Hydro Geomorphological Classification of the Albanian Coastline in the Mediterranean Sea

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Abstract. Albanian coastal area in the Mediterranean sea is about 380 km. long with about[1] 284 km along the Adriatic Sea, and the remain 96 km facing the Ionian Sea. This area represents the Easter side of Otranto Strait. River mouths and deltas, lagoons system, abandoned riverbeds, inland, marsh labyrinths, sandy beaches, dunes covered with vegetation, dens forests, represent Albanian littoral, with enormous international importance for its biodiversity and natural productivity. This area is considered one of the most complicated natural areas of the Mediterranean Sea. In this paper it is attempted to present a general evaluation of the natural particularities of the sea coast in Albania. Morphological classification and coastal evaluation are the principal components of the paper. Marine and onshore integrated surveys and the studies for investigation, monitoring and estimation of the physical characteristics of the Albanian coastal area were performed during the period 1958-2005. The natural particularities of the sea coast is mainly determined by variation of the impact of climate change, continental water discharge in the sea, suspended load discharge, wave refraction, trajectory of the main marine currents in the coastal area, etc. The shores have differences concerning geological, climatic, geomorphologic, sediment logic. Fluvial features in structure of a coastal zone and talasographic field. Six physiographic units-regions that have the original ways of development according to the modern morph dynamical and litho dynamical regime were distinguished. Various parameters of the shore dynamics are represented. Results of the integrated offshore and onshore geological-geophysical surveys and hydrographical studies in Albanian littoral are presented in this paper. Hydro morphological studies were performed to evaluate geomorphologic characteristics, and the migration of the Albanian coastline in the Mediterranean Sea. The wave refraction in the coastal area is analyzed by wave refraction diagrams. Determination of the littoral sediment transport and coastal sedimentation, the classification of the erosion and accumulation processes, under wave refraction, sea currents, are studied by analysis of marine onshore surveys data.

Key words: physiographic units, coastal area. Regionalization shore dynamics~ abrasion, sediment migration, regime, refraction diagrams.

1. Introduction

The Albanian coastal area on the East of the South Adriatic and North Ionian has a length of 447 km long (Fig. 1). This area represents the Easter side of Otranto Strait in the Mediterranean Sea. River mouths and deltas,

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lagoons system, abandoned riverbeds, marsh labyrinths, sandy beaches, dunes covered with vegetation, dense forests represent Albanian littoral.

According to the studies conclusions results that geomorphologic classification of the Albanian coastal area consist of two principal major pale geographic zones (Fig. 2, 3):

a)- Adriatic Coastline of Peri-Adriatic Depression in the central and northwestern part of Albania. There are three different segments:

- Accumulative segments, Erosive segments, and Submerged littoral areas, where is observed marine ingression toward the mainland.

The Adriatic coastline dynamics geomorphology is conditioned by geological setting of the western side of Albania, by the geotectonic developments, by the dynamics of the seawaters, solid material discharge from Albanian River network to the Adriatic Sea, and their deposition along the coastal zone.

b)- Erosion coastline of Ionian tectonic zone in the southwestern part of Albania

2. Material and methods

Marine and onshore-integrated surveys and studies for the investigation, monitoring and estimation of the physical characteristics of the Albanian coastal area have been performed during the period 1958-2005.

2.1. Hydrological and hydro geomorphologic, were based on the information of the Albanian hydrometric network that consists more than 220 meteorological and hydrometric stations, during the observed period of 20-100 years data of Albanian Hydro meteorological Institute. There are also 8 coastal stations and 12 other stations installed in the flow of the most important Albanian rivers near the sea.

2.1.1. Hydrological studies: Multi annual hydrometric observations on water levels, temperatures, water discharge into the Adriatic Sea, suspended material discharge; alluvial granulometric composition, water chemical composition etc. were performed in main Albanian rivers. Water potential and run-off discharge regime of the Albanian Mountainous River System have been evaluated by a specific way for two categories of river basins (Pano N. 1984, 1998):

1) Drini, Mati, Ishmi, Semani, Vjosa River systems, etc., where the run-off discharge depends from the altitude of the water level river section.

