Supplementary material: Guiding community discussions on human-water-related challenges by serious gaming in the upper Ewaso Ng'iro river basin, Kenya

Charles Nduhiu Wamucii[1], Pieter R. van Oel[2], Adriaan J. Teuling[1], Arend Ligtenberg[3], John Mwangi Gathenya[4], Gert Jan Hofstede[5,6], Meine van Noordwijk[7,8], Erika N. Speelman[3]

[1]Hydrology and Environmental Hydraulics Group, Wageningen University & Research, 6700 AA Wageningen, The Netherlands.

[2]Water Resources Management Group, Wageningen University & Research, 6700AA Wageningen, The Netherlands.

[3]Laboratory of Geo-information Science and Remote Sensing, Environmental Sciences, Wageningen University & Research, 6708 PB Wageningen, The Netherlands

[4]Soil, Water and Environmental Engineering Department, School of Biosystems and Environmental Engineering, Jomo Kenyatta University of Agriculture & Technology, P.O Box 62000 - 00200 Nairobi, Kenya

[5]Department of Social Sciences, Urban Economics Group Wageningen University, Hollandseweg 1, 6706KN Wageningen

[6]UARM, North-West University, South Africa

[7]Plant Production Systems, Wageningen University and Research, 6700 AK Wageningen, the Netherlands

[8]World Agroforestry (ICRAF), Bogor 16155, Indonesia

Annexes

Annex 1. Detailed game description

Name of the Game: ENGAGE_v1 – "**E**xploring **N**ew **G**aming **A**pproach to **G**uide and **E**nlighten"

Objective: To increase system understanding for collective decision-making in the river basin.
Goal: To win the game by accumulating the largest sum of money at minimal water-related conflicts.
Type: Goal seeking, cooperative type - classification by Klabbers (2006)
Form: Boardgame - classification by Klabbers (2006)
Time: Two and half hours - determined through game trials

Resources: A Board game, money in notes (a total of KES 800,000 i.e. KES 100,000 per household as a starter kit), 100 marbles (representing water resources 100=100% of available water resources), 24 green cards (representing natural vegetation), 24 yellow cards (representing croplands), 20 brown cards (representing livestock units i.e. the wealth of the downstream communities), tree symbols, extra marbles for water storage (e.g. domestic water tanks, water pans, etc), a dice for determining exogenous climate scenarios.

Game participants: There are a total of ten game participants per game session:

- 4 participants representing the upstream agricultural community
- 2 participants representing the midstream agricultural community
- 2 participants representing the pastoralists in the downstream zone
- 1 participant plays the role of local water regulations (i.e. WRUA) during the gameplay
- 1 participant plays the role of the national government.

The external observers were also allowed in the game sessions and included any persons interested in serious gaming but did not participate directly in the playing of the game (i.e. not part of ten active participants). They however participated during debriefing sessions.

Mechanics: The game is played to explore actions and consequences observed during the dry seasons in the upper Ewaso Ng'iro catchment. The river network (marbles) connects the communities as water flows from the elevated Mt Kenya water to the downstream areas. Each round is assumed to represent average dry season conditions for one decade. In the first round, participants will play the game under assumed 'normal' climate scenarios (i.e. full 100 marbles). In the subsequent rounds, a dice is used (Fig A1) to determine the exogenous conditions and hence the number of marbles to be available in the board game (between 70 and 100 marbles).

