The erosion along the Apulian coast near the Ofanto river

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Abstract

The Adriatic coast between the towns of Trani and Manfredonia in the Apulian Region in the South East of Italy, has seen changed of its morphology due to the effects of the human action. In the middle of this coast is located the Ofanto river. Its solid transport diminished during the second half of the 1900th directly influencing the coastal morphology. Other influence on the coastal evolution is related to the presence of coastal structures, coastal roads, resorts and houses along the coast in the neighbour of the river mouth. The river mouth is included between the port of Margherita di Savoia and the port of Barletta. Either the presence of those ports and the hydrological changes of the river caused the significant erosion of the coast. The analysis reported in the paper has been developed using the information obtained from historical maps and surveys and studying the hydrological rate data provided by the ministry surveys along the river. Even the information of the Municipalities and of the local population were very important to understand the evolution of the coast.

Fig. 1: The Apulian region and the coast between Trani and Manfredonia
1 Introduction

The areas of coastline near the mouths of the Adriatic rivers are subject to erosion [1]. In previous centuries, up to the end of the 1800s, the coastline was tendentially stable or, in some cases, was expanding towards the sea as a result of the increase in solid transport of the river due to deforestation of the fluvial basin and the draining of vast areas of the hinterland near the coast. The typical triangular form of river mouths, which comes from the significant amount of accumulated material transported there, from the beginning of the 1900s began to be progressively flattened by the start of the process of coastal erosion linked to reforestation, the removal of inert materials, the containment of the river banks, the creation of barriers and reservoirs, and the urbanisation of the coastal area [1]. This type of evolution has been observed on the coast under examination, the area from the town of Trani to that of Manfredonia (south-east Italy) which in recent decades has undergone significant change (fig. 1).

![Fig. 2: The coast between Trani and Manfredonia: a comparison between the situation in 1954 and in 1997.](image-url)
The evolution of this large stretch of coast, characterised both by rocky areas and sand and pebbles, is influenced by a series of causes of anthropical, hydrogeologic and maritime origins, typical of the Apulian Adriatic coast.

The gradual transformation of the area cited is due, above all, to the creation of port infrastructures at Barletta, Margherita di Savoia and Manfredonia, to progressive urbanisation and to the change in the volume of the River Ofanto due to the effects of flood control and the accumulation of reservoirs built in recent decades, as well as various types of work carried out on the basin and along the bed which have considerably altered the transport of material to the coast [2].

Figure 2 shows the evolution of the Trani-Manfredonia area and compares the coastline in 1954 and 1997, demonstrating that, in general, the evolution of the coast has been directly influenced by the presence of the port structures of Barletta and Margherita di Savoia, and by the variations at the mouth of the River Ofanto.

The analyses were carried out both by studying the hydrogeology of the River Ofanto and the phenomenon of the withdrawal of its mouth, and through historic research of all the elements, above all cartographic, which can give a reconstruction of the evolution of the Trani-Manfredonia coastline and help to focus on the principle causes of its changes.

Listed below are all the anthropic activities which can compromise the stability of the coast. The analysis shown in the current work aims at finding the possible relations between these activities and the instability seen on this stretch of coastline.

2 The catchment basin of the river Ofanto

The main anthropical interventions which have, over time, altered the transport of material from the catchment basin of the Ofanto are:

