CHAPTER 10

USE OF SENSORS TO MONITORING AND EVALUATING THE HYDROLOGY AND WATER QUALITY IN A SMALL AGRO-FORESTRY BASIN

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ABSTRACT

Considering the objectives of the Erasmus+ Domotic School Garden are, among others, the increase in motivation and academic performance in sciences and technology, this manuscript summarizes the use of some sensors to monitoring and evaluating the hydrology and water quality, in a small agro-forestry basin, under Mediterranean climatic conditions. For this porpuse it was used a multiparameter probe, with sensors of electrical conductivity, temperature, nitrates and turbidity in the return flows of the study basin. It was instaled as well a flume, as a hydraulic structure, and a ultrasonic sensor to evaluate the discharge at the outlet of the basin. With a small description of each sensor, the text is enriched with an example of results for each one, to perceive the kind of information is given to the researcher. For these summarized results, it´s possible the importance to understand the hydrologic beahvior and the dynamic of the pollutants in the basins, necessary to take measuments to prevent and mitigate the pollution of water bodies.

Keywords: water quality and hydrology sensors, agro-forestry activity, small agro-forestry basin

INTRODUCTION

Soil, water and production systems constitute the most important natural resources of a watershed in the rainfed and irrigated agro-forestry ecosystem. For sustainability of the production systems, they need to be in harmony with the environment. Agricultural activities, as part of the natural resource management practice, impact soil and water quality at the watershed level (Twomlow e*t al*, 2008). Soil and water conservation practices also help in reducing the loss of chemicals in runoff, and in maintaining water quality (Berry *et al*, 2003). The increases in nutrient losses and riverine nutrient loads have caused the eutrophication of many coastal and freshwater ecosystems (Carpenter *et al*, 1998). Non-point source (NPS) pollution is an important environmental and water quality management problem, closely related with hydrologic behavior of the territorial unit. NPS pollution occurs when rainfall, snowmelt, or irrigation water run over land or through the ground, pick up pollutants and deposit them into rivers, lakes, and coastal waters, or introduce them into ground water, but due to its distributed nature, it cannot be monitored directly in the same manner as point sources. The non-point source (NPS) pollution has grown into a global environmental issue and has been the most talk about environmental degradation caused in recent years (Thornton *et al*, 1999). In this context, watershed is the basic unit of all research, development and policy-making activities related to water at present. However, a watershed is a geographically dynamic unit, and its behavior varies both spatially and temporarily. Intensive study of individual watersheds is, therefore, necessary to develop management strategies for abating the agricultural NPS pollution. To solve the NPS pollution problem, one approach is to identify critical areas of a watershed responsible for disproportionate amount of the pollution and to implement best management practices (BMPs), such as conservation tillage, improved fertilizer and animal waste management in the critical sub-watersheds (Dickinson *et al*, 1990; Mostaghimi *et al*, 1997). Field monitoring is often used to evaluate and acquire knowledge of the impacts of management practices on productivity and environment. But, for the practically use, the simulation models, calibrate and validated for certain conditions, are indispensable tools to configure alternatives uses of soil, and contribute to define BMPs (Duarte *et al*, 2021).

1. LOCATION AND CARACTHERIZATION OF THE STUDY BASIN

The study catchment is located within the Idanha irrigation scheme, Idanha-a-Nova, Portugal, north of the Tagus River, and covers an area of 189 ha (Figure 1 a). The climate is Mediterranean continental. Average annual rainfall is 604 mm, with a rainless summer; the average temperature varies from 8.1 ◦C in January to 25.3 ◦C in August; and the average reference evapotranspiration (*ETo*) varies from 0.6 mm day^{-1} in December to 7.1 mm day^{-1} in July. According to the FAO classification system (FAO, 1998), the predominant soil groups in the catchment are *luvisol* and *cambisol*, which originated from fluvial deposits associated with the tributaries of the Tagus River. *Fluvisols* are also present in the catchment, originating from alluvial deposits associated with the main creek. The drainage density of the natural, permanent channels is 12.2 m ha^{-1}. The limits and topography of the catchment were determined from a digital elevation model with a precision of 1 m. Altitude varies from 212 m at the outlet of the catchment to 248 m at a plateau located towards the northeast (Figure 1 b-c-d). The slopes range from 0% to 4%, thus the topography is flat to gently undulating.

