A cooperative game for upstream-downstream river flooding risk prevention in four European river basins

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Abstract: This chapter tests whether a group of landowners living in the upstream part of a river basin could change land use to increase retention and thus decrease flood risk of the other group living in downstream parts of the river basin.
A cooperative game theory model combined with cost–benefit analysis is applied in four river basin settings in Europe: Stille Oder (Germany), Pysznica (Poland), Vipava (Slovenia), and Lea (Spain). These settings demonstrate various characteristics differentiating among catchments in terms of their size and land use, such as agricultural, forestry, and urbanisation.
Analysis reveals that in two of four river basins – Stille Oder (Germany) and Pysznica (Poland) - it is possible to find a mutually beneficial compromise between landowners to change land use (afforestation), which is economically reasonable for both of them, leading to flood risk reduction.
The cost-benefit analysis was applied to estimate the possible total benefit of afforestation that was an input data to the game theory model. The model applied in this chapter offers insights for flood risk reduction relying on nature-based solutions. It determines the benefits of cooperation that can be achieved by decision making process participants separately and their coalition when cooperating The sharing-rule function can help planners to distribute the total benefits from flood loss reduction among landowners fairly. Afforestation appears a feasible method for flood risk management.
The chapter also formulates further directions for game theory application in the field of environmental chemistry such as transportation of pollutants during flood events.

Key words: game theory, cost–benefit analysis, flood risk management, land use change.

1. Introduction

Flood is the most significant hydrological hazard worldwide in terms of risks to life and property [14, 20]. Climate change and increasing exposure of people and assets increase the probability of future flood eventsthat lead to a reduction in safety for local populations and higher costs for flood damage [23, 25, 30],. It is also expected that the damage caused by floods will increase in the coming decades, influencing infrastructure and the health and lives of the affected people [9, 24].

To cope with the growing flood risk, it is necessary to establish feasible flood protection measures. Recent developments suggest that nature-based solutions could play an important role instead of or in addition to traditional engineered approaches. Controlled flood retention is one strategy considered to have potential for flood risk management [27]. While nature-based solutions are claimed to provide effective solutions, they require land to reach the desired capacity, and land-use planning needs to be involved in the development of solutions. Taking into account inconsistent approaches of spatial planners and water engineers appears a difficult task [18]. Furthermore, spatial planning involves multiple stakeholders (such as sectors, interest groups, and individuals) driven by diverse interests that need to be integrated [15]. How to align these interests is subject to much debate, from theoretical and practical points of view. Consequently, a defined public interest concept needs to be developed [1, 31] that can provide legitimate solutions [19].

For flood risk management, the river basin scale is fundamental. The relation between the downstream and upstream of a river basin needs to be considered in terms of expected damage reduction, because actions undertaken upstream influence the risk of flood downstream. In general, downstream areas benefit from upstream flood retention services [39], whereby downstream homeowners, commercial businesses, public institutions, and infrastructure operators benefit directly from the reduction in flood risk. Moreover, landowners of flood-protected land, both agricultural and (undeveloped) building land, benefit indirectly from upstream flood retention, as land located in flood-prone areas would be exposed to lower flood risk or even classified outside flood hazard zones; thus, it may become legally suitable for development. This is usually accompanied by a significant appreciation in property value [27].

Afforestation in the upstream part of a river basin is usually considered for increasing retention capacity. However, the introduction of upstream flood retention requires a change in land use that involves costs. Therefore, convincing upstream landowners to modify their land use becomes a crucial step in establishing protection measures. Property rights and fairness are key in such negotiations. While one agent is expected to act for the good of others, the question of strategic behaviour becomes imminent. A proper distribution of resources, welfare, rights, duties, and opportunities need to be considered within a comprehensive framework to solve common distributive problems [35]. In addition, change in land use is strictly regulated in many countries. For instance, in Galicia (Spain) forest policy allows agricultural land that has been explicitly abandoned for more than ten years to be afforested [46]. At the same time, agricultural land abandonment is the largest land-use change process in Europe. More specifically, in the study area of Galicia, it is estimated the abandonment rate will reach 44% by 2030 [36]. This suggests significant potential for afforestation as a flood risk management measure.

