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Irrigania – a web-based game about sharing water resources

J. Seibert[1,2,3] and M. J. P. Vis[1]

[1]Department of Geography, University of Zurich, Switzerland
[2]Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden
[3]Department of Earth Sciences, Uppsala University, Sweden

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Correspondence to: J. Seibert (jan.seibert@geo.uzh.ch)

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Abstract

For teaching about collaboration and conflicts with regard to shared water resources various types of games offer valuable opportunities. Single-player computer games often give much power to the player and ignore the fact that the best for some group might be difficult to achieve in reality if the individuals have their own interests. Here we present a new game called Irrigania, which aims at representing water conflicts among several actors in a simplified way. While simple in its rules, this game illustrates several game-theoretical situations typical for water-related conflicts. The game has been implemented as a web-based computer game, which allows easy application in classes. First classroom applications of the game indicated that, despite the simple rules, interesting patterns can evolve when playing the game in a class. These patterns can be used to discuss game theoretical considerations related to water resource sharing.

1 Introduction

Sharing water resources often implies to find compromises between different interests. Games can be a suitable tool when teaching about these interest conflicts between different water uses. Different types of games are available for education. An example is the World-water game (http://www.wldelft.nl/soft/wwg/) where the player decides on different measures to avoid water shortages in the various regions of the world. In another game, developed by the Swiss Federal Office for the Environment (FOEN), the player can take different water management actions for a city and rural areas along a stream reach (http://www.bafu.admin.ch/wassernutzung/07805/). In some computer games it is tried to be as realistic as possible. This, however, can make the game complex and, thus, less attractive and more difficult to understand (Jones, 2011). One can also note that even in complex games, not everything is represented in a realistic way. An example is the computer game SimCity, where urban hydrology is included, but partly in an unrealistic way (Hellweger and D'Artista, 2007).

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In all these games, as in many other similar computer games, the player has the power to act as a monarch. In this case the issue is to find the right decisions for optimizing the prosperity defined in terms of wealth for the entire society or system. In most real situations such a single ruler is obviously unrealistic as there are many different actors who take decisions and each actor has his/her own interests. The issue, therefore, is often not only to know what the best solution for everyone on a long-term perspective would be, but also how to realize this solution in a situation where the best decision for a larger group might be different from the interests of single actors. This is especially the case in "tragedy of common goods" (Hardin, 1968) situations, where a group of self-interested individuals deplete a shared resource. Each individual is acting rational, optimizing his/her own profit, but ultimately this overuse will result in a situation that is not beneficial to anyone on the long term.

Role games are a type of games which allows for interaction between different actors. The negotiation game "Transboundary Waters Resolving Conflicts – Building Trust Negotiation Simulation" developed by Johan Kuylenstierna (personal communication) is an example of a role-game. Here the players take the roles of different actors in the negotiation of water-related issues between two countries. In this type of role games the players are not restricted to a limited number of possible actions, which can result in creative, but sometimes also unrealistic solutions, because actions are not evaluated in a quantitative way. Such role games can also be played online, which has been found to be beneficial for student learning (Maier, 2007; Varzaly and Baron, 2009).

Another type of role games are games, where players have limited decisions options and these decisions are evaluated in some quantitative way, which in some of the games is done computer-based. A good example are the games "River Basin Game" and "Globalization of Water Management" (Hoekstra, 2012), which are designed to demonstrate issues related to sharing a common resource in an up- and downstream setting respective the concepts of water footprint and virtual water trade. These games are played in a board-game like setting and the players are limited to a certain number of actions, which are then quantitatively evaluated using a computer.

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Here we present a new web-based game called Irrigania, which aims at representing water conflicts among farmers in a simplified way. While simple in its rules, this game illustrates several game-theoretical situations typical for water-related conflicts.

2 Background on game theory

Game theory is the mathematical analysis or modeling of the interaction between players, where the amount of payoff that a player receives is dependent on the player's own decision, as well as the decisions of the other players. Madani (2010) reviewed recently the applicability of game theory to water resource issues and concludes that game theory can help understanding and resolving water conflicts. Game theory can help to comprehend the use, or often misuse, of public goods or the hinder for cooperation. An example for an interesting game theoretical illustration in this regard is the "Public Good Experiment" game. In a group of 4 participants, everybody gets $5. The participants can choose to invest (part of) the money for the group. The total amount of invested money will be doubled and shared among the 4 participants. Since a participant only gets back half of the amount he invested himself, the optimal strategy for each of the participants is to "free ride" on the others, i.e. to invest nothing. However, the whole group would be better off when each participant would invest all his money (in that case each participant would receive $10, the Pareto optimal solution) (Ledyard, 1995).

