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RESEARCH PAPER

AGRICULTURAL TERRACES OF DAGESTAN: ANCIENT LEGACY FOR CLIMATE CHANGE ADAPTATION AND BUILDING RESILIENCE OF MOUNTAIN COMMUNITIES

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ABSTRACT. In agricultural mountain regions, changes in weather patterns force people to look for new agricultural activities, shift from agriculture to tourism services, or even leave the mountains. This study discusses the role of Dagestan's agricultural terraces as a potential resource for mountain people to adapt agricultural activities to climate change, thereby demonstrating the community resilience grounded on local traditional practices. We selected eight mountainous administrative districts of Dagestan as a case study area and tracked the changes of average annual, summer, and winter temperatures and precipitation for different altitudes in 2011–2020 compared to 2000–2010. We also conducted 30 informal exploratory interviews with local farmers and officials (purposive sampling) aiming at revealing common local narratives regarding climate change and its impact on agricultural activities, including the use of terraces. According to our results, respondents perceive the warming and drying of the Dagestan mountains as a growing water scarcity due to decreased precipitation and reduced snow cover, and as an opportunity to expand agricultural activities to higher altitudes. Agricultural terraces are seen as a prime land resource, preventing erosion and conserving soil moisture. Including terraces as a tourist attraction could increase interest in the local landscape and its history and may also indirectly serve to strengthen the resilience of local communities. While climate change may make it difficult to farm in the mountains, tourism becomes an additional source of income for farmers and supports agriculture.

KEYWORDS: North Caucasus, mountains, climate change perception, agriculture, historical heritage

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INTRODUCTION

The spatial diversity of climate change and its impacts on the environment and human activities requires a differentiated approach to assessing the adaptation measures needed on a particular territory. The IPCC reports specifically highlight mountain regions, as the increasing impacts of climate change on people and ecosystems here are reducing the resilience of mountain communities (Hock et al. 2019; Adler et al. 2022). Complex relief and altitude differences create a wide range of landscapes and biological diversity of mountain regions. However, they also make life hard for people because mountain areas tend to have fewer cities and people, making it harder to get to places and making them more vulnerable to extreme weather and slow-onset events.

All these challenges are also characteristic of the mountainous regions of the Caucasus. Over the past 30–40 years, the Caucasus has seen an increase in annual and seasonal temperatures, especially in summer, by an average of 0.5–0.7°C, a drier climate, and a growing frequency and intensity of meteorological extremes (Assessment 2022; Kozachek et al. 2017; Shvarev et al. 2021; Tashilova et al. 2019). Rapid glacier retreat (Solomina et al. 2024; Tielidze et al. 2022; Toropov et al. 2019) has cut off a lot of water in places where it is already scarce, such as the South Caucasus and the eastern flank of the North Caucasus. Overall, the environmental impacts of climate change are already posing a threat to the Caucasus population and its economic activities (Ahouissoussi et al. 2014; Sheludkov and Vinogradova 2024).

Many studies (Kohler et al. 2010; Ponce 2020; Salukvadze and Backhaus 2020; Gracheva et al. 2023) have reported that changes in weather patterns and their impact on agroecosystem productivity force people in agricultural mountain regions to look for new agricultural activities,

shift from agriculture to tourism services, or even leave the mountains. In seeking opportunities for building resilience of mountain communities, we argue that, alongside the new agricultural activities, a wide range of local practices and centuries-old experience can help mountain people to adapt to climate change (Gruneis et al. 2018). In particular, climate challenges are driving interest in revitalization of terrace farming (Stanchi et al. 2012; Birthal and Hazrana 2019; Cicinelli et al. 2021).

Terrace farming ensures soil conservation, water runoff regulation, and the possibility of using different crops along the altitudinal gradient (Ponce 2020). The loose substrate of the terraces retains the infiltrating water; thus, terraced slopes reduce peak flows in mountain rivers and store water in areas with a lack of moisture (FAO 2000). For centuries, these agricultural landscapes have been the basis of the resilience of mountain communities (e.g. Stanchi et al. 2012; Tarolli et al. 2014; Kiesow and Bork 2017; Gauci and Schembri 2019). Currently, farmers continue to use and modernize some terraces for the cultivation of high-quality crops, primarily grapes (Birthal and Hazrana 2019; Zoumides et al. 2022).

