CASPIAN COASTAL ZONE ENVIRONMENT AND RIVER DELTAS DYNAMICS: INVESTIGATIONS BY MULTITEMPORAL SPACE IMAGES

V.I.Kravtsova, V.N.Mikhailov
Faculty of Geography, Moscow State University, 119992 Moscow, Russia – vik@lakm.geogr.msu.su

Commission VII

KEYWORDS: Hydrology, Coast, Environment, Change detection, Imagery, Mapping

ABSTRACT:

In 1978-1995, the Caspian Sea was exposed to the intensive sea level rise by 2.35 m after its long downing. It gave valuable material for investigations of coastal zones of various types and river deltas response to sea level fluctuations. The interpretation of multitemporal satellite images was used for analyzing of changes and compiling of maps of coastal ecosystems statement and dynamics for Kalmykian coastal zone in 1978-1991, 1991-1997, 1997-2001. They show that sea transgression to land, which was waiting with sea level rise, is not characteristic feature for this type of coasts with reed mudflats. Reed opposites flooding and boundary between reed weeds and sea changes are relatively weak. But wetting of reed mudflat lead to its large widening in the landward direction from 2 to 8 km. After 1995, when sea level rise stopped and gradually lowered, returning moving of reed mudflat band in the seaward direction has took place. This event again has began from back side of mudflat. So the back boundary of mudflats is more sensitive to sea level fluctuations than the front boundary between reed weeds and sea.
The Caspian Sea level fluctuations also strongly influence on the river mouth processes, especially in large protruding deltas. Monitoring of the Caspian deltas was provided by space surveys for the Ural, Terek, Sulak, Kura river deltas. The analysis of created maps shows that the following changes during the sea level rise period are typical for protruding deltas of the Caspian Sea: flooding of low laying periphery parts; wave abrasion of more deep parts of the near shore slope and formation of spits from material of abrasion; formation of barrier-lagoon complex; hydrographical network reconstruction.
Investigated features of the Caspian coastal zone and river deltas dynamics can be used as an analogue phenomenon for forecasting of processes which can take place in world coastal zones and river deltas in the case of proposed global significant sea level rise.

1. INTRODUCTION

Recently the Caspian Sea level fast rise (from –29.01 m in 1977 to –26.66 m in 1995, with afterwards slow lowering to –27.10 by 2004) simulates the situation that is waiting on the World Ocean coasts in the XXI century due to global climate warming. Therefore the Caspian Sea can serve as a unique natural laboratory for study of the coastal zone and river mouths response to the sea level rise.

Laboratory of Aerospace methods, Department of Mapping and Geoinformatics, and Department of Hydrology (at Faculty of Geography, Moscow State University), carry out the monitoring of low laying North-Western Caspian coasts and main Caspian deltas response to changes of the sea level. It includes the interpretation of multitemporal satellite images and compilation of maps of coastal and deltaic ecosystems statement and dynamics.

