UDC 56.545

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HAZARDOUS PHENOMENA IN THE SLIDES ZONE OF THE UKRAINIAN SECTION IN AZOV SEA

М. А. Берлінський, М. О. Сагайдак. НЕБЕЗПЕЧНІ ЯВИЩА У ЗСУВНІЙ ЗОНІ УКРАЇНСЬКОЇ ДІЛЯНКИ АЗОВСЬКОГО МОРЯ. *Довготривалі спостереження за зсувними процесами в Україні свідчать про стабільні зсувні процеси на узбережжі Чорного і Азовського морів з активізацією в осінньо-весняний період. Активізація зсувів відбувається під впливом техногенних та природних факторів, з яких найбільш суттєвим є абразія берегів. Суть роботи полягає в оцінці факторів, відповідальних за* зміни прибережної зони *Азовського моря в сучасний період, таким чином, мета роботи - визначення причин формування динамічно нестабільних ділянок берегів і можливості захисту берегів, предмет - зсувні процеси, як результат абразії берегів, об'єкт - мінливість природних і антропогенних умов українського узбережжя Азовського моря. У береговій зоні Азовського моря в цілому виявлено циклічність різного ступеня швидкості абразії від 1 до 4 м·год$^{-1}$ (у виняткових випадках до 15м в рік). Високі швидкості руйнування берегів зафіксовані в періоди 2004-2005 та 2013-2014 рр., що пов'язано зі збільшенням повторюваності нагінних вітрів і хвилювань, катастрофічних підйомів рівня на південній ділянці моря і падінь рівня – на північному. Сильні згони та нагони не тільки порушують нормальну роботу цілого ряду промислових і виробничих об'єктів, а й іноді набувають характеру стихійних лих. При значних підйомах рівня можливе затоплення портів, зокрема причалів, руйнування гідротехнічних споруд, складських приміщень, житлових будівель. У східних районах азовського узбережжя України відзначається дефіцит наносів і відзначена висока ступінь мінливість абразійній форми прибережно-морського рельєфу, а в західних і північно-західних формується надлишок наносів. З 2007 року по теперішній час середньорічні величини перевищення рівня Азовського моря над затокою Сиваш збільшилися до 10-13 см.*

Ключові слова*: Азовське море, зсувна зона, абразія і седиментація, мінливість рівня моря.*

Н. А. Берлинский, М. А. Сагайдак. ОПАСНЫЕ ЯВЛЕНИЯ В ОПОЛЗНЕВОЙ ЗОНЕ УКРАИНСКОГО УЧАСТКА АЗОВСКОГО МОРЯ. *Долговременные наблюдения за оползневыми процессами в Украине свидетельствуют о стабильных оползневых процессах на побережье Черного и Азовского морей с активизацией в осенний и весенний периоды. Активизация оползней происходит под влиянием техногенных и природных факторов, из которых наиболее существенным является абразия берегов. Суть работы состоит в оценке факторов, ответственных за изменение прибрежной зоны Азовского моря в современный период, таким образом, цель работы – определение причин формирования динамически нестабильных участков берегов и возможности защиты берегов. Предмет - оползневые процессы, как результат абразии берегов, объект – изменчивость природных и антропогенных условий украинского побережья Азовского моря, объект – изменчивость природных и антропогенных условий украинского побережья Азовского моря. В береговой зоне Азовского моря в целом выявлена цикличность различной степени скорости абразии от 1 до 4 м·год$^{-1}$ (в исключительных случаях до 15м в год). Высокие скорости разрушения берегов зафиксированы в периоды 2004-2005 и 2013-2014 гг., что связано с увеличением повторяемости нагонных ветров и волнений, катастрофических подъемов уровня на южном участке моря и падений уровня – на северном. Сильные сгоны и нагоны не только нарушают нормальную работу целого ряда промышленных и производственных объектов, но и иногда приобретают характер грозных стихийных бедствий. Установлено, что в восточных районах азовского побережья Украины отмечается дефицит наносов и отмечена высокая степень изменчивости абразионной формы прибрежно-морского рельефа, а в западных и северо-западных формируется избыток наносов. С 2007 года по настоящее время среднегодовые величины превышения уровня Азовского моря над заливом Сиваш увеличились до 10–13 см.*

Ключевые слова*: Азовское море, оползневая зона, абразия и осадконакопление, изменчивость уровня моря.*

Problem statement. According long-term data analyses under the slides zone in Ukrainian part of the Azov sea sustainable processes had been marked. Landslides are most active in autumn and spring. The activation of landslides occurs under the influence of man-made and natural factors. The most significant factor is coastal abrasion [1]. As a result of landslide processes, the infrastructure of the sea coast, civil buildings and port facilities are destroyed, and the recreational zone is degraded.

