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OROGRAPHIC RISKS OF BOTTOM TOPOGRAPHY AND SUSTAINABILITY OF THE SEA COASTS OF THE KALININGRAD REGION, RUSSIA

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This study analyses a particular type of geo-ecological risk which leads to intensive erosion of beaches and bottom abrasion. A structural and functional study of the nature of the recurrent danger for the coastal zone of the Kaliningrad region in Russia has shown the possibility of formation of intensive pulsed bottom currents with suspended solids. These bottom currents, combined with storm saturation of coastal waters with suspended solids and a "bad" bottom topography can permanently carry away significant amounts of suspended material, including sand, to the deep part of the sea.

GENERAL ASSUMPTIONS

It is well known that recreational resources of the sea coast are significant factors in sustainable development of the Kaliningrad region, Russia. For the Kaliningrad region, which is a typical coastal zone, it is vitally important to develop its recreational resources considering the ongoing global economic crisis. Unfortunately, the regional climatic conditions do not identify the region as favorable for all kinds of tourism (Stont et al., 2010). Only in July and August do coastal waters warm up well enough for public bathing. However, other coastal recreational opportunities have a much wider time range - from April-May to September and October. Meanwhile the sea coast, which is one of the most significant regional recreational features, can be regularly eroded and often irretrievably lose sand from its beaches. Therefore, a clear understanding of the basic laws governing the existence and evolution of the coast is absolutely necessary for the development of the Kaliningrad region.

The issues of Kaliningrad coastal morpholythical dynamics are covered in a number of papers (Atlas of geological..., 2010; Balayan and Babakov, 1989; Zamorskis, 2000; Lashchenkov et al. 1990) many of which state the likelihood of a quasi-stationary in time integral alongshore sediment transport, which, in fact, maintains sustainability of our coasts. However, in recent years, due to some changes in meteorological conditions (Stont et al., 2010), beaches "disappear" more often, coasts get eroded, and the base of the Curonean Spit gets partly destroyed. The features of processes of bottom sediment transport have been studied insufficiently. Consequently, the occurrence of significant accumulations of sand at a depth of 30 m and deeper has remained without any explanation (Atlas of geological..., 2010).

Meanwhile, the model calculations (Samolyubov, 1999; Gritsenko and Sviridov, 1999) have shown a high possibility of bottom density currents that can carry sand from the shore into deeper parts of the sea. Such a possibility of self-sustaining currents was identified by Barenblatt (1953). Currently many studies focus on intense bottom currents carrying sediments (Zhmur et al., 2002; Kirlis, 1990; Krylenko et al., 2014; Leontiev, 2008; Lashchenkov et al. 1990; Shuisky, 1982; Gritsenko and Sviridov, 1999; Hsu, 2004; Puig et al., 2004).

All these facts allow the consideration of intense bottom gravity currents carrying sediments during storm periods as a real threat to the safety of the sea coast in the Kaliningrad region. The occasional combination of such currents in the wave breaking zone along with the "bad" topography can generate the possibility of intensive erosion of coasts and abrasion of the bottom. After (Karlin et al., 2008; Muzalevskii and Karlin, 2011) these kind of dangers or threats can be identified as geo-ecological risks.

The physical and geographical components of the possible damage to the coastal zone through coastal erosion, bottom abrasion and irrevocable sand "retreat" from the wave breaking zone to a depth by bottom gravity currents (Boldyrev et al., 1990; Kirlis, 1990; Krylenko et al., 2014; Puig et al., 2004) allows us to classify this hazard as an orographic risk of bottom topography.

The aim of this work was to study the potential occurrence of conditions and a preliminary assessment of the possible existence of orographic risk of the bottom topography of the sea coast in the Kaliningrad region.

Let us now consider the main components of the natural system of the coastal zone, which determine the potential occurrence of suspended material transfer from the zone affected by winds and waves deeper into the sea.

THE ORIGIN OF WATER CARRYING SUSPENDED MATERIAL

It is well known that the inflow of sediment in the coastal sea area of the Kaliningrad region mainly results from of abrasion of the underwater slope and shore erosion. The impact of each component is not constant and depends on the specific geological and geomorphological structure of the coast.

