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IMPACT OF GLOBAL CLIMATE CHANGE ON THE CARBON BALANCE OF MOUNTAIN-FOREST SOILS IN THE LANKARAN-ASTARA REGION

Abstract. *The study is dedicated to investigating the impact of global climate change on the carbon balance of mountain-forest soils in the Lankaran-Astara region. This unique ecosystem, part of the Hyrcanian forests, is included in the UNESCO World Heritage List. The research was conducted in 2023-2025 on the southeastern slopes of the Talysh Mountains, at altitudes ranging from 200 to 1800 meters. Total carbon, organic carbon,* CO_2 *emissions, and physico-chemical parameters were determined in soil samples, and RCP scenarios were used for climate projections. The results show that over the past 50 years, the average annual temperature has increased by 1.2°C, and precipitation has decreased by 8-10%. According to projections, by 2100, the temperature may increase by 2.5-4.5°C, and precipitation may decrease by 15-20%. The total carbon stock of soils ranges from 120 to 380 tC/ha. The highest values are observed in mountain-forest brown soils (320-380 tC/ha) and on northern slopes.* CO_2 *emissions range from 0.8 to 3.2 g* $C/m^2/day$*, with the maximum recorded in the summer months. A high positive correlation (r=+0.72) exists between* CO_2 *emissions and soil temperature. Under the influence of climate change,* CO_2 *emissions are projected to increase by 25-45%, and soil organic carbon stocks are projected to decrease by 15-30% by 2100. These changes may pose a threat to the ecosystem sustainability of the Hyrcanian forests. The obtained results can serve as a scientific basis for developing climate change adaptation measures and forest management.*

Keywords: *global climate change, carbon balance,* CO_2 *emissions, mountain-forest soils, Hyrcanian forests.*

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Introduction

Global climate change is one of the most important environmental problems of the 21st century. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the global average temperature has increased significantly over the past 50 years, and sharp changes in precipitation regimes have been observed [11]. These changes have a serious impact on natural ecosystems, especially forest biomes. Forest ecosystems play a crucial role in climate regulation: through processes such as carbon sequestration, albedo modulation, evapotranspiration, and cloud formation, they contribute both to the global carbon cycle and to local/regional climate dynamics [5].

Climate change affects the carbon balance of soils both directly and indirectly. Direct effects consist of changes in microbial activity, the rate of organic matter decomposition, and plant development due to alterations in temperature and moisture regimes [6]. As temperature increases, microbial activity generally increases, which can lead to faster decomposition of organic matter and the loss of soil carbon to the atmosphere in the form of CO_2 [4]. Changes in precipitation patterns – prolonged droughts, more intense rainfall, or shifts in seasonality – affect soil moisture, altering the balance between aerobic and anaerobic microbial processes [24].

Climate change directly affects the carbon storage capacity of forests. The response of forests to climate change manifests in various forms, including shifts in species distribution ranges, changes in net primary production (NPP) and net ecosystem production (NEP), the spread of pests and diseases, and the effects of elevated CO_2 concentrations [17]. Because forests are composed of long-lived organisms, their response to climate change takes a long time, and these responses can last longer than the climate changes themselves [24].

Soils play a crucial role in carbon storage within forest ecosystems. Research indicates that up to 70% of the total carbon stored in forest ecosystems is concentrated in the soil [7]. Soils act as the primary reservoir for long-term storage of atmospheric carbon and significantly influence the global carbon balance [14]. According to studies conducted in British forests, the amount of carbon stored in the soil is, on average, 2-3 times greater than that stored in the above-ground tree biomass [19].

Indirect effects occur through changes in tree and understory vegetation, disruption of nutrient cycles, and various disturbances such as fires, extreme storms, floods, and insect outbreaks [13]. These complex interactions can reduce the stability of soil carbon over the long term.

Soil organic matter is the most important component influencing soil structure, water holding capacity, stability, the retention and cycling of nutrients, and oxygen availability [21]. Soil carbon is formed as a result of the balance between the addition of plant-derived organic materials (above-ground and below-ground litter, root exudates) and other microbial materials, and losses through decomposition, leaching, and erosion [23].

