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Exodynamic Processes in Upper Racha

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Abstract

Upper Racha is among the most geologically and environmentally challenging regions of Georgia due to the frequency and intensity of exodynamic processes and the significant damage they inflict on the environment and local population. The southern slope of the Central Caucasus, encompassing the Shoda-Kedela and Lechkhumi ranges, is characterised by complex and diverse relief. The upper part of the territory lies within high-mountainous subalpine, alpine, and nival zones. The southern portion of Upper Racha is dominated by deeply incised erosional valleys of the Rioni River and its tributaries, with some valleys exhibiting incision depths exceeding 1,000 metres and slopes ranging between 40° and 60°. This erosional-denudation relief has developed on Jurassic sediments and is shaped by active exodynamic processes affecting strongly dislocated rocks of Liassic age. These processes give rise to a range of geomorphological phenomena, including erosion, riverine and lateral erosion, mudflows, landslides, rockfalls, and snow avalanches. The region's high seismicity and abundant atmospheric precipitation further exacerbate these dynamics. A striking example of these processes occurred in late July 2023, when Upper Racha experienced alternating periods of extreme heat and torrential rainfall. Combined with the active ablation of the Buba Glacier, these conditions significantly increased the saturation of moraine material with liquid water, disrupting the gravitational stability of the slope. This triggered a catastrophic landslide that destroyed buildings at the Shovi resort, resulting in the tragic loss of 35 lives. This study aims to investigate the exodynamic processes in Upper Racha, identify their driving factors and development patterns, analyse the mechanisms behind such natural events, assess their impact on the formation and sustainability of the Shovi–Glola tourist hub, predict the future deve lopment of these processes, and propose effective preventive measures.

Keywords: Exodynamic processes, nival zone, moraine material,

Introduction

Racha, located in the mountainous regions of western Georgia, represents one of the country's most picturesque yet geologically complex landscapes. The region is distinguished by the high frequency and intensity of exodynamic processes, which exert significant impacts on both the environment and local communities (Salukvadze, 2022). These processes, including riverine erosion, mudflows, denudation-gravitational phenomena, and snow avalanches, are integral to the geomorphological evolution of the region and warrant comprehensive investigation to understand their underlying mechanisms, triggers, and spatiotemporal patterns.

A salient feature of Racha's geodynamics is its high seismicity. Situated within a seismically active zone, with earthquakes reaching magnitudes up to 9 on the Richter scale, Racha is highly vulnerable to earthquake-induced geomorphic instability. Seismic events frequently act as catalysts for catastrophic exodynamic phenomena, amplifying the hazard potential of the terrain. Moreover, the region's steeply dissected relief, combined with abundant precipitation, intensifies the occurrence and scale of such

processes. This interplay of tectonic activity, climatic conditions, and relief complexity necessitates a multidisciplinary approach for effective hazard assessment and mitigation.

This study focuses particularly on the upper Rioni River basin, with detailed attention to the Chanchakhi, Jejora, Gharula, Sakaura valleys, and their tributaries. The Chanchakhi River basin lies on the southern slopes of the Central Caucasus, between the main Caucasus range and its southeastern branch, the Shoda-Kedela Ridge. This area exhibits considerable geomorphic diversity and also possesses substantial tourism potential, owing to its unique natural resources—coniferous forests, mountain trails conducive to trekking and equestrian activities, and the "Glola Boulders" (granite moraine formations listed in the Red Book of Georgia)—in addition to mineral springs and cultural heritage sites (Gavasheli, 1978).

Anthropogenic influences further compound the environmental dynamics of Racha. Agricultural activities—such as slope ploughing, deforestation, and annual crop cultivation—have significantly altered land cover and soil stability, contributing to erosion and increased vulnerability to exodynamic processes (Salukvadze, 2022). These human-environment interactions underscore the importance of integrating socio-economic factors into geomorphological and hazard assessments.

Geologically, the northern flank of the Upper Racha syncline is dominated by thick-bedded marls of Upper Jurassic age, carbonate shales, and interbedded limestones. Lower Cretaceous tectonic activity has generated folded structural formations, while the area is intersected by both young and ancient faults oriented along multiple latitudinal directions. These structures are further complicated by strike-slip and discontinuous dislocations, which strongly influence the morphology and stability of the terrain. Quaternary sediments—including eluvial, deluvial, colluvial, alluvial, proluvial, and fluvioglacial deposits—form a significant component of the surface cover, influencing hydrological dynamics and slope processes (fig. 1).

This research aims to systematically analyse the mechanisms driving these exodynamic processes, assess their spatial and temporal distribution, and develop predictive models to guide hazard mitigation and sustainable land-use strategies. Such integrated research is crucial for the preservation of both the environmental integrity and socio-economic resilience of Racha.

Figure 1. Glaciers Tbilisa and Buba. Photo by M. Gongadze

Methods and Materials

In the field studies, we utilized a combination of geomorphological and geological methods. The morphological method was used to identify the primary landforms in the study area, as well as their contours and spatial arrangement. The morphometric method was employed to measure the dimensions of these forms, while the morphostructural method helped to clarify the relationship between the landforms and underlying geological structures. Additionally, various geological techniques were applied, including lithological analysis of materials, determination of the sequence of sedimentary layer formation, and examination of granulometry and material rounding. In the office, we conducted a literature review and analyzed relevant cartographic materials. Based on the results from these methods, the conclusions presented at the end of the article were drawn.

Results

Relief Types and Morphostructural Characteristics of Upper Racha

Upper Racha exhibits two principal types of relief, each distinguished by specific morphostructural and lithological characteristics:

1. Nival High-Mountainous Relief

The first type is nival high-mountainous relief, displaying clear signs of both ancient and modern glaciation, notably in areas such as Zopkhito, Laboda, Tbilisa, Buba, and Chanchakhi. This relief type develops predominantly on sedimentary and metamorphic formations of Jurassic age (fig. 2). Erosion and denudation processes are particularly active here, shaping the terrain into steep slopes, sharp ridges, and deeply incised valleys. Morphostructurally, this zone is characterized by denudational forms bounded by major fault systems to the north and south. The presence of easily erodible flysch formations contributes to relatively subdued topographic forms and the development of deep erosional valleys.

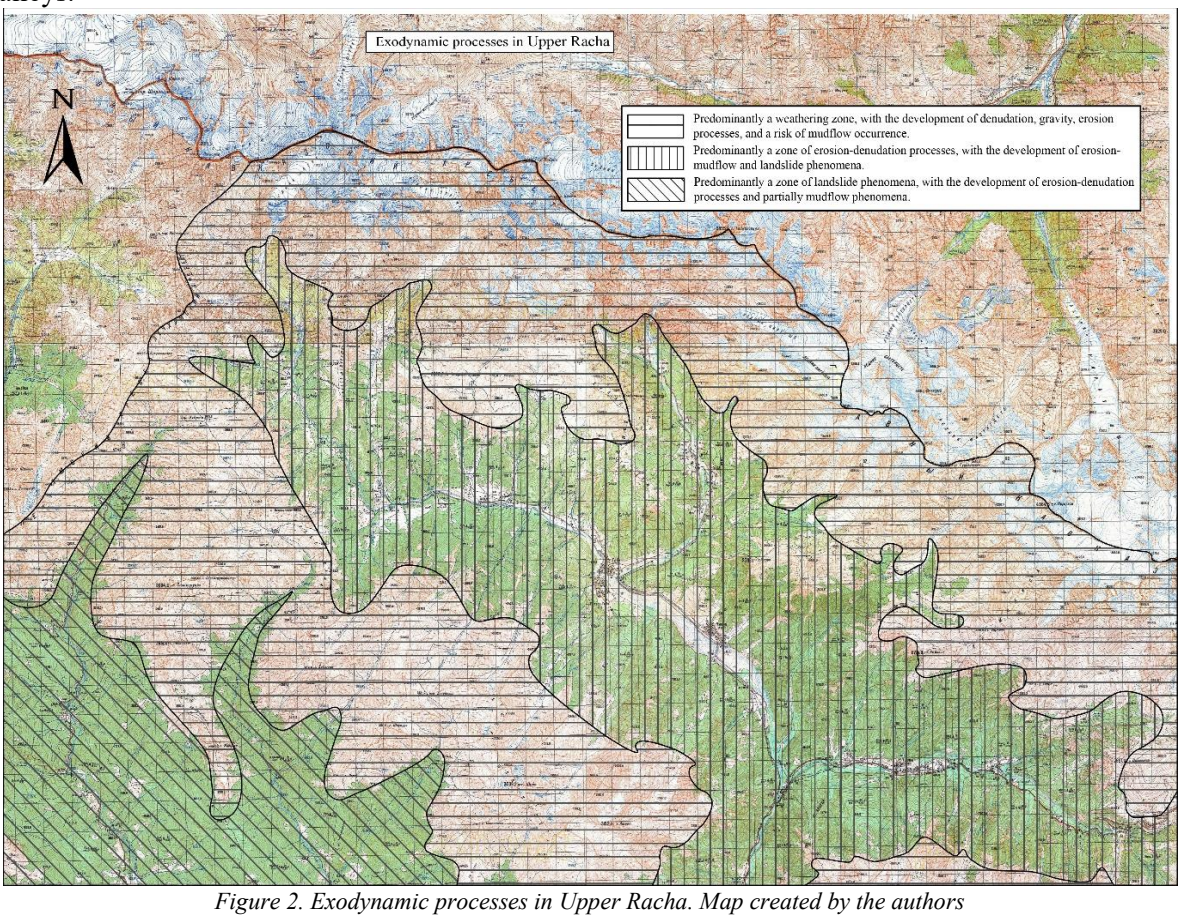

Figure 2. Exodynamic processes in Upper Racha. Map created by the authors

A distinct morphological feature in this region is the transverse uplift of the Buba River, which connects to the Bubistskali River valley through Upper Pleistocene moraine deposits. At relatively lower elevations within this relief type, denudational forms are accompanied by active manifestations of mudflows and landslides.

The southern slope of the Central Caucasus, including the Shoda-Kedela and Lechkhumi ranges, presents highly diverse relief forms. The uppermost parts of this area belong to the high-mountainous

subalpine and alpine zones, with elevations ranging from approximately 3,500 to 4,000 m above sea level and are dominated by nival-glacial and glacial-erosional morphologies. The lower slopes are deeply dissected by the Rioni River and its tributaries, with valley incisions exceeding 1,000 m in depth in certain locations and slope inclinations ranging between 40° and 60°.

Erosion-denudation relief in this context develops on a substrate of Jurassic sediments. The relatively smooth nature of some relief forms is determined by the impact of erosion-denudation processes acting upon strongly dislocated igneous sandstones and shales of Liassic age. Valley profiles are typically V-shaped; however, where slopes consist of shale, ravine-shaped valleys predominate. For example, near the village of Ghebi, the width of the Rioni floodplain is approximately 150 m, widening to 280 m between Ghebi and Chiora, and narrowing to 230 m near Chiora.

2. Erosion-Denudation Relief of Medium-Mountainous Terrain

The second type is erosion-denudation relief characteristic of medium-mountainous terrain, marked by valleys with erosional dissection ranging from 300 to 600 m in depth and slope inclinations between 30° and 45°. This relief type is widespread in the central and southern parts of Upper Racha and represents the eastern extension of the Racha-Lechkhumi synclinal depression. It develops primarily on clayey-sandy and carbonate rock formations from the Upper Jurassic, Cretaceous, and Tertiary periods.

This zone contains abundant remnants of ancient landslide forms, and contemporary landslide activity remains significant. Such processes are particularly active along the slopes of the Rioni and Jejora rivers and their tributaries, where intense mudflow activity is also observed. Villages most affected include Khideshlebi, Mazhieti, Somitso, Skhieri, Kristesi, and Khirkhonisi. Slope profiles in these locations often display stepped and wavy configurations, indicative of ongoing landslide movements.

In areas where massive chalk limestones are exposed, prominent cornices reaching heights of 20–50 m are common (e.g., in Khirkhonisi and Skhieri). Colluvial soils at the base of these cornices facilitate erosion and slope instability, thereby promoting further landslide development. Additionally, relict river terraces occur along the slopes of river valleys, notably in the vicinities of Skhieri, Kristesi, Somitso, and Komandeli. The first terraces situated approximately 1.5–4 m above the current riverbed, extend along the Rioni River, and the town of Oni itself is established upon one such terrace.

In areas dominated by Cretaceous and Tertiary limestones, active karst processes are widely observed, resulting in the formation of karst poljes, sinkholes, and cave systems. These features are particularly abundant in regions underlain by extensive Barremian limestones of Lower Cretaceous age, including the northern sector of the northwestern slope of the Racha Ridge and localities such as Khikhat, Khirkhonisi, Shkmere, Usholta, Kharistvali, Mravaldzali, Futieti, and Skhvava, as well as the Lower Bari, Upper Bari, and Mukhli areas (Gavasheli, 1978).

The valleys of the right and left tributaries of the Rioni River develop under comparable geomorphological, geological, and microclimatic conditions. This results in sharply inclined valley beds and steep, often denuded slopes, fostering intense erosion, denudation, and slope failure processes. These conditions, when coupled with periods of intense precipitation, create favourable conditions for catastrophic mudflows. A significant example occurred between 26 and 27 July 2020, when precipitation exceeded the daily norm, reaching 120 mm according to the Hydrometeorological Department of the National Environmental Agency. This extreme rainfall event resulted in extensive damage, including the destruction of tens of kilometres of highway embankments, as well as the impairment of bridges and agricultural infrastructure across the affected region. Notably, heavy precipitation was recorded not only in the lower reaches of the Rioni Gorge but also at higher altitudes. Field observations above the village of Chiora (altitudes between 2,200 and 2,600 m above sea level) confirmed evidence of intense atmospheric precipitation during this event.

The Chanchakhi River is characterised by a bifurcated bed, consisting of a main channel and a secondary channel activated during high-flow events. The incision depth of the main channel reaches up to 1.5 m, while both banks accumulate proluvial deposits containing organic matter such as wood and plant debris. Boulder sizes within the riverbed range from 0.2 to 0.7 m, with bulk deposit thicknesses reaching up to 1.5 m. River islands densely vegetated with alder trees exhibit clear evidence of historic mudflows (fig. 3).

During the July 2020 rainfall event, significant overflow occurred in the Rioni and Chanchakhi rivers, including their tributaries, resulting in destructive mudflows that severely damaged infrastructure, highways, and bridges within Upper Racha's villages (Tsereteli, 2020).

Further downstream, the Chanchakhi River receives inflow from the left bank via the Dgviora River. This tributary originates from a heavily deformed glacial cirque on the northern slope of the Shoda-Kedela Range, oriented parallel to the Central Caucasus. The region exhibits distinct glacial and erosional-glacial features, including sharply defined trough valleys, moraine deposits, and isolated erratic boulders. Alpine and subalpine landscapes extend to comparatively low elevations. In this system, the bedrock lithology, slope gradients, and prevailing climatic conditions serve as primary controls on the development of exodynamic processes.

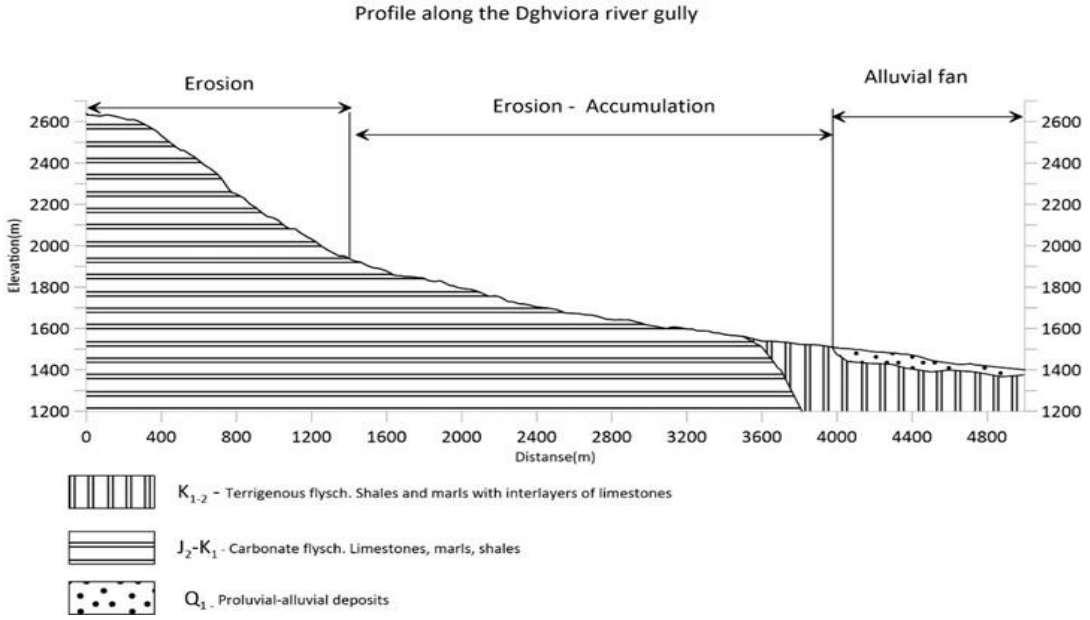

Figure 3. Profile along the Dghviora river gully

The confluence of the Dgviora and Chanchakhi rivers generates a substantial sedimentary cone, upon which the village of Glola is situated. This depositional feature is particularly susceptible to destructive mudflows during periods of heavy precipitation, frequently inflicting damage upon Glola and adjacent settlements. The July 2020 event again exemplifies this dynamic, with extreme rainfall leading to significant river swelling and consequent destructive mudflows across the Chanchakhi and Rioni basins.

Quantitative geomorphological analysis was conducted using lithofraction counting within systematically established 5 × 5 m polygons in the beds of the Gharula, Mushuani, and Dgviora rivers. These measurements identified alluvial-proluvial layers comprising between six and seven size fractions, with particle dimensions ranging from 1 cm to 1.5–2 m. Subsequent stratigraphic analysis of riverbed cuts enabled reconstruction of the timing and provenance of transported material, thereby distinguishing between natural and anthropogenic drivers of exodynamic activity. These findings are essential for developing targeted preventive strategies against such events.

The Sakaura River, entering the Rioni River from the right approximately 3 km upstream of Oni, extends over a gorge approximately 13–14 km in length, incised primarily within Middle and Upper Jurassic clay-shale and sandstone sequences. The floodplain and riverbed lithology are dominated by unprocessed large-fraction proluvial boulders (approximately 70%), supplemented by fine alluvial gravel and pebbles. Boulder sizes within the riverbed range between 0.4 and 1.2 m, with deposit thicknesses between 2.5 and 3 m above the river surface.

In the upper reaches above Khideshlebi, the left bank of the Sakaura is artificially reinforced with a 60 m long, up to 2 m high boulder wall. In the midsection of the river, near the bridge, intense incision has produced a deep, narrow erosional gorge, characterised by extensive proluvial boulder fields. Near the village of Mazhieti, the Sakaura's largest left tributary joins its bed. In 2020, mudflows entering this tributary washed away a bridge, which was rebuilt within the same year; remnants of the destroyed piers and the extensive proluvial boulder fields remain as evidence of this event.

Shovi Catastrophe

The Chanchakhi River basin is situated on the southern slope of the Central Caucasus, occupying a geomorphologically complex position between the main Caucasus range and its southeastern branch,

the Shoda-Kedela Ridge. The northern flank of the Upper Racha syncline is predominantly composed of thick-bedded Upper Jurassic marls, carbonate shales, and interbedded limestones. These lithological units have been significantly deformed by intense tectonic movements during the Lower Cretaceous, resulting in intricate folded structures.

The structural framework of the region is dominated by both young and ancient faults oriented along three principal latitudinal directions. These faults are further complicated by strike-slip dislocations and discontinuous faults of various orientations, all of which are clearly expressed in the regional relief. The Quaternary sediments in the basin include eluvial, deluvial, colluvial, alluvial, proluvial, and fluvioglacial deposits, which together form a diverse and dynamic sedimentary cover.

The Bubistskali River, originating from the Buba Glacier, is a major tributary of the Chanchakhi River, joining it from the right near the Shovi resort (fig. 4). Below the alpine zone, the Bubistskali Gorge is deeply incised into Jurassic and Lower Cretaceous sedimentary sequences, forming a sharply defined erosion-denudation relief.

On 3 August 2023, this gorge was the site of a catastrophic geomorphological event: a flash flood that rapidly transformed into a mudflow and subsequently developed into a high-velocity landslide. This event, hereafter referred to as the "Shovi catastrophe," was the result of a complex interplay of climatic, topographic, and geological factors. Over recent decades, the Buba Glacier has undergone significant retreat due to accelerated melting associated with climate change. This retreat has exposed extensive moraine deposits at the glacier's front, base, and lateral margins. These moraine bodies, reaching tens of metres in thickness and extending several hundred metres in length, consist of unprocessed, angular boulder material of varying size, interspersed with trapped snow that persists through the summer season.

The Bubistskali River, incising through this moraine complex, has been unable to fully mobilise and transport the accumulated debris due to its relatively gentle gradient and reduced hydraulic energy. This sediment accumulation increased the susceptibility of the system to blockage and sudden failure. Under conditions of intense rainfall and rapid snowmelt, the entrainment of moraine material triggered the cascade of processes that culminated in the flash flood, mudflow, and landslide observed in August 2023.

The Shovi event represents a striking example of the interaction between glacial retreat, moraine sediment dynamics, and extreme meteorological conditions, highlighting the growing hazard potential in high-mountain environments under climate change. Detailed geomorphological and sedimentological analysis of the Bubistskali-Chanchakhi system offers critical insights into the mechanisms governing such hazardous events and provides a basis for risk assessment and mitigation strategies in similar alpine catchments.