2. METHODS AND MATERIALS

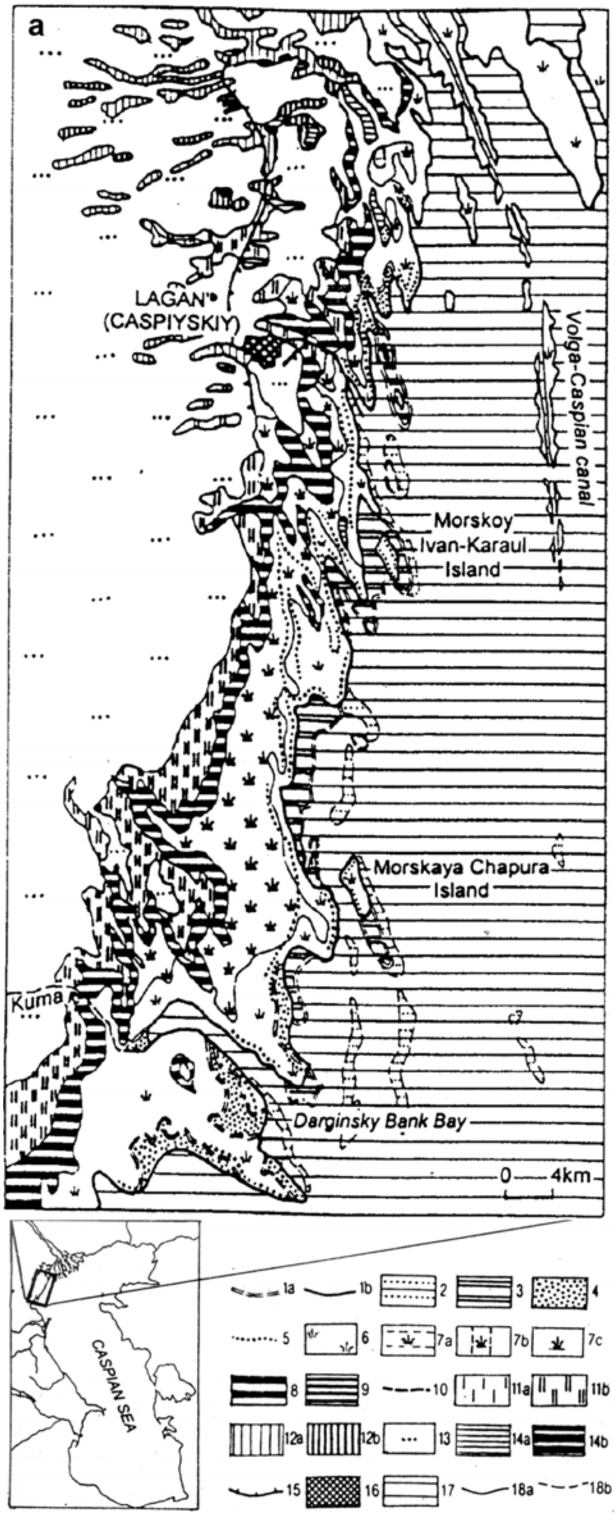
Dynamics studies require to use imagery with good resolution (R), which were variable in different periods of space investigations. During the sea regression, there were photo pictures from orbital stations “Salut-4”, KATE-140, R=60 m (1975); “Salut-6”, MKF-6, R=20 m (1978) and “Landsat-1,2”, MSS (R=80 m) images; during the fast sea-level rise – photos from “Resurs-F” satellites, KFA-1000, R=10 m (1982, 1983), MK-4, R=10 m (1991) and scanner images from “Resurs-O” satellite, MSU-E, R=35 m (1997); and for last period of the sea level stabilization and slow level lowering – “Landsat-7”, ETM+, R=30 m, “IRS”, LISS, R=23 m, “Terra”, ASTER, R=15 m, “Meteor-3M”, MSU-E, R=35m images (2001-2004).

Satellite images were used for compiling a series of dynamics maps for the low laying Kalmykian coast and the Ural, Terek, Sulak and Kura deltas. Maps of the coastal and deltaic ecosystems statement in 1977-78, 1991-92, 1996-97, 2000-02 and maps of transgressive changes in the coastal zone for periods 1978-1991, 1991-1997 and of post-transgressive changes for period 1997-2002 were compiled (in scale 1:200 000) by computer processing of multitemporal satellite images. Materials for coasts and deltas mapping are presented and analysed in the paper.

3. RESULTS OF IMAGES ANALYSIS FOR KALMYKIAN COAST

Kalmykian coast in the North-Western part of the Caspian Sea is very low lying coast affected by the wind-induced surges. The wide band of mudflats with the dense cover of reed has been formed here. Results of space images interpretation show that transgressive changes along this coast, extended from north to south by 120 km, are increased with the distance from the Volga delta, which gives some “buffer effect”, and with steepness of coastal zone slopes (Kravtsova, Lukyanova, 1999).

In **1978-1991**, when sea level rose by 1.75 m, the shoreline of the northern part of this coast changed very little (Figure. 1a). Weak influence of the sea level rise along this part of the coast is explained by the “buffer effect” of the extensive shallow-water area in front of the Volga delta. The southern part of Kalmykian coast (i.e. far from the Volga delta) experiences more signifi



