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Shoreline changes near river mouth: case study of Sant'Agata River (Reggio Calabria, Italy)

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ABSTRACT

The analysis of shoreline changes is very important for coastal planning and management. In territories such as Calabria (Italy), characterized by significant anthropogenic pressures and various eroded coasts, the knowledge of the shoreline changes, and the factors that influence them, is necessary for management and planning of coastal areas. In fact, shoreline position is one of the most important indicators of coastal dynamics. From this point of view recent advances in remote sensing and GIS techniques allow to estimate with great precision the shoreline changes over the years. The paper analyzes the shoreline changes near the mouth of the Sant'Agata River (Reggio Calabria, Italy), carried out through the comparison of various cartography data. Furthermore, the paper analyzes the main factors influencing the coastal dynamics in order to identify possible correlation between these factors and the shoreline changes. The analysis of these factors shows that, in this case study, the rainfall regime has a considerable influence on shoreline change. The methodology described in this paper is particularly useful for better understanding the factors that most influence the coastal balance and, therefore, is applicable to many contexts which are similar to the Sant'Agata river mouth.

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Shoreline changes; shoreline position; EPR; NSM; longshore transport; river transport

Introduction

Coastal areas represent the transition zone between sea and land and are of particular importance for the presence of housing settlements. In fact, over 30% of the world (Syvitski, Vorosmarty, Kettner, & Green, 2005) and the Mediterranean (European Union, 2012) population live a short distance from the coastline. The demographic increases and the remarkable anthropization that characterized the second half of the last century have had a major impact on the equilibrium of the coastal areas and this process is visible both near the coastal cities and at the river mouths.

From this point of view, the shoreline position and, above all, its changes have become one of the major environmental problems affecting coastal zones worldwide. Indeed, nearly 80% of the world's coasts are eroding, with rates ranging from 1 cm/year to 10m/year (Pilkey & Hume, 2011). In particular, shoreline position is the most important geoinicator of coastal evolution (Boak & Turner, 2005) and is related to the coastal sediment budget, whose changes may indicate natural or human-induced factors along the shoreline or in nearby river basins (Addo, 2013; Komar, 2000; Walling, 2006; Yang, Wang, Voisin, & Copping, 2015). Recent advances in remote sensing and geographical information system (GIS) techniques allow us to estimate with great precision the

shoreline position and the shoreline changes over the years (Alesheikh et al., 2007; Ayadi, Boutiba, Sabatier, & Guetouche, 2015; Braga, Tosi, Prati, & Alberotanza, 2013; Maglione, Parente, & Vallario, 2014; Maiti & Bhattacharya, 2009; Mills, Buckley, Mitchell, Clarke, & Edwards, 2005; Moore, 2000; Moussaid, Fora, Zourarah, Maanan, & Maanan, 2015; Natesan, Parthasarathy, Vishnunath, Kumar, & Ferrer, 2015; Palazzo et al., 2012; Pardo-Pascual, Almonacid-Caballer, Ruiz, & Palomar-Vázquez, 2012), and it should be noted that the use of any particular method of analysis being influenced by the data sources and the resources available.

Amongst the human-induced factors (Manca, Pascucci, Deluca, Cossu, & Andreucci, 2013), 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 (Fiori et al., 2014; Scionti et al., 2018), debris flow, storms and coastal flooding (Li, Yamazaki, Roeber, Cheung, & Chock, 2018), or a combination of these (Destro et al., 2018; Barbaro Petrucci et al., 2018). Furthermore, the construction of buildings, infrastructures, ports and coastal defence works are of particular importance. Other important factors are the construction of hydraulic structures interfering with fluvial dynamics such as levees, dams, inert drains from river beds and soil erosion by water (WSE).

Amongst the natural factors which influence the shoreline position, sea level (Rahman, Dragoni, & El-Masri, 2011), wave action (Arena, Barbaro, & Romolo, 2013) and the interaction between longshore and river transport (Borrello, Foti, & Puntorieri, 2017; Tomasicchio, D'Alessandro, Barbaro, Musci, & De Giosa, 2015) are of particular importance.