2) Scutary Lake-Drini River-Buna River water system, where the discharge of the Buna River, which flows away from the Scutary Lake (Q_2) to the sea, depends from the level of the water (H_2), and by the Drini River discharge in to the Buna River (Q_4):

$$Q_2 = \left\{ 0.025 \cdot \left[H_2 - \frac{Q_2^2}{(0.0073 \cdot H_2^{1.61413})^2} \right]^{1.85} - Q_4 \right\} \qquad (1)$$

The calculations have been performed for the models of dry and wet characteristic years. The evotranspiration potential has been calculated by different well-know methods.

Several physical-chemical parameters have been measured: the water velocity and discharge of the rivers and from the lagoons to the Adriatic Sea and to the Ionian seas, and the chemical water content.

2.1.2. Hydro geomorphologic studies *w*ere performed to evaluate the geomorphologic characteristics, the evolution and the migration of Albanian Adriatic coastline.

a)-The marine current analyses are based on examination of the filed surveys data and ocean logical calculation. The ocean logical calculations are realized by dynamic method. This method based on formula:

$$u(z) - u(H) = \frac{10\Delta D}{2\varpi h \sin\alpha} \qquad (2)$$

where: u(z) – the current speed in the sea surface (z=0)

u(H) – the current speed in the calculate surface

ΔH - the difference of the dynamic altitude

w - the vector of the speed

L - distance from two hydrological stations

α - geographical altitude

b)-The wave refraction in the coastal area is analyses by wave refraction diagrams, by numerical methods solving of system of equations:

$$\left\{ \begin{array}{l} \dfrac{d\theta}{dy} = \dfrac{1}{C}\left(\dfrac{\partial C}{\partial x} - ctg\theta \cdot \dfrac{\partial C}{\partial y} \right) \\ \dfrac{dx}{dy} = C \cdot tg\theta \end{array} \right\} \qquad (3)$$

where: $\theta(x, y)$ - is the angle between the x axis and the tangent of the wave rays at point M(x,y).

C(x,y) – is the wave speed and the same point

(x,y) - is the coordinates of the region.

c)-The geomorphologic regime of the Adriatic Sea coastline, have been analyzes based on the examination of archival documentation (Topographic Map of Albania of Austro-Hungarian Institute, 1870, Military Geographic Institute, 1918 and 1938, Soviet Naval Institute, 1955, Albanian Military Topographic Institute, 1958, Land sat imagery of 1978, 2000, 2002 etc). Determination of littoral sediment transport and coastal sedimentation, the classification of erosion and accumulation processes under the wave refraction etc. are studied by analyzing of marine and onshore surveys data.

2.1.3. Oceanographic studies: Water levels, temperatures and chemical content etc., formation and circulation of the water mass, wave and wind regimes of the Adriatic and Ionian coastline have been study in the hydrometric station network since 1958. Two Albanian oceanographic expedition “Saranda-1963” and “Patos-1964”, and two joint Italian-Albanian expeditions “Italica I -2000” and “Italica II-2001” were organized in the Southern Adriatic and Northern Ionian.

2.1.4. Integrated geological-geophysical: onshore surveys of the Albanian littoral areas have begun since 1958. Offshore geological-geophysical surveys on the Albanian Adriatic shoal shelf have started from 1976). Marine geological mapping has been performed using submarine surveys, shallow mapping boreholes and dredge’s sampling. Integrated offshore geophysical surveys have been carried out using reflection seismic of shoal littoral shelf, marine electrical soundings and profiling of apparent receptivity, marine magnetic recognition surveys and marine radiometric surveys. Offshore geological-geophysical surveys were performed in the shoal littoral shelf, with a width of 5-10 km parallel to the coastline. Electrical soundings have a depth of investigation is about 1000-1500 meters, and influence depth is up to 3000 meters.

2.1.5. Climate change was analyzed by inversion of the ground surface temperature history, using the temperature record in the deep wells and shallow boreholes, and by the meteorological observations data. The climate change impact on the Adriatic Sea hydrology and on the erosion process in the Albanian River Network has been study.

