Revista Brasileira de Recursos Hídricos
Brazilian Journal of Water Resources
Versão On-line ISSN 2318-0331
RBRH, Porto Alegre, v. 25, e25, 2020
Scientific/Technical Article

https://doi.org/10.1590/2318-0331.252020190100

The application of role-playing games and agent-based modelling to the collaborative water management in peri-urban communities

A aplicação de jogos de RPG e modelagem baseada em agentes para o gerenciamento colaborativo da água em comunidades peri-urbanas

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Received: July 11, 2019 - Revised: March 23, 2020 - Accepted: March 23, 2020

ABSTRACT

The environmental systems associated with water resources management have always been represented through physical factors and processes. In order to consider the social system coupled with the environmental system, a new modeling approach emerges, the agent-based modeling. Two steps are essential to build agent-based models-ABMs. The first step requires the agent behavior understanding and considers the influence of external factors in the agent decision-making. The second one is the system representation through an ABM. In this perspective, the WaDiGa water management role-playing game-RPG was applied to map the rural producers' behavior of a peri-urban region. In addition, an ABM was developed in the GAMA platform intended to represent the agents' behavior and its consequences in the environment configuration. After applying the proposed methodology, it was concluded that the WaDiGa was able to identify factors that influence the local agents' decision-making, and that the game fulfills the function of a dialogue platform on the water resource theme, and could be used as a tool for environmental education and socio-hydrological modeling. The ABM developed was able to represent the relationship between the agricultural production of the community and the water use, presenting results similar to the results obtained in the WaDiGa.

Keywords: Role-playing game; Socio-hydrology; Rural settlement.

RESUMO

Os sistemas ambientais associados à gestão de recursos hídricos têm sido representados na modelagem tradicionalista por meio de fatores e processos físicos. Com a intenção de conceber uma representação mais abrangente e dinâmica dos sistemas ambientais e hídricos, um novo tipo de simulação surge e engloba uma parte fundamental do sistema, os agentes e seus processos sociais. No intuito de realizar esse tipo de simulação, duas etapas são essenciais, o entendimento sobre o comportamento do agente e os fatores influenciadores na sua tomada de decisão e a representação do sistema por meio da modelagem baseada em agentes. Nessa perspectiva, no primeiro momento, o referido trabalho utilizou um jogo de representação de papéis voltado à gestão hídrica, o WaDiGa, com o objetivo de avaliar um possível mapeamento do comportamento hídrico de pequenos produtores rurais do Assentamento Canaã, região periurbana do Distrito Federal, e de servir como uma plataforma de diálogo entre os agentes. Na segunda parte da metodologia, foi desenvolvido um modelo baseado em agente na plataforma GAMA, que teria a função de representar o comportamento dos agentes e suas consequências no ambiente por meio de uma simulação baseada em agentes. Após a aplicação da metodologia proposta, pôde-se concluir que o jogo aplicado conseguiu identificar fatores que influenciam a tomada de decisão dos atores locais. Além disso, pôde-se observar que o jogo cumpre a função de plataforma de diálogo e discussão sobre a temática de uso de recursos hídricos, podendo, assim, também ser utilizada como uma ferramenta de educação ambiental e de modelagem sócio hidrológica. Já o modelo baseado em agentes implementado na plataforma GAMA conseguiu de forma satisfatória representar a relação entre a produção agrícola da comunidade estudada e o uso água, apresentando resultados semelhantes aos resultados obtidos no jogo WaDiGa.

Palavras-chave: Jogos de representação de papéis; Sócio hidrologia; Assentamento rural.

INTRODUCTION

The environmental issues have considerable uncertainties due to the lack of available scientific knowledge and the unpredictability of the complex systems. Considering the importance of natural resource planning and managing, a deep understanding of the systems and the way they evolve is essential. Historically, environmental systems associated with water resources management have always been represented by traditionalist modelling with greater emphasis on abiotic elements like physicochemical factors and processes.

In order to include the social system and processes in environmental simulations, agent-based models have evolved from computer science and ecology (Berglund, 2015). Emerging with the purpose of simulating complex systems, it has brought a greater focus on the interaction and representation of agents. Seen from this perspective, a broadly accepted definition for complex systems defines it as an interdisciplinary field of research that seeks to explain how a large number of agents with no central control and simple rules of operation give rise to complex collective behaviour, sophisticated information processing, and, in some cases, adaptation via learning or evolution (Mitchell, 2009). In cases which adaptation plays a large role, it is possible to define the complex systems as adaptive. Therefore, complex adaptive systems are dynamic systems in which the capacity to adapt and evolve on the face of changes in the environment is remarkable (Chan, 2001).

Emergence is another essential feature of complex adaptive systems. Since simple rules produce complex behaviour with difficult predictions, the macroscopic behaviour of such systems is emergent. Consequently, according to Mitchell (2009), there is an alternative definition for a complex adaptive system: a system that exhibits nontrivial emergent and self-organizing behaviours. The central question of the complexity sciences is how this emergent self-organized behaviour comes about.

In the interest of simulating this new approach, this article elucidates the uses of two tools intended to evaluate the self-organization of a peri-urban community considering their patterns, information and emergency on the face of a change in the environment. The first one is role-playing games and the second one is agent-based model. Therefore, role-playing games usually assess social interactions on a micro-scale, such as local community decision-making (Adamatti et al., 2005). In addition, role-playing game serves as a platform for dialogue and interaction between agents and can promote environmental education and the empowerment of the local community (Trebuil et al., 2017).

On the other hand, agent-based model serves as a tool for evaluating emerging processes, making it possible to explore connections between individuals' micro-behaviour and the macro-level patterns that emerge from their interactions (Berglund, 2015). The union of both processes within a single structure aims to design and delineate the different practices, knowledge, and experiences about a key element present in the system, as well as possible solutions and objectives to be collectively achieved in the local water resource management.

The purpose of this current study is to present a participatory modelling approach combining an agent-based model (ABM) designed in the GAMA platform and a modified version of the role-playing game WaDiGa. The modelling exercise took place in a periurban agricultural community in the Descoberto watershed in the Federal District of Brazil. The area has faced a recent water crisis (2015-2017), illegal urban expansion, and conflicts for water. .

The research analyzed in a schematic environment the modification of the land use, the quantity of water in the system and the total community profits resulting from the actor's decision-making. First, a role-playing game was applied in the study area intended to have a first contact with the community and collect some information about the local decision-making patterned. Then the model was improved with the results of the game, and another role-playing game session was organized. Finally, after the two sessions of the game and the improvement of the model, six scenarios with the modification of the external parameter, precipitation and market price, were compared. It is notable that the uncertainty in ABM arises from the nature of complex systems they try to represent and is an important issue for the validation of these models. Recent studies have focused on uncertainty analysis in ABM (Abreu & Ralha, 2018; Baustert & Benetto, 2017; Lee et al., 2015; Ligmann-Zielinska & Sun, 2010). However, in the present research the ABM is intended to educate and to motivate for cooperation in small communities, more than to predict system-social behaviour itself. So, a simple scenario discovery was implemented to illustrate alternatives that could arise from different decisions in a simple and graphical way so the stakeholders could evaluate the cause-effect of their decisions and improve their knowledge about the system.