Misdiagnosis of the factors listed above can lead to environmental disasters as in the case of Saline Joniche, near the Messina Strait (Barbaro, 2013), or in the case of Badolato, in the Calabrian Ionian coast (Miduri, Foti, & Puntorieri, 2017). Therefore, an accurate estimation of shoreline position and qualitative analysis of the causes of shoreline change (Li, Zhou, Zhang, & Kuang, 2014) is important for coastal zone planning and management (Barbaro, 2016). Moreover, for the Italian and Calabrian coasts, the importance of the aforementioned factors is accentuated by the high coastal development of both territories, over 7500 km of coast for Italy and over 700 km for Calabria, many of them in erosion (Barbaro, Foti, & Sicilia, 2014; Pranzini & Williams, 2013).

The paper, following the analysis of Barbaro, Bombino et al., (2018), describes a case study related to the mouth of the Sant'Agata River, where the analysis of the shoreline changes was carried out through the comparison of various cartography data. Furthermore, the paper analyzes the main factors influencing the coastal dynamics in order to identify possible correlation between these factors and the shoreline changes. In the following sections, after the description of the study area, will be analyzed: wave climate and longshore transport, and river sediment contribution, which depends on variations of hydraulic structures, rainfall time series, land cover and WSE. Finally, a cross-analysis of all these factors will be carried out, to understand the relative influence to shoreline changes.

Site description

The study area is located in the Southern part of Reggio Calabria, a city located in Italy in the southern part of the Calabria region near the Messina Strait (Figure 1), and it is characterized by the presence of both sea and mountains very close to each other and by the presence of “*fiumare*”. These are typical rivers of southern Italy with torrential and irregular regime, characterized by extensive dry periods and with frequent events of sudden flood, generated by short and intense rainfall (Terranova, Antronico, Coscarelli, & Iauinta, 2009). In Reggio Calabria there are more than 10 *fiumare* and, not far from the Sant'Agata, there are the Calopinace, Armo and Valanidi rivers, all enclosed in a few kilometers. The study area is heavily anthropized due to the presence, especially, of the airport, between Sant'Agata and Armo rivers, a sport center and various industrial activities (Figures 2–3) (Versaci, Minniti, Foti, Canale, & Barillà, 2018).

Shoreline changes

The analysis of the shoreline changes was carried out through the comparison of various cartography data, which consists of: aerophotogrammetry provided by Italian Military Geographic Institute, orthophotos taken from the Open Data section of the National Geoportal, and satellite imagery provided by Google Earth.

The analysis was divided into three phases as follows. The first phase concerned the manual digitization of the shoreline, for each cartography data and using QGIS for aerophotogrammetry and orthophotos and using the spatial analysis tools of Google Earth Pro for satellite imagery. The second phase concerned the evaluation of the beach width at a transept positioned at the mouth of the Sant'Agata river (Figures 4–8). Finally, the last phase

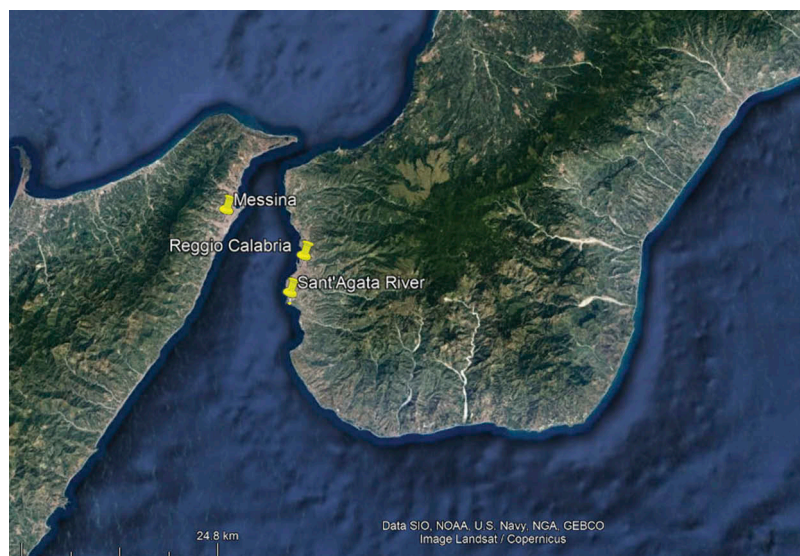


Figure 1. Study area location (source: satellite imagery of google earth pro).



Figure 2. Detail of the final part of Sant'Agata river (satellite imagery of google earth pro).

