels

Ecosystem services and livelihood

The same study in which the hydrological model was created (see Section A.6.2), was used for translating the water depths from that hydrological model to ecosystem services and

16 The data was downloaded from https://data.humdata.org/dataset/mali-settlements in August 2021. The dataset was developed in 2015 and updated every year.

livelihood (ISL et. al., 2020). For each agent group, one logical livelihood indicator was chosen. ISL et. al. (2020) have created regression formulas to calculate these indicators regionally. Because we needed an indication of livelihood on the household level, the regional regression formulas were modified to better represent household level livelihood. For rice production and fish traded (see the modified equations below), the total quantities calculated with the agent-based model are compared to the regional quantities from the study. Both the rice production and fish traded did not result in the same values but had a similar trend as in the study.

Rice production:

9.23 + (0.19 * nr_agents) - (307588 / nr_agents)

Fish traded: 1.77 + (4100 / nr_agents)

For the final model setup, we chose for a more simplified method of estimating livelihood by using thresholds of water depths that indicate sufficient or insufficient livelihood. A more elaborate translation from local water depths to per-household livelihood can namely entail many complexities, such as the division of yield for substance and for sales, and market prices. With a consideration of the large amount of time needed to model the more complex livelihood calculation, the assumed coarse precision with which the livelihood could potentially be estimated with the more complex calculation, and the small added value for the overall agent-based model, it was decided to go for this simple approach.

To represent the intervention that leads to an increase in production efficiency, arbitrary values for the water depth thresholds are chosen. With this intervention, agents can obtain sufficient livelihood with less water. Because of time constraints, no sensitivity analysis is done on the effect of these arbitrarily chosen values, but it is recommended to do this in later work on the model.

Bourgou growth for herders' livelihoods
It is assumed that herders have sufficient livelihood when the maximum water depth of the last wet season at the current location of the agent, is between 3 and 5 meters. Water depths below 3 meters are considered unsuitable for bourgou; water depths of more than 5 meter are considered as suboptimal growing conditions (ISL et. al., 2020). With an increased production efficiency, the water depth for sufficient livelihood is between 2 and 6 meters. For example, herders could plant another type of grass that could feed cattle, Didéré, which grows well in water depths of more than 2 meters.

Rice production for farmers' livelihoods
It is assumed that farmers have sufficient livelihood when the maximum water depth of the last wet season at the current location of the agent, is above 1 meter. Wild and cultivated floating rice, the species that were among others considered in the study by ISL et. al. (2020), are mainly found at locations with water depths between 1 and 2 meters (ISL et. al., 2020). With an increased production efficiency, the water depth for sufficient livelihood is above 0.75 meters.

Fish traded for fishers' livelihoods
It is assumed that fishers have sufficient livelihood when the maximum water depth of the last wet season at the current location of the agent, is above 1 meter. ISL et. al. (2020) consider optimal conditions for fish and fishing in two topics: the habitat for fisheries nursing area and the habitat for fisheries migration area. The former has optimal conditions with a water depth between 0 and 2 meters, the latter with a water depth equal to or larger than 0.5 meter. The threshold for sufficient livelihood of a water depth above 1 meter is chosen as the average between 0 and 2, and above 0.5 meter. Other required conditions for fishing that were considered by ISL et. al. (2020) like depths for navigable water are not included in the agent-based model because of its additional increase in complexity. With an increased production efficiency, the water depth for sufficient livelihood is above 0.75 meters.

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Appendix B. Workshops

Water, Peace and Security Mali – Agent-based model workshop – July 28, 2020 11:00 CEST

Method

Online whiteboard input session asking questions to define the agents, agent characteristics, (inter) actions of the agents, the environment and the impact of changes in the environment and interactions from others. Other input in the form of narratives was also requested. An impression of the online whiteboard is presented in the figure below.

Questions

The following questions were used to guide the input session.

Actors
- Who is/are the most important (groups) affected by water shortages?
- How can these groups be characterized?
- What are the differences within groups?
- Do the different actor groups live in the same areas?
- Are there actor groups that move around, and where are they going when they do that?

Actions
- What did the groups do before water shortage was an issue?
- What do they do when there is a water shortage?
- What are the options that they have?
- How do they decide what to do?
- Is there a large variety of actions taken within the group? What characteristics drive these actions?

Environment
- What is the impact of water shortage on these groups?
- What group is most/least impacted by water shortage?
- How long does a water shortage need to take before the actors take certain decisions? (short term effect vs long term effect)
- Is there an (environmental/institutional) trigger that makes them do something?
- What institutions are there that influence these groups?
- What is the impact of the government on the behaviour of these groups? And the impact of other institutions?
- Do other conditions, e.g. the economic situation, affect their decisions? And how?

Interactions
- How do the different actor groups interact with each other?
- Do different actor groups affect the actions of other actor groups? And how?
- Do the different actor groups depend on each other somehow?
- Are there any non-spoken rules between the groups?