After the methodology application, it was possible to conclude that the role-playing game was able to facilitate the dialogue and discussion among the actors on the water resources management subject. In addition, the game could also identify the main factors that influence the decision-making of local actors. According to Janssen & Ostrom (2006), achieving good statistical performance is not enough in case of empirical problems with data collection and explicit inclusion of cognitive, institutional, and social processes in ABMs. Considering this information, other criteria instead of the statistical methods were used to validate the empirical process: 1) the model given our plausible understanding of the processes; 2) we derived a better understanding of our empirical observations; and 3) the behaviors of the models coincide with the understanding of the relevant stakeholders about the system. The agent-based model was able to reproduce satisfactorily the relationship between land use and local water resources use. Additionally, the six generated scenarios can be shown to the local community with the proposal of illustrating the impacts generated in the water resources caused by their decision-making.

METHODOLOGY

To initiate the modelling process, a first conceptual model was developed and implemented using the platform GIS Agent-based Modelling Architecture (GAMA) which presents capabilities in the combination of 3D visualization, Geographic Information System (GIS) data management and multilevel modelling (Grignard et al., 2013). The GAMA platform has been widely used for water resource simulation (Farias et al., 2019; Truong, 2016; Grignard et al., 2016).

After the definition of the conceptual model, a specific role-playing game calls Water Distribution Game - WaDiGa (Trebuil et al., 2017) was applied to the study area. The WaDiGa RPG contributed to the ABM parameterization process intended to represent the decision making process in the community. WaDiGa differentiates from other RPGs in its adaptability to a wide variety of environment and human interactions (such as climate and social economic characteristics) in a community. This flexibility allows the analysis and comparison of different game session results in a broad range of scenarios. Besides that, the WaDiGa simulates the influence of collective water management decisions and agricultural transition for annual cropping systems, which is very similar to the purpose of the conceptual model developed in the present study. Therefore, the WaDiGa offers the players a clearer view of the advantages and drawbacks of collective water management decisions in small communities emphasizing the power of cooperation among users and with that, educating towards more profitable farming systems. The study area, the WaDiGa and the agent-based model construction process will be presented in detail hereafter.

Study area

In the Federal District of Brazil, municipalities are defined as Administrative Region (AR). This work was done in part of the Brazlândia AR. This research focused on one a peri-urban community called Canaan Settlement (Figure 1). The area, mainly rural, is comprised of 67 farms with an extension between 1ha and 5ha. The Canaan Settlement is located in Descoberto River Basin, which plays a key role in the water supply management, as it serves more than 60% of the Federal District population. The region also presents several water conflicts, which increased during the water crisis in the period of 2016 to 2018. Another alarming problem in the Descoberto River Basin is an irregular urban expansion (Zoneamento Ecológico-Econômico do Distrito Federal, 2017). Therefore, issues that characterize the Descoberto River Basin are: water conflicts; scientific knowledge of the hydrodynamic processes in a preliminary form; strategic water supply area; high rates of irregular urbanization; power asymmetries between stakeholders; and lack of participation of the population in decision-making.

Conceptual model

A grid of 50x50 plots depicts the fictitious environment. The environment has seven different types of land uses, which are denominated: urban, irrigable crop, non-irrigable crop, agroforestry, fallow, water and forest. The model is populated with 100 agents ("owner"). These agents are characterized by their properties, in other words, there are 100 properties that belong to 100 agents respectively. The properties can assume a different land use among irrigated, non-irrigated, agroforestry or fallow.

In order to explain the classes, attributes, and actions present in the model, a class diagram (Figure 2) was developed using the Unified Modelling Language (UML). The UML defines a series of artefacts that can help in the modelling, programming, and documenting object-oriented systems (Booch et al., 2005). All model plots have an association with coverage and must present at least

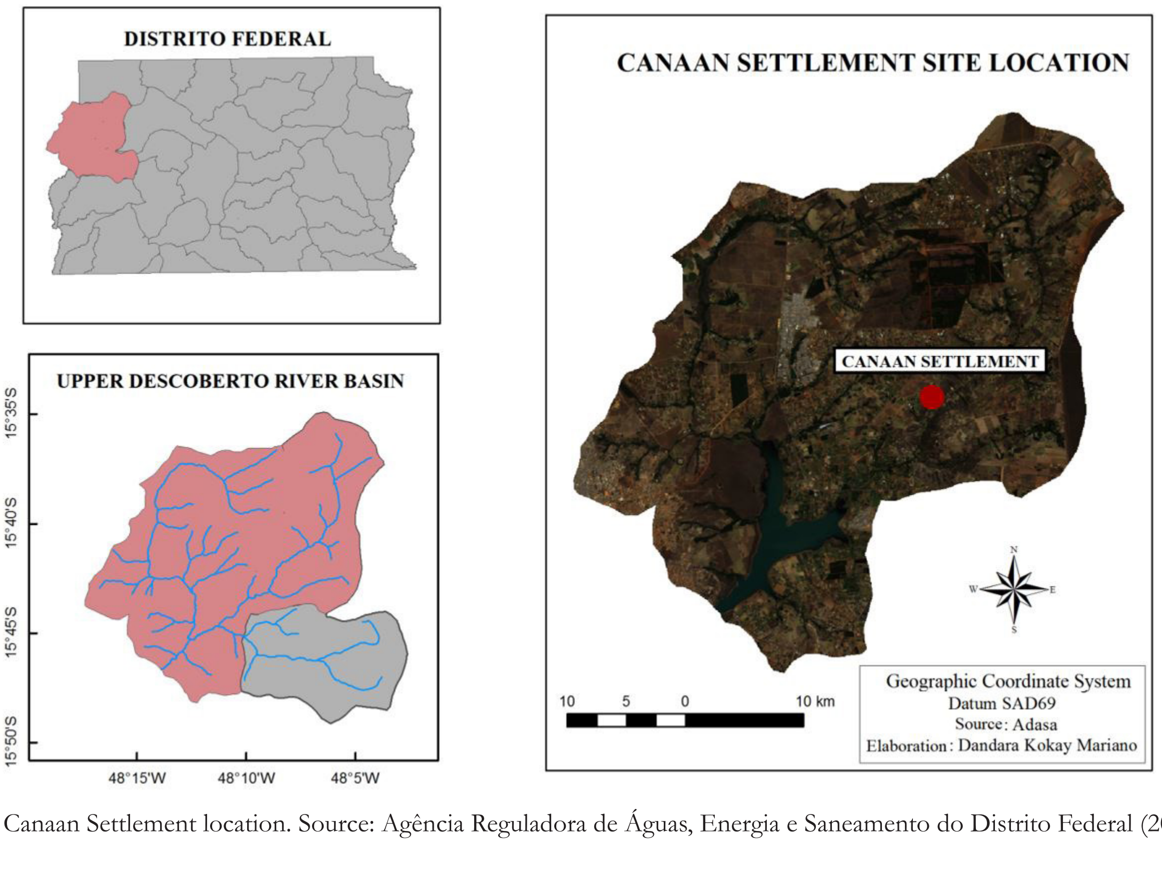


Figure 1. Canaan Settlement location. Source: Agência Reguladora de Águas, Energia e Saneamento do Distrito Federal (2019).

