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Viewpoint

A black-box approach on assessing the opportunity cost of deforestation

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ABSTRACT

The paper presents a new concept on assessing the opportunity cost of land use changes based on differentiating the ratio between the economic loss produced downstream by floods and the catchment area where different land uses eventually have different runoffs. Having the shares of different land uses and their corresponding runoff coefficients, the average loss per hectare within the watershed is further broken down according to the same land uses types and an average loss per hectare, for each type of land use, is finally appraised. Ceteris paribus, any further changes between different land uses, under the same rainfall regime, are assumed to produce different 'virtual' total losses, according to the degree to which high runoff land utilizations would have been changed in low runoff land utilizations or vice versa. The economic reasoning of the method is also presented in the broader context of the opportunity cost theory and a case study demonstrates the readiness of the method.

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Introduction

Floods are quite common all over the world, being more or less associated with climate change (Kundzewicz et al., 2008; Milly et al., 2002); although they have been reported since bygone ages their frequencies are higher nowadays, being also correlated with deforestation processes (van Beukering et al., 2003; van Dijk et al., 2009). Therefore, the common sense wisdom says that planting new forests, or keeping the existing ones in upper catchment areas are cost-effective measures to prevent floods downstream provided that local communities living in the those areas are aware and acknowledge the important role played by the forests in flood mitigation. Being a matter of communication, some metrics are still needed to better explain the cause-effect relationships between land use (or land cover) changes, expected runoff, and floods that may occur downstream.

The correlation between land use changes and runoff have long been documented in literature (Crooks and Davies, 2001; Neris et al., in press; Rai and Sharma, 1998; Zhang et al., 2012), as well as the influence of forest cover on the runoff process, especially when large floods are common events (San Miguel-Ayanz et al., 2000; Sriwongsitanon and Taesombat, 2011; van Beukering et al., 2003; David et al., 2010; Niţă et al., 2011). In the broader context of climate change, Mander et al. (1998) analyzed the land use variations and their combined impact onto the runoff values, considering the warmer winters that typified the last four decades and the mean annual water discharges, while Bhuyan et al. (2002) tested and gauged, on a watershed located above a large reservoir in United States, a more complex model, able to predict the runoff and soil loss having known the land use and expected rainfall.

A meta-analysis carried out on the data provided by a large network of permanent plots produced quite accurate values for the soil annual loss, annual runoff and annual runoff coefficients, under different land uses, soil textures and rainfall (Maetens et al., 2012), which can be used to assess the impact of different land use changes across the Europe and Mediterranean area.

In Romania, an important synthesis of all forest hydrology studies was published in late seventies (Arghiriade, 1977). Quite recently the connection between forest land use and runoff was thoroughly explained in a study concerning the water retained by crowns, trees' bark, and litter in four watersheds under different rainfall intensities (Miţă and Mătreaţă, 2008). Kuemmerle et al. (2009) documented the land use changes produced between 1990 and 2005 In Romania with Landsat images, and the only significant alteration was reported for cropland, due to the high rate of abandonment on marginal lands. However, a study carried out on the Tisa watershed, based on similar satellite images taken at sub-catchments level, showed that the forest land use decreased between 1993 and 2001 with 10–20% (Dezso et al., 2005); this process, combined with heavy rainfalls brought about serious floods in the area.

Another aspect that needs further discussion are the runoff coefficients themselves: the method employed and the input data may produce different results, depending on how many criteria are used to differentiate the coefficients. Starting with a research paper

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Table 1
Surface distribution across land uses, slopes and soil texture in Suha watershed (hectares).

Land use	Soil texture	Slope category			
		<5%	6–10%	11–30%	>30%
Forest	Sandy	110.63	195.20	2769.17	5015.60
	Loamy	195.42	520.70	8745.72	8491.57
	Clayey	306.63	1.755	69.84	280.12
Pastureland	Sandy	51.56	70.68	475.15	513.38
	Loamy	37.78	95.85	2004.93	1672.77
	Clayey			11.21	11.68
Cropland	Sandy	412.29	211.89	257.69	159.75
	Loamy	499.44	604.81	1985.20	849.82
	Clayey	0	0	0	0

produced in 1997, which demonstrated the functional dependency between soil loss and the density of vegetation cover (Morgan et al., 1997) numerous studies were focused on this very narrow but important issue. As demonstrated, the connection between land cover and runoff depends to a great extent on the rainfall regime and soil moisture (Sriwongsitanon and Taesombat, 2011), which makes any flood prediction more difficult, especially when different slopes are considered (Martinez-Murillo et al., 2013).

