Chapter 10

Vulnerability of Soil and Water in Mediterranean Agro-Forestry Systems

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Additional information is available at the end of the chapter

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Abstract

The study watershed is located within the Idanha Irrigation Scheme, Portugal. A hydrological and water quality station was installed at the outlet of the catchment. The AnnAGNPS model was applied in this study, and afterwards it was calibrated and validated to the conditions in the study catchment. The antecedent soil moisture conditions play an important role for rapid runoff and flash flooding. Relative Water Supply (RWS) is always bellow the unity value and sometimes below the value 0.5. Sometimes in very dry years, like the year 2004-2005 (302 mm), a runoff coefficient is equal to 0.40. Spatial distribution of runoff was primarily influenced by topography and soil management, which is common in Mediterranean agricultural systems, namely in grain crop systems such as oats and wheat. The simulation of spatial distribution of nitrate load shows a dependence of the spatial distribution of runoff, due to its high solubility. Spatial distribution of soil erosion by water indicates that the process does not depend directly on the runoff distribution in the catchment. Therefore, soil erosion is greatly influenced by deficient land cover whenever erosivity of rainfall is strong. Phosphorus losses were less than nitrate losses, due to their lower water solubility and mobility in soil.

Keywords: Mediterranean environment, agro-forestry systems, soil and water conservation, soil erosion, water scarcity, water pollution, Portugal

1. Introduction

Farming activities, as a part of natural resource management practice, impact both soil and water quality at the watershed level. The nonpoint source (NPS) pollution with nitrates and phosphates from agricultural areas, sometimes associated to soil erosion by water, is an important environmental problem [1]. For instance, the source of nitrates and phosphates from agriculture activities is reported as responsible for 46–87 and 20–40%, respectively, into European continental waters [2]. Soil and water conservation practices also help to reduce the loss of chemicals in runoff and maintain water quality [3]. Increases in nutrient losses and riverine nutrient loads have caused eutrophication of many coastal and freshwater ecosystems in many Mediterranean regions (**Figure 1**). Nonpoint source (NPS) pollution is an important environmental and water quality problem closely related to hydrologic behavior of watersheds as a basic management territorial unit [4]. However, watershed being a geographically dynamic unit, its behavior varies both spatially and temporarily. Nonpoint source pollution has become a global environmental issue and it has been a critical issue concerning environmental degradation caused in recent years.

The Mediterranean climate plays an important role in these environmental issues, like soil erosion and degradation of quality water bodies, given the irregularity and uncertainty of climatic patterns. The Mediterranean climate is characterized by irregular inter-annual and intra-annual precipitations (wet years mixed with recurrent droughts), and high concentrations of rainfall over a few months, many times over only a few days, and low rainfall during the summer [5, 6]. On the other hand, many of the conventional Mediterranean arable land cropping systems have a soil surface, which remains uncovered during long periods of time, corresponding to the soil preparation and crop establishment phases, which frequently occur during the periods of high rainfall concentration (**Figure 1**) [7, 8]. The runoff regime associated to this climatic condition determines in many years a low capacity for harvesting a convenient volume of water for agricultural activity and the implementation of some strategies for coping with water scarcity [9]. Both water scarcity and Mediterranean forestry systems create preferential conditions for wildfires, which can considerably change the hydrological processes and the landscape's vulnerability in major peak flow and erosion events [10]. Thus, to have a better understanding of the processes of soil erosion and nonpoint source pollution at the basin scale, to better actuate on their prevention, monitoring studies conducted at a watershed scale are difficult to replicate in the way that traditional plot-scale research is designed, in order to compare responses of alternative management practices using only field observations [11]. At plot scale, it is easier to conduct research actions to study those processes, but it is impossible to obtain accurate valid information for large areas (**Figure 2**). So, computer simulation models provide an efficient and effective alternative for evaluating the effects of agricultural practices on soil and water quality at the watershed level [12].

Figure 1. Soil erosion by water and consequences downstream, namely eutrophication of the water bodies.

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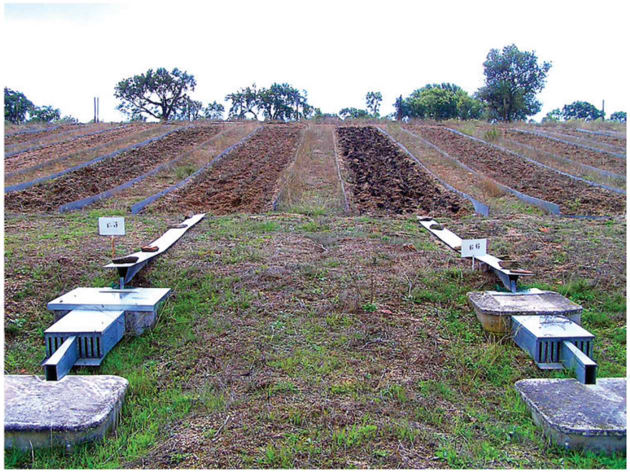

Figure 2. Plots to evaluate soil erosion by water under some crop rotations (Experimental Station in Polytechnic Institute of Castelo Branco/School of Agriculture).

Erosion is mainly due to climatic conditions, namely the precipitation patterns, and the inadequate use of soil by agriculture and forestry, but also through building constructions and uncontrolled water runoff from roads and other sealed surfaces. According to this, the regions of the Mediterranean basin where the higher rates of soil erosion are mapped are coincident with the regions where the highest values of erosivity density are verified (**Figure 3**). In more than one-third of the total land of the Mediterranean basin, average yearly soil losses can

