SHORELINE DYNAMICS OF THE DANUBE DELTA (2016-2023) MEASURED USING GNSS-RTK TECHNOLOGY

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Abstract. The Danube Delta shoreline has experienced significant changes due to both natural processes and human activities. This study investigates the shoreline dynamics of the Danube Delta from 2016 to 2023, focusing on its central and southern sedimentary cells, which include Sulina, Canalul cu Sondă, Câsla Vădanei, Sfântu Gheorghe, Sahalin North and South, Perișor, Periteasca, Portița North and South, and Periboina sectors. Using GNSS RTK technology, shoreline positions were measured annually during the summer months between 2016 and 2023. The measurements were analysed with QGIS software to calculate shoreline change rates and trends. The results highlight the variability in shoreline dynamics across different sectors. Erosion predominates in several areas, while other sectors exhibit stability or accretion. Key factors influencing these changes include sediment redistribution through waves, currents, and river processes, as well as human interventions such as coastal structures. Vegetation in certain areas may also play a role in mitigating erosion. This study provides an overview of the Danube Delta's evolving coastline and the factors shaping it.

Key words: coastal dynamics, erosion, accretion, trend, change rate, GNSS, Danube Delta

1. INTRODUCTION

The Danube Delta is located in Romania and Ukraine, where the Danube River discharges into the north-western Black Sea and is the second largest delta in the European Union (covering 580.000 ha). In 1991, it received the UNESCO World Heritage Site recognition and it was classified as a Biosphere Reserve; since then, it has been protected under the Ramsar Convention as a wetland of international importance. The Danube Delta coastline has a total length of approximately 240 km, with around 160 km in Romania. Over the past 160 years, the upstream segment of the Danube River, the delta itself, and the Black Sea coast faced considerable human pressure - construction of reservoirs, embankment, land use changes (Constantinescu *et al.*, 2015; Hein *et al.*, 2016; Habersack *et al.,* 2016), resulting in decrease of sediment supply to the delta and coastal erosion (Panin, 1999, Ungureanu and Stănică, 2000; Panin and Jipa, 2002, Stănică and Panin, 2009).

The Danube Delta coastal area has been extensively studied for many years using traditional surveys, and its dynamic is well-documented in numerous publications (Spătaru, 1962, Bondar *et al.*, 1973, Bondar *et al.*, 1983, Gâștescu and Driga, 1984, Panin, 1996, 1999, 2003, 2011, Panin and Overmars, 2012, Panin *et al.*, 2016, Ungureanu and Stănică, 2000, Stănică, 2003, Giosan *et al.*, 2006, Stănică *et al.*, 2007, Vespremeanu-Stroe *et al.*, 2007, Dan *et al.*, 2009, 2011, Stănică and Panin, 2009, Halcrow, 2012, Stănică *et al.*, 2011, Giosan *et al.*, 2013, Tătui and Vespremeanu-Stroe, 2014, 2017, Tătui *et al.*, 2021, Vespremeanu-Stroe *et al.*, 2016, 2017, Zăinescu *et al.*, 2017, 2019). These studies highlighted various trends in the Danube Delta coastal dynamics, such as: accumulation immediately south of the Sulina jetties; significant erosion at Canalul cu Sondă; slight erosion at

Câsla Vădanei; an oscillatory trend at Sfântu Gheorghe (close to the Danube mouth). Complex mechanisms have been observed at the Sahalin Spit (the spit tends to grow and elongate toward the southwest, with a clockwise rotation of its southern tip), while erosion is evident at Zătoane - Perişor and Gura Portiţei. Accumulation has been documented at Periteasca, with erosion at Periboina and slight advancement northwards the Midia Harbour jetties, that block the further longshore transfer of littoral sediments.

2. MATERIAL AND METHODS

2.1. Study zone

The coast of the Danube Delta is divided in three major sedimentary cells (Stănică *et al.*, 2011, Stănică *et al.*, 2013, Halcrow, 2012) based on concepts formulated by Marchand *et al.* (2011): (1) *Musura Lagoon* coastal sedimentary cell, with the northern limit in Ukraine and the southern one represented by Sulina jetties, (2) *Sulina – Sf. Gheorghe – Sahalin* coastal sedimentary cell, with the rigid northern boundary represented by the Sulina jetties and a southern limit, the southern end of Sahalin Island, and (3) *Zătoane – Cape Midia* coastal sedimentary cell that has the northern limit on the southern part of the Sahalin Island and the southern one at Midia Harbor. The measurements presented in the current study were done in the central and southern sedimentary cell, in the following beach sectors: Sulina, Canalul cu Sondă, Câsla Vădanei, Sfântu Gheorghe, Sahalin North, Sahalin South, Perişor, Periteasca, Portiţa North, Portiţa South and Periboina (Fig. 1).

The study of sedimentology and the dynamics of the Danube Delta coastal deposits started in 1965, with Panin (1967) examining the sedimentary structures of the coastal deposits along the northern Romanian Black Sea Shore. Since then, beach profiles were measured using classic topographic levels along all the Danube Delta beaches until 1994. A change in methodology was made in 1995, when the NIRD GeoEcoMar coastal dynamics team started using classic theodolite (followed 13 years after by total stations). The first measurements conducted by NIRD GeoEcoMar using high precision GPS with GNSS RTK technology started in 2016. Since then, regular measurements were performed yearly, along specific sections covering each beach sector of the Danube Delta shoreline.

In this study, we present the dynamics of the Danube Delta shoreline, from 2016 to 2023. The main influencing factors leading to the shoreline dynamics are also discussed herein.

2.2. Methodology

The position of the shoreline was measured annually in the period of July-August, between years 2016 – 2023. The upper swash limit position was measured using DGPS Trimble equipment with the GNSS RTK technique, recording a point at intervals of 3 meters. Meteorological conditions recorded daily for each location are presented in Annex 1. The measurements were analysed using the QGIS open-source software, on transects cast every 200 m on each beach sector. The measurements were used to (1) calculate the shoreline change rate using the distance between baseline and transect intersection points along transects for consecutive years and (2) calculate shoreline trend using the average position of the yearly shoreline at each transect. Each year, the shoreline positions across all transects were averaged to obtain a single value representing the annual average shoreline position. This approach was used to identify differences and track evolutionary trends over time.

3. RESULTS

A total of 8 shoreline positions (measured in the period July – August of each year between 2016 and 2023) were evaluated at beach sectors between Sulina and Periboina.

In the following section, due to its behaviour and dynamics, the Sahalin Spit is described separately from the other sectors that are grouped by sedimentary cells.

3.1. Sulina – Sfântu Gheorghe sedimentary cell

The analysed shoreline length in the *Sulina* sector is around 5 km. The sector shows an overall trend of accumulation between 2016 and 2023, with an average shoreline accretion rate of 2.1 m/year. The rate decreases from north to south, with accretion in the north, stability and slight accretion in the centre, and erosion in the south. The highest accretion rate is 4.2 m/year in the north, while the southern part experiences a rate of -0.25 m/year (Fig. 2).

The *Canalul cu Sondă* sector, with an analysed shoreline length of around 3 km is characterised by erosion, with an average rate of -4.4 m/year. Erosion is most pronounced in the southern section while the lowest rate, -0.5 m/year, occurs in the north (around Gârla Împuţită). In the south, the retreat rate averages -7.4 m/year (Fig. 3).

With an analysed shoreline length of about 5 km, *Câsla Vădanei* sector is also exhibiting an eroding trend with an average rate of -4.5 m /year. The rate decreases from north to south, with the highest rate of -7 m/year in the north and the lowest of -2.9 m/year in the south (Fig. 4).

In the *Sfântu Gheorghe* sector, over an analysed shoreline length of around 5 km, erosion is again the dominant trend, with an average retreat rate of -2.2 m/year. In the north, stability/slight accretion was observed, with an average rate of 0.3 m/year, while erosion intensifies towards the south. The highest erosion rate, measured at the mouth of the Sfântu Gheorghe branch, reaches -5.6 m/year. This is likely due to the complex redistribution of sediments at the river-sea interface (Fig. 5).

Fig. 1. Position of the beach sectors measured between 2016 and 2023 (source Google Earth).

