Original article

Dynamics of Accumulative Shores of Southwestern Crimea

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Abstract

In connection with the problem of developing the recreational infrastructure of the federal city of Sevastopol, the paper considers the dynamics of accumulative shores near the mouths of the Kacha and Belbek Rivers. The purpose of the article is to determine the quantitative characteristics of the coastline variability. The analysis also included the beach of Uchkuevka microdistrict, which is of great recreational importance. We used data from the digitization of coastlines of space images from the Google Earth service for 2011–2021 and materials of field observations of Marine Hydrophysical Institute of the Russian Academy of Sciences. It is established that the considered shores have been in a dynamic equilibrium in the last decade. Significant trends in changes in the average position of the coastline were not found. It is noted that earlier the coastline of the beaches underwent significant changes associated with anthropogenic activities (reduction of solid runoff, sand mining, construction of coastal protection structures). In each of the considered beaches, areas are identified with the maximum and minimum range of changes in the coastline over the past decade, and quantitative characteristics are given. The interannual variability of the coastline position averaged over beach length is considered. It is shown that intra-annual changes in the coastline position can exceed interannual ones in magnitude. To avoid false conclusions, when analyzing satellite data it is recommended not to use the images obtained on the first and last dates of observations, but the entire set of available images. The paper provides data on the dynamics of accumulative shores in other Black Sea countries in similar natural conditions.

Keywords: coastline, space images, river mouths, beaches, anthropogenic impact, Black Sea

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Динамика аккумулятивных берегов Юго-Западного Крыма

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Аннотация
В связи с проблемой развития рекреационной инфраструктуры города федерального значения Севастополя рассмотрена динамика аккумулятивных берегов вблизи устьев рек Качи и Бельбека. Цель статьи – определить количественные характеристики изменчивости береговой линии. В анализ был включен также пляж микрорайона Учкуевка, имеющий большое рекреационное значение. Использовались данные оцифровки береговых линий из космических снимков сервиса *Google Earth* для периода 2011–2021 гг. и материалы полевых наблюдений Морского гидрофизического института РАН. Установлено, что рассмотренные берега в последнее десятилетие находятся в динамическом равновесии. Значимых трендов изменений среднего положения береговой линии не обнаружено. Отмечено, что ранее береговая линия пляжей претерпела значительные изменения, связанные с антропогенной деятельностью (сокращение твердого стока, добыча песка, строительство берегозащитных сооружений). В каждом из рассмотренных пляжей выделены районы с максимальными и минимальными изменениями береговой линии за последнее десятилетие, приводятся количественные характеристики. Рассмотрена межгодовая изменчивость среднего по длине пляжей положения береговой линии. Показано, что внутригодовые изменения положения береговой линии могут превышать межгодовые. Во избежание ложных выводов рекомендуется при анализе спутниковых данных использовать не только снимки, полученные в крайние даты, а всю совокупность имеющихся изображений. Приводятся данные о динамике аккумулятивных берегов других причерноморских стран в сходных природных условиях.

Ключевые слова: береговая линия, космические снимки, устья рек, пляж, антропогенное воздействие, Черное море

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Introduction

Currently, some projects for the development of recreational infrastructure in the federal city of Sevastopol are being considered at various administrative levels. The length of the city coastline is about 170 km (for comparison: the coastline of Romania is 225 km; the coastline of Bulgaria is 300 km). The most populated and longest section of the region (about 73 km) – Sevastopol bays with few beaches – is of little use for recreation development, since it is densely built up and unsuitable for increasing the beach area. At the same time, to date, only 0.3 linear km or 10 % of the previously existing most valuable sandy beaches have been preserved here due to anthropogenic activity [1].

The southern coast from Cape Khersones to Cape Svyatoy Nicholay (about 72 km) is a mountainous area with few attached boulder and pebble beaches, dangerous due to landfalls and landslides. The recreational potential of Laspi Bay located on this section of the coast is almost exhausted. Therefore, it is not surprising that the authorities and investors' attention is drawn to the northern part of the region – the coast from Cape Tyubek to Cape Kosa Severnaya (about 26 km). Although this area has relatively wide beaches, most of the coast is prone to landfalls and landslides, and accidents have been repeatedly recorded here. Therefore, the importance acquired by accumulative full-profile beaches (two-slope beaches) located in the valley depression at the mouth of the Kacha and Belbek rivers should not be underestimated. Another beach of incomplete profile is located near Uchkuevka microdistrict. All three beaches occupy 20 % of the coast and are of great recreational importance due to good transport accessibility (Fig. 1).