1) Agricultural activity.
2) Human settlements and the relative infrastructure created in the basin.
3) Forestation: from 1951 to 1972 a continuous General Programme of Hydraulic, Forestry and Agrarian Improvement was carried out in an area of over 1000 square metres of the basin.
4) Barriers: a) Conza della Campania reservoir, an earth dam finished in 1985 and currently being filled experimentally (total capacity $63 \times 10^6$ m$^3$ – capacity in use $10 \times 10^6$ m$^3$); b) Saette reservoir (total capacity $3.5 \times 10^6$ m$^3$); c) San Pietro reservoir on the Osento stream (total capacity $17.5 \times 10^6$ m$^3$; the current useable capacity of the reservoir is less than $10 \times 10^6$ m$^3$); d) the Santa Venere crossing, created in the 1950s and placed on the main course of the Ofanto; e) the Abate Alonia reservoir on the Rendina (total capacity $22.8 \times 10^6$ m$^3$); f) the Marana Capacciotti reservoir (total capacity $50.5 \times 10^6$ m$^3$); g) the Locone reservoir (total capacity $115.3 \times 10^6$ m$^3$).
5) Flood control: according to the fifth volume of the basin plan [3], there are altogether 944 hydraulic works along the Ofanto River and its main tributaries. In the basin plan each work is described with its locality, type and its main geometrical characteristics.
6) The extraction of silt from the bed. This has been carried out since the beginning of the 1960s, mainly along the valley section of the waterway, where it has been possible to collect the sand and gravel which make up the flood bed. The holes in the bed created by this system of extraction make up a local depression from the bottom of which material arriving from upstream is continually taken. The extraction capability, referring to the total of all the units, is $2,546,000 \text{m}^3\text{year}$. This figure was reached from an analysis of the hourly productive capacity in the year 1986. In the period of time
from 1976 to 1983, however, the total number of licences issued by the office of Civil Engineers was only 390,060 m$^3$.

For the purpose of identifying the main causes of the withdrawal of the shoreline near the mouth of the Ofanto we needed to know the evolution of the river transport to be able to associate the changes in the hydro geological characteristics of the basin with the effects of anthropic actions. The values of liquid and suspended load flow were measured by the Hydrographic Service of Bari and are published in the Hydrological Annals [4]. Measurements were made along the fluvial axis and its main tributaries.

The analyses of liquid and silt flow have been commented on in previous publications [5], while below there is a synthesis of the main results obtained over time from data at the hydrometric station at San Samuèle di Cafiero, 25 kilometres from the mouth of the river, which subtends a basin of 2,716 km$^2$.

![Fig. 3: S. Samuèle di Cafiero - trend of the historic series of Qsomma>20 m$^3$/s data available and cumulative annual silt transport from 1935 to 1992.](image)

![Fig. 4: S. Samuèle di Cafiero - trend of Qsomma (10$^3$ m$^3$/s) relative to values of daily flow>150 m$^3$/s.](image)
We therefore know the data on suspended transport from 1956 to 1989, with the exception of the years from 1962 to 1966. In order to show the floods we considered the sum of the average daily flows (Qsomma) which are above a "threshold" which gives a significant transport of solids; this allowed us to examine the incidence of the various floods. In figure 3 we can see the trend of liquid and silt flow above 20 m³/s; it can be noted that the trend has declined, above all in the second half of the 1900s.

If we look at the trends of the Qsomma series relative to liquid flows above 150 m³/s (fig. 4), thus emphasising the floods, we can see how the values of figure 3 (Q>20 m³/s) diminish significantly. In particular it has been noted that in 1960 there was a reduction in flow values showing that from 1960 there were numerous light floods which did not give a transport equal to those of other years in which there was even sporadic, but more consistent, flooding. What has been observed on the effect of flood control corresponds with the data shown on construction and/or operation of the reservoirs, with the period in which most of the silt was removed, and with the reforestation.

3 The evolution of the coast

3.1 The coast between Trani and Barletta

The coast of Trani is mainly rocky; the important morphological changes are linked to the sandy areas which are subject to erosion. Among these are the area of the beach of Cape Colonna within the city of Trani, and the "Ariscianne" area between Trani and Barletta. In this area there is the first example of coastal erosion linked to excessive urbanisation. In Trani, in the Cape Colonna beach area, virtually in the city centre, Fig. 5 shows that at the end of the 1800s the "Colonna" area was outside the city walls, while from the aerial photograph of 1997 (fig. 6) we can see how the growth of the city has caused a clear withdrawal of the shore, which is now totally protected by barriers.

