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The Geomorphological Structure and Processes in Urban Areas of Abkhazia

R. O. Razumovskiy[a, *], E. A. Eremenko[b, **], S. I. Bolysov[b, *], Y. N. Fuzeina[b, ****], V. A. Bogoliubskii[a, *****], P. D. Zhuravlev[a, ******], R. Y. Zhiba[c, *******], A. A. Derkach[b, ********], A. V. Bredikhin[b, *********], and R. S. Dbar[c, **********]**

[a] *Department of Geology, Moscow State University, Moscow, 119991 Russia*
[b] *Department of Geography, Moscow State University, Moscow, 119991 Russia*
[c] *Institute of Ecology, Academy of Sciences of Abkhazia, Sukhum, Republic of Abkhazia*
**e-mail: ror1554@mail.ru*
***e-mail: eremenkoeaig@gmail.com*
****e-mail: sibol1954@bk.ru*
*****e-mail: donaldw@bk.ru*
******e-mail: Bogolubskiy@yandex.ru*
*******e-mail: paulegrus@gmail.com*
********e-mail: romazb@mail.ru*
*********e-mail: derkach1977@yandex.ru*
**********e-mail: avbredikhin@yandex.ru*
***********e-mail: romandbar@mail.ru*

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Abstract—Based on the results of expeditionary geomorphological studies carried out in 2021–2022 with the involvement of published materials, a large-scale (1 : 25000 to 1 : 100000) characterization of the relief of the urban areas of the Republic of Abkhazia (Gagra, Pitsunda, Gudauta, Noviy Afon, and Sukhum) was compiled for the first time. In addition, previously unparalleled general geomorphological maps were compiled, the legends of which were prepared following the morphogenetic principle. According to the morphostructural position and geomorphological structure, the cities are divided into three groups: (1) completely in the area of distribution of the coastal-marine relief (Pitsunda and Gudauta), (2) located mainly within the sea terraces and erosion-denudation hills (Sukhum and Gagra), and (3) completely located in the low mountains with a predominance of strongly dissected structural-denudation, fluvial and slope relief (Noviy Afon). A field survey revealed about 300 areas of manifestation of unfavorable and dangerous geomorphological processes in urban areas, of which 44% are in Sukhum, 26% in Gudauta, 11% in Gagra, 10% in Pitsunda, and 9% in Noviy Afon. The leading places in the spectrum of geomorphological hazards belong to suffusion, erosion, and biogenic processes. The composition of other processes in the spectrum is determined by the geomorphological position of cities under consideration. The widest range, including, in addition to the processes mentioned above, karst, mudflows and landslide processes (i.e., the most dangerous ones), is typical of urban areas with a complex relief structure, an abundance of steep slopes and located within a narrow zone, separating the spurs of the Main Caucasian Range from the sea (Gagra and Noviy Afon). A qualitative assessment of the risk of destruction of street infrastructure (roadbed, communications, etc.) by dangerous geomorphological processes has been carried out and a high degree of its dependence on the geomorphological position of a particular section of the city has been established. In particular, based on the distribution patterns of recorded manifestations of unfavorable and dangerous geomorphological processes, it has been established that the most favorable conditions for the construction and operation of urban infrastructure and buildings are created generally within the leveled surfaces of the Late Pleistocene marine terraces, as well as at the upper levels of floodplain terraces in the large river valleys. Other levels of relief reflect certain disadvantages that make the development of the territory under consideration difficult. Thus, construction on the surface of the Holocene marine terrace is possible only if the foundations are waterproofed and soil is dumped in the lower areas. The development of high sea terraces and erosional-denudation and structural-denudation relief is difficult due to the high density of erosional dissection.

Keywords: geomorphology of urban areas, hazardous geomorphological processes, Gagra, Pitsunda, Gudauta, Noviy Afon, Sukhum, hazard assessment

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INTRODUCTION

The geomorphology of cities as a scientific field has emerged relatively recently (in the 1990s) and has focused on "systematizing knowledge about the structure, external features, and properties, patterns of the formation and development, interrelations and interdependencies between the relief and geomorphological conditions within urban areas" (*Geomorfologiya*..., 2017, p. 7). For this reason, scientific works devoted to the relief and geomorphological processes in residential areas within the Republic of Abkhazia are still very few. In classical monographs on the physical geography and geomorphology of the Caucasus, the relief of the cities was not considered separately (Gvozdetsky, 1963; Safronov, 1969). In many historical-geographical essays, as well as works on ethnography and culturology, morphological descriptions of the relief of settlements in the Republic of Abkhazia have been presented since the mid-19th century (Seleznev, 1850; Chernyavsky, 1877; Barkov, 1904). Thus, the first brief monographic descriptions of the relief of Sukhum (the modern capital of the Republic of Abkhazia) and its surroundings can be found in the works of F. Dubois de Montpereux (1937). Some information about the relief of the Noviy Afon area can be found by studying notes and diaries of pilgrims of the Novoafonskiy monastery. Most of them describe vividly the monastery's park, slopes, and summit surfaces of the Iverskaya and Noviy Afon mountains (Sizikov, 1884; Barkov, 1904). In the early 20th century, the seaside cities of the Republic of Abkhazia became resorts of all-Russian and later all-Union importance. These areas have remarkable historical and natural features, which are covered in a number of publications dedicated to historical, cultural, and socio-cultural issues. These publications also contain more detailed descriptions of the general characteristics of the relief of residential areas, among other things. An ethnographer, A.N. Diyachkov-Tarasov, was the first to describe the morphology of the Gagra region, particularly the Arabika Massif, Katsyrka and Mamdzyshkha ridges, the valleys of Zhvava-Kvara, Gagripsh, and Tsikherva rivers. Prince A. Oldenburgsky, the founder of the Gagra resort, and therapist F.I. Pasternatsky emphasized in their sketches the potential for using a rather narrow, subhorizontal surfaces of the marine terraces for building summer houses and health resorts (Pasternatsky, 1899). They also noted that land prices there were higher than on the slopes (*Gagry*..., 1905). It was at the beginning of the 20th century that large-scale projects were initiated to transform the landscape (in particular, the filling of swamps on sites of marine terraces) with the aim of increasing the space available for the construction of housing and recreational infrastructure in resort cities (Pasternatsky, 1899). In general, the essays from the mid-19th to the beginning of the 20th century describe the relief of inhabited areas in the Republic of Abkhazia on a qualitative rather than quantitative level. The style of writing in these essays is more artistic than strictly scientific. The exceptions are the papers of researchers who first described the stratigraphy of deposits within the Sukhum area in detail (Prendel', 1879; Tanfiliev, 1904). These works were later used as a basis by geomorphologists and paleogeographers in the first half and middle of the 20th century (Kozlov, 1929; Fedorov, 1963). Additionally, there were few works dedicated to the dynamics of coastal processes in connection with the construction of the first cargo and passenger ports (Rummel, 1900).

