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Economic evaluation of hydrological ecosystem services in Mediterranean river basins applied to a case study in southern Italy

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Abstract: Land use affects the eco-hydrological processes with consequences on floods and droughts. Changes in land use affect ecosystems and hydrological services. The objective of this study is the analysis of hydrological services through the quantification of water resources, pollutant loads, land retention capacity and soil erosion. On the basis of a quantitative evaluation, the economic values of the ecosystem services are estimated. By assigning an economic value to the natural resources and to the hydraulic system, the hydrological services can be computed at the scale of catchment ecosystem. The proposed methodology has been applied to the basin "Bonis" (Calabria Region, Italy). The study analyses four land use scenarios: (i) forest cover with good vegetative status (baseline scenario); (ii) modification of the forest canopy; (iii) variation in forest and cultivated surfaces; (iv) insertion of impermeable areas. The simulations prove that the variations of the state of forest areas has considerable influence on the water balance, and then on the provided economic value. Small economic changes derive from reducing the impermeable areas. Increasing the agricultural area to 50% of the total, and reducing the forest surface, affects soil erosion, reduces the storage capacity of the water, and consequently the water harvesting. The suggested methodology can be considered a suitable tool for land planning.

Keywords: water harvesting; water runoff; soil erosion; land use planning; soil water balance

1. Introduction

The management of land and water resources are closely related [1, 2, 3] since the spatial planning addresses the localization of activities and the land use. The latter one affects water balance, water quality, hydraulic risk and soil loss [4, 3, 5]. Thus, land use and land management practices affect the eco-hydrological processes in combination with other factors such as topography of the basin, hydrological properties of agricultural land and characteristics of rainfalls [3, 6, 7, 8, 9].

In particular, land use affects soil erodibility and canopy cover. Both parameters are considered in estimating the values of the universal soil loss relation [10]. The latter one is usually used for estimating the soil amount removed by water runoff [11]. Soil use also influences the main terms of the water balance, i.e. canopy interception, evapotranspiration, infiltration, soil water storage, and surface outflow [12, 13, 14]. Moreover, the above parameters are also related to the characteristics of vegetation (species, crop management, leaf area, root depth, crop height) and soil (organic matter content, hydraulic conductivity, infiltration capacity, apparent density, porosity). An important action on soil properties is carried out by cropping systems and root characteristics [15, 16]. For example, the results of experimental observations show that forest soils are characterized by high values of hydraulic conductivity and porosity, having positive effect on water infiltration and retention capacity [17, 18, 19].

Several studies [20, 21, 22] demonstrate a complex and non-linear relationship between soil use and hydrological cycle. This relationship is more evident in small basins having a catchment area less than 40 km^2 [23, 24, 25]. In particular, the hydrological cycle depends on site-specific factors, such as the slope and the distance from the hydrographic grid [26], as well as the changes in the land use.

Furthermore, following [27, 28, 29, 6, 30, 22], soil surface sealing and intensive agricultural management have significant negative impacts on the hydrological cycle, as they result in a notable increase in the superficial flow rate and volume, while soil infiltration and water-table recharge are reducing.

In a catchment, the forest surfaces, and their conservation and management, modulate the whole water cycle by promoting evapotranspiration, reducing surface runoff, and regulating flood wave [29, 31, 22]. As a consequence, the agro-forestry management contribute to the mitigation of hydraulic risk, if it is planned by taking into account water resources and the hydraulic infrastructures [32, 33, 34]. Furthermore, the "soil-plant" system influences the availability of water resources by: (i) attenuating the kinetic energy of rainfall, (ii) increasing the soil water storage capacity, (iii) reducing the water evaporation and (iv) the deep drainage [35, 36, 37].

An important role in regulating the hydrological cycle can therefore be attributed to the ecosystems associated with land use and agro-forest management [38, 39, 40, 41]. The agro-forest ecosystems provide a series of direct and indirect hydrological services: (1) water provisioning (storage in water bodies and water harvesting), (2) flow regulating, (3) water purification [42] and (4) soil protection [43, 44]. The water balance and the soil characteristics are consequently influenced by the species in the agro-forest ecosystems and by the adopted cropping systems. Moreover, the crop and forest management has significant impact on quality and quantity characteristics of surface waters and groundwater.

Once the ecosystem service “water providing” is quantified, it is possible to estimate the water resources carrying capacity (i.e. the population able to be supplied in a sustainable way), and designing suitable water harvesting systems.