Among the terraced mountains, the terraces of the Caucasus and, in particular, of the North Caucasus are much less known in the world. Stretching along the mountain ranges from west to east, they form an almost continuous network of mountain-terrace complexes, which are the densest and most diverse in the Eastern Caucasus, primarily in Dagestan ('mountain country') (Gracheva and Idrisov 2021). Partially abandoned, these ancient terraces still form a primary base for local agriculture, serving as places for vegetable and fruit growing, viticulture, and livestock grazing.

This study discusses the role of Dagestan's agricultural terraces as a potential resource for mountain people to adapt agricultural activities to climate change, thereby demonstrating the community resilience grounded on local traditional practices. Resilience is considered the persistence, adaptability, and transformability of socio-ecological systems in the face of dynamic changes (Folke 2016; Wyss et al. 2022) and needs to be combined with United Nations Sustainable Development Theory (Vlasova et al. 2021). We will only talk about adaptation actions in agriculture here, but we will show that mountain communities' ability to be resilient comes from many places and things, such as local traditions, local government, and the sharing of knowledge across communities.

We start with a short discussion of the terraced farming phenomena, focusing on the terraced complex of Mountainous Dagestan and its links to other well-known cases of terraced farming in the world. Then we give a brief description of the study area and our research design. In the results section, we show the current trends of climate parameter change in the selected mountain districts of Dagestan and discuss the results of informal surveys of mountain residents and other stakeholders in the context of climate change. We consider the adaptation actions of the rural population to climate change from the point of view of the use of terraces as a land resource. Finally, we propose to include ancient agricultural terraces in the list of tourist sites in Dagestan as a unique cultural and historical heritage and human-shaped mountain landscapes.

TERRACE FARMING IN BUILDING RESILIENCE OF MOUNTAIN COMMUNITIES

Terrace farming is an ancient invention for farmers to adapt to local environmental conditions. One of the best examples of such adaptation is the Andean agriculture, with its 5,000-year history, where soil conservation is a part of the local culture. The Andean mountain agriculture shows how strengthening the identity and resilience of a community and a territory as a whole is achieved through traditional agriculture. The growing influence of modern technologies is eroding these traditions, but the outflow of young people and the loss of traditional knowledge can cause much more devastating consequences (Inbar and Llerena 2000).

The terraced agricultural landscapes of Southern Europe also reflect the efforts of people in supporting land resources and strengthening stability during centuries. Since the 15th century, the island of Madeira, Portugal, has served as an example of an almost perfectly adapted agricultural system of intensive farming (Kiesow and Bork 2017). The history of the terraces of the Maltese Islands, constructed on rocky slopes, goes back more than five thousand years. Grapes, which occupied the terraces over time, became the main crop of the island for many centuries (Gauci and Schembri 2019). Since the 1960s, the tourism industry has rapidly replaced the rural lifestyle, transforming the remains of grandiose Mediterranean terracing systems into tourist sites that serve as evidence of the region's distinctive culture (Gauci and Schembri 2019; Grove and Rackman 2003; Kiesow and Bork 2017). In some regions, land abandonment and growing tourism pressure lead to the destruction and disappearance of terraces and, in fact, to the collapse of the historical landscapes (Tarolli et al. 2014).

Dagestan is considered one of the centers of ancient terrace technologies, which emerged in the Bronze – Early Iron Ages and flourished in the Middle Ages (Vavilov 1936; Spenser and Hale 1961; Skripnikova 2007; Aglarov 2016). In conditions of extreme land shortage in the mountains, diverse terrace farming became widely used and highly advanced in Dagestan. One can find here almost all types of agricultural terraces characteristic of the Middle East, the Andes, the Mediterranean, and other regions with developed terrace farming (Aglarov 2016; Magomedkhanov et al. 2022). Terrace soils helped to maintain the stability of agriculture in a vulnerable environment, and terrace farming constituted an integral part of the socio-ecological system, created over centuries and supporting the resilience of mountain communities.
According to the remote sensing data, agricultural terraces in Dagestan cover an area of more than 3500 km, rising up the slopes to 2100–2400 m above sea level (Pinskoy et al. 2023). That is approximately 7% of the total area, or approximately 14% of the mountainous area of the republic.

The main area of terraces is located in the central limestone part of Mountain Dagestan at altitudes from 1000 to 1800–2100 m (Borisov et al. 2021). In the past, narrow strip terraces with retaining walls on steep slopes were planted with vineyards and orchards. Wide terraces without retaining walls with grassy slopes constructed on valley slopes and sloping plateaus were used for high-intensity, three-layer farming, with grain, legumes, and melons growing in one field and fruit trees on the edges of the terraces; grassy slopes were first-class hayfields (Aglarov 2016). Now, bushes and trees have overgrown the narrow terraces (Fig. 1a), while cabbage, potatoes, and other vegetables occupy the wide terraces (Fig. 1b).