In the middle of the 20th century, a significant number of scientific publications focused on the geology and geomorphology of the Western Caucasus and the Trans-Caucasus were published. These studies were fundamental and applied, at various scales depending on the specific subject matter. The geological structure and relief of Abkhazia have been described on a small scale in the works of S.S. Voskresensky (1968), A.I. Spiridonov (1978), N.V. Koronovsky (2011), N.A. Gvozdetsky (1963), V.N. Dublyansky (Dublyansky et al., 1985), N.S. Kuftyreva (1981), etc. On a medium and large scale, the mountainous and plain parts of Abkhazia have been studied less well than the coastal area, especially the sea shore. The fundamental publications on the geomorphology and paleogeography of the coast include those by M.S. Shevtsov (1929), P.V. Fedorov (1963), A.E. Fedina (1981), and I.P. Balabanov (2009). These studies pay special attention to the coastal-marine relief and the structure of different-aged marine terraces, as well as their stratigraphy.

In the middle and the second half of the 20th century, the Black Sea coast in the Republic of Abkhazia became a specific test polygon for coastal studies. The mosaic pattern of the coastal relief, its complex geological structure, relatively narrow shelf zone and humid subtropical climate determined the specificity of the development of the coastal zone of Abkhazia. Over a small length of about 240 km, several morphogenetic types of coastlines are distinguished here, and coastal erosion occurs over more than half the total length of the coastline. The results of extensive research by Russian marine geomorphologists were published in scientific monographs and articles (Zenkovich, 1958; Safyanov, 1978). The data obtained in the 1960s and 1970s formed the basis for the development of a series of all-union projects for the engineering scour protection of the shores of the Black Sea and, in particular, those of Georgia. During the Soviet period, the cities of Abkhazia became some of the most popular resorts on the Black Sea coast and their area expanded significantly. However, the anthropogenic impact on the coastal areas also increased considerably. Despite this, the relief of these cities and the geomorphological hazards associated with urban development remain relatively understudied. The probable reason for this was the generally favorable socio-economic environment. This allowed the

implementation of relatively expensive construction projects, without taking into account relief, as well as timely reconstruction and building renovations, facilities, and transport highways, without significant damage to the city budget. The situation changed dramatically at the end of the 20th century, following the Georgian–Abkhazian conflict in 1992–1993. During this period, significantly less funds were allocated for the maintenance of urban infrastructure. Due to not being controlled at the early stage, negative and hazardous geomorphological processes in the urban areas became more significant for the urban economy and the damage caused by their development increased significantly (Dbar et al., 2020). The revival of the tourism industry in Abkhazia in the early 21st century has been accompanied by the reconstruction of housing, resort infrastructure, coastal protection, and other special facilities. Additionally, there has often been an expansion of urban areas. To successfully implement these projects, it is necessary to have data on the relief structure of urban areas and the characteristic geomorphological hazards. This information allows one to significantly reduce the cost of construction and reconstruction, as well as to prevent potential damage to the infrastructure of cities. The first and only monograph dedicated to the current state of urban areas, in particular the city of Gagra, is the work of I.P. Balabanov and S.P. Nikiforov (2016). However, the section in this monograph dedicated to the description of relief is missing, as is the geomorphological map. There is only a general description of geomorphological processes, without any specifics regarding the localization or spatial patterns of their development within the Gagra city territory.

Despite almost 200 years of research on the relief of Abkhazia's coast, areas around resort cities remain poorly understood. Unlike in the Russian part of the Caucasus, where modern geographical science has gradually moved from detailed descriptions of geomorphological processes to hazard assessment and forecasting (for example, (Baburin and Badina, 2015, 2021)), the comprehensive research of the relief and geomorphological processes in the Abkhazia area is still ongoing.

This paper aims to characterize the geomorphological structure of urban areas in the Republic of Abkhazia and identify spatial patterns of the development of unfavorable and hazardous geomorphological processes in the largest cities. In particular, it focuses on Gagra, Pitsunda, Gudauta, Noviy Afon, and Sukhumi.

MATERIALS AND METHODS

The following basic geomorphological concepts and approaches were used as the methodological basis of research: the Penk–Shchukin morphoclimatic concept (Shchukin, 1964), regional geomorphologic analysis by Yu.G. Simonov (1972), K.K. Markov's conception of geomorphologic levels of relief formation (1964), the conception by O.K. Leontiev et al. (1975) on the formation of the equilibrium profile of the coastal zone and the development of coastal-marine areas, and the conception of anthropogenic geomorphology of urban areas developed by E.A Likhacheva (Likhacheva et al., 1996; Likhacheva and Timofeev, 2002), as well as the recreational geomorphology by A.V. Bredikhin (2008). Information about the general features of the geological and geomorphological structure of the studied area was collected through the analysis of published materials and fieldwork.

The objectives of our study were to collect, organize, and analyze all published data on urban areas, as well as to conduct field geomorphological research, and process the results using GIS in order to create large-scale geomorphological maps and plans for urban areas.

The expedition studies were conducted in 2021 and 2022, including those carried out within the framework of an expedition organized by the scientific student society of the Department of Geomorphology and Paleogeography at the Faculty of Geography at Moscow State University during the winter of 2022. The studies covered all the cities mentioned above and their vicinities. They involved a large-scale (1 : 25000) geomorphological survey of the coastal area, description of landforms and typical manifestations of morphogenetic processes (including gathering information from local residents), and an inventory of existing protection structures and their current condition. The geomorphological survey was conducted using the traditional method of describing landforms at observation points. The density of the observation network in urban areas varied from 2–3 to 8–10 points/km^2. At each observation point, the morphology of the landform elements where the point was located and adjacent ones was described.

The large-scale survey has allowed us to characterize the relief at the meso- and micro-levels. We have conducted a survey of the manifestations of unfavorable and hazardous geomorphological processes by fixing the coordinates of their locations, photographing the landforms created by these processes (erosion rills, suffusion subsidence, forms of biogenic roadway heaving, etc.), and describing their morphology. In addition, for some categories of geomorphologic hazards (in particular, swamping and abrasion), the results of interpretation of lidar survey carried out in 2014 that were provided by the Institute of Ecology of the Academy of Sciences of Abkhazia) were used. Special attention was given to the study of conservation and geomorphological hazards within the territories of natural, cultural, and historical monuments in the cities of the Republic of Abkhazia (Novoafonskaya cave and the Novoafonskiy monastery, gorges of the

Psyrtskha River, the grotto of Simon Kananit, Anakopia and Sukhumi fortresses, Bagrat Castle, etc.).