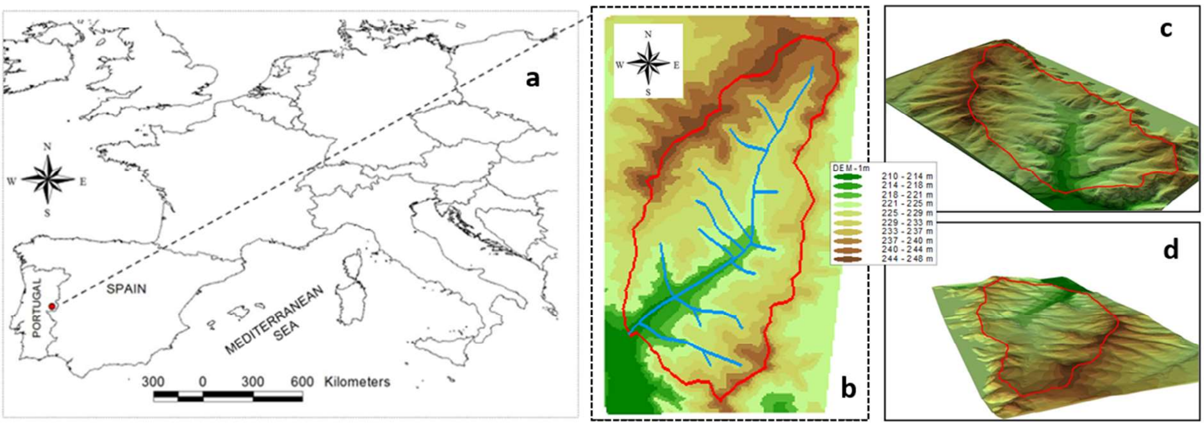


Figure 1: Location of the basin study (a), Digital Elevation Model (DEM), basin limits and natural drainage nerwork (b), and downstream view (c) and upstream view (d).

2. HYDROMETRIC AND WATER QUALITY STATION

A hydrological station was constructed and installed in 2004 to measure runoff at the outlet of the catchment (39^0 50′ 48″ N, 7^0 10′ 00″ W). The station consisted of a long-throated flume (with a triangular control section for shallow water conditions and a triangular/trapezoidal section for deep water conditions) (Figure 2 a-b), designed and calibrated following the procedure described by Bos *et al* (1991). An ultrasonic sensor ("The Probe", manufactured by Milltronics Process Instruments Inc., Ontario, Canada), connected to a datalogger, continuously measured and recorded the water level at the flume (Figure 3 a).

Figure 2: General view of hydrometric and water quality station.

The water quality was evaluated by a multiparameter probe (In-Situ TROLL 9500) installed inside a cup, that received water pumped from the stream in time steps of 15 minutes (Figure 3 b-c). The parameters of water quality evaluated are, electrical conductivity, temperature, nitrates and turbidity. Rainfall was measured continuously with a tipping bucket rain gauge located next to the hydrological station.

