

The Ecological Importance of Mountain Ecosystems and the Possibilities of Artificial Intelligence in Achieving Sustainable Management: The Example of Azerbaijan

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Abstract: Mountain ecosystems play an important role when it comes to forming water resources. They help protect soil and keep biodiversity safe. They also help control the climate. They help keep heritage protected and make sure local communities are happy and healthy. The article looks at the dangers, ways to protect these areas, and how digital tools can be used in mountain regions. This is all based on reports from around the world and official data from Azerbaijan. A lot of focus is given to using intelligence to look at pictures from satellites. This helps in studying snow and water movement finding risks of floods and landslides early and watching over wildlife. A step-by-step plan is suggested for a pilot project in Azerbaijan. This work does not come from field studies but from looking at scientific papers and collecting ideas that can be used.

Keywords: human resource management, artificial intelligence, recruitment, employee performance, HR analytics

1.Introduction

Mountains are natural systems, where multiple interactions between the natural shape of the mountain and its layers the rock of the mountains the nature of the mountains and the flora and fauna of the mountains come together. As the altitude and slope directions change over distances, different climatic zones and habitats arise in the mountains. This diversity makes mountains both an important part of the heritage and ecosystems vulnerable to external influences. IPCC assessments document the impacts of temperature increases and land use changes on mountain regions, including water and wildlife [1], [2].

The importance of mountains is not limited to the people who live in the mountains. Snow accumulation in the mountains, the conversion of rainfall into runoff, and the control of water by soil and vegetation cover affect the supply of drinking water, irrigation, and energy in the regions. UNESCO's 2025 World Water Report specifically emphasizes the role of mountains as "water towers" [3]. The simultaneous increase in pressures in regions—climate change, human impact, inefficient grazing, and unregulated tourism—requires integrated management, not individual measures.

2. Method of the research

The purpose is to analyze the functions and risks of mountain ecosystems using Azerbaijan as an example as well as to show real application directions for monitoring and decision support based on artificial intelligence. An analytical review of reports from IPCC, UNESCO, FAO, UNECE, and other authoritative organizations, as well as peer-reviewed scientific articles, was chosen as the method. The proposed SI scenarios are promising opportunities; they are not claimed to have been tested in Azerbaijan and have yielded results.

3. Natural And Social Functions Of Mountain Ecosystems

3.1. Formation and regulation of water resources

Mountains temporarily store precipitation in the form of snow, ice, soil moisture and groundwater, affecting its distribution throughout the year. Altitude, slope direction and vegetation cover change the water balance within the same basin. The UNESCO report indicates the role of mountain waters for drinking water supply, agriculture, hydropower and ecosystems [3]. Viviroli and co-authors' research predicts that water demand in lying areas dependent on mountain runoff will increase in the future [4]. Thus, deforestation and land degradation in the catchment are not just local problems; they can also affect water quality and seasonality in the lower catchment.

3.2. Biodiversity, altitudinal zones and ecosystem services

Mountain forests, scrublands, subalpine and alpine meadows and rocky areas form ecological niches. Differences in temperature, humidity and insolation on a slope determine the distribution of plants, flowering times and feeding zones of animals. Körner's fundamental research has extensively explained the adaptation of high-altitude plants to stress factors and the importance of zonation [5]. IPBES, in assessing the contributions of nature to well-being, highlights the risks of habitat loss and fragmentation on a global scale [6].

The benefits of biodiversity are not limited to the maintenance of species. Vegetation stabilizes slopes, supports pollinators, and forest and pasture systems contribute to the carbon cycle. In particular, the loss of soil matter is an ecological loss that is difficult to reverse. FAO and UNEP emphasize the link between the protection of forest diversity and the livelihoods of populations [7].

3.3. Communities, knowledge and sustainable tourism

For mountain villages, pastoralism and winter agriculture, beekeeping, local products, ecotourism and cultural routes can generate economic value. However, altitude, difficult transport conditions and seasonal incomes make some communities more vulnerable. FAO's analysis of mountain food security highlights the social dimensions of such vulnerability [8]. Tourism development should be coordinated with conservation regimes; erosion of trails, waste, transport loads, and seasonal water consumption should be taken into account in advance. Involving residents in monitoring and planning can strengthen the implementation of conservation measures.

4. Climate. Ecological risks

According to IPCC assessments dedicated to mountains in regions, the duration of snow cover and glacier mass are changing, the risk profile of natural phenomena is changing, and the ecological space for species to move uphill may be narrowing [1], [2]. The impacts differ from region to region; therefore, it is not correct to take results as a measured local indicator for Azerbaijan. The observation series and relief characteristics of each basin should be examined separately.

