Hydrol. Earth Syst. Sci., 28, 3495–3518, 2024
https://doi.org/10.5194/hess-28-3495-2024

Hydrology and Earth System Sciences
Open Access

Guiding community discussions on human–water challenges by serious gaming in the upper Ewaso Ngiro 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], **and 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, 6700 AA 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, 6706 KN Wageningen, the Netherlands
[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

Correspondence: Charles Nduhiu Wamucii (charles.wamucii@wur.nl)

Received: 23 October 2023 – Discussion started: 27 November 2023
Revised: 24 May 2024 – Accepted: 27 May 2024 – Published: 1 August 2024

Abstract. Water-related conflicts in river catchments occur due to both internal and external pressures that affect catchment water availability. Lack of common understanding of human–water perspectives by catchment stakeholders increases the complexity of human–water issues at the river catchment scale. Among a range of participatory approaches, the development and use of serious games gained prominence as a tool to stimulate discussion and reflection among stakeholders about sustainable resource use and collective action. This study designed and implemented the ENGAGE (Exploring New Gaming Approach to Guide and Enlighten) game that mimics the dynamics observed during the dry season in the upper Ewaso Ngiro catchment, northwest of Mount Kenya. The purpose of this study was to explore the potential role of serious gaming in subsequent steps of strengthening stakeholder engagement (agenda setting, shared understanding, commitment to collective action, and means of implementation) toward addressing complex human–water challenges at the catchment scale. We assessed the type of decisions made during gameplay, the communication dynamics, the active participation, and the implication of decisions made on water availability. The results of three game sessions show that the ENGAGE game raised awareness and provided a recognizable hydrologic background to conflicts while guiding community discussions toward implementable decisions. The results revealed increasing active participation, knowledge gain, and use of plural pronouns and decreasing individual interests and conflicts among game participants. This study presents important implications for creating a collective basis for water management and can inform human–water policies and modification of the process behind water allocation rules in a river catchment.

1 Introduction

Human decisions drive changes in the physical environment, with both desired and undesired consequences for the socio-ecological system in space and time. The changes in the physical environment, in turn, influence human behaviour, with human adaptation solving or deepening human–environmental crises (Folke et al., 2016; Tilman and

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Lehman, 2001). Water-related crises experienced by people in watersheds (at local or regional levels), for instance, may be mainly due to competition for water resources between upstream and downstream users, without sufficient coordination. Differences in human perceptions, decisions, and interests between upstream and downstream users drive human–water crises and conflicts (Lesrima et al., 2021; Wiesmann et al., 2000; Yousef, 2021). Problems with many interdependent factors that make them very hard to solve, such as the differences in how humans view and interact with the dynamic physical environment, can be described as "wicked problems" (Arroyave et al., 2021; Defries and Nagendra, 2017; Lawrence et al., 2022; Levin et al., 2012; Rittel and Webber, 1973). Phenomena such as the tragedy of the commons (Dutta and Sundaram, 1993; Ostrom, 1999) are likely to ensue. Addressing the wicked problems of the Anthropocene requires a combination of knowledge and collective action, where both the scientific space, e.g. scientists, and the non-scientific space, e.g. small-scale farmers, interact with Earth systems and human societies (Lawrence et al., 2022). For this type of interaction to happen, there is a need to explore and adapt methodologies that strengthen stakeholder engagement toward addressing complex human–environmental challenges. Five interacting phases of the public debate on engaging stakeholders in natural resource management were identified as (a) agenda setting, (b) shared understanding, (c) commitment to goals, (d) means of implementation, and (e) re-evaluation based on monitoring (van Noordwijk, 2019). Participatory approaches have been used in river catchments to bring catchment stakeholders together in an attempt to solve complex human–water challenges (Villamor et al., 2022). A well-known approach to addressing human–water wicked problems is integrated water resources management (IWRM). IWRM is a comprehensive, participatory planning and implementation process for managing and developing water resources in ways that balance the socio-economic and environmental needs of the present and future (Jain and Singh, 2003; Savenije and Van der Zaag, 2008). Despite the successes in the implementation of IWRM in balancing the social, environmental, and economical issues of a basin or catchment (Obando et al., 2017; Lenton and Muller, 2012; Najjar and Collier, 2011; Scott et al., 2003), some gaps and challenges still exist, such as power imbalances, inclusion, lack of common perspectives, collective actions, and sustainable collaborations (Biswas, 2008; Giordano and Shah, 2014; Godinez-Madrigal et al., 2019; Rahaman and Varis, 2005; Sivapalan et al., 2012; Sokhem et al., 2007).

Firstly, IWRM does not directly account for the dynamics of the interactions and feedback between water and people (Sivapalan et al., 2012). Secondly and most importantly, IWRM typically adopts participatory methodologies, such as workshops, focus group discussions, and dialogue groups. Such participatory methodologies are limited in the extent to which they encourage participants to interact, understand, and digest the human–water wicked problem. This is because the setup does not encourage scientific experts and local experts to directly engage with the wicked problem. For instance, expert workshops might work well where participants have comparable levels of education and common communication styles, but this may not be the case considering differences in cultural norms and power asymmetries that make it more difficult to reach an agreement that satisfies those who do not have power (Rodela et al., 2019; de Vente et al., 2016). Even stakeholder engagement standards such as AA100AP (Kim et al., 2018), applicable at local level, or Common Minimum Standards for Multi-stakeholder Engagement (UNSDG, 2022), applicable at national level, among other standards fail to create a learning space that goes beyond participation and allows stakeholders to directly engage with the wicked problem, testing scenarios in decision-making, and experiential learning for collective action. Bielsa and Cazcarro (2015) underlined the need for innovative ways of participatory approaches for IWRM to achieve its optimal goals.

Given the complexity of human–water wicked problems, there is a need to transcend the scientific space, e.g. scientists, modellers, and policymakers, to incorporate the non-scientific space, e.g. small-scale farmers, private water suppliers, pastoralists, and traders. This may help in finding and integrating sufficient knowledge, insights into attitudes, and perceptions from various sources to co-create solutions (Norris et al., 2016; Pohl et al., 2017; Worosz, 2022). Serious gaming is an alternative participatory approach and is regarded as a strong transdisciplinary method (Arnab and Clarke, 2017; Cavada and Rogers, 2020; Hobbs et al., 2015; Janssen et al., 2023; Speelman et al., 2021, 2023). Serious gaming may include, amongst others, board games, card games, computer games, role-playing games, or a combination of any of these forms (Speelman et al., 2017). The design of a serious game is an iterative process that evolves with the participative process whereby local stakeholders (i.e. local experts) are actively involved in defining the wicked problem, design of the questions, simulations, and outputs (Rodela et al., 2019; Speelman et al., 2014, 2019). Compared to the conventional approaches and modelling, where the "outsiders" (e.g. hydrological modellers and scientists) define the model components depending on the area of interest (Babel et al., 2019; Mayer et al., 2017), the outsiders have no exclusive power to dictate the serious game components. While the conventional models are "black-boxed" (Kouw, 2016; Melsen, 2022), the gaming process is open and defined in collaboration with stakeholders (scientists and non-scientists) at all stages, from game conceptualization and game refining to game implementation. This is one of major differences in how the serious gaming approach differs from other conventional participatory approaches such as workshops. There are different ways to increase the engagement of participants during workshops, such as participatory mapping and experimentation with art-based visuals (Basco-Carrera et al., 2017).

In their study, Flood et al. (2018) conducted a review of 43 serious gaming publications and identified the major shortcomings to effective game design and engagement as one-off engagement (i.e. several game sessions are needed to enhance learning), capturing complexity without overwhelming the stakeholders, and future planning (i.e. linking game results to plan an uncertain future). Serious games are also limited in the number of stakeholders who can be involved in a single game session, a the constraint that raises the politics of who should attend the game(s) and why (Edmunds and Wollenberg, 2001; Wesselow and Stoll-Kleemann, 2018). Studies have also reported that social differentiations and power asymmetries have a greater influence on the outcomes of a participatory process (Barnaud and Van Paassen, 2013; Mathevet et al., 2014). Both the facilitators and the stakeholders have various degrees at which they can influence the participatory process (Jonsson et al., 2007). Serious gaming can also exacerbate the contests of power due to constraints of simplifying the complex real worlds, balancing the interests of the locals and the outsiders, and different perspectives of the present and future (Venot et al., 2022). A co-construction process where the designers and the participants collaborate to define the entire process is seen as a way to improve legitimacy of the participatory process and enhancing multi-stakeholder cooperation (Barnaud and Van Paassen, 2013; Barreteau et al., 2014; Basco-Carrera et al., 2018; Étienne, 2014). In general, the quality of participatory process depends on how biases and interests of all stakeholders, including outsiders, are balanced (Biggs et al., 2021; Daniell et al., 2010). As aforementioned, the politics that shape conventional processes (e.g. the influence of the outsider) are dealt with in the gaming approach through an iterative process that evolves with participatory modelling (Barreteau et al., 2014; Marini et al., 2018; Rodela et al., 2019; Speelman, 2014; Speelman et al., 2019). Hence, this study can be viewed as having done something different from the conventional participatory approaches (such as workshops, where outsiders dictate the process) by creating a different type of collaborative engagement and a safe environment for stakeholders.

Due to a lack of uniformity in the ways of conducting participatory engagements in IWRM, there is undoubtedly a need to explore different collaborative approaches such as serious gaming. The gaming approach can help local stakeholders move beyond individual interests and perspectives to engage in collective action in addressing complex human–environmental issues (Carrera and Mendoza, 2017; Marini et al., 2018; Medema et al., 2016). Serious gaming can increase active participation and negotiation among stakeholders, thus potentially leading to collective understanding and actions (Medema et al., 2016; Ouariachi, 2021; Speelman et al., 2014, 2019). In the process, researchers/facilitators/data collectors have an opportunity to gather relevant data and observations that can help document the emerging patterns of the human–environmental system under investigation, including co-produced solutions to the existing wicked problems. Among the five stages of engaging stakeholders in natural resource management, the first two (agenda setting and shared understanding) can be readily supported by locally adapted games, but progress has also been reported on the commitment to goals and exploring means of implementation (Janssen et al., 2023).

Improving stakeholder engagement is a prerequisite for any innovative sustainable system of water resource management (Adom and Simatele, 2022; Lim et al., 2022; Loucks and van Beek, 2017). Board games have been reported to stimulate active participation among stakeholders, promote collective understanding, simplify complex issues and systems, and allow stakeholders to directly engage with the wicked problem and other participants (Bayeck, 2020; Damron, 2019; Jean et al., 2018; Noda et al., 2019; Radzi et al., 2020; Speelman et al., 2014, 2017, 2019). Therefore, board games can be seen as suitable tools for improving stakeholder engagement in addressing complex human–environmental issues. Communication is one of the social parameters that enable the manifestation of a group strategy, improved efficiency of strategies, and better decision-making (Isaac and Walker, 1988; Orduña Alegría et al., 2020; Ostrom, 2014). In a serious gaming environment, communication during gameplay is a key factor influencing game outcomes (Baijanova, 2022; Neset et al., 2020; Page et al., 2016). Hence, studying communication patterns during gameplay can help evaluate the stakeholders' engagement and interpret emergent game results. Hence, contributing to the body of knowledge using the serious gaming approach as an alternative tool to addressing complex wicked problems. Studying communication patterns can help with studying relational logic (value attached on how stakeholders relate to one another) or instrumental aspects (economic perspectives) or both (Githinji et al., 2023). In addition, games can explore multiple levels of internalization of external impacts of individual decisions based on rules, economic incentives, co-investment, peer pressure to reduce one's footprint, or genuine concerns about impacts on others (van Noordwijk et al., 2023). Games can pose a challenge to the players who remain selfish as long as they only consider their direct interests, but emergent collective action can bring new solutions.

The purpose of this study was to assess the potential role of the ENGAGE game in strengthening stakeholder engagement toward addressing complex human–water challenges in a river catchment. Using a board game, gaming sessions were organized, involving various stakeholders from upstream, midstream, and downstream zones of a river catchment. Our case study was the upper Ewaso Ngiro River basin in Kenya, a catchment that experiences complex human–water challenges, leading to annual conflicts between upstream and downstream societies (Gichuki, 2006; Kiteme, 2020; Lanari et al., 2018; Liniger et al., 2005; Mutiga et al., 2010; Wamucii et al., 2023). The key research question to be answered in this study was to what extent a gaming approach strength-

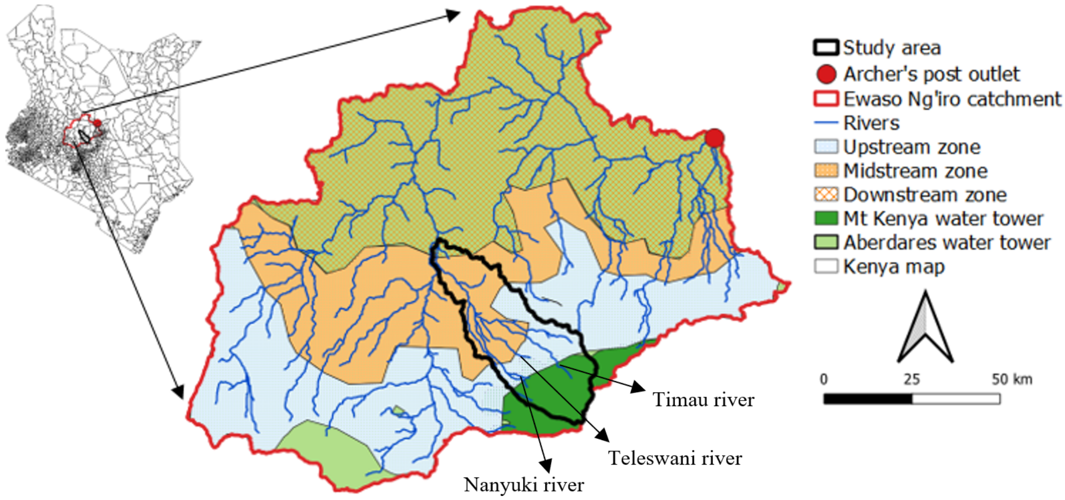

Figure 1. Case study area.

ens stakeholder engagement in and shared understanding of the human–water challenges as presented in the board game. The ENGAGE board game was used to model or mimic the real-life challenges experienced in the case study site.