The anthropogenic impact on the coastal zone of Crimea and Sevastopol has been increasing recently. Unfortunately, coastal development is often accompanied by negative consequences (including the loss of beaches). As a rule, they arise due to the lack of knowledge about the coastal zone dynamics, which is necessary when determining the impact of various economic projects on changes in the state of the shores, justifying coastal protection schemes and solving a number of other problems. This is especially relevant since the authorities of Sevastopol signed an agreement on the construction of a large recreational cluster worth 15 billion rubles in the beach area near the mouth of the Belbek River.

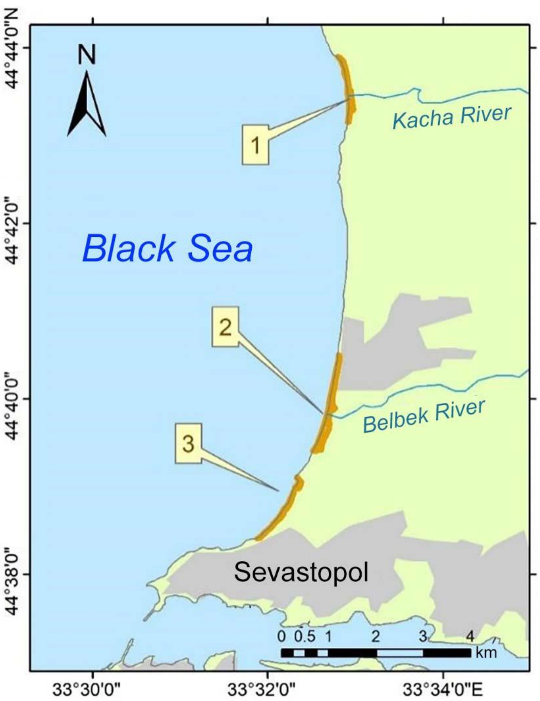


Fig. 1. Beaches in the northern Sevastopol area: *1* – near the village of Orlovka; *2* – in the microdistrict of Lyubimovka; *3* – in the microdistrict of Uchkuevka

Previously, scientific literature mainly considered the dynamics of a sandy beach at the mouth of the Belbek River [2–4]. Thus, in paper [2], based on the analysis of field observations in 2007 and 2009 it was shown that the most significant interannual variability in the position of the coastline is characteristic of the northern and central sections, where the displacement span reached 20 m. In the southern section, some displacement of the water line towards the sea was noted.

In [3], the satellite images from 1966 and the first decade of the 21st century were compared. It was noted that during this period the coastline in the southern section moved towards the sea by approximately 20–40 m. In [4], based on the analysis of satellite images for 2009–2014, it was noted that the beach near the mouth of the Belbek River generally retreated at an average rate of 1.4 m/year. In the southern part, accumulation was observed, with the beach moving forward by an average of 10 m. In the central and northern parts, the beach retreated by an average of 15 m. It was also noted that the typical values of interannual fluctuations were about 12 m, the minimum – 5 m, the maximum – up to 30 m; the central area was subject to the greatest changes. In a work devoted to the state of the shores of Sevastopol based on a comparison of a topographic map of 1955 and a satellite image of 2014, it is concluded that "the accumulative shore in the Kacha Valley is retreating at a speed of up to 5 m per year!" [5, p. 241].

To date, a significant array of satellite images has been accumulated, allowing for a more reasonable analysis of changes in the position of the coastline over time. The purpose of this work is to determine, on the basis of satellite images, the quantitative characteristics of the interannual variability of the coastline of the accumulative shores adjacent to the mouths of the Kacha and Belbek rivers. In addition, the analysis included the beach of Uchkuevka microdistrict, which is located within the abrasion-landslide shore and is of great recreational importance.

Materials and research methods

The work used digitization data of coastlines on satellite images of the Google Earth service for the period of 2011–2021 and a satellite image of the United States taken in 1966 for the United States Geological Survey (USGS). If there were several images per year, the image with maximum detail was selected. Almost all images (9 out of 11) were taken during the warm period of the year.

Distortion of linear structures was visually noted after creating digital arrays corresponding to the images and loading them into the GIS. It was due to the errors created in the process of generating continuous images. The latter consist of tile arrays of various resolutions, which are the basis of the technology for creating cartographic services [1), 2)] [6–7]. The Google Maps service used in the work enabled to perform vector drawing of objects with fairly high accuracy. This was further facilitated by two more factors: the insignificant absolute height of most objects in the coastal zone and the water edge lines in the horizontal plane. Digitized lines were tied to stationary objects to additionally correct distortions. The corner points of concrete piers were most often chosen as those stationary objects.

[1)] Labutina, I.A. and Baldina, E.A., 2011. [*Use of Remote Sensing Data for Monitoring of Protected Area Ecosystems*]. Moscow, 88 p. (in Russian).

[2)] Malysheva, N.V., 2012. [*Automated Interpretation of Aerial Photos of Forest Vegetation*]. Moscow: Izd-vo Moskovskogo Gosudarstvennogo Insituta Lesa, 151 p. (in Russian).