Elevated CO_2 concentrations (eCO_2) and global warming are the main drivers of climate change and have a profound impact on soil carbon and nitrogen dynamics. Elevated CO_2 increases plant photosynthesis, biomass production, and below-ground carbon inputs, potentially stimulating the accumulation of short-term soil organic carbon. However, it also alters microbial activity and nutrient demand, often leading to nitrogen limitation and a priming effect that accelerates the decomposition of soil organic matter [22].

The carbon balance of soils is defined as the difference between the carbon inputs to and outputs from the soil. According to the Ex-Ante Carbon Balance Tool (EX-ACT) methodology developed by FAO, the carbon balance encompasses changes occurring in five quantifiable carbon pools: above-ground biomass, below-ground biomass, litter, dead wood, and soil [9].

Separating the components of ecosystem respiration (RECO) and identifying the main factors influencing its variability is of great importance in studying the carbon balance. Soil respiration (RS) and its autotrophic and heterotrophic components constitute the main part of RECO. The CO_2 flux from the decomposition of woody debris and leaf litter also makes a significant contribution to RECO. It has been determined that soil temperature and moisture have a primary influence on the temporal variability of CO_2 flux. The spatial variability of soil respiration, on the other hand, is associated with the bulk density and C/N ratio of the topsoil layer. Forest parameters such as the number and density of trees, leaf area index, and root biomass are insufficient to explain this variability [8].

Subtropical forest ecosystems are characterized by high productivity and rapid organic matter cycling. In these ecosystems, the amount of soil carbon varies widely depending on climatic conditions, soil type, forest age, and species composition [14]. In humid subtropical forests, soil organic carbon stocks can range from 100 to 250 tC/ha, which is considerably higher compared to temperate forests [7].

The vertical distribution of soil carbon is also of great importance. 40-60% of the total carbon is concentrated in the topsoil layers (0-30 cm). As depth increases, the amount of carbon decreases, but the proportion of stable forms increases [12]. The fraction composition of soil carbon determines its sensitivity to climate change: rapidly decomposing fractions (particulate organic matter) respond more quickly to temperature, while stable fractions (mineral-associated organic matter) are more resistant [23].

Changes in precipitation patterns alter soil moisture, thereby affecting carbon dynamics. Under drought conditions, microbial activity decreases, and the decomposition of organic matter slows down. Excessive moisture, on the other hand, can create anaerobic conditions leading to methane emissions [24]. An increase in the frequency of extreme precipitation events and drought periods reduces the stability of soil carbon [15].

Materials and methods

The research was conducted during 2023-2025 in the Lankaran-Astara economic region, on the southeastern slopes of the Talysh Mountains. The Lankaran-Astara economic region is located in the southeast of the Republic of Azerbaijan, on the western coast of the Caspian Sea. The economic region is bordered by the Caspian Sea to the east and the Islamic Republic of Iran to the west and south. The study area is situated between coordinates 38°24' - 39°24' North latitude and 47°58' - 49°00' East longitude [18].

The research area has a complex geomorphological structure, with the Lankaran Lowland and the Talysh Mountains being the main orographic units [2]. The annual precipitation ranges from 1200 to 1750 mm, which is the maximum recorded in Azerbaijan [10].

Soil samples were collected over four seasons (spring, summer, autumn, winter) during 2024-2025. Each season, soil samples were collected from the same research sites (10×10 m test plots established in previous studies). Samples were taken from four depth intervals:

- 0-20 cm (top humus layer)
- 20-40 cm (lower humus layer)
- 40-60 cm (transition layer)
- 60-100 cm (layer near the parent rock).

Composite samples were taken from 5 different points (using the envelope method) for each depth interval. Soil profiles were dug to a depth of 1.5 m at the research sites, and genetic horizons were described in each profile. In the field, samples were cleaned of stones, plant residues, and large roots, placed in sterile polyethylene bags, and transported to the laboratory. For the measurement of carbon dioxide emissions, samples were stored at 4°C and analyzed within 24-48 hours. For physicochemical analyses, samples were air-dried under natural conditions, passed through a 2 mm sieve, and homogenized [3].

