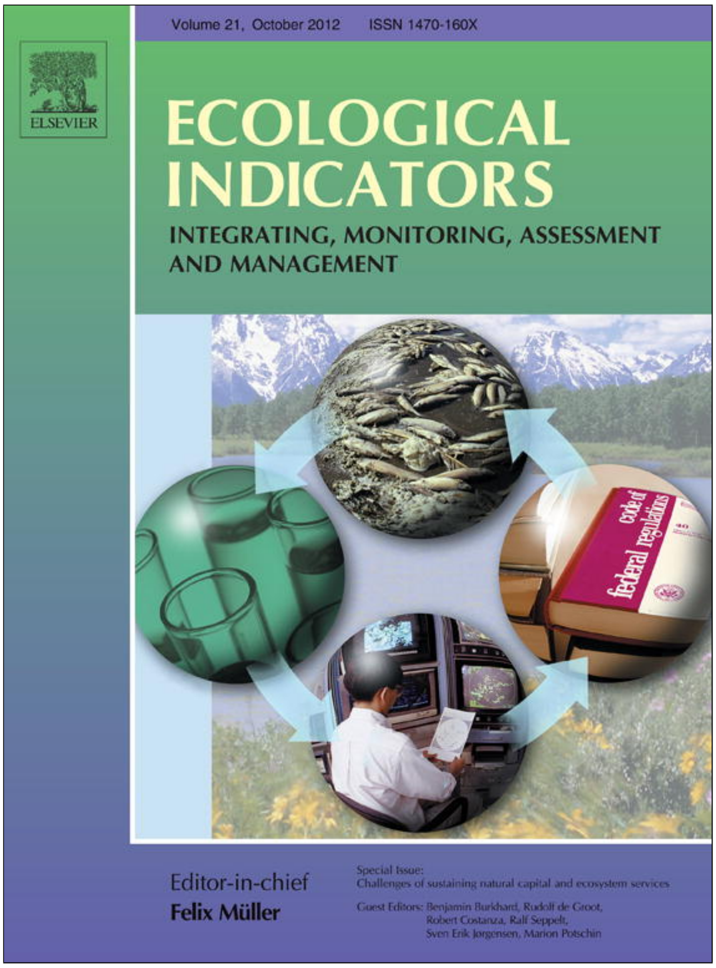
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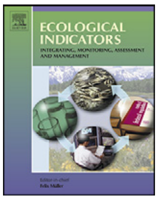

Flood regulating ecosystem services—Mapping supply and demand, in the Etropole municipality, Bulgaria

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ABSTRACT

Floods exert significant pressure on human societies. Assessments of an ecosystem's capacity to regulate and to prevent floods relative to human demands for flood regulating ecosystem services can provide important information for environmental management. In this study, the capacities of different ecosystems to regulate floods were assessed through investigations of water retention functions of the vegetation and soil cover. The use of the catchment based hydrologic model KINEROS and the GIS AGWA tool provided data about peak rivers' flows and the capability of different land cover types to "capture" and regulate some parts of the water. Based on spatial land cover units originating from CORINE and further data sets, these regulating ecosystem services were quantified and mapped. Resulting maps show the ecosystems' flood regulating service capacities in the case study area of the Malki Iskar river basin above the town of Etropole in the northern part of Bulgaria. There, the number of severe flood events causing significant damages in the settlements and infrastructure has been increasing during the last few years. Maps of demands for flood regulating ecosystem services in the study region were compiled based on a digital elevation model, land use information and accessibility data. Finally, the flood regulating ecosystem service supply and demand data were merged in order to produce a map showing regional supply-demand balances. The resulting map of flood regulation supply capacities shows that the Etropole municipality's area has relatively high capacities for flood regulation. Areas of high and very high relevant capacities cover about 34% of the study area. The flood regulation ecosystem service demand map shows that areas of low or no relevant demands far exceed the areas of high and very high demands, which comprise only 0.6% of the municipality's area. According to the flood regulation supply-demand balance map, areas of high relevant demands are located in places of low relevant supply capacities. The results show that the combination of data from different sources with hydrological modeling provides a suitable data base for the assessment of complex function–service–benefit relations.

1. Introduction

Ecosystems regulate essential ecological processes and life-supporting systems through bio-geochemical cycles and other natural processes (Daily, 1997; de Groot et al., 2010). The concept of ecosystem goods and services proposes an appropriate methodological framework to analyze these relations. Therefore, ecosystem services have become a very popular scientific topic, especially during the last two decades (Burkhard et al., 2010). The Millennium Ecosystem Assessment defined ecosystem services as "the benefits that people derive from ecosystems" (MA, 2005). de Groot et al. (2010) grouped them into the four broad categories: *provisioning services, regulating services, habitat or supporting services* and *cultural & amenity services*.

Besides a broad range of scientific publications about the further conceptualization of ecosystem services (Fisher and Turner, 2008; Boyd and Banzhaf, 2007; Chee, 2004), there is a clear lack of spatially explicit service assessments at regional, national and continental scales (Daily and Matson, 2008). Only few studies analyze the capacities of landscapes to supply services. But, resource managers need easily understandable, spatially explicit tools for management and trade-off decisions at landscape scales (Kienast et al., 2009). Therefore, we apply a spatially explicit concept that links biophysical conditions to ecological functions, ecosystem services and human benefits, using the example of flood regulation in a Bulgarian case study region.

1.1. Floods and flood regulation ecosystem services

Floods are among the most dangerous natural disasters that threaten large territories in Bulgaria (Nojarov, 2006). Mountain areas are even more vulnerable to that threat, because, they are

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formed in relatively small watersheds, the rivers' peak flows move very fast along the river bed. There are different kinds of floods and those which are typical for Bulgaria can be grouped in two main categories according to their formation:

i. rainy-fluvial floods are formed by torrential rains which cause rivers to rise quickly creating a significant overflow beyond the river banks and
ii. snow melting-fluvial floods producing the same effect but formed by both rains and melting snow.

The local authorities and civil defense organizations have limited options for reaction when such hazardous events occur. Therefore, flood prevention and mitigation measures are very important. The conventional practice is to build river protection dikes and other hydro-technical equipment in the vulnerable areas. But, the potential of natural landscapes to mitigate the negative effects of this extreme phenomenon is usually neglected (Jonkman et al., 2004).

If ecosystem services are the goods that people derive from nature, hazardous flood events are often considered as being part of the "bads", the ecosystem disservices (Lyytimäki et al., 2008). This is especially true in areas where people settled too close to water bodies or constructed their properties in previous flood plains. Additional problems arise when people actively modify water bodies, watersheds, or flood plains. Hence, most of the flood-related disservices are ecosystem functions created by human activities. On the other hand, flood protection is one of the most important regulating ecosystem services that may increase or reduce the negative effects of water-related disasters. In the ecosystem service classification scheme suggested by de Groot et al. (2002), flood-related ecosystem services are "flood prevention" and "drainage and natural irrigation". As related ecosystem processes and elements, "ecosystem structure's influence on dampening environmental disturbances" and "the role of land cover in regulating runoff and river discharge" are mentioned (de Groot et al., 2002). Forests especially provide natural hazard mitigation and water regulation services by reducing flood-danger, preventing damage to infrastructure and influencing water retention capacities (de Groot et al., 2010).

The human benefit of flood regulating ecosystem service provision is flood-damage mitigation and finally, the protection of human properties (Fisher et al., 2009; Boyd and Banzhaf, 2007). The latter being part of the demand side of ecosystem services. Fisher and Turner (2008) state that ecosystem services just contribute to other flood mitigation measures based on e.g. capital or dykes. In Chee (2004), flood regulation is based on "moderation of weather events, regulation of the hydrological cycle and maintenance of coastal and river channel stability" which all are part of the "stabilizing ecosystem services".

The regulating role of wetlands, floodplains and coastal ecosystems is usually emphasized (Ming et al., 2007; Posthumus et al., 2010) but it is also important to pay attention to the functions of other ecosystems throughout river basins which control the processes of water balance (Pert et al., 2010). For that reason, we have to separate service production (supply) areas from service benefit (demand) areas (Fisher et al., 2009). The ecosystems affect the water balance mainly through two processes: interception and infiltration. Interception depends on the structure of the ecosystem above ground (land cover) while the infiltration is strongly determined by the soil properties. The surface runoff, which is the main factor for flood formation, also depends on abiotic factors like rocks and topography.

Regulating ecosystem services can have preventive or mitigating functions. In the first case, the ecosystems (i.e. forests) redirect or absorb parts of the incoming water (from rainfall), reducing the surface runoff and consequently the amount of river discharge. This ecosystem service plays its role before flood occurrence and in some cases it can even prevent it. This is valid especially for the rainy-fluvial flood type, while for snow melting-fluvial floods the ecosystems' prevention capacity is far lower. One role of forests in mitigating flooding in the case of melting snow is the reduction of wind velocity and delay of snow melt caused by warm winds (e.g. foehn). However, the more important flood mitigation function comes into effect when the flood is already formed. The ecosystems (i.e. flood plains and wetlands) provide retention space for the water surplus to spill, thus reducing the flood's destructive power.

