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Application of remote sensing to estimate river sediment transport in the Calabrian basins (Italy)

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Abstract. Over recent decades, Soil Erosion by Water (WSE) has become a severe and extended issue affecting all European countries. The European Mediterranean countries are particularly prone to erosion because they are subject to prolonged dry periods followed by heavy erosive rains falling on steep slopes characterized by fragile soils. In particular, natural conditions and the human impact have made Calabria region, in southern Italy, particularly prone to intense WSE. The paper describes the methodology adopted to quantify solid transport in the Allaro river basin, located on the Ionian coast of Calabria. The methodology is divided into three phases, as follows: morphometric characterization of the river basin, identification of the available gauges and analysis of rainfall and temperature data and influence area of each gauge, and estimate of solid transport using the Gavrilovic model. This model is particularly valid for rivers such as the Calabrian ones where most of the solid transport is linked to the WSE. The methodology described in this paper is suitable to all basins with morphometric and hydrological characteristics like those Allaro and Calabrian basins. Furthermore, an improvement in the river transport estimate is important not only for the planning and management of the areas near the rivers but also for the coastal areas near the mouths.

1. Introduction

River sediment transport is a topic of interest for the planning and management of both river and coastal areas [1,2] because it influences the river morphological variations in terms of degradation and aggradation. Also, river dynamics strongly influences the coastal dynamics and can cause erosions and advances even at considerable distances from river mouths [3-8]. River and coastal dynamics depend on both natural and anthropogenic factors [9,10]. Regarding natural factors, the most important are wave motion [11,12] and river and coastal sediment transport [13-17]. Amongst the anthropogenic factors [18,19], the increase in anthropogenic pressure, observed in coastal areas over the last 50 years, has increased the vulnerability of the territory under the action of natural events such as floods [20-22], storms and coastal flooding [23,24], or a combination of these [25-27]. In coastal areas, anthropogenic pressure has led to the construction of ports, buildings, and infrastructures which, in many cases, have triggered erosive processes mitigated by coastal defense works. [28-30]. In river areas, anthropogenic pressure has led to the construction dams, levees and other hydraulic structures which, in many cases, which, in many cases, have caused an aggradation consequently reducing the solid contribution on the coasts [31]. About sediment transport mechanisms, the main ones in the river are bed load and suspended load [32] while at the basin scale the soil erosion by water (WSE) is important [33]. To quantify the bedload and suspended transport there are different formulas [34-36] and models [37-40]. Regarding

WSE, is particularly important in territories such as Calabria, characterized by basins with high slopes and irregular hydrological regimes, with alternation between dry periods and sudden flood events [41-45]. In this context, the Gavrilovic model [46] is particularly useful for quantifying the solid transport caused by WSEs.

The paper describes the methodology adopted to quantify solid transport in the Allaro river basin, located on the Ionian coast of Calabria. The methodology is divided into three phases, described in detail in the Methodology section, and is applicable to all basins with morphometric and hydrological characteristics like those in Calabria.

2. Site description

The Allaro river basin is in Calabria, a region of southern Italy. From a morphological point of view, this region is mainly characterized by hills and mountains, with a percentage of less than 10% of plains. Also, Calabria has a narrow and elongated conformation, with a considerable coastal extension, exceeding 700 km, and an alternation of beaches, mainly sandy and pebbly, and high coasts. Due to this conformation, many reliefs are close to the coast.

Calabria is bathed by two seas, Tyrrhenian, and Ionian, by the Strait of Messina and by the Gulf of Taranto (Figure 1), each of them with different climatic characteristics and different fetches extensions. These differences lead to a remarkable variability of meteorological conditions between the different areas of Calabria.

The Calabrian rivers are characterized by irregular hydrological regimes alternating between dry periods and sudden and violent flood events. Their basins are characterized by a small catchment area and due to the small distance between mountain and sea, longitudinal slopes of the rivers are extremely high. Therefore, they have short times of concentration.

Other peculiarities of this rivers include the presence of very wide beds with coarse grain size. The combination of hydrological and granulometric characteristics causes a high solid transport. This condition is typical of many rivers of southern Italy, also called "*fiumare*" [47,48].

Figure 1. Study area location. The Allaro river basin is in blue, on the left there is the Tyrrenian Sea and to the right there is the Ionian Sea.

3. Methodology

The methodology is divided into three phases, as follows: the first is the morphometric characterization of the river basin, the secondo is the identification of the available gauges and analysis of rainfall and temperature data and influence area of each gauge, and the last is the estimate of river transport (Figure 2).

