Risk assessment of hazardous abrasion and landslide processes in the coastal zone of the Azov Sea

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Abstract. The methodology was developed and the socio-economic risk of the manifestation of abrasion and landslide processes in the coastal zone of the Azov Sea was evaluated. The methodology includes assessing the degree of danger of coastal processes and determining possible material losses. The numerical index of socio-economic risk is calculated as the product of point estimates of these parameters. The main factors of dangerous coastal processes formation have been established, according to their similar combination in the coastal zone of the Azov Sea, 42 functional areas and the impact zone of hazardous abrasion and landslide processes predicted for a 20-year period have been identified. In the forecast zone, 112 socio-economic objects were identified that are subject to the influence of dangerous abrasion and landslide processes. For these socio-economic objects, using the standard set of tools of the public GIS service “Cadastral map of Rosreestr”, an enlarged calculation of possible economic damage has been made. The highest values of the socio-economic risk of the manifestation of abrasion and landslide processes in the coastal zone of the Azov Sea fall on abrasion and abrasion-landslide sections of the coast with a high rate of abrasion, a large number of capital construction projects and a high value of material losses.

1 Introduction

The length of the coastal zone of the Sea of Azov within Russia is more than 1000 km. On the coast there are urban and rural settlements, port facilities, industrial, social and recreational facilities, roads, electric lines, industrial and agricultural production is carried out, more than 2 million people live here.

The shores of the Azov Sea are subject to dangerous abrasion and landslide processes, which result in the destruction of coasts, residential and industrial buildings, industrial, agricultural and social facilities [1]. Since the southern coast of the Taganrog Bay and the eastern coast of the Azov Sea are characterized by the predominance of large agricultural areas, large agricultural holdings and a fairly low density of settlements, the considered

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hazardous processes primarily violate the integrity of agricultural lands, reduce the number of cultivated areas, and, ultimately as a result, they cause significant damage to the agro-industrial complex of the region.

In this regard, a comprehensive assessment of the current state of the coastal zone, determining the risk of dangerous coastal processes, analyzing the socio-economic and environmental consequences of their manifestation, developing measures to ensure safety and sustainable development of the coastal zone are important.

The works of many scientists are devoted to studies of the ecological state of coastal zone. Significant attention of modern researchers is given to studying theoretical and practical issues of coastal zone development [2]; managing of abrasion processes [3]; identification of problems of coastal zone erosion and pollution [4, 5]; studying of coastal ecosystems [6, 7]; assessing the effectiveness of initiatives for integrated coastal zone management for the formation of coastal sustainability [8]. The tasks of sustainable coastal zone planning [9] are being solved, an assessment of the human impact on the environment is assessed [10, 11], the ecological load on the coastal areas is being determined [12], and demographic forecasts for the coastal zone are being created within the framework of the general directions of the socio-economic development of the territory [13]. Existing studies emphasize the need for further development of methods for detecting changes in abrasion processes [14], control over the distribution of sediment [15]; analysis of created databases on coasts and inflammation of gaps existing in them [16].

The aim of the presented study is to develop a methodology and assess the socio-economic risk of dangerous abrasion and landslide processes in the coastal zone of the Azov Sea.

2 Materials and methods of research

According to ISO / IEC standards, risk assessment is a risk analysis and its qualitative or quantitative assessment. In accordance with ISO 31000: 2018, risk assessment is a single process of identification, analysis and risk assessment [17]. To assess the socio-economic risk of the manifestation of abrasion and landslide processes in the coastal zone of the Azov Sea, the danger of coastal processes was identified and possible material losses (damage) were determined. Socio-economic risk - R is calculated by the formula (1):

$$R = D \times M \quad (1)$$

Where D is the degree of danger of abrasion and landslide processes, M - material losses.

The methodology for assessing the socio-economic risk of the abrasion and landslide processes manifestation in the coastal zone includes:

- identification of the main factors in the formation of dangerous abrasion and landslide processes;
- allocation of elementary functional sections of the coast with the same combination of factors of formation of dangerous abrasion and landslide processes;
- identification of endangered socio-economic facilities in the coastal zone;
- assessment of the degree of danger of the manifestation of abrasion and landslide processes;
- assessment of possible material losses resulting from the manifestation of abrasion and landslide processes;
- definition of socio-economic risk and its significance for government.