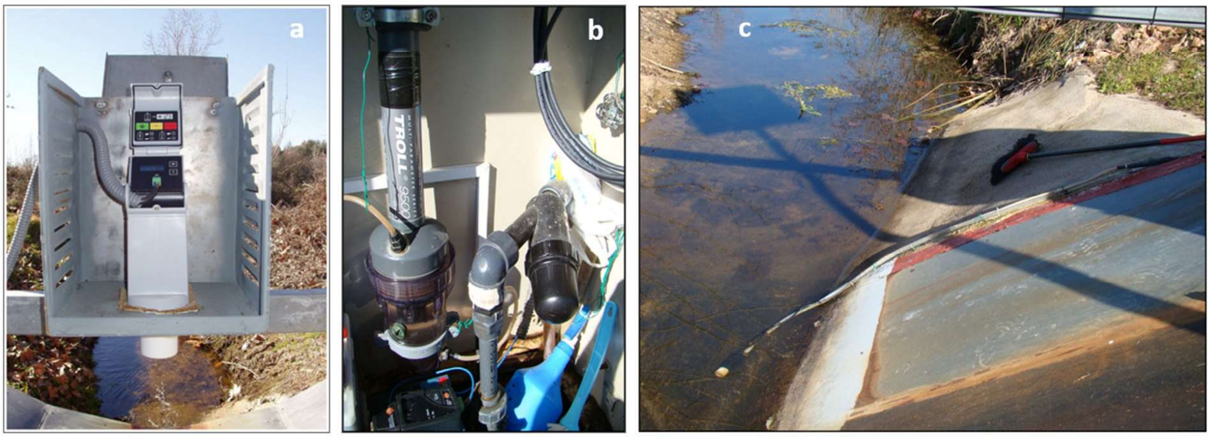
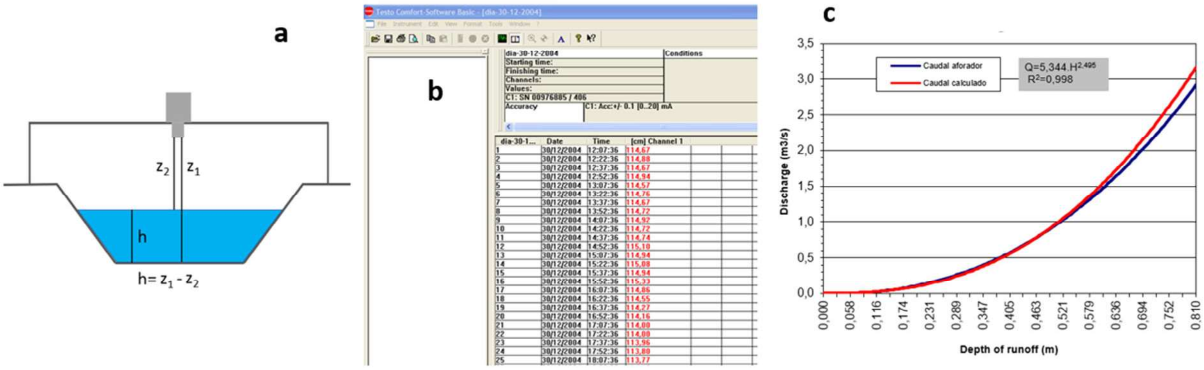


Figure 3: Ultrasonic sensor (a), multiparameter probe inside of a cup where is taken the evaluation of water quality (b), and small pump to derived the water to the cup (c).

2.1. EVALUATION THE DISCHARGE AT THE BASIN OUTLET

As is referred before, the hydrometric station is equipped with a a flume and an ultrasonic sensor, positioned in a mettalic portic inside a box in the middle of the flume (Figure 2 b; Figure 3 a). The runoff depth (h) is calculed by the difference between Z_1 (distance between the face of sensor and the flume bottom, is constante) and Z_2 (distance between the face of sensor and the runoff surface, is evalued by the sensor and variable) (Figure 4 a). The values of variable Z_2 are recorded in a datallogger by time steps defined by the user (Figure 4 b). The values of runoff depth are introduced in the discharge adjusted equation to calculate the flow rate (*Q*) (Figure 4 c), valid to the time step selecioned.