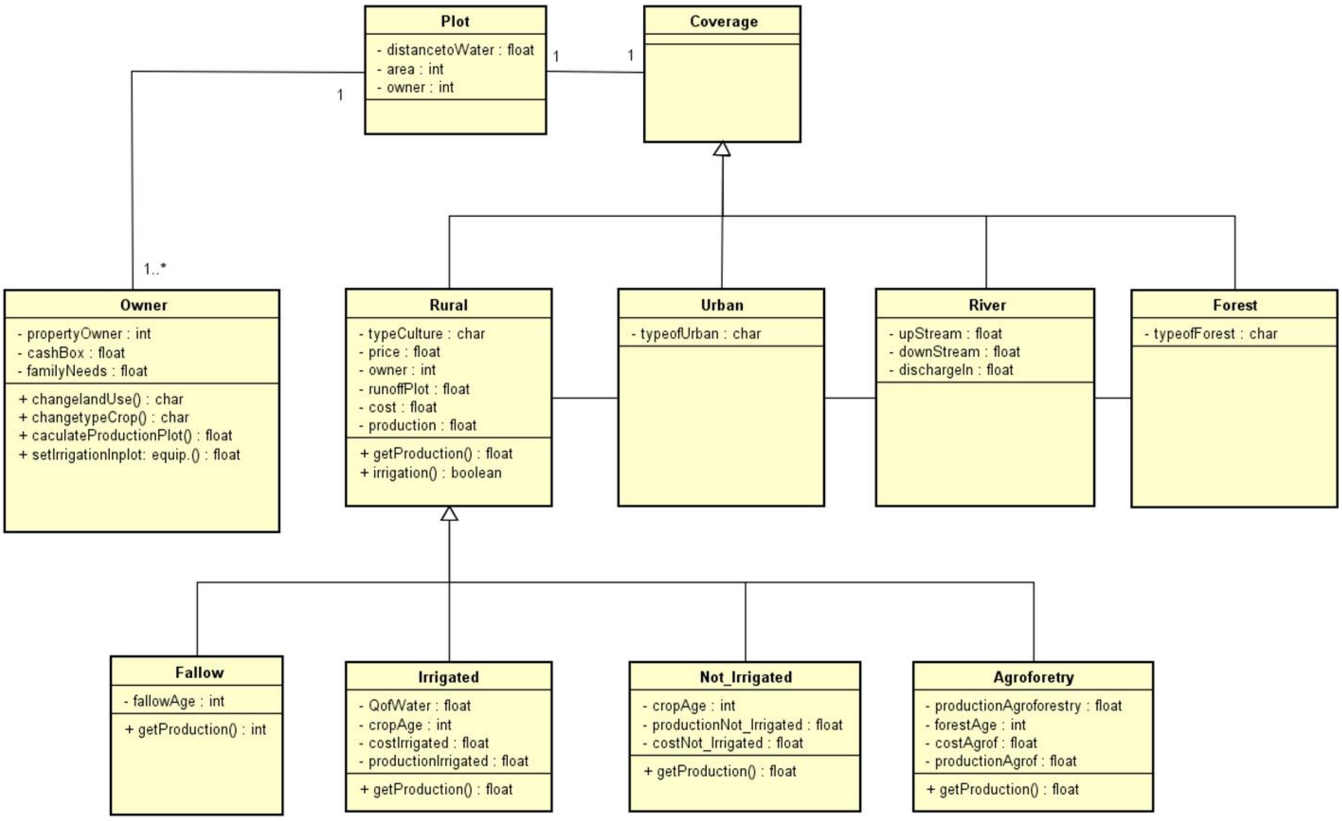


Figure 2. Class Diagram.

one type of the coverage. The subclasses of the model could be considered a specification set of coverage class; for example, the rural subclass has specification such as irrigated crop, non-irrigated crop, agroforestry, and fallow. The initialization of the subclasses was done in two ways, the first one was immutable (river, forest and urban) from a CSV file and the second one was changeable (rural) by the agent decision-making.

The agent decision-making choice was based on two factors, the proximity with the water resource and the money in the agent cashbox. The first one set the irrigation condition, where it was only possible to select the irrigable crop if the distance between the property and the river was less than two kilometers. The other crops could be selected independently from the proximity with the water source. The second condition was related to the amount of money in the agent cashbox. In the initialization of the model, each agent receives an amount of money and has family expenses, both of the values were generated randomly. Additionally, in each time step (1 year), there is a cost of crop implementing and crop income. The irrigable crops require higher investments than non-irrigable crops, but when harvested they provide a better income. In the other side, the fallow did not provide income, so it was selected when the cashbox was so low that it did not allow any other agricultural activity in the plot. The agroforestry system was considered as a low-cost crop that was an intermediate between the non-irrigable crop and the fallow. The conditions are presented in Figure 3, which represents the farmers' activity diagram.

In summary, as shown by the activity diagram (Figure 3), in this model, the dynamics of land use presents the motive force based on agents decision-making rules, which is related to the proximity of the river (access to water) and the quantity of money in the cashbox. Besides that, the model has a simplified water balance. The basic hydrological model is comprised of the following water balance in each spot of land that represents water in the system: Available Water (AW), the precipitation (*P*), the runoff from the rural areas (*R*), the water used for irrigation (*I*) and the time step t. (Equation 1).

$$AW(t+1) = AW(t) + P(t) + R(t) - I(t) \tag{1}$$

The water used for irrigation was calculated in function of two variables, the irrigated area, and the irrigation coefficient. The irrigation coefficient was based on the data obtained from the IPA (Instituto Agronômico de Pernambuco, 2008), so the generic amount of water needed to irrigate is 8 mm of water per day, that is, 80 m^3 of water per hectare-day. This coefficient is regardless of the crop type, soil, climate and irrigation system efficiency. Thus, the amount of water needed for irrigation is the multiplication of the irrigation coefficient by the irrigated area.

For the precipitation parameter, hydrological monitoring data were obtained through the National Water Resources Information System (Hidroweb) of the National Water Agency (Agência Nacional de Águas, 2019). The data are referring to a climate station near the dam identified by the code 1548008. The data were processed and the maximum and minimum average found was 500.5 and 161.8 mm. Another variable of the water balance is the flow, it was updated with each step and its initial value was 1.0 m^3/s. The runoff variable was calculated in function