The essence of the work is to evaluate the factors responsible for changing the coastal zone of the Azov Sea in the modern period, therefore, **the purpose of the work** is to determine the reasons for the formation of dynamically unstable sectors and the possibility of protecting the shores, **the subject** is landslide processes, as the result of the abrasion of the shores, **the object** is the variability of the natural and anthropogenic conditions of the Ukrainian coast of the Azov Sea in the area of interaction between the sea and land, or, using ecological and biological terminology, the so-called interstitial area of the sea, which is also very important from the point of view of preserving the native hydrobionts and the development of hydrobiological processes.

The study of the current state of the Ukrainian coast of the Sea of Azov is absolutely necessary. At present, negative trends are developing in the pro-

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https://doi.org/10.26565/2410-7360-2021-54-02

cess of deformation of the coastal part of the sea. Understanding of their causes will prevent significant damage to the infrastructure of the region by natural factors, in particular climatic, and possible man-made impacts. It is an important condition for the development of the economy, the recreational potential of the region and increasing the social level of the population.

Review of previous publications. The scientific literature notes modern climate changes in the atmosphere, which have led to changes in the ocean climate also. These changes affected not only the air temperature and precipitation, the temperature and salinity of sea waters, but also the hydrometeorological regime of the coastal zone and the water balance in the Black and Azov Seas. The rise in sea level has intensified over the past decades. All these changes found a response in the coastal zone, which reacted to them and acquired the corresponding trends. The impact of anthropogenic and natural factors affected to the composition of sea water of Ukraine and ultimately influenced to the nature of the flora and fauna on the coastal zone. The native characteristics of the coastal zone as an integral part of the World Ocean and its subdivisions, including the Black and Azov Seas, began to change. At the same time, long-term observations of landslide processes in Ukraine indicate to the development of stable landslide processes on the coast of the Black and Azov Seas with their activation in the autumn-spring period [1-4].

Since 2011 the annual reports "National Report on Technogenic and Natural Safety in Ukraine" of State Service of Ukraine for Emergency Situations is published by landslides in the coastal zone of the Azov Sea, the analysis of which was used in the present work. In addition, the expeditionary studies of the Black and Azov seas coastal zone are made by the staff of the Department of Physical Geography and Natural Management of the Odessa National University and researchers of the Institute of Sciences of the Earth of the Southern Federal University of Rostov on Don. The results of observations indicate the need to seriously attract attention to the problem of safety and rational use of the coastal zone of the sea, in particular partial decision with the help of artificial coastal hydroconstructions.

Previously unresolved parts of a common problem. Methods. It should be noted that there has been a sharp decline in thematic studies of the sea coast in the last five years. This is most likely due to economic reasons, i.e. reduction of targeted funding and, and lack of modern equipment in local research centers. In fact, this work is the first attempting to analyze the available retrospective material using modern satellite monitoring data to assess the prospects for the development of special nodes on the coast of the Azov Sea. To restore this gap, the physico-geographical and geomorphological data of the studying area were used, that including the adjacent coast, which is under the direct influence of the Azov Sea. A comparative analysis of modern hydrometeorological conditions, including the dominant influence of wind activity and sea level fluctuations, has been carried out. Images from Digital Globe's Earth remote sensing satellites and GNSS observations on the geodetic network were studied. Retrospective data of bathymetric surveys, using GIS technologies, standard methods of statistical data processing and national reports on the state of technogenic and natural safety in Ukraine were used. For the analysis of sea level, data from the tide gauge of the State Emergency Service of Ukraine installed in the port of Mariupol were used. The monitoring under the dynamics of landslides, a geodetic network was developed (points were laid for centering the GNSS receivers) in order to identify the exact values of the soil displacement.

Results and discussing. Among the technogenic factors influencing to the processes of sedimentation in the Azov Sea at the present stage, it is necessary to highlight the regulation of river runoff and emissions of pollutants, which cause the restructuring of the ecosystem of the reservoir. Industrial and agricultural production, the activities of port services, shipping and dredging, dumping, and recreational using of the coastline also determine the diverse and intensive input of man-made material into the water area (fig. 1). The volumes of the incoming technogenic material are comparable to the volumes of modern natural sedimentation, and sometimes exceed it [5]. At the same time, the modern state of the shores of the Azov Sea, as well as the Black Sea, is characterized by the predominance of abrasion processes. The shores, which are composed mainly of loess-like loams, underlain by Scythian clays, Khaprovsky and Tanais sands, are subject to destruction.

This is how the balance of flow and sedimentation is formed at present, an acute deficit of sediments, which developed during the Holocene, is becoming more and more evident [6-9]. As a result, the main amount of wind-wave energy is spent not on sediment movement, but on changing the abrasion forms of the coastal-sea relief.