dia-30-12-2004
Starting time:
Finishing time:
Channels:
Values:
C1: SN 00976885 / 406
Accuracy C1: Acc:+/- 0.1 [0..20] mA
Conditions

dia-30-1...	Date	Time	[cm] Channel 1
1	30/12/2004	12:07:36	114,67
2	30/12/2004	12:22:36	114,88
3	30/12/2004	12:37:36	114,67
4	30/12/2004	12:52:36	114,94
5	30/12/2004	13:07:36	114,57
6	30/12/2004	13:22:36	114,76
7	30/12/2004	13:37:36	114,67
8	30/12/2004	13:52:36	114,72
9	30/12/2004	14:07:36	114,92
10	30/12/2004	14:22:36	114,72
11	30/12/2004	14:37:36	114,74
12	30/12/2004	14:52:36	115,10
13	30/12/2004	15:07:36	114,94
14	30/12/2004	15:22:36	115,08
15	30/12/2004	15:37:36	114,94
16	30/12/2004	15:52:36	115,33
17	30/12/2004	16:07:36	114,86
18	30/12/2004	16:22:36	114,55
19	30/12/2004	16:37:36	114,27
20	30/12/2004	16:52:36	114,16
21	30/12/2004	17:07:36	114,00
22	30/12/2004	17:22:36	114,00
23	30/12/2004	17:37:36	113,96
24	30/12/2004	17:52:36	113,80
25	30/12/2004	18:07:36	113,77

Figure 4: Schematic of the runoff depth evaluation by using a flume and a ultrasonic sensor (a), records of runoff depth in a datalogger (b), and discharge curve of the flume (calculated, blue line; exponential adjustment, red line).

The following graphs (Figure 5) illustrate two examples to understand of the hydrologic behavior of the basin. 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. In a subsequent event, on October 27, 2004, in wet soil conditions, the total discharge was 80457 m^3 derived from 42.3 mm of precipitation. 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 (Duarte and Mateos, 2021). In Mediterranean climatic conditions, sometimes occurred very important runoff events, like this one illustrated in Figure 5. 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). 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%.

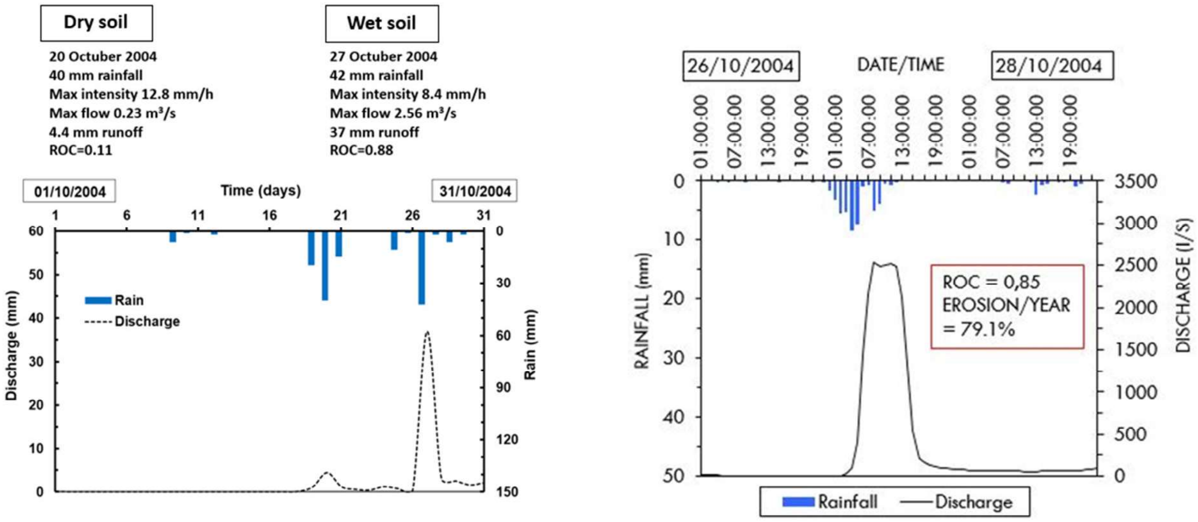


Figure 5: The influence of the antecedent soil moisture conditions in the magnitude of runoff events (first graph), and histogram and histogram observed in an extreme event at the study basin (second graph).

3. DESCRIPTION OF THE MULTIPARAMETER PROBE AND RESULTS OF SENSORS

The multiparameter probe is equipped with the sensors referred before, and still has an empty door where can be installed plus a sensor (Figure 6). The turbidity evaluated by the respective sensor need a calibration curve to tansforme the data in mass of sediments by volume of water, usually mg l^{-1}. The probe has an internal datallogger to record the data, and the nitrates and electrical conductivity sensors need a periodically calibration.

