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Discussions

The H_2Ours game to explore Water Use, Resources and Sustainability: connecting issues in two landscapes in Indonesia

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Abstract. Restoring hydrological functions affected by economic development trajectories faces social and economic challenges. Given that stakeholders often have a partial understanding of socio-hydrological systems, it is expected that knowledge sharing among them will help to enhance their understanding of the socio-hydrological system and the consequences of land-use choices. A tool that simplifies the social-hydrological system but still accommodate the crucial part of the social and technical aspects is needed to facilitate the collective learning. However, a simplification process has a risk that leads to very site specific and difficult to adopt for different conditions. To address those issues, this study aims to develop a highly adaptable serious game to make it easily applied to any situation in order to facilitate co-learning among stakeholders regarding complex socio-hydrological problems. We designed a 'serious' game that revolves around a simple water balance and economic accounting, with environmental and financial consequences for the land-users and balancing between relevant site-specificity and generic replicability of the game design. Here, we describe the development of the game and explore its capacity to visualise, discuss and explore Water: Use, Resources and Sustainability ('H_2Ours') issues at landscape scale. The game design for the H_2Ours game was based on a combination of the Actors, Resources, Dynamics and Interaction (ARDI) and the Drivers, Pressure, State, Impact, and Responses (DPSIR) frameworks. The design steps for constructing the game led to a generic version, and two localised versions for two different landscapes in Indonesia: a mountain slope to lowland paddy landscape impacting groundwater availability in East Java, and a peatland with drainage-rewetting, oil palm conversion and fire as issues triggering responses in West Kalimantan. Based on evaluation referring to credibility, salience and legitimacy criteria, the H_2Ours game can meet its purpose as a tool for knowledge transfer, learning and triggering action. We provide clear steps in designing and adapting the game to another area, which will facilitate the wider application and adaptation of the basic game design to other landscapes and policy-relevant issues.

1 Introduction

A recent call for collective action by the Global Commission on the Economics of Water (Mazzucato et al., 2023) asked for turning the tide, shifting from exploitation, over-use and wastage of freshwater resources to stewardship, wise use and social-hydrological restoration. To achieve this shift, a better understanding is needed on the relation between the social and hydrological systems, and on how this relation varies over time and space (D'Odorico et al., 2019). For example, many locations are experience hydrological problems due to changes in the use of land and water to meet food production, and other domestic and industrial needs (Djuwansyah, 2018). These uses often affect negatively the ability of water systems to retain their hydrological functions, which results in an increase in the water demand (Rosa et al., 2018), leading ultimately to degradation of the water system. Consequently, hydrological restoration aims to re-establish or restore the hydrological functions, and to avoid further hydrological degradation by managing water resources sustainably or eliminating the causal factors (Zhao et al., 2016).

Four interacting knowledge-to-action steps are needed to determine adequate strategies for social-hydrological restoration (Van Noordwijk, 2018). These steps are: A) understanding (technical agenda setting based on social relevance of environmental issues), B) commitment to goals (social understanding of urgency), C) operationalization of common but differentiated responsibility (in its social-ecological context) and D) innovation for better solutions (through monitoring and learning). Consequently, the first step for any restoration planning is developing a shared understanding of how the above- and belowground ecosystem structure and climate generate the hydrological functions and underpin the range of ecosystem services provided (van Noordwijk et al., 2022). Furthermore, the interactions between ecological-technical aspects and socio-economic conditions in a landscape (e.g., land tenure, the existence of regulations and incentive-disincentive mechanisms) make the socio-hydrological systems even more complex. Unfortunately, transfer of knowledge between and within different groups of stakeholders is often blocks the commitment, operationalization, and innovation stages of successful restoration (Creed et al., 2018).

Learning leads to information, knowledge, predictive ability, and ultimately to scenario development and knowledgeable decisions. However, providing data alone is not a catalyst that can trigger the associated knowledge to action chain (Marini et al., 2018). Therefore, 'services' that facilitate active learning and 'experiences' that provide a social context to technical aspects are needed for collective learning beyond knowledge transfer. In the 'learning' literature, there is a consensus that people learn more quickly through experiential learning where they can actively explore, engage with the process and then reflect on what happened during the exploration (Kolb and Kolb, 2005; Fanning and Gaba, 2007; Kolbe et al., 2015). Thus, we need tools that can show how a socio-hydrological system works as a whole, and allow people to see or experience the consequences of the decisions made, to strengthen knowledge sharing and to facilitate collective decision-making. Two tools are being increasingly used in this context: hydrological modelling (Guo, Y., Zhang, Y., Zhang, L. and Wang, 2021; Tsai et al., 2021) and serious gaming (Rossano et al., 2017; Feng et al., 2018; Ferguson et al., 2020). Hydrological modelling focuses on converting data to information, knowledge and understanding of technical aspects, and it is used to simulate various land-use change scenarios

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and quantify the likely consequences of various water management practices (Singh and Kumar, 2017). In contrast, serious gaming focuses on relating knowledge and understanding of social and technical aspects to enhance the credibility of decisions made. It adopts the basic elements of gaming, such as challenges, rewards, experiences, strategies, emotions, to allow stakeholders to safely explore management options (Fleming et al., 2014, 2016).

Games and models have developed as separate communities of practice (van Noordwijk et al., 2020), although these tools are conceptually related. Games are models as they are succinct representations of a more complex reality, and models are games as they allow the exploration of alternative strategies. In addition, both approaches require breaking down a complex hydrological system into several pieces, which is challenging as not all elements in the real conditions can and should be included in the models or games. Several considerations can serve as a guide in the simplification process from reality to model and game simulation (Medema et al., 2019), such as what knowledge we want to share with participants, what we want them to learn, and what changes/responses we expect from them. Although games and models have the potential to be combined, there are few studies where this has been done explicitly (Villamor et al. 2023, manuscript under review). In this paper, we explore the feasibility of transforming a hydrological model into a serious game to provide socio-hydrological dynamics to stakeholders with diverse backgrounds in order to develop restoration plans.

Simplifying the complexity of the system and highlighting the socio-hydrological issues from a hydrological model into a socio-hydrological game will facilitate knowledge transfer among stakeholders and offer a better decision-making tool (Savic et al., 2016). But such a simplification process can lead to serious games that are very specific to a given local context, making it difficult for the game to be applied to other places. For that reason, the elements and rules in the game should be easily adapted to other locations, or at least there should be guidelines on how the game can be applied elsewhere.

The objectives of this study are to develop an adaptable serious game to represent a generic socio-hydrological system, and to assess if this game facilitates the knowledge transfer and knowledge sharing regarding water use and management, and supports negotiation and coordination among various stakeholders. To achieve our objectives we developed a generic serious game, the H_2Ours game, for two specific locations in Indonesia that differ largely in hydrological characteristics. First, we developed the H_2Ours game based on the socio-hydrological characteristics of the Rejoso watershed in East Java. Then, we modified the H_2Ours game according to the conditions of the Pawan-Kepulu peatland, West Kalimantan.

We organised the paper by presenting as method the stages of how we prepared, designed, tested, implemented and evaluated the H_2Ours games. The game itself is the primary ‘result’, illustrated by the game dynamics during test settings and early applications with local stakeholders. Feedback by game participants is presented as an evaluation of the current games. We close by discussing the simplification process from reality to game, effectiveness of the game to achieve the goals set, and the lessons learned.

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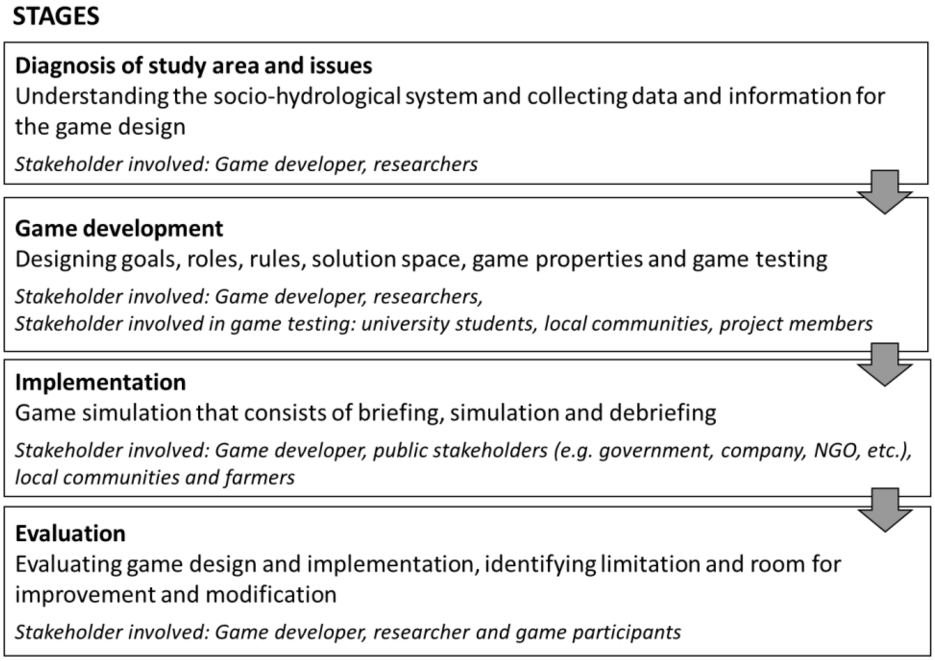
2 Methodology

This study consists of four stages from the diagnosis of the study area to the evaluation of the game (Fig. 1). The different stakeholders involved in each stage are also provided.



STAGES

Diagnosis of study area and issues
Understanding the socio-hydrological system and collecting data and information for the game design
Stakeholder involved: Game developer, researchers

Game development
Designing goals, roles, rules, solution space, game properties and game testing
Stakeholder involved: Game developer, researchers,
Stakeholder involved in game testing: university students, local communities, project members

Implementation
Game simulation that consists of briefing, simulation and debriefing
Stakeholder involved: Game developer, public stakeholders (e.g. government, company, NGO, etc.), local communities and farmers

Evaluation
Evaluating game design and implementation, identifying limitation and room for improvement and modification
Stakeholder involved: Game developer, researcher and game participants

Figure 1: Stages undertaken from the preparation to the evaluation of the H_2Ours game, including stakeholder involvement across the different stages of this study

2.1 Study areas

The two study areas used in this research, namely the Rejoso Watershed and the Pawan-Kepulu Peatlands (Fig. 2), differ in physical characteristics (hydrological system, land cover, soil type), but they experience similar socio-hydrological problems (lack of coordination and collective action). Rejoso watershed restoration was conducted by the 'Rejoso Kita' project in which World Agroforestry (ICRAF) had responsibility for research and development of conservation and restoration strategies, while Pawan-Kepulu peatland restoration is conducted by Tropenbos Indonesia through Working Landscape project and Fires project. Both areas have environmental problems because of the disruption of the hydrological functions buffering peak flow that contribute to floods due to lack of infiltration, which in turn is key to the supply of groundwater. To restore those hydrological functions, understanding about the relationship between land-use and (surface-ground) water management and water balance at the landscape level is crucial before developing a joint strategy (IPBES, 2018).

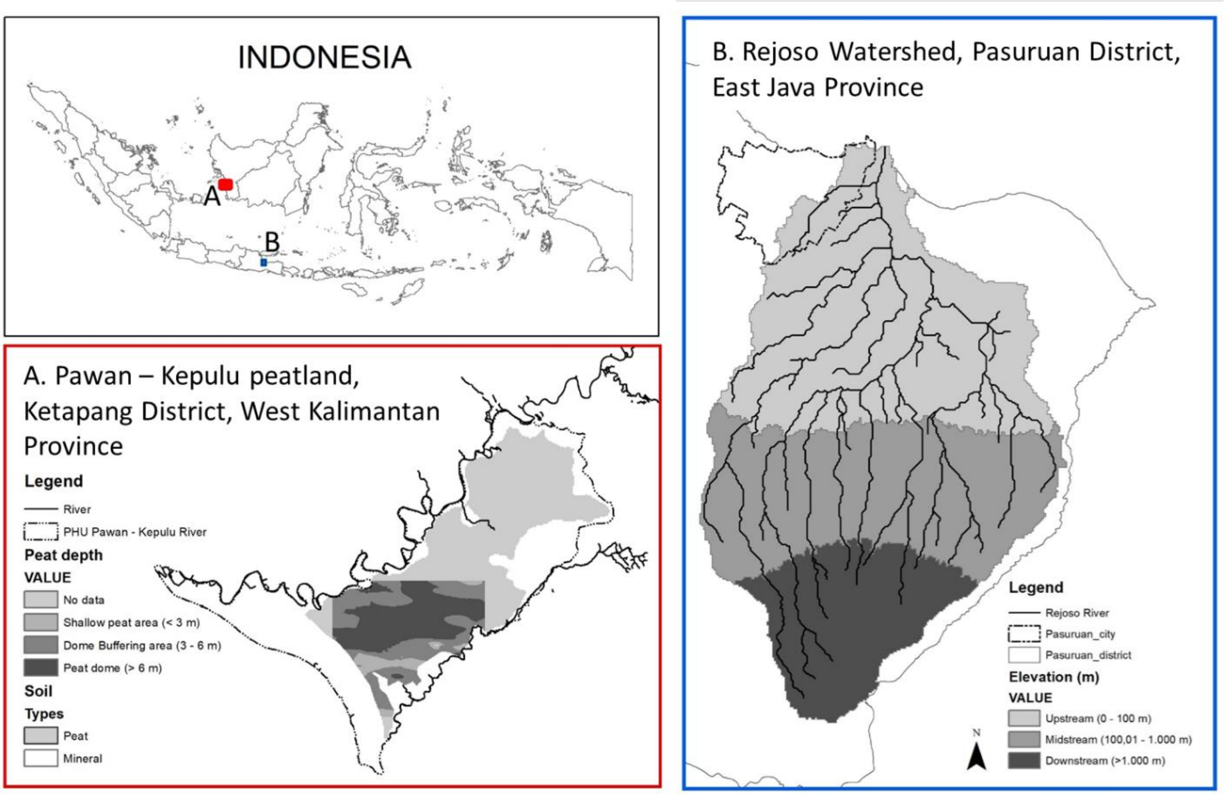


Figure 2: The two study areas of this study: A. Rejoso Wateshed that consists of upstream (elevation > 100 m above sea level (masl)), midstream (elevation 100–1000 masl) and downstream (elevation < 100 masl), and B. Pawan-Kepulu peatland that consists of peat dome (peat depth > 6 m, peat buffering dome (peat depth 3–6 m) and shallow peat (peat depth 1-3 m).