The rainfall regime influences runoff and erosion through multi-annual water discharges and average duration of floods, as demonstrated by a long-term study carried out in China (Fang et al., 2012; Peng and Wang, 2012). In Germany, a series of field experiments investigated the runoff differences between an old forest and a newly installed forest plantation and demonstrated that forest soils have a higher porosity and higher water conductivity rate beneath old stands of trees than beneath young plantation; consequently the surface runoff is smaller under mature forest than under newly established forest (Humann et al., 2011).

From a black-box perspective, a watershed is an area wherein the rainfall is the input while the outputs are the evapotranspiration, the water flow, the leakage to water table, and the accidental floods produced downstream. Simplifying more and changing the viewpoint, the loss produced downstream depends on the land use pattern, all other things (rainfall regime, leakage and evapotranspiration) being the same.

Materials and methods

Pilot area

Suha watershed, where the method was tested is located in the northern part of Romania, in the county of Suceava (see Fig. 1) and encompasses 36,322.31 ha. The forests (where Norway spruce is the main species) stretch over 70% of the total area, while the pastureland and agriculture land equally share the rest of the area. Typically for mountainous area, the pasturelands are to be sought on edges and plateaus, and cropland nearby settlements. The land uses, soils and slope distribution across the pilot area is presented in Table 1. The terrain configuration is pretty rugged, with steep slopes. Except for the small town of Frasin, the small hamlets of the two communes in the area are scattered along five valleys and are somewhat underdeveloped due to poor infrastructure; however their tourist potential is better and better managed since this small basin is crossed by a county road connecting two densely populated zones on both sides of the eastern chain of Carpathians.

Fig. 1. Location of the Suha watershed.

The floods in the pilot watershed have been recorded since 1998 as well as the damages they produced. The total losses were assessed by the local authorities and further reported to the Inspectorate for Emergency Situations. All economic losses, expressed in Romanian currency, have been updated to July, 2012 prices and discounted at 6% per year, as shown in Table 2.

Main assumptions supporting the assessment method

In economics the opportunity cost is the revenue forgone when a factor of production is withheld or gets an alternative use (Price, 1991); it could also mean an avoided loss, as happened in case of healthcare programs (French et al., 2002) or avoided carbon emissions (Damnyag et al., 2011; Golub et al., 2009). The decision to change the forest use of land for a short period of time (i.e. clear cutting) or indefinitely (deforestation) has an opportunity cost, which means more floods, under the same rainfall regime.

Now, assuming that a hypothetical watershed, featuring the same slope and soil texture, had been used only for pastureland, the flood produced downstream would be homogenously generated throughout the whole catchment area, and the average loss per hectare would be the same. But in real situations, due to different land uses, slopes and soils textures, the terrain has different runoff coefficients and it makes sense to differentiate the average loss according to these coefficients, considering that a higher runoff, combined with a larger area, brings about 'more' flood. The loss breaking-down model developed in this study was inspired by the procedure employed by the Romanian National Forest Administration[1] to differentiate the average reserve price of stumpage into 800 different prices, corresponding to 16 species, five grades, five categories of hauling distances and two types of products (main yield and secondary yield).

[1] The main author of this article had implemented and improved this procedure between 1993 and 2001, when the stumpage market was completely liberalized. Before 2001 the National Forest Administration had been bargaining the stumpage price with timber industry representatives and the whole procedure, including the calculations behind, had to be supervised and approved by the Romanian Competition Council.

Table 2
Flood history and economic loss produced in Suha watershed.