Figure 4. River Bubistskali gorge in the Shovi section before the disaster. Source: Esri. Maxar. Earthstar Geographics and the GIS User Company

Figure 5. River Bubistskali gorge in the Shovi section after the disaster. Source: Esri. Maxar. Earthstar Geographics and the GIS User Company

At the end of July 2023, Upper Racha experienced extreme heat followed by torrential rains, leading to a critical event in early August. The intense rainfall and melting snow increased the saturation of the moraine material, surpassing its critical threshold. This destabilised the gravitational equilibrium of the solid material, causing rainwater, melted snow, and a swollen river flow to mobilise a large number of debris. As it moved downhill, the mass uprooted coniferous vegetation and quickly advanced towards Shovi. The Bubistskali River, being short in length, was covered by the catastrophic mudflow in just 20 minutes (fig. 5).

Years earlier, an artificial barrier was built on the lower Bubistskali River, altering the course of the Chanchakhi River, and cottages were constructed in the area. Unfortunately, this region, along with the cottages, was hit by the mudslide. Eventually, with debris from the river's middle section, the mudflow turned into a landslide, burying the cottages and the plain in the centre of the resort under several metres of debris. Tragically, those in the cottages and nearby areas perished almost instantly. Only those in the older resort buildings and vacationers in the nearby forests survived.

The Shovi tragedy highlights the complexity and unpredictability of natural processes, as well as human negligence and ignorance towards these processes. Thankfully, buildings from the 1930s and 1940s were strategically placed in safe areas, allowing them to withstand the disaster. In contrast, the owners of cottages in the Bubistskali area were not as fortunate.

Conclusion

Exodynamic processes, based on their development characteristics, can be classified into three main groups: those that occur constantly, periodically, and catastrophically, both in general and specifically in Upper Racha.

Ongoing processes include erosion and denudation, which affect the entire territory of Upper Racha. However, erosion is more pronounced in the nival zone, while deeper erosion predominantly occurs in the upper reaches of the Rioni River tributaries. Lateral erosion is notably evident in the Rioni River valley below the village of Saglolo. Denudation processes primarily occur on steep slopes (25°–30° and greater), which are often sparsely vegetated. On such slopes, where vegetation cover is minimal, talus cones and rock avalanches are common.

Periodic processes include mudflows, which form due to a combination of heavy precipitation, the accumulation of depleted material in valleys, and the steep gradient of valley beds. Landslides also occur periodically, typically on deluvial slopes with gradients exceeding 25°, where the lower part of the slope is eroded by river flow.

Catastrophic natural processes are extreme manifestations of exodynamic processes. They occur as a result of the interaction of specific meteorological conditions such as intermittent heavy rains and increased melting of glaciers. Additionally, large amounts of weathered material accumulate in troughs

and valleys, with rain seeping through cracks on slopes and surface waters contributing to these processes. The catastrophic mudslide in Shovi on August 3, 2023, which ultimately transformed into a landslide and completely engulfed the resort area, was a direct result of the confluence of these factors. The mudslide destroyed the cottages designated for vacationers, significantly disrupting tourism activities in the region.

An important factor hindering the development of resorts and tourism in Racha is the increased risk of natural disasters. A tragic example of this is the mudslide that occurred in the resort of Shovi on August 3, 2023. It originated from the gorge of the river Bubustskali and covered the entire resort area. Cottages in the Bubistskali region were destroyed, and 35 people lost their lives. Initial estimates suggest that the total volume of the brought proluvial material reached 1 million m^3. The disaster dealt a severe blow to the resort, putting its operation in question.

The restoration and preservation of the Shovi resort are crucial not only for the economy of Shovi-Glola but also for the future of tourism development in Racha (Gongadze, 2024; Nadareishvili, 2024). This aspect should be the subject of further detailed research. The government has also expressed its intention to restore the resort. It is important to consider the nature of the exodynamic processes in the Shovi-Glola area when planning the restoration, with a focus on natural hazard factors. Safe zones for development should be designated based on data from pre-project studies and monitoring of natural hazards, as well as the implementation of containment and protection systems.

The authors suggest that the restoration of the resort should involve the removal of the accumulated landslide mass, which can then be used as construction inert material. This material holds special value in the current construction boom. This process will result in a cleared resort area, essential for the resort's operation.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

Merab Gongadze. and Giorgi Khomeriki. conceived of the presented idea. George Loninadze. and Giorgi Kavlashvili. performed the analytic calculations. Nikoloz Suknidze and Gela Talakhadze. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Assessment of the Climate Change Impact on the Characteristic Parameters of Freezing in Georgia by Regions

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Abstract

The change tendency in the duration of the frost-free period in the territory of Georgia is analysed by comparing the last 16 years of data (2007-2022) with the similar one of the previous periods (1951-1965). The early, average and late values of the last spring and first autumn frost dates in the study regions were evaluated. It was revealed that in the period 2007-2022 compared to 1951-1965, the average values of frosts shifted earlier for the last spring frost and later for the first autumn frost, which led to frost-free periods increasing and, accordingly, the length of the vegetation period. The map depicting the duration of increased frost-free periods is presented, the trend of increasing frost-free periods under climate change is revealed, and the dependence of these periods on the North Atlantic Oscillation is also fixed.

Keywords: Spring and autumn freezing, frost-free period, growth trend, North Atlantic Oscillation

Introduction

Agriculture is widely recognized as one of the most vulnerable sectors to climate change across the globe. Variations in temperature and precipitation regimes, evapotranspiration rates, and soil moisture—along with the increasing frequency of extreme weather events such as droughts, floods, and heavy rainfall—lead to soil degradation, erosion, and nutrient depletion. These processes reduce agricultural productivity and negatively impact both the quantity and quality of food production.

In Georgia, complex topography, diverse meteorological conditions, and significant anthropogenic pressures create particularly favourable conditions for the occurrence of various natural hazards. Recent decades have seen a marked increase in the frequency of such events, driven by deviations from long-term climatic norms in precipitation, air temperature, humidity, and other meteorological parameters. These deviations amplify the occurrence of catastrophic processes within the broader context of global climate change.

Among the hydrometeorological hazards affecting Georgian agriculture, frost represents one of the most significant threats. Notably, frost—despite its substantial impacts—has not been included in the internationally standardized classification of hazards established by the United Nations in the 2015 Sendai Framework for Disaster Risk Reduction (Sendai Framework 2015–2030) (NDRR / ISC Sendai Hazard Definition and Classification Review, Technical Report, 2019; Kapanadze et al., 2023). Nonetheless, frost continues to inflict considerable damage on agricultural systems in Georgia, as well as in many other countries worldwide (Mkurnalidze et al., 2023).

Given this context, there is growing scientific interest in assessing the impacts of contemporary climate change on frost characteristics across different regions of Georgia. Such assessments require the analysis of observational data from individual meteorological stations, which are located within diverse climatic zones and may therefore exhibit variations in frost dynamics under changing climatic conditions (Kapanadze et al., 2023; Kapanadze et al., 2024).

Accordingly, the central objective of this study is to quantify changes in the frost-free period—a key temperature-based indicator of climate change—and to determine the average timing of the last spring frost and the first autumn frost across different regions of Georgia. This regional approach will allow

for a more nuanced understanding of how frost regimes are shifting in response to ongoing climatic transformations.

Methods and Materials

To address the research objectives, data from 26 meteorological stations of the ground observation network operated by the National Environmental Agency of Georgia were utilized, covering the period 2007–2022. Based on these observational records, the frost-free periods and the dates marking the onset and cessation of freezing were calculated for each region. To assess the influence of climate change, these calculated values were compared with corresponding long-term averages derived from historical climate records (Handbook on the Climate of the USSR, 1967; Handbook on the Climate of the USSR, 1971).

Given that frosts are most pronounced under clear, calm conditions during the incursion of Arctic air masses from dry latitudes, it is important to consider broader climatic drivers. One such driver is the Arctic Oscillation (AO), a key indicator of Arctic climate variability that governs the state of atmospheric circulation in the high latitudes. The AO index, available from the Climate Prediction Center (CPC, 2025) was therefore incorporated into this analysis to explore potential links between global climate variability and regional frost dynamics in Georgia.

The Arctic Oscillation refers to an atmospheric circulation pattern over the mid-to-high latitudes of the Northern Hemisphere, whose most notable manifestation is the latitudinal shift of the mid-latitude jet stream. The AO strongly influences weather and climate patterns in North America, Europe, and Asia, particularly during winter.

During the AO's positive phase, surface air pressure is lower than average over the Arctic and higher than average over the northern Pacific and Atlantic Oceans. This configuration shifts the jet stream farther north, redirecting storm tracks and generally reducing the occurrence of cold air outbreaks in the mid-latitudes of North America, Europe, Siberia, and East Asia. Conversely, in the AO's negative phase, surface air pressure is higher than average over the Arctic and lower than average over the northern Pacific and Atlantic Oceans. This causes the jet stream to shift toward lower latitudes, facilitating the penetration of frigid polar air into the mid-latitudes and increasing the likelihood of severe frost events. For example, higher frequencies of coastal storms, such as Nor'easters in New England, have been linked to the AO's negative phase.

The AO index quantifies these dynamics by measuring surface atmospheric pressure anomalies at 1000 hPa across latitudes 20° N to 90° N. These anomalies are projected onto the AO loading pattern, defined as the first empirical orthogonal function (EOF) of monthly mean 1000 hPa geopotential height. The resulting time series is normalized by the monthly standard deviation of the index. Variations in the AO index thus directly reflect the degree of Arctic air penetration into middle latitudes, with a positive AO index corresponding to stronger zonal winds that confine cold Arctic air to the polar region, and a negative AO index corresponding to weaker zonal winds and greater incursions of polar air into temperate regions.

By comparing the AO index with frost-free period data from Georgia's regions, this study aims to elucidate potential connections between large-scale atmospheric circulation patterns and local frost dynamics under contemporary climate change.

Results

In spring, advection of warm air masses from the southwest frequently occurs, often persisting for extended periods. This process triggers the premature termination of plant dormancy and initiates the onset of vegetation. However, during this transitional period, Arctic and Siberian anticyclones frequently invade the entire territory of Georgia from the northwest almost simultaneously. Such incursions result in sudden cooling and intense frosts, significantly increasing the risk of damage to thermophilic crops.

The timing of plant vegetation onset and frost impacts on newly formed organs varies from year to year. Identifying these critical timings is essential, as they provide valuable information for predicting the likely dates of frost onset and cessation. This knowledge is crucial for farmers and agricultural practitioners to develop targeted strategies to prevent or mitigate frost-related damage.

Table 1 presents the average dates marking the beginning and end of frost-free periods for two study intervals (1951–1965 and 2007–2022) across various regions of Georgia. The data reveal notable spatial and temporal variations. In Samegrelo, the frost-free period begins earliest (March 13 and March 1 for periods I and II, respectively) and ends latest (December 7 and December 23). This region

is followed by Shida Kartli, where the average frost-free period spans from March 28 to November 21 in the first period and from March 16 to November 25 in the second period. Imereti and Adjara-Guria follow with slightly shorter frost-free durations.

Table 1. Average dates of the beginning and end of frost-free periods

Region	1951-1965	2007-2022
Shida Kakheti	28 III - 21 XI	16 III - 25 XI
Gare Kakheti	7 IV - 9 XI	27 III - 25 XI
Shida Kartli	7 IV - 4 XI	4 IV - 8 XI
Kvemo Kartli	17 IV - 27 X	16 IV - 30 X
Mtskheta-Mtianeti	18 IV - 20 X	18 IV - 27 X
Samtskhe-Javakheti	9 V - 7X	5 V - 12 X
Imereti	1 IV - 20 XI	22 III - 5 II
Samegrelo	13 III - 7 XII	1 III - 23 II
Adjara-Guria	1 IV - 24 XI	26 III - 29 XI
Racha	21 IV – 24 X	13 IV - 2 XI

Conversely, the latest onset of frost-free conditions occurs in Samtskhe-Javakheti, where average dates for the beginning of frost-free periods are in the first decade of May (May 9 and May 5 for periods I and II, respectively). The frost-free period in this region ends by October 7 and October 12, yielding the shortest vegetation period of approximately 150–159 days. Such variations in frost-free periods across regions underscore the influence of local climatic conditions on agricultural cycles and highlight the importance of region-specific frost prediction for sustainable crop management.

Overall, in the period 2007–2022, these shifts in frost timing have resulted in a notable increase in the duration of frost-free periods across most regions (Fig. 1). This pattern provides empirical evidence

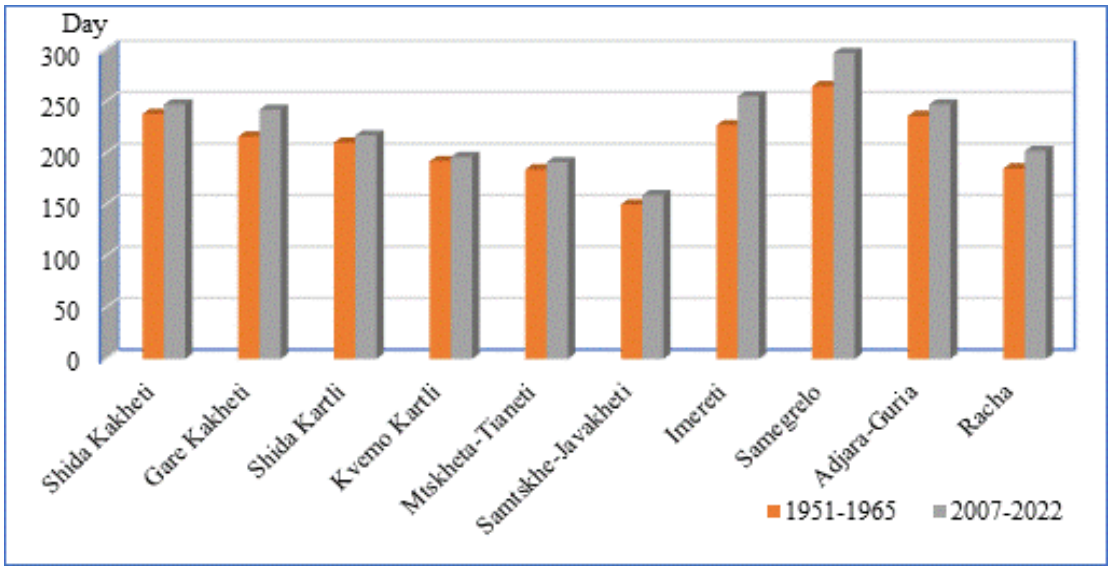

Figure 2. Change of frost-free periods according to regions 1951-1965 and between 2007-2022

of the influence of contemporary climate change on key frost-related climatic parameters.

It should also be noted that during the second study period (2007–2022), compared to the earlier period (1951–1965), the average dates of spring frosts tend to occur earlier, while autumn frosts occur later. This shift contributes to a general lengthening of the frost-free period. However, this trend is not uniform across all regions, as some local meteorological data reveal deviations. Specifically, at the Tsalka station in Kvemo Kartli and the Gori station in Shida Kartli, the second period records later average dates of spring frosts and earlier dates of autumn frosts compared to the earlier period.Fig. 2 shows the distribution of arctic oscillation indices and the duration of frost-free periods averaged by region as a temperature characteristic of climate change in the territory of Georgia in the 2007-2022 period.

Discussions

As illustrated in the figures, a pattern similar to that observed in graphs of frost-free period duration at individual stations (Kapanadze et al., 2023; Kapanadze et al., 2024; Kapanadze, Tatishvili et al., 2024) is evident across the regions. Specifically, a minor phase shift is observed until approximately 2013, after which each positive phase of the Arctic Oscillation (AO) corresponds to a relatively extended frost-free period (Fig. 2). This consistent relationship suggests that the climate of Georgia is,

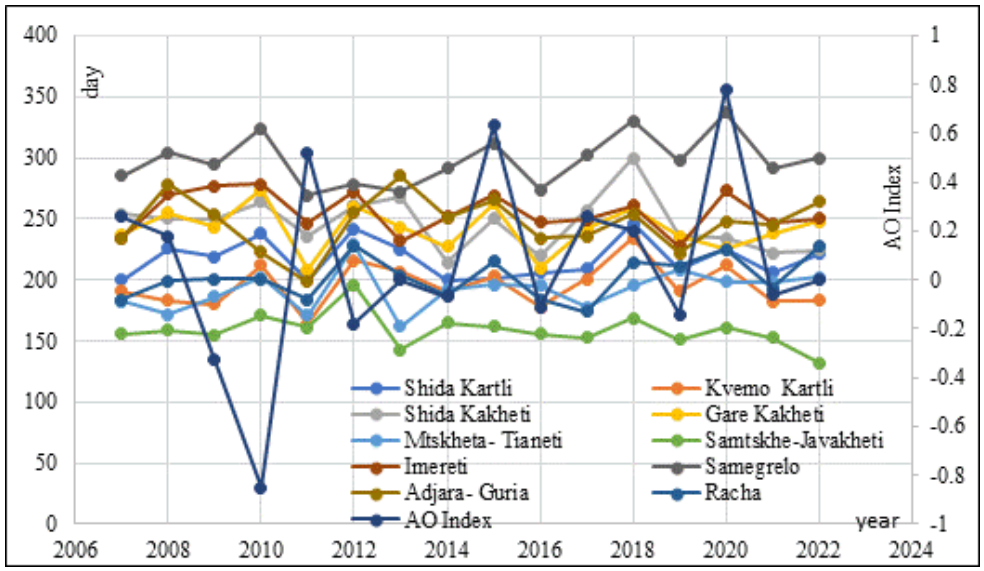

Figure 3. Distribution of the durations of frost-free periods averaged according to regions and Arctic Oscillation Indices in the territory of Georgia in the 2007-2022 period

to a notable extent, influenced by global climate variability.

Conclusion

Based on the analysis of our results, it can be concluded that contemporary climate change exerts a discernible influence on the key parameters of freezing. This influence is manifested in shifts in the average dates of frost occurrence and an extension of frost-free periods, which correspond to an overall lengthening of the vegetation period. However, changes in the length of the growing season may have both positive and negative implications for crop productivity.

An extended growing season can alter the functioning and structure of regional ecosystems, potentially changing the distribution of animal species, facilitating the spread of invasive plants or weeds, and increasing irrigation demands. Conversely, a longer warm period may offer agricultural benefits, enabling farmers to obtain multiple and more diverse harvests from the same plots. This could enhance the productivity and stability of agriculture, supporting higher and more reliable yields of crops in specific regions. These contrasting effects highlight the importance of region-specific strategies for adapting agricultural practices to evolving climatic conditions.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

N. K. and M. T. conceived of the presented idea. I. M., A. P. performed the analytic calculations. N. K. and M. T. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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The Scale of the Expected Largest Maximum High Water Discharges on the Rivers of Eastern Georgia

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Abstract

Based on a 70–100-year empirical series of stationary observations from 27 principal hydrological stations on the rivers of Eastern Georgia up to 2023, the probable maximum discharges of high waters have been estimated for exceedance probabilities of 0.01%, 0.1%, 1%, 2%, 5%, and 10%. These correspond to recurrence intervals of approximately 10,000, 1,000, 100, 60, 20, 10, and 5 years, respectively. The derived data provide a valuable resource for scientific, economic, and engineering applications, and should be utilised by relevant organisations for water management calculations. They are essential for the planning and design of hydraulic, civil, and industrial infrastructure—including roads, bridges, pipelines, and communication facilities—located along rivers and within their coastal zones. Moreover, these data underpin the substantiation of technical and economic parameters of such projects. The application of these findings will contribute significantly to enhancing the safety of populations, infrastructure, and the environment, thereby reducing the risks of structural damage, environmental degradation, and potential casualties associated with high-water events.

Keywords: probabilistic value, repeatability, provision, safety

Introduction

Since the second half of the 20th century, climate warming and increasing anthropogenic pressure on the environment have contributed to the intensification of elemental processes, accompanied by a clear upward trend and the emergence of critical ecological challenges.

The complex mountainous landscape of Georgia—with its diverse climatic, relief, and soil conditions, and numerous deep river valleys—creates a favourable environment for the occurrence of destructive floods. Such events have frequently resulted in the destruction of residential buildings and infrastructure, damage to agricultural land, and significant losses to the land fund. The presented flood photograph serves as documentary evidence of the urgent need for an objective and impartial assessment of flash floods, which is essential for developing recommendations to prevent catastrophic events and mitigate associated damages.

Floods and high-water events in the rivers of Eastern Georgia (fig. 1), along with the damage they have caused, are discussed in previous studies (Basilashvili et al., 2011; Basilashvili et al., 2012), which are based on observational data prior to 1991 and include corresponding estimates of maximum river discharges and their probable values.

More recently, under the conditions of ongoing global warming, Basilashvili (2024) extended this work by incorporating data from 1991–2021, updating the multi-year characteristic parameters of annual maximum flash flood discharges, and providing an appropriate statistical analysis of observational series spanning 70–100 years.

Looking ahead, continued climate warming is expected to further intensify natural hazards such as floods, avalanches, landslides, and erosion, often occurring in conjunction with frequent flooding events. Given the increasing scale of damage and casualties associated with such phenomena, determining the magnitude of expected maximum river discharges and refining their numerical estimates has become essential. These parameters are critical for the effective planning and

management of hydroeconomic calculations, and for the development of strategies to mitigate the adverse effects of hydrological disasters.

Figure 4. Gori flooded by flash flood on June 11, 1983

Methods and Materials

To estimate the expected changes in maximum river discharges, probability theory provision curves were applied to determine the scale of anticipated largest flash flood discharges (Ukleba, 1967; Luchsheva, 1976).

This study utilised long-term observational data from 27 hydrological stations in Eastern Georgia. Data prior to 1981 were sourced from published references, including Fundamental Characteristics (1967, 1977, 1978) and the State Water Cadastre (1987). More recent observations, up to 2022, were obtained from the National Environment Agency of Georgia (NEA).

Due to the inherent difficulties in measuring water discharges of mountain rivers during flash flood events, some observational records were incomplete. To address these gaps, correlation analyses of discharge relationships between analogous rivers were conducted, complemented by graphical interpolation methods. This approach enabled the reconstruction of missing data points. Correlation analysis was performed to establish relationships among maximum river discharges, followed by the formation of descending ranks of multi-year data and the determination of their corresponding exceedance probabilities, in accordance with the methodology proposed by Basilashvili (1977), implemented using computer software tools.

