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GEOSPATIAL ASSESSMENT OF ANTHROPOGENIC INFLUENCE IN HIRKAN NATIONAL PARK

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Abstract
Hirkan National Park is one of the most important protected areas of Azerbaijan, conserving valuable forest ecosystems with high biodiversity, relict vegetation, and significant conservation value. This study evaluates the spatial and temporal characteristics of anthropogenic influence in Hirkan National Park and its buffer zone using the annual terrestrial Human Footprint dataset. Multi-year raster data covering approximately two decades were processed in a GIS environment and classified into four categories of anthropogenic influence: very low, low, moderate, and highly modified areas. The results indicate that the study area is generally dominated by landscapes with limited anthropogenic transformation, while more modified zones occur mainly in accessible areas. Moderate and highly modified landscapes are concentrated near main road networks, and settlements. Although the overall landscape structure remains relatively stable, the analysis reveals a gradual reduction of the least affected areas and a slight expansion of highly modified zones. These changes indicate the need for continued monitoring, especially in buffer-zone and road-adjacent landscapes. The applied approach provides a spatially explicit basis for identifying vulnerable zones where anthropogenic transformation is more pronounced. These results can contribute to more targeted environmental monitoring, improved buffer-zone regulation, and the development of site-specific management strategies for Hirkan National Park.
Keywords: *Hirkan National Park; anthropogenic influence; protected areas; GIS; Azerbaijan; buffer zone; landscape transformation.*

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INTRODUCTION

Protected areas are among the most important mechanisms for conserving biodiversity, maintaining ecosystem stability, and reducing the negative impacts of human activity on natural landscapes [6; 8]. However, protected status alone does not always guarantee the full preservation of ecological integrity. Many protected areas across the world are increasingly exposed to anthropogenic influence associated with settlement expansion, agriculture, transportation infrastructure, tourism, resource use, and other forms of land transformation [4]. Global studies have shown that a considerable share of protected lands is still affected by intensive human activity, which can reduce their conservation effectiveness and threaten biodiversity values [5]. For example, Jones et al. (2018) reported that approximately one-third of the world's protected land is under intense human pressure, highlighting the need for regular spatial monitoring of protected areas [9].

In recent decades, geospatial technologies have become essential for assessing the spatial distribution and temporal dynamics of anthropogenic influence [2]. Remote sensing, geographic information systems, and global spatial datasets allow researchers to identify areas where natural landscapes remain relatively undisturbed and areas where human-induced transformation is increasing [1; 15; 20]. Among these approaches, the Human Footprint dataset has been widely used to quantify cumulative human influence on terrestrial ecosystems [12]. This dataset integrates several indicators of human activity, including land transformation, population density, human access, and infrastructure, and therefore provides a comprehensive spatial basis for evaluating anthropogenic influence over time. Annual Human Footprint datasets have made it possible to analyse temporal changes in human influence at global, regional, and local scales [19].

Hirkan National Park is one of the most valuable protected areas of Azerbaijan. It is located in the south-eastern part of the country, within the Lankaran and Astara districts, and protects an important part of the Hyrcanian forest ecosystem. The Hyrcanian forests are ancient broad-leaved forests that survived historical climatic fluctuations and now contain many relict, endangered, regional, and locally endemic species [11; 13]. UNESCO describes the Hyrcanian forests as ecosystems of high ecological value, with remarkable floristic diversity and more than 3,200 vascular plant species recorded in the wider Hyrcanian region [18]. These characteristics make Hirkan National Park highly significant for biodiversity conservation, ecological stability, and the protection of Azerbaijan's natural heritage [7].

Despite its conservation importance, Hirkan National Park and its surrounding landscapes are not completely isolated from human activity. The park is located in a region where rural settlements, agricultural lands, roads, tourism activities, and other forms of land use occur in close proximity to protected forest ecosystems. Such factors may create direct and indirect impacts on the park, particularly along its boundaries and in more accessible areas. Even relatively low levels of anthropogenic influence may become important in sensitive forest landscapes because they can contribute to habitat fragmentation, edge effects, disturbance of wildlife, and gradual transformation of ecological processes.

For this reason, the spatial assessment of anthropogenic influence in Hirkan National Park is important for both scientific and practical purposes. It allows the identification of relatively undisturbed zones, areas of moderate transformation, and locations where human-induced changes may require closer management attention [16; 17]. In addition, temporal comparison makes it possible to evaluate whether anthropogenic influence has increased, decreased, or remained stable during the study period. Such information is valuable for protected area management, buffer-zone planning, biodiversity conservation, and long-term environmental monitoring.