A Nash equilibrium is a set of strategies chosen by each of the individual players, with the characteristic that none of the players can increase his/her payoff by changing strategy when all other players are keeping their strategy fixed (Nash, 1951). In the Public Good Experiment, for example, a player can increase his payoff by investing less money for the group (assuming that all other players are keeping their investment fixed). Once a player is investing nothing for the group, no improvement can be accomplished anymore. Therefore, the situation where all players are investing nothing for the group is a Nash equilibrium.

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However, studies have shown that people do not always behave as would be expected from pure analytical game theory (Kahneman et al., 1986). A good example is the ultimatum version of "A piece of the pie". One player gets an amount of money (x). He then offers part of it (y) to the other player. The other player can accept or reject the offer. If he accepts, he will receive y, whereas the player who made the offer earns $x - y$. If he rejects, both players earn nothing. The optimal strategy for the receiver is to accept whatever amount he gets offered. Therefore, the optimal strategy for the first player would be to offer the minimum amount that is possible. However, studies have shown that the receiver does not always play the optimal strategy, but sometimes rejects an offer (e.g. Hoffman et al., 1996; List and Cherry, 2000) to punish the other player for not offering a "fair" amount of money (Kahneman et al., 1986). Also in many water-related issues actors might behave different than the optimal strategy, and behavioral game theory might provide better explanations than pure analytical game theory.

A game can be repeated several times. In a repeated game, players might adapt their strategy based on the decisions of the other players in previous rounds (Camerer, 2003) as well as take into account how their strategy will affect the future decisions of other players (Osborne and Rubinstein, 1994). A player might take into account how his strategy could change his reputation. If his behavior is seen by the other players as egoistic, they might punish him, possibly resulting in a bigger loss then the short-term profit.

A distinction can be made between non-cooperative games, where players cannot make any agreements, and cooperative games, where players can make (binding) agreements about the strategies they will play. Furthermore, games can be of complete or incomplete information. In a game of complete information, all players know exactly the payoff that each of the players will receive for all possible strategies till the end of the game. In a game of incomplete information at least one of the players does not know all the payoffs.

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3 Description of the game

3.1 Game idea

Irigania is a web-based game on the shared used of limited water resources. The idea behind the game is that there are different villages with a number of farmers in each of them. The goal for each farmer is to generate the largest net-income. This, however, requires a certain amount of cooperation within the village. Each player represents one farmer in one village and has 10 fields for which he/she can decide how to use them each year. There are three options: rainfed agriculture, irrigation using river water, and irrigation using groundwater. Different costs and revenues are associated with the different types of fields (Table 1) depending on a number of variables (see Table 2 for a parameter list). While largely simplified, these costs and revenues reflect some aspects of reality. Rainfed agriculture has the lowest costs, but also less revenue than the other options. With irrigation more can be produced both in terms of quantity and quality, which is reflected by higher revenues, but also by higher costs. In the case of river-water irrigation the cost is fixed, but the income can be reduced if the river water has to be distributed among too many fields in a village. In the case of groundwater based irrigation the revenue is fixed, but the costs increase if the depth to groundwater increases.

The reduction factor k for revenue from river-water irrigated fields due to overuse of the river water is calculated based on the precipitation conditions and the number of river-water irrigated fields (Eq. 1, Table 1). This implies that in a normal year, the revenue is reduced if there are on average more than 2.5 fields per farmer irrigated by river water. Note that the reduction is non-linear, which means that the revenue will drop at an increasing rate if there are too many river-water irrigated fields.

$$k = \left(\frac{1.5 + P}{\frac{F_{\text{river}}}{n}} \right)^2 \quad (1)$$

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The groundwater level, g in year t expressed as depth to groundwater, is updated based on precipitation conditions and number of groundwater irrigated fields (Eq. 2).

$$g_t = g_{t-1} - P - 0.5 + \frac{F_{\text{gw}}}{n} \tag{2}$$

This equation implies that under normal precipitation conditions groundwater levels will drop if there are on average more than 1.5 fields per farmer with groundwater irrigation. For both types of irrigation, dry, respectively wet precipitation conditions cause that one field less, respectively more can be irrigated without adverse affects. While any overuse of river water has an immediate effect, the effects for groundwater are rather visible in a longer perspective. On the other hand, for river-water there is no memory effect as there is for groundwater. It should be noted that in the game it is assumed that the different villages do not influence each other.