2 Methodology

To assess the extent of stakeholder engagement during gameplay and whether the ENGAGE game guided decisions toward addressing human–water challenges presented in the board game, the following game variables were pre-identified as key research items to be investigated: (i) the type of decisions made during gameplay, (ii) the type and direction of sentiments as players made various decisions, (iii) the active participation among players, and (iv) the implications of decisions made on water availability of the board game system – explored in the solution space defined by all possible responses to the rules of the game (Speelman, 2014) and developed by carrying out a large set of simulated runs of the game. The solution space of the board game elements was developed to determine the realm of possibilities of participant choices in the ENGAGE game. The possible ranges (the minimum and maximum limits of game results) were explored in the modelled solution space. The overall performance of the game was assessed by plotting the actual game results within the solution space. The communication analysis focused on the subtractive dynamics (i.e. sentiments revealing tension, conflicts, and selfishness) versus constructive dynamics (i.e. sentiments revealing cooperation, positive collaboration, knowledge gain, and collectiveness).

We hypothesized that engaging participants in a serious game that mimics real-life challenges using complex human–water dynamics would trigger debates on possible alternatives to the human–water challenges presented in the board game. This assumption borrows from the literature that opines that problems or dilemmas activate counterfactual thinking (i.e. thoughts about alternatives to the problems), which can be directly linked to behavioural changes (Epstude and Roese, 2008). Therefore, we recognize that subtractive dynamics are important triggers of stakeholders' reactions, which can influence decision-making during gameplay. Using this logic, we argue that communication patterns can reveal subtractive dynamics during gameplay in the form of tension, conflicts, and selfishness. As a result, it was important to evaluate how subtractive dynamics triggered the behaviour of players during gameplay (based on decisions made). This was assessed based on the extent to which players were collaborating, cooperating with set rules during gameplay, use of the plural pronouns (we rather than I), and knowledge gain. Nevertheless, the subtractive dynamics were expected to decrease with the buildup of constructive dynamics during gameplay. Three game sessions representing three different sub-catchments were used to explore emerging patterns during gameplay. The game sessions were video-recorded to allow for post-game analysis of sentiments.

2.1 Case study area

The case study area is the upper Ewaso Ngiro River basin – northwest of Mt Kenya forested water tower (Fig. 1). It is located 180 km north of Nairobi city (between 0.14° N and 0.09° S latitude and between 37.03 and 37.28° E longitude). It has a climatic gradient with precipitation ranging from 1500 mm yr^{-1} in the humid upstream zone to 350 mm yr^{-1} in the arid downstream zone (Mungai et al., 2004). Population densities range from 800 persons per km^2 in the upstream zone to less than 20 persons per km^2 in the downstream zone.

In the upstream and midstream zones, small-scale and large-scale forms of agriculture are mainly practised, while in the downstream zone, pastoralism and wildlife-oriented tourism are the key activities. The rivers in the sub-basins are managed by the community-based Water Resources Users Associations (WRUAs). WRUAs are the link between water resources and the livelihoods of local communities in a river basin (Richards and Syallow, 2018). WRUAs are legally recognized as community-based associations for the collaborative management of water resources and the resolution of conflicts concerning the use of water resources at the local level (The Water Act, 2016). This study focused on three river sub-basins: Nanyuki River, which is 95 km in length; Teleswani River, which has a length of 30 km; and Timau River, which is 45 km long (Fig. 1).

The water availability in the catchment is influenced by changes in land use and climate (Wamucii et al., 2021). The aridity in the catchment changes drastically between the upstream (humid) zone and downstream (semi-arid/arid) zone within a short distance of 40 to 50 km (i.e. distance from the forested water tower to dry downstream areas) (McCord et al., 2015; Ngigi et al., 2007). The changes in the downstream water availability are attributed to the river water abstractions in the upstream zone (e.g. water used in irrigation and domestic and urban water supplies) (Laikipia Forum, 2021; Gichuki, 2006; MKEWP, 2017; Orendo, 2000; Wamucii et al., 2023), hence reducing the downstream hydrological flows, and conflicts emerge when downstream communities cannot adapt to the changing hydrological conditions (Kiteme, 2020; Liniger et al., 2005; Wiesmann et al., 2000).

The major issues in the catchment are therefore identified in this study as reduced dry-season flows, violent water-related conflicts that intensify during dry seasons, increasing water demand due to human population growth, and agricultural land expansion, among other issues (Kiteme, 2020; Mutiga et al., 2010, 2011; Ngigi et al., 2007; Wamucii et al., 2023; Wiesmann et al., 2000). Violent conflicts exist between different water users at different levels: upstream versus downstream water users, competing irrigators, agro-pastoralists versus pastoralists, users versus authorities and environmentalists, etc. (Aarts, 2012; Ehrensperger and Kiteme, 2005). Wiesmann et al. (2000) noted that the upstream communities lack awareness of the magnitude of downstream effects caused by their activities. This indicates varying perspectives between upstream and downstream communities on human–water issues, hence complicating the management of water resources.

For over 30 years, the WRUAs have received support and capacity building to improve water resources management and governance from both government institutions and non-governmental organizations. This type of support is mainly done through the common approaches, involving workshops, stakeholder discussions, and focus group discussions. WRUAs face various challenges including weak enforcement of policies/laws, water abstraction regulations, water metering requirements, and protection of riparian corridors/forested areas. These challenges can relate to a lack of collective action due to the individualistic nature of the communities they represent. In addition to the lack of collective actions by the communities, studies have shown that climate change, rapid changes in land-use systems, and societal changes such as population increase constantly challenge the ability of WRUAs to modify rules for water allocation (Aarts, 2012; Dell'Angelo et al., 2014; Lesrima, 2019). With increasing violent water-related community conflicts, the national government reacts by closing water intakes (both legal and illegal) in the upstream zone in desperate attempts to resolve the downstream–upstream conflicts. This temporarily acts as a solution to downstream river flows but negatively affects the livelihoods in the upstream zone due to the termination of water for irrigation. In addition, such national government decisions affect other key amenities such as health facilities, schools, and several industries that are already connected to both legal and illegal water intakes. Given the context above and to explore possible alternatives to WRUA management styles (especially increasing stakeholder engagement), developing and testing an alternative participatory approach such as a serious game was considered timely.

2.2 Game conceptualization

This stage involved gathering all possible ideas to help in drafting a serious game that mimics the context of the case study area. We conceptualized a board-and-role-play game, which mimics the complex human–water challenges experienced in the upper Ewaso Ngiro catchment, especially with an understanding of how the human–water system works (Wamucii et al., 2023). Relevant catchment issues were sought from publications highlighting the major causes of the changing hydrological conditions and the water conflicts in the upper Ewaso Ngiro catchment. This was further reinforced by identifying the actors, resources used by actors, key dynamics, and interactions at the case study site in an approach that is commonly referred to as the ARDI approach (actors, resources, dynamics, and interactions) that directly engages stakeholders in the design and development of the serious game (Etienne et al., 2011). Focus group discussions were also carried out with the communities in the three sub-catchments. The community discussions were helpful in widely discussing the ideas and components included in the board game. The selection of participants and mobilization were done through respective WRUAs in the three sub-catchments. The ENGAGE game as developed and implemented in this study is summarized below and explained in detail in Supplement Sect. S1 in the Supplement.

2.2.1 Description of the board game and players

ENGAGE (i.e. Exploring New Gaming Approach to Guide and Enlighten) is a type of board-and-role-play game (see Supplement Sect. S2) that seeks to increase collaborative decision-making in the river basin through experiential learning. The goal of the game is to engage in and stimulate discussions and learning among participants. There are a total of 10 active game participants per game session:

- two participants representing the upstream agricultural community,
- four participants representing the midstream agricultural community,
- two participants representing the pastoralists in the downstream zone,
- one participant plays the role of implementing local water regulations (i.e. WRUA),
- one participant plays the role of the national government (imposing rules and fines).

The declared individual goal for the eight land-user participants is to win a game round by accumulating the largest sum of money (profits) at minimal water-related conflicts.

2.2.2 Game mechanics

The ENGAGE game mimics the dynamics observed during the dry seasons in the upper Ewaso Ngiro catchment. The river network (i.e. marbles on board game) connects the communities as water flows from the forested Mt Kenya water to the downstream areas. There were two phases in the implementation of the ENGAGE game in this study. Phase one mimics reality, whereby individual values and preferences of the players were allowed to shape the game results. The first two or three rounds were considered sufficient for players to learn from individual decisions and consequences. In the second phase (i.e. a final round or the reflection round), the players were guided to reflect on the game results and experiences from phase one and think objectively about what the potential solutions to the human–water challenges could be (observed in phase one). 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 h per game session in each sub-catchment (i.e. after four rounds). The ENGAGE game as implemented in this study was relatively closed and strictly followed the rules set out in Supplement Sect. S1. The rules remained relatively the same in all game rounds apart from the agricultural lands expansion that evolved in the succeeding game rounds. The external observers were also allowed to join the game sessions and included persons not directly involved in the playing of the game but instrumental during debriefing sessions. More information about the conceptualization and application of the ENGAGE game is given in Supplement Sect. S1.

2.2.3 Key actions and key outcomes expected in the game

The upstream communities earn their livelihoods from arable agricultural activities; hence, they will start by clearing natural vegetation to create cropland areas. Supplemental irrigation is a key decision for the opened agricultural patches. For every two patches cleared for agricultural activities, one marble is 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. In the downstream zone, the pastoralist households are concerned with the availability of water and grazing area for their livestock. With declining water resources, pastoralists must make quick decisions, including selling their livestock or migrating in search of water. One decision is to preferably migrate upwards (as there is the presumption of both sufficient pasture and water in the upslopes).

2.2.4 Potential impact on water resources availability

In the first round, participants play the game under an assumed normal climate scenario (i.e. with a maximum of 100 marbles). In the subsequent rounds, a dice is used to determine the exogenous conditions and, hence, the number of marbles to be placed on the board game (i.e. ranging between 70 and 100 marbles). 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). However, as marbles get abstracted, the length of the river network reduces and, hence, the river starts drying up from the downstream zone upwards.

2.2.5 Possible reactions expected by actors and feedback

The agricultural activities intensify in the upstream zone, affecting the water balance, due to increasing demand for direct water abstractions. The game participants may react by investing in rainwater harvesting or collectively agreeing on water rationing during gameplay. The effects of changes in the water balance are, however, most heavily 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. This causes massive destruction of crop fields as pastoralists migrate with their livestock, fuelling intensive conflicts. The authorities react by destroying all water intakes and imposing heavy fines on illegal water users.

2.3 Game pre-testing and validation

Game validation comprises a process of building arguments to support (or challenge) the claims, content, and outputs of a game (Hummel et al., 2017). Involving and learning from key stakeholders during the validation is a common practice

Figure 2. Pre-testing the game with PhD students at Wageningen University **(a, b)**, presentation of the game during the SESAM project outreach day on 12 April 2022 **(c, d)**, and one of the validation sessions with the targeted communities **(e)**.

to reinforce trust and ownership and to address the external and internal issues of a serious game (Jackson, 2012; Redpath et al., 2018). Three steps were followed in the validation of the game in this study (Fig. 2). The first step involved the conceptualization of a serious game as described above. This was followed by pre-testing the draft game with fellow game designers working on forest–water–people issues elsewhere in the tropics (Van Noordwijk et al., 2020). The pre-testing allowed for assessing the playability of the game and the suitability of the game in answering research questions. The final step involved conducting field trials with the communities in the upper Ewaso Ngiro River catchment to validate and adapt the final version of the serious game.

2.4 Data collection

2.4.1 Documenting gameplay decisions

A data collection sheet was used to document key decisions made during game sessions, such as the number of agricultural patches opened, the amount of water extracted from the river system, the amount of water harvested if any, the profit made at the end of each game round, and the number of livestock at the start and end of each game round. Other data collected during game sessions included the impact of climate variability on water availability in the board game (i.e. climate variability was mimicked by throwing a dice at the start of a game round that determined the flow available for each round), water demands in the households and urban towns, and net water availability at the end of each game round.

2.4.2 Analysing communication patterns

As participants engaged with one another and made various decisions, their verbalized sentiments were documented to evaluate the emergent patterns in the communication, which was used to evaluate stakeholders' engagement during gameplay. For each of the sentiments extracted, the following issues were considered:

i. The first issue is the direction of each sentiment (i.e. whether the sentiment was directed to the facilitator, to other participants, or as a spontaneous reaction from the board game outcomes).

ii. The second issue is the nature of the sentiment (i.e. subtractive and constructive dynamics). This involved scoring each sentiment against the game dynamics provided in Table 1.

The subtractive characteristics were scored with values ranging from −5 to 0 and the constructive characteristics were scored with values ranging from 0 to 5 (see Table 1). The summation of both subtractive and constructive dynamics provided the overall status of each game round. The maximum subtractive dynamics had a total of −15 points, and the maximum constructive dynamics had a total of 20 points (Table 1). Each game round resulted in a variety of sentiments, and their patterns were explored within this pre-defined scoring range (i.e. between −5 and +5). This was important to evaluate the communication patterns in the different game rounds and what that means in relation to stakeholders' engagement. The subtractive and constructive dynamics (Table 1) were based on the observation manual for collective serious games (Daré et al., 2021). The extraction of sentiments was done manually through post-game video analysis.

At the end of each game session, post-game feedback sessions were also conducted, where participants were allowed to give their feedback and key lessons from the game sessions. This qualitative feedback was useful in understanding participants' perceptions and reflections, which were critical in qualitatively discussing the game results of this study.

Table 1. The elements used to monitor game dynamics. The scoring was done by the first author, who was the main facilitator of all game sessions.