The Rejoso Watershed (1600 km^2) is in the Pasuruan district, East Java Province, Indonesia. Based on the elevation and hydrological system, we can divide the Rejoso watershed into three areas: downstream (0 - 100 masl. (meter above sea level), midstream (100 - 1000 masl.) and upstream (> 1000 masl.). This watershed is a national priority because the Umbulan spring is used, through a recent pipeline, to supply water to 1.1 million people in the surrounding metropolitan area. Land conversion from agroforestry to intensive agriculture in the recharge areas (> 700 masl. upstream and midstream area) and massive groundwater extraction using artesian wells in the downstream area for rice field were thought to cause the reduced discharge of the Umbulan spring, from 5 m^3/s (1980s) to 3.5 m^3/s (2017) (Toulier, 2019; Khasanah et al., 2021; Amaruzaman et al., 2018; Leimona et al., 2018). As the declining spring discharge is disrupting the water supply for drinking water, agriculture and industries, stakeholders in the Rejoso Watershed need to develop strategies to restore the hydrological function of their watershed through land-use management in the recharge area and groundwater utilization in the downstream to maintain the continuity of water supply in the Umbulan spring (Khasanah et al. 2021).

The Pawan-Kepulu peatland is a peat area between the Pawan and Kepulu Rivers, functioning as a unified hydrological system. This peatland is located in the Ketapang district, West Kalimantan Province, Indonesia. Based on the peatland characteristic, we divided the Pawan-Kepulu peatland into relatively shallow peat area (peat depth 0–3 m), buffering the dome area (peat depth 3–6 m) and dome (peat depth > 6 m). In the 2000s, local communities and oil palm companies started to build canals for artificial drainage to facilitate timber extraction and for managing oil palm and other forms of agriculture easier (Carlson et al., 2012). However, during the dry season, the canals cause a decrease in the groundwater level so that the peatland becomes drier and more vulnerable to fire. The impact of these land fires is detrimental to both the local area and at the global level with the haze and carbon emissions (Widayati et al., 2021). Therefore, there is interest to restore the hydrological function of peatlands to prevent or reduce land fires (Murdiarso et al., 2021); a complication is that the current zoning of production and protection forests is not based on accurate maps of peat depth.

2.2 Diagnosis of the study areas and issues

To make it easier to describe the interactions between components in a socio-hydrological system, we structured the socio-hydrological condition of the study area based on the Dynamic, Pressure, State, Impacts and Responses (DPSIR) and Actors, Resources, Dynamic and Interaction (ARDI) framework. DPSIR is a framework that is widely used to carry out hydrological assessments because of its superiority in connecting various components in a socio-hydrological system (Sun et al., 2016; Lu et al., 2022). We used DPSIR to trace the causes of problems, including interactions and relationships between social and hydrological components and to further explore various responses to socio-hydrological problems (Sun et al., 2016). ARDI is widely used in companion modeling to design serious games (Etienne et al., 2011). We used ARDI framework to identify main stakeholders involved in water management, main resources, main processes that affect changes in resources, and interaction between stakeholders and resources (Villamor et al., 2019). These frameworks became the basis for designing the H_2Ours game in two contrasting study areas in Indonesia.

2.3 Game development

In this step, we transformed the information from the DPSIR and ARDI analyses into components needed in the game design: goals, roles, rules, and solution space.

2.3.1 Scope and objective

The first stage in designing a serious game is to determine the topic and objective of the game (Silva, 2020; Mitgutsch and Alvarado, 2012). The scope of the game refers to the problem or issues to be addressed. The objective of the game refers to what kind of knowledge or impacts is expected to be obtained by players after participating in the game. We determined the topic and the objective of the game based on the socio-hydrological problem defined in the diagnostic of study and issues (Sect. 2.2).

2.3.2 Roles

According to the ARDI results (Sect. 2.2), we defined the roles in this game based on the main stakeholders involved in water management. Related to these roles, we designed goals that players must achieve during each simulation based on discussions and interviews with the related stakeholders according to their actual goal in the reality.

2.3.3 Rules

According to ARDI and DPSIR framework (Sect. 2.2), we transformed actors and resources interaction as the rules of the H_2Ours game. To show the dynamics of changes in resources, the rules consist of a set of values attached to each type of land-use and water infrastructure that describes both the economic and the water balance component. The economic component consists of the production costs/capital required to manage a certain land-use type and the income derived from that land-use. The water balance component consists of surface flow and infiltration of each land-use type and water infrastructures. The values used as rules for the economic component referred to research findings by ICRAF and Tropenbos Indonesia (section 2.1). For the water balance component, the Rejoso's data were obtained from the hydrological modelling and field measurement (Leimona et al., 2018; Suprayogo et al., 2020), while the Pawan-Kepulu's data was based on field measurement (Tanika et. al, manuscript in prep.). Several local communities then validated the values through a process of discussion and game testing (Sect. 2.3). We simplified the values for each land-use type as a ratio between land-uses to make the quantification process easier during the simulation process. A simple guideline for developing or modifying rules can be seen in the Appendix B.

There are two indicators that are used to mark the position of the participants towards their goals in the game, namely economic and environmental conditions. We derived the economic conditions based on a simple profit calculation equation, where profit is total income minus total capital. At the sub-landscape level (upstream, midstream, downstream, dome, buffering area, and shallow peat area), total profit is the difference between total revenue and total production costs. While the feedback system for the environment followed a simple water balance model used in Generic River Flow (GenRiver) model (https://www.worldagroforestry.org/output/genriver-generic-river-model-river-flow) (Van Noordwijk et al., 2017). The relationship between those two indicators allowed us to describe the socio-hydrological system of each study area.

2.3.4 Game solution space analysis

The solution space of the game was explored based on the average of economic and environmental conditions obtained from 3, 10, 30, 100, 300 and 1000 games with random-choice. One random-choice game consisted of 10 rounds in which climate conditions and land use decisions made by players are completely random. In addition, we assessed the probability of outcomes within the solution space under random decision-making as a point of reference for the actual game implementation.

2.3.5 Game properties

The purpose of game development is to bring the game design into a real form that players can play or touch such as a game board, various required tokens, and other attributes that support the simulation of the game. Because we expected the decisions made by the participants during the game simulation represented their actual decisions, we developed the game as close as possible to the reality. From all the game properties, the board game, land-use options, and water simulation model are the most crucial game properties that must be available. Therefore, we adjusted it according to the conditions of each study area.

2.3.6 Game testing

The purpose of game testing is to confirm some elements in the game and to test the game before being used for the actual simulation. We tested the game in two ways: checking all the quantification systems using an Excel spreadsheet and the complexity through role playing testing. In the role-playing testing, we tested the game several times with different categories of participants, namely members of the project, undergraduate students and non-targeted farmer groups. During the role-playing testing with project members, we checked the suitability and the game components with the reality; with the students, we calibrated and validated the rules and feedback system in the game and finally with the farmer groups, we checked if the rules of the game were sufficiently clear.

2.4 Game implementation

In this study, we executed ten game sessions with different participant groups with a total of 93 participants. The ten game sessions consisted of five sessions at each study areas. The five game sessions consisted of a session with a multi-stakeholder forum to get ideas on regulations and programs that would be offered to local communities/farmers, and four session with farmer groups to implement the regulations and programs resulting from the game simulation with the multi-stakeholder forum. In each session with farmer groups in Rejoso watershed, we invited a total 9-12 representatives of farmer groups from upstream, midstream and downstream village to a meeting hall where all participants could still reach it. While in each simulation in Pawan-Kepulu peatland, we invited 12-16 representatives of farmer group from four villages in that landscape. During the game simulation, we asked the invited farmers to behave as farmers in line with the position of their village in the landscape.

Each game session required half a day of implementation (briefing, simulation and debriefing), excluding game preparation and participant surveys for further research. We did to briefing around 10–15 minutes to help the participant connect with the simulation by establishing the environment, setting boundaries and goals, and clarifying the roles and rules (Rudolph et al., 2014). We did debriefing around 30–40 minutes to allow participants to reflect on what they learned (Kim and Yoo, 2020). To maintain consistency in the H_2Ours simulation process for different groups of participants, we used the simulation guideline provided in Appendix A

2.5 Game evaluation

The aim of the evaluation stage is to assess the game in achieving the objective of the game. Ideally, the assessment of the game can be evaluated after several simulations at various levels of simulation, and should be conducted before, during and after the game simulation (Oprins et al., 2015). With these conditions, the evaluation of the game can only be done after the game designer has done a lot of game trials and it requires numerous resources (in terms of funding, participants and time). To overcome this problem, several studies have proposed an assessment through an input-output process, which can integrate the assessments obtained from the designing and development process and after the simulation (Bedwell et al., 2012). We followed the latter approach and carried out the evaluation based on several criteria that refer to credibility, salience, and legitimacy (Table 1), using some criteria developed by Belcher et al. (2016). From the game development perspective, credibility refers to whether a game is built based on scientifically reliable knowledge, including the data and methods used to build the game. Salience refers to how far the game can show the relevance of goals, rules and finding to the actual situation. Finally, legitimacy refers to how the participant can accept the game by relating the game simulation to their actual situations (Cash et al. 2002).

Table 1: Criteria used to measure the credibility, salience and legitimacy of the H_2Ours game (adapted from Belcher et al. (2016). The criteria included were used to assess effectiveness in sharing understanding and encouraging collaboration for H_2Ours game development and simulation.

No	Criteria	Original definition according to (Belcher et al., 2016)	Adjustment of to meet the objective of H_2Ours game	How to include the criteria during the game design	Evaluation after game implementation
CREDIBILITY					
1	Clear problem definition	The research problem is clearly defined, researchable, grounded In the academic literature and relevant to the context	The issues handled in the H2Ours game are relevant to the actual situation	In diagnosis of the study area and issues using ARDI and DPSIR (Sect. 2.2)	Likert question: the possibility to apply the knowledge from the game in the reality
2	Clear objective	Research objectives are clearly stated	The objective of the H2Ours game is clearly stated	In scope and objective (Sect. 2.3.1)	Likert question: understanding the objective of the game
3	Appropriate methods	Methods are fit to purpose and well-suited to answering the research	Methods used are scientifically proven	The data and method used scientifically proven with some	There was no evaluation for this criterion after the game because we

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		questions and achieving the objectives.		publications (Sect. 2.1 and Sect. 2.2)	used scientifically proven method
4	Clearly presented argument	The movement from analysis through interpretation to conclusions is transparently and logically described. Sufficient evidence is provided to clearly demonstrate the relationship between evidence and conclusions	The rules, dynamics and interactions in the H2Ours game built based on logical interpretation supported by scientific data and methods	Component interaction analysis based on ARDI and DPSIR (Sect. 2.2 and Sec. 2.3)	Likert question: Understanding the rules of the game
SALIENCE/RELEVANCE					
5	Socially relevant research problem	Research problem is relevant to the problem context	The problems/issues raised in the H_2Ours game are in accordance with the issues/problems in actual conditions	The information used based on participatory approach (referring some publication in Sect. 2.1)	Likert question: The possibility to apply the knowledge from the game in the reality
6	Engagement with problem context	Researcher demonstrate appropriate breadth and depth of understanding of and sufficient interaction with the problem context	The H2Ours game is built by demonstrating the interaction of various elements (physical and social, interaction between stakeholders) that are shown in actual conditions.	Problem analysis based on DPSIR (Sect. 2.2)	Likert question: The possibility to apply the knowledge from the game in the reality

7	Explicit theory of change	The research explicitly identifies its main intended outcomes and how they are intended/expected to be realized and to contribute to longer-term outcomes and/or impacts	H_2Ours game was built explicitly to facilitate knowledge sharing and knowledge transfer to trigger collaborative action among various stakeholder	Set the purpose of the game in the game development proses (Sect. 2.3.1)	Likert question: Gaining new knowledge from the game simulation
8	Relevant research objective and design	The research objectives and design are relevant, timely, and appropriate to the problem context, including attention to stakeholder needs and values	The objectives and design of the H_2Ours game are relevant to the problem context, including taking into account what the stakeholder needs and values	Based on ARDI and DPSIR analysis (Sect. 2.2 and 2.3)	Likert survey: 1. understanding the objective of the game 2. the possibility to apply the knowledge from the game in the reality
9	Appropriated project implementation	Research execution is suitable to the problem context and the socially relevant research objectives	The solutions in the H_2Ours game is generated based on activities that can be implemented in the actual condition	The solutions based on the multidisciplinary research (Sect. 2.1)	Likert question: the possibility to apply the knowledge from the game in the reality
LEGITIMACY					
10	Effective collaboration	Appropriate processes are in the place to ensure effective collaboration (e.g. clear and explicit roles and responsibility agreed upon, transparent and appropriate decision-making structures)	The H_2Ours game shows transparency of roles, responsibilities, decision-making between game participants, so the players can build	Simple game rules based on actual condition to facilitate participant game understanding (Sect. 2.3)	Using before and after survey using q-methodology to identify the change in stakeholder perception

			collaboration between them		
11	Genuine and explicit inclusion	Inclusion of diverse actors in the research process is clearly defined. Representation of actors' perspectives, values, and unique contexts is ensured through adequate planning, explicit agreements, Communal reflection, and reflexivity.	Involvement of various stakeholders during the process of H_2Ours game preparation, design, implementation and evaluation to accommodate various perspectives, knowledge, values, interests of stakeholders	Involvement of various stakeholders in this study (Fig. 1)	Likert survey: the possibility to apply the knowledge from the game in the reality

We accommodated those criteria in Table 1 during designing process and after game implementation. How we included those criteria during the game design can be seen in the column five based on the research findings from ICRAF and Tropenbos Indonesia. After the implementation, we evaluated the game using Likert scale survey and q-method. In the Likert scale survey, we asked about their feeling during the game, their understanding about the rules of the game, the length of the game simulation, new knowledge that they got from the game, and how close the game to their reality.

