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Danger of Pollution of the Water Area due to the Peculiarities of the Coastal Dynamics of the Temryuk Gulf of the Azov Sea

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ABSTRACT: Danger of pollution of water areas of the Sea of Azov and the Kerch Strait from possible technogenic catastrophes is diagnosed as a result of comparison of wind power calculations and the current state of coast of the gulf. Ideas of a uniform West Temryuk stream of deposits are disproved. Three dynamic systems in the east and in the center of a coastal arch and the unidirectional alongshore stream of pollutants and energy in the western segment of the Temryuk gulf are revealed.

1 INTRODUCTION

1.1 *Relevance and purpose*

The purpose of the study is to assess the risk of pollution of the water area of the northeastern sector of the Azov Sea and the Kerch Strait in connection with the dynamics of the coastal zone of the Temryuk gulf (Fig. 1).

Figure 1. Location of Temryucsky Gulf.

The significance of this diagnosis increases due to the impending reconstruction of the port and the expansion of trans-shipment area for the food and perfume oil, petrochemical, bulk materials and lump sulfur. On the approaches to the port for large vessels wiring dredging from 5.5 to 6.4 m is planned (www.tamaninfo.ru).

1.2 *Problems of preservation of unique resources of the nature and culture*

Coasts and the waters of inland seas, mastered by ancient civilizations, are a vital source of water, biological, recreational, and other resources. Shipping provides cultural and commercial inter-regional and inter-state relations. But, on the sea accidents, especially oil-loading, transport and discharge of domestic waste water, stagnant hydrodynamic phenomena in shallow waters threaten the biodiversity of coastal marine ecosystems and reduce the quality of waters resources. Risks of this kind are typical for the Azov Sea Temryucsky Gulf, on the shores of which the village, wineries, resorts, sports, tourism and others are located. In the inner part of asymmetrically concave arc to the southeast coastline there is a famous port-fortress "Temryuk" - the main source of contaminants (pollutants) on this stretch of coastline (the mouth of the Kuban river).

2 OBJECTS AND METHODS

2.1 *Natural conditions*

The object of study is the eastern part of the southern shores of the Sea of Azov in the Temryuk gulf: from the village of Ilyich in the west to the port of Temryuk at the mouth of the Kuban River and to the border of the Temryuk District in the east. From the basal part of the spit of Chushka in the throat of the Kerch Strait to the section between the villages of Perekopskaya and Kuchugury, the length of the coastline is ~ 70 km. Abrasion-landslide and crumbling coast of the western sector of the Temryucsky Gulf are complicated by ravines, gullies and stacked like easily eroded loam and denser rocks on the headlands, where after the storm areas of rock and clay the bench are exposed. On the shores, abrasion prevails over locally manifested sediment accumulation. Shore with ledges 60 m in height are being destroyed at an average speed of 0.5-0.6 m / year – it is noted from the second half of the 20th century (Boldyrev & Nevessky 1961, Kasyan & Krylenko 2007). Shelly-sand (30-50%, and 90% detritus) beaches, narrow (5-10 m) in areas of abrasion, expand to 20-25 m on the banks of the dynamically stable sprinkling estuaries. Local abrasion in the areas of village Golubitskaya and Kurchansky liman is associated with storm surges (up to 4.2 m). Location of zones of concentration of their energy is controlled by the peculiarities of the transformation on the beach waves. Modern accumulation is seen in the following: a) shelly sand-semi-fixed dunes (up to 5 m) on the scarp near village Kuchugury (frontal section of the maximum exposure En stream); b) the extension of the sea estuarine bars and hard dismembered channels delta of river Kuban (Petrushinskoe sleeve mouth: silts, sands, shelly ground, pebbles); c) The bottom accumulation on Chaykinskoe shoal (provoked by the construction of breakwaters Glukhoy channel port) and capes Ahilleon, Kamenny, Pekly (with circulating vortex shedding). Sandy alluvium of Kuban has been involved in beach creation since 1909, when the flow of the river began to be carried directly into the sea through Petrushinskoe sleeve. By 1954, the border coastal sands with dark blue bottom silt has popped up from the depths of 4-5 m (1927) seaward – up to 8 m. Most of shelly ground is ejected from the bottom of storm erosion of silt and shelly cans (water depth of 8-12 meters) (Boldyrev & Nevessky 1961, Kasyan & Krylenko 2007).

