The Ancient Hydrographic Network of the Taman Peninsula, According to Earth Remote Sensing Data and Geomorphologic Research

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Abstract. The prevailing view is that the cause of significant changes in the shape of the Taman Peninsula during the past 2500 years is sea-level fluctuations. In our opinion, the leading role in the process of topography restructuring belongs to the tectonic factor. Therefore paleogeographic reconstructions made so far need to be evaluated and refined. This article is devoted to study the hydrographic network of the region. The presence of fresh water sources in ancient times is the main point when choosing the place founded settlement. At the turn of the 7th-6th centuries BC, during the Great Greek colonization, the first Greek immigrants from the cities of the Mediterranean and Asia Minor arrived on the shores of the archipelago. They established their own settlements here. The large number of settlements they founded implies the presence of a sufficient number of sources of fresh water. However, at present, space images show that even near the main cities of Asian Bosporus there are no permanent streams. Because of the data analysis from remote sensing and aerial photography, the ancient and modern hydrographic networks were localized, and types of fluvial landforms as well as landscape topography and morphology were identified. Matching ancient and modern watercourses showed that changes in the direction of water flow were happening on the part of the Taman Peninsula in the past 2500 years, probably caused by tectonic development. It was found that tectonic activization of the region occurred in separate blocks, and ancient watercourses formed and developed in periods of maximum humidity. Probable outlines of paleo straits were refined, and points for drilling wells were outlined.

Keywords: Taman Peninsula · Asiatic Bosporus · Neotectonics · Satellite images · Aerial photos · Hydrological system

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1 Introduction

The modern appearance of the Taman Peninsula is characterized by low-lying plains separated by hilly ridges. Mud volcanoes are also present. Elevation of the territory varies from 10to 60 m on average, and the height of the ridges reaches 100–150 m above sea level. The highest point of the peninsula is Mount Komendantskaya, which is 164 m high above sea level (Fig. 1).

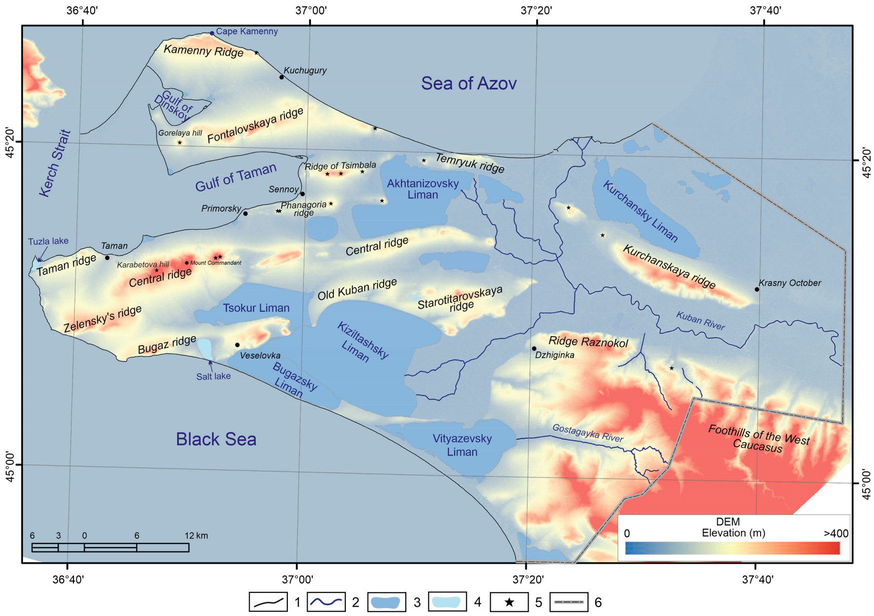

Fig. 1. Orographic scheme of the Taman Peninsula (1—coastline, 2—perennial stream, 3—limans, 4—salt lakes, 5—mud volcanoes, 6—eastern boundary of the study area)

The Taman Peninsula has a moderate continental climate (Korsakov et al. 2013). Summer is hot and arid, with an average temperature of +24 °C. Winter is relatively mild but overcast, with an average temperature of +6 °C (Korsakov et al. 2013). The shores of the peninsula are washed by waters the Black and Azov seas, there are many large limans (bay with winding low banks at the confluence of the river into the sea) within its boundaries, and at the same time, there are few permanent watercourses. In the east part of the peninsula, the valley of the Kuban River with numerous branches is located; in the south-east part, there is the valley of the Gostagaika River and other small rivers (Fig. 1).