In this study, a game-theory model is applied to four different European basins to simulate a decision-making process aimed at reducing the negative consequences of flood. The costs and benefits of actions/inactions are examined in terms of potential cooperation between both upstream and downstream agents. This approach is based on game theory, a mathematical tool that enables analysis to solve allocation problems where two or more agents have their own interests, both seeking to maximise benefits. Here, a cooperative 'game' is defined, where 'players' cooperate and a mutually beneficial compromise is possible.

2. Game theory in flood issues

Game theory is an analytical tool that enables interactions of rational players pursuing their interests to be modelled. Hence, it is a suitable tool to be applied in research on water resource management such as conflicts on irrigation or transboundary water conflicts, as well as for flood risk management, which involves parties with a conflict of interest. For instance, communities occupying both riversides may compete in heightening their levees. In this game, increasing safety on one riverside decreases safety on the other [21]. The same situation can occur when considering the upstream–downstream distinction. Machac et al. [28] discuss scenarios for negotiations between upstream and downstream from a game theory perspective. The authors analysed how changes in conditions (such as a preference for upstream or downstream) influence the outcomes of the game.

Many types of games have been developed and can be applied to specific conflict situations related to flood risk management. Parrachino et al. [35], Zara et al. [50] provide the basics and a review of some applications of cooperative game theory to issues of water resources. There is also a wide literature devoted to the study of allocation problems to solve issues related to trans-boundary rivers using cooperative game theory. Applications include water resource development [63], water allocation [51], pollution control costs (Shi et al., 2016), and flood cost sharing [53]. Non-cooperative game theory has also been applied to water management problems [29], water right conflicts [54], and efficient allocation of water [55]. Gómez-Rúa [13], van den Brink R. et al.[56], and Sun et al. [57] address the problem of sharing the cost of cleaning a polluted river, for example using environmental taxes. Béal et al. [58] and Beard [59] provide surveys on the use of cooperative game theory to model water allocation problems.

There is an important distinction between cooperative and non-cooperative games. In non-cooperative games, players compete and make decisions independently, whereas in cooperative game players make decisions together [29]. Hui et al. [21] argue that cooperative games involve methods of optimisation that assume perfect cooperation between players. However, in many areas of natural resource management, non-cooperation is players' dominant strategy [8]. For example, the prisoner's dilemma and other non-cooperative types of games depict such situations leading to non-Pareto optimal results.

To make further progress in this field of research, a multi-model and multidisciplinary approach is recommended [40]. In particular, flood damage is attributed to increasing exposure due to high population growth and economic development in flood-prone areas [7, 33, 44]; therefore, awareness of floods and effectiveness of flood protection measures are also

taken into account as factors that influence the decisions of private landowners in land management cases [11].
Álvarez et al. [3] apply game theory to study the problem of incentivising land owners to use their land in a way that reduces flood risk. Mitigating flood risk has numerous benefits; for instance, a reduction of the costs derived from flooding. Using the game theory framework, a wide literature related to transboundary rivers exists that studies different problems associated with the river. This literature developed in two directions. First, models were proposed that study how to share the costs of cleaning a river among the regions located along it. Second, other models have been proposed for studying how to share water resources among the different regions located along a river.
The first problem consists of two main approaches: some studies consider a river a segment divided into different regions and assume that the cost of cleaning each region is exogenously given (observable) [2, 17, 32, 41]. These studies propose different allocation rules for distributing the cost of cleaning the river among the regions. The second approach is taken in Gengenbach et al. [16] and van der Laan and Moes [42], where the cost allocation method adopted is thought to affect the decision of each region about how much waste to discharge.
For other types of problems, the focus is on analysing water allocation and achieving fair distribution of welfare resulting from distributing river water among different regions. The first paper by Ambec and Sprumont analysed how water should be allocated among agents, proposing monetary transfers among them from the point of view of the game theory [4]. Several other papers followed considering this topic [5, 45].