In the southern part of Mountain Dagestan, terraces rise to 2400 m; here, soils of terraces built on the easily destroyed shale and slate rocks are suitable for cultivation with modern technology. Some researchers think that over 50–60 years, the amount of loose soil material on such terraces increased by 2-3 times on average (Borisov et al. 2016; Pinskoy et al. 2023).

Fig. 1a. Abandoned narrow-strip terraces. Interior Dagestan (Photo courtesy of I. Idrisov.)

Fig. 1b. Terraces with cabbage fields. Levashinsky district, Dagestan (Photo courtesy of Sh. I.Sharipov. After Gracheva, Idrisov, 2021)

In the 1930s, the Soviet authorities initiated the construction of new terrace complexes, however many of the old terraces had already been abandoned by that time. From the 1960s to the end of the 1980s, terrace farming ceased in many mountainous areas of Dagestan. According to experts from the Ministry of Agriculture of Dagestan, no more than 20% of terraced lands are currently used in crop production, and only those located near villages and roads no higher than 1500–1800 m above sea level. Many terraces serve only as pastures. At the same time, in the areas of cabbage farming and in the southern areas of horticulture and viticulture, especially in the Derbent area, more than 30% of terraced land is used[1].

While the old terraces of Dagestan are mostly well preserved and show no signs of destruction, a new cycle of terrace construction has begun in recent years for vineyards and intensive orchards (Gracheva et al. 2023). However, when comparing ancient and modern terraces, it turned out that ancient terraces, built by hand and carefully cultivated over centuries, are much more resistant to erosion than bulldozer and excavator terraces (Boziev 2008). The same results were obtained from a study of terraces built for vineyards using machinery in one of the provinces of Spain. It turned out that one heavy rain was enough for the terrace to slide and destroy the plantings of the lower third of the slope (Ramos et al. 2007).

Currently, the terraced lands of Dagestan and the remaining knowledge about terrace farming are not fully used. We seek to answer if the abandoned terraced lands will be in demand with new agricultural trends driven by the need to adapt to climate change.

STUDY AREA AND METHODS

Study area. The Republic of Dagestan lies on the eastern end of the northern flank of the Greater Caucasus along the western shore of the Caspian Sea. With an area of 50,300 km^2, Dagestan is the largest of the seven republics of the North Caucasus; it extends from north to south for 405 km and a latitude of about 213 km (Fig. 2).

[1] *Estimates from our field observations confirmed by local authorities.*

Fig. 2. Dagestan. Key study districts of Mountain Dagestan: 1 – Khunzakhsky, 2 – Gunibsky, 3 – Levashinsky, 4 – Akushinsky, 5 – Charodinsky, 6 – Laksky, 7 – Kulinsky, 8 – Agulsky (map content prepared by authors[2])

The southern half of Dagestan lies in the Caucasus Mountains, and the southern border runs along the Main Caucasus Range. The highest peak here is Mount Bazarduzu (4466 ma.s.l.) on the border with the Azerbaijan Republic. In the north lies a huge territory of steep mountain ranges and plateaus with deep river canyons, called Mountain Dagestan, or Inland Dagestan. In central and southern parts, heights are from 900–1000 m to 3000 and more than 4000 m. In the northwest, the ridges with heights greater than 2000 m separate Dagestan from the mountains of Chechnya. To the north and northeast, mountains decrease to 600–1000 m, forming a chain of foothills. The vast dry steppe and semi-desert Caspian Lowland extend to the north of the Sulak River.

The climate of Dagestan as a whole is temperate continental, dry and semi-dry in the lowlands, semi-dry in the inner valleys, and with a gradual increase in humidity with height. According to Akaev et al. (1996), the highlands with permanent snow cover have a cold climate without a dry season. These characteristics coincide with the Köppen-Geiger classification (Peel et al. 2007), according to which the climate of Dagestan belongs to two classes, moderate and cold. Foothill ridges, creating a "rain shadow" from the Caspian Sea and northern moisture-containing air currents, protect Inland Dagestan in the east and northeast; from the south and southwest it is fenced off by the spurs of the Greater Caucasus (Akaev et al. 1996). Some climatic data for Eastern Caucases obtained by ERA5-Land reanalysis are shown in Table A.1 in Appendix A.