Hence, flood regulating ecosystem service assessments should conform to the biophysical characteristics and the likelihood of a flood in the particular area. There has been a significant increase in the number of extreme rain events (Velev, 2005; Bocheva et al., 2009) and thus, disastrous floods in Bulgaria (Nikolova, 2001; Nikolova et al., 2008) and other European countries (Kundzewicz et al., 2005, 2010; Barredo, 2007; Lugeri et al., 2010) caused by torrential rains during the last decades as well as the damages and casualties caused by them (Loster, 1999; Jonkman, 2005). The area of the Etropole municipality is among the most seriously affected in Bulgaria by these hazardous events. Creating a high demand for flood regulating ecosystem services, making it an appropriate case study example.

1.2. *Capacities of different land cover types to provide flood regulating ecosystem services*

Different ecosystems have different functions and therefore also different capacities to provide ecosystem services. Following the concept for land-cover based ecosystem service assessments suggested by Burkhard et al. (2009, 2012), ecosystem service supply capacities were assessed for 12 different land cover types occurring in the study region. These capacities represent the current state of flood regulation performance as indicated by the model simulations and data analyses (capacities are not the same as potentials or option values in this case). Using the models described above we provide an assessment matrix which links the different land cover types in the study area and their biophysical attributes to their capacities to provide flood regulating ecosystem services.

1.3. *Mapping flood regulating ecosystem services supply and demand*

Mapping of ecosystem services has been mentioned as one of the main challenges for the ecosystem service concept's implementation into decision making (Daily and Matson, 2008). Several promising approaches to spatially analyze landscape functions and ecosystem services have been published recently (Blaschke, 2006; Burkhard et al., 2009, 2012; Egoh et al., 2008; Kienast et al., 2009; Naidoo et al., 2008; Tallis and Polasky, 2009; Troy and Wilson, 2006; Willemen et al., 2008; Haines-Young et al., 2012). Due to the immense complexity of ecosystems and their service provision, all mapping methods at hand (including the one presented here) are still in the development and testing phase. Moreover, all studies mentioned above differ with regard to their methods of ecosystem service evaluation, the selection of ecosystem services to be assessed, and the spatial scale to which they refer (see Burkhard et al., 2009 for a short review).

Mapping with focus on flood regulating ecosystem services has been rather rare up to now. In many cases flood regulation has been assessed together with other ecosystem services (e.g. Egoh et al., 2008; Posthumus et al., 2010) or in connection with the derivation of risk maps of flood and earthquake hazards over Europe (Schmidt-Thomé et al., 2006). Ming et al. (2007) created maps of water balance-related ecosystem functions and flood mitigation ecosystem services for wetland soils in a case study in China. Syrbe and Walz (2012) presented a map of Service providing areas (SPA), service benefiting areas (SBA) and service connecting areas (SCA) for the flood regulating service in Saxony (Germany). The study presented here is one of the first ecosystem service assessments exclusively focusing on flood regulating ecosystem services on a landscape scale.

In addition to the flood regulating ecosystem services supply capacities' assessment, we will integrate the demand for flood regulation in the study region as well. The demands for flood regulation are linked to the benefits that people obtain by this service. In our case, benefits are the protection of property such as houses infrastructure, farmlands and of course, human life. If efficient natural flood protection and mitigation are to be achieved in this region, the supply of flood regulating ecosystem services by nature on the one hand should spatially match the demands of society on the other hand. This is especially interesting in the case of flood regulation as related services have to be provided in regions which are directly linked to the area where the demand is located, for example along the same watercourse or within the same watershed. In contrast to many other ecosystem services, flood regulating services cannot be imported from other regions. In the case of flood regulation, the service production areas (after Fisher et al., 2009) have to be physically linked to the service benefit area. Thus, there must be a close connection between the area of service supply and service demand. Water retention in regulating ecosystem service supply areas prevents excessive water flows during flood events, providing direct benefits to people living in affected regions. Forests for example, which in our case study are located in mountainous areas within the same watershed, contribute greatly to flood regulation which protects settlements further downhill. By merging the maps of flood regulating ecosystem services supply and demand, regional patterns and balances between supply and demand can be visualized (Burkhard and Kroll, 2010; Burkhard et al., 2012).

1.4. Indicators for the quantification of flood regulating ecosystem services

Appropriate indicators that represent quantitatively the processes by which ecosystems regulate water balance are needed in order to assess the capacity of ecosystems to prevent and mitigate floods. They can help to determine quantitative relationships between the various steps of service provisioning and how to measure the benefits derived from ecosystem services (van Oudenhoven et al., 2012). de Groot et al. (2010) propose the use of state indicators for natural hazard mitigation services such as "water storage capacity (buffer) in m^3" and performance indicators like "reduction of flood danger and prevented damage to infrastructure". Water storage capacity is a good indicator for the damage mitigation function of floodplains and wetlands and their spatial dimensions can be measured. However, it would be more difficult and uncertain to derive such an indicator for the prevention function of ecosystems like forests or grasslands. This is so due to the fact that their regulation function depends not only on their storage capacity but also on a number of other factors and functional processes such as interception and infiltration, surface parameters like roughness and slope as well as external factors like rainfall quantity and intensity, seasonal state of the vegetation and initial soil saturation. The use of catchment based hydrologic models provides the basis to reveal the varying importance of factors and processes responsible for the formation of river swellings as well as the capability of different land cover types to "capture" part of the incoming water, which reveals their regulation capacity. The GIS based AGWA (Automated Geospatial Watershed Assessment) tool and its constituent models KINEROS (KINematic Runoff and EROSion model) and SWAT (Soil and Water Assessment Tool) have been used for flood hazard assessment in two case study areas in the Stara Planina Mountains (Nedkov and Nikolova, 2006; Nikolova et al., 2007, 2009; Nedkov, 2010) as well as to determine the influence of land cover changes on flood formation processes (Vatseva et al., 2008). Here we use these models to further develop the indicators for the capacity of flood regulation ecosystem services.

The main objectives of this article are:

- to utilize hydrologic modelling to identify and assess flood regulating ecosystem services in the case study area,
- to define the capacity of different land cover types in the study area to contribute to flood regulation,
- to define areas of flood regulation ecosystem services' demands, and
- to further develop the concept of mapping of ecosystem services.

2. Materials and methods

Our approach is based on a combination of different biogeophysical GIS data with results of hydrological modeling. The outcomes of this data-model combination are used to calculate local capacities to supply ecosystem services that are relevant for flood regulation as well as the demands for respective ecosystem services in a case study area in Bulgaria.

2.1. Case study area

The municipality of Etropole is situated in the northern part of Bulgaria and covers an area of 371.7 km^2 (Fig. 1). It occupies the northern slopes of the easternmost part of the West Stara Planina Mountains (called Etropolska Mountains) whose average elevation is 914 m. The climate is temperate-continental characterized by relatively warm summers and cold winters. The mean annual temperatures gradually decrease from 9.5 to 2 °C as the elevation increases. The annual precipitation varies from 750 to 800 mm in the northern part to 1100 mm at the highest parts of the mountains. Due to the mountainous character of the region, the extreme precipitation is intensive and most often concentrated in certain parts of the catchment areas. Most of the municipality area is drained by the Malki Iskar river with its tributaries Ravna, Suha, Jablanitsa and Strara reka. A limited area in the eastern part drains to the watershed of river Vit. River Malki Iskar has a mean annual runoff of l.02 m^3/s with a maximum value in June (2.59 m^3/s) and a minimum value in October (0.07 m^3/s). River Ravna has a mean annual runoff of 0.36 m^3/s with a maximum value in June (1.29 m^3/s) and a minimum value in October (0.04 m^3/s).

The soils in the area of the Etropole municipality are represented by five main soil types with several subtypes. The initial data in the Bulgarian classification system has been transformed into the FAO 1974 classification system which is adapted for the use in the AGWA tool. The highest mountainous part is covered by Cambisols (B), which makes up 25% of the area. Most of them are district Cambisols (Bd), which have mainly silt-loam texture. Rankers (U) are represented by two main subtypes: U3 situated in the eastern and northern parts of the municipality and U5 in the western part. Rankers cover the largest part of the area (about 30%) and have sandy-loam texture. Lithosols (I) have limited distribution in the higher part of some mountain ridges. Luvisols (L) are represented by two subtypes: chromic Luvisols (Lc) are located in the lower parts of the area alongside river valleys, while orthic Luvisols (Lo) occupy relatively higher altitudes. They cover about 25% of the area and have clay-loam structure. Eutric Fluvisols (Jd) are situated predominantly in the river valleys covering about 7% of the area. They are characterized by loam texture.