3. Method

This study applies the cooperative game theory model combined with cost-benefit analysis. The main goal is to use a sharing-rule function to distribute the total benefit among agents. A sharing-rule function determines the way benefits of cooperation should be shared for a given situation modelled by a cooperative game. A cooperative game determines the benefits of cooperation that can be achieved by: (a) each agent separately, and (b) each coalition when cooperating. This enables us to determine the most stable and fair share given by the sharing-rule function. The sharing rule can be used to set compensations and incentives to achieve a fair allocation of costs and benefits, as proposed in the cooperative game theory model presented by Álvarez et al. [3]. The model establishes distribution rules that satisfy a core idea of stability, namely that no agent or group of agents can find themselves in a worse position than working separately. Álvarez et al. [3] propose three such rules. The first rule is the most favourable possible for the upstream agent. The second is the most favourable possible for the downstream agent. Finally, the third balances both approaches by taking a compromise solution between the previous two.
This study is explorative; therefore, the model is simplified with the following assumptions: (i) there are only two agents in the drainage basin; (ii) two main land uses are considered (defined as ‘forest’ and ‘other’). According to Bentley and Coomes [6], afforestation of lands previously degraded by agriculture helps to repair the soil so that it can retain more water and reduce the flow of the nearby river.

Agents in a so-called flood game (as defined in [3]) are spatial units located in different parts of the drainage basin. In this study, for each of four selected basins, two agents (players) were defined as decisions-making process participants. Agent represent the regions including all subbasins in each part of the drainage basins and were delineated as follows: (a) upstream agent, located in the upstream part of the river where the flood risk is low and flood protection measures and actions are to be undertaken (agent 1); (b) downstream agent, located in the downstream part of the river where the flood risk is high (agent 2).Agents have the freedom to change the use of their own land and the right to deny any change on their own land that they do not agree with. Although game theory enables to represent each landowner as a separate agent, the approach had to be simplified. Because this analysis is the first attempt to apply this model, the agents represent collectives of landowners located in each part of the drainage basin. Delimitation for each basin was considered separately. The main factor was delimitation of the flood extent based on flood hazard maps at both a European and global scale based on streamflow data from the European and Global Flood Awareness System (Flood Maps). The shape and size of the basin were also considered.
Areas for each agent for each selected basin are presented in Table 1.

Table 1. Area for each agent in selected basins (ha)

	Stille Oder (Germany)	**Pysznica** (Poland)	**Vipava** (Slovenia)	**Lea** (Spain)
Agent 1 (upstream)	5,729	3,517	38,605	13,219
Agent 2 (downstream)	4,229	3,026	19,317	2,011
Total	9,958	6,543	57,922	15,230

To apply the game theory model, we need to consider the worth of upstream and downstream agents (w_1 and w_2, respectively) when acting individually, and the worth of both agents when they cooperate (w_{12}). For the former, we have $w_1 = \max(A; F)$, and for the later, $w_{12} = \max(A, F + B)$, where:

A = How much agent 1 gets if it does not change the land use to forest.

F = How much agent 1 gets if it does change the land use to forest.

B = Benefit provided by the decrease in flood damage due to agent 1 changing the land use to forest.

We also normalise $w_2 = 0$, since it does not play a role in the share.

Given these values, a stable sharing rule should provide the following payoff allocation (x_1 and x_2):

- Agent 1: $x_1 = w_1 + (w_{12} – w_1– \mathrm{w}_2)\cdot d$
- Agent 2: $x_2 = w_2 + (w_{12} – w_1– w_2)\cdot(1 – d)$

where d is a value between 0 and 1. For d = 1, we obtain the most favourable deal for agent 1. For d = 0, we obtain the most favourable deal for agent 2. For d = 0.5, we obtain a compromise deal.