3.2 Software implementation

Irrigania has been implemented as a web application that is built in Visual Basic ASP.NET 4.0 and is running under IIS 6.0. User authentication is used to give users access to their personal pages. Two different types of users can be distinguished, teachers and students. Based on their type, users can either enter the teacher pages or the student pages. Irrigania includes two Microsoft SQL Server 2005 databases. The ASPNETDB database is used by ASP.NET to store membership data. The Irrigation game database contains teacher, game, village and farmer settings and status. HTML Help files are available, providing the user with information about the functionality of the game and the user interface.

Teachers need to register before they can use Irrigania, for which a password is needed that can be requested from the authors. After registration, a teacher can log in to his/her personal pages. Teachers can setup one or more games by specifying the villages and corresponding farmers within that game (Fig. 1). Teachers can define the length of a game, the precipitation conditions, and decide if farmers can see each

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other's input values. Furthermore, teachers can follow the status of a game while students are playing. In an overview, the current year, status of the villages (groundwater level and average number of fields irrigated by river water) and farmer status (water supply input values and (accumulated) balance) are given.

Players (e.g., students) obtain login details from their teacher. After logging in, students are redirected to the game page, where the decision on how to use the fields can be entered (Fig. 2). Each year, a farmer (or the player) has to submit values how to supply his/her 10 fields with water. When all farmers have submitted their values, computations are carried out on the server, after which the game continues with the next year. During the game, farmers can see their (accumulated) balance, the current hydrological conditions, and last year's input values of the other farmers (optional). Once the game has finished, farmers can go to the results page to watch the game results. Results are published per farmer as well as per village.

Since overuse of resources could lower the payoff drastically, and the ground water level might take several years to recover, a certain cooperation within the village and a willingness to not overuse the resources is necessary to be able to win the game. However, in order to win, a farmer needs to do better than the other farmers within the village. Therefore, a farmer needs to find the subtle balance between supporting the village in not overusing the resources, but meanwhile using a bit more than the other farmers within his village.

3.3 Irrigania in teaching

In a class it is useful to play several rounds of Irrigania, especially because the game can be played in different settings. A recommended series of Irrigania games in a class (about 2–3 h) consists of several games, each played over about 15 rounds (= years). Usually Irrigania will be played in a computer class room. Technically Irrigania of course also can be played with students sitting at a distance from each other, although this requires some possibility for communication among the students. In those versions

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where the students know who belongs to which village, students are allowed to talk to each other. These discussions are an important part of Irrigania.

1. Normal years, no information provided on the sustainable number of fields for the two irrigation types, students know who is who and see the decisions of the others after each year
   - Cooperative
   - Incomplete information
   - Students do not know the cost and profit system yet. They can develop their strategy by experimenting.
2. As (1) but information provided (i.e. Eqs. 1 and 2)
   - Cooperative
   - Complete information
   - Game has changed from incomplete to complete information. Students can confirm their strategy and further improve their strategy based on the equations.
3. As (2) but students do not know who the other farmers in their village are (practically it is most efficient to randomly assign the students to different villages in this case)
   - Non-cooperative
   - Complete information
   - Game has changed from cooperative to non-cooperative. This may lead to more selfish behavior (Hoffman et al., 1996). A player might try to act more selfish to benefit, at least more than the others, from over-using the resources.

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4. As (2) or (3) but with randomly varying years (dry-normal-wet)
   - Cooperative/non-cooperative
   - Incomplete information
   - The game has changed to a game with incomplete information again, (being played either cooperative or non-cooperative). Although students of course still know the Eqs. (1) and (2), information about the yearly rainfall conditions is missing this time, making the game harder, but more realistic.
5. As any of the above, but students do not see the decisions of the others
   - Cooperative/non-cooperative
   - Complete/incomplete information
   - This option gives the players a certain amount of anonymity. Especially the cooperative version might be interesting. Thrust becomes important: are farmers playing according to how they agreed to play, or will some players betray the others?

