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The Effects of Anthropogenic Pressure on Rivers: A Case Study in the Metropolitan City of Reggio Calabria

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Abstract: In the second half of the twentieth century, after the end of the Second World War, a considerable anthropogenic pressure was observed in most of the Mediterranean territories. This process has caused the expansion of existing settlements and the construction of numerous new towns, often located very close to rivers. A frequent consequence of this process is the transformation of several rivers through planform changes, narrowing, channelization and culverting to recover spaces where inhabited centers expanded, and the construction of structures interacting with rivers. This issue is very important in territories such as the Metropolitan City of Reggio Calabria, in southern Italy, which is an interesting case study due to the considerable anthropogenic pressures observed in the last 70 years. The main goal of this paper is to evaluate the effects of anthropogenic pressure in the last 70 years on some rivers of the Metropolitan City of Reggio Calabria in terms of the following issues: planform changes, channelization, culverting, and the presence of structures and infrastructures interacting with rivers. The specific goals of this paper are the quantification of the effects of anthropogenic pressure on the rivers of the study area analyzing sixteen parameters, the identification of possible conditions of hydraulic hazard through the analysis of past events, and the proposal of structural and non-structural mitigation interventions. In many rivers of the study area, the significant effects of anthropogenic pressure are visible through rivers that pass above highways, barred rivers, rivers replaced by roads and numerous crossing roads with a missing levee.

Keywords: anthropogenic pressure; inhabited center expansion; river changes; remote sensing; GIS

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1. Introduction

In the second half of the twentieth century, after the end of the Second World War, a considerable anthropogenic pressure was observed in most of the Mediterranean territories [1,2]. This process has caused the expansion of existing settlements and the construction of numerous new towns, often located very close to rivers for the ease of supplying water and other resources, and for facilitating travel and trade [3–10]. A frequent consequence of this process is the transformation of several rivers through planform changes, channelization and culverting to recover spaces where inhabited centers expanded, and the construction of structures interacting with rivers [11–29]. In addition, the expansion of inhabited centers near rivers has led to the construction of numerous flood protection works such as levees, dams and check dams, as well as the construction of infrastructures interacting with rivers [30–36]. Alone, these consequences can all directly increase or decrease the flooding risk, but, due to anthropogenic expansion, the potential damage can significantly increase and, consequently, can guarantee increased flooding risk [37–42]. Moreover, these works have often altered the river balance with hydrological, sedimentological, ecological and landscape consequences [43–58].

The analysis of river changes can be carried out through field surveys or in GIS environments. In general, high levels of detail and accuracy can be obtained with the former but, depending on the size and the accessibility of the surveyed area, they can be very expensive in economic and temporal terms [59,60]. On the other hand, the GIS allows for the analysis, in an efficient, comparable and homogeneous way, of very large areas in different time periods, based on cartographic data and remote sensing [61–73]. Regarding remote sensing, Google Earth is a useful open source of satellite images [74].

This paper, following and expanding upon the study by Versaci et al. [75], evaluates the effects of anthropogenic pressure in the last 70 years on some rivers of the Metropolitan City of Reggio Calabria, through the comparison of cartographic data of different years using QGIS. The main goal is to evaluate the effects of anthropogenic pressure in terms of the following issues: planform changes, channelization, culverting, and the presence of structures and infrastructures interacting with rivers. The specific goals of this paper are the quantification of the effects of anthropogenic pressure on the rivers of the study area analyzing sixteen parameters, the identification of possible conditions of hydraulic hazard through the analysis of past events, and the proposal of structural and non-structural mitigation interventions.

2. Materials and Methods

2.1. Site Description

The study area is in Calabria, a region of southern Italy that is in the center of the Mediterranean Sea (Figure 1). From an administrative point of view, the Calabria region is divided into four provinces, Cosenza, Catanzaro, Crotone and Vibo Valentia, and the Metropolitan City, Reggio Calabria. The Metropolitan City is in the southern part of Calabria, has an area of over 3000 km^2 and is almost totally bounded by the sea, with a strip of land about 60 km long which borders the provinces of Catanzaro and Vibo Valentia to the north. Specifically, the total length of the Metropolitan City of Reggio Calabria's coast is more than 200 km, and it is bathed by the Ionian Sea to the south and the east, the Tyrrhenian Sea to the west, and the Strait of Messina between them, where the city of Reggio Calabria is located.

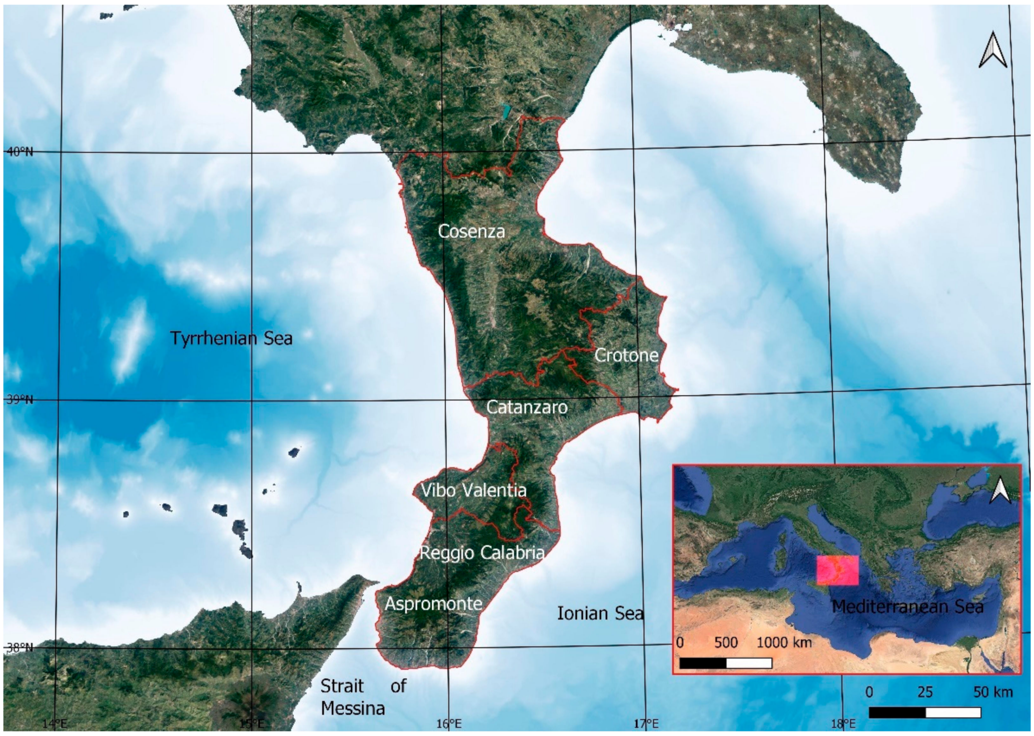

Figure 1. The Calabria region and its provinces (large panel). The geographical position of the Calabria region in the center of the Mediterranean Sea (small panel).

From the geomorphological point of view, most of the territory is mountainous or hilly with some small coastal alluvial plains. The main relief is the Aspromonte Massif, with a maximum altitude of almost 2000 m, while the only extensive coastal plain is that of Gioia Tauro in the northeastern part of the study area.

From the hydrological point of view, almost all of the rivers, locally called *fiumare*, are characterized by a torrential and irregular hydrological regime, with extensive dry periods and frequent sudden flooding, caused by short and intense rainfalls [76,77]. The peak of the Aspromonte Massif is located a short planimetric distance from the coast, generally just over 20 km, so many of these rivers have high slopes and a modest corrivation time. In addition, these rivers have very wide beds with coarse grain size. This combination of hydrological and granulometric characteristics often causes high solid transport and erosion capacity, with consequences on the valley parts and on the mouths. In the valley parts, aggradation is often observed due to the sedimentation of the solid material caused by the reduction of the slope [78]. Therefore, the solid material that reaches the mouth contributes significantly to the shoreline evolution [79–81]. Since the last century, the beds of many *fiumare* have been heavily modified due to the considerable anthropogenic pressures [82].