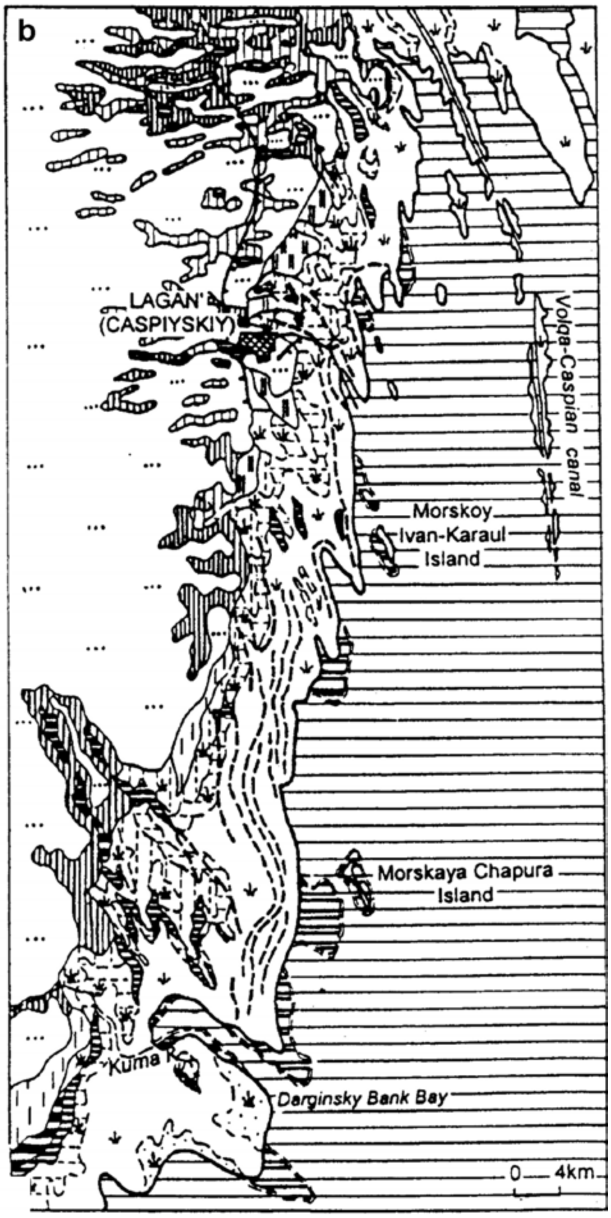


Figure.1**.** The Kalmykian coast of the Caspian Sea. Dynamics of the coastal zone: (a) – in 1978–1991 and (b) in 1991–1998 (according to Kravtsova, Lukyanova, 1999):

Legend to Figure 1

1 - shoreline (outer limit of the reed-covered mudflats): 1a - in the beginning of period, 1b - in the end of period; 2 - offshore depositional features eroded; 3 - submerged reed-covered mudflats (zone of the coast retreat); 4 - sand flat appeared (zone of the coast accretion); 5 - beach ridges; 6 - reed-covered mud flat retained; 7 - reed-covered mud flat newly appeared in place of: 7a – lagoon behind the reed-covered mudflat, 7b – waterlogged area along the lagoon, 7c – semidesert plain; 8 – lagoons formed behind the reed-covered mud flat; 9 - retained segments of the lagoon behind of the reed-covered mud flat; 10 - narrow strips of water appeared along beach ridges within the reed-covered mudflats; 11 - waterlogged zone along the reed-covered mudflats: 11a - retained, 11b - newly appeared in place of semidesert plain; 12 - solonchak meadows in troughs between Baer's mounds and in erosional basins: 12a - retained, 12b - newly appeared; 13 - semidesert plain; 14 - inner water bodies (lakes, man-made reservoirs): 14a - retained, 14b - newly appeared; 15 - canals; 16 - urban area; 17 - sea; 18 - boundaries of: 18a - retained and newly appeared objects, 18b - disappeared objects

cant influence of the sea level rise. Submergence of the outer edge of mudflat by sea waters and shoreline retreat (to 1-3 km)with some reconstruction of the coastal zone profile (new beach ridges appeared along water-edge) are predominated here. Mudflat widened to the land-side direction from 1-2 to 6-10 km. In the beginning of the sea level rise, a lagoon was formed behind the mudflats due to waves introduction and upgrade of underground waters. By 1990-s this lagoon (1-2 km wide) was seen along all the north-western coast of the Caspian Sea. Shore plain at backside of mudflats was influenced by underground water. The color images show a waterlogged zone about 3 km wide appeared at the back of lagoon; it is well distinguished by lush vegetation against the background of the surrounding semideserts.

In **1991-1997**, when sea the level had continued its rise for 1995, and then stopped at –26.6 m and had some stabilization, shoreline in the northern half of the Kalmykian coast, near the Volga delta, had little changes, as before (Fig. 1B). However, wetting of the nearshore plain noticeably increased, especially in troughs between Baer’s mounds. In the southern half of the Kalmykian coast, shoreline at some places locally retreated by 4-5 km. The reed flat surface changed noticeably. Its former dense vegetable cover thinned, open water windows become very frequent, especially in the narrow and prolonged (some kilometers) troughs between beach ridges. The backside of the mudflat changed essentially. The wide lagoon began to disintegrate into separate segments and then disappeared in the most part of the coast. Landward widening of the mudflat was continued and it increased more than 2-4 km. The general width of the mudflat did not change after 1991, but the mudflat stripe was shifted landwards.