3. Analyze and results

3.1. Albanian Adriatic Sea Littoral and Quaternary Evolution

Adriatic coastal line from southern city Vlora up to Shëngjini Bay, in the north, have the marine accumulation flattened littoral, the marine erosion coast, and the submerged areas, where is observed marine ingressions toward the mainland. In some areas there is cliffed coastline.

3.1.1. Accumulative areas represents main part of the coastline

Accumulative areas of the Albanian Adriatic Sea Littoral are extended over the edge of western Albanian plains .This littoral is characterized by presence of the different Quaternary (Q) deposits genetic types

Marine Quaternary littoral deposits, presented by fine, medium, and coarse gray—white, gray-yellow sand, salty clay and mud interbeds present marine Quaternary littoral deposits. Interbeds thickness varies from 1-10-15 meters. Present day’s micro and macro fauna of seawaters comes across everywhere.

Very beautiful sandy beaches are extended in Drini, Lalezi, and Durrësi bays, Divjaka, Semani and Vjosa River mouths and at the Vlora Bay. Present time shore sand knolls have a length up to 4-5 km, width 35-80 m and some meters highs. At the northern bays, the coarse sand is predominated. Toward the southern part of Adriatic coastal line, fine and medium sand are predominated. This sand belt is composed by two or three parallel onshore dunes: the first dune is extended directly at the water line, the second at the distance 90-100 m and the third dune 150-200 m. There are concentrated placers of heavy rare and precious minerals. Placers lens have a western dipping with an angle about 5-10^{o}.

According to the integrated marine geological-geophysical surveys, in the shore shoal zone, which represents a flat depression up to –50m depths, the Pleistocene up to actually Quaternary sand and sandy silt sediments were distributed, under the waves process and marine currents. Towards the flat shelf depression, up to –100m depths, the sandy-silt sediments are representative. In inclined shelf area, up to –200 m depths where are also some submarine hillocks, the muddy silt deposits are distributed. Continental slope by argillaceous sediments is characterized. Litho logical changes from the shore to the continental slope area are gradually...

Buried sand knolls are situated along littoral belt at the mainland. Sandy littoral belt along the accumulative littoral have a width up to 5 km .Sand dunes belts have a length of 25 km. Dunes have a length 2-5-6 km and an average width more of 50-100 m.

Generally, the granulometry of quartzite sand deposits represented by very fine up to medium sand. Thickness of the sand dunes is some meters (2-10 m). Under the sand, the salty-clay or clay layers are located, with a thickness some meters. In many sections, the fine, polymictic, gray sand lays under the clay, which have a thickness more than 10 meters. Loose sand in the coastal line and clay mud is layered far from coastline lagoons and coastal marsh deposits. These deposits are presented by thin alteration of compact clays, silt-clays and silt beds, with vegetable debris and blue-gray fine organic mater, and saline water macro fauna. These entire Holocene marine deposits layers lies horizontally or with small western dip angle, 7-8^{o} . Alluvial deposits and clayey earth are layered far from the coastline.

Filling process is intensive, generally, in river mouths.

In these accumulative coastline areas there are some relatively small erosion sectors, which are located at the Mati, Erzeni, Shkumbini, Ishmi and Vjosa river mouths. Typical is shore erosion that developed by Darçi River flow in Golemi-Karpen beach sector in the Durrësi Bay, with an erosion rate of 0.5 m/year.

In the shoal shelf zone, at the alluvial sea floor are observed the sandy splits. Typical is a submarine bar, which has been formed by solid load discharged by Buna River in Drini Bay. This split is extended up to Drini River Mouth.

3.1.2. Erosive zones Marine deep erosion zones were developed over some sectors in accumulation littoral of Adriatic shoal. These zones are located in the uplifted side of the active reverse fault & thrust.

The Rodoni, Palla, Selita and Zvërneci capes of the molasses bedrocks of the littoral anticlines of the Periadriatic Depressions have represented the erosion configurations of the Albanian Adriatic sea coastline.