Affected localities	Flood date or period	Price index as of July, 2012	Economic loss (Euro) in prices updated to July, 2012								
			1998	1999	2002	2006	2007	2008	2010	2011	Total
Ostra, commune	May–June 2011	1.0264								166,573	166,573
	June–August 2010	1.0775							1,439,444		1,439,444
	July 24 2008	1.2156						1,381,178			1,381,178
	August 2007	1.3142					549,043				549,043
Stulpicani, commune	June–August 2010	1.0775							493,219		493,219
	May–June 2010	1.1078							547,144		547,144
	July 24 2008	1.2156						4,843,219			4,843,219
	August 2007	1.3142					359,506				359,506
	May 2007	1.3312					1183.29				1183.29
	July 30, 2006	1.3784				707,578					707,578
	July 29, 2002	2.0599			91,551						91,551
Frasin (small town)	June–August 2010	1.0775							587,769		587,769
	May–June 2010	1.1078							443,848		443,848
	July 24, 2008	1.2156						333,020			333,020.37
	May 2007.	1.3312					1,583,993				1,583,993
	July 30, 1999	4.8285		2,146,000							2,146,000
	July 22, 1998	7.1772	63,797								63,797.33
Total economic loss in current prices			63,797	2,146,000	91,551	707,578	2,493,726	6,557,417	3,511,426	166,573	15,738,071
Present economic loss (6%)			144,239	4,577,264	163,954	1,003,713	3,337,168	8,278,588	3,945,438	166,573	21,616,941

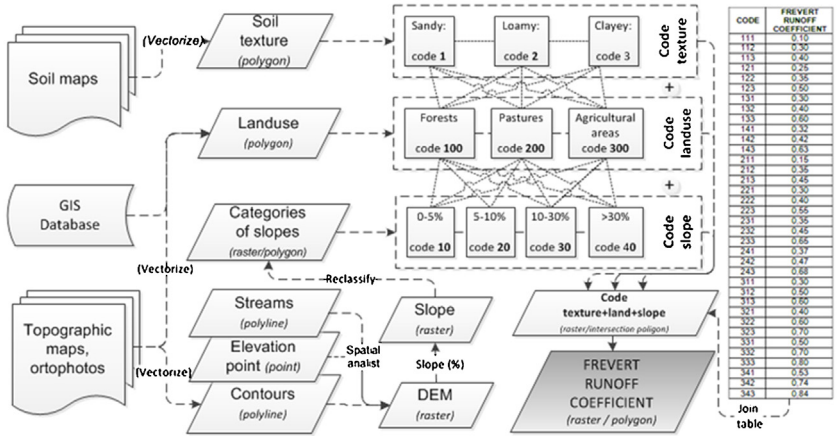

Fig. 2. Flowchart of computing runoff coefficients according to Frevert method.

Because the aim of the study is to evaluate an annual opportunity cost of changing the forest land use, the first operation required is to assess an average flood damage cost per year (L) brought about by floods at watershed level, using relation (1)

$$L = \frac{\sum_{j=1}^{m} d_j (1+p)^{m-j}}{m} \tag{1}$$

where m is the time frame of flood records, p is the discount rate and d_j is the loss produced by floods in year j.

For sake of text simplicity, further we will be using 'land use' for any plausible combination of land use, slope and soil texture. Now the average annual social loss, divided by the total area of the watershed turns into an average social cost per year and hectare (l), which further can be broken down into n values, each corresponding to a given land use, according to the double equality (2)

$$L = l \cdot A = \sum_{i=1}^{n} c_i \cdot a_i \tag{2}$$

where A is the total area of the watershed (in hectares), c_i is the unknown social cost per year and hectare associated to land use i, while a_i is the area of land use i (also in hectares). It also holds to consider that

$$c_i = l \cdot k_i \qquad i = \overline{1, n} \tag{3}$$

where k_i is a proxy of the contribution brought by the land use i to the social cost l; it given by relation (4)

$$k_i = \frac{r_i}{\sum_i r_i \cdot s_i} \tag{4}$$

where r_i is the runoff coefficient corresponding to land use i, while s_i is the share of land use i.

Combining the first equality of condition (1) with the relations (3) and (4) we have

$$c_i = \frac{L}{A} \cdot r_i \cdot \sum_{i=1}^{n} r_i \cdot s_i \quad i = \overline{1, n} \tag{5}$$

The next step is to conceive one or many land use change scenarios: increasing (or decreasing) some land uses, one may have new areas a_i' and we may also assume the expected total loss (L') would have been:

$$L' = \left(\frac{R'}{R}\right) \sum_{i=1}^{n} a_i' \cdot c_i \quad i = \overline{1, n} \tag{6}$$

where R' is the new average runoff coefficient of the whole basin, corresponding to the new hypothetical land use distribution, while R is the baseline average runoff coefficient.