1997-2001. In the last period changes are not so great. The position of shoreline near the Volga delta, as it was at previous time, did not changed (Fig.2). In southern part (more than 30 km from the Volga delta) changes in both directions take place – flooding of mudflat (retreat of shoreline) and appearing of new reed belts and capes along the shore (shoreline advancing) by 1-2 km. The stabilization and some lowering of the sea level lead to decreasing of mudflat humidity. The lagoon in the back part of mudflat is completely disappeared, but narrow water strips along beach ridges are conserved. Disappearing of reed and appearing of dry steppe vegetation instead of it took place along back mudflat boundary at the band of 3-5 km wide. Displacement of the backside mudflat boundary in the seaward direction at some plots takes place earlier, than shoreline moving in the seaward direction. The tendency to semidesert plain aridization is shown by images – reed vegetation in throughs again changed to solonchak meadows.

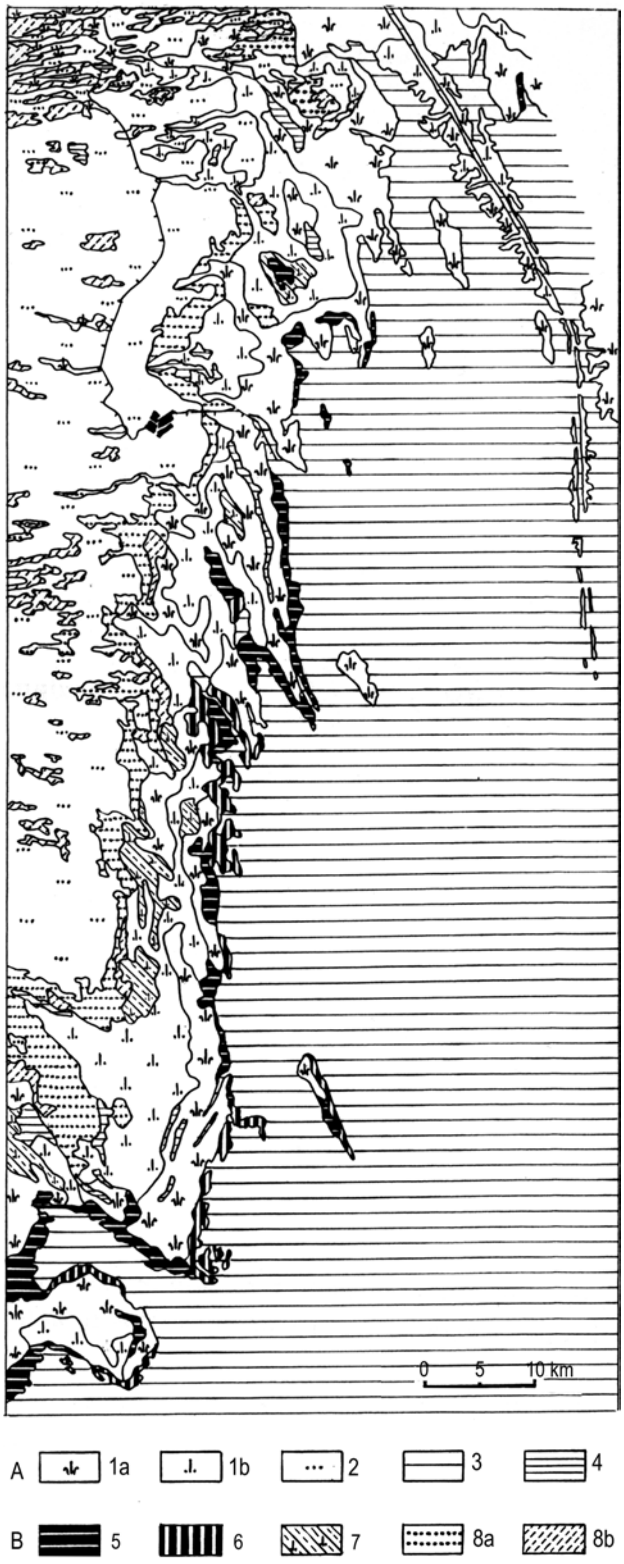


Figure 2. Dynamics of Kalmykian coastal zone in 1997-2001

Legend to Figure 2

A. Ecosystems without significant changes: 1 – reed covered mudflat: 1a – with dense vegetation cover, 1b – with sparse vegetation cover; 2 – steppe and semidesert vegetation of shore plains; 3 – sea; 4 – lakes.

B. Ecosystems with significant changes: 5 – submerged reed covered mudflats (zone of shoreline retreat); 6 – reed covered mudflats, new appeared in place of sea water (zone of coast accretion); 7 – reed covered mudflats with deteriorated vegetation; 8 – steppe and semidesert vegetation, appeared in place of: 8a - reed covered mudflats with deteriorated vegetation, 8b – reed covered mudflat and troughs with healthy vegetation.