3 Results

We organized the results side by side between Rejoso watershed version and Pawan-Kepulu peatland to make it easier to see the similarities and differences even though the Pawan-Kepulu peatland version of the H_2Ours game was developed after the Rejoso watershed version.

3.1 Diagnosis of the study areas and issues

Based on the results from the DPSIR and ARDI analyses, we found that the Rejoso Watershed and the Pawan-Kepulu peatland have similarities in the socio-hydrology context (Table 2). Expectations on better economic conditions led to changes in land cover, and excessive extraction of water resources (groundwater) caused disruption of the water balance. This disruption resulted in various hydrological problems, such as water shortages (or decreasing the groundwater level) and flooding. However, these two sites are also different regarding their hydrological contexts, such as hydrological boundaries, topography, and water management, and interactions among stakeholders and landscape (Fig. 3, Appendix C). Two solutions (responses) were identified to restore hydrological functions in watersheds and peatlands, namely land cover management and (ground) water management (Table 2; component 7-Response).

Table 2. Framing problem definition for the Rejoso Watershed and Pawan-Kepulu Peatland, Indonesia. Problem definition was done the using Driver, Pressure, State, Impact and Response (DPSIR) and Actor, Resource, Dynamic and Interaction (ARDI) frameworks, based on ICRAF and Tropenbos research findings

	COMPONENTS	REJOSO WATERSHED	PAWAN-KEPULU PEATLAND
1	Hydrological boundary/ landscape	Watershed (and/or groundwater catchment)	Peatland hydrological unit
2	Zone partition	(1) Upstream: elevation > 1000 meter above sea level (masl) (2) Midstream: elevation 100 – 1000 masl (3) Downstream: elevation <100 masl	(1) Dome: peat depth > 6 m (2) Buffering area: peat depth 3 – 6 m (3) Shallow peat area: peat depth <3 m
3	**D**river	To get a better household income and livelihood	
4	**P**ressure	(1) Land-use conversion into non-tree-based system in the recharge area (upstream and midstream) (2) Massive artesian well construction for paddy field (downstream area)	(1) Land-use conversion into oil palm (dome and buffering area) (2) Massive canal construction to drain peatland water
5	**S**tate	(1) Increasing runoff and reducing infiltration (upstream and midstream) (2) Increasing groundwater uptake (downstream)	Increasing water outflow from peatland -> decreasing peatland water level -> peatland become drier, particularly during the dry season
6	**I**mpact	(1) Decreasing groundwater supply in the Umbulan spring (2) Floods (during rainy season)	(1) Peat fires (during the dry season) (2) Floods (during the rainy season)
7	**R**esponse	(1) Land-use/cover management (2) Better groundwater management through artesian well management	(1) Land-use/cover management (2) Better groundwater level through canal blocking management/ distribution
8	**A**ctors	Multi-stakeholder forum and farmers/local communities	
9	**R**esources	(1) Money (2) Water balance (especially groundwater and surface water)	(1) Money (2) Water balance (especially groundwater and surface water)
10	**D**ynamic	(1) Land-use/cover change (2) Water management (artesian well management)	(1) Land-use/cover change (2) Water management (canal blocking management)
11	**I**nteraction	Fig. 3	Fig. C1

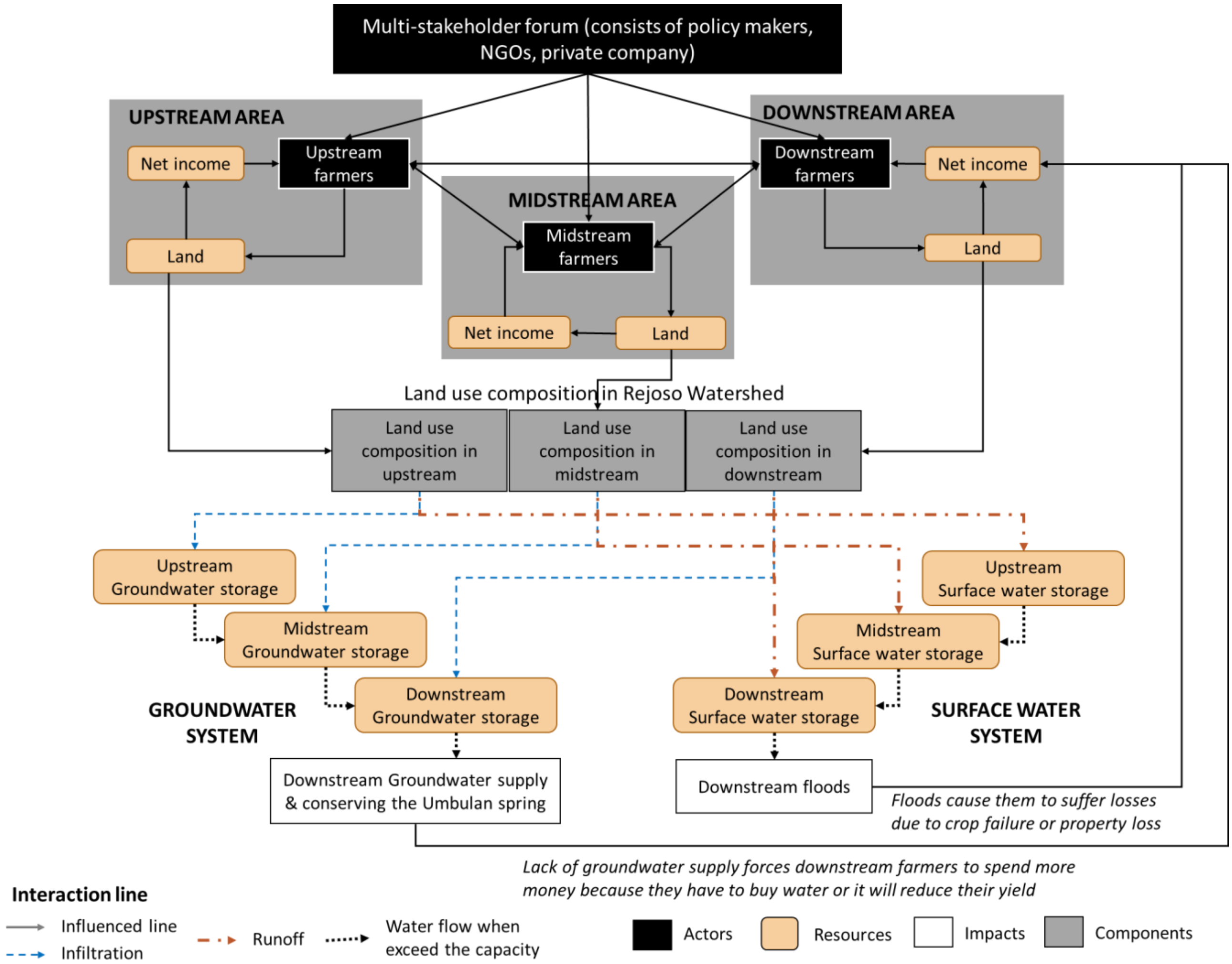

Figure 3: Socio-hydrological model for the Rejoso watershed, defined using the ARDI framework. Interactions among actors and between actors to landscape influence land-use composition. The land composition affects the hydrological and economic situation, which influences back to the interactions. A similar socio-hydrological model with some adjustments for Pawan-Kepulu peatland was also developed (Appendix C).

3.2 Game development: H2Ours game

3.2.1 Scope and objective of the game

As a serious game, the H_2Ours game has the objective of becoming a tool to help sharing knowledge and building collaboration between stakeholders to restore hydrological functions in a landscape. Based on Table 2, we determined the goal for H_2Ours game simulation in those two study areas are for knowledge sharing and facilitating collaboration, specifically for groundwater water restoration and flood prevention. However, the H_2Ours game in Rejoso watershed addressed the supply and utilization of deep groundwater, while in Pawan-Kepulu peatland it addressed peatland's groundwater as an indicator of the wettability of peatlands and its vulnerability to land fires.

3.2.2 Roles

Based on the stakeholder identification survey in Rejoso Watershed and Pawan-Kepulu peatland, we defined two key roles for this game, namely local communities and a multi-stakeholder forum. The local communities represent land owners and their goal is to live happily by fulfilling their needs (food and taxes). The multi-stakeholder forum is a forum that consists of public stakeholders (NGOs, university, etc.) and policy makers (local governments). Their goals is to prevent natural disasters (water scarcity and floods in Rejoso watershed, and fires and floods in Pawan-Kepulu peatland). The H_2Ours game brings the various interests of these actors together and shows how they make their decisions regarding the management of land and water resources to meet their economic and environmental expectations.

3.2.3 Rules

At the start of the game, players received a limited amount of money. Community members were asked to manage their land with the money provided, while we asked multi-stakeholder forums to run programs or to help reduce the local community's economic problems. Once players decided on how they would manage their land or community programs, the economic and environmental rules linked to those land use decisions were applied (Table 3). These rules then defined the dynamics of the economic and environmental conditions (Table 3, and for the Pawan-Kepulu peatland in Appendix C). When the environmental situation resulted in flooding during wet years or water shortages (in Rejoso watershed) or land fires (in Pawan-Kepulu peatland) during dry years, the community income decrease. As the consequence of this situation, they might not have enough money to manage their land, buy food or pay taxes in the next round of the game. The multi-stakeholder forums with their limited budget could then choose to help them by providing financial help or making regulations/programs to prevent these environmental problems. Through this gameplay, we expected to promote all actors to work together and collaborate to achieve their goals.

Table 3. Economic and environmental impacts as the rules of the H_2Ours game in the Rejoso Watershed. The variation of environmental components resulting from different land-use options in the upstream and midstream depends on the ability of the land-use options to infiltrate water, while the variation of environmental components downstream depends on the use of water based on farmers' perceptions. The rules of H_2Ours game in the Pawan-Kepulu peatland are in the Appendix C. (AF= agroforestry).

Land-use	Production Cost (unit money)	Income/year (unit money)		Environment impacts during wet year (ml)			Environment impacts during dry year (ml)		
		Wet year	Dry year	Runoff	Infiltration	Water use	Runoff	Infiltration	Water use
UPSTREAM AND MISTREAM									
All crop	12	25	13	40	0	0	0	0	5

Mixed AF low density	9	17	9	30	10	0	0	0	5
Mixed AF moderate density	6	9	6	20	20	0	0	0	0
Mixed AF high density	3	6	4	10	30	0	0	0	0
All trees	1	0	0	0	40	0	0	0	0
DOWNSTREAM									
Paddy	12	12	25	0	0	10	0	0	15
Maize	9	15	18	0	0	5	0	0	10
Orange	7	11	15	0	0	0	0	0	5
Cucumber	9	15	13	0	0	2.5	0	0	7.5
Banana	5	10	10	0	0	0	0	0	0

In addition, the economic and environmental conditions are also influenced by the yearly weather (wet year of dry year). In each round, participants decided on land-use without knowing whether the next round would be a ‘dry’ or ‘wet’ year (and rounds did not simply alternate).

3.2.4 Game solution space analysis

Based on 300 random decision making, the groundwater distribution varies depending on the location, while the distribution of surface water in the upstream and midstream is almost the same, and in the downstream is wider (Fig. 4A and Fig. 4B). Upstream and midstream have almost the same distribution of surface water because the runoff produced in the upstream and midstream only occurs during wet years, which then may potentially cause flooding downstream in the same year. Different form surface water, the contribution of groundwater from upstream and midstream occurs in wet years, but groundwater utilization by downstream occurs mostly during the dry years. Therefore, the dynamics of groundwater changes more often than of surface water.