In the alluviation of an artificial sandy beach in the Filinsakya bay (1987-1990) the amount of suspended solids in coastal waters along the underwater slope were monitored (Babakov, 2003; Blazhchishin et al., 1998; Leontiev, 2008; Shuisky, 1982). The measurements were performed on six stationary gauges at depths ranging from 5 to 20 meters at five different levels (20, 40, 60, 100 and 150 cm from the bottom). The predominance of the concentration of suspended material in the bottom half-meter layer was recorded along the surveyed coastline. At the shallow water stations (with ~ 5 m depth) from the bottom to the 0.4-0.6 m level sediment concentration decreases rapidly and then decreases slightly at higher layers from the bottom. Further away from the coast the vertical heterogeneity in the content of suspended material is reduced.

During a storm of moderate strength the suspended content ranged from 0.5 to 50-70 g/l in 5 cm bottom layer, with a mean value of about 10 g/l (Basinsky et al., 1978). Average monthly concentration of suspended solids in the bottom layers in the north of the Sambia Peninsula reached 15 mg/l in the wave breaking zone, dropping to values -4.5 mg/l at depths of 13-15m (Babakov, 2003; Blazhchishin et al., 1998).

It is known (Aibulatov, 1990; Longinov, 1963) that different components of the soil, washed out from the eroded coastal ledges, are involved in a cross (from and to the shore) and longitudinal (along the coastline) movement in coastal waters. Transport and redeposition of suspended material results in accumulative forms of relief - beaches, coastal and underwater shafts, bars and spits. Easily stirred and slowly sedimented fine silty material is carried away by the currents to the sea and reaches the bottom at great depths, where the silt-pelitic fraction begin to dominate the composition of sediments.

Instrumental measurements have shown (Babakov, 2003; Boynagryan, 1966; Lashchenkov et al., 1990) that the distribution of surface sediments at the bottom of the Svetlogorsk Bay are predominant alongshore distribution of sand and silt. The seaward boundary of fine sand and silt is usually within a 15-meter isobath. The outer areas of fine sand and silt up to 18-20 m were found. After extreme storms they were occasionally recorded up to a depth of 30 m. It should be noted that such outer areas of fine sand and coarse silt occasionally tended to spread eastward, which may result from the interaction of bottom gravity and alongshore surface currents.

So experimental studies revealed significant volumes of water with a high concentration of suspended material - more than 70 g/l during extreme storms in the wave-breaking zone. Such level of excess water density is more than enough for formation of intensive bottom currents (Samolyubov, 1999; Benjamin, 1968; Simpson, 1987), including catastrophic ones (Zhmur et al., 2002).

THE DEVELOPMENT OF THE RELIEF OF THE UNDERWATER SLOPE

It is well known (Aibulatov, 1990; Kirlis, 1990; Knaps, 1968) that noticeable bottom relief development occurs both over a long period of time (season or year), and over one storm which lasts 2 or 3 days. For example, storms in the Svetlogorsk Bay repeatedly deformed the profile of the bottom up to 4-5 m (Babakov, 2003; Shuisky, 1982). Also recorded were the sediment shifts of up to 300 thousand m^3 after storms of medium strength. Deformations of the bottom at this time were observed at a depth up to 17 m with maximum amplitude of about 2 m (Boynagryan, 1966). Comparative evaluation of the annual deformations to bottom relief and the rate of the Svetlogorsk Bay coastal retreat indicate an excess of abrasion intensity of bottom over the coastal erosion (Boldyrev et al., 1990; Lashchenkov et al., 1990). Echo sounding in 1974-1989 confirmed the high dynamics of bottom sediments of the Sambia Peninsula up to isobath 15-18 m (Babakov, 2003; Lashchenkov et al., 1990).

Consequently, underwater slope development has been shown to actually exist and it can be recorded instrumentally. Sedimentation and sand transport from the shore to the deep part of the sea is a real phenomenon.