The main calculation algorithms described in the DSAS module were used for further analysis [3)]. The module constructs a series of lines of cross sections of the beach from a conditional line taken as the base line through a given distance. Taking into account the length of the beaches and the desired detail, the cross sections for all three beaches were carried out at 20 m intervals. Subsequently, the distances from the base line to the water edge lines for each section were compiled into a spreadsheet, by means of which the maximum deviations (positive range values, independent of the date) and the distances between two lines corresponding to the extreme dates (resulting displacements) were calculated. The graphs of coastline displacement are plotted on a bidirectional x-axis, with the direction to the left corresponding to the extension of the coast towards the sea, i.e. in a westerly direction. In addition to satellite data, we used field observation materials from Marine Hydrophysical Institute of the Russian Academy of Sciences.

Results and discussion

Accumulative shore near the mouth of the Kacha River. The length of the beach in this area is about 1.4 km; on the southern side there are two sections with rock ripraps perpendicular to the shore. With this consideration in mind, the length equal to 1.2 km was taken for calculations.

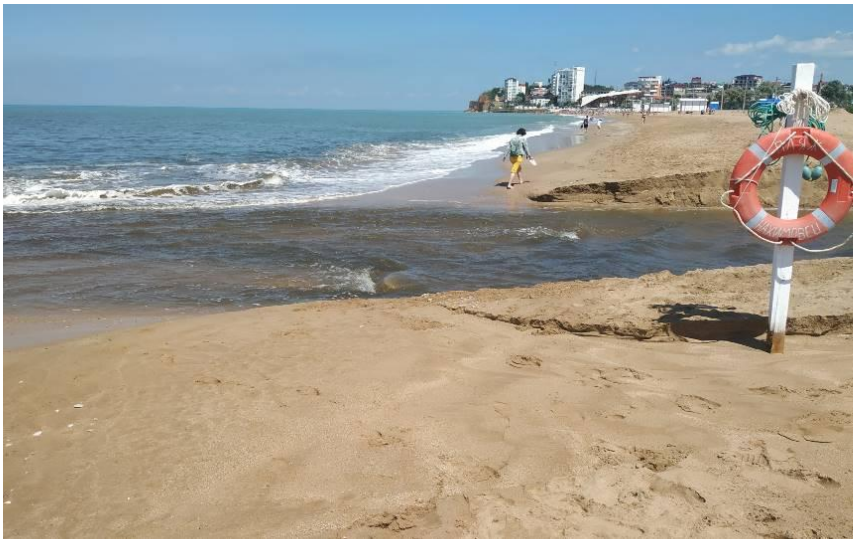
The width of the beach, composed of well-sorted medium-grained sand with small pebbles, currently ranges from 30 to 50 m. It is difficult to identify the rear boundary of the beach in a number of areas, since there is a wave barrier (built in 2009), an artificial parapet and some other objects. The mouth zone is formed by alluvium with a predominance of clays and sands. The geological structure indicates that this place was previously occupied by an estuary, which was subsequently filled with alluvium [4)].

A natural hydrological regime of the Kacha River has changed a lot. Two large reservoirs were built on the river – Bakhchisarayskoye (6.9 million m^3, built in 1934) and Zagorskoye (27.8 million m^3, built in 1975), which, along with the withdrawal of water for economic needs, led to a significant reduction in the solid runoff of the river. Currently, the river runoff, even during periods of intense precipitation, is insignificant (Fig. 2).

When ponds located in the estuary area are filled, in certain periods the runoff is close to zero. The place where the river flows into the sea changes only within the beach strip in both directions, usually up to 100 m, in more rare cases – up to 250 m from the average position. Sometimes the mouth does not come into direct contact with the sea, but forms a small lagoon parallel to the coastline and separated by a wave ridge through which the water filters into the sea.

[3)] Woods Hole Coastal and Marine Science Center. 2023. *Digital Shoreline Analysis System (DSAS).* [online] Available at: https://www.usgs.gov/centers/whcmsc/science/digital-shoreline-analysis-system-dsas [Accessed: 07 September 2023].

[4)] Zenkovich, V.P., 1960. [*Morphology and Dynamics of the Soviet Black Sea Coast*]. Vol. 2. Moscow: AS USSR Publ., 216 p. (in Russian).