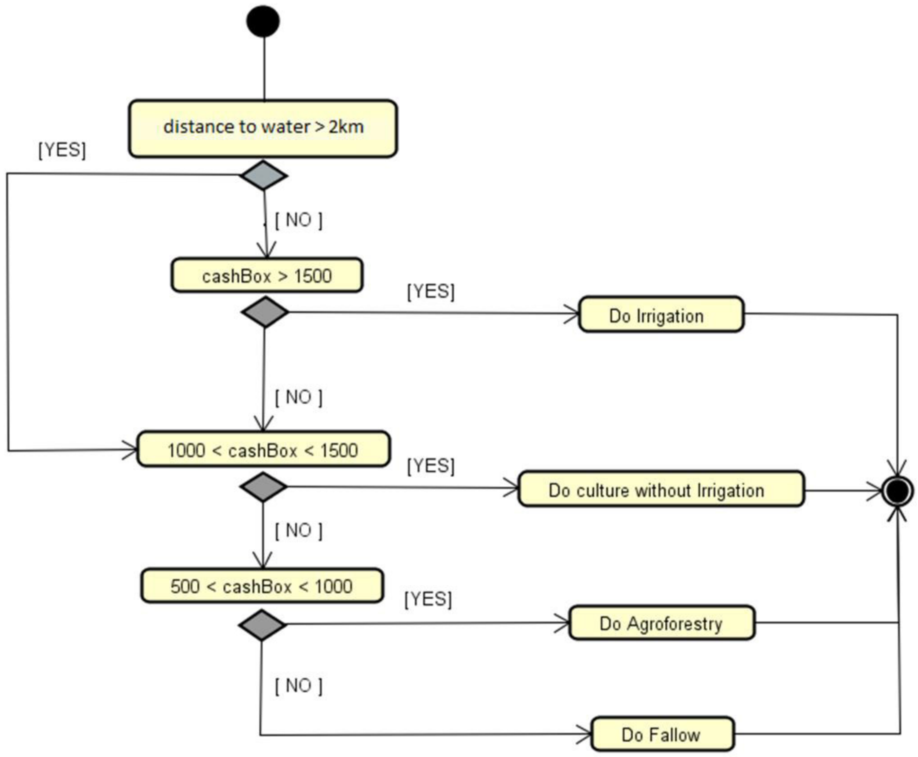


Figure 3. Agents' activity diagram.

of the precipitation and the water needed for irrigation, in other words, the runoff was defined as 5% of the sum of water used for irrigation and precipitation.

Role-playing game – WaDiGa

The first game session was based on the WaDiGa original format (Trebuil et al., 2017). The principal element of the WaDiGa is a medium-sized board (64x87 cm), which was used to characterize the game environment. The board was created schematically to represent a lightly sloping valley in which a river flows into the centre. In addition, the board had 32 plots of the same size (10x12cm) with 0.5 ha. In each plot, the players could choose three different types of crops: non-irrigable crops (food crops), agroforestry systems (AFS), and irrigable crops.

In the first moment of the game session, the players took out randomly a number. The numbers were fixed in the centre of the plot in order to identify the player. The number also defined the amount of plots (properties), which would be managed by the player. Different 3D symbols were used to represent each type of crop and to facilitate the immersion of the players in the game (Figure 4).

Transparent marbles represented the volumes of water manipulated by the players to irrigate their respective crops. In each game round, the available amount of water was arranged in transparent glass containers with the objective of making visible the marbles to the players. The transparent glass containers represented the river, which flows from the upstream to the downstream. The players closest to the river and in an upstream place have a preference to take water off from the "river".

The monetary representation was made by the use of board games ballots because the manipulation of fictitious money brings a real perspective of economic decisions. In order to simulate the socioeconomic difference between farm owners, players received different amounts of "money" depending on the number of their properties. During a round of the session, each farmer had to perform the following actions: decide their crops by assigning a given production to each of their plots; fix the volume of water that he or she would use to irrigate; and whether or not to borrow a loan from the bank to invest in new crops.

The amount of water that the players could use was based on the type of climatic data, dry, normal or wet (Table 1). At the end of each round, the players received a sum of money related to the following factors: number of plots cultivated; selected cultures; volume of water used to irrigate their crops (whether or not they satisfy the water requirements of the crop); and market price of the year (high, medium or low). Thus, the players evaluate the production means, number of plots, cultivated area, available money and, eventually, update their strategy in the next round.

The second session of the game focused on bringing a closer approach to the settlement reality with the purpose of studying the local community decision-making, and promoting collaborative management. Therefore, some changes in the game were made based on the contact with the local community and analysis of the players' behaviours from the first game session. The second session was mainly related to water supply, in the case of the Canaan settlement, wells instead of river.

The game components were similar to those in the first session. However, the river that flowed to the centre of the board in this new version forms four collective wells schematically

Figure 4. The game board and the elements used in the first WaDiGa session.

Table 1. The climatic profile year and agricultural water volumes available.

Precipitation	Water volume per property	Range	Maximum volume
Wet	2	±6	58-70
Normal	1	±4	28-36
Drought	0.75	±2	22-26

represented by transparent plastic pots located in the centre of the board. In addition, individual wells could also be implemented, which were represented by brown cardboard cylinders (Figure 5). A slope was also considered on the board to identify higher and lower elevation.

During a second version round, each farmer had to perform the following actions: divide their crops by assigning a given production to their plots; implement or not a well; fix the water volume used for irrigation; and whether or not to borrow a loan from the bank to invest in a crop or wells construction. The water in the wells was also related to rainfall. It is known that the hydrogeodynamic processes of underground water recharge present a greater complexity than the simple relation between underground water level and precipitation. However, in daily life, the lack of water is always represented in the user's imagination as consequence of low precipitation, for that reason, the simple relation between the precipitation and the underground water level was considered.

The individual well price is based on the property location on the board. Similarly, to the local reality, the zones with higher elevations have water only in a deep depth; consequently, the wells in those areas are more expensive than the ones located at lower elevations. Therefore, the board was divided into four parts (four tracks containing two property lines). The first part was on the upstream of the board, and in this area, the cost of

Figure 5. The game board and the elements used in the second WaDiGa session.

well implementation was greater than downstream due to the underground water depth. In the subsequent parts, the cost was gradually reduced. After the changes related to the water supply in the game rules, the succeeding steps followed the same process presented in the first version. The crop costs and profits stayed the same in the second game version and the amount of water demanded by the three crops did not change.

The agent-based model

The role-playing game, WaDiGa, provided a closer approximation to the local community and the gathering of some information that was used as a model parameterization. The first useful information was the issue related to the real estate speculation. One of the players mentioned that the properties, which there were low profit and water lack, probably tend to become condominiums. Therefore, the first modification in the model was the transformation of the fallow areas (in the first version) into the condominium.

Another modification was the introduction of a specific crop type in the model. The crops that were previously defined as irrigable and non-irrigable now are, respectively, passion fruit and corn. The choice of these types of culture was because it is the main agricultural production in the settlement. The corn requires a low amount of water and it is a frequent production in the settlement. The passion fruit is also very common and there are different species plantations.

Some values associated with passion fruit and organic corns were used as a reference for the second model version. The implementing and maintaining costs of passion fruit and organic corns were obtained through the Federal District Technical Assistance and Extension Company – Emater (acronym in Portuguese)(2019). Emater collected the data used by farmers in production systems in the Federal District. Those values are R$ 37,675.76/ha.year for passion fruit and R$ 5,043.14 /ha.year for organic corns (Empresa de Assistência Técnica e Extensão Rural, 2019).

The annual revenue for passion fruit and organic corns were calculated based on its productivity (Empresa de Assistência Técnica e Extensão Rural, 2019) and the price per kilogram at the Federal District Supply Centers - Ceasa (Centrais de Abastecimento do Distrito Federal, 2019). Consequently, the total annual passion fruit revenue is R$ 67,500/ha.year and the total annual revenue for the organic corn is R$ 33,750/ha.year.