The Taman Peninsula is known for numerous archeological sites of different cultures and periods (Paromov 2015); extensive archaeological and historical work is devoted to studying them (Berenbeim 1959; Nikonov 1998; Paromov 2015). From works of ancient authors (in particular, from Strabo's "Geographica"), it appears that the Asian Bosporus (lands to the east of the Kerch Straight) used to be an archipelago of islands divided by sea straits and river branches. At the turn of the 7th–6th centuries BCE, during the Greek colonization, first Greek settlers arrived on the shores of the archipelago from the Mediterranean and Asia Minor cities. Several settlements implied the presence of enough fresh water sources, whereas nowadays, there are no permanent watercourses even around the main cities of Asian Bosporus (Phanagoria, Hermonassa), what can be seen in space images (https://earthexplorer.usgs.gov).

Despite the extensive research on the subject, the identification of settlements of the Taman Peninsula with toponyms, known from written sources, is sometimes disputed. The reasons for this are an almost complete absence of dedicatory inscriptions mentioning the settlements where they were found and an absence or minimal volumes of pottery production and coinage (Paromov, 2015). Attempts to use data from peripli,—the pilot charts of coastal sailing, sequentially listing ports and distances between them,—were also unsuccessful, as descriptions contained there did not correspond to the modern coastline contours. Besides, areas of submerged cultural layers were revealed in the waters of the Taman Bay near the modern settlements of Sennoy, Primorsky, Yubileyny, Garkusha, Beregovoy, Taman; this includes wells, rims of which are now located under the water 1–1.5 m deep (Nikonov 1998; Paromov 2015). Undoubtedly, such settlements existed also at the coast of the Kerch Straight (in the vicinity of modern Tuzla Spit and Chushka Spit), but because of the hydrological situation, a convincing localization and identification is still difficult.

The nonconformity of the peripls with the modern coastal contour and the semi-submerged nature of some coastal settlements is attributed by some authors to sea-level fluctuations. During the last 4000 years, both the transgressive (Novochernomorskay, Nymphaean, Srednevekovay, Sovremennay) and regressive (Phanagorian, Rannesrednevekovay, Pozdnesrednevekovay) epochs were recorded for the seas surrounding the peninsula (Berenbeim 1959; Nikonov 1998; Paromov 2015; Dikarev 2018). The disagreement between researches concerns only the estimates of the water level fluctuations in one or another period.

When reconstructing the paleogeography of the region's contours, both the height of the sea level and the fact that the tectonic factor plays a dominant role in the process of topography reconstruction should be considered. The activity of the latest movements was determined by 7-year geodetic observations using the GPS (Yubko et al. 2016), which recorded different amplitude rates of vertical movements from −2 to +12 mm/year at the shores of the Taman Peninsula. The presence of more than 20 mud volcanoes (geological formation, a depression on the surface of the earth or a cone-shaped elevation with a crater from which mud masses and gases erupt constantly or periodically on the surface of the Earth) of different activity levels (Shnyukov et al. 1986) confirms the intense recent tectonics in the Taman Peninsula.

The topic of this research is to localize the contour of the ancient hydrographic network and determine its informativity for the tasks of paleogeographic reconstruction of the outlines of the Asian Bosporus. By the term "hydrographic network" we mean ancient and modern talvegs (a line connecting the lowest sections of the valley, beams and other elongated landforms) of watercourses and contours of Limans and paleo straits. By "watercourses" we mean various genetic types (valleys, gullies, scour, etc.) of modern and ancient fluvial landforms. Hanging valleys—valleys which mouths have lost their connection with the modern base of erosion.

2 Materials and Methods

To localize the hydrographic network of the Taman Peninsula, we performed a visual interpretation of the available remote sensing data, considering the morphological and topographic features of the region (Petrusevich 1961; Garbuzov 2016, 2020). Corona, SPOT, and Landsat satellite images (from the 1960s to the present), downloaded from the USGS website (https://earthexplorer.usgs.gov), the World War II aerial photography and topographic maps of different scales were used in the analysis. A digital elevation model was also used, constructed on SRTM radar data with a resolution of 1 arc-second, downloaded from Global Mapper software. The listed data are collected in the GIS project. Interpretation was performed in ArcMap software.