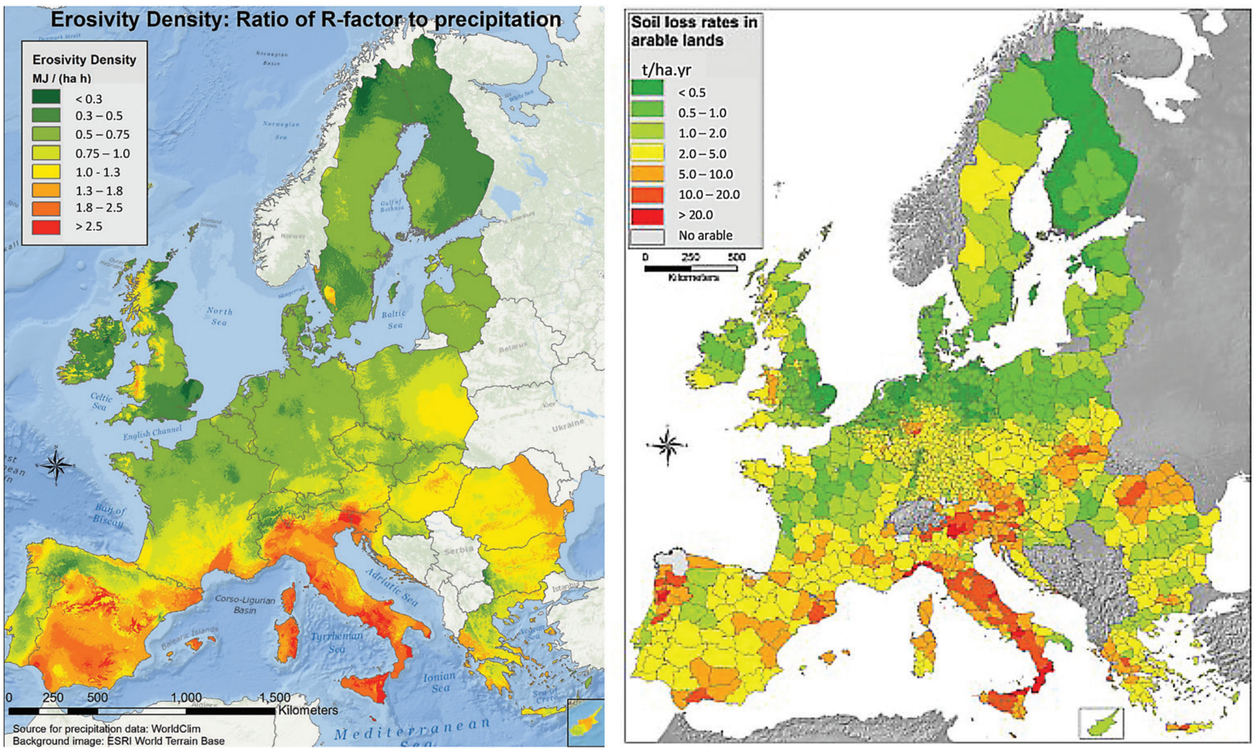

Figure 3. Erosivity density (erosivity factor per precipitation unit) and soil erosion by water in Europe [13].

exceed 15 tons ha^{-1}. On the other hand, loss of organic matter is mainly due to intensive use of the land by agriculture, especially when organic residues are not sufficiently produced or recycled to soil. Agronomists consider soil with less than 1.7% organic matter to be in predesertification stage [13].

The main objective of this study is to understand the dynamics of pollutant sediments, nitrates, and phosphorus in close relation to hydrologic behavior of a small basin in typical Mediterranean environmental conditions.

2. Methodology

The study watershed is located within the Idanha Irrigation Scheme, Idanha-a-Nova County, Portugal, near the border with Spain and just north of the Tagus River (**Figure 4**). The study area is close to the International Tagus Natural Park, where we can find many terrestrial and aquatic unique ecosystems, like a Mediterranean forest very well adapted to these conditions (holm oak forest—*Quercus ilex L.*), and some communities of rare birds of prey (imperial eagle) and black stork. Therefore, this region is very sensitive from an environmental point of view. It covers an area of 189 ha and a perimeter of 6510 m, and presents a third-order hierarchy stream. The main natural stream is 2300 m long and runs north-southwest. The drainage density of the perennial streams is 12.2 m ha^{-1} [14].

Altitude varies from 212 m at the outlet of the basin to 248 m, and the slopes range from 0 to 4%; thus, the topography is flat to gently undulating (**Figure 5**). The limits of the study catchment are well defined.

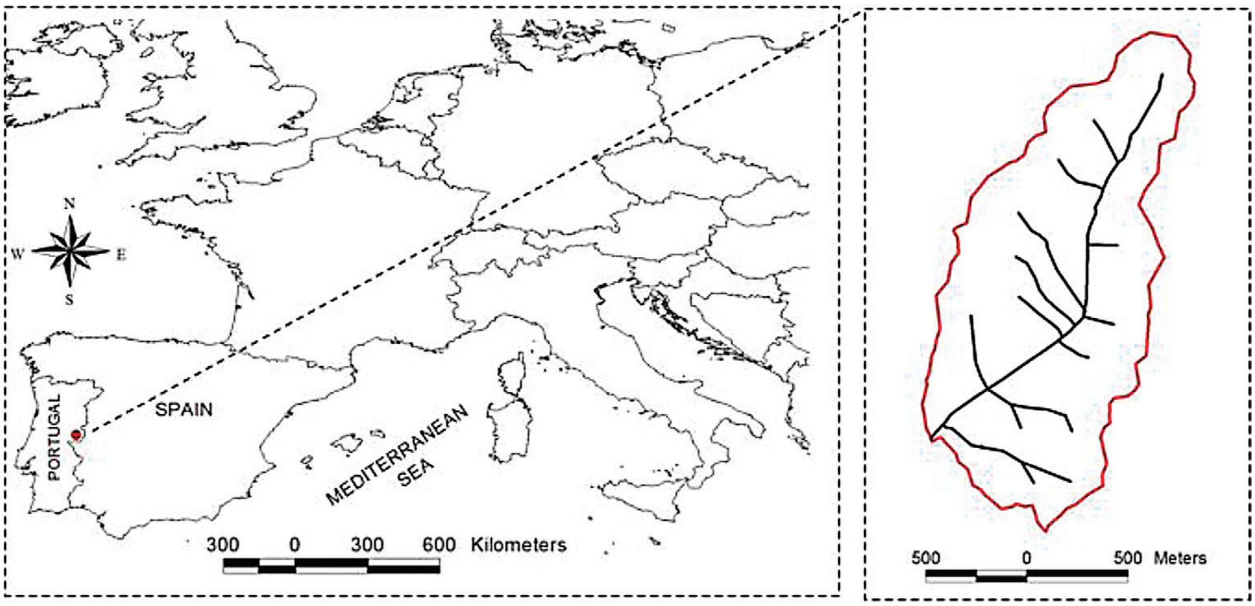

Figure 4. Location of the study catchment in Portugal.

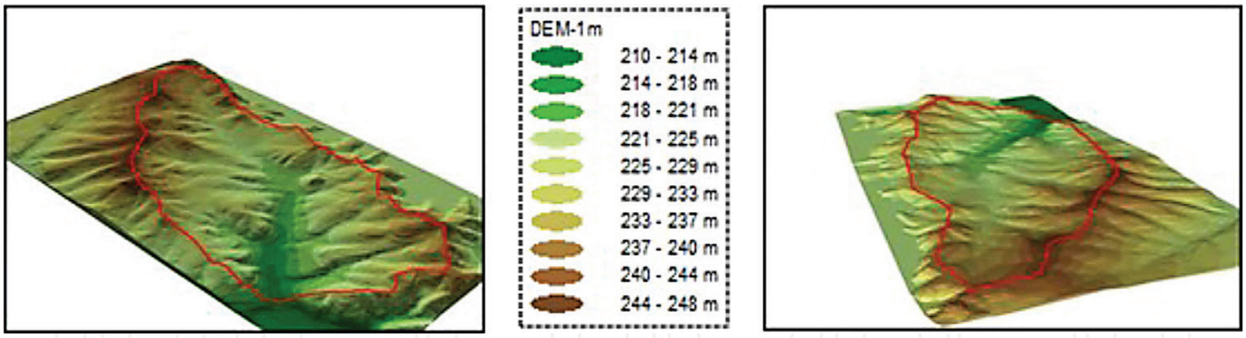

Figure 5. Topography of the study catchment and a downstream and upstream view.