COASTAL CURRENTS

It is obvious that the transfer of suspended material can only be carried out through progressive movements of water as various kinds of currents. The currents dominating the Baltic Sea coastal waters are wind, drift and bottom gravity currents. These types of currents can be briefly characterized.

It is a well-known fact (Aibulatov, 1990; Balayan and Babakov, 1989; Longinov, 1963), that in the event of drift coastal currents, an important role is played by the wind speed and its angle to the coastline. The longitudinal component of the wind and wave action creates the alongshore current while the latitudinal (transversal) one causes a surge of water, a water level change and compensational outflow of water towards the sea in the bottom layer.

The intensity of the alongshore and transversal sediment transport varies in space and is determined by varying power and the angle of wind, the magnitude of the surge, as well as the morphological features of the bottom and the shoreline (Knaps, 1968; Leontiev, 2008; Longinov, 1963).

It is recognized (Babakov, 2003; Leontiev, 2008) that towards the open sea the speed of bottom currents in the storm rapidly weakens. Extreme values of the speed at the northern coast of Sambia Peninsula were observed in the area of the largest waves breaking (depth 4-5 m) and reached 120-150 cm/sec. At depths of 15-20 m bottom currents did not exceed 30 cm/s, while maintaining stable alongshore orientation during storms. On the northern coast of Sambia Peninsula in Otradnyi at a depth 36 m some currents gained the speed of 55 cm/s (Babakov, 2003). It should be noted that these measurements were made on a small number of cross-sections.

Another important class of currents in the coastal zone is the dense currents of gravitational nature which go along the slopes. It is known (Hydrometeorology…, 1992; Simpson, 1987), that such currents can play a significant role in transferring suspended material from the coastal zone to the sea depths. The major views on the process of involvement and mixing on the borders of the bottom density currents were stated in the classical papers of Barenblatt (1953), Benjamin (1968) and Simpson (1987). Those studies resulted in the ideas on the basic elements of the currents structure, the phenomenological evaluation and models of involvement and mixing processes.

Through active engagement with bottom sediments and the ability to transfer the material suspended in the water bottom gravity currents can make a significant contribution to the dynamics of bottom sediments (Zhmur et al., 2002; Samolyubov, 1999; Puig et al., 2004). For example, in the Baltic Sea (Sviridov et al., 1997) the areas of inflow and distribution of dense water from the North Sea show a clear channel system formed through erosion activity of bottom gravity currents. Moreover, numerous studies of water dynamics in submarine canyons (Leontiev, 2008; Safyanov et al., 2007; Hsu, 2004) have shown that this kind of morphological features of the bottom relief are the main transport routes (as bottom gravity currents) for considerable volumes of water saturated with suspended material further into the sea during storms. Thus, the assessment of the impact on sediment material would be incomplete if it doesn't consider specific characteristics of bottom topography and their impact on the development of bottom gravity currents.

Experimental observations confirm the evidence of significant deformations of the shore and the bottom under the influence of storms. The presence of sand at the depth confirms the likelihood of sand transport further into the deep part of the sea. However, only almost stable and weak compensational currents which can hardly transport sediments to sea depth can be registered on the extended and relatively smooth bottom areas. Meanwhile, the entire volume of instrumental measurements of water speed was focused on the assessment of the medium, quasi-stationary currents. The lack of detail in the measurements could not let "notice" localized jet bottom currents and its influence on sediment transport from the wave breaking zone to the deeper part of the sea.

SMALL-SCALE FEATURES OF THE BOTTOM

Another aspect of the orographic risks to the coast of the Kaliningrad region deals with spatial characteristics of bottom topography. The bottom relief on our shores is rather complex. In this study we used the results of measurements of a single beam (and multibeam) echo sounder for first three kilometers from the Kaliningrad region coast obtained during monitoring conducted by State Organization of the Kaliningrad region "Baltberegozaschita". A representative set of data supported the bottom topography picture with a high spatial resolution for depth (0.5-1 m) up too isobaths 30 m (Figure 1) all along the coast.