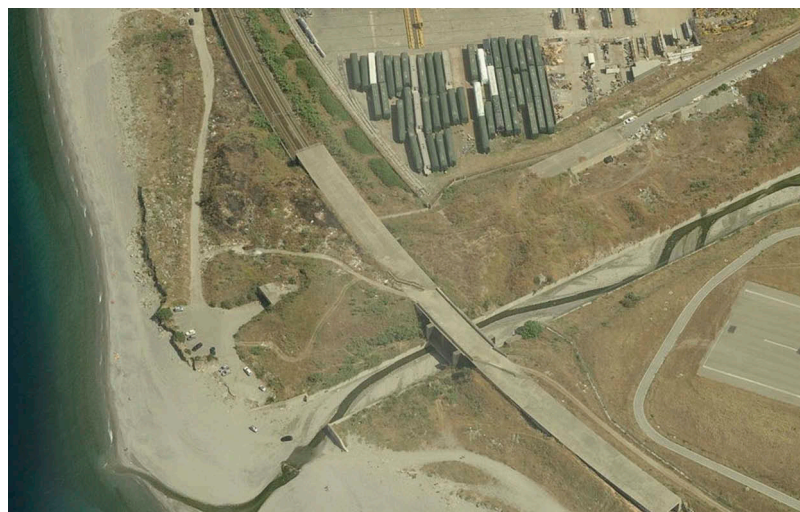


Figure 3. Detail of the final part of Sant'Agata river, it is possible to observe the airport, a sport center and some industrial activities (source: satellite imagery of bing maps).



Figure 4. Shorelines and transept digitized using QGIS (scale 1:1000).

Legend: dark blue = 2012, light green = 2006, violet = 1998, yellow = 1996, brown = 1985, dark green = 1954. The transept is shown in red and the background is the orthophotos of 2012.

concerned the determination of shoreline rates of change using end point rate (EPR) and net shoreline movement (NSM) statistics (Table 1).

Regarding the identification of the correct shoreline, it should be noted that there are many reference lines representing the shoreline position (Boak & Turner,



Figure 5. Shorelines of July 2002 and transept digitized using the spatial analysis tools of google earth pro. Legend: yellow = shoreline, red = transept. (source: satellite imagery of google earth pro).



Figure 6. Shorelines of July 2007 and transept digitized using the spatial analysis tools of Google Earth Pro. Legend: yellow = shoreline, red = transept. (source: satellite imagery of Google Earth Pro).

2005). In the framework of a study based on photo-interpretation, the choice and extraction of a common line used for different images is required. In this paper, due to the varying oceanographic conditions among the different cartographies, the reference line chosen was the wet/dry line. It has been shown that the wet/dry line closely approximates the High Water Line (HWL, Moore, 2000). Furthermore, in the area under examination the tidal excursion is of the order of tens of centimeters (Sannino, Carillo, Pisacane, & Naranjo, 2015) so the effects on the variation of the shoreline position are negligible. The digitalization of the shoreline was carried out on a scale of 1:1000 on QGIS and on a higher scale on Google Earth Pro. Therefore, the shoreline position has precision of the order of the meter and the shoreline changes have been approximated to the meter. This accuracy is in agreement with the aims of the paper, which concern the evaluate of the erosion and advancement trends, and not their precise quantification.

Regarding the evaluation of the beach width at the transept, to automate the calculation a function which can determine the distance from a given point was implemented on QGIS, using the “field calculator” in the program attribute table as the starting point. Furthermore, the transept originates from a fixed point, represented by the end point of the levee located in the hydraulic left of the Sant’Agata River.

From the analysis of the results shown in Table 1 and in Figures 4–8, it is possible to observe how advancement and erosion phases alternated from 1954 to today, from these data it is clear that: minimum width was observed in 2002 (32 m) while the maximum width was observed in 2015 (82 m).

Wave climate and longshore transport

The wave climate was analyzed starting from the wave data provided by the ABRC-MaCRO software,



Figure 7. Shorelines of March 2015 and transept digitized using the spatial analysis tools of google earth pro.
Legend: yellow = shoreline, red = transept.
(source: satellite imagery of Google Earth Pro).



Figure 8. Shorelines of September 2017 and transept digitized using the spatial analysis tools of Google Earth Pro.
Legend: yellow = shoreline, red = transept. (source: satellite imagery of Google Earth Pro).

Table 1. Beach width at a transept positioned at river mouth, and NSM and EPR statistics.