The climate is typically Mediterranean continental. Average annual rainfall is 638 mm, with a rainless summer. The average temperature varies from 8.1°C in January to 25.3°C in August; the average reference evapotranspiration (ET_o) ranges from 0.5 mm day^{-1} in January to 9.0 mm day^{-1} in July (**Figure 6**) [14]. According to the Köppen climate classification, the study catchment enters a Mediterranean Csa type climate (humid temperate with a dry and hot summer).

The study catchment covers an area of 189 ha and it is subdivided into 18 fields. About one-third (31%) of the catchment is not irrigable and is now devoted to a young cork (*Quercus suber* L.) and oak tree (*Quercus rotundifolia* Lam.) forest that was planted in 2001. Three distinct areas can be identified in terms of agricultural practices: uncultivated zone (area with cork and oak young forest), an area with intensive agricultural use in monoculture (maize and tobacco), that in some recent years has remained fallow, and an area with diversity of agricultural uses with smaller fields. The area with young cork and oak forest, located in the eastern part of the basin, can be seen in long fallow as it has not been cultivated for several years [14]. The irrigated fields use sprinklers with either center pivot units or stationary systems. As a consequence of the Common Agriculture Policy, that was put in practice at the beginning of this century, namely almost disappearing with tobacco, the irrigated area decreased to less than half after 2005 irrigation season, with a corresponding increase in fallow area. This reduction has clear implications on the hydrologic behavior of the basin during the irrigation season and subsequent rainfall season [15].

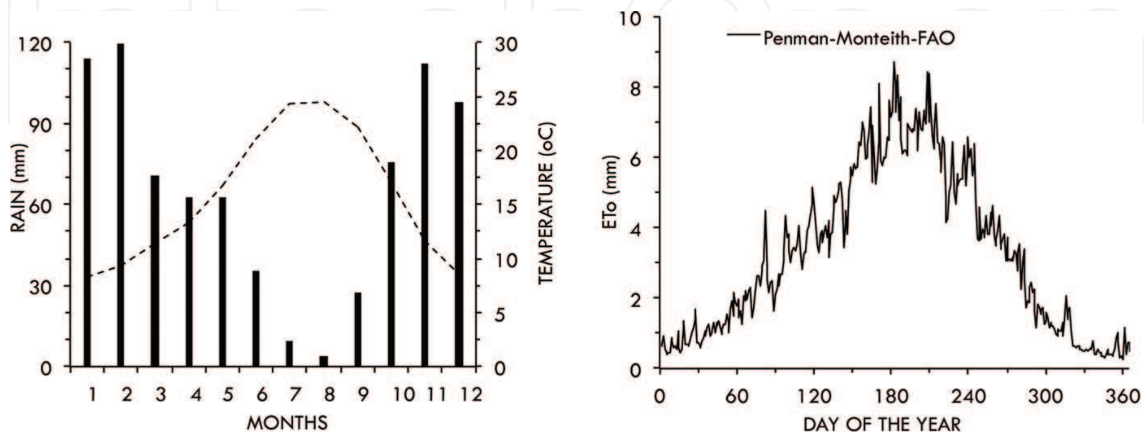

Figure 6. Characterization of climate in the study catchment through parameters of rainfall, temperature, and evapo transpiration.

Soils in the catchment were mapped from preexisting unpublished studies, field inspections, photo-interpretation techniques, and detailed characterization of one soil profile per soil group. According to the FAO classification system [16, 17], the predominant soil groups in the watershed are Luvisols and Cambisol, these ones originated from fluvial deposits associated with the tributaries of the Tagus River (**Figure 7**). Fluvisols are also present in the catchment area, these originated from alluvial deposits associated with the main creek. An impermeable, fractured soil layer underlies the Luvisols classes at a depth of approximately 0.4 m. Luvisols[1] are soils with a subsurface horizon of high activity clay accumulation and high base saturation and show marked textural differences within the profile. The surface horizon is depleted in clay while the subsurface argic horizon has accumulated clay (Bt horizon). A wide range of parent materials and environmental conditions lead to a great diversity of soils in this Reference Soil Group. Other names used for this soil type include sols lessivés (France), Alfisols (Soil Taxonomy), and Mediterranean soils (Portugal). The Luvisols of the Mediterranean region are widely distributed throughout Portugal, Spain, Italy, Greece, Albania, Croatia, Turkey, and Cyprus, which represent a significant percentage of the total area of soils in these countries. Luvisol is a fertile soil suitable for a wide range of agricultural uses. In the Mediterranean, it is commonly used for cereals. On sloping land, it requires measures such as man-made terraces to control erosion, and it is best suited for fruit trees, vineyards, olives, and grazing [13].

A hydrological station was constructed and installed in 2004 at the outlet of a catchment (39°50′48″ N, 7°10′00″ W). The station consisted of (i) a long-throated flume, with a triangular control section for small water depths and triangular/trapezoidal control section for large water depths [18] and (ii) an ultrasonic sensor ("The Probe," manufactured by Milltronics, Siemens Milltronics Process Instruments Inc., Ontario, Canada) connected to a data logger continuously measuring and recording the water level at the flume (**Figure 8**). Pollutants, nitrates, sediments, and salts, were evaluated with a multiparameter probe for monitoring and logging water quality (TROLL 9500 Water Quality Instruments, manufactured by In-Situ Inc.,

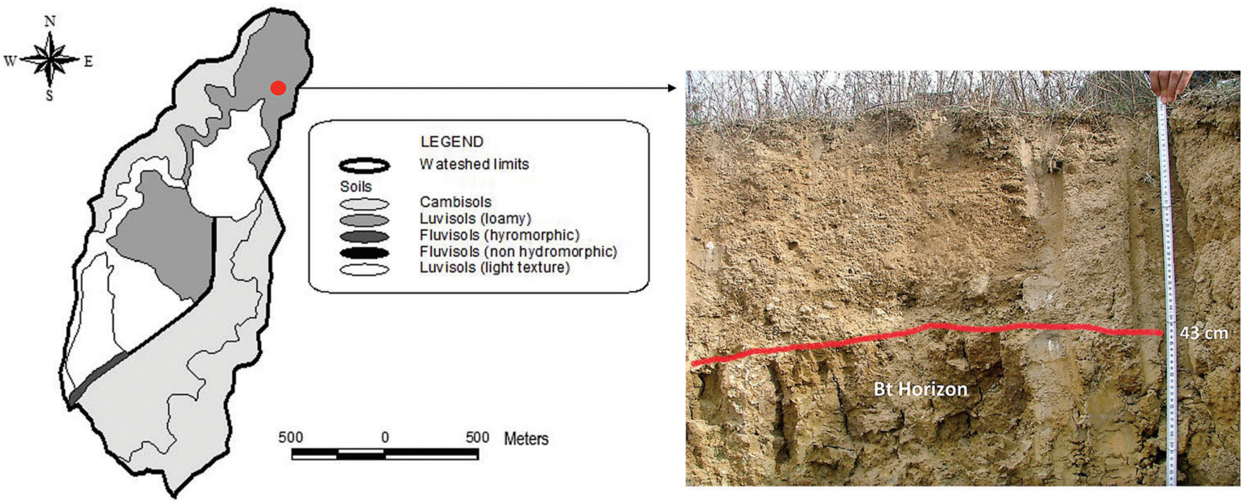

Figure 7. Soils in the study catchment (FAO nomenclature), and a soil profile from a Luvisol.