4. Study areas

Four European river basins were subjected to analysis: the Stille Oder river basin (Germany), the Pysznica river basin (Poland), the Vipava river basin (Slovenia), and the Lea river basin (Spain) (see Figure 1). The criteria for the selection of case studies were as follows: an area where a significant flood risk exists and where a potential upstream-downstream conflict could be present was selected, the idea was to capture different climate zones and different hydro-meteorological conditions within the Europe and finally the selected catchment need to have the required data available.

The Stille Oder river, also known as Mucker, is a former branch of the Oder River. It is located in the north-east part of the federal state of Brandenburg in Germany, as part of the Oderbruch, a former delta of the Oder river. Today, the Oder’s main channel is restrained to the eastern edge of the depression, and the remnants of the former branches bear designations like the Stille Oder. Approximately 86% of the basin area consists of non-irrigated arable land, with another 11% of pasture, 3% of discontinuous urban fabric, and the remaining consisting of small percentages of agricultural land with significant areas of natural vegetation, broad-leaved and coniferous forests, inland marshes and water courses [50]. The Oderbruch suffered from heavy flooding in 1785, 1838, 1947, 1981/82, 1997, and 2010, the most recent event reaching a water level above 7 m due to rainfall of up to 200 l/m^3 [60].

The Pysznica River basin is a right tributary of the Parsęta River located in the north-west of Poland. Dominant types of land use in the catchment include agricultural areas (74%), which is mainly non-irrigated arable land, pastures, complex cultivation patterns, and land principally occupied by agriculture, with significant areas of natural vegetation). Complementary types of land use are broad-leaved, coniferous and mixed forests (24%) and discontinuous urban fabric (2%) [50]. According to Polish maps of flood risk and flood danger [61], flood risk on the Pysznica river catchment is low; however, it is assumed it will increase significantly over the next 10 years.

The Vipava River catchment (upstream of the Miren discharge gauging station) is located approximately 1 km before the border with Italy and 2.5 km before the confluence with the Soča River. The annual maximum discharge at the location of the Miren station can be as much as 400 m^3/s, while minimum annual flows can be less than 1 m^3/s [49]. Thus, the difference between minimum and maximum flows is quite large, which is a consequence of rainfall generation mechanisms in the area where extreme rainfall events are relatively frequent. Forest covers approximately 65% of the Vipava River catchment and agricultural areas around 32%, while urban areas represent approximately 3% of the total area [50]). Since the climate is Mediterranean, the agriculture is well-developed in the area and at specific locations supported by irrigation systems.

The Lea River basin, located in Galicia (North-western Spain), is a tributary of the Miño River in the upper part of the basin. The river catchment is associated with complex cultivation patterns (38%), forests and semi natural areas (59%), land principally occupied by agriculture (1.5%) and artificial surfaces (1.5%) [50]. According to Spanish maps of flood risk [61], it exhibits a medium risk of flooding for the lower basin and a very low risk for the upper river basin. Therefore, it would not change its level of risk for the next 10 years.

Figure 1. Location of the studied basins: A) Stille Oder, B) Pysznica, C) Vipava, D) Lea

5. Costs and benefits

Costs related to flood damage can be all assigned to agent 2, since according to the flood maps, the risk of flooding only occurs in the downstream part of the river basin. Agent 1's strategy for initial land use is defined as the initial state where none of the costs or benefits appear. The flood risk has not been reduced, no costs are incurred, and the payoffs are normalised to zero. Payoffs for agent 1's forest strategy constitute the difference between flood damage before and after land use change. The total benefit derived from land use change has been assigned to agent 1, as all activities related to change of land use are undertaken only in the upstream part of the basin.