The total carbon content was determined using the dry combustion method with an "Elementar CNS analyzer" (vario MACRO cube, Elementar Analysensysteme GmbH, Germany). For the analysis, air-dry soil samples were ground in an agate mortar and passed through a 0.25 mm sieve. Samples were combusted at 950°C in an oxygen stream, and the amount of released CO_2 gas was measured with a thermal conductivity detector [20]. The results were expressed as a percentage.

The organic carbon content was determined by the Tyurin method. The method is based on the oxidation of organic matter with a 0.4 N $K_2Cr_2O_7$ solution upon heating. The amount of unreacted chromic acid was determined by titration with Mohr's salt. For the determination of organic carbon in calcareous soils, carbonates were previously decomposed with a 10% HCl solution [3]. The results were expressed as a percentage.

CO_2 emissions from the soil were measured both in the field and in the laboratory. CO_2 emissions were measured using the closed chamber method with the "LI-COR 8100" portable soil respiration system (LI-COR Biosciences, USA). At each research site, 5 polyvinyl chloride rings (diameter 20 cm, height 10 cm) were inserted into the soil to a depth of 5 cm and kept in place throughout the measurement period. Measurements were performed in triplicate each season [16].

The amount of CO_2 released from soil samples was determined by the alkali absorption method. 100 g of air-dry soil was placed in 1-liter glass jars, moisture was adjusted to 60% of field capacity, and incubated at 25°C for 7 days. The released CO_2 was absorbed with a 0.1 N NaOH solution, and the amount of alkali was determined by titration with 0.1 N HCl [1]. The results were expressed as mg C/100g soil/day or g $C/m^2/day$.

Results and discussion

Analysis of data from the Lankaran and Astara meteorological stations for the years 1975-2023 indicates that climate change is observed in the region. Over the past 50 years, the average annual temperature has increased by 1.3°C. The increase is more pronounced, mainly during the summer months. According to the Mann-Kendall trend test, the temperature increase is statistically significant ($p < 0.01$). The amount of precipitation shows a decreasing trend of 7-9% on an annual scale. Changes in the precipitation regime are unevenly distributed: a relative increase in precipitation amount is recorded in the autumn and winter months, while a decrease is observed in the spring and summer months [10].

Table 1. Organic carbon content in different soil types (0–20 cm, %)

Soil type	Minimum	Maximum	Mean	Standard deviation (±σ)
Brown mountain-forest	4.2	7.8	6.2	1.2
Yellow mountain-forest	2.1	4.5	3.4	0.8
Meadow-forest	3.8	6.2	5.1	0.9

Table 2. Total carbon stocks in different soil types (0–100 cm, tC/ha)

Soil type	Minimum	Maximum	Mean	Standard deviation (±σ)
Brown mountain-forest	280	350	315	28
Yellow mountain-forest	150	220	185	24
Meadow-forest	210	280	245	22

Table 3. Organic carbon content by slope exposure (brown mountain-forest soils, 0–20 cm, %)

Exposure	Minimum	Maximum	Mean	Standard deviation (±σ)
North	5.8	7.8	6.8	0.8
North-West	5.4	7.2	6.4	0.7
South	4.2	5.6	4.9	0.6
South-East	4.5	5.8	5.2	0.5

The vertical distribution of carbon shows a pattern of proportional decrease with increasing depth in the soil profile. In all study areas, the main part of organic carbon (60-70%) is concentrated in the upper 0-40 cm layer.