5. Mountain Areas Of Azerbaijan: Potential And Challenges

5.1. The need for management of different landscapes

The mountain systems of Azerbaijan are characterized by the Greater Caucasus, the Lesser Caucasus, the Talysh Mountains, as well as the mountain ranges of Nakhchivan. Different altitudes, precipitation, and geological conditions create a mosaic of watersheds, forests, alpine-subalpine meadows, and arid mountain landscapes. Therefore, it is not efficient to apply the same protection measure to all mountain regions: for example, the sources of erosion on a forested slope and the factors of degradation on a dry high mountain pasture are different.

The official information of the Ministry of Ecology and Natural Resources of the Republic includes parks such as Shahdag, Goygol and Zangezur as part of the network of protected areas [9]. However, protection should not be carried out within the park boundaries. The impacts caused by roads, agricultural areas, and tourism on the outskirts of the parks can weaken ecological connectivity. The third UNECE environmental review of Azerbaijan covers the aspects of environmental management, information systems, monitoring and climate policy [10].

5.2. Water, soil and natural hazards.

Heavy rain, hills, loss of soil cover and certain rock conditions can raise the risk of floods and landslides in many areas. Risk is set by more than the chance of an event; it also depends on where roads, bridges, houses, power lines and water systems lie inside the risk area. Therefore, it is vital to join the hazard map with the map that shows where people and economies are at risk. In addition to this, the UNDRR global report further states that it is necessary to have an effective process of disaster risk management through a well-defined approach [11].

5.3. Loading and management failures

If cattle grazing is not restricted, soil gets compacted, garbage gets disposed of improperly, road works and construction pass through many sites, and there are many tourists visiting a site, then there is degradation of landscape quality. These issues are generally recorded on maps and in data. There should be a well-used system of mapping that will use the metrics and make the exchange of information possible among different agencies. Such actions should take into account the financial requirements of people, ecological regulations, and tourism plans [7], [9], [10].

6. Key Principles Of Management

Planning the primary concentration areas is done through watersheds. These secure soil and plant cover on slopes, match grazing to the actual carrying capacity of the land, develop tourist trails, and monitor with appropriate signage. To make informed decisions on ground posts, the people on the ground and the satellite images have to cooperate; either one is not sufficient.

7. The Role Of Artificial Intelligence In The Conservation Of Mountain Ecosystems

The artificial intelligence approach is promising for analyzing any peculiarities in data collected from certain sources. In addition, it helps identify risk maps and allocate resources appropriately. The analysis can include various data such as satellite imagery, records of weather stations, digital elevation models, trail cameras, acoustic sensors, and humans' measurements. According to Pettorelli et al., remote sensing provides necessary information for observing nature. Furthermore, Reichstein et al. claim that integrating machine learning with Earth science is crucial for researching Earth's systems [12], [13].

7.1. Automatic change detection by satellite imagery

Light and radar satellite images of several years and different seasons can be used to cluster forest cover changes, vegetation changes, bare soil areas, fire scars, and snow areas. For instance, trained computer programs can separate areas such as forest, grassland, water, rock and houses on a map.. The signals from satellites do not explain why changes happen. Lack of water, shade, seasonal changes, and clouds may make false change signals appear. The findings must be checked with visits and expert insight [12], [13], [14]

7.2. Forecasting snow, river flow and water demand.

When we combine data on precipitation, temperature, snow cover, soil moisture and observed river discharge, we can create short-term forecasts of river flow. Artificial intelligence can act as an assistant in this process. It helps find weaknesses in hydrological models and reduces forecast errors without replacing them. The idea of mixing laws with machine learning methods is well explained in scientific studies [13], [15]. In water management, it is wiser to show uncertainty ranges rather than giving just one "exact" forecast number.

7.3. Decision support for floods, landslides and other hazards.

Risk can be mapped based on the results from an elevation model, slope, type of rocks and soils, precipitation level, rivers and streams network, and past records of occurrence. Upon receiving data in real time, the decision support system sends warning messages whenever there is a risk. A high risk score from the decision support system does not mean that the event will necessarily occur. It is important to look into alarms and false warnings. The decision support system should take into account the responsibility of the emergency services in decision-making [11], [14].

7.4. Species detection and conservation planning

Species detection involves using classification models that process the images from camera-traps and sounds from bioacoustic records. Such a tool allows the researcher to make rapid categorizations of observations. Maps showing where the rare species occur, how do they migrate seasonally and what is the fragmentation of their habitat are useful for conservation planning. Species detection has to protect against wrong identification of species, sampling biases, and threats associated with potential illegal hunting [6], [12], [13].