The total population size of Dagestan exceeds 3,2 million people. Compared to other regions of the North Caucasus, Dagestan is distinguished by high population density in the mountainous areas[3] (about 50 people/km2); more than half of the region's rural population lives here (Imangulov & Safronov 2023). 70% of all Dagestan settlements are mountain villages; most of them – about 800 – are located at the altitudes between 1000 and 2000 m (Muduev 2022).

About 42% of Dagestan's agricultural land lies in the mountains. More than half of them are pastures and hayfields; the rest are arable lands and perennial plantations – orchards and vineyards. About 80% of agricultural production comes from small family farms, the share of which in the mountains is more than 90%[4]. In addition to livestock farming, which increases with altitude, crop farming plays a significant role. The most common crops in Mountain Dagestan are traditional horticulture, which includes apricot, peach, plum, and cherries, as well as the cultivation of cabbage, potatoes, and, in recent years, tomatoes. It is known that back in the mid-19th century

[2] *Map source: Russia_Dagestan_location_map.svg, https://commons.wikimedia.org/w/index.php?curid=14036356*

[3] *Territories above 500 m above sea level are considered mountainous, according to the Mountain Law of Dagestan (2010). https://docs.cntd.ru/document/895279692 (accessed 17.05.2024).*

[4] *Rosstat. (2022). Agricultural Micro Census 2021. https://rosstat.gov.ru/folder/75792 (accessed 17.05.2024) (in Russian).*

there were about 1,500 orchards in the Derbent area (Basiev et al. 2016). Crop production is concentrated mainly on agricultural terraces, currently used, as mentioned above, near roads and villages, in an altitude range not exceeding 1800 m above sea level.

Methods. We conducted our study in 2022-2023, which involved investigating climatic trends, conducting field observations, and conducting exploratory surveys with local residents and officials (purposive sampling). We chose eight Dagestan administrative districts (see Fig. 2) as case study areas because they are in the middle of Mountain Dagestan and have different average elevations, areas, populations, and main crops: Khunzakhsky, Levashinsky, Laksky, Charodinsky, Gunibsky, Akushinsky, Kulinsky, and Agulsky.

Climate change investigation. We relied on our previous study of climate change in the Eastern Caucasus (41°–45° N, 45°–49° E) over the past 20 years (Gracheva et al. 2023) by extending it with four other mountain districts. Based on high-resolution (0.1° × 0.1°) reanalysis data from ERA5-Land (Hersbach et al. 2023), we looked at how average annual, summer, and winter temperatures and precipitation changed at different elevations from 2011 to 2020 compared to 2000 to 2010. Since the article focuses on the population adaptation to modern climate change, a shorter period (2000–2020 – 21) was chosen, divided into 2 decades. We paid special attention to the sum of average daily temperatures exceeding 10°C (the so-called active temperatures), which characterizes the biological minimum temperature required for plant growth (Losev 1994).

Field observations and exploratory surveys. Our field observations included several car trips in July 2022 and September 2023 which covered selected districts and adjacent mountain areas. Particular attention was paid to possibly new agricultural activities and the use of agrarian terraces.

During the field trips, we conducted 30 informal exploratory interviews with local residents and administrations (purposive sampling). The interviews aimed at obtaining first insights relating to local stakeholders' views on climate change, its impact on agricultural activities including the use of terraces, possible adaptation options, and growing tourism activities. Conversations took place in four districts differing in altitude (Khunzakhsky, Levashinsky, Laksky, and Charodinsky) with representatives of local authorities (9) and local residents (21) including farmers (17), schoolteachers (2), street fruit sellers, and guesthouse employees. The age of the participants ranged from 30 to 55; there were 20 men and 10 women. All respondents had their own land plots and were involved in farming.

We also sought information on agricultural development from municipal authorities in four other districts, namely Gunibsky, Akushinsky, Kulinsky, and Agulsky. Additionally, we participated in a working meeting of the Public Chamber of Dagestan in July 2022, where representatives from 33 mountain municipalities discussed the social and economic issues facing these areas. Valuable information on adaptation to climate change in agriculture was obtained during informal meetings with government officials and two businesspersons who produced greenhouse equipment and represented a seed company. We also analyzed official documents and information from official websites of the Dagestan government, municipalities, and regional media.

RESULTS AND DISCUSSION

Observed trends in changing climate. Our previous assessment of the trends in climate parameters in the eastern part of the North Caucasus showed an increase in summer, winter, and average annual temperatures over the period of 2000–2020 while precipitation had negative annual and seasonal trends, especially noticeable recently (2011–2020) (Gracheva et al. 2023). The most marked increase in temperatures was in the middle mountains, at altitudes from 500 to 2000 m above sea level, in the most populated and developed areas (Table 1). In general, the mountains of the Eastern Caucasus and Dagestan in particular are becoming warmer and drier, as it is happening in many other mountain regions of the world (Beniston and Stoffel 2014, 2016).