3.4 Discussion

During first tests in class several interesting patterns could be observed. In cooperating villages, where farmers agreed to not over-use resources, farmers did best on average, but single "egoistic" farmers could still win. The game is designed in such a way that the profit quickly decreases if water resources are overused and, thus, it is important for the farmers of a village that the maximum number of fields, that can be sustainably irrigated by ground water, respectively river water, is not exceeded. An egoistic farmer might be hoping that the other farmers are taking care of restoring the water level. However, during class it was observed that if one farmer behaves too egoistic, the others might start to punish him/her and the income of the entire village will decrease. Such a behavior is not rational from a perspective of maximizing individual profits, but

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can be explained from a fairness viewpoint. Also, if several rounds of Irrigania are played, i.e. if Irrigania is played as a repeated game, punishment of egoistic farmers might show that being egoistic could result in lower payoff, and therefore makes this strategy less attractive in next rounds.

When the students did not know who the other farmers in their village were, the lack of social control leads to more overuse of the water and thus less income on average. Hoffman et al. (1996) showed that during the dictator game higher social isolation results in more selfish behavior, and Bohnet and Frey (1999) showed that solidarity increases with decreasing social distance. However, information about the farming decisions of the other players in previous rounds might still be of help by giving a farmer some insight in the strategies of the other players. Therefore, it might be expected that there could be even more overuse of water in case the students cannot see the decisions of the others.

Another observation was that good decisions are more difficult with randomly varying rainfall conditions. The option to use randomly varying rainfall conditions changes the game into a game with incomplete information. For each of the three rainfall conditions there is a separate payoff matrix. The user doesn't know which payoff matrix corresponds to each round, and therefore playing an optimal strategy becomes more difficult. Some players might be willing to take higher risks, whereas others might tend towards more conservative decisions.

In general the aim of the game is being the best farmer, i.e. making most profit. For pedagogical reasons, however, it is recommended to not emphasize this too much. Some groups also defined other goals such as being the best village or having the winning farmer within their village. In one case a group also decided to do all for "punishing" a farmer who was accused to act egoistically and to ignore agreements.

All the above observations can be related to general patterns of real-world conflicts. The game provides an illustration of a tragedy-of-the-commons situation related to water management. In the short-term it can be profitable to over-use resources, especially if only a few players do so. In the long run, however, over-use leads to decreased profits

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for everyone. The game also demonstrates a difference between the use of water from a river and from groundwater. While water shortages might happen more quickly for river water, there is no year to year memory. For groundwater, on the other hand, over use might not cause shortages directly, but once shortages become notable, it takes longer before the groundwater levels are back to normal.

Studies have shown that people only look a limited number of steps forward (iterated rationality) (Nagel, 1995). This might to some degree also apply for students playing Irrigania. Players might look only a few years in future, ignoring the long term effect of a lower ground water level. It can be argued, that this effect is even larger in reality, where other objectives than those considered in Irrigania are of importance, such as political uncertainties or varying revenues due to changing market prices. There is also a difference between the non-cooperative and the cooperative version, i.e. cooperation might influence the awareness of the students for the groundwater level and the willingness to keep the ground water level stable compared to the case of no cooperation where the strategy might rather be to secure at least short-term profits.

4 Concluding remarks

Irrigania is a very simple game with only few options for decisions. Still, interesting patterns evolve when playing the game in class. Similar as the games presented by Hoekstra (2012), Irrigania can be used as an additional element in courses related to water management conflicts and collaboration. While the game obviously is a vast simplification, it will nevertheless help in teaching about real-world water resources challenges. After playing the game the students will have experienced a water-related example of the tragedy of the commons. They will furthermore have understood the difference between streamwater resources and groundwater resources in their response to overuse and their potential recovery. They will also have seen that uncertainty about the coming weather conditions complicates optimal water resource planning. With these learning goals, the game Irrigania is a valuable complement to other course elements when teaching water resource conflicts and collaborations.

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Table 1. Costs and revenues for fields with different water supply. For variable explanations see Table 2.

Type of water supply for field	Cost per field	Revenue per field
Rainfed	5	30 (in normal year) 10 (in dry year) 40 (in wet year)
Irrigation with river water	20	$\min(100, k \cdot 100)$ with $k = \left(\frac{1.5+P}{\frac{F_{\text{river}}}{n}}\right)^2$
Irrigation with groundwater	$g < 8$: 20 $g \geq 8$: $20 + (g-8)^2$	100

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Table 2. Explanation of variables.