The third type of crop to be considered in the model was agroforestry systems – AFS. Also present in the first model version, its implementation and maintenance costs is R$ 7,580.72/ha.year for manual agroforestry systems type, which is more similar to the AFS type used in the settlement (Moura & Hoffmann, 2009). The annual revenue is equal to R$ 47,274.00/ha.year (Hoffmann, 2005). All the above-mentioned values can be seen in a summary form (Table 2).

In this version, the AFSs present a more relevant position in relation to the conceptual model. Based on the two WaDiGa sessions, the settlement families prioritize the implementation of AFSs, so a new agent activities sequence was used, where AFSs presents priority in relation to the corn cultivation. In addition, regarding the water issue, in order to be more similar to the local reality, which it was notable that the principal water supply in the community area is wells, the river was divided into 37 plots, which would represent collective wells. Therefore, the flow (Equation 1) represent availability of water AW (t+1) in the plot area. In order to be closer to the reality, the agent cash box values was a random number between one and two minimum wages, and for the family expenses a random number between R$ 250 and R$ 800.

Table 2. Cost and revenue of the three crops present in the model second version.

	Passion Fruit	Corn	AFS
Operation Cost (R$/ha.year)	37,675.76	15,311.22	7,580.72
Revenue (R$/ha.year)	67,500.00	33,750.00	47,274.00

Considering the new conceptual model version and its implementation in the GAMA, different scenarios were simulated. These scenarios were defined based on the role-play game, WaDiGa. Consequently, the variation was done in function of the external parameters, which were not influenced by the agents, the precipitation and the market. For the climatic year, three values we considered: wet (average annual of 1000 mm), medium (annual average of 500 mm) and drought (annual average of 100 mm). For the market were considered two types of market, a normal where the agent earn the normal values shown in Table 2, and a bad market, where there is a 40% reduction in the revenue value. Therefore, considering the combination of these precipitation and market values, six scenarios were simulated.

RESULTS AND DISCUSSION

Water distribution game - WaDiGa

The first session game had eleven participants with a high diversity of gender and age. The first session consisted of five successive rounds, each corresponding to an agricultural year, making it possible to see on the board and in the collective organization of the players an evolution on the land and water use. In the first moment, the players did not know the game rules, so at the beginning, we observed the way that the participants chose their properties. It was possible to observe that the main point in the players' choice was the proximity to the river. In addition, taking into account the reality of the settlement, some participants chose properties in the river downstream, because the main water supply system in the Canaan is based on wells; consequently, due to the topography levels the quantity of water in the downstream is bigger than in the upstream.

In the first round, due to the total participation of the players in an agroforestry group, the SAF crop type had good acceptability. Considering the climate influence, the first round presented low precipitation. As a result, the participants already started to negotiate the water amount and complained about excessive and unnecessary water use allocation. It was also noted that the non-irrigable crop location was preferably in the farthest river properties. On the other hand, the SAF crops were predominantly arranged close to the river because the players understanded that the SAF needs more water than other crops do, and would provide the preservation of the riparian forest.

In the second round, the year presented higher precipitation. At the water allocation time, the players chose not to discuss the strategies that could be adopted or a possible collective agreement. Due to the abundance of water generated by the good climatic year (randomly defined), some players put more water than necessary on their properties, showing that the concern for water occurs more in times of scarcity. It was also noted that the participants presented great concern about the SAF crop type, giving priority to this type of cultivation. A large amount of water and the good market operation made the players profits increase in the second round.

It is worth mentioning that, in the second round, the good community revenue was due to high precipitation and good market functioning, not due to collective water management, which did not exist during the game. In the third round, because of the revenue of the previous round, there was a great crop change (Figure 6). The number of SAFs notably increased whereas the number of irrigated crops slightly increased; therefore, significantly changing in the game board was remarkable. From this result, it is possible to infer that the local income growth could collaborate with the SAF implementation in the Canaan settlement.

Despite all the players' expected projection for the third round, the year presented low precipitation. Therefore, the community chose to have a dialogue. In the conversation, it was pointed out that some players had more access to the water, which suited to the settlement reality. During the conversation, no one wanted to negotiate or propose collaborative water management. Despite the absence of agreements, the low precipitation helped to reduce the water uptake by the

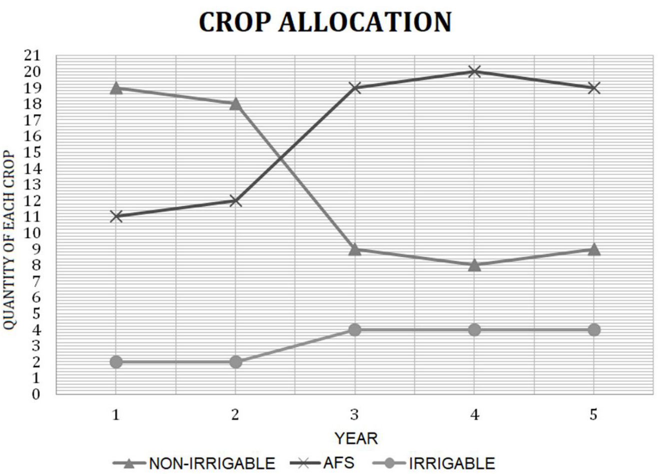
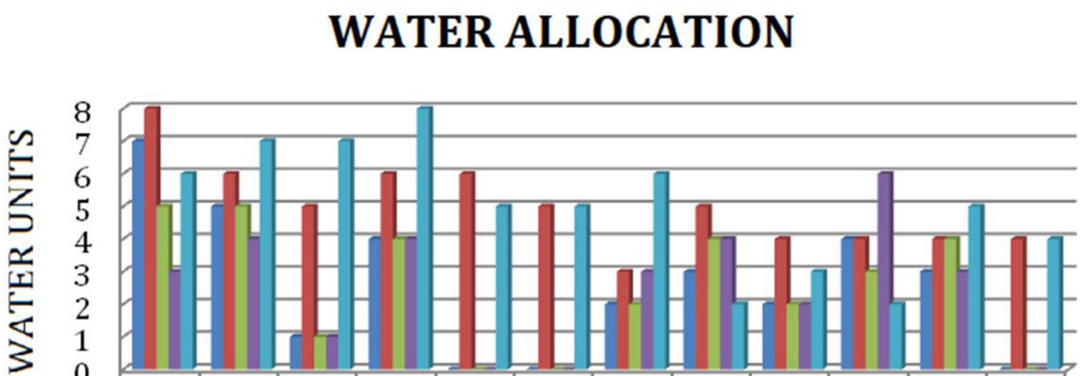


Figure 6. Quantity of crops allocated by the players on their properties in the first game session.

upstream players (Figure 7). This shows that the talk before the distribution of water contributed to a greater awareness of who had more access to water.

After the impasses and reflections of the third round, in the next round, players began to make analogies between the game and the real life, citing "who has access to the water resource does not matter about the others one" and making references about the individualistic water management issue. It was notorious during the game that the lack of water and the proximity to the water resource can strongly influence the local farmer decision-making related to land use. Within this perspective, one of the most remarkable comments was that if the downstream properties continued without water and low income, they would eventually become condominiums, which in fact expresses the reality of real estate speculation in the region.