Currently, the Southern Federal University and the Southern Scientific Center of the Russian Academy of Sciences are conducting research to study the geomorphological

features and patterns of formation of the shores of the Azov Sea, to identify and evaluate dangerous coastal processes [1, 18].

Based on these studies, the following main factors can be distinguished for the formation of dangerous abrasion and landslide processes in the coastal zone of the Azov Sea:

- type of coast and nature of coastal processes,
- activity manifestations of abrasion and landslide processes,
- type of economic activity and the nature of development of the coast.

In the coastal zone of the Azov Sea, abrasion, abrasion-landslide and landslide types of dangerous coastal processes are common.

By the nature of the manifestation of the danger, abrasion and landslide processes differ significantly. In general, abrasion processes are relatively uniform and to some extent predictable. Landslide processes are extremely uneven and unpredictable. Abrasion-landslide processes occupy an intermediate position. The activity of the manifestation of dangerous abrasion and landslide processes is determined by the speed of abrasion and the horizontal displacement of landslide bodies. The annual speed of wave destruction of abrasive shores varies between 0.1-6.0 m/year. The horizontal displacement of landslides is 0.1 - 3.3 m/year. Long-term studies [18] found that within the coast of the Azov Sea the average coastal retreat rates range from 1.0-1.5 m/year to 4.0-6.0 m/year. According to the activity of manifestations of dangerous abrasion and landslide processes, the coast of the Azov Sea was divided into zones with weak (less than 1 m/year), medium (1-2 m/year), severe (2-4 m/year) and very severe abrasion (more 4 m/year). About 30% of the coasts are characterized by severe abrasion, 33% of the coasts are covered by very strong abrasion [18].

By the type of economic activity and the nature of the settlement in the coastal zone of the Azov Sea, the following are distinguished: urban settlements and districts, rural settlements, summer cottages, farmland, natural landscapes.

The main technological factors that increase the degree of danger of abrasion and landslide processes in the coastal zone of the Azov Sea include: high density of settlements and intensive economic development of the coast, plowing of land, deforestation, development of irrigated agriculture in the coastal zone.

To take into account the main factors of the coastal zone formation when determining the degree of danger of abrasion and landslide processes, elementary functional sections of the coast were selected, which are homogeneous sections of the coastal zone with a certain (similar) combination of the main factors of its formation (Table 1).

Table 1. The allocation of functional areas in the coastal zone of the Azov Sea.

The main factors in the formation of the coastal zone			Functional area of the coast
Type of economic activity and nature of the settlement	Types of hazardous coastal processes	The speed of abrasion, m/year	Rozhkovskoye settlement with abrasion shore and medium abrasion
1. Urban settlements and counties 2. Rural settlements 3. Cottages 4. Farmland 5. Natural landscapes	1. Abrasion 2. Abrasion-landslide 3. Landslide	1. Weak - less than 1 2. Average - 1-4 3. Severe - more than 4	

The establishment of socio-economic objects subject to the influence of abrasion and landslide processes is carried out in separate functional areas. Such socio-economic facilities include settlements and detached houses, industrial, social and recreational

facilities, agricultural land, etc., located in the zone of the predicted impact of hazardous abrasion and landslide processes.

Given the great influence of anthropogenic factors that significantly change the conditions for the formation of coastal processes, socio-economic objects located in the coastal zone of urban districts (Taganrog, Yeysk, Primorsko-Akhtarsk) were not considered in this work.

The forecast period is assumed to be 20 years. Based on this, the width of the zone of impact of dangerous abrasion and landslide processes will be: offshore with weak abrasion 20 m, with medium abrasion - 40 m, with severe abrasion - 80 m.

Functional areas and socio-economic objects in the area of the predicted impact of hazardous coastal processes are identified on the basis of the study of cartographic material, satellite imagery, field research, and the collection and analysis of data characterizing the activity and social significance of these objects (Table 2).

For a qualitative assessment of the degree of danger of abrasion and landslide processes in the coastal zone, the system of scoring was used [19]. The degree of danger of abrasion and landslide processes was determined for the functional sections of the coast according to three parameters that characterize: N - the nature of the manifestations of hazardous processes; F - features of their distribution; O - the degree of danger to the population and the economy of hazardous processes. For each of the three parameters, criteria for determining scores have been developed - from 1 to 3 (Table 3).