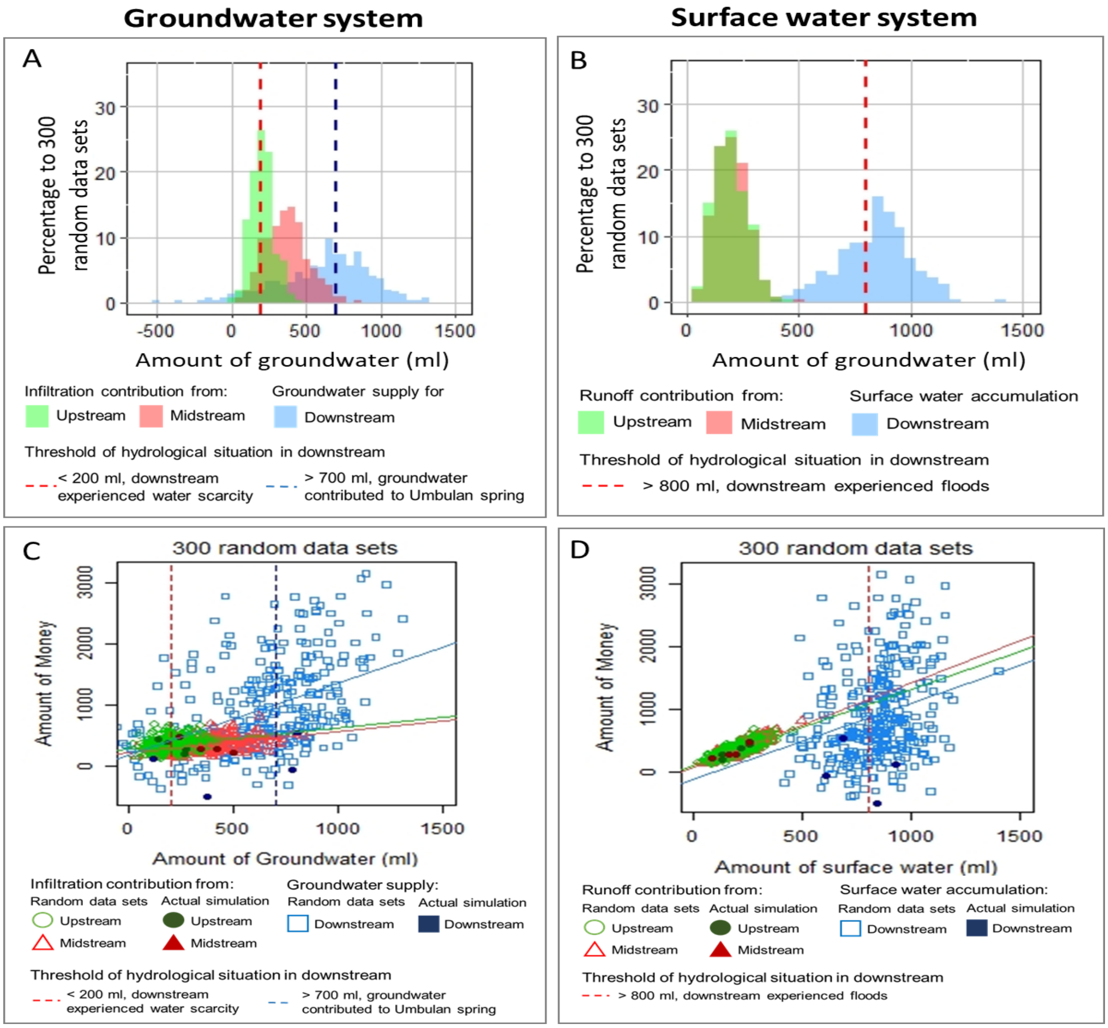

Figure 4: Simulation of hydrological and economic situation in H_2Ours game using random value (N = 300) and game actual simulation (obs.) results (N = 4) for the Rejoso watershed. A. Distribution of infiltration contribution from upstream and midstream and groundwater supply in downstream based on simulation with the random value; B. Distribution of runoff contribution from upstream and midstream and surface water accumulation downstream based on simulation with the random value; C. Groundwater situation and economic situation based on random value simulation and actual simulation; D. Runoff situation and economic situation based on random value simulation and actual simulation. You can see further analysis of the solution space in the Appendix D

Related to the economic conditions (Fig. 4C and Fig. 4D), efforts to increase infiltration in the upstream and midstream have not contributed much to increasing the income of the community. However, the efforts of farmers in the upstream and midstream areas to improve their economic conditions resulted in increased runoff, which causes flooding in the downstream areas. Therefore, for the downstream area, the relationship between environmental and economic conditions varies because of the influence from upstream and middle conditions.

3.2.5 Game properties

To make the game more interesting and stimulate engagement, we prepared some game materials such as a game board to represent the landscape, land-use tiles according to the existing and future land cover types, money token, and water infrastructures token (Fig. 5). We also created, water balance miniatures (Fig. 6) to demonstrate the water flow and availability of the surface water and the groundwater.

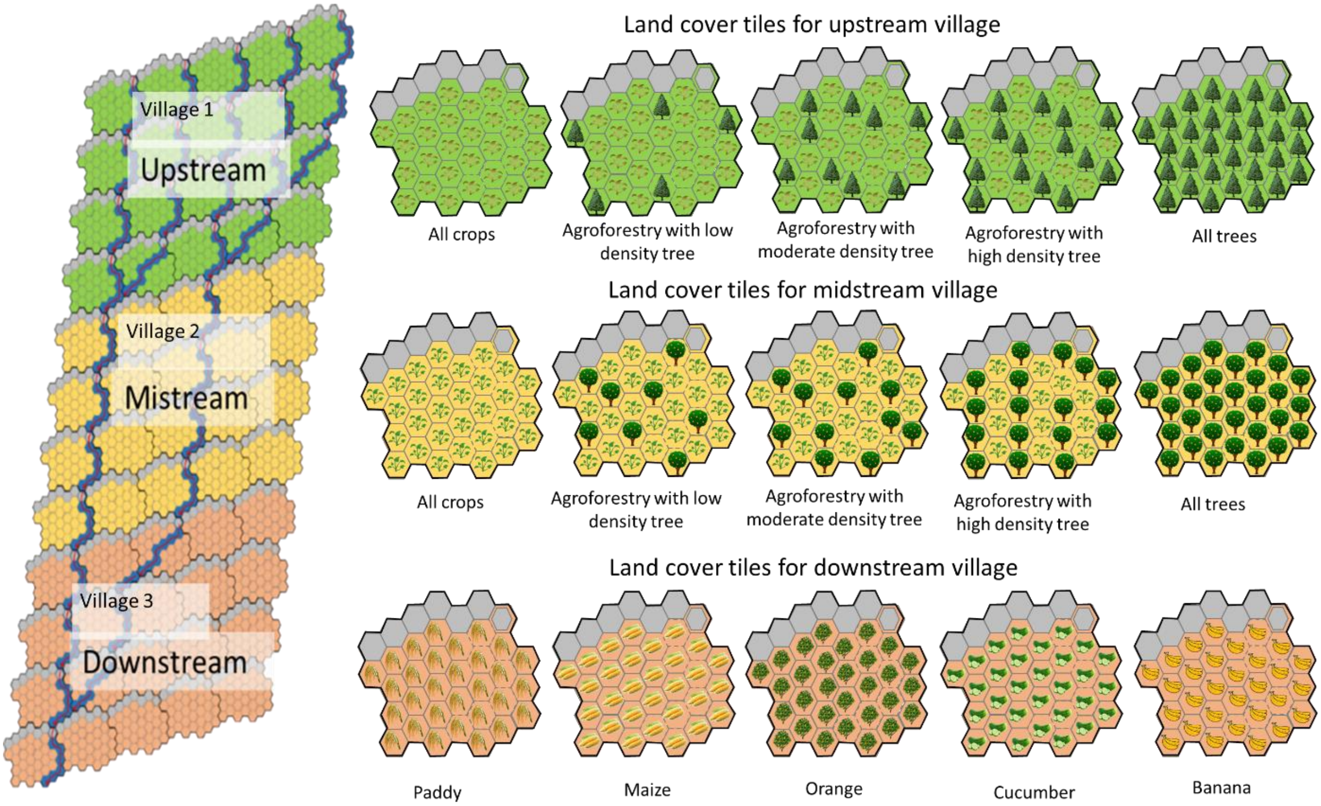

Figure 5: Gameboard and land cover tiles of the H_2Ours game in Rejoso Watershed. The land cover options in the upstream and midstream area varies based on their ability to infiltrate water, while in the downstream area varies based on farmer's perception on water utilization. See appendix C for the game materials for the Pawan-Kepulu peatland.

Figure 6: Simple water balance model of H_2Ours game in Rejoso watershed to show the dynamics of changes in hydrological conditions as a result of land-use change and water utilization. See appendix C for the simple water balance model for the Pawan-Kepulu peatland

3.2.6 Game testing

From the results of checking the quantification system in excel, we adjusted the values used in the rules to ensure that these values are sensitive enough to changes in strategy by players, i.e., the initial money given to players, as well as the initial water for groundwater and surface water. The role-playing testing with project members allowed us to validate the game scenarios that would be applied in the game implementation; with the university students, we adjusted the flow of the game, the number of rounds to 8-10 rounds, and the length of simulation time to two hours; and with the local communities (non-targeted participants), we checked the terminology used during the simulation.

3.3 Game implementation

During the simulation, players acting as a farmer/local community tried to improve their household income and livelihood, at least to a level that would allow them to manage their household for the next year. The results of the game implementation showed that there was a trade-off between economic and environmental conditions, and among the upstream, midstream and downstream groups (Fig. 4, below). In the Rejoso watershed, the efforts of the upstream and midstream communities to improve their economic situation by increasing crop area brought a negative environmental impact as flooding and water scarcity for downstream communities. The efforts of upstream and midstream communities to reduce these problems resulted in a reduction of their economic conditions. This situation led to negotiation among those communities. In contrast, the negotiation process in the Pawan-Kepulu peatland was related to the canal blocking construction among villages and between villages with the multi-stakeholder forum. To achieve a closed hydrological system to maintain the wetness of the peatland, the construction of canal blocking must be carried out collectively by all villages according to the location suggested by the multi-stakeholder forum. The construction of canal blocking reduced the income of farmers/local communities due to

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decreased yield or increased harvesting costs. Furthermore, the multi-stakeholder forum also persuaded the community by giving them some compensation to protect the peat dome area by maintaining more trees.

During the debriefing of the session, the participants in Rejoso watershed and Pawan-Kepulu peatland mentioned that the game showed that any decision at the plot level had an effect on the hydrological function at the landscape level. They also mentioned that as long as they had not met their economic needs, the economic conditions became their priority. They also indicated that they would accept any regulation or program from other stakeholders as long as their income is not reduced significantly. But, if that happened, they hoped for compensation. From the multi-stakeholder forum's perspective, they said that it would be easier if the village knew what they wanted in advance, so that the programs and assistances would be able to match their needs. In addition, regulations should also be complemented by supporting schemes, such as compensation or incentive schemes, not just regulations issued by the government.

3.4 Game evaluation

After playing the game, the participants of both study areas were asked to fill a survey to assess the credibility, salience and legitimacy (Table 3). For the credibility of the game, based on the average of Rejoso watershed and Pawan-Kepulu peatland, the survey shows that 87% of the participants indicated that they understood well and very well the rules of the game, while 78% of participants indicated to know the purpose of the game. For the salience and legitimacy of the game, the survey show that 92% of participants gained new understanding and 87% said that they could apply this simulation in their real life. Besides the credibility, salience and legitimacy criteria, we also asked the participants about their opinion regarding the simulation process. From the survey, 87% of the participants enjoyed the simulation and 79% of them feel that the length of simulation time was fair.

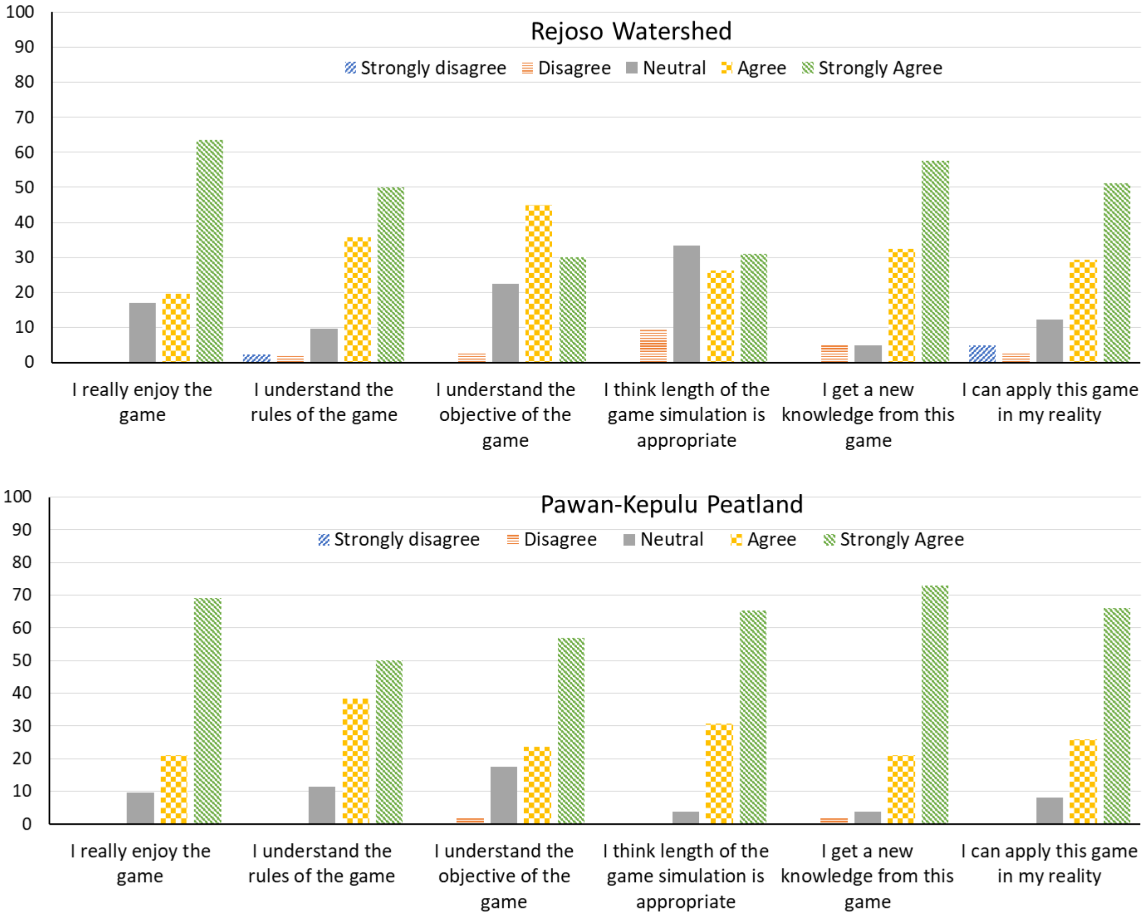

Figure 7: Game evaluation from the participants in the Rejoso watershed (N = 41 people) Watershed and Pawan-Kepulu peatland (N= 52 people)

4 Discussion

To meet the first objective of this paper to develop an adaptable serious game that can represent the socio-hydrological system, we show the generic version of the H_2Ours game as the result of the development and modification process in two different landscapes in Indonesia (Sect. 4.1). Then, to assess whether H_2Ours games can facilitate the knowledge transfer and knowledge sharing regarding water use and management, and supports negotiation and coordination among various stakeholders as the second objective, we evaluated H_2Ours game based on input-output assessment according to evaluation criteria (Sect. 4.2).