On the other hand, the shores of Ukraine are mainly composed of sedimentary rocks of the Neogene-Paleogene age. They are represented by clayey rocks, clays, loams and sandy loams, which noticeably react to moisture, undergo disintegration and dissolution. Some of the rocks are represented by rock varieties, mainly limestones (shell, bryozoan, oolitic), partially – sandstones, shales and igneous rocks. They are subject to abrasion and dissolution. In many areas, the rock layers are crumpled, diluvial

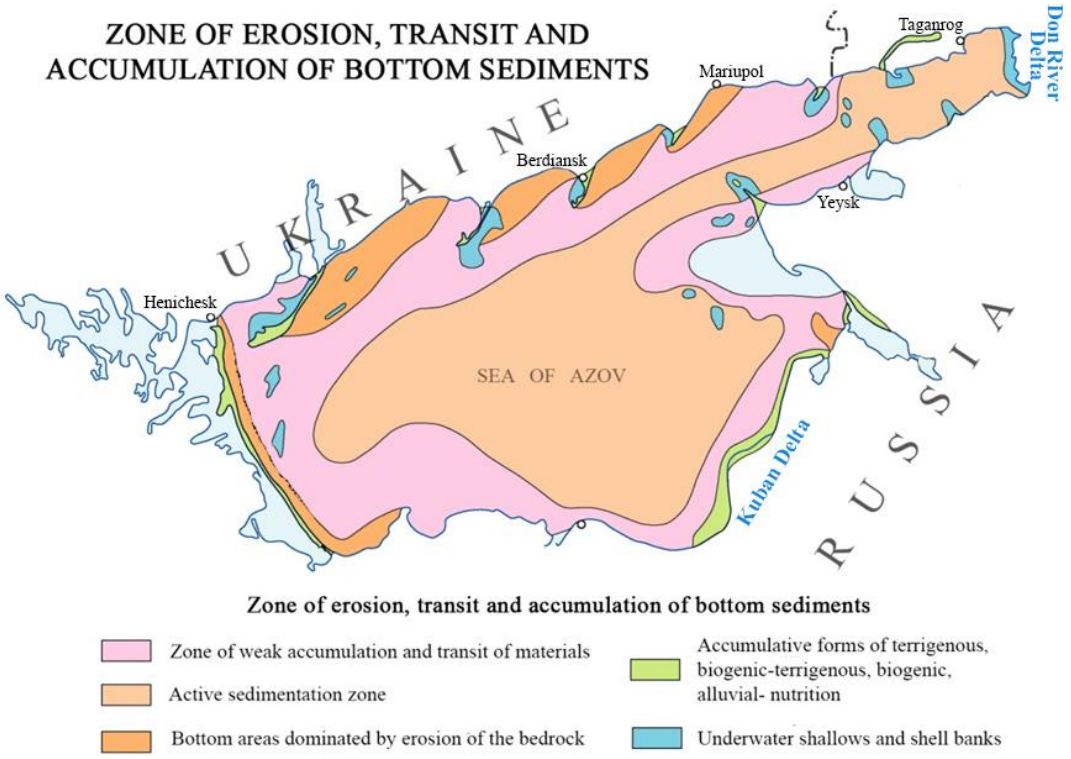

Fig. 1. Zones of erosion, transit and accumulation of bottom sediments, according to [7]

deposits are widespread [6, 7]. Therefore, it is necessary to take into account that the strength of rocks of IV-V classes prevails in terms of the degree of abrasion resistance, on which not only the abrasion rate depends, but also the lithodynamic abrasion ability. In this regard, in reality, it was a typical natural process during the Holocene period of the formation of the modern coastal zone (fig. 2). The transgression was reflected unevenly along the sea coast. Sea waters moved faster into river valleys and into the bottoms of folds of the earth's crust. As a result, ingression bays were formed, which later turned into estuaries and lagoons. The watersheds between them stood on the path of transgression and were subjected to abrasion shear. In the Upper Holocene, an active leveling of the coast began due to the cutting off of bays, estuaries and lagoons by barrows, as well as due to the abrasion of cliffs. Such a general abrasion cut mobilized a significant amount of sedimentary material, which was spent on the formation of barrows, spits and terraces of coastal-marine origin. In some areas, these forms are composed of shell material, in particular, the majority – on the Azov Sea (Arabat Strelka, "Azov type" spits).