As a result of this comprehensive research, a robust database of multi-year (70–100 years) empirical series of annual maximum river flood discharges was compiled. The hydrographic and hypsometric characteristics of the river basins monitored at the 27 hydrological stations are presented in Table 1.

Table 2. The hydrographic and hypsometric characteristics of the river basins at the 27 hydrological stations

№	River - Point	Area of Basin	Length of River	Height of Basin	Woodiness of Basin	Height of Source	Height of Point	Fall of River	Slope of Basin	Slope of River
		F km^2	L km	H m	W %	H_S m	H_P m	H_Δ m	S_B ‰	S_R ‰
1	Mtkvari - Khertvisi	4980	223			2720	1120	1600		
2	Mtkvari - Minadze	8010	265			2720	944	1776		
3	Mtkvari - Borjomi	10500	315			2720	781	1939		
4	Mtkvari - Dzegvi	18000	444			2720	456	2264		
5	Mtkvari - Tbilisi	21100	474			2720	391	2329		
6	Faravani - Khertvisi	2350	73	2120	0	2080	1120	960	91	13.8

7	Potskhovi - Skhvilisi	1730	54	1870	11	1231	969	262		32.2
8	Kvabliani -Mlashe	468	19	1940	38	2540	1162	1378	132	35.0
9	Abastumani - Abastumani	99	10	1830	32	1373	1272	101	360	94.0
10	Borjomula - Borjomi	165	18	1810	65	2400	781	1619	256	50.7
11	Didi Liakhvi - Kekhvi	924	59	2100	25	3032	960	2072	373	38.2
12	Patara Liakhvi - Vanati	422	41	1940	35	2966	1015	1951	373	46.2
13	Ksani – Korinta	461	46	1830	50	2820	909	1911	260	45.0
14	Aragvi - Zhinvali	1900	28	1890	45	3126	718	2408	380	35.5
15	White Aragvi - Fasanauri	335	41	2140	22	3126	1035	2091	362	51.2
16	Black Aragvi - Shesartavi	235	29	2030	27	3392	1070	2322	416	66.4
17	Pshavis Aragvi - Magaroskari	736	38	2060	40	2731	920	1811	452	40.6
18	Yori - Lelovani	484	43	1640	59	2827	1090	1731	262	31.3
19	Alazani - Birkiani	282	9	2200	42	2750	758	1992	469	61.7
20	Alazani - Shakriani	2190	72	1260	61	2750	340	2410	270	26.2
21	Ktsia Khrami - Edikilisa	544	51	2040	0	2422	1516	906	135	18.9
22	Ktsia Khrami - Dagetkhachini	2150	136	1720	17	2422	526	1896	142	14.0
23	Ktsia Khrami - Imiri	3840	171	1510	29	2422	345	2077	147	12.6
24	Ktsia Khrami - Red bridge	8260	196	1530	33	2422	265	2157	179	11.3
25	Algeti - Partskhisi	359	40	1320	50	1900	672	1228	191	23.4
26	Mashavera - Dmanisi	570	25	1660	19	1358	795	623	155	43.0
27	Debeda - Sadakhlo	3790	150	1680	18	480	413	67	174	12.0

Results

To determine the probabilistic values of maximum river discharges, the annual peak discharges from all individual hydro-catchments were arranged in descending order, from largest to smallest. This approach, representing the simplest form of their distribution, demonstrates that a given maximum discharge on a river can occur multiple times during the observation period, corresponding to the number of values exceeding it in the descending sequence.

The integration of values arranged in descending order produces the provision curve, with provision typically expressed as a percentage. According to Luchsheva (1976), the corresponding percentage value for each member of the descending sequence is calculated using the following formula:

$$P\ \% = ((m - 0.3) / (n + 0.4)) \cdot 100,$$

where m represents the sequence number in the descending order of maximum discharges, and n denotes the total number of members in the sequence.

Based on the parameters reported by Basilashvili (2024), the coefficients of variation for the maximum discharges of the rivers under study are notably high ($Cv \geq 0.5$and asymmetry $Cs \geq 2.0$). Therefore, in accordance with Luchsheva (1976), provision curves were constructed using high-asymmetry cells rather than moderate-asymmetry cells to better reflect the statistical characteristics of the data.

Using the ordinates of the provision curves and relevant calculations, the probable values of the largest maximum discharges at different provision levels are presented in Table 2. Each probability value corresponds to a specific recurrence interval, indicating the average number of years in which the corresponding maximum discharge is expected to occur at least once.

Table 3. Probable values of the largest maximum discharges (Q m3/s) of the rivers of Eastern Georgia with different provision (%) and frequency (years)

№	Provision (%)	0,01	0,1	1	2	5	10	20
	Recurrence (years)	10000	1000	100	80	20	10	5
	Characterization of waterfalls	Disastrous		Very strong	Strong	High	Moderate	Average
1	Mtkvari - Khertvisi	930	770	610	560	495	445	390
2	Mtkvari - Minadze	1900	1430	1040	920	770	660	540
3	Mtkvari - Borjomi	2280	1780	1350	1220	1050	920	780
4	Mtkvari - Dzegvi	3880	2960	2180	1950	1700	1440	1200
5	Mtkvari - Tbilisi	4080	3220	2460	2220	1940	1700	1450
6	Faravani - Khertvisi	330	255	198	179	154	135	114

7	Potskhovi - Skhvilisi	960	700	490	425	350	298	240
8	Kvabliani -Mlashe	450	328	230	204	168	142	115
9	Abastumani - Abastumani	92	64	42	36	28	24	19
10	Borjomula - Borjomi	187	100	64	56	47	43	37
11	Didi Liakhvi - Kekhvi	550	432	330	300	260	228	192
12	Patara Liakhvi - Vanati	484	300	173	142	105	80	60
13	Ksani – Korinta	523	376	245	210	158	136	105
14	Aragvi - Zhinvali	1005	960	840	780	660	530	360
15	White Aragvi - Fasanauri	290	235	178	158	133	110	76
16	Black Aragvi - Shesartavi	600	420	260	211	155	114	60
17	Pshavi Aragvi - Magaroskari	1450	1100	685	540	390	270	160
18	Yori - Lelovani	556	522	470	430	400	350	250
19	Alazani - Birkiani	820	560	340	280	205	150	90
20	Alazani - Shakriani	1560	1100	890	770	623	504	360
21	Ktsia Khrami - Edikilisa	200	160	126	117	104	98	92
22	Ktsia Khrami - Dagetkhachini	790	594	420	360	285	230	155
23	Ktsia Khrami - Imiri	1200	840	580	490	388	306	280
24	Ktsia Khrami - Red bridge	2660	1860	1240	1030	790	600	420
25	Algeti - Partskhisi	490	360	240	203	256	123	84
26	Mashavera - Dmanisi	790	540	335	274	200	147	88
27	Debeda - Sadakhlo	880	744	600	555	485	426	346

It should be emphasised that any probable value of maximum discharge derived at a given provision level provides critical information for assessing the safety of structures and other engineering measures under specific hydrological conditions. Such estimates are therefore essential for informed decision-making in hydraulic engineering and water resource management.

Discussions

Probable values of the largest maximum river discharges, based on observational data available before 1981 and 1991, have been published in earlier studies (Water Resources, 1988; Basilashvili, 2017). A comparison of these historical estimates with the values presented in Table 2, derived from data up to 2022, reveals a general reduction in the largest maximum discharges of flash floods across nearly all hydro-catchments in Eastern Georgia. This reduction is particularly pronounced for high-recurrence discharge events.

This trend is likely attributable to changes in the precipitation regime in Northeastern Georgia, notably a reduction in snow cover. In mountainous terrain, snowmelt during melting periods typically contributes meltwater directly to river channels, and under conditions of heavy rainfall, this process can trigger substantial floods. However, climate warming has extended the warm season, and liquid precipitation is increasingly lost to evaporation and infiltration into dry soils within river basins due to higher air temperatures. Consequently, the magnitude of flood discharges has diminished. Furthermore, in certain river basins, the area of existing glaciers has already decreased, leading to a corresponding decline in glacial runoff, which further contributes to the observed reduction in maximum flood discharges.

Conclusion

Thus, based on stationary observation data up to 2022 from 27 hydro-catchments of rivers in Eastern Georgia, the projected development of the largest maximum flood discharges has been analysed. Through rigorous statistical analysis of a 70–100-year empirical dataset of river discharges, updated and refined probabilistic estimates of the largest maximum flood discharges have been obtained for various provision levels (0.01%, 0.1%, 1%, 2%, 5%, 10%, 20%), corresponding to specific recurrence intervals of 10,000, 1,000, 100, 80, 20, 10, and 5 years, respectively.

These results are of critical importance for hydroeconomic planning, as they provide the basis for justifying the technical and economic parameters of hydraulic structures and other measures planned along rivers and within their floodplains. Moreover, such data support informed decision-making in water resource management and help mitigate potential damages from future flood events.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

T.B. and K.B. performed the analytic calculations. M.J. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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GIS Served Car Travel Times to Maternity Hospitals in the Kvemo Kartli Region, Georgia

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Abstract

This study aimed to evaluate car travel times to maternity hospitals in the Kvemo Kartli region of Georgia, with the objective of identifying underserved areas and informing priority interventions to reduce spatial inequalities in access to maternal healthcare services. The isochrone map showing car travel times to the maternity hospitals was created using geographical information systems (GIS), taking into account the location of the maternity hospitals, the length of the roads, and data on the maximum allowed speeds of the vehicles. The research highlights discrepancies in women's access to maternity hospitals in the Kvemo Kartli region. All three maternity hospitals are located in the most densely populated areas, close to each other. Access to maternity hospitals is markedly constrained across large parts of the Kvemo Kartli region, particularly in areas characterised by lower population density. Overall, 51% of women aged 15–49 reside within adequately served zones (car travel time < 30 minutes), while the remaining 49% live in underserved zones (car travel time > 30 minutes). This spatial disparity underscores substantial risks to maternal and infant health, highlighting the urgent need for targeted interventions to improve healthcare accessibility. The most effective solution for reducing inequality in women's access to maternity hospitals is to either establish a new maternity hospital or relocate one of the three existing facilities to Bolnisi.

Keywords: isochrone, inequality, sustainable development

Introduction

Timely access to medical care during pregnancy, labour, and delivery is crucial to ensuring the mother's and baby's health and well-being (Pacagnella et al., 2014). International studies (Grzybowski et al., 2011; Ravelli et al., 2011b) have shown that travel time to the maternity ward is associated with increased intrapartum and neonatal mortality and morbidity risks. According to some authors (Blondel et al., 2011; Dietsch et al., 2010), travel time and unplanned out-of-hospital deliveries also have a positive association. Out-of-hospital deliveries are also associated with a higher risk of perinatal mortality than in-hospital births. According to Combier (2013), significant positive associations exist between travel time to the nearest maternity unit and critical risk factors for perinatal mortality, morbidity, and unexpected out-of-hospital deliveries.

A study carried out in the Netherlands showed that women who have 20 minutes or more of car travel to the nearest maternity hospital are at higher risks for harmful outcomes and mortality (Ravelli et al., 2011a). Similar results were reported in France (Blondel et al., 2011) and in other international studies (Grzybowski et al., 2011; Lisonkova et al., 2011; Tromp et al., 2009).

Research conducted in various countries worldwide indicates that patients who require longer travel times to reach a healthcare facility are less likely to seek care at these facilities when needed (Syed et al., 2013). Regular check-ups are vital for monitoring the health of the woman. Women may miss or delay these crucial appointments if the maternity hospital is far away, leading to potential health problems that go unnoticed. In recent years, driven by the impact of COVID-19, people have grown increasingly concerned with the quality of hospitals in their living environment. As a result, hospital accessibility has become a key factor in determining housing prices (Chen et al., 2022).

Access to health services is a key indicator of sustainable development at both urban and regional levels and should be ensured for everyone equally and fairly (Soltani et al., 2019).

This study is linked to several Sustainable Development Goals (SDGs), primarily:

SDG 3: Good Health and Well-being: Improving access to maternity hospitals can reduce maternal mortality and guarantee access to reproductive healthcare services (https://sdgs.un.org/goals)

SDG 10: Reduced Inequalities: aims to reduce inequalities (https://sdgs.un.org/goals). By identifying "served" and "underserved" areas regarding access to maternity hospitals, interventions can be prioritized to reduce inequalities in healthcare access.

SDG 11: Sustainable Cities and Communities: https://sdgs.un.org/goals Improving access to healthcare facilities, including maternity hospitals, contributes to creating more inclusive and resilient communities.

SDG 17: Partnerships for the Goals: https://sdgs.un.org/goals. This goal emphasizes the importance of partnerships in achieving the SDGs. Collaborative efforts between governments, healthcare providers, and community stakeholders are essential to improving access to maternity hospitals and achieving the related SDG targets.

Achieving the SDGs is crucial because it represents a global commitment to creating a more sustainable, equitable, and prosperous world for all people, now and in the future.

Every individual is entitled to quality healthcare, so medical services must be strategically allocated. Prioritizing sufficiency and accessibility as key spatial dimensions of healthcare access will facilitate the effective distribution of health facilities to meet growing demand. Identifying areas with inadequate access to healthcare facilities can also support proactive hospital site selection. This data-driven approach could be integrated into regional healthcare planning, promoting both equity in access and sufficiency, ultimately contributing to greater health equity.

Our objective was to create an isochrone map illustrating car travel times to the nearest maternity hospitals to identify underserved areas, prioritize interventions to address inequalities, and contribute to achieving multiple health and SDGs.

Methods and Materials

Case Study

According to Yin, case studies are a valuable and valid research approach, particularly for examining complex real-world phenomena (Yin, 2014). Research using case studies on travel time to maternity hospitals allows for an in-depth exploration of specific cases, offering detailed and insightful findings that may be difficult to achieve with other research methods. This thorough analysis can enhance our understanding and provide a valuable means of gaining deep insights into the complexity of this issue, informing policies and interventions aimed at improving access to maternity care.

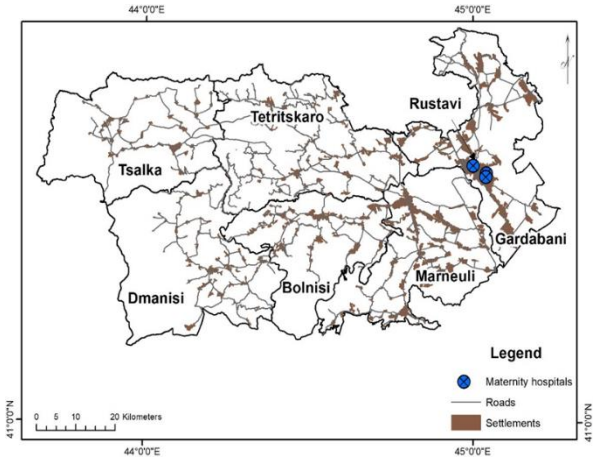

Figure 1. A map of settlements, maternity hospitals, and the road network in Kvemo Kartli
Note: The bold black lines on the map represent the municipal boundary

For the case study, we selected one of the border regions of Georgia - Kvemo Kartli (Elizbarashvili et al., 2024a). To the north of the country's capital, Tbilisi, to the southeast, it is bordered by the Republic of Azerbaijan, and to the south, by the Republic of Armenia. The administrative center of Kvemo Kartli is Rustavi. Apart from Rustavi, it includes the following municipalities: Bolnisi,

Gardabani, Dmanisi, Tetritskaro, Marneuli, and Tsalka. The region's area is 6,528 km2, 10% of Georgia's total area. According to the Georgian National Statistics Office, the population of Kvemo Kartli is 428,799, which is 11.42% of the population of Georgia. The Kvemo Kartli region features industrial centers and farmlands. The industrial cities in the area are Rustavi and Marneuli. Within Kvemo Kartli, the population density varies extensively (Elizbarashvili et al., 2024b). There are three maternity hospitals in the Kvemo Kartli region, all located close to each other in the key industrial city of the region – Rustavi. Figure 1 shows the settlements, maternity hospitals, and the road network of Kvemo Kartli. Based on all these features, the Kvemo Kartli region is a representative geographic area for the case study. The research will give us a broad idea of how access to maternity hospitals changes for women living in different areas in Kvemo Kartli, what contextual factors affect this, and what measures need to be taken to reduce inequalities and contribute to achieving multiple SDGs related to health and sustainable development.

By studying car travel time to maternity hospitals and identifying underserved areas, interventions can be targeted to improve healthcare access, reduce inequalities, and contribute to achieving SDGs related to health and sustainable development.

Data collection

Data for medical stations were obtained from both official government sources: "Ministry of Internally Displaced Persons from the Occupied Territories of Georgia, Labor, Health, and Social Protection", web pages of medical institutions, and direct fieldwork, including visits to medical institutions in the Kvemo Kartli region (Elizbarashvili et al., 2024a, Elizbarashvili et al., 2024b).

Mapping and calculations

In this study, we used the 1:10000 scale geographic information system of the healthcare infrastructure of the Kvemo Kartli region, which includes information on settlements, population, roads, bridges, healthcare facilities (hospital, emergency medical care, pharmacy network, dental clinics, diagnostic centers, etc.), data on the maximum allowed vehicle speeds on each road segment (Elizbarashvili et al., 2024a). Based on this GIS, the isochrone map showing the car travel times to the nearest maternity hospital was compiled, and the percentage of women aged 15- 49 years living within different travel-time intervals to the maternity hospitals was calculated.

Results

The isochrone map showing the car travel times to the nearest maternity hospital

The isochrone map presented in Figure 2 shows the spatial distribution of (red, yellow, blue, green, purple, and light brown) areas, which correspond to the following car travel time intervals: 0-8 min, >8-15min, >15-30 min, >30-45 min, >45-60 min, >60 min.

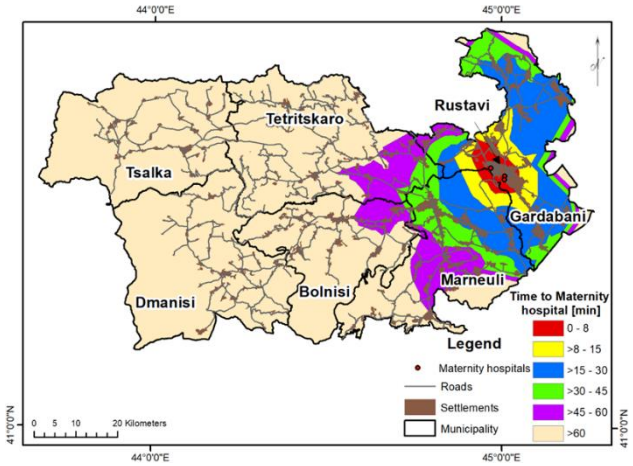

Figure 2. An isochrone map showing the car travel times to the nearest maternity hospital

People living in the red area will reach the nearest maternity hospital by car within 8 minutes, it will take 8 to 15 minutes for people living in the yellow area to reach the nearest maternity hospital by car, 15 to 30 minutes for people living in the blue area, 30 to 45 minutes for people living in the green area, 45 to 60 minutes for people living in the purple area. People who live in the brown area will need more

than 1 hour to get to the nearest maternity hospital by car. The brown area covers a large part of the Kvemo Kartli region.

Women of reproductive age living within the different travel time intervals

Women of reproductive age are usually considered to be in the age range of approximately 15 to 49 years old. This age range is chosen because it encompasses the years during which women typically experience menstruation, ovulation, and the potential for pregnancy. According to data from the "National Statistical Service of Georgia," 103,758 women of this age live in the Kvemo Kartli region, which is slightly more than 24% of the total population of Kvemo Kartli.

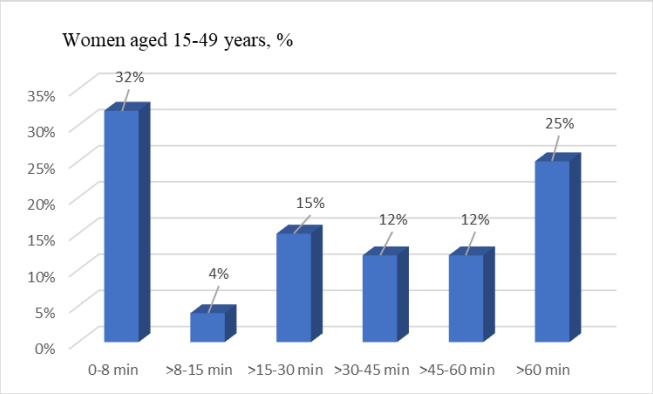

Figure 3. Distribution of the percentage of women aged 15- 49 years in the Kvemo Kartli region according to the different travel time intervals to the nearest maternity hospital

Based on GIS analyses, it was assessed that about 32 % of women aged 15-49 years of Kvemo Kartli live within the 8 min car travel time to the nearest maternity hospital, about 4 % live within > 8-15 min car travel time, about 15% live within the >15-30 min car travel time, 12 % within the >30-45 min car travel time, 12 % within the >45-60 min car travel time and almost 25% life outside the 60 min car travel time (Figure 3). Such a percentage distribution is determined by the location of maternity hospitals and the region's population density change.

Table 1. The density of women aged 15-49 years

Municipality	The density of women aged 15-49 years, people/km²
Rustavi	448.82
Marneuli	24.86
Gardabani	20.58
Bolnisi	16.99
Tsalka	4.54
Tetritskaro	4.24
Dmanisi	3.28

There are three maternity hospitals in the Kvemo Kartli region. However, all of them are located in Rustavi, the most highly populated area where the density of women aged 15-49 years is the highest in the region. Rustavi is followed by Marneuli municipality, where the density of women aged 15- 49 years is nearly 20 times lower than that of Rustavi. The density decreases in the Gardabani and Bolnisi municipalities and significantly decreases in the Tsalka, Tetritskaro, and Dmanisi municipalities (Table 1).