4.1 The adaptable of H_2Ours game allows simplifying the complexity of the socio-hydrological systems

The complexity of a system is closely related to the number of interdependent information and interactions between elements in the system (Vidal and Marle, 2008; Rumeser and Emsley, 2019). Models and games simplify this complexity by reducing the amount of information and interactions, only showing the relevant information through the holistic view (Strait and Dawson, 2006; Rumeser and Emsley, 2019). In the H_2Ours game, we used the DPSIR and ARDI frameworks to identify the interconnections of the components of the complex socio-hydrological system of the Rejoso watershed (Table 2). Then we modified that version of the H_2Ours game to the Pawan-Kepulu peatland by changing the components in Table 2 based on the socio-hydrological condition of the peatland. Therefore, these well-established frameworks (act as the generic version of the H_2Ours game, which can easily be modified according to other socio-hydrological realities.

The two study sites experience more complex socio-hydrological problems than it was possible to represent in the H_2Ours game. In our game, the water quantity issues were represented, which resulted in groundwater scarcity and floods for Rejoso, (Fig. 3) and fire and floods for Pawan-Kepulu peatland (Appendix C). In reality, the Rejoso Watershed also experience other hydrological problem, such as erosion and landslides from upstream areas, water quality degradation because of chemical fertilizer (Amaruzaman et al., 2018; Leimona et al., 2018), while the Pawan-Kepulu peatland also experience land degradation and water contamination because of mining in the upper area of peatland (Widayati et al., 2021). The complexity in a socio-hydrological system is formed due to many relationships and inter-connection of the various components (aggregate complexity), therefore self-organization through gradual learning is the key to a better transformation (Manson, 2001). If all the problems would have been included at once in the game, there would have been a higher risk of making people without technical background even more confused, which would preclude their understanding of the causes and effects of the problem. Therefore, by unraveling each individual problem and showing its cause-impact, players were allowed to build understanding gradually. We believe that the generic game H_2Ours allows simulating different problems, allowing the players to gain further understanding and start building connections among various problems. In this way, it is possible to create opportunities to build overall socio-hydrological understanding in the future.

If we compared the H_2Ours game in the two contrasting study areas, we found that there were game components that remained the same while others had to be adjusted to the local situation. Game components related to the interaction among humans or between humans and the environment (relational value) are similar in our study areas (e.g. land-use management to maximize profits, effort scenarios to restore hydrological functions, the need for coordination and negotiation among stakeholders), and are the maintained components from one location to another (Driver and Pressure in Table 2). However, the environmental response to the drivers and pressure requires technical adjustments (State and Impact in Table 2) to local conditions (e.g., hydrological boundaries, land-use types and composition, water infrastructures, hydrological systems). Therefore, our generic H_2Ours game (defined using the components of Table 2) is easy to adapt to other problems or other locations. In addition, it is expected to overcome the complexity of a system as we can choose what interactions are considered the most important and most influential to the socio-hydrological problems that want to be addressed.

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4.2 Game evaluation and lesson learned

During the game design, we evaluated the H_2Ours game using the input-output assessment process (Bedwell et al., 2012). Here, credibility, salience and legitimacy (Table 1) were assessed throughout the different stages of H_2Ours game development (Fig. 1). During the game development of the Rejoso watershed, we accommodated the credibility of H_2Ours game by relaying on the biophysical and hydrological research, including hydrological modeling through the GenRiver model (Suprayogo et al., 2020; Leimona et al., 2018), while in the Pawan-Kepulu peatland based on the biophysical measurement and hydrological modelling (Tanika et. al, manuscript in prep.). For the salience and legitimacy, we relied on results of participatory research done involving various stakeholders in Rejoso watershed and Pawan-Kepulu peatland (Amaruzaman et al., 2018; Leimona et al., 2018; Widayati et al., 2021). By taking into account the criteria of credibility, salience and legitimacy since the data and information collection, it was easier for the H_2Ours game to fulfil these criteria during the evaluation after the simulation.

As hydrological problems are usually quite complex and fundamental, their solution requires quite a long time for integrated planning, which requires all stakeholders to have the bigger picture (Medema et al., 2019). The evaluation of the game after the simulation (Fig. 7) indicates that most of the participants gained new knowledge from the game that could be applied in the reality. Transparency of the rules of H_2Ours game allowed players to see more clearly the interdependent connections between elements in the complex socio-hydrological system. This situation made it easier for players to explore various possibilities and to gain lessons from the reflection results (Kolbe et al., 2015; Kolb and Kolb, 2005; Fanning and Gaba, 2007). During the simulation, after the players began to understand how the H_2Ours game works, the players started to initiate communication in the form of negotiations or coordination between groups or with external parties such as multi-stakeholder forum. This is in accordance with the four interacting knowledge to action steps in restoration strategies, which commitment begins after the mutual understanding have been made (Van Noordwijk, 2018). One of the advantages of a serious game is that participants interact directly with the environment and get feedback as quickly as possible so that they can immediately analyze and correct inappropriate strategies (Bartolome et al., 2011; Feng et al., 2018). Moreover, during the H_2Ours simulation, players were also faced with the game situation that resemble actual situation, so they are indirectly encouraged to find solutions together as two last parts of restoration strategies related to operationalization and innovation.

There are several lessons learned from the H_2Ours game development and simulation process in this study. First, setting up the game material with attributes of the local context helped participants to build emotions during the simulation. Second, to maintain participant commitments on restoration after the game simulation, it is important to show that their collaborative and collective actions really work in achieving their goals in the end of the game simulation. Third, based on the evaluation and debriefing results, even if they stated they can apply the ideal collaborative actions that simulated in the game, in real life, it still needs to build the enabling condition that support it (e.g. regulation, integrated planning strategies, etc.). Therefore, the commitment, as referred in the four knowledge to action chains, still cannot be carried out directly because still needs external factors that are beyond their control.

5 Conclusion

The H_2Ours game is a generic game that solves the complexity of a socio-hydrological system and allows modifications according to different needs and conditions. The complexity of the socio-hydrological system can be applied separately and/or simultaneously depending on the knowledge level of the intended participants. With an adaptable game as the one developed, the game designer can adjust the level of complexity included in the game, and even include an advanced simulation that combines all possible problems and interactions found in a socio-hydrological system.

The H_2Ours game can facilitate learning, share knowledge and trigger collaborative and collective actions during the game simulation. By exploring various strategies and scenarios during the game simulation, the game allows players to see that the restoration target is something that can be achieved from a clearer perspective. In addition, they can also inventory the various enabling conditions needed to make the strategies in the game can be implemented in real terms (e.g. need of for multi-stakeholder collaboration, restoration masterplan).

Appendix A. Guideline for facilitating H_2Ours game

Overview	Simulation of the impact of land-use/cover change and water management on hydrological situation (water balance)
Objective	Knowledge sharing and decision making to support collaborative and collective actions among stakeholders
Benefits	1. Players can explore many scenarios of land-use/cover and water management and see its impact to their hydrological situation 2. Players can feel the trade-off between economic and environment and explore the solutions 3. Players can learn about negotiation and collaboration
Duration	2 hours (or around 8 – 10 rounds)
Number of players	6 – 16 player
Material	1. Board of the game 2. Land-use tokens 3. Money tokens 4. Mini water balance simulation model 5. Water infrastructure token (optional)

Game play

1. Welcoming all the players and give a general introduction about the workshop and game/simulation
2. Selecting 2-3 people from players to act as public stakeholders whose role is responsible for the management of the whole watershed or peatlands by providing regulations or programs to prevent various environmental problems (opsional)

3. Grouping the remaining the players into 3 groups (for watershed version) or 4 groups (for peatland version) to represent the farmers from different villages. During the game simulation, their goals are to live happily by fulfilling their needs.
4. Briefing players by giving explanations/definitions about the terminology that is often used in the game and building connection between the game properties with their actual situation so the decision made by the players can be very close to their reality.
5. Introducing co-facilitator for each group who help calculation of economic resources (optional)
6. Giving initial money to players (300 – 450 per group) and initial groundwater and surface water into the water balance simulation model
7. Starting round by asking player to decide their land-use system, then calculation of the economic and environmental impact based on the (random) weather situation in that round
8. Repeat step 6 for round 2 and 3 as the warming up
9. Repeat step 6 for the rest of the rounds with additional scenarios, such as announcing regulation by government, providing payment for ecosystem program, etc. You can develop the scenarios based on the stakeholder perceptions of what they should do to restore the hydrological function through discussion or interview.
10. Debriefing session, by asking the player their strategies to achieve their goal and their feeling during the game simulation

Appendix B. H_2Ours rule development

One of the challenges in developing or modifying the H2Ours game is providing values for the economic and environmental impact components for each type of land-use. Here is a simple guidance to modifying the H_2Ours game rules:

1. Determine the types of land-use in the landscape. If the land-use types are varied enough, take the 4-6 most dominant land covers, including the new land-use types that might be intervened.
2. For each type of land-use, determined the amount of the economic value (production costs and income) and environmental value (runoff, infiltration, water use/utilization). The value used as a rule does not have to be the actual value. You can only use the ratio value between land-use types after setting up the maximum and minimum value. A simple method to collect this information is by conducting survey to several farmers and ask them to rank or make score the land-use type based on their economic and environmental impacts (Fig. B1).
3. Determine infrastructures that will be used in games that might affect economic and environmental conditions (e.g. artesian wells for irrigation, canal blocking, water storage, etc.).
4. Determine how each of these infrastructures affects economic and environmental conditions (e.g. artesian wells: construction cost, threat, amount of groundwater extraction, etc.). You can conduct a survey to collect those information, then normalize the value following the economic and environmental value.
5. During the game testing, evaluate those values with the participant whether it is reasonable and represents their actual condition

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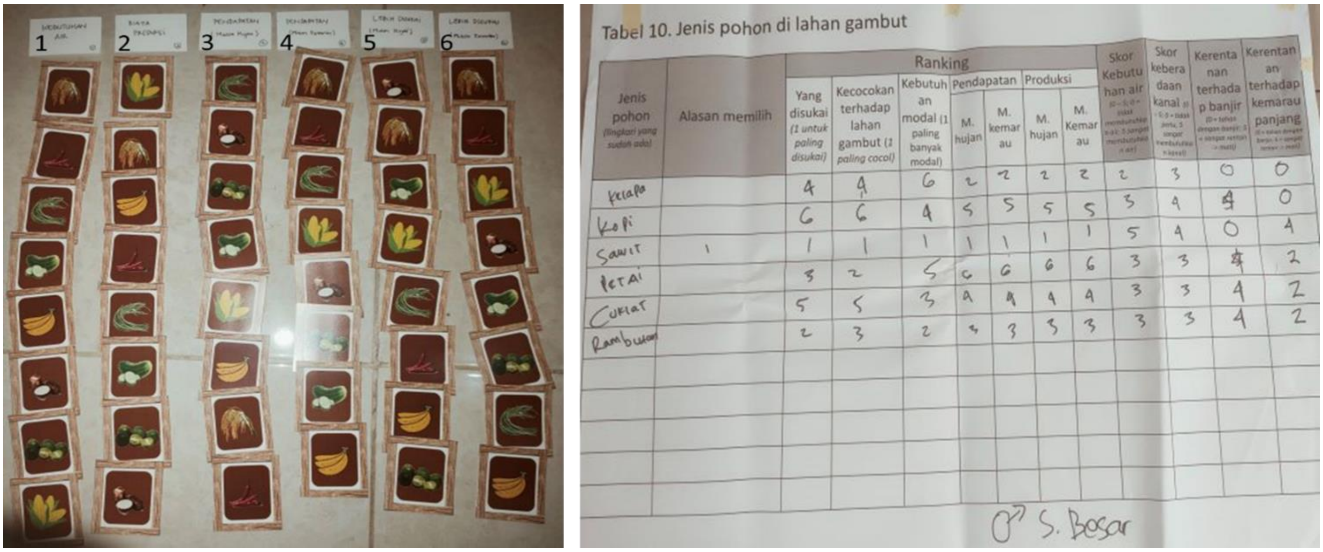

