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THE ANALYSIS OF THE TRANSFORMATION OF FOREST LANDSCAPES IN THE EASTERN ZANGEZUR REGION OF AZERBAIJAN BASED ON SATELLITE IMAGERY

АНАЛИЗ ТРАНСФОРМАЦИИ ЛЕСНЫХ ЛАНДШАФТОВ ВОСТОЧНО-ЗАНГЕЗУРСКОГО РЕГИОНА АЗЕРБАЙДЖАНА НА ОСНОВЕ СПУТНИКОВЫХ СНИМКОВ

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Abstract. In the article, the forest areas in the Eastern Zangezur region have been thoroughly investigated, and the transformation of forests over the years has been assessed based on the analysis of satellite imagery. For study, we have used images get from LANDSAT and AzerSky satellites. The level of degradation of the forest area in the region was calculated with the help of GIS and Mathematical methods. As a result of this assessment, maps and diagrams have been prepared.

This information will play a major role in the evaluation of the forest area of the Eastern Zangezur region, the proper conduct of forest restoration and construction works, as well as the placement of agriculture. It will also show the environmental damages caused by wars.

Аннотация. В статье подробно исследованы лесные массивы Восточного Зангезура, а также на основе анализа спутниковых снимков оценена трансформация лесов за эти годы. Для исследования использовались снимки, полученные со спутников LANDSAT и AzerSky. Уровень деградации лесного массива региона был рассчитан с помощью ГИС и математических методов. В результате этой оценки были подготовлены карты и диаграммы.

Эта информация будет играть важную роль в оценке лесного массива Восточного Зангезура, правильном проведении лесовосстановительных и строительных работ, а также размещении сельского хозяйства. Она также покажет экологический ущерб, нанесенный войнами.

Keywords: The Eastern Zangezur region, Forest, Landscape, The south and south-eastern slope of the Lesser Caucasus, Geographic Information Systems (GIS)

Ключевые слова: Восточный Зангезурский район, Лес, Ландшафт, Южный и юго-восточный склон Малого Кавказа, Географические информационные системы (ГИС)

INTRODUCTION

The global forest cover extends over an area of 4 billion hectares. Out of this, 809 million hectares belong to the Russian Federation, 478 million hectares to Brazil, 310 million hectares to Canada, and 303 million hectares to the United States (https://azkurs.org/forest-is-a-unity-of-soil-water-trees-shrubs-and-grasses-anima.html). Europe is considered the most forest-rich region. According to the Food and Agriculture Organization (FAO) of the United Nations' data for the year 2020, the total forest area on this continent exceeds 1 billion hectares, positioning Europe ahead of other regions in terms of forested land (Table 1).

Region	Forest area (thousand hectares)
Europe (including Russia)	1 017 461
South America	844 186
North and Central America	752 710
Africa	636 639
Asia	622 687
Australia and Oceania	185 248
Total	**4 058 931**

Table 1. Forest area by world regions (in thousand hectares)

Forests play a role as moisture collectors and regulate the distribution of water, maintaining a relatively balanced state. Additionally, forests prevent soil erosion and mitigate the occurrence of landslides in mountainous areas. Furthermore, forests possess phytosanitary characteristics and eliminate harmful microorganisms. They protect plants, soil, water basins, roads, residential areas, monuments, and natural elements from detrimental effects, modify microclimate, reduce the impact of dry, hot, and strong winds. Forests stabilize valleys, dunes, and shifting sands, allowing for even distribution and gradual melting of snow cover, reducing desertification and lowering groundwater levels. Moreover, the most significant role of forests in nature is their ability to absorb 10-20 tons of carbon dioxide (CO_2) per hectare annually and release oxygen (O_2) in return. One hectare of forest emits 8 kg of carbon dioxide per hour, which is equivalent to the volume of carbon dioxide released into the air by 200 individuals' breaths in one hour.

