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ASSESSMENT OF CLIMATE CHANGE IMPACT ON ARMENIA'S FOREST ECOSYSTEMS AND MITIGATION MEASURES

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The article analyzes the impact of climate change on forest ecosystems in Armenia. Historical and projected climate data were studied, and the impact of changes in temperature and precipitation on forest distribution, species composition and biodiversity was assessed. The article also presents climate change maps and vulnerability analysis of forest areas. Mitigation and adaptation strategies are proposed, including the use of drought-tolerant species, fire and pest management systems, and conservation of genetic resources. The article also emphasizes the need for a systemic and localized approach to forest policy development and biodiversity conservation.

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***Keywords*:** climate change, forest ecosystems, Armenia, impact assessment, mitigation measures, adaptation strategies.

Introduction. Climate change poses a significant threat to global ecosystems, with particularly pronounced effects in mountainous regions, where climatic zones shift rapidly over short distances [1]. Forests, which are vital for biodiversity, carbon sequestration, and socio-economic stability, are especially vulnerable to these changes. Armenia, a mountainous country in the South Caucasus, exemplifies this vulnerability due to its diverse terrain and semi-arid to temperate climate. Covering approximately 11.2% of Armenia's territory, forests play a key role in maintaining ecological balance and providing livelihoods, yet they face increasing pressure from rising temperatures, changing precipitation patterns, and associated risks such as droughts and wildfires [2].

The aim of this study is to assess the impact of climate change on Armenia's forest ecosystems and propose effective mitigation measures. By relying on historical and projected climate data, the study evaluates shifts in climatic zones, identifies vulnerable forest areas, and explores adaptive strategies to enhance forest resilience. The significance of this work lies in integrating global climate models with local ecological data, providing a basis for informed forest management in Armenia amid global warming.

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On a global scale, climate change has accelerated over the past century, with rising temperatures and extreme weather events disrupting ecosystems [3]. In Armenia, these trends are evident: from 1935 to 2022, the temperature has risen by 1.5℃, while annual precipitation has decreased by 19.5% [4]. Such changes threaten forest health, species distribution, and ecosystem services, necessitating urgent scientific, practical, and legislative action [5].

Materials and Methods. This study employed a multi-faceted approach to assess the impact of climate change on Armenia's forest ecosystems, combining historical data analysis, climate modeling, and spatial mapping. The methodology was based on guidelines from the Intergovernmental Panel on Climate Change (IPCC) [5] and adapted to Armenia's unique ecological context.

Historical climate data for 1961–1990 were obtained from the different sources [6], which provides maps of annual mean temperature, precipitation, and evaporation. These data were digitized using Geographic Information System (GIS) tools (ArcGIS) for spatial analysis. Projected climate data for 2011–2040 were derived from the Community Climate System Model version 4 (CCSM4) and the regional climate model METRAS, as reported in Armenia's Third and Fourth National Communications to the UNFCCC [7, 8]. The RCP8.5 scenario (worst case) was adopted, predicting a temperature increase of 1.7℃ and a slight 1% decrease in precipitation. Current forest cover and species distribution data were obtained from national forest inventories and supplemented by satellite imagery to map the extent and condition of forests.

The IPCC methodology was applied to classify Armenia's climatic zones based on mean annual temperature, mean annual precipitation, and potential evapotranspiration (PET). PET was calculated using the Thornthwaite equation, adjusted for temperature increases. Forest vulnerability was assessed by overlaying climate zone maps onto forest cover data, identifying areas, where shifts in temperature and moisture regimes could affect tree growth. Key indicators included changes in forest area within climatic zones and altitudinal shifts in zone boundaries. Proposed mitigation measures were formulated based on observed impacts, international best practices [9], and local forest management plans, focusing on enhancing resilience and reducing degradation.

It should be noted that despite the reliability of the climate models used (CCSM4 and METRAS), certain limitations exist – particularly in regions with complex mountainous terrain such as Armenia. Orographic effects, microclimatic variations, and limited spatial resolution may lead to potential inaccuracies in temperature and precipitation projections.

GIS tools were used to create historical (1961–1990) and projected (2011–2040) maps of climate zones, allowing visualization of shifts relevant to forests. Forest areas were categorized by vulnerability levels (e.g., high vulnerability, low vulnerability) based on their exposure to warmer and drier conditions.

Results and Discussion. Analysis of historical data revealed a 1.5℃ increase in Armenia's annual mean temperature from 1935 to 2022, with the most pronounced warming occurring in summer at 2.0℃ [3]. Precipitation has declined by 19.5%, with a notable 32% decrease in summer, exacerbating arid conditions. Projections for 2011–2040 under the RCP8.5 scenario indicate a further temperature rise of 1.7℃ and a 14.9% increase in evaporation, despite only a minimal 1% decrease in

precipitation. These trends suggest a shift towards a warmer and drier climate, particularly affecting lower-altitude forest zones. This highlights an overall trend of worsening conditions for forests, as rising temperatures and decreasing precipitation increase ecosystem stress, particularly concerning water availability.