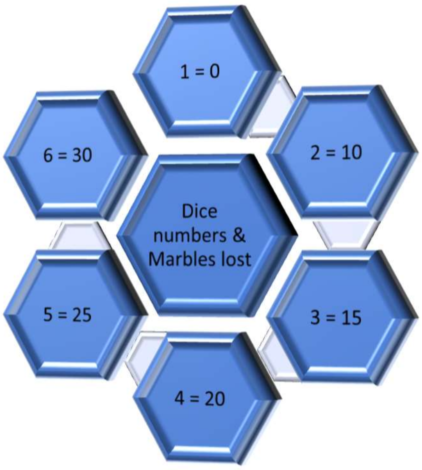


Figure A 1. The number of marbles lost due to climate uncertainty as dictated by dice numbers

There are two phases in this game. In phase one, the individual values and preferences of the players are allowed to shape the game results (in the first two or three rounds). A break of a minimum of 15 minutes is allowed between the first and the second phase. In the second phase (i.e. round 4), the players are allowed to reflect on the game results from phase one and think objectively about what could be the potential solutions to the 'wicked problem'.

Phase I:
The game session starts with an extensive introduction and explanations from the facilitator, including trial rounds. At the start of the game, all land is assumed to be under natural vegetation (i.e. tree cover, bushland, grassland, etc.). In the 1st round, all eight households have a start capital of **KES 100,000.** The players simultaneously utilize the land resources on the board game.

In each round, the facilitator calculates the net profits of each player. The winner in each round is the player with the largest sum of money. If water levels reduce to levels 1 or 2 (see board game in Annex 6.2.), the facilitator then terms that round as a loss to all the players regardless of the individual profits. For the upstream communities, the net profit is the net income from agricultural activities. For the downstream households, the total income/value is calculated as an aggregation of the total number of livestock units (LUs) per household that survive in a single round. When there are zero conflicts, one livestock unit is given a value of **KES 20,000**. However, if at the end of the game, there are water-related conflicts, then the value changes to **KES 15,000, KES 10,000,** and **KES 5,000** in water levels 1, 2, and 3 respectively.

Phase II:
After two or three rounds, the facilitator guides the game participants to reflect on the game results from phase one. The facilitator requests the players to think of possible solutions given the pressures from climate change and human dynamics observed in the board game. There is a break of a minimum of 15 minutes to allow significant 'free' interactions among game participants. When the game resumes, the players play the game for the final round with the mission to attain the 'best case scenario'. However, the objectives and goals of the game remain the same. It is paramount to mention that there are no maximum rounds of the ENGAGE game, players can continue playing as long as they are willing. However, in this

study, four rounds were considered sufficient given the time factor which averaged 2.5 hours per game session in each sub-catchment (i.e. after four rounds).

Rules:

The demand for water resources: The water is required for crop irrigation (i.e. in the upstream and midstream zones), household consumption (in all three zones, and livestock production (i.e. in the downstream).

- One basic rule is that as marbles get abstracted, this reduces the length of the river network and hence the river starts drying up from the downstream zone upwards.
- One marble is required to cater to water needs per household (hence, a total of 8 marbles must be allocated per household in each round). This represents 8% of available water that goes to household consumption.
- The number of marbles that go to irrigation is determined by the number of opened agricultural patches and location in the board game. One marble per agricultural patch is required for irrigation in the upstream zone. Two marbles per agricultural patch are required to cater for irrigation in the midstream zone. However, the maximum number of marbles abstracted, if all green patches are converted to agricultural patches, would be 40 marbles (i.e. 40% of available water resources would go into irrigation demands).
- One marble is needed to cater for water needed by one livestock unit (LU), hence 20 marbles must be available in the downstream zone to avoid potential conflicts. This means that at least 20% of available water must be allowed to reach downstream. Hence, the participant representing the WRUA will strive to ensure water flows to the downstream areas.
- Besides the demand for water by the agricultural and livestock-keeping activities, the pressure of the growing population is also mimicked by allocating marbles into the growing town in the board game. Hence, the facilitator allocates 3, 5, 7, and 10 marbles in rounds 1, 2, 3, and 4 respectively.
- For legal water abstractions, participants are required to register with WRUAs at a cost estimated as **KES 2000** per household willing to utilize river water. However, since there is no clear regulation structure by WRUAs, the game participants may choose to ignore legal registration and decide to abstract water illegally - of course, this saves some cash for game participants.
- When a participant is not registered for legal abstraction with WRUAs, he/she is likely to suffer total damage during the high level of water-related conflicts. This is because all illegal water abstraction points (including portable pumps) are destroyed by the national government representative during a high level of conflict. The participants illegally abstracting water can be fined up to KES **50,000** by the national government representative.
- **Note:** The WRUAs can only fully regulate water allocated for domestic use in the households and water allocated to town areas in the board game. This assumption is based on real-life situations where households are connected to permanent gravity flow water intakes that are formally registered with WRUAs. It is easy to come up with a rationing program and control water that is abstracted by gravity flow water intakes since it only requires temporally closing and opening the gate valve at regular intervals e.g. opening the water intake once a week. However, this is not always possible when it comes to river water abstraction for irrigation through the use of portable water pumps that are used entropically in the Upper Ewaso Ng'iro catchment (Wamucii et al. 2023).

