SHORELINE CHANGES ALONG ADRIATIC SEA IN ALBANIA

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ABSTRACT

Satellite imagery and radar interferometry were used to assess the hypothesis of ground subsidence in the Preadriatic Depression in Albania as one of the possible factors linked to the significant Adriatic Sea transgression that has covered parts of the beaches in the Patoku and Semani areas, causing negative socio-economic and ecological effects. This study initially investigates the movement of shorelines using NIR bands of LANDSAT and Google Earth imagery.
Keywords: Adriatic Sea, shoreline changes, satellite imagery, Albania

Overview of possible subsidence cases in PreAdriatic Depression

Combining Landsat Near-Infrared (NIR) images acquired across multiple years has enabled the distinction of beach extensions over time. This is due to the fact that water surfaces have low reflectance for infrared light in contrast with ground surfaces. In a combination of two or three grayscale NIR images as a Red-Green-Blue (RGB) false color image, continuous free water surfaces appear as black, ground surfaces as shades of gray, and areas where shorelines have moved as distinctive clear one- or two-color nuances (Frasheri *et al*., 2010). In Figure 1, the Google Map view of Albania is presented, featuring sections of Semani Beach and Patoku Lagoon displayed as Red-Green-Blue (RGB) combinations of NIR images. For Semani, 1972 is represented as Red, 1981 as Green, and Blue for both; while for Patoku, 1972 is Red, 1977 is Green, and 1986 is Blue.

There are at least two segments of the Adriatic coast in the Preadriatic Depression in Albania: Semani Beach and Patoku Beach. In the Semani area: a1) in the year 1972 and a2) in the year 1981, deltas of the Shkumbini River are visible, showing sediments brought into the sea by the Shkumbini in 1972; b1) in the year 1972 and b2) in the year 1981, deltas of the Semani River exhibit sediments brought into the sea by Semani in 1972; c) an old delta of a river (Semani or Vjosa) used as a beach in 1972 is submerged in later years.

Many papers provide information about significant sea transgression occurrences in Semani and Patoku, which have caused damage to urbanized areas. This is illustrated in Figure 2 for Semani and Patoku, respectively (Simeoni *et al*., 1997; Pano *et al*., 2006; Fouache *et al*., 2010; Frasheri *et al*., 2011a; Frasheri *et al*., 2011b; Frasheri *et al*., 2014; Frasheri *et al*., 2015; De Leo *et al*., 2016).