Game dynamics		Sentiment scoring details	Minimum and maximum scores	Total scores
Subtractive dynamics	1. Tension	This represents the extent to which the sentiment indicates the participant is worried about or uncomfortable with the game dynamics during the game session. The sentiment can express the tension; e.g. one participant is uncomfortable with/worried about the action of the other, but no visible conflict is observed yet. Score of 0: no tension was detected at all. Score of −1: very low-level tension. Score of −2: slightly tensed. Score of −3: somewhat tensed. Score of −4: moderately tensed. Score of −5: extremely tensed.	Minimum score = −5 Maximum score = 0	Subtractive dynamics minimum score = −15 and maximum score = 0
	2. Conflict	This represents the condition in which the sentiment is made in regard to the level of aggression of participants and/or visible conflicts during the game session. A visible conflict can be observed during gameplay, e.g. denying access to a resource resulting in the deaths of livestock, losses, etc. Note that when there exists a visible conflict, the scoring for tension is set at a minimum score of −5. Score of 0: no aggression/visible conflicts were observed at all. Score of −1: very low aggression/visible conflicts. Score of −2: slightly aggressive. Score of −3: somewhat aggressive. Score of −4: moderately aggressive. Score of −5: extremely aggressive/visible conflicts were observed.	Minimum score = −5 Maximum score = 0	
	3. Selfishness	This represents the extent to which the sentiment indicates the level of selfishness/self-seeking behaviour during the game session, e.g. when a player refuses to share a resource. Score of 0: no selfishness was detected at all. Score of −1: very low selfishness. Score of −2: slight selfishness. Score of −3: some selfishness. Score of −4: moderate selfishness. Score of −5: extreme selfishness.	Minimum score = −5 Maximum score = 0	
Constructive dynamics	1. Cooperation	This represents the extent to which the sentiment indicates the level of positive cooperation with the existing rules set by other participants or facilitators during gameplay. (Score of 0: no cooperation at all. Score of 1: very low cooperation. Score of 2: slight cooperation. Score of 3: some cooperation. Score of 4: moderate cooperation. Score of 5: extreme cooperation.	Minimum score = 0 Maximum score = 5	Constructive dynamics minimum score = 0 and maximum score = 20
	2. Collaboration	This represents the extent to which the sentiment indicates the level of positive collaboration toward solving the issues at hand during gameplay. For instance, two participants or more agree to reduce water abstraction in a given round to allow the river to flow to the downstream zone. Score of 0: no collaboration at all. Score of 1: very low collaboration. Score of 2: slight collaboration. Score of 3: some collaboration. Score of 4: moderate collaboration. Score of 5: extreme collaboration.	Minimum score = 0 Maximum score = 5	
	3. Knowledge gain	This represents the extent to which the sentiment indicates a new realization or knowledge gained by the participants during gameplay. Score of 0: no knowledge gain was detected at all. Score of 1: very low knowledge gain. Score of 2: slight knowledge gain. Score of 3: some knowledge gain. Score of 4: moderate knowledge gain. Score of 5: extreme knowledge gain.	Minimum score = 0 Maximum score = 5	
	4. Presence of plural pronouns	This represents the presence or absence of plural pronouns in the sentiment. Examples of plural pronouns included we, our, us, and their. Note that the study focused on inclusive we as described in van Noordwijk et al. (2023). Score of 0: absence of plural pronouns. Score of 5: presence of plural pronouns. Note that a score of 5 (in cases of the presence of plural pronouns) was preferred to ensure the fitting of all the constructive dynamics on a similar scale of 0 to 5.	Minimum score = 0 Maximum score = 5	

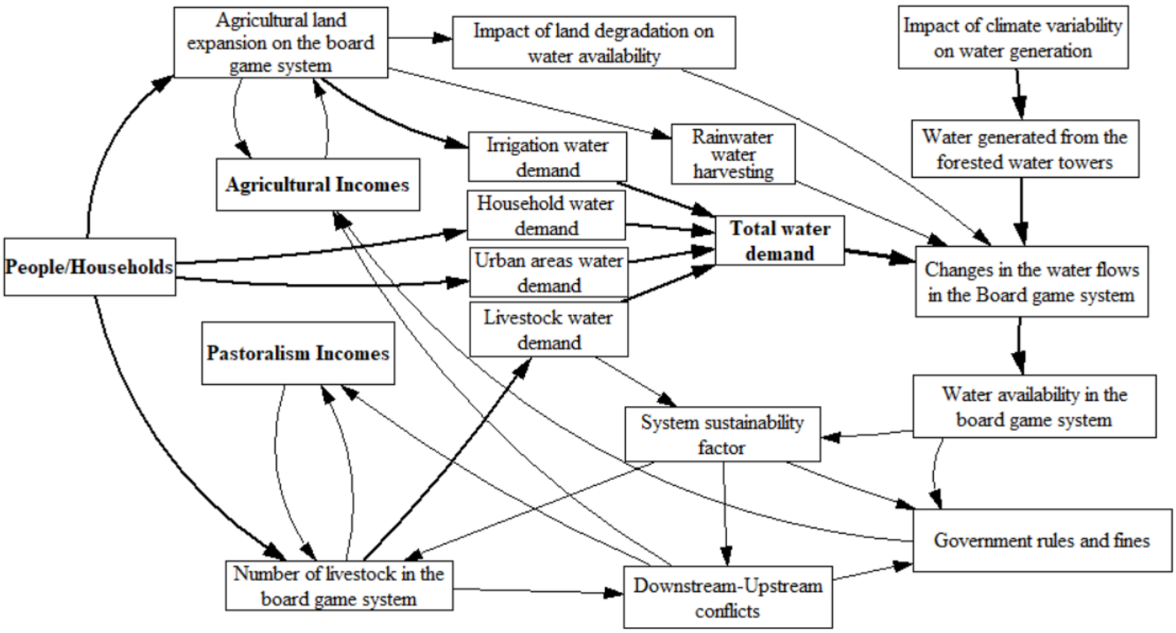

Figure 3. The schematic representation of the system dynamics modelling of the elements of the board game.

2.4.3 Modelling the game solution space

A system dynamic model of the board game elements was developed to determine the solution space of all possible participant choices in the ENGAGE game. This was important to establish the envelope within which the ENGAGE game operates by understanding the minimum and maximum values of the various game metrics. Figure 3 illustrates the system dynamics modelling of the board game elements. The possible ranges of game outcomes were explored in the modelled solution space. The solution space was constructed by a total of 1000 runs (more details are provided in Supplement Sect. S3).

Water resources in the board game are generated from the Mt Kenya forested water tower, and a river network is represented by 100 marbles (string-connected), as illustrated in Supplement Sect. S2. The 100 marbles mimic the normal climatic scenarios, i.e. 100 % of water availability. To represent interannual rainfall variability, a dice was thrown and the value obtained determined the flow for the game round indicated by the number of marbles, between 70 and 100 (Fig. S1 in the Supplement). Within the board game, there is competition for water due to various water demands, such as water for irrigation, household consumption, livestock, and urban water demand. Water availability was accounted for as the difference between the water generated from the water tower and total water demand. Rainwater harvesting was considered additional water for the board game, as this was done during the transition of game rounds. A detailed description of the development of the solution space is provided in Supplement Sect. S3 and Table S1 in the Supplement.

3 Results

3.1 Decisions made during game sessions

For the agricultural community in the upstream and midstream zones (i.e. players 1 to 6), the results from the three game sessions showed that the players adopted a systematic approach to opening up agricultural patches. The players began by opening up only a few agricultural patches in the initial rounds, but this increased in the succeeding rounds, as shown in Fig. 4a–c. River water abstractions increased with increasing numbers of agricultural patches, especially in the midstream zone (i.e. players 3, 4, 5, and 6) – a relatively dry zone (Fig. 4d–f). Water harvesting was increasingly selected in the succeeding game rounds (Fig. 4g–i). In the downstream zone, the game results revealed unsystematic stocking of livestock units by pastoralists (i.e. players 7 and 8). The number of livestock that survived within the board game system (at the end of each game round) was observed to be equal to or lower than the available stock at the start of the game. Toward the end of a game session, we observed stability in the number of livestock that survived in the system (Fig. 4j–l). This stability coincided with rainwater harvesting adopted by all the players in the succeeding rounds. The key characteristics of the final round included moderate water availability in the board game, reduced upward migration of livestock units, reduced losses of crop damages, minimal or no conflicts, and reduced government interference and fines.

The profits earned seem to have an increasing trend among the agriculturalist players (i.e. players 1 to 6) in the succeed-

Figure 4. Summary of game results in the three sub-catchments: the number of agricultural patches opened per player **(a–c)**, number of marbles extracted from the board game per player **(d–f)**, number of extra marbles available per player (harvested during rainy season) at the start of each round **(g–i)**, and number of livestock at the start of the game and the end of the game **(j–l)**. R represents game rounds.

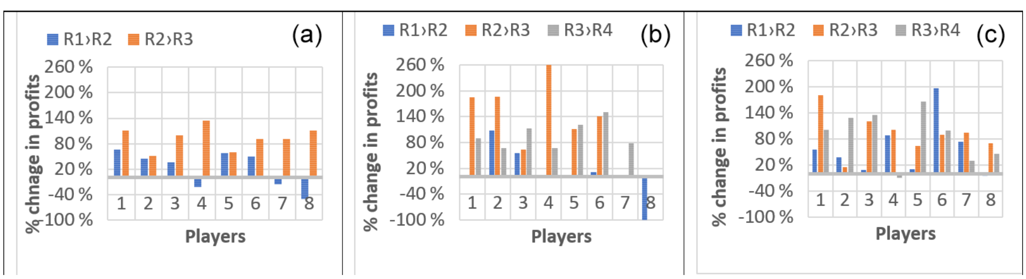

Figure 5. Percentage in profits between consecutive rounds in the different game sessions in **(a)** Nanyuki, **(b)** Teleswani, and **(c)** Timau.

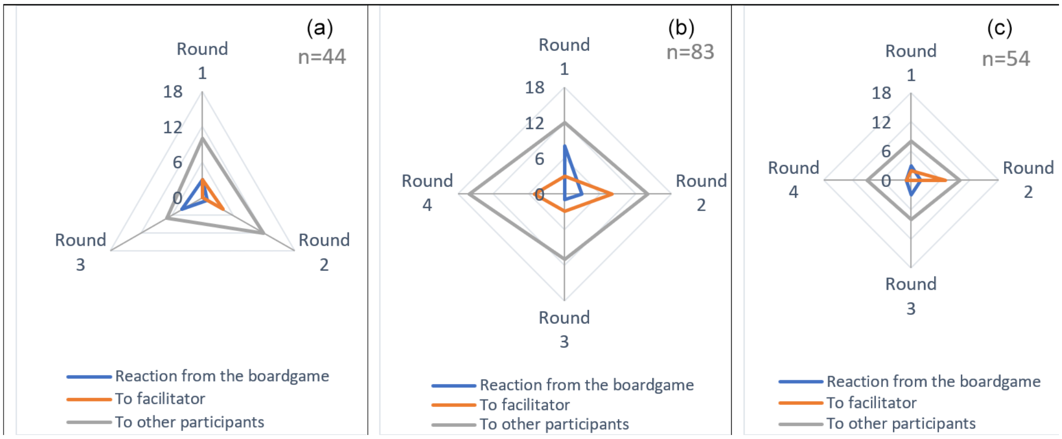

Figure 6. The summary of the direction of the sentiments extracted during the game sessions in Nanyuki **(a)**, Teleswani **(b)**, and Timau **(c)**.

ing rounds, which coincided with the land expansion in the board game (Fig. 5). On the contrary, profits earned by pastoralists (i.e. players 7 and 8) varied, and they were dependent on the number of livestock units that survived in the board game system for each round. There were some game rounds where pastoralists did not sell livestock units, resulting in debts or negative net profits (Fig. 5a and b). Interestingly, the rate of change in profits between the game rounds was the lowest among pastoralist players compared to that of the agriculturalist players (Fig. 5). In the three-game sessions, the average change in profits ranged between 0 % and 65 % for pastoralists, while for agriculturalists, the average change in profits ranged between 48 % and 128 %. A general observation is that higher profits were realized toward the final rounds when the board game system was relatively stable. Profits were observed to be affected by several factors during gameplay, including the number of agricultural patches (and whether they are irrigated or non-irrigated), number of livestock units in the board game, government fines, crop losses due to pastoralist migration, corruption, and players' debt during gameplay.

3.2 Communication analysis

3.2.1 Participation during gameplay

During game sessions, participants engaged with one another as they interacted with the dynamics of the board game. A total of 181 sentiments were extracted from the video records of the three-game sessions: 44 sentiments from three rounds in Nanyuki, 83 sentiments from four rounds in the Teleswani sub-catchment, and 54 sentiments from four rounds in the Timau sub-catchment. The results of this study show that most of the sentiments raised in a game round were mainly directed to other participants (Fig. 6a–c). This indicates that the gaming approach stimulated and sustained active participation among the participants throughout the game rounds.

3.2.2 Communication patterns during gameplay

The sentiments were further analysed to identify their subtractive and constructive characteristics using the set criteria in Table 1. The results from the three game sessions reveal patterns of communication emerging in the different game rounds. Subtractive dynamics seem to reduce in the successive game rounds (Fig. 7a, c, and e). To some extent, the scores for conflict and selfishness appeared to reduce to zero, especially in the final round. However, tension during gameplay remained relatively high and, in some cases, had a reversal, as demonstrated in Fig. 7c and e. An increasing trend for constructive dynamics was observed especially with the increase in knowledge gain and the increased use of plural pronouns (Fig. 7b, d, and f). Collaboration and cooperation had the lowest scores among the constructive dynamics in the different game rounds. One important finding of this analysis is that even with a sudden increase in tension and conflicts (i.e. scores approaching −5), knowledge gain maintained a continuous increase throughout the different game rounds.