With reference to the surface and groundwater purification issues, vegetation and the microbial soil community act on absorption and biochemical transformation of nutrients and contaminants [45].

On the other hand, intensive farming systems, requiring high external inputs (fertilizers or other agro-chemicals), may have negative effects on the quality of water resources which in some cases might become unsuitable for drinking if the agro-chemicals are not adequately supplied and scheduled.

From the analysis of the above reported literature it results that a territorial planning is required to optimize the eco-hydrological cycle. Such planning activity should consider at the same time the regulation, purification and provision of water resources [46] since on these services depend the hydraulic security of the territory [47], as well as the water carrying capacity [48] and the sustainability of water purification processes [49]. Nevertheless, with respect to the soil protection service, vegetation affects the plant cover factor (C-factor) used to estimate soil loss [50]. Forests are generally retained to protect soil from erosion more efficiently than cropping systems do. However, recent agronomic studies on conservation agriculture show that the C-factor is influenced by crop residues and soil tillage [51, 52, 53, 54]. Reducing soil tillage, combined with suitable management of the crop residues, can contribute to control the soil erosion [55].

A possible approach for a sustainable planning starts from the definition of the physical variables involved in the ecosystem services by mean of indicators which can be quantified by giving an appropriate economic value. The general objective of this study was to quantify, in physical and economic terms, the ecosystem services provided by the territory planning of Mediterranean basins. To achieve this objective, the following issues have been addressed: (i) water resources availability, (ii) rainfall effects on soil surface, (iii) water carrying capacity.

Specific objectives of this study were:

- to develop the conceptual method for quantifying the technical and economic value of the hydrological services provided by the ecosystems. In particular, four services have been considered: 1) water provisioning; 2) flow regulating; 3) water purification; 4) soil protection;
- to apply the developed methodology to an emblematic case of a gauged watershed in southern Italy (the Bonis basin in Calabria), mainly covered by Mediterranean forest systems;
- to analyze possible planning scenarios by using the proposed methodology.

This methodology is conceived as a tool for identifying and implementing territorial plans at the meso-scale suitable for preventing floods and degradation (in quality and quantity) of water resources.

2. Materials and Methods

In order to assess the impact of basin ecosystems on hydrological cycle and water quality of a watershed, the proposed methodology is based on the use of both temporal and timeless indicators and it is applied to different scenarios of land use and soil management. Time indicators were evaluated at annual scale in accordance with [56].

2.1. Assessment of hydrological ecosystem services

2.1.1. Water provisioning (WS)

The service "water provisioning" from an eco-systemic point of view is defined as water storage in rivers, lakes and aquifers [57]. This service is correlated to inflows into the water bodies and to the water harvesting systems and infrastructures [58]. To quantify this service, the “water supply” indicator is used. It can be expressed in different ways by combining the following terms: (i) the runoff [59], (ii) the ratio between availability and demand for water resources [60], (iii) the total volume of uptake water [61] for different socio-economic purposes.

The approach proposed in this study is based on parameters which are generally available from meteorological and hydrological data-sets. So the water supply (WS in mm yr^{-1}) was estimated following the model developed by [62]:

$$\mathrm{WS} = \mathrm{S}_{\mathrm{PTC}} - \mathrm{ET} - \mathrm{EF} \tag{1}$$

where S_{PTC} is the precipitation water [mm yr^{-1}], ET is evapotranspiration [mm yr^{-1}] and EF is the water requirement for maintaining the aquatic ecosystems [mm yr^{-1}], which for the Italian territory is 30% of the rains [63]. As for ET, the literature annual average values have been considered. They were calculated by using the water balance at the plot scale and then spatialized at the watershed level. The economic value of the “water provisioning” service was assessed in accordance with [49], using the unit average Italian water rate: 0.71 € m^{-3}. This fixed economic value is established by the National Authority for Energy, Gas and the Water System. Alternatively, the water rate can be more accurately estimated, taking into account the relationship between availability and demand [60].

2.1.2. Flow regulating (WC)

Ecosystems offer the service "flow regulating" through the influence of soil-plant system on hydrological flows [57]. This service is directly related to the volume of water intercepted by vegetation and stored into the soil profile or in the aquifers [64]. These hydrological parameters depend on soil tillage and agro-forest management. For this reason, the “flow regulating” directly affects the processes of rainfall – runoff transformation and, consequently, the hydraulic hazard. For the quantification of flow regulating by “rainfall – runoff” process evaluation, several indicators have been proposed, such as: (i) soil - water storage capacity [65], (ii) soil infiltration capacity [61] and (iii) water conservation efficiency. These indicators refer to the water amount which is stored into the soil profile and withdrawn from the surface runoff [49, 66].