Rodoni Cape erosive area is located at the western and northern part of the Cape. Tortonian sandstone-clay banks have been mapped in Adriatic shelf over these sectors.

Durrësi–Pallë Cape area is one most typical erosive segment of the Albanian Adriatic littoral. Durrës-Kepi Pallës coastline is extended along the western flank of the Miocene-Pliocene molasses anticline. Northern pericline and western fold flank are lies under the Adriatic Sea waters. The structure is asymmetric and eastern flank is tectonically abrupt. Anticline top is located under the seawater, about 1600 m at the west of the shoreline. Molasse deposits are covered by different kinds of the Quaternary loose deposits.

Geodynamics of the coastline is demonstrated also by historical and old shoreline migration. At erosion Currila sector, northern of Durresi city was observed an ingression of the shore during post Alerodiane glacier period and later up to present coastline location. Marine geological surveys have observed gravel and coarse sands under 20 m thick a salty-clay layer, and 20 m sea depth, at 2 km from the shore. Gravel and sand transgressively have covered the Tortonian bedrocks. These depositions are represented Pleistocene old shore.

Selita Cape, in the northern edge of the Kryevidhi Pliocene Hills.

Zvërneci hilly zone is located at northwestern direction of Vlora city. The old sand split from Vjosa River mouth to the northern edge of the Zvërneci Tortonian hills and these hilly chain separated Narta lagoon from the Adriatic Sea. The southward shift of the Vjosa River mouth during the XX century has created serious erosion problems in the northern coast of the Narta lagoon. The sediments input to the old delta ceased, the latter has almost been completely eroded and the sediment was removed to create a split, which formed an accumulative zone in the southern part of the Vjosa River old mouth

In the Rodoni, Selite and Zverneci caps of the shoal shelf zone are observed the same sea floor morphology and sediments that in the Durresi-Palla Cape zone, with many bedrocks submarine banks.

3.1.3. Submerged areas, where is observed marine transgression toward the mainland

Semani beach at western Albanian region and Patoku beach in the southern side of the Shëngjini Bay represent submerged areas within accumulative coastline. Submerged process is caused by the neotectonics activity, consequently there are observed a marine transgression.

Re-activation of the disjunctive tectonics at the littoral area Vjosa River mouth to Mati River mouth is observed. In the littoral segment Seman beach - Karavasta Lagoon -Shkumbini River mouth, in the both flanks of the Semani asymmetric anticline structure the disjunctive tectonics, with small amplitudes of 200-400m, are reactivated. According to the neotectonics studies, an active reversed fault with western thrust direction, from Vjosa River Mouth to south of the Semani River Mouth, is laid in the mainland, parallel with the coast. According to the marine electrical resistively tomography, performed by marine electrical soundings, the morphology of the marine Quaternary loose deposits has a horizontal layering (Fig. 12) at the western side of the Semani beach. In south and east northern sides of the geoelectrical line is observed reversed fault impact. Consequently, the Semani sandy beach, which is located at western side of this fault, in the submerged process, is found, from 4 km of south of the Semani River Mouth up to Semani Beach area, in the about 10 km long segment (Fig. 3, 5). So many objects that 20-35 years ago have been constructed in the mainland, at the present under the seawaters are found, ex. the Seman-3 deep oil and gas well basement (Photo 9). Semani-3 well has been drilled in 1969 in the mainland, 265m from the coastline

Uplifted side of the reverse fault & thrust, at northeastern Semani River Mouth-Karavasta Lagoon and Shkumbini River Mouth, under the neotectonics uplift process is found. There are observed marine regression.

Second submerged are at the Adriatic littoral is observed at the Patoku beach, between Ishmi River Mouth at the south and Mati River Mouth at the north .This area is located at northern direction of the Rodoni Cape. This submerged area has more complicated development. In 1972, the sand beach there has a width about 175m. In 1982, the width of the beach only 100m was...

Small submerged area in the Porto Romano area is observed, too, which is located between Durrësi City and Palla Cape.