Tabel 10. Jenis pohon di lahan gambut

Jenis pohon (lingkari yang sudah ada)	Alasan memilih	Ranking							Skor Kebutuhan air	Skor kebergantungan kanal	Kerentanan terhadap banjir	Kerentanan terhadap kemarau panjang
		Yang disukai (1 untuk paling disukai)	Kecocokan terhadap lahan gambut (1 paling cocol)	Kebutuhan modal (1 paling banyak modal)	Pendapatan		Produksi					
					M. hujan	M. kemarau	M. hujan	M. Kemarau				
Kelapa		4	4	6	2	2	2	2	2	3	0	0
Kopi		6	6	4	5	5	5	5	3	4	4	0
Sawit	1	1	1	1	1	1	1	1	5	4	0	4
Petai		3	2	5	6	6	6	6	3	3	4	2
Coklat		5	5	3	4	4	4	4	3	3	4	2
Rambutan		2	3	2	3	3	3	3	3	3	4	2

♂ S. Besar

Figure B1. Left: an example of the results of sorting the types of land-use in Rejoso watershed by one of the local farmers, respectively: 1. Water use, 2. production cost, 3. income during wet season, 4. income during dry season, 5. preferences during wet season and 6. preferences during dry season. For the water balance component, we derived from hydrological model parameterization. Right: example results of scoring of land-use type during focus group discussion with some farmers in the Pawan-Kepulu peatland to collect information about: preferences, suitable to peat soil, production cost, income during wet and dry season, yield during wet and dry season, water use, and dependence on the present of canal, vulnerability rate to floods, and vulnerability rate to drought.

Appendix C. H_2Ours game for peatland version (case study Pawan-Kepulu peatland)

Based on the some references, focus ground discussion and interview with various stakeholders in Pawan-Kepulu peatland, we found that this area experiences land and forest fires during the dry year (season) and flood during the wet year (season). Land cover conversion from forest to oil palm plantation and crop season has led massive canal construction to get better production. This situation makes this landscape drier during the dry year and vulnerable to fires.

The hydrological boundary of peatland in peatland hydrological unit (PHU) as an area between two rivers. Usually inside this landscape we can find a dome (the deepest peat area), area surrounding dome (buffering dome area) and shallow peat area. Figure C1 shows the conceptual game model of H_2Ours game for peatland version.

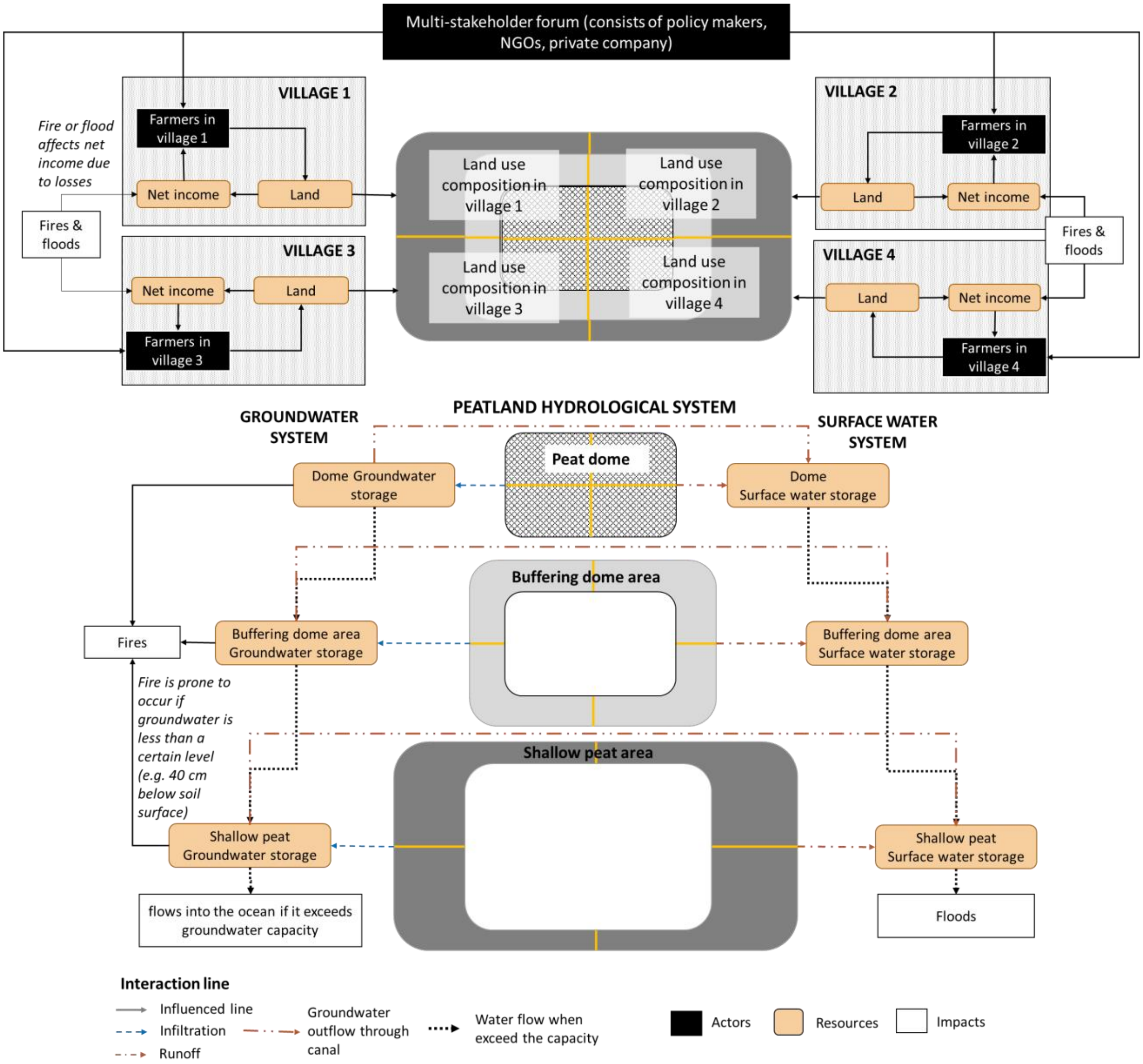

Figure C1. Socio-hydrological model defined using the ARDI framework that was used to design the H$_2$Ours game for Pawan-Kepulu peatland. Interaction among actors and between actors to landscape influence land-use composition which affect the hydrological and economic situation, then its influences back to interaction. 510

Rules of game

Based on measurement data, focus group discussion with local farmers and some references, we design the rules of the H$_2$Ours game for peatland version by combining six land-use options (all trees, all oil palm, oil palm + trees, oil palm + crop, all crop, 515 and shrub/burned area) and three canal density options (without canal, low-density canal and high-density canal) (Table C1 and C2).

Table C1. Economic impacts in Pawan-Kepulu peatland version, the production cost in dome area +2/plot and in the buffering dome area +1/plot

Land-use options	Canal density options	Production cost/year in the shallow peat area (unit: money)	Income/year (unit: money)	
			Wet Year	Dry year
All tree	Without	1	0	3
	Low	1	0	3
	High	1	0	3
All Oil palm	Without	6	6	9
	Low	9	9	17
	High	12	17	25
Oil palm + trees	Without	3	4	6
	Low	4	6	9
	High	6	9	17
Oil palm + seasonal crop	Without	5	4	8
	Low	7	7	15
	High	10	12	20
Crop	Without	4	3	7
	Low	5	5	13
	High	8	7	15
Shrub	Without	0	0	0
	Low	0	0	0
	High	0	0	0

Table C2. Environmental impacts in Pawan-Kepulu peatland version, we assumed during the dry year there is no runoff or infiltration (a = dome area, b = buffering dome area, c = shallow peat area, x = runoff (unit: ml), y = infiltration (unit: ml) and z = groundwater out flow through canal (unit: ml))

		Dry year			Wet Year								
Land-use	Canal density	a	b	c	a			b			c		
			z		x	y	z	x	y	z	x	y	z
All tree	Without	0	0	0	0	20	0	2.5	17.5	0	5	15	0
	Low	7.5	5	2.5	2.5	17.5	10	5	15	7.5	7.5	12.5	5
	High	15	10	5	5	15	20	7.5	12.5	15	10	10	10
All Oil palm	Without	0	0	0	10	7.5	0	12.5	5	0	15	5	0

	Low	7.5	5	2.5	12.5	5	10	15	2.5	7.5	17.5	2.5	5
	High	15	10	5	15	2.5	20	17.5	1	15	17.5	1	10
Oil palm + trees	Without	0	0	0	5	15	0	7.5	12.5	0	10	10	0
	Low	7.5	5	2.5	7.5	12.5	10	10	10	7.5	12.5	7.5	5
	High	15	10	5	10	10	20	12.5	7.5	15	15	5	10
Oil palm + seasonal crop	Without	0	0	0	15	2.5	0	17.5	1	0	17.5	1	0
	Low	7.5	5	2.5	17.5	1	10	19	1	7.5	19	1	5
	High	15	10	5	17.5	1	20	19	1	15	19	1	10
Crop	Without	0	0	0	19	1	0	19	1	0	19	1	0
	Low	7.5	5	2.5	19	1	10	19	1	7.5	19	1	5
	High	15	10	5	19	1	20	19	1	15	19	1	10
Shrub	Without	0	0	0	20	0	0	20	0	0	20	0	0
	Low	7.5	5	2.5	20	0	10	20	0	7.5	20	0	5
	High	15	10	5	20	0	20	20	0	15	20	0	10

Game Properties

The component of the H_2Ours game for peatland version is similar with watershed version with modification in the board as the landscape and the land-use options (Fig. C2). The board is designed in such a way that it resembles a PHU with a dome in the middle, a buffering area around the dome and shallow peat on the outside. In the real simulation, we can add river and road to help player have a connection with their real situation.

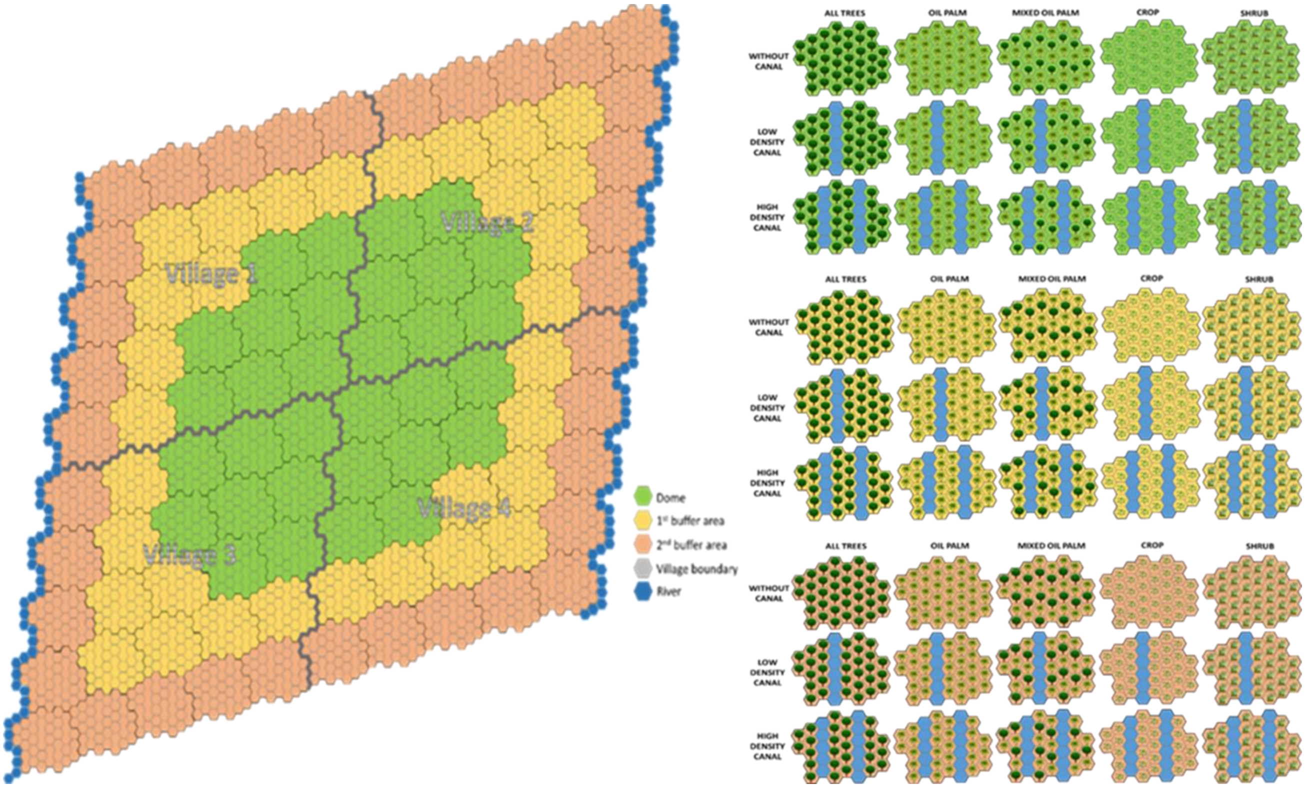

Figure C2. Board of H2Ours game for peatland version that consist of dome area, buffering dome area and shallow peat area (left); and land-use option (all trees, all oil palm, oilpalm+trees, all crop and shrub) with various canal density (without canal low canal density and high canal density) for Pawan-Kepulu peatland area (right)

Similar with the Rejoso watershed, the H2Ours game for peatlands also has the same water balance model (Fig. C3). This water balance model follows the hydrological system in Fig. C1. In the groundwater system, each tank has a fire vulnerable threshold. This threshold represents 40 cm below soil surface in its actual condition as stipulated by government regulations. If the groundwater in each zone is below this limit, then the area has the potential for fires which causes harm to the local community.