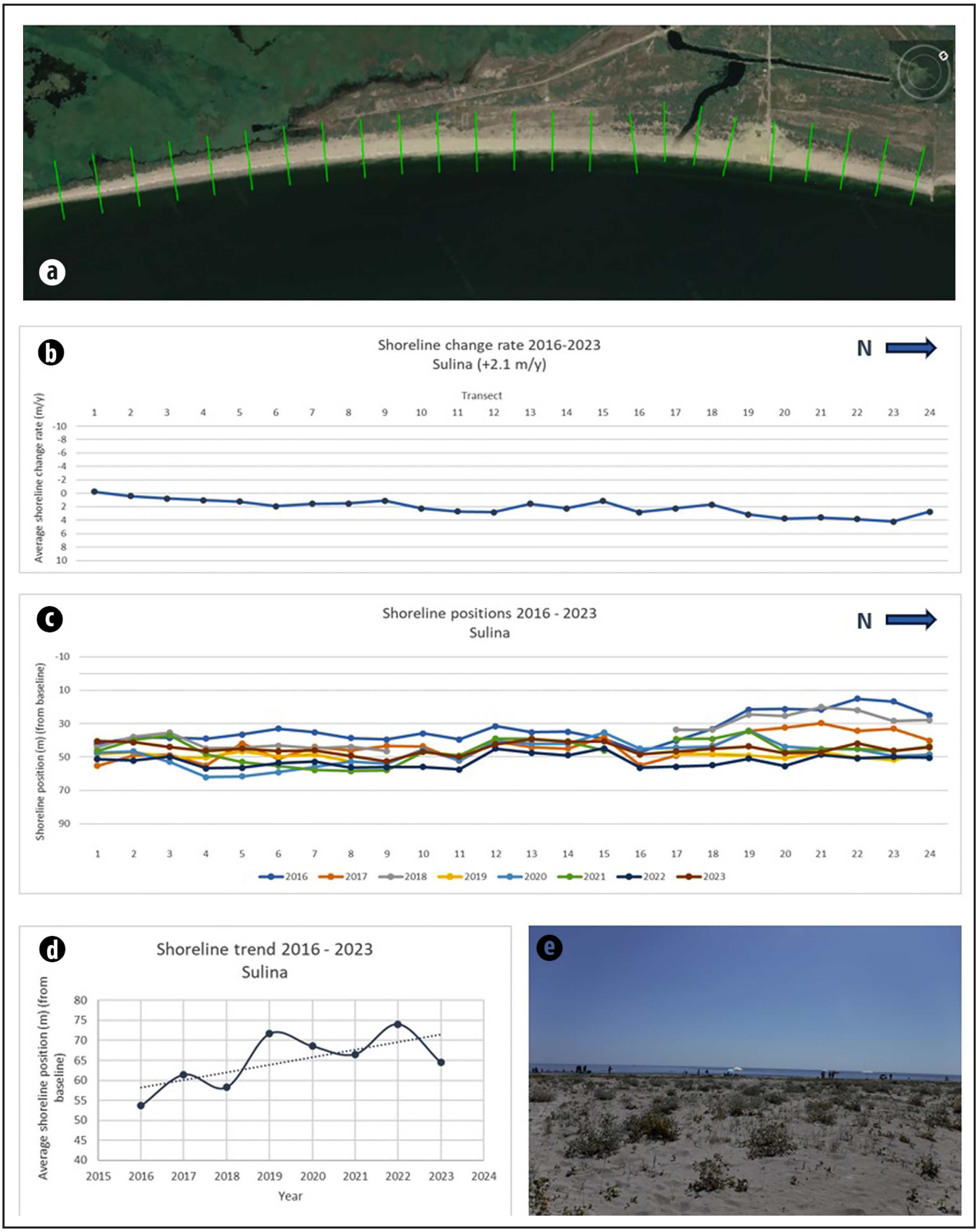

Fig. 2. Sulina. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Sulina (2019).

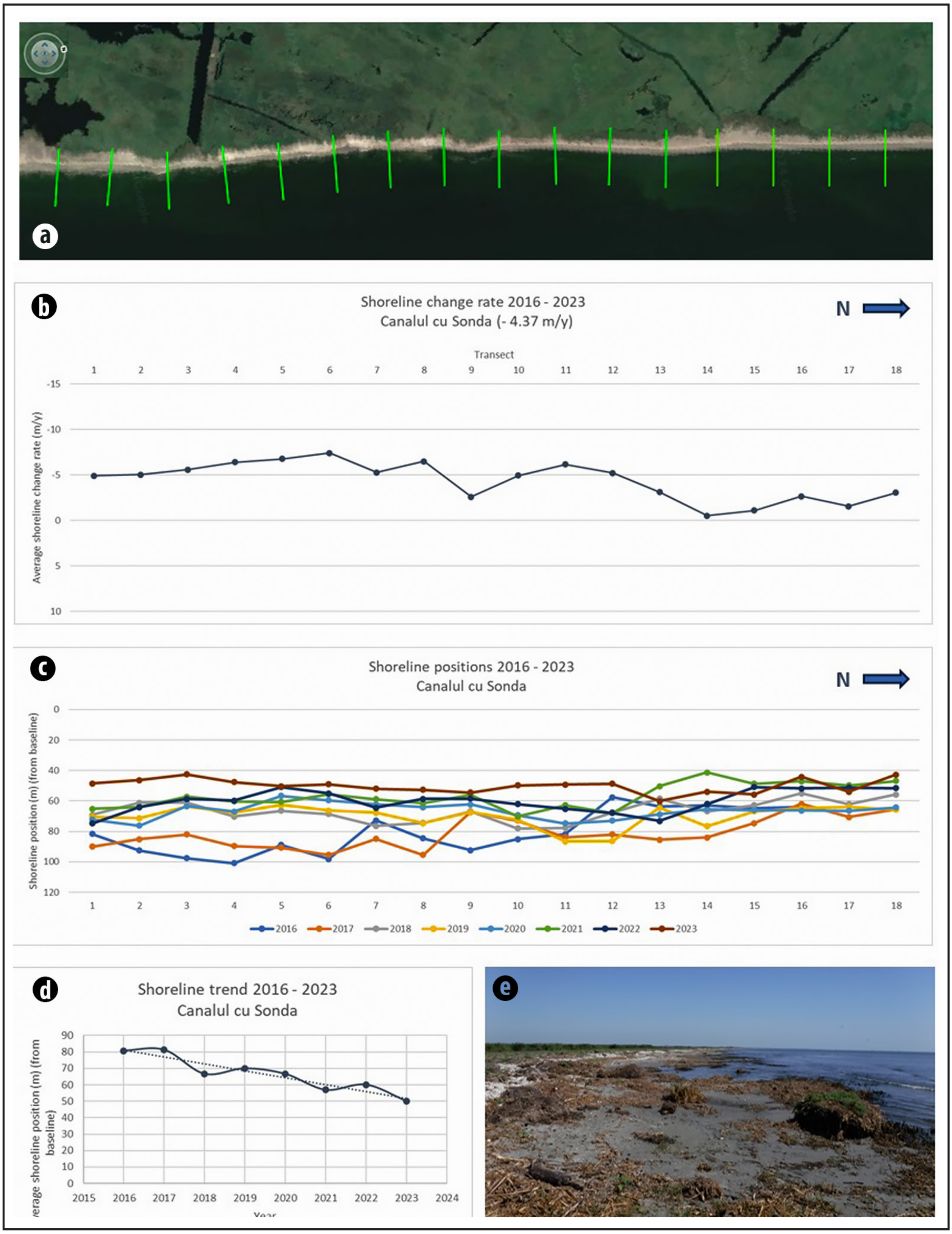

Fig. 3. Canalul cu Sondă. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Canalul cu Sondă (2019).

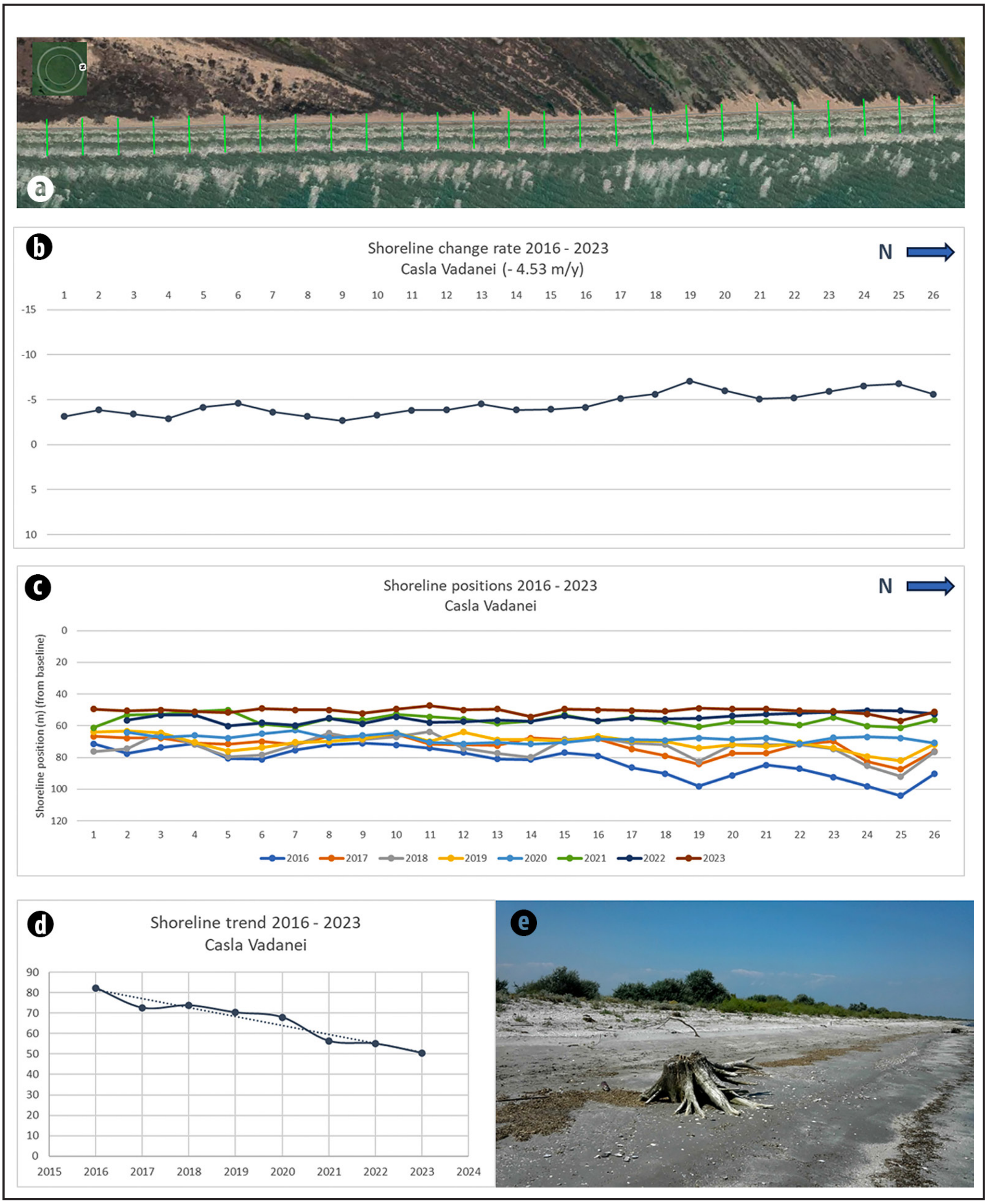

Fig. 4. Câsla Vădanei. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Câsla Vădanei (2019).