The area of the Etropole municipality is dominated by forest land cover. The CORINE 2000 land cover data (see Section 2.1.2) show

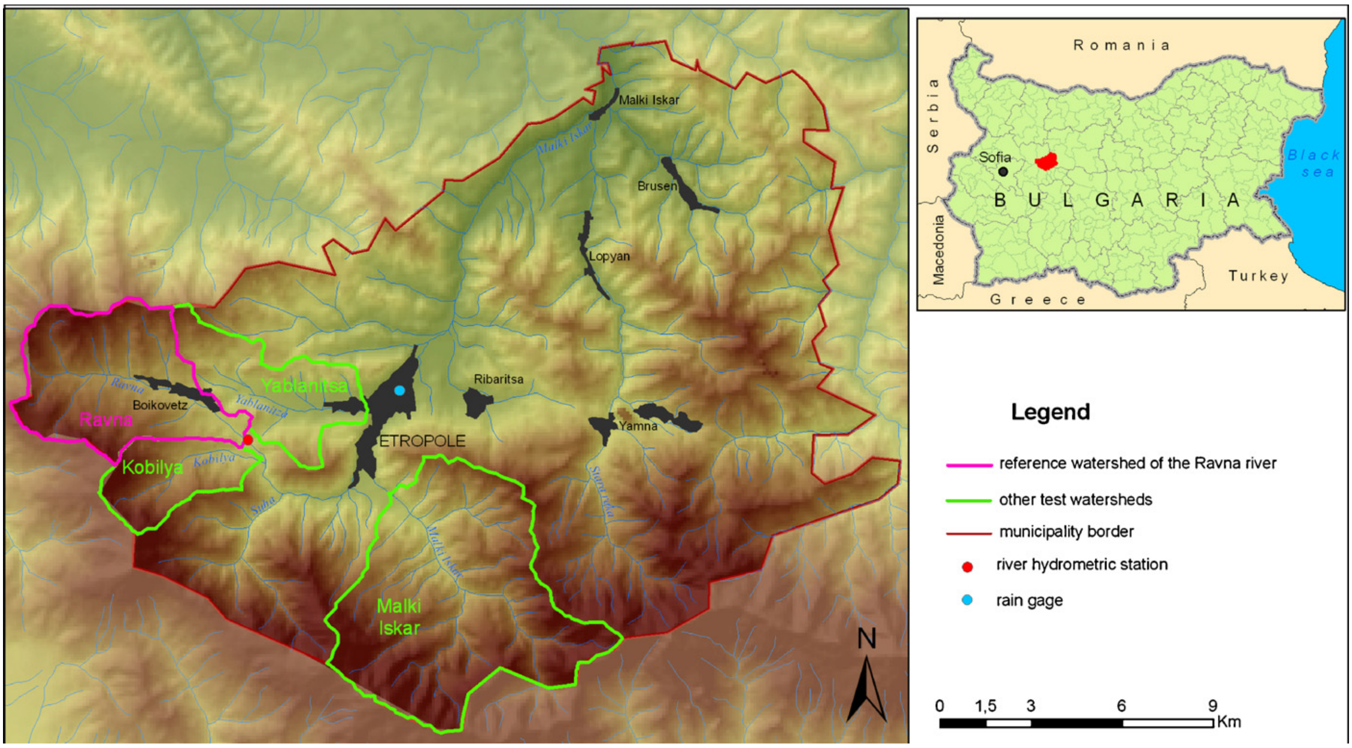


Fig. 1. Map and location of the case study area.

that 65% of the Etropole municipality are covered by forests, most of which (47%) are deciduous, represented mainly by beech in the south and hornbeam-oak forests in the north. Coniferous forests are predominantly planted and cover about 16% of the area. Agricultural lands make up about 20% of the area but only 2% of them belong to the arable land cover class. This is because the arable fields are usually divided in smaller parts separated by natural or other agricultural areas. According to the CORINE classification, these lands belong to the mixed class 243 (land principally occupied by agriculture with significant areas of natural vegetation). Agricultural areas are located mainly in the northern, lower part of the municipality and around the rivers. Grasslands and pastures occupy limited areas (5% of the municipality) mainly in the eastern and southern part. Anthropogenic objects cover 3.5% of the area, with 2% urban and 1.2% mineral extraction sites.

2.1.1. Flood hazard

According to the map of flood hazards in Bulgaria (Nikolova and Nedkov, 2010), based on the investigations of the frequency of river swellings and flooding (Zyapkov, 1988, 1997), the Etropole area lies in the zone of the highest level of flood hazard in the country. The main factors for flood formation there are torrential rains and the mountainous relief which facilitates fast downstream movement of the river swellings. The extreme precipitations usually have "patchy" spatial distribution, with the highest rainfall values concentrated in separate parts of the watershed, thus causing great differences in water quantities of the different tributaries. For example, there is almost no correlation of times of maximum discharge values between the rivers Ravna and Malki Iskar (Nikolova et al., 2008), which occupy neighbouring sub-watersheds. The highest quantity of the discharge in the river Ravna was 94.8 m^3/s, observed on 05.08.2005; while at the same time the Malki Iskar river with a catchment area twice as large had a discharge of 41.2 m^3/s. The damage caused by this extreme event were mainly in the town of Etropole with 65 objects (houses, industrial places and public buildings) and about 15 ha of arable land inundated and eight bridges damaged or completely destroyed. The total losses were calculated to be approximately 5 million EUR. Another flood occurred in June 2007, inundating more than 30 objects. The long term trend of increasing numbers and intensities of torrential rains observed in the area during the last decades shows that the flood hazard is likely to increase (Nikolova et al., 2007).

The investigation of flood hazards and flood regulating ecosystem services in such mountainous terrain necessitates the use of a distributed hydrologic model suitable for application in small watersheds with predominant surface runoff during the flood event as well as the possibility to estimate the influence of land cover/ecosystems in this process. The AGWA tool and the KINEROS model have appropriate functionalities to solve these problems.

2.1.2. Database

The use of hydrologic models and KINEROS in particular, necessitates the availability of an appropriate dataset including a digital elevation model (DEM), land cover data, soil data, hydrological and climatic data. They should be in a particular format compatible with AGWA GIS standards. Additional data are necessary for the flood regulation demand's assessment. In the current investigation, spatial and non-spatial data have been collected for the study area and transformed into appropriate formats. They have been used to build up a database for hydrologic modeling and spatial analyses, and to be used in the flood regulating ecosystem services' capacity assessment.

A DEM with 25 m resolution has been extracted from 1:25.000 topographic maps. The use of the widely accessible SRTM (Shuttle Radar Topography Mission) 90 m DEM is also possible, but the accuracy of the results would be lower (Nedkov, 2007). The CORINE land cover (CLC) 2000 data was used as a main source for the capacity assessment and the mapping of flood regulation supply and demand. CLC provides cost-effective data which are also comparable across Europe. The CLC GIS data contain a minimum mapping unit (MMU) of 25 ha and a resolution corresponding to the map scale 1:100.000. The CLC2000 data are not detailed enough

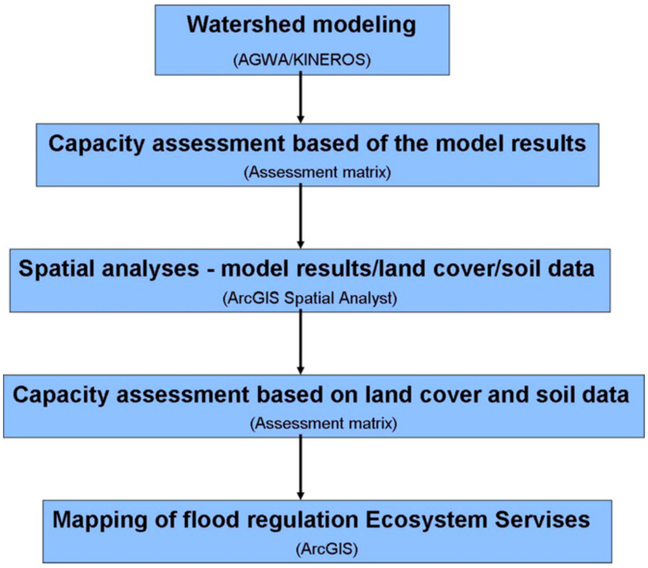


Fig. 2. Methodological approach of the assessment and mapping of flood regulating ecosystem services.

to ensure the initial adjustment and calibration of the KINEROS model, which is applicable for small watersheds not larger than 100 km^2. For this reason, an additional interpretation of Landsat ETM+ satellite images and aerial photographs with very high resolution has been made for the river Ravna watershed. The resulting revised and amended land cover database, using the same CORINE nomenclature, contains 14 classes for the area of the Ravna watershed, while the standard CLC2000 contains 11. It is also far more detailed, containing 449 separate spatial units compared with 65 for the standard CLC2000. This ensures the possibility of assessing the different land cover classes' flood regulation capacities more in detail.