In this study the flow regulating was quantified by the timeless water conservation (WC, in m^3) indicator, it takes into account potential water losses due to evapotranspiration and soil - water storage. This indicator has been calculated with reference to rainfall with a return time of 200 years. This time period is usually considered in assessing the territory protection from flood. Therefore, the volume of rainfall accumulated into the soil and removed from the runoff was calculated by subtracting the flowed volume in the different land uses to the rainfall amount, characterized by a return time of 200 years:

$$\mathrm{WC} = \mathrm{Vol_{rain}} - \mathrm{Vol_{runoff}} \tag{2}$$

where $\mathrm{Vol_{rain}}$ [m^3] is the 200-year rainfall volume estimated on the basis of climatic possible curves and $\mathrm{Vol_{runoff}}$ is the runoff volume through the stream gauging station, estimated through the "rational formula" described in section 2.3 (assessment of surface runoff).

The economic value of the flow regulating service has been calculated with reference to the WC indicator on the basis of the costs for the construction of storm-water retention system with equivalent volume. Analysis of storm-water retention system project shows that the unit cost varies from 5 to 15 € m^{-3}. This value does not take into account the management and maintenance costs. The chosen value has been assumed to be 5.16 € m^{-3} of detention basin [67] (Autorità di Bacino dei FiumiTrigno, Biferno e Minori, Saccione e Fortore). This evaluation is consistent with that proposed by [68]. So the presence of a forested area is economically equivalent to water retention system that can contain the same water quantity.

2.1.3. *Water purification (COD)*

The service "water purification" is defined as the attitude of ecosystems to remove pollutants by means of chemical, physical, micro-biological and mechanical processes [44]. The most used indicators for quantifying this service are the percentage of forest surface and the percentage of riparian forests along the river [68, 69].

In this study, for quantifying the "water purification" service, the water quality parameters influenced by land use have been used as indicator. The concentration of pollutants in surface water has been assessed on the basis of the forest surface and other land uses within the same basin [2]. In particular, it is possible to estimate the Chemical Oxygen Demand (COD in mg l^{-1}) parameter, which describes the surface water pollution, on the basis of the following formula:

$$\ln(\mathrm{COD}) = -0.08\mathrm{C} - 5.47\mathrm{F} - 2.93\mathrm{G} + 0.29\mathrm{W} + 0.7\mathrm{B} + 1.69 \tag{3}$$

where C is the conventional cultivated area [%], F forest [%], G pasture [%], W water bodies [%] and B the impermeable surfaces [%] calculated respect to total basin surface. The coefficients used in the relation (3) were determined by [2] through data processing related to land use and water quality. By means of the ratio COD/TOC = 3, it is possible to estimate the Total Organic Carbon (TOC in mg l^{-1}) which represents an indirect measure of the organic matter in the waters. This parameter makes it possible to establish the economic suitability of water treatment for drinking use (TOC ≤ 4 mg l^{-1}) and for the next human consumption (TOC ≤ 2 mg l^{-1}) [70].

The economic evaluation of the "water purification" service can be carried out based on changes in TOC resulting from changes in soil use. In this paper, the cost of the active carbon needed to reduce the TOC to the most suitable values for drinking use has been calculated. In fact, through the reduction of TOC, it is possible to estimate the amount of powdered activated carbon (PAC in mg l^{-1}) needed for the purification of the water and the relative costs [71]:

$$\mathrm{PAC} = \frac{\mathrm{TOC_{reduction}}}{0.063} \tag{4}$$

Analysis of water treatment plant project shows that the unit PAC cost varies from 1.6 (adopted value) to 1.9 € kg^{-1}.

2.1.4. *Soil protection (β_e)*

The "soil protection" service has been evaluated from the close interrelations between erosion, solid transport and water quality. Actually this ecosystem service is the most complex to define and quantify. The indicator here adopted for quantifying soil protection is the "ecosystem service mitigated impact on soil erosion" (β_e in t ha^{-1} yr^{-1}), it is the basin potentiality, provided by the presence of areas covered with vegetation [72, 73] as:

$$\beta_e = \Gamma \times C_{factor} \quad (5)$$

where C_{factor} (dimensionless) is vegetation cover factor and Γ is the structural impact [74]. Γ is calculated as:

$$\Gamma = R \times LS \times K \quad (6)$$

R is the rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1}), LS is the topographic factor (dimensionless), and K is the soil erodibility (t h MJ^{-1} mm^{-1}).