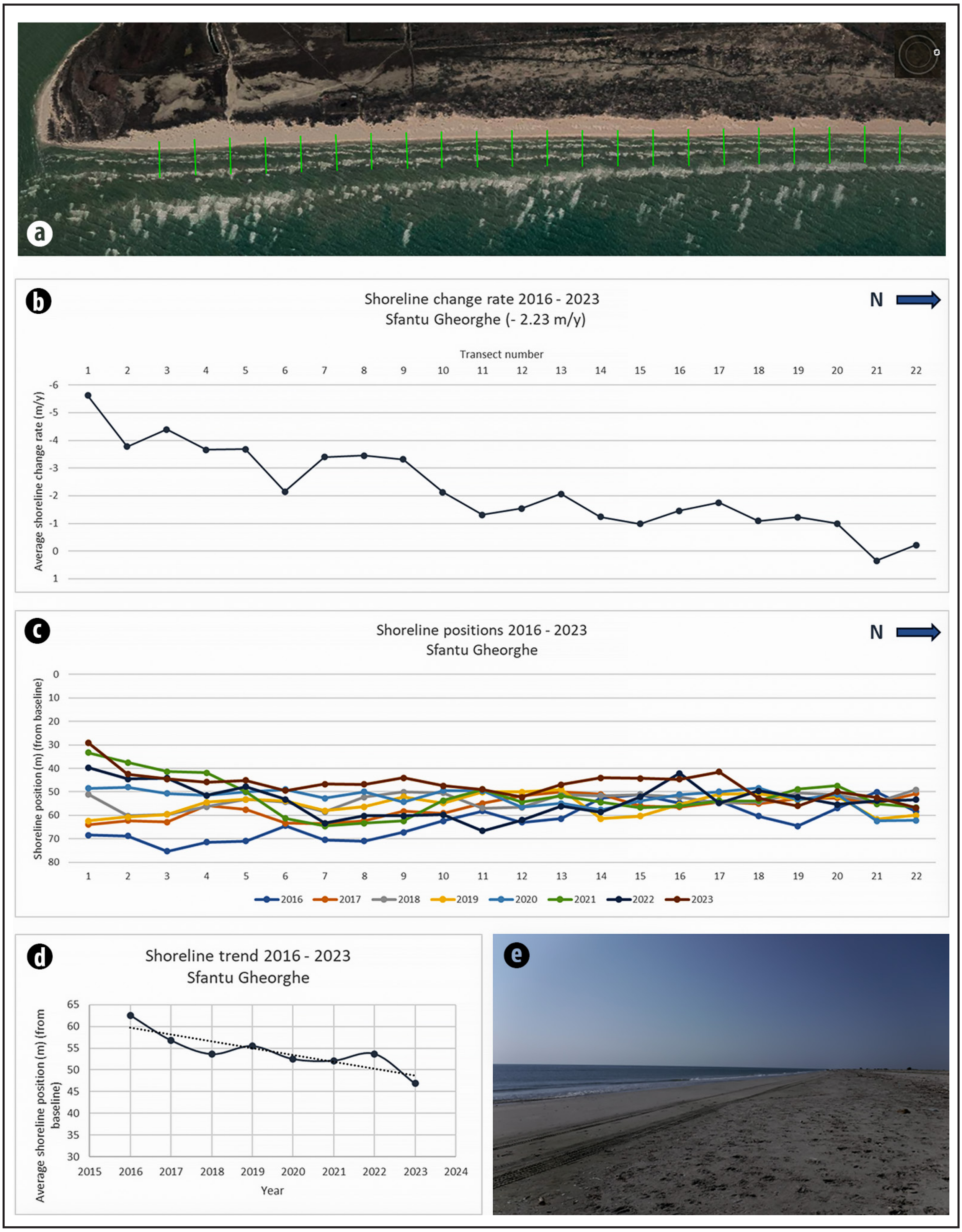

Fig. 5. Sfântu Gheorghe. (**a**) Transect positions along the sector; (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Sfântu Gheorghe (2019).

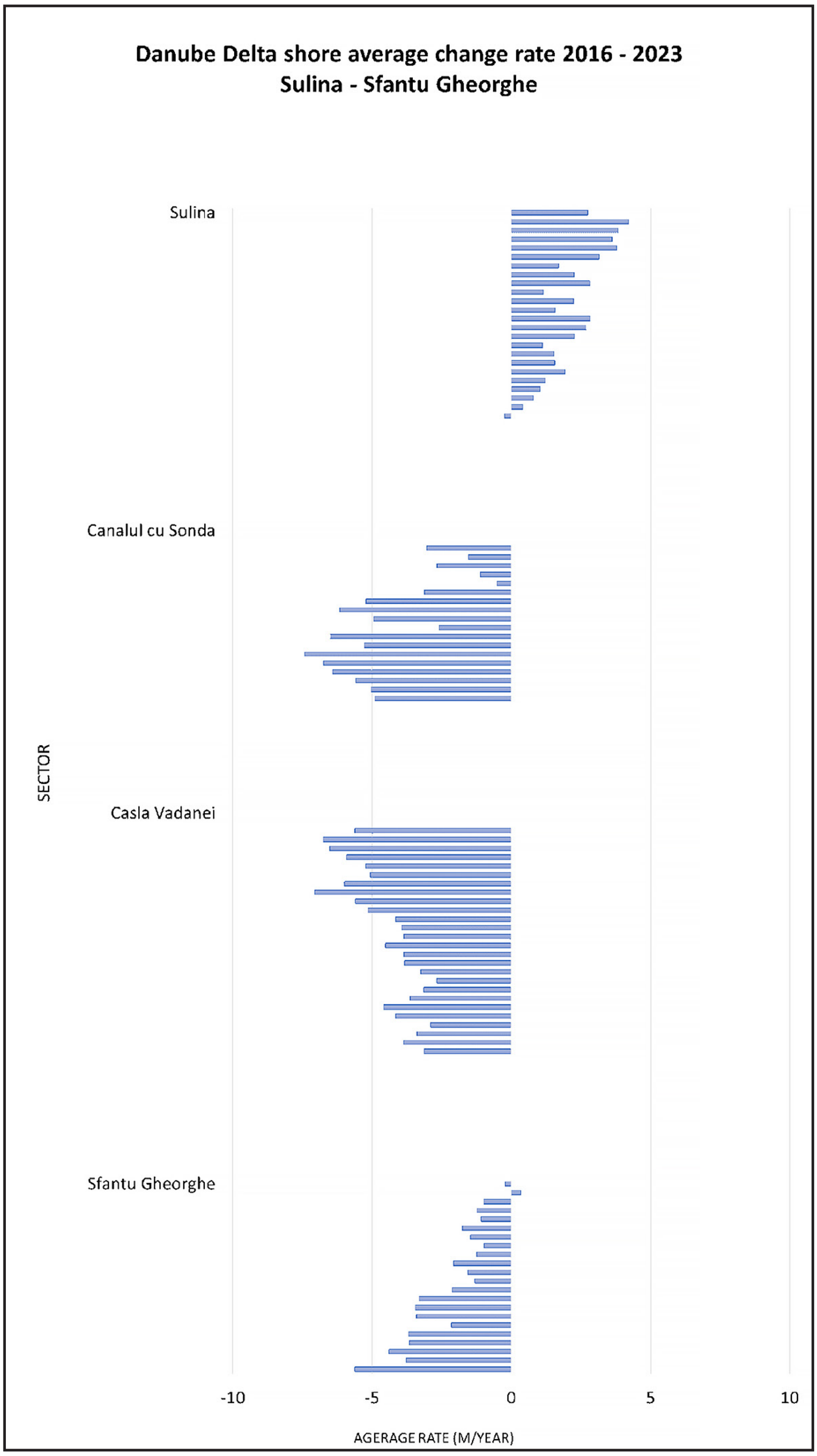

Fig. 6. Average change rate for the Danube Delta shore along the Sulina – Sfântu Gheorghe sedimentary cell between 2016 and 2023.

3.2. Sahalin spit

With an analysed shoreline length of around 11 km, the *Sahalin North* sector is characterised by overall erosion, with an average rate of -1.4 m/year. The southern part of this sector corresponds to the former breach between Sahalin North and Sahalin South which is filling up at a rate of 15 m/year (Figs. 7-9).

The *Sahalin South* sector, with around 8 km analysed shoreline length, is characterised by elongation in the southern part and erosion in north. The overall average change rate is positive of about 22.9 m/year. The most noticeable change in the southern region took place between 2016 and 2017, with smaller changes occurring in the years that followed (Figs. 8, 9).