There is no possibility to use widely available soil data because the FAO world soil map, adapted for use in AGWA (Levick et al., 2004), is too coarse for the study area. The available soil dataset for Bulgaria provided by the Research Institute for Soil Science uses a different soil classification system. For that reason, the soil data for the study area have been transformed into the FAO1974 classification system using the correspondence between the FAO scheme and the Bulgarian classification system given in the works of Penkov (1996) and Ninov (2000). The precipitation and river discharge data provided by the National Institute of Hydrology and Meteorology include only one rain gage station in the study area (located in the town of Etropole) and one river hydrometric stations in the river Ravna (Fig. 1). Therefore, the watershed of the river Ravna has been used as a reference site for the hydrologic modeling. Additional field measurements of the precipitation and river discharge, collected during previous investigations (Nikolova et al., 2007, 2009), have been used for the KINEROS modeling. Statistical data from the local authorities and National Statistical Institute have been used to determine the flood regulation demand.

2.2. Assessment approach for flood regulating ecosystem services

As it was described above (Section 1.4), hydrologic models can be used to quantify indicators that represent the flood prevention function of ecosystems. Our approach is applicable for areas with the rainy fluvial type of floods which are typical for the study area. At the first stage, different hydrologic parameters at the watershed level were derived using the KINEROS model and the AGWA tool (Fig. 2). Then, at the second stage, the flood regulation capacities of the different areas within the watershed (in form of model elements) were assessed on the base of the relative scale developed by Burkhard et al. (2009; see the following Section 2.4). The third stage applied different spatial analysis techniques in order to link the capacity of the model elements, defined on the previous stage, with land cover and soil data. This is needed because the model is applicable for relatively small areas and its results cannot cover the whole area of interest. At the next stage we defined the flood regulation capacity of the different land cover classes and soil types in the study area. Thus, an assessment matrix, that includes all land cover classes, soil types and their capacities, has been formed. Once the assessment matrix was filled with data, map compilation (at the final stage) was rather easy (Burkhard and Kroll, 2010).

2.3. GIS based hydrologic modeling

KINEROS is a distributed, physically based, event model describing the processes of interception, dynamic infiltration, surface runoff and erosion from watersheds characterized by predominantly overland flow. The watershed is conceptualized as a cascade and the channels, over which the flow is routed in a top–down approach, are using a finite difference solution of the one-dimensional kinematic wave equations (Semmens et al., 2005). Rainfall excess, which leads to runoff, is defined as the difference between precipitation amount and interception and infiltration depth. The rate at which infiltration occurs is not constant but depends on the rainfall rate and the accumulated infiltration amount, or the available moisture condition of the soil. The AGWA tool is a multipurpose hydrologic analysis system addressed to: (1) provide a simple, direct and repeatable method for hydrologic modeling; (2) use basic, attainable GIS data; (3) be compatible with other geospatial basin-based environmental analysis software; and (4) be useful for scenario development and alternative future simulation work at multiple scales (Miller et al., 2002). AGWA provides the functionality to conduct the processes of modeling and assessment for SWAT and KINEROS.

The process of modeling in the AGWA GIS environment consists of five main stages, including watershed delineation and discretization, land cover and soil parameterization, writing rainfall files, running the model, and finally, the results' visualization. Initially, the model has been applied for the reference watershed of the river Ravna in order to make a precise calibration with more detailed land cover data. In order to achieve more precise modeling of the interception rates, which is very important for the assessment of the flood regulation capacity, the values for the interception in the KINEROS look-up-table have been adjusted by using the results from studies on this parameter published by various authors (Table 1).

The simulated data were calibrated against runoff and precipitation data for two storm events with high discharge. The information about the first one was extracted from the dataset of the National Institute for Meteorology and Hydrology (NIMH), while the data about the second event was received as a result of field measurements taken during a previous investigation in the area (Nikolova et al., 2009). Then the model was applied for the other three test watersheds (see Fig. 1), using the adjustments made for the same two storm events. In this case, the standard CORINE land cover dataset was used. The watershed was, in KINEROS modeling, divided into spatial model elements (planes and channels). The model calculates all parameters of the water balance during the simulated storm events for every one of these elements. In order to assess the flood regulation capacity, we used three main hydrologic parameters. They are infiltration, surface runoff and peak flow. The infiltration rate is important in order to estimate the regulation function of the soils. As the flash floods in the case study area are formed predominantly by the surface runoff, the soils with higher

Table 1
Interception rates of selected vegetation types according to different data sources.

Type of vegetation	Interception				Source
	mm		% of annual precipitation		
	Average	Dimension	Average	Dimension	
Forests		0.15–7.5			Kittredge (1948)
Coniferous forests		0.3–7.5			Zinke (1967)
	3.9	0.3–7.6			Zinke (1967)
			30		Tate (1996)
			26		Carlyle-Moses and Price (2007)
Spruce forests	4.3	2–5.2			Nedyalkov and Raev (1988)
			29		Florov and Dimitrov (1968)
Pine forests	1.8	0.9–4			Nedyalkov and Raev (1988)
	5.2	4.8–5.4			Polyakov et al. (2008)
Deciduous forests		0.2–2			Zinke (1967)
			13		Carlyle-Moses and Price (2007)
Hardwoods	4.8	0.5–9.1			Zinke (1967)
Eastern hardwood forest			13	10.0–16.0	Tate (1996)
Beech forests			14		Florov and Dimitrov (1968)
	3.1 (2.9)	2.6–3.2			Polyakov et al. (2008)
Oak forests	2.4 (1.9)	0.9–2.8			Polyakov et al. (2008)
			21		Tate (1996)
Litter	5.8	0.5–11.2			Zinke (1967)
Litter coniferous forests			5		Tate (1996)
Litter deciduous forests			3		Tate (1996)
Shrubs	1	0.3–1.8			Zinke (1967)
Grasslands	1.3	1–1.5			Zinke (1967)
			15	10.0–20.0	Tate (1996)

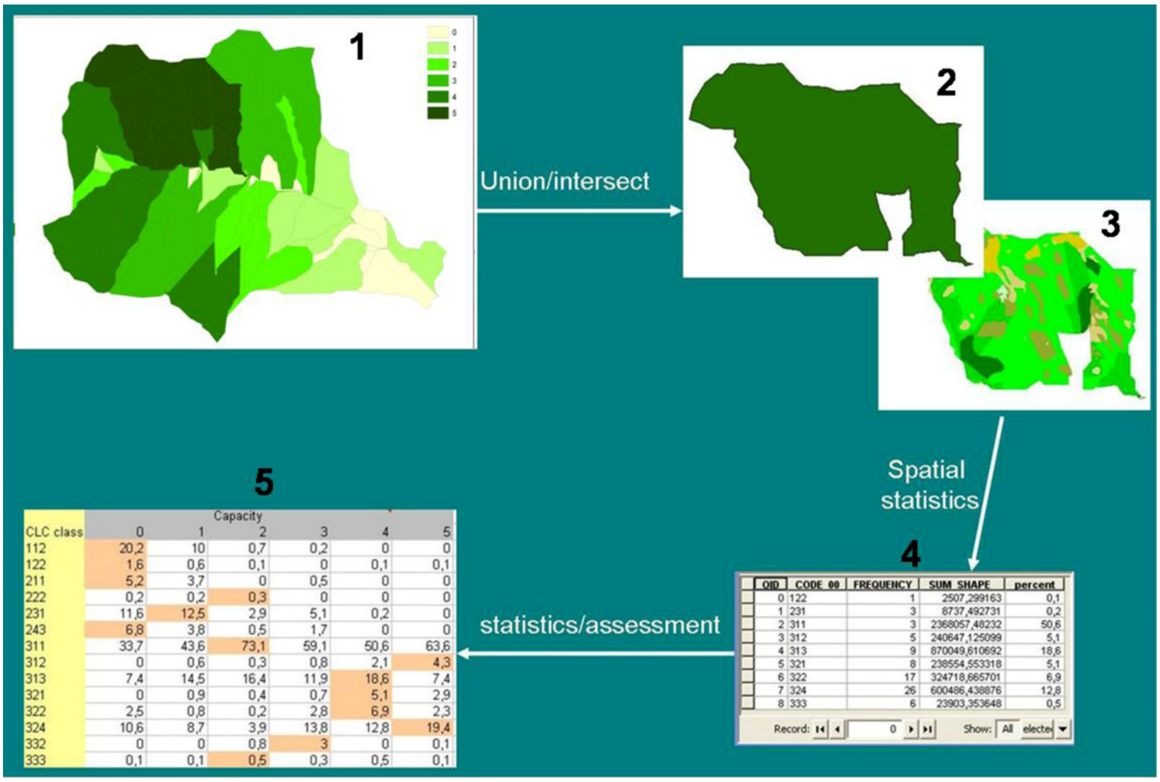
infiltration capability can "absorb" more water, thus reducing the amount of the surface runoff and the flood hazard. Therefore the soils with the highest infiltration rate will have the highest water regulation capacity. The other two parameters represent the function of the land cover to redirect part of the incoming water and to delay the movement of the surface runoff. The relationship in this case is opposite: the model elements with lower surface runoff and peak flow will have a higher water regulation capacity.