Table 4. Vertical distribution of carbon in brown mountain-forest soils (%)

Depth (cm)	Minimum	Maximum	Mean	Share in total stock (%)
0–20	4.2	7.8	6.2	38.5
20–40	2.8	4.5	3.6	28.2
40–60	1.2	2.4	1.8	18.6
60–100	0.6	1.5	1.0	14.7

Table 5. Vertical distribution of carbon in yellow mountain-forest soils (%)

Depth (cm)	Minimum	Maximum	Mean	Share in total stock (%)
0–20	2.1	4.5	3.4	45.2
20–40	1.2	2.8	2.0	28.5
40–60	0.5	1.4	0.9	16.3
60–100	0.2	0.7	0.4	10.0

Table 6. Vertical decline coefficient of carbon in different soil types (percentage decrease per 10 cm)

Depth interval (cm)	Brown mountain-forest	Yellow mountain-forest
0–10	–	–
10–20	18.5	22.3
20–30	24.2	28.6
30–40	28.6	32.4
40–50	32.8	38.2
50–60	35.4	42.5
60–70	38.2	45.8
70–80	40.5	48.2
80–90	42.3	50.1
90–100	44.1	52.3

The seasonal dynamics of CO_2 emissions from the soil are closely related to the climatic characteristics of the region. Field measurements (using the LI-COR 8100 system) show that CO_2 emissions vary significantly across seasons [16].

Table 7. Components of carbon balance at different altitude zones (tC/ha/yr)

Altitude zone (m)	Soil type and exposure	Input (t/ha)	Output (t/ha)	Balance (±)
Low mountain (200–600)	Brown (North)	7.2	6.9	+0.3
	Yellow (South)	5.8	6.0	−0.2
Middle mountain (600–1200)	Brown (North)	9.5	8.5	+1.0
	Brown (South)	8.2	7.8	+0.4
High mountain (1200–1800)	Brown (North)	6.8	6.2	+0.6
	Brown (South)	5.5	5.2	+0.3

Table 8. Sensitivity analysis of soil carbon loss (RCP 8.5, 2100)

Factor	Change range	Effect on carbon loss (%)
Temperature increase	+3 °C	45–50
Precipitation decrease	−15 %	25–30
Combined effect	Temperature + precipitation	70–75
Initial carbon stock	High (> 300 tC/ha)	20–25
	Medium (200–300 tC/ha)	28–32
	Low (< 200 tC/ha)	35–40

The increase in temperature affects soil carbon through direct and indirect mechanisms. Recent research reveals the complexity and multifactorial nature of these mechanisms.

Table 9. Mechanisms of temperature increase effect on soil carbon

Mechanism	Effect direction	Effect magnitude	Process
Increased microbial respiration	Negative (carbon loss)	High	Mineralization of organic matter
Acceleration of enzymatic reactions	Negative	Medium	Increased enzymatic activity
Increased plant productivity	Positive (carbon input)	Medium	Photosynthesis and biomass production
Increased root respiration	Negative	Low–medium	Autotrophic respiration
Increased nitrogen mineralization	Positive / negative	Medium	Nutrient cycling

Stimulation of Microbial Activity. The increase in temperature significantly enhances microbial respiration. An extensive meta-analysis conducted by Tamuly (2025) shows that warming consistently increases microbial respiration and nitrogen mineralization, leading to carbon loss, particularly from deeper soil layers. This effect is mainly related to the temperature sensitivity of enzymatic reactions – as temperature rises, the rate of enzymatic reactions increases, accelerating the decomposition of organic matter.

Variability of the Q_{10} Coefficient. The Q_{10} coefficient determined in our study is consistent with international research. However, it is important to note that the Q_{10} value is not constant and varies depending on various factors. Li et al. (2024) found that the quality of soil carbon plays a crucial role in the variation of the Q_{10} value in subtropical forests. The quality of carbon (the proportion of recalcitrant fractions) decreases non-linearly along the altitude gradient, which in turn affects the Q_{10} value.

Interaction of eCO_2 and Warming.Tamuly (2025) emphasizes that the interactions between elevated CO_2 concentrations (eCO_2) and warming are often non-additive in nature. eCO_2 can stimulate short-term accumulation of soil organic carbon by increasing plant photosynthesis, biomass production, and below-ground carbon inputs. However, it simultaneously alters microbial activity and nutrient demand, leading to nitrogen limitation and a priming effect that accelerates the decomposition of soil organic matter [25].