[1]From the Latin, luere, meaning to wash.

Figure 8. Hydrometric and water quality station located at the outlet of the study catchment.

Fort Collins, Colorado, USA). Farming practices, related to Mediterranean crops rotations, were recorded by farmers and verified by direct observations during visits to the catchment to apply to a computer model. The irrigation methods used in the study watershed are sprinkler center pivot and stationary sprinkler (in the areas not covered by the pivot machines).

Several available hydrologic models were evaluated and the Annualized **Ag**ricultural **N**on-**P**oint **S**ource (AnnAGNPS) pollution model was selected as the simulation tool to be used in this study. AGNPS is a suite of computer models resulting from the joint effort between the Agricultural Research Service (ARS) and Natural Resources Conservation Service (NRCS) agencies and it has been developed to evaluate farming and conservation practices through prediction of nonpoint source pollutant loadings within agricultural watersheds. Within AGNPS, AnnAGNPS is a continuous simulation, mixed-land use, watershed-scale computer model designed to predict the origin and movement of water, sediment, and chemicals at any location in agricultural watersheds [19]. The model estimates erosion caused by different processes such as sheet and rill, tillage-induced gullies, classical gullies, and streambed and bank sources [20]. AnnAGNPS has been calibrated, validated, and applied for runoff and sediment yield losses from watersheds in different geographic locations, conditions, and management practices [21, 22]. The AnnAGNPS model was applied in this study and afterward was calibrated and validated to the conditions in the study catchment [23]. **Table 1** lists the main input parameters commonly used in AnnAGNPS simulations.

Irrigation performance and catchment water usage were quantified for various irrigation and rainfed seasons using the following indicators [35, 36]:

$$\text{Runoff coefficient:} \quad ROC = \frac{RO}{R + I} \tag{1}$$

$$\text{Relative irrigation supply:} \quad RIS = \frac{I}{I_{\text{required}}} \tag{2}$$

where ROC is the fraction of rainfall and irrigation that contribute to runoff verified at the outlet of the basin, RO (mm) is the runoff verified at the outlet of the study catchment, R (mm) is rainfall, I is irrigation applied on the irrigated fields in the study basin, and I_{required} is the required irrigation calculated by FAO methodology, as the water requirements to satisfy the full water needs of the crop [37].

Group of parameters	Input variables	Methods
Climate	Daily rainfall	Measurements at the Ladoeiro [24] and Ribeiro de Freixo stations (data not published)
	Daily maximum and minimum temperatures, wind direction and speed, daily percentage cloud cover and dew point temperature	Measurements at the Ribeiro de Freixo station (data not published)
	Annual distribution EI_{30}	Calculated with measured data, from Ladoeiro data [24] and the methodology described by Wischmeier and Smith [25]
	Type of rainfall distribution (TR-55)	Comparison with the 24 h rainfall distribution curve calculated with the data from Ladoeiro station [24]
	Two year 24 h precipitation	Gumbel method [26] applied to the data from Ladoeiro station [24]
Topography	Drainage area and limit of the catchment, cells area, reaches length, mean slope of cells and reaches, RUSLE LS factors	Application of TopAGNPS and AgFlow [27]—ArcView interface 3.2, using a DEM with 1 m vertical resolution
	Topographic and hydrologic configuration	Manipulation of the CSA and MSCL parameters, and comparison to observed and simulated natural stable reaches
Soils	Depth (horizons)	Field observations, cleaning of profiles
	Texture	Method of Robison pipette [28]
	Saturated hydraulic conductivity	Rawls and Brakensiek [29]
	Bulk density	Mass/volume of clods with wax to measure their submerged weight
	Field capacity and wilting point	Richard's methodology
	Percentage of organic matter	Methodology of Walkley-Black [30]
	pH	ISO [31]
	Coarse elements (%)	Field observations
Operations and Management	Crop data	Farmer's information and some bibliography related with crops in the catchment
	Crop operations, included irrigation	Farmer's information and some observation in the fields
	Irrigation application rate	Measured in field [32, 33]
	RUSLE-factors C and P	Wischmeier and Smith [25]
Others	CN	TR-55 [34]
	Manning's n	Wischmeier and Smith [25]

Note: DEM, digital elevation model; CSA, critical source area; MSCL, minimum source critical length; CN, curve number.

Table 1. AnnAGNPS Input parameters and methods used in their evaluation.

3. Results

In Mediterranean climatic conditions, the accumulated erosivity curve shows a stationary phase in the summer months (June, July, August, and September), because it has not practically rained, and two phases of growth, one in the first five months of the year and another, more intense, in the last months of the year. This phase is particularly important, specifically

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for winter crops such as cereals, since the surface of the soil is unprotected [38, 39]. In contrast, the annual erosive rain is less than 50% of the total annual rain, according to the results of 14 years (2001–2014). The adjustment of linear tendency shows that the larger the total rainfall, the less is the erosive rain (**Figure 9**). Therefore, the analysis of rainfall and erosivity (EI30 methodology, as a compound index of kinetic energy of the rain, E, and the maximum 30-min intensity) [25] distribution over many years (2001–2014) shows typically Mediterranean climate conditions.

Case of a single event (**Figure 10**) shows that the superficial runoff dominates the hydrological response of this basin during the most significant events, known as Hortonian model [40]. This behavior is in part responsible for an almost impermeable layer (horizon Bt), characteristic of Luvisols. The significant variability in runoff is justified not only by differences in characteristics of storms and surface soil moisture content, but also by preceding long dry periods which were likely to ease the effects of rainfall [41, 42]. So, the event occurred on October 20, 2004, in dry soil conditions, reached a discharge equal to 8289 m^3 in sequence of 39.9 mm of precipitation (**Figure 9**). In a subsequent event, on October 27, 2004, in wet soil conditions, the total discharge was 80,457 m^3 derived from 42.3 mm of precipitation (**Figure 10**). This significant difference between two runoff events caused by almost the same precipitation illustrates the decisive influence of the antecedent soil moisture conditions in the magnitude of the flash floods at the small basin scale. It is considered by some authors (e.g., [43]) as the most important soil factor for rapid runoff and flash flooding, with a tendency to produce in Mediterranean region more extreme floods than other European regions [44].