In the study area, there are about 330 rivers. Of these, only two have a fluvial regime, the Mesima River and the Petrace River, with basin areas of 815 and 420 km^2, respectively. Moreover, the Mesima River mouth flows into the study area but most of its basin is located in the province of Vibo Valentia. Most of the remaining rivers are characterized by small- to medium-sized basins. In fact, only 5 river basins have an area greater than 100 km^2 and only another 36 river basins have an area greater than 10 km^2, while 180 river basins have an area of less than 1 km^2.

2.2. Methodology

The methodology involved the comparison of cartographic data of different years using QGIS version 3.10 'A Coruna' to evaluate the effects of anthropogenic pressure in some rivers of the Metropolitan City of Reggio Calabria. Thirteen rivers were chosen, all with a *fiumara* regime. Eight of these have a basin area between 10 and 100 km^2, Molaro, Valanidi, Armo, Sant'Agata, Calopinace, Annunziata, Scaccioti and Budello; three of these have a basin area between 1 and 10 km^2, Solano, Fosso Marina Grande and Gaziano; while Zagarella and Piria have a basin area less than 1 km^2 (Figure 2).

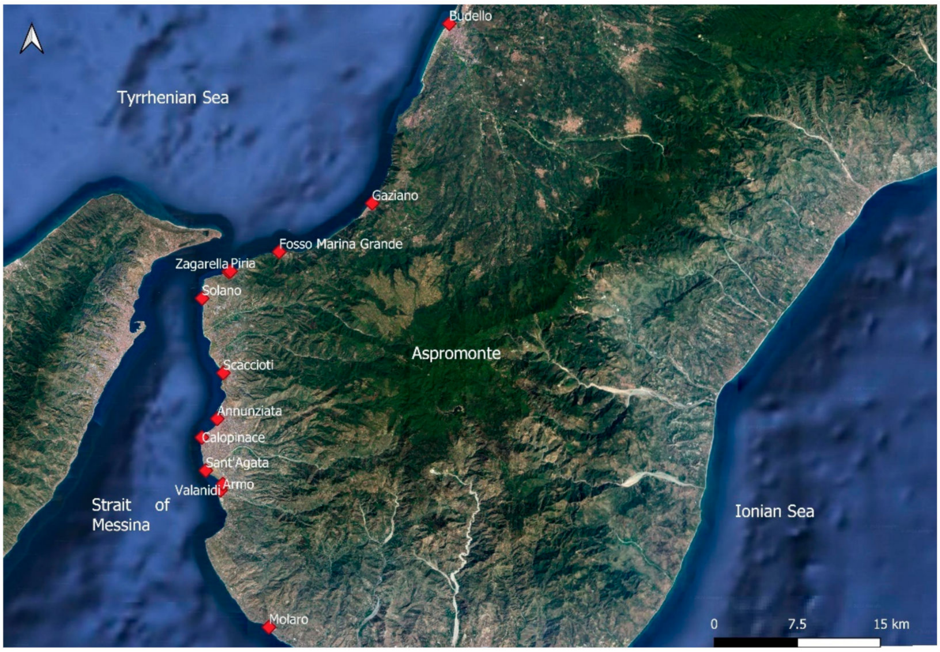

Figure 2. The analyzed rivers.

The input data were from the CASMEZ, "*Cassa del Mezzogiorno*", cartography from 1954 taken from the Open Data section of the Calabrian Geoportal (http://geoportale.regione.calabria.it/opendata, accessed on 10 May 2022). The aerial photogrammetries from 1976 were acquired by the Military Geographic Institute (https://www.igmi.org/it/geoprodotti#b_start=0, accessed on 5 April 2022). The orthophotos from 1989, 1996, 2006 and 2012, were available from the Web Map Service (WMS) of the Open Data section of the Italian Geoportal (http://www.pcn.minambiente.it/mattm/servizio-wms/, accessed on 10 May 2022). Lastly, the most recent Google satellite imagery, was provided by Google Earth Pro and all relating to September 2021. The CASMEZ cartography, orthophotos and Google satellite imagery all have formats that can be used directly on QGIS, while the aerial photogrammetries were acquired as images and then georeferenced on QGIS.

In detail, the CASMEZ cartography was scaled 1:10,000; the aerial photogrammetries in black and white at 2500 DPI, were taken from altitudes of just under 3000 m, and scaled between 1:17,000 and 1:19,000; the 1989 and 1996 orthophotos in black and white, were acquired with a Leica RC30 digital camera, and scaled 1:10,000; the orthophotos from 2006 and 2012 in color, were acquired with a Leica AD40 digital camera, and scaled 1:10,000; and the 2012 orthophotos had pixels of 50 cm.

In this analysis, there were two main types of uncertainties: relating to the photogrammetric process, evaluable by scanning error that depended on image pixel size; and relating to the georeferencing process, evaluable by georeferencing error that depended on the availability of Ground Control Points (GPC) and on the RMS error of the process [83,84].

Regarding the photogrammetric process, the first and most evident source of uncertainty was the intrinsic distortions affecting the photographs. These distortions were due to different causes related to the geometry of the aerial photographs, such as scale changes between adjacent photographs due to changing altitude along the line of flight, oblique and radial deformations, or topographical and relief displacement [85].

The georeferencing was carried out by the QGIS Georeferencer plugin, using polynomic correction based on the GCP corresponding to the fixed points present both in the historical photo and currently, such as buildings, roads, etc., evenly distributed across the whole photograph. For each image, at least 6 GCP were identified.

Both the scanning error and the georeferencing error were modest, generally with values of the order of one meter and with slightly higher values only for aerial photogrammetry. However, this accuracy was consistent with the aims of this paper, which concern the evaluation of the effects of anthropogenic pressure on rivers without their detailed quantification.

The CASMEZ cartography from 1954 was acquired by the Calabrian Geoportal in georeferenced raster format. Furthermore, buildings, rivers, roads and anything else of interest for the purposes of this study were coded according to a legend. To limit the uncertainties associated with georeferencing and the interpretation of the cartography, some GCP were used.

Finally, the comparison of cartographic data of different years concerned the river parts within urban areas and analyzed the following issues: planform changes, channelization, culverting, and the presence of structures and infrastructures interacting with rivers. To quantify the effects of anthropogenic pressure on the rivers of the study area, the following parameters were analyzed: the basin area; the mainstream reach lengths; the lengths of the river sections where the effects of anthropogenic pressure occur; the maximum river width in the 1950s; the maximum river width in the 2020s; the variation in the maximum river width between the 1950s and the 2020s; the percentage variation of the maximum river width between the 1950s and the 2020s; the minimum river width in the 1950s; the minimum river width in the 2020s; the variation in the minimum river width between the 1950s and the 2020s; the percentage variation of the minimum river width between the 1950s and the 2020s; the percentage of manmade area within 200 m of the river banks in the 1950s; the percentage of manmade area within 200 m of the river banks in the 2020s; the exposure class of the areas within 200 m of the river banks in the 1950s; the exposure class of the areas within 200 m of the river banks in the 2020s; and the percentage variation of the exposure class width between the 1950s and the 2020s. In addition, the possible conditions of hydraulic hazard were identified through the analysis of past events.

To define the exposure classes underlying the flood risk estimate, the shapefiles of the CORINE Land Cover (CLC) fourth level of 2018, available in the Open Data section of the Italian Higher Institute for Environmental Protection and Research (https://groupware.sinanet.isprambiente.it/uso-copertura-e-consumo-di-suolo/library/copertura-del-suolo/corine-land-cover/corine-land-cover-2018-iv-livello, accessed on 25 August 2022), were analyzed. An exposure class from 1 (very low) to 5 (very high) was associated with each category of the CLC according to the following scheme: Class 1 (very low) the rocks, waters and wetlands. Class 2 (low) the woods, pastures, vegetated areas, beaches and dunes. Class 3 (moderate) the agricultural areas, permanent crops and arable land. Class 4 (high) the geological site, landfills, mining areas and cemeteries. Class 5 (very high) the manmade areas, industrial and commercial areas, infrastructures, urban green areas, recreational and sports areas, historical monuments, archaeological sites, parks, oases and reserves.