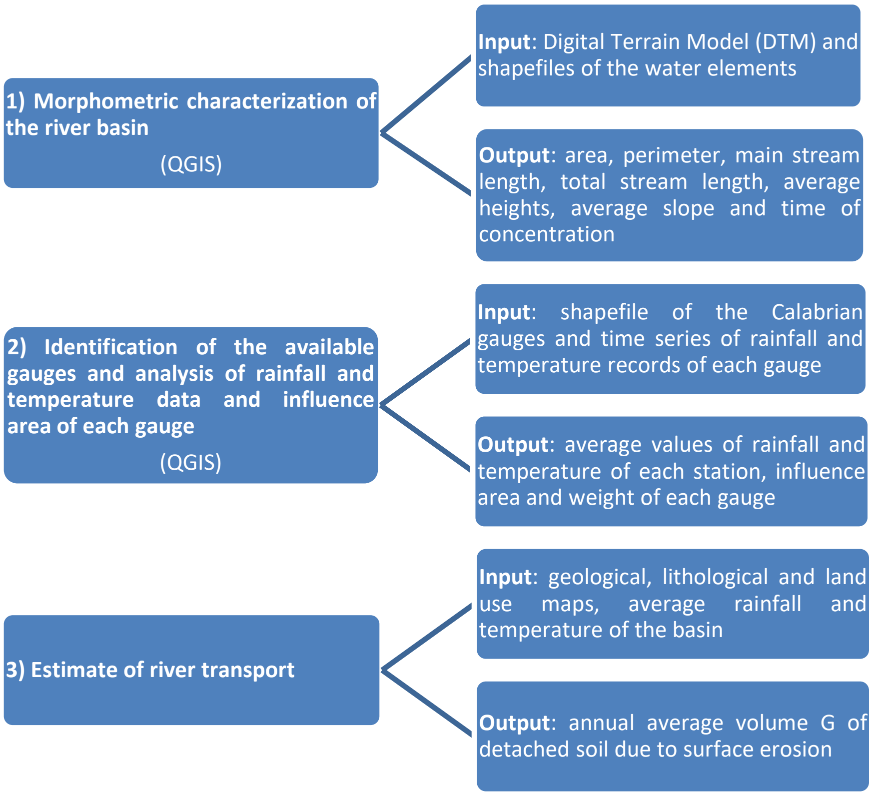

Figure 2. Flow diagram of the methodology phases.

In detail, about the first phase, as input data the shapefile and raster available in the Open Data section of the Calabrian Geoportal (http://geoportale.regione.calabria.it/) was analyzed on QGIS. These data are the Digital Terrain Model (DTM) with square mesh of 5 m and the shapefiles of the water elements. Instead, as output the area, the perimeter, the main stream length, the total stream length, the average heights, the average slope and the time of concentration were calculated. Regarding the last parameters, the formulas of Giandotti [49], Kirpich [50] and NRCS [51] were used to estimate it.

Regarding the second phase, as input data the shapefile of the Calabrian gauges, also available in the OpenData section of the Calabrian Geoportal, was analyzed on QGIS. These data have been crossed with the time series of rainfall and temperature records of each gauge, available in the Historical Data section of the Calabrian Multi-Risk Functional Center (http://www.cfd.calabria.it/), in order to identify the gauges with statistically significant time series. As output, the average values of rainfall and temperature of each station were obtained. Also, the influence area and the weight of each gauge were estimated on QGIS using the Thiessen polygon method [52], corresponding on QGIS to the Voronoi polygons function.

The last phase concerns the estimate of river transport using the Gavrilovic model [46], particularly useful for rivers such as the Calabrian ones where most of the solid transport is linked to the WSE. Firstly, it is necessary to analyze on QGIS the geological, lithological and land use maps, available in open data sections of Calabrian Geoportal to calculate the model coefficients. Indeed, for the Gavrilovic

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model the annual average volume G of detached soil due to surface erosion is obtained by means of the following analytical equation:

$$G = W\,R \tag{1}$$

This equation depends on the potential annual volume W of detached soil and on a retention coefficient R:

$$W = T\,h\,\pi\,Z^{3/2}\,S \tag{2}$$

$$R = \frac{\sqrt{O\,D}}{0.25\,(L+10)} \tag{3}$$

$$T = \sqrt{\frac{t}{10} + 0.1} \tag{4}$$

$$Z = X\,Y\left(\theta + \sqrt{I}\right) \tag{5}$$

With: T is a temperature coefficient; h is the average yearly precipitation; Z is a relative erosion coefficient, that depends on a soil protection coefficient X (function of the type of vegetation cover), on a erodibility coefficient Y (function of type of rock), on an erosion typology coefficient θ and on the average slope of the basin I; S is the basin area; O is the basin perimeter; D is the average height of the basin; L is the main stream length and t is the average yearly temperature.