2.4. *Capacity assessment of flood regulating ecosystem service supply*

The capacities of the identified spatial units were assessed on a relative scale ranging from 0 to 5 (after Burkhard et al., 2009). A 0-value indicates that there is no relevant capacity to supply flood regulating services and a 5-value indicates the highest relevant capacity for the supply of these services in the case study region. Values of 2, 3 and 4 represent respective intermediate supply capacities. Of course it depends on the observer's estimation and knowledge which function–service relations in general are supposed to be relevant. But, this scale offers an alternative relative evaluation scheme, avoiding the presentation of monetary or normative value-transfer results. The 0–5 capacity values' classifications for the different land cover types were based on the spatial analyses of different biogeophysical and land use data combined with hydrological modeling as described before (Section 2.3).

Interception is supposed to be the most important factor in the process of water regulation by ecosystems. Therefore, the different land cover types' interception rates were used for the initial capacity assessment. No relevant capacity was defined for four classes (bare rocks, sparse vegetation, roads, and urban areas), while the highest relevant capacities were defined for mixed and coniferous forests. In a next step, the initial results of the peak flow and surface runoff in the modeling elements of the river Ravna watershed were compared with the interception rates calculated for the same model elements. There was low correlation between the two maps, which argues that, besides the interception, there are other flood regulation factors which should be taken into account when assessing flood regulation capacity. Therefore, we developed an algorithm that uses the modeling results (spatially represented in form of model elements) to define the flood regulation capacity of the different land cover classes and soil types, based on the above assumption (Section 2.4) that the regulation capacity of a model element depends on the rate of the hydrologic parameters (infiltration, surface runoff and peak flow). The model elements in the reference watershed were classified into six categories according to their surface runoff. The polygons with the highest values were defined as having no relevant capacity (Fig. 3 stage 1) and the next categories correspond to the other classes from the capacities' relative scale.

Then, using ArcGIS Spatial Analyst, the polygons with the same capacity were united and intersected with the land cover map (Fig. 3 stages 2 and 3). The distribution of the different land cover classes within every spatial unit (with a particular capacity) was analyzed using spatial statistics. The calculations were made using the ArcGIS Summary Statistics tool, which gives the opportunity to sum the areas of every land cover class within a spatial unit and to extract their proportions in percents. The distribution of every land cover class (in %) within the polygon with very high relevant capacity is represented in Fig. 3 (stage 4). Then the same procedure was repeated for every group of model elements with the same capacity. The results of this procedure represent in a table (Fig. 3 section 5) the percentages of different land cover classes within every capacity class. As forests are the predominant land cover in the case study area, their percentages are the highest in all columns. The capacity of the particular land cover class is defined as the corresponding row. Thus the capacity of the coniferous forests (CLC class 312) is 5 because the highest value (4,3) corresponds to this capacity class (Fig. 3 section 5). The same procedure was repeated for the interception and peak flow. Finally, average values were calculated. Thus the final table represents the distribution (in %) of the land cover classes between the different capacities. The highest percentage identifies the corresponding capacity of every land cover type. The same algorithm was applied for the soil types again with the same three hydrologic parameters. Then the algorithm was applied for the other three test watersheds (see Fig. 1). Thus, the capacity of every land cover class was defined on the base of results from at least three different watersheds. The number of land cover classes



OID	CODE_00	FREQUENCY	SUM_SHAPE	percent
0	122	1	2507,299163	0,1
1	231	3	8737,492731	0,2
2	311	3	2368057,48232	50,6
3	312	5	240647,125099	5,1
4	313	9	870049,610692	18,6
5	321	8	238554,553318	5,1
6	322	17	324718,665701	6,9
7	324	26	600486,438876	12,8
8	333	6	23903,353648	0,5

	Capacity					
CLC class	0	1	2	3	4	5
112	20,2	10	0,7	0,2	0	0
122	1,6	0,6	0,1	0	0,1	0,1
211	5,2	3,7	0	0,5	0	0
222	0,2	0,2	0,3	0	0	0
231	11,6	12,5	2,9	5,1	0,2	0
243	6,8	3,8	0,5	1,7	0	0
311	33,7	43,6	73,1	59,1	50,6	63,6
312	0	0,6	0,3	0,8	2,1	4,3
313	7,4	14,5	16,4	11,9	18,6	7,4
321	0	0,9	0,4	0,7	5,1	2,9
322	2,5	0,8	0,2	2,8	6,9	2,3
324	10,6	8,7	3,9	13,8	12,8	19,4
332	0	0	0,8	3	0	0,1
333	0,1	0,1	0,5	0,3	0,5	0,1

Fig. 3. Capacity assessment of the flood regulating ecosystem services based on the modeling results: 1 – the model elements in the reference watershed classified into capacity classes according to the surface runoff rates derived from KINEROS results; 2 – the model elements of very high capacity united into single polygon (the color scheme corresponds to that in Fig. 4); 3 – intersection between the polygon at step 2 and the land cover map; 4 – spatial statistic derived from the land cover map at step 3 (the procedure of the steps 2–4 is repeated for every group of model elements with the same capacity); 5 – defining the capacity for every land cover type on the base of their representation (in percent) within the polygons of corresponding capacity.

presented in a watershed varies. Therefore, more test watersheds ensure better representativeness of the results. The same procedure was applied to the soil types and, as a result, their capacity was defined in the same way.

The relief parameters (especially altitude and slopes) have also significant influence on flood regulation functions. The areas in the higher parts of the mountains usually have higher amounts of precipitation and the steeper slopes facilitate a faster downward movement of the water. The vegetation there has a very important function in the regulation of the water balance. The results from KINEROS simulations using different scenarios of land cover change show significant increase in the river discharge from the model elements at higher altitudes, steepest slopes and removed vegetation (Nikolova et al., 2009). Therefore, the flood regulating services of the forests and the other vegetated ecosystems in these areas would have higher capacities. The results from KINEROS simulations gave no opportunity to outline these differences in flood regulation capacity on the map of the municipality, although, there is a clear trend of increase in the amount of precipitation with increasing altitude. Therefore we used the differentiation of the study area into landscape regions made by Nedkov (2010), based on a regression model of interpolation using correlation dependencies between four hydro-climatic indices (representing the heat-moisture ratio) and the altitude (Gikov and Nedkov, 2008). In this work, the Etropole municipality's area was divided into two landscape regions: (1) *temperate subhumid landscapes in the beech forest belt*, which occupy the areas with elevations above 450 m; (2) *warm subhumid landscapes in the belt of hornbeam-oak forests*, which occupy the lower part. Most of the testing watersheds are located within the first region (which is also the bigger one). Therefore, the results of the capacity assessment are defined as representative for this region. The region with *warm sub-humid* landscapes is characterized by lower values of the hydro-climatic indices which are caused mainly by the altitude. Consequently, it is assumed that the forests and the other vegetated ecosystems there would have a lower flood regulation capacity and the supply capacity values were reduced by one class.

2.5. Assessment of demands for flood regulating ecosystem services

A similar relative scale ranging from 0 to 5 was applied to assess the demands for flood regulation. A 0-value indicates that there is no relevant demand for flood regulation and 5 would indicate the highest demand for flood regulation within the case study region. Values of 2, 3 and 4 represent respective intermediate demands. The calculations were based on the assumption that the most vulnerable areas would have the highest demand for flood regulation. The vulnerability, defined as "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UN/ISDR, 2009), has different dimensions (e.g. social, economic, environmental, institutional). The most vulnerable places in the case study area were defined by using different sources of demographic, statistical, topographic and economic data (Nikolova et al., 2009). These areas will have the highest (5-value) demand for flood regulation.

The analyses of their spatial extent showed that they are located within the floodplains and occupy the urban land cover class. The other urban areas within the floodplains are under lower direct hazard but they will be also affected indirectly during flood events in the form of infrastructure losses. Other indirect losses include disturbed transport, losses of some social facilities as a result of reductions in municipality's budget caused by flood damages etc.

These areas were assessed with high relevant demand (4-value). The urban areas outside floodplains are not under direct threat but they will suffer all of the above mentioned indirect losses. They were defined as areas with medium relevant demand (3-value). The agriculture areas within the floodplains are also under low direct hazard in cases of flood events so they were marked by relevant demand (2-value). The other agriculture areas are under indirect threat so they have low relevant demand (1-value). All other areas were indicated to have no relevant demand (0-value).

2.6. Mapping of flood regulating ecosystem services

Based on the spatial units identified from the land cover classes (with the integrated additional biogeophysical information), the values of the supply capacities' and the demands' assessments, maps of supply and demand of flood regulating ecosystem services were derived.

The supply capacities of the land cover classes and soil types in the study area (see Section 2.4) were assigned to every unit in their databases. GIS map layers, containing information about the capacity to supply flood regulation for every polygon, were created. The map of supply capacities of flood regulating ecosystem services was elaborated by overlaying the GIS map layers of the land cover and the soils' capacities. After this operation, the capacity's values in the region with *warm sub-humid* landscapes were reduced by one degree in order to account the influence of the relief (see Section 2.4).

The map of the demand for flood regulating ecosystem services was prepared on the base of three main sources of information:

i. data for topography of the area (30 m DEM, topographic maps)—used to outline the floodplains;
ii. CORINE land cover data—used to define the areas with properties with flood regulation demands;
iii. field work and statistical data for the areas which have been flooded during the recent flood events and the damages caused by them—used to define the most vulnerable areas.