A cost–benefit analysis has been conducted for a time period of 100 years, which means the most important aspects (described in the following) can be captured. Notice that money in the present is worth more than the same amount in the future because of both inflation and earnings from alternative investments that could be made during the 100-year period. For

example, any investor would prefer to get 100 € today than 100 € next year. We expect, however, that there is an amount (e.g. 105 €), so that an average investor would be indifferent between obtaining 100 € today and 105 € next year. In that case, we say that that the money has a yearly discount rate of 5%. In the economic literature, a standard way to compare cash flows in different periods of time is by the net present value (NPV), which represents the value inflows in present currency.
Concerning the discount rate for the analysis, the '*Guide to Cost Benefit Analysis of Investment Projects'* proposed a 5.5% discount rate for cohesion countries and 3.5% for other countries for the 2007–2013 period. However, taking a 100-year time horizon, the discount rate applied was 3.5% for all four basins. Similar values were adopted in other studies [48]. All costs and benefits were assigned to three main groups: (a) expected flood damage related to initial land use; (b) expected costs and benefits related to initial land use; and (c) expected costs and benefits related to land use change. These groups are presented in the following description.

(a) Expected flood damage for initial land use, including all the costs related to potential damage caused by flood both before and after land use change. Calculations (before land use changes) were conducted on the basis of global flood depth–damage functions developed by Huizinga et al. [22]. The damage curves depict fractional damage as a function of water depth as well as the relevant maximum damage values for specific assets and land use classes. Damage curves and maximum damage values were adjusted for local circumstances for each of the four analysed basins. Flood extent was attributed following the flood maps. Equation 1 displays the formula for calculating expected damage for initial land use.

Equation 1.

$$T1 = A * D * M$$

where:
$T1$ = total damage [€]
A = area covered by specific impact category (Residential, Commercial, Industrial, Agriculture, Infrastructure) [ha]
D = damage function (adjustment for specific flood depth)
M = max damage (according to EU flood depth-damage functions) [€/ha]

Flood damage after land use change was calculated, based on the assumption of Salazar et al. [38] regarding the influence of afforestation on peak discharge reduction. Specific peak discharges for each basin were compared to the function defined by Salazar et al. [38] on the basis of case study analysis in different European hydro-climatological regions. Then, the flood damage after land use change was estimated, assuming the total damage would decrease by the same percentage as the peak discharge. Although this method does not allow for costs to be precisely specified, it is still possible to estimate the general tendency for how afforestation influences flood risk and flood damage.

(b) Expected costs and benefits related to initial land use.

The total benefit of initial land use was calculated using the NPV, and by including (i) potential benefit from harvested crops (Equation 2) defined as a generalised benefit from agricultural land, (ii) costs of land cultivation (Equation 3), and (iii) subsidies for agricultural activities. Equation 4 presents the formula for calculating the total benefit from initial land use. All three equations considers the discount rate for 100 years period, including the first year for which the initial costs, benefits and subsidies were defined.
Costs and benefits were considered only for part of the area that is meant to be afforested, located upstream.

Equation 2.

$$(1+d)$$
$$1/¿$$
$$¿$$
$$¿101$$
$$1-¿$$
$$T2=A*P*¿$$

where:
*T*2 = total benefit from harvests [€]
A = area cover by agriculture [ha]
P = price in 2020 [€/ha]
d = discount rate (3.5%)

Equation 3.

$$(1+d)$$
$$1/¿$$
$$¿$$
$$¿101$$
$$1-¿$$
$$T3=A*C*¿$$

where:
*T*3 = total cost of cultivation [€]
A = area cover by agriculture [ha]
C = cost of land cultivation in 2020 [€/ha]
d = discount rate (3.5%)

Equation 4.

$$T = T2 - T3 + S$$

where:
T = total benefit from initial land use [€]
*T*2 = total benefit from harvests [€]
*T*3 = total cost of cultivation [€]
S = agricultural subsidies [€]

(c) Costs and benefits related to land use change

The main assumption of the study is that the change of land use upstream would reduce flood risk and limit flood damage downstream. To assess the positive potential influence of land-use change, the costs and the benefits were analysed, including (i) cost of land use change and land cultivation after change, including one-off investment costs and land cultivation for the whole period of analysis (Equation 5); (ii) subsidies for afforestation; and (iii) benefits from harvesting (Equations 6 and 7). Equation 8 displays the formula for the total benefit from afforested land. Equations 6, 7, and 8 use the NPV that was also used in Equations 2 and 3. However, here the benefit flow total value of harvest is null during the first years and increases steadily until reaching the optimal flow in 10 years' time.