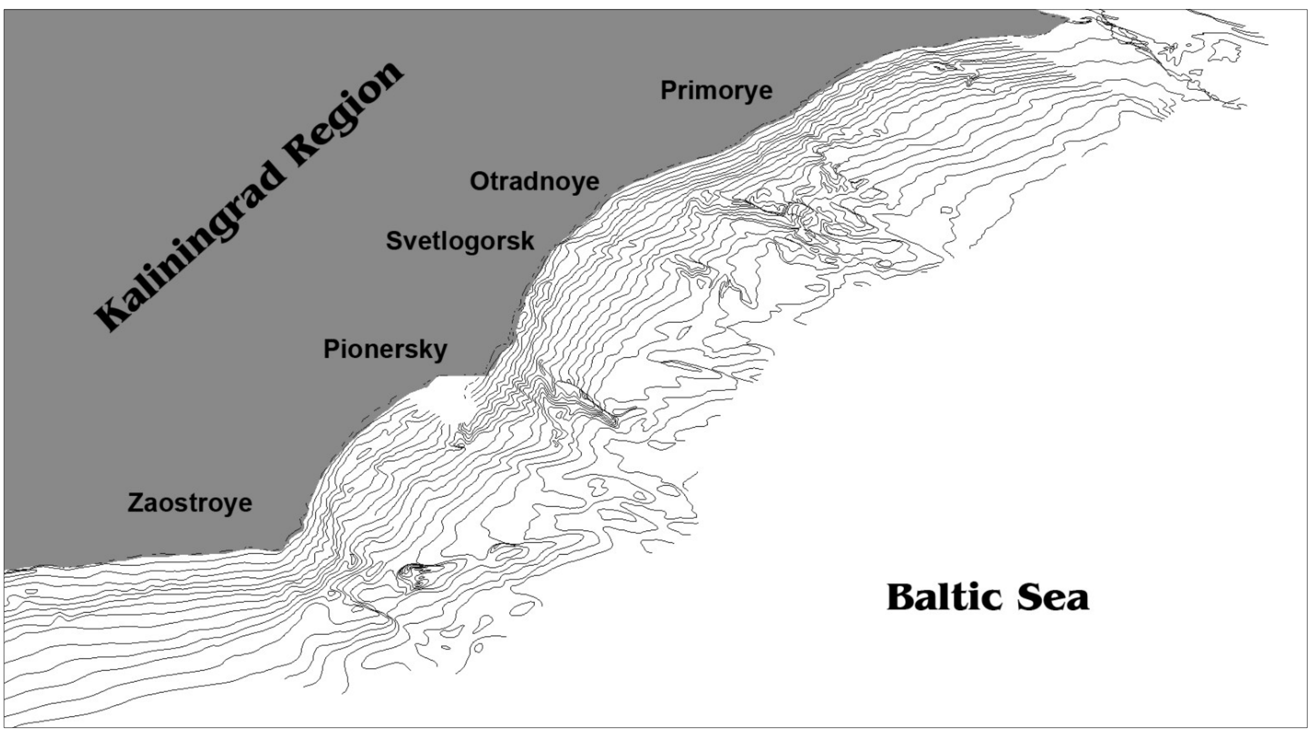

Figure 1. The bottom topography along the northern part of Sambia Peninsula from Cape Gvardeisky to Cape Taran. Isobaths (black lines) successively run from 0 to -30 meters values with 1 m interval. The view from the north-east.

Analysis of the data showed a significant spatial heterogeneity of the whole bottom topography. However, against the background of the Kaliningrad region coast there are clearly distinguished areas where the bottom surface varies a lot: the Svetlogorsk Bay, Cape Gvardeisky, Cape Taran and the area around village Sinyavino (near Yantarny). In these areas the charts recorded submarine "channel" systems on the bottom, which are characterized by high values of tilt angles. The maximum tilt angle values in the marked areas range from 1.5 to 2 degrees. In other parts of the coast of the Curonian and Vistula spits, from Yantarny to Baltiysk there are more gentle underwater slopes, with angles less than 0.7 degrees on average and the lack of the bottom irregularities.