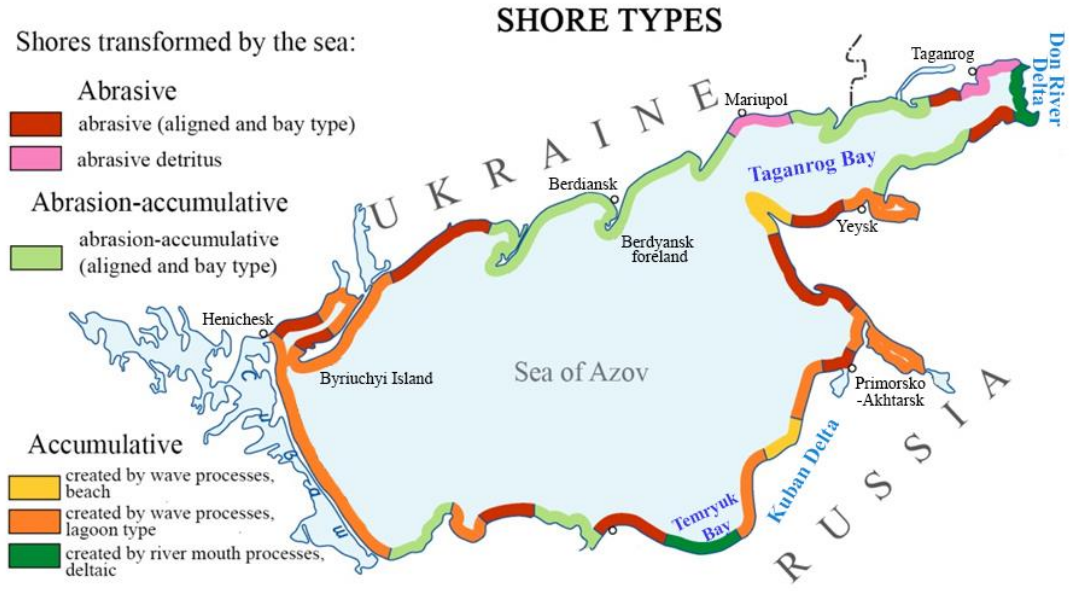

Fig. 2. Types of banks. According to [7]

The dynamics of the waters of the Azov Sea forms marine accumulative landforms as a result of the accumulation process, i.e. accumulation and sedimentation of suspended matter. These formations include numerous spits of the Azov Sea. On the coast, on the slopes of the valleys, detachment and movement of rock masses occur, causing rock falls, talus and landslides, which form gravitational landforms. They are typical for places where a large height difference and the presence of an aquifer, as well as mechanical loads, are combined. Landslides lead to significant destruction and costs in the restoration of various objects. By origin, the basin of the Sea of Azov is a neotectonic depression on the border of the East European platform and the Mediterranean mobile belt. Therefore, the relief of the bottom of the sea and its bays is monotonous: the slope, steep enough for the coast, turns into a flat bottom, in the center of which the greatest depths are observed. The strata of rocks prone to the development of exogenous geological processes in them is composed of Paleogene, Neogene and Quaternary deposits [9]. A large number of spits is a characteristic feature of the shores of the Azov Sea. All braids of this region are located in the zone of faults in the earth's crust, and their direction coincides with the direction of these faults. The zones of deep faults were an important belief-forming factor, since they contributed to the braking of the flow of the nanos and the formation of accumulative forms. There are braids in the east and south. However, there are spits oriented deep into the Sea of Azov only on the northern coast, this is the result of the long-term operation of sea waves and currents that have washed up shell rock along the coast (fig. 3). The velocities of currents in the bottom layer of the sea, caused by the action of storm winds, reaching values of 0.59 $m \cdot s^{-1}$, can cause intense lithodynamic processes in the coastal zone of the Sea of Azov (fig. 4) [10, 11].

Sea level rising from 1977 to 2002 was linked with an increasing of the western component of the winds, which led to an increase in the frequency of surges, both in the Taganrog Bay and in the Azov Sea itself, as well as an increase of the amount of precipitation brought by western winds from the Atlantic [13]. At the same time, the average annual level of the Azov Sea tended to increase. The maximum average monthly levels were observed in June-July, the minimum – in October-November. In the coastal zone for the whole Azov Sea, a cyclicity of varying degrees of abrasion rate from 1 to 4 m high rates of coastal destruction were recorded in the periods of 2004-2005 and 2013-2014, which is linked with an increasing of the frequency of surge winds and waves, catastrophic level rises in the Southern part of the Sea and level drops in the Northern one [14, 15].

Fluctuations of the level of the Azov Sea are caused by many factors acting simultaneously and, in turn, are often reflected in abrasion processes. At the Sea, two main types of level fluctuations can be distinguished – volumetric perennial and displacement (surge and seiche). The largest range of fluctuations is linked with the upwelling and down welling phenomena. Strong Westerly and Southwesterly winds bring water from the Sea of Azov to the Taganrog Bay and create backwaters at the mouth of the Don. Eastern and Northeastern winds, the most likely in the Taganrog Bay, on the contrary, drive the water away, reducing its volume in the bay. With significant level rises, the flooding of ports, in particular, berths, destruction of hydraulic structures, storage facilities, and residential buildings is possible. With a significant decreasing of the Sea level, the depth in the approach channels decreases, which disrupts the operation of the fleet. Oscillations near the shores of the Taganrog Bay are the largest for the entire Azov Sea. Strong wind surges disrupt the normal operation of a number of industrial facilities and sometimes they take on the character of formidable natural disasters. As an example, private landslides in the Donetsk region should be noted: Mangush and Novoazovsky districts, Priazovsky district in Zaporozhye region. It has become catastrophic phenomena in the area of the Azov Sea coast in the last 10-12 years.

