ORIGINAL PAPER

Natural radioactivity of coastal sediments as tracer in dynamic sedimentology

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Abstract. Natural radioactivity of coastal sediments could provide interesting information on sediment dynamics. Natural radioactivity measurements were performed in two areas of the Adriatic Sea littoral of Albanian cost, in the gulfs of Durres and Vlora, where complex studies were carried out in the framework of the maintenance of existing Durres harbour and the design of a new harbour in Vlora. Dynamic mapping of the gamma total radioactivity at the sea bottom sediment was carried out using a 2” × 2” NaI probe. Radiometric data were converted to lithological map, and the sand and silt distribution configuration was interpreted in terms of sediment transport. The obtained results have shown that the natural radioactivity of sediments provides qualitative data about the sediment dynamics. This cost-effective method is recommended to be used as complementary to other tracer techniques for sediment transport in coastal engineering investigations.

Key words: gamma natural radioactivity • coastal sediments • natural tracer • lithology • sediment dynamics

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Introduction

Radiometric measurement of natural gamma radiation is a simple and fast technique for lithological mapping of the sea bottom that could provide useful information about the origin and transport of sediments [2, 5, 11–13, 16]. Natural radioactivity of sea bottom sediments can provide:

– granulometric characterization of sediments,
– depth limit of wave effect on the sediments at the sea bottom,
– direction and distance of transport of fluvial sediments,
– identification of accretion and erosion zones along the coastal line.

Natural radioisotopes incorporated in sediments are U-238 (and its decay series), Th-232 (and its decay series) and K-40 [1, 6, 7, 9, 15]. The radioactive decays of these three radioisotopes show that:

– 1 g of U-238, (in equilibrium), emits 33300 gammas/s and 84000 betas/s of energy from some tens keV to several MeV;
– 1 g of Th-232, (in equilibrium), emits 17400 gammas/s and 15000 betas/s of energy from some tens keV to several MeV;
– 10 g of potassium (natural potassium contents 0.0118% K-40) emit 33 gammas/s of energy 1.46 MeV and 275 betas/s with a maximal energy of 1.35 MeV.

Fig. 1. The gulfs of Durres (left) and of Vlora (right).

The concentrations of U-238, Th-232 and K-40 in sediments depend on sediment nature and origin. In the coastal sediments of Albania, the following values were found [14]:

Silts:
- U-238 – 3–5 ppm;
- Th-232 – 10–12 ppm;
- K – 1–2%;

Sands:
- U-238 – 1–2 ppm;
- Th-232 – 5–6 ppm;
- K – 0.5–1%.

Based on these concentrations, it can be calculated that the major contributor of gamma natural radioactivity of sediments is Th-232 (over 55%), thus Th-232 can be considered as a natural tracer of sediments. Th-232 is always in equilibrium and is very resistant to chemical and mechanical agents, so this makes it a reliable tracer for long-period transport of sediments.

The scope of the study was to validate the natural radioactivity method for tracing sediment transport. A natural radioactivity investigation was undertaken in two important areas of the Adriatic Sea littoral of the Albanian coast, in the gulfs of Durres and Vlora, where complex studies (radiotracers included) were carried out in the framework of the maintenance of the existing Durres harbour, and the design of a new harbour in Vlora [3]. Figure 1 shows the beaches of Durres (left) and Vlora (right) where the natural radioactivity of sediments was measured on-line at the sea bottom at a depth from 1–2 m to 20–25 m.

Radiometric measurements in the gulfs of Durres and Vlora

50 keV was the detection threshold for on-line total counting rate measurement, while the spectrometric gamma natural radioactivity of samples taken from the sea bottom and beaches was measured with the following windows:
- 1.36–1.60 MeV for K-40 (photopeak at 1.46 MeV),
- 1.65–1.95 MeV the for U-238 series (photopeak at 1.76 MeV),
- 2.40–2.80 MeV for the Th-232 series (photopeak at 2.62 MeV).