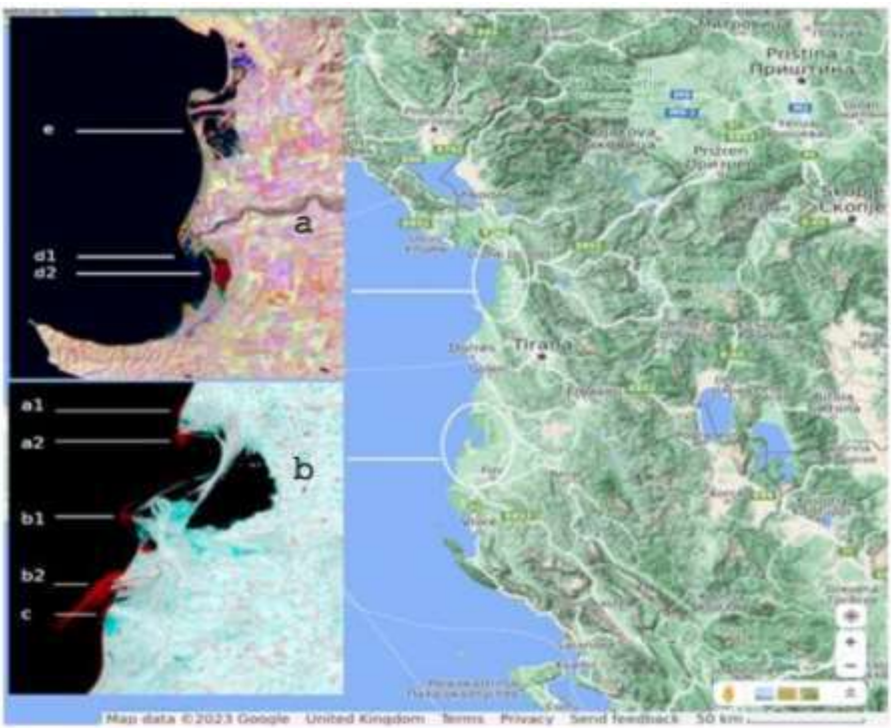

Fig.1: Combination as RGB of Landsat NIR images: (a) Patoku with 1972 as Red, 1977 as Green and 1986 as Blue; (b) Semani with 1972 as Red and 1981 as Green and Blue.

Fig.2*:* Semani beach: **(a)** concrete borehole basement; **(b)** beach view from the bridge; **(c)** submersed water tower; **d)** shore abrasion in Qerreti beach.

Semani Beach

In Semani Beach (Fig. 2), at least two significant structures have been submerged by the sea: the basement of the deep borehole (Fig. 2a) and a water tower (Fig. 2c). The submerged concrete blocks from the "Semani 3" borehole drill equipment in Fig. 2a were repurposed as a platform for building a bar. The original height of the top basement from sea level was 5 meters (Tego 2022), with the ground level at 2 meters. As shown in Fig. 2b, viewed from the borehole bridge, there is no apparent 2-meter difference in height from sea level on the beach, as would be expected in the case of beaches subject to abrasion from sea waves. Figure 2d illustrates shore abrasion in Qerreti Beach, the southern part of Durresi Bay, north of Semani, for comparison with Fig. 2b.

Old topographic maps are compared in Figure 3, indicating the positions of a deep borehole named Se3 and the water tower. Numerical values (Frasheri *et al*., 2011; Frasheri *et al*., 2015; Tego 2022) visible along the shore represent the height in meters of the ground surface above sea level. According to Tego (2022), the borehole's original height was 5 meters. From Figure 3 and on-site observations, the height of the concrete blocks still in place is approximately 3 meters, suggesting a ground surface height of 2 meters at the time of drilling (similar to Qerreti).

Sea transgression due to wave abrasion would typically create a visible step of at least 2 meters (similar to the case of Qerreti), which is not apparent in the photo. Additionally, concrete blocks should have fallen down over the years, contrary to what has been observed.

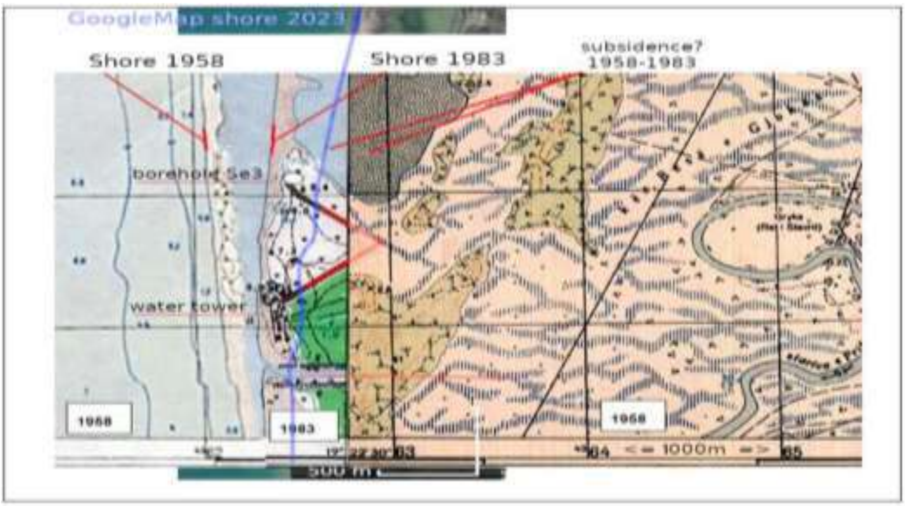

Fig.3: Position of Semani shoreline in old maps of 1958 and 1983, blue line shows the shore from Google Earth 2023 [modified version from Frasheri *et al.*, 2011].