Date	Source	Beach width [m]	NSM [m]	EPR [m/year]
2017 (September)	Satellite	81	-1	-0.5
2015 (March)	Satellite	82	0	0
2012 (June)	Orthophotos	82	36	7.2
2007 (July)	Satellite	46	-30	-30
2006 (May)	Orthophotos	76	44	11
2002 (July)	Satellite	32	-33	-8.3
1998 (May)	Orthophotos	65	7	3.5
1996 (August)	Orthophotos	58	5	0.5
1985	Aerophotogr.	53	-18	-1
1954	Aerophotogr	71		

developed by HR Wallingford Ltd. This software allowed us to obtain a time series of wave data, starting from the information available at the Met Office database. This database is composed of data reconstructed via the European Wave Model starting from wind field data. The time series obtained using this software extends from 16 October 1986 to 31 March 2006 and consists of 147467 sea states, for each of which

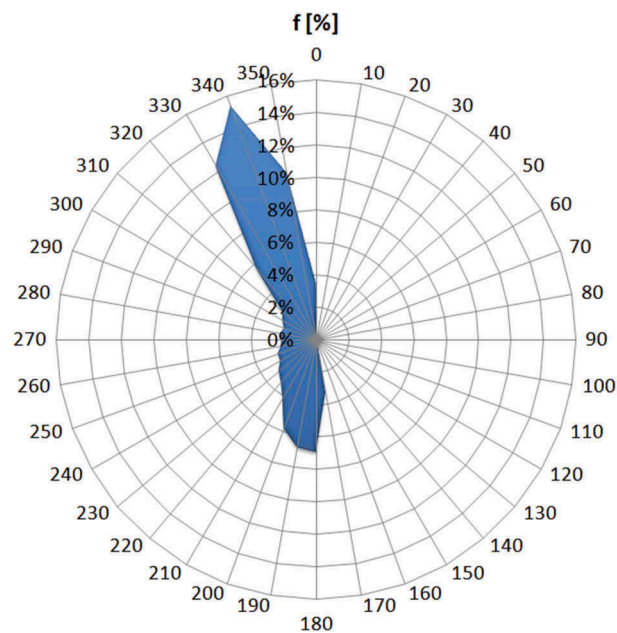
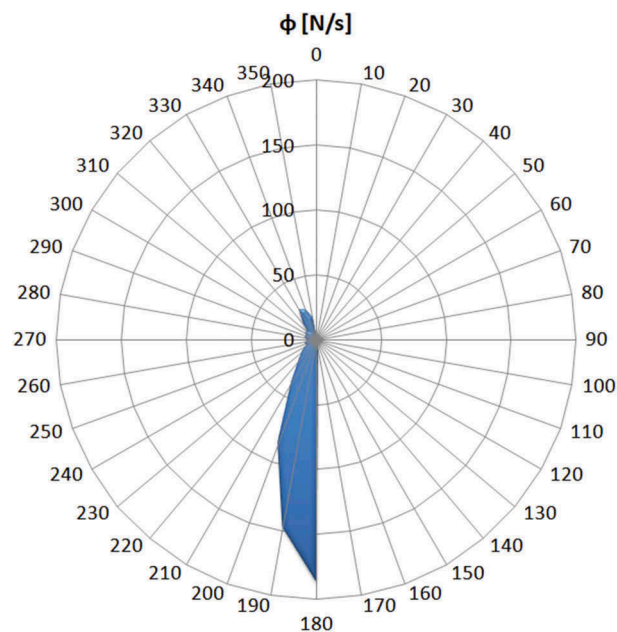
significant height, mean and peak periods and direction are available. These data were grouped in sectors of 10° each and in classes with a significant height of 0.5 m each and a further grouping was made in time intervals (Table 2). These intervals were in agreement with the intervals emerged from the analysis of the shoreline changes. Starting with the time series, the following was calculated: frequency of occurrence of

Table 2. Wave data, grouped in classes and in time intervals.

H _s [m]/Recorded	1986–2006	1986–1996	1996–1998	1998–2002	2002–2006
0.0–0.5	125595	62953	12449	29430	20763
0.5–1.0	19240	12885	768	3632	1955
1.0–1.5	1777	1695	1	64	17
1.5–2.0	732	709	0	0	23
2.0–2.5	113	113	0	0	0
2.5–3.0	10	10	0	0	0
Total	147467	78365	13218	33126	22758

sea state (hereinafter referred to as frequency) (Figure 9), mean energy flux (Figure 10) and longshore transport.