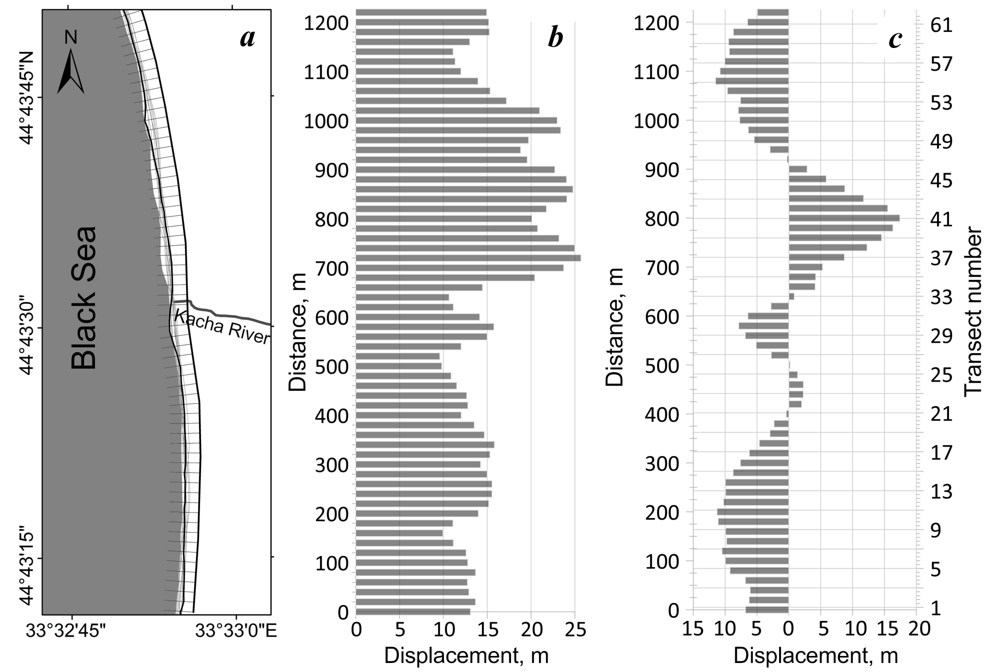


F i g . 2 . View of the Kacha River mouth during a strong freshet, 19 June 2021

To determine the dynamics of the coastline, 62 transects of the beach were used (Fig. 3). The analysis showed that the largest maximum span of displacement of the coastline position is typical for the area north of the Kacha River mouth, where it reaches 26 m with an average value of 20 m. Only in the northern part, adjacent to the cliff for 200 m, the average displacement value decreases to 13 m with a maximum of 16 m.

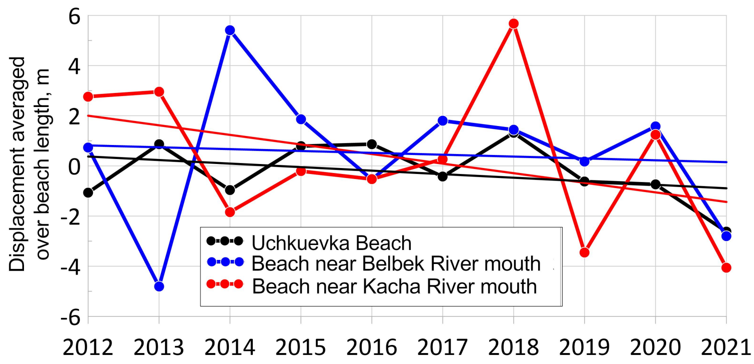
In the area south of the Kacha River mouth, the maximum displacement span is reduced to 16 m, and the average is reduced to 13 m. If we take the changes between the extreme dates (2011–2021), then a different picture emerges. During the indicated period, half of the area north of the mouth moved towards the sea by a distance of up to 10 m (on average by 6 m), and the other half, adjacent to the mouth, retreated up to 15 m (by the same 6 m on average). In other words, the configuration of the coast has changed in this area. The area south of the mouth as a whole, with a few exceptions, moved towards the sea by an average distance of up to 5 m with a maximum of 11 m.

It is clear from the analysis that the maximum displacement span is significantly greater over almost the entire length of the beach than the displacement values for the period under consideration. This suggests that when analyzing coastline trends, it is necessary to take into account interannual variability. There is no doubt that it is also necessary to take into account seasonal variability, but the currently available number of images during the year does not make this possible. In our work, this problem is eliminated to some extent by using images taken during the warm period of the year, when the coastline variability is minimal.