The relation between the water entry in the catchment and the runoff coefficient is completely different under irrigation and rainy seasons. In fact, it is possible to establish a good positive correlation in irrigation, while in the rainy season no relation is possible (**Figure 11**). As is comprehensible, in irrigation conditions, the runoff coefficient is proportional to the volume of irrigation water provided to the fields, given that the water is supplied by a regular behavior. Nevertheless, only from a minimum value of water supplied to the irrigation fields, start to have runoff at the outlet of the catchment. For example, in the 2007 and 2009 irrigations seasons,

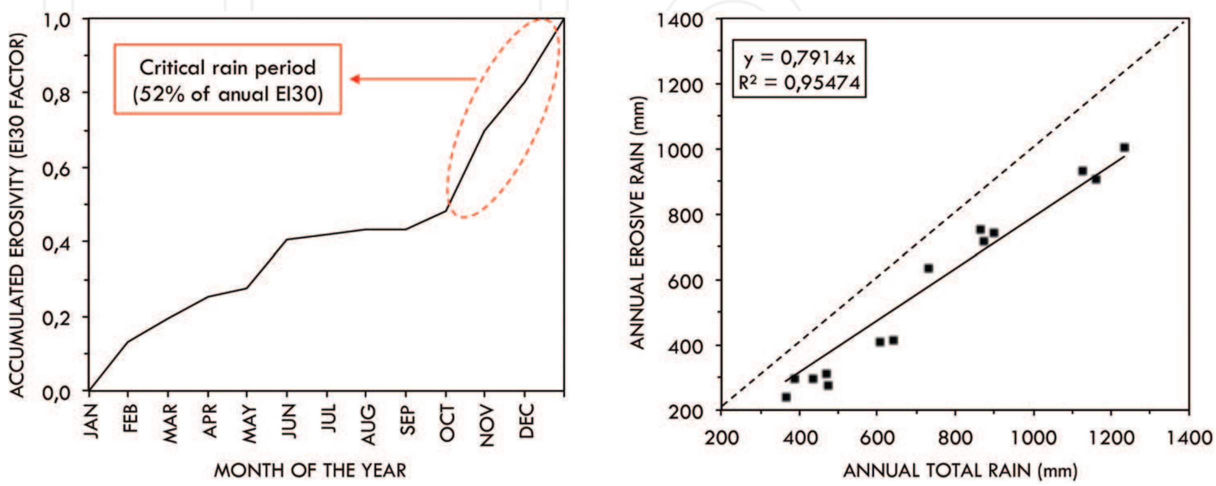

Figure 9. Distribution of average EI30 factor (MJ mm ha^{-1} h^{-1} yr^{-1}), total rainfall, and erosive rainfall.

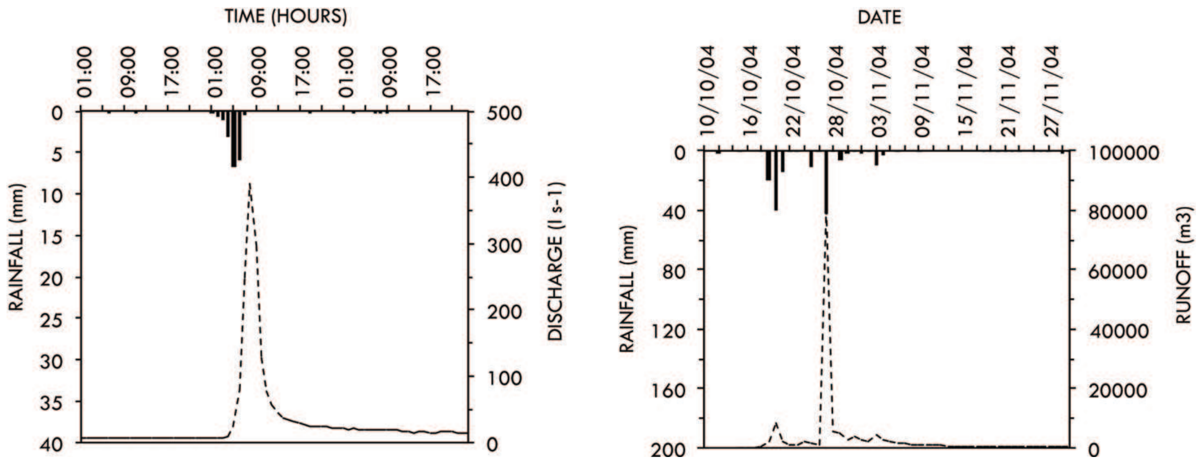

Figure 10. Precipitation and hydrograph (dotted line), recorded between November 30 and December 2, 2004, showing a hortonian behavior [40], and influence of the antecedent soil moisture conditions on the magnitude of hydrologic events.

the water supplied to the irrigations fields was 56 mm and 54 mm respectively **(Table 2)**, and the runoff observed in the outlet of the study basin was 0 mm in both irrigation seasons (**Figure 11**, left chart). On the other hand, as was concluded earlier [14], the reduction of the runoff coefficient is more than proportional relatively to the reduction of water supplied to the catchment. Therefore, it is necessary to make difference on the concept irrigation efficiency at different territorial scales; performance indicators of irrigation at field scale or at catchment scale are not the same [45]. During usual rainy seasons, as in the irrigation seasons, it is possible to obtain a good positive relation between rainfall and runoff coefficient, but in some unusual years the relation is completely shuffled. That is characteristic for Mediterranean climatic conditions, namely precipitation patterns (**Figure 11**, right chart). The highest value of runoff coefficient verified in the study catchment (0.36) is obtained for the rainfall of only 302 mm in a very dry season (2004/2005).

In many regions in the Mediterranean basin, like in the study catchment, the indicator cropping intensity (*CI*), defined as the ratio of arable to cultivated area, is low due to some climatic,

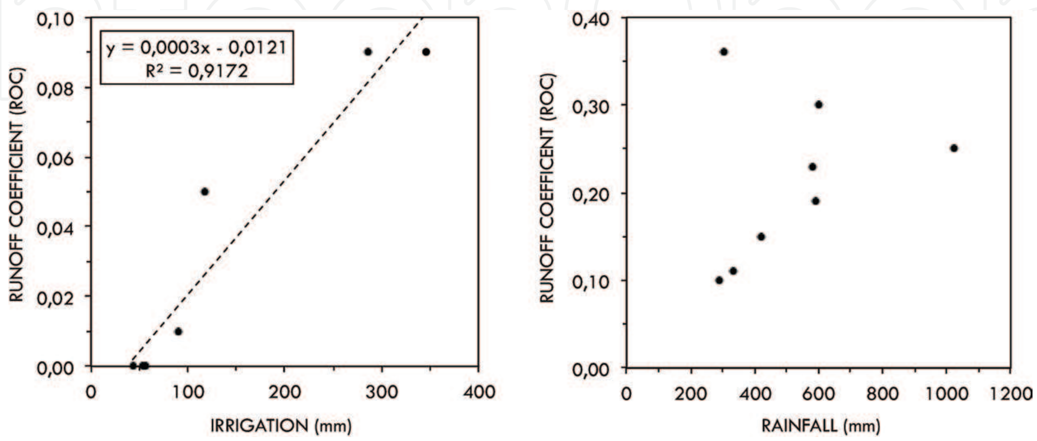

Figure 11. Runoff coefficient (*ROC*) in irrigation and rainfed seasons evaluated in the study catchment.