Forests also play a crucial role in the purification of polluted air. According to the World Health Organization (WHO), every year, 7 million people worldwide die prematurely due to dirty air. Based on research conducted in the United States,

trees have the capacity to purify 17.4 million cubic meters of polluted air per year, which translates to saving an average of 850 lives annually [2].

The rich natural resources, biodiversity, picturesque nature, favorable climate and agro-climatic conditions, diverse geological formations and various relief forms have attracted the attention of travellers and researchers to the selected areas of the Eastern Zangezur region since ancient times, leading to the exploration of the region. The region is situated on the south-eastern slopes of the Lesser Caucasus Mountains and has witnessed numerous historical events. These areas were among the first territories in Azerbaijan to be freed from the waters of the Caspian Sea regression and transformed into dry land as a result of orogenic processes. Even in ancient times, the parts of these areas with tourism significance and the Karabakh Volcanic Plateau were described and studied and extensive research began later. Examples of such early travellers and researchers include Herodotus in the 5th century BC, Strabo in the 1st century AD, Ptolemy in the 2nd century AD, and others. In the Middle Ages, the territory attracted the attention of Arab travellers and researchers, who noted rich information about the climate, relief, flora and fauna, inhabitants, nature, and economy of the south-eastern slopes of the Lesser Caucasus. However, the information from that period is mainly descriptive and factual, carrying historical importance due to its non-scientific nature. Nevertheless, these accounts should not be considered insignificant, as they have increased the interest of various researchers and travelers in the region (Museyibov M.A. (1998), Khalilov Sh. (2006)).

The study of the territorial landscapes from a geographical perspective began in the early 19th century. During this period, known for its industrial development and increasing demand for natural resources, especially mineral resources in mountainous areas, the scope and objectives of research expanded significantly. From 1920, when Azerbaijan and 14 other republics united under the name of the Soviet Union, until 1991, when the former Soviet countries gained independence, extensive and comprehensive research was conducted in all territories, including the Lesser Caucasus Mountains of Azerbaijan, by Russia. In these studies, it is

important to mention the significant contribution of B.A.Budagov, who played a major role in landscape science. He also established the Laboratory of Aerospace Methods at the Geographical Institute named after H.Aliyev of the Azerbaijan National Academy of Sciences (ANAS), utilizing aerospace materials extensively. B.A.Budagov provided valuable information on the territory of the Lesser Caucasus in his works such as "Newly Discovered Upper Sarmatian Sediments in the Shahdagh Zone and Related Tectonic Movements," "Erosion and Accumulative Relief Forms of Ancient Glaciers in the Shahdagh Massif (Azerbaijan SSR)," "Natural Landscapes of the Azerbaijan SSR and Their Conservation," and "Shahdagh Differentiation of the Landscape of the Azerbaijan SSR". In addition, S.I.Mirzayev defended his candidate dissertation on "Pale and Dark Forests in the Upper Part of the Hekerichay Basin: Soil Formation and Forestry Characteristics" and provided detailed research on the genetic-geographical and agroforestry characteristics of the developing mountainous-forest soils in the south-eastern slope of the Lesser Caucasus. During his scientific activities, he extensively studied the biological cycle of ash elements in forest types under stationary conditions, as well as the afforestation characteristics, bonitet assessment, and efficient utilization of forest soils, offering scientific-practical recommendations for increasing soil fertility, forest restoration and more [3].