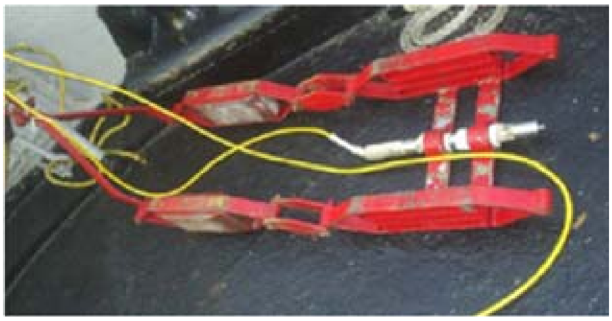

Fig. 2. Detection probe.

On-line radiometric mapping of the sea bottom

Gamma rays were measured dynamically with an average speed of 1.5 m/s, along profiles (250 m from each other) perpendicular to the coastal line. The detection probe (NaI(Tl)) scintillator 2" × 2") was mounted in a special support which kept a constant distance of 5 cm between probe and sea bottom (Fig. 2). Each profile had a length of several kilometres. Taking into account the boat speed of 1.5 m/s and the measuring interval of 30 s, then each measured value represents a length of around 50 m and this is acceptable in radiometric mapping of relatively large natural zones where sharp changes in sediment size and nature are not expected.

Treatment of radiometric field data

The plot of radiometric data was treated according to the following methods:

Treatment with a Gauss chart. For each lithology, the distribution of counting rates is normal, meaning its graph in Gauss chart is linear with a mean value characteristic of that kind of sediment. Two counting rate populations are considered significantly different when $I_1^* + s_1 < I_2^* - s_2$, where I_1^*, I_2^*, – are the mean values of two successive populations ($I_2^* > I_1^*$) and s_1, s_2 – are their standard deviations. Each radioactive population corresponds to particular sediment (lithology). To correspond lithology to radioactivity, several sediment samples were taken from the sea bottom and analysed in the laboratory (granulometric analysis).

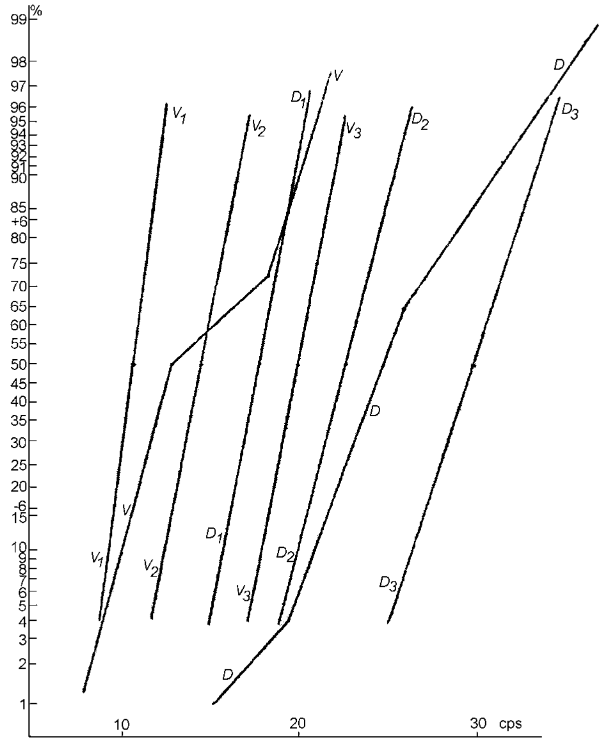

Fig. 3. Statistical distribution of sediment radioactivity in Vlora and Durres.

Figure 3 presents the distribution of radiometric data of sediments of Vlora and Durres plotted in the Gauss chart (x – counts per second, and y – frequency or probability in %).

Taking into account samples from these zones, the following relation radioactivity-lithology (granulometric classes of sediments) was found:

Gulf of Vlora:

$I_1^* = 11 \pm 1$ cps (sand grain size 100–200 μm),

$I_2^* = 14.5 \pm 1.5$ cps (sand grain size 63–100 μm),

$I_3^* = 19.5 \pm 1.5$ cps (silt < 63 μm).