The average long-term sea level in the port of Mariupol, calculated from 1923 to 2007, is 471 cm. The average long-term level for the last 30 years (1977-2007) is 480 cm. The registered maximum level – 600 cm was 07/06/1985, and the minimum – 324 cm 11/11/1993 According to the Navigation of the Black and Azov Seas: 540 cm – critical during the water surge; 560 cm – dangerous during surge; 601 cm - spontaneous during the surge; 430 cm – critical when water driving; 411 cm – dangerous when water driven; 351 cm – spontaneous when water driven. When considering monthly average levels in the port of Mariupol from 1985 to 2016 and plotting a trend line, an increasing in sea level in the coastal area was noted (fig. 5).

In the figure 5, the value of the vertical axis is referred to November 2010, when, according to the State Emergency Service of Ukraine, the landslide process intensified and a new landslide block was formed. At the same time, from January to August 2010, an average monthly elevated sea level was recorded from 486 to 508 cm, and in February and March 2010, the maximum values of the level of 551 and 538 cm, respectively, were recorded, which is practically a critical level during a surge wind. Unfortunately, in the 80-90s of the last century, modern, profile observations were not carried out, and the geodetic network created in this research

Fig. 3. Bottom sediments, according to [7]

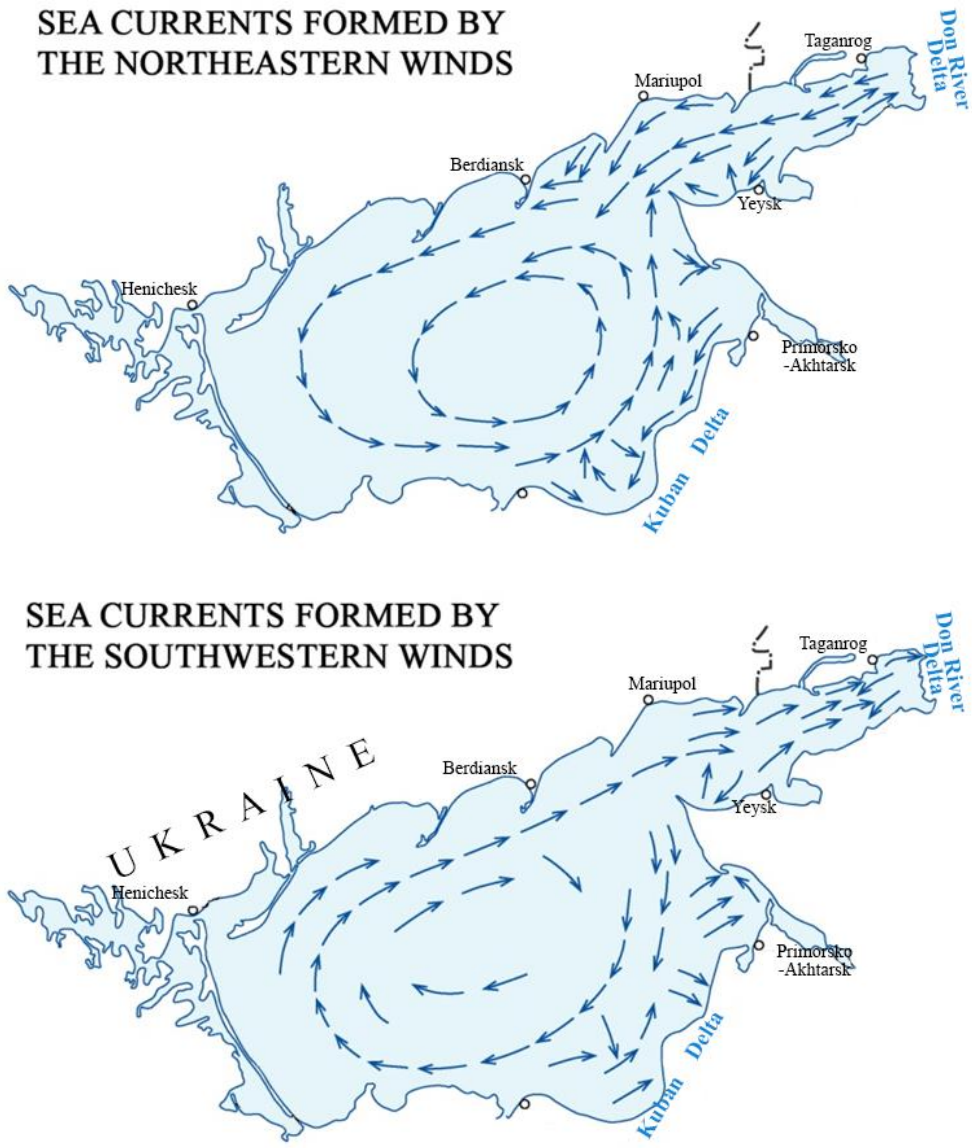

Fig. 4. Wind currents of the Sea of Azov, according to [12]