Until 1991, the territories included in the Eastern Zangezur region of Azerbaijan were studied through field research. However, starting from that year, due to the occupation of the lands, practical research was no longer possible, and theoretical studies began. During this period, many scholars and researchers analyzed the landscapes of the south-eastern slopes of the Lesser Caucasus and produced valuable works. K.S.Allahverdiyev defended his doctoral dissertation on the topic "Quality Assessment of Mountain-Steppe Landscapes in the South-eastern slope of the Lesser Caucasus for their Rational Use." He also wrote scientific papers such as "Quality Assessment of Mountain-Steppe Landscapes in the South-eastern slope of the Lesser Caucasus," "Main Criteria for Assessing

Mountain-Steppe Landscapes in the South-eastern slope of the Lesser Caucasus," "Comparative Analysis of Mountain-Steppe Landscapes in the South-eastern slope of the Lesser Caucasus" and others. Finally, after the liberation of the territories in 2020, monitoring work started in the area, and the study and evaluation of landscapes continued for the establishment of agricultural areas. During this period, several interesting scientific works related to landscape research were written. A.H.Valiyev's article "Evaluation of the Potential of Agricultural Soils in the Occupied Territories" analyzed the territory's soil for agricultural establishment and management purposes, evaluating the potential of these soils using the bonitic scale. The article also included tables with indicators of agricultural activities in the area. In another article, “Soil and climatic factors of agricultural development in the liberated territories” A.H.Valiyev provided information about the composition, usability, and quality characteristics of the occupied lands, as well as the climatic features of the area (Valiyev A.H. (2020)). F.F.Fikratzade and S.I.Hajiyeva's article "Directions and Production Indicators for the Restoration of Agricultural Areas in the Liberated Territories" discussed the damages caused by conflicts and wars to the agricultural sector, the restoration and development of agriculture in post-conflict zones based on global experiences, issues and directions of agricultural restoration in the liberated territories, possible options for soil improvement, and issues related to agricultural areas and their forecasting (Fikratzade, Hajiyeva (2020)). This article extensively analyzed the data provided by the Agricultural Research Center and the State Statistics Committee of the Republic of Azerbaijan [1].

Within the Eastern Zangezur region, the slopes of the Lesser Caucasus Mountains extend from approximately 1,200 to 1,800 metres, reaching heights of 2,000 to 2,200 metres in some areas. This area mainly consists of broad-leaved forests and forest-steppe landscapes beyond the forest zone. These landscapes are composed of Jurassic and Cretaceous limestones, sandstones, shale, and volcanic-collapse breccias. The terrain is severely fragmented, characterized by denudation structures. Mountain peaks and landslides are widely spread, while valleys

primarily serve as transit routes. Steep and narrow ravines are common features. The climate is cold and temperate, with temperatures ranging from -6°C to -2°C in January, 13-19°C in July, and an annual rainfall of 600-1,300 mm [2]. Mountain-forest and karstic mountain-forest soils are prevalent in the area (Jafarov M.I. (2005), Mammadov Q.Sh. (2002, 2007), Mammadov R.M. (2009), Valiyev (2020), Khalilov, Jafarova (2022), Mammadova, Abdurahmanov (2022)). In many parts of the forests, particularly at elevations of 1,400-1,600 metres, Caucasian oak (Quercus macranthera) dominates, while Oriental beech, and in some areas, oak and silver birch trees form the canopy at higher elevations. Further up, the forest transitions to subalpine meadows. The upper part of the forest landscape is characterized by moisture-loving tree species, while the lower part is more arid. The uneven distribution of atmospheric precipitation throughout the seasons has led to the diverse development and extent of forests in the region. Intensive deforestation has resulted in the replacement of forests with various herbaceous plants, particularly in the forest-steppe transition zones. This landscape is rich in fauna, including ungulates, rodents, reptiles, and various bird species. Red deer, wild goat, leopard, brown bear, and other species are widespread. Many tree species are valuable for timber and wood processing industries. Wild fruits are also collected in this area [3, 4].