The identification features of modern watercourses on space photos are: the darkening of image tone relative to the general background and irregular, linear-wavy, or tree-like shape of contours, expressed on topographic maps as a depression in the topography. The gullies are also characterized by the presence of vegetation on the slopes and bottoms (Fig. 2, A1–3).

The main identification signs in the localization of ancient watercourses on satellite images and aerial photos are linearity, change of image color to darker tones relative to the background in the developed areas (plowed fields, buildings, etc.), and tree-like structure of lines (Fig. 2, B1–3). The change in phototone is explained by the peculiarities of the watercourse section, which is represented by water permeable sediments and bedrock, e.g., pebbles, sands, and sandy loam. Water accumulated in the sections covered by permeable rocks rises to the surface due to capillary forces; as a result, the areas of soils covering the ancient watercourses have a darker tone on the image. Thus, the watered areas of soils, especially after intensive precipitation, correspond to the contours of ancient watercourses (Petrusevich 1961). Note that the contours of ancient watercourses usually do not reach the modern base of erosion; they either abruptly cut off or pass into modern watercourses.

During remote sensing data interpretation, we localized modern permanent and temporary watercourses of the Taman Peninsula and traces of ancient watercourses, after which we compared features of the structure of modern and ancient hydrographic network.

To test the observation results, in the summer of 2022, we conducted geological and geomorphological field studies: we studied geomorphological features of the streams of the Phanagoria Ridge, the coastal zone and estuaries of the northwestern and southern parts of the Taman Gulf, and the areas of the alleged ancient straits "Subbotin yerik" and "Shimardan Arm".

3 Results and Discussion

Comprehensive analysis of the Earth's remote sensing and topography, as well as the results of geomorphological observations, provide schemes of the modern (Fig. 3) and ancient (Fig. 4) drainage systems of the Taman Peninsula. Modern watercourses are

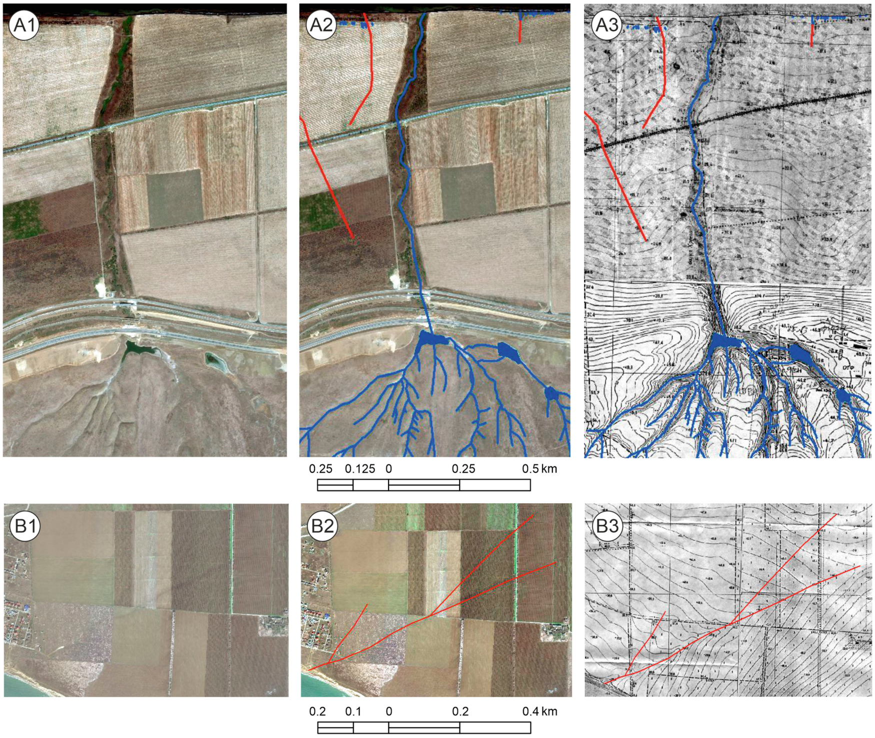

Fig. 2. Watercourses display: A1–3—modern watercourses (blue lines) on a Landsat satellite image (A1—original image; A2—after interpretation) and on a topographic map (A3); B1–3—ancient watercourses (red lines) on a Landsat satellite image (B1—original image, B2—after interpretation) and on a topographic map (B3)