Table 3. Criteria for determining the degree of danger of the manifestation of abrasion and landslide processes in the coastal zone of the Azov Sea.

Parameters of manifestation of abrasion and landslide processes	Score		
	1	2	3
K - type of hazardous coastal processes	Abrasion	Abrasion-landslide	Landslide
P - average coastal abrasion rate, m/year	Less than 1	1-4	More than 4
B - the number of socio-economic objects in the zone of abrasion	Less than 3	3-10	More than 10

The degree of danger of the manifestation of abrasion and landslide processes (Table 4) was calculated as the product of a point estimate of the above parameters (2):

$$O = K \times P \times B \tag{2}$$

Assessment of possible material losses was carried out for socio-economic facilities located in the zone of the predicted impact of hazardous abrasion and landslide processes. Using the standard set of tools of the public GIS service “Cadastral map of Rosreestr”, the areas of socio-economic objects, their cadastral value were determined and an enlarged calculation of possible economic damage was made (Table 2).

Material losses were converted into points using the following scale:

1 point - losses of less than 1 million rubles, 2 points - 1-5 million rubles, 3 points - 5-10 million rubles, 4 points - 10-50 million rubles, 5 points - 50-100 million rubles, 6 points - more than 100 million rubles.

Table 2. Functional areas and projected material damage in the coastal zone of the Azov Sea (northern coast of the Taganrog Bay).

	Functional coastal areas	Hazardous coastal processes	The speed of abrasion, medium (min-max)	Type of economic activity and nature of the settlement	The length of the site, km	The number of construction objects in the zone of abrasion	Projected material damage, thousand rubles		
							land plots	construction objects	total
1	Veselo-Voznesenovskiy -1	Abrasion	2.0 (0.2-5.6)	AGR	6.15	-	1 629	0	1 629
2	Veselo-Voznesenovskiy -2	Abrasion	2.0 (0.2-5.6)	RS	2.79	7	4 254	1 371	5 625
3	Bokovskiy -1	Abrasion	1.4 (0.1-6.4)	RS	1.11	-	693	0	693
4	Bokovskiy -2	Abrasion	1.4 (0.1-6.4)	SL	1.75	-	312	0	312
5	Rozhkovskiy-1	Abrasion	3.4 (0.4-6.4)	RS	1.24	3	3 354	1 598	4 952
6	Rozhkovskiy-2	Abrasion	0.4 (0.1-0.9)	SL	1.11	2	383	0	383
7	Beglitskiy-1	Abrasion	0.4 (0.1-0.9)	AGR	2.86	2	669	0	669
8	Beglitskiy-2	Abrasion - landslides	0.4 (0.1-0.9)	RS	3.38	2	1 346	0	1 346
9	Zolotokosovskiy	Abrasion	3.0 (2.0-4.0)	RS	4.28	14	11 321	16 414	27 735
10	Novolakodemo novskiy	Abrasion	0.3 (0.1-0.5)	RS	1.08	-	268	0	268
11	Russkoslobodskoy	Abrasion	0.2 (0.1-0.5)	RS	5.8	4	1 397	6 508	7 906
12	Botsmanovskiy	Abrasion	3.7 (0.8-6.5)	RS	3.09	40	8 088	50 158	58 246
13	Petrushinskiy	Abrasion	0.4 (0.2-0.8)	RS	7.73	1	229	3 529	3 758
14	Primorskiy	Abrasion - landslides	0.2 (0.1-0.3)	RS	3.12	-	830	0	830

15	Merzhanovsky	Landslide	0.2 (0.1-0.2)	GNP	15.8	-	-	-	-
TOTAL:							34 779	79 580	114 359

RS - rural settlements
LS - lands of settlements (residential and recreational zone)
AGR- agricultural land and agricultural land
GNP- garden non-profit partnerships

The calculation of the numerical index of socio-economic risk was carried out in accordance with the above formula, as a product of point estimates of the degree of danger of coastal processes and material losses (Table 4).

Table 4. Risk assessment of hazardous abrasion and landslide processes in the coastal zone of the Azov Sea (northern shore of the Taganrog Bay).