In the maps of 1958 and 1983, an inland area is marked with the term "subsidence." In 1958, this region was reported as sandy, while in 1983, it was identified as a free water surface.

Figure 4 depicts the Adriatic shoreline for the years 1972-1981-1989-2001-2010-2022, calculated from NIR bands of Landsat satellites (NASA, USGS, and ESA repositories). It is evident that the most significant sea transgression occurred during the period 1972-1989, slowing down in subsequent years. Notably, there is abrasion of the old Semani delta (west of Karavasta lagoon) and the formation of a new one further south, just north of the destroyed Semani beach. This suggests that sediment flow from the river has persisted over the years. A small lagoon between the new and old Semani river deltas was mostly sandy in 1972 but became submerged in later years. The Semani beach situation appears to be an old delta river, likely that of the Vjosa, and its abrasion from sea waves could be expected. However, the overall shoreline dynamics hint at the potential presence of subsidence.

The analysis of shoreline changes over time yielded the following results. Three east-west profiles were established, cutting through the Semani delta

(A), the former Semani beach (B), and the beach between the latter and Vjosa delta in the south. Distances in pixels were measured starting from the pixel indicating the shoreline position in 1972 (Figure 5, left). The graphical representation of these distances in pixels is presented in the chart (Figure 5, right). For the former Semani beach, approximately 70% of sea transgression occurred between 1970 and 1990. The shape of the former Semani beach shoreline suggests the presence of the old Semani river delta. During the same period, there was sea regression with the development of the new Semani delta, as well as sand accumulation in the south towards the present Vjosa delta. Additionally, in one of the 1972 Landsat NIR images, a strong flow of sediment or biomass from the Semani delta towards the south is visible (Figure 1b).

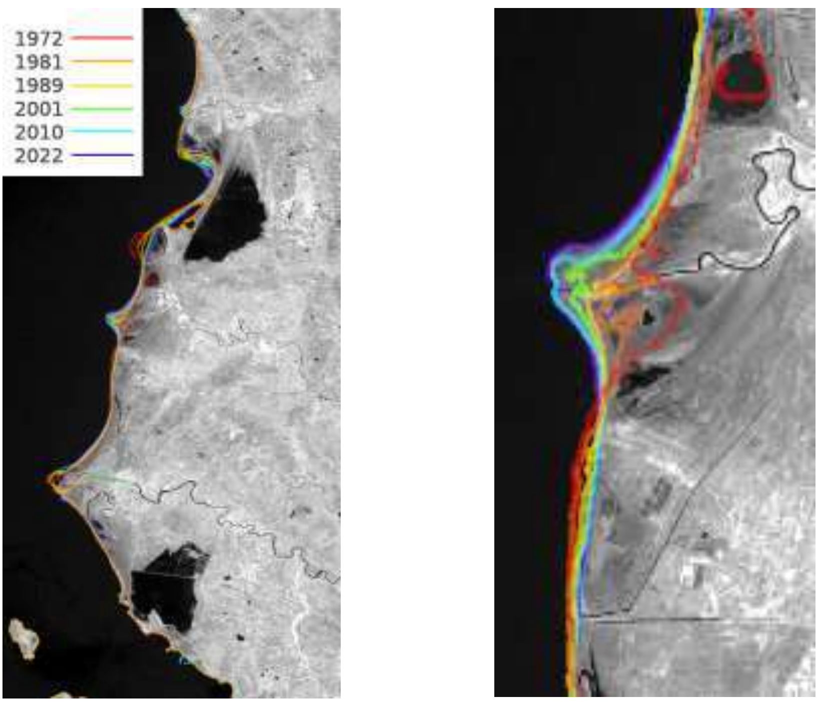

Fig. 4: Position of Adriatic shoreline in years 72-81-89-01-10-22 from NIR bands of Landsat satellites [NASA, USGS and ESA repositories.