represented by two types: permanent and temporary. Permanent watercourses include rivers located in the eastern part of the region—the Kuban River, the Gostagayka River, and smaller rivers originating in the Caucasus Mountains (Fig. 3, 1). Temporary watercourses are represented by the following genetic types: erosion furrows, rain channels, balkas, and hanging valleys. These fluvial landforms were formed mainly due to rain-fed stream, groundwater seepage to the surface, and the thawing of seasonal snow.

The erosion furrows and rain channels are confined to hilly ridges (Tsentralnaya, Fontalovskaya, Fanagorian, etc.). These watercourses form a tree-like, lattice pattern in some places (Fig. 3, 2). The same fluvial landforms are noted on the slopes of conical mud volcanoes (Gorelaya and Karabetov volcanoes, etc.) with steepness from 6–9º at the tops to 3–4º at the base. They form a radially divergent (centrifugal) pattern from the top of the mud volcano to its base, where they flatten out and usually end their development (Fig. 3, 3). According to geomorphological observations, the depth of this erosion furrows and rain channels varies on average from 0.5 m to 2–3 m, with widths from 0.3 m to 10–16 m.

Along the shoreline of the Taman Peninsula, there are rain channels (Figs. 3 and 4), mainly near the Cape Kamenny (the north shore), the Akhtanizovsky (the south shore),

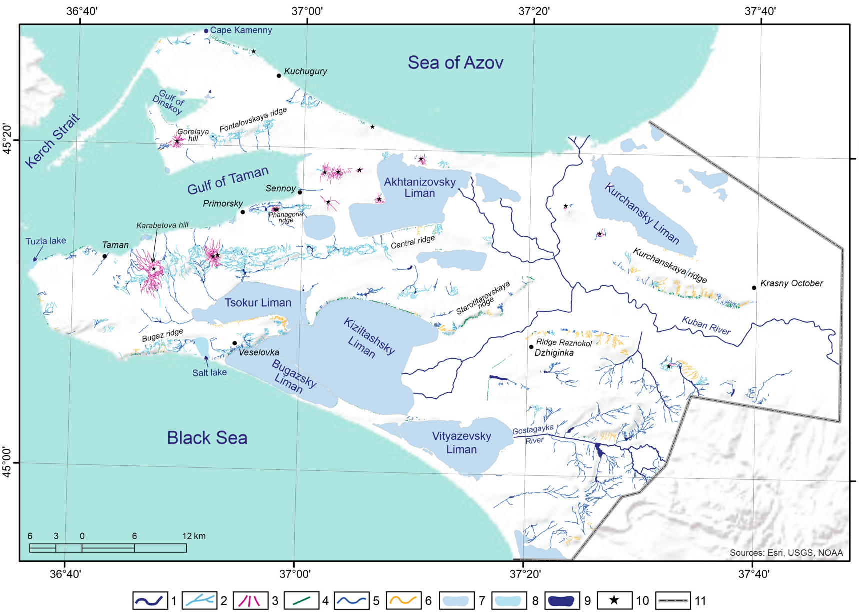

Fig. 3. The scheme of modern watercourses of the Taman Peninsula (1—permanent watercourses; 2–6—temporary watercourses: 2—erosion furrows and rain channels developed on the surface of ridges; 3—erosion furrows and rain channels restricted to the slopes of mud volcanoes; 4—rain channels; 5–6—temporarily inherited watercourses: 5—balkas; 6—hanging valleys; 7—limans; 8—salt lakes; 9—stakes; 10—mud volcanoes; 11—the eastern boundary of the study area)

Kiziltashsky (the north shore) and Akhtanizovsky (the south shore) limans. There are both single rain channels and series where rain channels are parallel to each other with 10–20 m spacing over 100–400 m. The depth of these negative landforms corresponds to the cliff height (~5–10 m), with an average length of 7–10 m. In addition, rain channels were identified in the areas of landslide processes: in the southeastern part of the Kurchanskaya ridge, from the northern slope of the Raznokol ridge to the Vityazevsky liman, and in the southern and southeastern parts of the Starotitarovskaya ridge. They are located parallel to each other with a step of 25–50 m over a distance of 0.4 km to ~3 km.