Among the especially dangerous weather phenomena affecting the safety of navigation, the operation of the port and the risk of spillage over the water area, it is possible to identify such characteristics as frost, ice conditions, wind, waves, currents (About ..., 2015).

The most severe frosts during the last 80 years - 28.70C occurred in February (1954). The average annual rainfall is 519 mm. There are droughts lasting up to 2 months and showers - up to 150 mm of precipitation in 1-2 hours. The average annual humidity is 79%. During the autumn fogs it reaches 100%.

Strong winds cause surges and water drifts near the shore, the extreme characteristics of which have been studied little. Driving-surging phenomena can take a catastrophic character, causing flooding of low-lying areas with up to 3.5-4.2 m above the current level. The level regime is determined by the water exchange with the Black Sea (the incoming part of the balance is 38%, the expenditure part is 50%). Seiche fluctuations in the level of the sea are small because of the small size of the water area.

The average number of storms at wind speed> 15 m / s (8-10 points) - 20 cases per year. Among them, on 9-point storms there are, on average, 5 cases per year. Storms force 10 points - 1 time in 5 years. Average duration of the storm: 12 hours (in August) and 28 hours (in December and March).

Wind is the cause of most different kinds of sea currents. On average, a wind speed of 5.3 m / s generates a current of 13.1 cm / s. Flow rates of 20-30 cm / s (capable of moving sand deposits) account for 7% of recurrence per year. Very rarely, in the conditions of spring and autumn-winter storms, speeds of> 40 cm / s can develop. Discharge currents at the outlet from the girth of estuaries and in the area of the mouth of the Kuban are up to 1.5-2 m / s. The directions of the current in the wave zone are controlled in the gulf by the configuration of the shoreline and tend to take the direction along the isobaths. At S and NE winds, the current in the surface layer deviates to the right from the direction of the wind, and at W and NW the wind - to the left. In both cases - towards the sea. For the wave zone, discontinuous compensating currents in the bottom layer are characteristic. In strong winds, the current can cover the entire thickness of the water, which in 27% of cases occurs in weak and moderate winds.

Wind wave type prevails during the year. Its parameters are limited by small dispersals and shallow water. Waves are very steep. They reach heights of 3-3.5 m, a period of ≤4-5 s and a length of ≤50 m. Wind waves rapidly increase, but after 4-6 hours the growth of the wave parameters ceases. The wave height of 3 m is reached at a wave of 0.1% of the supply. The average maximum waves of 0.8-1.1 m in height prevailing in the autumn-winter period are destroyed at depths of 1-1.04 m, determining the average dimensions of the wavefront zone. Storms of NE, E, SW and W directions have a repeatability of 80%. The strongest disturbances in the Temryuk district are observed in the W and NW winds with the maximum wave heights of 1.8 and 1.6 m, respectively. The wave breaking zone extends to depths of ~ 2.3 m, and at a maximum wave height of 3 m - to 3.4 m of the sea depth. In the NE wind, the average maximum wave height is 1.2 m. Violations of ≥4 points occur in February - from SW, W and NW.

The ice period continues, on average, about 70 days: from January 2 (the appearance of the initial forms of ice) to 10-12 March (complete cleansing from ice). Ice-free period - 295 days.

2.2 *Assessment of environmental risk*

Study of pollution scenarios of the coastal zone as a result of accidents and ill-conceived economic activity is based on calculations of the components of the coastal stream of wave energy (*En* - normal, *Eτ* - longshore, *Eo* - result). Mean annual and seasonal morphodynamics define their characteristics and trends redistribution along the coast waters, sediments and pollutants.