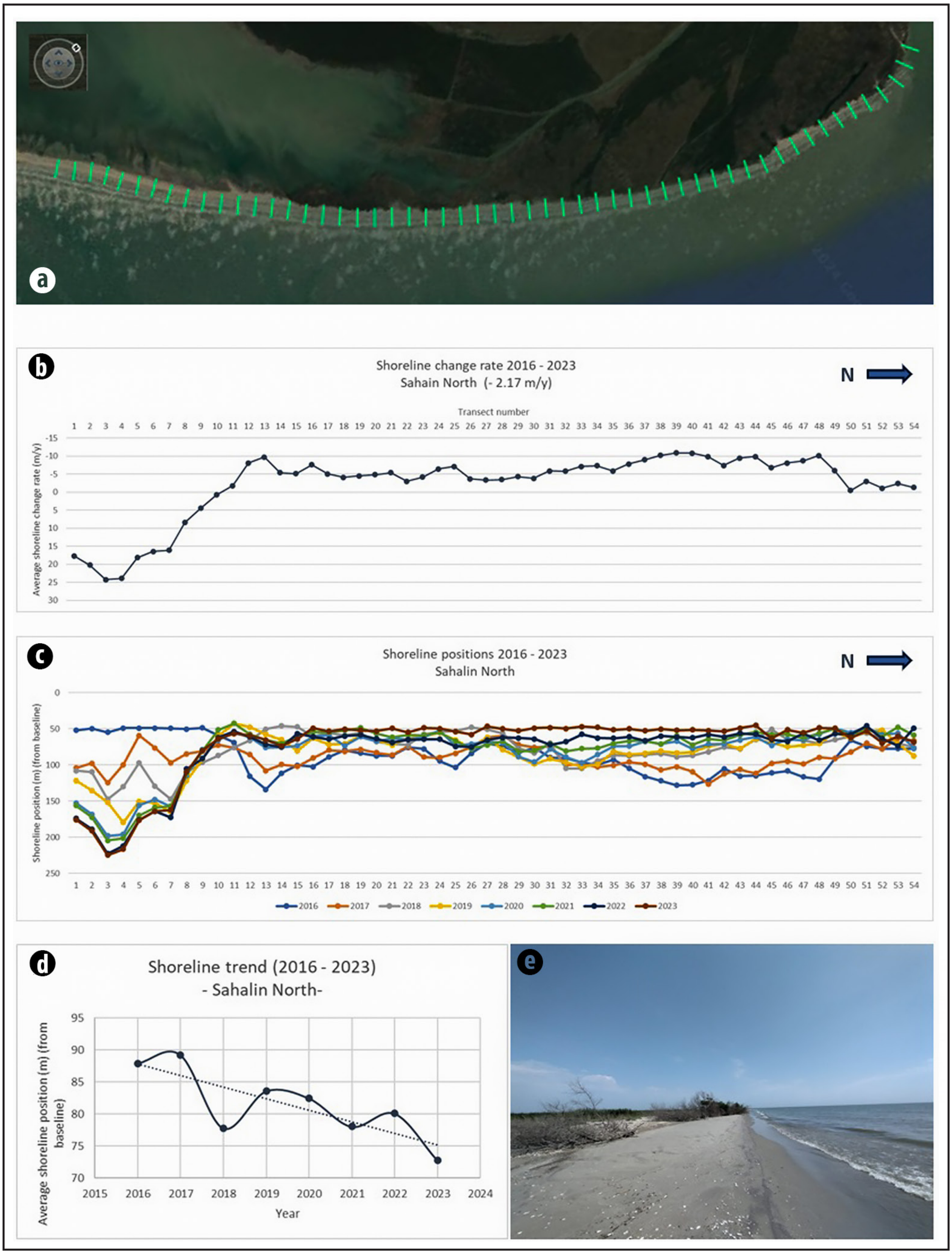

Fig. 7. Sahalin North. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Sahalin North (2023).

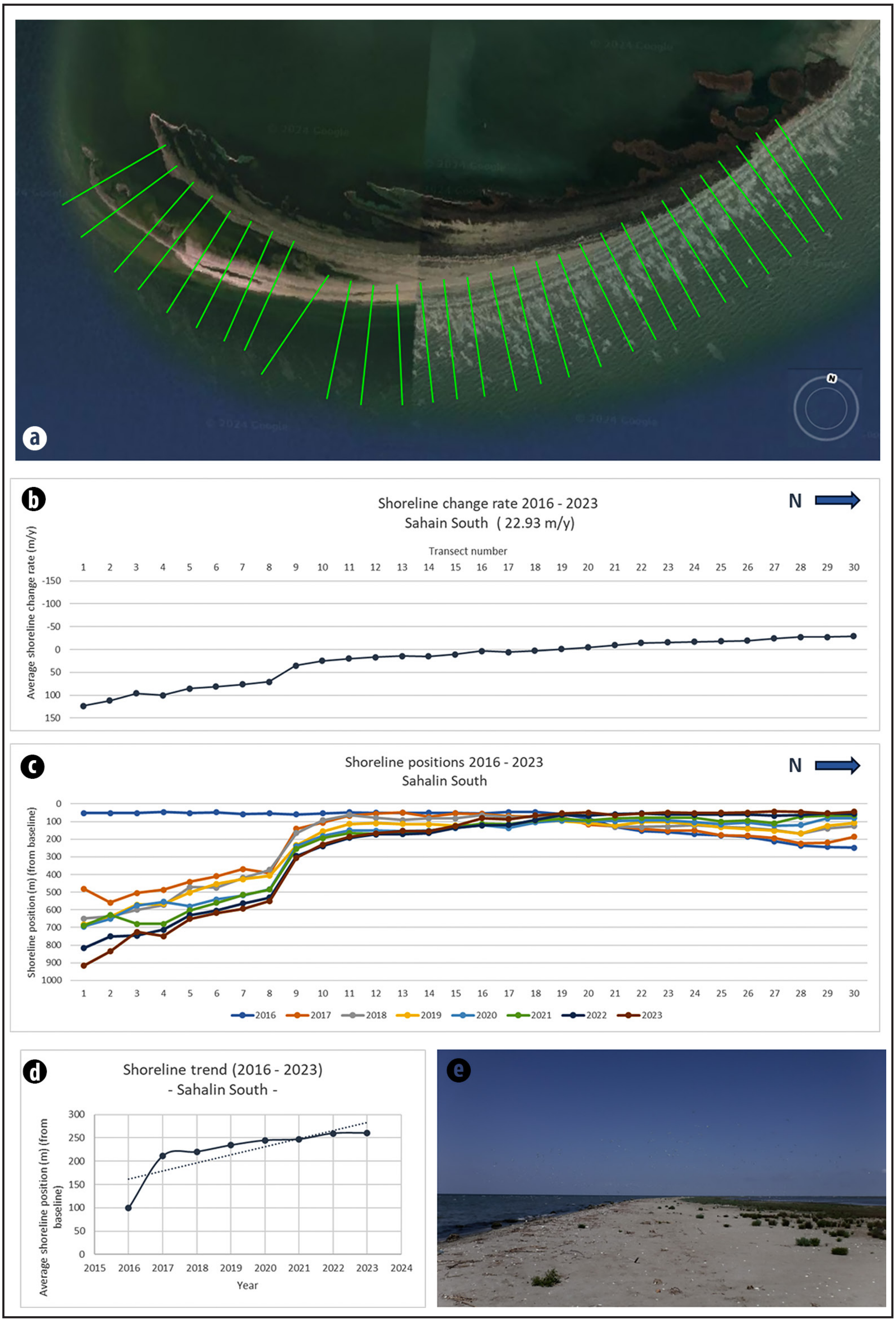

Fig. 8. Sahalin South. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Sahalin South (2017).

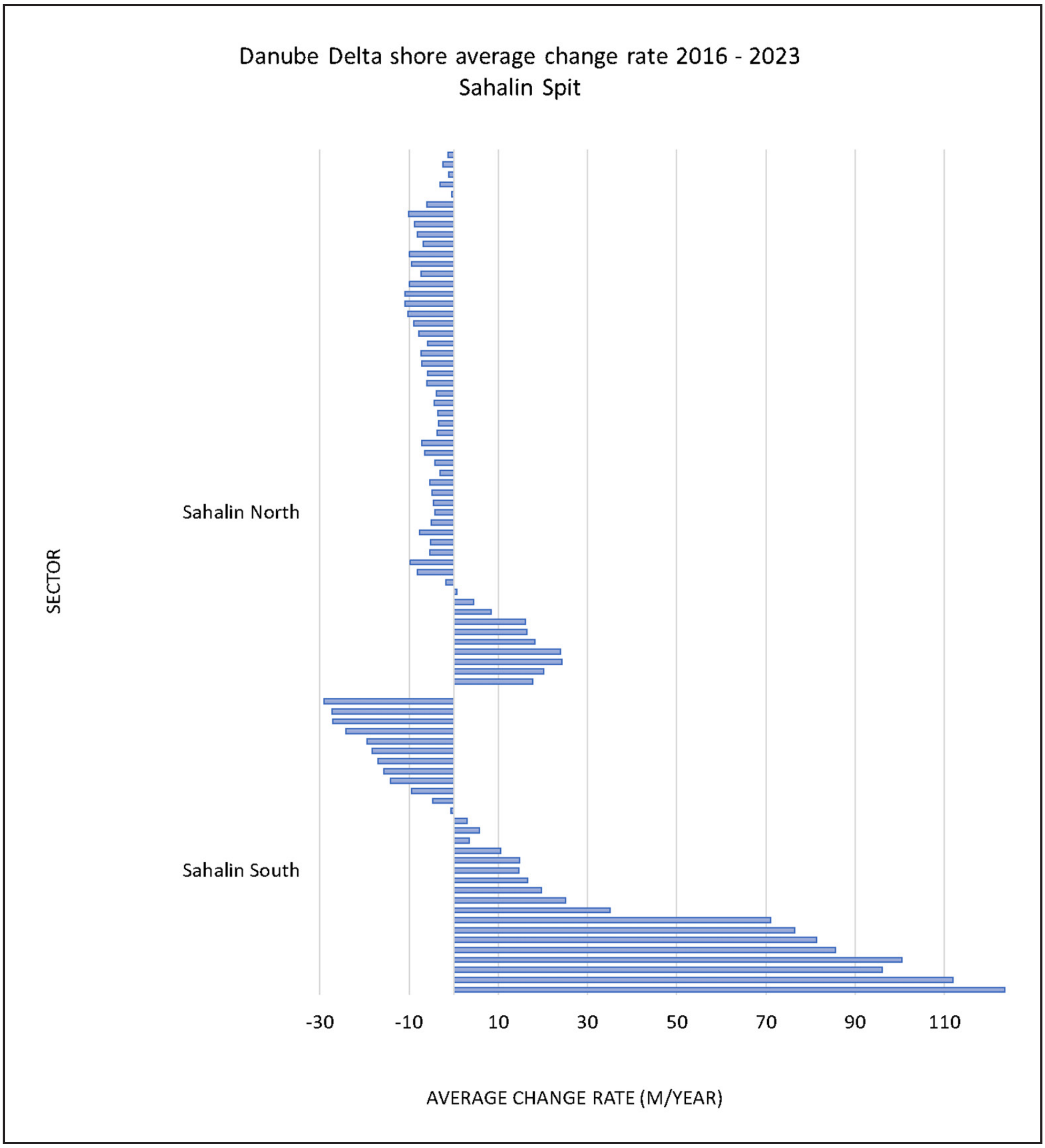

Fig. 9. Average change rate for the Danube Delta shore along the Sahalin Spit between 2016 and 2023.