3. Results

As shown in Table 1, rivers with significantly variable basin areas were examined. The river with the largest basin area is the Budello, with an area greater than 80 km^2. Two rivers, Sant'Agata and Calopinace, have basin areas greater than 50 km^2 and three rivers, Valanidi, Annunziata and Molaro, have an area greater than 10 km^2. Finally, four rivers, Scaccioti, Gaziano, Solano and Fosso Marina Grande, have an area between 1 and 10 km^2, and Zagarella and Piria have an area of less than 1 km^2. Furthermore, the mainstream reach lengths are never more than 30 km, even in rivers with larger basin areas, and are less than 10 km in rivers with basin areas of less than 10 km^2. The lengths of the river sections where the effects of anthropogenic pressure occur vary from a few hundred meters, in the Zagarella, Piria, Gaziano and Fosso Marina Grande rivers, up to 3 km in the Sant'Agata River. The maximum river width in the 1950s was between 10 m, in the Fosso Marina Grande and Gaziano rivers, and 350 m in the Valanidi River. The maximum river width in the 2020s is between 5 m, in the Solano and Piria rivers, and 350 m in the Valanidi River. The variation in the maximum river width between the 1950s and today is between 5 m in Zagarella River and 115 m in the Scaccioti River while the Valanidi, Armo, Annunziata, Fosso Marina Grande, Gaziano and Budello rivers have not undergone variations in maximum river width. The relative percentage variation of the maximum river width between the 1950s and today is between 33% in the Zagarella River and 77% in the Scaccioti River, and only the Zagarella and Molaro rivers have undergone variations of less than 50%. The minimum river width in the 1950s was between 5 m, in the Solano, Fosso Marina Grande and Gaziano rivers, and 110 m in the Molaro River. The minimum river width in the 2020s is between 5 m, in the Solano, Zagarella, Piria, Fosso Marina Grande and Gaziano rivers, and 90 m in the Molaro River. The variation in the minimum river width between the 1950s and today is between 5 m in the Zagarella and Piria rivers and 70 m in the Sant'Agata river, while the Valanidi, Calopinace, Annunziata, Solano, Fosso Marina Grande, Gaziano and Budello rivers have not undergone variations in minimum river width. The relative percentage variation in the minimum river width between the 1950s and today is between 18% in the Molaro River and 78% in the Sant'Agata river, and only the Molaro and Armo rivers have undergone variations of less than 50%. The percentage of man-made area within 200 m of both riverbanks in the 1950s varied from a few percentage points in the Molaro, Valanidi and Armo rivers to up to 75% in the Annunziata and Fosso Marina Grande rivers. The percentage of manmade area within 200 m of both riverbanks in the 2020s has always had values higher than 60%, except for the Molaro River with 25%, and the highest values are observed in the Calopinace, Annunziata and Gaziano rivers with 95%. The exposure class in the 1950s was between 3.02 in the Molaro River and 4.5 in the Annunziata and Fosso Marina Grande rivers. The exposure class in the 2020s varies between 3.5 in the Molaro River and 4.9 in the Annunziata and Gaziano rivers.

Finally, the variation in the exposure class between the 1950s and today is between 0.4 in the Annunziata River and 1.54 in the Sant'Agata River.

Table 1. The parameters analyzed for each river. Legend: A is the basin area; L_m is the mainstream reach length; L_a is the length of the river section where the effects of anthropogenic pressure occur; $W_{max,'50}$ is the maximum river width in the 1950s; $W_{max,'20}$ is the maximum river width in the 2020s; ΔW_{max} is the variation in the maximum river width between the 1950s and the 2020s; $\Delta W_{max\%}$ is the percentage variation of the maximum river width between the 1950s and the 2020s; $W_{min,'50}$ is the minimum river width in the 1950s; $W_{min,'20}$ is the minimum river width in the 2020s; ΔW_{min} is the variation in the minimum river width between the 1950s and the 2020s; $\Delta W_{min\%}$ is the percentage variation of the minimum river width between the 1950s and the 2020s; $A_{m'50}$ is the percentage of manmade area within 200 m of the river banks in the 1950s; $A_{m'20}$ is the percentage of manmade area within 200 m of the river banks in the 2020s; $E_{'50}$ is the exposure class of the areas within 200 m of the river banks in the 1950s; $E_{'20}$ is the exposure class of the areas within 200 m of the river banks in the 2020s; and ΔE is the percentage variation of the exposure class width between the 1950s and the 2020s.

River	A [km^2]	L_m [km]	L_a [km]	$W_{max,'50}$ [m]	$W_{max,'20}$ [m]	ΔW_{max} [m]	ΔW_{max} [%]	$W_{min,'50}$ [m]	$W_{min,'20}$ [m]	$\Delta W_{min\%}$ [m]	$\Delta W_{min\%}$ [%]	$A_{m,'50}$ [%]	$A_{m,'20}$ [%]	$E_{'50}$	$E_{'20}$	ΔE
Molaro	14.5	7.9	0.9	170	100	70	41	110	90	20	18	<5	25	3.02	3.5	0.48
Valanidi	29.0	19.9	2.0	350	350	0	0	30	30	0	0	<5	60	3.06	4.2	1.14
Armo	15.0	10.5	0.7	60	60	0	0	30	20	10	33	<5	60	3.04	4.2	1.16
Sant'Agata	52.3	28.5	3.0	190	80	110	58	90	20	70	78	10	85	3.16	4.7	1.54
Calopinace	53.5	22.7	2.8	80	35	45	56	15	15	0	0	60	95	4.2	4.9	0.7
Annunziata	22.5	21.3	1.5	25	25	0	0	25	25	0	0	75	95	4.5	4.9	0.4
Scaccioti	7.3	7.3	1.2	150	35	115	77	100	35	65	65	10	65	3.2	4.3	1.1
Solano	2.1	3.6	1.3	20	5	15	75	5	5	0	0	40	70	3.8	4.4	0.6
Zagarella	0.6	1.8	0.3	15	10	5	33	10	5	5	50	15	80	3.3	4.6	1.3
Piria	0.6	1.8	0.3	15	5	10	67	10	5	5	50	15	80	3.3	4.6	1.3
Fosso Marina Grande	1.3	2.3	0.2	10	10	0	0	5	5	0	0	75	90	4.5	4.8	0.3
Gaziano	2.5	2.0	0.3	10	10	0	0	5	5	0	0	20	95	3.4	4.9	1.5
Budello	84.2	18.9	1.3	15	15	0	0	10	10	0	0	10	60	3.2	4.2	1.0

The information below is a detailed analysis of each river.

The Molaro (Figure 3) is a river that flows into Saline Joniche, a town located about 30 km south of Reggio Calabria. Near the inhabited center, the river channel divides into two branches called Molaro I, to the north, and Molaro II, to the south, both about 2 km long. The main effect of anthropogenic pressure concerns the planform changes. In fact, starting from the second half of the 1970s, an industrial site was built in the area between the two branches. Consequently, a levee was built at the confluence between the two branches to convey the discharge only along the Molaro I. Thus, the Molaro II was barred and channeled with a width of less than 10 m, and is adjacent to the industrial site. Moreover, the terminal part of Molaro I has undergone width reduction on the hydraulic left of up to 85 m and, currently, there are some crossing roads with missing levees.

The Valanidi (Figure 4) is a river that flows a few kilometers south of Reggio Calabria. The terminal part of this river is divided into two branches called Valanidi I, to the north, and Valanidi II, to the south, both of which are about 1.5 km long. The main effect of anthropogenic pressure concerns the construction of a highway that passes under both branches. The highway was built in the 1960s and initially crossed the two branches of the Valanidi River by two bridges. In the 1980s, the highway was widened and lowered in altitude, passing below the riverbed through two tunnels. From the point of view of width and planform changes, no variations were observed over the years in either of the two branches. Instead, currently, there are crossing roads with missing levees. In addition, within the Valanidi I just downstream of the junction, there is an extensive anthropized area with buildings, an industrial site and sport centers. This area is bordered by levees but there are numerous missing levees. In October 1953, in the Valanidi River, there was an intense rainfall event with extensive floods that caused extensive damage, with numerous deaths and hundreds of displaced people.