There is a zone with mixed grain sizes, called alevrit (mixture of silt with very fine size of sand). The following correlation was found between the counting rates I (cps) and silt (argil) content in the alevrit Cs(%):

I (cps) = 14.5 + 0.05 × Cs(%).

Gulf of Durres:

$I_1^* = 17.5 \pm 1.5$ cps (sand grain size = 63–100 μm),

$I_2^* = 21.5 \pm 2$ cps (alevrit = 50% fine sand + 50% silt),

$I_3^* = 28 \pm 3$ cps (silt < 63 μm).

The relation counting rates-silt content for Durres was found as follows:

I (cps) = 17.5 + 0.105 × Cs(%).

Treatment with regressive analysis (trend surface analysis). Trend surface analysis is, in many respects, similar to the normal regression analysis [13]. "Trend"means the least squares trend. Given a set of data, and the desire to produce some kind of "model"of these data (model, in this case, meaning a function fitted through the data), there are a variety of functions that can be chosen for the fit. The trend surface analysis can, for example, be used to derive a continuous smooth surface from irregular data or isolating regional trends from local variations. Trend surface for natural radiation values are approached with a polynomial:

$$X(ui, vj) = P(ui, vj) + aij,$$

where: $X(ui, vj)$ – counting rate I measured at bottom point (ui, vj); $P(ui, vj)$ – most probable value; aij – error.

Figure 4 presents the isocount trend surfaces for bottom sea sediments in the gulfs of Vlora and Durres. The isocounting trend surfaces in Vlora are parallel to bathymetry lines, passing gradually from sand to alevrits up to silt (> 20 cps at a 15 m depth). This picture is a result of wave action coming mostly from the south-western direction perpendicular to the coast line, which seems to be the predominant factor of sediment transport normal with the beach line. There is no evidence of the sediment transport along the shore, at least at a 2–3 m depth.

The isocounting map in the Durres gulf shows the curved lines perpendicular to the shore line and ba-

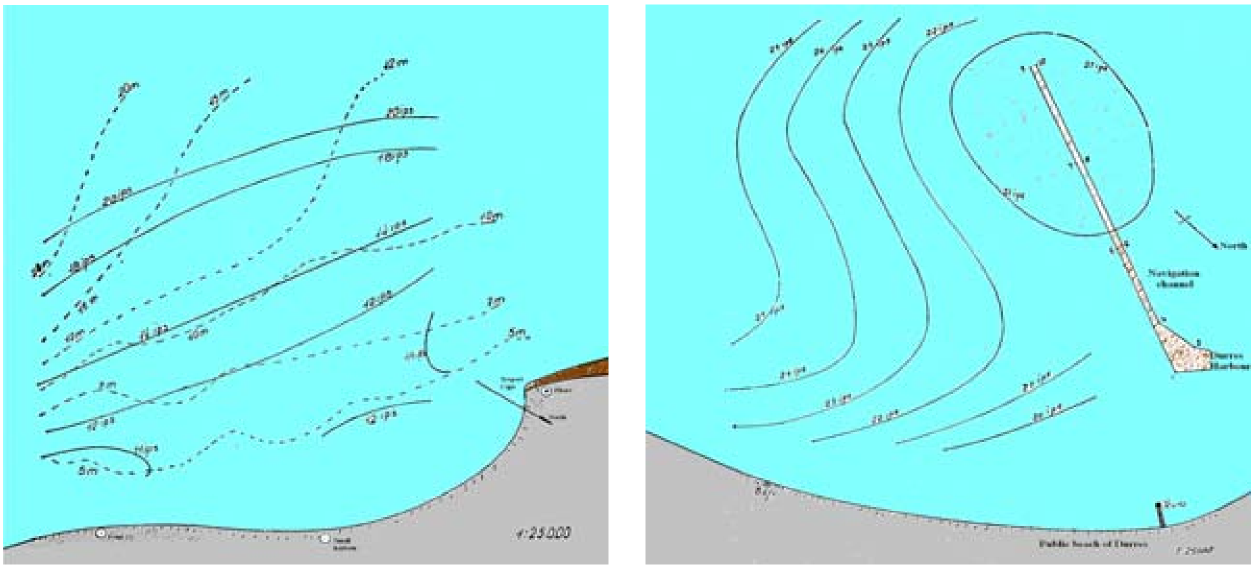

Fig. 4. Isocounting trend surfaces for sediments in the gulfs of Vlora (left) and Durres (right).