In our study area, average annual temperatures were increasing by approximately 0.4–0.5°C per 10 years, while annual precipitation was noticeably decreasing: by 50–60 mm in 10 years (Table 1). At all altitudes, we observed an increase in the sum of active temperatures: by 89°C per decade above 3500 m above sea level and by 148–155°C at altitudes of 500–2000 m above sea level (see also Table A.1). The increase in this parameter with altitude indicates the possibility of expanding the areas of some agricultural crops.

Local views on climate change and adopted adaptation strategies: mountain terraces as a land resource. Much to our surprise, we had very similar responses to the questions in the interviews, which made it easier to reconstruct common local opinions regarding climate change, its impacts on living in the mountains, and the future of agricultural terraces. These narratives are summarized in Table A.2 in Appendix A. They reveal climate-induced risks, although not always explicitly linked to climate change, as well as the adopted adaptation strategies by respondents. Notably, the answers from the officials were in line with those from farmers: many members of the administration came from mountain villages and knew the local reality well.

According to the interviews, the most visible and crucial effect of climate change in Mountain Dagestan is the growing water scarcity caused by both the decrease in precipitation and the reduction of the snow cover. For example, 160 springs that fed the vegetable gardens, orchards, and livestock have disappeared in the Khunzakhsky district alone. Water deficit forces farmers to drill deep wells and even to purchase and transport water in tanks from the canal running through the Caspian Lowland. Farmers also note a shift in seasons, with a delay in autumn and spring and a shorter winter season overall. Due to the unpredictability of the weather, especially in spring and early summer, it is often impossible to apply traditional planting dates.

Previously, we identified three adaptation strategies adopted by farmers: switching to more resistant crops, intensive orchards, and greenhouse construction (Gracheva et al 2023). Mountain terraces are seen as a major land resource to support existing agricultural activities as well as to expand agriculture to new areas and to higher altitudes. Excavators made it easier to build new terraces, even though they could only restore and use terraces close to roads.

Temperature fluctuations and lack of moisture force farmers to switch to new, more resistant crop varieties. The challenge has required the cooperation of farmers with breeding institutes and seed enterprises, and they responded effectively due to the support of the

Table 1. Some data on the study municipal districts (official data) and differences in climate characteristics in 2011–2020 compared to 2000–2010, Dagestan (author's calculations using ERA5-Land data, Hersbach et al. 2023)

Municipal district	Altitude range, m.a.s.l.	Area sq.km	Population people (2021)	Agri cultural land, ha	Cropland, ha	Δt °C*	Δp mm**	ΔΣT>10 °C ***	ΔHTC****	Main crops
Khunzakhsky	1500–2000	552	31000	108200	9000	0.39	–56	157	–0.02	Fruits, legumes, vegetables
Gunibsky	1500–2100	609	25800	158300	7000	0.40	–59	155	–0.05	Fruits, vegetables
Levashinsky	1200–1500	813	80400	78526	14200	**0.53**	–65	**181**	–0.06	Cabbage, fruits, vegetables
Akushinsky	1300–2500	622	59000	62300	20600	0.43	–59	144	–0.08	Cabbage, potatoes, vegetables
Laksky	1400–2200	700	12000	104800	4400	0.33	–52	112	–0.07	Potatoes, vegetables, fruits
Charodinsky	2000–3000	894	13600	131300	760	0,34	–47	138	–0.03	Potatoes, vegetables
Kulinsky	2000–3000	651	10400	120924	2909	0,44	–82	151	–0.07	Potatoes, vegetables
Agulsky	2000–3000	793	10400	70500	1200	0,36	–65	132	–0.04	Potatoes, vegetables

Significant changes are highlighted in bold.
* Δt – the difference in annual temperature values between the periods 2000–2020 and 2011–2020 at altitudes of 1000–2000 m a.s.l.
** Δp – the difference in annual precipitation values between the periods 2000–2020 and 2011–2020 at altitudes of 1000-2000 m a.s.l.
*** ΔΣT >10 – the difference in annual sum of temperatures >10°C between periods 2000–2020 and 2011–2020 at altitudes of 1000–-2000 m a.s.l.
**** ΔHTC – the difference in hydrothermal coefficient (HTC = p × 10 / ∑ t>10) between the periods 2000–2020 and 2011–2020 at altitudes of 1000-2000 m a.s.l.

administration[5]. Selected resistant varieties and hybrids, including local varieties, have made it possible to preserve and expand terrace cabbage plantations, although the problem of water supply remains tense.