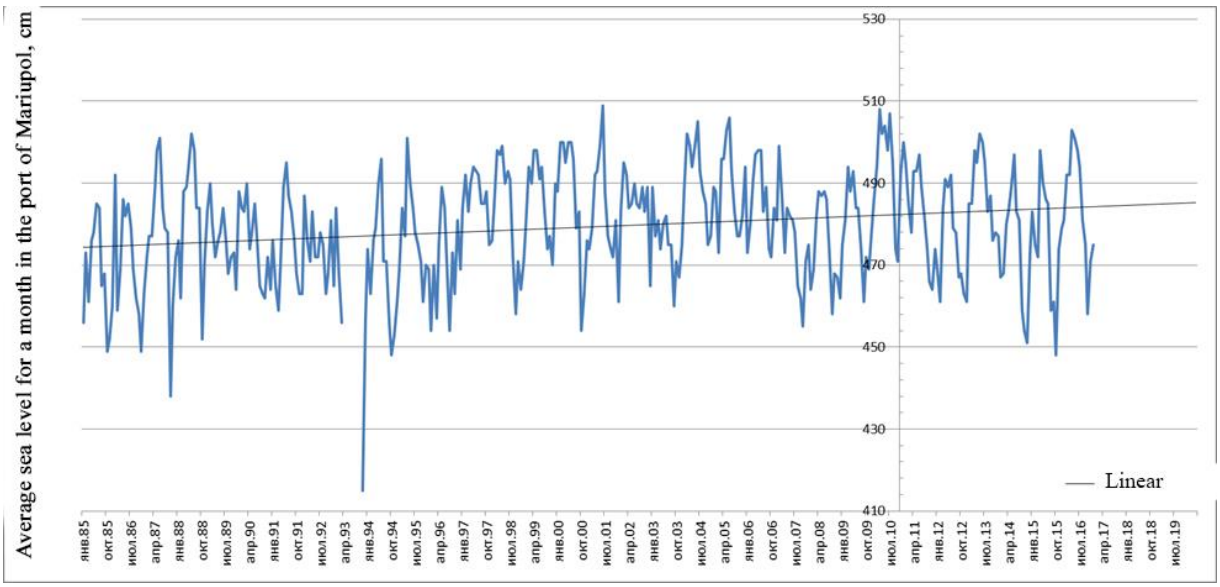

Fig. 5. Dynamics of sea level in the port of Mariupol

area and fixed on the ground by laying centers was absent at that time, which does not allow studying the dependence of processes in the previous terms.

As an example of the practical using and relevance of research, analysis of direct measurements data and graphic material in 2014 showed the sustainable development of landslides, in particular in the area of the village Melekino. At the same time, no direct statistical relationship between surface displacement and coastline erosion was noted. It is quite obvious that the main influence on the development of landslide processes in this area is determined by the erosion of the coastline, including by wind waves with an increasing of the average sea level, where the geodetic network of the Krymgeologiya enterprise was used. But after the events of 2014, these data were lost.

During the studying the images of Earth remote sensing satellites by DigitalGlobe, USGS LandLook and Sentinel, the following places with pronounced coastal dynamic processes (fig. 6) on the Ukrainian coast of the Sea of Azov can be identified, which require special attention: 1). The mouth of the Tonkaya channel (Genichesk, Kherson region); 2). Head of the Biryuchiy Island spit (Kherson region); 3). Mouth of the Molochny liman (Zaporozhye region); 4). Orlovka coastal region (Zaporozhye region); 5). Head of the Obitochnaya spit (Zaporozhye region); 6). Coastal region of Primorsk (Zaporozhye region); 7). Coastal region of Lunacharsky (Zaporozhye region); 8). Coastal region Babakh-Tarama (Donetsk region); 9). Coastal region of Yuryevka (Donetsk region); 10). Coastal region Melekino (Donetsk region); 11). Coastal region Bezymennoe (Donetsk region).

Analyzing of satellite images in the region of both branches (Tonky and Arabatsky), one can notice a sharp increase of sediment input after 2014. One of the possible reasons is the termination of irrigated agriculture in Crimea since 2014 due to the cancellation of water supply to Crimea through the North Crimean Canal, as a result of which water discharges into the
Sivash bay sharply decreased.

As for the Western Ukrainian coast, one should pay attention to the Genichesky Strait, which consists of two branches – Tonky and Arabatsky. In recent years, there has been a stable shallowing of the approach channel with the formation of a sediment island along the channel. The depths in the area of the Genichesk port are supported by the runoff from the Sivash.

