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A Procedure for Evaluating Historical Land Use Change and Resilience in Highly Reclaimed Coastal Areas: The Case of the Tavoliere di Puglia (Southern Italy)

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Abstract: In this research, an operative procedure for the evaluation of land use change that occurred in highly reclaimed coastal areas from the middle of the XIX century up to the present day is proposed. The multitemporal analysis envisages the use of historical maps, aerial photographs, and satellite images, whose interpretation is performed in a GIS environment. The proposed methodological approach starts from the interpretation of the symbols used in the legend of the historical maps. Subsequently, in order to compare historical information with the most recent land use classifications (i.e., CORINE land cover), a set of twenty-two macro-categories is proposed to find a compromise between a highly detailed land use classification and its applicability to both historical and present-day data. The study area is located in the coastal sector of the Tavoliere di Puglia (Apulia region, Southern Italy), the second-largest coastal plain in Italy. In this area, environmental changes were mostly driven by extensive reclamation and drainage works, which allowed more than 170 km^2 of land to be removed from coastal marshes and wetlands. The results show a strong increase in the surface occupied by arable land, urban areas, and saltwork, which today occupy about 57%, 3%, and 23% of the total investigated area, respectively. In contrast, the total surface occupied by grassland, pasture, meadow, and shrubland decreased from 59.6% in 1869 to 4.6% in the present-day setting. It is worth noting that although fluvial sediments were trapped and used to fill the marshy areas, the coastline prograded up to the first half of the XX century, favouring the formation of wide coastal dune systems. Nevertheless, the natural coastal resilience of the investigated system has been reduced since the second half of the XX century, probably as a consequence of the construction of numerous dams in the Ofanto River catchment, which represents the main river in the investigated area.

Keywords: land use analysis; land use categories; coastal landscape; resilience; Apulia region

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Citation: De Santis, V.; Rizzo, A.; Scardino, G.; Scicchitano, G.; Caldara, M. A Procedure for Evaluating Historical Land Use Change and Resilience in Highly Reclaimed Coastal Areas: The Case of the Tavoliere di Puglia (Southern Italy). *Land* **2023**, *12*, 775. https://doi.org/10.3390/land12040775

Academic Editor: Salvador García-Ayllón Veintimilla

Received: 7 February 2023
Revised: 22 March 2023
Accepted: 25 March 2023
Published: 29 March 2023

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1. Introduction

Differently from the land cover concept, which identifies "the biophysical state of the Earth's surface and immediate subsurface" [1], land use "denotes the human employment of land" [2] and "the purpose for which the land is used" [1].

As highlighted by the most relevant literature ([3] and references therein), the analysis of land use/cover change includes both modification and conversion processes. In particular, the "modification" involves the change of the land structure without influencing the type of land use, while the "conversion" represents the change from one use/type to another type.

Modifications in land use/cover are the results of the interactions between natural and anthropogenic processes. Climate variations, volcanic eruptions, and changes in the river pattern are the most relevant natural processes affecting land cover over the long term, while human-related activities (i.e., urbanisation, agriculture, industry, energy production, recreation, and water catchment and storage) are the predominant factors in the recent past and present time.

Quantifying land use change is a critical issue for global societal challenges such as food security, climate change, and biodiversity loss [4]. The historical reconstruction of past land use and land cover changes is based on some fundamental sources, such as historical documents, historical maps and pictures, natural archives, and models of historical reconstruction [5]. Nevertheless, the reconstruction of land use/cover changes at the global and local level in space and time is limited by a lack of data and the large variability of parameters and categories used in the reconstructions of land use/land cover change [6,7].

The recent land use change data from satellites are still affected by fragmented content and different scales, spatial or temporal detail, time series, and categories of land use [8]. Satellite remote sensing provides high spatial resolution, but short temporal coverage. In contrast, national and regional inventories (if available) encompass long time spans, but are affected by administrative borders and, thus, a lack of spatial extension. Each data source on its own lacks a critical component—especially space or time—and, thus, is unable to capture the full scale of land use dynamics [4].

At the global scale, some of the most recent and more temporally spanned land use change analyses are reported by Liu et al. [9], which assess the land cover change at a significant spatial resolution (5 km) and temporal coverage (1982–2015), and by Winkler et al. [4] that analyse the dynamics of global land use change at an unprecedented spatial resolution in six decades (1960–2019).

In the USA, multiple land use/land cover products are available, but these datasets were generated using remote sensing images and cannot be used to characterise the century-long land use dynamics ([10] and references therein). Thus, a lot of effort has been made to reconstruct and analyse the spatial and temporal pattern of land use/land cover during 1630–2020 by integrating high-resolution satellite data, historical census data, and model-based data [10].

In Europe, the CORINE Land Cover (CLC) project was initiated in 1985 to produce a standardised collection of data related to land. The reference year for the first inventory was 1990; updates were produced in 2000, 2006, 2012, and 2018. The CLC project is managed and controlled by the European Environmental Agency (EEA). The total number of participating countries increased from 27 to 39 (https://land.copernicus.eu/pan-european/corine-land-cover (accessed on 5 February 2023)). It currently covers an area of 6 Gm^2. CLC data represent the oldest and the most used dataset available from the Copernicus Land Monitoring web platform, which is the European reference platform for geographical information on land cover and its changes, land use, vegetation state, water cycle, and Earth surface energy variables. According to the CLC programme, 44 land use/cover classes are provided.

In Italy, the analysis of the land use change and the related land consumption is carried out by the Italian Institute for the Environmental Protection and Research (ISPRA), which periodically releases data on land use change at the national, regional, and municipal level (https://www.snpambiente.it/2020/07/22/consumo-di-suolo-dinamiche-territoriali-e-servizi-ecosistemici-edizione-2020/ (accessed on 5 February 2023)).

In recent times, the land use/land cover changes in a rural area located in southern Italy (Basilicata region) have been reconstructed using GIS-based territorial analysis in which data from historical maps were implemented [11]. This study analyses land use from 1829 to 2013 through a comparative examination of different historical cartographic supports and more recent maps. In order to compare changes through time, similar categories of land use in different times were aggregated into five more general classes: natural land, agricultural land, urbanised area, road network, and river.

Previously, land use/land cover changes were studied in central Italy by analysing historical and recent remote sensing-derived maps [12]. Also in this case, a reclassification of the modern land use classes in seven more general sections has been realised for historical land use comparison.

With regard to the evaluation of the potential environmental and socioeconomic impacts of land use/cover change, several studies have focused on this issue worldwide. By way of example, in Tolessa et al. [13], the changes in land use/cover are assessed to estimate the direct impacts on ecosystem services. Similarly, Quintas-Soriano et al. [14] analysed the impacts of land use change on ecosystem services and their implications for human welfare. In Tran et al. [15], the relationship between land use/cover change and land surface temperature is investigated. Findell et al. [16] investigated the regional impacts of land use/cover change on combined extremes of temperature and humidity at the global scale. Hayakawa et al. [17] analysed the impact of wetland distribution on stream water quality, while Shi et al. [18] investigated the influence of land use/cover patterns on seasonal water quality. Salazar et al. [19] provided a review of the regional climate impacts of land use/cover in the non-Amazonian South America area as a consequence of modifications in the water balance and energy budget.

Worldwide, numerous studies have focused on the assessment of the impacts of land use change on coastal modifications. Recently, the effect of land use change on the coastal vulnerability to saltwater intrusion was investigated by Bhattachan et al. [20]. In their study, the authors analysed how the increase in artificial drainage infrastructure (canals, ditches, and drains) occurring in the last century along a coastal landscape in North Carolina as a result of drainage activities affected local coastal ecosystems. Another direct consequence of coastal land use change is represented by the modification of shoreline dynamics [21] and the increase in shoreline retreat, which is mainly due to the reduction in sediment transportation to the coast, land subsidence, and the destruction of the natural coastal environments [22].

Most of the studies addressing the issue of land use change in coastal areas have evaluated such modifications in terms of land reclamation, which is the conversion of the sea or coastal wetlands into agriculture, urban, or industrial districts [23–30]. Land reclamation also includes the creation of new land near the sea or enclosing tidal flats, thus representing one of the most significant stressors on coastal ecosystems [31–33]. In fact, throughout history, people have settled in coastal zones due to the presence of natural resources, easy transport and trade, and better defence opportunities. In relation to the rapid population growth and high populations living in coastal areas, coastal systems reach very high population density values; in this context, land reclamation is often a solution to provide new space and counteract erosion [34,35]. According to numerous studies and official publications, China is the country with the most reclaimed land, with ca. 13,000 km^2 [36]. It is followed by the Netherlands, with 7000 km^2, and South Korea with 1550 km^2.

Such analyses have remarkable importance both in the current management of the coastal systems and in light of future impacts of rising temperatures and expected sea level change. In addition, several studies focused on the assessment of coastal response to land reclamation activities with the purpose of identifying sustainable land use planning strategies and enhancing coastal resilience [26,37,38].

In order to allow the comparison between historical and present-day settings, this research aimed to define a set of land use categories for both areal and linear landforms. The identification of macro-categories useful for the long-term land use change analysis is based on the following phases: firstly, the legends available in the historical cartographical products are taken into account, and then the CORINE Land Cover categories are used to include the most recent classification.

In previous work dealing with the multitemporal analysis of land use change, few categories useful for multitemporal analysis are defined; however, generally, they are all-encompassing, and therefore some details of land use are lost. Thus, this study aims to provide a set of macro-categories that allows both highly detailed land use classification and applicability to historical and current periods. Furthermore, in order to provide a qualitative assessment of the potential coastal resilience to land use modifications, the shoreline displacement trend is proposed as a morpho-dynamic indicator.

Coastal retreat occurs when beach sediments decrease due to natural and anthropogenic causes [39]. Nevertheless, land use changes do not necessarily result in shoreline regression. A positive balance in sediment yield can be caused by the degradation of the upper- and mid-reaches of the river basins, brought about by land use change [40]. Therefore, based on the total sediment budget, coastal areas can respond to inland modifications by prograding. For this reason, in order to analyse the potential capacity of the investigated coastal stretch to cope with factors that may lead to a reduction in the sediment budget, the temporal evolution of the shoreline position was related to the main land use changes that occurred since 1869.

The paper is structured as follows: in the first section, an overview of the general morpho-evolutive trend of the Tavoliere di Puglia is illustrated; in the second section, the methods used to evaluate the land use change as well as the shoreline displacements from 1869 up to the present day are described; in the third section, the results of each analysis are presented; and finally, the obtained data are discussed and used to propose a qualitative assessment of the coastal resilience in terms of response to land reclamation activities. In the discussion section, we focus on the main anthropogenic factors that enhanced the local land use change. For this reason, a detailed discussion on the "filled polder" creation is proposed.

2. Study Area

From the geo-morphological point of view, the study area represents the coastal portion of the Tavoliere di Puglia Plain, the second-largest plain in Italy (Figure 1). Tavoliere di Puglia is an alluvial plain mainly composed of Pleistocene–Holocene alluvial and marine deposits [41–43], which are diffused in the whole Apulia region as a consequence of the combination between eustatic oscillations and regional uplift in the Middle-Late Pleistocene [44–46]. The Manfredonia Gulf is the offshore continuation of the Tavoliere di Puglia Plain and is characterised by a very gently sloping sea bottom toward the east, interrupted by incised valleys dating back to the last glacial period [44,47–49].