En - flow at the sea boundary of the wave zone, oriented towards the shore and acting along its normal. It characterizes the variability of the values of the frontal wave loads, the differentiation of abrasion hazard on the banks and the intensity of transverse sediment delivery from depth to the water's edge.

Eτ is the alongshore wave energy flux. It illustrates the variability of trends in the movement of water, sediments and pollutants along the shore in terms of intensity and direction (Fig. 2).

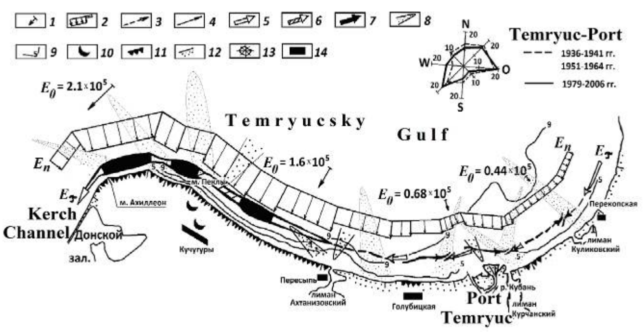

Figure 2. Trends of modern dynamics of coasts of Temryucsky Gulf: Ice-free period 1979-2006 (effective wind speed V_{10} >5 m/s). ***1-7*** - term average annual flow of the components of the coastal wave energy, *t/s*: ***1*** - resultant of coastal areas, *Eo*; ***2*** - cross, the diagram on the outer boundary wave-cut zone, referred to 1 running m length of the coastline, *En* = (3.7-18.8) x 10^4; ***3-7*** - longshore, 1 m wide wave-cut zone *Eτ* = (0.1-8.1) x 10^3: ***3*** - 0.1-0.5, ***4*** - 0.5-1.0, ***5*** - 1 -2.5, ***6*** – 2.5-5, ***7*** - 5-8.1; ***8*** - speculative, long-term sustainable coastal zone circulation (water, sediment and pollutants); ***9*** - isobath, m; ***10-12*** - elements of morphology and types of shores (according to [2]): ***10*** - semi-fixed dunes of shell detritus and quartz sand, ***11*** - abrasion-landslide and landslide areas, ***12*** - accumulative and stable beaches; ***13*** - wind rose, %; ***14*** – village

The distribution of the alongshore flows of wave energy and sediment, the structure of the field of coastal currents and pollutants depend mainly on the shoreline exposure and isobaths to prevailing winds that generate the corresponding disturbances with a certain resultant *Eo*.

The wave energy arriving at the outer boundary of the wave breaking zone (wave-surfacing zone) is transformed into the potential energy of the up-going water masses and into the kinetic energy of the currents. The front of the wave as it approaches the shore is experiencing ever greater transformations from interaction with the relief and deposits of the bottom, seeking to take the outlines of isobaths (lines of equal depths). Gradient, including compensating runoff and discontinuous currents, are gaining an increasing share in the wave-surging zone. Their occurrence is associated with an uneven water surge along the coast, due to unevenness of the bottom relief and the tortuosity of the coastline. Various kinds of energy and gradient currents are one of the decisive factors in the transfer of sand deposits, fine suspensions and pollutants.

3 DISCUSSION OF RESULTS

3.1 *Coastal dynamics of the gulf*

There is no consensus regarding the shore dynamics of the Gulf: 1) according to A.F. Flerov (1931) substance and energy flows rush to the NW and NE - from the middle of the coastal arc; 2) A.I. Simonov (1958): a single energy flow - to the west, along the shores of the entire Gulf (including the predominance of eastern and NE winds). This view was supported by V.L. Boldyrev & E.N. Nevessky (1961) (on the basis of ground surveying). In unidirectional West Temryuk stream of sediment, identified by them, (Sector East Coast arc - Spit Chushka) mechanical and mineralogical differentiation of Kuban sand alluvium was recorded (Bogdanov & Sovershaev, Zhindarev, Agapov 1989). However, it may be related to the diffusion of sediment along the shore (Bogdanov & Sovershaev, Zhindarev, Agapov 1989), but the basis of differences lays in the long-term variability of the resulting wind vector (Fig. 2).