The flat topographic surfaces in the area were derived from the DEM using the ArcGIS Spatial Analyst. Then, the map layer with these surfaces was intersected with the river network in order to derive the flood plains. The final map layer representing the flood plains in the study area was made after precise correction and verification using 1:25.000 topographic maps. The urban and agriculture areas, as territories defined with flood regulation demand, were derived from the CORINE dataset. The two map layers (urban/agriculture and flood plains) were intersected using the ArcGIS overlay option in order to outline the areas with different relevant demand. As a result of this operation, the areas with low to high relevant demand (1–4 value) were defined. The areas with very high relevant demand (the most vulnerable areas) were outlined on the base of field work and statistical data (see Section 2.5) and the resulting map layer was intersected with the map of flood regulation demand created at the previous stage.

For analyzing source and sink dynamics and to identify flows of ecosystem services, the information in the matrixes and in the maps of ecosystem service supply and demand can be merged (Burkhard et al., 2012). As the landscapes' flood regulation supply and demand are not analyzed and modeled in the same units it is not possible to calculate the balance between them quantitatively. Using the relative scale (0–5) it becomes possible to compare them and to calculate supply-demand budgets. Although this does not provide a clear indication of whether there is excess supply or demand, the resulting map shows where areas of qualitatively high demand correspond with low supply and vice versa.

The map of flood regulating ecosystem service budget was created as a result of a spatial overlay between the supply and demand map layers. For that reason, the scale for flood regulation demand was transformed into negative values, so every polygon created as a result of the overlay, received a value which is the result of an addition between supply and demand values. For example, a polygon of a medium relevant capacity (value 3) and a low relevant demand (-1) will have a budget where supply exceeds demand by 2. If the supply matches exactly the demand, no demand or supply (0) would be the result.

3. Results

The results of the above described assessments are presented in matrix tables, showing the flood regulating ecosystem services' supply capacities for different land covers and soil types. In a next step, maps based on the results shown in the tables were compiled and thereby, a spatial dimension was included.

3.1. Supply of flood regulating ecosystem services assessment by land cover

In a first step, the supply capacities of the different CORINE land cover classes were defined on the base of their interception rates. As can be seen in Table 2, the land cover classes with higher vegetation cover (i.e. forests) have higher capacities. This is due to their higher ability to "catch" part of the incoming water from precipitation. Coniferous forests have higher interception rates than deciduous forests (Table 1), so their relevant capacity is defined as very high while deciduous have high relevant capacity (4-value). The land cover classes with almost no vegetation cover (i.e. urban, bare rocks) have no relevant capacity. The relevant capacities of the land cover classes in the test watersheds, presented in Table 2, were defined using the algorithm presented in Section 2.4 (see Fig. 3). The figures in Table 2 are average values of the results calculated on the base of the infiltration, surface runoff and peak flow.

The overall relevant capacities of the land cover classes were defined as average values between the capacities based on the interception rates and the model results. Three land cover classes (*road and rail networks*, *bare rocks*, and *sparsely vegetated areas*) were presented only in the detailed land cover data available only for the Ravna watershed. The capacity of the *road and rail networks* class can be defined as 0-value, as both results show the same values but the results for *bare rocks* and *sparsely vegetated areas* classes are totally different. The reason for that could be their limited area within the model elements, most of which were dominated by forests. Therefore, the results for these classes were considered as not representative and no overall capacity was assigned.

The capacities of the land cover classes, derived on the base of the modeling results, differ between the four test watersheds. The coniferous forests in the Ravna and Kobilya watersheds have very high capacities, while coniferous forests in the Jablanitsa watershed have a medium capacity. One of the reasons for this variation is that the coniferous forests in the area are predominantly planted. Therefore, they can be found in form of relatively small patches within a surrounding forested or agricultural territory. In the more urbanized Jablanitsa watershed, they are situated within predominantly agricultural or urban areas. Thus, the model results from the elements where they are incorporated show a higher surface runoff and have a respectively lower flood regulation capacity. In the other two test watersheds patches of coniferous forests are located within other forests, where the overall flood regulation capacity of the model elements is the highest. The capacity of the natural grasslands varies from medium to very high in the three watersheds where this class is presented (Table 2).

Table 2
Flood regulating ecosystem service supply capacities of the different land cover classes (0 = no relevant capacity, 5 = maximum supply capacity in the study area, empty fields indicate that the land cover class was not present in the respective watershed).

Land cover	Interception	Test watersheds				Overall
		Ravna	Kobilya	Malki Iskar	Jablanitza	
Discontinuous urban fabric	0	0	0		0	0
Road and rail networks	0	0				0
Mineral extraction sites	0			0		0
Non-irrigated arable lands	1	0	1			1
Fruit trees and berries	3	0			2	2
Pastures	2	1	1		4	2
Agriculture and natural vegetation	2	1		2	2	2
Broad-leaved forests	4	4	4	5	5	4
Coniferous forests	5	5	5		3	5
Mixed forests	5	4	5	4		5
Natural grasslands	2	4	3	2		3
Moors and heatlands	2	5	2	2		3
Transitional woodland-shrub	3	3	2	4	3	3
Bare rocks	0	2				
Sparcely vegetated areas	0	3				

3.2. Supply of flood regulating ecosystem services assessment by soil types

The flood regulation service supply capacities of the soils in the study area were defined using model results only. Of course, measured values of the soils' water storage capacities would have been a very good indicator of the flood regulation ecosystem services. But unfortunately, there are no appropriate data for the soils' depths and their lower layers' properties available.

In our modeling examples with flash floods, where the peak flow is formed predominantly by surface runoff, the soils regulate floods formation mainly by their surface infiltration capacity. This infiltration capacity depends especially on the soil texture. Thus, the Fluvisols and Luvisols, which contain more clay and have a respectively lower infiltration capacity, were denoted to have a lower flood regulation capacity (Table 3). The soils with silt-loam and sandy-loam textures (like Cambisols and Rankers) have higher infiltration capacities and consequently, higher flood regulation supply capacities. The results for the Rankers and the orthic Luvisols Lo2-2b were the same for all test watersheds (Table 3), while for the other soil types they were more or less different. The biggest discrepancies ascertained for district Fluvisols, which have no relevant capacities in the Ravna and Malki Iskar watersheds and very high relevant capacities in the other two watersheds. This difference was mainly due to the limited spatial extension of this soil type. Therefore, the calculation of these capacities depends on the predominant soil type in the model elements. The calculation would be high if the predominant soil type has a high capacity and the calculation would be low in case the predominant soil type has a low capacity. This means that the results for soil types with limited spatial extend could not be truly reliable and the approach needs to be tested in other case studies.

3.3. Mapping of flood regulation supply

The map of flood regulation supply capacities (Fig. 4) shows that Etropole municipality's area has relatively high capacities for flood regulation. Areas of high and very high relevant capacities cover about 34% of the study area. They are located predominantly in the southern, more mountainous, part of the municipality. This is mainly due to the relatively high share of forest land cover types in this area. The areas of very high flood regulation capacities are located especially in mixed and coniferous forests and the share of floodplains and wetlands is only 2.5%. This means that the prevention regulation function exceeds by far the mitigation function of the ecosystem services in the municipality of Etropole. The areas with low and no relevant capacities comprise about 9% of the municipality. They are located mainly along the river streams occupying the flat surfaces, most of them in the flood plain zone, which also contributes for the low share of the mitigation regulation function. More than half of the municipality's area (57%) has ecosystems with relevant or medium relevant capacity. They are predominantly broad-leaved forests (which have high relevant capacity) located in areas with soils of lower relevant capacities.

3.4. Mapping demands for flood regulating ecosystem services

The map showing the demands for flood regulating ecosystem services (Fig. 5) shows that the areas of low or no relevant demands exceed by far the areas of high and very high demands, which comprise only 0.6% of the municipality area. Although the areas with high and very high demand have limited extents at the municipality level, their share in the urban territories is about 35%, which means that at least one third of the population lives in areas with high and very high flood regulation demand. As there are also a lot of urban areas downstream of the municipality, the demand at the larger Malki Iskar watershed scale would be higher, while the areas of high flood regulation supply capacity would remain almost the same, because the watershed's upstream part lies predominantly in the Etropole municipality. The areas with relevant and medium relevant demand cover about 2.5% of the municipality. They are located predominantly along the river streams with the exception of the "Elatsite" open mine in the southern part of the municipality (Fig. 5).

3.5. Mapping the budget between flood regulation supply and demand

The map of the flood regulation supply and demand budget (Fig. 6) shows that in most cases the areas of high relevant demands are located in places of low relevant supply capacities. Therefore, the areas where the demand exceeds the supply by 4–5 are predominant and the areas with −4 to −5 budget cover almost 80% of the areas of high and very high relevant demand. One the other hand, the areas of high and very high relevant supply capacities can fully perform their flood regulation function in part because they overlap with areas of no relevant demand. The supply is higher than the demand by 4 and 5 in these areas which cover 33% of the municipality's total area. This means they are only 1% smaller than all areas of high and very high relevant capacities, which cover about 34% (Section 4.3). The most significant change is in the areas with low capacity (value 1), which are 7% smaller than areas on the map of

Table 3
Flood regulating ecosystem service supply capacities of the different soil types and subtypes.