Discussion

Travel time to maternity hospitals

According to this study, many women in the Kvemo Kartli region face challenges in reaching the nearest maternity hospitals on time. Specifically, 68% of women aged 15 to 49 cannot reach the nearest maternity hospital within 8 minutes, a critical time frame for emergencies. 64% of women aged 15 to 49 cannot access the nearest maternity hospital within 15 minutes, 49 % of women aged 15-49 cannot access the nearest maternity hospitals within 30 minutes, 37 % of women within 45 minutes,

and 25% - within 60 minutes. Figure 4 shows the distribution of the percentage of women aged 15- 49 years in the Kvemo Kartli region according to the reaching not reaching the nearest maternity hospital within different travel time intervals. Logically, more women face challenges when reaching maternity hospitals without a car, as public transport is not developed in Kvemo Karli.

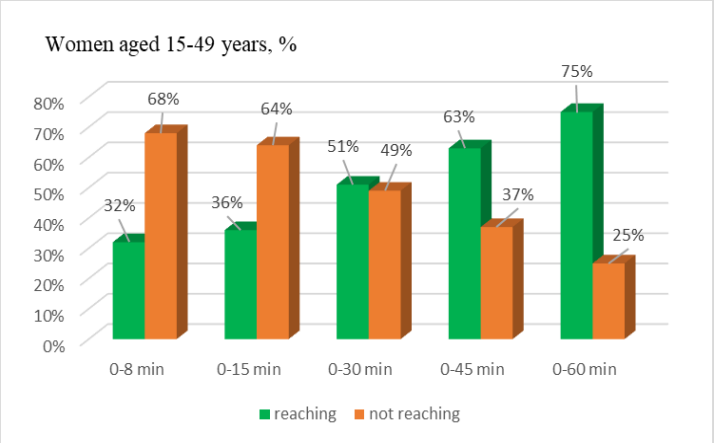

Figure 4. Distribution of the percentage of women aged 15- 49 years in the Kvemo Kartli region according to the reaching not reaching the nearest maternity hospital within different travel time intervals

For pregnant women, it is essential to have convenient access to healthcare facilities. Delays in accessing care can lead to birth complications and hurt both maternal and neonatal outcomes (Pacagnella et al., 2018). Longer travel times may contribute to delays in receiving necessary medical attention, which can be critical during childbirth, particularly in emergencies. The labor process can sometimes progress rapidly and can lead to accidental out-of-hospital births. Without appropriate medical assistance, it can pose risks to both the mother and child (Blondel et al., 2011). Quick access to healthcare can help prevent complications and ensure safe deliveries.

The study conducted in the rural region of France in Burgundy showed that a travel time of 30 min or more to maternity units could delay the delivery of the baby, increasing risks of fetal heart rate anomalies, out-of-hospital births, and pregnancy hospitalization (Combier et al., 2013). The finding related to travel time from home to the hospital in the Netherlands and its association with adverse outcomes in pregnant women suggests that a longer travel time, specifically 20 minutes or more by car, is linked to an increased risk of mortality and other negative outcomes (Ravelli et al., 2011a).

According to the Belgian National Geographic Institute, over 99% of women aged 15 to 49 can reach one or more maternity services within a 30-minute drive under typical traffic conditions. Additionally, 92.3% of women in the same age group can access maternity services within a 15-minute drive (Lefèvre et al., 2019).

In the Kvemo Kartli region, only 36% of women aged 15 to 49 can access maternity services within a 15-minute drive. Approximately 51% of women aged 15 to 49 can access maternity services within 30 minutes by car.

Research conducted in Northern Sweden shows that 40% of women need more than 20 minutes to reach maternity hospitals. The same study shows that in 2013, approximately 90% of women could reach their nearest maternity hospital in Northern Sweden within one hour, compared to around 80% in 2019 (Elin, 2019). In the Kvemo Kartli Region, about 75 % of women can reach the nearest maternity hospital by car within one hour.

On the map presented in Figure 3, the red, yellow, and blue areas where it takes 30 minutes to reach the maternity hospital by car were evaluated as "served"; approximately 51% of women aged 15 to 49 live there. Green, purple, and light brown areas, where it takes more than 30 minutes to reach the maternity hospital by car, are classified as "underserved;" 49% of women aged 15 to 49 live there.

Addressing Pregnant Women's Healthcare Access in Rural Kvemo Kartli: Limitations of Maternity Waiting Homes and the Need for Localized Solutions

To address the challenge of long distances to healthcare facilities for pregnant women, many countries have established maternity waiting homes (MWHs) near maternity units. These facilities (Stekelenburg et al., 2006, Sialubanje et al., 2015) are designed for women living in remote rural areas.

MWHs allow these women to stay close to a hospital during the final weeks before delivery, ensuring timely access to care when labor begins. Additionally, in rural areas, MWHs can provide a respite from strenuous fieldwork, which may otherwise contribute to pregnancy and childbirth-related complications (Agbla et al., 2006). However, we believe that MWHs cannot work in the Kvemo Kartli region due to the cultural characteristics and mentality of the population. The opening of MWHs also fails to ensure regular visits of pregnant women to Maternity hospitals for prenatal check-ups, which are essential for monitoring the health of both the mother and the baby. Therefore, we consider it most optimal to create a new maternity hospital or move one of the three existing maternity hospitals to Bolnisi, which is in the "underserved" area and where the density of women aged 15- 49 years is the highest after Rustavi, Marneuli, and Gardabani. Such a change will improve the current situation to some extent. Bolnisi borders Marneuli municipality and is also close to Rustavi, where the population density is highest; on the other hand, Bolnisi municipality borders Dmanisi and Tetritskaro municipalities, which are also in the "underserved" area. It is essential to develop roads and public transport in the Kvemo Kartli region, which will help women to go to maternity hospitals for regular check-ups and examinations.

Limitations and strengths of the study

This study has important limitations. Firstly, we have made all discussions and conclusions considering all 15- to 49-year-old women who live in the Kvemo Kartli region. However, the level of accessibility to maternity hospitals can be more crucial in some situations than in others, one of which is childbirth.

Secondly, isochrone maps are a valuable tool in planning as they visually represent accessibility within a certain time frame. However, isochrone maps have limitations, as they simplify travel time calculations and do not consider real-world factors such as traffic conditions, road closures, or weather.

However, the strength of our research lies in the use of GIS with the road layer created at a larger scale of 1:1,000 and the maximum permissible car travel speeds in each segment along the road between two places. The advantage of using the maximum permissible car travel speed is that it already considers road surface conditions, terrain, steep bends, or other real-world difficulties that may affect real-time travel (Elizbarashvili et al., 2024a, Elizbarashvili et al., 2024b).

Conclusion

The research underlines disparities in women's access to maternity hospitals in the Kvemo Kartli region. It helps us understand what contextual factors affect this situation and how to address it.

- All three maternity hospitals are located in the most densely populated areas close to each other, which means that access is significantly limited in a large part of the Kvemo Kartli region, where the population density is significantly lower.
- This study identifies key regions in Kvemo Kartli where maternity hospitals are lacking, based on driving travel time distance assessments. 51% of women aged 15 to 49 live in the served area (car travel time < 30 min), while 49% (50,332 women) live in the underserved area (car travel time >30 min). The mapped findings could have policy implications and be valuable for future decision-making and analysis.
- The most optimal solution to reduce inequality in women's access to maternity hospitals is to create a new maternity hospital or move one of the three existing maternity hospitals to Bolnisi.
- Regarding population density, Kvemo Kartli is slightly behind only one region of Georgia and much higher than the population density of the rest of Georgia. This makes it clear that the accessibility problem will be even more acute in the other regions, where the population is much more sparsely distributed than in the Kvemo Kartli region. Low population density areas may have fewer hospitals or healthcare facilities due to lower demand, leaving residents underserved. Therefore, creating an isochrone map illustrating car travel times to the nearest maternity hospitals in other regions of Georgia is crucial. This map can help identify underserved areas and support the development of targeted interventions to improve healthcare access, reduce inequalities, and contribute to achieving various SDGs related to health, equality, and sustainable development in Georgia.

The information obtained from the study can serve as a basis for policy recommendations and interventions aimed at improving access to maternity care in the Kvemo Kartli region. Policymakers,

healthcare professionals, and other stakeholders can use these data to develop targeted strategies that address specific challenges and improve the general well-being of mothers and babies in the region.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

M.E. conceptualization, methodology, writing- original draft preparation supervision. B.K. data curation, writing - original draft preparation. Sh.E. software, investigation. N.Ch. and E.E. writing - reviewing and editing. T.K. visualization, software, validation. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Demographic Crisis in the Mountainous Adjara: Challenges and the Solutions

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Abstract

Due to political and social-economic processes in independent Georgia, there are serious issues observed in the demographic development of the country, especially in mountainous regions, where the demographic crisis is obviously shaped. Similar problems are observed in mountainous Adjara, the population of which decreased from 85.1 thousand to 58.9 thousand (or by 31.8%) during the 1989-2023 years. Therefore, a population decrease in the region with high reproduction up to recent years would negatively affect the demographic policy of the country. Coming out of this, the topic is quite urgent and needs the evaluation of existing problems and the setting of ways to improve the demographics. Via application of traditional and contemporary (modern) research methods, there were assessed the spatial originalities of quantitative indicators of natural and mechanical movement of population of mountainous Adjara, including those forced to displace – the ecomigrants. The results of qualitative properties of demographic development were found out, and the main reasons causing the crisis were determined. There are analyses of the challenges (related to sustainable development of the region) due to the decrease of the population of mountainous Adjara, and there are solutions set for the demographic crisis.

Introduction

The tendency of population decline in mountainous regions represents a global trend, shaped by a range of social and economic challenges, while also bearing distinct regional characteristics. In Georgia, this issue has long affected the country's highland areas. However, until recent decades, mountainous Adjara stood out as a region with relatively high levels of population reproduction. In recent years, the demographic situation has shifted dramatically, with signs of a demographic crisis becoming increasingly evident. Against this background, the problem acquires particular urgency, and its comprehensive study, together with the identification of measures aimed at improving the situation, is of critical importance.

The main objective of this research is to examine the demographic development of mountainous Adjara, with particular emphasis on identifying both the quantitative and qualitative characteristics of population dynamics, analyzing the mechanisms underlying the current demographic crisis, and outlining potential pathways for its mitigation. To achieve this aim, the study addresses the following specific objectives:

- Assess the distinctive features of population dynamics in mountainous Adjara and identify the key patterns of quantitative change;
- Examine the characteristics of natural population movement and evaluate the principal causes of the observed shifts;
- Analyze the quantitative dimensions of migration processes and their role in shaping the regional demographic crisis;
- Identify the main directions for overcoming the demographic challenges in mountainous Adjara.

The study focuses on the municipalities of Keda, Khulo, and Shuakhevi, which collectively represent the highland region of Adjara. By using these areas as case studies, the research not only provides an

in-depth assessment of the demographic crisis in a specific regional context but also generates insights with broader applicability for addressing demographic challenges across Georgia as a whole.

Methods and Materials

For determination of demographic crisis of mountainous Adjara, the following methods were used: statistical method, field research method, comparative method, space-time analysis method, GIS (Geographic Information System) method and other research methods.

Research database is based on the data of General Population Census in 1989, 2002 and 2014, also population estimation data in 2020-2023. Besides, the research is based on theoretical sources regarding evaluation of demographic condition of the country (Jaoshvili,1996; Meladze, 2007; Tsuladze et al., 2008).

Results

Difference between the standards of living and peculiarities of urbanization processes in the modern world have significantly influenced over the demographic development of mountainous regions. Therefore, almost in every mountainous region there is obviously shaped demographic crisis, but researches (Coleman, 2008; Ehrlich et al., 2021; Gretter et al., 2017; Mladenov, 2011; Thornton et al., 2022), those conducted in direction of evaluation and solution of the problem grant an opportunity to share an international experience for specific region. Besides, on the basis of analysis of researches (Kohler et al., 2017; Meladze, 2007; Putkaradze & Putkaradze, 2019; Tsuladze et al., 2008) performed throughout the country in this regard, there will be developed the solution for demographic crisis in the mountainous Adjara.

Mountainous Adjara was one of the prominent regions of Georgia for its wide reproduction of population until the recent period, where the population was gradually increasing until 1989. Due to political, social and economic changes occurred in the country during the Georgia`s independence period, significant decrease of rural population has commenced, which still continues in some particular municipalities of mountainous Adjara. As a result of enactment of the Law of Georgia on the Development of High-mountainous Regions and due to immigration processes in recent years, slow increase tendencies of population at the study area are observed somehow (see Table 1).

Table 1. Population size dynamics of mountainous Adjara in 1989-2023 (thousand man); Source: table is made according to materials of National Statistics Office of Georgia

Municipalities	1989 (Population census)	2002 (Population census)	2014 (Population census)	2020 (Estimate)	2021 (Estimate)	2022 (Estimate)	2023 (Estimate)
Keda	20.1	17.0	16.7	16.8	16.7	16.6	16.5
Shuakhevi	25.4	18.4	15.2	15.0	14.9	14.8	14.8
Khulo	39.6	28.6	23.5	26.3	26.6	26.8	27.6
Total, mountainous Adjara	85.1	63.6	55.4	58.1	58.2	58.2	58.9

Table 1 displays that population number of mountainous Adjara in 1989-2023 years decreased by 26,2 thousand - from 85,1 thousand to 58,9 thousand or it was decreased by 31,8%. There should be noted that the number of regional population was increasing during the whole twentieth century – up to 1989, but population size started decreasing after the migration flows triggered by natural disasters and the political, social and economic changes occurred in the country. Population decrease in the region with special intensity starts in 1989 until 2002 and decreases by 21,5 thousand persons – from 85,1 thousand to 63.6 thousand. The main reason for population`s decrease by that period of time was not only forced displacement due to natural disaster processes, but rural population`s free migration as well, which mainly implemented to coastal region of Adjara – the principal direction was Batumi City. In 2002-2014 years, slow decrease of population was observed still (see Table 1), but in 2014-2023 years the number of population was increased by 3500 persons, which constitutes unprecedented occurrence comparing to other mountainous regions of Georgia. If we discuss the topic according to intra-regional standpoint, in 1989-2023 years, the number of population was decreased in all the

municipalities, especially in Shuakhevi Municipality (decreased by 41,8%) but in Keda Municipality it was decreased in a relatively small amount (decreased by 18%). The mentioned peculiarity is partially explained the fact that Keda Municipality is located closer to Batumi City, the part of the population of which is employed in Batumi. As of huge decrease in Shuakhevi Municipality`s population, it was mainly conditioned by eco-migrants and peculiarities of urbanization processes. As of population dynamics during recent years, quite different situation is observed in Khulo Municipality, which was decreased by 12 thousand persons (or 30,4%) during the study period, but after 2014, a slow increase tendencies of population are observed herein. In particular, local population was increased by 4,1 thousand persons in 2014-2023 years, that is firstly related to development of social and economic processes in rural areas, existence of the Law of Georgia on the Development of High-mountainous Regions (so-called "Mountain Law"), development of agricultural manufacturing and tourism comparing to other municipalities. During the same period, a positive migration balance was observed in Khulo Municipality, which was due to return of eco-migrants from Meskheti and Javakheti Regions. Positive migration balance was somehow influenced by enactment of the Law of Georgia on the Development of High-mountainous Regions (so-called "Mountain Law"), as a result of which, population consisting of retirement pensioners returned due to the higher pension rates.

If we compare the numerical dynamics of the population of mountainous Adjara to similar indicators of mountainous regions of the country, we will observe that population decrease is obvious in each mountainous region, especially in Racha-lechkhumi (Kohler et al., 2017; Putkaradze &Putkaradze 2019), which is the result of political, social and economic processes observed in the country (Jaoshvili, 1996; Putkaradze & Putkaradze, 2018; Putkaradze & Abuselidze, 2022; Tsuladze et al., 2008).

Number of population of mountainous Adjara until the recent year was absolutely depended on the natural increase. Region was on the first place in Georgia according to its wide reproduction of population, but during the recent period, on the background of common reproduction of country`s population (where the depopulation is shaped during the several years already), the natural increase is observed still (see Figure 1).

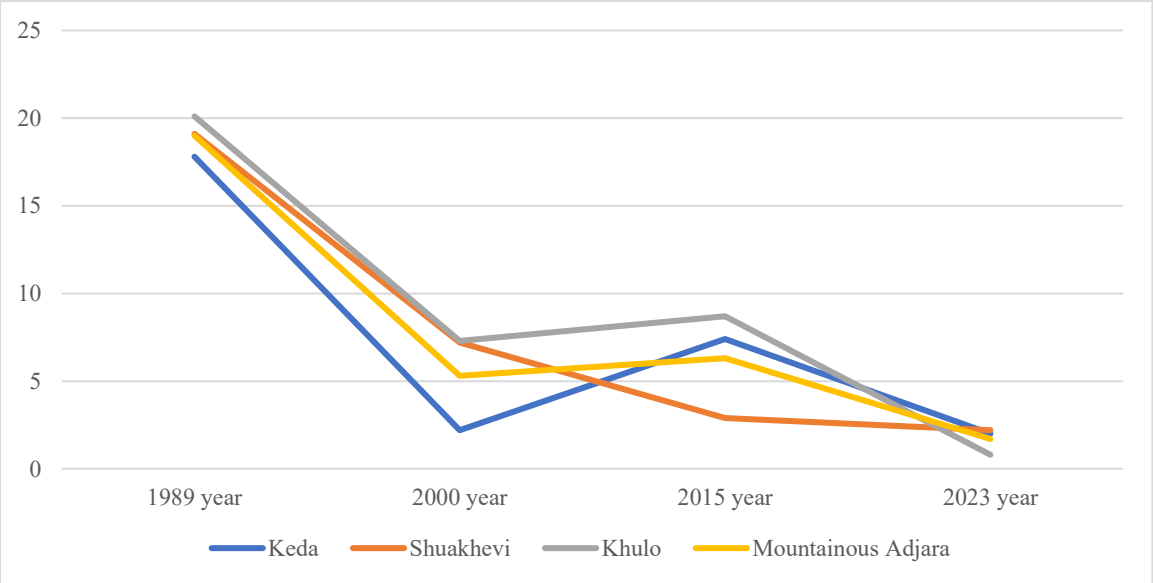

Figure 1. Natural increase of population of Mountainous Adjara in 1989-2023 years; Source: table is created according to materials of National Statistics Office of Georgia

Figure 1 displays that in 1989-2023 years, natural increase indicator of regional population was decreased from 19,0 promille to 1,7 promille. The mentioned peculiarity firstly is related to changes into demographic condition in the country, that by itself is connected to weakening of traditions of large families, worsening the age structure, increase of median age of marriage, migration processes and other factors. If we discuss the indicators of population`s natural increase from an intra-regional standpoint, worsening tendencies are observed everywhere, especially in Khulo Municipality (see Figure 1). If we overview the population of Autonomous Republic of Adjara in the direction of natural movement where an average indicator for 2023 was up to 4,8 promille and the same for the country

was 0,7 promille, then we can see that mountainous Adjara (which was the center of wide reproduction of population until the recent years), obviously develops in the direction of demographic crisis.

One of the basic reasons for decrease of natural increase indicators of the population of the study area during recent years is related to changes in the age structure, though the gender structure did not worsen. In particular, number of men in 1989 was 49,2% and this indicator increased to 50,0% for 2014. The mentioned peculiarity is more related to immigration processes. As of age structure, noticeable changes of worsening are observed herein (see figure 2).

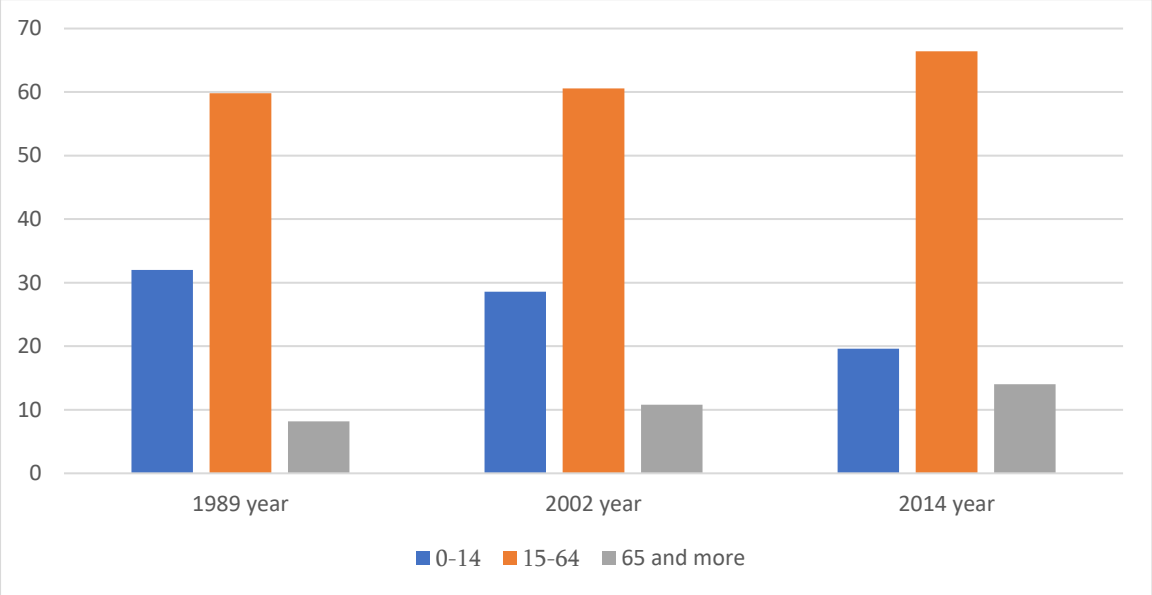

Figure 2. Age structure of Mountainous Adjara in 1989-2014 years; Source: table is made according to materials of National Statistics Office of Georgia

Figure 2 displays that 0-14 age group gradually decreases in the population age structure and the population of retirement age increase. The data brought and the factors named above constitute the main reasons of demographic crisis`s formation in the region.