The water levels and conflicts: The agricultural activities intensify in the upstream zone affecting the water balance due to increasing demand for direct water abstractions. The effects of changes in the water balance are felt in the downstream zone. With time the river dries up from the downstream zone upwards. This forces the downstream community to go upstream to find out where the water has gone! (Daily Nation Newspaper, 2002). This causes massive destruction of crop fields as pastoralists migrate with their livestock, fuelling intensive conflicts.

Three water levels and conflicts are conceptualized in the board game:

- *The river has dried up to level 1 (L1_Mpala)* - the conflicts are mainly between the pastoralists in the board game and other pastoralists immigrating from the far downstream zone. That is downstream pastoralists and remote pastoralists move upstream to enter the game environment in the downstream zone.
- *The river has dried up to level 2, (L2_Naibor)* - the pressure is too much in the downstream zone and this marks the start of conflicts between downstream communities (pastoralists) and the agricultural communities in the upslopes.
- *The river has dried up to level 3, (L3_Mukima/Muramati)* - the conflicts between downstream and upstream communities are too extreme, such that the national government reacts by closing all the illegal water intakes. This causes water to flow downstream, convincing the pastoralists to go back to their 'normal' locations. However, a total loss has already occurred in the upstream zone due to the damages caused by livestock grazing in the cropland fields and the loss of irrigation water (i.e. after the intakes are forcefully closed). The value of livestock units drops proportionally as we assume livestock markets are inaccessible during high levels of conflicts in the board game.

The choices/decisions in the upstream zone

The households are presented with a starter kit of **KES 100,000.** At the start of the game, all land is assumed to be under natural vegetation (i.e. with green cards to represent tree cover, bushland, grassland, etc.). The upstream communities earn their livelihoods from agricultural activities; hence they will start by clearing natural vegetation to create cropland areas. In the board game, the agricultural households can clear up to 4 patches. The conversion of natural vegetation to cropland correlates with the declining river flows in the downstream zone during the dry season (Mungai et al. 2004; Mutiga et al. 2010; Wamucii et al. 2023). To mimic this scenario in the game, for every two patches cleared for agricultural activities, one marble will be permanently lost from the river network.

Agricultural households have the choice of investing in water storage or directly abstracting available water from the river network. They can also opt to reclaim part of the agricultural land back to natural vegetation through tree planting – which is assumed can proportionally restore the lost marbles to the river network in the dry seasons.

Investment costs in the mid/upstream zone:

The agricultural communities will invest in:

1. Cost UA: Expanding agricultural land - opening one patch for agriculture **costs KES 50,000.**
2. Cost UB: Estimated crop production costs, each agricultural patch will cost **KES 10,000**.

3. Cost UC: Irrigation water costs – abstracting marbles directly from the river system costs **KES 10,000/marble**
4. Cost UD: Rainwater harvesting costs – harvesting water equivalent to one marble costs **KES 50,000** (these are assumed to be one-off installation costs). Note: Participants can only invest in rainwater harvesting during the transition period/wet season, i.e. before the start of the next round.
5. Cost UE: Land reclamation/conservation efforts - costs **KES 10,000** per patch.