Over the past 70 years the share of the winds from the W, SW and E increased and repeatability of other areas decreased. Among the points of the compass offshore wind exposure NE-E and SW-W-NW air flow is almost the same (35% and 37%, respectively). Configuration of the coastline, bottom topography, and the share of the north wind (up to 11%) are crucial in the direction of the generated flow of wave energy. The area of destruction of maximum waves, limited by height of the shallow reservoir, is located at a depth of 1-3.5 m (http://meteorf.ru).

3.2 *Possibility of the forecast of a rating of pollutants*

Trends of dynamics, identified by the calculations, are in good agreement with the above features of the current state of the Gulf coast. Joint analysis of relations and flows *Eτ En* morphological and lithological features of the coastal zone, allows to predict the separation of pollutants in the water area.

The calculations used wind energy method of B.A. Popov & V.A. Sovershaev (1981), the application of which is based on: a) the absence of representative wave-measuring observations, b) the reliability and validity of the results in relation to the shores of tide-free sea, c) taking into account the relationship between wind speed and the parameters of the created waves (calculation error - no more than ± 5%) (Bogdanov & Sovershaev, Zhindarev, Agapov 1989, Popov & Sovershaev 1981, Bogdanov & Vorontsov, Morozov 2004, Pateev 2009, About a state … 2015, Porotov and Kaplin, Myslivets 2016).

Topographic and navigation maps of scale 1: 200,000 and 1: 500,000 (provided by V.I. Myslivec; D.I. Korzinin was involved in collecting raw data) lay the basis for preliminary constructions and angular measurements. We used the standard table of wind speeds at rhumbs repeatability for a representative period of 1976-2006. The long-term statistics of repeatability of speeds of wind on the directions is taken from the official site Roshydromet. Average annual duration of ice-free period is 295 days (HMS «Temryuk» [http://meteorf.ru]). The amendments in the calculations have been introduced for: true north, bend coastline, the roughness of the underlying surface, the height of the station above sea level. It takes into account the overlap of the offshore bank of the points of the compass and the ratio "t^0C water < t^0C air". Anemometer wind speed is given to the true - at a height of 10 m (V_{10}). The maximum length of acceleration of waves is aligned with the specific natural conditions (reservoir size curves of the coastline, the presence of shoals, islands and braid for overclocking sector, affecting the wind and wave power and other parameters.). Alluvium-moving and relief-creating effects of waves currents, coastal circulation of water, sediment and pollutants are generated by the efficient (> 5 m/s) wind [Popov & Sovershaev 1981, Bogdanov & Vorontsov, Morozov 2004, Guidance on … 1975). Trends of dynamics that determine the risk of contamination of the Temryucsky Gulf are summarized in the following key findings (Figure 2-3)