Finally, this service can be quantified, on an annual basis (t ha^{-1} yr^{-1}), through the difference between water erosion in different types of land use with respect to bare soil conditions. Values of β_e [t ha^{-1} yr^{-1}] allow determining the positive or negative impact of land use on the amount of average annual soil loss per surface unit.

The capacity of ecosystems to protect the soil is expressed by means of the parameter e_s [adimensional], according the definition by [72]:

$$E_s = 1 - C_{factor} \quad (7)$$

In literature there are different C_{factor} values in relation to soil use [12], plant species and agricultural practices [55]. Only soil related values have been used in this work due to the lack of site-specific knowledge on soil tillage, pruning and green (or crop) residues management.

By the above definitions, the unit economic value of the soil for replacement varies between 44.6 e 255.1 € t^{-1}, including transport and filling costs [75]. A value of 45 € t^{-1} was assumed in this study and it represents the Italian situation. This value is consistent with the prices for backfilling operations in public works.

2.1.5. Assessment of the economic values

For the economic evaluation of ecosystem services, it is worth noting that there is no overlaps between the range of asset cost values: water 0.71 € m^{-3}; powdered activated carbon 1.6 ÷ 1.9 € kg^{-1}; storm-water retention system 5 ÷ 15 € m^{-3}; soil replacement 44.6 ÷ 255.1 € t^{-1}(soil and hydraulic works). Furthermore, since all indicators are linearly related to specific costs, the variation of that are linearly reported in the final values of the indicators in object.

Other ecosystem services not strictly related to the water cycle have not considered in this study.

2.2. Assessment of water carrying capacity

The water resources carrying capacity (WRCC in inhabitants) is a key indicator for the study of available water resources and their sustainable management [76]. It allows to compare the availability and the requirement of water resources. The WRCC can be estimated on the basis of socio-economic and ecological parameters [48, 76, 77]. Considering that the carrying capacity is the number of individuals that the environment can support [78], the largest population supported with water resources produced by ecosystems in a specific river basin can be defined as:

$$\mathrm{WRCC} = \frac{\mathrm{WS}}{\mathrm{WD} \times \alpha} \quad (8)$$

where WS is available water [m^3 yr^{-1}], WD is the water supply equal to 92 m^3 inh.$^{-1}$ [79] (National Regulatory Plan for Aqueducts, 1963), and α is the use coefficient, assumed equal to 0.8, which is the value commonly used for designing city sewers.

2.3. Assessment of surface runoff

The peak flow during flood events is an important parameter for dimensioning hydraulic infrastructures and for defining the floodplain areas (Flood Directive 2007/60/CE) [80]. In order to realistically estimate the runoff value, advanced methodologies for rainfall – runoff transformation are available [81]. The most commonly used method is the "rational formula" for its simplicity and the reduced amount of input data required [82]. In order to estimate peak flow (Q_P) this formula is particularly used in small basins:

$$Q_P = C \times \frac{i_{tr}}{3.6} \times A \tag{9}$$

where C [adimensional] is runoff coefficient, i_{tr} [mm h^{-1}] is the rainfall intensity for assigned return time, A [km^2] is the watershed surface. Specific experimental data are available concerning the runoff coefficient in the analyzed basin [83]. Assuming a return time of 200 years, the rainfall intensity for the study area is 18.2 mm h^{-1}. This value was calculated on the basis of pluviometric probabilistic curves for the studied area [84].

2.4. The study area

The “Bonis” hydrographic basin (39°25′15′′N e 16°12′38′′E) is located in the province of Cosenza in the Calabrian Region (Figure 1). From the hydrological point of view, an annual average rainfall of 1200 mm and average losses for evapotranspiration of 300 mm are reported [85].

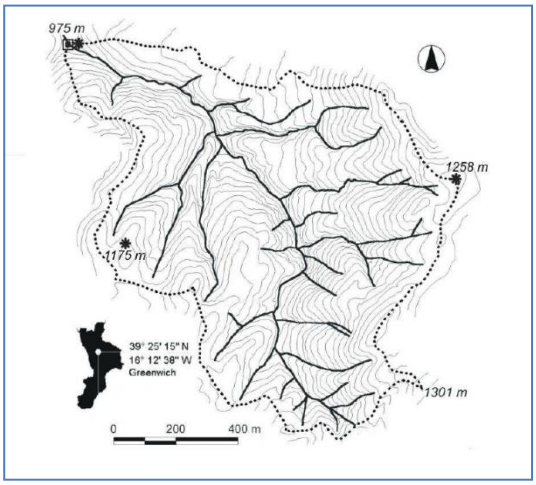

Figure 1 - Bonis River Basin [84]