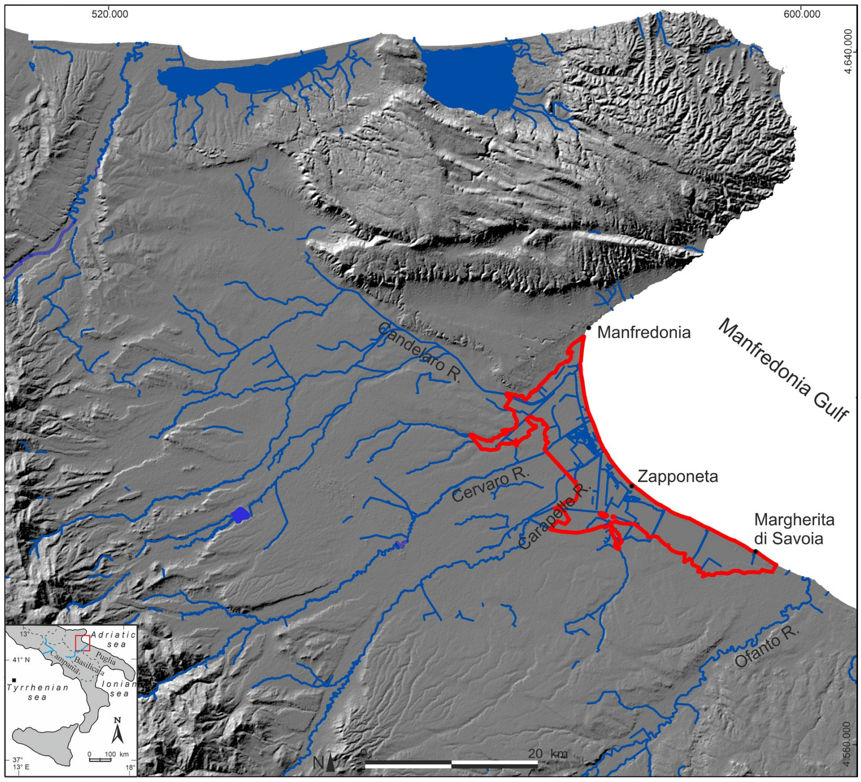

Figure 1. Study area location. The red line identifies the boundary of the investigated area, corresponding to the area strongly affected by land reclamation and drainage activities since the beginning of the XIX century (Digital Elevation Model from TINITALY [50]).

In detail, during the Holocene, the area was characterised by the presence of a wide lagoon (Salpi lagoon) extended from the Gargano Promontory to the Ofanto river [51–54]. During the Roman period, as a consequence of the deposition of alluvial sediments delivered by the Carapelle river, the lagoon was divided into two smaller lakes [55,56]: a larger one to the south (Salpi Lake) and a smaller one to the north (Salso Lake). Few data allowed the reconstruction of the conditions of the two lakes during the following Middle Ages. This geomorphological asset, identifiable in the historical cartography from the XVI century onwards, remained more or less unchanged until the XVII century and the first two decades of the XIX century [53,57] (Figure 2), limiting the availability of agricultural land and making the area unhealthy.

Later, the area underwent extensive hydraulic drainage and land reclamation work. In fact, the history of reclamation in the Tavoliere area began with the Regno di Napoli (1806–1815), ruled by Giuseppe Bonaparte. A strong transformation of the territory was due to the entry into force of the law of the 2nd August 1806, which abolished the feudal and ecclesiastical system with the consequent division of the land ownerships to the settlers and thus opened the way for the reclamation of marshy areas. In 1807, Giuseppe Bonaparte allocated between 17% and 25% of the state revenues to carry out the first land reclamation work in the Regno di Napoli [58]. The first extensive drainage and reclaiming interventions occurred during the Regno delle due Sicilie (1815–1861) ruled by Borbone and then they continued even later with the establishment of the Regno d'Italia (1861) when the management passed to the Genio Civile del Regno d'Italia. Land reclamation became more intense in the XX century when many extensive works began after the implementation of several land management laws and projects (e.g., the Serpieri–Iandolo law, 1933; the Project for Agrarian Transformation, 1938; and the Project for Land Transformation, 1948). Since 1934, the reclamation work was continued by the Capitanata Land Reclamation Consortium. The investigated area coincides with the area that was interested, since the XIX century, by the most extensive reclamation and hydraulic drainage work (Figure 1).

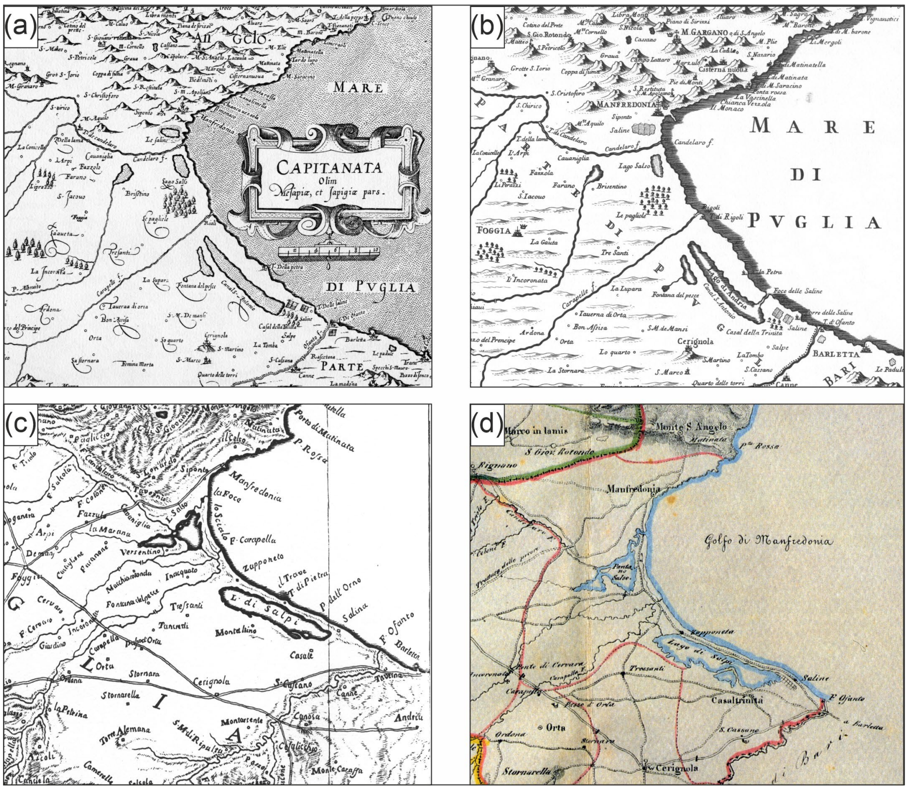

Figure 2. Coastal area of Tavoliere di Puglia plain as represented in the main cartographical products available for the XVII and XX centuries. (**a**) Magini, 1620 [59], (**b**) De Rossi, 1714 [60], (**c**) Rosati, 1787 [61]; (**d**) Marzolla, 1832 [62].

3. Materials and Methods

The objective of this study is to propose a GIS-based procedure to assess land use modifications in highly reclaimed coastal areas based on the quantitative comparison between historical and current land uses. The fundamental basis for this type of analysis is the definition of land use macro-categories recognisable both in the historical maps and in the current land use/cover products (i.e., maps, satellite images), which, for the European territory, are generally based on the CORINE Land Cover (CLC) classification.

The definition of macro-categories based on this approach constitutes a replicable methodology of analysis in all situations where it is necessary to carry out an assessment of land use change over a time span ranging from periods covered only by historical cartography to modern times, for which high-resolution satellite data are available. In addition, in order to assess the potential coastal resilience to the impacts of the land reclamation and drainage works, the shoreline displacements that occurred in the study period are also evaluated. The flow chart shown in Figure 3 synthesises the applied methodological procedure. Details for each step of analysis are provided in the following subsections.

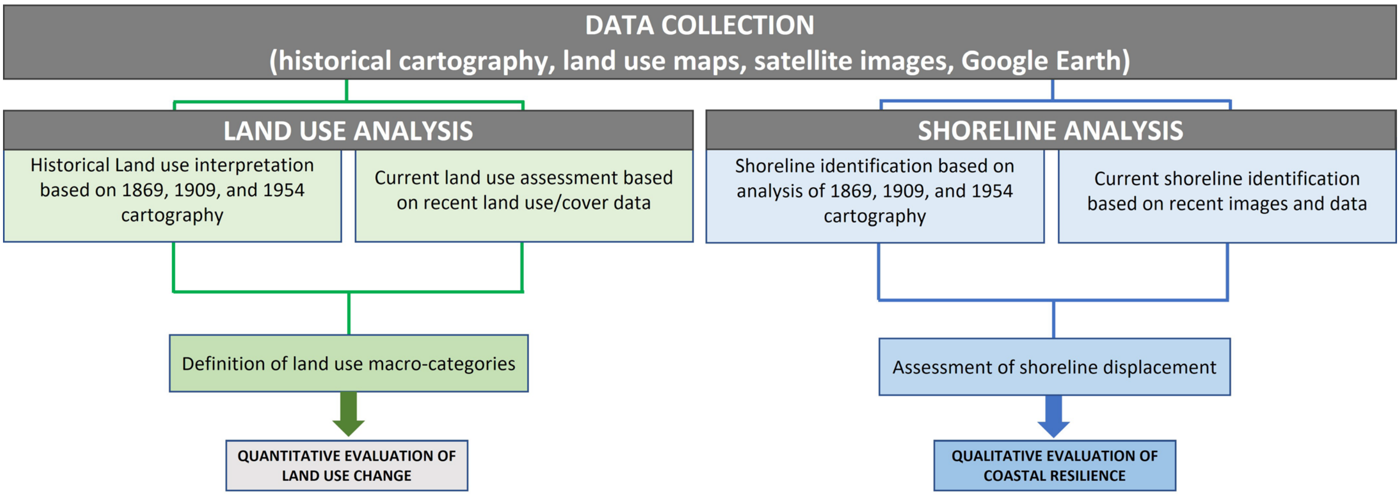

Figure 3. Methodological approach proposed for the quantitative assessment of land use change and the quality evaluation of potential coastal resilience.

3.1. Data Collection

Data collection can be considered a preparatory phase for both the quantitative analysis of land use variation and the quality evaluation of potential coastal resilience. The data to be collected include historical cartographical products, land use/cover maps, topographic maps, satellite images, and the use of web platforms such as Google Earth.

For the Italian territory, historical cartographical products (i.e., topographic maps) are provided by the Italian Military Geographic Institute. The data used in this study are indicated in Table 1. All of the available cartographic products have been imported in a GIS project and georeferenced in the WGS84/UTM zone 33N reference system.

Table 1. Cartographic products used for the definition of land use categories in the study area from 1869 to the present day.

Type	Year	Scale	Source
Topographic map	1869	1:50.000	Italian Military Geographic Institute
Topographic map	1909	1:50.000	Italian Military Geographic Institute
Topographic map	1954	1:25.000	Italian Military Geographic Institute
Land use/cover map	Present day	1:5.000	Regione Puglia

3.2. Land Use Analysis

Once all of the informative products available for the investigated area are collected, the land use categories are defined for each time period so that their surface can be compared and quantitative variations can be evaluated. To this end, the following methodological approach is proposed:

Step 1—Interpretation of the symbology of the historical maps and definition of a preliminary set of land use categories;

Step 2—Analysis of currently used land use categories;

Step 3—Proposal of a set of macro-categories useful for land use analysis encompassing both historical and current land use.