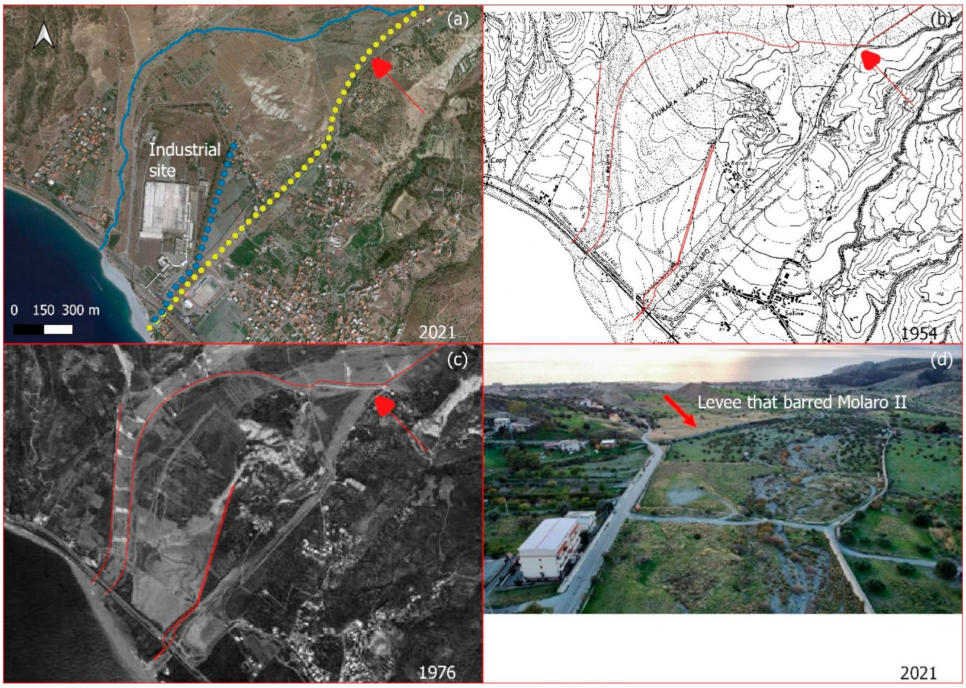

Figure 3. The Molaro River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography of 1954. (**c**) The aerial photogrammetry of 1976. (**d**) The view from a drone of the levee that barred Molaro II (view from the mountain to the valley). The yellow lines are the 1954 riverbanks, the red lines are the 2021 riverbanks, the blue line is the 2021 Molaro I River, the dashed blue line is the 2021 Molaro II River and the dashed yellow line is the 1954 Molaro I River. The arrows identify the point where the levee that barred the Molaro II River was built.

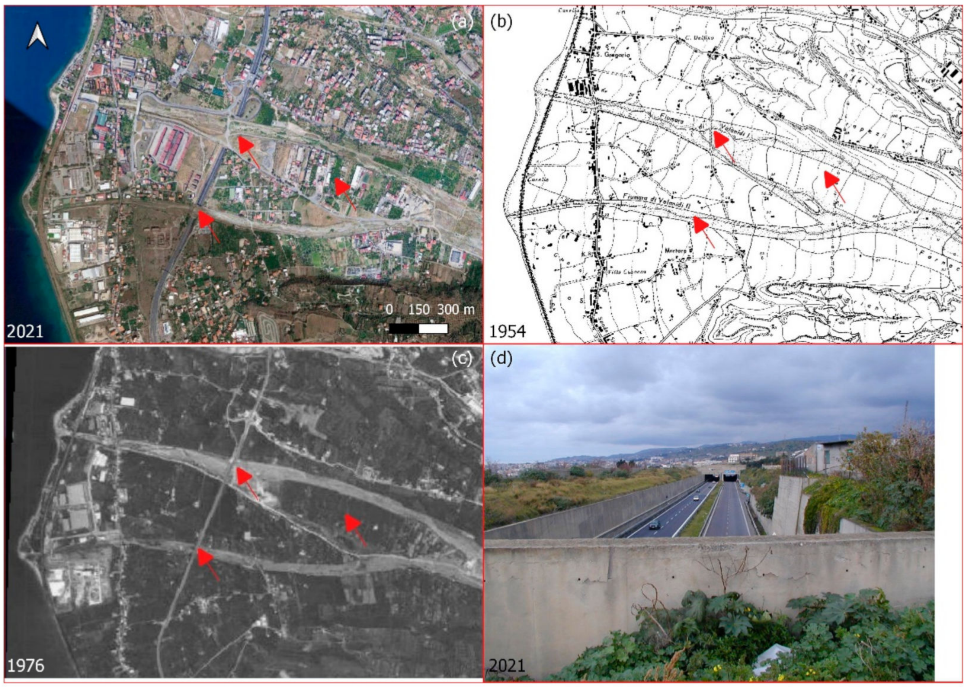

Figure 4. The Valanidi River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography of 1954. (**c**) The aerial photogrammetry of 1976. (**d**) The view from Valanidi II toward Valanidi I. The arrows identify the current anthropized area downstream of the junction and the points where the rivers currently pass over the highway.

The Armo (Figure 5) is a river that flows into the southern part of Reggio Calabria and its terminal part borders the southern part of the airport. The main effects of anthropogenic pressure concern the channelization of the last 700 m, with the narrowing of the section from over 50 to a little more than 15 m; the culverting of a section by about 150 m through three rectangular pipes about 5 m wide, each separated by concrete partitions; the planform changes of the last 150 m; and the presence of some crossing roads with missing levees. In fact, in this last part the river has been diverted and currently curves to the right just before the mouth. These changes were made around 2010 due to the extension of the southern end of the airport runway in correspondence with the culvert.

Figure 5. The Armo River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The orthophoto from 2006. (**d**) The orthophoto from 2012. The arrows identify the point where the southern end of the airport runway has been extended.

The Sant'Agata (Figure 6) is a river that flows into the southern part of Reggio Calabria and its terminal part borders the northern part of the airport. The main effects of anthropogenic pressure concern the channelization of the last 3 km, with a narrowing of the section from over 80 to just over 15 m; the culverting of a section of about 150 m through three rectangular pipes about 5 m wide, each separated by concrete partitions; and the construction of a sports center on the hydraulic left between the current channel limit and that of the 1950s. The changes were made between the 1980s and 1990s and, also in this case, the culvert was built due to the extension of the airport runway to the north. In the part between the current channel limits and those of the 1950s, a sports center was built in the early 1990s.

The Calopinace (Figure 7) is a river that flows near the southern part of the center of Reggio Calabria. The main effect of anthropogenic pressure concerns the channelization of the last 3 km, with a narrowing of the section from over 60 to just over 15 m. In the part between the current channel limits and those of the 1950s, two roads connecting the highway with the city center were built in different time phases up to the beginning of the 1990s. Currently, the concrete riverbed is damaged and in a part close to the inhabited center, there is dense vegetation that exceeds the level of the roads.