Table 1 - Morphometric parameters of the Bonis basin

Basin area	1.387	km^2
Basin perimeter	5.7	km
Length of river	2.2	km
Average height of basin	1’131	m
Maximum height of the basin	1’301	m
Height of runoff measurement station	975	m
Average slope of the basin	43.4	%
Slope of river	12.5	%
Average slope of the drainage network	24.5	%
Altitude difference of the main river	275	m
Altitude difference between basin’s closing section and watershed	326	m
Drainage density	7.43	km km^{-2}
Gravelius coefficient	1.37	

Table 2 - Land use in the Bonis basin

	surface

	ha	%
Populations of autochthonous larch pine	17.6	12.7
Larch pine reforestation	42.9	30.9
Chestnut reforestation	7.9	5.7
Larch pine and chestnut reforestation	13.4	9.7
Degraded afforested land	25.6	18.5
Spare larch pines and natural vegetation	11.2	8.1
Poplar and alder	1.6	1.2
Glades and clearings	2.8	2.0
Burnt areas	2.3	1.6
Riverbeds colonized by alder	11.3	8.2
Arable fields	2.0	1.4
TOTAL	138.7	100

The basin has been the object of numerous experimental studies and it is characterized in detail by the hydro-geomorphologic and territorial points of view (Tables 1 and 2). Soil use determines a flow coefficient between 0.18, in the case of forests having good vegetative status, and 0.35 as a result of the cuttings for maintenance and fire-fighting actions [83].

2.5. Scenarios

Since the proposed methodology allows either the evaluation of hydrological services provided by the ecosystems, or the determination of the carrying capacity, or the effects on the soil of the rainy events, different scenarios of land use and canopy management were analyzed to evaluate the effects on hydrological eco-services. Specifically, the following scenarios were considered: 1) forest cover with good vegetative status (baseline scenario); 2) forest with low vegetation vigor (e.g. after cutting or fire-fighting actions); 3) agricultural conversion on 50% of the basin surface; 4) soil sealing on 1.5% of the basin surface (e.g., roads, tourist resorts). Scenarios 1 and 2 are related to the current land use (Table 2) but with two different levels of forest vegetation vigor. Scenarios 3 and 4 are related to a change in land use compared to that described in Table 2 with the insertion of agricultural or impervious areas and relative reduction of the forest area.

3. Results

The application of the proposed methodology allows the quantitative and economic evaluation of the hydrological services provided by the ecosystems in the Bonis basin. The four above defined indicators have been calculated for four land use scenarios and they are reported as following: Table 3 "water provisioning" (WS), Table 4 "water flow regulation" (WC), Table 5 “water purification” (COD) and Table 6 “soil protection” (β_e). In the Table 4, in addition to the quantification of the "water regulation" service, the 2-century peak flow (Equation 9) was also reported, indicative of the effects of meteoric events at the soil surface.

WS has highest values (Table 3), both in terms of water provisioning and economic value when the forest cover is characterized by low plants’ vigor, while the lowest value is estimated in the case of forest having high values of leaf area. This information can be successfully used to improve decisions planning, with particular attention to (i) agro-forestry, (ii) water management, (iii) plan of hydraulic infrastructures to meet the water demand from the various socio-economic sectors. From the economic point of view, the value of the water provisioning service depends mainly on climatological aspects (rainfall and evapotranspiration) that cannot be significantly controlled by anthropic action on the basin. Actually the choice of dry farming systems or of species drought-tolerant, or having a reduced leaf area, can increase the amount of water provision (and, as a consequence, the economic benefit from this ecosystem service).

Table 3 - Ecosystem service "water provisioning" of the Bonis basin: variations at annual scale time of physical and economic values in four land use scenarios of quantitative (WS) and economic values

Land use scenarios	**Water supply (WS) [m³ yr⁻¹]**	**Economic Value [€ of 2017]**
Forest with good vegetative status	607’200	431’112
Forest with low vigor	883’200	627’072
50% forest; 50% cropped areas	710’700	504’597
Soil sealing 1.45%	614’100	436’011