Soil types and subtypes	Test watersheds				Average
	Ravna	Malki Iskar	Jablanitza	Kobilya	
Cambisols Bd3-2b	3	5	4		4
Cambisols Bd-48-2c	3	2	4	2	3
Dystric Fluvisols	0	0	4	5	2
Eutric Fluvisols	0	0	0	1	0
Chromic Luvisols	0		1	0	0
Orthic Luvisols Lo2-2b	1		1	1	1
Orthic Luvisols Lo2-2c	1	2	2		2
Rankers U3-2c	5	5	5	5	5
Rankers U5-1bc	2	4	5		4
Lithosols	1	1	3	1	1
Rocks	0	1	0	0	0

supply capacity. The area of this supply capacity class was reduced to 4% on the map of supply-demand budget (the areas where supply is higher than demand by 1). The areas where demand is higher than supply cover about 7% of the municipality but most of them (5.1%) are with −1 budget while the areas with −4 and −5 cover only 0.1% and 0.5% respectively.

4. Discussion

The results show that the combination of data from different sources with hydrological modeling provides a suitable data base for the assessment of complex function–service–benefit relations. Matrix tables and maps enable an illustrative presentation of the results. Comparing the values calculated for the service supply capacities with the exemplary expert assessment-based values provided in Burkhard et al. (2009, 2012) shows consistent evaluations. Considering the flood regulation-related ecosystem services “flood protection” and “groundwater recharge” from Burkhard et al., the same capacities were derived in both studies for the land cover classes “discontinuous urban fabric”, “road and rail networks”, “mineral extraction sites”, “non-irrigated arable land” and “fruit trees and berries”. For the classes “pastures”, “agricultural and natural vegetation”, “natural grassland”, “moors and heathland” and broad-leaved forests, the values from the Bulgarian study were calculated to be slightly higher. Significantly higher capacities were defined for the coniferous and mixed forest classes, natural grasslands and transitional woodland shrubs in the Bulgarian area. The reason could be that the model estimates only the prevention ecosystem function which is higher for the land cover classes with higher interception like coniferous forests.

4.1. The use of hydrologic models for the assessment of flood regulation ecosystem services

The use of hydrologic models gives the opportunity to quantify flood regulating ecosystem services and to define the capacities of different land cover types to supply flood regulation. A combination of model results with further data from hydrological measurements or monitoring is possible. This would add further opportunities of acquiring better model input data as well as for model calibration. Nevertheless, the results presented here seem to deliver a good

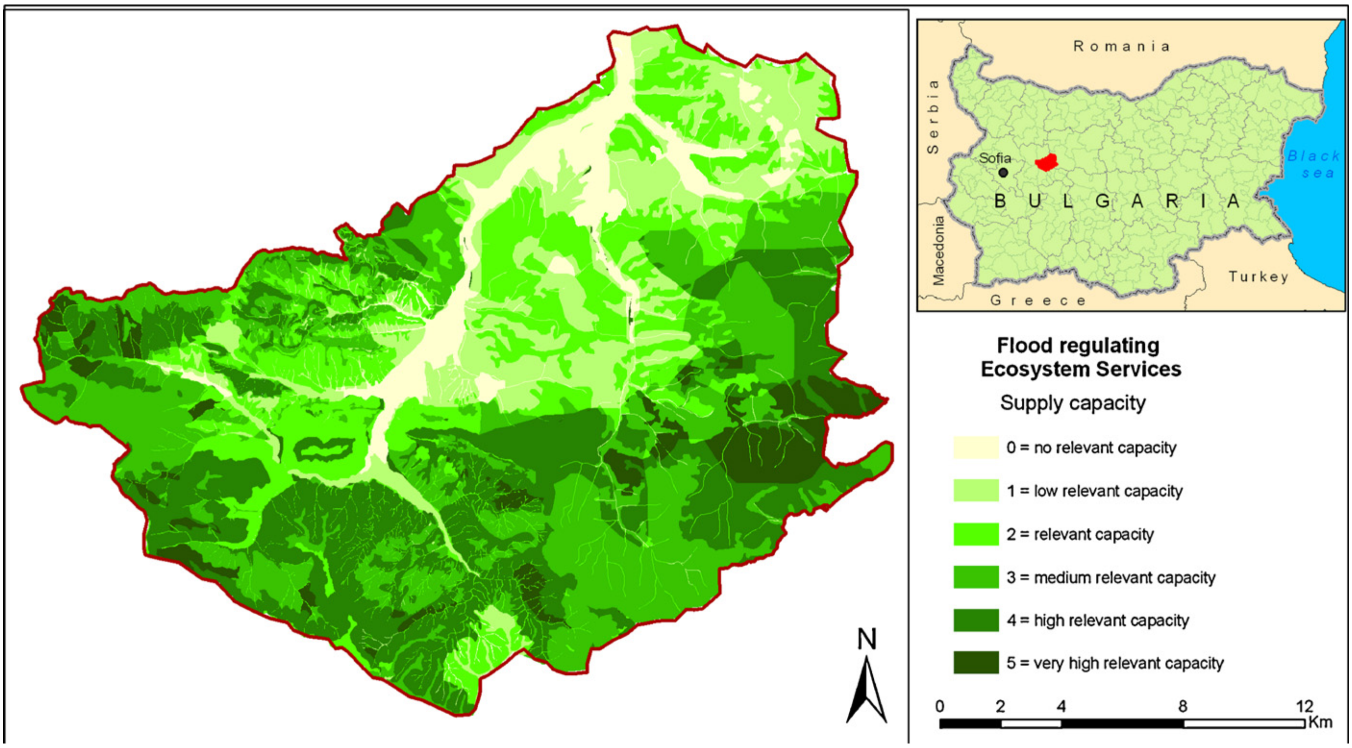


Fig. 4. Map of flood regulating ecosystem services supply capacities.

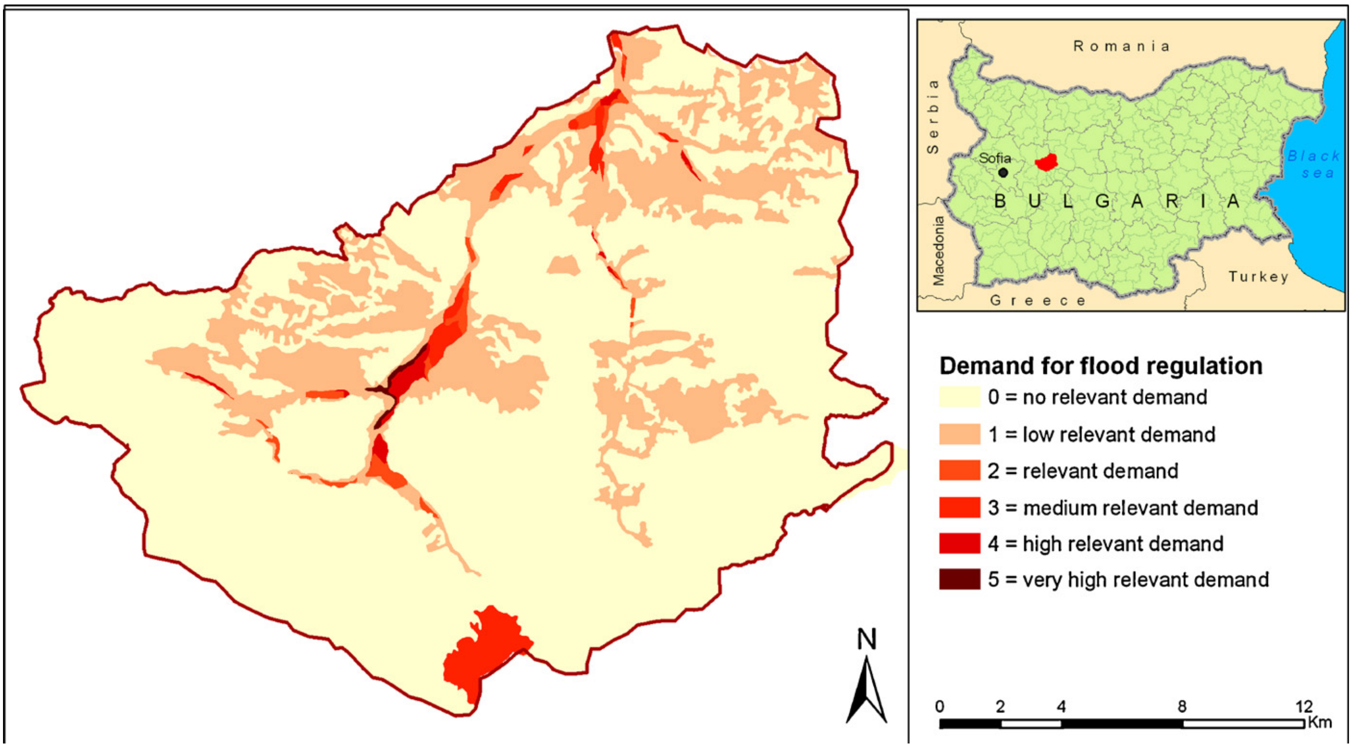


Fig. 5. Map of demands for flood regulating ecosystem services.

representation of the prevention flood regulation function. Better estimations of the mitigation function could be achieved by incorporating a hydrologic model that ensures the calculation of the amount of water absorbed by floodplains and wetlands. This would give the opportunity for a more precise capacity assessment of ecosystems which have predominantly prevention flood regulation function like forests (their capacity seems a bit overestimated) and ecosystems with predominant mitigation flood regulation function like floodplains.