institutional, or socio-economic factors. This is one of the threats to the region, as a result of the higher susceptibility to environmental damage, like wild fires, and the consequences of soil erosion [46]. In the last century, many rural regions in the Mediterranean basin had significant demographic and socio-economic changes, which determined a substantial decrease in population, abandonment of agricultural land and increase of the human-induced desertification process [47]. Water scarcity and more frequent droughts are other serious problems in the Mediterranean region, which require an enhancement in water management and more efficient water allocation, distribution, and use [48]. Relative water supply (RWS) is always below the unity value, except in the irrigation seasons of 2004 and 2008 in the study catchment, and sometimes even below the value 0.5, clearly denoting water scarcity in most of the irrigation seasons (**Table 2**). Both, deficient water distribution in many irrigation districts and/or low water storage in the reservoirs, are the most frequent reasons that determine water scarcity conditions on the irrigation fields.

Mediterranean climate, as referred earlier, presents a strong intra- and inter-annual irregularity, being especially evident in the rainfall patterns [49]. Additionally, studies of hydrological behavior in Mediterranean climate using precipitation and discharge averages are not relevant, since this kind of climate is dominated by extreme events [50]. The two graphics in

Cropping season	Year	Rain (mm)	Irrigation (mm)	Runoff (mm)	*CI*	*ROC*	*RIS*
Irrigation	2004		346	32	0.81	0.09	1.11
	2005		118	6	0.39	0.05	0.66
	2006		90	1	0.38	0.01	0.62
	2007		56	0	0.24	0.00	0.60
	2008		286	25	0.64	0.09	1.03
	2009		54	0	0.16	0.00	0.42
	2010						
	2011						
	2012		43	0	0.21	0	0.49
Rainfed	2004–2005	302		109	0.23	0.36	
	2005–2006	591		112	0.14	0.19	
	2006–2007	1021		255	0.14	0.25	
	2007–2008	422		62	0.06	0.15	
	2008–2009	333		36	0.16	0.11	
	2009–2010	601		180	0.32	0.30	
	2010–2011	579		134	0.24	0.23	
	2011–2012	288		28	0.24	0.10	

Table 2. Level of agricultural intensification (*CI*), runoff coefficient (*ROC*), and relative irrigation supply (*RIS*), in the study catchment, during seven irrigation seasons and eight rainfed seasons.

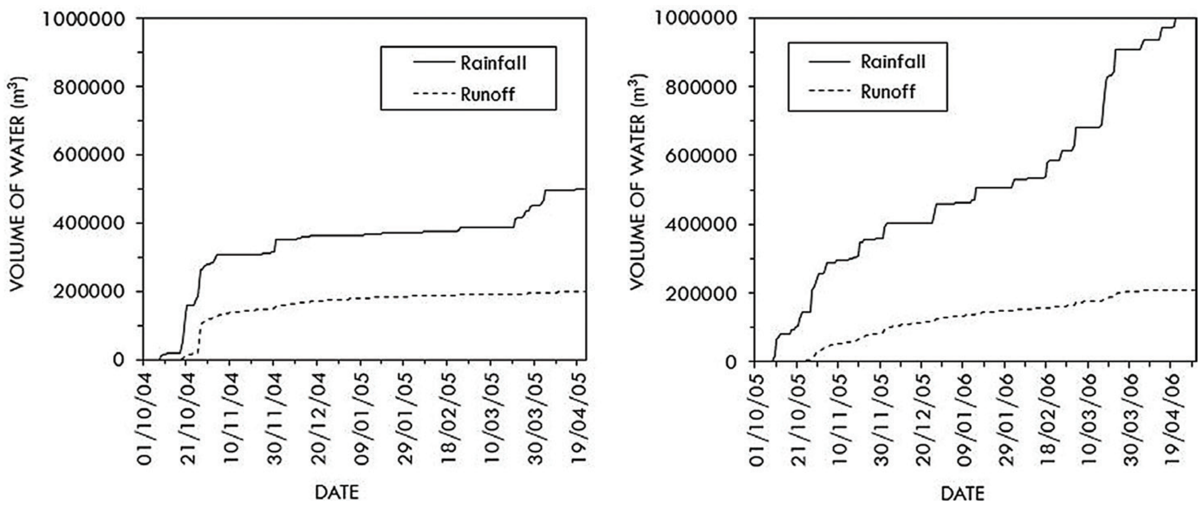

Figure 12. Rainfall and runoff verified in the rainfed seasons 2004–2005, as a dry year, and 2005–2006, as a meteorologically normal year.

Figure 12 show exactly what is a very abnormal (2004–2005) and normal year (2005–2006), as to the quantity and the distribution of rainfall and runoff. In fact, in 2004–2005, the amount of precipitation was 302 mm, distributed mainly into five events and giving a few more intense runoff events, highlighting the first event with a great magnitude. In the same period of time, the amount of runoff was 109 mm, determining a runoff coefficient equal to 0.36, a value which is uncommon in these conditions. In the hydrological year 2005–2006, the amount of rainfall (591 mm) was close to the average value in this region (638 mm) and was distributed by many more rainfall events. It should be noted that the amount of runoff (112 mm) was almost the same as that of the previous year, but giving a lower runoff coefficient (0.19). In the first year of analysis (2004–2005), the runoff started on October 19 and finished on April 20, without any gap in this period (**Figure 12**). Considering that, between December 13 and March 20 the amount of precipitation was 15.3 mm, and the continuous runoff was possible only because the natural channels' network was not disconnected from the aquifers or groundwater table [51].