3.3. Zătoane – Cape Midia sedimentary cell

At *Perișor,* the analysed shoreline length of around 4 km illustrates a generalised erosion trend in the north and centre with rates up to -4.6 m/year, while in the south the rates are up to -0.4 m/year. The average change rate for the entire sector is -2.9 m/year (Fig. 10).

With an analysed shoreline length of around 8.5 km, *Periteasca* sector is overall accumulating with a rate of 1.8 m/year (Fig. 11).

Portița North, with around 4 km analysed shoreline length, is generally stable, with an average rate of -0.7 m/year with higher erosion rates in the south, up to -2.3 m/year (Fig. 12).

Portița South, with an analysed shoreline length of around 3 km is eroding with an average of -2.2 m/year (Fig. 13).

North of *Periboina* inlet, the analysed shoreline length of around 2 km is rather stable. The average change rate for the period 2016 – 2023 is -0.25 m / year (Fig. 14).

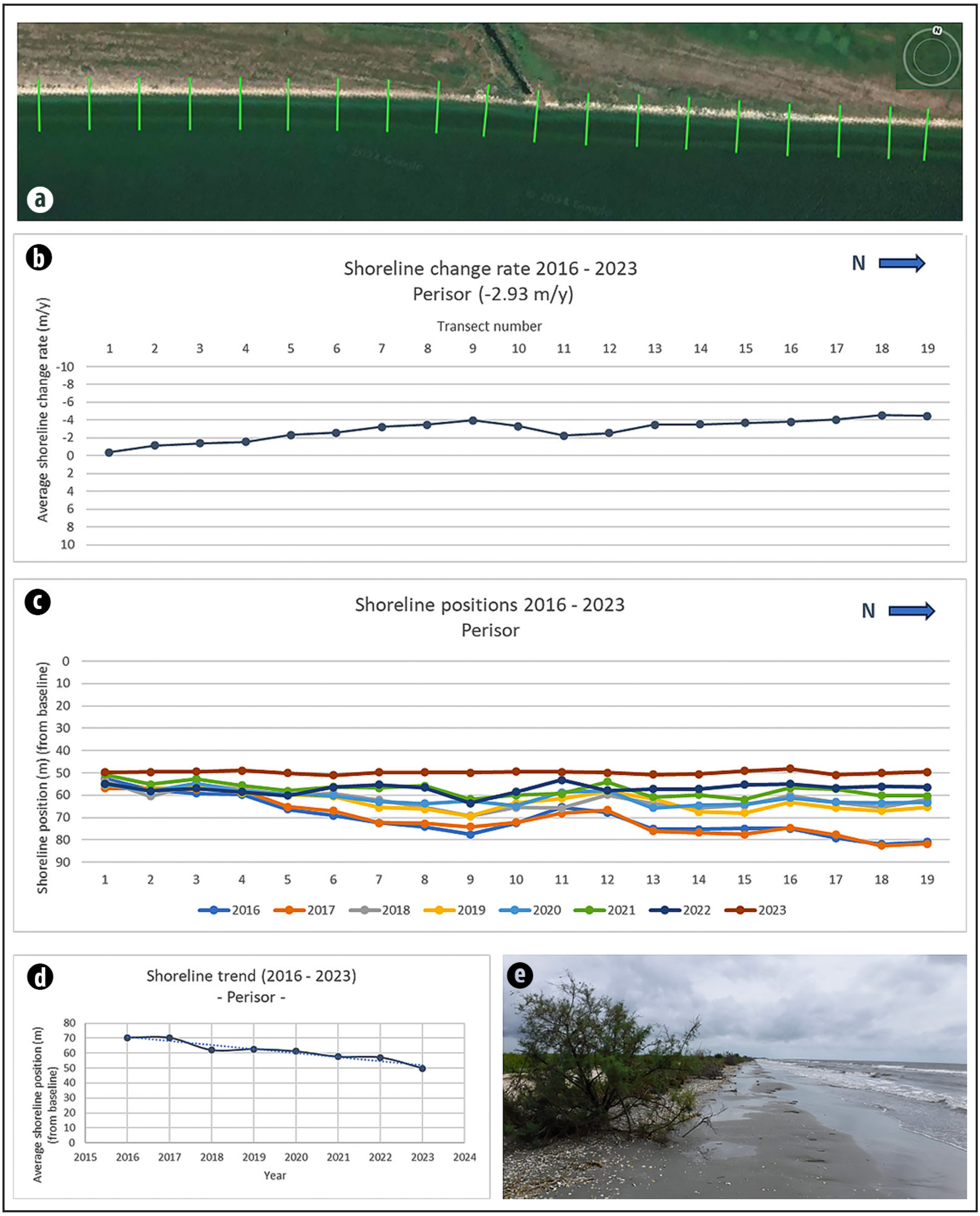

Fig. 10. Perișor. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Perișor North (2018).

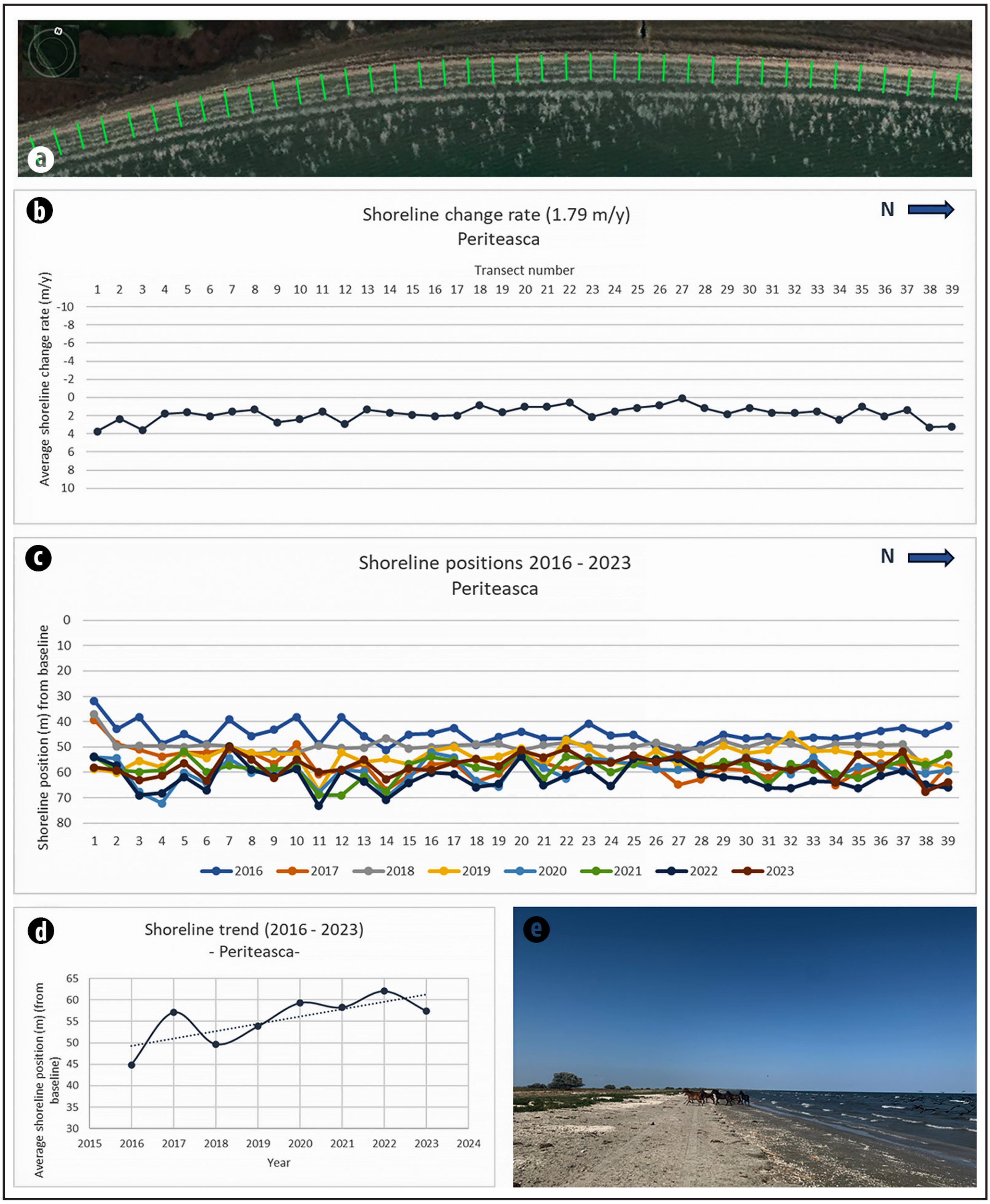

Fig. 11. Periteasca. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Periteasca (2023).