Regulating water flow is an eco-systemic service (WC, Table 4) closely related to meteoric events, and specifically to runoff. From the values reported in table 4 it is evident that the amount of water flow does not change at a yearly scale in the different scenarios. However WC affects the peak flow and, consequently, the hydraulic hazard of the basin. Peak flow is closely related to soil use and vegetation management. Moreover, when the area is covered by forest, the lamination effect on water flows is better distributed than in other scenarios. This relation is linked to the runoff coefficient, experimentally determined for the Bonis basin by [83] Veltri et al. (2013) before and after the vegetation cutting. In the scenarios “forest” and “forest with low vigor” the runoff coefficients were experimentally determined, while in agricultural conversion scenarios, and under soil sealing conditions, the outflow coefficients were obtained from table values commonly used for hydrological models. Furthermore, the economic value of the water flow regulating ecosystem service (Table 4) has been closely related to vegetation, whose characteristics significantly affect interception, evapotranspiration and infiltration processes.

Crops with high leaf area and developed root system subtract further meteoric water from the runoff component of the hydrological balance, having positive effects on the economic value of the eco-systemic service “water flow regulating”. And the results show that the reduction of leaf area, due to forest cutting, results in a reduction in the economic value of the water regulation service of approximately 12’000 €.

The water purification service has been quantified by estimating the TOC and COD quality parameters (Table 5). Values reported in Table 5 do not indicate any difference among different forest managements. Moreover, the results show that the agricultural conversion of forestland causes an increase in the organic and inorganic compounds present in the waters. However, in all scenarios, the COD and TOC values are suitable for the human consumption. In fact, the estimated concentrations are lower than the quality thresholds established by national and international drinking water regulations (Legislative Decree 31/2001) [86]. The economic value of the ecosystem service can not be estimated in absolute terms as it is related to the variations in quality caused by land use changes. For this reason, relatively to the total water volume produced annually from the basin, the active charcoal (PAC) was estimated as the amount needed to reduce the TOC from agriculture scenario to the TOC values calculated in the forest scenario. The required activated charcoal costs € 1’871.

Table 4 - Ecosystem service "water flow regulation" of the Bonis basin: variations of physical (WC) and economic values in four land use scenarios. Peak flow and runoff (2-century return time) are also reported.

Land use scenarios	**Peak flow [m³ s⁻¹]**	**Runoff [m³]**	**Water conservation (WC)[m³]**	**Economic value [€ of 2017]**
Forest with good vegetative status	1.26	2’464	108’901	561’929
Forest with low vigor	2.46	4’812	106’553	549’811
50% forest, 50% cropped areas	3.49	6’524	104’541	539’436
Soil sealing 1.45%	1.34	2’617	108’828	561’553

Table 5 - Ecosystem service "water purification" of the Bonis basin: variations of physical and economic values in four land use scenarios. COD is Chemical Oxygen Demand; TOC is Total Organic Carbon; PAC is powdered activated carbon.

Land use scenarios	**COD [mgl^{-1}]**	**TOC [mgl^{-1}]**	**PAC [mg l^{-1}]**	**Water purification cost [€ of 2017]**	
				***per* liter**	**basin scale**
Forest with good vegetative status	0.029	0.010	-		
Forest with low vigor	0.029	0.010	-		
50% forest; 50% cropped areas	0.340	0.113	1.65	2.63 x 10^{-6}	1'871
Soil sealing 1.45%	0.032	0.011	0.02	2.53 x 10^{-8}	15

The "soil protection" service (Table 6) was evaluated in all scenarios. The results show a marked increase in soil loss due to the variation of the C_{factor} from 0.02 (forest areas) to 0.20 (cultivated areas) in half the area of the basin.

Table 6 - Eco-systemic service "soil protection" of the Bonis basin (mitigated impact on soil erosion): variations of quantitative and economic values in four land use scenarios. Water erosion prevention: avoided soil losses for basin surface (t year^{-1}) respect to the "bare soil" conditions.

Land use scenarios	**Ecosystem service "soil protection" [t yr^{-1}]**	**Value of the avoided erosion [€ of 2017]**
Forest with good vegetative status	2376.9	106'961
Forest with low vigor	2189.3	98'516
50% forest; 50% cropped areas	1813.9	81'628
Soil sealing 1.45%	2377.8	107'001

As for the water purification, the service can not be estimated in absolute terms, but only by comparing the current situation with the "bare soil" conditions. It follows that the soil necessary to restore the amount lost in the agricultural conversion (563 t yr^{-1}) in one year is 25'335 € yr^{-1}.