Population dynamics of mountainous Adjara is essentially connected to migration processes. Actually, during recent 150 years, region had a negative migration balance, which had a different progress during some particular periods of independent Georgia. Population of study region increased by 47387 persons as a natural increase in 1990-2023 years. If the population of the region was 85,100 in 1989 and 47 387 persons were added as a natural increase, then a negative migration balance in 1989-2023 years equals to 73587 persons [(85100+47387)-58900] coming out of it. It turns out that annually region was left by 2164 persons in average, or average migration intensity was 31 persons per 1000. Migration intensity during the study period was quite different according to separate periods. In particular, as a result of natural disaster emerged in 1989-1990 years, 19138 forced displaced migrants from the region was settled in some other different regions, including the Krasnodar Kray of Russian Federation [Putkaradze, 1996] Migration intensity in 1991-1994 years, was decreased at its minimum due to difficult political, social and economic processes created in the country, moreover – some particular part of the population returned back at their old dwelling places. Migration begins to activate with slow pace in 1995-2014 years still, but number of population in 2014-2023 years was increased by 3500 persons (from 55,4 thousand to 58,9 thousand). During the mentioned period, region had a natural increase of 1951 persons. It is obvious, that regional population was increased by 1549 persons in a way of migration, that constitutes an unprecedented occurrence regarding mountainous regions. Actually, during the whole 140 years, region had a negative migration balance. The mentioned demographic condition relates only to Khulo Municipality. In particular, some part of the population settled in Meskheti and Javakheti regions due to natural disaster processes returned back. Besides, some particular part of immigrants are presented by population or retirement age.

Discussions

One of the originalities of modern demographic development of mountainous Adjara is also that so-called “hidden migration” is observed in the region, or the number of actual population from the

permanent population is decreased by 30-35% on average. Actually, a big part of the labour resources of the region are temporarily employed in Batumi. The mentioned circumstance somehow hinders the rate of application of regional natural resources, which by itself presents one of the hindering circumstances for the development of highlands, the regulation of which in the whole country is quite an important problem, and it requires a separate study.By evaluating the modern demographic condition of mountainous Adjara, it is found out that the region actually is under demographic crisis. Notwithstanding the fact that recently only in Khulo Municipality has a population's slow increase been observed, in general the natural increase of the region is decreased at its minimum, and it is at the edge of depopulation. Age structure is worsened, where the specific share of the population of young age is obviously decreased. A negative migration balance is observed in Keda and Shuakhevi Municipalities, but "hidden migration" is obviously shaped everywhere, or the present population (compared to the permanent population) is decreased by 30-35%.

Conclusion

In order to stop the demographic crisis in mountainous Adjara, the following important measures should be applied:

1. Social and economic development of the region should be increased more, and by foreseeing the worsened ecological condition, implementation of effective policy of sustainable economic development should be prioritised;
2. Operation of the Law of Georgia on the Development of High-mountainous Regions (so-called "Mountain Law") should become more effective in the direction of improvement of regional demographic condition. In particular, immigration processes should be promoted with state subsidies, large families should be encouraged with financial assistance and other;
3. In order to stop the migration processes, especially "hidden migration", it is necessary to create jobs and renovate the sectoral structure of the economy, and tourism should be prioritised in the sustainable development of the region;
4. Maintenance and stay of the population in mountainous Adjara and its social and economic development should be implemented by issuing low-interest loans and working out an effective taxation system. Stoppage of the demographic crisis in mountainous Adjara and the measures to be applied in this regard actually will be an effective event implemented in order to improve the demographic policy of the country.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Evaluation of Tourist-recreational Resources in the Background of Climate Change in Georgia

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Abstract

Environmental protection and the sustainable use of natural resources represent some of the most pressing challenges of the modern era. Effective decision-making in both ecological and economic contexts is increasingly dependent on an accurate understanding of environmental conditions. Key drivers of environmental degradation include the decline of biosphere components and biodiversity, climate change, and the intensification of damages caused by natural disasters. Recognizing these challenges, the World Meteorological Organization (WMO) and the World Tourism Organization (WTO) have emphasized the need to integrate climate change considerations into the evaluation of tourism and recreational resources. As a full member of both organizations since the 1990s, Georgia is required to assess its tourism potential in light of changing climatic conditions. This study examines the impacts of climate and climate change on the development of the tourism sector in Georgia, with a particular focus on mountain and ski tourism. For the first time, several Tourism Climatic Indexes were applied to evaluate recreational resources by integrating diverse meteorological parameters. The findings highlight the importance of incorporating climatic variability into tourism planning and tour design across different climatic zones, particularly in relation to the risks posed by negative climatic events. Furthermore, long-term changes in snow cover duration were analyzed across multiple mountain and ski resorts by comparing two time periods (1961–1985 and 1986–2015). The results underscore the critical need for climate-informed strategies to ensure the sustainable development of Georgia's tourism sector under changing environmental conditions.

Keywords: Climate change, Tourism Climatic Index, Glacier recession, World Tourism Organization (WTO), Natural resources, Tourism industry

Introduction

The dynamism and sustainability of the tourism industry are inherently linked to the geographical location, topography, vegetation, weather, and climate of a region (Becken, 2017). Among these factors, weather and climate are particularly significant, as they constitute the primary determinants of a region's bioclimatic resources, which are essential for the planning, organization, and development of the resort and tourism sector (Mieczkowski, 1985; Scott et al., 2012). Climate exerts both direct and indirect influences on tourism, shaping the attractiveness of destinations and affecting tourist flows and activity patterns (Amelung et al., 2007).

Adverse climatic conditions and climate variability can significantly alter tourism demand, influencing seasonal patterns and the distribution of visitor flows (Hall & Higham, 2005). Such changes have cascading effects on related sectors, making the understanding of tourism seasonality crucial for sustainable destination management. Investigating the seasonality of tourism enables researchers and planners to quantify the influence of natural-climatic conditions on tourism product

formation, identify key drivers of seasonal variation, and develop targeted strategies to mitigate seasonal inequalities (Peeters, 2017). Thus, the study of bioclimatic resources and climate-induced seasonality represents a fundamental aspect of modern tourism research, particularly in the context of climate change and evolving tourist preferences.

Methods and Materials

Climatic indices have long been employed to assess the suitability of tourism and recreational resources. To date, over 200 climate indices have been developed. Broadly, tourism climate indices can be classified into three main categories. Among these, elementary indices synthesize values from several meteorological parameters; however, they generally lack biometeorological information, which limits their applicability for evaluating tourism and recreational resources comprehensively.

To evaluate tourism-recreational resources in Georgia for the first time, the Tourism Climatic Index (TCI) (Kartvelishvili et al., 2023) was applied. The TCI integrates multiple meteorological parameters, including air temperature, atmospheric precipitation, relative humidity, and the average duration of sunshine, thus providing a composite measure of climatic suitability for tourism. The TCI enables the identification of tourism resource potential across different seasons and months and allows for the calculation of annual values. Nevertheless, the TCI does not fully incorporate the thermophysiological component essential for a comprehensive assessment of tourism comfort and demand.

To address these limitations and to better examine the impacts of climate change on tourism development, the Holiday Climate Index (HCI) was adopted in this study. The HCI is a more complex climatic index that incorporates a broader range of meteorological variables. Its development specifically addresses the deficiencies identified in the TCI, taking into account that different destinations require tailored climate information for diverse tourism segments, notably urban and mass tourism.

The HCI incorporates five key climatic variables: maximum air temperature (T_max, °C), relative humidity (RH), cloud cover (A), precipitation (R_d, mm), and wind speed (W, m/s). The combination of air temperature and relative humidity is expressed as the effective air temperature (T), calculated using a specialized nomogram (Japaridze & Khazaradze, 2019). The HCI is defined as:

$$HCI=4\times T+2\times A+3\times Rd+W \qquad (1)$$

Unlike most other climate indices, HCI values are expressed in points, allowing for a standardized evaluation of climatic conditions for tourism (Table 1). This framework enables a more nuanced assessment of tourism climates, providing a robust basis for both seasonal and annual planning in the tourism sector.

Table 4. HCI Categories and Rating

HCI Score	Rating	Category
90 – 100	1	Ideal
80 – 89	2	Excellent
70 – 79	3	Very good
60 – 69	4	Good
50 – 59	5	Acceptable
40 – 49	6	Marginal
30 – 39	7	Very unfavorable
20 – 29	8	Extremely unfavorable
10 – 19	9	Impossible
- 30 – 9	10	Impossible

Results

Georgia's unique geographical location, complex and highly dissected relief, diverse land cover, and specific climatic conditions result in the presence of nearly every type of climatic zone within its territory. This diversity makes Georgia particularly suitable for assessing the spatial and temporal distribution of tourism climates. Accordingly, the Holiday Climate Index (HCI) was analyzed across various locations in Georgia to determine its monthly distribution patterns (Fig. 1).

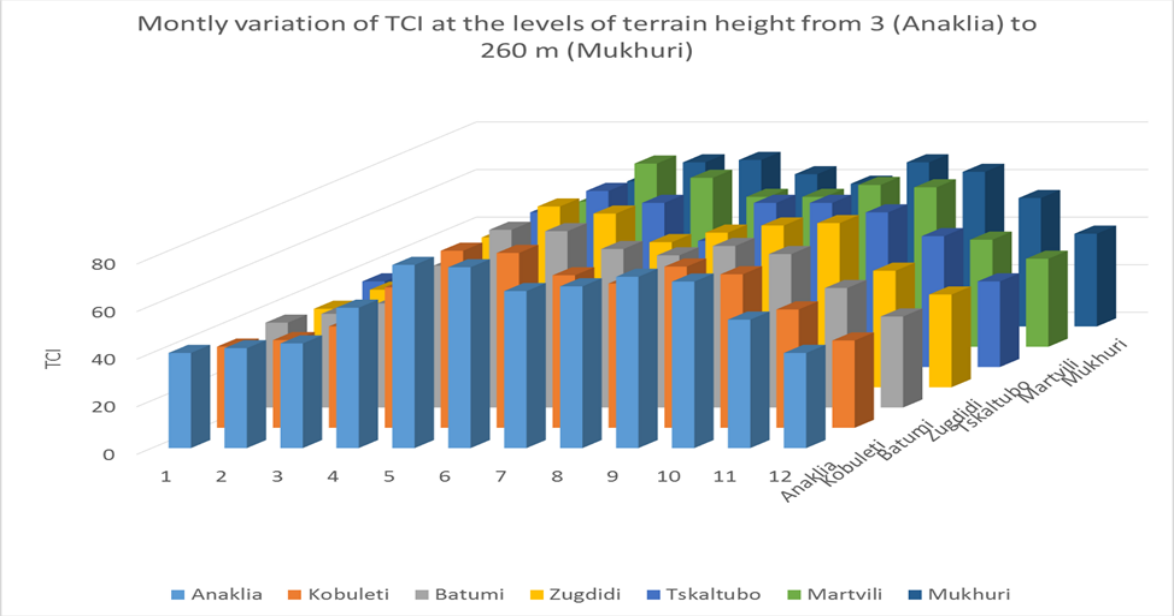

Figure 5. The distribution of the Holiday Climatic Index of rest according to the months

In Mestia, monthly HCI values recorded between 1956 and 2015 ranged from 34 (classified as "Unfavourable" in January) to 95 (classified as "Ideal" in September–October). The average monthly values over the entire observation period varied from 56.2 ("Pleasant" category in January) to 83.5 ("Excellent" category in August).

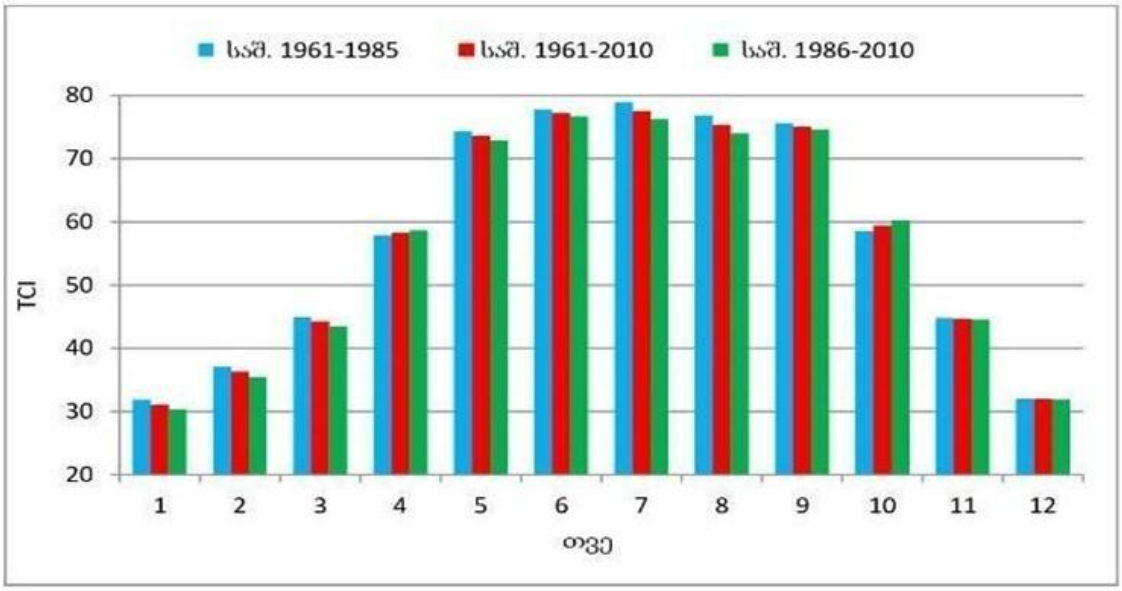

Figure 2. Average monthly values of HCI over the three observation periods

Analysis of the long-term trend in average monthly HCI values for Mestia revealed an overall negative tendency (Fig. 2). Specifically, a significant linear decrease in HCI values was observed for January, July, August, and December, as well as during both the cold and warm seasons of the year.

These trends suggest a gradual deterioration of bioclimatic conditions favourable for tourism in certain periods, which may have implications for the seasonal planning of tourism activities in the region.

To address the limitations of the Tourism Climatic Index (TCI), the Holiday Climate Index (HCI) was developed. According to its authors, the HCI provides a more representative assessment of the climatic suitability of a given area for tourism activities. The term "holiday" was purposefully chosen to reflect the index's specific focus on leisure tourism, distinguishing it from the broader concept of tourism, which is defined as: "a social, cultural, and economic phenomenon involving the movement of people between countries and places outside their normal environment for personal or business/professional purposes" (Amiranashvili et al., 2022).

A notable advancement of the HCI lies in its well-defined rating scale variables and the component weighting system. These features allow for a more nuanced and accurate evaluation of climatic conditions, thereby improving the capacity to assess tourism potential across different destinations and time periods.

Conclusion

The analysis indicates that the projected climate change in Georgia is unlikely to exert a significant impact on its tourism bioclimatic resources. Accordingly, it can be concluded that the bioclimatic conditions in Georgia have remained relatively stable, with only minor changes in the Holiday Climate Index (HCI), corresponding to a one-step variation in category, either upward or downward.

To enhance the resort and tourism potential of the country, it is essential to conduct a more focused and differentiated assessment of bioclimatic conditions. Such an approach would involve detailed studies of the bioclimatic resources of specific territories, enabling their optimal utilization for different types of tourism and diverse target groups.

Improving the quality and attractiveness of the resort and tourism industry requires systematic research aimed at understanding the spatial distribution of bioclimatic resources. This will support informed planning and development strategies, thereby maximizing the potential of Georgia's natural resources for sustainable tourism growth.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Possibilities and Prospects for the Development of Family wine tourism in Georgia

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Abstract

Wine tourism is considered a sustainable segment of tourism in the world and an important factor of rural socio-economic development. Wine tourism is, on the one hand, a type of agriculture-based tourism. Therefore, the development of these two fields is related to each other. Nowadays, many families who used to produce wine only for themselves have moved on to a new stage and are involved in wine tours and hosting guests. The increase in the number of wine companies has led to a high demand for grapes, which is beneficial for the rural population. Therefore, this sector creates new jobs and has a good impact on both the social and economic aspects of the country. Like all over the world, family farms dominate the wine-growing area of Georgia, which are small-scale farms according to the volume of their activities. When we discuss Georgian wine tourism, we consider that the issue concerns small family viticulture and winemaking enterprises. There are unique opportunities for the development of family wine tourism in Georgia, of which the relationship between the tourist and the viticulture and wine production staff is important, which is the best opportunity provided by family farms. Based on the study of the literature, the main motives for which tourists engage in wine tourism were determined. Accordingly, the direction and method of the research were identified. A telephone survey (interview) was used as the research method, and the survey was about the needs of wine tourism product producers. The needs of wine tourism product producers were identified, the solution of which will contribute to the development of wine tourism and meeting the needs of wine tourism product consumers.

Keywords: wine tourism, viticulture-winemaking, wine tourism product, family farms

Introduction

Wine tourism is visiting and observing vineyards and wineries, attending festivals and other events dedicated to wine, during which the main motivating factor for visitors is wine tasting and registration. Acquaintance with the attributes of viticulture and winemaking (Hall & Macionis, 1998, Hall et al. 2000, Carlsen and Charters 2006).

Today, wine tourism is on the rise and is the fastest growing segment of tourism worldwide. According to the international experience, the tourism development strategy considers wine tourism as the most important direction of the regional development of tourism. (Taylor, 2006). It plays an important role in the development and marketing of wineries as popular places. (Getz & Braun, 2006; Petrevska & Deleva, 2014).

Wine tourism is a rapidly growing trend of tourist activity in Georgia as well, the product of which has motivated consumers and producers. Wine tourism, like any economic activity, depends on its environment. The study of this environment is necessary to determine the actual growth and development prospects of wine tourism in the country, and thus it represents an actual economic task.

In the conditions of today's globalization, the development of wine production and wine tourism is justified for the country from both a social and a political point of view. On the one hand, wine tourism is a type of tourism based on rural economy. Therefore, the separation of these two fields is related to the country. Nowadays, many families, who used to produce wine only for themselves, have moved to a new stage, are involved in the wine industry and receive guests. This sector creates new jobs and has a good impact on both the social and economic aspects of the country.

In the wine-growing countries of the world, including Georgia, wine tourism, which is also a practical activity, aims to provide a wine tourism product and consumption. Wine tourism is a relatively new field of business. Its development significantly contributes to solving social and economic problems in rural areas. The main goal of the wine tourism business is to systematically increase the efficiency of the wine tourism product delivery and realization, which means, on the one hand, that Satisfying the demand for one's tourist product, on the other hand, the production and realization of the tourist product. To increase profits. The identification of existing problems in Georgian family wine tourism and the search for ways to overcome them is the main goal of the previous article.

Methods and Materials

In order to investigate the problems, we conducted a survey of family wine cellars, for which we used both the Google Drive application and the common method of quantitative research - a mass survey, which was used regularly. We obtained interesting results by means of telephone interviews of producers of wine tourism products in Ukraine and by processing specially prepared questionnaires.

Results

Georgia, distinguished by the variety of agro-climatic resources and the abundance of historical and cultural heritage, is one of the unique countries in the world. All of this is a sign of the development of the country's wine industry. Georgia has all the advantages that are related to the development of wine tourism: the history of winemaking, the uniqueness of wine production. The technology, the simplicity of the grape varieties and the natural conditions that contribute to the production of unique wine. The fact that the method of making Kvevri wine was included in the UNESCO list of intangible cultural heritage is also important (UNESCO, 2025).

According to the 2023 report of the National Wine Agency, according to the data of January-January-June of this year, 43.4 million litres of wine are exported from Georgia to 56 countries of the world, an increase compared to the same volume in 2022. It is 27%. Wine export income increased by 26% and amounted to 126.2 million US dollars (Wine Agency, 2025)

In recent years, numerous wine-themed festivals, events, exhibitions and competitions have been taking place more and more frequently in Georgia, which helps to attract tourists interested in wine tourism. For the second time this year, on the initiative of the Prime Minister and the organization of the Government Administration, the festival "Wine Days 2023" is being held, in which 850 winemakers in 23 municipalities will share one square during which he will participate" Georgian Wine Festival" is being held for the first time together with "Meidan Group". On October 21, "Wine Club" within the framework of the Georgian Wine Days, "Ghinobistive 2023", which has been holding a festival action for several years with the support of the National Wine Agency: "A new small Men in the big arena in 2023". For the second time, Georgia is hosting one of the most prestigious international wine and spirits competitions in the world, IWSC 2024 Wine Judging in Georgia. Last year, out of 487 female wines registered at the competition, medals were awarded to 288 wines (16 gold, 63 silver and 209 bronze). It is worth noting that most of the 150 registered enterprises were small and medium-sized wineries (Entrepreneur, 2022)

Festivals, exhibitions and competitions allow family farms to present their products to both Georgian consumers and foreigners interested in exporting Georgian wine.

World winemaking is dominated by family farming (Rauhut Kompaniets & Nilson, 2019). It is the same in Georgia, for example. According to Kharaishvili, more than 75% of farms employed in viticulture are small-scale (Kharaishvili, 2017). Farmers do not have information about markets, most of them do not have education in the field of farming, they suffer from a lack of food resources for production. The amount of grape and wine production per unit of land occupied by vineyards is low; In particular, 19 hectoliters per hectare, e. 1,900 liters of wine are produced, while 62 hectoliters are produced in the new countries of viticulture and winemaking, i.e. It is 3.2 times less. The small scale of enterprises severely limits access to financial resources, qualified labor force and other factors, etc.

In such a situation, the formation of cooperatives in agriculture and agriculture is relevant. For most of the interviewed farmers and winegrowers, the form of cooperatives in the field today is represented by an informal union rather than a legal status. Monitoring of family farms and small wineries found that they have low income, which limits access to investments and credits, own or hired technical equipment. The possibility of the distribution of rights, the sale of productive grapes and wine. The researcher believes that the unification of small-scale farms and wine producers into cooperatives in the winemaking sector will lead to: increasing access to local markets, reducing costs during the purchase of large quantities of agricultural resources (fertilizers, chemicals, etc.) (reduction) reduction of purchase costs, the combination of land and technical means will significantly increase productivity. Creation of cooperatives in viticulture will significantly reduce dependence on wine companies, especially in terms of wine prices, increase access to export markets, as well as additional knowledge and resources. Possibilities of receiving EB, etc. (Kharaishvili, 2017).