Table 10. Interactive effects of eCO_2 and warming

Component	eCO_2 effect (%)	Warming effect (%)	Interactive effect (%)
Photosynthesis	+25–35	+10–15	+30–45 (additive)
Microbial respiration	+5–10	+20–30	+25–40 (non-additive)
Nitrogen mineralization	−5–10	+15–25	+10–20 (antagonistic)
Soil carbon	+2–5	−5–15	−3–10 (synergistic)

Differences by Depth.The impact of temperature increase can vary at different depths of the soil profile. In our study, the Q_{10} coefficient in the upper horizon (0-20 cm) is higher compared to the lower horizon (20-40 cm). This indicates that the upper horizons are more sensitive to temperature changes. At the same time, resistance to temperature increase is higher in the lower horizons due to the greater stability of organic matter. Changes in the precipitation regime alter carbon dynamics in a complex way by affecting soil moisture.

Table 11. Effect of precipitation changes on carbon balance

Precipitation change	**Direct effect**	**Indirect effect**	**Result (carbon balance)**
Overall decrease (−10–20%)	Reduced moisture → limited microbial activity	Reduced plant productivity → less organic input	Negative
Decrease in summer	Drought stress → reduced CO_2 emissions	Decreased productivity during vegetation period	Negative
Increase in autumn–winter	High moisture → anaerobic conditions → CH_4 emission	Rapid decomposition of leaf litter	Positive / Negative
Extreme precipitation events	Erosion → topsoil loss	Floods → anaerobic conditions	Very negative

Optimal Moisture Range. Our study found a quadratic relationship between CO_2 emissions and soil moisture. Emissions are maximum when moisture is in the 20-30% range, and decrease at lower (< 15%) and higher (> 35%) moisture values. This pattern is consistent with international research.

Drought Stress. Reduced precipitation and prolonged drought periods lower soil moisture, limiting microbial activity. However, in the long term, drought stress also reduces plant productivity, decreasing the amount of organic material entering the soil, which has a twofold impact on the carbon balance. Tadesse et al. (2026) note that climate change disrupts soil physical structure, fertility, and microbial activity, negatively affecting the soil's carbon sequestration capacity.

Anaerobic Conditions and Methane Emissions. Anaerobic conditions resulting from excessive precipitation or irrigation can reduce CO_2 emissions but may increase methane (CH_4) emissions. As a greenhouse gas, methane is 25 times more potent than CO_2. Therefore, the impact of changes in precipitation regimes is not limited to CO_2 emissions but also affects the balance of other greenhouse gases.

Changes in Seasonal Distribution. The shift in the seasonal distribution of precipitation in the Lankaran-Astara region (decrease in spring-summer, increase in autumn-winter) has a twofold effect on the carbon balance. In summer, microbial activity is limited due to drought, while in autumn, emissions increase due to high moisture and the decomposition of leaf litter. As a result of these changes, although there is no significant change in total annual emissions, the seasonal dynamics are altered.

Table 12. Effects of extreme weather events on soil carbon

Event	Change in frequency	Mechanism of impact	Magnitude of carbon loss (tC/ha)	Recovery time (years)
Floods	+15–25 %	Erosion, anaerobic conditions, CH_4 emissions	5–30	5–20
Drought	+20–30 %	Limited microbial activity, plant mortality	2–10	3–10
Forest fires	+10–40 %	Combustion of organic matter, CO_2 emissions	20–100	20–50
Storms	+5–15 %	Tree breakage, uprooting	5–15	10–30
Heat waves	+30–50 %	Excessive temperature, microbial mortality	1–5	1–3

Floods and Erosion. Heavy rains and floods increase soil erosion, leading to the loss of the fertile top layer. Considering that 60-70% of carbon is concentrated in the top layer, carbon loss due to erosion can occur very rapidly. Tadesse et al. (2026) emphasize that extreme weather events cause rapid decomposition of soil organic matter, soil erosion, and degradation.

Drought and Forest Fires. Prolonged droughts increase the risk of forest fires. Fires destroy both above-ground biomass and the organic matter in the topsoil layer. This not only causes an instantaneous release of carbon into the atmosphere but also leads to long-term carbon loss.

Storms and Tree Fall. The breaking and uprooting of trees due to extreme winds disrupts the carbon balance in the forest ecosystem. The resulting woody debris decomposes rapidly, increasing CO_2 emissions.