Mediterranean rainfall can reach, sometimes with very high intensity, very important runoff events, like this one illustrated in **Figure 13**, which occurred in the hydrological year 2004–2005. This event occurred in the conditions of saturated soil, due to the amount of rainfall in the previous days (October 21–23; 77.9 mm), but, as noted before [52], big events can be reached when the intensity of precipitation exceeds the initial capacity of soil infiltration, or the maximum intensity of precipitation occurs in a favorable moment of the storm. In the present event, verified in a very dry year (302 mm), the runoff coefficient was equal to 0.85, characteristic to streams with torrential patterns, and the erosion annual rate in this event was 79.1%; with the potential to carry coarse elements outside the basin. Among the two different types of events identified by Camarasa-Belmonte [53], this one is related to the type with high intensity, occurring at the beginning of the storm and generating hydrographs that are very similar to the hyetographs. The other type of events, according to Camarasa-Belmonte [53], occur in the conditions of low intensity of precipitation and rain peaks at the end of the

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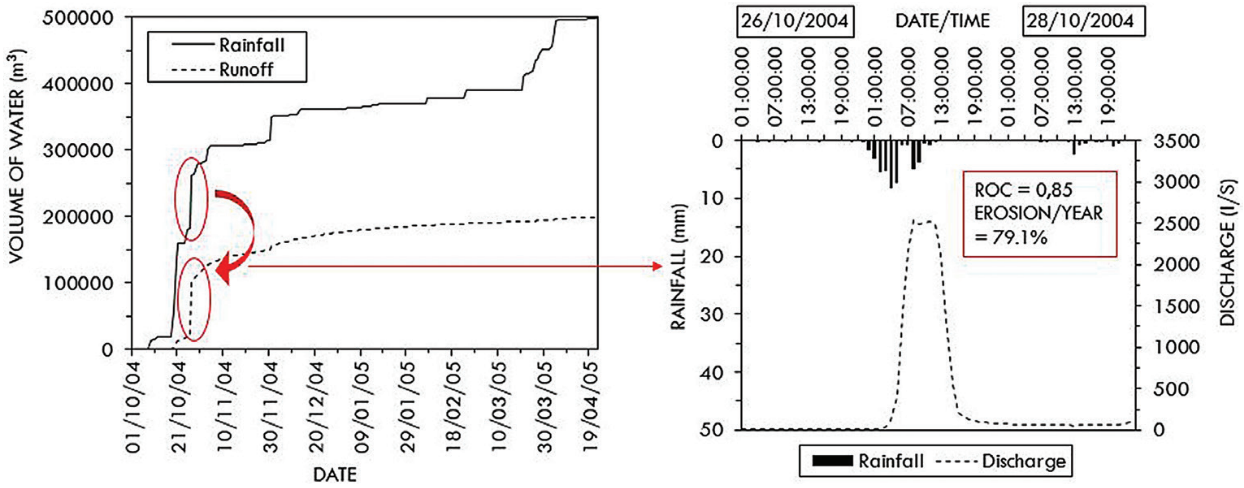

Figure 13. Runoff and erosion rates verified in a very strong event in October 2004.

event, generating hydrographs quite different from hyetographs. Both rising time and recession time are reached relatively quickly, due to the characteristics of this storm and the physical conditions of the catchment. Since this catchment does not have important water storage in the channels, soil and surface, rapid recession time is verified, when the storm stops [54].

The effects of surface runoff and soil erosion, as well as nonpoint source pollution at watershed scale, can be predicted with hydrological models. They are effective to simulate various combinations and scenarios, and indicate the best management practices to minimize these processes [55]. Several hydrological models were evaluated to simulate runoff and soil erosion, as well as nonpoint source pollution by nitrates and phosphorus. The selection indicates the AnnAGNPS model (Annualized Agricultural NonPoint Source), as the most suitable for this task. As for spatial distribution of runoff volume and the ratio of erosion in the basin, the results based on observations (**Figure 14**) seem to indicate that there is a distinction between

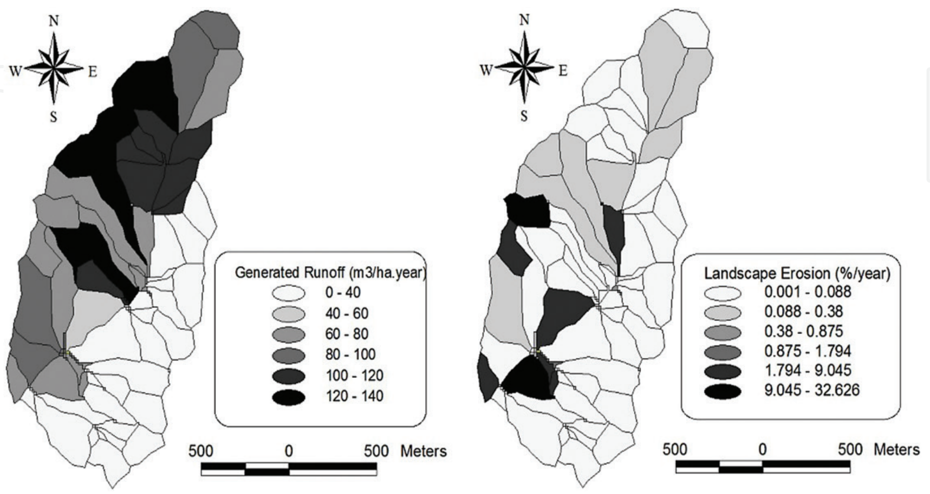

Figure 14. Average simulated runoff and erosion rates, generated in each cell and subcatchment, by AnnAGNPS model (period 2003–2005).

the two runoff-producing areas in the basin: one that generates low runoff (0–40 m^3 ha^{-1} yr^{-1}), which corresponds to the uncultivated area in the basin (58.6 ha), and another, which corresponds to the remaining area of the watershed (130.4 ha) occupied by various crops, producing higher runoff (41–140 m^3 ha^{-1} yr^{-1}). The variation of runoff in the cultivated part of the basin depends on the topography, the type of soil, and their intrinsic characteristics. The relations showed in **Figure 6** enable to conclude that there is no correlation between the average sediment production and the average runoff volume in most of the cells in the basin [38]. Although having an influence on the erosion process, the average volume of runoff is not the determining factor. Other factors such as land cover throughout the year, especially during the concentration of rainfall, and the occurrence of more or less erosive storms appear to have more significant influence [56, 39].

The massive use of fertilizers is common to all the agricultural systems around the world. Nitrogen losses, from the agricultural nonpoint sources, has become one the most significant threats to the quality of water bodies [57]. Due to the solubility of this contaminant (inorganic-N), there is a close relationship between hydrological processes and the loss of nitrogen, with the superficial and subsuperficial runoff. Organic-N is adsorbed in the fine soil particles, while their loss occurs preferably through soil erosion [58]. The loss of nitrates is not affected by rainfall variability as the sediment loss. According to some earlier studies, the base flow is the main source of nitrates at the surface of water bodies [59]. Regarding the nonpoint source pollution of nitrates (**Figure 15**), the research has shown that the process occurs when there is significant runoff, given the solubility of nitrates, and when there is availability of this nutrient in the soil, in sequence of more or less intense fertilization [60]. The values simulated by AnnAGNPS are similar to the reference values obtained in other studies: pristine watersheds and organic agriculture (0.76–10.85 kg NO_3-N ha^{-1} yr^{-1}) [61]; nonirrigated agriculture (26.10 kg NO_3-N ha^{-1} yr^{-1}) [59]; irrigated agriculture (59.00 kg NO_3-N ha^{-1} yr^{-1}) [60]. Moreover, only about 0.3 mg l^{-1} of nitrates is needed for growth of algal and to promote the eutrophication [62]. The critical value was