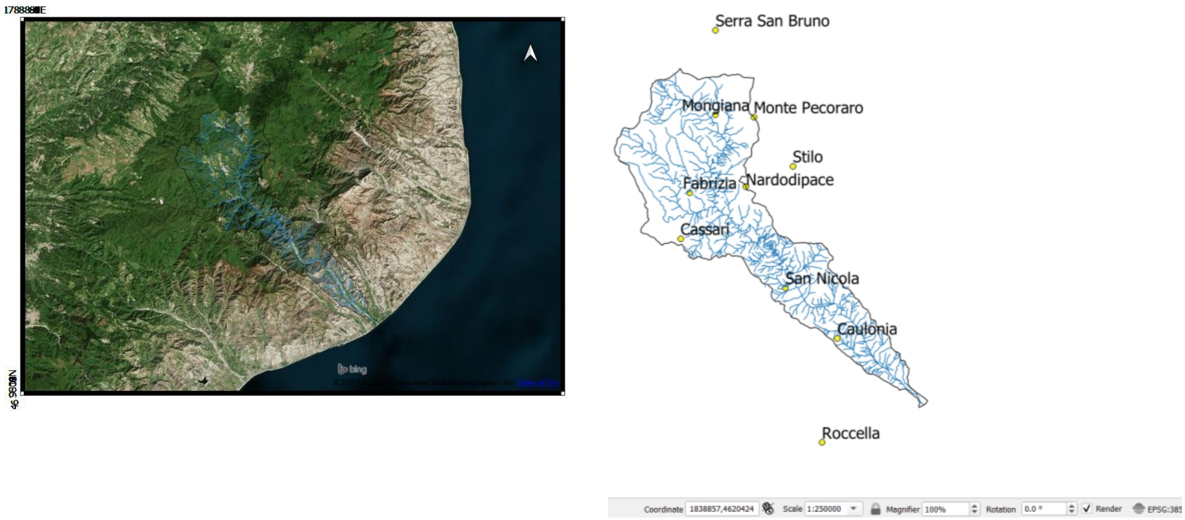

Figure 3. On the left: Allaro river basin. To the right: gauges within and near to the basin.

4. Results

About the first modeling, the Allaro river basin (Figure 3 left) has an area of about 130 km^2, a perimeter of 76.1 km, a main stream length of about 38 km, a total stream length of over 630 km, an average height of about 730 m, an average slope of about 24%, and a time of concentration of about 4.7 hours.

Regarding the second phase, within and near to the basin there are 10 gauges (see Figure 3 right). Of these, 9 gauges recorded rainfall data and 6 gauges recorded temperature data. Figure 4 show the results of the Thiessen polygon method. Also, Table 1 lists the gauges within and near the Allaro river basin. For each gauge, the main characteristics useful for the estimation of solid transport using the Gavrilovic model are indicated. In detail, the gauge elevation, the time periods in which rainfall and temperature records are available, the average values of rainfall and temperature and the weights of each gauge, estimated by the Thiessen polygon method, are indicated. Finally, the weighted average rainfall of the

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Allaro river basin is about 1520 mm and the weighted average temperature of this basin is about 13.5° C.

Regarding the results of the last phase, the annual average volume of detached soil due to surface erosion G is about 80000 m^3/year, with a potential annual volume W of about 100000 m^3/year, a retention coefficient of about 0.8 and a specific erosion of over 600 m^3/year for km^2. This is a high value compared to those obtained from previous studies carried out throughout Calabria [53]. Also, this value, being correlated to precipitation, is subject to frequent oscillations. These oscillations can affect both the valley part of the river and the coasts near the mouth. Indeed, an excess of sediments can cause a riverbed aggradation, with a consequent increase in flood risk, while a less than average transport value can trigger coastal erosion. In this regard, Figure 5 shows the shoreline variations at the mouth of the Allaro river, obtained by analyzing the data available in the Open Data section of the Calabrian and Italian Geoportals (http://www.pcn.minambiente.it/GN/). In detail, the shapefiles of the shorelines of 1954 and 2008 of the Calabrian Geoportal were used as input data. Also, the 1989 and 2012 orthophotos of the Italian Geoportal were used, through which the relative shoreline was traced on QGIS. Figure 4 shows a strong erosion at the Allaro river mouth, with a loss of about 130 m of beach between 1954 and 1989 and with a loss of a further 70 m between 1989 and 2008, for a total loss of about 200 m between 1954 and 1989. This trend was reversed between 2008 and 2012, in which an advancement of the shoreline of about 20 m was observed.