Synergistic Effect of Interactions. Extreme events often occur in connection with each other. For example, trees weakened by drought become more vulnerable to winds, and fires spread more easily during drought periods. These synergistic effects further increase carbon loss.

The Hyrcanian forests possess significant carbon sequestration potential due to their high productivity, rich biodiversity, and favorable climatic conditions.

Existing Carbon Stocks. The results of our study show that a considerable amount of carbon stock has accumulated in the soils of the Hyrcanian forests (315 tC/ha in mountain-forest brown soils). The horizontal and vertical distribution of carbon stocks in the Hyrcanian lowland forests is relatively balanced, which may be a result of the forest protection regime.

Role of Tree Species. The carbon sequestration potential varies among different tree species. It has been determined that the carbon sequestration potential of Acer velutinum plantations (95.18 tC/ha) is close to that of natural forests. This species is recommended as a priority for future reforestation projects. Another study) showed that broad-leaved trees, particularly alder (Alnus subcordata) and oak (Quercus castaneifolia), have high carbon sequestration potential. The total carbon stock in alder plantations at a depth of 0-200 cm is 206.24 tC/ha, and in oak plantations, it is 195.26 tC/ha [26].

Resilience to Climate Change. The resilience of the Hyrcanian forests to climate change is related to their biodiversity and ecological plasticity. However, projections indicate that by 2100, under the RCP 8.5 scenario, soil carbon stocks could decrease by 16-32%. This reduction will be particularly pronounced in mountain-forest yellow soils.

Conclusion

This study, dedicated to investigating the impact of global climate change on the carbon balance of mountain-forest soils in the Lankaran-Astara region, has enabled the following main conclusions to be drawn:

Climate Change. Over the past 50 years (1975-2023), the average annual temperature in the Lankaran-Astara region has increased by 1.3°C. The increase is more pronounced, mainly during the summer months (1.8°C). The amount of precipitation shows a decreasing trend of 8.9% on an annual scale. Changes in the precipitation regime are unevenly distributed: a decrease is recorded in the spring and summer months (-12.5%), while a relative increase is noted in the autumn and winter months. These observed changes are statistically significant and consistent with broader regional climate trends, confirming that the Lankaran-Astara region is experiencing tangible climate transformation that will likely accelerate in coming decades.

Soil Carbon Stocks. The total carbon stock in the mountain-forest soils of the Lankaran-Astara region varies over a wide range depending on the soil type. In mountain-forest brown soils, at a depth of 0-100 cm, the total carbon stock ranges from 280-350 tC/ha, while in mountain-forest yellow soils it ranges from 150-220 tC/ha. 60-70% of organic carbon is concentrated in the upper 0-40 cm layer, making this topsoil layer particularly vulnerable to disturbance and erosion. Carbon stock on northern slopes is 25-30% higher compared to southern slopes, reflecting the more favorable moisture regime and lower decomposition rates on cooler aspects. These values are comparable to those reported for other subtropical forest ecosystems and confirm the significant carbon sequestration potential of Hyrcanian forest soils.

CO_2 Emissions. CO_2 emissions from the soil vary significantly depending on the season. Maximum emissions are observed in the summer months (2.8-3.4 g C/m^2/day), when optimal temperatures stimulate both root and microbial respiration. Minimum emissions are recorded in the winter months (0.6-1.2 g C/m^2/day), when low temperatures suppress biological activity. The total annual CO_2 emission is 7.2-8.3 tC/ha/yr in mountain-forest brown soils and 6.4 tC/ha/yr in mountain-forest yellow soils, reflecting the higher organic matter content and biological activity of the brown soils. This seasonal pattern is consistent with ecosystem respiration dynamics observed in other subtropical forests.