In the area of the Svetlogorsk Bay, which is particularly important for the Kaliningrad region for recreation and tourism, there are several potential ways for beach material to "depart" from the shore to deeper sea (Figure 2). Bottom tilt angles in the vicinity of the marked channels (in Figure 2 they are marked with ovals) are on average 1 degree, in some areas reaching 2 degrees. As it has been shown in (Hsu, 2004), a self-sustaining gravity current transporting suspended material requires a bottom angle of no more than 0.5 degrees. The bottom angle of approximately 3 degrees (Zhmur et al., 2002) though can lead to catastrophic bottom currents which carry suspended material.

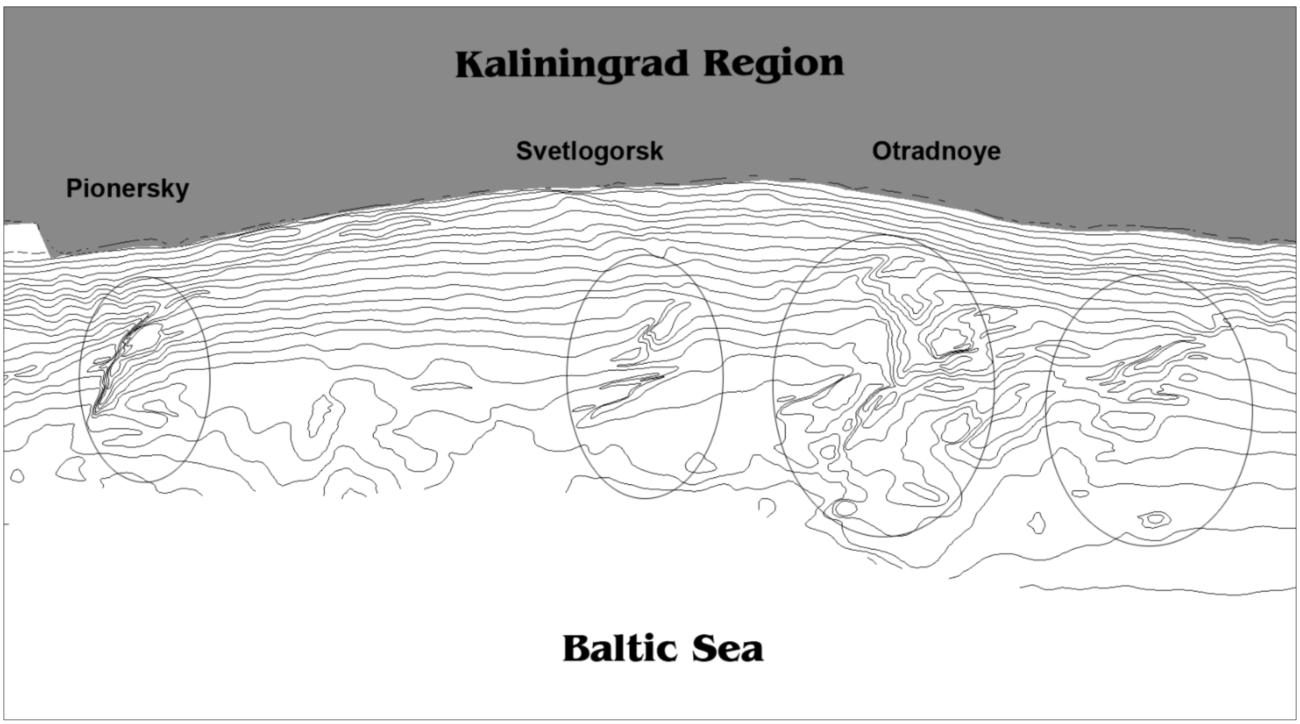

Figure 2. Features of the bottom topography in the vicinity of the Svetlogorsk Bay. The areas of potential "channels" of sand material transport to a depth during storms in the form of gravity currents carrying suspended material are marked with black ovals. Isobaths (black lines) successively run from 0 to -30 meters values with 1 m interval.