The need for greenhouses has arisen in recent years due to the increasing unpredictability of spring and early summer weather and the increasing frequency of spring frost and summer hail. In a short time, greenhouses occupied more than 700 hectares in the mountains, located on terraces near villages, especially on the southern mountain slopes (Dagpravda 2022), and this area is growing every year. The demand for greenhouses caused a sharp emergence of industry producing modern greenhouse equipment.

Some farmers are starting to look for additional opportunities to maintain income and are turning to intensive orchards (see Table A.2; personal communications). Development of intensive and super-intensive orchards is a direct response to climate change and a way to support mountain agriculture. Intensive orchards are especially relevant for the Eastern Caucasus and the Lesser Caucasus with a water scarcity. A case in point is Armenia, where planting intensive orchards is considered one of the ways to increase the resilience of rural areas in the face of climate change[6]. Intensive orchard technologies were developed primarily to maximize yields due to planting density (Barritt and Van Dalfsen 1992). In recent decades, such a property of intensive planting as reducing the vulnerability of trees to lack of moisture and sudden temperature changes has become very important (Palese et al. 2010; Aznar-Sánchez et al. 2011). Although intensive orchards require large investments in infrastructure and plant nurseries (Shakhmirzoev et al. 2017), interest in them quickly spread widely among small family farms in Mountain Dagestan. In response, nurseries and training centers for farmers appeared (Muduev 2022) (Fig. 3). Currently the area of intensive and super-intensive orchards in the region is more than 4000 ha and grows rapidly due to the renewal of old terraces and newly built ones (official reports[7]). The area of intensive orchards is expanding due to the conversion of the part of cabbage plantations to fruit production (information from a regional administration expert). The scale of these transfers has not yet been assessed, and there is no data on the area of new terraces.

Currently, in addition to the orchards, vineyards are being restored and planted on the terraces. New terraces are built using excavators, usually on accessible mountain slopes near roads. As mentioned, new terraces may not be resistant to erosion and sliding. Strengthened control will

[5] Riadagestan. (2022). White cabbage seed production is revived in Dagestan. https://riadagestan.ru/news/the_government_of_the/v_dagestane_vozrozhdaetsya_semenovodstvo_belokochannoy_kapusty/ (accessed 5.11.2022) (in Russian).
[6] MRD Talk1. (2022). Climate Change Adaptation in Mountains. https://www.mrd-journal.org/?mrd-talks=climate-change-adaptation-in-mountains-how-to-close-the-gap-between-policies-and-local-realities (accessed 30.06.2022).
[7] Fertilizer Daily (2022). Horticulture is developing intensively in Dagestan. https://www.fertilizerdaily.ru/20220531-v-dagestane-intensivno-razvivaetsya-sadovodstvo/ (accessed 11.11.2022) (in Russian).

Fig. 3. Agronomist (left) trains farmers in planting intensive orchards (Photo courtesy of Sh. Muduev)

be required, including over the safety of adjacent roads, especially as natural processes become extreme.

Adaptation to climate change includes not only actions taken to reduce existing or potential risks but also taking advantage of opportunities associated with climate change[8]. This opportunity could be the expansion of orchard areas above the altitude limits of their usual growth due to an increase in heat supply and, above all, an increase in the sum of active temperatures (Losev 1994). The Botanical Garden of Dagestan has already planted local fruit varieties on terraces up to 2000 m above sea level (Asadulaev and Magomedmirzaev 2018).

Adaptation initiatives of the rural mountain population are supported by the Program for the Socio-Economic Development of Mountain Territories developed by scientists of Dagestan and adopted by authorities. The Program includes financial support of small mountain farms by subsidies and grants[9]. This is an effective example where initiatives from below ("bottom-up") were supported by decisions from above ("top-down") (Eicken et al. 2021). However, the program does not include the revival of terraces, leaving it to the discretion and responsibility of farmers. To introduce the huge land resource of terraces into the economy, a program for inventorying terraces and determining the possibility of their use for different crops is necessary.

Agricultural terraces as cultural heritage and tourist sites. Among the views on the mountain terraces, there is the idea of terraces as the cultural heritage of mountain peoples. In our interviews, this issue was raised primarily by officials and public figures (see Table A.2).