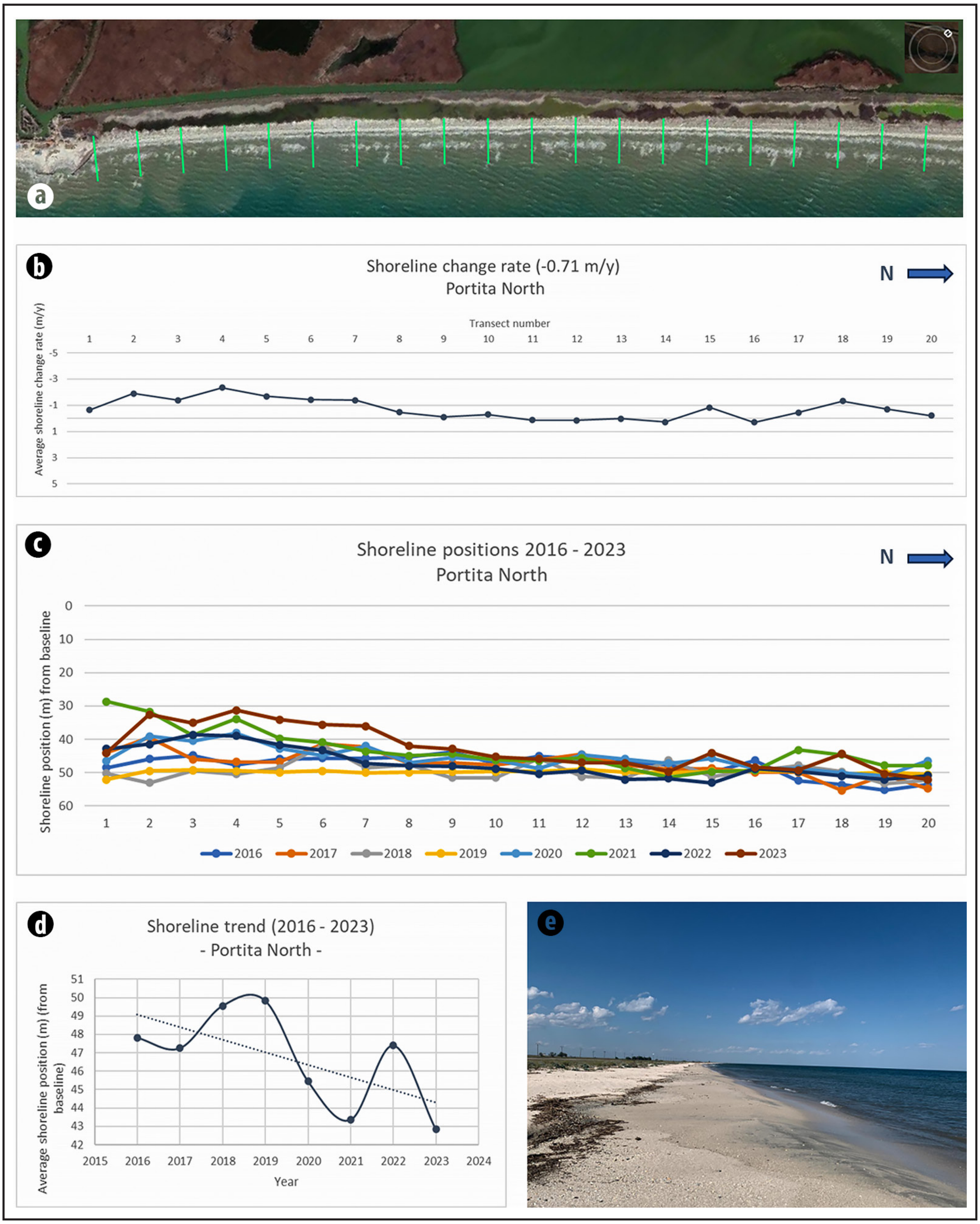

Fig. 12. Portița North. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Portița North (2023).

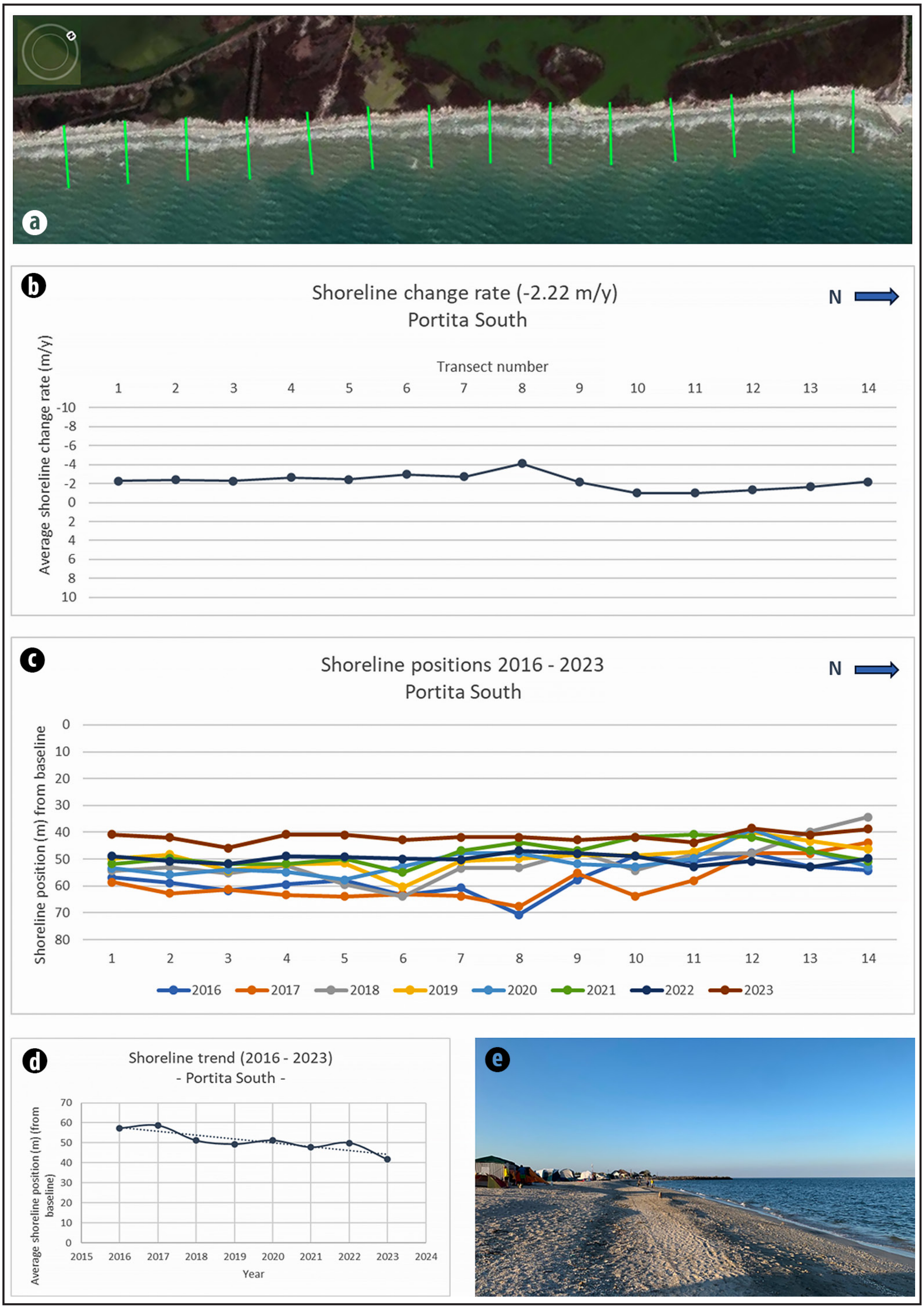

Fig. 13. Portița South. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Portița South (2024).