F i g . 3 . Map of transects on the beach near the Kacha River mouth (*a*); coastline displacement span for the whole period (*b*); resulting coastline displacements between the first and last dates of observations (*c*)

Fig. 4 shows the interannual variability of the coastline, calculated along the entire length of the beach. It shows that against the background of a small negative trend (retreat of the shore by 0.38 m/year), fluctuations with a range of up to 10 m are observed, especially pronounced since 2017. A comparison of the coastlines of 1966 and 2021 showed that in the northern part of the beach the total retreat was 15–20 m, and in the southern part – up to 40 m. The fact of this retreat can be associated with a significant reduction in the flow of solid sediments from the Kacha River caused by the commissioning of the Zagorskoye reservoir. It should also be noted: in paper [5] it is shown that in place of the previously leveled shore, a concavity of the coastline has now formed, coinciding with the beach at the mouth of the Kacha River. Indeed, such a trend can be traced, but the author attributes this to the period after 1985, from which he makes an incorrect conclusion that the beach is receding at a rate of 5 m/year. There is no doubt that the beach previously experienced significant retreat, caused, firstly, by sand mining, which was carried out at a distance of about 200 m from the shore by refuelers during the 1950s (Sevastopolskiy deposit), and secondly, due to a reduction in solid runoff as a result of river regulation. However, available data do not enable quantification of shoreline retreat due to these factors.



F i g . 4 . Interannual variability of the coastline position averaged over beach length. The straight lines are linear trends

Construction of a transverse rock riprap in the southern part of the beach significantly influenced its dynamics. According to our observations, during southern and southwestern storms, when the movement of bottom sediments is directed to the north, the phenomena of bottom erosion are observed here. Several such cases have been recorded on satellite images. The coastal retreat in the riprap area can reach 10–20 m. At the same time, prolonged storms can threaten the integrity of coastal structures, since the distance to them from the water edge is reduced to 10 m, which is clearly not enough to effectively dampen wave energy.

Accumulative shore near the Belbek River mouth. A full-profile beach of Lyubimovka microdistrict, the unturfed part of which is up to 70–80 m wide and 1.1 km long, is located at the mouth of the Belbek River. It is composed mainly of sandy material, and directly near the water edge – of gravel and pebbles. A section of the former abrasion landslide shore adjacent to it from the south was terraced in the late 70s of the past century. At the same time, a coastal protection structure was built there, consisting of an embankment, a retaining wall and a system of six piers, which led to a partial blocking of the alongshore sediment flow. To the north of the full-profile beach, there is a beach 25–40 m wide, attached to a clay cliff and of the same material composition. Both beaches belong to the same lithodynamic cell. Its northern border is the southern border of the Big Lyubimovskiy landslide [8], and its southern border is the northern pier of the above-mentioned system of six piers. Just like on the Kacha River, there used to be an estuary on the site of a floodplain valley, which was subsequently covered with alluvium [4)].

Belbek is the most water-abundant river in Crimea. To date, only 20 % of its flow has been regulated after the construction of three reservoirs in 1964 with a total volume of more than 12 million m^3. The supply of alluvium throughout the year is extremely uneven. The budget formation of beach-forming material and the corresponding changes in the coastline dynamics are to the greatest extent determined by the redistribution of sediment volumes along the coast and the influx of alluvium with the solid runoff from the Belbek River. Another source of material is coastal and bottom abrasion. The contribution of the latter to the sediment budget remains a controversial issue due to the lack of observations. A special feature of this coastal area is the existence of a yearly sediment flow directed from north to south.

After strong storms, a wave-breaking ridge is formed in the surf zone, blocking the mouth, while river water enters the sea, filtering through this ridge. According to our observations, two main conditions are necessary for its formation: a strong and prolonged frontal western storm and a weak river flow. During southwestern storms, the mouth usually deviates to the right, in which case the river flow is directed parallel to the shore at a distance of up to 200 m. During northwestern storms, the mouth previously deviated to the left in a similar way. In critical cases, bulldozers were used to dig through an artificial river bed.

In 2010, to the south of the mouth, a rock riprap boom was built to protect the beach, and the left shore of the mouth was reinforced with a stepped structure. The inclination angle of the pier towards the sea is about 3° and is equal to the natural slope of the beach. The beach topped the pier with sand and stabilized within the first three years after construction. After the completion of the work, the river mouth began to shift only to the right, to the north. Currently, the upper part of the pier is exposed only after a strong and prolonged storm with rapid attenuation before the first storm with slow attenuation. During the catastrophic flood in June 2021, a strong river current washed away only a small part of the structure, which was then covered with sand again within a few days.

The analysis of coastline changes shows that the beach formation on a significant area of the central section of the beach occurred previously as a result of meandering of the Belbek River mouth in both directions from the mouth. After the construction of a coastal protection structure, which prevented the river mouth from turning south, the influence of this factor on the configuration of the coastline in the northern part increased sharply. As a result of freshets, a river breakthrough along the coast parallel to the coastal ridge in the northern direction for a distance of up to 400 m was repeatedly observed, as well as formation of main and secondary ridges. This was accompanied by the destruction of coastal buildings, erosion of cliffs and other negative consequences. During periods of very strong freshets, the beach can be severely eroded over a distance of up to 200 m, but after a decrease in flow it is restored quite quickly (Fig. 5).