The study identified significant shifts in Armenia's climate zones affecting forests, illustrating the transformation from 1961–1990 to 2011–2040. This transformation underscores that forest in regions such as Tavush and Syunik are becoming increasingly vulnerable to climate change within their territories.

Forest ecosystems are most vulnerable at the lower limits of their distribution, where forests face hotter and drier conditions, threatening species such as Georgian oak (*Quercus iberica*). At the same time, a "new growth zone" is emerging near the upper boundaries, where warming may allow forests to establish in previously colder areas. This simple yet powerful visual representation reflects the dual nature of climate change impacts: while some forest ecosystems are at risk, others may potentially thrive in new locations, though soil conditions, terrain, and competition with grassland vegetation may limit this growth potential.

To quantify these changes, we present shifts in both climate zones (Fig. 1) and forest areas across different climate zones (Fig. 2).

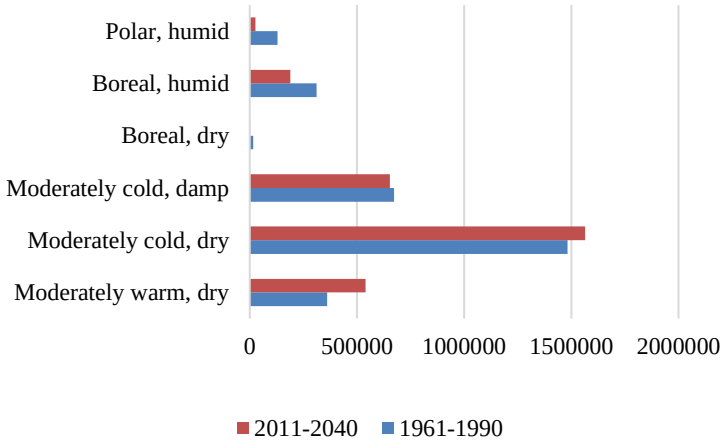

Fig. 1. Areas (*ha*) occupied by climatic zones.

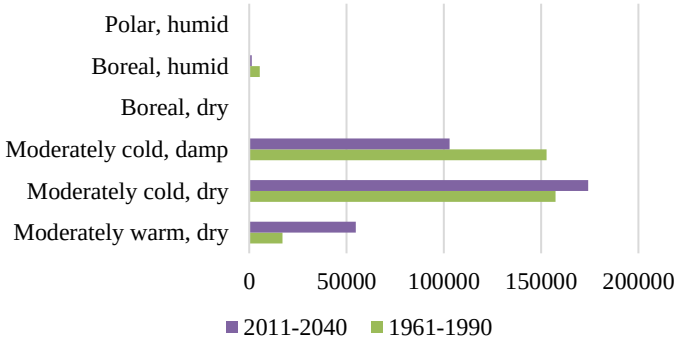

Fig. 2. Distribution of forest areas (*ha*) across different climatic zones.

The analysis of the graphs shows that in the past, the moderately warm dry zone covered 17 115.3 *ha* of forested land. However, by 2040, it is projected to expand to 54 711.5 *ha*. Meanwhile, the moderately cold humid zone, which previously occupied 152 818.54 *ha*, is expected to shrink significantly to 102,887.41 *ha*. These graphs provide specific figures supported by data, illustrating how forests are increasingly being pushed into hotter and drier conditions, where survival becomes uncertain.

Based on the changes in climatic zones and forest growth conditions, we have developed a forest vulnerability map (Fig. 3) to assess the impact of climate change, using a classification system.

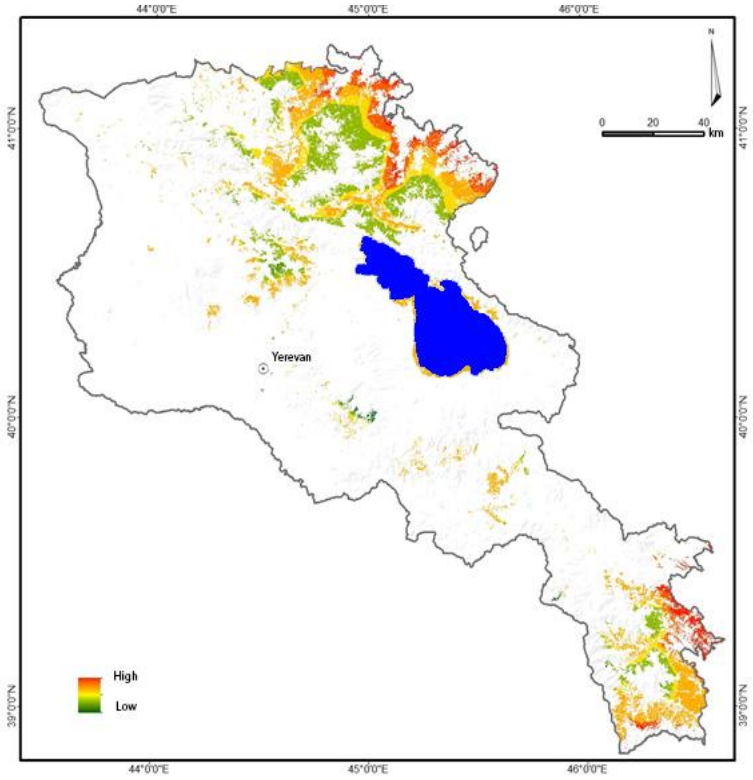

Fig. 3. Degree of vulnerability of Armenia's forested areas to climate change.