The main aim of this study is to assess the spatial and temporal patterns of anthropogenic influence in Hirkan National Park using geospatial data. The specific objectives are: (1) to classify the intensity of anthropogenic influence within the park; (2) to calculate the area and percentage of different influence classes for selected years; (3) to identify spatial patterns of increasing or decreasing transformation; and (4) to discuss the implications of these changes for conservation planning and protected area management in National Park.

Material və method

Data source. To assess anthropogenic influence in Hirkan National Park and its buffer zone, this study used the annual terrestrial Human Footprint dataset. The dataset provides spatially explicit information on cumulative human influence on terrestrial environments and allows changes to be compared over time [3; 14]. In this study, the buffer zone of the national park was defined as a 3,000 m zone along the park perimeter, in accordance with national legislation.

The Human Footprint dataset integrates several indicators of human activity, including built environments, population density, croplands, pasturelands, roads, railways, navigable waterways, and night-time lights. These variables reflect different forms of land transformation, infrastructure development, accessibility, and settlement-related influence. Therefore, the dataset is suitable for evaluating anthropogenic influence both within protected areas and in their surrounding landscapes.

For this study, raster layers were selected for four time periods: 2001, 2010, 2015, and 2020. These years were chosen to represent long-term changes in anthropogenic influence over approximately two decades and to identify both gradual and more recent spatial changes in and around Hirkan National Park.

Data preparation and GIS processing. The spatial analysis was carried out using GIS software. First, the boundary of Hirkan National Park and surroundings was prepared as a vector layer. The Human Footprint raster layers for the selected years were then imported into the GIS environment. To ensure spatial consistency, all datasets were checked for coordinate system, spatial resolution, and alignment. The raster layers were clipped using the boundary of study area. This made it possible to analyze only the area located within the protected area. After clipping, the raster values were reclassified into anthropogenic influence categories. The area of each class was calculated for every selected year and expressed both in square kilometres and as a percentage of the total area.

The Human Footprint values were classified into four categories in order to assess the intensity of anthropogenic influence in the study area [10]. The classification was based on the numerical values of the raster dataset and grouped into very low, low, moderate, and high influence classes (Table 1).

Table 1
Classification of human influence values

Human Footprint value	Anthropogenic influence class
< 1.0	Very low influence / relatively undisturbed landscapes
1.0–2.0	Low influence
2.0–3.0	Moderate influence
≥ 3.0	High influence / highly modified landscapes

This classification allowed the spatial comparison of anthropogenic influence levels. Areas with values below 1.0 were interpreted as relatively undisturbed or close-to-natural landscapes. Values between 1.0 and 2.0 indicated low levels of influence, while values between 2.0 and 3.0 represented moderate transformation. Areas with values equal to or higher than 3.0 were considered highly modified or strongly affected by human activity.

The final stage of the methodology involved the preparation of thematic maps showing the spatial distribution of anthropogenic influence classes in Hirkan National Park and its buffer zone. These maps were used to visually compare changes over time and identify the most affected areas.

Analysis and discussion

The spatial distribution of anthropogenic influence in Hirkan National Park and its buffer zone for 2001, 2010, 2015, and 2020 is presented in Figure 1a-d. The results show that the study area is generally dominated by very low and low influence classes, indicating that a large part of the national park and its surrounding buffer zone still maintains relatively natural landscape conditions. However, the temporal comparison also reveals noticeable changes in the proportion of different anthropogenic influence classes over the study period.