Concerning the identification of land use in the historical time (Step 1), the symbology included in the 1869 and 1909 maps was used as the main reference. Furthermore, in order to avoid misinterpretations and to reconstruct the vocation of an area for a certain land use typology, the 1954 aerial photos were also used, provided by the Italian Military Geographic Institute (IGM) in 1954/55 with a fly named "G.A.I.—Gruppo Aereo Rilevatore". With regard to the middle of the XX century, the legend included in the 1954 topographic maps was used as the main reference. Also in this case, the photointerpretation of the aerial photos supported the accurate classification of each land use typology. During the first phase of analysis, a set of preliminary categories was defined for the evaluation of land use in the years 1869, 1909, and 1954. These preliminary categories were used to classify each specific polygon created in the GIS environment. Concerning the current land use (Step 2), the available regional data were used (https://pugliacon.regione.puglia.it/web/sit-puglia-sit/uso-del-suolo#mains (accessed on 5 February 2023)). In this case, the CORINE Land Cover (CLC) classification was adopted. At the national level, the CLC classification defines three levels of detail for all categories and, for some categories, up to the fourth level (http://www.pcn.minambiente.it/viewer/; https://www.isprambiente.gov.it/files/legendacorine.pdf (accessed on 5 February 2023)).

In order to propose an easily replicable methodological procedure, a definitive set of macro-categories (Step 3) is proposed by integrating the categories previously defined to classify historical land uses with the CORINE classes. These macro-categories can be identified both in the historical and the present-day cartographies, allowing the interpretation and description of both historical and current land use and enabling their multitemporal analysis.

It is worth noting that in the older cartographic products, rivers, channels, canals, and embankments are represented and identified as lines. Nevertheless, according to the CORINE classification, natural and anthropogenic channels (i.e., rivers and canals) as well as embankments are defined as polygons. Therefore, in order to allow the evaluation of the variation in length through time, such polygons were converted into polylines. Also in this case, specific landforms categories were defined.

The variation, expressed as a percentage, of the surface occupied by each macro-categories was calculated and the main land use changes quantified. At the same time, the variation in length (expressed in km) of the linear features were also evaluated.

3.3. Shoreline Analysis

All of the available cartographic products were digitally processed in a GIS environment in order to identify a highly accurate representation of the shoreline position in 1869, 1909, and 1954. Furthermore, the present-day position was downloaded by the Apulian Regional web portal (http://www.sit.puglia.it/portal/portale_cartografie_tecniche_tematiche/Download/Cartografie (accessed on 5 February 2023)), with reference to the following dataset: Zapponeta (409), Torre Pietra (410), and Barletta (423), and referred to the year 2009.

The digitalised shorelines were subjected to comparison and geostatistical analysis through the application of the Digital Shoreline Analysis Tool (DSAS), an extension of ESRI ArcGIS software developed by the US Geological Survey [63,64]. The measurement locations and statistics of rate-of-change and measurement locations for the accounted time period were automatically calculated using transects with an interval of 100 m. The application allows the identification of erosion or accretion trends by evaluating the shoreline change envelope (SCE), which represents the greatest distance among all of the shorelines; the net shoreline movement (NSM), which represents the distance between the oldest and the youngest shorelines; and the end point rate (EPR), which is calculated by dividing the distance of the shoreline movement by the time elapsed between the oldest and the most recent shorelines. In this study, NSM values were used as a reference for the identification of sectors with homogeneous trends. To this end, NSM values were classified according to the range proposed in Table 2. Finally, the comparison between reclamation work carried out during the historical period and the shoreline dynamics was used as informative support for the assessment of potential coastal resilience.

Table 2. Defined ranges to classify the net shoreline movement values and to assess predominant shoreline evolutive trends.

	Retreat	Low Retreat	Equilibrium	Low Progradation	Progradation
NSM	>−10 m	−10–1 m	−1–1 m	1–10 m	>10 m

4. Results

4.1. Definition of Land Use Macro-Categories and Quantitative Land Use Change

The first phase of land use analysis was based on the study area classification, carried out by considering a preliminary set of macro-categories exclusively based on the legends included in the historical topographical maps. According to this classification, the recognised land use categories were those reported in Table 3 (“Preliminary land use categories”).

Table 3. Land use categories proposed for the land use classification. In column 1, the ID number is indicated; in column 2, the macro-categories proposed for the long-term comparison are indicated; in column 3, the categories defined by analysing the historical cartographic maps are listed; in column 4, the CORINE Land Cover codes indicated in national and regional repositories are reported.

ID	Land Use Macro-Categories	Preliminary Land Use Categories	CORINE Land Cover Codes
1	Arable land with or without scattered trees	Arable land; arable land with trees	2.1.1; 2.1.2; 2.1.1.2
2	Dune area and back-dune sandy shore, depression or inter-dune discontinuity, and beach	Dune area; back-dune sandbars; interdune depressions; beach	3.2.3; 3.3.1
3	Farmyard and agricultural production site	Farmyard; agricultural production site	1.2.1.6
4	Grassland, pasture, meadow, and shrubland with or without scattered trees	Grassland; pasture; meadow; shrubland; treed meadows; treed pastures	2.3.1; 3.2.1; 3.2.2; 3.3.3; 3.3.4; 3.2.4.1
5	Lagoon and estuary	-	5.2.1; 5.2.2
6	Lake	Lake	5.1.2; 5.1.2.1
7	Landfill	-	1.3.2; 1.3.2.1; 1.3.2.2
8	Marsh area and brackish area (wetland)	Marsh area	4.1.1; 4.2.1; 4.2.3
9	Olive and almond groves and/or other permanent crops	Olive and almond groves	2.2.4
10	Olive grove	Olive groves	2.2.3
11	Orchard	Orchard	2.2.2
12	Photovoltaic panel area and technical infrastructure in general	-	1.2.2; 1.2.2.5
13	Quarry	Sandy quarry	1.3.2; 1.3.2.1; 1.3.2.2
14	Reservoir and reservoir for irrigation purpose	Reservoir	5.1.2; 5.1.2.2
15	Rice field	Rice field	2.1.3
16	Saltwork	Saltwork	4.2.2
17	Urban area, industrial area, commercial area, port area, construction site, and recreational area	Urban area	1.1.1; 1.1.2; 1.2.1; 1.2.3; 1.2.4; 1.3.3;1.4.1; 1.4.2; 1.1.1.1; 1.1.1.2; 1.1.1.3; 1.1.2.1; 1.1.2.2; 1.1.2.3; 1.2.1.1; 1.2.1.2; 1.2.1.4; 1.2.1.5; 1.2.1.7; 1.3.3.1; 1.4.2.1; 1.4.2.2; 1.4.2.3; 1.4.2.4
18	Vegetable gardens, complex plot cultivation systems, seasonally irrigated crops, and seasonally rotated crops	Vegetable gardens	2.4.1; 2.4.2; 2.1.1.1
19	Vineyard with or without scattered trees	Vineyard and treed vineyard	2.2.1
20	Woodland (coniferous)	Coniferous woodland	3.1.2
21	Woodland (deciduous) and exotic woodland	Eucalyptus forest	3.1.1; 3.1.1.7
22	Woodland (mixed)	-	3.1.3

Nevertheless, being based on macro-categories not available in the present-day European land use classification (CLC, 2018), this analysis is not suitable for the assessment of long-term land use trends. For this reason, in the second phase of the analysis, all of the available land use data (1869, 1909, 1954, present day) were reclassified based on the definitive set of macro-categories, which were proposed accounting for both historical and recent land use classifications. In this way, the long-term variation of each proposed macro-category from 1869 up to the present day could be evaluated. The list of definitive proposed macro-categories is reported in Table 3 ("Land use macro-categories", column 1). The results of this analysis are graphically reported in Figure 4 and synthesised in Figure 5.

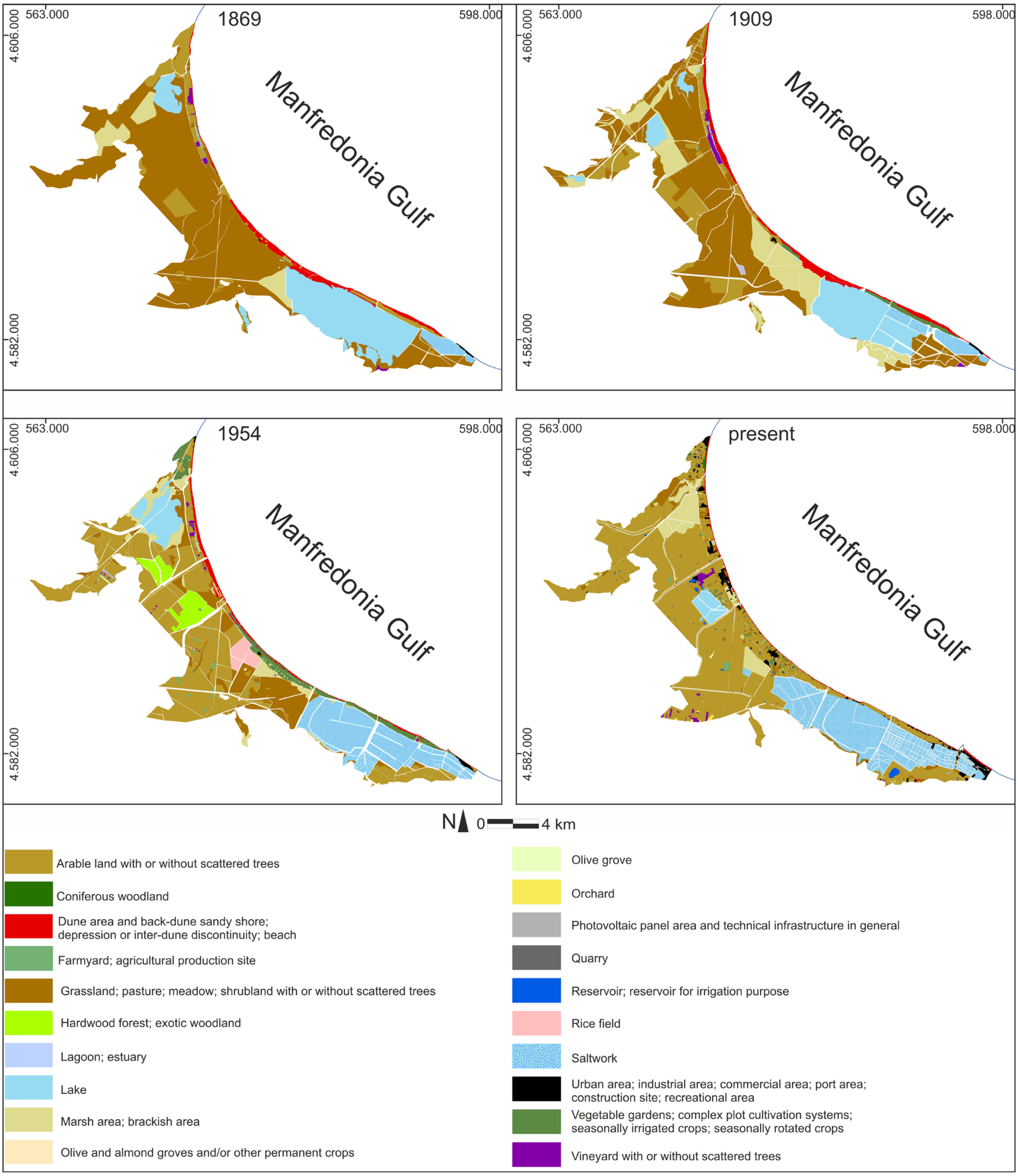

Figure 4. Spatial classification of the land use categories identified in the study area in 1869, 1909, 1954, and the present day.