Thus, during storms material from the bottom and the beach (including sand of various fractions) may be carried as a gravity bottom current to a depth below the isobath of 30 meters along the marked "channels". The sand is carried away and cannot return to the beach, which leads to accumulations of sand at 30 m depths (Atlas of geological..., 2010). This process which is repeated in every storm leads to a deficiency of sandy material near the shore, intensive erosion and coastal retreat in these areas.

An indirect proof of the above scenarios can be found in the results of longterm observations of the coastal zone (Bobykina and Karmanov, 2014), which showed that in the areas with higher tilt angles and “bad” bottom the strongest coastal erosion is registered. So, while an average rate of coastal retreat is 0.1 to 0.25 meters per year, on the northern coast of Sambia Peninsula, near Cape Gvardeysky, Pionersky and Svetlogorsk, the rate of retreat reaches more than 1 meter a year. A similar situation is typical for the west coast, where the coast retreats in the areas with marked inhomogeneities, and in the areas with gentle underwater slopes the shore remains stable. These observations show a good correlation, on a qualitative level, between parts of the coast in the Kaliningrad region with strong erosion of beaches and isolated areas of the underwater slope, which are characterized with underwater "channels" on the bottom.

CONCLUSION

The analysis of the abrasion processes in the coastal zone of the Kaliningrad region allowed us to identify another type of geo-ecological risk affecting coasts - the orographic risk of bottom topography.

A structural and functional study of the nature of recurrent danger for the coastal zone in the Kaliningrad region has shown the possibility of development of strong short-lived bottom currents which carry suspended material. When coastal waters are saturated with suspended material during storms and it is combined with the bottom morphological features transverse to the shore, the currents of this class are capable of irreversibly carrying away significant amounts of suspended material, including sand, into the depths of the sea.

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REFERENCES

Aibulatov, N.A. 1990. Dynamics of solid matter in shelf zone. Leningrad, Gidrometeoizdat, p. 270.

Petrov, O.V. (ed.) 2010. Atlas of Geological and Environmental Geological Maps of the Russian area of the Baltic Sea. St Petersburg, VSEGEI.

Barenblatt, G.I. 1953. On the motion of suspended particles in a turbulent flow. Prikl. Mat. Mekh., Vol. 17(3), pp. 261-274.

Babakov, A.N. 2003. Spatial and Temporal Structure of Sediment Flows and Migration in the Baltic South-Eastern Coastal Zone (Sambia Peninsula and Curonian Spit). Ph.D. in Geography thesis. Kaliningrad, Kaliningrad State University.

Balayan, B.M., and A.N. Babakov. 1989. Alongshore currents in coastal zone of the Baltic Sea in Kaliningrad. Bulletin of the All-Russian Geographical Society, Vol. 121(4), pp. 329-334.

Basinsky, T., E. Onishchenko, N. Pykhov, and L. Oktaba. 1978. Ionization device for measuring the profile of suspended sediment concentration in the continental shelf. Coastal processes of non-tidal sea, Lyubyatovo-76, Gdansk, pp. 257-277.

Blazhchishin, A.I., A.N. Babakov, and V.A. Chechko. 1998. The concentration and composition of suspended sediment in Kaliningrad seashore waters. Issues of study and protection of the Curonian Spit. Kaliningrad, Institute of Oceanology RAS Press, pp. 31-58.

Bobykina, V.P., and K.V. Karmanov. 2014. To the geoecology of the Kaliningrad region coastline (monitoring results). Bulletin of the Kaliningrad State Technical University, Vol. 35, pp. 44-57.

Boynagryan, V.R. 1966. The morphometric analysis of the short-term changes in the relief of the coastal zone. Oceanology, Vol. 6(4), pp. 651-658.

Boldyrev, V.L., V.M. Lashchenkov, and O.I. Ryabkova. 1990. Storm shore erosion on the Kaliningrad coast, the Baltic Sea. Problems of the Shore Dynamics and Paleogeography of the Baltic Sea, Vol. 1, pp. 97-129.