This map can serve as a crucial tool in planning and implementing forest management measures for climate change adaptation. Areas with a high degree of vulnerability should be prioritized, with mitigation efforts being implemented first in these regions.

In light of the above, we propose mitigation and adaptation strategies [10] to address the negative impacts, focusing on practical steps. These include:

- Reforestation and afforestation efforts aimed at expanding forest cover using drought-resistant species, particularly in degraded lowland areas. The targeted implementation period is 2025–2050, supported by government and other funding sources.

• Enhanced fire, pest, and diseases prevention management through modern monitoring systems for early detection and rapid response to wildfires and pest outbreaks.

• Species adaptation strategies, including the use of climate-resilient tree species and the establishment of seed banks to preserve genetic material, ensuring long-term forest sustainability.

• Ecosystem monitoring, incorporating continuous assessments of climate impacts on forests and integrating findings into adaptive management plans to maintain resilience.

The expansion of arid zones threatens the productivity and biodiversity of Armenia's forests, increasing ecological risks, while the reduction of humid zones limits habitats for moisture-dependent species. Mitigation measures, such as reforestation and forest transformation with climate-adapted species, offer a proactive response. However, their success depends on adequate funding, community involvement, and precise implementation.

Beyond ecological consequences, the projected climate-driven shifts in forest zones also have important economic implications. For example, the expansion of arid zones and the decline of productive humid forests may reduce the availability of timber and non-timber forest products, impacting local livelihoods and forest-dependent industries. In addition, changes in forest cover and landscape quality could influence Armenia's tourism sector, especially ecotourism in forested regions like Dilijan or Jermuk. Understanding and preparing for these socio-economic effects is essential for comprehensive climate adaptation planning. These findings highlight the urgent need for an integrated climate and forest policy in Armenia, ensuring a balance between environmental conservation and socio-economic benefits.

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ՀԱՅԱՍՏԱՆԻ ԱՆՏԱՌԱՅԻՆ ԷԿՈՀԱՄԱԿԱՐԳԵՐԻ ՎՐԱ ԿԼԻՄԱՅԻ ՓՈՓՈԽՈՒԹՅՈՒՆՆԵՐԻ ԱԶԴԵՑՈՒԹՅԱՆ ԳՆԱՀԱՏՈՒՄ ԵՎ ՄԵՂՄՄԱՆ ՄԻՋՈՑԱՌՈՒՄՆԵՐ

Ամփոփում

Հոդվածում վերլուծվում է կլիմայի փոփոխության ազդեցությունը Հայաստանի անտառային էկոհամակարգերի վրա: Ուսումնասիրել են պատմական և կանխատեսվող կլիմայական տվյալները՝ գնահատելով ջերմաստիճանի և տեղումների փոփոխությունների ազդեցությունը անտառների տարածման, տեսակային կազմի և կենսաբազմազանության վրա: Հոդվածում ներկայացված են նաև կլիմայի փոփոխությունների քարտեզներ և անտառային տարածքների խոցելիության վերլուծություն: Առաջարկվում են մեղմման և հարմարվողականության ռազմավարություններ, այդ թվում՝ երաշտադիմացկուն տեսակների օգտագործում, հրդեհների և վնասատուների կառավարման համակարգերի ներդրում, ինչպես նաև գենետիկ ռեսուրսների պահպանում: Հոդվածը նաև ընդգծում է անտառային քաղաքականության մշակման և կենսաբազմազանության պահպանման համար համակարգային և տեղայնացված մոտեցման անհրաժեշտությունը:

А. З. АЛАВЕРДЯН, З. Т. ТАРХАНЯН

ОЦЕНКА ВОЗДЕЙСТВИЯ ИЗМЕНЕНИЯ КЛИМАТА НА ЛЕСНЫЕ ЭКОСИСТЕМЫ АРМЕНИИ И МЕРЫ ПО СМЯГЧЕНИЮ ПОСЛЕДСТВИЙ

Резюме

В статье анализируется влияние изменения климата на лесные экосистемы Армении. Были изучены исторические и прогнозируемые климатические данные, оценено влияние изменений температуры и осадков на распространение лесов, видовой состав и биоразнообразие. В статье также представлены карты изменения климата и анализ уязвимости лесных территорий. Предлагаются стратегии смягчения последствий и адаптации, в том числе использование засухоустойчивых видов, систем борьбы с пожарами и вредителями, а также, сохранение генетических ресурсов. В статье подчеркивается необходимость системного и локализованного подхода к разработке лесной политики и сохранению биоразнообразия.