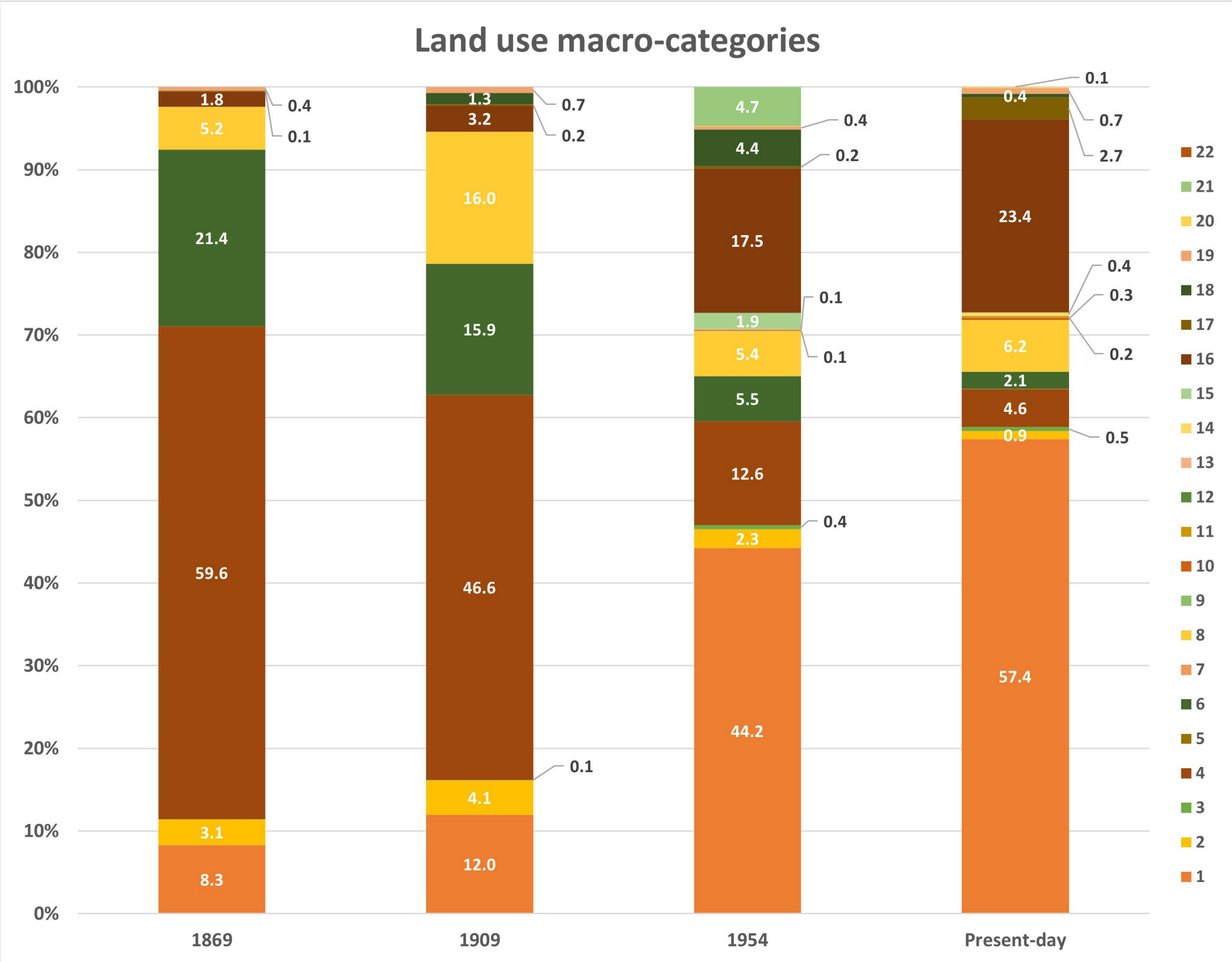

Figure 5. Land use categories are expressed as a percentage of the total investigated area in 1869, 1909, 1954, and present day. The numbers in the legend refer to the proposed land use macro-categories (cf. ID field in Table 3).

As a general trend, it is possible to observe a strong increase in the surface occupied by arable land that has risen from 1.6 km^2 in 1869 (8.3% of the total investigated surface) to 11.3 km^2 in the present day (57.4% of the total investigated surface), with a rate of 3.5 km^2/yr. Similarly, the surface occupied by urban areas, which include industrial, commercial, and recreational areas, ports and related facilities, and construction sites, increased from 0.1 km^2 in 1896 to 0.5 km^2 in the present day (approximately 3% of the total investigated surface), with a high increasing rate in the last decades (from 1954 to the present day). The third category that exhibited a strong increase is represented by saltwork; in this case, the total surface was 0.4 km^2 (1.4% of the total investigated surface) in 1869, 0.6 km^2 (3.2% of the total investigated surface) in 1909, 3.2 km^2 (17.5% of the total investigated surface) in 1954, and 4.6 km^2 (23.4% of the total investigated surface) in the present-day context.

In contrast, two macro-categories were characterised by a strong decreasing trend. In particular, the total surface occupied by grassland, pasture, meadow, and shrubland with or without scattered trees was 11.7 km^2 in 1869 (59.6% of the total investigated surface), 8.8 km^2 in 1909 (46.6% of the total investigated surface), 2.3 km^2 in 1954 (12.6% of the total investigated surface), and 0.9 km^2 in the present-day setting (4.6% of the total investigated surface). The second category affected by a general decreasing trend was represented by the coastal landforms (dune and back-dune areas, sandy shore; depression or inter-dune discontinuity areas, beaches). In this case, the surface occupied by coastal areas was

0.6 km^2 in 1869 (3.1% of the total investigated surface) and 0.2 km^2 to date (0.9% of the total investigated surface). The estimated decreasing trend is 0.2 km^2/yr. Finally, as expected, the surface of the lake strongly decreased. In fact, the lake surface occupied a total surface of 4.2 km^2 in 1869, while at present, it only occupies 0.4 km^2. In this case, a decreasing trend of 1.3 km^2/yr is observed. Finally, it is worth noting that some of the proposed macro-categories (e.g., technical infrastructure, including areas covered by photovoltaic panels) were not present in the historical time and for this reason, no variation trends could be evaluated. Nevertheless, the technical infrastructure macro-category represents only 0.007 km^2 of the current land use.

With regard to the modification of the landforms identified as linear features (embankments, main canals, secondary canals, and natural rivers), their evolutive trend is characterised by a strong increase in the total length of the "secondary canals" category (Figures 6 and 7). This category includes the network of minor, unbanked drainage canals that convey water into main canals. In 1869, the length of the secondary canals within the study area was 45.5 km, while the total length is now 575 km in the present day. In contrast, the length of natural rivers reduced from 43.5 km (in 1869) to 8.5 km (present day). The category "main canals" includes: (i) large, embanked drainage canals built ex novo, (ii) canals resulting from the transformation (by means of rectification of the watercourse, always accompanied by the construction of embankments) of stream proximal sections running through the study area (Candelaro, Cervaro, and Carapelle), and (iii) derivative canals, i.e., canals branching off from the main streams.

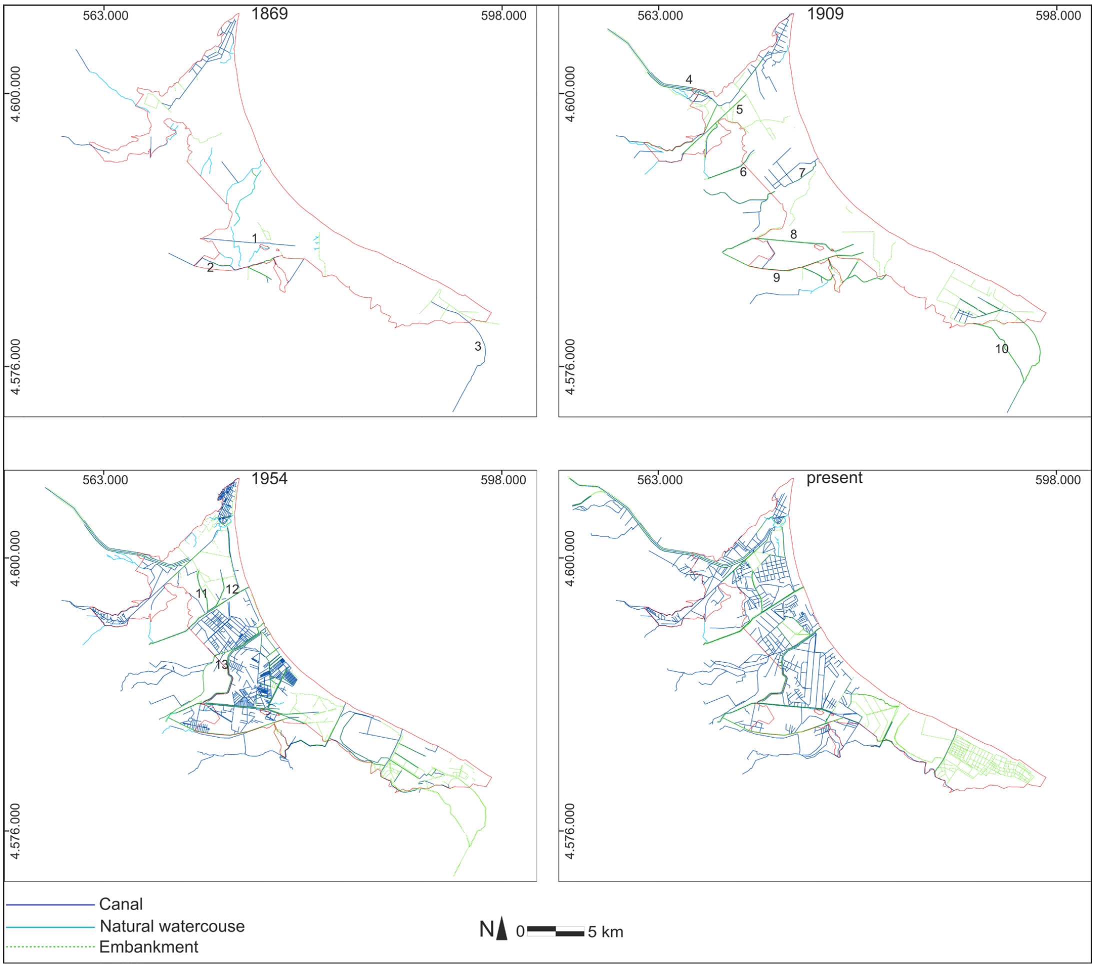

Figure 6. Evolution of the linear landforms functional to the reclamation of the study area in 1869, 1909, 1954, and the present day. The identified linear landforms are classified into four categories: embankments, main channels, natural rivers, and secondary channels.

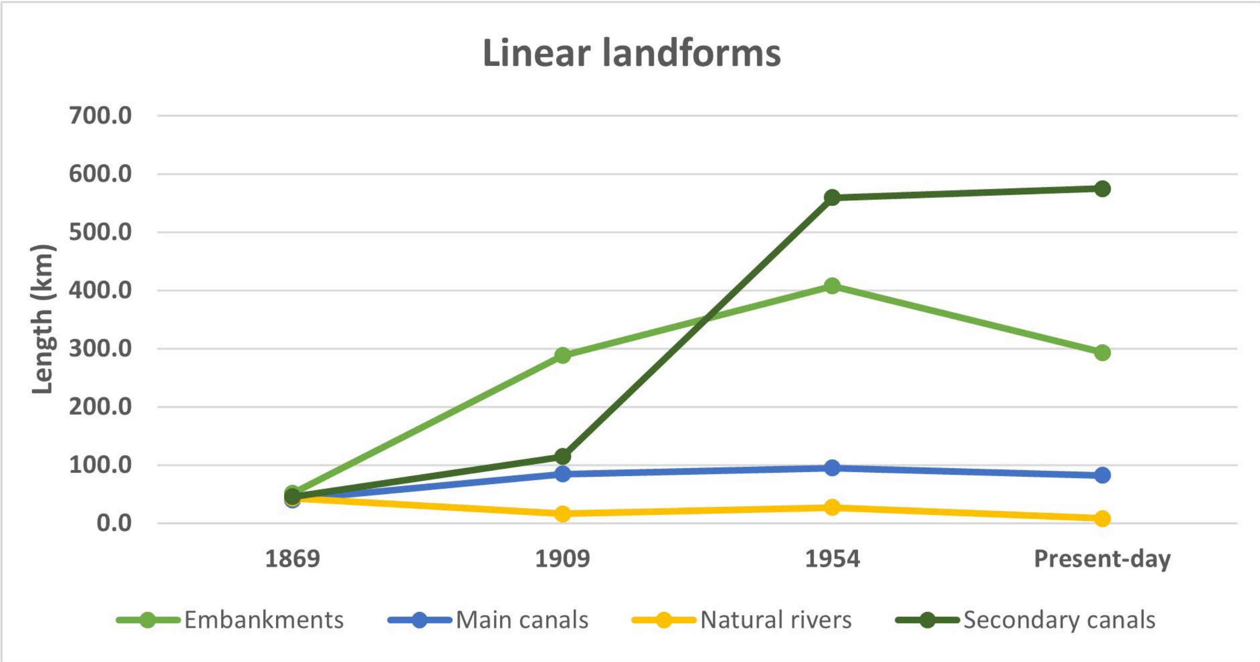

Figure 7. Evolutive trend of the linear landforms identified in the study area.