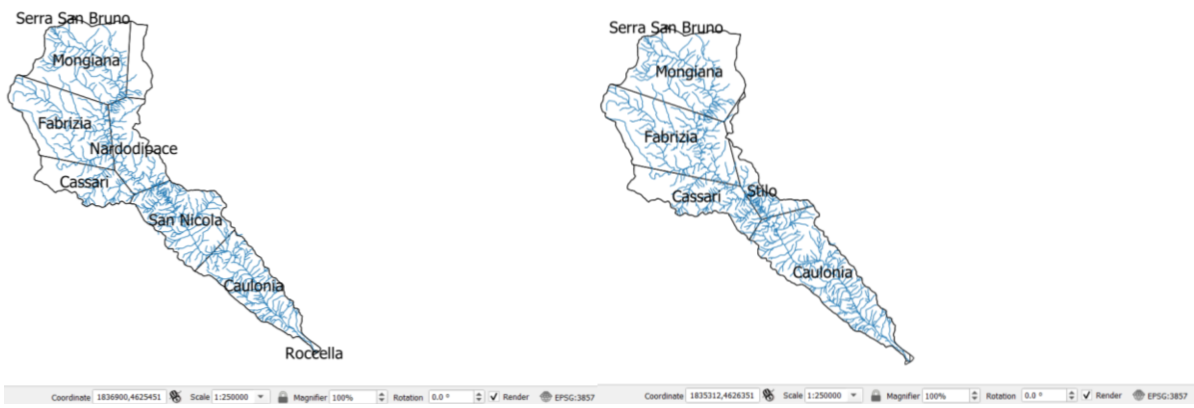

Figure 4. On the left: influence area of the rainfall gauges. To the right: influence area of the temperature gauges.

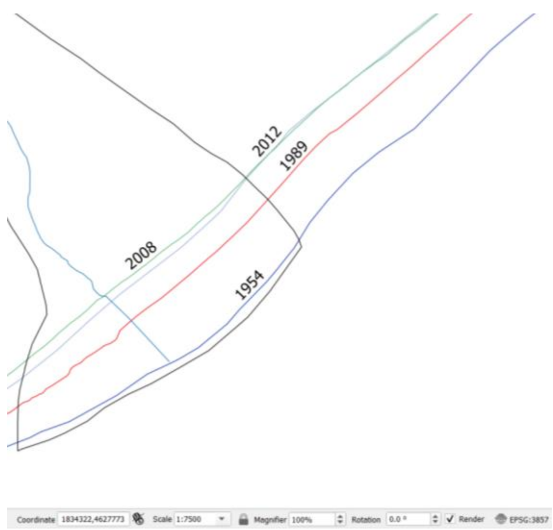

Figure 5. Shoreline changes near the Allaro river mouth. Legend: dark blue = 1954, red = 1989, light green = 2008, light blue = 2012 (source: Open Data section of the Calabrian and Italian Geoportals).

Table 1. Gauges within and near the Allaro river basin. For each gauge are shown elevation, recorded periods, number of years available, average values of rainfall and temperature, influence area and weight.

Gauges	Elev. [m]	Rainfall rec. period	Rainfall rec. years	h_{av} [mm]	Temp. rec. period	Temp. rec. years	t_{av} [°]	Rainfall weight [%]	Temperature weight [%]
Serra San Bruno	790	1920-2020	101	1781.2	1926-2020	94	11.5	0.04	0.04
Stilo	1050	n.a.	n.a.	n.a.	1958-2005	30	10.8	n.a.	6
Monte Pecoraro	1420	1916-1944	29	1790.9	n.a.	n.a.	n.a.	4.55	n.a.
Mongiana	921	1928-2020	52	1789.8	1992-2020	29	11.4	20.95	26
Fabrizia	948	1920-2020	92	1733.2	1992-2020	29	12.9	20.55	26
Nardodipace	670	1916-2000	67	1488.0	n.a.	n.a.	n.a.	11.07	n.a.
San Nicola	225	1922-1964	37	1239.5	n.a.	n.a.	n.a.	17.21	n.a.
Caulonia	275	1916-2006	90	963.8	1925-2006	81	17.9	15.87	27
Roccella	5	1940-2020	73	740.9	n.a.	n.a.	n.a.	0.03	n.a.
Cassari	970	1922-2020	99	1827.3	1992-2020	29	11.8	9.73	14

5. Conclusions

The paper describes the methodology adopted to quantify solid transport in the Allaro river basin. The climatic and morphological peculiarities of Calabrian river basins, with a high solid transport, make this topic of considerable interest in the river field to identify phenomena of riverbed aggradation, with a consequent increase in flood risk and a decrease in the solid material reaching the beaches. So, an improvement in the river transport estimate is important for the planning and management of the river areas and of the coastal areas near the river mouths. Finally, this methodology is suitable to all basins with morphometric and hydrological characteristics like those Allaro and Calabrian basins.

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