In just the same way as the case of initial land use, costs and benefits were considered only for the area that is meant to be afforested. The subsidies were not included for the Slovene case because afforestation is not governmentally supported. For Germany, Poland, and Spain, national and regional government support is provided, which includes one-off support for afforestation either care or maintenance bonus for a 5–20 year period.

Equation 5.

$(1+d)$

$1/¿$

$¿$

$¿101$

$1-¿$

$T4 = A*I + A*M*¿$

where:

$T4$ = total cost of land use change and management [€]

A = area meant to change land use [ha]

I = investment costs (once for the whole area) [€/ha]

M = management costs [€/ha]

d = discount rate (3.5%)

Equation 6.

$$T5 = NPV (A * W * P, d)$$

Equation 7.

$$T6 = NPV (A * P, d)$$

where $NPV(X,d)$ is the function used to compute the NPV depending on the value of the 100-year cash flow (X) and the discount rate (d = 3.5%), and where:

$T5$ = benefit from harvests for Poland and Germany [€]

$T6$ = benefit from harvest for Slovenia and Spain [€]

A = area covered by forest [ha]

W = amount of wood [m^3/ha]

P = price of wood [€/m^3] or [€/ha]

Equation 8.

$$TF = T5 - T4 + S \quad \text{or} \quad TF = T6 - T4 + S$$

where:

TF = total benefit of land use change [€]
*T*4 = total cost of land use change and management [€]
*T*5 = benefit from harvests for Poland and Germany [€]
*T*6 = benefit from harvests for Slovenia and Spain [€]
S = subsidies [€]

6. Results

Due to defined flood risk in each of the analysed regions, the damage caused by flood events were estimated as input data for the game theory model. The differences in total damage values for each basin are related to the land use structure, the area of flooded land, and the depth of flood. The results of calculations for flood damage before land use change (Equation 1) are presented in Table 2.

Table 2. Flood damage related to initial land use

Damage class	Damage (million €)			
	Stille Oder (Germany)	Pysznica (Poland)	Vipava (Slovenia)	Lea (Spain)
Residential buildings	0.091	0.143	50.315	0.244
Industrial buildings	-	-	26.916	1.242
Agriculture	10.719	0.323	0.246	0.071
Infrastructure	0.010	0.048	1.708	0.064
Total	**10.820**	**0.514**	**79.185**	**1.621**

The highest costs in the Vipava River basin (Slovenia) reflect the significant area covered by residential and industrial buildings, for which the highest maximum damage values were defined. The Stille Oder basin costs were mostly derived from agriculture as this comprises almost 95% of land use. Relatively small damages counted for the Lea river basin (Spain) are related to the area least endangered by flood risk of all the analysed basins. The least damage quantified for the Pysznica River basin (Poland) are the results of the small water depth and the high percentage of land covered by agricultural areas.

The results of cost–benefit analysis are the payoffs of the game for each agent in case of two undertaken strategies. The results of game theory model application and payoffs for each agent in the four analysed basins are presented in Table 3.