From the analysis of the results shown in Table 2 and in Figures 9–10, it is possible to observe that the

**Figure 9.** Frequency of occurrence of the entire time series.**Figure 10.** Mean energy flux of the entire time series.

study area is characterized by modest wave motion: indeed, less than 1% of the recorded sea states exceeds the threshold of 1.5 m and no sea level exceeds the threshold of 3 m. This result is due to the morphology of the territory: the study area is located within the Strait of Messina, in an area characterized by small fetch, of the order of ten km. The frequency is concentrated in two main directions: one from the North-West and one from the South. Regarding the first direction, it is associated with a high frequency but has a low energy content due to the small fetches. Regarding the second direction, it is characterized by a lower frequency than the first but has much higher energy content due to exposure to the wave coming from the southern mouth of the Strait.

Longshore transport was estimated using the Tomasicchio, D'Alessandro, Barbaro, and Malara (2013) model (Table 3) and the study area was divided into two sections, one to the north and one to the south of the mouth, due to the different exposure to wave motion (Figure 11). The southern section has a small beach, of the order of meters, while the northern section has greater width, on average between 20 and 30 m.

From the analysis of the results shown in Table 3 and in Figure 11, it is possible to observe that in the northern section the average value is about 20,000 m³/year while in the southern section the average value is about 11,000 m³/year, in both cases it is directed from South to North.

River sediment contribution

To study the river sediment contribution, variations of hydraulic structures, rainfall time series, land cover and WSE, estimated using the Gavrilovic (1959) model, were analyzed as for below. Preliminarily it was necessary to identify and morphometrically characterize the catchment area using QGIS and MapWindow and its Watershed Delineation plugin.

Table 3. Longshore transport on southern and northern sections in different time periods.

Time period	Longshore transport on southern section [m ³ /year]	Longshore transport on northern section [m ³ /year]
1986–2006	20000	11000
1986–1996	32000	14000
1996–1998	3600	6000
1998–2002	4500	7300
2002–2006	11600	9000



Figure 11. Southern and northern sections in which the study area was divided.

Morphometric characteristics of the Sant'Agata River basin

The identification and morphometric characterization phase of the catchment area was carried out by starting with the data available in the OpenData section of the Calabrian Geoportal (<http://geoportale.regione.calabria.it/>). In particular, the DEM with square mesh of 5 m and the shapefile of the watercourses were used and the river basin (Figure 12), the perimeter, the main stream length, the maximum, minimum and the average heights, the average slope, the Horton order, the run-off time and the Gravelius index were calculated (Table 4). The basin has an elongated shape, has a considerable altitude difference between mountain and mouth sections, over 1600 m, a high slope, about 40%, and a modest run-off, less than 3 hours.

Hydraulic structures

The latest census of hydraulic structures in the Sant'Agata River dates back to 2010, the results have been implemented in the Archimede information

system (Labate, 2010). This system is a section of the territorial information system of Calabria region civil protection. The first structures date back to 1880; subsequent interventions were carried out several times in 1913, between the years 1924 and 1937, between the years 1950 and 1956, around the years 1980 and 2000. Currently, 130 transverse works were surveyed along the main stream and along 3 tributaries (Sant'Elia, Cropazzoli and Basile) and about 75% of these are in good condition.

Rainfall data

There are 2 gauges in the Sant'Agata River basin and in its neighboring areas (Figure 13). Table 5 shows the registration period, the number of years available, the elevation, the weight, calculated using the Thiessen polygon method (ASCE, 1996; Fiedler, 2003), and the average rainfall and temperature for each gauge. Table 6 shows the average annual rainfall values for each gauge from a sufficiently large period before 1954 to today, divided into time intervals consistent with those identified in the

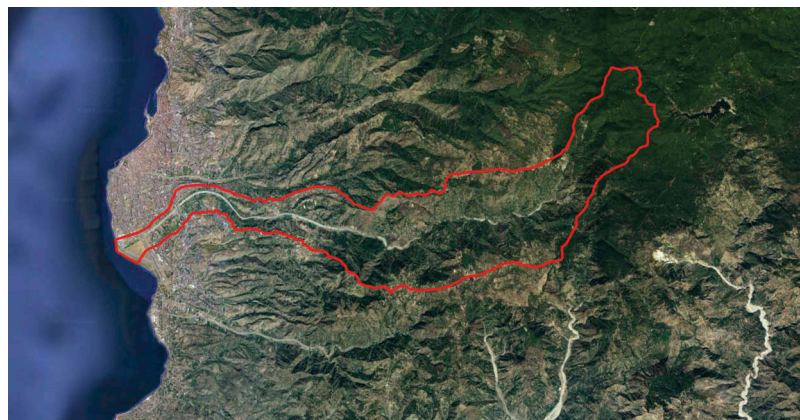


Figure 12. Sant'Agata River basin.