Studies have shown that personal relationships between the tourist and the winemaker, as well as the staff of the wine industry, have a significant impact on the impression of the wine tour. Tourists are requested to be treated with care during the tour. According to this sign, compared to visiting a large wine factory, tourists prefer visiting small enterprises, where they receive it more warmly, while visiting a wine enterprise Good customer service can become a decisive factor for repeat visits to this company (Roberts and Sparks, 2006).

In the study by the same authors, the focus of the interviewees was on the use of wine, some of them were interested in local food products along with wine, and some of them were interested in the handicrafts of the region, for example, wood carving. with working objects. It was found that information about the region is an important factor in terms of strengthening the experiences experienced by the tour for the visitors of the region. Respondents pay special attention to three sources of information: print, provided by information centers and popular voices.

For the majority of the respondents, the wine tour was interesting not only in terms of wine, but also in the fact that they enjoyed the nature and local beauty, and learned about the history of the region, acquainting yourself with wine and food, talking with the local population, communicating with the employees of the winery, getting to know the need for pairing wine and food, everything together creates pleasant memories of the tour (Roberts and Sparks, 2006).

Wine tourism in the wine-growing countries of the world, including Georgia, as a practical activity, aims at the production and consumption of the wine tourism product. Its development significantly contributes to solving socio-economic problems in the country. The main goal of the wine tourism business is to systematically increase the effectiveness of the production and sale of wine tourism products, which means, on the one hand, increasing the demand for wine tourism products. to satisfy, on the other hand, to increase the profit from the production and sale of the tourism product of wine.

According to the data of the National Statistical Service of Georgia, as of October-February 2023, 842 wine enterprises are registered, 6 large enterprises, 27 medium and 809 small enterprises are registered. Despite the fact that the questionnaire was sent to all operating companies and wineries, the level of activity was still not great, although problems and ways to solve them were still identified. A total of 144 respondents were surveyed (number of questions 12). Two or 1.4% were large enterprises, six enterprises (4.2%) were medium-sized wine companies. 136 (94.4%) family-type enterprises, of which 122 (84.7%) enterprises were engaged in wine tourism, 22 enterprises (15.2%) were engaged only in wine production (although Of these, 13 entrepreneurs were thinking of producing wine tourism in the future), so we continued the further survey with wine tourism entrepreneurs. All 122 wineries offered wine tasting to tourists; 93% to visit the cellar and get to know the technological processes of wine production; 91, 8% for vineyard management and participation in the harvest; Overnight stay with food service - 19.6%; overnight stay without food service 21.3%; Other services (only food without overnight stay) - 38%.

On the question of how many tourists you can receive on average - 11.4% can receive 10 people, 37.7% - 15 to 20 people, 30.3% - 25 to 30 people, 40- 13% can accommodate from to 50 people, and 7.3% can accommodate more than 70 tourists.

When asked whether wine tourism met your expectations, 89% of the respondents answered that it fully met their expectations, 9.8% partially met their expectations, and only one respondent gave a negative answer.

To the question, how much is the average cost of the tour per person, the answers were as follows: if they only want a tasting - 25-30 GEL, a tasting with a meal - 70-150 GEL, and 26.2% of the wineries

could not offer this service. Yes, 3.2% answered that the average cost of the tour per person is 150 GEL and more.

Tourists were mainly from Georgia, the countries of the former Soviet Union, Asia, Europe and the United States of America. In response to the question of what effect does the visit of wine tourists have on the sale of wine at the place, 86% of the respondents answered that it has a significant effect, according to 9% insignificant impact, while 4.9% think it has no significant impact. However, all respondents believe that without the tight connection between winemaking and tourism, wine production will decrease significantly.

The vast majority of family wineries and wine tourism businesses are run by family members. 72.9% of the surveyed respondents have a problem with qualified labor. Wine production and wine tourism

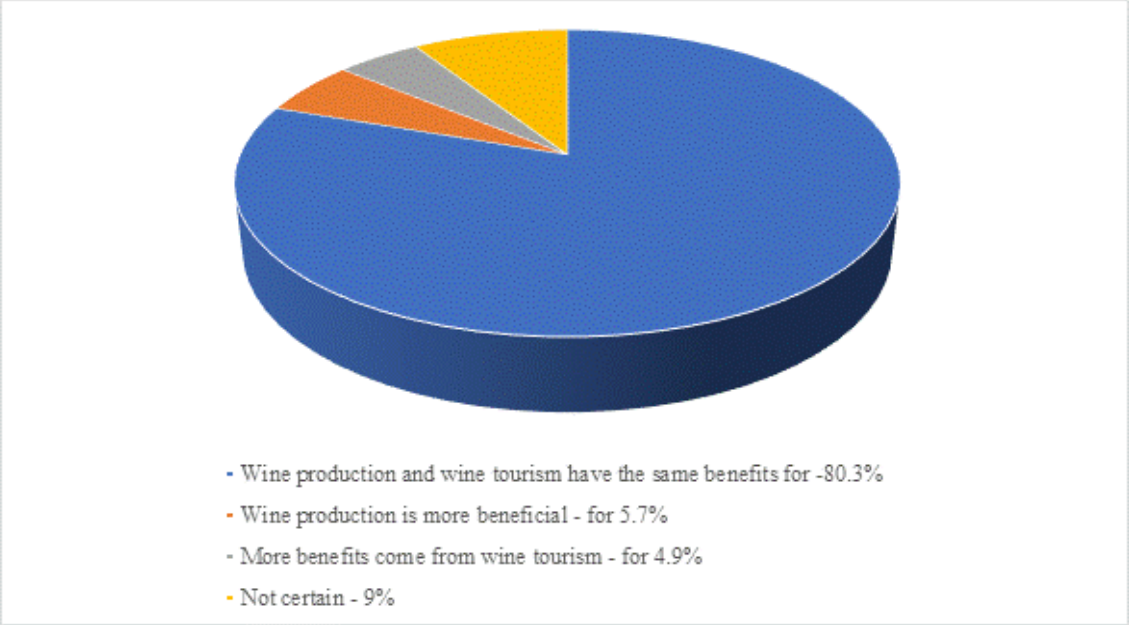

Figure 6. The vision of the interviewed wine companies and family wineries in the direction of profits from wine tourism and wine production (%)

bring the same benefits to 80.3%; wine production brings more benefits - to 5.7%, and wine tourism - to 4.9%; 9% are not sure. (Fig.1)

Entrepreneurs consider the following necessary for the development of wine tourism: financial

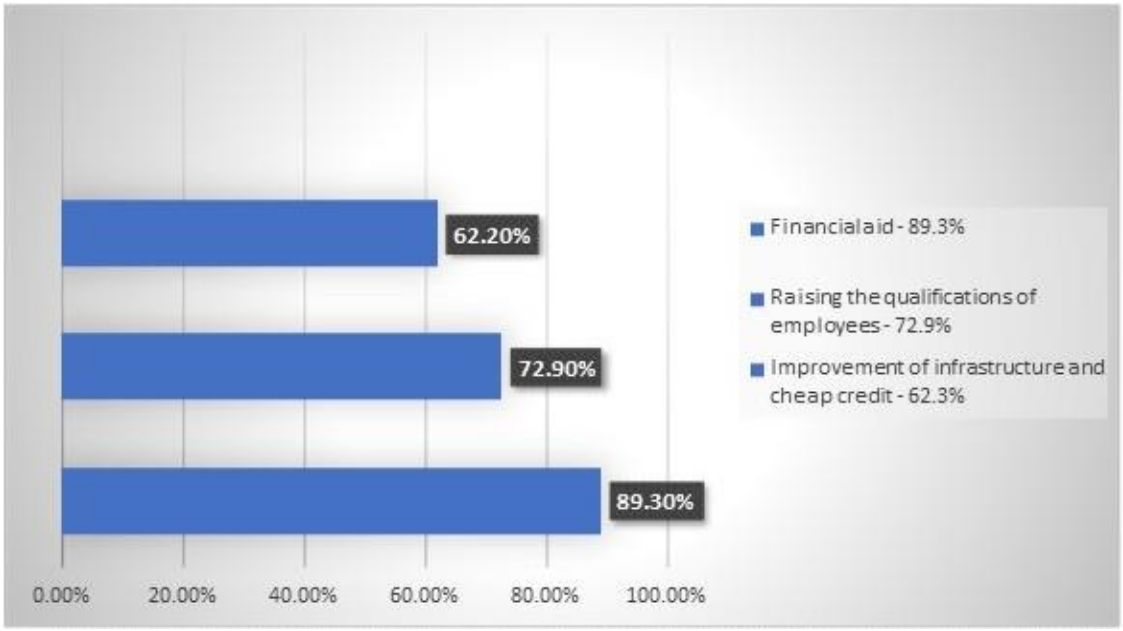

Figure 2. The vision of the interviewed wine companies and family wineries in the direction of promoting the development of wine tourism (%)

assistance (89.3%), improving the qualifications of employees (72.9%), improving infrastructure and cheap credit (62.2%) (Fig.2).

Conclusion

Based on the analysis of the research, it can be seen that tourists prefer to visit a small family business, where they receive them more warmly, compared to visiting a large wine company. One of the important contributing conditions for the development of family wine tourism is the formation of positive attitudes of people. As we have seen, out of 144 surveyed wineries, 122 wineries are engaged in wine tourism, and 89% think that wine tourism fully justified their expectations. It is also important that 86% of the surveyed respondents confirmed that the visit of Wine production and wine tourism have the same benefits for -80.3% wine tourists has a significant impact on the on-site sale of wine. Wine production and wine tourism have the same benefits for 80.3%. It should also be noted that all respondents believe that wine production will increase as a result of the close connection between winemaking and tourism.

In our opinion, family wine tourism is getting bigger and bigger and has great potential for development. The state should be interested in wine tourism as an object of health business, as a strategy for socio-economic development of the village, and more active steps should be taken by small wineries. It helps, namely:

- Assistance in order of infrastructure;
- Creation and provision of long-term financing programs adapted to small wineries;
- Activation of the involvement of the banking sector in the direction of providing low-interest loans to small and medium-sized wineries;
- Initiation of educational projects for the owners of small wineries (retraining of professional personnel, training in a foreign language).
- To raise awareness about Georgian wine, create a single electronic platform where video reviews about wineries will be posted.
- Online stores, which are not easily accessible for wine lovers. This will be a good advertisement and will increase the awareness of family wineries, which will allow family wineries to attract both local and foreigners interested in wine export.

For family farms, viticulture is a traditional branch, while tourism is an innovation. Wine tourism should be considered as a strategy based on the unity of viticulture and winemaking as a traditional family business and tourism as an innovative activity of a family farm. Wine tourism should be considered as a business model of a combination of family farming, family viticulture and tourism.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

M.Kh and M.A., in order to highlight the problems, conducted a survey of family wine cellars by means of a quantitative research method - a mass survey and analysis of existing literature. I.V. is responsible for formulating the main terms of the work and developing conclusions and important recommendations based on it.

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Recreational Landscapes and Load Norms in the Coastal Zone of Adjara

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Abstract

The coastal zone of Adjara represents one of Georgia's most resource-rich regions for tourism and recreation, owing to its favorable climatic conditions, proximity to the Black Sea, availability of mineral and thermal waters, diverse vegetation, and aesthetically valuable landscapes. The relatively gentle terrain further contributes to the formation of a comfortable climate that enhances the attractiveness of the region for visitors. In recent years, the number of vacationers in both coastal and mountainous areas has been steadily increasing, placing considerable pressure on recreational landscapes. Estimates indicate substantial variation in recreational load: from approximately 10 people per hectare in less crowded areas such as the Akhalsofli plain, to 100 people per hectare in heavily utilized areas such as Batumi. In hilly regions, the carrying capacity depends on slope steepness, with loads averaging 25 people per hectare on slopes up to 10°, and decreasing to 10 people per hectare on slopes of 20–35°. These values are relatively high and point to significant overuse of the recreational natural-territorial complex, raising concerns about long-term sustainability. The findings highlight the need for balanced management strategies to ensure both the preservation of natural resources and the continued development of tourism in Adjara.

Keywords: recreation, vacationer, resort, climate, visitor

Introduction

Tourism and recreation are increasingly recognized as key drivers of regional development, contributing significantly to economic growth, social well-being, and cultural exchange (UNWTO, 2020). Coastal zones, in particular, possess high tourism potential due to the concentration of natural and recreational resources, including favourable climatic conditions, sea access, mineral and thermal waters, diverse vegetation, and visually appealing landscapes (Gössling & Hall, 2006). These factors collectively create unique opportunities for the development of sustainable resort and recreational industries.

The coastal zone of Adjara, located in southwestern Georgia along the Black Sea, exemplifies such a resource-rich region. The relatively gentle terrain frequently generates favorable microclimatic conditions, which, in combination with abundant natural assets, have established Adjara as one of Georgia's leading tourist destinations. In recent decades, both the coastal and mountainous areas of the region have experienced steady growth in the number of vacationers, reflecting broader global trends of increasing tourism demand (Sharpley, 2020). The coastal zone of Adjara, Georgia, is endowed with abundant tourist and recreational resources. Its mild and relatively gentle terrain contributes to the creation of a "comfortable climate" during certain periods of the year. Significant natural endowments—such as the climate moderated by the Black Sea, mineral and thermal waters, rich vegetation, and attractive landscapes—serve as key factors fostering tourism and recreation development in the region.

In recent decades, Adjara has experienced a steady increase in vacationers in both its coastal and mountainous territories (Tourism Institute, Georgia; Cushman & Wakefield Georgia, 2023). Batumi, as the coastal centre of Adjara, illustrates this rising demand: its humid subtropical climate, substantial

sunshine hours, warm sea temperatures, and lush vegetation make it an appealing all-season destination (Travel in Georgia: Climate – Adjara; GoBatumi). However, such growth has led to observable stress on the natural-territorial complex, particularly through high densities of recreational use.

This research builds on prior and related work. For instance, Putkaradze et al. (2023) examined tourism challenges and resource usage in mountainous Adjara (Beshumi resort), emphasizing the need for sustainable management of natural recreation resources; likewise, studies of rural tourism development recovery in Adjara after COVID-19 (Beridze, Kordzaia, Diasamidze & Beridze, 2020) highlight growing demand and attendant pressures on infrastructure and environment. These precedents underscore the urgency of quantitatively understanding load capacities across different terrain and usage regimes for coastal Adjara, particularly as tourism continues to expand.

However, this growth has also introduced significant challenges, most notably the overloading of recreational landscapes. Current estimates indicate that the recreational load varies considerably across Adjara: approximately 10 people per hectare in relatively low-use areas such as the Akhalsofli plain, around 30 people per hectare on average, and up to 100 people per hectare in highly concentrated destinations such as Batumi. In hilly areas, the carrying capacity is strongly influenced by slope inclination, with acceptable loads estimated at 25 people per hectare on slopes up to 10°, but only 10 people per hectare on slopes between 20° and 35°. These figures suggest that certain areas may be experiencing considerable overuse, which could lead to environmental degradation and long-term disruption of the natural-territorial complex if left unmanaged.

The aim of this paper is to examine the recreational use of the coastal zone of Adjara, with a particular focus on assessing recreational load and its ecological implications. By evaluating load norms in relation to landscape characteristics, this study seeks to identify thresholds that will help preserve ecological balance while supporting the continued development of the resort and tourism industry in the region. Addressing these issues is essential for ensuring that tourism growth in Adjara remains both environmentally sustainable and economically beneficial.

Methods and Materials

This study is based on a combination of qualitative and quantitative research approaches, integrating geographical and statistical methods to ensure a comprehensive analysis of tourism and recreational resources in the coastal zone of Adjara. A complex methodological framework was employed, which included comparative–geographical analysis, statistical analysis, and synthesis of secondary data.

The research relied on diverse sources of information. Existing literary and scientific publications formed the theoretical foundation, while cartographic materials were used to examine spatial patterns and regional differentiation. In addition, digital and online resources provided updated datasets and complementary information relevant to the study objectives. Official statistical data and reports obtained from the Department of Tourism and Resorts of the Autonomous Republic of Adjara were also incorporated, serving as a key empirical basis for assessing the dynamics and current state of tourism development in the region.

All collected data were systematically processed, compared, and interpreted within the framework of geographical analysis. The comparative–geographical method allowed for the identification of spatial and temporal variations in tourism–climatic resources, while statistical techniques facilitated the evaluation of quantitative indicators and trends. This integrated methodological approach ensured the reliability and validity of the research findings.

Results

Analysis of statistical data obtained from the Department of Tourism and Resorts of the Autonomous Republic of Adjara reveals a dynamic pattern of growth in tourism over the past two decades, alongside notable fluctuations influenced by socio-political and global factors. Between 2005 and 2020, the total number of tourists visiting Adjara exhibited significant growth. In 2005, the region welcomed 147,000 visitors, predominantly domestic tourists (120,000), with international arrivals accounting for 27,000. By 2006, this figure had risen to 250,000, comprising 182,523 domestic and 67,447 international tourists, marking a substantial growth of approximately 70% within one year. Notably, Armenia, Turkey, and Azerbaijan were the primary sources of international visitors in this period.

In 2007, the upward trend continued, with total arrivals reaching 352,085, representing a 19.1% increase compared to 2006. Domestic tourism grew strongly (239,786 visitors), reflecting increased local mobility and interest, while international tourism reached 112,299 visitors. Early 2008 also saw growth, with August data showing a 25% rise in total arrivals compared to the same period in 2007. However, the escalation of geopolitical tensions following the Russian aggression led to a decrease in total visitors by the end of 2008, which dropped to 285,000. This decline was driven primarily by reductions in both domestic and international flows, although notable increases were observed from certain countries, including Israel (+82%), the USA (+45.3%), and Great Britain (+80%).

By 2009, tourism numbers rebounded sharply to 554,150, indicating strong recovery and sustained growth. Turkey and Armenia remained the leading sources of international visitors, followed by Azerbaijan and Israel. This recovery reflects Adjara's resilience as a tourism destination, supported by diverse recreational offerings and improved infrastructure. Over the following decade, tourism continued to expand significantly, with a notable surge in 2017, where visitor numbers increased by 98% compared to 2016. Key attractions such as the Machakhela and Mtirala routes, wine cellars in Keda, and cultural heritage sites in Khulo emerged as popular destinations.

Table 5. Number of visitors to Adjara (materials of the Department of Tourism and Resorts of Adjara 2024)

	2019	2023	2024 (January-June data)	change % 2019-2024	change % 2023-2024
Visits by foreign visitors	768 427,1	995 630, 3	932 267, 4	21,3%	6,4%
Internal visits	824 855 ,7	910 917, 3	1 001 101, 4	21,4%	8,8%
Sum	1 593 282,83	1 915 547,61	1 933 368, 77	21,3 %	0,9%

The COVID-19 pandemic (2020–2021) caused a sharp decline in tourism, consistent with global trends. However, preliminary data from the first half of 2024 indicate a strong recovery (Table 1), with 1,993,282 visits recorded — a 1% increase compared to the same period in 2023, and a 21.3% increase compared to the same period in 2019. This recovery underscores the continued attractiveness of Adjara as a tourist destination and suggests a return to pre-pandemic growth trajectories.

Spatial analysis of the coastal area of Adjara reveals significant variation in recreational capacity of natural-territorial complexes (NTCs). Three categories were identified (Table 2):

High Recreational Capacity: These areas are characterized by diverse recreational resources, favourable topography, rich vegetation, accessibility, and high tourist attractiveness. Notable examples include the Batumi coastline from Gonio to Kvariati Beach. These areas host high tourist concentrations and well-developed infrastructure but are vulnerable to environmental pressures such as coastal erosion and infrastructure damage due to sea-level changes.

Medium Recreational Capacity: Areas with moderately favourable recreational conditions, often altered by human activities and including cultural–historical elements. Examples include Upper Makhinjauri, known for sulphurous thermal waters, Chakhati, Gvara, Machakhela Gorge, and Mtirala National Park. These sites offer balanced opportunities for nature-based tourism and cultural experiences.

Low Recreational Capacity: Landscapes with high levels of agricultural use and less diversity in recreational resources. These include certain hilly and floodplain areas with dense population settlements, where tourism potential is limited.

Table 2. Recreational load norms (from 20-30 m to 200 m above sea level in the coastal zone of Adjara)

Recreational areas	Area in ha	Slope of the area in degrees	Load per ha	Total load
Batumi	250 ha	25^0	15 people	3750 people
Mahindjauri	220 ha	20^0	20 people	440 people
Chakvi hill - hills	300 ha	$18,5^0$	25 people	7500 people

Green cape	280 ha	16^0	25 people	7000 people
Hutcubani hill - hills	320 ha	15^0	25 people	8000 people
Nobokvati	359 ha	22^0	15 people	6250 people
Alambari, Muhaetate hill - hills	600 ha	12- 15^0	30 people	18000 people
Hills of Akhalsopli and Gonio	800 ha	30-35^0	10 people	8000 people
Salibauri hill - hills	450 ha	$15,5^0$	30 people	13 500 people
Cape of Tsikhisdziri	750 ha	25^0	15 people	11250 people

Based on slope analysis, norms for recreational load in the coastal area of Adjara were developed to guide sustainable tourism planning. The expansion of tourism in the region has been supported by investments in infrastructure, including modern hotels, improved picnic areas, designated tourist facilities, and marked mountain-biking trails. Additionally, cultural and recreational events such as the Summer Festival, Rural Tourism Festival "Gandagana", and the International Bird Watching Festival have strengthened Adjara's tourism appeal.

Overall, the results demonstrate that Adjara has experienced sustained tourism growth over the past two decades, punctuated by occasional declines due to external disruptions. The diverse natural resources, cultural heritage, and strategic development of recreational facilities have collectively contributed to the region's resilience and attractiveness. However, continued monitoring of visitor flows and environmental impacts remains essential to ensure sustainable tourism development and the preservation of Adjara's unique natural–territorial complexes.

Conclusion

The analysis of tourism development in the coastal zone of Adjara demonstrates that the region possesses abundant and diverse recreational resources, including a favorable climate, varied terrain, rich natural and historical heritage, and valuable mineral waters. These resources are effectively utilized for tourism and recreation, supported by well-developed infrastructure, and present significant potential for further development.