thymetry, that is characteristic of alongshore transport of alevrit sediments near the sea bottom.

Discussion of on-line gamma total counting rate measurements

Main conclusions obtained from the on-line mapping of gamma natural radioactivity in the Vlora and Durres gulfs are:
- Sediments in Vlora have a lower radioactivity for the same granulometry than in Durres and this reflects their origins from different land stratifications.
- The gulfs of Vlora and Duress have different lithological distributions; the sea bottom of Vlora consists mostly of sand, while the sea bottom of Durres contains mostly alevrits (a mixture of fine sand and silt).
- In the Vlora gulf there is a sediment selection in profiles, normal to the coast line, resulting under the influence of waves perpendicular to the shore line.
- In the Durres gulf no sediment selection is observed in profiles normal to the coast line; this could be explained as an alongshore transport of alevrit sediments near the sea bottom towards the harbour and its channel.

Radiometric profiles in the Durres navigation channel

Radiometric measurements along the navigation channel (on its axis and both sides) of the port of Durres (4 km long) were performed to obtain a silting map (Fig. 5). In fact, the channel was almost non-existent because it was filled up with sediments (estimated at around 1 million m^3 of sediments).

Correlation analysis of the counting rates vs. distances was used to find out any regulation in radiometric data along each profile. Correlation coefficient r determines the extent to which changes in the sediment radioactivity are associated with changes in distance from the beach; low r (< 0.5) indicates the radioactivity along the profile is nearly the same.

The results of four profiles measured at different periods were:

Fig. 5. The gulf of Durres, harbour, navigation channel and the main direction of sediment transport (red arrow) under the action of waves coming from the south-eastern direction.

- Profile 1: The average $I_{ch} = 22.6 \pm 0.5$ cps ($r = 0.22$),
- Profile 2: The average: $I_{ch} = 22.4 \pm 0.4$ cps ($r = 0.22$),
- Profile 3: The average: $I_{ch} = 22.1 \pm 0.3$ cps ($r = 0.25$),
- Profile 4: The average: $I_{ch} = 22.2 \pm 0.3$ cps ($r = 0.20$).

For the whole channel, the average value was calculated $I_{ch} = 22.3 \pm 0.5$ cps. This value of radioactivity is characteristic of alevrits (a mixture of very fine sand with silt in different proportions). There was a very good reproducibility of the measurements, which make them very reliable for interpreting even relatively small differences.

There was observed a significant difference between the average activities of the first (harbour entry) and the second (large sea) part of the channel: $I_{ch1} = 24.1 \pm 0.5$ cps (nearly 70% silt), while the second part: $I_{ch2} = 20.5 \pm 0.5$ cps (nearly 30% silt). This indicates that the first part of the channel (half of it near the harbour) is silted more than the second part.

The average activities of two parallel profiles, both sides of the channel, was found to be 21.0 ± 0.5 cps, a value similar to the activity of sediment within the second part of the channel. Comparison of radioactivity distributions within the channel and both sides of it indicates that the first half part of the channel is prone to higher silt deposition. The silt deposited mostly in the first part of the channel is coming very probably from the gulf centre (because they have the same radioactivity). Waves coming from the south-eastern direction move suspended silt towards the harbour, where silt settles down trapped by harbour structures.