Beyond Trani, to the west before Barletta, the coast is rocky, and the first sandy area is near "Ariscianne". Here the combined effects of coastal urbanisation and the construction of the port of Barletta have caused the coast to withdraw.
3.2 The port of Barletta

Near the port of Barletta the beach is being nourished by the presence of the eastern jetty of the port. The precise date of construction of the oldest port in Barletta is not known. The first certain date is that of the enlargement between 1880 and 1889. The maps at the end of the 1800s (1872 - 1886) show the city of Barletta already with an imposing port structure. The map of the city in 1886, scale 1:5000 (fig. 7), which can be examined at the Barletta city archives, show how the western bastions of the city (the walls of Via Carmine), immediately next to the older Western jetty of the port, were already affected by nourishment for a length of about 700m (from the jetty to Fortino Paraticchio) and the nourishment was evidently progressing. Next to the more recent Eastern jetty (as we have said, built between 1880 and 1885) the nourishment stretched for approximately 40m. The maps of 1898 (scale 1:10,000) show the progression of the nourishment both to the East and to the West. Until the beginning of the 1900s the shoreline had not yet passed the Fortino Paraticchio. In the first decades of the 1900s it did, however, as can be seen from maps of the period. By the end of the first half of the 1900s a large beach had formed to the west of the city, and the coast road was built heading towards the Ofanto. In 1985 the Western jetty of the port was enlarged to limit the continuous silting up of the mouth of the port.
Figure 8 is an aerial photograph of the city in 1997, showing a coastline not greatly different from that of recent decades: the nourishment has also affected the areas farther from the Western jetty. Figure 9 shows the movement of the shoreline (a) at the Eastern jetty with the distance measured from the coast road, (b) at the Western jetty with the distance measured from the Porta della Marina (Marine Gate) at the end of the walls of Via Carmine (Fig. 7), (c) near the western limits of the old town, with the distance measured from Fortino Paraticchio (Fig. 8). In general we have noted that in recent decades the nourishment process both to the west and to the east, although still happening, is tending towards stability.

3.3 The area Barletta – Margherita di Savoia

The ports of Margherita di Savoia and Barletta, enclosing the mouth of the Ofanto, make up an area which, already in 1931-1954 began to show the first signs of what is today a notable change (Fig. 10).

Fig.10: The coast between Barletta and Margherita di S. in the years 1954-1997.
In that period the area around the mouth of the river was subject to considerable draining and urbanisation. Generally, in that period, the area between Margherita and Barletta underwent change both because of the building of the jetty at Margherita, and because of the start of flood control on the River Ofanto. It should be stressed that anthropic activity caused a considerable movement of the final part of the bed of the river during the period 1930-1954, before the effect of withdrawal of the mouth seen since the end of the 1950s (Fig. 10a). In the period 1954-1997 (Fig. 10b, 10c) the erosion of the mouth is more evident, off set by the nourishment to its west and east, in correspondence with the ports of Margherita and Barletta. In the second half of the 1900s we see the process of erosion of the mouth and the general flattening of the area. It can be seen that the point of inversion between erosion and nourishment tends to be further from the mouth with the passing of time. The area under erosion near the mouth is tending gradually to lengthen, affecting an ever greater area. A confirmation of this comes from the gradual disappearance of the old coast road, built in the 1950s. Near the mouth of the river the road is now covered by the sea (traces of the road can still be seen about 100m from the current shoreline going out to sea) and the road is already no longer usable about half way between the mouth and Barletta.

It is the remains of the road near the mouth of the river (Fig. 11) which have caused the irregular erosion of the coast, since they are clearly more resistant to erosion than the nearby sandy areas which withdraw much quicker. Another element which resists the process of erosion of the shoreline at the apex of the mouth is the area near the “La Fiumara” holiday village (Fig. 11). This has been subject to protection through a system of artificial nourishment of mixed particle size [6], which resists the advancement of the sea. This protection, together with the remains of the coast road and other virtually inerresible anthropic elements, has directly influenced the evolution of the coast, which is still today subject to morphological changes. The process of erosion in the area of the river mouth and of nourishment near the ports is ongoing (Fig 10c), so much so that the mouth withdrew as much in 1984-1997 as it did in the period 1954-1984.