To determine coastline dynamics, 105 beach transects were used (Fig. 6). The figure shows that the largest span of coastline displacement typical for a short section north of the Belbek River mouth is 260 m long. Here the maximum value is 30 m with an average value of 20 m. North of this area, for 900 m to the northern boundary of the beach, the maximum values are 13 m with an average of 8 m.

F i g . 5 . View of the Belbek River from south during a strong freshet, 19 June 2021

To the south of the river mouth the values are slightly higher: the maximum is up to 23 m, and the average for this area is 14 m. It should be noted that the highest values of the displacement span are identified in a narrow zone of 60 m in length adjacent to the pier on the southern border of the beach, where, depending on the direction of the alongshore movement of sediment, alternate erosion or accumulation of beach material occurs.

The changes between the extreme dates (2011–2021) are relatively small. North of the Belbek River mouth, the beach during this period remained relatively stable with small displacements within ±5...8 m. In the southern part, there was an extension of the shore to an average distance of 10 m along the entire length. The graph of interannual variability of the average position of the coastline along the length shows a statistically insignificant trend (−0.07 m/year) against the background of interannual fluctuations of up to 9 m (2013–2014). It can be noted that after this period, the interannual changes were extremely small: 1...4 m (Fig. 4). Our earlier tacheometric measurements showed that intra-annual changes reached 20 m [2].

If we take the period of 1966–2021, an advance of the coastline in the southern part of the beach was recorded over 55 years. Its average value was 30 m or 0.5 m/year. In the northern part, where the cliff is located, there was a retreat of the water edge by 10–20 m with an increase to the north, or an average of 0.3 m/year. However, most of the changes occurred between 1966 and 2005 [3]. Most likely, this period is even shorter, but the available data do not make it possible to draw a more reasonable conclusion. We attribute these changes to the construction of a 600 m embankment and six piers, each 65 m long, at the southern edge of the beach, which began in 1982 and was completed in 1989. As it is known, transverse hydraulic structures contribute to the accumulation of beach material or erosion.

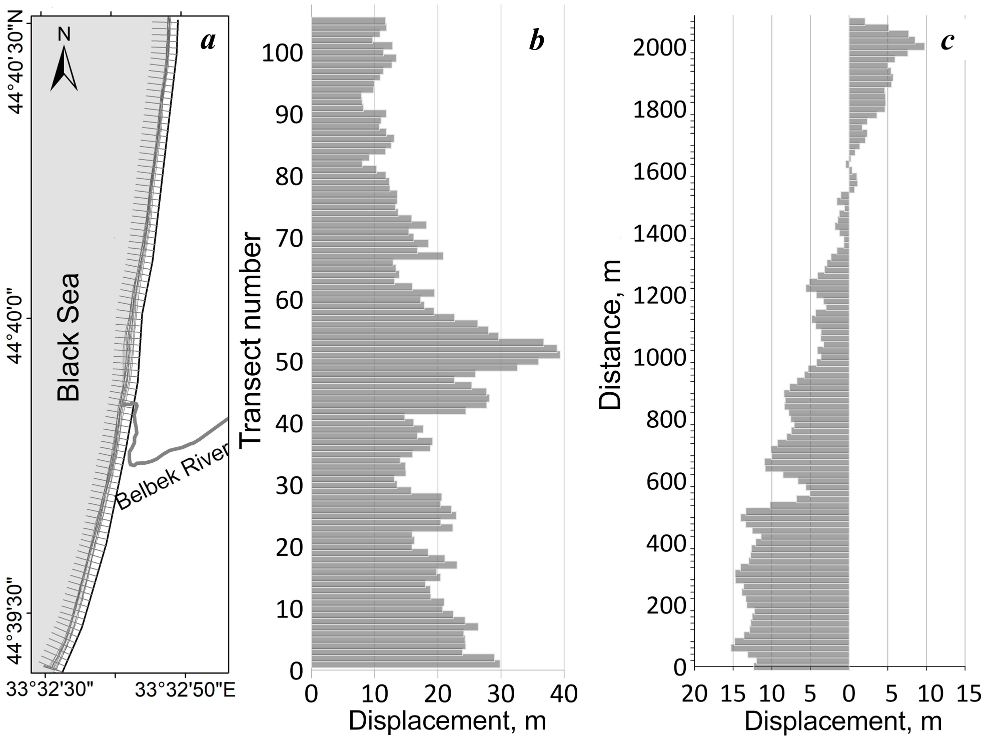


Fig. 6. Map of transects on the beach near the Belbek River mouth (*a*); coastline displacement span for the whole period (*b*); resulting coastline displacements between the first and last dates of observations (*c*)

Our observations have shown that accumulation here is expressed not only in the extension of the shore, but also in an increase in the vertical thickness of the beach, while excess material is even thrown over the crest of the piers.