Considering the resulting value from all ecosystem services associated to each scenario (Table 7), the most convenient one, if compared to the baseline scenario, results to be the forest with a low vigor. Here the runoff increases to the advantage of the water provisioning but to the slight disadvantage of the water retention capacity. In order to evaluate the ecosystem service, for scenarios 3 and 4, the cost for water purification are negative because represent a degradation of water quality.

Table 7– Hydrological eco-systemic service value of the Bonis basin and comparison with baseline scenario

Land use scenarios	**Ecosystem service value [€ of 2017]**	**Relative ecosystem service value [€ of 2017]**
Forest with good vegetative status	1'100'002	/
Forest with low vigor	1'275'399	175'397
50% forest; 50% cropped areas	1'123'790	23'788
Soil sealing 1.45%	1'104'550	4'548

Regarding the capacity of water resources produced in the Bonis basin, the WRCC indicator was equal to 8'500 people in the forest cover scenario. The reduction of leaf coverage by means of cutting, or agricultural conversion, results in an increase in carrying capacity as the greater production of water allows to meet the needs of a larger number of inhabitants (about 10'000 people).

Given the close dependence of WRCC on WC indicator, which depends on rainfall, particular attention must be paid to future climate scenarios.

In addition, in order to align water availability to requirements, it can be advisable to introduce unconventional water (reclaimed water) for alternative uses (industry, irrigation) and alleviating the pressure on resources for the direct human consumption (drinking water).

In planning a Mediterranean agro-forest area, the reduction of the evapotranspiration levels should be suitable, and, in case of irrigated farming systems, species growing with both conventional and non-conventional water resources should be preferred. However, this issue needs to be properly harmonized with the aim of protecting the territory from the adverse effects of floods [87].

Results of this study show that the intensity of these phenomena is closely related to the soil use and management. Specifically, the amount of runoff and its hydrodynamic characteristic depend significantly on the type of canopy and its vegetative state. With regard to the Bonis basin (Table 4), the available data allowed to estimate the peak flow QP for rainy events with a return time of 200 years. In conditions of good vegetative status, the estimated QP200 was 1.26 m^3s^{-1}. This value increases to 2.46 m^3s^{-1} in the immediate post-cutting period. The increase in the flow rate caused by the forest system management is thus 100%, with significant effects on the intensity of alluvial phenomena. The magnitude of the negative impact on runoff increases further in the case of agricultural conversion of 50% of the basin, resulting in a peak flow of 3.49 m^3s^{-1}.

4. Discussion

Interventions on the eco-systems and on the territory described above mainly affect soil loss, water provisioning and its purification. Once quantified the available water, the water harvesting systems can be planned at a basin scale. In fact, water losses associated with vegetation transpiration have a positive impact on the water flow regulating service and potentially negative for the supply of water resources. At the same time, forest vegetation results in a strong protective action against the soil removal caused by erosion. However these aspects needs to be properly analyzed since the presence of vegetation also determines the space-time distribution of water resources by reducing runoff velocity and the potential for increasing groundwater storage and infiltration [88, 83, 56]. The different dynamics of these hydrological processes affect the hydraulic residence time in the basin and the reduction of the seasonal variation of the seasonal fluctuations [89]. It has been shown that the increase in the forest area reduces irregularities in the runoff and increases the water retention time within the catchment area [88]. A significant negative correlation between forest area and water pollution has been also identified [2]. The amount of water with qualitative characteristics suitable for anthropic uses is a key element for determining the environmental carry capacity. This capacity is in fact defined as the maximum consumption of natural resources that can be supported in an area, without compromising the state of quality and quantity of water in an ecosystem [90, 91, 92].

Modelling studies of the water balance and evapotranspiration can improve the estimation of the hydrological quantities with positive effects on the evaluation of ecosystem services.

In perspective, the potential of this methodology, developed for territorial planning at micro-scales, can increase if the empirical functions used in this exercise will be replaced by mathematical models.

To transform the quantitative results in economic value achievable from the eco-system services, the unit costs are taken into account. In the paragraph 2.1.5 the ranges of these costs are reported for each considered service. In the exercise here reported for the Bonis watershed case study, the effective costs usually used in Italy have been considered. These values generally correspond to the minimum economic values of the indicated ranges, mainly for two costs items: storm – water retention and soil replacement.

In order to validate the robustness of the proposed methodology, the results of a sensitivity test are analyzed. It consists in using different unitary costs for estimating the values of an ecosystem service and then to compare the results. Therefore, the ecosystem economic value has been recalculated for the following hypotheses: case i) unit costs (see paragraph 2.1.5) referred to the minimum values of ranges; case ii) maximum unit cost for storm - water retention systems and invariance of other economic parameters; case iii) maximum unit cost for soil replacement and invariance of the other economic parameters; case iv) average unit costs for storm - water retention systems and for soil replacement, invariance of other economic parameters.