As we ascend from the forest landscapes to higher elevations ranging from 2,000-2,200 metres up to 3,000 metres, we encounter the high mountain, subalpine, and alpine-tundra landscapes of the high mountains, such as the Shahdagh, Murovdagh, and Zangezur ranges, and the Karabakh Plateau. These landscapes are mainly composed of Jurassic and Cretaceous carbonate-terrigenous, volcanic, and tuffaceous deposits. The terrain is severely fragmented and characterized by denudation structures. Strong torrents occur frequently, primarily in rocky and mountainous areas. River valleys begin to take shape within this landscape. The climate is cold, with temperatures ranging from -12°C to -7°C in January and 8-17°C in July. Annual precipitation can reach up to 900 mm. The predominant soils are grassy mountain-steppe soils. Species such as bezoar goat, chamois, Caucasian

vipers, Caucasian tetra, Caucasian agama, and rock lizard inhabit this area. The high mountain, subalpine, and alpine-tundra subtypes can be distinguished. Alpine-tundra landscapes occur at elevations above 2,400-2,500 metres. The vegetation in these areas is characterized by short stature and low species diversity. Below the alpine-tundra, from 2,000-2,200 metres to 2,400-2,500 metres, subalpine meadows extend. Subalpine meadows are characterized by tall vegetation, predominantly consisting of grasses, including many forage plants. The subalpine and alpine-tundra landscapes of the Lesser Caucasus differ slightly in terms of xerophytic adaptations compared to those of the Greater Caucasus. The alpine-tundra serves as a pastureland, while both pastureland and fodder are utilized in the subalpine meadows. The alpine-tundra subtype is also suitable for apiculture development (Mammadov Q.Sh. (2007), Valiyev A.H. (2020)).

The goal of the above-mentioned information is to get the right results in doing study. For that reason, that play an important role for analysis of the transformation of forest landscapes in the Eastern Zangezur region [5, 6, 7, 8].

MATERIALS AND METHODS

Unfortunately, over the past 200 years, the forest area worldwide has decreased by more than half. In the 18th and 19th centuries, the current territory of Azerbaijan was covered with forests, accounting for 35% of its land area. Currently, the total forest area in Azerbaijan is 1,021,000 hectares, representing 11.8% of the country's territory. In comparison, forests make up 44% of the territory in the Russian Federation, 41% in Latvia, and 39% in Georgia (https://azkurs.org/forest-is-a-unity-of-soil-water-trees-shrubs-and-grasses-anima.html). Within Azerbaijan, 49% of the forest reserves are located in the Greater Caucasus region, 34% in the Lesser Caucasus region, 15% in the Talysh zone, and 2% in the Aran zone (including the Nakhchivan Autonomous Republic). The main causes of deforestation are attributed to wars, forest fires, illegal logging, and other factors.

During the research on the transformation of forest landscapes in the Eastern Zangezur region, we have used various literary and archival materials, as well as

the analysis of maps prepared for the territory in different periods and the analysis of satellite images obtained from LANDSAT and AzerSky satellites which provided data up to 1.5 m spatial resolution panchromatic and multispectral. The other instrument details of AzerSky satellite are given below (Figure 1). The vegetation instrument was carried on its board. This instrument could cover almost all of the Earth's surface in a day because of its swath size of 2250 km. It captured reflected light in four spectral bands (blue, red, near-infrared, and middle-infrared) (https://earth.esa.int/eogateway/missions/spot-7).

Type	High-resolution optical pushbroom imager	
Ground Sample Distance	Panchromatic: 1.5 m at nadir Multispectral: 6 m at nadir	
Swath Width	60 km	
Field of Regard	±30° (spacecraft tilting capability about nadir for event monitoring)	
Bands	PAN	0.45-0.75 µm
	Blue	0.45-0.52 µm
	Green	0.53-0.59 µm
	Red	0.62-0.69 µm
	NIR (Near Infrared)	0.76-0.89 µm

Figure 1. Details of Optical Modular Instrument of AzerSky

When obtaining satellite images, preference was given to images with cloud cover levels of 0-1% and taken during the same period. We selected the end of July and the first week of August which is the most suitable time for this research for all obtained images from LANDSAT and AzerSky. And we calculated the degree of transformation of forest landscapes within the region by comparing the satellite images and conducting a statistical analysis by using GIS technologies. First of all, we compared the satellite images of the Eastern Zangezur region, taken on the same date in different years (2000-2021). Additionally, comparative images reflecting the real appearance of forest areas in the Eastern Zangezur region in 2018, 2020 and 2022 were prepared through the use of Geographic Information Systems (GIS). Because forest areas in the region suffered the most damage

between those years. Therefore, analysis, comparison, GIS, and statistical methods were employed in the study by us.