Table 4. Morphometric characteristics of Sant'Agata River basin.

Parameter	Value
Area	52.3 km ²
Perimeter	54.3 km
Main stream length	26.2 km
Maximum height	1665 m
Minimum height	0 m
Average height	865.6 m
Average slope	37.4%
Horton order	5
Run-off time	2.9 hour
Gravelius index	2

paragraph on the shoreline changes. Table 6 also shows the percentage variations, compared to the average rainfall, for each gauge and for each time interval.

From the analysis of the results shown in Tables 5–6, it is possible to observe that in each interval the percentage variations are of an agreed sign for both stations. Moreover, the greatest positive variation for both stations were observed in the same period, 2007–2012, with about 16% more for Reggio Calabria gauge and 7% more for Cardeto gauge. Also, the major negative variations for both stations were observed in the same period, 2006–2007, with about 10.5% less for Reggio Calabria gauge and about 17% less for Cardeto gauge. Other significant variations were observed in the 2012–2017 period, between 5 and 5.5% positive for both stations, and in the 1998–2002 period, between 8 and 9% negative for both stations.

Land cover

The land cover data used was from the Corine Land Cover project and relates to the years 1990 to 2012. This was divided into three periods, being 1990–2000, 2000–2006 and 2006–2012, and was freely available on the government agency website “Istituto Superiore per la

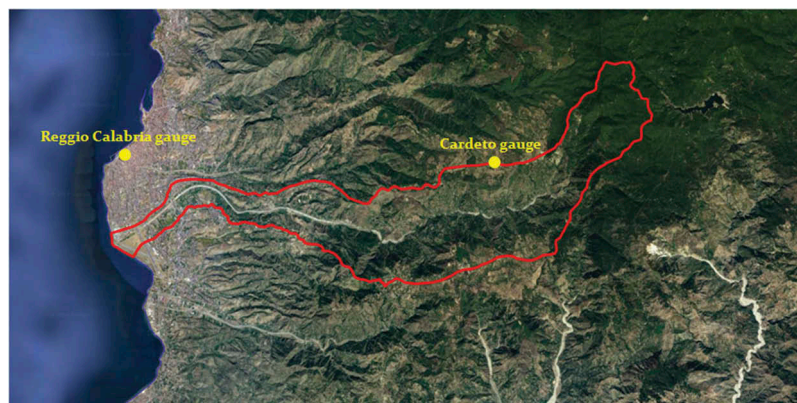
Protezione e la Ricerca Ambientale (ISPRA)”. It should be noted that data before 1990 and after 2012 is not available. Comparing these periods, it is possible to observe that only negligible percentages of the entire surface of the basin have undergone changes (Figure 14).

Soil erosion by water (WSE)

Over recent decades, WSE has become a severe and extended issue affecting all European countries, although to varying degrees. 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 (Grimm, Jones, & Montanarella, 2002, 2003; Van der Knijff, Jones, & Montanarella, 1999). In particular, natural conditions and the human impact have made Calabria in southern Italy particularly prone to intense WSE (Terranova et al., 2009). For this reason, river sediment contribution was evaluated using the Gavrilovic (1959) model, which is based on an analytical equation to determine the annual volume of detached soil due to surface erosion. This equation depends on the average yearly precipitation, the average yearly temperature, the drainage area, the average slope of the basin and some coefficients related to the soil protection (a function of the type of vegetation cover), the erodibility (a function of type of rock), the erosion, and the stream network development (a function of the type of basin erosion). The annual river sediment transport averages 20,000 m³/year.