In conclusion, we note that in 2021 a water intake was built on the Belbek River in the area of Verkhnesadovoe village. The first year of operation showed that sediment accumulates very quickly in the concrete channel of the river bed along the length of the structure. This requires periodic cleaning, as a result of which the supply of sediment to the beach area will decrease.

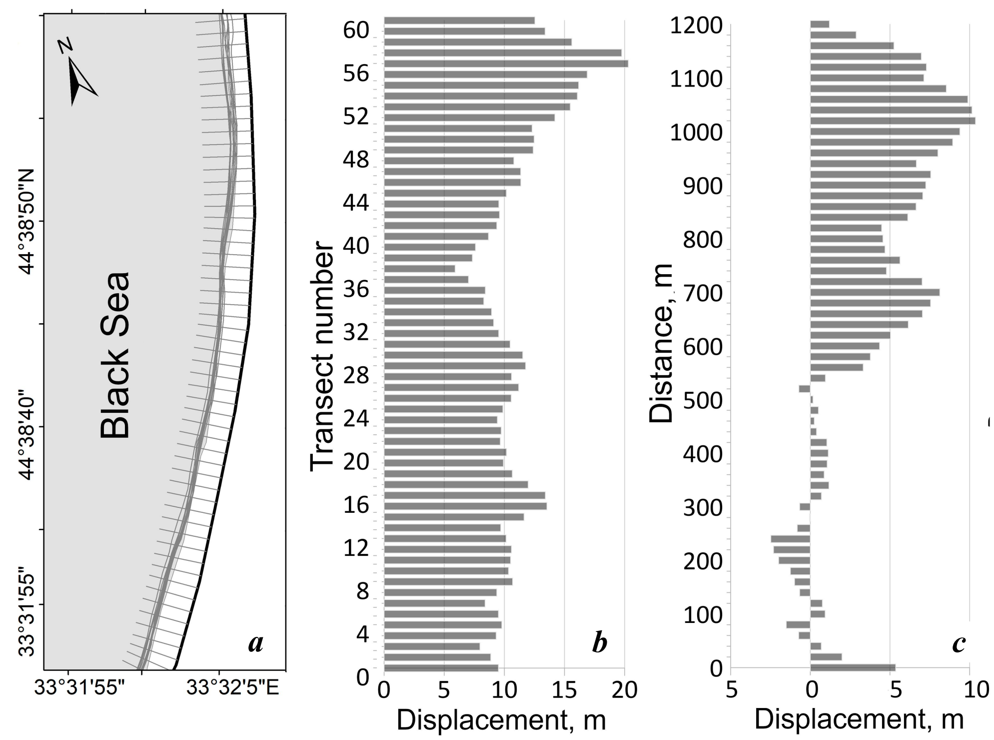
The Uchkuevka Beach. The beach boundaries of Uchkuevka microdistrict in the north are an unnamed cape to the south of the above-mentioned coastal protection structure consisting of an embankment and six piers and in the south – another unnamed cape. The beach has a length of 1.2 km, its width is from 20 to 50 m with a typical width of about 30 m. The beach is attached, composed of well-sorted sand with inclusions of small pebbles, in the rear of the beach there is an embankment and various objects necessary for its operation. The beach is one of the main recreational facilities in the city of Sevastopol. The beach was previously fed by moving material from the mouth of the Belbek River in the southern direction and the destruction products of the cliff that existed here before terracing. After the construction of the embankment and piers north of the beach, this source disappeared.

Unfortunately, the lack of well-defined landmarks in the images of 1941 and 1966 does not allow for georeferencing that is acceptable in accuracy, however, qualitative analysis apparently indicates a relatively small long-term variability of both the area and the configuration of the beach over 80 years (Fig. 7). One can even note a slight increase in the width of the beach in 1966 compared to 1941.

To determine the coastline dynamics, 60 transects of the beach were used (Fig. 8). The figure shows that, in general, the span of long-term coastline displacements is relatively small over a larger length and lies in the range of 6–13 m with an average value of 9 m. Only in a small area in the northern part with a length of 140 m does it increase to 15–20 m. The changes between the extreme dates (2011–2021) are relatively small. In the southern half of the beach, they are almost zero, and in the northern half they average 7 m with a maximum of 10 m. Interannual changes in the average position of the coastline are extremely small (Fig. 3), they do not exceed 1–2 m, the linear trend is not statistically significant (−0.1 m/year).

At the same time, as our observations show, intra-annual changes can be more significant. Thus, on October 18–19, 2013, as a result of a storm of rare frequency (mainly due to its anomalous duration), beach accumulations were partially washed away for 360 m in the northern part of the beach (Fig. 9).