8. Proposed Si-Based Pilot Model For Azerbaijan

For the pilot study in these regions, we propose the Greater and Lesser Caucasus mountain basins. The criteria for selecting these regions will be the availability of data, geology, status of conservation, risks of impact on settlements, and accessibility of data. We do not want to demonstrate any technology here, but only check if AI helps in basin management.

8.1. Data. Quality control

Initially, the data sets will consist of satellite images, DEMs, weather and hydrological information, land cover information, protection zone boundary information, and field observations. All data sets should be provided in the common coordinate system, and appropriate scale and time period are also necessary. Independent verification is necessary. If the training and testing data sets are too close spatially and temporally, the results will appear more successful than they actually are. Thus, testing is necessary for other years and different basins [12], [13], [15].

8.2. Four practical modules and their indicators

The first module develops change maps of land and vegetation cover. Its performance is evaluated by the F1-score. Using accuracy based on field data not included in the training set. The second module analyzes snow cover and short-term predictions of river runoff. Its evaluation includes comparison with physical models based on metrics like mean absolute error. The third module prioritizes zones vulnerable to flooding

and landslides. Its outputs include detection rate, false alarm rate, and warning generation time. The fourth module groups other ecological data. The species detection errors are estimated by expert validation of samples.

The success of the pilot will be determined by indicators such as frequency of updates, map reliability, time saving for experts, alarm rate, and managerial use of outcomes. They are not commitments here but evaluation tools. An overview by Rolnick illustrates how machine learning can be used in climate science [14].

8.3. Limitations and proper use of AI

Although the presence of opportunities to monitor mountain ecosystems via AI and environmental management with the help of AI comes with limitations, which concern methodology, technology, ethics, and institutions. AI technologies allow managing the vast quantities of data about the environment, detecting complex patterns, and making predictions about the future. The effectiveness of AI depends greatly on the quality of data, algorithms used and places where the technology is applied. Therefore, AI needs to be considered as an additional instrument of support for science and environmental management [13], [14].

One significant issue is data itself. Mountainous areas are difficult to examine due to numerous slopes, substantial variations in elevation, rapidly changing weather conditions, and significant discrepancies between microclimates. All these factors make it rather difficult to get consistent and representative data. Weather stations are unevenly distributed across highlands. Satellites also have trouble seeing through clouds, atmospheric disturbances, shadows of mountains, and snow cover. Thus, the models trained on the data might provide faulty and misleading outcomes in other mountain areas. This is especially evident in the case of Azerbaijan, with three mountain systems (the Greater Caucasus, Lesser Caucasus, and Talysh Mountains) having their distinct climates, geology, and ecology [1], [2].

In my opinion, algorithm bias and adaptability of machine learning algorithms in specific locations is another problem. The model developed with the use of data collected in a certain region would not necessarily perform well in another location due to differences in vegetation, precipitation, soil, and anthropogenic activity. Climate change adds an additional level of uncertainty as the historical patterns might not be suitable for predicting conditions. Due to the above-mentioned factors, AI models should be validated, adjusted, and verified with local data [13], [15]

Moreover, it seems essential that decision makers have an understanding of the meaning of AI predictions. Some AI models have high accuracy, but they are complicated. In such cases, explanations of why the model made a particular prediction are required. It is even more crucial when AI predicts environmental problems such as landslides, flood risks, ecological system impairment, or water management. Otherwise, the wrong prediction can cause wrong actions, financial expenditures, and missed threats. Therefore, environmental systems should be built on AI technology, modeling techniques, and measurement of uncertainty [14 15].

AI-based predictions should be viewed as less than 100% certain. It is well known that natural hazards have a probabilistic character. They depend on many interacting factors that cause the problem. Landslides, for instance, are caused by several factors like rains, wet soils, steep slopes, no vegetation, human impact. The most advanced algorithms can miss relationships between all those factors. Hence, it is necessary that the prediction be accompanied by the confidence level and uncertainties. The risk assessment categories should be clear. Environmental agencies should consider the results of AI, together with the empirical observations, scientific approach, and experts' opinion.

9. Conclusions And Recommendations

The protection of the mountains is vital for the region's water security, biodiversity, soil conservation, and sustainable development. Some of the major initiatives needed by Azerbaijan are the improvement of long-term ecological monitoring and watershed management in a unified system.

Author Contributions

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript

Conflict of Interest

The authors declare no conflicts of interest

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