The processing of the collected field data allowed us to create large-scale geomorphological maps of urban areas at scales of 1 : 25000 to 1 : 100000. The explanatory notes for the general geomorphological maps are based on the principle of chronomorphogenesis. A catalog of hazardous geomorphological processes in urban areas has been compiled. It lists the hazards of different genetic types and the areas of their manifestation (with geographical coordinates), as well as the morphometric parameters of landforms. When assessing the proportions of different geomorphological hazards in the spectrum characteristic of a particular city, we took into account the absolute number of recorded manifestations of the process. The detailed field survey has made it possible to create maps of modern geomorphological hazards in cities at a scale of 1 : 25000 to 1 : 100000. These maps can be used by various categories of land users and urban services to assess general risks and determine the direction of priority work on road repair and reconstruction.

RESEARCH RESULTS AND DISCUSSION

Relief of Urban Areas

The studied cities (Gagra, Pitsunda, Gudauta, Noviy Afon, and Sukhum) are predominantly located near the coastline. The main relief features of this area are created by coastal processes at different sea levels, including modern ones (Safyanov, 1996). Along with the relief of marine origin, there are also other forms of genesis, such as structural-denudation, fluvial, karst, slope, modern coastal, and anthropogenic, which is also distributed throughout a considerable area. The absolute elevations within the studied cities range from 4–5 to 40–50 m on average in Pitsunda, Gudauta, and Sukhum. In Gagra and Noviy Afon, these are up to 150–200 m. The geomorphological structure of the Eastern Black Sea coast within Abkhazia (in particular, the number, absolute marks, and ages of marine terraces) has been described in some parts of the coast in several generalizing works (Kozlov, 1929; Fedorov, 1963; Balabanov, 2009; Balabanov and Nikiforov, 2016). There is still no clear chronological interpretation of the surfaces that formed in the Pre-Late Pleistocene period. During the geomorphological survey, the authors carefully described the relief of terrace levels and recorded their maximum and minimum heights. The chronological reference for the terraces is given by taking into account the published works (Kozlov, 1932; Fedorov, 1963; Balabanov, 2009; Balabanov and Nikiforov, 2016).

The width of the coastal zone varies significantly along the coastline. It widens to 8–10 km near the mouths of major rivers (Bzyb', Aapsta, Khipsta, and Gumista) and narrows to the present-day beach zone, which is approximately 40–50-m wide, where the spurs of the Main Caucasus Range meet the sea. Near the mouths of large rivers, which supply a large amount of clastic material to the sea (for example, the suspended sediment load of the Bzyb' River averages 670000 t/yr, and that of the Bzyb' River 239000 t/yr (Balabanov and Nikiforov, 2016)), there is enough sediment to form coastal-marine landforms. These landforms can then become marine terraces as a result of tectonic or eustatic changes. For example, the suspended sediment load of the Bzyb' River averages 670000 tons per year, and that of the Byblos River averages 239000 tons per year (Balabanov and Nikiforov, 2016). The relief of large cities (Sukhum, Gagra, and Gudauta) is characterized by a stepped appearance associated with their location within the ladder of marine terraces that formed in Pleistocene and Holocene. The geological structure of Quaternary terraces is complex, due to lateral migration of paleodelta arms and the movement of the coastal line during their formation. Sand and gravelstone dominate in the composition of marine deposits, while locally (especially, on the Holocene terrace), there are interbeds and lenses of lagoonal peats and peaty loams. The sand-gravelstone deposits of the Early-Middle Pleistocene terraces are sometimes strongly cemented, often transforming into massive conglomerates in some areas.

The Novochernomorskaya marine terrace of the Holocene age with absolute heights from 3–4 to 6–7 m occupies the largest areas within the urban areas (Fig. 1). Its gently dipping surface, which in some places is complicated by coastal bars, was heavily waterlogged before the beginning of large-scale filling for construction (in the mid-20th century). These swamps are preserved only in the central parts of the Pitsunda and Sukhum peninsulas, where the absolute heights have been reduced to 1–2 m and there are depressions below sea level occupied by lakes (Inkit and Sukhum lakes).

The absolute heights of the Novochernomorskaya terrace (as well as other ancient terraces) change along the coastal line due to ongoing tectonic deformations in the area bordering the actively uplifting Greater Caucasus orogen. The economic development of the Holocene terrace was accompanied by significant transformation of the natural coastal-marine relief (the combination of coastal bars and the depressions separating them), expressed in the shearing of positive forms and dumping of pebble-sandy mixtures in the depressed areas. The Pitsunda city the central and southern parts of the Gagra city, the central and eastern parts of the Sukhum city are completely located on the Novochernomorskaya marine terrace (Fig. 1). However, Noviy Afon is the only one of these cities where the Novochernomorskaya terrace is not clearly visible in the modern landscape due to intensive abrasion and fluvial and slope processes.

The Late Pleistocene marine terraces are represented by the Surozh (at elevations ranging from 5–8