During our study, we calibrated images and compared them by using Intersect tools, then calculated the quantity of the deforestation in the region by using Calculate Geometry. The compatibility of our research results with the reports of the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan proved the accuracy of the results in the article.

RESULT AND DISCUSSION

In general, the total forest area in the district amounts to 178,100 hectares, with the majority being attributed to Lachin (63,300 hectares) and Kalbajar (62,800 hectares). The remaining districts, namely Gubadli, Zengilan, and Jabrayil, account for 18,400 hectares, 19,600 hectares and 14,000 hectares respectively (Figure 2) [9, 10].

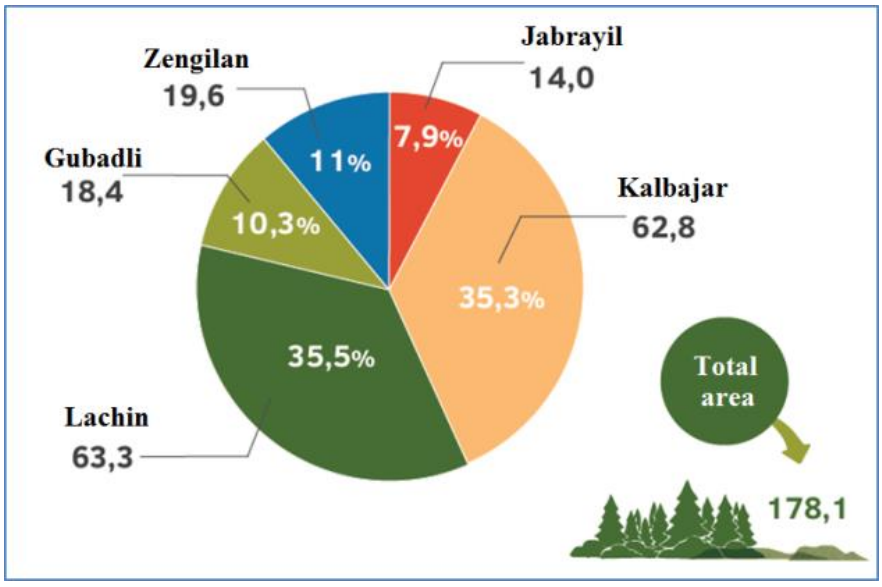

Figure 2. Forest reserves of the Eastern Zangezur region (thousand hectares)

The analysis of the satellite imagery obtained from LANDSAT confirms this fact (Figure 3 and Figure 4). It is evident from the processed images that forest landscapes dominate in the territories of Kalbajar and Lachin. These primarily encompass the north-eastern and south-western slopes of the region [9].