It is worth noting that the variation in the length of the waterways included in the category "main canals" has shown a non-uniform trend, being characterised by a strong increase from 1869 to 1909, with the total length almost doubling (from 40 km to 85 km). Then, from 1909 to the present day, the length remained almost stable, with a slight increase occurring between 1909 and 1954.

Finally, the length of the landforms included in the "embankments" category increased from 1869 to 1954 and then decreased over recent decades. In the 1869 map, the total embankment length was approximately 50 km, and now it is approximately 295 km (almost similar to the length in 1909). Nevertheless, the maximum length (approximately 410 km) was reached in 1954.

4.2. Assessment of Shoreline Displacements and Qualitative Analysis of Coastal Resilience

The evaluation of the shoreline displacements along the coast of the study area was carried out by considering the change in the shoreline position over the study period. The NSM was considered the most suitable indicator, since it evaluates the distance between the studied shorelines. In detail, considering the period 1869–1909, the mean value calculated for the entire investigated coastal sector was 10.5 m. The maximum and minimum values were 263.7 m and −75.7 m, respectively. Accounting for the period 1909–1954, the mean value calculated for the entire investigated coastal sector was 7.1 m, and the maximum and minimum NSM values were 270.2 m and −422.2 m, respectively. Concerning the last decades, the mean, maximum, and minimum NSM values evaluated for the period 1954–2010 were 27.3 m, 175.5 m, and −558.2 m, respectively.

From these results, it is clear that since 1954, the shoreline of the investigated area has undergone a very strong retreat. In fact, despite the average and the maximum progradation values being almost similar during the investigated periods, the retreat values are significantly higher for the most recent period.

In order to define potential coastal resilience in a qualitative way, coastal stretches with homogeneous shoreline evolutive trends were identified along the investigated sector (Figure 8). The values reported in Table 2 were used to identify predominant trends. In detail, in the period 1869–1909, coastal stretches characterised by a general retreat were mainly located in the central and southernmost part of the investigated area (Figure 8a). Considering the period 1909–1954, the retreat process characterised the central part of the study area; furthermore, a retreat focus was also located in the northern part (Figure 8b). Finally, in the last time period (from 1954 to the present day), the coastal stretches characterised by the retreat process increased, with only a few exceptions for the areas south of Margherita di Savoia city and north of Ippocampo village (Figure 8c).

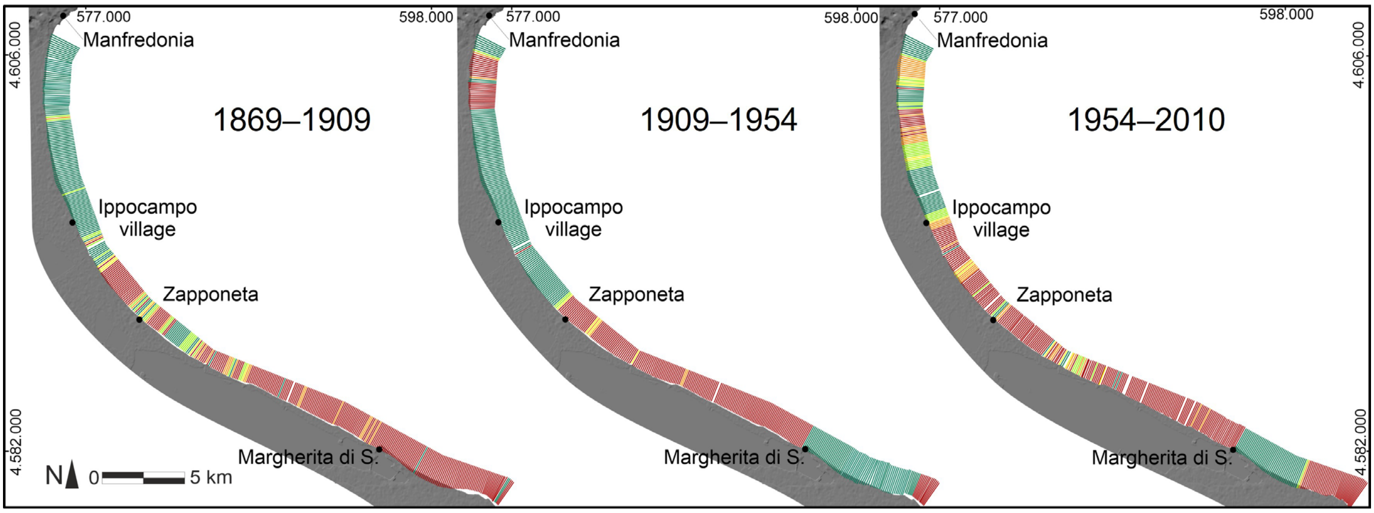

Figure 8. Shoreline trends evaluated for the investigated coastal sector for the period 1869–1909, 1909–1954, and 1954–2010. The colours refer to the classes proposed in Table 2: light green: low progradation; green: progradation; yellow: equilibrium; orange: low retreat; red: retreat (see Table 2).

5. Discussion

5.1. Land Use Change

The land use change analysis showed a fairly clear trend in the evolution of land use from 1869 to the present day. In general, the most important changes consist of a decrease in the areas occupied by grassland, pasture, natural lakes, and marshes (and wetlands in general) and an increase in the areas occupied by arable land and salt marshes (Figures 4 and 5). This transformation was mainly caused by intensive land reclamation activities, which deeply transformed the landscape. The wide areas of the ancient Salso and Salpi coastal lakes and the surrounding marshes and wetlands were removed, allowing the development of cereal crops (barley and wheat) in their place. This transformation occurred simultaneously with the decrease in the practice of pastoralism in favour of agriculture, a trend that affected the whole of Italy from the latter part of the XIX century [65]. In the case of Salpi lake, the landscape modification work involved the transformation of the entire remaining part of the lake not affected by the land reclamation into saltworks. In fact, to date, there is not even a residual portion of the ancient Salpi lake that has remained in its natural state. These reclamation works consisted mainly of the construction of the so-called "filled polders" (cf. Section 5.1.1). The increase in reclamation work and the change in land use have led to an increase in the length of canals and embankments (Figures 6 and 7). In particular, the main canals were built to: (i) collect water drained by a dense network of minor drainage canals, facilitating the outflow of excess surface water, (ii) transform the streams themselves into canals that fill the polders, preventing the dispersion of turbid load during floods; once the polders were filled, the canals were brought to the next polder or directly to the sea, and (iii) divert into polders part of the turbid load of rivers and streams that flow within the study area (Candelaro, Cervaro, Carapelle) or that pass close to it (Ofanto).

The main canals built in the study area are:

(1) Nuovo Carapellotto and Carapella (1, 2 in Figure 6), subsequently modified and renamed Regina and Carapellotto, respectively (8, 9 in Figure 6), which for a certain period of time diverted part of the turbid load of the Carapelle stream to fill the north-western parts of Salpi lake, which had been divided into polders by the construction of embankments;

(2) Contro Ofantino (3 in Figure 6), which for a certain period of time diverted part of the turbid load of the Ofanto river to fill the south-eastern parts of Salpi lake, which had been divided into a first set of polders by the construction of embankments;

(3) The channelled sections of the Candelaro and Cervaro streams (4, 6 in Figure 6), built to convey all of their turbid load into the polders set up in marshes and wetlands surrounding Salso lake;

(4) Contessa and Peluso (5, 7 in Figure 6), two of the main collectors of water drained by a wide network of small secondary drainage canals in the area of the former Versentino marsh (the westernmost in the study area) and in the area between the Salpi and Salso lakes, respectively;

(5) Nuovo derivativo Ofantino (10 in Figure 6), built to divert part of the turbid load of the Ofantto river, in order to fill new sectors in the south-eastern part of Salpi lake, which had been divided into new polders by the construction of embankments;

(6) Roncone and Salinetri (11 and 12 in Figure 6), which diverted part of the turbid load of the Cervaro stream at different times in order to fill part of Salso lake;

(7) The channelled section of the terminal course of the Carapelle stream (13 in Figure 6), which was built to prevent floods on the plain.

Almost all of the terminal sections of the streams that cross the part of the Tavoliere di Puglia plain facing the Manfredonia Gulf (Candelaro, Cervaro, and Carapelle) have been transformed into artificial canals by rectifying the watercourse, generally accompanied by the construction of embankments. Other canals, main and secondary, were built ex novo. In addition to delimiting the main canals, embankments were also built to delimit the basins of the Margherita di Savoia saltworks or to construct the aforementioned filled polders.

This kind of strong anthropogenic intervention in a lowland coastal plain certainly will involve some consequences in the near future in light of predicted sea-level rise. In fact, the coastal sector of the Tavoliere di Puglia plain is expected to be strongly affected by the sea-level rise that is occurring as a consequence of global warming [54,57]. The substitution of natural environments (wetlands and marshes) with arable land is already posing problems, and these will only increase further in the future when managing the entire coastal sector of the Tavoliere di Puglia Plain.

While marshes and wetlands are generally resilient, at least to a certain extent, allowing the coastline to cushion and adapt to rising sea levels, the same cannot be said for anthropogenic structures such as cultivated land or saltworks. Currently, local administrations are attempting to tackle the problem of marine erosion in the study area through the construction of adherent barriers, groins, and breakwaters that currently affect, without interruption, approximately 22 of the total 37 km of coastline in the study area.

These works are built based on short-term management strategies to try to prevent the loss of cultivated land and infrastructure due to erosion as quickly as possible. However, very often, their effectiveness proves to be ephemeral, and they must be continually rebuilt for different coastal stretches. It is evident that it is necessary to develop more long-term management policies for the area to mitigate the anthropogenic changes that have taken place in the study area.

5.1.1. Land reclamation by Means of "Filled Polders" Structures

Land reclamation (International Association of Dredging Companies; IADC; https://www.iadc-dredging.com (accessed on 5 February 2023)) is the process of creating new land using the following strategies:

(1) Pumping water out of muddy land or marshes (poldering). The area is enclosed by dykes;

(2) Raising the elevation of a seabed or riverbed or low-lying land. Raising the elevation can generally be achieved by dry earth movement or hydraulic fill.

As a result of land reclamation, natural habitats (e.g., marshes and mudflats) are rapidly being replaced by artificial "habitats" [66–68], with the consequent loss of valuable ecosystems. It is estimated that by the year 2030, up to 12.5 million km^2 of natural habitat will potentially have been replaced by artificial habitats [69,70].