Figure 2 shows an economic sensitivity analysis which allows to validate the robustness of the proposed approach. The maximum increase (respect to case i) in the total value of ecosystem services is obtained (130%) in the case iii). As for the case ii) the increment is 92% and it corresponds to about 50% in the case iv).

If the unit cost attributed to the ecosystem services varies within the above-reported ranges (paragraph 2.1.5), the trends do not change with the land use scenario. The only exception is observed for the third land use scenario: where the 50% of lands is used by cropping systems to the detriment of the forest territory: here the economic value of the hydrological eco-services is systematically the lowest. The sensitivity analysis suggests that any increase in the cost of soil replacement (as for the cases iii and iv) entails the economic significance of the forest surfaces in a watershed, in terms of their extend, care and sound management.

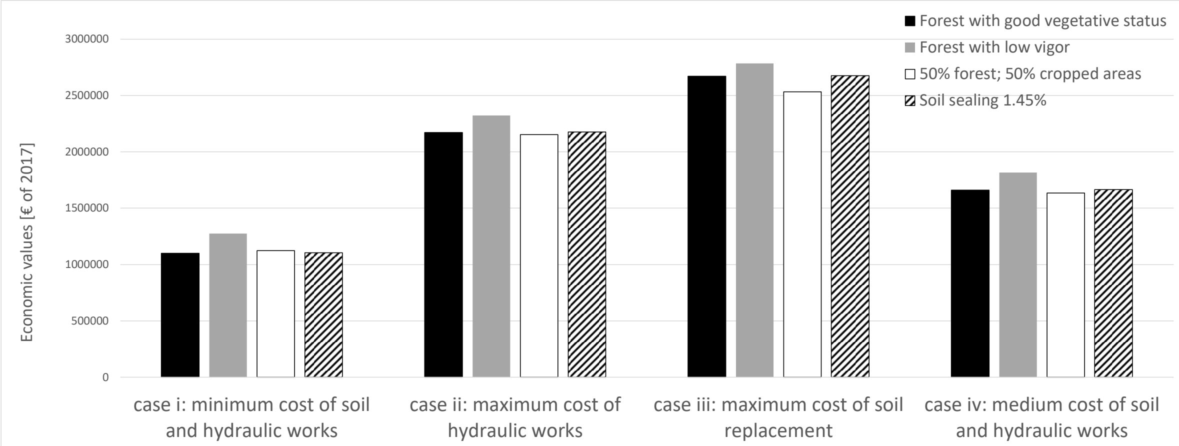

Figure 2 – Sensitivity analysis: variations of the economic values of the hydrological eco-services according four cost cases in four land use scenarios

5. Conclusions

The research has shown that, under typical Mediterranean conditions, changes in land use and vegetation management have a significant impact on eco-hydrological processes occurring at the watershed scale. For this reason, the analysis of the effects of territorial planning on the hydrological cycle and on the quality is a prerequisite in order to protect the state of water resources and hydrogeological equilibria at the same time. As an example, water provisioning (WS) could be improved by 17 % when the forest surface is halved, however the peak flow increases (by 176%) as well the soil erosion (563 t y^{-1}). These figures change when the forest is adequately managed (low vigor due to the cutting): respect to the forest not properly managed (Forest with good vegetative status) WS improves by 45% and the peak flow increases by 95% (about the half of the previous scenario when the cropped areas occupy the 50 % of the watershed) and the soil erosion is of the same extent: 188 t y^{-1} more.

The proposed methodology is an useful tool for designing appropriate water harvesting systems. Moreover the methodology allows to quantitatively analyze the effects of planning land use on actual or future water resources availability, water quality and the intensity of flood phenomena. It also provides a rigorous economic quantification of ecosystem services, in order to be able to tailor more precise and suitable policies measures for forest areas or for managing the land use in a watershed.

The sensitivity analysis confirms that the proposed approach provides effective results also in estimating economic values of the ecosystem services, even if unit cost (mainly for the soil replacement or the storm - water retention systems) considerably changes.

In perspective, the economic estimation of the ecosystem services allows to consider incentives, or tax policy, as a tool for the river basin planning, by supporting the land use variations which might improve the state of water resources. These measures are also foreseen in the Water Management Plans (2000/60 / CE) and the Floods (Dir. 2007/60 / EC) to improve water status and water retention.

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