Table 3. The share of costs and benefits (million €)

	Stille Oder (Germany)	**Pysznica** (Poland)	**Vipava** (Slovenia)	**Lea** (Spain)
The benefit for agent 1 if does not change the land use *(A)*	51.522	5.303	0.506	1.620
The benefit for agent 1 if does change the land use *(F)*	30.955	12.667	-5.209	9.944
Benefit from flood damage decrease if agent 1 change the land use *(B)*	1.407	0.093	1.822	0.073
The worth of agent 1 without cooperation (w_1)	51.522	12.667	0.506	9.944
The worth of both agents when they cooperate (w_{12})	51.522	12.760	0.506	10.017
Payoff allocation (x_1)	51.522	12.667 + 0.093d	0.506	9.944 + 0.073d

Differences between the benefits from initial land use for each basin are related to the area covered by agricultural land, the type of crop, and possible subsidies for agricultural activities. The difference in the total benefit between Germany and the other countries is mainly related to the fact that almost 95% of the basin area is covered by non-irrigated arable land. However, this result is only achieved with the help of state payments (decoupled farm payment, compensation payments, and subsidies).

Differences in the benefits of land use change are influenced by relatively high subsidies for afforestation in Germany and a lack of them in Slovenia, which is depicted in Table 4 (results of the application of Equations 2 and 3).

Table 4. Benefit from land use change (million €)

	Stille Oder (Germany)	Pysznica (Poland)	Vipava (Slovenia)	Lea (Spain)
Cost of land use change and land cultivation	3.714	5.605	9.744	1.908
Subsidies	10.017	4.362	-	2.868
Benefits from harvesting	24.652	13.910	4.536	8.984
Total benefit	30.955	12.667	-5.209	9.944

Possible benefit distribution was analysed to assess the possibility of land use change. Table 5 presents the information about possible land use change and the transfer that agent 2 should make to agent 1 for compensation for land use change.

Table 5. Benefit transfer and possible land use change (million €)

	Stille Oder (Germany)	**Pysznica** (Poland)	**Vipava** (Slovenia)	**Lea** (Spain)
Land use change	No	Yes	No	Yes
Transfer more favourable to agent 1	-	0.093	-	0.073
Transfer more favourable to agent 2	-	No transfer	-	No transfer
Compromise deal	-	0.0465	-	0.0365

According to the information presented in Table 5, it was assumed that land use change in the Stille Oder (Germany) and Vipava (Slovenia) river basins is not a probable scenario. For both upstream and downstream players, land use change is unfavourable and no benefit is obtained. Therefore, the analysis of possible benefit transfer was performed only for the Pysznica (Poland) and Lea (Spain) river basins. In both cases, the benefit transfer direction from downstream to upstream agent is presented and the compromise deal constitutes a transfer of 0.0465 and 0.0365 million € (for Poland and Spain, respectively), which would gratify both players in the basin. Note that the compromise deal constitutes the half of the transfer more favourable to agent 2 (from agent 1). It is also the half of the benefit from flood damage decrease if agent 1 change the land use. According to above the compromise deal is directly related to avoided damages caused by flood that appears downstream when upstream agent decides to change the land use.

7. Discussion

The main aim of this study was to investigate the potential cooperation between decision-making process participants to distribute the total costs and benefits related to land-use change that leads to flood risk reduction. The findings of the analysis depict that in two of four analysed river basins it is possible to find a mutually beneficial compromise among landowners for flood-risk reduction if land-use change (afforestation) is economically reasonable for both agents.

This study offers a methodological contribution to establishing and applying distribution rules for sharing the benefits and the costs related to flood-risk reduction and land-use change.

The chapter presents the results of the application of a game theory model on four European basins, offering the first empirical approach to the theoretical model. Therefore, analysis was based on a number of assumptions. First, flood damage (both before and after land use change) was estimated rather than precisely modelled. Although the applied method does not allow direct specification of the costs, it is possible to estimate the general tendency for flood damage change. This simplification may influence the final result of the analysis; therefore, it is recommended for future analysis to apply combined hydrological and hydraulic models to accurately define the losses caused by flood events. Second, this work applies to only one scenario and a 100-year time horizon. Multiple scenarios, assuming different time spans, different land uses, or a different course of afforestation could enrich the analysis.