Figure C3. Simple water balance model of H_2Ours game in Pawan-Kepulu peatland to show the dynamics of changes in hydrological conditions as a result of the changes in land-use and canal density. The red line in each tank in the groundwater system represent the fire vulnerable threshold.

In addition to the H_2Ours game for the peatland version, there is a peat infrastructure token in the form of canal blocking and fire fighters (Fig. C4). In the reality, the canal blocking blocks the canal to reduce/stop the groundwater outflow. In this game simulation the canal blocking change the land-use from high to low density canal or from low to without canal. The firefighter help to prevent plot from fires during the dry year/season. However, providing canal blockings and firefighters cost some money.

Figure C4. Additional token as canal blocking (left) and firefighters (right) for H_2Ours game

Appendix D. Solution space of H_2Ours game in Rejoso watershed

The rules of the game determine the possible outcomes or 'solution space', within which the specific choices made by game participants are located. If all choices would be random (equal probability of all choices available), without response to the outcomes so far, a substantial variation in outcomes is possible. The primary outcomes of interest are the surface water flows (rainfall not used as canopy interception evaporation or infiltration into the soil), and the groundwater flows (water infiltrating and not used for subsequent evapotranspiration), all depending on both land cover and rainfall.

A first question in defining this solution space is the number of random series that need to be evaluated to accurately estimate the frequency distributions of outcomes in various response parameters. We present data for 3, 10, 30, 100, 300 and 1000 iterations (Fig. D1 – D4) (each including 10 rounds and three zones, thus 30 land-use choices and 10 weather conditions (dry or wet)). The actual game simulation was actually only done 4 times, therefore the closest solution space is with 3 or 10 random values, which is have not sufficiently representative the distribution. Based on Fig. D1 and D2, the solution space distribution pattern starts to appear in 30 random data sets. Therefore, to see the actual distribution of the farmer's decision making, at least we need 30 game simulations. Figure D3 and D4 show the relationship between economic conditions (money) and environment (groundwater and surface water) in the downstream area is more scatter compared to upstream and midstream. However, related to groundwater supply in downstream (Fig. D3), the more groundwater supply, and the higher the economic benefits obtained. On the contrary, the more runoff obtained from upstream and midstream (Fig. D4), it will decrease their economic benefits.

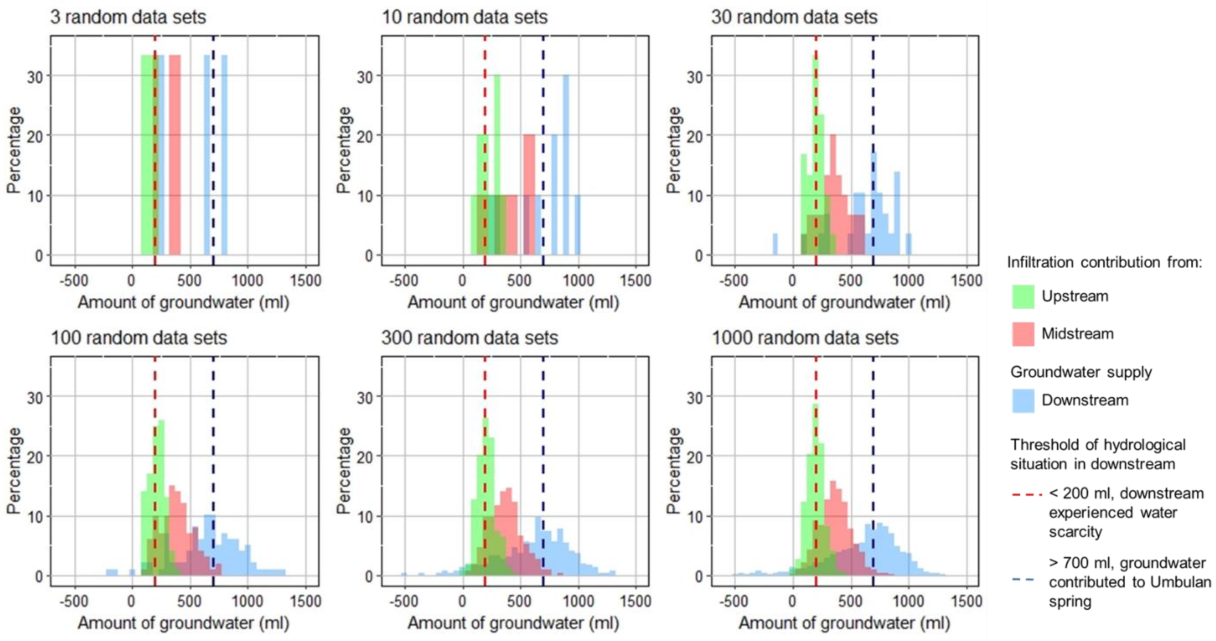

Figure D1. Distribution of infiltration contribution from upstream and midstream and groundwater supply in downstream based on simulation with the random value

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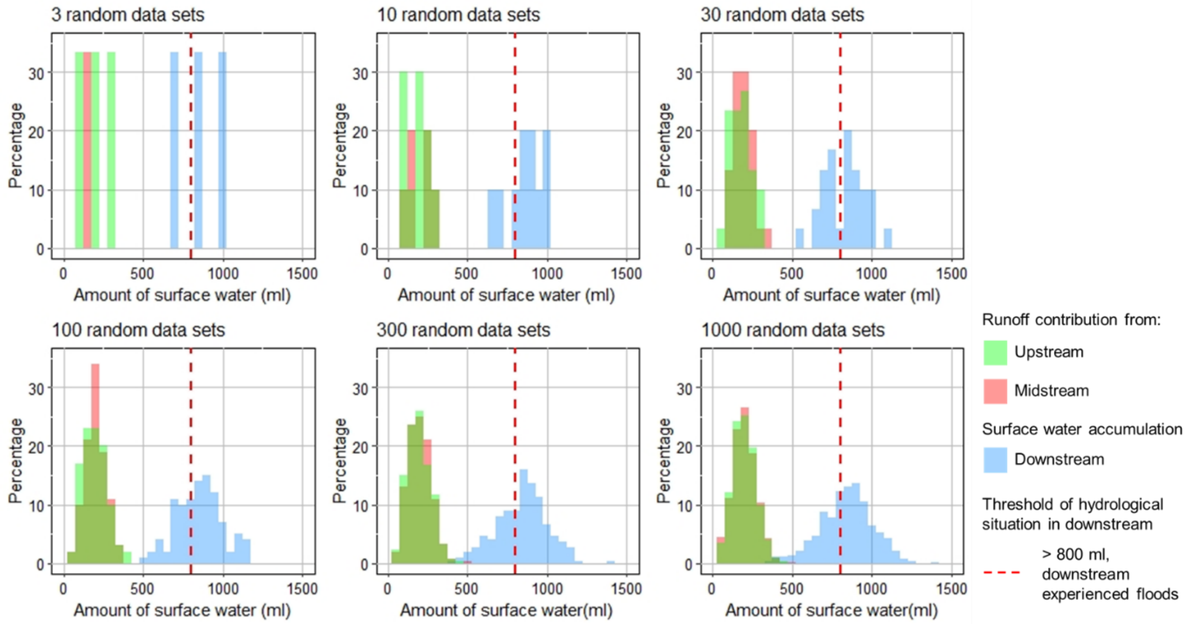

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Figure D2. Distribution of runoff contribution from upstream and midstream and surface water accumulation downstream based on simulation with the random value

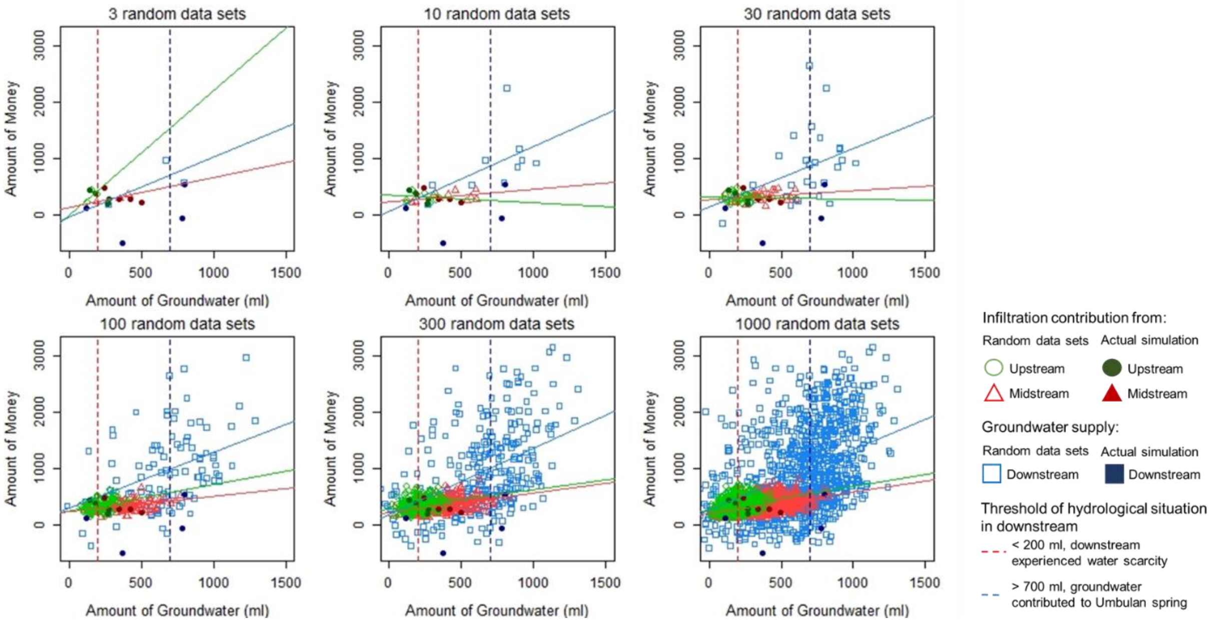

Figure D3. Groundwater situation and economic situation based on random value simulation and actual simulation

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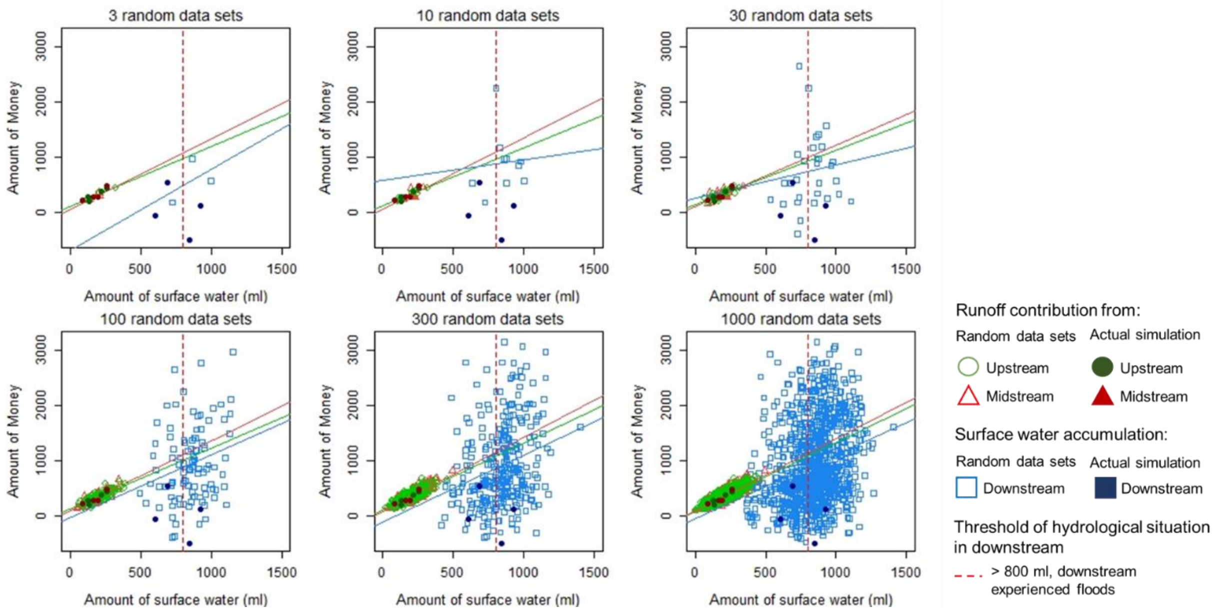

Figure D4. Runoff situation and economic situation based on random value simulation and actual simulation

Data availability

All raw data can be provided by the corresponding authors upon request

Competing interests

The authors declare that they have no conflict of interest.