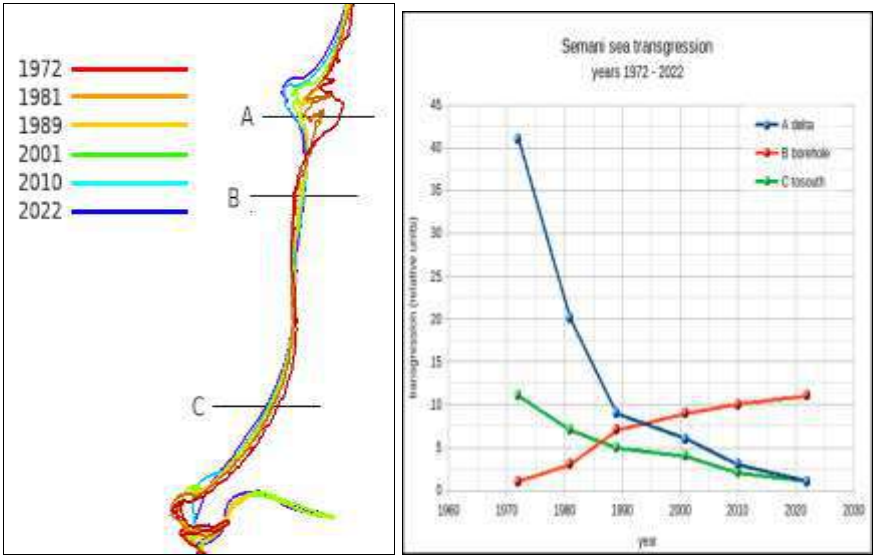

Fig.5. Profiles in Semani area: A ~ new Seamni delta, B ~ former Semani beach, C ~ beach between former Semani and Vjosa delta; and respective sea transgression chart. Relative units are image pixels (25m/pixel).

The two visits to Semani beach in 2014 and 2023 allowed for the collection of GPS coordinates at points located 1-3 meters near the waterline. Google Earth images from 2020 and 2023 were utilized to measure sea transgression during the same period, with point P# representing 2014 and Q# representing 2023 (see Figure 6).

Fig. 6: Comparison of water line based on GPS measurements of 2014 and 2023, using Google Earth image of 2023 and 2020.

Distances of waterline movement were calculated using two methods. First, when two coordinate measurements were available for the same site from GPS, the difference in arc seconds of longitudes was utilized, with 1 arcsec of longitude at 40° equalling 23.6 meters. Second, the distance in meters was measured in Google Earth images from the old point of observation to the waterline or the new observation points. The results are presented in Table 1. Observed differences between the two methods are also associated with the oscillations of tides (of amplitude 10-20cm, causing 1-2m oscillation of shoreline) and the changes of distances of measurement points from waterlines (2-4m). It's worth noting that errors from cell phone GPS measurements are unknown.

Table1. Calculation of waterline movement 2014-2023 ("S" - difference in arcseconds and related meters, "M" - distance in meters from Google Earth), points ordered from north to south.

Point identifier	Coordinates 2014	Coordinates 2023	Difference S	Distance S	Dinstance M
Pv3 seashore (delta)	19°22’30.00”				-40
Pv2 seashore (lagoon)	19°22’29.70”	19°22’30.90”	1.20”	28.38	40
point A [between Pv6:Pv2]		19°22’22.08”			55
Pv6 borehole stucture	19°22’15.18”	19°22’19.02”	4.84”	90.8	75
Pv5 water tower	19°22’12.42”	19°22’15.06”	2.64”	62.44	50

The data in Table 1 show that the delta of Semani continues to advance (Pv3), while the rest of the shore from the edge of the Semani delta to the midpoint between the deltas of Semani and Vjosa is undergoing continuous sea transgression. This phenomenon is more evident in the middle of the section, particularly in front of the former borehole basement.