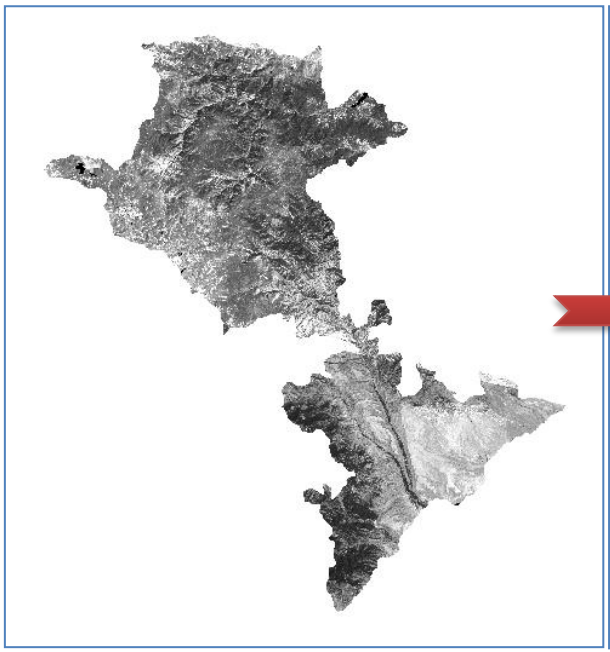

Figure 3. Satellite image of the Eastern Zangezur region obtained from LANDSAT satellite (combination of bands for 1990)

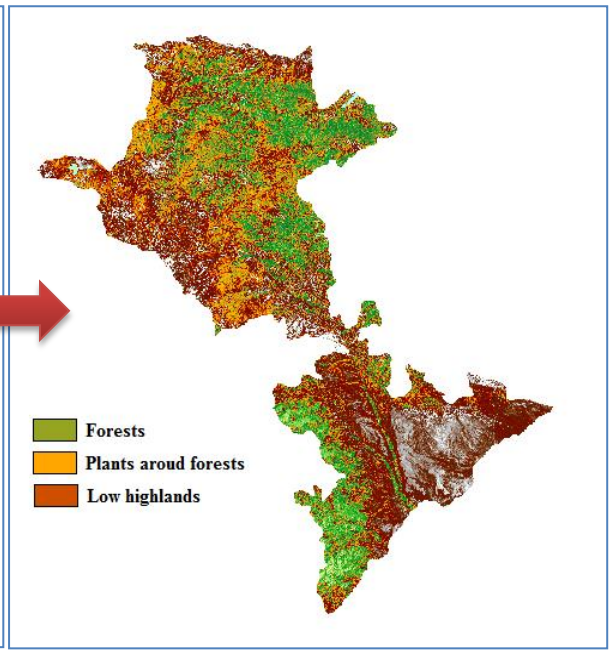

Figure 4. The visual appearance of the processed satellite image obtained from LANDSAT satellite (NDVI analysis to determine the vegetation cover of Figure 3)

As seen in Figure 3 and 4, the northern and south-western parts of the region are covered with green areas, including cultivated fields, grasslands, and forests. Thus, approximately 60% of the area is covered with vegetation. However, in the southeastern part where an arid climate prevails, vegetation is sparse or absent.

According to official sources, a total of 54,328 hectares of our occupied territories have been devastated, which accounts for approximately one-third of the current forest area. The destruction of forested areas by the enemy dates back to the Soviet imperial era. Starting from the cutting of Azerbaijan's ancient Topkhana Forests in 1988 to the Armenians setting fire to the forests upon leaving the Lachin region on August 15, 2022, our forests have suffered significant damage over the years.

In accordance with the Decree of the President of the Republic of Azerbaijan dated October 29, 2020, titled “On the Organization of Temporary Special

Administration in the Liberated Territories of the Republic of Azerbaijan" the employees of the Ministry of Ecology and Natural Resources (MENR) represented in the Operational Headquarters have initiated monitoring activities in the territories of Gubadli, Zengilan, Jabrayil, Fuzuli, and Khojavend regions for the purpose of environmental protection, sustainable use of natural resources, and their initial assessment. The conducted monitoring and observations in the field have revealed deliberate fires in forests and green massifs, resulting in the destruction of vegetation, fertile soil layers, and other living organisms [10]. One of the observed facts is the deliberate cutting of ancient small-sized trees, which were included in the list of unique natural monuments under special protection status since the Soviet era, leading to the gradual disappearance of the rich natural heritage. During the monitoring conducted over several days, it has been determined that the ancient Oriental Plane trees, aged 1600, 900, and 500 years, were destroyed in the territories of Gubadli, Fuzuli, and Jabrayil regions, respectively. The presence of stumps measuring up to 2 metres in height in the place of these trees confirms that these ancient plane trees were cut down several years ago.