The decreasing of depths in the area of the Genichesk and Arabat Strait began to be observed after March 1970, since the formation of the Arabat Strait. The current regime in the Genichesk Strait is determined mainly by the longitudinal pressure gradient due to the level difference at its boundaries and the prevailing winds in the region. A feature of the currents in the strait is their unidirectionality. An analysis of the field observations data [17-20] showed that the predominant water transport in the strait is observed from the Azov Sea to the Sivash bay. In April-May period characterized by elevated sea level values, due to the flood of the Don and Kuban, as well as fairly high average monthly wind speeds, the frequency of the Azov currents for 1939-2008 amounted to 61-67%, at average speeds of 23-24 $cm \cdot s^{-1}$ and water flow rates of 58-62 $m^3 \cdot s^{-1}$. Sivash currents are observed in the Tonkiy Strait under the influence of winds from the West. For the period 1939-2008 their repeatability was 36% at an average speed of 16 $cm \cdot s^{-1}$. From 2007 to the present, the average annual values of the sea level rise of the

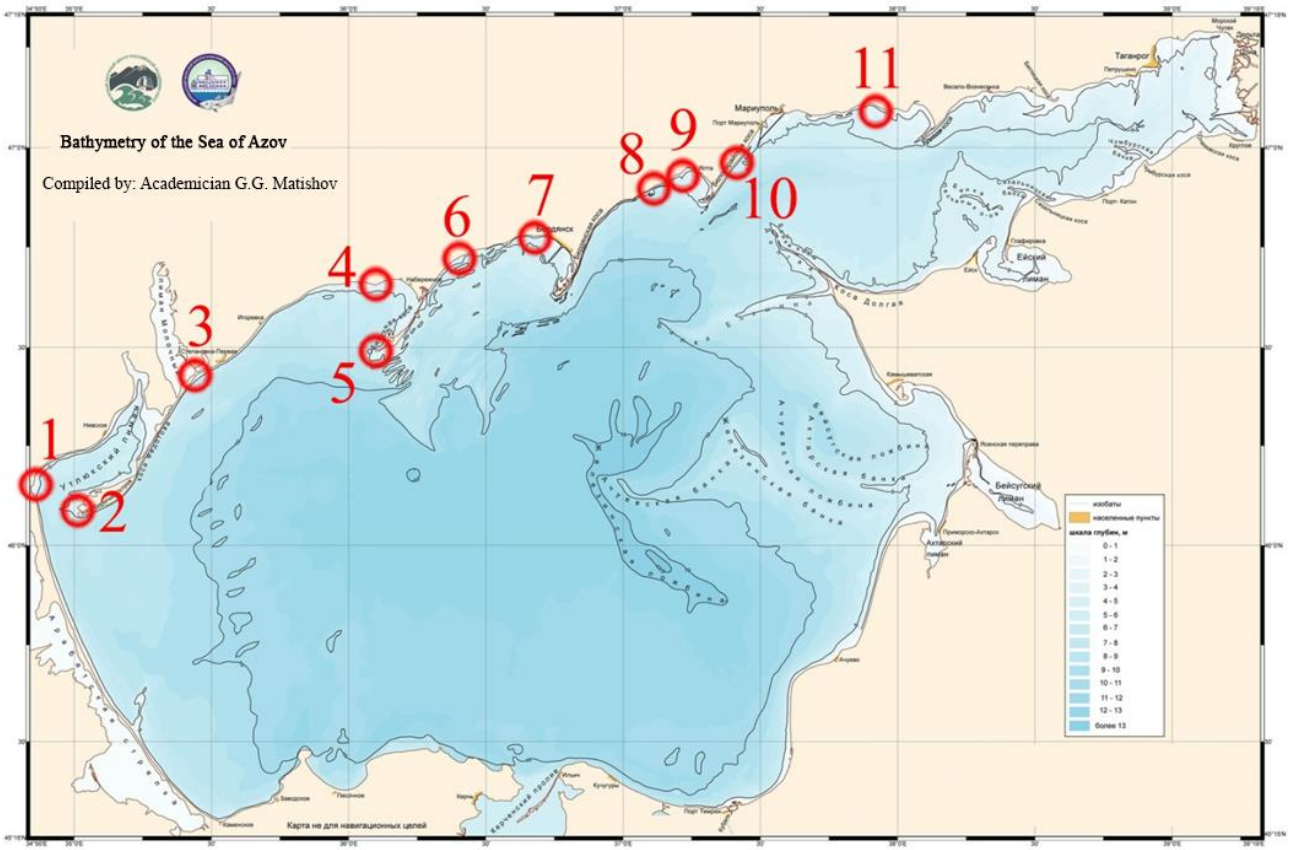

Fig. 6. Locations of pronounced coastal dynamic processes

Azov Sea over the Sivash bay have increased to 10-13 cm. The termination of irrigated agriculture in Crimea after 2014 led to the salinization of the Sivash bay and its shallowing. The increasing of the frequency of currents from the Azov Sea to the Sivash bay links with the transport of sediments in the coastal zone. At the same time the morphology of the shores and straits maintains the natural depths for the given water area in the channel of the watercourse. East and North-east winds prevail for the coast and the open part of the Azov Sea. In the initial period, under the action of a moderate Northeastern direction of wind, the direction of the currents coincides with the direction of the wind throughout the sea area. Then, with a prolonged Northeastern wind near the Arabat Spit, a surge of water is noted and two different flow patterns are formed in the sea area. If over the whole Sea the speed of the northeastern wind is uniform or in the Northern part of the Sea it is higher than in the Southern part, then in the Western part of the Sea a cyclonic is formed. Observation of the coastline dynamic in the area of the head of the Biryuchiy Ostrov spit also shows the growth of coastal sediments because of the accumulation of shell rock.

Conclusions.

1. In the eastern regions of the Azov coast of Ukraine, there is a deficit of sediment and a high degree of variability of the abrasion form of the coastal-sea relief is noted, and in the western and north-western regions, an excess of sediment is formed.

2. Sediments are formed by wind-wave currents from the Taganrog Bay towards to the Arabat Spit and then move counterclockwise to the Utlyutsky Liman.

3. The increasing of the frequency of currents from the Azov Sea to the Sivash Bay links with the transport and deposition of sediments in the coastal zone, where the morphology of the shores and straits is a concomitant factor, i.e. maintains natural depths in the stream bed for a given water area. Observation of the coastline dynamic in the area of the head of the Biryuchiy Ostrov spit also shows the growth of coastal sediments because of the accumulation of shell rock.

4. Since 2007 to the present, the average annual values of the sea level rise in the Azov Sea of over the gulf Sivash increased to 10-13 cm, except for the termination of the irrigated agriculture in Crimea after 2014, the gulf became salinized and shallowed.