Balkas are formed at the confluence of erosion furrows and rain channels holes that originate on the slopes of ridges (Figs. 3, 4, and 5). They are mainly characterized by a single clearly visible thalweg (a line connecting the lowest sections of the valley, beams and other elongated landforms). The beginning of balka development starts at the foot of hilly ridges (including mud volcanoes) and reaches the modern erosion base along gentle surfaces with an inclination angle of 1–2°. According to field observations, the average depth of the balkas is 2–4 m, with widths varying from 50 to 250 m. In some places, the valleys of ancient watercourses adjoin the balkas (Fig. 4). On this basis, some modern gullies may be inherited, that is, developed in place of ancient watercourses.

Modern inherited watercourses can also include hanging valleys, which mouths have lost their connection with the modern base of erosion (Figs. 3, 4, 5, and, 6). Hanging valleys have a tree-like or, in some places, non-branching pattern. They are 2–5 m deep and 10–20 m to 50–90 m wide. On the Taman Peninsula, they are found on the southern slope of the Kurchanskaya Ridge, on the northern slope of the Raznokol Ridge in the vicinity of the village of Dzhiginka, and further to the east on the northeastern slope of the Bugaz Ridge (at the junction of the Tsokur and Kiziltashsky limans). The formation of these relief elements may be related to the tectonic uplift of some parts of the study area (Arkhipov et al. 1976). Separated hanging valleys were also observed along the coastline, for example, near the foot of Gorelaya Mountain and, in places, from Lake Tuzla to Lake Solyonoye. Their formation is associated either with a sharp tectonic uplift of the area or with a process in which coastal erosion occurs more intensively than the watercourse has time to reach the local base level of erosion.

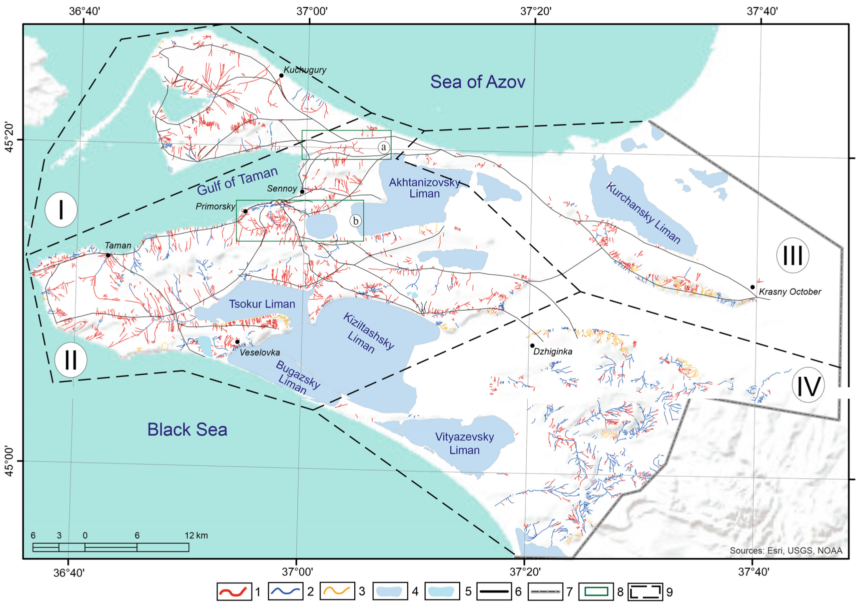

Fig. 4. Scheme of the paleohydrosystem of the Taman Peninsula (1—permanent and temporary ancient watercourses; 2–3—modern inherited watercourses developing along ancient valleys: 2—balkas, 3—hanging valleys; 4—limans; 5—salt lakes; 6—ancient roads (Garbuzov 2020); 7—eastern boundary of the study area; a–b—areas, enlarged fragments of which are shown in Fig. 5: a—"the Subbotin yerik"; b—"the Shimardan Arm"; I–IV—areas differing in the density of modern and ancient watercourses, their distribution and flow direction)

The scheme of the paleohydrosystem of the Taman Peninsula (Fig. 4) shows ancient watercourses, which are not pronounced in the modern terrain due to climate change (Bolikhovskaya et al. 2002, 2018) and anthropogenic activities, and modern watercourses (balkas and hanging valleys), which form on ancient valleys, that is, they are inherited. We refer both to the thalweg of permanent and temporary watercourses and regions of possible sea straits to ancient fluvial landforms (Fig. 4a,b).