During the conflict, the Armenians used banned phosphorus bombs, which caused extensive devastation in the areas where they were dropped. According to the information of Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, as a result of intentionally set fires in the occupied territories of Azerbaijan, approximately 110,000 hectares of land have been affected. Armenia inflicted irreparable damage to the forests of Shusha by deliberately using toxic, non-extinguishable, and prohibited white phosphorus bombs. Currently, efforts have been undertaken to address the environmental catastrophe in the liberated territories. In the recently freed regions of Fuzuli, Zengilan, and Aghdam, various tree species, including the Oriental Plane trees, have been planted, totaling up to 2,000 trees. Additionally, more than 100 kilograms of seeds of various forest trees, including oriental spruce, have been sown. Tree planting campaigns continue in Gubadli and Jabrayil (official web pages of the regions).

Based on the analysis of satellite imagery obtained from AzerSky, LANDSAT satellites for various periods, it has been determined during the occupation, nearly 50 thousand hectares of forests in our research area were destroyed. After the liberation of the occupied territories, Azerbaijan initiated restoration and rehabilitation efforts with the aim of restoring the ecological balance in these areas. Currently, reforestation activities are ongoing (Figure 5).

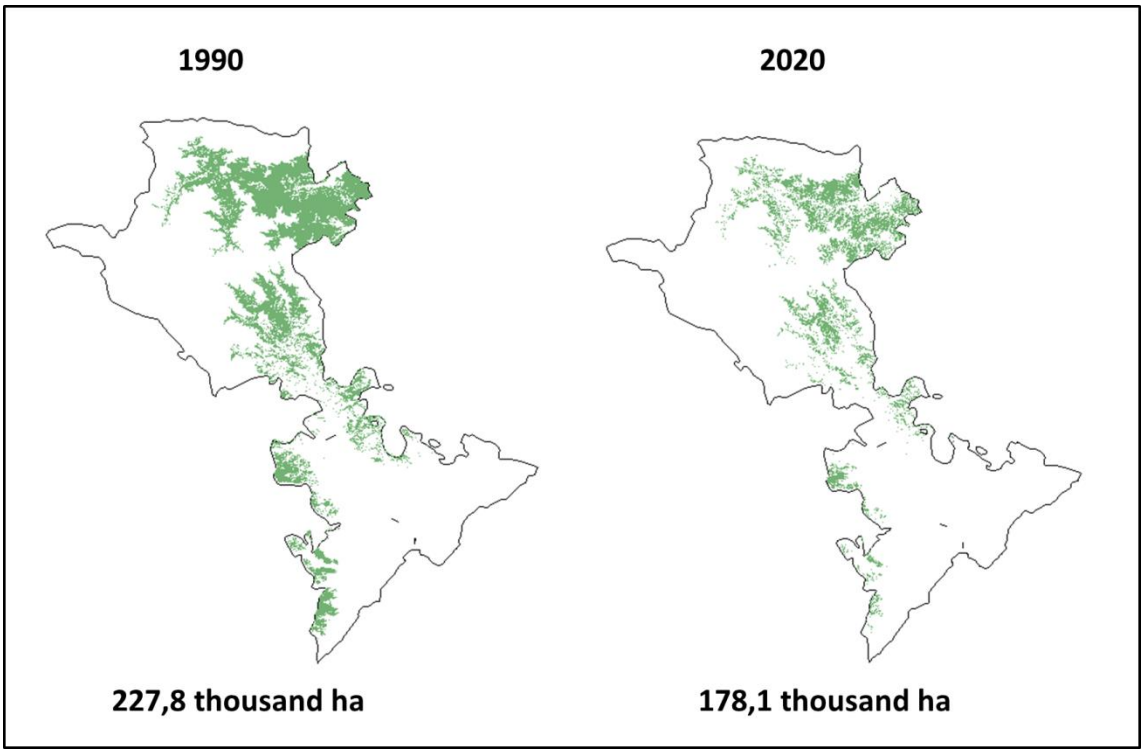

Figure 5. The ecological condition of the forests in the Eastern Zangezur region between 1990 and 2020.