The study highlights those certain areas, particularly the Black Sea coastal plains and the hilly natural–territorial complexes (NTCs) of Adjara, experience excessive recreational loads, often surpassing sustainable limits. This overloading poses potential risks to the ecological integrity of the region and underscores the need for proactive environmental management. To preserve the sustainability of these landscapes, measures such as soil loosening, afforestation, herb sowing, and erosion control should be systematically implemented.

Based on the assessment of terrain structure, load intensity, and the ecological capacity of the territory, the following zoning of recreational load is proposed:

High Recreational Load Zones: Plains and hilly areas, particularly park-like landscapes, where permissible loads may reach up to 30 people per hectare. In certain high-demand urban locations, such as Batumi, loads can reach up to 100 people per hectare.

Moderate Recreational Load Zones: Hilly terrains with slopes up to 10°, where the recommended load is approximately 25 people per hectare, and slopes between 20°–35° where loads should not exceed 10 people per hectare.

Low Recreational Load Zones: Forest–park landscapes where the permissible load should not exceed 3 people per hectare.

The determination of maximum recreational loads is grounded in ecological capacity assessments, ensuring a balance between tourism development and environmental sustainability. The continued growth of tourism in Adjara, especially in Batumi, requires careful planning that respects the natural and climatic conditions of the region. This approach will not only protect recreational landscapes but also optimize the economic benefits of tourism.

Sustainable tourism development in Adjara must be guided by the principles of rational resource use, integrating proper marketing strategies and effective management practices that preserve the ecological potential of the region. Ultimately, the success of tourism in Adjara will depend on

harmonizing the needs of visitors with environmental preservation, ensuring that the natural and cultural wealth of the region remains a foundation for long-term tourism growth.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Using Digital Technologies in the Geography Lesson

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Abstract

Rapid advances in technology have profoundly transformed daily life and all spheres of human activity, including education. In this context, one of the central responsibilities of geography teachers is the development of students' geographical information competence, or geographical literacy, which is inseparable from digital and media literacy. The integration of digital technologies in geography lessons facilitates the presentation of educational material in diverse forms and formats, thereby enhancing the effectiveness of the learning process and optimizing student engagement. The multimedia nature of digital resources makes it possible to visualize geographical phenomena, processes, objects, and locations, effectively creating virtual journeys to various regions, countries, cities, or villages. Such technologies thus provide powerful learning environments that enrich students' educational experiences. Given that smartphones, computers, social media, and the Internet are already integral to students' daily lives, leveraging these tools provides access to a wide range of geographic information sources and strengthens geographical competence and literacy. A variety of digital resources are commonly employed in geography teaching, including multimedia products, digital educational platforms, websites of scientific and educational institutions, electronic interactive maps, online calculators, digital simulations, and educational computer games. In recent years, the integration of artificial intelligence (AI) into education has become increasingly widespread, offering unique opportunities to improve learning quality, foster engagement, and support personalized education. Within geography education, AI not only expands the pedagogical toolkit available to teachers but also enables students to acquire deeper and more interactive knowledge. Personalized learning pathways, interactive and virtual environments, data-driven analysis, and audiovisual resources all contribute to richer and more engaging learning experiences. The application of AI in geography lessons significantly enhances teaching effectiveness and student motivation. With the assistance of AI-based tools, students can explore diverse geographical objects and their characteristics, examine the scale and dynamics of geographical processes and events, generate forecasts, and apply acquired information to conduct geographical research. Moreover, the use of digital technologies supports teachers in assessing students' knowledge and skills, organizing and consolidating learning outcomes, managing classroom time more efficiently, and presenting instructional content in a vivid and engaging manner.

Keywords: teaching geography, digital technologies, artificial intelligence, education

Introduction

As Lambert notes, "*Geography in education has a reputation for being an early adopter of technologies – after all, it is an information-rich subject with an intrinsic interest in a rapidly changing world, and information is now instantly available at the touch of a button; indeed, we are soaked in information*" (Walshe & Healy, 2020).

Rapid technological advances have transformed virtually every aspect of modern life, including education (Selwyn, 2017). Digital technologies have reshaped pedagogical practices, creating new opportunities for interaction, collaboration, and information sharing (Redecker, 2017). Within this evolving educational landscape, geography education has increasingly embraced digital tools to foster geographical literacy—a competency that encompasses the ability to acquire, evaluate, and apply geographic information (Lambert, 2019). Geographical literacy today is inseparable from digital and media literacy, as these skills enable students to navigate, interpret, and critically assess digital information sources (Hobbs, 2017; Buckingham, 2013).

The integration of digital technologies in geography lessons has been shown to enhance teaching effectiveness by presenting educational content in diverse formats and enabling richer learning experiences (Jenkins et al., 2009; Goodchild, 2010). Multimedia resources, including interactive maps, virtual simulations, and audiovisual materials, allow students to visualize complex geographical phenomena and processes, effectively creating virtual journeys to different regions, countries, or environments (Demirci et al., 2013). Such approaches foster engagement and support deeper conceptual understanding by providing immersive and experiential learning opportunities.

Given the centrality of smartphones, computers, social media, and the Internet in students' daily lives, geography teachers are increasingly encouraged to leverage these tools as authentic learning resources (Selwyn, 2016; Warschauer & Grimes, 2007). Digital platforms and resources—such as educational websites, online calculators, GIS applications, and interactive simulations—offer rich opportunities for accessing geographic data and fostering critical thinking skills (Voogt & Roblin, 2012).

In recent years, the integration of artificial intelligence (AI) in education has emerged as a transformative trend. AI provides personalized learning pathways, adaptive feedback, and advanced data analysis capabilities, thereby enhancing both teaching and learning processes (Luckin et al., 2016; Holmes et al., 2019). Within geography education, AI-powered tools such as spatial data analysis software, immersive VR platforms, and intelligent tutoring systems enable students to explore geographic objects, analyse spatial processes, and model geographic phenomena at unprecedented levels of depth (Batty, 2018; Goodchild, 2010). These capabilities not only enrich students' engagement but also strengthen their geographical competence by facilitating the integration of real-world data into learning activities.

Furthermore, digital and AI-based technologies support teachers in planning, assessing, and delivering geography lessons more effectively. They offer tools for monitoring student progress, organising learning materials, and optimising classroom time (Redecker, 2017; Jisc, 2019). Interactive digital environments, simulations, and data visualisations allow for more vivid and meaningful presentations of geographic content, thereby fostering deeper learning and critical inquiry (Demirci et al., 2013).

Thus, the growing body of research underscores that the effective integration of digital and AI technologies into geography education not only enhances instructional quality but also equips students with the knowledge, skills, and critical capacities necessary to navigate the complexities of a digitally mediated and interconnected world (Lambert, 2019).

Within this context, one of the central responsibilities of geography teachers is the development of students' geographical information competence—or, more broadly, geographical literacy (Bliadze, 2015; Bliadze, 2020a; Bliadze, 2020b). This competence encompasses the ability to independently locate, select, analyze, process, and apply geographic information, as well as to communicate findings effectively through oral, written, and digital means.

Methods and Materials

The development of geographical literacy in contemporary education is inseparable from digital and media literacy, which encompasses not only knowledge and skills but also attitudes. When guided by legal and ethical principles, this literacy enables the effective and purposeful use of digital technologies through the acquisition, organization, evaluation, and creation of information.

In the modern classroom, the global information network is a shared space for both teachers and students. Consequently, teachers are expected to possess not only adequate computer literacy but also a solid grounding in pedagogy and child psychology. Professional experience in schools serves as a filter that allows teachers to select, adapt, and integrate information effectively. Combined with tailored teaching materials, the internet thus provides valuable opportunities to design engaging and innovative geography lessons. Rather than prescribing a fixed set of methods, digital resources contribute to more flexible and creative instructional practices, supporting the development of meaningful learning activities.

The integration of digital technologies allows educational content to be presented in multiple formats, thereby improving the efficiency of the learning process and optimizing students' participation. Digital resources can make geographical phenomena, processes, and locations more visible, offering students the opportunity to virtually "travel" across regions, countries, cities, and villages. As smartphones, computers, social media, and the internet are already central to students' daily lives, leveraging these tools in the classroom provides access to diverse geographic information sources while simultaneously strengthening both geographical competence and literacy.

Digital resources also support personalized and individualized learning, enabling teachers to design flexible learning pathways that encourage innovation and creativity. In geography lessons, technologies are employed with two primary aims: (1) to enhance the effectiveness of teaching through technical means and (2) to provide students with opportunities to adapt learning content and create digital products of their own. Depending on the topic and objectives of a lesson, geography teachers may utilize a wide range of digital tools, including hardware (cameras, recorders, scanners, printers), software (office applications, media editors, GIS programs, associative mapping tools), and online resources for searching, publishing, and sharing materials. Sequencing these tools strategically ensures novelty and sustained engagement; for instance, students might begin by creating tables or graphs, progress to using digital mapping software, and ultimately produce presentations, interactive maps, or multimedia projects. Such activities encourage students to compile original outputs that synthesize knowledge around specific topics.

Digital technologies further allow for the rapid manipulation of maps, graphs, and data at varying scales, which greatly enhances students' analytical skills. Applications such as Google Earth, *Worldmapper*, and *Gapminder* provide interactive opportunities to reframe perspectives on global and regional issues, fostering critical engagement with spatial information. Unlike static printed maps, electronic tools not only present material more dynamically but also empowers students to become active creators of learning resources. They are equally valuable in project-based learning, especially in the preparation of final presentations. Platforms such as Adobe Spark, Canva, and Microsoft PowerPoint allow the integration of maps, images, videos, and text into coherent, visually engaging outputs. Collaborative tools such as Google My Maps and ArcGIS StoryMaps further enable students to co-create digital maps, annotate content, and share results in real time, reinforcing teamwork and digital collaboration skills.

- ✓ A wide array of resources can be employed in teaching geography, including:
- ✓ Multimedia products (documentaries, films, animations, audio recordings).
- ✓ Educational websites (e.g., National Geographic, Khan Academy).
- ✓ Websites of academic and research institutions (e.g., *World Resources Institute, GEBCO, Vakhushti Bagrationi Institute of Geography, Ivane Javakhishvili Tbilisi State University*).
- ✓ Interactive maps (e.g., *Google Earth, National Geographic MapMaker, Earthquakes & Volcanoes, UN SDG* dashboards).
- ✓ Online calculators (e.g., *CO_2 footprint calculators, water use calculators*).
- ✓ Digital simulations (e.g., *PhET, Our World in Data*).
- ✓ Official databases (e.g., *Census Bureau, Geostat, DataLab*).
- ✓ Websites of international organizations (e.g., *World Economic Forum, UNICEF, NATO/EU Information Center, National Environmental Agency of Georgia*).
- ✓ Blogs and specialized geography portals (e.g., *Geography.ge*).
- ✓ Educational computer games (e.g., *World Geography Games, Geojigsaw, PurposeGames*).

Together, these tools enrich geography education by fostering creativity, critical thinking, and digital competence, while also broadening students' spatial awareness and global perspective.

Results

In recent years, the use of artificial intelligence (AI) in education has gained considerable popularity. AI offers unique opportunities to enhance learning quality, foster student engagement, and support personalized instruction.

The integration of AI into geography education provides substantial benefits for both teachers and students. In geography lessons, AI not only expands the range of teaching tools available but also enables students to acquire deeper and more interactive knowledge. Personalized learning pathways, immersive virtual environments, advanced data analysis, and the incorporation of audiovisual resources contribute to richer and more engaging educational experiences. As a result, the integration of AI into geography lessons significantly improves teaching effectiveness and strengthens student motivation.

Through modern technologies and instruments, AI can collect, process, and analyze vast amounts of geographic data, allowing students to explore diverse aspects of geography—from the geological structure of mountains and climate dynamics to demographic trends, cultural traditions, and settlement patterns. This capacity enables a comprehensive and multi-layered understanding of both natural and human processes.

Opportunities of AI in Geography Education

Personalized learning: AI-powered systems such as intelligent tutors, adaptive platforms, and individualized study plans provide tailored support aligned with students' prior knowledge, learning pace, and needs. For instance, systems like IBM Watson can generate personalized curricula that adjust dynamically to students' progress.

Interactive and virtual environments: The combination of AI and virtual reality (VR) creates unique opportunities for experiential learning. Tools such as Google Earth VR and National Geographic VR allow students to virtually explore different regions, observe climate change impacts, and gain first-hand insights into natural processes.

Data analysis and visualization: AI tools facilitate big data analysis and visualization, which are crucial for geographical research. Platforms such as Tableau and Power BI enable students and teachers to examine trends in climate change, population dynamics, and resource distribution.

Audiovisual resources: AI applications in speech and image recognition, such as Google Voice and Amazon Rekognition, can enrich lectures, webinars, and digital teaching materials, making them more interactive and accessible.

Interactive maps: AI-powered mapping tools such as ESRI ArcGIS enable students to analyze real-time geographic data, track environmental and demographic changes, and engage in spatial problem-solving.

Geographic simulations: Simulation platforms, such as those developed by UNIGIS, allow students to model and explore natural and human processes, thereby deepening their understanding of environmental and social interactions at both global and local scales.

Challenges of AI Integration

The implementation of AI in geography education is not without challenges. Successful integration requires careful curriculum planning, comprehensive teacher training, and equitable access to technology. In Georgia, particularly in rural areas, many public schools remain inadequately equipped with technical resources. Limited internet access further restricts the use of digital and AI-based tools. Additionally, not all students have access to personal computers or laptops at home, creating disparities in opportunities for digital learning.

Language barriers present another significant obstacle. Geographic information resources in the Georgian language remain limited, while a large proportion of teachers and students lack proficiency in English or other languages, restricting their access to high-quality international materials.

The Role of Technology in Geography Education

Despite these challenges, technology plays a crucial role in supporting teachers. It assists with assessing students' knowledge and skills, organizing and consolidating learning outcomes, optimizing lesson time, and presenting content in a vivid and dynamic manner. However, the integration of educational technologies should not replace traditional teaching methods. Rather, digital tools should complement established pedagogical approaches as part of a balanced methodology.

When planning the use of AI and other technologies, teachers must consider three key factors: (1) students' level of digital competence, (2) the availability of technical infrastructure, and (3) the

specific objectives of the lesson. While the preparation and effective use of technology-based resources can be time-consuming—requiring teachers to identify, adapt, and evaluate online materials—the benefits in terms of student engagement and learning outcomes make this investment worthwhile.

Ultimately, AI and digital technologies, when used thoughtfully and inclusively, have the potential to transform geography education into a more interactive, personalized, and meaningful learning experience, equipping students with the skills and knowledge necessary to understand and navigate the complexities of the modern world.

Conclusion

Therefore, incorporating technology into geography lessons enables teachers to create dynamic, interactive learning experiences that enhance student engagement while deepening their geographical competence and understanding of the world's diverse environments.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

M.B. and M. S. conceived of the presented idea. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Spatial Thinking in Primary Geography Education: A Design-Based Intervention in Georgia

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Abstract

Students' spatial thinking and problem-solving skills are crucial components of modern primary education. While the Georgian National Curriculum emphasises spatial representations and environmental perception skills, significant challenges exist in their practical implementation. Textbooks often lack tasks that engage students with real spatial problems and develop argumentative thinking. This article presents design research conducted in a fifth-grade class at a Tbilisi public school. The study aimed to improve students' spatial thinking and decision-making skills using the Problem-Based Learning (PBL) model. Five interventions addressed real geographical situations, including settlement planning, protected area selection, and infrastructure placement. Results showed that targeted and consistent work on spatial tasks significantly improved students' abilities to read maps, recognise spatial relationships, and make rational choices. Despite progress, certain difficulties persisted, particularly in aligning self-assessment with actual performance and developing analytical thinking components. The article examines contradictions between standards and textbooks, identifying characteristics of pedagogical practice that either facilitate or hinder spatial skills development.

Keywords: Spatial thinking, primary level, problem-based learning, standard, design research, geography education

Introduction

Spatial thinking is an essential component of human cognitive development, enabling individuals to understand relationships between objects and space while visualising, interpreting, and predicting spatial patterns (NRC, 2006). Developing these skills is particularly crucial in geography education, where spatial representations form the basis for both information analysis and decision-making. International educational research demonstrates that establishing spatial thinking foundations at the primary level is critically important for students' subsequent subject-specific and metacognitive success. However, in the Georgian educational environment, this component is insufficiently integrated into both standards and textbooks. Consequently, students often struggle with map reading and recognising spatial connections between environmental elements. This deficit undermines the teaching-learning process and hinders students' ability to solve real spatial problems. Teachers are frequently forced to develop appropriate activities independently, as existing resources provide insufficient support. This article presents a pedagogical intervention designed to develop spatial thinking competence using Problem-Based Learning (PBL) methodology. The article describes the design research process, frameworks and tools used, presents data analysis and discussion, and offers recommendations to policymakers and educators for improving instruction in this area.

Conceptual Framework

Developing effective instructional design requires robust theoretical foundations, especially when cultivating complex skills such as spatial thinking. This study relies on three primary theoretical frameworks: Problem-Based Learning (PBL), the Geographic Reasoning Framework, and Design-Based Research.

1. **Problem-Based Learning (PBL)** PBL is a constructivist approach where learning is based on real and multifaceted tasks. In this model, the student becomes an active learner who tries to define issues, find information, analyze, evaluate, and solve problems (Barrows, 1986). In geography education, PBL is particularly effective because it allows students to consider real-world geographical problems.
2. **Geographic Reasoning Framework** Gersmehl and Gersmehl (2011) propose a geographic reasoning model consisting of seven components: identifying location, analyzing spatial distribution, explaining patterns, understanding movement patterns, evaluating connections, comparing regions, and making decisions. Using this framework allows students to conduct structured spatial analysis.
3. **Design Research (DBR)** is one of the most promising methodologies in education research, especially when the goal is to solve practical problems and improve teaching. According to Arthur Bakker (2018), design research has a clear structure, theoretical basis, and practical purpose.

*Key Aspects of Design Research (*Bakker, 2018*):*

- **Problem-Oriented Approach**: Design research begins by identifying urgent educational problems. It seeks to solve real problems through innovative means rather than merely describing existing practices.
- **Interconnection of Theory and Practice**: This methodology integrates theory and practice. Products developed during research (learning materials, activities, frameworks) are built on theoretical foundations and enrich theory in return.
- **Interventionist Nature and Innovative Design**: Design research involves creating and testing interventions to improve learning environments. Interventions can include new teaching methods, structured activities, or technological tools.
- **Iterative Cycles**: The research process is characterized by repetitive cycles—design creation, testing, analysis, and revision. This enables continuous improvement and refinement in real contexts.

According to Bakker's approach, design research is a rich, theoretically grounded, and practice-oriented methodology that is particularly powerful when learning standards inadequately support student cognitive development. During this research, all three frameworks were used interactively.

Literature Review: Spatial Problem-Solving in Primary Geography Education

Spatial thinking is increasingly recognized as a fundamental competence in geography education, especially at the primary level, where it enables students to engage in critical analysis and decision-making about their environment. Research indicates the importance of creating learning experiences that are not only age-appropriate but also address shortcomings in learning standards and textbooks (Bakker, 2018; Buckley et al., 2018).

Spatial skills development begins in early childhood with topological concepts (e.g., "near," "inside," "around") and gradually progresses to more complex spatial-projective concepts such as scale, symbols, and coordinates. Research by National Geographic shows that primary school students (especially grades II-IV) begin understanding maps but still need support in interpreting spatial connections and symbols (National Geographic Society, 2016).

Cognitively, Buckley et al. (2018) emphasize that spatial skills are multifactorial and include visualization, orientation, mental rotation, and spatial perception—all directly related to academic achievement, especially in STEM disciplines. These skills develop through targeted tasks and activities such as understanding directions, creating maps, or making decisions about specific spatial problems—which directly aligns with primary geography education contexts.

Fiveable (2024) clearly states that spatial thinking extends beyond map reading to encompass a full cycle of geographical inquiry: asking spatial questions, acquiring and organizing information, analyzing connections, and making relevant decisions. This approach is compatible with problem-based learning models that promote active student engagement and encourage thinking development.

Nevertheless, spatial thinking remains incompletely integrated into primary education standards. Textbooks often emphasize memorizing facts and technical map reading rather than spatial-cognitive tasks. A learning design-based approach can address this gap, especially when linking students' real needs with evolving research strategies (Bakker, 2018).

Primary geography education focused on spatial problem-solving requires both recognizing the diversity and developmental potential of spatial skills and implementing research-based instructional design. The synthesis of various academic disciplines—cognitive psychology, educational design, and practice—creates a solid foundation for developing spatial thinking and problem-solving skills in students.

Methods and Materials

This research is based on Design-Based Research (DBR) methodology, which aims to develop innovative educational practices and test them in real contexts. DBR involves cyclical planning, implementation, evaluation, and redesign of educational interventions (Anderson & Shattuck, 2012). This approach is particularly important when developing complex skills in resource-limited conditions. The study was conducted in the academic year 2024-2025 in a fifth-grade class at Tbilisi Public School No. 51, with 23 students. Teacher Maia Madzgharashvili was involved as an equal partner and active observer. Student teachers from the training programme, Mariam Gagua and Keso Kankia, conducted the interventions. Student teacher involvement proved particularly effective, as students felt comfortable with younger facilitators, experienced less stress, and could ask questions freely. This approach promotes more active student involvement and reduces barriers between teacher and student.