4. RESULTS OF IMAGES ANALYSIS FOR CASPIAN DELTAS

River deltas are among of the most changeable geographical objects on the Earth. Their evolution depends on interaction between river (sediment discharges, at first) and sea factors (waves activity, tides, large-scale sea level changes). Natural and anthropogenic variations of these factors lead to acceleration or retarding of delta progradation into the sea or to wave abrasion and degradation of deltas.

The Caspian Sea level fluctuations are rendering strong impact not only to coastal zone but also to river mouth processes. River deltas on the Caspian Sea coasts are characterized by large-scale changes connected with deep fall of the sea level during 1930th - 1970th and fast rise by 2.35 m in 1978-1995, changed by gradual falling and some stabilization in 1995-2004, as well as with anthropogenic reduction in the sediment discharges (especially of the Sulak and Kura Rivers). This stage of Caspian deltas dynamics was investigated by authors practically for all large deltas (except of the largest Volga delta) on the Caspian coasts – deltas of the Ural, Terek, Sulak, Kura Rivers (Fig.3A).

4.1. The Ural River Delta

As other Caspian deltas, the Ural River delta changed its position and dimension for a long period of sea regression. The formation of modern delta began from XVIII century. Delta growth was stipulated by sea level falling and with sedimentation of deposits. Rapid protruding of the delta in 1940th-1960th was also caused by construction of Ural-Caspian Sea channel. By 1977, when the sea level was the lowest, the Ural River delta was prolonged at 32 km, its area was 522 km^2 and included Peshnoy Peninsula, before having been an island.

In **1977-1995** the sea level rise has lead to flooding the periphery part of the delta and to growth of reed, which formed wide belt along the shoreline (Fig.1B). By 1992 this reed belt was of 15-30 km wide. Open water windows – lagoons - along the back site of the reed belt were formed; they were of 3-5 km wide. Therefore the dry delta became to wetting one, turned to wet marches. If to account the boundary between sea and reed as a coastline, there were no significant changes in coastline position for the first part of this period in spite of rapid sea level rise; the coastline even moved a little in the seaward direction due to reed expansion. But after 1992, when the sea level rise exceeded 1.7 m, the reed belt began to destroy itself along seaside and so the coastline began to move in the landward direction. It was stipulated by waves activity and ice breaking. In 1992-1996 this retreat of coastline reached 3-5 km. Open water windows in marches (lagoons) widened to 7 km. River channels, having been dry before, were filled with water.

In **1996-2000**, when the sea level gradually began to fall down, the reed belt again widened and its outer boundaries moved in the seaward direction by 1 km; reed expanded into lagoons and large windows of open water turned into the narrow stripes of 1-2 km wide. Wet river channels again became dry.

So in the Ural delta region the following specific reaction to sea level fluctuations took place: formation of reed belt along the shore, expansion or reducing of reed weeds in dependence of water depth.

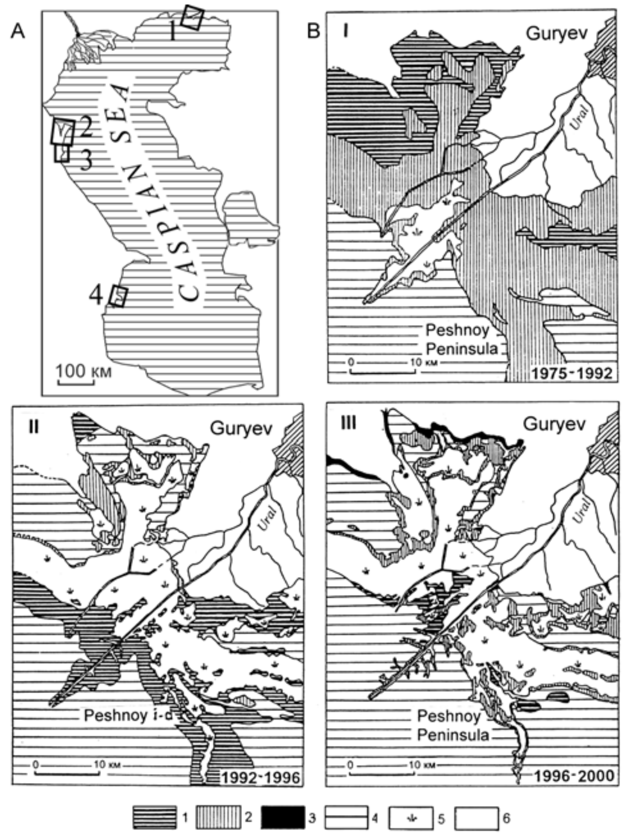


Figure 3 A. Location of the investigated Caspian river deltas: 1–Ural; 2-Terek; 3–Sulak; 4–Kura;
B. Changes of the Ural River delta in 1977-1992 (I), 1992-1996 (II), 1996-2000 (III): 1 – water instead of land and reed; 2 – reed instead of land and water; 3 – land instead of water and reed; 4 – water; 5 - reed; 6 – land.