CONCLUSION

In conclusion, taking into account the aforementioned, it is possible to note the following results regarding the transformation of forest landscapes in the Eastern Zangezur region;

1. Within the Eastern Zangezur region, the slopes of the Lesser Caucasus Mountains encompass a range of approximately 1200 to 1800 metres, with some areas reaching heights of 2000-2200 metres, forming the landscape of the middle mountainous region. These areas constitute a significant portion of the mountainous landscape zones within the country. They are predominantly

characterized by deciduous forest, rocky-carbonate forest, typical forest, and wetland forest soils. In many parts of these forests, particularly at elevations of 1400-1600 metres, birch and maple prevail, while at higher elevations, Oriental beech and Caucasian oak (Quercus macranthera) trees dominate. Further up, the forests transition into subalpine meadows landscape. In the upper parts of the forest landscape, moisture-loving tree species are prevalent, while in the lower parts, drought-resistant tree species are distributed.

2. Currently, the total area of forests within the Eastern Zangezur region amounts to 178.1 thousand hectares. This includes 63.3 thousand hectares in Lachin, 62.8 thousand hectares in Kalbajar, 19.6 thousand hectares in Zengilan, 18.4 thousand hectares in Gubadli, and 14 thousand hectares in Jabrayil. In general, forests constitute 35.5% of the territory in Lachin, 35.3% in Kalbajar, 11% in Zengilan, 10.3% in Gubadli, and 7.9% in Jabrayil, respectively, in terms of their land cover.

3. During the occupation period, the forests in the Eastern Zangezur region were destroyed through intentional burning, illegal logging, and other activities. According to official sources, a total of 54,328 hectares of our forest areas have been devastated in the occupied territories.

4. The monitoring and observations conducted by the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan across the territories have revealed that intentional fires in forests and green massifs have resulted in the destruction of vegetation cover, fertile soil layers, and other living organisms. One of the notable facts is the deliberate cutting of ancient, small-sized trees that were included in the list of specially protected natural monuments since the Soviet era, leading to the gradual erasure of the rich natural history. It has been determined that Oriental Plane trees, with ages of 1600, 900, and 500 years, have been destroyed in the territories of Gubadli, Fuzuli, and Jabrayil. The presence of seedlings up to 2 metres in height in place of these ancient plane trees confirms that they were cut down several years ago.

5. Based on the analysis of satellite imagery obtained from AzerSky, LANDSAT satellites for various periods, it has been determined during the occupation, nearly 50 thousand hectares of forests in our research area were destroyed.

The paper also covers various aspects such as the history, geography, and environmental impact of the region, as well as the efforts being made for restoration. Many researchers can get several key messages from this research paper on the transformation of forest landscapes in the Eastern Zangezur region and also other regions as this. They are noted below;

1. Understanding of these causes is crucial for implementing effective conservation and restoration strategies.

2. The using of satellite imagery and Geographic Information Systems (GIS) for analysis and assessment is a powerful tool for understanding the extent of degradation of the forest. This technology can aid in decision-making and resource allocation for conservation efforts.

3. The paper highlights the importance of reforestation and rehabilitation efforts in the liberated territories. Land use managers and nature conservationists should prioritize and support initiatives aimed at restoring the ecological balance and preserving valuable forests.

4. The destruction of ancient and unique tree species in the region underscores the need to protect and conserve natural heritage.

In summary, this research paper provides valuable insights for land use managers and nature conservationists, highlighting the urgency of addressing forest degradation, the importance of using technology for analysis, and the need for concerted efforts to restore and preserve valuable natural resources in the Eastern Zangezur region.

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