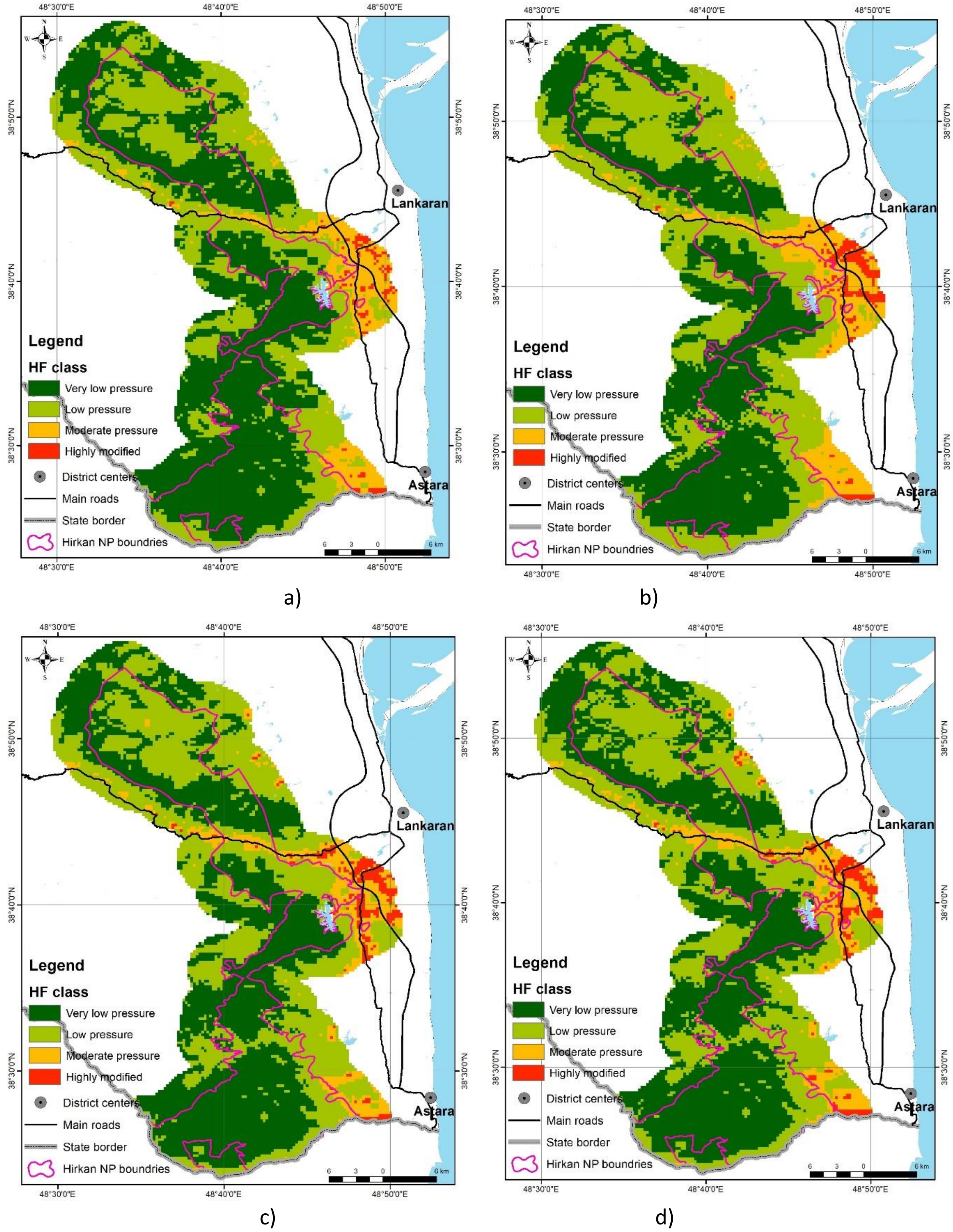

Fig. 1. Spatial distribution of anthropogenic influence in Hirkan National Park and its buffer zone based on Human Footprint classes: (a) 2001, (b) 2010, (c) 2015, and (d) 2020

The results indicate that in 2001, very low influence areas occupied 444.4 km², corresponding to 52.7% of the total study area (Table 2). This was the dominant class in the initial year of the analysis. Low influence areas covered 317.1 km², or 37.6%. Moderate influence areas accounted for 71.5 km², representing 8.5%, while highly modified areas occupied only 9.7 km², or 1.2% of the total area. These values show that at the beginning of the study period, more than half of the territory was characterized by very low anthropogenic influence.

Table 2

Area distribution of anthropogenic influence classes in Hirkan National Park and its buffer zone

HF class	Area in 2001		Area in 2010		Area in 2015		Area in 2020	
	km²	%	km²	%	km²	%	km²	%
Very low pressure	444.4	52.7	378.1	44.9	394.1	46.8	400.3	47.5
Low pressure	317.1	37.6	357.4	42.4	365.6	43.4	354.5	42.1
Moderate pressure	71.5	8.5	88.3	10.5	62.1	7.4	65.0	7.7
Highly modified	9.7	1.2	18.9	2.2	20.9	2.5	22.8	2.7
Total	**842.7**	**100**	**842.7**	**100**	**842.7**	**100**	**842.7**	**100**

By 2010, the area of the very low influence class had decreased considerably to 378.1 km², or 44.9%. This represents a decrease of 66.3 km² compared with 2001. At the same time, the low influence class increased to 357.4 km², or 42.4%, while moderate influence areas expanded to 88.3 km², or 10.5%. Highly modified areas also increased to 18.9 km², or 2.2%. This period therefore reflects the most pronounced shift from very low influence landscapes toward low, moderate, and highly modified categories.