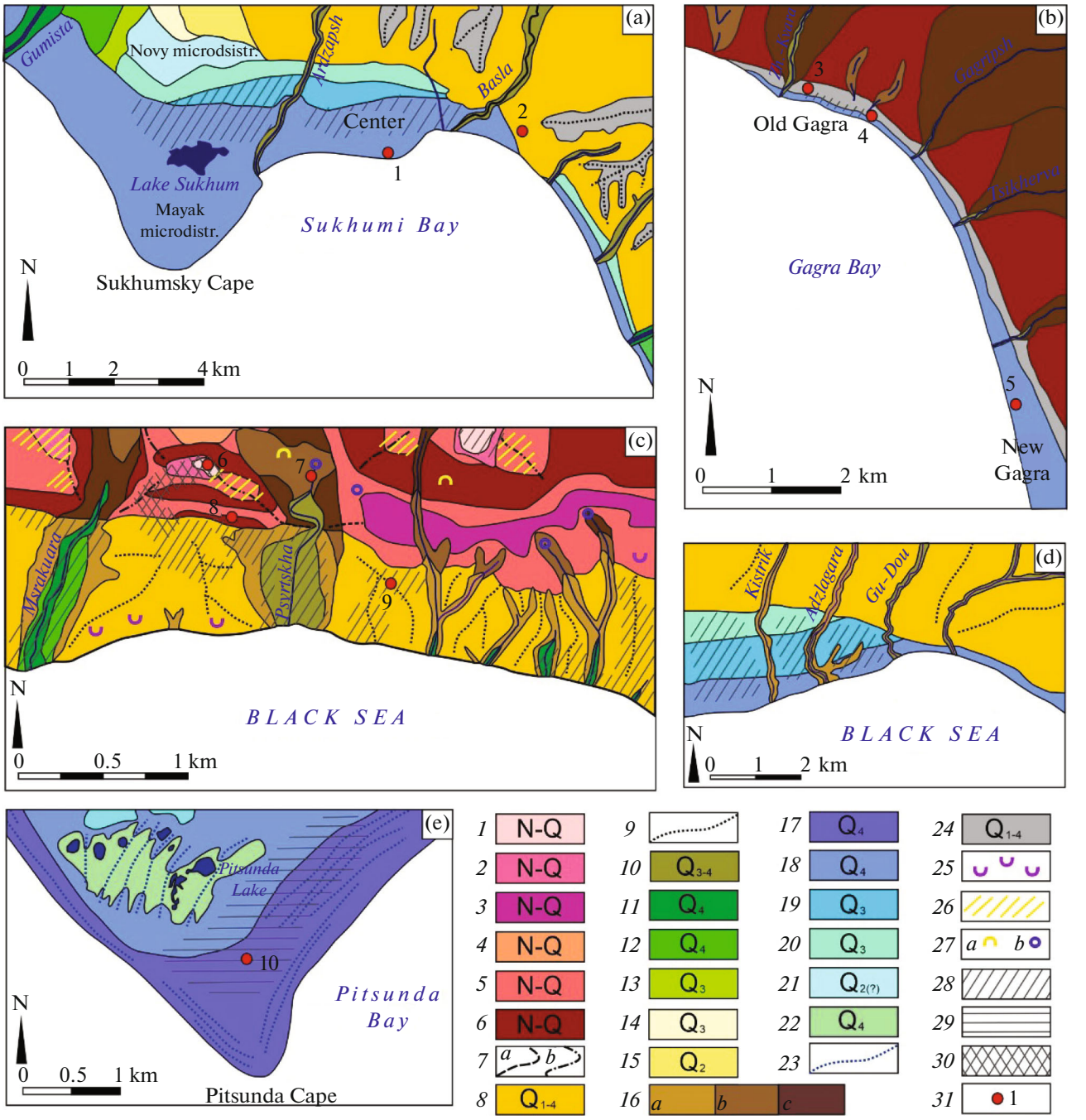

Fig. 1. Geomorphological maps of Sukhum (a), Gagra (b), Noviy Afon (c), Gudauta (d), and Pitsunda (e). *Structural-denudation relief* (N–Q): (*1–2*) summit surfaces ((*1*) flat, (*2*) gently sloping); (*3*) structural pseudo-terraces, structural slopes ((*4*) up to 15°, (*5*) 15°–35°; (*6*) more than 35°); (*7*) summit ridges ((a) sharp, (b) rounded). *Accumulative fluvial-slope (and proluvial-slope) relief, reworked by erosional and denudation processes* (Q_{1-4}): (*8*) surfaces of fluvial-slope and proluvial-slope plumes; (*9*) remnant ridges of accumulative plumes. *Fluvial, fluvial-coastal, and erosional-denudation relief of the valleys of large and small rivers*: (*10*) bottoms of small valleys with an undivided complex of floodplains and terraces (Q_{3-4}); (*11*) floodplain (Q_4); (*12*) first river terrace (Q_4); (*13*) second river terrace (Q_3); (*14*) third river terrace (Q_3); (*15*) fourth river terrace (Q_2); (*16*) erosional slopes (a) up to 15°, (b) 15°–35°, (c) more than 35°). *Coastal-marine relief*: (*17–21*) marine terraces ((*17*) Nymphean (Q_4), (*18*) Novocherno-morskaya (Q_4), (*19*) Surozh (Q_3), (*20*) Karangat (Q_3), (*21*) Ashei/Uzunlar (Q_2)); (*22*) lagoons (Q_4); (*23*) coastal bars (Q_4). Slope relief: (*24*) colluvial plumes (Q_{1-4}); (*25*) landslide bodies (Q). Karst relief ((*26*) karrs, (*27a*) caves, (*27b*) vaucluse). *Areas of anthropogenic transformation of the relief*: (*28*) by general leveling of the original surface; (*29*) by areal dumping of sediments; (*30*) by terracing (on steep slopes); (*31*) cultural, historical, and natural monuments ((1) Sukhumi fortress (II century AD), (2) Bagrat castle (10th to 11th centuries), (3) Abaat fortress (V–VI centuries), (4) Gagra Colonnade (early 20th century), (5) New Colonnade (21st century), (6) Anakopia fortress (7th to 11th centuries), (7) Psyrtskha river gorge (including the grotto of Simon Kananit 1st to 2nd centuries), (8) Novoafonskaya cave (discovered in 1961), (9) Novoafonskiy monastery (19th century), (10) Great Pitiunt (IV century BC)).

to 12 m a.s.l.) and Karangat (17–24 m), which in some places merge into a gently sloping (3°–6°) surface towards the sea, at elevations from 5 to 20–22 m. In the rear and central areas, these surfaces are covered by a relatively thick (up to 5–6 m) layer of sandy loam deposits. The rear seams of the Late Pleistocene terraces, in areas with restricted urban conditions, are not well defined in the landscape. The largest areas of the terrace, which formed at the stage of the Karangat transgression, occur in Sukhum and Gudauta (Fig. 1). These levels are not present in Pitsunda and Noviy Afon. The anthropogenic transformation of the landscape, accompanying the development of the territory, is primarily expressed in the leveling and man-made terracing of the terrace areas and their gentle escarpments.

Within the studied cities, marine terraces, formed in the Early (Chauda or Yashtukha, after (Fedorov, 1963), 95–110 m in elevation) and Middle Pleistocene (Ashei (30–40 m in elevation) after (Kozlov, 1932) or Euxine–Uzunlar (35–50 m in elevation) after (Fedorov, 1963)), are preserved only in Sukhum. These terraces are composed of gravel with sandstone interbeds, which are overlain by a thick stratum of eluvial-deluvial sandy loams and loams, edges and rear seams are not well-defined in the relief. The ancient marine terraces are largely transformed by denudation processes and are characterized by a high density of erosion dissection. In fact, it is difficult to identify the primary surfaces in the modern relief, as they have been transformed by denudation processes in hills and ridges with slopes often exceeding 30°–35°.