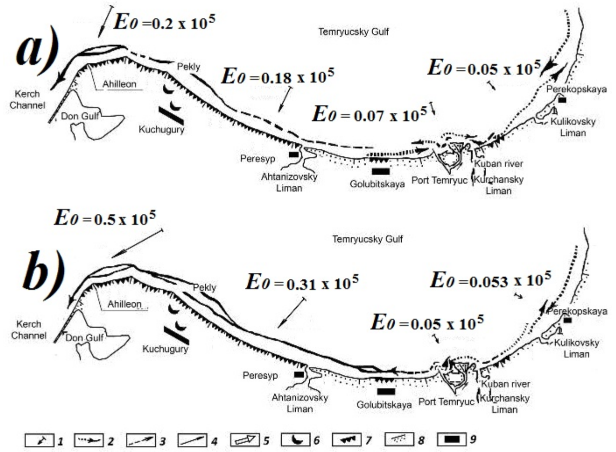

Figure 3. Trends of dynamics of coasts of Temryucsky Gulf, period 1976-2006: effective in December and storm for the year wind speed (>5 and 15 m/s, respectively). *1, 3, 4, 5, 6, 7, 8* and *9* refer to clauses *1, 3, 4, 5, 10, 11, 12* and *14* in Fig. 1; *2* – Эτ <0,1 *t/s*; *a)* E_n =(0.43-2.47) x 10^4, E_τ =(0.016-1.05) x 10^3; *b)* E_n =(0.45-4.05) x 10^4, E_τ =(0.004-2.2) x 10^3

3.3 *Key points in the interpretation of results of calculation.*

The parameters of the wave energy characteristics allow us to judge not only the trends in the development of the coast, but also the dynamics of water, sediment and pollutants in the coastal zone of the sea. The final value and the direction along the bank of the flow values *Eτ* represents the integral characteristic (the result of the algebraic addition of multidirectional values for each aquatorial rumba on this elementary part of the shoreline). The total value of the flux value *Eτ* indicates the tendency of directionality along the shore of the transport of matter and energy, taking into account refraction and transformation of waves in shallow water during the calculation period. The diagram *En* is the result of summing up the values of the rumba components of the wave energy normal to the shore (always at least an order of magnitude higher than the flow *Eτ*). The analysis of the mutual combination of the parameters *Eτ*, *En* with the relief of the coastal zone of the reservoir represents a key moment in the interpretation of the computational schemes of coastal dynamics [Guidance on ... 1975; Popov & Sovershaev, 1981; Bogdanov & Vorontsov, Morozov 2004; Bogdanov, 2009; Bogdanov & Paranina, 2017; Bogdanov, 2017].

Thus, the magnitude of the flow *En* is maximal at the portion of the shore perpendicular to the vector of the resultant energy *Eo*. The flow *Eτ* "is pressed" to the neck. The velocities of alongshore currents and the intensity of coast abrasion are increasing. Under favorable lithological conditions, the energy flow is saturated with matter (for example, dynamic situations in the vicinity of the village of Kuchugura and the capes of Pekly, Kamenny, and Achilleion).

Changes in the exposure of the shore and the bottom relief in the unidirectional flow transfer zone *Eτ* lead to a "detachment" from the alongshore branch towards the aquatory of the circulation vortices with a vertical axis of rotation (currents, sediment and pollutant flows). The phenomenon is typical for areas with a sharp drop in the values of the transverse flow *En* to the shore, which "presses" to the shore and "accelerates" the velocity of the long-distance flow *Eτ* on the adjacent (upstream) section of the wave zone (for example, west of Cape Pecly, Kamenny, Achilleion capes).

The mentioned vortices, under favorable hydrographic conditions, extend deep into the water area from the areas of their separation (up to several kilometers). From these eddy currents, the energetically weakened streams of energy, sediment and pollutants are again deflected by the *Eo* and *En* streams to the shore. The development of circulations in the water column determines the relief of the bottom of coastal shallow water. Between the rises and depressions of the bottom relief, the streams of matter and energy are redistributed toward greater depths. Circulatory cells with predominant transport of water, sediment and pollutants to the shore over positive elements of the bottom relief arise. The pulsating outflow develops along the beds of adjacent transverse subterranean troughs towards the water area (various compensatory currents).

In areas of convergence or a sharp weakening of the *Eτ* flux, counterbursts and accumulation of sediments of different hydraulic size develop. Here one should expect stagnant hydro- and lithodynamic phenomena and the accumulation of pollutants. The risk of logging of hydraulic structures here is also increasing (for example, Petrushansky shore section).