F i g . 7 . The beach area of the microdistrict of Uchkuevka – aerial photo dated 1941 (*a*), satellite images dated 1966 (*b*) and 2021 (*c*)



F i g . 8 . Map of transects on the Uchkuevka Beach (*a*); coastline displacement span for the whole period (*b*); resulting coastline displacements between the first and last dates of observations (*c*)

A pronounced coastal ledge formed in the rear part of the beach, boulders were exposed near the water edge, and a significant part of the material was moved to the south. The volume of sand and gravel moved to the south and carried to a depth from one linear meter of the beach and underwater slope was estimated by us to range from 20 to 35 m^3. The total volume of beach reduction in the northern part was about 10 thousand m^3. The width of the beach in the northern part decreased by 5–10 m, and the coast in the southern part, up to the nameless cape, advanced by approximately the same amount. On the southern half, on a 550 m long section of the coast, the volume of beach material increased by 5–6 thousand m^3, and about a half of the washed away material in the north went to depth. By April–May 2014, the water edge position had almost recovered, but until 2017, instability was noted in the northern part. Periodically, the shore retreated or moved forward by 10–15 m, and later became more stable, but the previous profile of the beach was not restored. It is characteristic that, since this event was recorded in the interval between images, it did not appear in any way on the graph of interannual variability of the average beach width (see Fig. 3). It is interesting to compare the dynamics of the beaches discussed above with the dynamics of accumulative shores in similar natural conditions of other Black Sea countries.

F i g . 9 . The northern Uchkuevka Beach on 18 October 2010 (*a*), 2 November 2013 (*b*)

Currently, more than half of the total length of the Danube Delta coastline is subject to erosion, 30% is characterized by accumulation, 15% is in dynamic equilibrium and is relatively stable, typical erosion rates are up to 5–25 m/year [9]. Romanian scientists associate this ratio with the construction of dams for hydroelectric purposes, construction of various embankments, channel straightening and other hydraulic engineering works in the lower reaches of the Danube, as a result of which the annual sediment runoff was halved [10, 11]. The famous Mamaia Beach in Romania is problematic. It was 100 m wide in the 60s of 20th century, and by 1985 it decreased to 50 m. Over the next 15 years, the beach continued to shrink at an average rate of 2.25 m/year. The reason is hydraulic engineering construction, due to which the alongshore sediment transport was blocked [12]. In the 80s of 20th century, in Varna Bay (Bulgaria), a coastal dam and a system of impenetrable concrete piers were built; due to the drift of the fairways, dredging was regularly carried out. In addition, in recent decades, the construction of buildings directly on the beaches has been practiced. All this activity led to the disruption of natural dynamic processes, and the coastline of Varna Bay was irreversibly changed. Thus, before human intervention, the Asparukhovo Beach was constantly growing due to unloading of two counter flows of sediment here, and now its length has decreased by 800 m. As a result of the disruption of the natural nutrition of the adjacent sandy beaches, individual beaches either disappeared or were significantly reduced [13–15].

Conclusion

Based on the above, the following main conclusions can be drawn.

1. The accumulative shores in valley depressions of the Kacha and Belbek rivers, as well as the Uchkuevka Beach, were in dynamic equilibrium in the last decade (2011–2021). No significant trends in changes of the coastline average position for the period of 2011–2021 were detected. Previously, the beaches experienced significant changes in the coastline associated with anthropogenic activities (reduction of solid runoff, sand extraction, construction of coastal protection structures).

2. The largest maximum span of coastline displacement in the period of 2011–2021 is typical of the area north of the Kacha River mouth – 26 m with an average value of 20 m. In the area south of the Kacha River mouth, the maximum displacement span is reduced to 16 m, and the average is reduced to 13 m.

3. The largest maximum span of coastline displacement in the period of 2011–2021 is typical of a 260 m long section north of the Belbek River mouth – 30 m with an average value of 20 m. North of this area, for 900 m to the northern boundary of the beach, the maximum values are 13 m with an average of 8 m. South of the river mouth, the maximum values are 23 m and the average values are 14 m. The highest values of the displacement span are identified in a narrow zone 60 m long adjacent to the pier on the southern border of the beach, where, depending on the direction of the alongshore movement of sediment, alternate erosion or accumulation is observed.

4. At a greater length of the Uchkuevka Beach in 2011–2021, the span of the long-term coastline displacements is relatively small and lies in the range of 6–13 m with an average value of 9 m. Only in a small area in the northern part with a length of 140 m does it increase to 15–20 m.

5. The maximum interannual variability of the average length position of the coastline reaches 10 m for beaches at the mouths of the Kacha and Belbek rivers, and up to 2 m for the Uchkuevka Beach.

6. The intra-annual changes in the position of the coastline may exceed interannual changes in magnitude. When analyzing satellite data to determine the dynamics of coastlines, it is necessary to use not only images obtained on extreme dates, but the entire set of available images.

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