The results of different game rounds were analysed by plotting the total scores in Fig. 7 into scatter graphs with four quadrants (Fig. 8). This helped evaluate the scores of a game round in relation to tension, conflicts, selfishness (i.e. subtractive dynamics) and/or cooperation, collaboration, increase in knowledge gain, and use of plural pronouns (i.e. constructive dynamics). A game round in quadrant 1 (Q1) means the sentiments raised during gameplay reveal higher characteristics of both subtractive and constructive dynamics. A game round in quadrant 2 (Q2) has high constructive dynamics and low subtractive dynamics. Quadrant 3 (Q3) revealed high subtractive dynamics and low constructive dynamics. A game round in quadrant four means low characteristics of both subtractive and constructive dynamics. Apart from the Nanyuki game session, where the first round was plotted in quadrant three, all the game rounds in the three sessions were plotted in quadrant 4 (Q4). These results show

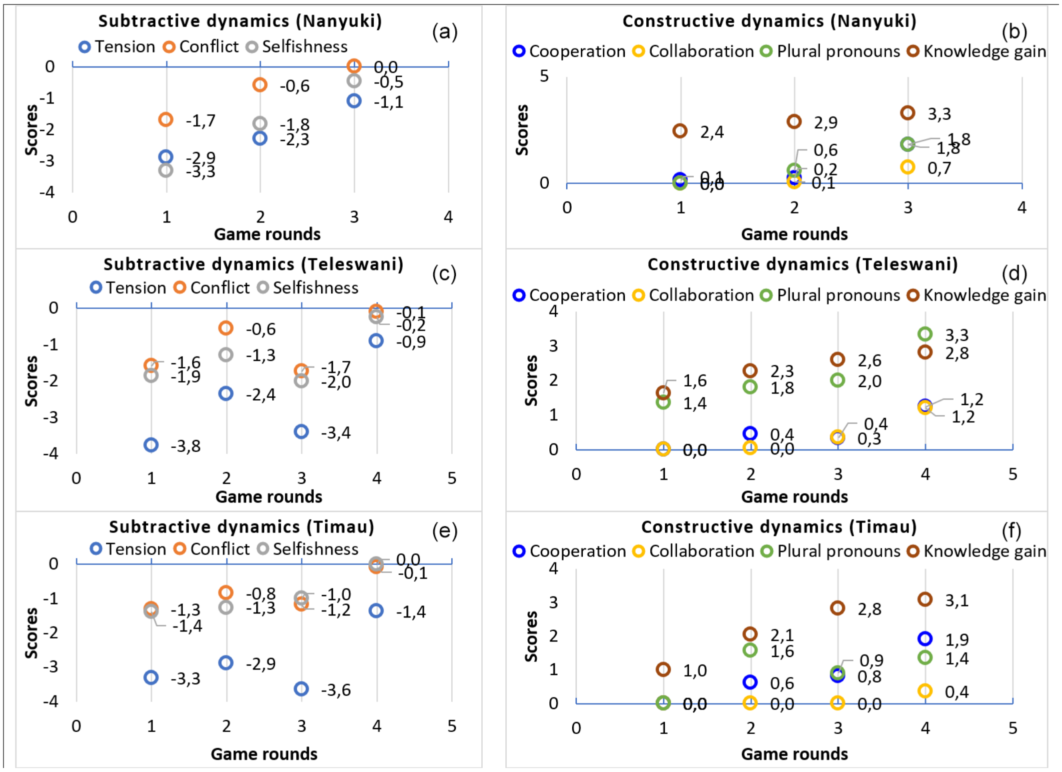

Figure 7. The scoring outcomes for the subtractive and constructive dynamics for the three game sessions.

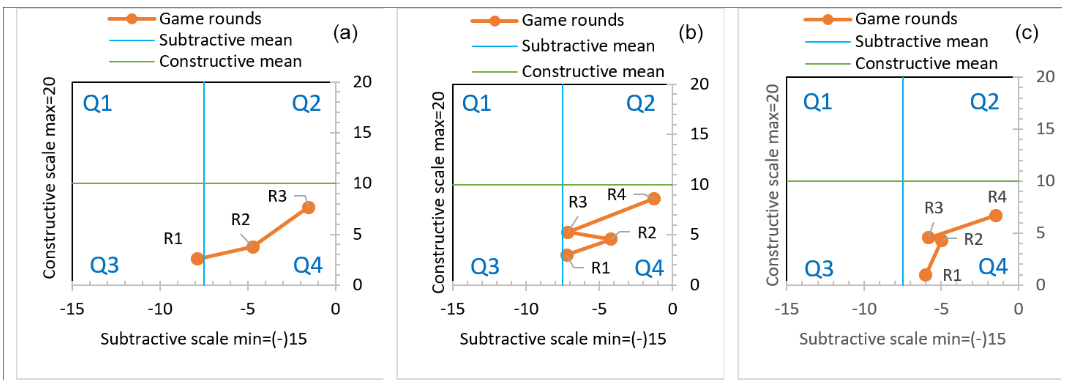

Figure 8. The status of game rounds based on total scores (i.e. the summation of subtractive scores, min = −15, and constructive scores, max = 20) for game sessions in Nanyuki **(a)**, Teleswani **(b)**, and Timau **(c)**. A game round ending up in quadrant 2 would be desirable, as this would indicate increased cooperation, collaboration, knowledge gain, and plural pronouns and at the same time a reduction in tension, conflicts, and selfishness.

that the game sessions did not reveal extreme levels of both the subtractive and constructive dynamics.

One key observation with this type of analysis is that succeeding game rounds revealed a clear pattern toward quadrant 2, mainly due to the constant increase in constructive dynamics. However, the subtractive dynamics revealed an oscillation pattern (i.e. an increase in one game round and a decrease in another game round) (Fig. 8b and c). Although the game sessions had a few rounds of up to four rounds, this type of analysis helps shed more light on the engagement of stakeholders and their experiences during a game session. The pattern of a constant increase in constructive dynamics was further emphasized by plotting the subtractive and constructive dynamics against the major decisions made by game participants (Fig. S4 in the Supplement). The results show that the oscillations on the subtractive dynamics in each round could only see a delay in the change in constructive dynamics but did not reverse the gains.

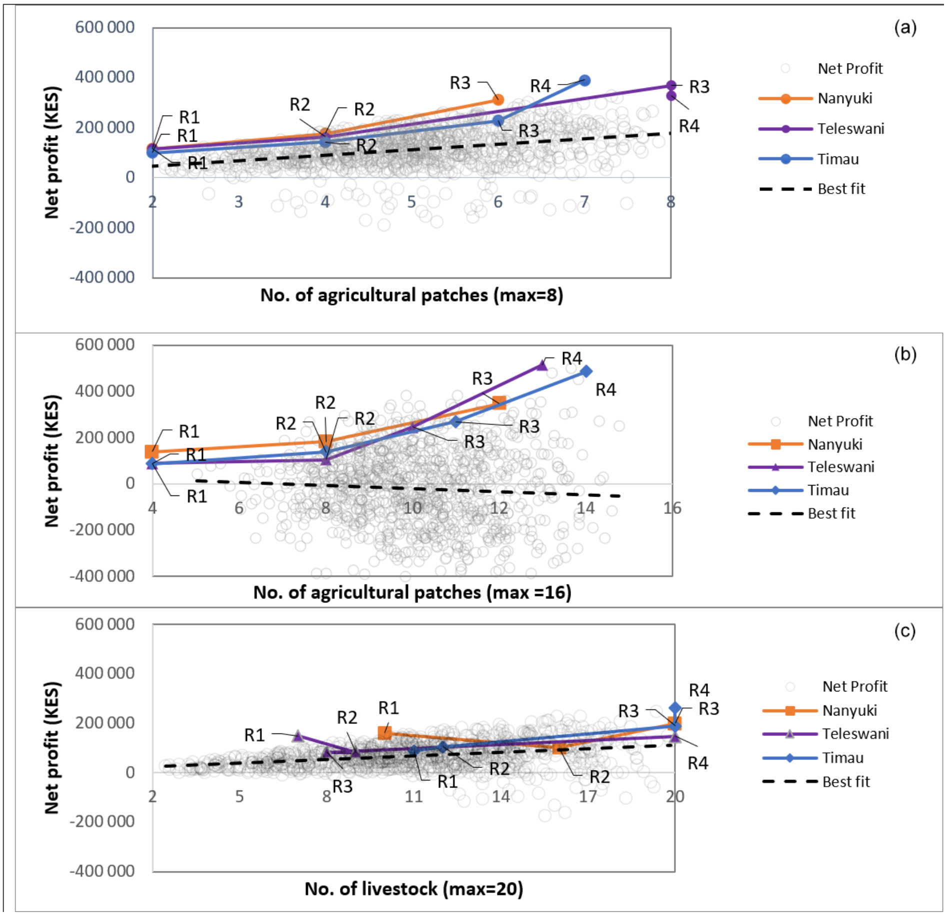

Figure 9. The board game economics in the upstream **(a)**, midstream **(b)**, and downstream **(c)** zones of the board game.

3.2.3 The solution space and game results

The solution space was used to plot the actual game results to help in the interpretation of emerging patterns. The actual game results on net profits for upstream and midstream zones seem to lie in the upper limits of the solution space compared to those of the pastoralist players in the downstream zone (Fig. 9a–c). Plotting the game session results in the game solution space showed that investment in agricultural expansion in the midstream zone may not necessarily lead to an increase in net profit (Fig. 9b).

The agricultural expansion in the upstream and midstream zones of the board game was one of the major contributors to river water extraction during gameplay. The results show that water availability decreased with an increase in agricultural expansion (Fig. 10). However, the actual game results showed the reverse of this trend, where water availability increased in Teleswani and Timau game sessions, especially toward the final game rounds (Fig. 10). A game round in Q2 in Fig. 10 would be preferable as it means increased water availability despite the extreme agricultural expansion in the board game landscape.

The results reveal that an increase in water availability toward the final game rounds seems to coincide with increasing water harvesting decisions made by game participants (Fig. 11a). Figure 11b compares actual game results that incorporated water harvesting decisions and projected game results, assuming no water harvesting decisions were made. The results showed that by the end of the game session, water availability increased by 59 %, 91 %, and 50 % in Nanyuki, Teleswani, and Timau, respectively. This puts a strong emphasis on the importance of water-harvesting decisions on the actual water availability against increasing agricultural expansion and livestock units during gameplay.

4 Discussion

This study aimed to assess the potential role of the ENGAGE game in strengthening stakeholder engagement toward addressing complex human–water challenges of a river catchment. The study designed and implemented the ENGAGE game that mimicked the dynamics observed during the dry seasons in the upper Ewaso Ngiro catchment. We assessed the type of decisions made during gameplay, the communi-

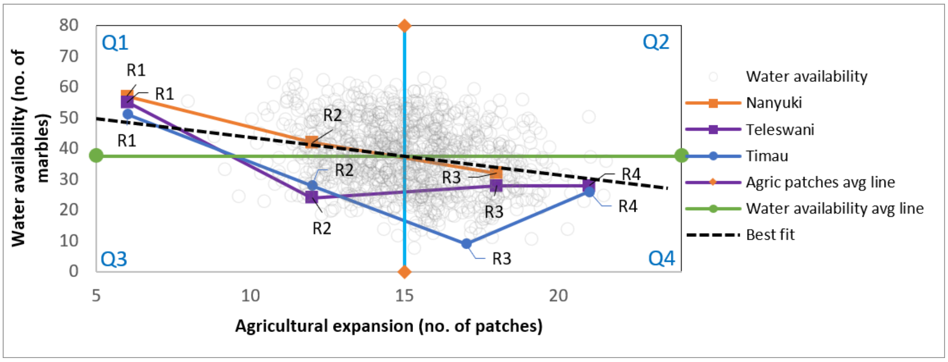

Figure 10. A solution space that links agricultural expansion and water availability on the board game.

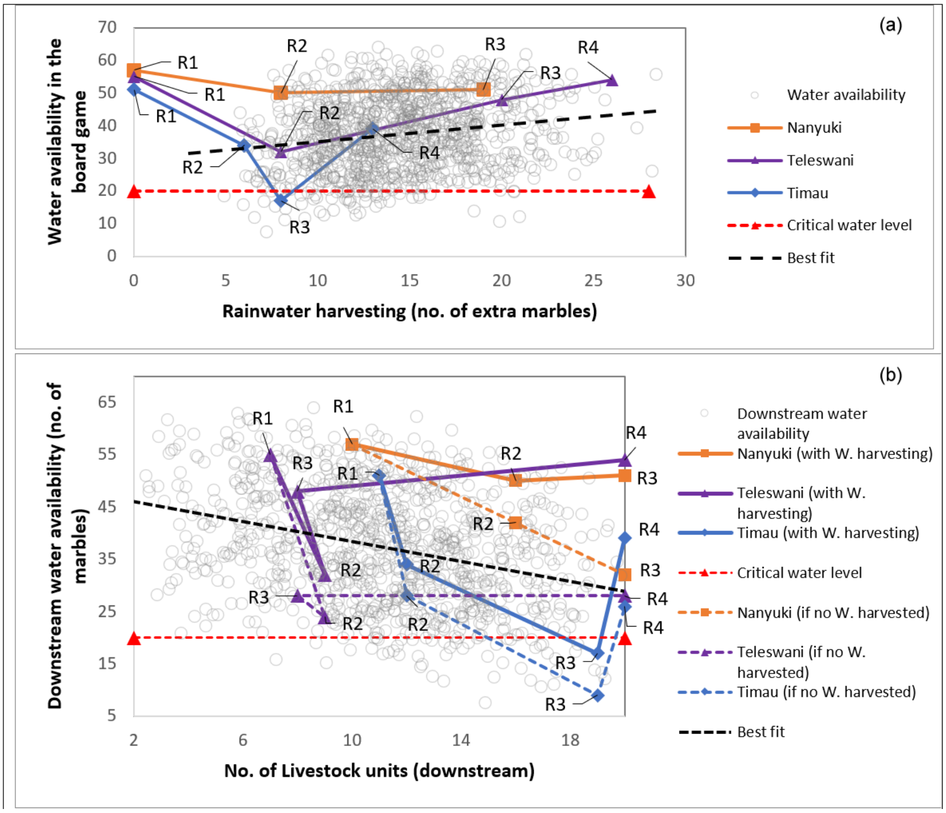

Figure 11. A solution that shows the effect of rainwater harvesting on water availability in the board game. General water availability in the board game **(a)** and downstream water availability **(b)**. Actual game rounds with rainwater harvesting are shown with solid lines. Dashed lines are projected game rounds if no rainwater harvesting decision was made. In the ENGAGE game, the critical water level is assumed to occur when water availability goes below 20 marbles. This is because of the likelihood of livestock units in the downstream zone reaching the maximum of 20 (given that each livestock unit requires one marble), hence the critical point where conflicts would occur regardless of other decisions made during gameplay.

cation dynamics, the active participation, and the implication of decisions made on water availability. Overall, the results show that implementation of the ENGAGE game as implemented in this study revealed the potential to strengthen stakeholders' engagement and shared understanding through stimulating active participation, increasing knowledge gain and collectiveness, and minimizing individual interests and conflicts among game participants.