Note: One marble is required per agricultural patch opened in the upstream zone. Two marbles are required per agricultural patch opened in the midstream zone.

Earnings in the mid/upstream zone:

1. Earning UA: Each agricultural patch will give maximum returns of **KES 100,000**.
2. Earning UB: When LUs migrate upwards and occupy a grey patch (see boardgame - annex 6.2) that is next to an agricultural patch, the potential value of that agricultural patch **reduces by 50%**.
3. Earning UC: If no irrigation (i.e. no marbles allocated to agricultural patches), there will be no earnings as this is done during the dry season.

The choices/decisions in the downstream zone

The pastoralist households are also given a **start-up kit of KES 100,000**. They can make choices to invest in livestock units (LU) or rainwater harvesting. Agriculture is not feasible in the downstream zone due to agro-climatical limitations. The pastoralist communities are therefore concerned with the availability of water and grazing for their livestock. The maximum number of livestock units per pastoralist is 10 LUs. There must be at least 20 marbles in the downstream zone, otherwise, not all LUs can survive. Pastoralists must make quick decisions including selling their LUs or migrating in search of water. If none of these actions are taken, the LUs will die. For instance, assuming a maximum of 20 livestock units and only 15 marbles are available in the downstream zone, only 15 livestock units can survive in these conditions. Hence, action is needed for the 'vulnerable' 5 LUs if they are to survive. One decision is to migrate preferably upwards (as there is the presumption of both sufficient pasture and water in the upslopes). The grey patches in the mid/upstream zone (see boardgame - annex 6.2) are areas that LUs can occupy. If LUs occupy a grey patch that is next to an agricultural patch, the potential value of the agricultural patch reduces by 50%.

Note that there are only 12 grey boxes upstream, hence only 12 LUs can fit in the upstream zone without considerable damage to croplands. If more LUs need to migrate to the upslopes, the pastoralists can make decisions to forcefully occupy the patches belonging to the upstream households. The preference will be to find a patch with natural vegetation, if not, the pastoralists will be forced to invade the agricultural patches leading to total damage to crops and intensive conflicts. The limited number of grey patches upstream is set to mimic reducing areas for grazing within the study site.

Investment costs in the downstream zone:

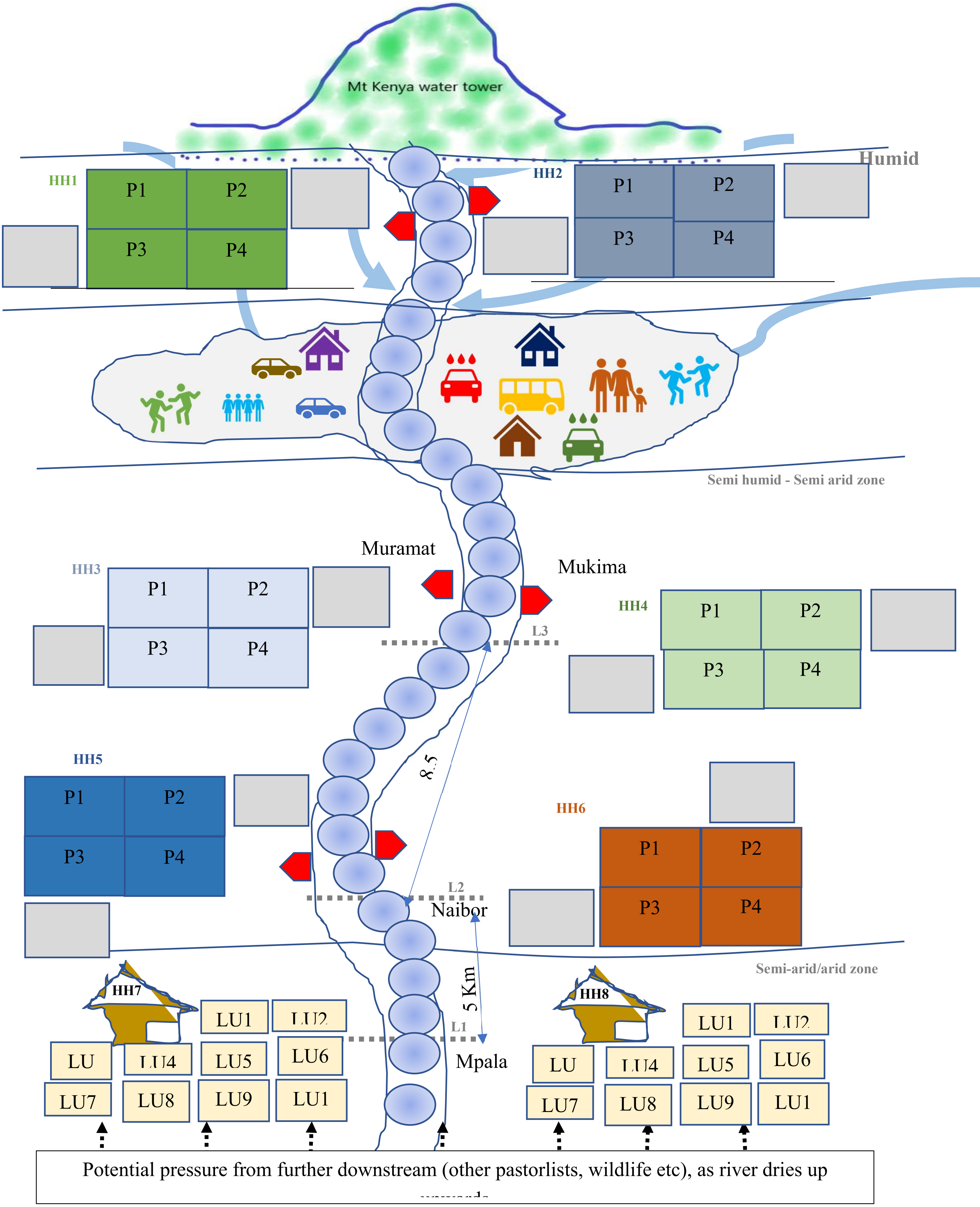
1. Cost DA: Investing in livestock will cost **KES 5,000** per LU. One pastoralist can keep a maximum of 10 livestock units**.**
2. Cost DB: Rainwater harvesting costs – harvesting water equal to one marble costs **KES 50,000** (these are assumed to be one-off installation costs).

Earnings in the downstream zone:

The total income/value is calculated as an aggregation of the total number of livestock units (LUs) per household that survive in a single round. One livestock unit under zero conflicts is given a value of **KES 20,000.** In case of conflicts, the value changes to **KES 15,000**, **KES 10,000**, and **KES 5,000** in levels 1, 2, and 3 of conflicts respectively.

Transition window - in-game rounds:
There is a transition window before the beginning of the next round. The facilitator guides the game participants by reminding them that the wet season is not simulated in the board game. The assumption is that in the wet season, the water is plenty, and all households are assumed to be comfortable. Rainwater harvesting can only be done in the transition window, i.e. before the start of the next round. If they invest in water harvesting, extra marbles will become available and placed next to the households. There are no limitations on the number of marbles that can be harvested during the rainy season. This is dependent on the willingness to invest in rainwater harvesting, the accumulation of new knowledge as the game progresses, and the financial capability of the game participants during gameplay. At the start of the next round, a dice is thrown to determine the climatic scenario and hence the number of marbles that will be available in the river network for the next round of the game.