Now the marginal opportunity cost per year and hectare of land use change (E) is given by relation (7)

$$E = \frac{(L' - L)}{\Delta a} \tag{7}$$

where Δa is the area that goes from low runoff land use to higher runoff land use.

Runoff coefficients

When it comes to runoff assessment, the benchmark method is Soil Conservation Service Curve Number (SCS-CN), which takes into account not only a larger range of land uses but also the soil moisture before the rainfall, which had produced the flood (Zhan and Huang, 2004). However, according to Romanian technical standards in water protection, the runoff coefficients are estimated by Frevert method (Frevert, 1953). In spite of its limitations regarding the few input data (three land uses, four categories of slope and three soil textures), this empirical method was used just for demonstrating how runoff coefficients can be employed to assess the flood control ecosystem service; as a matter of fact, the decision to use either SCS-CN or Frevert method depends on how detailed the available digital maps are.

The area distribution across land uses, slopes, and soil textures is presented in Table 1 and Fig. 3a and the runoff coefficients were produced by a GIS tool, obeying the flowchart shown in Fig. 2. According to Frevert's procedure, a numerical code is assigned to each type of soil, land use and slope and each combination of codes corresponds to a certain runoff coefficient. The spatial distribution of runoff coefficients is presented in Fig. 3b.

Land use change scenarios

The three scenarios that have been tested considered that some forest might have been removed nearby the existing settlements (villages and hamlets) in order to enlarge the agriculture land, which is quite plausible without a strong legal framework in place. The only difference between the three settings is the width of the

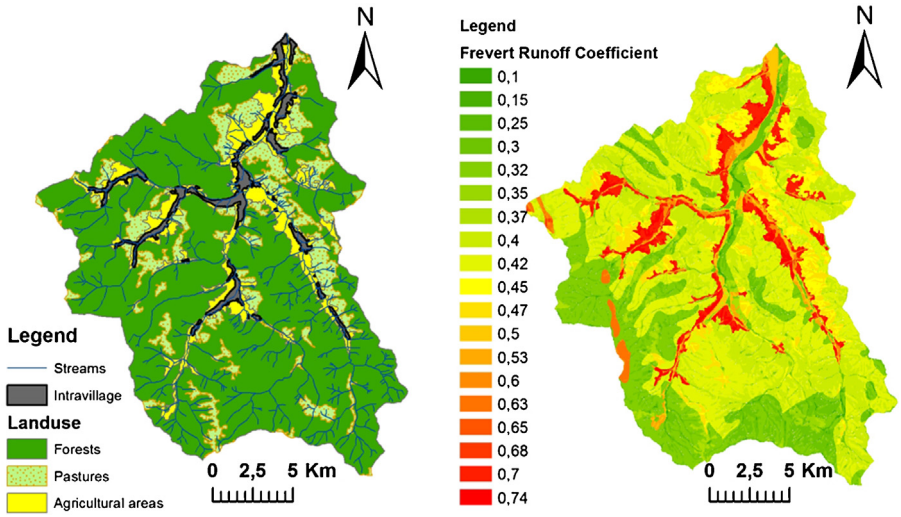

Fig. 3. (a) Land uses across Suha watershed. (b) Frevert runoff coefficients mapped on Suha watershed.

band within the forest use was changed: 250 m, 500 m and 700 m around each locality.

The three delineations are presented in Fig. 4 and they were produced by the ArcGIS buffer wizard. Although these hypothetical new boundaries are erroneous in many situations, on long tern they are realistic, because the most of the forests are in private ownership. Having the new pattern of land uses, the steps describes in the prior section were pursued.