4.2. Spatial aspects of the flood regulating ecosystem services

The flood regulation depends not only on the existence of particular land cover classes but also on their spatial context

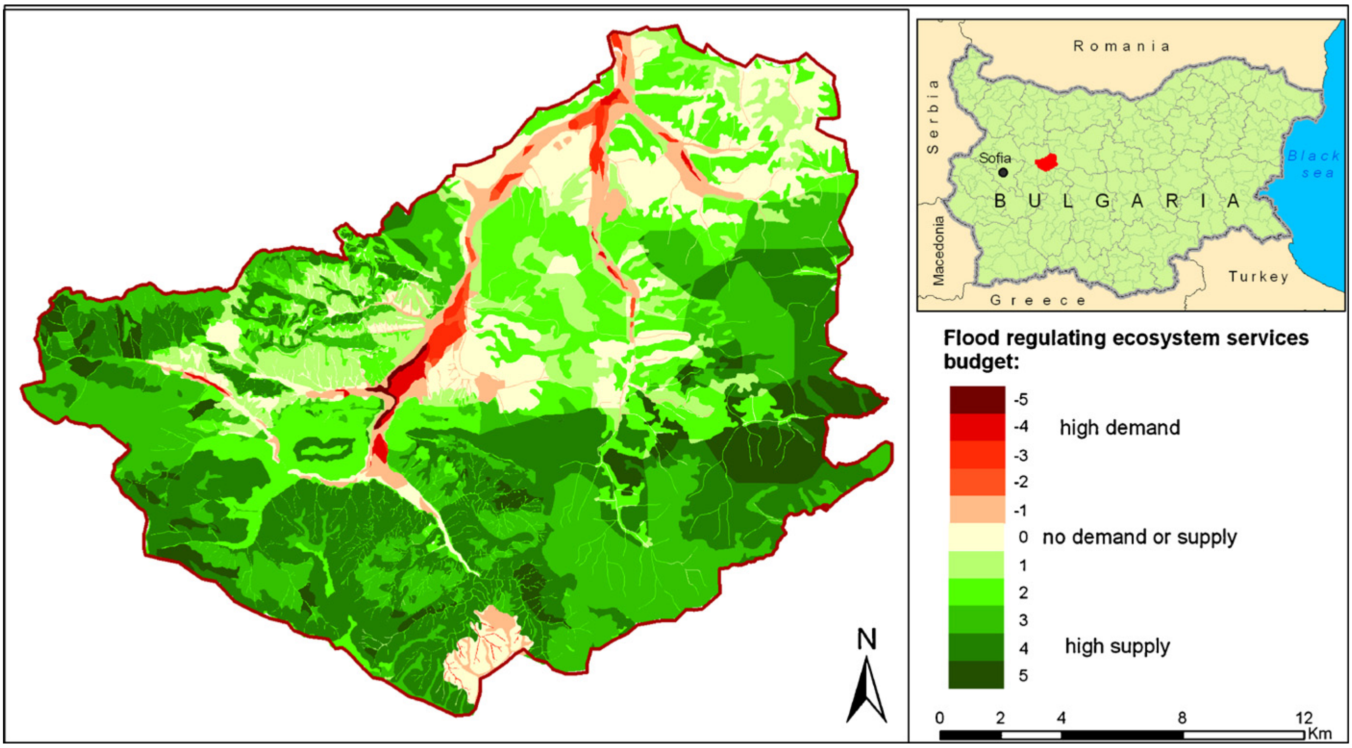


Fig. 6. Map of flood regulating ecosystem services supply-demand budget.

(landscape pattern). Therefore, the choice of appropriate landscape metrics is a challenge for future work. Some possibilities of using landscape metrics in ecosystem services assessment are given by Frank et al. (2012). Regulating ecosystem services are clearly dependent on spatial landscape patterns and interactions between adjacent ecosystems, which have to be taken into account in the assessment of their capacity. Interactions between adjacent ecosystems are also relevant for the analysis of the connections between supply areas and demand areas more in detail. The rather static maps presented here do not provide quantitative information about this connectivity; neither do they quantify flows of regulating services from supply areas to demand areas. What is shown are spatially explicit areas of flood regulation supply, demands and budget between them. So far, our demand assessments do not consider where the flood regulating ecosystem services actually are provided. Nevertheless do the supply-demand budget maps provide an overview on areas where qualitatively high demand corresponds with low supply and vice versa, giving important basic information for future analyses and landscape planning.

One main advantage of the approach is that there are numerous options to include further data of e.g. biophysical properties, land use conditions or data in better spatial or temporal resolutions (Burkhard et al., 2009). The resulting maps can be used to recommend management measures directed to sustainable land use. For example the areas with high and very high flood regulation supply capacity can be put under protection. In the case study area of the Etropole municipality this means for example to reduce logging activities in the forests.

4.3. Limitations of the approach

Besides the advantages of the approach described above, there are some shortcomings. For example, due to model limitations, this assessment procedure is not applicable for floods caused by snow melting. Moreover, the model results do not correspond directly to the land cover data, which necessitates time-consuming additional processing. Another problem is that the model results represent mainly surface runoff. Additionally, infiltration was considered for the surface layer only. As the model is event-based, some important parameters like evapotranspiration could not be taken into account. Some of these limitations can be resolved using the SWAT model, which is also incorporated in the AGWA tool and can be easily adapted to the approach here. Another limitation concerns the nonlinear relationship between the increasing amount of rainfalls and the "reaction" of the soil-land cover complex especially in the context of climate change. Our previous investigation (Nedkov, 2010) showed that the correlation between rainfall and discharge changes rapidly when reaching a particular point of rainfall increase. The main reason is that the saturation level of the soil is reached and the result is enormous increase of the flood hazard. The correlations differ also between different watersheds. This means that the land cover and soil capacities presented in this paper need to be verified in different areas and biophysical conditions in order to produce results which are representative for particular areas.

5. Conclusions

Flood regulation proved to be an example suitable for the assessment of a selected ecosystem service. In the particular case of flood regulation, the ecosystem function–service–benefit chain can be linked to a relatively clear supply and demand scheme. For other ecosystem services, this differentiation tends to be rather difficult (Burkhard et al., 2012; de Groot et al., 2010). As our case study area was rather small and only one ecosystem service was included, further applications using a similar approach in other case study areas and with a broader number of ecosystem services would help to produce more sophisticated results.

One major advantage of the general mapping approach presented is that initial assessments can be carried out with rather easily available basic data, like CORINE land cover data or expert assessments of supply capacities and demands. Using this data, a broad spatial coverage, from local to landscapes, can be achieved. Based on this kind of "rapid assessment" of ecosystem services (Kienast et al., 2009), additional data from measurements, monitoring, further modeling, statistics or expert interviews can be integrated. Moreover, alternative land cover scenarios reflecting past and potential future conditions could be integrated to assess changes in the provision of flood regulating ecosystem services. Information on changes in service provision and related service value information can be used for proactive management of ecosystems for the respective services.

Finally, the matrix-tables and ecosystem service maps are very illustrative outcomes, adding value to socio-ecological information which otherwise might be difficult to comprehend. One major disadvantage is that the assessment matrixes and the 0–5 class values' assignments are not always easy to fix. In several cases, the capacities are difficult to define due to spatial or temporal scale peculiarity, habitat heterogeneities or lack of appropriate data. For example, the land cover classes used in our study seemed to be appropriate for assessing flood regulating ecosystem services at the landscape scale. However, when considering smaller scales, transition zones, merging different land cover types like forests in or around urban areas, can become important.

Moreover, some kind of reproducible weighting algorithm when assigning the values for the particular flood regulating functions and demands might be needed. Nevertheless, a relative assessment scale like our 0–5 approach provides easily understandable information. It promotes the non-monetary valuation of ecosystem functions and regulating ecosystem services. The final illustration in maps helps to discover spatial distributions and patterns of ecosystem service supply and demand. In future, the implementation of these data and information into management guidelines is needed, but caution is demanded as expectations from practitioners are very high (Kienast et al., 2009). At the current state, the assessment results are not really suitable for concrete application in environmental management. In future and with better background data, e.g. resulting from specific ecosystem service monitoring schemes, the potential of spatial ecosystem service mapping approaches for environmental management will be very high.

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