Third, this analysis relies on two players. As a future line of research, the number of players included in the game theory model could reflect the number of landowners in the basins, as this would imply a more complex model and consequently more precise results. However, this would require detailed land ownership structure analysis and adaptation of the model to account for local conditions. It should also be underlined that subsidies play a crucial role in the structure of costs and benefits, and local or national governments should be considered as a separate agent.

Fourth, cost–benefit analysis (CBA) could be extended by ecosystem co-benefits or regulating services like water quality improvement provided by reforestations. Game theory has significant potential in the field of water quality changes and transportation of pollutants during flood events. For example, Alcalde-Unzu et al. [2] use the clean-up cost vector to estimate the transfer rate of the waste in a polluted river. They use estimation to share of cost of cleaning the river. On the other side Wei and Luo [64] focuses on how to reach a balance between the sustainable development of local economy and the effective protection of water resources from an ecological perspective for the local government, and how to maximize the profit of the local firm in an ecological compensation system. Besides a reduction in the risk of flooding, afforestation entails several other benefits, such as improving the landscape and the environment, and providing a source of income for forest owners. The payment for environmental services (PES) can be considered a method to incorporate services provided by the environment into calculations of costs and benefits. Moreover, PES could encourage forest owners to maintain or implant forests by compensating them at equivalent or better rates than other activities that would otherwise provoke deforestation [10]. Thus, owners who are located in strategic areas for flood risk reduction (such as upstream) may consider reforestation as a viable alternative for land use. PES can be estimated through game theory and can be considered a way to assess and plan an efficient forest policy.

A possible negative aspect is that if reforestations are carried out without planning it is possible that the flow of a river is reduced (even disappearing) in regions where there are water shortages. Therefore, it is important to consider the impact on regional water availability. Bentley and Coomes [6] point out that afforestation of lands previously degraded by agriculture helps to repair the soil, enabling it to retain more water and reduce the flow of the nearby river. If this action were carried out in natural grasslands where the soil is in good condition, the flow of the river would be considerably reduced.

Within the planning and management of these reforestations, and taking into account the criteria of improving the water quality, one strategy commonly advanced to achieve this goal is the management of riparian vegetation [1]. Several studies have documented that riparian forest can strongly influence the chemical content of adjacent streams [37, 43], particularly through the removal of nutrients in runoffs from agricultural uplands [12]. Therefore, vegetation restoration and management in riparian areas is widely recommended and promoted, especially in agricultural areas [34], but also in those areas of medium-high risk of flooding. In the four basins in this study, a restoration of the riparian vegetation could be planned (both in forest areas and in those lands for agricultural use) and framed within the proposed reforestation. Accordingly, the ecosystem services of riparian vegetation can be helped through the improvement of chemical water quality in streams, while reducing the risk of flooding in these areas. Conversely, the managed change of agricultural land to forest cover proposed in this study is recommended to address the issue of high nitrate in groundwater, ensuring good quality groundwater in the long term [47]. This would lead to savings in the treatment of drinking water, since Lopez et al. [26] have found a positive and significant effect of local forest cover on water treatment cost savings. Although this study does not focus on the specific benefits that changes in land use can generate in water quality, it implies that such effects can be highlighted.

8. Conclusion

The chapter presents an application of the game theory concept to four catchments located in parts of Europe with diverse climate characteristics. The investigation revealed that in two of four cases (Poland and Spain) mutually beneficial compromise between landowners to change land use (afforestation) could be detected, while Germany and Slovenia would not benefit from such a change, due to the considerable influence of subsidies.

Presented results reflect the possible direction for further actions in compensation for establishing new flood protection measures, however the undertaken scope of analysis, based on several assumptions such us limited number of agents and simplified flood risk assessment could influence the results. We recommend further, investigations using a larger number of agents and more detailed analysis (e.g., more detailed definition of the flood risk before and after afforestation or investigation of other measures) in order to enhance the knowledge about the upstream-downstream relationship in the flood risk management.

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