Due to the pressure, in the fifth round, players who had a great income ended up opting to leave some water to the downstream players. It was clear at this stage that the collective mindset more pronounced in periods of much precipitation and weakened in periods of scarcity. At the end of the game, when we asked the players about the dynamics, they answered that they liked a lot and felt that the game could help in fostering water management initiatives. In addition, many players concluded that the game reflected the actors' behaviour in which predominates the lack of fellowship and discussion in the community. Wishing to improve collaborative water management, the players realized that debates and collective actions are very important to initiate conservation process. Another analysis emphasized the issue of collective pressure that presented the power to change the crop type of certain participants in order to save water. Thus, the players' interest in the tool and the notion that the game could bring benefits to the community was perceptible. In addition, the game would have the potential to identify the behaviours of community agents.



	1	2	3	4	5	6	7	8	9	10	11	12
Year 1	7	5	1	4	0	0	2	3	2	4	3	0
Year 2	8	6	5	6	6	5	3	5	4	4	4	4
Year 3	5	5	1	4	0	0	2	4	2	3	4	0
Year 4	3	4	1	4	0	0	3	4	2	6	3	0
Year 5	6	7	7	8	5	5	6	2	3	2	5	4

Figure 7. Water allocation per player and per year.

In order to have a good game operation, the players should have the reality well represented. This similarity corroborates for a more effective calibration of decision-making. By identifying their reality, players end up reproducing their real decisions in the game and explaining their priorities and preferences. Take into account this perspective, the second session of the game was held and, again, counted on the participation of eleven players. Age and gender heterogeneity was still important, however, the game was performed with a different group than the first one, having in common only two players. This session lasted only three rounds due to the fatigue of the players, who remained all day in an agroforestry community work. Another factor that also influenced the round number decrease was the greater number of steps in that session.

As mentioned in the methodology, in the second session, players had the option of placing individual wells on their properties. In the first round only four wells were placed, all located in the lower part of the land, where the price was cheaper than in the higher part. Normal precipitation and an average market characterized the first year. In the first round, the normal precipitation led to the water abundance; therefore, at the end of the round, collective wells still had water. Due to a normal precipitation year, there were not many conflicts regarding water use, so in that sense, the players choose not to discuss water use strategic management for the next rounds.

Considering the normality of the first round, in the second, there was a crop transition from non-irrigable crop to AFS (Figure 8). This transition follows the same trend observed during the first session of the game, where there was an increase in AFS and a maintaining of the irrigable crops. It is notable that the board configuration was similar in the two game sessions, showing that, although the players were not the same, the local community shares the same view of the land use configuration.

The second round was characterized by the allocation of individual wells. The players who owned money chose to buy wells, they claimed that the individual well was a guarantee in case of drought. Therefore, there was a significant increase in the number of wells, increasing from four in the first round to seventeen in the second. The increase of the individual wells number reflects the reality of the settlement. According to the players, it is impossible to produce without the wells during all the year. Most of the agents aim to have wells on their properties; however, because of the price it often becomes inaccessible. It was notable that the wells have a significant importance for the community water supply. One alternative for the water supply is the use of collective wells, but local internal conflicts hamper the process.

It was also notable that there was no dialogue in the game about a strategy of collective wells use. The players who earned money in the first round thought only about investing in individual wells, again showing the lack of collaborative water management in the region. The second round was marked by a year of high amount of individual wells and precipitation. The high water availability has led players to use more water than necessary. According to the games results, in the end of the second round, the properties, which presented more water than necessary, increased 44.5%. The growth for water demand shows that with a larger number of individual wells in the tray, participants changed their way of using water. After having bought a well, players ended up not worrying about the waste.

The third round also had an increase in the number of wells, slightly lower than the second round, so in the end of the game, the board had 20 individual wells in 62.5% of the properties. The wells concentration was bigger in the low part of the board; many players of the high part could not invest in wells due to its high price in the region. The high precipitation and bad year for market characterized the third round. The abundance of water in the last round and the implementation of several individual contributed to the increase of irrigable crops.

At the end of the game, the players were asked what they considered to be most significant about the game. It was answered that the game was nice and very similar to the reality. It was also told that in the settlement, there are many water conflicts problems; some farmers take more water than others and it would be good to apply the game more times, so that everyone could learn to share water. Some players pointed out that the game brought an interesting insight that if each one drilled a well, the effect of it could be important and an alternative would be to share wells. The game was considered good by the players for portraying the reality of the settlement.

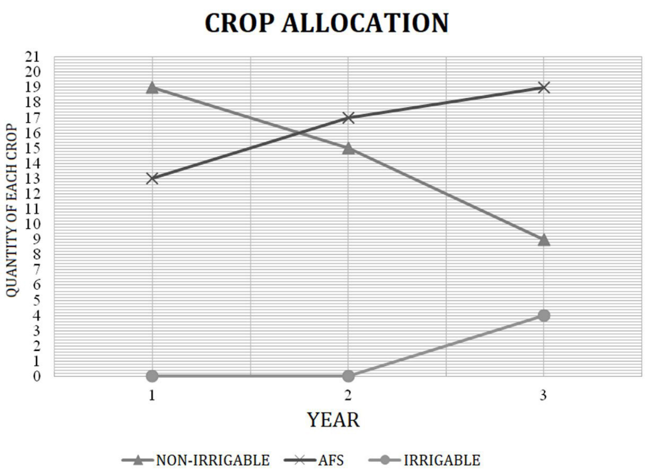


Figure 8. Quantity of crops allocated by the players on their properties in the second game session.

The agent-based model

The outputs of the model present three indicators: the land use; the quantity of water used in the system; and the total community profit. In the first scenario, it was possible to observe that with a high market and a year with much precipitation, the total amount of water of the system was zero with only 5.8 years of simulation and had as predominance the use of agroforestry and irrigable crops (Figure 9, Figure 10). The wealth generation fractions at the end of the simulation were between 44% for agroforestry, 31% for corn and 25% for passion fruit in total community revenue. The simulation profit presented high values like R$ 1,100,000.0 of monetary units, as shown in Figure 11.