In the submerged zone are observed integrated factors of the coastline evolution: neotectonic, erosion by marine currents and accumulation of the solid river discharge and eroded shore sediments. This factors complex has caused important changes on the coastline geomorphology, marine shoal and littoral landscape. Typical are Patoku and Semani area. Submergence in Patoku area has caused replacement of the Mati River Mouth towards the south, start from the 1978 year. From the 1982 year, the river solid discharge has started to form sand split, from the mouth up to 300 in southeast direction (Fig. 4). According to the satellite images of 2000 year, this bank has been with a length about 1400 m and has been emerged over the sea surface. In 2005, this sand slit has a length over 2 km and is covered by dense vegetation.

3.1.4. Outlook on coastal evolution Adriatic coastline has an intensive changes and continuously modifying its shape (Boçi S. 1981, Pano N. 1994, Simeoni U. et al. 1997, Shuitsky Yu. D. 1999).

There we are analysed three most representative areas:

Drini Bay. Intensive change dynamics, Viluni Lagoon and Shëngjini portal town characterized this littoral area. The decreased sediment load of the Drini River, caused by its diversion into the Buna, has triggered coastal recession between Shëngjini and Tale, with greater intensity on the southern lobe of delta. Moving southwards, the coast becomes part of the sedimentary system of Mati River. The coastal area between Tale and Patok can be considered as having a positive sediment budget (Pano N. 1998).

Karavasta Bay. The Seman and Shkumbini rivers are the main source of coastal sediments in Karavasta Bay. The average water discharge is 62 m^3/s. The average annual water discharge of the Semani River (Q_o) to the Adriatic Sea is 0.9m^3/s; and the annual load sediment discharges is R_o=399kg/s, which has a correlation with the water discharges-Q_o (in $m^3 s^{-1}$) for two main branches (Pano N. et al. 2003, 2004):

$R_o = 0,605.Q_o^{1.46}$ - for Osumi River, and

$R_{o.2}=0,219.Q_o^{1.69}$;   - for Devolli River

The total sediment discharge by this river to the Adriatic Sea is W_T= 15,7.10^6 tons/year. About 19% of total sediment load is equivalent to W_F=3,15.10^6 tons/year is carried bad load, and 81%, equivalent to W_F=12,6.10^6 ton/year, is suspended sediments. The wave highest in the Seman River mouth observed along the coastline, have a deep-water direction from the NW and the W and a maximum wave height of 4.0 m seashore. The dominant winds are south-easterly, easterly, and north-westerly winds. Maximum waves converge towards north-eastern zone of coastline. This coastline corresponds to an extensive delta coast (microtidale: 0,50 tidal range) with a large alluvial plain of Myzeqe.

In ten last years, the coastline has advanced some hundred meters. Semani River mouth has changed in position in the last centuries six times and this displacements have covered on area of the littoral about 15-20 km long in a direction North-South; South-North during period 1870 to 1994 years. In these conditions in the coast area there are two important sources of coastal sediments: the actual rivers mouth and the olds rivers mouths. The outlet of Semani River was shifted from position A and A_1, the old mouths, to the actual position B", that is up date position. The old mouths of this river (coastal area A' and coast A") is undergoing on important submerged process under the neotectonics activity and erosion from the wave action.

Vjosa River Mouth-Vlora Bay. The general evolution map of coastline in fig. 8 is presented (Pano N. 1994). Vjosa River Mouth has changed its position in the last century two times and these replacements have covered an area of the littoral about 10 km long in the northern direction. The old mouth of this river is undergoing on important erosion process under the wave action. There are two sources of coastal sediments: first, the present Vjosa River Mouth, and second the old Vjosa River Mouth.

4. Conclusions

- Albanian littoral has two major units: accumulative Adriatic coastline and erosive Ionian seaside.
- Albanian Adriatic coastline has an intensive change and continuously modifying its shape.
- Submerged process, caused by neotectonic activity, is observed in some sectors within accumulative Adriatic coastline.
- The climate at coastal plane region of Western of Albania has a warming of 0.6 K occurred, from last quarter of 19th until present-day. These climate changes have their impact on country water system, on and water resources, on the erosion processes, and on the hydrographic regime of the Adriatic Sea.

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