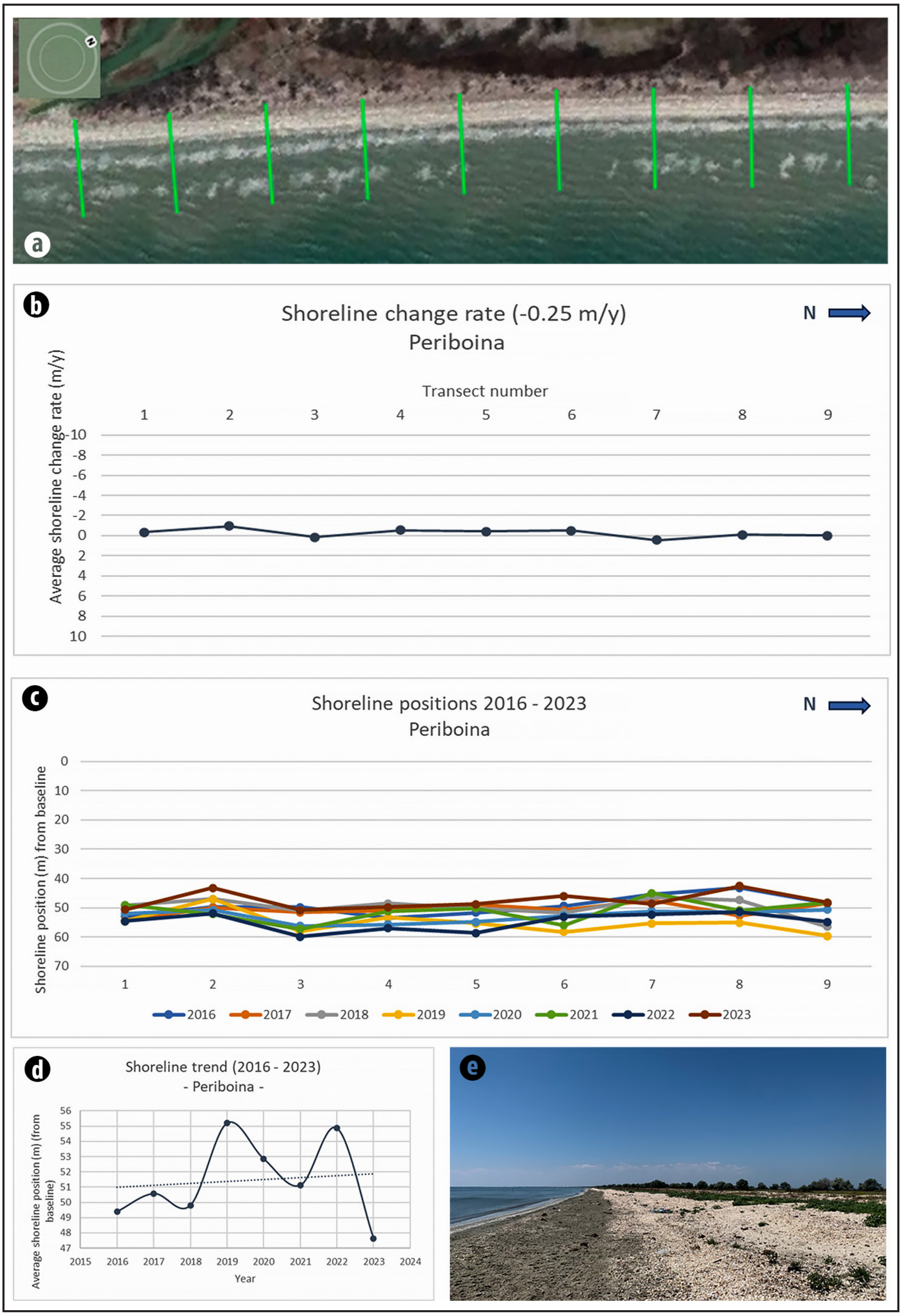

Fig. 14. Periboina. (**a**) Transect positions along the sector (background source Google Earth); (**b**) Shoreline change rate 2016 – 2023 with negative values indicating erosion and positive values indicating accretion; (**c**) Measured shoreline positions 2016 – 2023 relative to baseline; (**d**) Shoreline trend 2016 – 2023; (**e**) Image from the beach of Periboina (2023).

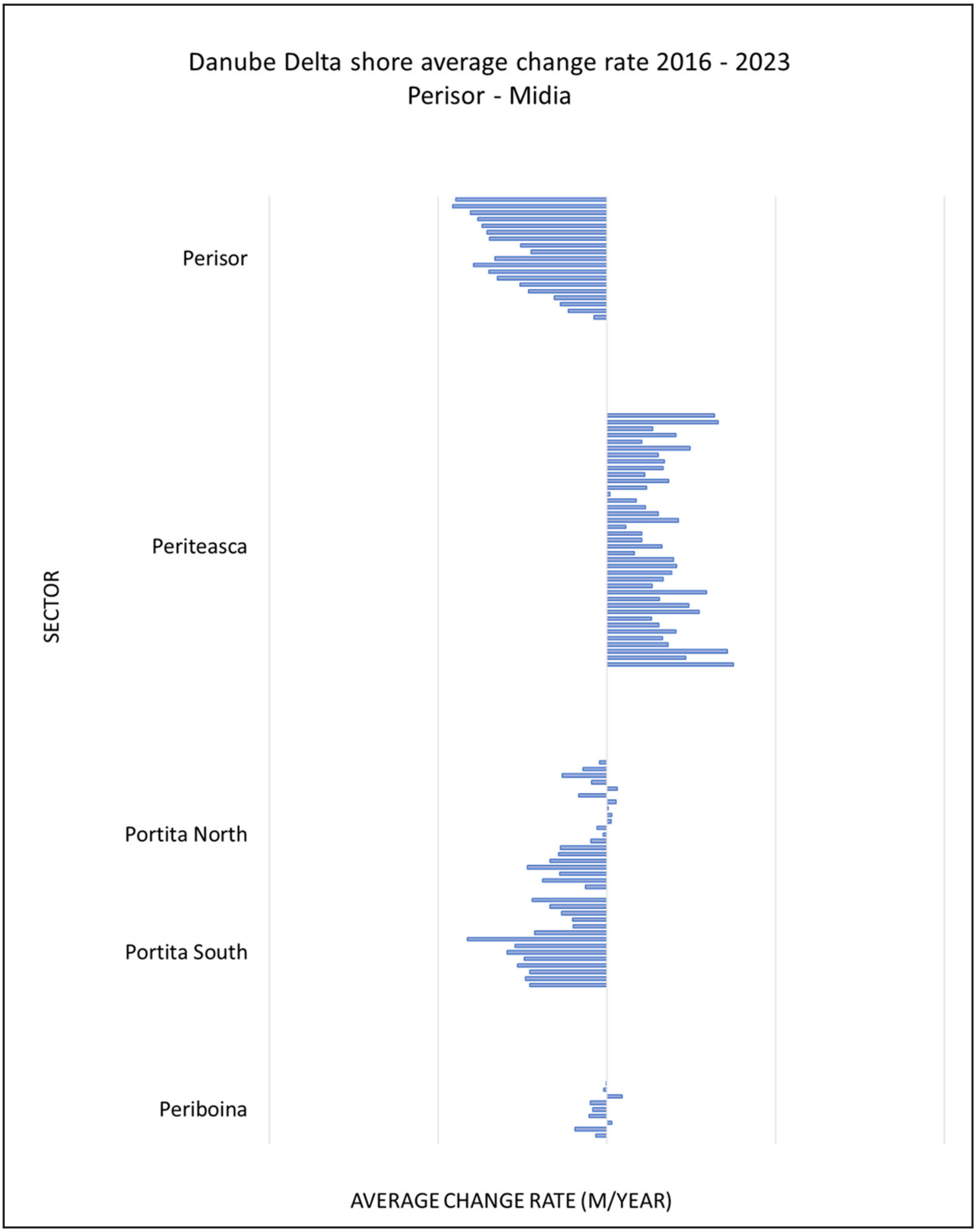

Fig. 15. Average change rate for the Danube Delta shore along the Sahalin South – Zătoane – Cape Midia sedimentary cell between 2016 and 2023.

Table 1. Minimum, maximum and average shoreline change rate for (a) yearly measurements 2016 – 2023.

Sector	Lowest shoreline change rate (m/y)	Highest shoreline change rate (m/y)	Average shoreline change rate (m/y)
Sulina	-0.25	4.21	**2.10**
Canalul cu Sondă	-7.40	-0.50	**-4.37**
Câsla Vădanei	-7.05	-2.67	**-4.37**
Sfântu Gheorghe	-5.62	0.30	**-2.23**
Sahalin North*	-9.77*	24.28*	**-2.17***
Sahalin South*	-29.00*	123.48*	**22.93***
Perișor	-3.95	-0.39	**-2.93**
Periteasca	0.09	3.70	**1.79**
Portița North	-2.35	0.30	**-0.71**
Portița South	-4.12	-0.99	**-2.22**
Periboina	-0.94	0.44	**-0.25**

* Sahalin North and Sahalin South change rates appear mostly due to the behaviour and dynamic of the spit with rapid shift in the southern part of Sahalin North (filling in the previous breach) and Sahalin South (creation of a new spit) and erosion in the northern parts.

4. DISCUSSION

Shoreline dynamics, including retreat and advancement trends, are influenced by both natural processes and human activities. Prograding sectors tend to form around active deltaic lobes, at the mouths of Danube branches, and near hard coastal structures (Stănică and Panin, 2009, Vespremeanu-Stroe *et al.*, 2017). Erosive sectors, on the other hand, are typically found at the borders of inactive deltaic lobes, where coastal sedimentary cells meet, or in updrift zones due to the divergence of nearshore currents (Vespremeanu-Stroe *et al.*, 2017).

The shoreline dynamics of the Danube Delta are varying across different sectors (Table 1), due to the influence of both natural processes, past and present human activities (Panin, 1999, Ungureanu and Stănică, 2000, Stănică and Panin, 2009). While most of these areas are experiencing erosion, some are stable and some are accreting (Table 1; Figs. 6 and 15). Despite the fluctuations caused by meteorological conditions on the day of the measurements, the overall trend of the shoreline in a specific sector highlights its erosional or accretional dynamics.

4.1. Sulina – Sfântu Gheorghe sedimentary cell

Mainly influenced by the presence of the jetties, the Sulina sector is characterised by accretion in its northern part, stability in the centre and retreat towards its southern part. This trend is consistent with findings from previous studies (Stănică *et al.*, 2007, Vespremeanu-Stroe *et al.*, 2007, Stănică and Panin, 2009, Vespremeanu-Stroe *et al.*, 2017), however, currently measured average rates of 2.1 m/year are lower than the rates observed by Vespremeanu-Stroe *et al.* (2017) and mentioned by Halcrow (2012), for data covering the period 1979 – 2006, of 8.1m/year. This can be due to the fact the current measurements were conducted only in the central and southern part of the Sulina sector, excluding the northern area, and the region just south of the jetties, where the highest accretion rates occur.

Erosion is evident at both Canalul cu Sondă and Câsla Vădanei sectors. This aligns with historical patterns documented in previous research. Erosion in this sector was amplified by past human activities (Panin, 1999). The sector is located in the divergence zone between the south-north oriented anticyclonic current, caused by the Sulina jetties, and the north-south oriented longitudinal current, leading to a sediment deficit (Giosan *et al.*, 1999). The average erosion rate at Canalul cu Sondă was found to be between -6 and -9 metres per year in previous studies (Stănică, 2003, Vespremeanu-Stroe *et al.*, 2007, Halcrow, 2012). Current results indicate a decline in the erosion rate with a calculated average of -4.4 m/year. The northern part of Canalul cu Sondă sector is more advanced than the south and eroding at smaller rates. This can be due both to the presence of both living and relict vegetation on shore with the ability to mitigate erosion but also to the fact that the area is in the immediate vicinity of Sulina sector, which exhibits accretion under the protection of the jetties. Câsla Vădanei however doesn't have any type of vegetation on shore and here both its absence and the lack of sediment input, have contributed to an erosional trend over the years.