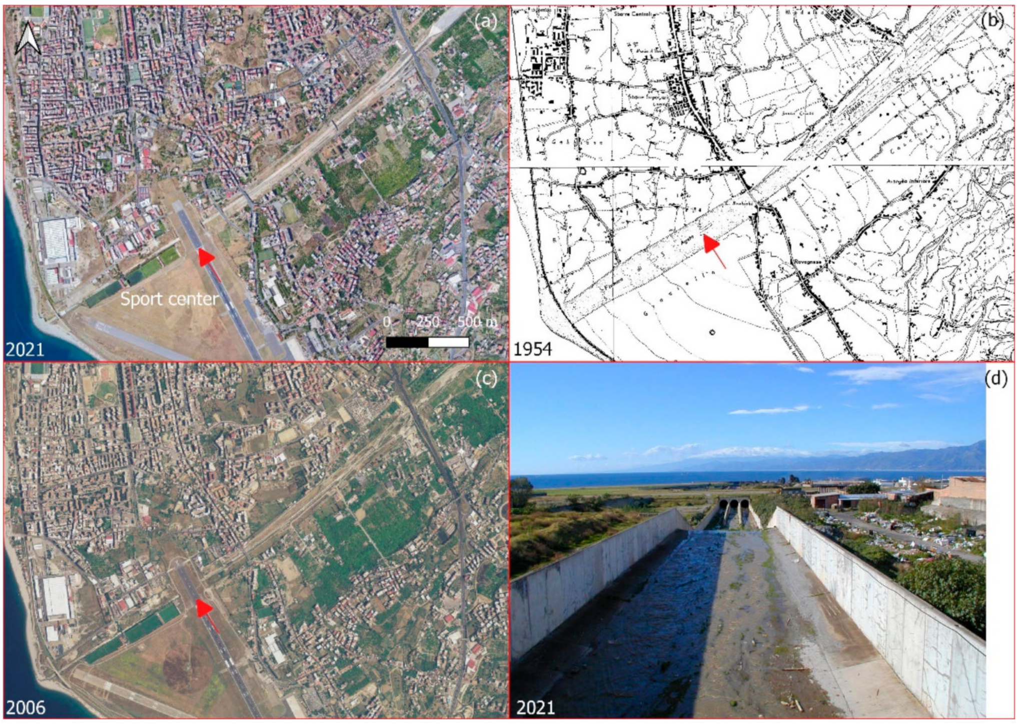

Figure 6. The Sant'Agata River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The orthophoto from 2006. (**d**) The view towards the mouth of the culvert below the airport runway. The arrows identify the point where the northern end of the airport runway has been extended.

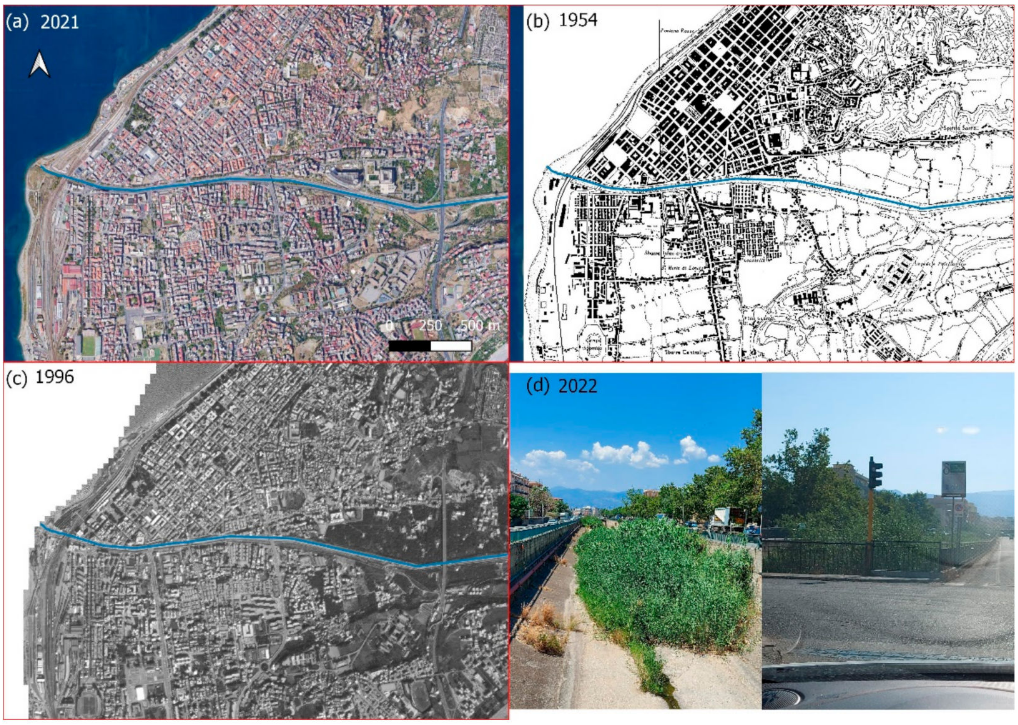

Figure 7. The Calopinace River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The orthophoto from 2006. (**d**) On the left, the view towards the mouth of the part with dense vegetation, and to the right, the view towards the mountains of the part with dense vegetation. The blue line is the Calopinace River.

The Annunziata (Figure 8) is a river that flows near the northern part of the center of Reggio Calabria. The main effect of anthropogenic pressure concerns the culverting of the last 1.5 km through a rectangular channel about 20 m wide, built between the 1980s and 1990s.

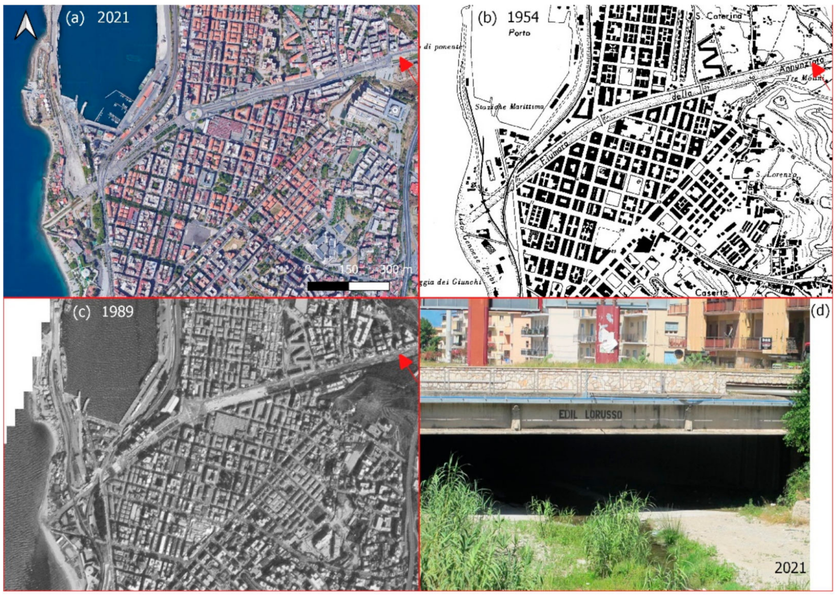

Figure 8. The Annunziata River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The orthophoto from 1989. (**d**) The detail of the culvert (view from the mountain to the valley). The arrows identify the upstream section of the culvert.

The Scaccioti (Figure 9) is a river that flows a few kilometers north of Reggio Calabria. The main effect of anthropogenic pressure concerns the construction, in the 1960s, of a highway that passes under the river through a tunnel. In addition, there are some crossing roads with missing levees. At the end of October 2010, a heavy rainfall caused a partial flooding of the river near the southern entrance of the tunnel (Video S2).

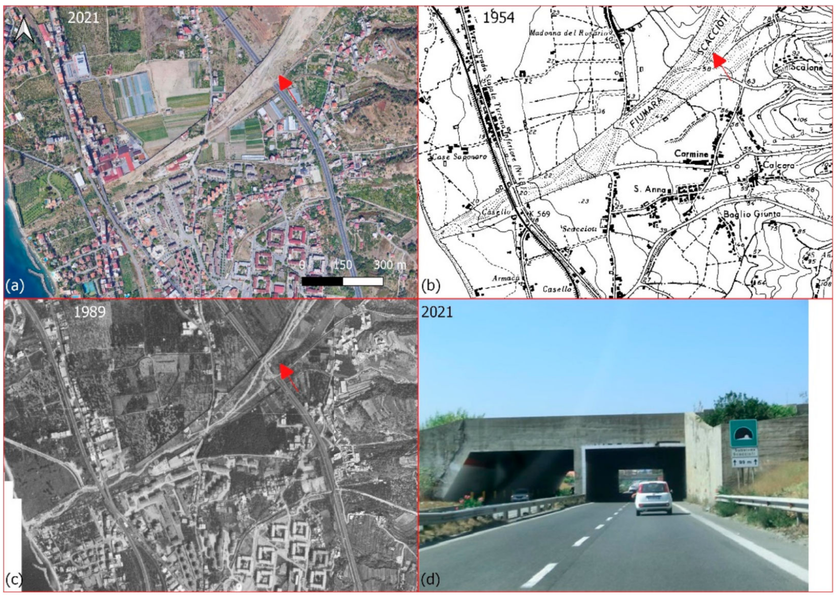

Figure 9. The Scaccioti River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The orthophoto from 1989. (**d**) The view of the highway under the river. The arrows identify the highway tunnel under the river.