Hydrometeorology and hydrochemistry of the seas of the USSR. The project of "Sea USSR". 1992. Saint-Petersburg, Gidrometeoizdat, Vol. 3, p. 451.

Žaromskis, R. 2000. The movement of sediment in the coastal zone of the south-eastern Baltic Sea. Water Resources, Vol. 27(1), pp. 53-62.

Zhmur, V.V., D.A. Sapov, I.D. Nechaev, M.V. Ryzhakov, and Y.V. Grigorieva. 2002. Intensive gravitational currents in the bottom layer of the ocean. Bulletin of the Academy of Sciences, Physics, Vol. 66(12), pp. 1721-1726.

Karlin, L.N., R.E. Vankevich, S.M. Tumanovskaya, and others. 2008. Hydrometeorological risks, a monograph. Saint Petersburg, Russian State Hydrometeorological University Press, p. 282.

Kirlis, V.I. 1990. The impact of the hurricane (extreme) storms in the shallow sandy beaches of the south-eastern part of the Baltic Sea. Problems of the Shore Dynamics and Paleogeography of the Baltic Sea, Vol. 1(1), pp. 83-96.

Knaps, R.D. 1968. On calculating the power of alongshore sediment transport in the sea. Oceanology,. Vol. 8, pp. 848-857.

Krylenko, V.V., R.D. Kosyan, M.V. Krylenko, and I.S. Podymov. 2014. Transport of solid material to the coastal zone near Gelendzhik after extremely heavy rains. Oceanology, Vol. 54(1), pp. 88-94.

Leontyev, I.O. 2008. An estimate of the cross-shore sediment flux at the boundary of the coastal zone. Oceanology, Vol. 48(1), pp. 132-138.

Lashchenkov, V.M., A.B. Kozhahmetov, and O.I. Ryabkova. 1990. The deformation of the underwater coastal slope of a bay of the south-eastern coast of the Baltic Sea. Problems of the Shore Dynamics and Paleogeography of the Baltic Sea, Vol. 1(1), pp. 52-66.

Longinov, V.V. 1963. The dynamics of coastal zone of non-tidal seas. Moscow, USSR Academy of Sciences, p. 379.

Muzalevskii, A.A., and L.N. Karlin. 2011. Environmental risks: theory and practice. Saint Petersburg, Russian State Hydrometeorological University Press, p. 448.

Samolyubov, B.I. 1999. Bottom Stratified Currents. Moscow, Nauch. Mir, p. 463.

Safyanov, G.A., V.L. Menshikov, and V.M. Peshkov. 2007. Submarine canyons - their dynamics and interaction with coastal ocean zone. Krasnodar, Edart-print, p. 392.

Sviridov, N.I., V.V. Sivkov, and M.V. Rudenko. 1997. Geological traces of bottom currents in the Gotland Basin of the Baltic Sea. Oceanology, Vol. 37,(6), pp. 928-935.

Stont, Z.I., B.V. Chubarenko, and O.A. Gushch. 2010. The variability of meteorological characteristics for the coast of south-eastern Baltic. Bulletin of the Russian Geographical Society, Vol. 142(4), pp. 48-56.

Shuisky, Y.D. 1982. Abrasion of the underwater slope in the eastern part of the Baltic Sea. Baltica, Vol. 7, pp. 223-234.

Benjamin, T.B. 1968. Gravity currents and related phenomena. J. Fluid Mech., Vol. 31, pp. 209-248.

Gritsenko, V., and N. Sviridov. 1999. Role of Storms in Formation of Turbulent Sea Currents in the Near-Shore Zone. Baltica, Vol. 12, pp. 28-31.

Hsu, K.J. 2004. Physics of Sedimentology. Springer, p. 240.

Puig, P., A.S. Ogston, B.L. Mullenbach, C.A. Nittriuer, J.D. Parsons, and R.W. Sternberg. 2004. Storm-induced sediment gravity flows at the head of the Eel submarine canyon, northern California margin. J. of Geophys. Res., V. 109, c03019.

Simpson, J.E. 1987. Gravity currents in the environment and the laboratory. England, Ellis Horwood Ltd., p. 244.

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