Within Gagra and Noviy Afon, sandwiched in a narrow zone of coastal lowlands between the sea and spurs of the Main Caucasian Ridge, the complex denudation relief caused by geological structures and faults occupies significant areas. In particular, the northern and northeastern parts of Gagra located on the steeply sloping (from 30–35° to 50°–55°) spurs of the Gagra Ridge, composed of Jurassic and Cretaceous limestones. Most of the territory of Noviy Afon is represented by the surfaces created by denudation in folded Cretaceous and Paleogene deposits. This area is characterized by the development of the structural-denudation relief with a predominance of slopes ranging from 15°–20° to 35°–40° (Fig. 1). The anthropogenic development of such highly dissected areas at all stages (beginning from the VII century) was accompanied by man-made terracing of slopes and levelling of gently sloping summit surfaces and structural steps.

Some small areas of urban development (in particular, northwestern part of Gagra, northern part of Sukhum) are located in the foothill zone with absolute heights ranging from 150 to 200 m and highly dissected erosion-denudation landforms developed in the Miocene–Pliocene piedmont plumes. These areas are composed of conglomerates and, less commonly, gravels with sandy loam and clay cement. That is, we deal with molasses that accumulated at the early stages of the Alpine Orogeny. This type of the relief is characterized by the highest density and a depth of dissection up to 100–150 m. The erosion-denudation relief of the foothills is extremely difficult for urban development, which is why there is little urban infrastructure and few buildings in this area. In general, the degree of anthropogenic transformation of the natural relief is insignificant here.

Due to humid subtropical climatic conditions in Abkhazia, there are many rivers that flow year-round, some of them directly into the Black Sea in urban areas. This is the reason that fluvial landforms are common in these areas. In Sukhum, the valleys of Gumista, Kelasur, Ardzapsh, Basla, and Dzhiguta rivers occur; in the Gagra areas, the Zhvava-Kvara, Gagrpish, Tsikherva, and Olginka rivers; in Gudauta—Kistrik, Gu-Dou, and Adzlagara rivers; and in Noviy Afon, the Psyrtskha and Msrakuara rivers, as well as (in all cities) small erosional landforms (SELs), represented by ravines and gullies. The structure of river valleys incudes erosion slopes (20°–25° to 70°–85°), as well as a series of accumulative and basement river terraces and floodplains. The large rivers (Gumista and Kelasur) have four–five gravelstone-sandstone terraces, while in other rivers, only one-two terraces. Thus, in the wide valley (up to 2.5 km) of the Gumista River there are four river terraces (RTs), on the surfaces of which western and northwestern parts of Sukhum are located. The first RT and floodplain were formed during the Holocene; their relative heights of 2.5–3 m and up to 2 m, respectively. The width of the floodplain does not exceed 100 m; the first RT is 500–600 high. The second and third RTs were formed during the Late Pleistocene (Balabanov, 2009); their relative height is 4–6 and 12–16 m, respectively. The fourth RT in the Gumista River valley was formed in the Middle Pleistocene; its relative height is 25–30 m and its width reaches 1 km. The valleys of other rivers are significantly smaller than the Gumista River valley and are characterized by a narrow floodplain and one–two river terraces, with relative heights of about 3–4 and 8–10 m, respectively. In general, the surfaces of river terraces in large valleys are slightly transformed during development, but scarps and rear seams are not clearly defined. This is associated with the layout of urban communications and roads, as well as the leveling of sites for buildings and structures. The ravine and gully network has a low density in coastal lowlands. Only in the foothills of Noviy Afon and the northern part of Sukhum do these landforms significantly complicate development due to their great depth (up to 50–60 m), steep slopes (up to 35°–40°), and narrow bottoms (see Fig. 1).

Other meso- and micro-landforms (karst, suffusion, slope, and anthropogenic) complicate the relief of the main genetic types described above (Table 1). In particular, karst relief (and sub-relief) is developed within the territories of Gagra and Noviy Afon, and is

represented by karrs, sinkholes, and caves (including large caves: St. Eupatius and Noviy Afon), as well as sinter deposits (inside karst cavities and locally in the river valleys). The diversity of landforms of slope origin, that is, blocks of subsidence, landslide pseudoterraces, and cirques, colluvial and deluvial plumes, is most fully represented in these two cities (Fig. 1). The slope relief in Gagra is only widespread in the northern mountainous part of the city, where buildings are very sparse and the network of streets is not well developed. In Noviy Afon, this relief is widespread almost everywhere, on slopes of varying steepness. Some areas of Noviy Afon have been completely built on gently sloping surfaces of large blocks of subsidence up to several hundred meters wide and long. According to the morphological features, the largest blocks of subsidence and rock landslides were formed during the Neogene–Quaternary and modern movements are unlikely. On the erosion slopes of river valleys and the SELs in all the studied cities, except Pitsunda, landslide cirques and shallow bodies (up to 5–7-m deep), as well as landslides 1-m thick, affecting only the slope cover, are often found. Usually, small landslides and earthflows are confined to eroded slopes, dipping at an angle from 25° to 45°. The distribution areas of these small landslides in cities, as a rule, belong to the category of inconvenient areas, and due to this, there is no development there. In the central parts of Sukhum, Gagra, and Gudauta, the relief of the river valleys has been significantly transformed. In particular, the slopes have been artificially flattened into terraces. Due to this, landslide landforms are not pronounced. The suffusion landforms, which are common within the cities, belong to the microlandforms and are represented by shallow (up to 1–1.5 m) saucer-shaped depressions and sinkholes up to 3–4-m across. They are confined to near-edge parts of sloping interfluvial surfaces (in particular, marine terraces) and are often formed as a result of the improper location of surface runoff collectors or accidents involving water-bearing underground utilities. The suffusion relief is most common in Gudauta and Sukhum, which is primarily due to the deterioration of municipal infrastructure.

All the studied cities are located in the coastal area, thus, the modern coastal landscape is developed within their borders. The landscape is characterized by denudational and accumulative forms and elements created by wave action at the present sea level. The abrasion landforms include wave-cut niches and benches, as well as erosional ledges and cliffs that can reach up to 4–5-m high. Accumulative landforms include pebble to pebble-sand beaches that can be up to 50–55-m wide, as well as estuarine spurs and navoloks.

Thus, the natural relief of an urban area that has been transformed to varying degrees during development can be represented by a range of genetic types. Based on the morphostructural position, the history of relief development and the modern climatic conditions of morphogenesis, cities can be divided into three groups according to their relief structure. The first group includes the cities that lie entirely in the distribution area of the coastal-marine relief (Pitsunda and Gudauta). These are located on gently sloping, subhorizontal surfaces, and as a consequence, they are characterized by monotony in both relief and surrounding landscapes. The second group includes Sukhum and Gagra, where marine terraces play a significant role, but areas with structural-denudation relief (in Gagra) and erosional-denudation relief (in Sukhum) fall within urban areas. The third group includes Noviy Afon, where coastal-marine landforms occur rarely and the dominant types of relief are structural-denudation, fluvial, and slope. There are large karst landforms.