4.1 Decisions made during gameplay

Based on the decisions made, upstream participants were observed, to start, by opening a few agricultural patches in the initial rounds, but this increased in the succeeding rounds, consequently increasing the demand for river water. This systematic approach could be attributed to equal capital distribution (i.e. money allocated to players) at the start of the game. However, as more profits were realized, we observed increased agricultural land expansion. Plotting actual game results on net profits in the solution space revealed maximum profits for the upstream and midstream players compared to those of the pastoralist players in the downstream zone. In addition, the solution space revealed that investment in agricultural expansion in the midstream zone may not necessarily lead to an increase in net profit. This can be attributed to higher costs of farming activities in the midstream zone. For instance, since the midstream zone is relatively dry, players are required to invest in two marbles per agricultural patch (for irrigation) compared to one marble in the upstream zone. Additionally, they are vulnerable to making losses due to the immigration of livestock units from the downstream zone even with moderate decreases in downstream water availability.

The downstream participants could not sustain their livestock numbers within the board game system, especially during the initial game rounds. This was mainly due to decreasing water availability and negative reception by the upstream participants, who opposed the movement of livestock upwards into the agricultural zone. However, as the game sessions advanced toward the final rounds, we observed an increase in the use of plural pronouns, knowledge gain, and active participation among players during gameplay. As a result, the need to find remedies to reverse human–water challenges experienced by players as a result of their decisions manifested toward the end of the game. For instance, the need to adopt rainwater harvesting as a strategy to reverse the negative consequences spontaneously emerged among the players. This concurs with other studies that reported that game participants revise their initial decisions as they focus on possible solutions for the challenges observed during gameplay. For instance, in a serious game designed to explore and understand the complexities of flood mitigation options in urban–rural catchments, Khoury et al. (2018) reported that 70 % of the game participants changed their initial decisions, and the best solutions were observed at the end of their game sessions.

This study provides a good example that demonstrates how streamflow variation in a river network connects the livelihoods of different communities within a catchment. For instance, the uncertainty in profits observed among downstream participants revealed how pastoralist livelihoods are affected as a result of the upstream river water abstraction activities. Water scarcity has been reported as being the main trigger of system instability during the dry season in the upper Ewaso Ngiro catchment (Gichuki, 2006; Kiteme, 2020). Nevertheless, besides the water scarcity during the dry season, pastoralists also have to deal with pasture availability, hence migrating to humid zones in search of both pasture and water (Gichuki, 2004; The Star, 2023). This study further reveals that in the context of agricultural land expansion, the situation gets worse for pastoralists, who are in the transition zone (i.e. between the agricultural zone and pastoralist zone). This is because they face pressure from other pastoralists, who immigrate from far downstream in search of water and pasture while their upward migration faces inflexible resistance from the agricultural communities in the upslopes. This can explain the manifestation of fatal seasonal conflicts observed between upstream and downstream communities in the upper Ewaso Ngiro catchment (Kiteme, 2020; Lesrima, 2019). Within the game environment, higher profits were realized toward the final rounds, when the board game system was relatively stable. This is after significant investments in rainwater harvesting by all players during gameplay.

4.2 Engagement of stakeholders

The ENGAGE game, as implemented in this study, was observed to stimulate and maintain active participation among players throughout the gaming sessions. Increased active participation in the game experimental environment has also been reported in the literature (Jääskä and Aaltonen, 2022; Riivari et al., 2021; Speelman et al., 2014). Maintaining active participation among targeted stakeholders is key to promoting local solutions to complex catchment challenges (Lim et al., 2022; Stosch et al., 2022). Similarly, this study observed relatively fewer questions and sentiments directed at the facilitator. This concurs with other studies that opined that scientists' role in a game environment is mainly to moderate the gaming session; hence, they were commonly referred to as facilitators (Javed and Kohda, 2020; Taylor, 2014). This indicates that with sufficient briefing and pregame trials, the stakeholders can independently engage with one another as they confront the human–water challenges presented in the game environment. We think that the ENGAGE game in its current form is easily transferable to other game facilitators working or interested in forested water towers and arid environments.

Based on sentiments raised by players, conflict and selfishness appeared to decrease in succeeding game rounds. However, tension during gameplay remained relatively high, and in some cases, there was a reverse trend. Tension and annoyance are common experiences in serious games where players compete during gameplay (Cidota et al., 2016; Oksanen, 2013; Poels et al., 2007). One important finding is that even with a sudden increase in tension and conflicts, knowledge gain maintains a continuous increase throughout the different game rounds. This indicates the strength of a gaming approach in increasing the knowledge among game participants. In addition, the sustained increase in constructive dynamics amid oscillations of subtractive dynamics reveals the experiences within a game environment; for instance, the stakeholders can have a back-and-forth experience of selfishness, tension, and conflicts but at the same time attain a persistent increase in constructive dynamics. We therefore argue that the gaming approach can be seen as an improvement to stakeholders' engagement leading to a persistent increase in the build-up of knowledge gain and the use of plural pronouns. We also recognize that it is likely that the perceptions by game participants of the game facilitator matter and that the "priming" with pre-game information and relational clues can influence game results, but this is a topic beyond this study and may need to be further explored.

The WRUAs have been in existence for over 30 years, employing conventional participatory approaches to engage catchment stakeholders, especially in minimizing human–water-related tensions and conflicts. This study shows that the first two "issue cycle" steps, agenda setting (acknowledging that there is a problem) and shared understanding of its causes and consequences, were readily addressed by the game in all three game sessions. As an alternative to existing conventional approaches, WRUAs can readily adopt the ENGAGE approach to engage catchment stakeholders in minimizing conflicts and promoting collectiveness and dialogues through active participation, increasing knowledge on human–water interactions. The next steps in commitment to goals and means of implementation would depend on the way the game is made part of a longer-term process of interactions. Collaboration and cooperation were observed to have relatively minimal increases, which can be attributed to the nature of constructive dynamics. Knowledge gain and the use of plural pronouns can have a stronger individual bearing compared to collaboration and cooperation, which have a strong system-based bearing (i.e. inclined to the processes in the system). For instance, the sustained tension throughout the game rounds could mean players have limited interest in cooperating with the existing rules or collaborating with others.

The results in this study seem to contradict other studies that have reported that a serious gaming approach reduces tension and increases cooperation and collaboration among game participants during gameplay (Morschheuser et al., 2017; van Peppen et al., 2022; Wendel et al., 2020). However, the notable difference between our study and other studies is game design and mechanics. An increase in cooperation and collaboration would directly manifest in a game design that intentionally forces players to cooperate and collaborate during gameplay (Wang and Huang, 2021). The ENGAGE game promoted independent decisions among players, in this case as they seek to amass huge profits. This explains the sustained tension during gameplay as players competed to attain individual goals. The assumption was that the players would learn from how individual decisions affect the system and thereby organically provoke a solution-seeking attitude during gameplay. Therefore, collaboration and cooperation, in this case, manifest as a result of learning through the game process and are not embedded as part of key game mechanics.

4.3 Implications on water availability

The gaming approach can be seen as strengthening stakeholders' engagement and guiding decisions toward addressing the complex human water challenges presented in the board game. The use of fines was one of the external motivations for pro-environment behaviour in the ENGAGE game. The game participants were penalized for excessive water abstractions and the manifestation of re-imagination as one of the levels of internalization during gameplay (van Noordwijk et al., 2023), where participants felt peer-pressured to regulate their ecological footprint to reduce the impact on the system. There was a decline in water availability in the initial game rounds and then an increase toward the final game rounds. This could be attributed to rainwater-harvesting decisions made by game participants in the final game rounds, which saw water availability increase between 50 % and 91 % in the three game sessions. Therefore, despite increases in agricultural land expansion and livestock units, guiding stakeholders to practically understand the importance of rainwater harvesting and storage is an important factor for water availability in the river catchment. This finding concurs with other studies that opine that rainwater harvesting can be a feasible solution for water scarcity problems during dry seasons (Irshad et al., 2007; Velasco-Muñoz et al., 2019). However, these are supply-side solutions which can readily fit the context of water scarcity problems where there is urgent need to provide additional water to quell existing conflicts as conceptualized in this study. Overall, there could be thresholds to the extent to which the supply-side solutions are sustainable. Increasing water storage capacity despite improving water supply can increase stakeholders' vulnerability due to the reservoir effect (Di Baldassarre et al., 2018), human displacement (Asmal, 2000; Kuil et al., 2018), and inefficiency due to excess water reallocation (Kuil et al., 2018), among other anticipated effects.

The ENGAGE game showed it is able to guide catchment stakeholder discussions involving small-scale farmers, pastoralists, water resources managers, etc. toward addressing the water availability challenges of a river catchment. Gaming can be an important practical tool that can be used by river-based organizations (RBOs) to increase understanding among catchment stakeholders. The adoption of a gaming approach in existing participatory approaches, as often used for implementing IWRM, can enhance participation and allow stakeholders to directly interact with the wicked problem, testing scenarios in decision-making, and social learning for collective action. This can lead to the production of informed IWRM outputs, such as farm and catchment management plans. The challenge for serious gamers is the extent to which the gaming lessons can be scaled out beyond the game experiment environment to cover a larger population of a river catchment.

4.4 Limitations of the study

Despite the promising results of this gaming approach, we highlight a few limitations of this study that may have led to bias in the study results. First of all, the ENGAGE game sessions can only accommodate 10 participants at a time. This means the results can only be interpreted at the experimental stage and that more time and resources may be needed to cover a larger sample of catchment stakeholders. Given the time and resources, the study conducted three pilot-game sessions, with the maximum number of game rounds being set to four. The assumption was that phase 1, consisting of two to three rounds, was sufficient to expose players to the system dynamics and that a final round would allow for reflection on possible solutions. We argue that conducting several game rounds without subjecting the participants to a final reflection round may be an alternative way of assessing the emergence of gaming outcomes. Without a reflection round, we speculate some game sessions would have ended with worst-case scenarios, which still would have been important results, putting an emphasis on the wicked nature of human–water challenges, although this would require a larger number of game sessions to gather a sufficiently large sample size of game sessions. Assessing game outcomes from such a larger sample size may be desirable to study more patterns and more emergent patterns of this gaming approach.

In this study, the communication analyses focused on sentiments related to human–water issues expressed by the game participants in each game round. A game round took an average of 15 to 20 min. Non-verbal aspects of communication such as intonation, pitch, tempo, and cues such as posture and gesture (Duncan, 1969; Gozalova et al., 2016) were not directly accounted for in this study. However, during the video analyses, the scoring considered some of the qualitative aspects in determining the scores. For instance, a sentiment such as "You can't settle here, the river is already dry here" when said by a participant at a lower pitch and seated may indicate there is tension, but the scores for level of conflict may be lower than when said by a participant with visible physical gestures such as standing up, pointing a finger at a participant, and blocking a participant from completing a particular task. Besides, this study did not consider things such as the personality differences between the participants, or their real-world relationships. Some participants may be shyer than others during gameplay due to such factors.

Nevertheless, the results of this study can contribute to the body of knowledge on using the serious gaming approach to address complex human–water problems. Therefore, despite the small sample size, the results in this study can be used to inform human–water policies and modification of water allocation rules at a river catchment. Serious gaming presents an opportunity for stakeholders to interact with the wicked socio-hydrological problem and guide stakeholder discussions on water management. The game environment allows for real-time reflection through the creation of a fictional setting and a common pool for the stakeholders to explore decisions and impacts simultaneously. This creates the opportunity to step away from one's usual position and see the wider picture in a safe environment. This is different from the real-world situation in which a blame game exists of the "person living upslope as the contributor" to the water problem experienced downstream, as noted in Wamucii et al. (2023). Furthermore, as reported in other studies, the ENGAGE game also showed the valuable properties of simulation games mentioned in the literature for motivating the intentions of the stakeholders toward sustainable behaviours (Bassanelli et al., 2022; Douglas and Brauer, 2021; Hirsch et al., 2010; Lieberoth et al., 2018). Some of the unique qualities relatable to the ENGAGE game as reported in literature include universal appeal, the ability to capture and retain participants' imaginations and intentions, simulation of near reality, immediacy, interactivity, and visual feedback (Fox et al., 2020; Sajjadi et al., 2022; Schuller et al., 2013; Wolf, 2020). These qualities enable game participants to interpret, relate, argue, criticize, investigate, and construct new knowledge – hence the manifestation of pro-environmental behaviours (Fox et al., 2020; Sajjadi et al., 2022). This study observed that the board game allowed participants to reflect on complex human–water issues in the catchment, such as water scarcity, downstream–upstream conflicts, economic losses, rainfall uncertainty, crop failure, harsh national government rules, and fines.

Additionally, since each participant in the game has a role to play, they have a stake during the game. They tend to be active in pursuing their stake while focusing on their roles. This is different from other participatory methodologies where there is a claim to engage participants, e.g. through group discussions or dividing the participants into random small group discussions (Global water partnership 2005; Voinov and Gaddis 2008; Hare 2011). This often results in some members less actively contributing to group activities (The University of Queensland, 2023; Burke, 2011), which is mainly due to power differentials among stakeholders (Daré et al., 2018). In a serious gaming environment, all participants are engaged and glued to their specific roles, and they do not necessarily have come to a common position. The end outcomes in a game environment depend on individual experiences in the different game rounds.