Some interpretations of the main causes of the withdrawal of the mouth and the part of the bed immediately upstream from it (Fig. 12), have been given by the Nucleo di Vigilanza Iettico Faunistico Ambientale ed Ecologico di Barletta (squad for the surveillance of the fish, fauna, environment and ecology).

Before the installation of the first flood controls, flooding and damaging overflows were frequent along the river in the cultivated areas. Near the mouth, these overflows went mainly in the direction of Margherita di Savoia because of the particular orographic nature of the land whereby the left of the river was on average lower than the right. After each flood work was carried out by the landowners to repair banks and protect the land. Each owner tended to take the opportunity to extend his own land by draining a greater area, and moving the border and therefore also the river bed. The succession of these
activities changed the shape of the river bed as can be seen in figure 12, where the original line of the bed (1931) carried the river to flow into the sea where there is now the “La Fiumara” holiday village.

Over time the river has been moved to the west forming large meanders. Furthermore the landowners illegally took sand from near the mouth of the river, thus contributing to the flattening of the apex of the mouth. As well as the flooding and draining, bombing during the second world war also contributed to changing the course of the river, causing barriers and forcing the river to create a new course towards the sea near the old course.

In the 1931-1954 period the mouth of the Ofanto did not withdraw significantly, but clearly moved about 1,200m towards Margherita di Savoia. This was caused mainly by the tendency of the last part of the river bed to move towards the west. This is confirmed also by studies carried out by Barletta city council which conducted historical research into the processes of erosion on the western coast road, the results of which can be seen on the land registry maps.

Further proof of the morphological transformation of the coast, caused by the presence of the ports of Barletta and Margherita, comes from an analysis of the variations in the sea bed in front of the stretch of coast under examination. The bathymetric curves of the area in front of the mouth of the Ofanto at the beginning of the century followed the focal apex: the large amounts of material carried by the river were deposited partly in front of the mouth and partly along the coast, without finding any particular barriers in their way. As a result of the decrease in solid transport, in front of the mouth the material forming the sea bed has been dispersed (at the same distance from the coast, the bathymetric measurements are deeper now than at the beginning of the century). On the other hand, the construction and enlargement of the port structures has stopped the flow along the coast, and today part of the material can be found on the sea bed in front of the two ports, with the result that at the same distance from the coast, the depth of the sea bed in front of the ports was greater than it is today. Furthermore, the current shape of the bathymetric curves shows a tendency to change the direction of the flow of materials from the mouth of the river and to carry them away from the coast.

Some analyses of the evolution of the coastline were carried out using the plotting of the aerial photographs of the coast taken between 1984 and 1997. Figure 13 shows the progressive distances from the eastern jetty of Margherita di Savoia to the western jetty of the port of Barletta (about 14 km), the trend of the movements of volumes of materials
Fig. 13: The coast between Margherita and Barletta: trend of movement of volumes of materials in the period 1984-1987.

along this area of coast, measured in m³/m, or unit of depth. The total result of this is an accumulation of excess material of about 8,700 m³/m, approximately 670 m³/m per year. Recent analyses [5] have shown that the river’s suspended load transport to the sea, up to the second half of the 1950s was on average approximately \(3.0 \times 10^6\) tons/year, and that from 1960 to the end of the 1970s suspended load transport gradually diminished (average of less than \(1.0 \times 10^6\) tons/year), to settle in the 1990s at about \(0.2 \times 10^6\) tons/year.