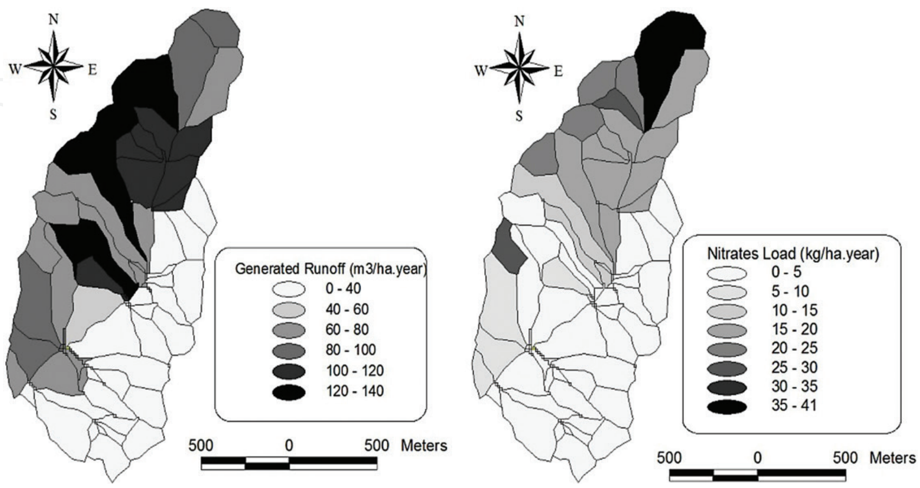

Figure 15. Average simulated runoff and nitrates load, generated in each cell and subcatchment, by AnnAGNPS model (period 2003–2005).

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largely surpassed in the period of simulation, as shown in **Figure 15**. According to the efficiency of nitrogen fertilization practices, the loss of nitrates can reach high values (30–80%) in intensive cropping systems [63], like maize or tobacco in the study catchment. So, the riparian buffers and vegetation strips on stream water can be a very good measure to improve water quality downstream of the agricultural fields, as observed and analyzed in some earlier studies [64, 65].

The continuous use of phosphorus in agriculture, many times with little P-use efficiency by crops, increases in phosphorus concentration in the soil, and increasing the risk of phosphorus in runoff along with leaching to water bodies, contribute to the eutrophication [66, 67]. Phosphorus is an element with little mobility in the soil, and can be transferred from agricultural systems to water bodies dissolved in the superficial runoff, leaching to deeper soil layers, or in conjunction with mineral and organic sediment in the water erosion process. Similar to this study, Olness et al. [68] observed losses of P to agricultural watersheds lower than 5% of the most recent P fertilization, with a total P discharge in runoff waters ranging from 1.0 to 11.5 kg P ha^{-1}. Considering the volume of runoff verified in our basin, the value highlighted by some authors as the level to prevent the risk of eutrophication (0.05 mg L^{-1}) [69] is probably often exceeded. Most of the phosphorus used in the agricultural fields, as in our basin, is for winter cereals crops (oat, wheat, rye), most common in Mediterranean agricultural systems. Phosphorus can load in solution outside the basin in surface or subsurface runoff, depending on the nature of P-forms (mineral or organic) and in the soil texture, or attached to the finest soil particles [70, 56]. The analysis of the relation showed in **Figure 16**, referent to the simulated phosphorus load by AnnAGNPS model, suggests that most of the phosphorus is lost in solution and not with the soil colloidal particles loaded outside the watershed, given the subcatchments where high values of P-load occurred (10–12 kg ha^{-1}.yr), and relatively low rates of soil erosion were verified. The phosphorus loss clearly occurred mostly in the agricultural fields and almost null in the forested area, while the high loss values were verified in the fields occupied by winter cereals.

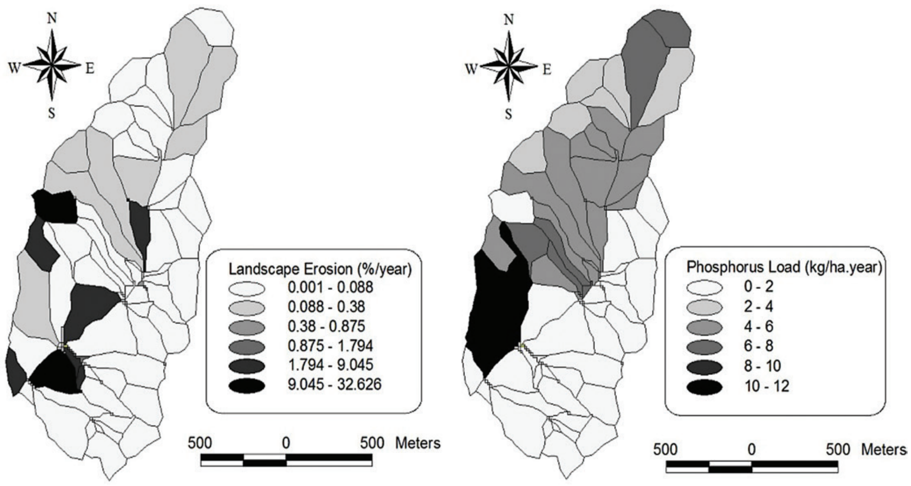

Figure 16. Simulated average phosphorus load by AnnAGNPS model, generated in each subcatchment (period 2003–2005).

4. Conclusions

Both soil and water resources in the Mediterranean environmental conditions are exposed to physical, chemical, and biological degradation. The phase of pronounced erosivity in the Mediterranean climatic condition corresponds to the last 3 months of the year and it is particularly important, mainly for winter crops such as cereals, since the surface of the soil is unprotected. The superficial runoff dominates the hydrological response of the study basin during the most significant events. The antecedent soil moisture condition is considered a factor of greater importance. The irregularity of intra- and inter- annual precipitation is a pattern specific to the Mediterranean climate, that usually determines the grade of soil cover and the soil erosion process. The climate change can additionally aggravate this situation. Water scarcity is another threat in the irrigated agricultural systems of the Mediterranean region. It is verified in many irrigation seasons in this study, where the indicator RWS was much higher. Mediterranean rainfall, sometimes with very high intensity and verified in dry years, can reach very important runoff events like the one that occurred at the end of October in the hydrological year 2004–2005. Runoff coefficient was equal to 0.85 and an annual erosion rate equal to 79.1%. Spatial distribution of runoff was primarily influenced by topography and soil management, which is common to Mediterranean agricultural systems, namely in grain crops systems such as oats and wheat. The simulation of spatial distribution of nitrate loads shows a dependence of the spatial distribution of runoff, due to its high solubility. Despite the close relation between soil erosion, water and runoff, the simulation using the AnnAGNPS model of spatial distribution of soil erosion by water indicates that the process does not directly depend on it. Therefore, soil erosion is mostly influenced by deficient land cover whenever erosivity of rainfall is strong. Phosphorus losses were less than nitrate losses, due to their lower water solubility and mobility in soil.

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