5 Conclusion

This study assessed the potential role of serious gaming in guiding community discussions on water-related challenges. We did this by creating a game, the ENGAGE game, and playing three sessions with farmers and other stakeholders from the target region. Overall, game players actively participated, gained knowledge, acquired a sense of collectiveness, and minimized conflicts. The subtractive dynamic oscillations, especially due to tension during gameplay, could only see a delay in the change in constructive dynamics but did not reverse the overall gains. Even under complex human–water challenges of expanding agricultural lands in the upstream and midstream zones and increasing number of livestock units in the downstream zone, practical solutions can easily be explored in a gaming environment. For instance, it was observed that there are possibilities of reversing the dry season water scarcity problem in the river catchment through rainwater harvesting. Whether the results realized in a gaming environment could impact reality is still unclear. Post-game discussion revealed a positive impression of the usefulness of the gaming approach in promoting sustainable behaviours, where game participants indicated willingness to adopt a few lessons from the game. However, it may require more game sessions and long-term studies to assess the impact of serious games on strengthening stakeholders' engagement and maintaining sustainable behaviours in real life. Nevertheless, the results of this study have important implications for water management and can be used to inform human–water policies and modification of water allocation rules at a river catchment. Water resources management stakeholders can work with the ENGAGE game as a starting point for catchments with a similar context as the upper Ewaso Ngiro Basin.

Data availability. Data and materials can be made available by contacting the first author.

Supplement. The supplement related to this article is available online at: https://doi.org/10.5194/hess-28-3495-2024-supplement.

Author contributions. CNW is responsible for study conceptualization, data collection, formal analysis, methodology, and writing (original draft). PRvO, AJT, AL, JMG, GJH, and MvN contributed to the analysis of the results and reflection on the study results. ENS guided game conceptualization, methodological design, and data collection and critically reflected on the analysis and interpretation.

Competing interests. At least one of the (co-)authors is a member of the editorial board of *Hydrology and Earth System Sciences*. The peer-review process was guided by an independent editor, and the authors also have no other competing interests to declare.

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Acknowledgements. The authors would like to extend gratitude to the households that participated in the game sessions. We also acknowledge the respective Water Resources Users Associations (WRUAs) for supporting the first author in the mobilization of game participants during field data collection.

Financial support. This research was made possible by Wageningen University through the Scenario Evaluation for Sustainable Agro-forestry Management (SESAM) project that was funded by its Interdisciplinary Research and Education Fund (INREF).

Review statement. This paper was edited by Pieter van der Zaag and reviewed by Jean-Philippe Venot.

References

Aarts, J.: Will Community-based Water Management Solve Africa's Water Problems? The performance of Water Resource User Associations in the Upper Ewaso Ng'iro river basin, Kenya, University of Nijmegen, Nijmegen, 1–139, https://www.semanticscholar.org/paper/Will-Community-based-Water-Management-Solve-Water-Aarts/d9c8a47efa4f4431f62daec79f1c57979277a1f1 (last access: 13 December 2022), 2012.

Adom, R. K. and Simatele, M. D.: The role of stakeholder engagement in sustainable water resource management in South Africa, Nat. Resour. Forum, 46, 410–427, https://doi.org/10.1111/1477-8947.12264, 2022.

Arnab, S. and Clarke, S.: Towards a trans-disciplinary methodology for a game-based intervention development process, Brit. J. Educ. Technol., 48, 279–312, https://doi.org/10.1111/bjet.12377, 2017.

Arroyave, F. J., Goyeneche, O. Y. R., Gore, M., Heimeriks, G., Jenkins, J., and Petersen, A. M.: On the social and cognitive dimensions of wicked environmental problems characterized by conceptual and solution uncertainty, Adv. Complex Syst., 24, 215005, https://doi.org/10.1142/S0219525921500053, 2021.

Asmal, K.: Dams and development: a new framework for decision-making. The report of the World Commission on dams, Earthscan Publications Ltd, London, ISBN 13:978-1-85383-797-5, 2000.

Babel, L., Vinck, D., and Karssenberg, D.: Decision-making in model construction: Unveiling habits, Environ. Modell. Softw., 120, 104490, https://doi.org/10.1016/j.envsoft.2019.07.015, 2019.

Baijanova, F.: Talk That Talk: The Evaluation and Redesign of a Persuasive Game for Tackling Sexual Violence Among Students in Dutch Universities, Delft University of Technology, Delft, https://pure.tudelft.nl/ws/portalfiles/portal/157416291/TalkThatTalk_final.pdf (last access: 11 March 2023), 2022.

Barnaud, C. and Van Paassen, A.: Dilemmas of Participatory Natural Resource Management, Ecol. Soc., 18, 21, https://doi.org/10.5751/ES-05459-180221, 2013.

Barreteau, O., Bousquet, F., Étienne, M., Souchère, V., and d'Aquino, P.: Companion Modelling: A Method of Adaptive and Participatory Research, in: Companion Modelling, Springer Netherlands, Dordrecht, 13–40, https://doi.org/10.1007/978-94-017-8557-0_2, 2014.

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., and Giardino, A.: Collaborative modelling or participatory modelling? A framework for water resources management, Environ. Modell. Softw., 91, 95–110, https://doi.org/10.1016/j.envsoft.2017.01.014, 2017.

Basco-Carrera, L., Meijers, E., Sarısoy, H. D., Şanli, N. O., Coşkun, S., Oliemans, W., van Beek, E., Karaaslan, Y., and Jonoski, A.: An adapted companion modelling approach for enhancing multi-stakeholder cooperation in complex river basins, Int. J. Sust. Dev. World, 25, 747–764, https://doi.org/10.1080/13504509.2018.1445668, 2018.

Bassanelli, S., Vasta, N., Bucchiarone, A., and Marconi, A.: Gamification for behavior change: A scientometric review, Acta Psychol. (Amst), 228, 103657, https://doi.org/10.1016/j.actpsy.2022.103657, 2022.

Bayeck, R. Y.: Examining Board Gameplay and Learning: A Multidisciplinary Review of Recent Research, Simulat. Gaming, 51, 411–431, https://doi.org/10.1177/1046878119901286, 2020.

Bielsa, J. and Cazcarro, I.: Implementing integrated water resources management in the Ebro River Basin: From theory to facts, Sustainability (Switzerland), 7, 441–464, https://doi.org/10.3390/su7010441, 2015.

Biggs, R., Preiser, R., de Vos, A., Schlüter, M., Maciejewski, K., and Clements, H.: The Routledge Handbook of Research Methods for Social-Ecological Systems, Routledge, London, https://doi.org/10.4324/9781003021339, 2021.

Biswas, A. K.: Integrated water resources management: Is it working?, Int. J. Water Resour. D., 24, 5–22, https://doi.org/10.1080/07900620701871718, 2008.

Burke, A.: Group Work: How to Use Groups Effectively, Journal of Effective Teaching, 11, 87–95, 2011.

Carrera, L. B. and Mendoza, G. F.: Collaborative modelling – Engaging stakeholders in solving complex problems of water management, Global Water Partnership, https://www.researchgate.net/publication/319008238_Collaborative_modelling_-_Engaging_stakeholders_in_solving_complex_problems_of_water_management (last access: 17 April 2024), 2017.

Cavada, M. and Rogers, C. D. F.: Serious gaming as a means of facilitating truly smart cities: a narrative review, Behav. Inform. Technol., 39, 695–710, https://doi.org/10.1080/0144929X.2019.1677775, 2020.

Cidota, M. A., Lukosch, S. G., Dezentje, P., Bank, P. J. M., Lukosch, H. K., and Clifford, R. M. S.: Serious Gaming in Augmented Reality using HMDs for Assessment of Upper Extremity Motor Dysfunctions, i-com, 15, 155–169, https://doi.org/10.1515/icom-2016-0020, 2016.

Damron, K.: Using Board Games to Engage Non-interested Students in Accounting Classes, Journal of Instructional Research, 8, https://doi.org/10.9743/jir.2019.8.2.11, 2019.

Daniell, K. A., White, I., Ferrand, N., Ribarova, I. S., Coad, P., Rougier, J.-E., Hare, M., Jones, N. A., Popova, A., Rollin, D., Perez, P., and Burn, S.: Co-engineering Participatory Water Management Processes: Theory and Insights from Australian and Bulgarian Interventions, Ecol. Soc., 15, art11, https://doi.org/10.5751/ES-03567-150411, 2010.

Daré, W., Venot, J.-P., Le Page, C., and Aduna, A.: Problemshed or Watershed? Participatory Modelling towards IWRM in North Ghana, Water (Basel), 10, 721, https://doi.org/10.3390/w10060721, 2018.

Daré, W., Hassenforder, E., and Dray, A.: Observation manual for collective serious games, CIRAD – ComMod Association, https://doi.org/10.19182/agritrop/00144, 2021.

Defries, R. and Nagendra, H.: Ecosystem management as a wicked problem, Science (1979), 356, 265–270, https://doi.org/10.1126/science.aal1950, 2017.

Dell'Angelo, J., McCord, P. F., Baldwin, E., Cox, M. E., Gower, D., Caylor, K., and Evans, T. P.: Multilevel Governance of Irrigation Systems and Adaptation to Climate Change in Kenya, in: The Global Water System in the Anthropocene: Challenges for Science and Governance, edited by: Bhaduri, A., Bogardi, J., Leentvaar, J., and Marx, S., Springer, Cham, https://doi.org/10.1007/978-3-319-07548-8_21, 1–437, 2014.

de Vente, J., Reed, M. S., Stringer, L. C., Valente, S., and Newig, J.: How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands, Ecol. Soc., 21, https://doi.org/10.5751/ES-08053-210224, 2016.

Di Baldassarre, G., Wanders, N., AghaKouchak, A., Kuil, L., Rangecroft, S., Veldkamp, T. I. E., Garcia, M., van Oel, P. R., Breinl, K., and Van Loon, A. F.: Water shortages worsened by reservoir effects, Nat. Sustain., 1, 617–622, https://doi.org/10.1038/s41893-018-0159-0, 2018.

Douglas, B. D. and Brauer, M.: Gamification to prevent climate change: a review of games and apps for sustainability, Curr. Opin. Psychol., 42, 89–94, https://doi.org/10.1016/j.copsyc.2021.04.008, 2021.

Duncan, S.: Nonverbal communication, Psychol. Bull., 72, 118–137, https://doi.org/10.1037/h0027795, 1969.

Dutta, P. K. and Sundaram, R. K.: The Tragedy of the Commons?, Econ. Theory, 3, 413–426, 1993.

Edmunds, D. and Wollenberg, E.: A Strategic Approach to Multistakeholder Negotiations, Dev. Change, 32, 231–253, https://doi.org/10.1111/1467-7660.00204, 2001.

Ehrensperger, A. and Kiteme, B.: Upper Ewaso Ngiro River Basin Water Management Information Platform: Survey on Development priorities, Information Needs and Conflict Management Efforts, Nanyuki, Kenya, University of Bern, https://boris.unibe.ch/71791/1/Survey_report_ewaso_2b.pdf (last access: 4 April 2023), 2005.

Epstude, K. and Roese, N. J.: The functional theory of counterfactual thinking, Pers. Soc. Psychol. Rev., 12, 168–192, https://doi.org/10.1177/1088868308316091, 2008.

Étienne, M.: Companion Modelling: A participatory approach to support sustainable development, Springer Netherlands, Dordrecht, https://doi.org/10.1007/978-94-017-8557-0, 2014.

Etienne, M., du Toit, D. R., and Pollard, S.: ARDI: A co-construction method for participatory modelling in natural resources management, Ecol. Soc., 16, 44, https://doi.org/10.5751/ES-03748-160144, 2011.

Flood, S., Cradock-Henry, N. A., Blackett, P., and Edwards, P.: Adaptive and interactive climate futures: systematic review of 'serious games' for engagement and decision-making, Environ. Res. Lett., 13, 063005, https://doi.org/10.1088/1748-9326/aac1c6, 2018.

Folke, C., Biggs, R., Norström, A. V., Reyers, B., and Rockström, J.: Social-ecological resilience and biosphere-based sustainability science, Ecol. Soc., 21, art41, https://doi.org/10.5751/ES-08748-210341, 2016.

Fox, J., McKnight, J., Sun, Y., Maung, D., and Crawfis, R.: Using a serious game to communicate risk and minimize psychological distance regarding environmental pollution, Telemat. Inform., 46, 101320, https://doi.org/10.1016/j.tele.2019.101320, 2020.

Gichuki, F. N.: Managing the externalities of declining dry season river flow: A case study from the Ewaso Ngiro North River Basin, Kenya, Water Resour. Res., 40, W08S03, https://doi.org/10.1029/2004WR003106, 2004.

Gichuki, F. N.: Water Scarcity and Conflicts: A Case Study of the Upper Ewaso Ng'iro North Basin, in: The Changing Face of Irrigation in Kenya: Opportunities for Anticipating Change in Eastern and Southern Africa, edited by: Blank, H. G.; Mutero, C. M., and Murray-Rust, H., IWMI, 113–134, https://hdl.handle.net/10568/37008 (last access: 27 June 2023), 2006.

Giordano, M. and Shah, T.: From IWRM back to integrated water resources management, Int. J. Water Resour. D., 30, 364–376, https://doi.org/10.1080/07900627.2013.851521, 2014.

Githinji, M., van Noordwijk, M., Muthuri, C., Speelman, E. N., and Jan Hofstede, G.: Farmer land-use decision-making from an instrumental and relational perspective, Curr. Opin. Env. Sust., 63, 101303, https://doi.org/10.1016/j.cosust.2023.101303, 2023.

Global Water Partnership: Integrated water resources management plans: Training manual and operational guide, CIDA – Canadian International Development Agency, http://www.cap-net.org/TMUploadedFiles/FileFor67/IWRM_Plan.doc (last access: 12 January 2023), 2005.