In 2015, some improvement was observed in the structure of anthropogenic influence classes. The area of very low influence increased to 394.1 km², or 46.8%, while the moderate influence class decreased to 62.1 km², or 7.4%. Low influence areas continued to occupy a large share of the study area, reaching 365.6 km², or 43.4%. However, highly modified areas continued to increase and reached 20.9 km², or 2.5%. This indicates that although moderate influence decreased after 2010, the most transformed areas did not decline.

By 2020, very low influence areas slightly increased again to 400.3 km², or 47.5%. Low influence areas covered 354.5 km², or 42.1%, showing a slight decrease compared with 2015. Moderate influence areas occupied 65.0 km², or 7.7%, while highly modified areas increased to 22.8 km², or 2.7%. Thus, by the end of the study period, very low and low influence classes together still accounted for almost 89.6% of the total study area, confirming the generally preserved character of the national park and its buffer zone.

The long-term comparison between 2001 and 2020 shows that the very low influence class decreased from 444.4 km² to 400.3 km², corresponding to a reduction of 44.1 km². Its share declined from 52.7% to 47.5%. This suggests that some relatively undisturbed landscapes were transformed into classes with higher levels of anthropogenic influence during the study period. In contrast, the low influence class increased from 317.1 km² to 354.5 km², gaining 37.4 km². This change may indicate a gradual transition from near-natural landscapes to slightly modified conditions.

The moderate influence class decreased slightly over the full period, from 71.5 km² in 2001 to 65.0 km² in 2020. However, its highest value was recorded in 2010, when it reached 88.3 km². This suggests that anthropogenic influence intensified during the first decade of the study period, followed by partial stabilization or redistribution by 2015 and 2020. The highly modified class showed a consistent increase in all analyzed years, rising from 9.7 km² in 2001 to 22.8 km² in 2020. Although this class occupies a relatively small part of the study area, its continuous growth is important from a conservation perspective.

The moderate and highly modified areas mainly correspond to zones associated with main roads and settlements. These areas are more accessible and are therefore more exposed to land-use transformation, infrastructure development, agricultural activity, and settlement-related influence. The concentration of higher anthropogenic influence near roads and settlements confirms the important role of accessibility in shaping the spatial structure of landscape transformation.

The persistence and expansion of highly modified areas, especially near transport corridors and settlement zones, may create ecological risks for Hirkan National Park and its buffer zone. Even when highly modified areas occupy a small percentage of the total territory, they may contribute to habitat fragmentation, edge effects, disturbance of forest ecosystems, and weakening of ecological connectivity. This is particularly important for Hirkan National Park because the area protects valuable Hyrcanian forest ecosystems with high biodiversity and conservation significance.

At the same time, the dominance of very low and low influence classes throughout the study period indicates that the overall ecological condition of the study area remains relatively stable. In 2020, these two classes together occupied 754.8 km², or 89.6% of the total area. This shows that despite localized increases in anthropogenic transformation, most of the national park and its buffer zone still consists of landscapes with limited human influence. This is a positive indicator for protected area management and biodiversity conservation.

The vertical distribution graphs of raster values for 2001 and 2020 provide additional insight into the frequency structure of anthropogenic influence within Hirkan National Park and its buffer zone (Fig. 2). In both graphs, the highest counts are concentrated in the lower Human Footprint value ranges, especially below approximately 1.0-1.5, confirming the dominance of very low and low influence landscapes in the study area. However, the 2020 graph shows a wider range of values and a more visible extension toward higher classes, reaching values close to 4.8, compared with about 4.2 in 2001. This indicates that although the general distribution remains strongly concentrated in low-value classes, some areas experienced increased anthropogenic transformation by the end of the study period.

The results demonstrate that anthropogenic influence in Hirkan National Park and its buffer zone has not increased uniformly across the entire territory. Instead, the changes are spatially concentrated in specific areas, especially around roads, settlements, and accessible peripheral zones. This pattern suggests that accessibility is one of the main factors controlling the distribution of anthropogenic transformation, as areas located closer to transport routes and residential zones are more exposed to land-use pressure. In contrast, less accessible forested and mountainous parts of the study area continue to function as relatively stable ecological zones with lower levels of transformation. Therefore, future conservation measures should focus on these more vulnerable locations. Strengthening land-use control in the buffer zone, monitoring areas near road networks, regulating settlement-related expansion, and maintaining forest connectivity should be considered important priorities for the long-term protection of the National Park. These measures would help reduce fragmentation risks, limit further expansion of highly modified areas, and support the ecological integrity of the Hyrcanian forest landscapes.