As for recommendations, one should take into account the possibility of adjusting the regulated factors of anthropogenic impact, dredging and dumping, the expediency of which is based on the materials of seasonal, after the flood wave, monitoring of the investigated area.

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Submitted October 10, 2020
Accepted March 18, 2021

Authors Contribution: *All authors have contributed equally to this work.*

UDC 56.545

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HAZARDOUS PHENOMENA IN THE SLIDES ZONE OF THE UKRAINIAN SECTION IN AZOV SEA

Formulation of the problem. According long- term data analyses under the slides zone in Ukrainian part of the Azov sea sustainable processes had been marked. Landslides are most active in autumn and spring. The activation of landslides occurs under the influence of man-made and natural factors. The most significant factor is coastal abrasion.

Review of previous publications. It was established that the air temperature and precipitation, the temperature and salinity of sea waters and the hydrometeorological regime of the coastal zone and the water balance of the Black and Azov seas as well depends on climatic changes. The rising of the sea level has intensified over the past decades. These changes found a response in the coastal zone that reacted to them and acquired corresponding trends.

Purpose is to determine the reasons for the formation of dynamically unstable sectors and the possibility of protecting the shores on the Ukrainian coast in the Azov Sea, **the subject** is landslide processes, as the result of the abrasion of the shores, **the object** is the variability of the natural and anthropogenic conditions of the Ukrainian coast of the Azov Sea in the area of interaction between the sea and land.

Methods. Analyses of images space and temporal dynamic of Earth remote sensing satellites by DigitalGlobe, USGS LandLook and Sentinel were used and also retrospective long term of hydrometeorological data and standard statistical methods.

Results. The places (areas) with pronounced coastal dynamic processes on the Ukrainian coast of the Azov Sea were identified, that require special attention: two in the Kherson region, five in the Zaporozhye region and four in Donetsk. In the coastal zone of the Azov Sea the rate of abrasion from 1 to 4 m per year (in exceptional cases up to 15 m per year) was marked. In a period of significant level rises, the flooding of ports, berths, the destruction of hydraulic engineering structures, storage facilities, and residential buildings is possible. Also, during the period of the significant decreasing of the sea level, the already limited depth of the approach channels decreases again, that disrupts the operation of the fleet. **Conclusions.** Investigations of the current state of the Ukrainian coastal zone of the Azov Sea, that is significant importance for the sustainable the economy development, the recreational region's potential and the social level of the population.

It has been established that in the eastern regions of the Azov coast of Ukraine there are a deficit of sediments and a high degree of variability of the abrasion form of the coastal-sea relief is noted, and an excess of sediments are formed in the western and northwestern regions.

Keywords: Sea of Azov, landslide zone, abrasion and sedimentation, sea level variability.

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