The anthropogenic relief in urban areas is characterized by both accumulative (embankment pseudoterraces, roadway embankments, dams) and denudation (excavations, including roadway, drainage, and reclamation ditches) landforms. The areas occupied by the anthropogenic landforms are determined by the size of the city (first of all, the population) and characteristic differences in relative elevations. The capital of Abkhazia, with a current population of approximately 65000 (according to 2020 data), has seen the most significant transformation in its relief over time. It presents the widest range of anthropogenic relief types. Over the centuries, the city's framework lines have largely been levelled. Generally, it should be noted that the surfaces of Late Pleistocene sea terraces and high RTs in river valleys are most favorable for building construction. These surfaces, composed of cemented sand and gravel stones, rarely conglomerate, are well-drained and occupy significant areas in the northern parts of Sukhum and Gudauta. The development of the Novochernomorskaya marine terrace has been complicated due to poor drainage and the subsurface groundwater level. At the same time, the historical centers of Gagra, Pitsunda, and Sukhum are located exactly at this level, on ancient coastal bars and dumping grounds. Deeply incised ravines and gullies of high marine terraces and erosion-denudation hills are extremely inconvenient for urban construction. Due to this, the outskirts of cities are within their limits, with the predominance of private development.

Geomorphological Hazards within the Urban Areas

The above-described structural features of the relief of cities in the Republic of Abkhazia, as well as the extent of wear (dilapidation) of urban infrastructure (primarily, transport and communication) determined the differences in the spectra of geomorphological processes, including dangerous and unfavorable. Based on the materials from expeditionary research, large-scale maps of geomorphological hazards in urban areas have been created (Fig. 2), indicating not only their localization, but also the results of a qualita-

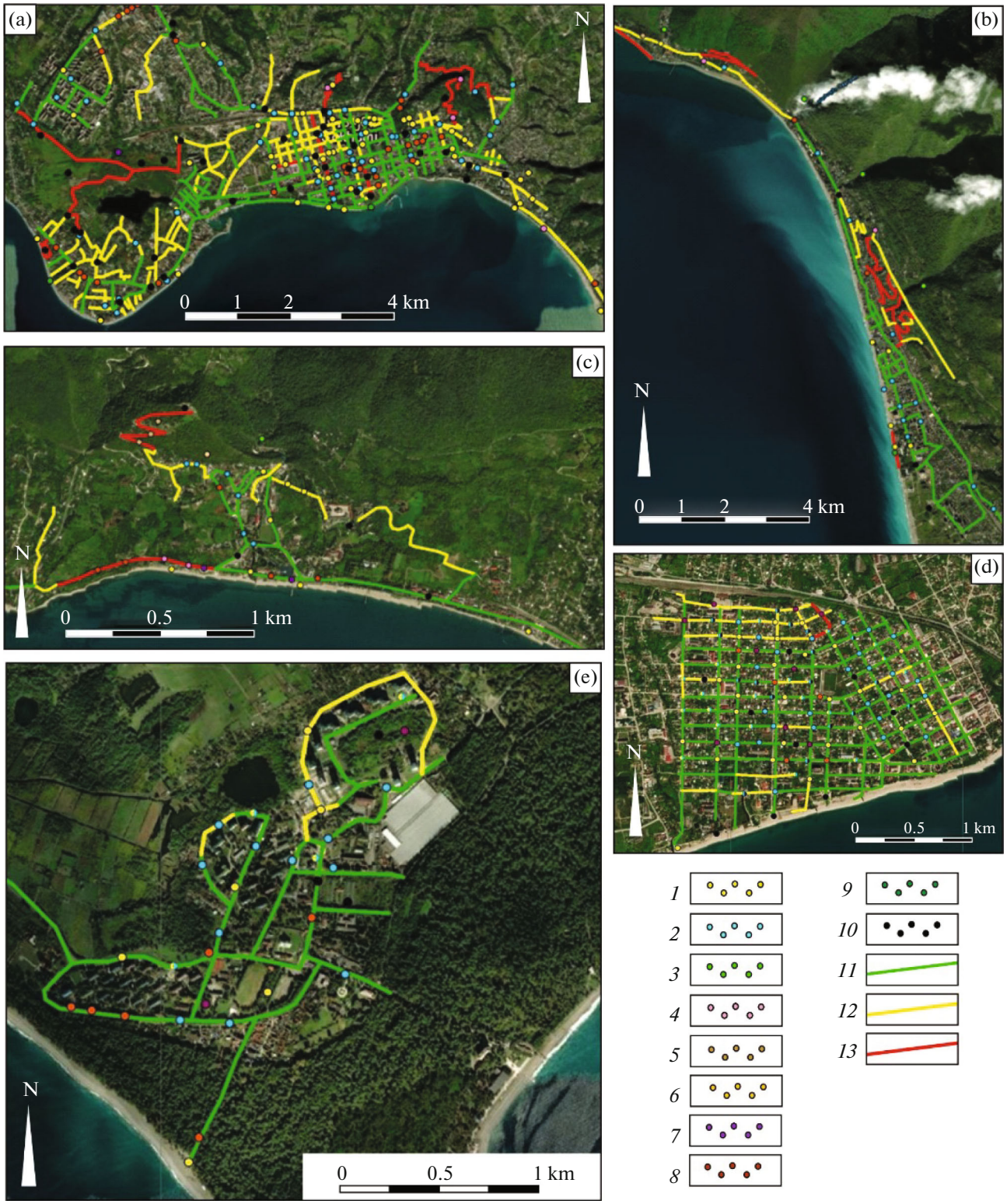

Fig. 2. The geomorphological hazards in the territories of Sukhum (a), Gagra (b), Noviy Afon (c), Gudauta (d), and Pitsunda (e) and the results of a qualitative assessment of the risk of street surface destruction. *Unfavorable and dangerous geomorphological processes*: (*1*) erosion, (*2*) suffusion, (*3*) mudflow, (*4*) landslide, (*5*) talus, (*6*) karst, (*7*) swamping, (*8*) biogenic, (*9*) coastal erosion, (*10*) anthropogenic. The risk of street surface destruction: (*11*) low (rare manifestations of unfavorable and dangerous processes); (*12*) medium, (*13*) high (numerous manifestations of unfavorable and dangerous processes).