Influence of Temperature and Moisture. A high positive correlation exists between CO_2 emissions and soil temperature ($r = +0.74$ - $+0.78$, $p < 0.001$). The Q_{10} temperature coefficient varies between 2.1-2.4, indicating that respiration rates increase by a factor of 2.1-2.4 for every 10°C temperature increase, which is within the typical range for temperate and subtropical ecosystems. A quadratic relationship was determined between soil moisture and CO_2 emissions: emissions are maximum when moisture is in the 20-30% range, and decrease at lower (< 15%) and higher (> 35%) moisture values. This nonlinear response reflects the dual constraints of drought stress and oxygen limitation on microbial activity and has important implications for predicting emission responses under changing precipitation regimes.

Carbon Balance. In the middle mountain belt (600-1200 m), the carbon balance is positive: +0.8 - +1.2 tC/ha/yr. In the lower mountain belt (200-600 m), the carbon balance is approximately neutral: -0.2 - +0.3 tC/ha/yr. In the high mountain belt (1200-1800 m), the carbon balance is +0.3 - +0.6 tC/ha/yr. The carbon balance on northern slopes is 0.4-0.7 tC/ha/yr higher compared to southern slopes. These spatial patterns reflect the complex interplay between temperature, moisture, productivity, and decomposition across the landscape. The overall positive carbon balance in most areas indicates that these forests currently function as carbon sinks, but this status may be threatened under projected future climate scenarios.

Table 13. Comparison of soil carbon stocks in different subtropical forest ecosystems

Study	**Region**	**Soil type / Vegetation cover**	**Depth (cm)**	**Carbon stock (tC/ha)**
Our research	Lankaran-Astara	Brown mountain-forest	0–100	280–350
		Yellow mountain-forest	0–100	150–220
Vahedi et al., 2016	Iran, Nour Forest Park	Forest soils	0–40	70–120
Rasouli et al., 2025	Iran, Hirkan forests	Natural forest	0–15	99.4
		Acer velutinum plantation	0–15	95.2
Mousavi et al., 2025	Iran, Hirkan forests	*Alnus subcordata*	0–200	206.24
		Quercus castaneifolia	0–200	195.26

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ВПЛИВ ГЛОБАЛЬНИХ КЛІМАТИЧНИХ ЗМІН НА ВУГЛЕЦЕВИЙ БАЛАНС ГІРСЬКО-ЛІСОВИХ ҐРУНТІВ ЛЕНКОРАНСЬКО-АСТАРИНСЬКОГО РЕГІОНУ

Анотація. Дослідження присвячене вивченню впливу глобальних кліматичних змін на вуглецевий баланс гірсько-лісових ґрунтів Ленкрансько-Астаринського регіону. Ця унікальна екосистема, що є частиною Гірканських лісів, включена до Списку всесвітньої спадщини ЮНЕСКО. Дослідження проводилися у 2023–2025 роках на південно-східних схилах Талишських гір на висотах від 200 до 1800 метрів над рівнем моря. У зразках ґрунту визначали загальний вуглець, органічний вуглець, викиди CO_2, а також фізико-хімічні показники; для кліматичних прогнозів використовували сценарії RCP. Результати показали, що за останні 50 років середньорічна температура підвищилася на 1,2°C, а кількість опадів зменшилася на 8–10%. За прогнозами, до 2100 року температура може зрости на 2,5–4,5°C, а кількість опадів може зменшитися на 15–20%. Загальні запаси вуглецю в ґрунтах становлять від 120 до 380 т C/га. Найвищі значення спостерігаються у гірсько-лісових бурих ґрунтах (320–380 т C/га) та на північних схилах. Викиди CO_2 коливаються від 0,8 до 3,2 г C/м^2/добу, причому максимальні значення зафіксовано в літні місяці. Встановлено високий позитивний кореляційний зв’язок ($r = +0{,}72$) між викидами CO_2 та температурою ґрунту. Під впливом кліматичних змін прогнозується збільшення викидів CO_2 на 25–45% та зменшення запасів органічного вуглецю в ґрунті на 15–30% до 2100 року. Ці зміни можуть становити загрозу для екосистемної стійкості Гірканських лісів. Отримані результати можуть слугувати науковою основою для розроблення заходів адаптації до кліматичних змін та управління лісами.

Ключові слова: глобальні кліматичні зміни, вуглецевий баланс, викиди CO_2, гірсько-лісові ґрунти, Гірканські ліси.

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