	Functional area of the coast	Danger Parameters			Danger Degree $O = K \times P \times B$	Material loss ratio M	Numerical risk index $R = O \times M$
		K	P	B			
1	Veselo-Voznesenovskiy -1	1	2	1	2	2	4
2	Veselo-Voznesenovskiy -2	1	2	2	4	3	12
3	Bokovskiy -1	1	2	1	2	1	2
4	Bokovskiy-2	1	2	1	2	1	2
5	Rozhkovskiy-1	1	3	2	6	3	18
6	Rozhkovskiy-2	1	1	1	1	1	1
7	Beglitskiy-1	1	1	1	1	1	1
8	Beglitskiy-2	2	1	1	2	2	4
9	Zolotokosovskiy	1	3	3	9	4	36
10	Novolakodemonovskiy	1	1	1	1	1	1
11	Russkoslobodskoy	1	1	2	2	3	6
12	Botsmanovskiy	1	3	3	9	5	45
13	Petrushinskiy	2	1	1	2	2	4
14	Primorskoy	2	1	1	2	1	2
15	Merzhanovskiy	3	1	1	3	1	3

3 Results and discussion

In the coastal zone of the Azov Sea, 42 functional areas have been identified, characterized by the same type of combination of the main factors in the formation of dangerous coastal processes. This made it possible to predict the development of dangerous coastal processes taking into account the specific natural and anthropogenic conditions of each section of the coastal zone.

In the projected for a 20-year period impact zone of hazardous abrasion and landslide processes there are 112 socio-economic facilities, including residential buildings, industrial facilities, educational institutions, hotels, etc., of which 75 are located on the northern shore of the Taganrog Bay, 13 are located in the southern coast of the Taganrog Bay and 24 on the eastern coast of the Azov Sea (Table 5).

Table 5. The main indicators of the predicted impact of abrasion and landslide processes in the coastal zone of the Azov Sea.

Coastal areas	Number of functional areas	Number of socio-economic objects	Material losses. million rubles		
			land plots	construction objects	Total
The northern coast of	15	75	34.8	79.6	114.4

the Taganrog Bay					
The southern coast of the Taganrog Bay	18	13	261.3	11.3	272.5
The eastern coast of the Azov Sea	9	24	220.2	184.0	404.2
Total	42	112	516.3	274.9	791.1

The increased hazard values for the manifestation of abrasion and landslide processes in the coastal zone of the Sea of Azov are distinguished by abrasion and abrasion-landslide sections of the coast with a high rate of abrasion and a large number of capital construction projects.

Possible material losses due to the manifestation of abrasion and landslide processes in the coastal zone of the Azov Sea during the forecasted 20-year period will amount to: 114.4 million rubles for the northern coast of the Taganrog Bay, 272.5 million rubles for the southern coast of the Taganrog Bay, the eastern coast of the Azov Sea is 404.2 million rubles, a total of 791.1 million rubles. (Table 5).

The structure of economic damage is dominated by losses associated with the loss of farmland due to their large area and relatively low development of the southern coast of the Taganrog Bay and the eastern coast of the Sea of Azov. The numerical index of socio-economic risk of the manifestation of abrasion and landslide processes in the coastal zone of the Azov Sea varies from 1 to 48. The most dangerous areas of the manifestation of abrasion and landslide processes in the coastal zone of the Azov Sea are: Peresyp - numerical risk index 48, Botzmanovsky - 45, Zolotokosovsky - 36, Rozhkovsky-1 - 18.

4 Conclusions

1. The developed methodology for assessing the socio-economic risk of the manifestation of abrasion and landslide processes includes assessing the degree of danger of coastal processes and determining possible material losses. The numerical index of socio-economic risk is calculated as the product of point estimates of these parameters.

2. The highest values of the socio-economic risk of the manifestation of abrasion and landslide processes in the coastal zone of the Azov Sea fall on abrasion and abrasion-landslide sections of the coast with a high rate of abrasion, a large number of capital construction projects and a high value of material losses.

3. The projected material losses from the impact of hazardous abrasion and landslide processes in the coastal zone of the Azov Sea over a 20-year period will amount to 791.1 million rubles, of which 274.9 million rubles are accounted for by capital buildings and 516.3 million rubles on land, mainly agricultural land.

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