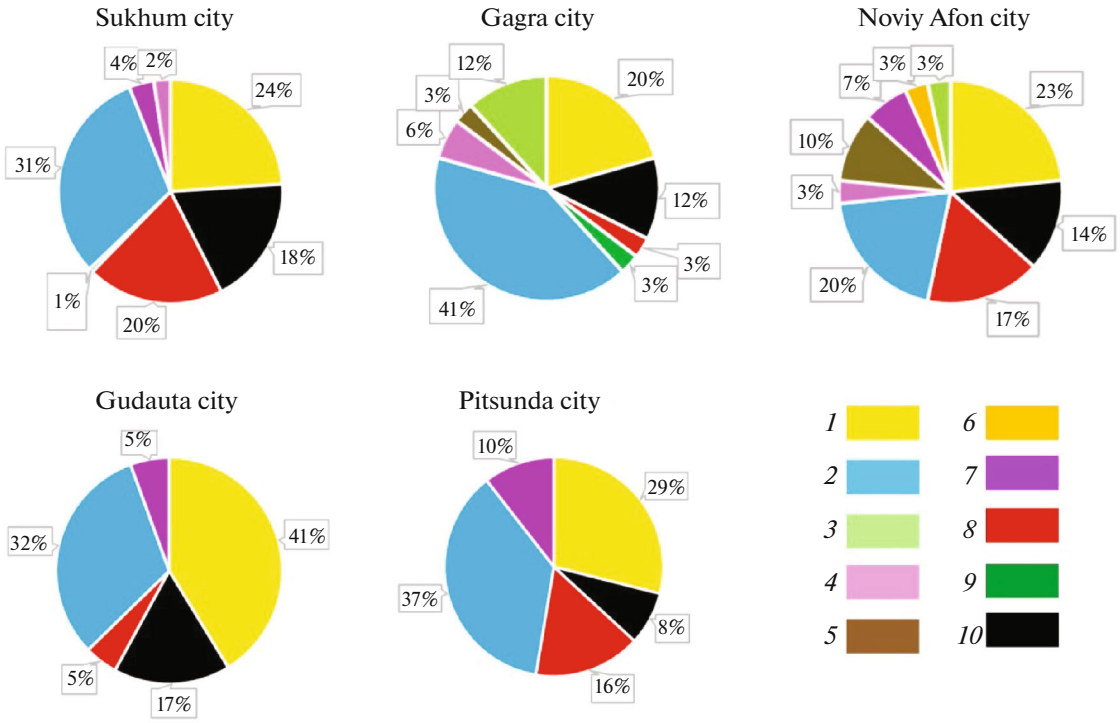

Fig. 3. The spectra of geomorphological hazards in urban areas (as a percentage of the total number of manifestations recorded throughout the territory of each of the cities). *Unfavorable and dangerous geomorphological processes*: (*1*) erosion, (*2*) suffusion, (*3*) mudflow, (*4*) landslide, (*5*) talus, (*6*) karst, (*7*) swamping, (*8*) biogenic, (*9*) coastal erosion, (*10*) anthropogenic.

tive assessment of damage to urban infrastructure. In particular, the manifestation areas of geomorphologic hazards of different genetic types are shown by out-of-scale symbols, while linear symbols represent street sections that have been subject to various degrees of superimposed hazardous geomorphological processes.

The spectrum of geomorphological hazards in the cities of the Republic of Abkhazia is diverse. It includes not only erosional and suffusion processes, which are the scourge of many urban areas, but also talus, landslide, coastal and biogenic processes, karst, swamping, and even mudflows (as a special type of fluvial processes). Waterlogging, a common hydrogeological process in urban areas, is less developed here. Among more than 300 recorded manifestations of dangerous and unfavorable processes, 44% occurred in Sukhum, 26% in Gudauta, 11% in Gagra, and 9% each in Pitsunda and Noviy Afon. The spectrum of recorded hazards is determined by three key factors: the natural relief, the degree of anthropogenic transformation, which depends on the size of the settlement, primarily on the population, and the state of urban communications, including the roadway.

The hazardous erosion processes (furrow erosion along roads, lateral and deep erosion in valleys and MEF) and suffusion processes along the lines of underground communications and urban streets are the most widespread within all studied cities (Fig. 3). Thus, the proportion of erosion processes among all recorded manifestations is as follows: 24% in Sukhum, 20% in Gagra, 2% in Noviy Afon, 41% in Gudauta, and 29% in Pitsunda, while the proportion of the suffusion processes is 31, 41, 20, 32, and 37%, respectively.

Cities with a dissected relief of structural-denudation or erosional-denudation genesis (Gagra and Noviy Afon) are characterized by a wide range of hazards. Some of these hazards are caused by anthropogenic factors, such as talus (3% in Gagra and 10% in Noviy Afon) and landslide (6 and 3%, respectively). These processes are mainly manifested on the sides of roadways and other semi-embankments on steep slopes. Within the studied cities, mudflows occur in some river valleys (Zhvavy-Kvary and Psyrtskhi), which is due to not only dissected mountainous relief of the adjacent area, but also the large amount of precipitation and high concentration of loose (predominantly, slope) deposits in mudflow foci at altitudes of 1000 m and above.

The cities that are located entirely on the surfaces of marine terraces (Pitsunda and Gudauta) are characterized by a significantly smaller range of geomorphological hazards, the leading role in which belongs to erosional and suffusion processes, as well as swamping. Comparing the ranges of geomorphological hazards in Pitsunda and Gudauta, one can note that there is a significantly higher number of swamping manifes-

tations in Pitsunda (10%) compared to Gudauta (5%). This difference is due to the unequal absolute heights (and ages) of the terrace levels and, as a consequence, different hydrogeological conditions. The range of geomorphological hazards, typical of the capital of the Republic of Abkhazia, is also wide. This is associated with the high density of buildings, extensive road network, poor preservation of urban communications, and a rather dissected relief, especially in the northern and eastern parts of the city.

In terms of the range of processes in the Sukhum city area, it is located closer to the cities located entirely within the distribution areas of the coastal-marine relief. This is due, first of all, to its geomorphological position (within the ladder of marine terraces), as well as to the leveling of the relief over the millennial history of development.

Biogenic processes pose a certain danger to urban areas, particularly the swelling of asphalt and concrete pavements due to root growth and the formation of iskors. These swells appear infrequently on roadbeds and are repaired during road maintenance. However, on sidewalks, these deformations can lead to the development of a specific micro-terrain, which can cause injuries. The proportion of biogenic geomorphic hazards ranges from 8% in Pitsunda to 18% in Sukhum, depending on the number of large trees along transportation routes and their total stretch. The hazardous anthropogenic processes includes littering of the area, including the organization of landfills of solid domestic and other wastes, illegal dumping, which often lead to deflation and soil and groundwater pollution. These processes are most common in Sukhum (18% of all cases) and Gudauta (17%). In Sukhum, this is mainly due to its dense population and the presence of a landfill for solid waste, while in Gudauta, it is due to insufficient attention from city services to these phenomena.