4.2. The Terek River Delta

The Terek River delta has long and very complex history. Seven various stages of delta formation during the last 500 years have been investigated (Mikhailov, 1997). After Kargalinsky channel break in 1914, the large-scale inundation of the old delta took place and the northern old branches were abandoned. Gradually within the flooded zone an inner delta and then one branch delta were formed. River flow was concentrated in the main eastern channel. By the time when the Caspian Sea level was lowest in 1977 the eastern branch of the Terek – Alikazgan – discharged into Agrakhan Bay and rapidly protruded its delta into the bay. The dangerous of flooding caused the construction of artificial cannel through the Agrakhan Peninsula in 1960th years. In 1973 water broke throw protection embankment, and this event created the formation of small “new” delta at the open Caspian nearshore. But it also led to drying of the Agrakhan bay; artificial channel was then closed to prevent undesirable ecological consequences. In 1977 it was opened again and at the eastern coast of the Agrakhan Peninsula the formation of “new” Terek delta prolonged.

In **1978-1991**, in the period of the rapid sea level rise, delta changed significantly (Fig.4). The Agrakhan bay, being before nearly dry and weeding with reed, again filled with water and widened. The barrier-lagoon complex was formed along the coasts of the Agrakhan Peninsula at the place of reed marches; this is a typical reaction of the low Caspian coasts to the sea level rise. Rising of ground water level led to the appearance of green vegetation on sand dunes of the Agrakhan Peninsula and along the Agrakhan Bay coasts.

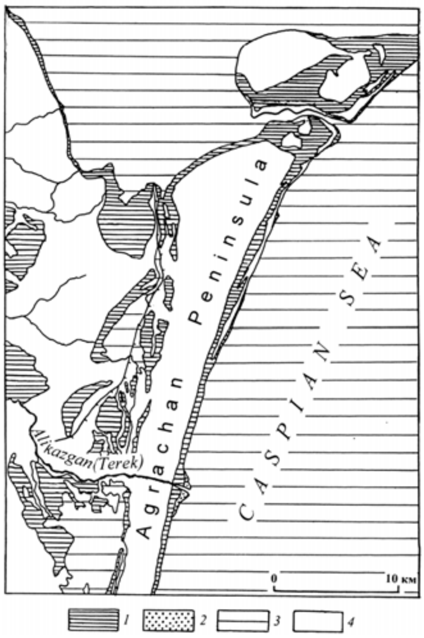


Figure 4. Changes of eastern part of the Terek River delta with the Agrakhan Peninsula in 1978-1991: 1 – water instead of land; 2 – land instead of water; 3 – water; 4 – land.

On the eastern coast of the Agrakhan Peninsula “new” Terek delta, which was prograded by 0.4 km to the beginning of the transgression, continued its growth in spite of the sea level rise; processes of the sediment accumulation overgrowth the sea level rise (Fig.5). By 1991 the mouth prograded by 1.8 km; delta spits and coastal barriers have been formed along the shores, lagoons were separated by them. To 1997, when the sea level began stabilized and gradually lowered, the growth of “new” delta prolonged for 2 km, new spits and coastal barriers were formed and new lagoons were separated. Former lagoons were overgrown by reed and became marches and lands.

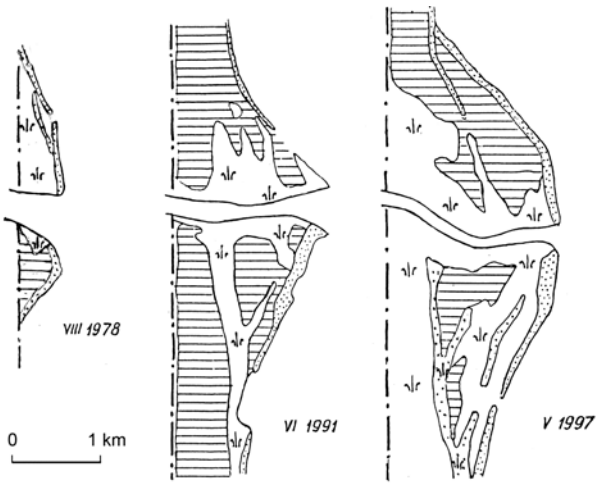


Figure 5. Evolution of the “new” Terek delta in 1979-1997.