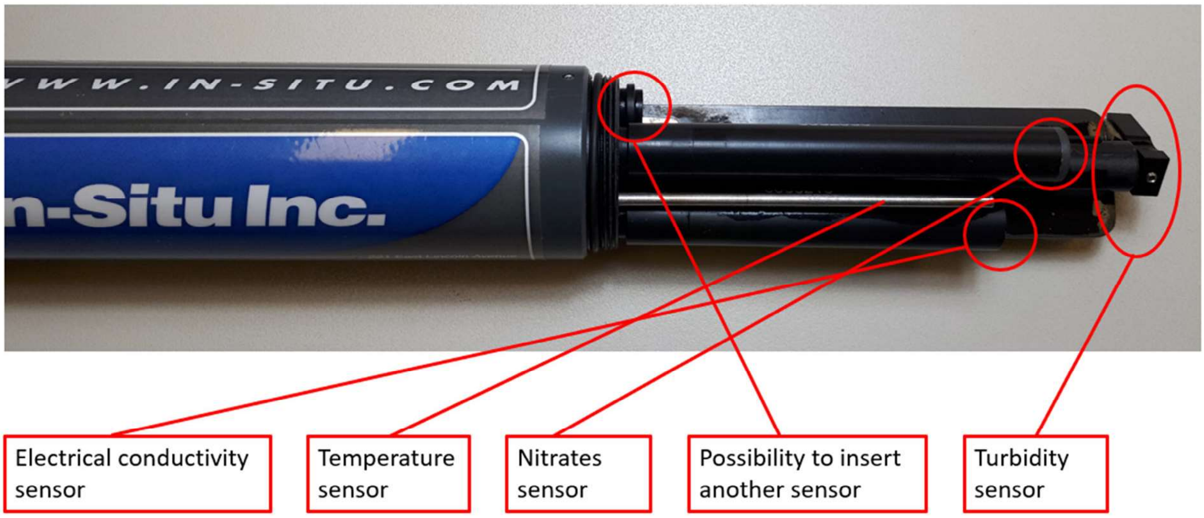


Figure 6: Probe sensors identification (electrical conductivity, temperature nitrates and turbidity) (Multipameter Probe In-Situ).

3.1. NITRATES SENSOR

In the 2004 irrigation season, only two values, from a set of 53 values, were above to 3.0 mg l^{-1}. It is also important to remark that, especially to the end of the irrigation season, the values of nitrate concentrations in return flows and in the water delivered from the channel will be approaching, while there are a couple of examples where the water quality increased with respect to this contaminant (Figure 7). The rainfall season 2004/2005 was very abnormal with respect to the total volume of precipitation and its distribution. This determined that the runoff and pollutants load curves were conditioned by a few precipitation events, basically only one very extreme event. So, the accumulated pollutant load curve of ammonium, show during the more intense hydrological events dependence on the runoff volume, and then remained practically constant until the end of rainfall season. The evolution of accumulated nitrate nitrogen load from the basin always followed the evolution of the accumulated volume of runoff, due the high solubility of nitrate in water (Duarte, 2017) (Figure 7).