The main trend in the modern development of the coastlines of Abkhazia is erosion along most of their length, which is associated with the ongoing tectonic uplift of the Caucasus and, as a rule, the undeveloped profiles of the dynamic equilibrium of the coastal zone (Balabanov, 2009; Balabanov and Nikiforov, 2016; Wang et al., 2022). Over the 100 years, the natural relief of the coastal zone has been significantly transformed by humans. In particular, coastal protection constructions have been built to protect the shores from erosion. As a result, man-made shores have become the dominant morphogenetic type of shore within the urban areas, while the proportion of natural shores is no more than 30% of the overall length of urban coastlines. In particular, this proportion decreases to 5% in Gagra, Gudauta and Noviy Afon, to about 35% in Sukhum, and to about 95% in Pitsunda.

The special protected status of the Pitsunda Peninsula area has contributed to the preservation of the natural appearance of the shores of the tip of peninsula. The narrow, up to 400-m wide, zone of the coastal lowland, separating the main urban areas from the sea, has been given protected status. The southeastern part of the peninsula is characterized by the presence of an accumulative coastline with wide pebble beaches of the complete profile; the coast is growing at a rate of about 0.5 m/yr. The southwestern part has an abrasion coastline with beach scarps up to 2-m high and attached pebble-sandy beaches. The coastal erosion rate reaches 0.5–0.7 m/yr. Hereinafter, the coastal line retreat rates were calculated using aerial and space images over 1943–2021. Within the Sukhum area, natural shores are preserved only in the eastern part of the city (coastal erosional-accumulative, generally stable) and on Sukhum Peninsula. The coast from the Sukhum Cape to the cargo port is classified as coastal erosional-accumulative, stable, with wide pebble beaches, while to the west of the cape, the coast is mostly coastal erosional, with bench scarps up to 1.5-m high and attached pebble-sandy beaches, with typical retreat rates of up to 1 m/yr. The coastal erosion rate changes from 0.2 to 1/0 m/yr. Abrasion causes tangible damage to urban areas, but it is localized mainly in the zone of private development. For example, on the southwestern shores of the Sukhum and Pitsunda peninsulas, annual coastline retreat is observed, affecting the territory of cemeteries as well as a number of private houses. To protect the coastline from scouring, locals build wire-wrapped dams, concrete structures, blocks, and boulders in the rear zone of the beach. In the central parts of all resort cities (except Pitsunda), man-made coasts with sea walls, beach groynes, and narrow pebble beaches are common. The only area where the beach is completely absent is the Sukhum embankment near the passenger sea station. The maintenance of beaches on coastlines often requires systematic dumping of the sandy-pebble material in the coastal zone. In general, however, one can conclude that coast protection works do fulfill their functions. The coastal scarp edge on man-made coasts is armored with walls and practically does not retreat. However, the recreational attractiveness of such areas is undoubtedly very low due to the abundance of concrete structures.

Analyzing the geomorphological risks for the road network in cities on a qualitative level, as well as the current state of roads (see Fig. 2), we can conclude that the safest road sections for operation are concentrated in central urban areas. This is due to two reasons. First, historical centers of resort cities are located on subhorizontal surfaces of marine or, more rarely, river terraces, which have less geomorphological hazards. Second, to maintain the attractiveness of pedestrian areas, it is necessary to keep the roads, sidewalks, and roadways in good condition. Perhaps, the latter issue determines the obviously higher quality and timely repair of street surfaces. At the same time, the road network in urban suburbs is generally in a poor

condition. In particular, on asphalted and unpaved roads there are many furrows, potholes, and cracks on the road surface and sidewalks. Therefore, the state of the road network is, to some extent, determined by its geomorphic position. For example, in the northern parts of Sukhum, Gudauta, and Noviy Afon, roads run in semi-excavations along steep and very steep slopes. Due to this, this territory is less frequently visited by tourists and is much less populated. The uniformity of the roadbed on such sections is often broken due to slope, erosional, and suffusion processes. As they are apparently rarely repaired, the danger of operating such roads is very high.

CONCLUSIONS

The key factor of morphogenesis in the studied area is the geological structure (morphostructural features). In general, the topography of urban areas is determined by the proximity or remoteness from the coastal zone of the ridges and spurs of the Greater Caucasus. The peculiarities of morphogenesis in urban areas are largely determined by the history of development of the coastal zone and the humid subtropical climate. Anthropogenic transformation of the relief to varying degrees is also present in all cities.

According to the morphostructural position and the history of the relief development and recent climatic conditions of morphogenesis, the cities are divided into three groups: (1) completely occurring in the area of distribution of the coastal-marine relief (Pitsunda and Gudauta), (2) located mainly within the sea terraces and erosion-denudation hills (Sukhum and Gagra), and (3) completely located in the low mountains with a predominance of strongly dissected structural-denudation, fluvial and slope relief (Noviy Afon).

The leading places in the spectrum of geomorphological hazards in all urban areas belong to suffusion, erosion, and biogenic processes. The composition of other processes in the spectrum is determined by the geomorphological position of cities. The widest range, including, in addition to the processes mentioned above, also karst, mudflows, and landslide processes (the most hazardous), is typical of urban areas with a complex geomorphological structure, abundance of steep slopes, and confinement to the narrow zone, separating the spurs of the Main Caucasus Ridge from the sea (Gagra, Noviy Afon).

Resort cities (except Pitsunda) are most characterized by technogenic shores that combine wave land forms (beaches and benches) and coast protection works (groynes, breakwaters, breakwater walls, etc.). The natural tendency of modern development of the coasts of Abkhazia is their erosion, i.e., the tendency of coastline retreat is characteristic of 78% of the coastal zone of Abkhazia). The man-made shores of resort cities are generally stable, as the edge of the coastal scarp is supported by a sea wall. However, with sea level rise and increased frequency of strong waves, regular dumping of pebble material into the coastal zone is required to preserve beaches in the cities, otherwise, the width of the beach will gradually decrease as in the southern part of Gagra, in the eastern part of Sukhum. The greatest threat to urban infrastructure is coastal erosion on the southwestern flanks of the Pitsunda and Sukhum peninsulas and in the southern part of Gagra.

This qualitative assessment has revealed a strong correlation between the risk of damage to urban facilities and communication networks due to geomorphological processes and their location within the relief. In general, the most favorable conditions for the construction and operation of urban infrastructure and buildings are found on the leveled surfaces such as the Late Pleistocene marine terraces and the upper levels of river terraces in large river valleys. Other levels have various disadvantages that make development difficult. For example, construction on the surface of the Novochernomorskaya (Holocene) marine terrace is only possible with the use of waterproofing measures and soil dumping in low areas. The development of high-altitude marine terraces, erosional-denudation and structural-denudation relief is difficult due to the high level of erosion.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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