This study reveals an erosional trend in Sfântu Gheorghe, with rates increasing from north towards the south, contrasting with the findings of Vespremeanu-Stroe *et al.* (2017) and Halcrow (2012), who noted positive trends. According to Stănică (2003), the sector experiences alternating periods of advancement and erosion; additionally. Stănică and Panin (2009) observed a dynamic equilibrium in the shoreline, influenced by sediment redistribution at the river-sea interface.

4.2. Sahalin Spit

The shoreline at Sahalin Spit is primarily shaped by longshore currents and sediment supply, with storms, wind patterns, and sea-level changes also impacting the area (Giosan *et al.*, 1999). Between 2016 and the following years, significant changes were observed, particularly in Sahalin South, where new spits developed. Meanwhile, Sahalin North experienced retreat (Fig. 9). The breach in Sahalin North, which occurred in the winter of 2012 – 2013 (Zăinescu *et al.*, 2019), is gradually filling with sediment from the Sfântu Gheorghe branch of the Danube Delta. In addition, the presence of partially submerged trees along the shore of Sahalin South may have an important influence on the coastal dynamics in that area. We observed that the presence of dense trees may delay erosion and shoreline retreat, even if the trees are not alive.

4.3. Zătoane - Cape Midia sedimentary cell

Perișor sector is facing generalised erosion with smaller rates (approximately -3 m/year) compared with the ones from literature (up to -17 m/year between 2008 and 2010; Halcrow, 2012). This may be due to the shorter analysed shoreline length (not including the Zătoane area from the north, which is historically characterised by high erosion).

Periteasca sector is characterised by stability and slight accumulation, similar with findings of previous studies (Vespremeanu-Stroe *et al.*, 2007 and Halcrow, 2012). While the erosion rates in Portița area are generally lower than the ones from earlier studies, of around -2 m/year in Portița South compared to -3 m/year in Vespremeanu-Stroe *et al.* (2007) and -3.9 m/year in Halcrow (2012). Portița North area is stable in the northern part influenced by the vicinity of Periteasca. The highest erosion rate observed during summer measurements in Portița South appears in the area that has been impacted by storms since 2018, with a breach forming between December and February/March. This area also corresponds to the former Portița Inlet, which was artificially closed in 1974, and is expected to reopen in the near future due to specific hydrodynamic conditions that will re-establish the connection between the lagoon and the sea (Stănică *et al.*, 2024 – Danube4all workshop).

The Periboina sector, despite having similar conditions to Portița, in terms of currents and sediment supply, remains almost stable with only a slight retreat. This might be due to the sand dredged from the Periboina channel being re-distributed along the shore.

Current measurements show a reduction in erosion rates in areas that previously experienced high rates of shoreline retreat. This decline may have multiple causes: a new equilibrium in sediment distribution, meaning there was enough sediment in the near-shore system in the studied period; sediment redistribution of the near-coast depocentres Sulina and Sfântu Gheorghe mouths (Zăinescu *et al.*, 2019); lower storminess in the north-western Black Sea (Vespremeanu-Stroe *et al.*, 2007, Zăinescu *et al.*, 2017), which decreases erosion.

5. CONCLUSIONS

The Danube Delta shoreline, between Sulina and Periboina, as observed over 8 years (2016-2023), displays erosion, accretion and stability across different sectors, with significant variations in rates and trends. With lower rates compared to historical data, Sulina sector is accreting mostly due to the influence of the jetties from the north, which block the longshore current and facilitate the accumulation of sediments. The longshore current resumes and starts to grow in Canalul cu Sondă and Câsla Vădanei areas. These sectors exhibit clear erosional trends, with lower rates compared to existing studies.

In contrast to existing literature, Sfântu Gheorghe sector has a shift toward erosion, particularly in the south, deviating from past positive trends observed in earlier studies.

Due to its dynamics and influenced by the longshore current, storms and changes in sediment supply, the Sahalin Spit demonstrates significant change, with Sahalin South elongating and Sahalin North experiencing erosion.

The Perișor sector exhibits a general trend of erosion, with higher retreat rates in the northern and central parts, while the southern section experiences lower erosion rates, while Periteasca sector is characterised by stability and slight accumulation, with shoreline conditions remaining consistent with previous studies. The Portița sectors reflect erosion and storm-induced breaches, particularly in the south, while the Periboina sector remains almost stable.

The primary drivers of local coastal dynamics remain the sediment input and redistribution by waves, currents, and river processes. While the current study provides valuable insights, it does have some limitations. The *in situ* measurements, though precise, only reflect the shoreline position at a specific moment and under certain conditions. To improve future research, it would be helpful to correlate shoreline data with wave conditions from the day prior to the measurements. This would offer a deeper understanding of shoreline changes, as the state of the sea before and during the measurements plays a crucial role in shaping the coastline.

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Annex 1

	Sulina	Canalul cu Sondă	Câsla Vădanei	Sfântu Gheorghe	Sahalin North	Sahalin South	Perişor	Periteaşca	Portița North	Portița South	Periboina
2016	Relatively calm sea, clear sky, light east wind	Relatively calm sea, clear sky, light east wind	Calm sea, clear sky, light south wind	Clear sky, light-moderate northeast wind, relatively calm sea	Clear sky, light northwest wind, relatively calm sea	Clear sky, very calm sea, light south-southeast wind	Very calm sea, moderate northwest wind, clear sky	Partially clear sky, strong northwest wind, relatively calm sea	Clear sky, strong northeast wind, rough sea	Clear sky, strong northeast wind, rough sea	Clear sky, light north wind, calm sea
2017	Light northeast wind, calm sea	Clear sky, good visibility, light northeast wind, calm sea		Cloudy sky, rough sea, northwest wind	Clear sky, northwest wind, relatively calm sea	Calm sea, light southeast wind	Clear sky, moderate northeast wind, calm sea	Calm sea, clear sky, light northeast wind	Clear sky, calm sea, no wind	Clear sky, light wind, calm sea	North-northwest wind, clear sky, rough sea
2018	Clear sky, light wind, relatively calm sea	Clear sky, calm sea, light wind	Clear sky, light wind, relatively calm sea	Clear sky, no wind, calm sea	Moderate wind, sea grade 2	Moderate wind, sea grade 2	Cloudy sky, torrential rain, moderate wind	Partially cloudy sky, relatively rough sea, moderate north-south wind	Clear sky, no wind, sea grade 0	Clear sky, no wind, sea grade 0	Clear sky, sea grade 0, no wind
2019	Light west wind, calm sea, clear sky	Clear sky, light wind, calm sea	Clear sky, moderate southeast wind, relatively rough sea	Light northwest-north wind, calm sea, clear sky	Very calm sea, light southeast wind	Sea grade 1, light south-southeast wind, clear sky	Clear sky, light wind, calm sea	Moderate southeast wind, relatively rough sea	Light/moderate northwest wind, calm sea, clear sky	Clear sky, moderate souteast wind, calm sea	Rough sea, moderate north-northeast wind, clear sky
2020	Moderate southeast wind, clear sky, sea grade 1	Sea grade 1, light-moderate northeast wind, clear sky	Very calm sea, 10-15 cm waves, north-northwest wind, clear sky	Clear sky, light north wind, rough sea grade 1-2	Clear sky, northeast wind, sea grade 2	Clear sky, sea grade 1, light southeast wind	Light northeast wind, clear sky, calm sea	Clear sky	Moderate/ strong north-northeast wind, clear sky, sea grade 3	Light/moderate west wind, 30 cm waves	
2021	Sunny, strong south wind	Northeast wind 15-20 km/h, partially cloudy sky	Clear sky, sea grade 2, light-moderate northeast wind	Clear sky, moderate south-southeast wind, sea grade 2	Relatively light north-northeast wind, relatively calm sea, clear sky	Partially cloudy sky, light northeast wind, calm sea	Clear sky, sea grade 2-3, moderate northeast wind	Clear sky, northeast wind	Clear sky, northeast-southwest wind	Clear sky, north-northeast wind	Clear sky, very calm sea, northwest wind 5 km/h

Annex 1 (*continued*)

	Sulina	Canalul cu Sondă	Câsla Vădanei	Sfântu Gheorghe	Sahalin North	Sahalin South	Perişor	Periteaşca	Portiţa North	Portiţa South	Periboina
2022	Very calm sea, light northeast wind	Very calm sea, light southeast wind, clear sky	50 cm waves at the shore, moderate northeast wind, clear sky	Very calm sea, clear sky, moderate northwest wind	Clear sky, very calm sea, light northwest wind		Partially cloudy sky, calm sea, northwest wind	Very calm sea, clear sky, southwest wind	Clear sky, very calm sea, southeast wind	Cloudy sky, calm sea, northwest wind 12-28 km/h	Clear sky, very calm sea, southeast wind
2023	Moderate north wind, calm sea, clear sky	South-southeast wind, rough sea, partially cloudy sky	Clear sky, calm sea, northwest wind	Clear sky, calm sea, northwest wind	Clear sky, sea grade 1-2, southwest wind	Partially cloudy sky, sea grade 1-2, wind	Clear sky, moderate southeast wind, calm sea	Light northwest wind, calm sea	Moderate northwest wind, calm sea, clear sky	Moderate south-southeast wind, rough sea (strong current), clear sky	Moderate south-southeast wind, rough sea (strong current), clear sky

Weather conditions in the days of measurement in Sulina, Canalul cu Sondă, Câsla Vădanei, Sfântu Gheorghe, Sahalin North, Sahalin South, Perişor, Periteaşca, Portiţa North, Portiţa South and Periboina between 2016 and 2023. No meteo info was recorded in Câsla Vadanei 2017, Sahalin South 2022 and Periboina 2020.

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