Godinez-Madrigal, J., Van Cauwenbergh, N., and van der Zaag, P.: Production of competing water knowledge in the face of water crises: Revisiting the IWRM success story of the Lerma-Chapala Basin, Mexico, Geoforum, 103, 3–15, https://doi.org/10.1016/j.geoforum.2019.02.002, 2019.

Gozalova, M. R., Gazilov, M. G., Kobeleva, O. V., Seredina, M. I., and Loseva, E. S.: Non-Verbal Communication in the Modern World, Mediterr. J. Soc. Sci., 7, 553–558, https://doi.org/10.5901/mjss.2016.v7n4p553, 2016.

Hare, M.: Forms of Participatory Modelling and its Potential for Widespread Adoption in the Water Sector, Environ. Policy Gov., 21, 386–402, https://doi.org/10.1002/eet.590, 2011.

Hirsch, D., Abrami, G., Giordano, R., Liersch, S., Matin, N., and Schlüter, M.: Participatory research for adaptive water management in a transition country – a case study from Uzbekistan, Ecol. Soc., 15, 23, https://doi.org/10.5751/ES-03549-150323, 2010.

Hobbs, D. A., Walker, A. W., Wilkinson, B. G., Hughes, M., Wesson, B. R., Hillier, S., Russo, R. N., and Reynolds, K. J.: Using a trans-disciplinary and trans-institutional team approach and co-design principles to develop an accessible serious gaming system for children with limited hand function, in: Design4Health, Proceedings of the Third European Conference on Design4Health, 13–16 July 2015, Sheffield, ISBN 978-1-84387-385-3, 2015.

Hummel, H. G. K., Joosten-ten Brinke, D., Nadolski, R. J., and Baartman, L. K. J.: Content validity of game-based assessment: case study of a serious game for ICT managers in training, Technol. Pedagog. Educ., 26, 225–240, https://doi.org/10.1080/1475939X.2016.1192060, 2017.

Irshad, M., Inoue, M., Ashraf, M., and Al-Busaidi, A.: The Management Options of Water for the Development of Agriculture in Dry Areas, J. Appl. Sci., 7, 1551–1557, https://doi.org/10.3923/jas.2007.1551.1557, 2007.

Isaac, R. M. and Walker, J. M.: Communication and Free-Riding Behavior: The Voluntary Contribution Mechanisim, Econ. Inq., 26, 585–608, https://doi.org/10.1111/j.1465-7295.1988.tb01519.x, 1988.

Jackson, C.: Internal and External Validity in Experimental Games: A Social Reality Check, Eur. J. Dev. Res., 24, 71–88, https://doi.org/10.1057/ejdr.2011.47, 2012.

Jääskä, E. and Aaltonen, K.: Teachers' experiences of using game-based learning methods in project management higher education, Project Leadership and Society, 3, 100041, https://doi.org/10.1016/j.plas.2022.100041, 2022.

Jain, S. and Singh, V. P.: River Basin Planning and Management, in: Water Resources Systems Planning and Management, Elsevier, 787–842, ISBN 9780444514295, https://doi.org/10.1016/S0167-5648(03)80068-0, 2003.

Janssen, M. A., Falk, T., Meinzen-Dick, R., and Vollan, B.: Using games for social learning to promote self-governance, Curr. Opin. Env. Sust., 62, 101289, https://doi.org/10.1016/j.cosust.2023.101289, 2023.

Javed, A. and Kohda, Y.: Facilitation Engineering: A realization of Dense Learning Through Facilitation Embedded in Serious Game, in: 2020 6th International Conference on Information Management (ICIM), 27–29 March 2020, London, UK, 306–313, https://doi.org/10.1109/ICIM49319.2020.244716, 2020.

Jean, S., Medema, W., Adamowski, J., Chew, C., Delaney, P., and Wals, A.: Serious games as a catalyst for boundary crossing, collaboration and knowledge co-creation in a watershed governance context, J. Environ. Manage., 223, 1010–1022, https://doi.org/10.1016/j.jenvman.2018.05.021, 2018.

Jonsson, A., Andersson, L., Alkan-Olsson, J., and Arheimer, B.: How participatory can participatory modelling be? Degrees of influence of stakeholder and expert perspectives in six dimensions of participatory modelling, Water Sci. Technol., 56, 207–214, https://doi.org/10.2166/wst.2007.453, 2007.

Khoury, M., Gibson, M. J., Savic, D., Chen, A. S., Vamvakeridou-Lyroudia, L., Langford, H., and Wigley, S.: A Serious Game Designed to Explore and Understand the Complexities of Flood Mitigation Options in Urban–Rural Catchments, Water (Basel), 10, 1885, https://doi.org/10.3390/w10121885, 2018.

Kim, D., Stewart Carter, A. L., and Misser, S. A.: AA1000 Stakeholder Engagement Standard, Accountability, 1–40 pp., 2018.

Kiteme, B.: Hotspots of Water Scarcity and Conflicts in the Ewaso Ng'iro North Basin, Centre for Training and Integrated Research in ASAL Development (CETRAD), https://www.cetrad.org/hotspots-of-water-scarcity-and-conflicts-in-the-ewaso-ngiro (last access: 22 December 2022), 2020.

Kouw, M.: Standing on the Shoulders of Giants—And Then Looking the Other Way? Epistemic Opacity, Immersion, and Modelling in Hydraulic Engineering, Perspectives on Science, 24, 206–227, https://doi.org/10.1162/POSC_a_00201, 2016.

Kuil, L., Evans, T., McCord, P. F., Salinas, J. L., and Blöschl, G.: Exploring the Influence of Smallholders' Perceptions Regarding Water Availability on Crop Choice and Water Allocation Through Socio–Hydrological Modelling, Water Resour. Res., 54, 2580–2604, https://doi.org/10.1002/2017WR021420, 2018.

Laikipia Forum: Water and Resilience, Laikipia Forum, https://www.youtube.com/watch?v=bgeKCyu-vd4 (last access: 6 July 2021), 2021.

Lanari, N., Schuler, R., Kohler, T., and Liniger, H.: The impact of commercial horticulture on river water resources in the Upper Ewaso Ng'iro River Basin, Kenya, Mt. Res. Dev., 38, 114–124, https://doi.org/10.1659/MRD-JOURNAL-D-16-00135, 2018.

Lawrence, M. G., Williams, S., Nanz, P., and Renn, O.: Characteristics, potentials, and challenges of transdisciplinary research, One Earth, 5, 44–61, https://doi.org/10.1016/j.oneear.2021.12.010, 2022.

Lenton, R. and Muller, M.: Integrated Water Resources Management in Practice, Routledge, https://doi.org/10.4324/9781849771740, 2012.

Lesrima, S., Nyamasyo, G., and Kiemo, K.: Unresolved Water Conflicts by Water Sector Institutions in Ewaso Ng'iro North River Sub-Basin, Kenya, Journal of Applied Sciences and Environmental Management, 25, 269–275, https://doi.org/10.4314/jasem.v25i2.21, 2021.

Lesrima, S. S.: Access to water resources and conflicts in the upper Ewaso Ng'iro North river sub-basin: A case of Laikipia County, Kenya, PhD thesis, University of Nairobi, Nairobi, Kenya, http://erepository.uonbi.ac.ke/handle/11295/107219 (last access: 6 December 2022), 2019.

Levin, K., Cashore, B., Bernstein, S., and Auld, G.: Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change, Policy Sci., 45, 123–152, https://doi.org/10.1007/s11077-012-9151-0, 2012.

Lieberoth, A., Holm Jensen, N., and Bredahl, T.: Selective psychological effects of nudging, gamification and rational information in converting commuters from cars to buses: A controlled field experiment, Transp. Res. Part F Traffic Psychol. Behav., 55, 246–261, https://doi.org/10.1016/j.trf.2018.02.016, 2018.

Lim, C. H., Wong, H. L., Elfithri, R., and Teo, F. Y.: A Review of Stakeholder Engagement in Integrated River Basin Management, Water (Switzerland), 14, https://doi.org/10.3390/w14192973, 2022.

Liniger, H., Gikonyo, J., Kiteme, B., and Wiesmann, U.: Assessing and Managing Scarce Tropical Mountain Water Resources, Mt. Res. Dev., 25, 163–173, https://doi.org/10.1659/0276-4741(2005)025[0163:aamstm]2.0.co;2, 2005.

Loucks, D. P. and van Beek, E.: Water Resources Planning and Management: An Overview, in: Water Resource Systems Planning and Management, Springer, Cham, 1–49, https://doi.org/10.1007/978-3-319-44234-1_1, 2017.

Marini, D., Medema, W., Adamowski, J., Veissière, S., Mayer, I., and Wals, A.: Socio-Psychological Perspectives on the Potential for Serious Games to Promote Transcendental Values in IWRM Decision-Making, Water (Basel), 10, 1097, https://doi.org/10.3390/w10081097, 2018.

Mathevet, R., Antona, M., Barnaud, C., Fourage, C., Trébuil, G., and Aubert, S.: Contexts and Dependencies in the ComMod Processes, in: Companion Modelling, edited by: Étienne, M., Springer Netherlands, Dordrecht, 103–125, https://doi.org/10.1007/978-94-017-8557-0_5, 2014.

Mayer, L. A., Loa, K., Cwik, B., Tuana, N., Keller, K., Gonnerman, C., Parker, A. M., and Lempert, R. J.: Understanding scientists' computational modelling decisions about climate risk management strategies using values-informed mental models, Global Environ. Chang., 42, 107–116, https://doi.org/10.1016/j.gloenvcha.2016.12.007, 2017.

McCord, P. F., Cox, M., Schmitt-Harsh, M., and Evans, T.: Crop diversification as a smallholder livelihood strategy within semi-arid agricultural systems near Mount Kenya, Land Use Policy, 42, 738–750, https://doi.org/10.1016/j.landusepol.2014.10.012, 2015.

Medema, W., Furber, A., Adamowski, J., Zhou, Q., and Mayer, I.: Exploring the Potential Impact of Serious Games on Social Learning and Stakeholder Collaborations for Transboundary Watershed Management of the St. Lawrence River Basin, Water (Basel), 8, 175, https://doi.org/10.3390/w8050175, 2016.

Melsen, L. A.: It Takes a Village to Run a Model—The Social Practices of Hydrological Modelling, Water Resour. Res., 58, e2021WR030, https://doi.org/10.1029/2021WR030600, 2022.

MKEWP: The Mount Kenya–Ewaso Water Partnership (MKEWP) strategic plan 2018-2022, Laikipia Wildlife Forum, https://www.laikipia.org/wp-content/uploads/2019/11/MKEWP-Strategic-Plan.pdf (last access: 3 November 2022), 2017.

Morschheuser, B., Riar, M., Hamari, J., and Maedche, A.: How games induce cooperation? A study on the relationship between game features and we-intentions in an augmented reality game, Comput. Hum. Behav., 77, 169–183, https://doi.org/10.1016/j.chb.2017.08.026, 2017.

Mungai, D. N., Ong, C. K., Kiteme, B., Elkaduwa, W., and Sakthivadivel, R.: Lessons from two long-term hydrological studies in Kenya and Sri Lanka, Agr. Ecosyst. Environ., 104, 135–143, https://doi.org/10.1016/j.agee.2004.01.011, 2004.

Mutiga, J. K., Mavengano, S. T., Zhongbo, S., Woldai, T., and Becht, R.: Water Allocation as a Planning Tool to Minimise Water Use Conflicts in the Upper Ewaso Ng'iro North Basin, Kenya, Water Resour. Manag., 24, 3939–3959, https://doi.org/10.1007/s11269-010-9641-9, 2010.

Mutiga, J. K., Zhongbo, S., and Woldai, T.: Impacts of agricultural intensification through upscaling of suitable rainwater harvesting technologies in the upper Ewaso Ng'iro North basin, Kenya, Hydrol. Earth Syst. Sci. Discuss., 8, 2477–2501, https://doi.org/10.5194/hessd-8-2477-2011, 2011.

Najjar, K. F. and Collier, C. R.: Integrated Water Resources Management: Bringing It All Together, Water Resources IMPACT, 13, 3–8, 2011.

Neset, T.-S., Andersson, L., Uhrqvist, O., and Navarra, C.: Serious Gaming for Climate Adaptation—Assessing the Potential and Challenges of a Digital Serious Game for Urban Climate Adaptation, Sustainability, 12, 1789, https://doi.org/10.3390/su12051789, 2020.

Ngigi, S. N., Savenije, H. H. G., and Gichuki, F. N.: Land use changes and hydrological impacts related to up-scaling of rainwater harvesting and management in upper Ewaso Ng'iro river basin, Kenya, Land Use Policy, 24, 129–140, https://doi.org/10.1016/j.landusepol.2005.10.002, 2007.

Noda, S., Shirotsuki, K., and Nakao, M.: The effectiveness of intervention with board games: A systematic review, Biopsychosoc Med, https://doi.org/10.1186/s13030-019-0164-1, 2019.

Norris, P. E., O'Rourke, M., Mayer, A. S., and Halvorsen, K. E.: Managing the wicked problem of transdisciplinary team formation in socio-ecological systems, Landscape Urban Plan., 154, 115–122, https://doi.org/10.1016/j.landurbplan.2016.01.008, 2016.

Obando, J. A., Opiyo, A. O., Luwesi, C. N., Shisanya, C., Förch, N., and Förch, G.: Kenya success story in water resources management: Participatory capacity building in integrated watershed management, in: Hydrology and Best Practices for Managing Water Resources in Arid and Semi-Arid Lands, edited by: Ondieki, C. M. and Kitheka, J., IGI Global, 185–208, https://doi.org/10.4018/978-1-5225-2719-0.ch010, 2017.

Oksanen, K.: Subjective Experience and Sociability in a Collaborative Serious Game, Simulat. Gaming, 44, 767–793, https://doi.org/10.1177/1046878113513079, 2013.