Data Collection

The instruments used included:

- Standard and textbook analysis
- Analysis of student work (maps, tables, arguments for choices)
- Student self-assessment forms
- Interviews with the teacher

Intervention Design

Each intervention included the following structure, shown on the scheme

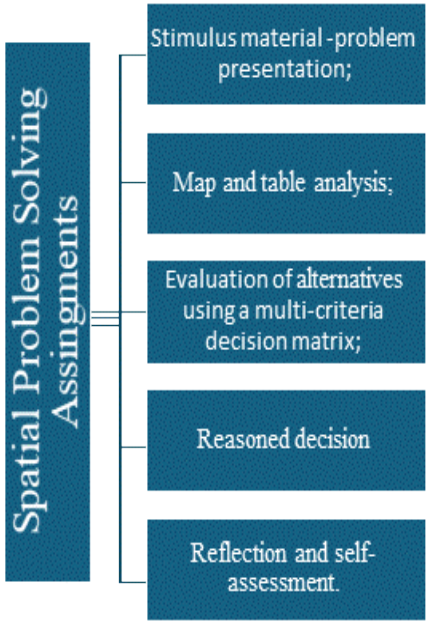

Figure 7. Design elements

The study included five interventions, each planned at three-week intervals. Each intervention was based on the PBL model and represented a task based on real geographical contexts, such as:

- Planning a prototype settlement
- Selecting the location of a protected area
- Analyzing infrastructure placement (school, clinic)
- Assessing natural disaster risk and planning routes
- Planning recreational zones considering residents' interests

Data Analysis

Data analysis divided information according to three main components:

- Map reading and spatial identification ability
- Reasoned decision-making ability
- Accuracy of self-assessment

Qualitative and quantitative data analysis was conducted using Excel. Student work was evaluated according to a rubric (satisfactory, partially improved, incompetent) and analyzed after each intervention.

Participant Selection for Analysis

Important Note on Sample Size: While 23 students are in the class, only 9 students attended all five interventions and were included in the final analysis. This reduction was necessary to maintain data integrity, as the cyclical nature of the interventions required consistent participation to track skill development progression.

Absenteeism poses particular challenges for this age group (fifth graders) as they are not yet independent learners. Unlike older students, fifth graders cannot effectively review missed spatial thinking activities at home, especially since these activities are not part of licensed textbooks. The hands-on, collaborative nature of the interventions—involving map work, group discussions, and guided problem-solving—cannot be replicated through traditional homework assignments. Students who missed interventions lacked the foundational skills needed for subsequent activities, making it methodologically inappropriate to include incomplete data sets in the analysis. This limitation highlights the importance of consistent attendance for cumulative skill development in primary education.

Ethical Considerations

With parental and school agreement, all students participated anonymously. Materials used contain no names and strictly adhere to confidentiality principles. The teacher and school received summarized analysis results.

Analysis of Standards and Textbooks

The Georgian National Curriculum (MoE, 2018) defines compulsory achievements for students in "Our Georgia," which includes geographical components alongside history. Although the document generally addresses spatial connections between environmental elements, it lacks specific instructions for developing spatial thinking as a separate competence.

The standard presents terms such as "recognizing spatial connections," "map reading," and "representing the environment," but these are not accompanied by relevant explanations, minimal indicators, or task typologies, increasing the risk of multiple interpretations. Consequently, teachers often remain unclear about what teaching these competencies means in practice.

Despite the Georgian National Curriculum's stated emphasis on developing spatial representations and environmental perception skills, practical implementation faces significant challenges stemming from current educational materials' shortcomings. A typical exercise from the widely used "Our Georgia" textbook (Avtandilashvili et al., 2018) asks students: "What is the location of Kartli on the map of Georgia? Which historical-geographical regions of Georgia border it? Are there more hills or plains in Kartli?" Similarly, page 52 asks students to "List, with the help of the map, which regions of Georgia border Imereti?"

These tasks, and many others like them, are purely descriptive and extractive, requiring only direct information retrieval from maps rather than fostering genuine problem-solving or analytical engagement with spatial data. This reliance on rote recall rather than critical thinking fundamentally hinders true spatial reasoning development.

The root of this issue lies in the national standard's generalized directives, which fail to compel textbook authors to create situation-based problems demanding analytical map work. For instance, within the "Space" concept, the standard merely requires students to "discuss the reasons for the diversity of landscapes characteristic of Georgia." This level of abstraction falls far short of fostering robust spatial thinking.

In contrast, by fourth grade, National Geographic's standards expect students to "analyze geographic contexts in which current events and issues occur," exemplified by tasks like describing "geographic

factors that would influence the decision on where to locate a new school in the local community" (National Geographic Society, n.d.). This disparity highlights a significant competency gap, where Georgian primary students engage with spatial concepts at far less complex and practical levels than international peers, ultimately impeding their ability to apply spatial thinking to real-world scenarios.

Furthermore, comprehensive visual resources (diagrams, maps, pictures) essential for developing spatial representations are often absent in textbooks. This resource lacks forces educators to find or create materials independently, increasing teacher workload and leading to teaching quality inconsistencies.

The discrepancy between standards and textbooks was highlighted during intervention planning. It became clear that standard minimum requirements do not correspond to skills students need. For example, understanding spatial sequences between water, forest, village, and mountain objects on maps and formulating reasoned choices is required by neither the standard nor textbook tasks.

Teacher interviews revealed the need for clear guidelines for spatial task work and practical examples aligning with national curriculum goals. One educator noted: "I rarely have the opportunity or time to create spatial tasks myself. The textbook focuses more on factual knowledge."

The analysis indicates a systemic challenge—current standards and textbooks at Georgia's primary level do not ensure development of spatial thinking competencies essential for modern education. This discrepancy creates barriers to learning effectiveness and increases individual teacher workload.

Design Description and Its Use as a Problem-Solving Tool

The design developed within this study was based on the SPBL (Spatial Problem-Based Learning) model and aimed to overcome difficulties caused by the lack of spatial thinking components in standards and textbooks. The combined integration of PBL and the Geographic Reasoning Framework allowed us to create tasks based on real contexts, considering spatial relationships, natural-geographical factors, and reasoned decisions.

One main innovation was the interventions' cyclical nature. Each intervention combined problem presentation, data comprehension, map reading and spatial reasoning, alternative comparison, and reasoned decision-making. All five interventions relied on active student participation, cognitive stimulation, and self-assessment.

Each intervention followed a structured five-step process designed to guide students through comprehensive spatial problem-solving (see Fig. 1):

Step 1: Problem Presentation

Students were presented with an authentic geographical scenario that required spatial decision-making. For example, they might receive a scenario stating: "A group of early humans needs to establish a permanent settlement. As their advisor, you must help them choose the best location from three possible sites." The problem was introduced through storytelling to engage students and establish the real-world relevance of their task.

Step 2: Data Analysis

Students examined multiple information sources including topographic maps, climate data, resource availability charts, and contextual information about the geographical area. They were guided to identify key spatial elements such as water sources, elevation patterns, vegetation cover, and proximity to resources. This step required students to extract relevant information from visual and textual sources systematically.

Step 3: Alternative Evaluation

Students worked in small groups to compare multiple location options using predetermined criteria. They used evaluation matrices where each potential site was assessed against factors such as water accessibility, defensibility, resource availability, climate suitability, and transportation routes. Students assigned numerical scores to each criterion and calculated total scores for each alternative, fostering analytical thinking and systematic comparison.

Step 4: Reasoned Decision

Based on their analysis, students selected their preferred location and constructed written arguments justifying their choice. They were required to explain not only why their chosen site was optimal but also why they rejected the alternatives. This step emphasized the development of argumentation skills and required students to synthesize their spatial analysis into coherent reasoning.

Step 5: Reflection/self-assessment

Students assessed their decision-making process and outcomes through structured self-evaluation forms. They considered questions such as: "Which factors were most important in your decision?"

"What additional information would have been helpful?" and "How confident are you in your choice?" This metacognitive component helped students understand their own learning processes and identify areas for improvement in future spatial problem-solving tasks.

Tasks were designed so students genuinely considered the appropriateness of placing various objects according to specific criteria, such as where primitive humans should settle; which area is most appropriate for creating a protected area; where a school building or alpine base should be built. Tasks involved comparing several parameters—proximity to water, terrain, climate, safety, infrastructure accessibility, and others. Students worked with tables, evaluating each parameter with points, then made in-depth reasoned choices.

Another important design element was map use. Each task began with a schematic map that students needed to read to analyze spatial characteristics. Map work offered visual and analytical links between problems and environmental elements, enabling skill development in determining location, estimating distance, distinguishing directions, and establishing object connections.

Starting from the fourth intervention, students began working on spatial problems where their chosen locations were based on strong argumentation and alternative comparison. The design's consistent development was precisely the factor contributing to competency deepening. The teacher used reflection stages after each task, where students evaluated their decisions and explored how better choices could have been made.

The design solved several significant problems:

- **Gap between standard and tasks**: PBL interventions created alternative spaces for working in real geographical contexts
- **Teaching monotony**: Tasks diversified student activities
- **Teacher challenge**: The design was easily reproducible and adaptable by teachers
- **Lack of self-assessment and reflection**: Integrated self-assessment modules ensured metacognitive skills development

As a result, students not only gained better understanding of geographical concepts but also developed decision-making, argumentation, and spatial visualization skills, contributing to their overall academic development. The research clearly showed that using this design type effectively overcomes shortcomings caused by standard generality and resource scarcity at the primary level.

Results

Analysis of design research results clearly showed that students' spatial thinking and reasoned decision-making skills significantly improved as a result of interventions. This progress is reflected in student work, teacher reflections, and self-assessment forms.

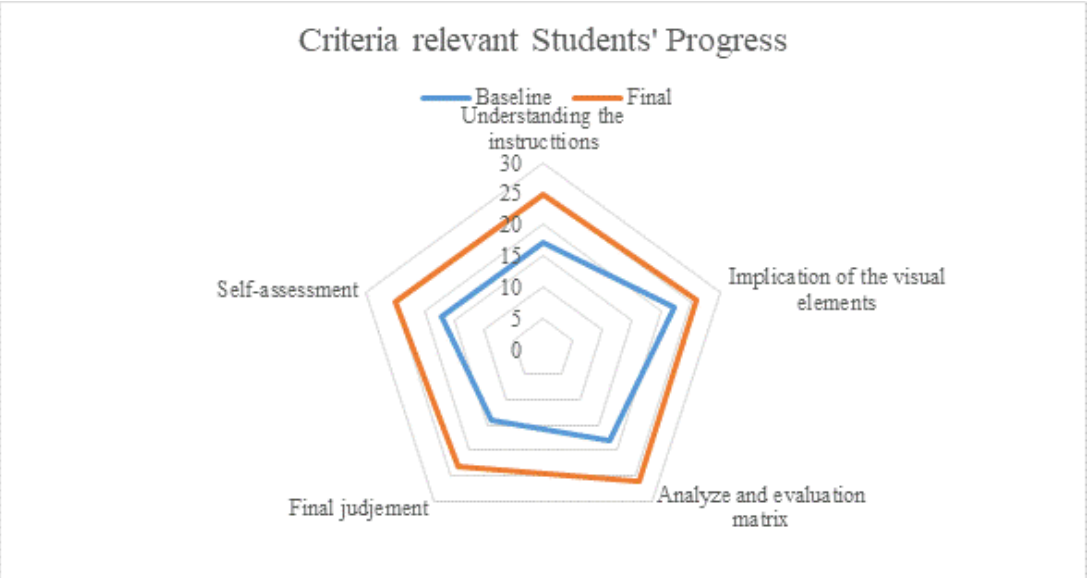

Figure 2. Competency development from preliminary to final stages

Figure 2 shows evaluation results comparing preliminary and final stages across key competencies. This clearly demonstrates that students made progress in each competence. Of these competencies, the

least progress was recorded in visual elements use, indicating that students had already developed this competence substantially and could use it as needed.

Understanding instructions for multi-stage tasks was initially problematic. Textbook analysis showed that most tasks were one or two-stage, preventing students from concentrating on topics for extended periods. Therefore, incomplete or unsuccessful task completion initially raised questions about whether this was due to student competence deficiencies or instruction comprehension problems. Thus, explaining instructions and presenting tasks was critically important.

Figure 3 presents the progression of student performance across all five interventions, showing steady improvement in spatial reasoning abilities. The data shows the evaluation results of 9 students, as only 9 students attended all interventions. Under conditions of incomplete attendance, drawing conclusions based on participants' competencies becomes difficult. In general, absenteeism is a problem that reduces the effectiveness of planned and implemented activities. In the Georgian reality, such a study, which examines the impact of absenteeism in this context, does not exist.

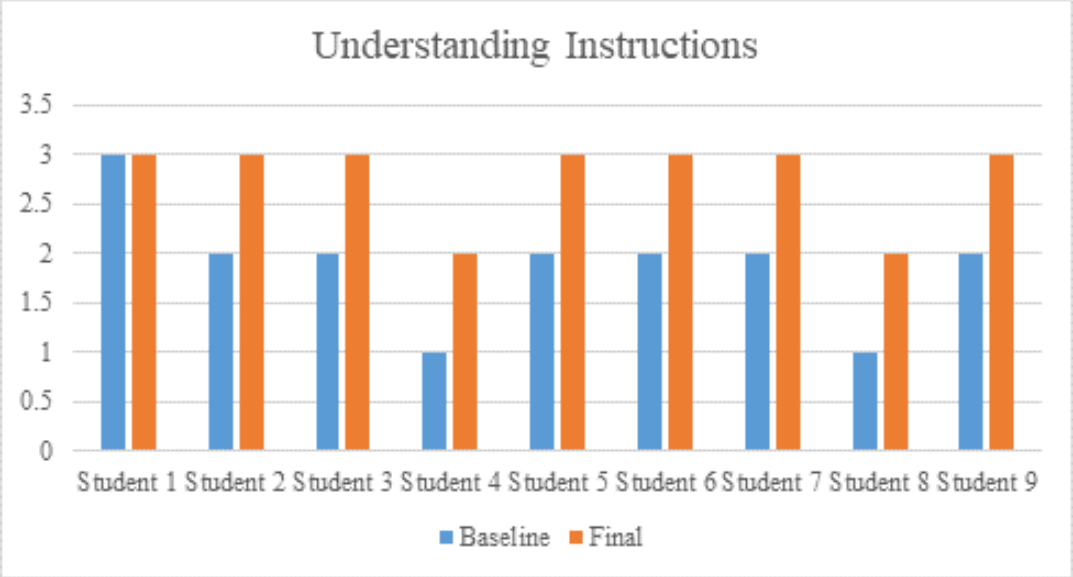

Figure 3. Student performance progression across interventions

Self-assessment data showed that most students initially assessed their work with maximum scores, despite errors. However, by the fifth intervention, as a result of active teacher feedback and group discussions, students' self-assessments aligned with actual performance in over 70% of cases. This indicates progress in metacognitive skills—students learned how and why to assess their own learning.

Figure 4 illustrates the alignment between student self-assessment and actual performance across the intervention period.

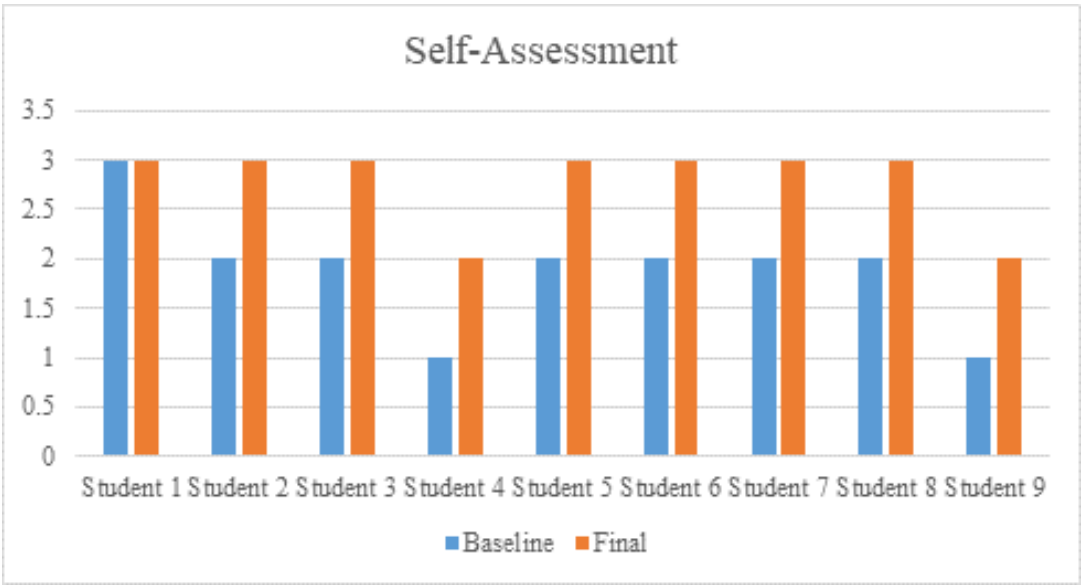

Figure 4. Convergence of self-assessment and actual performance

Data confirms that with design progress, students' approaches to tasks and instruction understanding changed. While the first intervention was characterized by template-based perception and difficulty in functional map use, from the third intervention students began better perceiving information and reasoning. For example, on given map territories, they evaluated not only geographical factors but also environmental impact (e.g., roads running through forests requiring maintenance).

According to the teacher, student engagement significantly increased during proposed tasks when decisions depended on them rather than just finding correct answers. This reflects PBL approach effectiveness—interest and motivation increase when students are responsible for thinking and choice.

Analysis also revealed several challenges, as represented in figure 5. For some students, map orientation remained problematic—especially correctly reading scale and symbols. However, the main challenge was argumentation, the clear, academic formulation of their results. These difficulties indicate that teaching spatial thinking should include not only problem-solving but also consistent work on developing appropriate domain-specific vocabulary and argument formation.

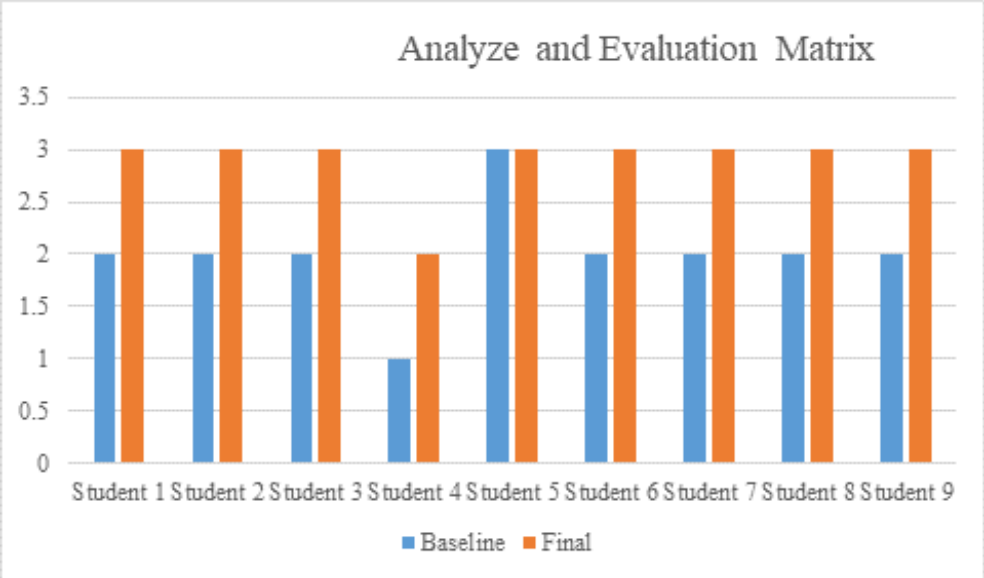

Figure 5. Comparison of how the analytical competence developed

According to the teacher's assessment, students who had self-confidence deficits in teamwork struggled with analysis and justifying their positions, but over time, they began formulating arguments better. This confirms that, under supportive environment conditions and consistent stimulation, spatial thinking competence is accessible to a wide range of students.

The intervention's consistent nature proved to be an important success factor. While first tasks were based on simpler scenarios, each subsequent intervention increased demands—parameter numbers became more complex, conflicting choices were added, and argumentation required refinement. Thus, progress was conditioned not by one-time activities but by structured and adapted intervention sequences.

The ability to make reasoned choices, which initially was based primarily on single-sentence evaluations (e.g., "It's a good place"), gradually evolved into multi-factorial reasoning: "The selection of this territory is due to its proximity to water, high elevation, and forest protection, which creates a safe environment for a primitive settlement."

Finally, analysis clearly shows that through effectively planned and consistent interventions, it is possible to develop complex skills that empower students not only in subject knowledge but also in general thinking and self-reflection. This research demonstrates that, given appropriate design, students begin to think spatially—not mechanically, but consciously, critically, and argumentatively.

Conclusion

The main findings clearly demonstrate that developing spatial thinking and problem-solving skills at the primary level is possible if teaching is based on problem-based, consistent, context-oriented design. The interventions revealed students' increasing progress not only in map reading and identifying spatial relationships but also in argumentation quality, decision-making processes, and self-assessment accuracy.

Findings:

• Clear discrepancy exists between standards and practice—standards are general and do not define minimum levels for spatial skill competencies

• Textbooks are dominated by superficial, descriptive tasks that induce neither critical thinking nor reasoned choice

• Problem-based interventions create learning environments that develop spatial thinking with both subject-specific and metacognitive components

• Student engagement significantly increases when they are allowed to work on real problems and make decisions independently

• Teacher support and professional development are critically important for designing tasks that meet students' evolving needs

Recommendations:

For Policy Makers:

• Revise the National Curriculum to include clear formulation of spatial thinking competencies and definition of key indicators; develop frameworks to measure spatial reasoning rather than factual recall

• Create platforms for schools to exchange experiences and design examples based on practical interventions

For Publishers:

• Include age-appropriate examples of problem-based, multi-factorial tasks in textbooks, along with maps and visual analytical resources

• Develop supplementary materials that support spatial thinking development

For Teacher Training:

• Prioritize intervention strategies based on design research foundations and SPBL model mastery in teacher training programs

• Support teachers in developing skills for creating and adapting spatial problem-solving tasks

For Schools:

• Ensure all students have access to visual materials and opportunities to practice spatial interpretation skills; create supportive environments for spatial problem-solving

• Address absenteeism issues that particularly affect cumulative skill development

This research confirms that spatial thinking-based learning is possible; it requires only the right approach, consistent intervention, and strong theoretical foundations that provide subject-oriented and critical thinking-oriented teaching and learning.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

M.R. conceived the study, designed the research methodology, and took the lead in writing the manuscript. **M.M.** facilitated the implementation of the research intervention and assisted in the data validation process. Both authors have read and approved the final manuscript.

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