Annex 2. The Board Game



Annex 3. The integration of board game elements in the construction of solution space

The game participants interact with the physical environment of the board game as they seek economic gains. This may be in the form of opening up land for agricultural expansion (in the upstream zone) or livestock keeping in the downstream zone. The number of people and their livelihood activities have a direct impact on water availability in the system due to increasing water demands. Rainwater harvesting is an option to reduce the pressure on limited water resources. Besides human influence, changes in water availability in the system are also affected by the uncertainty of climate change. In the end, the resulting water availability threshold dictates the system sustainability, emergence of human-water conflicts, government actions and policies including fines, etc. These outcomes have a reverse loop and affect the potential incomes of people. For instance, the government may forcefully close down river water abstractions even if you are a legal abstractor for the sake of downstream river flows. Such government decisions will directly lead to losses due to crop failures, affecting upstream economic livelihoods. Diminishing water resources in the system may result in the migration of pastoralists to the upstream zone in search of water. Migration will result in the downstream-upstream conflicts and more losses might occur due to grazing on agricultural fields, further worsening the situation for the upstream community. At the same time, the emergence of conflicts will also reduce the accessibility to livestock markets, hence reducing the 'market value' for livestock, and hence reducing economic returns for pastoralists.

Table A 1. The description of the system dynamic of the board game elements

Board game element	Integration in the system dynamic modeling
1. Water generation in the forested water tower	In the first game round, there are 100 marbles on the board game, which assumes 100% of water availability. However, in the succeeding rounds, a dice was used to vary water generated from the water tower between 70 and 100 marbles. A randomized equation was used in the system dynamic model to vary the number of marbles. $W_{gn} = 100 - (Cl_{mn0 \dots mx30})$ (Eq 1) where; W_{gn} is the net water generated from the forested water tower, $Cl_{mn0 \dots mx30}$ is the estimated number of marbles lost (Randomized between 0 and 30, Fig A 1) due to the uncertainty of climate changes.
2. Agricultural patches	In the upstream zone and midstream zones, agricultural patches were randomized between 1 and 4 per participant. There are eight participants representing the agricultural community in the board game (two in the upstream and four in the midstream zone).

3. Livestock numbers in the downstream zone	These were randomized between 1 and 10 per downstream participant (maximum is 20). There are two participants representing the pastoralist community in the downstream zone. Note: The number of participants in the board; *two-four-two* was used to mimic the population numbers in the *upstream-midstream-downstream* gradient of the case study site. The midstream zone of the upper Ewaso Ng'iro catchment is the most populated (including the urban towns) compared to the population in the upstream and downstream zones (Wamucii et al. 2023).
4. Human water demand (W_d)	This is given as: $W_d = I_{ag} + HH_w + Lv_w + Ur_w + ag_{wl}$ (Eq 2) where; I_{ag} is irrigation water demand, HH_w is household water demand, Lv_w is livestock water demand, Ur_w is urban water demand, ag_{wl} is the estimated water loss due to agricultural expansion (i.e. degradation). - The irrigation water demand was randomized between 0 and maximum limits described in 2 and 3 above. - Household water demand was a constant value (i.e. one marble per household) - The urban water demand was randomized to vary between 0 and 15 marbles. - Livestock water demand was randomized to vary between zero and maximum limits described in 4 above. - The estimated water loss was accounted for as one marble is permanently lost from the river network for every two agricultural patches opened. *Note: The term 'human water demand' is preferred here as the model focuses on surface flow and does not account for underground water, and atmospheric energy demand.*
5. Rainwater harvesting (W_h)	– For the agricultural community in the upstream zone, randomization was done on the number of marbles that can be harvested to vary between 0 and (X) per participant. X represents the number of agricultural patches opened. In the upstream zone, one marble is required per agricultural patch. – For the agricultural community in the midstream zone, randomization was done on the number of marbles that can be harvested to vary between 0 and (2X) per participant. The midstream zone is relatively dry; hence, two marbles are required per agricultural patch opened during gameplay – hence a multiplication by 2. – In the downstream zone, it was assumed that one marble could be harvested to sustain three livestock units, hence randomization was done to vary the number of marbles that can be harvested between 0 and 3. *Note that when a participant harvests water during gameplay, this is regarded as 'additional water' as this was done during the wet season (i.e. the transition period between the game rounds), which becomes additional water available during the dry season. Note that the ENGAGE game mimics what happens during dry seasons.*
6. Water availability in the board game system W_{av}	The net water availability in the board game system was accounted as the difference between water generated from the forested water tower and the total water demand in the system: $W_{av} = W_{gn} - W_d + W_h$ (Eq 3) where; W_{gn} is the net water generated from the forested water tower, W_d is the total water demand, and W_h represents the rainwater harvested during game transition periods. The values of W_h were randomized to vary between 0 and the limits described in 5 above. This was to capture runs with and without rainwater harvesting.
7. System sustainability factor S_{st}	The system sustainability factor was set as a function of water scarcity and livestock pressure in the downstream zone: The water scarcity condition is defined as water availability in the board game system (W_{av}) which is below 20 marbles. Livestock pressure will emerge if the number of livestock is above 12 (i.e. 12 livestock units – see Annexes 6.1 and 6.2). This triggers upward migration by pastoralists in search of water and grazing areas. *If Water availability (W_{av}) is below 20 marbles, the water scarcity is deemed present and given a value of 1.* *Condition i* *If livestock numbers in the downstream zone are above 12, the livestock pressure is deemed present and given a value of 1.* *Condition ii* The system sustainability factor was then calculated as follows: $S_{st} = W_{Sct} + Lv_{pr}$ (Eq 4) where; W_{Sct} is the water scarcity, and Lv_{pr} is the livestock pressure.