Orduña Alegría, M. E., Schütze, N., and Zipper, S. C.: A serious board game to analyze socio-ecological dynamics towards collaboration in agriculture+, Sustainability (Switzerland), 12, 5301, https://doi.org/10.3390/su12135301, 2020.

Orendo, S. T. J.: Water Resource Management in Upper Ewaso Ng'Iro North Catchment, University of Nairobi, http://erepository.uonbi.ac.ke:8080/xmlui/handle/123456789/28764 (last access: 21 January 2023), 2000.

Ostrom, E.: Coping with tragedies of the commons, Annu. Rev. Polit. Sci., 2, 493–535, https://doi.org/10.1146/annurev.polisci.2.1.493, 1999.

Ostrom, E.: Collective action and the evolution of social norms, J. Nat. Resour. Policy Res., 6, 235–252, https://doi.org/10.1080/19390459.2014.935173, 2014.

Ouariachi, T.: Facilitating Multi-Stakeholder Dialogue and Collaboration in the Energy Transition of Municipalities through Serious Gaming, Energies (Basel), 14, 3374, https://doi.org/10.3390/en14123374, 2021.

Page, C. Le, Dray, A., Perez, P., and Garcia, C.: Exploring How Knowledge and Communication Influence Natural Resources Management With REHAB, Simulat. Gaming, 47, 257–284, https://doi.org/10.1177/1046878116632900, 2016.

Poels, K., de Kort, Y. A. W., and Ijsselsteijn, W. A.: D3.3: Game Experience Questionnaire: development of a self-report measure to assess the psychological impact of digital games, Technische Universiteit Eindhoven, 47 pp., https://research.tue.nl/en/publications/d33-game-experience-questionnaire-development-of-a-self (last access: 3 December 2022), 2007.

Pohl, C., Truffer, B., and Hirsch-Hadorn, G.: Addressing Wicked Problems through Transdisciplinary Research, The Oxford Handbook of Interdisciplinarity, edited by: Frodeman, R., Oxford Academic, 319–331, https://doi.org/10.1093/oxfordhb/9780198733522.013.26, 2017.

Radzi, S. H. B. M., Ying, T. Y., Abidin, M. Z. Z., and Ahmad, P. A.: The effectiveness of board game towards soft skills development for higher education, Elementary Education Online, 94–106, https://www.bibliomed.org/?mno=19009 (last access: 28 July 2024), 2020.

Rahaman, M. M. and Varis, O.: Integrated water resources management: evolution, prospects and future challenges, Sustainability: Science, Practice and Policy, 1, 15–21, https://doi.org/10.1080/15487733.2005.11907961, 2005.

Redpath, S. M., Keane, A., Andrén, H., Baynham-Herd, Z., Bunnefeld, N., Duthie, A. B., Frank, J., Garcia, C. A., Månsson, J., Nilsson, L., Pollard, C. R. J., Rakotonarivo, O. S., Salk, C. F., and Travers, H.: Games as Tools to Address Conservation Conflicts, Trends Ecol. Evol., 33, 415–426, https://doi.org/10.1016/j.tree.2018.03.005, 2018.

Richards, N. and Syallow, D.: Water resources users associations in the Mara Basin, Kenya: Pitfalls and opportunities for community based natural resources management, Front. Environ. Sci. En., 6, 138, https://doi.org/10.3389/fenvs.2018.00138, 2018.

Riivari, E., Kivijärvi, M., and Lämsä, A.-M.: Learning teamwork through a computer game: for the sake of performance or collaborative learning?, ETR&D-Educ. Tech. Res., 69, 1753–1771, https://doi.org/10.1007/s11423-021-10009-4, 2021.

Rittel, H. W. J. and Webber, M. M.: Dilemmas in a General Theory of Planning, Policy Sci., 4, 155–169, 1973.

Rodela, R., Ligtenberg, A., and Bosma, R.: Conceptualizing serious games as a learning-based intervention in the context of natural resources and environmental governance, Water (Switzerland), 11, 245, https://doi.org/10.3390/w11020245, 2019.

Sajjadi, P., Bagher, M. M., Myrick, J. G., Guerriero, J. G., White, T. S., Klippel, A., and Swim, J. K.: Promoting systems thinking and pro-environmental policy support through serious games, Front. Environ. Sci., 10, 9572014, https://doi.org/10.3389/fenvs.2022.957204, 2022.

Savenije, H. H. G. and Van der Zaag, P.: Integrated water resources management: Concepts and issues, Phys. Chem. Earth, 33, 290–297, https://doi.org/10.1016/j.pce.2008.02.003, 2008.

Schuller, B. W., Dunwell, I., Weninger, F., and Paletta, L.: Serious gaming for behavior change: The state of play, IEEE Pervas. Comput., 12, 48–55, https://doi.org/10.1109/MPRV.2013.54, 2013.

Scott, C. A., El-Naser, H., Hagan, R. E., and Hijazi, A.: Facing Water Scarcity in Jordan: Reuse, Demand Reduction, Energy, and Transboundary Approaches to Assure Future Water Supplies, Water Int., 28, 209–216, https://doi.org/10.1080/02508060308691686, 2003.

Sivapalan, M., Savenije, H. H. G., and Blöschl, G.: Socio-hydrology: A new science of people and water, Hydrol. Process., 26, 1270–1276, https://doi.org/10.1002/hyp.8426, 2012.

Sokhem, P., Sunada, K., and Oishi, S.: Managing transboundary rivers: The case of the Mekong River Basin, Water Int., 32, 503–523, https://doi.org/10.1080/02508060.2007.9709685, 2007.

Speelman, E. N.: Gaming and Simulation to Explore Resilience of Contested Agricultural Landscapes, Wageningen University, 222 pp., https://research.wur.nl/en/publications/gaming-and-simulation-to-explore-resilience-of-contested-agricult (last access: 3 March 2023), 2014.

Speelman, E. N., García-Barrios, L. E., Groot, J. C. J., and Tittonell, P.: Gaming for smallholder participation in the design of more sustainable agricultural landscapes, Agr. Syst., 126, 62–75, https://doi.org/10.1016/j.agsy.2013.09.002, 2014.

Speelman, E. N., Van Noordwijk, M., and Garcia, C.: Gaming to better manage complex natural resource landscapes, in: Coinvestment in ecosystem services: global lessons from payment and incentive schemes, edited by: Namirembe, S., Leimona, B., van Noordwijk, M., and Minang, P., World Agroforestry (ICRAF), 1–11, https://research.wur.nl/en/publications/gaming-to-better-manage-complex-natural-resource-landscapes (last access: 22 April 2023), 2017.

Speelman, E. N., Rodela, R., Doddema, M., and Ligtenberg, A.: Serious gaming as a tool to facilitate inclusive business; a review of untapped potential, Curr. Opin. Env. Sust., 41, 31–37, https://doi.org/10.1016/j.cosust.2019.09.010, 2019.

Speelman, E. N., Rodela, R., van Noordwijk, M., and Hofstede, G. J.: Games, Sustainable Developmental Goals, Local Communities and Natural Resource Management Systems: An Expert Event SESAM Research Program, Wageningen University and Research Centre, https://doi.org/10.18174/565515, 2021.

Speelman, E. N., Escano, E., Marcos, D., and Becu, N.: Serious games and citizen science; from parallel pathways to greater synergies, Curr. Opin. Env. Sust., 64, https://doi.org/10.1016/j.cosust.2023.101320, 2023.

Stosch, K. C., Quilliam, R. S., Bunnefeld, N., and Oliver, D. M.: Rapid Characterisation of Stakeholder Networks in Three Catchments Reveals Contrasting Land-Water Management Issues, Land (Basel), 11, 2324, https://doi.org/10.3390/land11122324, 2022.

Taylor, A.-S. A.: Facilitation Matters: A framework for instructor-led serious gaming, University of Skövde, https://his.diva-portal.org/smash/record.jsf?pid=diva2:745056&dswid=5896 (last access: 12 November 2022), 2014.

The Star: How water shortage triggers Laikipia's conflicts: Pastoralists don't harvest it, farmers over-irrigate, https://www.the-star.co.ke/news/big-read/2017-10-29-how-water-shortage-triggers-laikipias-conflicts-pastoralists-dont-harvest-it-farmers-over-irrigate/ (last access: 22 April 2023), 2023.

The University of Queensland: Resolving group work issues, University of Queensland, https://my.uq.edu.au/information-and-services/student-support/study-skills/group-work/resolving-group-work-issues (last access: 14 November 2023), 2023.

The Water Act: Kenya Gazette Supplement: The Water Act of 2016, No. 164 (Acts No. 43), Kenya Gazette, https://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/WaterAct_No43of2016.pdf (last access: 7 October 2022), 2016.

Tilman, D. and Lehman, C.: Human-caused environmental change: Impacts on plant diversity and evolution, P. Natl. Acad. Sci. USA, 98, 5433–5440, https://doi.org/10.1073/pnas.091093198, 2001.

UNSDG: Common Minimum Standards for Multi-stakeholder Engagement in the UNDAF, United Nations Sustainable Development Group, https://unsdg.un.org/resources/common-minimum-standards-multi-stakeholder-engagement (last access: 6 December 2022), 2022.

van Noordwijk, M.: Integrated natural resource management as pathway to poverty reduction: Innovating practices, institutions and policies, Agr. Syst., 172, 60–71, https://doi.org/10.1016/j.agsy.2017.10.008, 2019.

Van Noordwijk, M., Speelman, E., Hofstede, G. J., Farida, A., Wamucii, C. N., Kimbowa, G., Geraud, G., Assogba, C., Best, L., Tanika, L., Githinji, M., Rosero, P., Sari, R. R., Satnarain, U., Adiwibowo, S., Ligtenberg, A., Muthuri, C., Marielos Purwanto, E. P.-C., van Oel, P., Rozendaal, D., Suprayogo, D., and Teuling, A. J.: Sustainable Agroforestry Landscape Management: Changing the Game, Land (Basel), 9, 1–38, https://doi.org/10.3390/land9080243, 2020.

van Noordwijk, M., Leimona, B., Amaruzaman, S., Pascual, U., Minang, P. A., and Prabhu, R.: Five levels of internalizing environmental externalities: decision-making based on instrumental and relational values of nature, Curr. Opin. Env. Sust., 63, 101299, https://doi.org/10.1016/j.cosust.2023.101299, 2023.

van Peppen, L., Faber, T. J. E., Erasmus, V., and Dankbaar, M. E. W.: Teamwork Training With a Multiplayer Game in Health Care: Content Analysis of the Teamwork Principles Applied, JMIR Serious Games, 10, e38009, https://doi.org/10.2196/38009, 2022.

Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., Batlles-delaFuente, A., and Fidelibus, M. D.: Rainwater Harvesting for Agricultural Irrigation: An Analysis of Global Research, Water (Basel), 11, 1320, https://doi.org/10.3390/w11071320, 2019.

Venot, J.-P., Jensen, C. B., Delay, E., and Daré, W.: Mosaic glimpses: Serious games, generous constraints, and sustainable futures in Kandal, Cambodia, World Dev., 151, 105779, https://doi.org/10.1016/j.worlddev.2021.105779, 2022.

Villamor, G. B., Sharma-Wallace, L., van Noordwijk, M., Barnard, T., and Meason, D. F.: A systematic review of participatory integrated assessment at the catchment scale: Lessons learned from practice, Current Research in Environmental Sustainability, 4, 100167, https://doi.org/10.1016/j.crsust.2022.100167, 2022.

Voinov, A. and Gaddis, E. J. B.: Lessons for successful participatory watershed modelling: A perspective from modelling practitioners, Ecol. Model., 216, 197–207, https://doi.org/10.1016/j.ecolmodel.2008.03.010, 2008.

Wamucii, C. N., van Oel, P. R., Ligtenberg, A., Gathenya, J. M., and Teuling, A. J.: Land use and climate change effects on water yield from East African forested water towers, Hydrol. Earth Syst. Sci., 25, 5641–5665, https://doi.org/10.5194/hess-25-5641-2021, 2021.

Wamucii, C. N., Teuling, A. J., Ligtenberg, A., Gathenya, J. M., and van Oel, P. R.: Human influence on water availability variations in the upper Ewaso Ng'iro river basin, Kenya, J. Hydrol. Reg. Stud., 47, 101432, https://doi.org/10.1016/j.ejrh.2023.101432, 2023.

Wang, C. and Huang, L.: A Systematic Review of Serious Games for Collaborative Learning: Theoretical Framework, Game Mechanic and Efficiency Assessment, International Journal of Emerging Technologies in Learning (iJET), 16, 88, https://doi.org/10.3991/ijet.v16i06.18495, 2021.

Wendel, V., Hertin, F., Göbel, S., and Steinmetz, R.: Collaborative Learning by means of MultiplayerSerious Games, Proceedings of ICWL, 6483, 289–298, 2020.

Wesselow, M. and Stoll-Kleemann, S.: Role-playing games in natural resource management and research: Lessons learned from theory and practice, Geogr. J., 184, 298–309, https://doi.org/10.1111/geoj.12248, 2018.

Wiesmann, U., Gichuki, F. N., Kiteme, B. P., and Liniger, H.: Mitigating conflicts over scarce water resources in the highland-lowland system of Mount Kenya, Mt. Res. Dev., 20, 10–15, https://doi.org/10.1659/0276-4741(2000)020[0010:MCOSWR]2.0.CO;2, 2000.

Wolf, T.: Green gamification: How gamified information presentation affects pro-environmental behavior, in: CEUR Workshop Proc., 1–3 April 2020, Levi, Finland, 2637, 82–91, https://ceur-ws.org/Vol-2637/paper9.pdf (last access: 9 February 2023), 2020.

Worosz, M. R.: Transdisciplinary research for wicked problems, Agric. Human Values, 39, 1185–1189, https://doi.org/10.1007/s10460-022-10371-w, 2022.

Yousef, S. F.: Water Scarcity and Conflict between Upstream and Downstream Riparian Countries, Water Economics and Policy, 7, 1–61, https://doi.org/10.1142/S2382624X21500120, 2021.