4.3. The Sulak River Delta

The Sulak River delta on the western coast of the Caspian Sea is one of the most changeable delta region. It was caused by repeatedly changes of river channel direction and mouth place. Modern delta began to form 200 years ago. The stages of its formation had been analysed in details (Leontyev et al., 1987; Mikhailov, 1997). During the long period of the sea level drop from the middle of XVIII-th century, four cycles of the delta formation took place: up to 1920 - pioneer delta formation; after river break in the northern-eastern direction - formation of the first lateral delta; after break in the northern direction in 1929 - formation of the second lateral delta ("old"), which separated the Sulak Bay; after water diversion by artificial channel in the eastern direction in 1957 - formation of the third lateral delta ("new") (Mikhailov et al, 2004). Dramatic changes of the delta happened with the sea level rise were investigated by space images. The map of the delta dynamics in 1978-1991 (Fig.6) shows the Sulak delta reaction to the sea level rise.

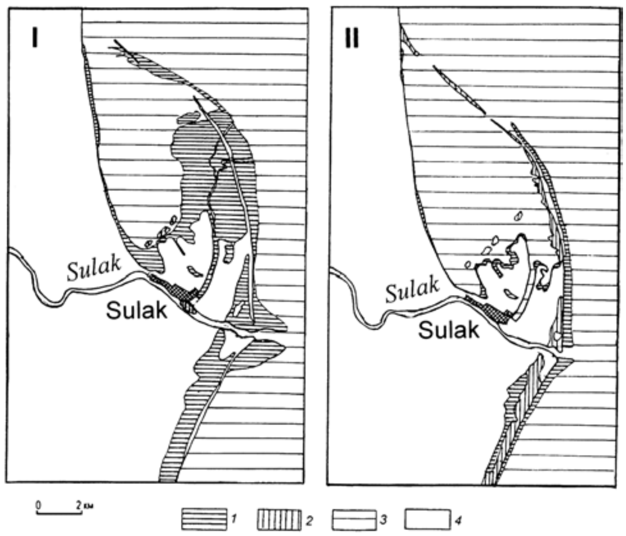


Figure 6. Changes of the Sulak River delta in 1978-1991 (I), 1991-2000 (II): 1 – water; 2 – water instead of land; 3 – land instead of water; 4 – land.

1978-1991. In the period of the fast sea level rise, sea water flooded the main parts of the "old" and "new" deltas. The eastern delta coast was washing away by sea waves, shoreline moved by 1 km to the west and the coastal barrier was formed here. The Sulak Spit has been shorten by 4 km due to processes of inundation and abrasion and replaced by 1 km in the western direction. So the Sulak Bay in 1991 was open to the sea. The area of the "old" delta reduced by 21 km^2 . The "new" delta was nearly washed out, its area reduced by more than 3 km^2. Lagoons were formed along the both sides of the mouth. The delta area reduced during this period from 70.6 to 46.4 km^2 (34%). Annual decrease of the area was 1.86 km^2/year. The river channel length was shorten by 15 km.

1991-1997. In this period delta's changes were not so significant, as in previous one, due to the sea level rise stopping in 1995 and its some stabilization and even falling. Decrease of the delta area slowed down to 0.2 km^2/year. Washing out of the eastern part of the "old" delta was continued, the Sulak Spit increased by 12 km and jointed to the Agrakhan Peninsula coast. Only some small breaks in the Sulak Spit connected the Sulak Bay with the sea. The "new" delta's destruction was continued too, the coast line replaced to the west by 700 m; lagoons were overgrown with reed, that is the evidence of their shallowing. In this period the delta area at whole reduced only by 1.2 km^2.

So the analyses of multitemporal space images shows the processes of inundation and abrasion of the "old" and "new" Sulak River deltas, formation and then overgrowing lagoons, washing out the Sulak Spit and formation of the new long Sulak Spit mainly from the material of abrasion of the "new" Sulak delta.

4.4. The Kura River Delta

The modern Kura River delta in the southern part of the western Caspian Sea coast was advanced into the sea at the mouth of river with large sediment discharge. Dynamics of the Kura River delta in XIX-XX centuries was mainly depended on the Caspian Sea level changes. During the period of sea level drop up to 1976 the delta prograded far into the sea. In spite of sediment discharge decrease after the Mingechaur reservoir construction (1953), delta prograding was continued, because the sea level fall compensated sediment discharge reduction (Mikhailov et al., 2003). By 1976, the delta area reached 189 km^2, and the delta length was 30 km.