The Solano (Figure 10) is a river that flows into the southern part of Villa San Giovanni, a town located about 10 km north of Reggio Calabria, at the northern mouth of the Strait of Messina. The main effects of anthropogenic pressure concern the channelization of a section of about 1 km upstream of the mouth, with a narrowing of the section from 15 to 5 m, and the culverting of a section of about 400 m through a rectangular channel of about 5 m in width in correspondence with the inhabited center. In the canalized section, a road was built that connects Villa San Giovanni to Campo Calabro, a small town a few kilometers upstream. In addition, a stadium was built near this road.

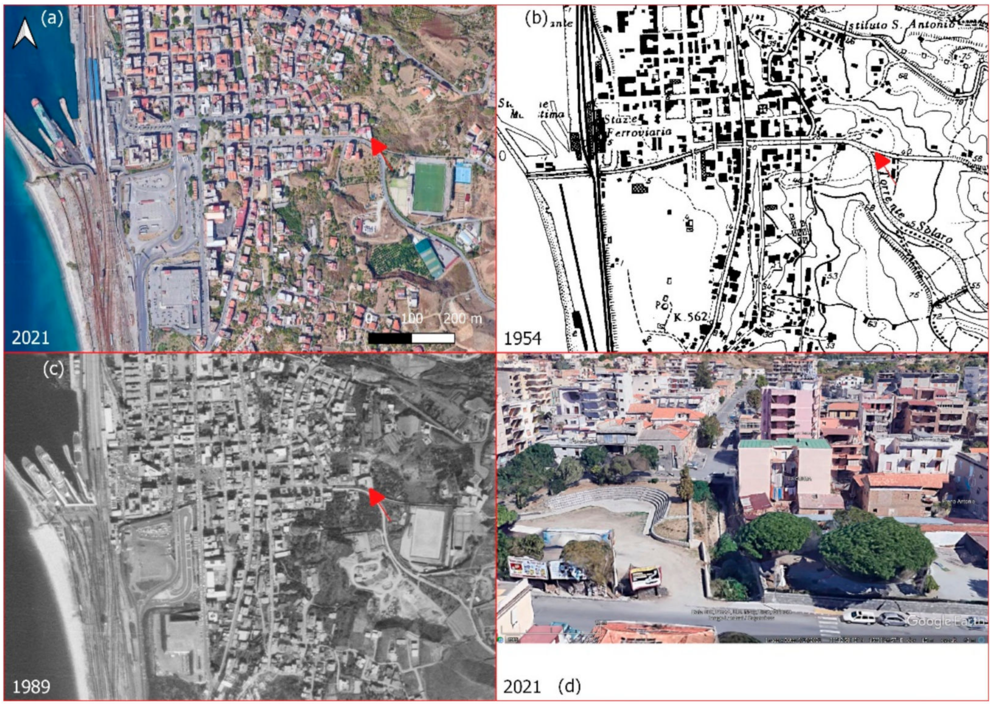

Figure 10. The Solano River. (**a**) An image of Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**)The orthophoto from 1989. (**d**) The view of the culvert towards upstream (source: Google Earth). The arrows identify the upstream section of the culvert.

The Zagarella and the Piria (Figure 11) are two rivers that flow into the northern part of Villa San Giovanni about 150 m away from each other. Regarding the Zagarella River, the main effect of anthropogenic pressure concerns the transformation of the last 250 m of the riverbed into a street, without building channels or a culvert. On the other hand, regarding Piria River, the main effect of anthropogenic pressure concerns the channelization of the last 500 m of the river, with the narrowing of the section from about 15 to less than 3 m and the construction of roads near the channel. In August 2018, due to heavy rainfall, there were numerous floods along the Zagarella and in the adjacent streets and buildings.

The Fosso Marina Grande (Figure 12) is a river that flows into Scilla, a town located about 20 km north of Reggio Calabria. The main effect of anthropogenic pressure concerns the culverting of the last 200 m of the river through a grid and a circular pipe placed just downstream of a check dam that delimits the natural part of the river. During intense rainfall events, such as those of 2017, 2018, 2020 and 2022, the pipe was unable to convey the discharge, which than flowed along the road, which was also due to the considerable sediment transport from upstream.

The Gaziano (Figure 13) is a river that flows into Bagnara Calabra, a town located about 30 km north of Reggio Calabria. The main effect of anthropogenic pressure concerns the considerable anthropization at a very short distance from the river, which has a width of just over 10 m in correspondence with the inhabited center. In addition, some buildings on the left bank act as levees, with culverting through a rectangular channel with a width of about 10 m built under the promenade. At the end of December 2019, there was a flood near the river mouth, flooding the promenade and many nearby buildings. The flooding was caused not only by the modest river width but also by the concurrent storm that contributed to the obstruction of the culvert.

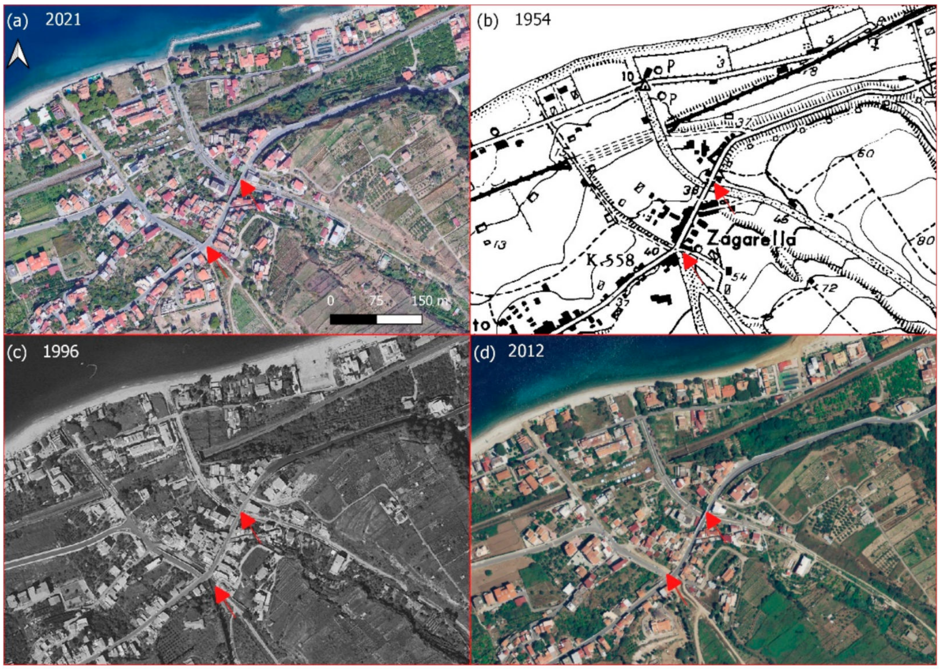

Figure 11. The Zagarella and Piria rivers. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The orthophoto from 1996. (**d**) The orthophoto from 2012. The arrows identify the section where the riverbed was transformed into a street.

Figure 12. The Fosso Marina Grande River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The point where the natural river becomes artificial. (**d**) The effect of the rainfall events of 2017, 2018 and 2022. The arrows identify the upstream section of the culvert.