Radiometric profiles of sediments to the south of Vjosa river

The Vjosa river mouth is nearly 15 km out of the gulf of Vlora, to the north of the river (Fig. 6). The Vjosa river has changed its position two times in the last century; the actual river mouth is located nearly 5 km to the north of the old river mouth. Consequently, the old mouth is undergoing important erosion process under the wave actions. Natural radioactivity of nearshore sediments was measured for investigation of the fluvial sediment

Fig. 6. Location of the Vjosa river mouth to the north of the gulf of Vlora.

distribution and the alongshore transport away from the mouth of the river (if any).

Radiometric measurements of beach sediments to the south of the Vjosa river were carried out in profiles normal to the shore line (from dunes up to a 1.5 m water depth). Along each profile, the radioactivity was measured in two stations: near the sand dunes, with a NaI 3" × 3" detector introduced 50 cm under the surface (4π geometry), and at the nearshore sea bottom (depth 1.5 m). Samples were taken also at the wet part of the beach (at shoreline) and analysed in the laboratory.

Figure 7 shows the results of radiometric survey of the sediments to the south of the Vjosa river. The investigated shore map is presented as well as the graphs of three sets of measurements in the dunes, nearshore and shore line. Graphs in horizontal scale (*x* axis) show the distance from the Vjosa river mouth, while those in vertical scale are the respective radiometric measuring units.

Both on-line measurements in the dunes and sea bottom have almost similar trends, while the sampling data show some deviations that were related more with sampling technique, and a relatively small quantity of samples that do not represent the whole site.

There are some assumptions helping the interpretation of radiometric data near river mouth shorelines [4, 5, 8, 10, 11, 14]. Normally, in open shorelines relatively far from the river mouth, erosion is characterized by a relatively high activity of sediments because under the wave action light and inert sediments (fine sand) leave the shore, while cohesive sediments (silt with higher radioactivity than that of sand) remain. Near the river mouth (both sides) there is another assumption; fluvial sediments (mostly sand) rich in heavy elements remain near the mouth showing higher activity, while the lower size grains (lighter) move along the shoreline under the effect of waves and currents. The decrease of sediment radioactivity away from the river mouth is almost exponential; the end of exponential curve indicates the end of sediment transport coming from the river mouth. The exponential curve characterizes an accretion zone, and just further the coast line is exposed to the erosion.

The above-mentioned assumptions should be carefully and creatively applied in local conditions. Visual inspection of the coastal line and comparison of different maps help interpretation of natural radiometric data.

Figure 7 indicates some phenomena that could be related with local erosion and accumulation processes, as well as allowing to judge of the distribution to the south of fluvial sediments. The erosion zone (visual inspection) nearly 5 km to the south of the Vjosa river mouth (where there is the old river mouth) helped interpretation of the radiometric data. Taking into account the alteration of accretion and erosion zones along the littoral south of the Vjosa river mouth, it could be assumed that there is not any dominant alongshore drift transport to the south of the Vjosa river, thus the influence of this river influence is limited to a few kilometres.

Summary

Natural radiometric survey of the sediments of sea bottom provided some qualitative sediment transport