Permanent and temporary ancient watercourses are located all over the Taman Peninsula, but the majority is located in the western part of the region and within the Kurchanskaya ridge (Fig. 4, I–III). In the south-east part of the region, inherited watercourses predominate (Fig. 4, IV). This can be due to the region's location near the foothills of the Western Caucasus, its dissected relief and a more humid climate; therefore, the modern valleys develop on the ancient watercourses.

Ancient watercourses are characterized by a faint, sometimes dendritic pattern, which is located along the slope, its tree-like part is usually located closer to the watershed. The thalweg length varies from 0.3 to ~5.5 km. Note that a darker image tone on the aerial photography materials is typical for ancient watercourses, as is a blue and dark-blue tone on the satellite images, because they record wetlands, especially after heavy rains. Ancient roads also have similar visual pattern (Garbuzov 2020), but for them, a pattern typically has a form of a single straight or slightly curved line that crosses slope regardless of their landscape (Figs. 4, 5, 6).

On the scheme of the paleohydrosystem, we identified two objects: «the Subbotin yerik»—«the northern straight» (Fig. 4a) and «the Shimardan Arm»—«the southern straight» (Fig. 4b). These objects are manifested as depressions, and their genesis has become a subject of lengthy discussion. (Garbuzov 2016). Anomalous rainfall in August 2021 in the Taman Peninsula drastically and for a long time raised the groundwater level, making it possible to identify some features of these objects. On the satellite image «Landsat Explorer» with the «Agriculture» filter (Fig. 5, A2, B2) of August 25th, 2021 (https://livingatlas2.arcgis.com/landsatexplorer, last accessed the May 2023), the border of a flooded contour is marked with a red line, and points to geomorphological observations of the summer 2022—with yellow rhombuses. In these observations, water was detected on the surface (Fig. 5, A3), and heavily flooded areas were identified (Fig. 5, B3). All observation points are located within the red contour, that confirms the permanent water cut of this zone.

In satellite imagery (Fig. 5), it can be seen that the flooded contour of "the Subbotin yerik" stretches continuously from the Taman Bay to the ancient contour of the Akhtanizovsky liman, expanding to the coastline and narrowing in the middle part. The flooded contour of "the Shimardan Arm" adjoins the Akhtanizovsky liman and has a very complex branched configuration; its direct connection with the Taman Bay is interrupted only on one small site. The scheme of the ancient settlement location (Fig. 5, B2, black lines) provided by Garbuzov (2016) does not contradict such a configuration of the straight.

Because of the geomorphological observations, we identified points by drilling a series of wells that will allow definitive conclusions about the existence of "the Subbotin yerik" and "the Shimardan Arm" in the historical time.

While comparing the schemes of modern and ancient watercourses, we determined some features of their localization and structure. First, ancient watercourses are much thicker than modern ones (mainly confined to the watershed sections of the relief). This may indicate that ancient watercourses were formed in a wet climate.

Second, four areas on the Taman Peninsula differ in the density of modern and ancient watercourses, their distribution, and the flow direction.