In the study area, the main type of reclamation work has been carried out by filling marshes and wetlands through turbid load discharged by streams or artificial canals into 'filled polders'. The polder construction is discussed here as this represents the main anthropogenic factor through which local land use changes have occurred. In other words, the assessed land use changes in the study area are a consequence of polder construction. The chronology of this type of construction work can be reconstructed fairly faithfully both from the interpretation of historical cartography (cf. Section 3) and from direct and indirect historical sources. Among the direct historical sources, the most important are the works of Pecorari (1784) [71], Giustiniani (1805) [72], Manicone (1806) [73], and De Angelis (1830) [74].

Among the indirect historical sources, the most important are Pascale (1912) [75], Ciasca (1928) [65], Rotella (1984) [76], Russo (1987) [77], Di Benedetto (1988) [58], and Caldara and Pennetta [53].

The main areas subjected to land reclamation by filling were:

(1) The whole area around Salso lake;

(2) The north-west part of Salpi lake;

(3) The south-eastern part of Salpi.

This particular technique of land reclamation by filled polders, although falling within the general definition of land reclamation, has so far no been mentioned in any detail in the scientific literature; several examples of land reclamation were conducted with methods comparable to those used in the coastal areas of the Tavoliere di Puglia plain, but not equal.

For example, in the Encyclopaedia Britannica (https://www.britannica.com/science/land-reclamation (accessed on 5 February 2023)), the following land reclamation method of the coastal areas is described: "Where offshore lands or tidal marshes are covered by shallow water and additional land is critically needed, the land can be reclaimed by the construction of dikes roughly parallel to the shoreline, followed by drainage of the area between the dikes and the natural coastline. Where a sediment-laden stream can be diverted into the area between the dikes and the shoreline, the sediment from the stream may be used to build the diked-off land to a higher level, thus facilitating the drainage operation".

Another similar example comes from Bangladesh [78], where its south-western region has been seriously affected by perennial waterlogging over the last few decades. It is primarily due to excessive riverbed siltation outside the polders after the construction of embankments along both sides of the tidal rivers. These embankments restricted a gradual process of natural deposition inside the polders. Temporary de-poldering (embankment cuts) at designated locations has substantially solved these issues. The temporary restoration of tidal flooding by de-poldering is based on the idea of allowing high tides to bring muddy water flow with a thick concentration of sediment into a designated tidal basin and releasing the tidal flow back into the river during the low tides. During the repetitive process of such tidal restoration, a large amount of sediment deposits into the polders, which otherwise would deposit in the river channel if there were no de-poldering.

The procedures for filling marshes, wetlands, or lakes through the construction of "filled polders" can be divided into the following steps (Figure 9):

(1) The delimitation of a part of the lacustrine, marshes, and wetlands area to be reclaimed by means of an earth embankment, equipped with at least two openings made in the upper part of the embankment: one for the inflow of water and sediment, and the other for the discharge of excess water (of the "overflow" type);

(2) The construction of a canal to divert part of the turbid load of a stream or river up to the polder, or the total diversion of a stream through its canalisation until the polder. If the stream already flows naturally into an area to be reclaimed, it is limited to channelling the last stretch of the stream before its outlet;

(3) The filling of the polder by the sediments transported there by the canal. In this phase, a small delta may be formed at the point where the stream or the canal discharges the sediments into the polder (Figure 10);

(4) Once the backfill has been obtained, the canal or the stream itself is extended towards the next polder by excavating and embanking the new course within the previously filled polder.

In the study area, the process of filling the basins has always involved raising the ground level to at least 1.5 m above sea level. This has been conducted to ensure water flow and prevent salt rising, which would make the land unusable for agricultural purposes. To achieve this, the filling process generally lasted from a few years up to 15–20 years [76], depending on the size of the basins and the regime of the watercourses used to fill the basins. Along with the filling, another strategy widely applied in the polders for improving the reclamation was the extensive afforestation with Eucalyptus, an exotic tree that absorbs a lot of water from the ground, which kept the surface water table low. For this reason, in the "Preliminary land use categories" (column 2 of Table 3), the Eucalyptus forest has been recognised.

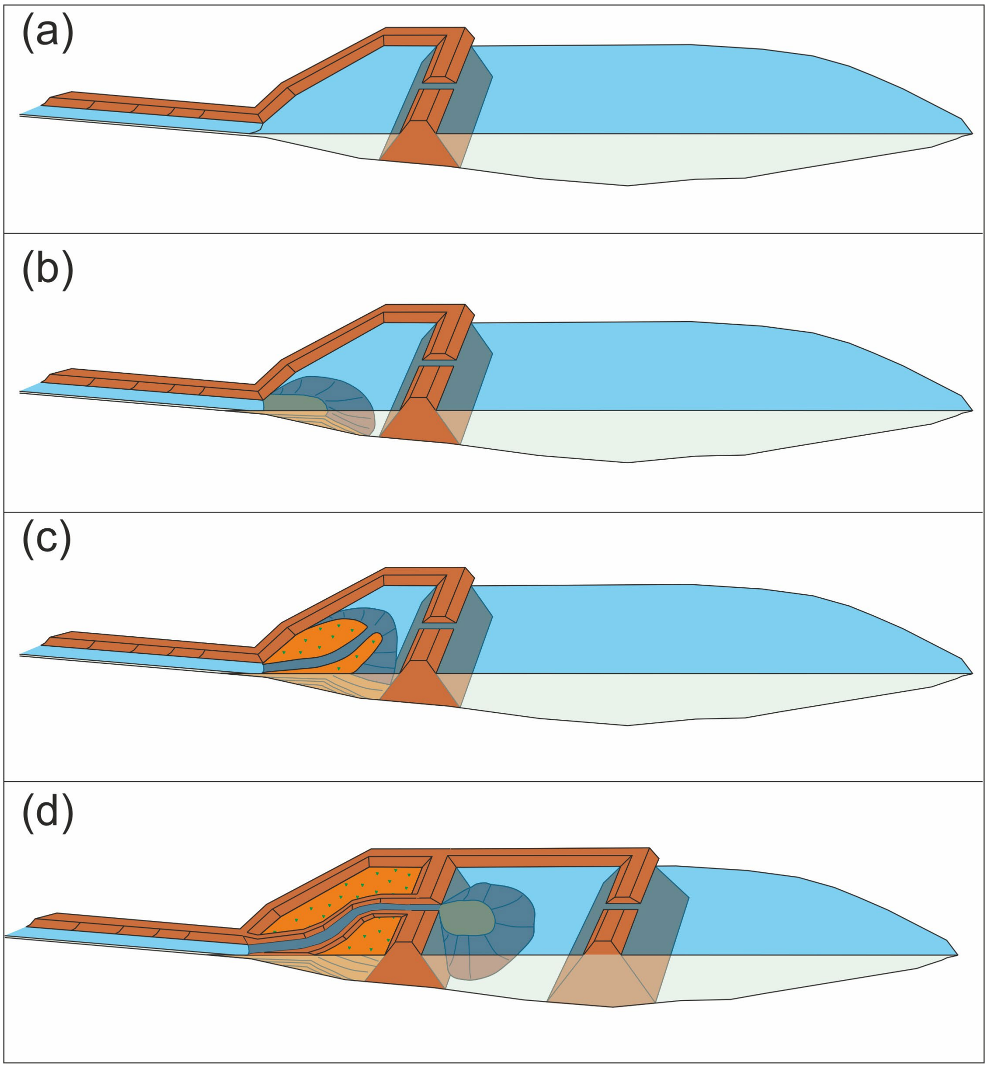

Figure 9. Schematic diagram of the process of the functioning of a filled polder: (**a**) delimitation with an embankment of a part of the area to be reclaimed (creation of a backfill basin), into which a natural stream or an artificial canal flows; (**b**,**c**) filling phase of the polder: the sediment transported by the stream or canal is deposited in the basin, and the water escapes from the basin through an 'overflow' type opening; (**d**) once the basin is filled, a new stretch of the canal is created within it and the filling of the next polder, built in the meantime, starts.

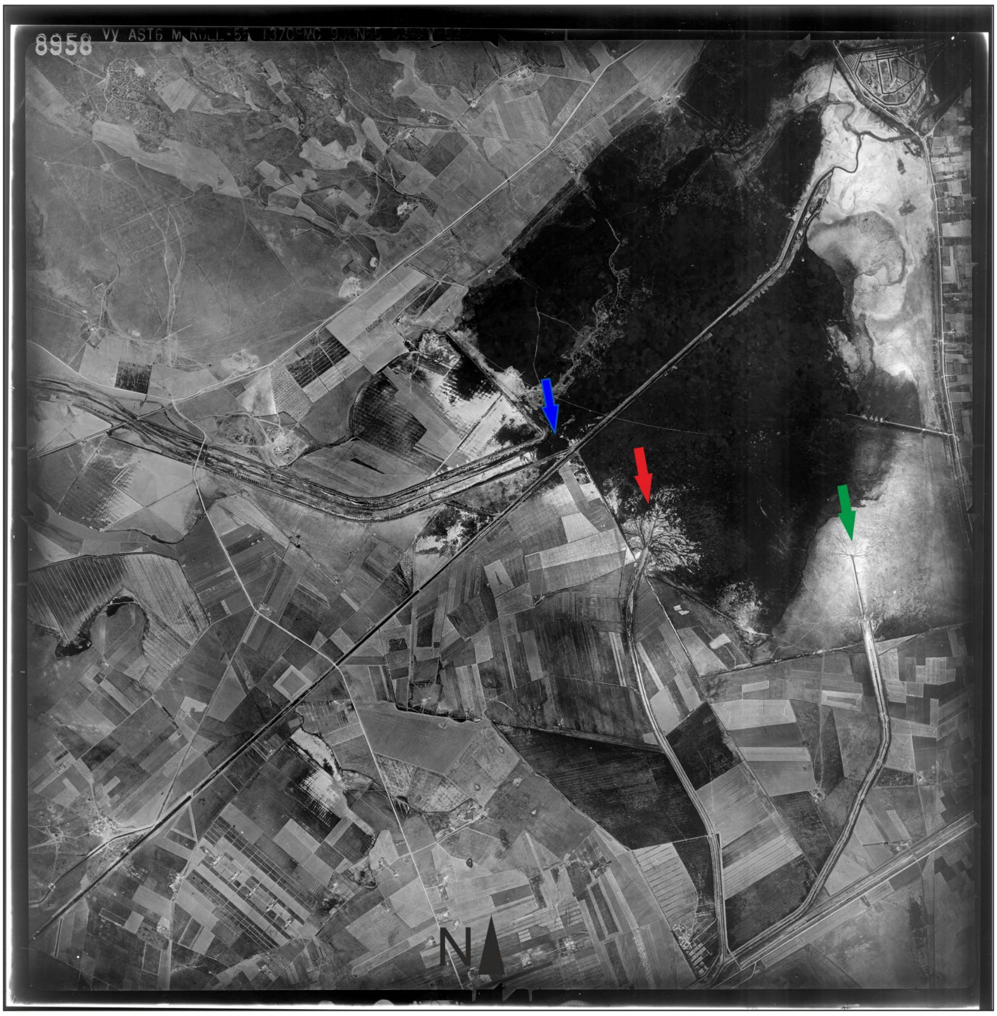

Figure 10. Aerial photo from 1954 (sheet 164, swath 138, photography 8958; aerial photo of Istituto Geografico Militare; licence number 7156 of 15 March 2023; www.igmi.org (accessed on 5 February 2023) showing the filling of polders obtained by the compartmentalisation of the Salso lake by means of embankments. The filling is obtained by the canals Roncone del Cervaro and Salinetri (which diverted the turbid load by the Cervaro stream and are indicated by the red and the green arrows, respectively), and by the canalised section of the Candelaro stream (blue arrow). Note the deltas of sediment that the canals Roncone del Cervaro and Salinetri formed in the polder and how it was already partially filled in the southern and eastern edges. In 1960, the canals Roncone del Cervaro and Salinetris were decommissioned and the Salso lake landfill was terminated. Compare this figure with Figure 9b,c.