Author contribution:

LT, RRS and ALH designed the research project, LT, RRS and ENS designed the game, LT performed the game simulation and game analysed, LT, MvN, MPC and ENS wrote the manuscript, EP and BL gave input on the performance of game simulation in each case study area.

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References

Amaruzaman, S., Khasanah, N., Tanika, L., Dwiyanti, E., Lusiana, B., Leimona, B., and Janudianto: Landscape characteristics of Rejoso Watershed: land cover dynamics, farming systems and community strategies, Bogor-Indonesia, 106 pp., 2018.

Bartolome, N. A., Zorrilla, A. M., and Zapirain, B. G.: Can game-based therapies be trusted? Is game-based education effective? A systematic review of the Serious Games for health and education, in: 16th International Conference on Computer Games (CGAMES), 275–282, https://doi.org/10.1109/CGAMES.2011.6000353., 2011.

Bedwell, W. L., Pavlas, D., Heyne, K., Lazzara, E. H., and Salas, E.: Toward a taxonomy linking game attributes to learning: An empirical study, Simul. Gaming, 43, 729–760, https://doi.org/10.1177/1046878112439444, 2012.

Belcher, B. M., Rasmussen, K. E., Kemshaw, M. R., and Zornes, D. A.: Defining and assessing research quality in a transdisciplinary context, Res. Eval., 25, 1–17, https://doi.org/10.1093/reseval/rvv025, 2016.

Carlson, K. M., Curran, L. M., Ratnasari, D., Pittman, A. M., Soares-Filho, B. S., Asner, G. P., Trigg, S. N., Gaveau, D. A., Lawrence, D., and Rodrigues, H. O.: Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia, Proc. Natl. Acad. Sci. U. S. A., 109, 7559–7564, https://doi.org/10.1073/pnas.1200452109, 2012.

Creed, I., van Noordwijk, M., Archer, E., Claassen, M., Ellison, D., Jones, J. A., McNulty, S. G., Vira, B., and others: Forest, trees and water on a changing planet: How contemporary science can inform policy and practice, For. Water a Chang. Planet Vulnerability, Adapt. Gov. Oppor. A Glob. Assess. Rep. (IF Creed M. van Noordwijk, eds.). IUFRO World Ser., 38, 171–175, 2018.

D'Odorico, P., Carr, J., Dalin, C., Dell'Angelo, J., Konar, M., Laio, F., Ridolfi, L., Rosa, L., Suweis, S., Tamea, S., and Tuninetti, M.: Global virtual water trade and the hydrological cycle: Patterns, drivers, and socio-environmental impacts, Environ. Res. Lett., 14, https://doi.org/10.1088/1748-9326/ab05f4, 2019.

Djuwansyah, M. R.: Environmental sustainability control by water resources carrying capacity concept: Application significance in Indonesia, IOP Conf. Ser. Earth Environ. Sci., 118, 1–6, https://doi.org/10.1088/1755-1315/118/1/012027, 2018.

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

Fanning, R. M. and Gaba, D. M.: The role of debriefing in simulation-based learning, Simul. Healthc., 2, 115–125, https://doi.org/10.1097/SIH.0b013e3180315539, 2007.

Feng, Z., González, V. A., Amor, R., Lovreglio, R., and Cabrera-Guerrero, G.: Immersive virtual reality serious games for evacuation training and research: A systematic literature review, Comput. Educ., 127, 252–266, https://doi.org/10.1016/j.compedu.2018.09.002, 2018.

Ferguson, C., van den Broek, E. L., and van Oostendorp, H.: On the role of interaction mode and story structure in virtual reality serious games, Comput. Educ., 143, 1–13, https://doi.org/10.1016/j.compedu.2019.103671, 2020.

Fleming, T. M., Cheek, C., Merry, S. N., Thabrew, H., Bridgman, H., Stasiak, K., Shepherd, M., Perry, Y., and Hetrick, S.: Serious games for the treatment or prevention of depression: A systematic review, Rev. Psicopatol. y Psicol. Clin., https://doi.org/10.5944/rppc.vol.19.num.3.2014.13904, 2014.

Fleming, T. M., de Beurs, D., Khazaal, Y., Gaggioli, A., Riva, G., Botella, C., Baños, R. M., Aschieri, F., Bavin, L. M., Kleiboer, A., Merry, S., Lau, H. M., and Riper, H.: Maximizing the impact of E-Therapy and Serious Gaming: Time for a paradigm shift, Front. Psychiatry, https://doi.org/10.3389/fpsyt.2016.00065, 2016.

Guo, Y., Zhang, Y., Zhang, L. and Wang, Z.: Regionalization of hydrological modeling for predicting streamflow in ungauged catchments: A comprehensive review, Wiley Interdiscip. Rev. Water, 8(1), e1487, https://doi.org/https://doi.org/10.1002/wat2.1487, 2021.

IPBES: The IPBES assessment report on land degradation and restoration, edited by: Montanarella, L., Scholes, R., and Brainich, A., Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, 744 pp., https://doi.org/10.4324/9781315640051-105, 2018.

Khasanah, N., Tanika, L., Pratama, L. D. Y., Leimona, B., Prasetiyo, E., Marulani, F., Hendriatna, A., Zulkarnain, M. T., Toulier, A., and Noordwijk, M. van: Groundwater-Extracting Rice Production in the Rejoso, Land, 10, 586, 2021.

Kim, Y. J. and Yoo, J. H.: The utilization of debriefing for simulation in healthcare: A literature review, Nurse Educ. Pract., 43, 102698, https://doi.org/10.1016/j.nepr.2020.102698, 2020.

Kolb, A. Y. and Kolb, D. A.: Learning styles and learning spaces: Enhancing experiential learning in higher education, Acad. Manag. Learn. Educ., 4, 193–212, https://doi.org/10.5465/AMLE.2005.17268566, 2005.

Kolbe, M., Grande, B., and Spahn, D. R.: Briefing and debriefing during simulation-based training and beyond: Content, structure, attitude and setting, Best Pract. Res. Clin. Anaesthesiol., 29, 87–96, https://doi.org/10.1016/j.bpa.2015.01.002, 2015.

Leimona, B., Khasanah, N., Lusiana, B., and ...: A business case: co-investing for ecosystem service provisions and local livelihoods in Rejoso watershed, 2018.

Lu, M., Wang, S., Wang, X., Liao, W., Wang, C., Lei, X., and Wang, H.: An Assessment of Temporal and Spatial Dynamics of Regional Water Resources Security in the DPSIR Framework in Jiangxi Province, China, Int. J. Environ. Res. Public Health, 19, https://doi.org/10.3390/ijerph19063650, 2022.

Manson, S. M.: Simplifying complexity: a review of complexity theory, Geoforum, 32, 405–414, https://doi.org/https://doi.org/10.1016/S0016-7185(00)00035-X, 2001.

Marini, D., Medema, W., Adamowski, J., Veissière, S. P. L., Mayer, I., and Wals, A. E. J.: Socio-psychological perspectives on the potential for serious games to promote transcendental values in IWRM decision-making, Water (Switzerland), 10, https://doi.org/10.3390/w10081097, 2018.

Mazzucato, M., Okonjo-Iweala, N., Rockstrom, J., and Shanmugaratnam, T.: Turning the Tide: A Call to Collective Action, Global Commission on the Economics of Water, Paris, 2023.

Medema, W., Mayer, I., Adamowski, J., Wals, A. E. J., and Chew, C.: The potential of serious games to solve water problems: Editorial to the special issue on game-based approaches to sustainable water governance, Water (Switzerland), 11, https://doi.org/10.3390/w11122562, 2019.

Mitgutsch, K. and Alvarado, N.: Purposeful by design?: A serious game design assessment framework, in: Foundations of Digital Games 2012, FDG 2012 - Conference Program, 121–128, https://doi.org/10.1145/2282338.2282364, 2012.

Murdiarso, D., Lestari, I., Hanggara, B. B., Saragi-Sasmito, M., Basuki, I., and Taufik, M.: Managing Water Regimes Controlling Greenhouse Gas Emissions and Fires in Indonesian Tropical Peat Swamp Forests, in: Wetland Carbon and Environmental Management, 355–369, https://doi.org/https://doi.org/10.1002/9781119639305.ch19, 2021.

van Noordwijk, M., Speelman, E., Hofstede, G. J., Farida, A., Kimbowa, G., Geraud, G., Assogba, C., Best, L., and Tanika, L.: Sustainable Agroforestry Landscape Management :, Land, 9, 1–38, 2020.

van Noordwijk, M., van Oel, P., Muthuri, C., Satnarain, U., Sari, R. R., Rosero, P., Githinji, M., Tanika, L., Best, L., Comlan Assogba, G. G., Kimbowa, G., Andreotti, F., Lagneaux, E., Wamucii, C. N., Hakim, A. L., Miccolis, A., Abdurrahim, A. Y., Farida, A., Speelman, E., and Hofstede, G. J.: Mimicking nature to reduce agricultural impact on water cycles: A set of mimetrics, Outlook Agric., 51, 114–128, https://doi.org/10.1177/00307270211073813, 2022.

Van Noordwijk, M.: Agroforestry as part of climate change response, IOP Conf. Ser. Earth Environ. Sci., 200, https://doi.org/10.1088/1755-1315/200/1/012002, 2018.

Van Noordwijk, M., Tanika, L., and Lusiana, B.: Flood risk reduction and flow buffering as ecosystem services - Part 2: Land use and rainfall intensity effects in Southeast Asia, Hydrol. Earth Syst. Sci., 21, 2341–2360, https://doi.org/10.5194/hess-21-2341-2017, 2017.

Oprins, E., Visschedijk, G., Roozeboom, M. B., Dankbaar, M., Trooster, W., and Schuit, S. C. E.: The game-based learning evaluation model (GEM): Measuring the effectiveness of serious games using a standardised method, Int. J. Technol. Enhanc. Learn., 7, 326–345, https://doi.org/10.1504/IJTEL.2015.074189, 2015.

Rosa, L., Rulli, M. C., Davis, K. F., Chiarelli, D. D., Passera, C., and D'Odorico, P.: Closing the yield gap while ensuring water sustainability, Environ. Res. Lett., 13, https://doi.org/10.1088/1748-9326/aadeef, 2018.

Rossano, V., Roselli, T., and Calvano, G.: A serious game to promote environmental attitude, Smart Innov. Syst. Technol., 75, 48–55, https://doi.org/10.1007/978-3-319-59451-4_5, 2017.

Rudolph, J. W., Raemer, D. B., and Simon, R.: Establishing a safe container for learning in simulation the role of the presimulation briefing, Simul. Healthc., 9, 339–349, https://doi.org/10.1097/SIH.0000000000000047, 2014.

Rumeser, D. and Emsley, M.: Can Serious Games Improve Project Management Decision Making Under Complexity?, Proj. Manag. J., 50, 23–39, https://doi.org/10.1177/8756972818808982, 2019.

Savic, D. A., Morley, M. S., and Khoury, M.: Serious gaming for water systems planning and management, Water (Switzerland), https://doi.org/10.3390/w8100456, 2016.

Silva, F. G. M.: Practical methodology for the design of educational serious games, Inf., 11, 1–13, https://doi.org/10.3390/info11010014, 2020.

Singh, G. and Kumar, E.: Input data scale impacts on modeling output results : A review, J. Spat. Hydrol., 13, 2017.

Strait, C. and Dawson, R.: Too much information, https://www.pmi.org/learning/library/point-information-overload-management-process-2769#, 2006.

Sun, S., Wang, Y., Liu, J., Cai, H., Wu, P., Geng, Q., and Xu, L.: Sustainability assessment of regional water resources under the DPSIR framework, J. Hydrol., https://doi.org/10.1016/j.jhydrol.2015.11.028, 2016.

Suprayogo, D., Van Noordwijk, M., Hairiah, K., Meilasari, N., Rabbani, A. L., Ishaq, R. M., and Widianto, W.: Infiltration-Friendly Agroforestry Land Uses on, Land, 9, 2020.

Toulier, A.: Multidisciplinary study for the characterization of volcanic aquifers hydrogeological functioning : case of Bromo-Tengger volcano (East Java, Indonesia), Thèse, 272, 2019.

Tsai, W. P., Feng, D., Pan, M., Beck, H., Lawson, K., Yang, Y., Liu, J., and Shen, C.: From calibration to parameter learning: Harnessing the scaling effects of big data in geoscientific modeling, Nat. Commun., 12, https://doi.org/10.1038/s41467-021-26107-z, 2021.

Vidal, L. A. and Marle, F.: Understanding project complexity: Implications on project management, Kybernetes, 37, 1094–1110, https://doi.org/10.1108/03684920810884928, 2008.

Villamor, G. B., Griffith, D. L., Kliskey, A., and Alessa, L.: Contrasting stakeholder and scientist conceptual models of food-energy-water systems: a case study in Magic Valley, Southern Idaho, Socio-Environmental Syst. Model., 2, 16312, https://doi.org/10.18174/sesmo.2020a16312, 2019.

Widayati, A., Louman, B., Mulyoutami, E., Purwanto, E., Kusters, K., and Zagt, R.: Communities' adaptation and vulnerability to climate change: Implications for achieving a climate-smart landscape, Land, 10, 1–20, https://doi.org/10.3390/land10080816, 2021.

Zhao, Q., Bai, J., Huang, L., Gu, B., Lu, Q., and Gao, Z.: A review of methodologies and success indicators for coastal wetland restoration, Ecol. Indic., 60, 442–452, https://doi.org/10.1016/j.ecolind.2015.07.003, 2016.