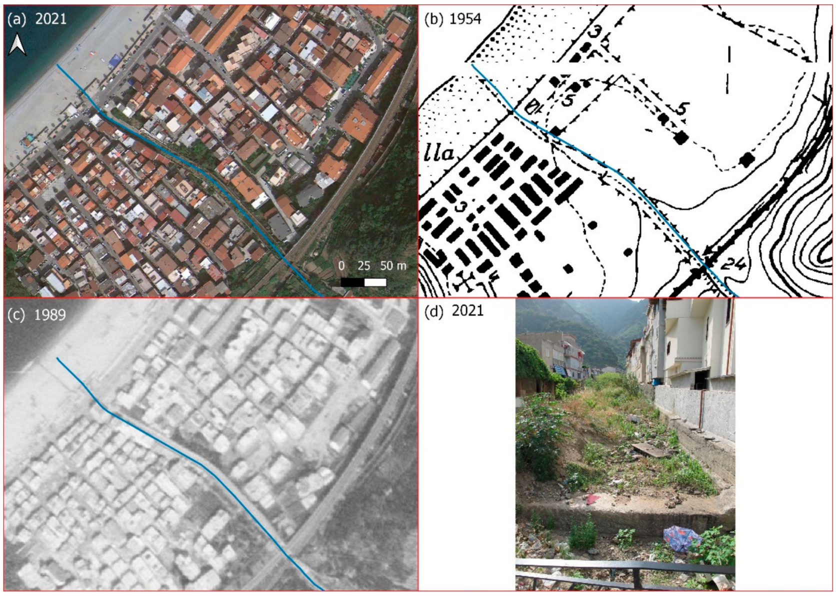

Figure 13. The Gaziano River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The orthophoto from 1989. (**d**) The view of the river towards upstream. The blue line is the Gaziano River.

The Budello (Figure 14) is a river that flows into Gioia Tauro, a town located about 50 km north of Reggio Calabria. The main effect of anthropogenic pressure concerns the considerable anthropization at a very short distance from the river, which has a width of just over 20 m in correspondence with the inhabited center. At the beginning of November 2010, there was a flood that caused extensive damage and the displacement of hundreds of people (Video S1). The flood was caused by a rainfall of over 200 mm in less than 3 h and was increased by the modest river width.

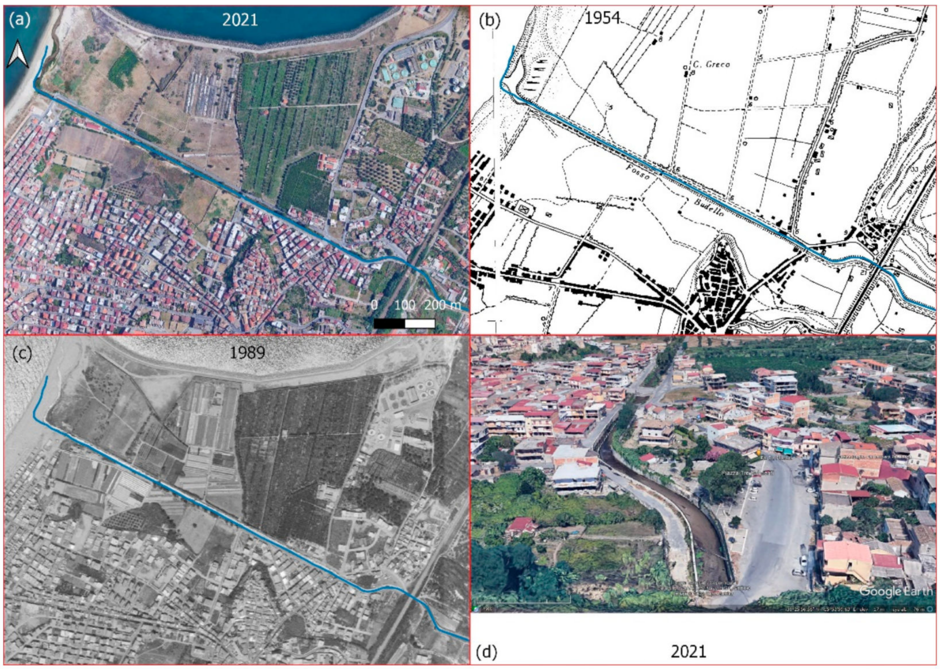

Figure 14. The Budello River. (**a**) An image from Google Earth from September 2021. (**b**) The CASMEZ cartography from 1954. (**c**) The orthophoto from 1989. (**d**) The view of the river towards downstream (source: Google Earth). The blue line is the Budello River.

4. Discussion

The analysis described in the previous section concerned 13 rivers of the Metropolitan City of Reggio Calabria. The main goal was to evaluate the effects of anthropogenic pressure in the study area in terms of the following issues: planform changes, channelization, culverting, and the presence of structures and infrastructures interacting with rivers. The specific goals were the quantification of the effects of anthropogenic pressure on the rivers of the study area analyzing sixteen parameters, the identification of possible conditions of hydraulic hazard through the analysis of past events, and the proposal of structural and non-structural mitigation interventions. This analysis started from the end of the Second World War in concomitance with the period whereby a considerable expansion of the inhabited centers occurred in numerous areas of the Mediterranean and Calabrian territories.

To analyze as many conditions as possible, rivers of various sizes and with different types of anthropization were chosen. In detail, the basin area varied from over 80 km^2, as in the case of the Budello River, to less than 1 km^2 as in the case of the Zagarella and Piria rivers. In addition, both rivers that cross the major city, Reggio Calabria, with a population of over 170,000 inhabitants, and rivers that cross smaller towns such as Saline Joniche, Villa San Giovanni, Scilla, Bagnara and Gioia Tauro, with populations between 5000 and 20,000 inhabitants, were chosen.

Regarding the width parameter, both current and past maximum and minimum widths were analyzed. From this point of view, in the study area, there are rivers with very different characteristics. Specifically, the current maximum width varied between 350 m, as in the Valanidi River, and 5 m, as in the Solano and Piria rivers. The current minimum width was always between 5 and 35 m, except for the Molaro River where it was equal to 90 m. Comparing the current widths with those from the 1950s, high reductions were observed especially in the Sant'Agata River, equal to 110 m regarding the maximum width and 70 m regarding the minimum width, and in the Scaccioti River, equal to 115 m regarding the maximum width and 65 m regarding the minimum width. Width reductions of this order of magnitude or even greater are frequent in many rivers that flow within the cities, as in the case of the Bisagno River in Genoa (Italy) [86], where in some places the width is reduced from 280 to 70 m. Other significant percentage width changes concerned the Solano River, in terms of maximum width, the Zagarella River, in terms of minimum width, and the Piria River, in terms of both maximum and minimum widths. However, all three rivers had modest widths. Among these rivers, the Sant'Agata was the one characterized by the greatest increase in anthropized areas within 200 m of the riverbanks and by the greatest increase in the exposure class. These increases were correlated to the expansion of the city of Reggio Calabria, which until the 1950s developed mainly between the Calopinace River in the south and the Annunziata River in the north but then expanded mainly towards the south between the Calopinace and Sant'Agata rivers. Instead, the Scaccioti River had lower increases in manmade areas within 200 m of the riverbanks and a lower exposure class than the Sant'Agata River despite having similar width variations. In fact, the Scaccioti River is in the northern suburbs of Reggio Calabria in an area that has expanded less than the southern suburbs. Other significant increases both in manmade areas within 200 m of the riverbanks and in exposure class were observed in the Zagarella, Piria and Gaziano rivers, due to the expansion of the inhabited centers of Villa San Giovanni and Bagnara Calabra towards these areas, which in the 1950s were suburban.

In summary, there were planform changes in two rivers, one of which was barred, canalizations in five rivers, culverting in six rivers, and in almost all of the rivers, there were structures and infrastructures interacting with the river itself. In addition, in the analyzed period, floods occurred in six rivers. The practice of river culverting in urban areas has been widespread in the past decades not only in the study area but also in many Italian cities, such as for example in the Bisagno River [86]. Therefore, in 2006, a legislative decree was issued prohibiting river culverting.