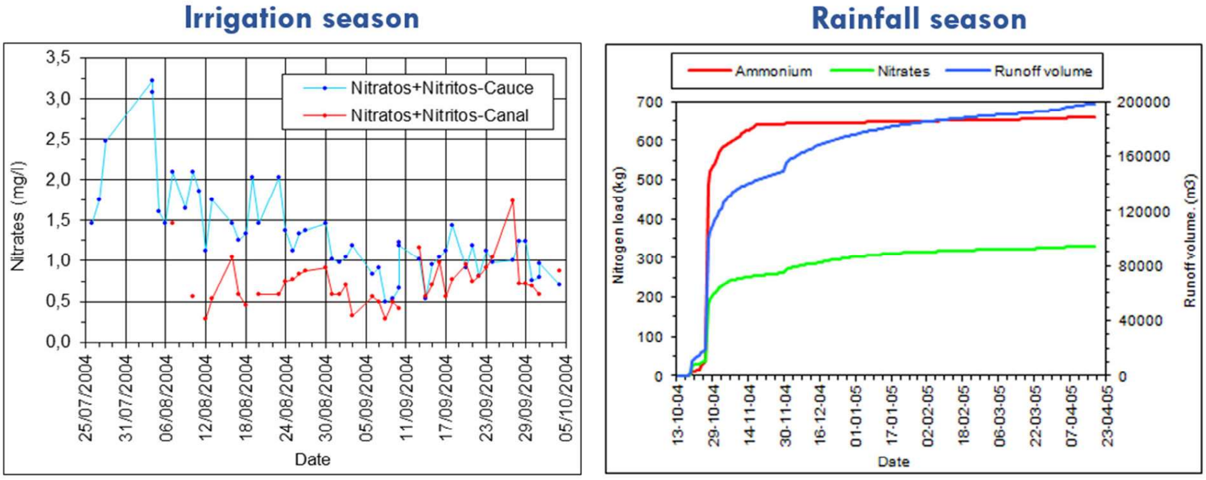


Figure 7: Evolution of nitrates concentration in flow returns in an irrigation season and subsequent rainfall season.

3.2. ELECTRICAL CONDUCTIVITY SENSOR

One of the interesting patterns of salts dynamic in relation with the volume of runoff, is the effect of dilution, as a decrease of salts concentration, in great volumes of water. It is the observed in successive peak runoff events, between 04/12/2010 and 12/12/2010 (Figure 8). The dilution effect is more evident in the first event, due to two reasons, greater volume of water in the greater peak events, and, in successive events, larger availability of salts than in the subsequent events. Due the high solubility of salts presents in the return flows, it´s expectable, and observed, that the accumulated curve of salts along the season has a development very closed to the accumulated curve of runoff, regardless of it is surface or subsurface runoff (Figure 8). A formula very used to transform electrical conductivity in mass of salts per water volume, it´s the one above the graphs, where: SDT is Total of Dissolved Solids (mg l^{-1}) and EC is electrical conductivity (dS m^{-1}) (Duarte, 2014).

SDT (mg/l)=CE (dS/m)x640

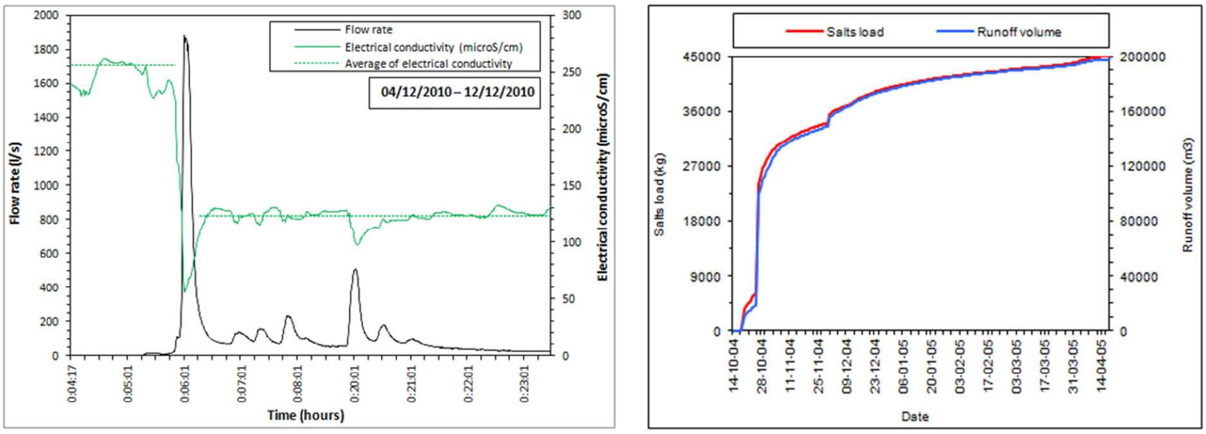


Figure 8: Dilution effect of peak flows on the salt concentrations (first graph), and the relation between the evolution along a rainfall season of accumulated salts load and accumulated runoff volume (second graph).