The Ofanto river has, therefore, in recent years deposited in the sea an average of \(5 \times 10^6\) m³ of material. On the one hand this justifies the excess of material in the total sum of material moved along this stretch of coast, on the other we can see how this suspended load has been mainly dispersed in a cross-shore direction. The erosion of the mouth of the Ofanto is immediately confirmed (maximum withdrawal approximately 180m) and the nourishment along the jetties of the ports, which is more evident around the port of Margherita (maximum growth about 90m). It can be seen that the mouth of the river Ofanto in 1984 was at the progressive distance of 6,450m and in 1997 at 6,250m, showing a drift towards the west of about 200m. In particular one can see how the solid transport tends more towards the west; the mouth tends to erode more on the western side with, as has been said, a slight drift in that direction. As described previously, the system for protecting the coast by the “La Fiumara” holiday village (progressive distance about 7,000m) acts as a groyne on the progressive process of erosion of the area, tending to accentuate the erosion downstream of the average solid transport and to nourish upstream; the local process of nourishment is also favoured by the former coast road which, on the stretch to the east of the mouth still has some inerisible parts which are now underwater, near the coast (between progressive distances 6,500 and 8,100).

3.4 The port of Margherita di Savoia

In the same way as has been seen for that of Barletta, ever since its construction in the early 1950s, the port of Margherita di Savoia has had a considerable influence on the dynamics of this stretch of coastline. The present port structure (Fig. 14) was built in two separate moments: first the eastern jetty of the so-called channel port was built (early 1950s) and then at the end of the 1970s it was enlarged, and the western jetty was built.
The port of Margherita di Savoia, from the moment of construction of the first jetty, substantially changed this stretch of coast. The later enlargements which led to the construction of the two arms changed this new equilibrium again, giving rise to the creation of a wide beach to the east, and erosion to the west, so much so that the construction of defences became necessary. The new port structure, being in the longitudinal direction of the solid transport, immediately altered the sedimentological regimen of the coast. The structure, in fact, caused the local process of nourishment and erosion respectively to the east and the west of the jetty. This process of erosion to the west made it necessary to place barriers and groynes to protect the coast.

3.5 The stretch from Margherita di Savoia to Manfredonia.

During the 20th century the principle changes to the coast to the north of Margherita di Savoia mainly affect the Sub-Appenine Dauno area immediately to the north of Zapponeta (20 km south of Manfredonia), between the settlements of Ippocampo and Siponto (Fig. 2). In that stretch the first anthropic structures were built in the 1900s and therefore there was no obstacle to limit the flow of meteoric water from inland to the sea; the same applies to solid transport by the waves along the coast, mainly towards the west, which brought material from the river Ofanto without interruption caused by constructions in the sea. In fact, especially in the second half of the century there is no nourishment along the coast between Margherita and Manfredonia. Near to Trani and Manfredonia no notable changes have been observed because of the rocky nature of the coast. The cliffs near Trani and Manfredonia have undergone a slow process of erosion which is certainly less evident than in the other areas under examination where the coast is made up of sand and pebbles. The reduction in the solid transport of the river Ofanto has altered the entire stretch of coast under examination, and not only the equilibrium of the river mouth. As well as this, the enlargement of the port at Margherita di Savoia has drastically interrupted the solid transport along the Sub-Appenine Dauno coast, which is now tending to erode.
Conclusion

The mouths of the Adriatic rivers, in recent decades, have been subject to a progressive flattening due to the beginning of erosion along the coastline in the 1950s.

In particular, the evolution of the stretch of coastline between Trani and Manfredonia has been influenced by the presence of the mouth of the river Ofanto. The building of the structure of the ports of Barletta and Margherita di Savoia has had a great impact on the dynamics of this coast, influencing the long-shore transport and starting processes of erosion and nourishment near to the ports themselves. As well as this phenomenon, the progressive urbanisation of the coast and the alterations to the hydro geological regimen of the basin of the river Ofanto have caused a decrease in the solid transport towards the sea, because of the construction of reservoirs along the main course of the river, barriers, and generally anthropic activity along the entire river basin. The reduction in solids transported by the river has been the main cause of the evolution of the coast near the mouth of the river Ofanto, which, in the last 50 years, has withdrawn about 500m.

The analysis of the morphological evolution of the entire stretch of coast between the ports of Barletta and Margherita di Savoia shows that this erosive process is still happening, and that the outline of the coast is tending to flatten, with the exception of some inerosible structures present along the coast.

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