From the 1960s onwards, land reclamation activities by filling ended. This is due to three main reasons.

(1) The reduction of the turbid load of the Cervaro, Carapelle, and Candelaro streams and of the Ofanto river.

(2) Limited number of residual marshy areas that can potentially be filled.

(3) An increased sensibility towards the preservation of coastal wetlands.

It is no coincidence that land reclamation by filling was conceived and implemented mainly during the XIX century and the first half of the XX century; in fact, this phase of using the method of filling is a direct consequence of a broader period characterised by an increase in the flow rate of the streams and rivers that cross the study area, attained between the second half of the XVIII century and the 1950s. In fact, numerous flood events due to rivers and streams flowing into the coastal sector of the Tavoliere di Puglia are reported in the aforementioned period by direct [71,72,79] or indirect [80,81] historical sources. In addition, two construction phases of the Ofanto delta in the intervals 1808–1869 and 1911–1957 confirm the river's higher turbid flows [81].

Finally, beginning in the second half of the 1950s, thus during the last phase of the reclamation by filling polders, a dense network of drainage canals connected to hydropump systems was built to better drain superficial water. This system was integrated with the previously existing system of the drainage network canals, and its creation was also due to the increasingly evident effects of the subsidence in the area [82–84].

5.1.2. Turnings

Since the 1990s, the so-called "turning" agricultural practice has become widespread in the coastal sector of the Tavoliere di Puglia, and in particular in the areas of the filled polders (Figure 11). The sediments used for the landfills, mainly composed of silty-clayey material, have proved unsuitable for growing cereals as they are subject to water stagnation during the autumn and winter and tend to crack in the summer. The purpose of this agricultural practice is to make the polders more suitable for agricultural purposes; in fact, this practice makes the soils suitable for growing vegetables characterised by tubers that can expand well in the sandy sediment.

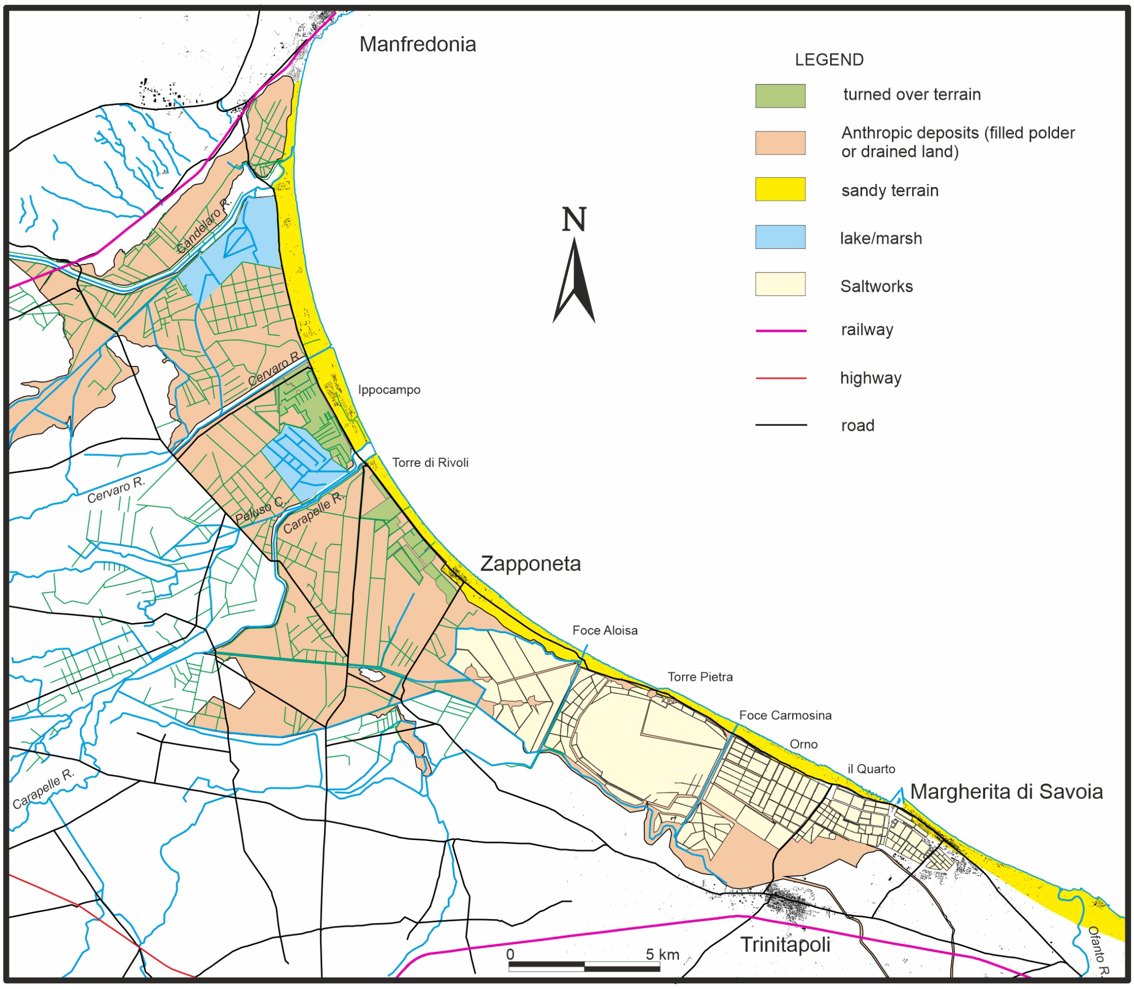

Figure 11. Coastal areas affected by the agricultural practice of "turning".

The agricultural practice of "turning" consisted of exhuming the underlying sandy soils and replacing them with the predominantly clayey deposits of the fill (Figure 12a). It consisted of four steps, as in Figure 12:

(1) The removal of the superficial layer of clayey fill deposits (anthropogenic deposits) (Figure 12b);
(2) The removal of a thickness of underlying sandy deposits (Figure 12b);
(3) The backfilling of the lower part of the excavation with a mixture of predominantly clay and clayey sand, obtained by mixing parts of the previous sediments (Figure 12c);
(4) The filling of the upper part of the excavation with a mixture of predominantly sandy clay and sand, obtained by mixing the remaining part of the previously removed clays and sands (Figure 12d).

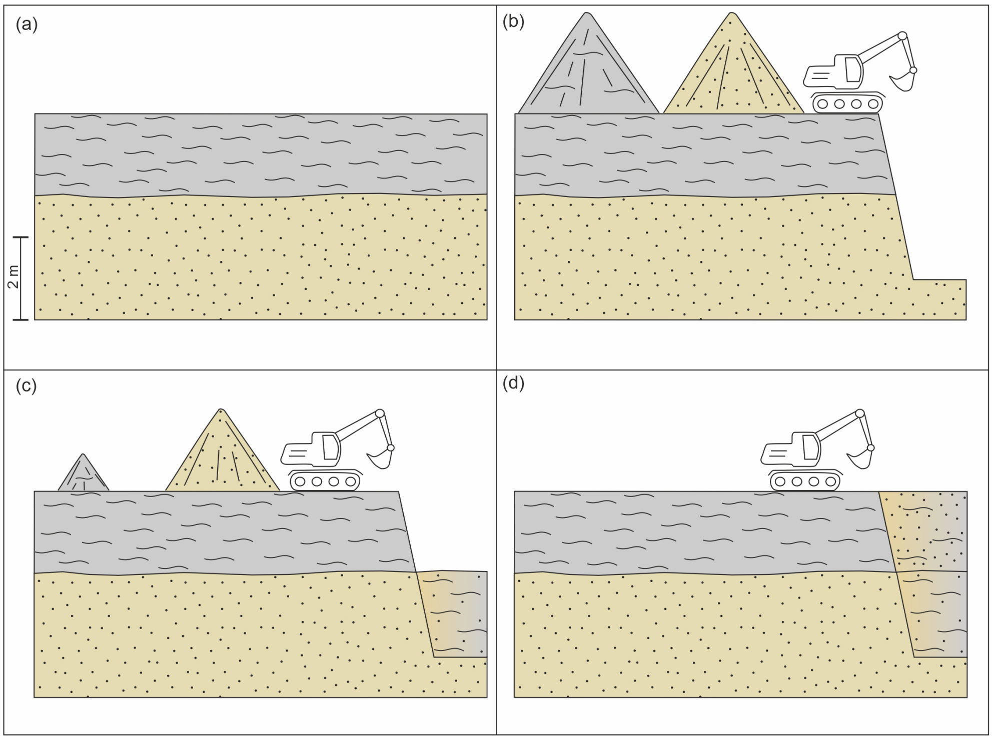

Figure 12. Outline of the stages of the agricultural practice of "turning". (**a**) sandy deposits to be replaced are shown in light brown while clayey deposits are shown in grey; (**b**) removal of the superficial layers; (**c**) the lower part of the excavation is filled with a mixture of predominantly clay and clayey sand; (**d**) the upper part of the excavation is filled with a mixture of predominantly sandy clay and sand.

All of these steps involve, on the whole, the first four metres below ground level.

The implementation of this kind of agricultural practice has enhanced the transformation of low-productivity land into very highly productive land and, as a consequence, the area has been characterised by a significant increase in employment rates.

Currently, from an agronomic point of view, the "turned lands" allow the production of high-quality vegetables with three harvests per year. Some of the products farmed in this area (such as potatoes, onions, and carrots) are included in the Traditional Italian Agrifood Product list. The white onion of Zapponeta also obtained the Protected Geographical Indication (PGI) mark in 2015.

5.2. Coastal Resilience

Some general trends emerge from the analysis of the evolution of the coastline. Besides the climatic reasons already analysed by De Santis et al. [81], these trends can also be explained by anthropogenic interventions, including land reclamation. Generally speaking, the south-central sector is the one that shows, overall, retreating trends, in contrast to the northern sector, which shows advancing trends overall. This background trend is the result of the littoral drift that, in the study area, goes from south-east to north-west [85].

In the first period analysed (1869–1909; Figure 8a), the southern sector appears to be in total retreat, while the central region, around Zapponeta, is mainly in retreat. This situation can be attributed mostly to the reduction in the terrigenous inputs of the Ofanto river, the main river in the Apulia region in terms of both flow and catchment area, due to the start of the operation of two canals: Contro Ofantino canal (for the first time), which became operational in 1843 [79,86] and was implemented in 1881 [77] (3 in Figure 6a), and Nuovo Derivativo Ofantino canal (for a second time), which became operational in 1898 [77] (10 in Figure 6a). Both canals diverted part of the Ofanto's turbid load to fill the polders in the south-eastern sector of Salpi lake.

On the other hand, the Carapelle stream was totally diverted by the Carapella and Nuovo Carapellotto canals during this period, which were completed around 1850 (1 and 3, respectively, in Figure 6a; [77]) and subsequently modified and renamed Carapellotto and Regina, respectively (8 and 9, respectively, in Figure 6b). The subtraction of turbid water by these two canals influenced the evolutionary trend of prevalent retreat in the central coastal stretch around Zapponeta, where the Carapelle stream flowed (and still flows).