3.3. TURBIDITY SENSOR

Concerning the dynamic of sediments in the basin, Figure 9 shows the close relation between the hydrograph peaks and the sediment concentration observed in the outlet of the basin (4-12 December, 2010), especially in the rising limb. In the descending limb the observed deviations have also been appointed by other authors (Seeger *et al*, 2004). On the other hand, the load of sediments does not seem dependent on the total runoff volume of a certain event, except when flow has enough power to detach and transport the particles outside of the drainage network (transport resulting from sheet and rill erosion on the slopes) (Duarte *et al*, 2014). Therefore, the amount of sediment load along the rainy season was mainly associated with extremes rainfall-runoff events, and consequently the accumulated curve of sediments along the season evolute by levels (Duarte, 2022) (Figure 9).

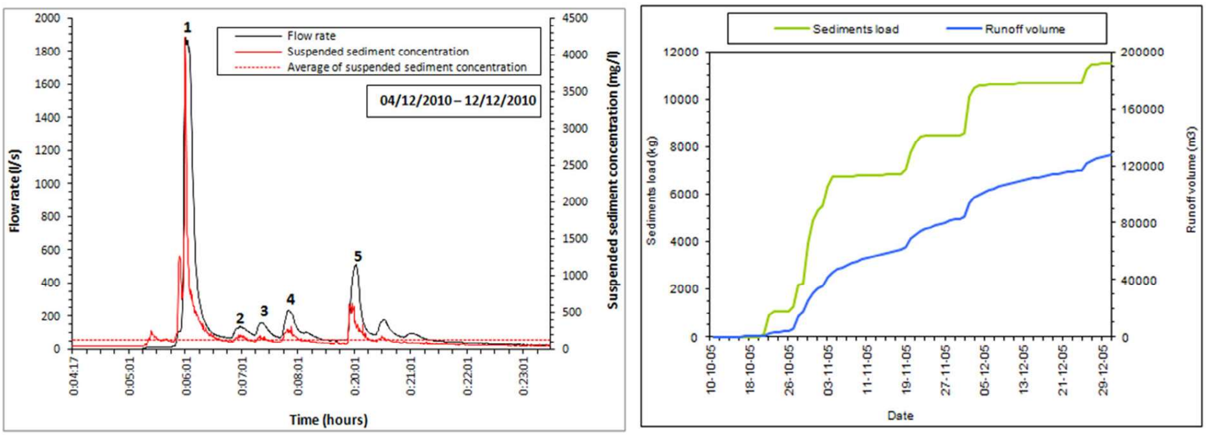


Figure 9: Behavior of five sedigrams during five sucessives peak flow (first graph), and the relation between the evolution along a rainfall season of accumulated sediment load and accumulated runoff volume (second graph).

CONCLUSIONS

The superficial runoff dominates the hydrological response of the study basin during the most significant rainfall events, and the antecedent soil moisture condition is considered a factor of greater importance in the magnitude of the runoff events. The evolution of the nitric nitrogen daily pollution load depends on the volume of runoff at any stage of analysis period and availability of this nutrient in the soil. Its high solubility and mobility determine what appears in both surface runoff and in base flow. For the total dissolved solids daily pollution load, the situation shows, both in the irrigation season and in the rainfall season, an absolute dependence of the runoff volume at the outlet of the study basin, regardless of it is surface or subsurface runoff. The daily pollution load of suspended sediment does not seem dependent on the volume of runoff, except when it has enough power to detach and load the particles out of the basin.

As a final conclusion, the dynamics of contaminants at basin level appears to be dependent on the hydrologic behavior in this territorial unit, also depending on the nature and availability of the nutrients/contaminants and magnitude of hydrologic events.

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