The first scenario shows that even with a huge amount of profit the water would end in a few years, which would significantly

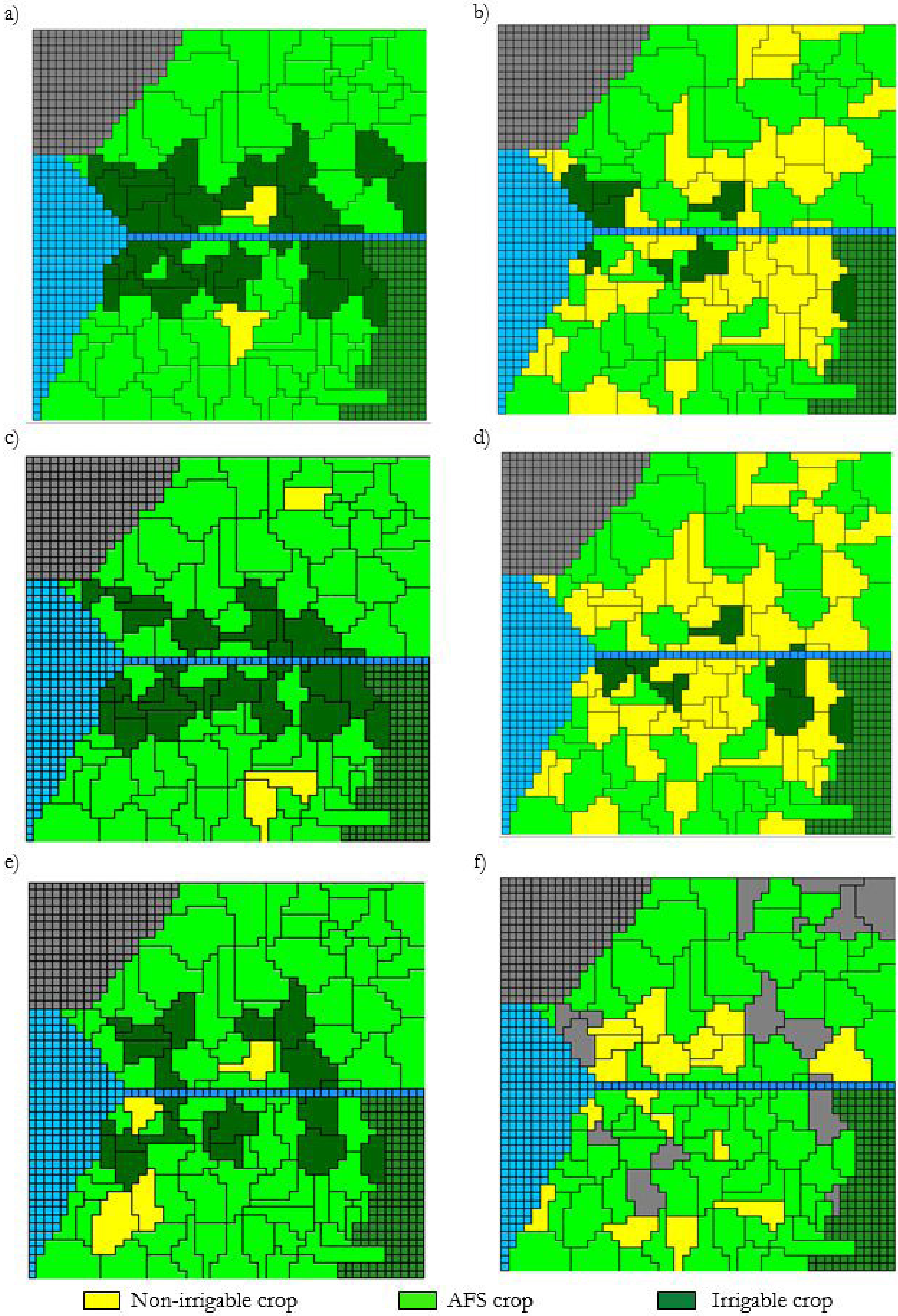


Figure 9. The land use scenario results (a) first scenario: high precipitation levels and good market; (b) second scenario: high precipitation levels and bad market; (c) third scenario: medium precipitation levels and good market; (d) fourth scenario: medium precipitation levels and bad market; (e) fifth scenario: low precipitation levels and good market; (f) sixth scenario: low precipitation levels and bad market.

a)

b)

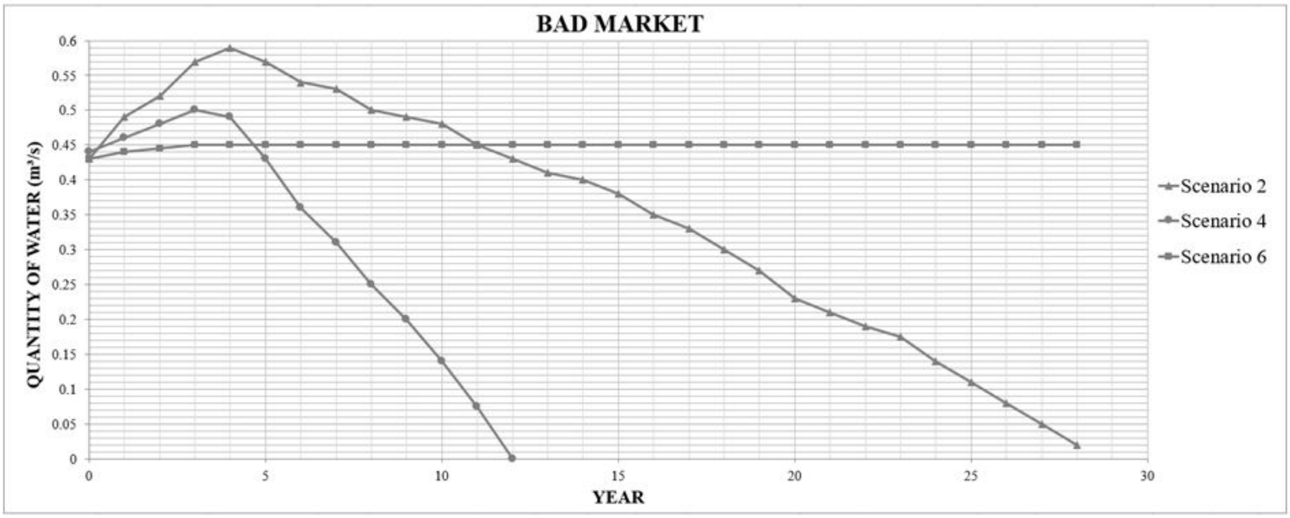


Figure 10. Available water in the system scenarios (a) Good Market Scenarios: high precipitation (Scenario 1); medium precipitation (Scenario 3); low precipitation (Scenario 5); (b) Bad market scenarios: high precipitation (Scenario 2); medium precipitation (Scenario 4); low precipitation (Scenario 6).

affect and harm the environment, the production and the future generations. It is also possible to notice a discrepant relation between the water availability and water conscious consumption, because the presence of high precipitation levels can cause a greater consumption of water, occasioning rapid exhaustion of the water resource. Interestingly, this result is in line with what happened during the role-playing game, where the same scenario led to a similar response from the participants, namely an increase in irrigable crops.