Patoku Lagoon

Figure 6a illustrates the Patoku Lagoon. As can be clearly noted, there are old buildings from the former Patoku beach (Fig. 6b), which are now accessible through a passageway and used by fishermen. Typically, semi-enclosed coastal areas are characterized by the accumulation of sand, and the zone of the actual lagoon has been separated and protected from the sea by a line of remaining buildings that are still visible.

Fig.7: (a) aerial view of Patoku lagoon and Mati River delta; (b) view of submersed buildings situated in the middle of the lagoon.

In the Patoku area, as shown in Fig. 1, the following features are identified: e - Kune Vaini Lagoon, where no visible changes occurred during the period 1972-1986; d1 - delta of Mati River; d2 - Patoku lagoon, with red color indicating areas covered by sand in 1972 but submerged in later years. The analysis of shoreline variation in space and time for Patoku lagoon was based on three profiles East-West cutting through the former Mati delta (A), Patoku lagoon (B), and former Ishmi delta (C) (Fig. 7 and 8). The actual lagoon has two North-South sand dunes; on the central one, there are remains of buildings from the former Patoku beach, serving as the zero point for distance measurement in pixels. The western dune was recently formed from the Mati River (not considered in our analysis). It is observed that the internal part of the Patoku lagoon was filled with water in a short period between 1970 and 1985, with insignificant movements afterward (Fig. 9).

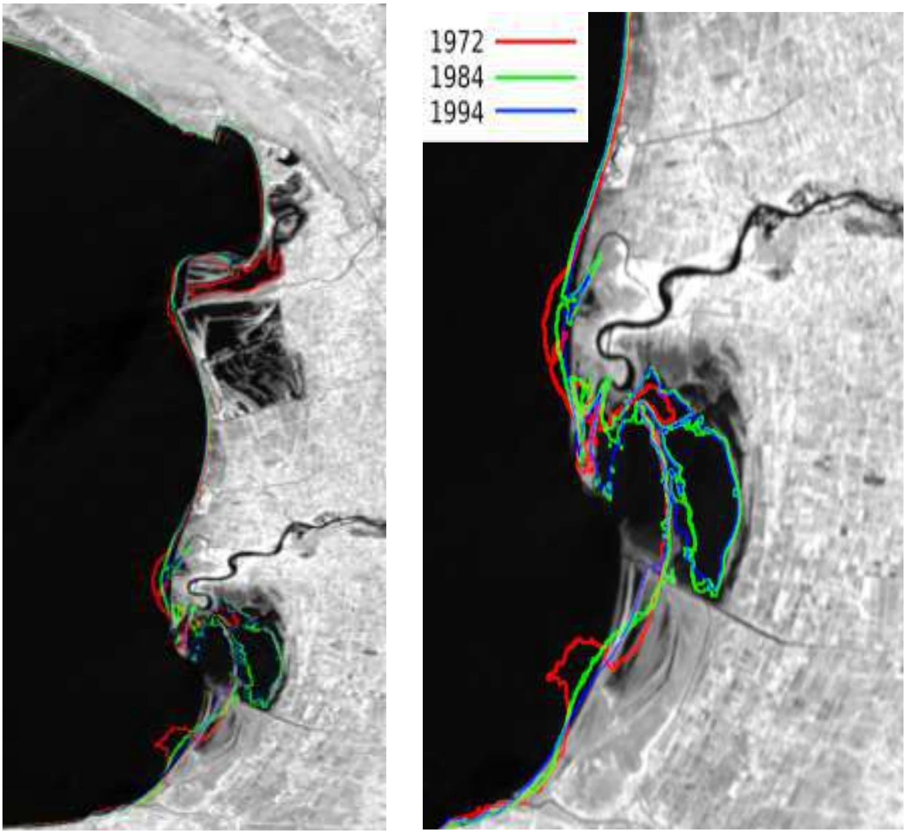

Fig.8: Shorelines in years in Patoku area, with profiles A ~ old Mati delta, B ~ Patoku Lagoon, C ~ old Ishmi delta.