Variable	Explanation
F_{river}	Number of fields with river-water irrigation
F_{gw}	Number of fields with groundwater irrigation
g	Depth to groundwater
n	Number of farmers in a village
P	Precipitation indicator (normal year: 1, dry year: 0, wet year 2)

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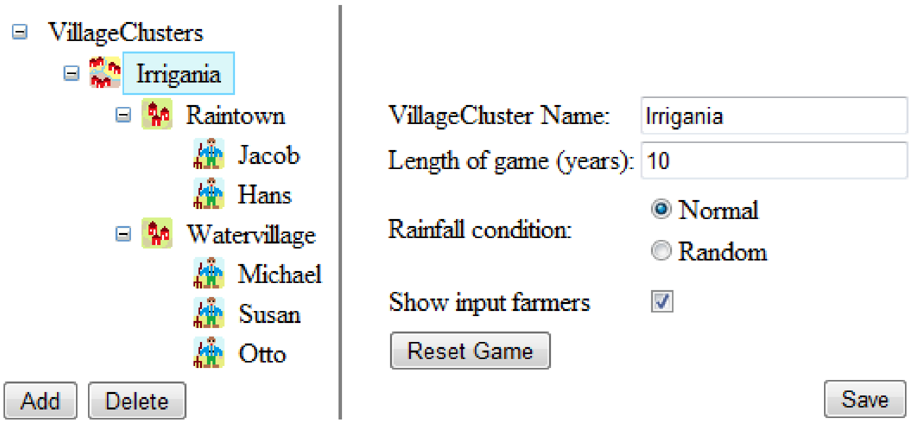

Fig. 1. Screenshot of the teacher interface when setting up a game.

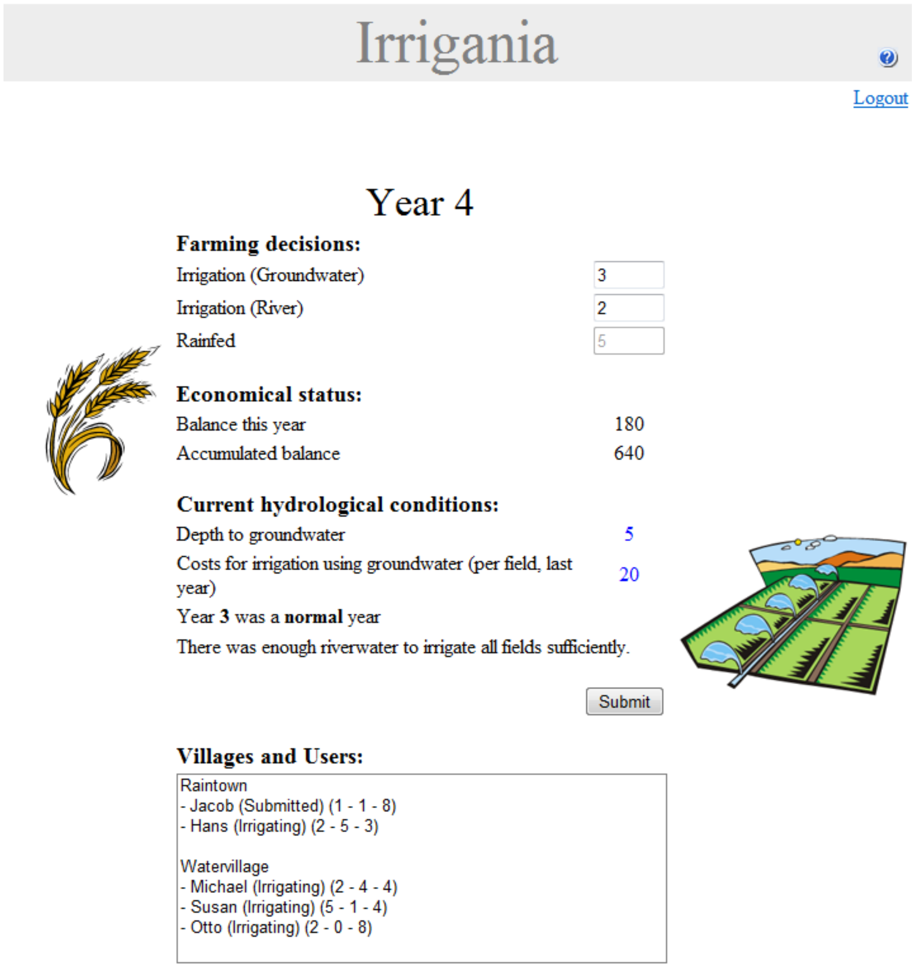

Fig. 2. Screenshot of the student interface when playing the Irrigania game.

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