The river changes described above are due to various factors, the main one being the irregular urban sprawl without an adequate regulatory plan. This situation has also been observed in many Brazilian cities as evidenced, for example, by Coates [41] in Rio de Janeiro and by de Souza et al. [39] in Jurere (Florianopolis), where an irregular urban sprawl caused the Meio River, Faustino River and some tributaries to become barred. Other similar studies have been carried out by Manawadu and Wijeratne [87], and Wijeratne and Li [42] in Colombo, the commercial capital of Sri Lanka, by Tom et al. [88] in Nairobi, Kenya, and by Nassar and Elsayed [89] in Alexandria, Egypt. Another important factor is the land use change, which increases the exposure class and the flood peaks [90–96]. In many cases, the expansion of the inhabited centers is influenced by the morphological peculiarities of the territory, especially by the presence of mountainous relief very close to the coast, as occurs in the Tyrrhenian coast of the study area in Scilla and Bagnara Calabra. On the Ionian coast of the study area, there is generally a greater distance between the coast and the reliefs, so several inhabited centers have been built away from the coast in a more orderly way and without significant changes to the rivers present. Another case where the expansion of inhabited centers is strongly influenced by the morphology of the territory is the Liguria region, in northern Italy [21,25,97]. In fact, Liguria has a conformation very similar to the study area, with the relief being very close to the coast, the coastal plains being narrow and, therefore, rivers having high steep slopes. In addition, an irregular urban sprawl occurred in the second half of the last century that has significantly changed numerous rivers. As in the study area, there was an abandonment of inland areas with the expansion of coastal settlements, especially in Genoa, the region capital of Liguria, that is one of the most critical urban settings in Italy [86,98–101].

Other important factors observed in the study area concern the construction of an industrial site, the extension of an airport runway, the construction of highways below the level of the riverbed and the construction of roads instead of parts of rivers.

In the latter case, the cases of the Zagarella and Piria rivers and of the Fosso Marina Grande River should be highlighted. In the first two rivers, a significant shoreline retreat was observed after the changes described above. This retreat can be correlated to the reduced solid transport due to the transformation of the riverbeds from natural to artificial. This is a frequent situation in rivers such as those of Calabria and is related to the peculiarity of these rivers [102]. In the case of the Fosso Marina Grande River [103], on the other hand, the effects on the shoreline evolution are modest as the beach of Scilla is a pocket beach. Instead, the flood events described above were often coupled by high solid transport, causing debris flows that also obstructed part of the waterfront and roads adjacent to the river [104].

Regarding the six cases of flooding, it should be highlighted that in two cases, the main cause was related to particularly heavy rainfall events, as in the Budello River; however, the width was very modest, especially related to the basin area. In two other cases, the main cause was related to a modest river width while in the remaining two cases, the main cause was correlated to a transformation of the riverbed from natural to artificial, without canalizations or by insufficient ones. In this regard, a significant aspect is that not all the analyzed rivers were affected by past flood events.

In the case of the Gaziano, the flooding occurred near the river mouth and was also caused by the simultaneous sea storm that contributed to the obstruction of the culvert. The contemporaneity between floods and sea storms is a frequent phenomenon in territories such as Calabria, characterized by mountainous reliefs located a short distance from the sea and subject to sufficiently extensive perturbations that act simultaneously on the sea and on the river basins, thus causing concomitant floods and sea storms [105–107].

The increases in the exposure class described above caused an increase in the flood risk assuming the same flood event and, therefore, the same hazard. Some possible solutions to reduce the flood risk can follow two main directions: hazard reduction, through structural measures; and vulnerability and exposure reduction, through non-structural interventions. Among the possible interventions to reduce the hazard are: the construction of storage areas and levees, the cleaning and reshaping of the riverbed, and the increase in the soil infiltration capacity. Meanwhile, among the possible measures to reduce vulnerability and exposure are: the introduction of regulatory constraints, the relocation of buildings, infrastructures and sites of interest, and the development of early warning systems. In this case study, storage areas are difficult to build due to the morphology of the territory with little availability of flat areas that are not previously manmade. This type of intervention would be possible only in the Budello River which is in the plain of Gioia Tauro. Regarding the levees, they are present in many of the analyzed rivers, except for those culverting or transformed into roads. However, the levees are often not continuous and missing parts that should be filled with a high priority. Furthermore, almost all the levees were built in the years between the 1950s and 1970s so their functionality should be verified considering possible morphological changes of the riverbed, for example, over-flooding that is frequent in Calabrian rivers [78], and climate change [108–111]. The interventions of cleaning and reshaping the riverbed should be carried out at least annually, due to the high solid transport during flood events that is frequent in Calabrian rivers and due to the frequent presence of dense vegetation, as visible in the Calopinace River, especially where there are obstructible culverts, as occurred in the Gaziano River. Interventions that increase the infiltration capacity of the soil, such as Low Impact Development (LID) and Best Management Practices (BMPs), can be useful in the case of rivers transformed into roads such as the Zagarella, Piria and Fosso Marina Grande rivers [112]. In the latter case, cleaning of the grids is required, to be carried out immediately after each rainfall event. In addition to this, the pipe size which is frequently insufficient to convey the discharge as observed especially in recent years, should be increased, and early warning systems would be useful. These systems would also be useful in many other analyzed rivers, especially in the Budello and Gaziano rivers, due to the small flow section and neighboring houses, in the Scaccioti and Valanidi rivers, due to their passage above important road infrastructures, and in the Sant'Agata e Armo rivers, due to the presence of the airport runway. However, early warning systems are particularly complex to set up in small basins characterized by torrential hydrologic regimes such as many of the ones in the study area. Regarding the introduction of regulatory constraints, this study highlighted that most of the analyzed rivers are in an attention area for the Flood Risk Management Plan of the Southern Apennine District, which is the Hydraulic Authority competent for the study area. Regarding the relocation of buildings, infrastructures, and sites of interest, this study highlighted that it would be an optimal solution, especially in rivers with the greatest increases in manmade areas adjacent to the rivers themselves and in rivers crossed by important road and airport infrastructures. However, this would be a solution with significant economic, temporal and social impacts.

Finally, most scientific research focuses on the assessment of the hydraulic hazard and risk in rivers and cities of medium-large sizes, as in the case of Guangzhou, China, and Phoenix, USA [113], Yellow River, China [114], and in rivers where flood events have already occurred [86,98,99,115]. Very little research has been conducted to explain the effects of anthropogenic pressure on rivers [86], especially where flood events have not yet occurred. In addition, very few research has focused on the analysis of many parameters and issues concerning planform changes, channelization, culverting, and the presence of structures and infrastructures interacting with rivers and exposure class changes as in this paper.

5. Conclusions

This paper evaluated the effects of anthropogenic pressure on some rivers of the Metropolitan City of Reggio Calabria, through the comparison of cartographic data of different years using QGIS.

The area with the greatest anthropogenic pressures is the one near the Strait of Messina, especially in Reggio Calabria, and the area along the Tyrrhenian coast, both due to an uncontrolled and disordered urban sprawl and due to the morphological peculiarities of the territory.

The main results of this study include rivers that pass above highways, barred rivers, rivers replaced by roads, rivers with crossing roads and missing levees, and channelized and culverted rivers. In addition, in the analyzed period, floods occurred in six rivers. Other important results concern the considerable increase in the manmade areas near rivers, which in four cases reached percentages higher than 90%, and the significant increase in the exposure class observed in these areas. Finally, the main structural and non-structural flood risk mitigation interventions were analyzed to assess their adaptability to the analyzed rivers.

This study also highlighted that anthropogenic pressure should not be assessed only in rivers where floods have already occurred. On the contrary, it should mainly concern rivers without past flood events where criticalities that increase their danger are identified, as in this case study, to start or improve the planning and management phases of these territories.

Finally, this methodology is easily replicable in any other context, as it is based on open-source software and cartographic data, and is of interest to decision makers and stakeholders in the field of planning and management of rivers and urban territories as possible guidelines for a sustainable management of these areas. Indeed, the sustainable management of riverbeds in urban areas is one of the main objectives of the 2030 Agenda for sustainable development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/rs14194781/s1, Video S1: The Budello flood, Video S2: The Scaccioti flood.

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