In the second simulated scenario, it was still considered a wet climate year, but in contrast, the financial market was considered bad. It can be observed that in this scenario, the amount of non-irrigable crop increased considerably and the irrigable crop decreased (Figure 9). Thus, the irrigable crop generated only 8% of the total profit. Compared with the previous scenario, there was a 32% reduction in the portion of profit generated by passion fruit. Because of this reduction, the total community monetary gains decreased, with a reduction of 45% if compared to the first scenario. However, even with the revenue reduction, the amount of available water reached zero only after 28 simulation years (Figure 10). In this scenario, the water remained available for more 22.2 years than in the previous scenario. Despite the smaller revenue, the water resource was available in a longer time. The model response to the first and second simulated scenarios, a)

b)

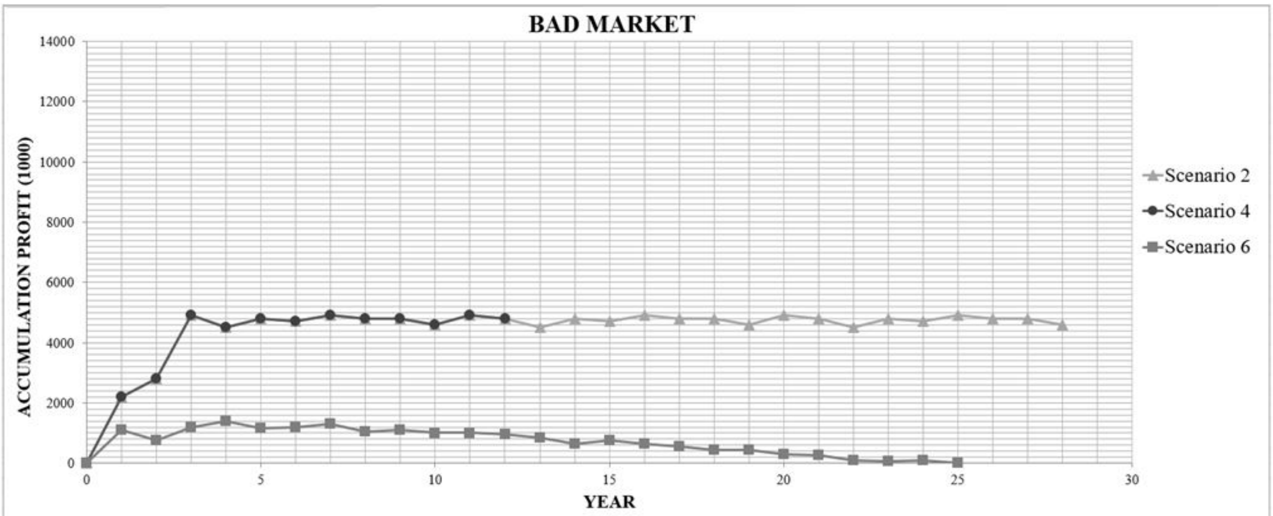


Figure 11. Total profits scenarios (a) Good Market Scenarios: high precipitation (Scenario 1); medium precipitation (Scenario 3); low precipitation (Scenario 5) ; (b) Bad market scenarios: high precipitation (Scenario 2); medium precipitation (Scenario 4); low precipitation (Scenario 6).

where there was no water scarcity, shows the relationship between the total profit generated and the duration of water availability.

The third scenario was related to a medium precipitation and a good market. It is possible to notice that there was not a very significant variation in relation to the first scenario, only a small reduction in the number of years with water availability, going from 5.8 years in the first scenario to 5.5 years in the third scenario (Figure 10). In the third scenario, there was also a slight increase in profit and corn crop properties (Figure 11). There was also a decrease from 30 to 26 properties growing passion fruit in the first scenario to the third scenario; this can be a consequence of the precipitation decrease (Figure 9).

The fourth scenario was related to an average climate year and a bad market. As expected, the fourth scenario results were similar to the second scenario results; especially in the land use configuration, where the predominant land use was agroforestry systems, followed by corn crops (Figure 9). Here again the simulation result is in line with what we observed during the role-playing game rounds, where the predominant land use was AFSs. Despite the similarity in the land use, in the fourth scenario, the average water quantity in the system reached zero in 12 simulation years, compared to the 28 years in the second scenario (Figure 10). This difference shows that even with a similar land use configuration; a dry climatic period can negatively affect the water availability over time if consumption patterns remain the same. It is worth noting that the model does not consider infrastructural water management factors, even so, micro-scale management can contribute to prevent water crises.

The fifth scenario, characterized by bad climatic conditions and a good financial market, was similar to the first and third scenarios, but with a shorter period (around 5 years) of water availability (Figure 10). In addition, the amount of irrigable crops was lower than the one observed in the first and third scenario, reaching a number of 19 properties (Figure 9).

The sixth scenario brings an approach to low water availability and a poor feature market. This scenario was the most different, being the only one showing some urbanized properties and no irrigable properties (Figure 9). The sixth scenario results represented the local reality because, according to the players, the low water availability and the low profits end up promoting the local urbanization. It is possible to notice that the water level remained constant since there was no presence of irrigable properties, which resulted in a decrease to near zero for the total community profit (Figure 11). This scenario is interesting for two reasons: i) it mirrors the reality lived in the locality; ii) it shows that factors such as the low precipitation and the dependence of the market are significant in enabling profit.

In general, all simulations attested that the market dependence is high and its variation can significantly change the profit-earning scenario, but at the same time, a large demand for water negatively affects the water resource and could exhaust it. The scenarios without water and a declining market could bring many irreversible damages to the region such as unplanned urbanization, characterizing an emerging system process.

Another important feature was the strong similarity between the model results and the role-playing game. Therefore, the methodology proposed shows a good alignment between the role-playing game and the agent-based model developed, supporting the idea, that it is possible to map the agent decision-making by the role-playing game and integrate it in an agent-based model.

CONCLUSIONS

This work is a contribution in evaluating role-playing games as a tool for mapping local actors' decision-making processes and of agent-based simulation as a methodology that enables representing agents' behaviours and exploring their consequences. The authors concluded that:

(1) The current area of Canaan Settlement presents a trend in the behaviours of the water users because the game board configuration was similar at the end of the two game sessions, showing that, although the players were not the same, the local community has the same view of the land use configuration;

(2) The role-playing game, WaDiGa, proved to be a very useful platform for dialogue and discussion about collective water resource management among the local actors;

(3) The role-playing game also proved to be an efficient tool to identify the agents' behaviour in relation to local water resources management, since it maps some important features in the decision-making of its participants;

(4) Besides RPG, there is a variety of empirical methods that helps the design of ABMs. Despite of this, the RPG seemed to be the most appropriate choice for the case study in the Canaan Settlement given that the WaDiGa had many features similar to the decisions related to the water consumption in the community and the participatory water management;

(5) The model developed represented very well the role-playing game and the agent decision-making. The simulations were quite similar to the WaDiGa results and represented, in a satisfactory way, the local agricultural production;

(6) For alternative approaches of future WaDiGa researches, the study suggests the "random" determination of climate and market factors. The information could be kept unknown to the participants, but under control of the organizers who could prepare a "random" condition in advance. The suggestion is interesting especially for the purpose of replication of the experiment in different groups of users or communities, preserving the organizer´s control of scenarios.

ACKNOWLEDGEMENTS

The authors would like to express especial gratitude to Emilie Coudel (UR Green/CIRAD), Christophe Le Page (UR Green/CIRAD) and Benoit Gaudou (University of Toulouse-UT1) for sharing thoughts and efforts during the game sessions, to the Canaan Settlement community for enlightening us with their participation during the game sessions, and to CNPq for the research grants.

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Authors contributions

Dandara Jucá Kokay Mariano: Responsible for collecting the data, coordinating the methodology application, processing and analyzing the data and writing the manuscript.

Conceição de Maria Albuquerque Alves: Supervised the research that resulted in this paper and revised the manuscript.