Discussion and conclusions

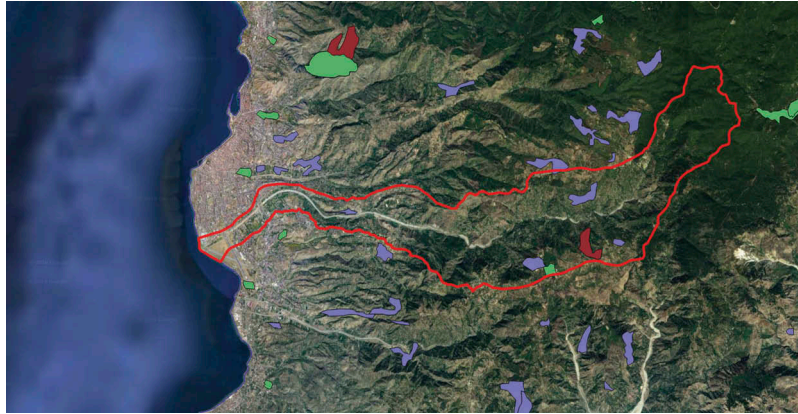
The analysis of shoreline changes is very important for coastal planning and management. This paper describes a case study on the analysis of shoreline changes near the mouth of the Sant'Agata river, which analyzed the

**Figure 13.** Active gauges in Sant'Agata River basin and in its neighboring areas.**Table 5.** Registration period, number of years available, elevation, weight and average rainfall and temperature for each gauge.

Gauge	Registration period	Years available	Elevation[m]	Weight [%]	Average rainfall [mm]	Average temperature [°C]
Reggio Calabria	1917–2017	98	10	20	594.4	18.9
Cardeto	1999–2017	19	690	80	1300.6	11.1

Table 6. Average rainfall and percentage variations, compared to the average rainfall, for each gauge.

Time period	Average rainfall of Reggio Calabria gauge [mm]	Percentage variation for Reggio Calabria gauge [%]	Average rainfall of Cardeto gauge [mm]	Percentage variation for Cardeto gauge [%]
1954–1985	607.9	2.3	n.a.	n.a.
1985–1998	583.7	−1.8	n.a.	n.a.
1998–2002	542.8	−8.7	1200.9	−7.7
2002–2006	614.3	3.3	1352.3	4.0
2006–2007	532.6	−10.4	1083.0	−16.7
2007–2012	688.6	15.8	1393.4	7.1
2012–2017	624.4	5.0	1370.8	5.4

**Figure 14.** Land cover variations in the Sant'Agata River basin.

Legend: violet = changes between 1990 and 2000, red = changes between 2000 and 2006, green = changes between 2006 and 2012.

possible correlations between the shoreline changes and the main factors that influence it. In particular, the wave climate, the longshore transport and the contribution of river sediments were analyzed, influenced by changes in hydraulic structures, precipitation regime, land cover and WSE. This last factor has been analyzed because the Mediterranean European countries, including the Calabria region, are particularly exposed to the WSE.

The analysis of possible correlations between the shoreline changes and the main factors that influence it was carried out using an empirical decomposition method, which is one of the classic models of time series analysis. The method was applied to each factor examined, to compare the evolutionary trend of this factor with the evolutionary trend of the shoreline to assess if there is a correlation between them. This analysis was restricted mainly to the interval 1986–2006, in which data of all the parameters examined are available. In particular, it is possible to observe that river transport is, on average, of the same amount of longshore transport south of the mouth, and in this section the beach is a few meters wide, while north of the mouth is larger, and in this section the beach is between 20 and 30 m wide.

Moreover, due to the morphology of the territory, both the wave motion and, consequently, the longshore transport are modest. During the period 1986–1996, where the shoreline has progressed slightly, longshore transport has assumed the highest values. In the period 1996–1998, where the shoreline

advanced at a speed of 3.5 m/year, longshore transport has assumed the lowest values. In the period 1998–2002, where the shoreline has eroded at a speed of over 8 m/year, longshore transport has assumed lower than average values. In the period 2002–2006, in which the shoreline advanced at a speed of 11 m/year, on the other hand, longshore transport has assumed values above the previous interval, but still below average values. Therefore, there seems to be no correlation between these parameters.

Regarding the contribution of river sediments, the influence of hydraulic structures is limited because most of them were built before the period analyzed and the changes to the land cover affected a negligible portion of the basin. Furthermore, changes in precipitation have always been consistent with shifts in the shoreline in all periods analyzed. Therefore, in this case study, there seems to be a direct correlation between precipitation and changes in the coastline. This is consistent with the hydrological characteristics of most of the Calabrian rivers and, in general, of many Mediterranean rivers in which the WSE plays an important role.

The methodology for analyzing shoreline changes, as described in this article, is particularly useful to better understand the factors that most influence the coastal sediment balance and, therefore, is applicable to many contexts that are similar to the mouth of the Sant'Agata river.

Disclosure statement

No potential conflict of interest was reported by the authors.

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