In the divergence zones of the *Eτ* and *En* fluxes, erosion of the bottom and shores is typical. An important role in the ecological situation in the water area is played by the degree of contamination of sediments. In the presence of transverse hydraulic structures, there is often a relative lack of access along the shore of water, sediment and pollutants (for example, sections of the coastal zone near the village of Golubitskaya, in the delta of the Kuban River and near the Kurchanskiy estuary).

3.4 *Main regularities of dynamics of a coastal zone and rating of pollution*

The values of the components of the wave energy flux in the Gulf are comparable to those in the gulfs of inland seas (such as the Vistula gulf of the Baltic Sea) (Bogdanov & Vorontsov, Morozov 2004, Bogdanov 2009). Complex coastal circulation flows, sediment and impurities in shallow reservoirs are controlled mainly not by wind and waves acceleration distance, but by the variability of the depths to shallow coastal waters, and the configuration of the coastline.

Qualitative characteristics mean annual dynamics of the coastal zone of the Gulf are stable for the full range of effective velocities > 5 m/s, and storm winds (> 5 m/s). The differences lie in the quantitative characteristics of flows *Eo*, *En* and $E\tau$ and whose values are from a few to tens of times lower than in the east (including Temryuk district) than in the western sector of the coastal arc. Reduction of head-loads to the NE helps to activate the removal of the water masses, suspended solids and pollutants deep into the dynamically attenuated Sea.

During the year, as in the most dynamically active December, at least three classic lithodynamic system, including the central areas of convergence and divergence $E\tau$ flows on the flanks operate along the shores. Systems are located in areas (east - west): 1) village Perekopskaya - rerash Kulikovskii of Kurchansky liman, 2) spit Kurchansky Estuary - Seaside Kuban wellhead, 3) Glukhoy port channel - Chaykinskoe shallow water - art. Golubitskaya.

The unidirectional flow of matter and energy rushes to the west of the site of erosion of the coast in the stable localized divergence Eτ flow zone in Golubitskaya. In this area most of the year and alongshore currents carry pollutants. Some of them are coastal circulation vortices arising in capes, taken out to sea and back to the shore deflected stream En. When rounding cape Ahilleon real-energy flow splits at the offshore and longshore (inertial) branch - to the south (towards the spit Chushka) and NW (the area of the northern coast of the Kerch Peninsula), respectively.

In storm conditions the number of systems is reduced to two (supposedly Glukhoy channel port – Kulikovskoe delta arm and north of it, near village Perekopskaya). Unidirectional west flow originates at the port piers (Fig. 3).

The dynamic conditions in the port area determine holding most of the pollutants in the areas of counter alongshore migrations (in the area of village Golubitskaya – Perekopskaya). Removal of pollutants in the water area of the Gulf of discontinuous and the drain currents is possible in conditions of impaired frontal impact En flow in the coastal arc sector. In storm conditions spills of pollutants on the approaches to the port will be redistributed to the west and the delayed input longshore current in the throat of the Kerch Strait, and inertial branch - to the northern shores of the peninsula.

Possible oil spills and other pollutants in the "Temryuk" port area and in the Kuban river may cause contamination of the adjacent shores of the gulf, as well as the Kerch channel and the adjacent sector of the Azov Sea.

4 CONCLUSIONS

Results of the conducted researches can be generalized in the form of several provisions.

Along coast of Temryuk Bay three litodinamichesky systems comparable on a power engineering to the Vistula lagoon of the Baltic Sea are diagnosed. The most potent of them leads to catastrophic abrasion of coast of the western sector of the gulf and stretches to an entrance to the Kerch Strait in the direction of the Black Sea.

The weakened dynamics of a coastal zone near the port of Temryuk promotes stagnation of pollution. Technogenic catastrophes here, especially during the periods of storm, are dangerous by carrying out of pollution, both to the Sea of Azov, and into the Black Sea through the Kerch Strait.

Morphodynamic zoning – a fundamental basis of actions for decrease in environmental risk on the sea coasts.

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