	If the system sustainability factor (S_{st}) is 2, pastoralists are forced to migrate upwards resulting in downstream-upstream conflicts. The government will also take action by imposing fines on upstream communities. *Condition iii*
8. Board game economics	For the upstream community, the potential income is KES 100,000 per agricultural patch. For the downstream community, the potential income is KES 20,000 per livestock unit that survives in a single round. However, the upward migration of pastoralists will result in a reduction of agricultural income by 20% to 50% due to the interference of livestock and potential grazing in the agricultural fields. The agricultural communities are also subjected to government fines randomized between KES 10,000 and KES 50,000 for those with no rainwater harvesting and directly abstract water from the river network in the board game. The fines are randomized between KES 10,000 and KES 50,000 to account for the chances of bribery in the process of managing water resources. The livestock market value is also affected by the downstream-upstream conflicts and market prices were randomized between KES 5,000 and KES 15,000.

Annex 4. Plotting the subtractive and constructive dynamics against the decisions made by game participants

The subtractive and constructive dynamics were plotted on a horizontal scale on the X-axis against major decisions made in the up/midstream and downstream zones on the Y-axis. The results further revealed a consistent increase of constructive dynamics against decisions to increase agricultural lands (Fig A2-A, D, and G), livestock units (Fig A2-B, E, and H), and rainwater harvesting decisions (Fig A2-C, F, and I). One major observation from Fig A2 is that the oscillations on the subtractive dynamics in each round could only see a delay in the change of constructive dynamics but did not reverse the overall gains. Even in a game round that was observed to have decisions to reduce livestock units, there was a reverse oscillation of the subtractive dynamics but still, an increase in constructive dynamics (although with a reduced rate of change) as illustrated in Fig A2.