Tourism in Dagestan has been booming in recent years: in 2022, more than 1.5 million tourists visited the republic (Mintourism 2023). In addition to popular tourist sites, agricultural terraces can be a "calling card" of Dagestan (Fig. 4). Educational and scientific tourist programs should incorporate the history of their creation, their role in the resilience of mountain communities, and their value as sources of scientific information. The construction and further maintenance of the terraces was a labor-intensive and lengthy process, requiring the joint efforts of many people. Thus, terraces are witnesses to the solidarity of community, concern for its stable existence, the transfer of knowledge and skills from generation to generation, and respect for the achievements of predecessors (Aglarov 1986; Magomedkhanov et al. 2022).

While climate change, i.e., water scarcity, may make it difficult to farm in the mountains, tourism becomes an additional source of income for farmers and supports agriculture by adapting agricultural products to the requirements of tourism, as it has been seen in other parts of the world (Debarbieux et al. 2014).

Agricultural terraces are sources of scientific information about natural changes and the history of society (Aglarov 1986; Kiesow, Bork 2017). During the construction of the terraces, wood remains and roots were burned or buried, and thus a valuable paleoarchive was created, storing information about the natural conditions at the time of the terrace building. Unfortunately, this archive is still almost unclaimed in Dagestan. Moreover, some methods of terrace formation have caused scientific confusion. To compact the terrace, a mountain stream was sometimes directed onto it; the water leveled and compacted the soil, left sand and small pebbles in it, and filled the retaining wall with stone material, strengthening it (Aglarov 2016). For researchers, the presence of pebbles sometimes serves as a reason to classify such terraces as river or lake terraces, which significantly confuses the natural history of the region (according to discussions at scientific conferences).

Agricultural terraces have become special multifunctional landscapes, integral elements of geodiversity, influencing spatial patterns and the functioning of modern natural ecosystems in Dagestan, and forming a unique aesthetic appearance of mountain slopes. Including terraces as a tourist attraction could increase interest in the local landscape and its history and may also indirectly serve to strengthen the resilience of local communities.

[8]*UNFCC. (2023). United Nations Framework Convention on Climate Change. Introduction. https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/introduction (accessed 17.05.2024).*

[9]*Program. (2020). On approval of the state program of the Republic of Dagestan «Socio-economic development of mountain territories of the Republic of Dagestan». https://docs.cntd.ru/document/561752993 (accessed on 8 August 2022) (in Russian).*

Fig. 4. Old agricultural terraces in Khunzakhsky district, Dagestan. Photo by A. Sheludkov

CONCLUSION

Climate changes add new risks to the vulnerable mountain environment and livelihood of mountain communities and reduce the resilience of mountain territories. In the Eastern Caucasus and, in particular, in Dagestan, trends in climate parameters show gradual warming and aridization. The population response to these processes in the mountains of Dagestan is almost the same as is observed in many mountain regions of the world (Adler 2022; Debarbieux et al 2014; Hussein et al 2021; Ponce 2020). People are adapting to climate change by changing agricultural ways, trying to solve water problems, and combining farming with tourism.

In the face of climate change, there is a noticeable trend in Dagestan toward the involvement of agricultural terraces as a land resource. Restoring terrace farming is in line with mountain agriculture by preventing erosion and conserving soil moisture while water resources are gradually reduced (FAO 2000; Dorren and Rey 2004). Terraces regulated the relationship between the mountain community and the environment, maintaining land productivity, protecting from dangerous natural processes, and limiting land conflicts that were inevitable due to a shortage of land resources in the mountains.

Building resilience in mountain communities in the face of climate change involves multiple actors. Horizontal knowledge transfer plays a huge role here. It enables the dissemination of best practices among farmers, involves scientific organizations such as the experimental stations for new varieties of agricultural plants, and gives impetus to the development of supporting industries such as producing greenhouse equipment. Yet there is also a great role for local and regional authorities, which can support local initiatives. By now, the Dagestan authorities have not yet included terrace farming in the supporting programs, and this issue remains the responsibility of farmers. Researchers are facing increasing importance in inventorying terraces, assessing the agronomic value of soils, and determining the economic feasibility of terrace reclamation.

The agricultural terraces of many mountainous regions can be considered as genius loci, the "genius of the place", which created life-supporting environment and the unique appearance of the territory. The inclusion of terraces in the list of tourist sites, as in many mountainous regions of the world, will increase interest in scientific tourism and, in general, the interest in the local landscape that stores information about the history of nature and societies of the mountains of Dagestan.

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APPENDIX A

Table A.1. Changes in temperature (T) and precipitation (P) in 2011–2020 compared to 2000–2010 at different altitudes according to ERA-5 reanalysis data (Hersbach et al. 2023). Eastern Caucasus 41–45° N 45–49° E.