In **1978-1995**, evolution of the delta was determined by the sea level rise by 2.35 m. Low laying periphery parts of the delta began to be flooded. Images show also the formation of coastal barrier along the northern-eastern coast of the delta. It is typical consequence of the sea level rise on the low laying Caspian Sea coasts. Extreme changes of the Kura delta took place up by 1993 (Fig.7) – just before maximum of the last sea transgression. The main part of the delta lobe was flooded, the delta length decreased by 10 km. Along the former river channel some long narrow islands (old natural levees) were retained. In comparison with 1978, delta area decreased by 78 km^2 (34%) and equaled 111 km^2.

In **1995-2001** a slow drop of the sea level (0,54 m by 2001) led to new changes in delta morphology. Shallow water parts of the flooded delta became more dry, overgrown with reed. Delta area increased by 25 km^2, and in 2001 reached 136 km^2.Barrier-lagoon complex along the north-eastern coast of the delta still conserved. Wide depressions within the delta were flooded by water broken through coastal barriers. Important changes in the hydrographic network of the delta took place. During the period of the high sea level stage, river water broke through the right bank of the main channel and turned to the south-west. Water flow through the former south-eastern delta channel ceased, the former channel was overgrown with reed. In the sea, near former mouth, a new spit formed in the south-western direction from material of the old delta abrasion. In 2001, this spit had 3 km in length.

CONCLUSIONS

The main features of low-laying coast response to the sea level rise discovered by space images are the following: formation of lagoon complex, widening of mudflat zone, its shifting in the landward direction and its destruction after sea-level rise by 2 m. Changes after the sea level rise and during its small lowering lead to moving of the back boundary of the mudflat in the seaward direction earlier, than its outer (marine) edge shoreline.

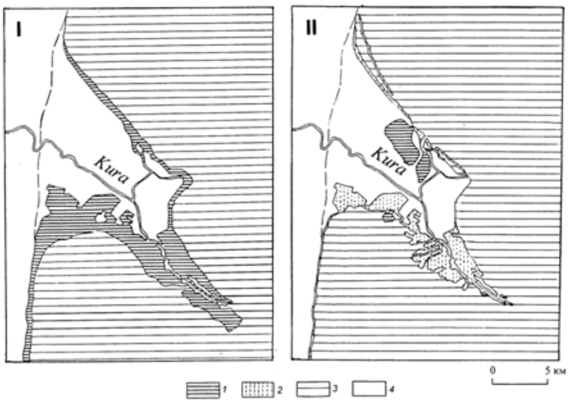


Figure 7. Changes of the Kura River delta in 1978-1993 (I), 1993-2000 (II): 1 – water instead of land; 2 – land instead of water; 3 – water; 4 – land.

The analyses of compiled maps shows that the following changes during the sea level rise period are typical for protruding deltas of the Caspian Sea: flooding of low laying periphery parts; wave abrasion of more deep parts of the nearshore slope and formation of spits from material of abrasion; formation of barrier-lagoon complex; hydrographic network reconstruction.

The discovered feature of low-lying mudflats coasts dynamics under the sea level fluctuations shows that coastal ecosystems statement depends of reed response to water regime changes. This feature is confirmed at other parts of the Caspian coastal zone – in particular in the Ural River delta.. So it is important to investigate the ecological niche of reed weeds, the influence of the depth to reed growth and statement.

The reaction of the Kalmykian coastal zone and deltas to the Caspian Sea level rise can be used as an analogue phenomenon for forecasting of processes which can take place in the world coastal zones and river deltas in the case of proposed global sea level rise.

REFERENCES

Kravtsova, V.I., Lukyanova, S.A.,1999. Dynamics of low-lying Kalmykian coast under the Caspian Sea level rise conditions; 1990's. In: *Procedings of 19 International Cartographic Conference*. Ottawa. CD-ROM.

Leontyev, O.K., Lukyanova, S.A., Solovyeva, G.D., 1987. Dynamics of the sea side of the Sulak River delta, *Vestnik Moskovskogo universiteta, Ser.5.Geografiya*, N2, pp.83-87 (in Russian).

Mikhailov, V.N., 1997. River mouths of Russia and adjacent countries: past, present and future. Moscow, GEOS . (in Russian).

Mikhailov, V.N., Kravtsova, V.I., Magritskii, D.V, 2003. Hydrological and Morphological Processes in the Kura River Delta. *Water Resources*, vol.30, N5, pp.495-508.

Mikhailov, V.N., Kravtsova, V.I., Magritskii, D.V, 2004. Spicific Feachures of Development of the Modern Sulak River delta. *Water Resources*, vol.31, N2, pp.117-131.

ACKNOWLEDGEMENTS

The investigations were carried out under the support of Russian Foundation of Basic Research (grants 04-05-64149, 05-05-65110).