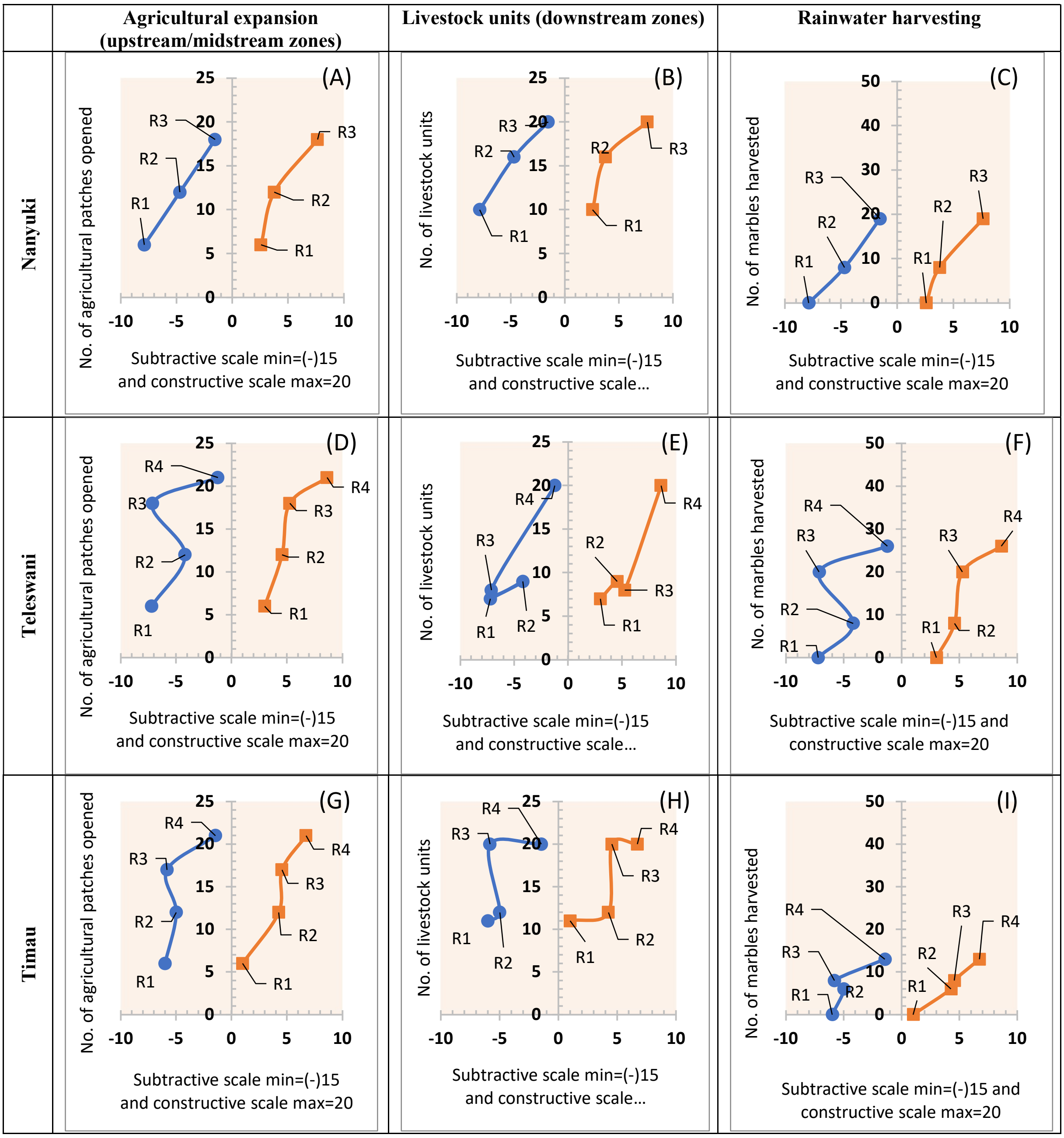


Figure A 2. Plotting subtractive and constructive dynamics against the decisions made by game participants. Along the X-axis, a subtractive scale of 0 would mean a total reduction of tension, conflicts, and selfishness. A constructive scale of 20 would mean maximum values for cooperation, collaboration, plural pronouns, and knowledge gain.

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