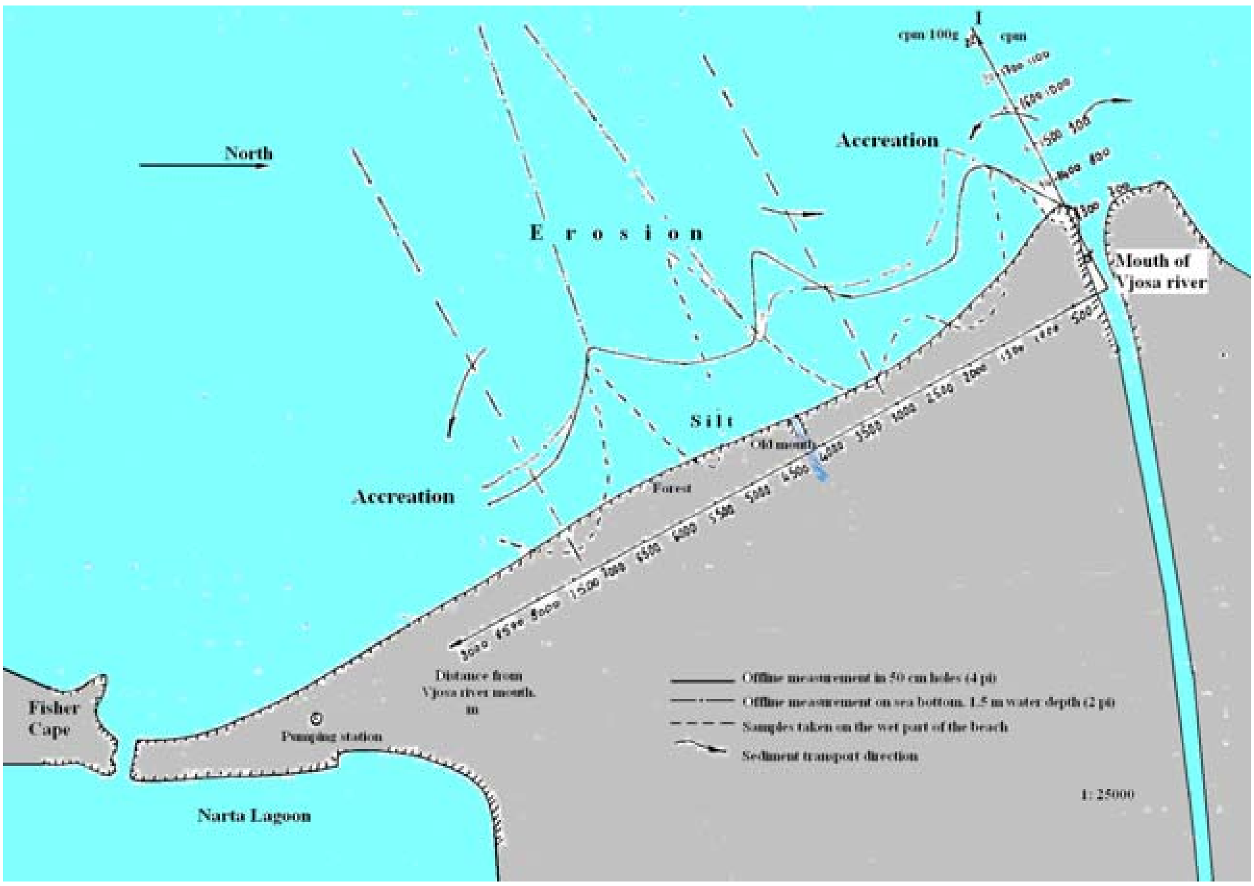

Fig. 7. Distribution of radioactivity of sediments to the south of the Vjosa river.

features, characteristics and parameters similar to those obtained with radiotracers, in particular, the resultant direction and mechanism of sediment transport were made evident. This simple and low-cost technique can be used for sediment transport studies as complementary to other techniques.

The radiometric survey of the sediments of sea bottom and beaches in the gulfs of Vlora and Durres has provided the following major conclusions:

Vlora

1. Waves coming from the west move sands normal to the beach line. The influence of waves of this sector is up to a depth of 15 m, where is the boundary between sand and silt.
2. There was an accumulation zone from the Vjosa river mouth up to nearly 3 km to the south, which was nourished by the fluvial sediments. From 3 to 7.3 km, there was another zone, which seemed to be in erosion. In this zone, there was the old mouth of the Vjosa river that is not bringing any more sediment, and consequently the zone was under erosion. Further to the south, is another accumulation zone nourished with sediments that are eroded above.
3. There were found alternating erosion and accretion zones to the south of the Vjosa river that indicate more a local transport phenomenon than any long distance alongshore drift transport in the investigated zone.

Durres

1. There was not any visible granulometric selection of sea bottom sediments in the gulf of Durres.
2. There was an indication of sediment transport trend from the south to the north of the gulf under the influence of waves coming from the southern sector.
3. There was evidence of silting process, in particular, in the first part of the navigation channel near the harbour.

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