Results

Floods' history in pilot area and damage assessment

Having the total loss produced in the last 14 years, the first calculations consisted in updating the worth of the damages reported by local authorities. The general price indices were collected from yearbooks, and the total present value of all damages produced by floods is presented in the right-bottom cell of Table 2. All reported events occurred in summer and the most serious damages were produced between 2006 and 2010. The damages recorded in the last but one line of Table 2 exceeded two million Euros in 1999, 2007, 2008 and 2010, while the longest period without floods lasted five years, between 2002 and 2006. The opportunity costs per year and hectare, corresponding to all possible combinations of land uses, soil textures and slopes, are presented in Table 3. These costs were plugged into relation (6) allowing further sensitivity analyses, corresponding to possible scenarios of land use changes.

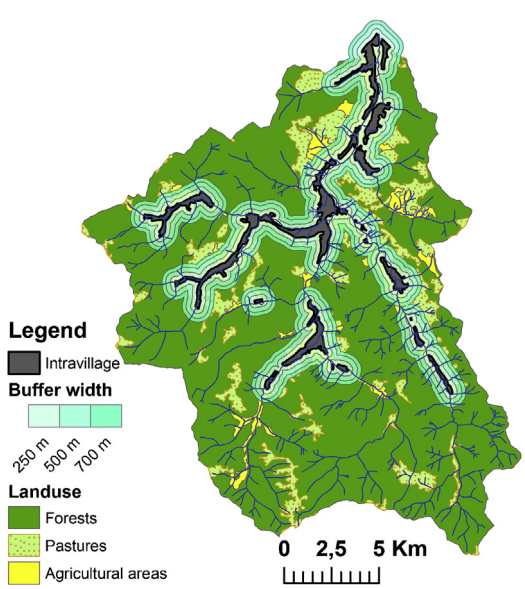

Fig. 4. Three scenarios of land use changes from forest to cropland.

Land use change sensitivity analysis

The assumption that changing the land use would have produced more floods than actually had happened was tested using the three scenarios already described. The most important values describing the outcomes of each scenario are summarized in Table 4. Since the key factors are the runoff coefficients, their averages, at four digits accuracy, are also presented and one may notice that, in relative values, although the forest use diminished with more than 10% from the baseline to the worst scenario, the corresponding runoff yet slightly increased. Instead, the average runoff for cropland increased. Nothing happened with the pastureland, because it was excluded from sensitivity analysis for the simple fact that pasturelands are too far from existing settlements. Because the cropland use is a substitute for all uses with higher runoff coefficients, like roads and constructions, the assessments presented in Table 4 could be considered conservative.

Table 3
Opportunity cost of preserving actual land use in Suha Watershed (€/year/hectare).

Land use	Soil texture	Slope			
		<5%	6–10%	11–30%	>30%
Forest	Sandy	10.07	25.17	30.20	32.22
	Loamy	30.20	35.24	40.27	42.28
	Clayey	40.27	50.34	60.41	63.43
Pastureland	Sandy	15.10	30.20	35.24	37.25
	Loamy	35.24	40.27	45.31	47.32
	Clayey	0.00	0.00	65.44	68.46
Agriculture	Sandy	30.20	40.27	50.34	53.36
	Loamy	50.34	60.41	70.47	74.50
	Clayey	0.00	0.00	0.00	0.00

Table 4
Sensitivity analysis and marginal opportunity costs of changing the forestland into cropland.

Scenario	Average runoff coeff.	Average runoff on land use...			% of land use...			D'/D	Marginal opportunity cost (€/year/ha)
		Forest	Pasture-land	Crop-land	Forest	Pasture-land	Crop-land		
Baseline	0.4187	0.3799	0.4328	0.6130	72.9%	13.5%	13.6%	1.000	
250 m	0.4243	0.3799	0.4328	0.6172	70.7%	13.6%	15.7%	1.005	3.70
500 m	0.4366	0.3794	0.4328	0.6296	66.4%	13.6%	19.9%	1.034	10.23
700 m	0.4522	0.3785	0.4328	0.6402	61.0%	13.6%	25.4%	1.071	12.34

Discussion

As expected, the main concern is the accuracy and the reliability of input data. The first source of errors, which has deterred us from downscaling the analysis to sub-basin level, is the administrative delineation of the localities, which does not overlap the sub-basin delineation. It means that a certain pixel may physically fall into a sub-basin but, from administrative point of view, it belongs to an administrative unit which falls in another sub-basin or even in a different watershed. This is the case with the town of Frasin, which is located on the confluence of Suha and Moldova River (see Fig. 1), and one may assume the flood produced here in 1998 is also a consequence of land use changes produced elsewhere, upstream Moldova River. Nevertheless, on much larger watersheds this problem can be easily overcome because each sub-basin has its own average runoff coefficient (R) and the total loss can be broken down twice: firstly, on sub-basins, according to their areas and average runoff coefficients, and secondly within each sub-basin, on land uses, as this case study demonstrated.