In the second analysed period (1909–1954; Figure 8b), the most striking datum is that, although this was the period of greatest activity of the polder filling works, and therefore of the removal of sediment from the rivers and streams in the area, large coastal stretches of the study area appear to be advancing. The advancing stretch south of Margherita di Savoia is a consequence of the construction of the pier of the city's canal port (already present in the 1909 topographic map), with an accumulation of sand on the updrift side. However, this accumulation, as well as the advancement of almost the entire coastal stretch north of Zapponeta, is probably also justified by a resumption of the turbid load of the Ofanto, which also occurred due to the deactivation of the Contro Ofantino and Nuovo Derivativo Ofantino canals, in turn, due to the interruption of the infillings of the south-eastern part of the Salpi lake in 1927, when the area passed to the State Monopoly Administration [76]. For this reason, the two canals in the 1954 topographical map appear devoid of water (Figure 6c).

This resumption of the Ofanto's turbid load was probably one of the reasons why the advancement of large stretches of coastline occurred despite the fact that all of the other streams in the area (Candelaro, Cervaro, and Carapelle) were partially or totally diverted into polders at the same time.

In the third period analysed (1954–2010; Figure 8c), the most striking datum is a generalised increase in the number and extent of retreating stretches of the coastline. In contrast to the previous period, this period is characterised by the phasing out of land reclamation by means of filled polders. Theoretically, this should have resulted in a greater availability of sediment carried out to the sea by the rivers and streams in the area, yet the trend is of generalised retreat, with the exception of small advancing stretches, including the stretch south of Margherita di Savoia (still as an effect of accumulation on the updrift side of the city's canal port) and some areas north of the Ippocampo village, in response to the combined effect of the construction of coastal defence works and small local sand accumulation due to the littoral drift regime.

The analysis of the coastal response (in terms of shoreline dynamic and displacement) to land reclamation activities and, more generally, to past land use change can be considered an indirect tool for the evaluation of potential coastal resilience and of the factors that contribute to it. As emerged from the shoreline displacements evaluated in this study (c.f. Section 4.2), the investigated coastal sector has shown a general progradation trend during the period of maximum implementation of reclamation activities (1909–1954), as appears clearly, for example, from the sector near to the mouth of the Cervaro stream (Figure 13).

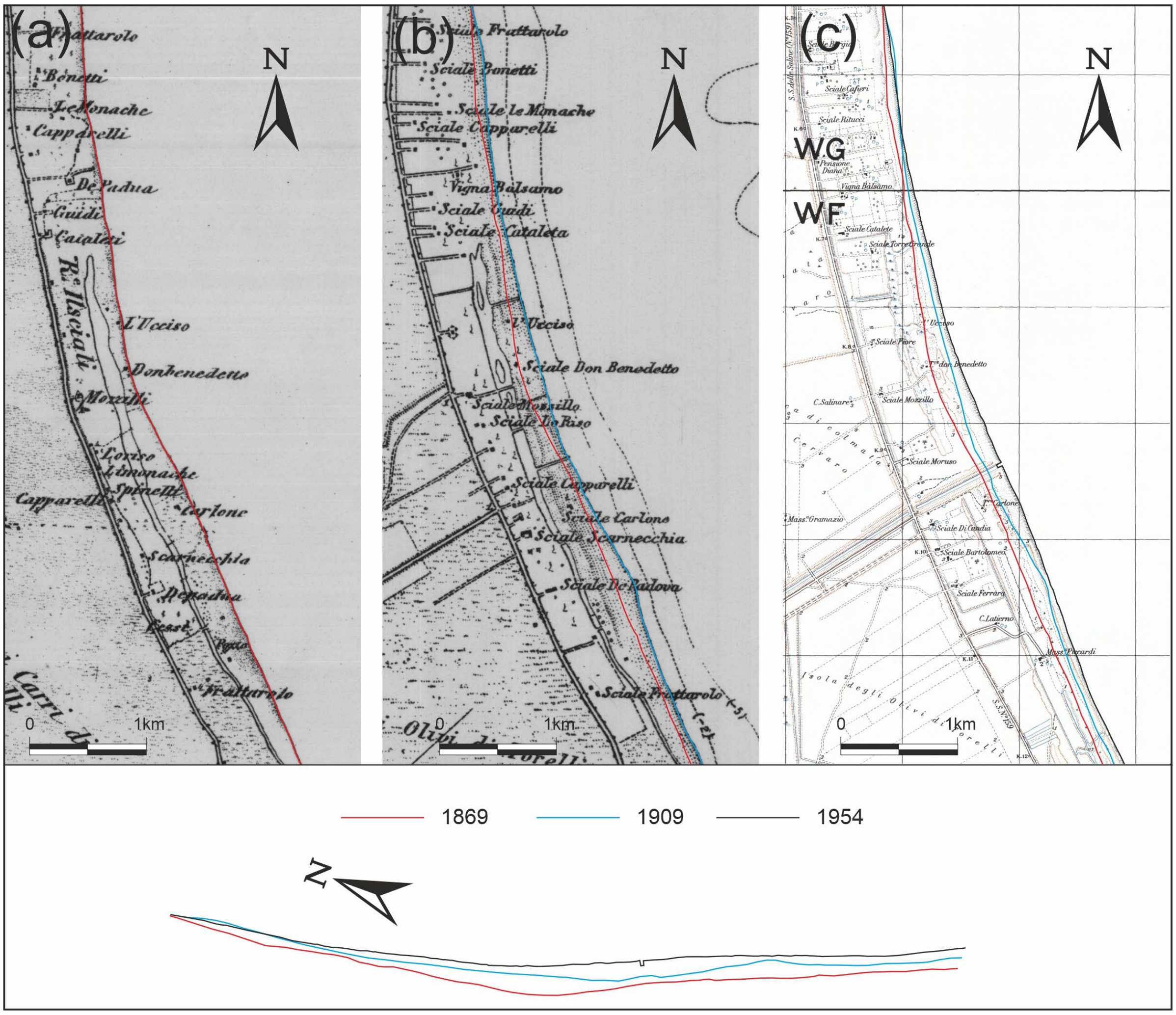

Figure 13. Shoreline displacement around the Cervaro stream mouth between 1869 and 1954, reconstructed based on topographic maps of (**a**) 1869, (**b**) 1909, and (**c**) 1954. Note that the Cervaro stream only flows to the sea in the 1954 topographic map, as previously it flowed more inland in the coastal marshes/polders around Salso lake. Maps from Istituto Geografico Militare (licence number 7156 of 15 March 2023; www.igmi.org (accessed on 5 February 2023).

This coastal system response can be considered an example of natural resilience due to the temporary increase in the sediment load of the Ofanto river, the main river of the Apulia region and the main feeder of the beaches of the Manfredonia Gulf. This temporary increase was, in turn, due to the deactivation of the two derivative canals which, in the previous period, diverted part of the turbid load of the Ofanto river. Thus, the availability of sediments carried by the Ofanto river mitigated the effects of sediment removal from other streams that flow into the investigated coastal section (Candelaro, Cervaro, and Carapelle).

Afterwards, although reclamation activities stopped, the coastal system was affected by a general retreat process (Figure 8) due to the construction of many dams throughout the Ofanto river basin [81], which started in the second half of the XX century and has drastically reduced the turbid load of this river.

These results indicate that the watercourse regulation activities can be considered one of the causes of sediment load reduction and, as a consequence, of the coastline retreat. The issue related to the reduction in sediment supply affects many of the Mediterranean rivers, resulting in severe effects on deltas and adjacent shorelines [38,87–90]. For this reason, recent studies and programmes have focused on the identification of tailored management strategies at both the catchment and the coastal scale to support the restoration of the rivers' sediment supply and the resilience of coastal systems and their adaptation to modifications induced by natural factors. This latter aspect is of paramount importance in a climate change context, since rising sea levels are expected to gradually flood coastal low-lying areas [83,91–93] unless enough sediment is supplied to compensate for the sea ingression [94].

6. Conclusions

In this study, a methodological procedure for the evaluation of land use change from the historical period to the present day is proposed. In detail, a set of twenty-two macro-categories was defined by taking into account both the legends available on the historical cartographical maps and the recent CORINE Land Cover classes. The study area is represented by a wide coastal sector in southern Italy (the Tavoliere di Puglia area in the Apulia region). Since the beginning of the XX century, the area has been subjected to strong land reclamation activities, which have led to drastic land use modifications. In particular, the results highlighted a strong increase in the surface occupied by arable land, which increased from 1.6 km^2 in 1869 to 11.3 km^2 in the present day. Similarly, the surface occupied by urban areas increased from 0.1 km^2 in 1896 to 0.5 km^2 in the present day (approximately 3% of the total investigated surface). Furthermore, saltwork areas have exhibited a constantly increasing trend, occupying 0.4 km^2 in 1869, 0.6 km^2 in 1909, 3.2 km^2 in 1954, and 4.6 km^2 at present (approximately 25% of the total investigated surface). On the other hand, the area occupied by grassland, pasture, meadow, and shrubland has been characterised by a marked decrease, reducing from 11.7 km^2 in 1869 to 0.9 km^2 in the present-day setting. Similarly, the investigated area has been characterised by a general decrease in the main coastal landforms (dune and back-dune areas, sandy shore; depression or inter-dune discontinuity areas, beaches). Focusing on the distribution over time of the linear landforms (embankments, main canals, secondary canals, and natural rivers), their evolutive trend has been influenced by the strong development of drainage canals, which were built to facilitate land reclamation by filling the marsh and wetland areas through the accumulation of turbid load into the so-called 'filled polders' structures. The maximum development of the drainage network occurred in the period 1909–1954, during which the total length of secondary canals increased from 115 km to 560 km. The increase in the canals' distribution was coupled with an increase in the creation of embankments. The study also focuses on the qualitative evaluation of the potential coastal resilience to land modifications. To this end, the shoreline displacement over the investigated time period was analysed by comparing the different shoreline positions and evaluating the net shoreline movement (NSM) values. The analysis of the coastline dynamic highlighted that during the period of maximum implementation of land reclamation activities (1909–1954), the study area was characterised by a predominant coastal progradation. Nevertheless, despite the fact that the reclamation works were finished, an overall shoreline retreat occurred over the last 60 years. These considerations allow us to state that the morphodynamical pattern of the investigated coastal sector was not directly affected by the land reclamation activities, but this natural resilience has decreased as a consequence of the strong decrease in the sediment load transported to the sea by the Ofanto river. This strong decrease in the sediment load of the Ofanto river was, in turn, due to the construction of many dams in its catchment, which started in the second half of the XX century [81].

The proposed methodological approach can be considered a useful tool for the quantitative evaluation of long-term land use changes, providing a set of macro-categories that can be used for the analysis of both historical cartographic products and recent datasets. Compared with those used in similar previous work, the macro-categories proposed in this study represent a better compromise between a highly detailed land use classification and its applicability to both historical and current periods. Finally, these types of analyses also provide useful information on potential coastal resilience and the expected responses to future modifications induced by natural and anthropogenic factors.

Author Contributions: Conceptualisation, V.D.S. and M.C.; methodology, V.D.S., A.R., G.S. (Giovanni Scicchitano) and M.C.; software, V.D.S., A.R., G.S. (Giovanni Scardino) and M.C.; formal analysis, V.D.S., A.R., G.S. (Giovanni Scicchitano) and M.C.; investigation, V.D.S. and M.C.; data curation, V.D.S., A.R., M.C. and G.S. (Giovanni Scardino); writing—original draft preparation, V.D.S. and A.R.; writing—review and editing, V.D.S., A.R., G.S. (Giovanni Scardino), G.S. (Giovanni Scicchitano) and M.C.; supervision, M.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. Furthermore, the GIS-layer for the automatic classification of the land use macro-categories can be also provided.

Conflicts of Interest: The authors declare no conflict of interest.

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