H, m	T average annual, °C			T average summer, °C			T average winter, °C			Σ T > +10°C,			P average annual, mm			P average summer, mm			P average winter, mm		
	2000–2010 1	2011–2020 2	ΔT 2–1	2000–2010 1	2011–2020 2	ΔT 2–1	2000–2010 1	2011–2020 2	ΔT 2–1	2000–2010 1	2011–2020 2	ΔT 2–1	2000–2010 1	2011–2022 0	ΔP 2–1	2000–2010 1	2011–2020 2	ΔP 2–1	2000–2010 1	2011–2020 2	ΔP 2–1
0–500	13.2	13.6	0.4	24.7	25.5	0.7	2.5	2.6	0.1	4240	4360	120	440	397	–43	94	87	–7	97	95	–2
500–1000	10.2	10.7	0.5	20.9	21.5	0.7	–0.6	0.1	0.7	3351	3498	148	876	815	–61	266	248	–18	111	115	4
1000–2000	5.5	6.0	0.4	15.7	16.3	0.6	–4.9	–4.3	0.6	2037	2192	155	1099	1039	–60	426	407	–19	107	110	2
2000–2500	2.8	3.2	0.4	13.0	13.6	0.6	–7.4	–7.0	0.4	1349	1480	130	1051	998	–53	416	395	–21	104	106	2
2500–2800	1.4	1.8	0.4	11.6	12.2	0.6	–8.9	–8.5	0.4	1014	1126	112	1001	959	–42	394	380	–14	104	105	1
2800–3000	0.9	1.3	0.4	11.1	11.8	0.7	–9.3	–8.9	0.4	897	1017	120	946	893	–53	348	324	–24	106	108	2
3000–3500	0.7	1.1	0.4	10.8	11.4	0.6	–9.2	–8.8	0.4	834	936	102	1008	951	–57	384	361	–24	106	107	1
3500–5000	–0.5	–0.1	0.4	9.5	10.2	0.6	–10.5	–10.1	0.4	571	660	89	1063	1002	–62	431	402	–29	102	104	2

Table A. 2. Exploratory interviews: questions and most common opinions

Questions	Most common opinions
Do you/people notice climate change? If yes, which ones?	- "In recent years, farming has become hard. The seasons have shifted, fall is late, little snow, and spring weather is unpredictable". - "The hardest thing is that there is less and less water. Previously, wells were drilled up to 50 m, now up to 250 m and even deeper". - "There is often intense heat. Apricots and apples began to ripen where they had not even bloomed before".
What are you doing to overcome climate challenges? How do you/people adapt?	- "Cabbage requires water. We are forced to buy and transport water in tanks from the Caspian lowland, from the canal". - "I replaced the water supply system with a drip irrigation system, and many people do this". -"We have to change the varieties of cabbage and other vegetables. Now it is possible to buy new varieties or hybrids, they are better than others in temperature changes. There are demonstration sites; you can buy new seeds". - "Now many people are switching to intensive orchards, it is profitable, and they are more resistant to heat. I will wait and see; they say you can get subsidies". -"I have an orchard, it's a family tradition. We have a plot with an intensive orchard, still very young. Indeed they are resistant, but you need to keep a close eye on the spring weather". -"Greenhouses are saving us. You have to invest money, but you don't have to worry about the weather".
Terraces: are they necessary? Do you use them? For what? Do old terraces need to be restored?	-"You see what mountains we have. Many villages stand on old terraces. Cabbage, potatoes, orchards - all on the terraces". -"Where to put greenhouses? On the terraces. Now we are building new terraces for the orchards, using excavators, my family does it". -"I'll plant an intensive orchard on part of the terrace land under cabbage; it's more profitable". -"Not all old terraces can now be used. They are overgrown and expensive to restore. Only those that are close. Not everywhere there are roads". -"These are good pastures; let them remain so, thanks to our ancestors".
Does agriculture provide a sufficient livelihood?	(This is the only question that is answered without much desire). -"If cabbage is bad, potatoes or fruit may be good. Everyone has livestock". -"You can always earn extra money if something goes wrong; in transport, in warehouses..." -"The youth? They will always find money, tourism is nearby".
What is more important for you: tourism or agriculture? For mountainous areas? For Dagestan?	-"There can only be one answer: the main thing in the mountains is agriculture". -"We welcome tourism and welcome tourists. However, we live by agriculture". -"I cannot say the same about my children..."

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