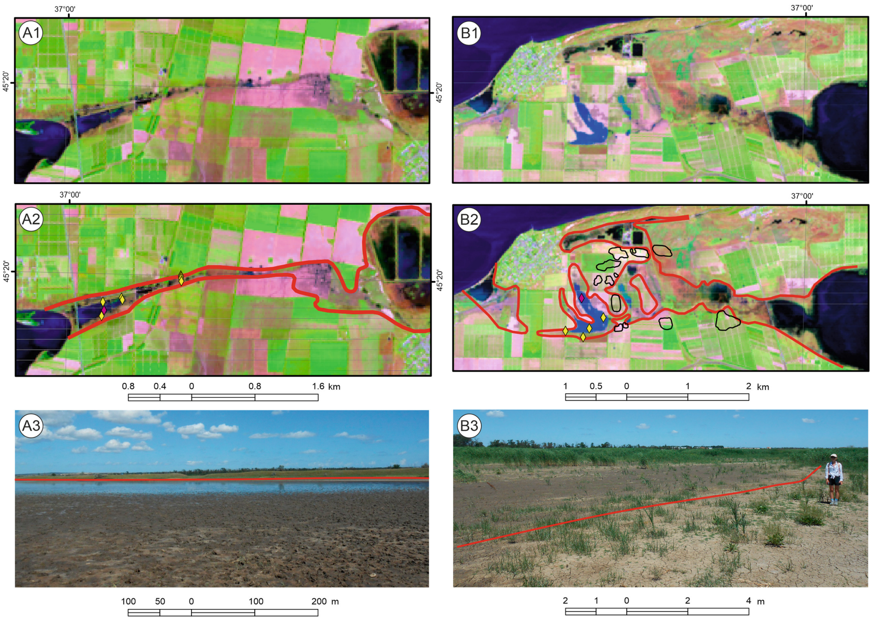

Fig. 5. Ancient watercourses (heavily wetted surface areas) shown in blue and black-blue tones on space images: A1–A3—"the Subbotin yerik"; B1–B3—"the Shimardan Arm". A1, B1—original Landsat space images with the "Agriculture" filter; A2, B2—space images after interpretation; A3, B3—photos of watered soil areas. Red line—the contour of watered areas of soils; rhombuses—points of geomorphological observations of 2022, which recorded highly watered areas; purple rhombuses—points where the images were taken A3, B3; black line—the contour of ancient settlements some settlements according to materials (Garbuzov 2016)

The first region (Fig. 4, I) is located in the north-northwestern part of the peninsula. Here ancient watercourses are evenly distributed over the area, and their density significantly prevails over modern ones, mainly confined to the southern slope of the Fontalovskaya ridge. In addition, the flow direction of modern watercourses is mainly directed to the Taman Bay and ancient watercourses—to the Gulf of Dinskoy. Perhaps this indicates a tectonic restructuring in this part of the peninsula.

The second region (Fig. 4, II) is west-central, where the greatest concentration of modern watercourses is confined to the slopes of hilly ridges and mud volcanoes, which indicates the modern tectonic activity of these sites. Ancient watercourses, including inherited ones, are evenly distributed throughout the territory and begin their development mainly at the foot of hilly ridges and are located on flatter areas. The flow direction for ancient and modern watercourses is toward the Taman Bay, Black Sea, and estuaries in this area. This indicates that the flow direction in this area has remained unchanged over the past 2500 years. In addition, some estuaries of ancient watercourses are "revived" by washouts, i.e., they continue their erosive activity, which indicates their inherited development.

The third region (Fig. 4, III) is located in the north and northeast of the peninsula. Mainly ancient and inherited watercourses are developed here, among which hanging valleys predominate. The watercourses are located mainly on the southern and south-western slopes of the Kurchanskaya ridge, on the right bank of the Kuban River.

The left bank of the Kuban River belongs *to the fourth* (SE) *region* (Fig. 4, IV), and there are also hanging valleys, which indicate the simultaneous tectonic uplift of blocks with valleys of this type. Within the fourth region, inherited watercourses are mainly developed. The flow direction of modern and ancient watercourses located within the last two regions is opposite—toward the valley of the Kuban River.

4 Conclusions

We localized the system of ancient watercourses by reconstructing the Taman Peninsula outlines based on visual interpretation of remote sensing data, topography, and geomorphological observations. We reconstructed the scheme of watercourse location and substantiated the hypothesis of the localization of the "Subbotin yerik" and the "Shimardan Arm" straits based on the watering contour, and determined points of the test wells. We also identified four areas on the Taman Peninsula, which differ in the density of modern and ancient watercourses and the distribution and direction of their flow. It was found that within the boundaries of the first (NNW) area in the last 2500 years, the flow direction has changed: the ancient watercourses were directed toward the Gulf of Dinskoy, and the modern ones flow towards the Taman Gulf. Analysis of the density and spatial distribution of the hydrological system allows us to conclude about the influence of tectonic activation of individual blocks and climate on the formation of ancient watercourses.

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