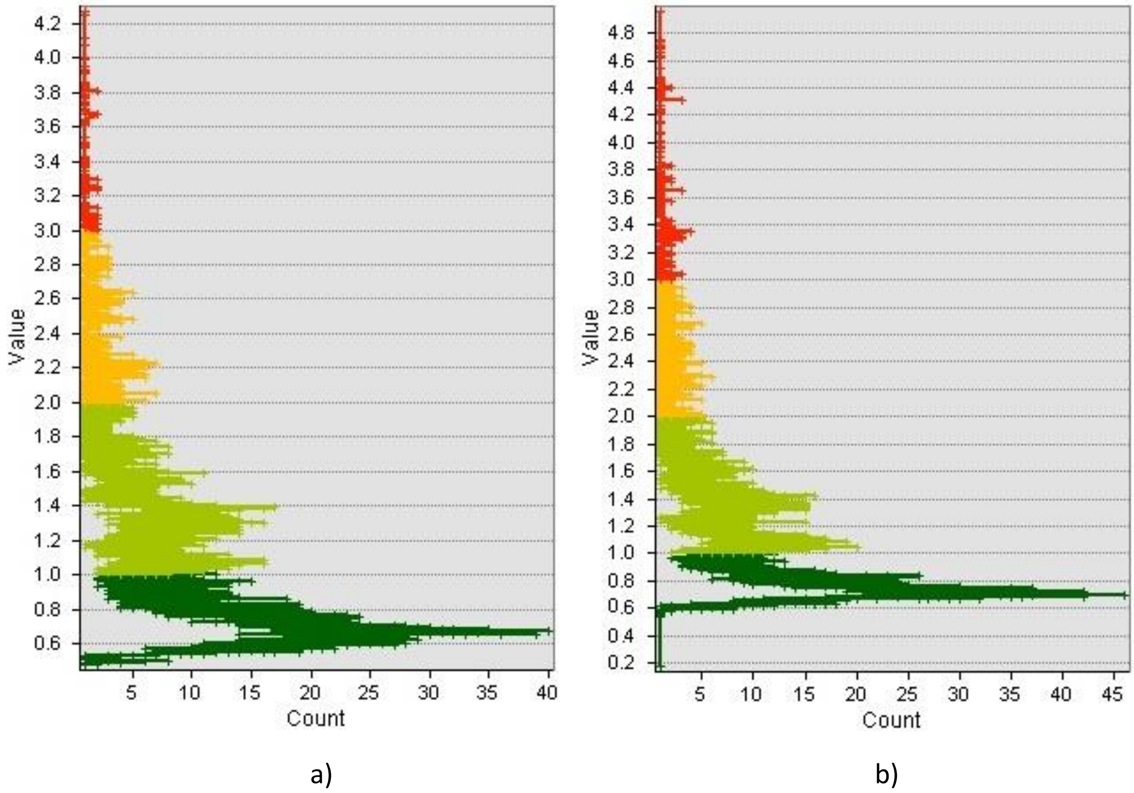

Fig. 2. Frequency distribution of Human Footprint values in Hirkan National Park and its buffer zone: (a) 2001 and (b) 2020

CONCLUSİON

The results show that the study area is mainly characterized by very low and low levels of anthropogenic influence, indicating that a large part of the national park and its surrounding landscapes has remained relatively well preserved during the study period. In 2020, these two classes together occupied 754.8 km², or 89.6% of the total study area, confirming the predominance of relatively low-transformation landscapes.

The analysis revealed that very low influence areas decreased from 444.4 km² in 2001 to 400.3 km² in 2020, while their share declined from 52.7% to 47.5%. At the same time, low influence areas increased from 317.1 km² to 354.5 km², suggesting a gradual transition of some near-natural landscapes toward slightly modified conditions. Moderate influence areas changed from 71.5 km² in 2001 to 65.0 km² in 2020, although their highest value was recorded in 2010. Highly modified areas showed a continuous increase, rising from 9.7 km² in 2001 to 22.8 km² in 2020. Although this class occupies a relatively small proportion of the territory, its steady growth is important from a conservation perspective.

Spatially, moderate and highly modified areas are mainly associated with road networks, villages, settlements, and zones located in the direction of Lankaran and Astara cities. This indicates that accessibility and settlement-related land use are among the main factors influencing the spatial distribution of anthropogenic transformation in the study area. Therefore, special attention should be given to buffer-zone management, road-adjacent landscapes, settlement-near areas, and ecological corridors. Strengthening land-use regulation, limiting uncontrolled expansion, and maintaining forest connectivity are important for preserving the ecological integrity of Hirkan National Park. Overall, the study demonstrates the usefulness of geospatial datasets for long-term monitoring of protected areas in Azerbaijan and can support future conservation planning and sustainable landscape management.

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