Participants

- 4 participants from the Wetlands International Sahel Office with experience in the Inner Niger Delta
- 2 participants from International Alert Mali office with experience in the Inner Niger Delta
- 2 participants from International Alert
- 2 participants from Wetlands International
- 2 participants from IHE

Water, Peace and Security Mali – Agent-based model workshop – June 18, 2021 15:00 CEST

Program

- Introductions WPS Mali team + IND experts
- Short introduction project results last year + what is ABM? + method and planning for today
- We ask everyone to tell a short story or narrative in max. 3 minutes: "How do you know the Inner Niger Delta?"
- Break
- Presentation of agents and their characteristics. Go through all decision rules and ask for feedback. Make sure everyone has the chance to speak.
- Time for additional feedback and questions.
- Explanation next steps and actions for the independent IND experts
- Closing remarks

Participants

- 2 individual participants with experience in the Inner Niger Delta
- 3 participants from the Wetlands International Sahel Office with experience in the Inner Niger Delta
- 2 participants from International Alert Mali office with experience in the Inner Niger Delta
- 1 participant from International Alert
- 2 participants from Wetlands International
- 1 participant from IHE

Water, Peace and Security Mali – Agent-based model workshop – February 21, 2022 11:00 CEST

Program

- Presentation Dashboard + Short Q&A
- Presentation Agent-based model (ABM) + Short Q&A
- Proposed next steps for the ABM
- Discussion next steps for the ABM

Participants

- 1 individual participant with experience in the Inner Niger Delta
- 3 participants from the Wetlands International Sahel Office with experience in the Inner Niger Delta
- 1 participant from International Alert Mali office with experience in the Inner Niger Delta
- 1 participant from International Alert
- 1 participant from Wetlands International
- 1 participant from IHE
- 2 participants from GIZ

Appendix c. Expert reflection on weights of factors determining conflict risk

Aïda Zare, 19-8-2022

In view of what underlies the conflicts in the IND, I was going to emit the following values instead:

- w-resentment = 25 (percentage increase in risk of conflict if the resentment is higher than threshold-resentment).
- w-regulation-preference = 15 (percentage increase in risk of conflict if the agents in a dispute have a different resource regulation preference).
- w-livelihood = 10 but more tempted to 15 (percentage increase in risk of conflict if the agent has no livelihood). But I wouldn't say no access but rather livelihood limited access

With regard to the causes of conflicts in the IND, it is resentment that predominates the risks of conflicts (without concealing climatic factors). The risks of conflict are higher because of rivalries for access between farmers and herders (as in sub-Saharan Africa).

The work of Kone (2007) illustrates my remarks. He made a census of the conflicts by highlighting the frequencies of appearance as well as the causes in the region of Mopti:

- **Conflict between farmers and herders:** 43.5%; early return of animals to the IND and straying of animals, damage to fields following non-respect of tracks by farmers and breeders, transformation of a pasture into a field, refusal of the right of way for animals, non-respect of tracks of rangeland by farmers and breeders, insufficient land for cultivation, insufficient water points, refusal of a farmer or breeder to leave;

- **Conflict between farmers**: 25%; overstepping of cultivation limits, unauthorized occupation of land, refusal to pay a fee, attempt to transform pre-trial detention into permanent detention;

- **Conflict between breeders:** 17.5%; revendication of dioro title or pasture, violation of the crossing order, non-payment of dues to the dioro, ignorance of the lodges;

- **Conflict between fishermen:** 7.29% ; non-compliance with traditional rules on prohibitions and fishing periods, damage to fishing structures;

- **Conflict between fishermen and herders:** 6.61% ; damage to fishing equipment, claims of customary properties, non-compliance with traditional rules.

Thus, starting from the most recurrent conflicts, namely farmers and herders, and relying on the work of Moseley et al. (2002) and other works I have read; it appears that the causes of these conflicts are often linked to resentment on the side of the farmers (early entry of animals, late exit of the animals) because of the damage and on the side of the breeders because of the occupation of the pastoral space by the farmer and often calendar non- respect (early sowing, late harvesting).

Tableau 2
Activités saisonnières et risques de conflits
entre éleveurs et agriculteurs.

Activités / *Conflits*	Déc.-Juin saison sèche	Juin-Juillet début des pluies	Juillet-Nov. saison des pluies	Nov.-Déc. saison sèche
Eleveurs transhumants	pâturage dans le delta	déplacement vers les terres sèches	pâturage dans les terres sèches	déplacement des terres sèches vers le delta
Agriculteurs	morte-saison agricole	labours et semis	activités agricoles intenses	*récolte*
Risques de conflits	*faibles*	*modérés*	*faibles*	*élevés*

See this screenshot of the article by Moseley et al. (2002), the risk of conflict between farmer and breeder is higher in November-December due to the risk of crop damage (farmer resentment). The risk of conflict is moderate between June and July corresponding to the exit of the animals from the delta and the sowing period (therefore risk of destruction of the seedlings, also resentment).

I did a weighting exercise that depends on the cause and what it can create consequences that can contribute to the risk of conflict.

The weighting ranges from 1 to 5, with 1 being the lowest risk occurrence and 5 the highest.

Cause	Resentment	Regulation preference[17]	Livelihood
Increasingly incompatible calendars of activities	5	2	4
Nationalization of land and water and modern administration	5	4	1
Early return of animals to the IND and straying of animals	5	4	2
Non-respect of tracks by farmers and breeders	5	2	1
Transformation of a pasture into a field	5	2	3
Denial of animal right of way	4	3	2
Insufficient cropland	4	2	3
Refusal to evict a farmer or breeder	4	4	2
Exceeding cultural limits	4	2	2
Unauthorized occupation of land	4	3	2
Refusal to pay a fee	3	4	1
Attempt to transform pre-trial detention into final detention	5	2	1
Claiming dioro or grazing title	2	4	2
Crossing order violation	4	3	2
Non-payment of royalties to the dioro	4	3	1
Ignorance of stopover lodges	3	4	2
Non-compliance with traditional rules on prohibitions and fishing periods	4	4	2
Damage to fishing structures	5	1	2
Damage to fishing gear	5	1	2
Claiming customary properties	4	5	1
Non-respect of traditional rules	4	5	1
Traditional and modern ruler overlay	4	5	1

17 the weighting that I do is rather a function of the regulation factor and not regulation preference

Ex: for the 'Increasingly incompatible calendars of activities', it is more resentment that will be the cause of the increased risk of conflict, but also reduction of resources access (livelihood).

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