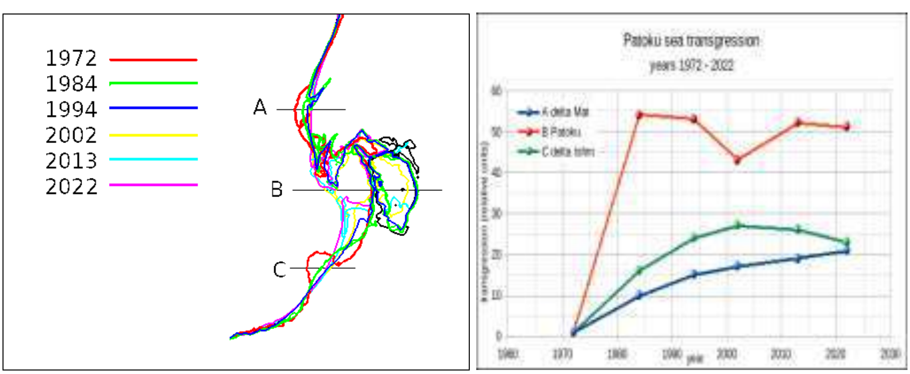

Fig.9: Profiles in Patoku area: A ~ old Mati delta, B ~ Patoku lagoon, C ~ old Ishmi delta; and respective sea transgression chart. Relative units are image pixels (25m/pixel).

DISCUSSION

The sea and sandy beach are in dynamic equilibrium. The creation of a delta disrupts this equilibrium, as a result, when the river changes its mouth, the sea 'will claim occupied terrain,' and sediments of the old delta will be gradually removed by waves. Creation and destruction of deltas and lagoon dunes modifies sea water flow and distribution of sediments brought by rivers. Natural changes in rivers beds coupled with exploitation of sand ang gravel from riverbeds, building of dams, changes in terrain and vegetation over river catchments, impact of urbanisation, climate changes all those impact the regime of river sediments and as consequence changes in the equilibrium between sea and shore. Such phenomena are visible in the deltas of the Mati, Ishmi, Shkumbini, and Semani rivers. However, the Adriatic shores in the Patoku lagoon and Semani beach indicate other factors at play.

In Patoku, a new lagoon was created within a time span of ten years, while being separated and protected from sea abrasion by a line of buildings. Another hypothesis is subsidence; if true, the cause should be local within the actual lagoon (seashores on both sides of the lagoon show no signs of significant sea transgression).

In Semani Beach, a small tourist village was built in the ancient delta of the river, and its abrasion seems normal. However, objects such as a borehole concrete basement (drilled for oil and gas) were initially at a height of 5 (five) meters and are now situated at a depth of 2-3 meters. Such differences cannot be due to abrasion alone, and subsidence must be considered as well.

Studies using radar interferometry have encountered challenges due to environmental factors such as vegetation noise (Lamaj *et al*., 2015; Kuçaj, 2011; Frasheri *et al*., 2017a, b, c, d; Frasheri, 2021). Calculations of phase interferograms from ESA Sentinel-1 radar satellite data for the strong earthquakes of 2019 in the Durres-Lalzi area demonstrated that while the impact of the earthquake on vertical ground movement is clearly visible in short-term interferograms, it is not visible in long-term interferograms. This indicates the presence of other factors, such as noise from variations in vegetation cover, obscuring the subsidence signal. Traces of millimetric-per-year subsidence have been documented for rural areas northeast of Semani Beach (Lamaj *et al*., 2015). However, this amount of subsidence is too small to explain the observed sea transgression in Semani and Patoku beaches.

CONCLUSIONS

The final conclusion is that the sea transgression phenomena observed in Semani and Patoku are very complex. Changes in river regimes and sea currents have their impact, and although subsidence has not been clearly documented, it must be considered as one of the possible factors, including geo-engineering factors such as the exploitation of underground water resources. The presence of sea transgression in Adriatic shores due to a combination of natural and anthropogenic factors indicates the need for careful and combined preliminary studies before undertaking important economic activities in Adriatic beaches.

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