As suggested in some of the quoted articles, the runoff process and its quantification are also debated issues. For our purpose, the SCS-CN method will yield more accurate estimations, because the floods brought about by extreme rainfalls on soils that had already reached the field moisture capacity shall be ruled out from analysis. This opportunity was demonstrated by a Monte Carlo simulations carried out on ten alpine catchments in Tyrol, where differences produced by two flood assessment methods were analyzed (Rogger et al., 2012).

Assessing the economic loss is another questionable issue; in our study we actually took for granted the damages reported by inhabitants to local authorities, and this information could be extremely biased. Integrated models, based also on GIS tools, like the ones developed for the Netherlands (Jonkman et al., 2008), Japan (Dutta et al., 2003), Italy (Oliveri and Santoro, 2000), or Malaysia (Shattri et al., 2004) are important for implementing flood prevention measures within local and regional development policies and public awareness programs.

In EU countries harmonizing the spatial data infrastructure is hopefully pursued by member states due to the INSPIRE Directive, assumed to facilitate the implementation of Water Framework Directive (del Campo, 2012), even though a lot of formal and informal barriers are still deterring researches on water management (Beniston et al., 2012). This directive is important for this kind of studies, able to produce valuable information from small amount of data, providing that digital maps have been produced in a consistent manner over much larger areas than a small watershed.

Theoretically, a last questionable issue is the extent to which averaging present values of losses produced in the past is consistent with the economic theory. In our study we considered the latest floods occurred after 1998, discounted at 6% per year, which could be considered an arbitrary rate of interest. It makes sense to discount the damages produced during a certain period of time but, if that period is too long, the present loss per year has lesser sense. Without discounting, the opportunity cost of the capital lost would have been zero, which makes no sense, since the assets destroyed by floods had been somehow replaced and the money spent would have had a different destination. Actually, the only reason for averaging along a period of time the losses produced by floods is the need for having an opportunity cost per year, which conveys a baseline for any economic instruments needed: subsidies for afforestation, fees for land use changes, or compensations for giving up clear-cuttings.

Conclusions

First of all, the black-box approach presented in this paper is straightforward and easy to be applied on large watersheds, wherein the inconsistencies produced by mismatched boundaries of sub-basins and localities can be ignored, since the whole watershed is considered a unique black-box, where the rainfall is the input and flood damage the output.

The differentiation technique this study came up with could disappoint those who expect more money per year and hectare for flood control ecosystem service, but the outcome depends both on the size of the catchment area considered and how many floods had been recorded. Being related to the land use pattern, such analyses could be better integrated in studies aiming a much larger scope, as required by the land-use-land-use-changed-to-forestry (LULUCF) reports, which are so important in mitigating the green house effects (Khatun, 2012; Schlamadinger et al., 2007).

Another field of interest, where such studies might be useful, is the forest management itself, namely the cost–benefit analysis on reducing the rotation of Norway spruce forests, where clear cuttings are the best compromise between economic and ecologic concerns. Since a shorter rotation means a larger annual felling area, a certain economic loss produced by future floods could be estimated, and that loss will be summed up to other ecosystem services that would be deteriorated from more intensive logging. The same outcome, or even worse, might have a large windthrow or a forest fire, and the method can also produce a better evaluation of the side effects produced by such natural disasters. Basically, the land planners have a very simple tool to estimate the worth lost downstream when the upstream land use pattern is being altered from land uses with low runoff to land uses with high runoff, like agriculture and whatever constructed areas (buildings, highways, parking lots and alike). Conversely, decisions to increase the forest area may be better supported by such analyses.

All in all, taking for granted that climate change is ongoing, the 'marginal' role played by forests in reducing the damages produced by floods is more important, and studied like this, carried out on larger areas, could support awareness campaigns on non-structural measures against floods (Harries and Penning-Rowsell, 2011).

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