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CLIMATE-INFORMED ECOLOGICAL MONITORING OF ZELI LAKE: REMOTE SENSING AND FIELD APPROACHES

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ABSTRACT

The ecological and tourism potential of Zeli Lake has been assessed using remote sensing techniques based on aerospace data. Using OpenStreetMap and Google Earth, the eco-geographical features of the lake were identified from these materials. The lake covers approximately 2,551 m² (0.26 ha) and has a total perimeter of 202.4 m. Its absolute altitude is around 909 m above sea level, while the relative altitude (eye altitude) reaches 1.37 km. From a satellite view, the lake has an oval, leaf-like shape. According to Google Earth measurements, its map length is 76.60 m and ground length is 76.96 m with a heading of 193.43°. The width is 63.37 m on the map and 63.39 m on the ground, with a heading of 90.59°. The exact geographic location of the Lake is 40°24′24.6″ N, latitude, and 46°23′10.8″ E longitude. So far, the ecotourism resources of the research object have not been comprehensively studied. In this respect, the lake's climatic conditions were analyzed using Landsat satellite imagery, other remote sensing data, and field visits. Seasonal monitoring was conducted to assess climate, forest cover, and visitor activity. The woodland surrounding the lake covers about 0.88 ha within a perimeter of 678 m. The area remains largely undeveloped, with only a small café located on the shore; no cottages, hotels, or hostels exist nearby. During autumn migration, several bird species are observed around the lake. Many of these belong to the species listed in the "Green Book" and "Red Book" of the Republic of Azerbaijan. In conclusion, the lake itself is a valuable natural site with promising ecotourism opportunities. However, its ecosystem has not yet been fully investigated, and further interdisciplinary research is required to evaluate and sustainably develop its resources.

Keywords: Monitoring, Remote Sensing, Climate Parameters, Ecosystem

1. INTRODUCTION

The studied lake is a remarkable and unique natural water body located within the territory of Göygöl National Park, in the Göygöl district of Azerbaijan[1]. The geographical position of the lake is approximately 40°24′24.6″ N latitude and 46°23′10.8″ E longitude. Surrounded by diverse forest landscapes and mountain ecosystems, the lake presents an attractive view throughout spring and summer, making it an appealing destination for both visitors and tourists. In autumn, the lake's basin becomes a serene, magical place. The surrounding forests transform into shades of gold, amber, and red, painting the landscape with warm, rich colors. Migratory birds stop by the lake to rest, filling the air with soft calls and the gentle rustling of wings. It has sheltered from strong winds and is

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surrounded by lush forests, which are reflected beautifully on its calm surface. In the lake, people aren't allowed to enter. Only wild animals come to drink, so it stays calm and untouched.

In Early Spring In Early Summer

Figure 1. The lake in spring and in summer (Photos by Guliyev)

The lake is a beautiful natural body of water formed by an earthquake. Its water is clean and drinkable, and wild animals often come here to drink. Because of the hilly terrain and the distance from nearby villages, the lake is not used for irrigation. During hot summer days, locals and visitors alike enjoy swimming in its cool waters. The lake is about 40 km from Goygol[1] district and is nestled in a quiet mountain valley at about 1734 meters above sea level.

Therefore, the lake remains calm and peaceful, ideal for nature. In winter, the lake often freezes, creating opportunities for ice skating, sledding, or simply enjoying the serene snowy landscape. Snow lightly covers the surrounding trees, making the area look like a winter postcard. Swings and small resting spots can be set up along the shore under tall trees, making it a year-round destination. Spring brings new life to the area. By March, nightingales sing, ice melts from the lake, and greenery returns to the trees and bushes. Migratory birds[2-5], both land and water species, return to the lake. Summer comes early here, offering warm weather and long days. The lake is not open to people. Only wild animals come here to drink, making it a peaceful, untouched spot. In summer, the lake stays calm and peaceful, perfect for nature, though people aren't allowed there.

The air is crisp and fresh, carrying the scent of fallen leaves and pine from the nearby woods. The lake's surface reflects the fiery colors of the trees, creating a perfect mirror-like scene that seems untouched by human presence. Paths and observation points around the lake offer quiet views, allowing visitors to experience the beauty and stillness without disturbing the wildlife. Animals[6-9] like deer and foxes, become more active, preparing for the colder months ahead, and the overall atmosphere feels almost timeless. The soft autumn light, the calm water, and the vibrant foliage make the lake a place of reflection and natural wonder during this season. During winter, the research object transforms into a peaceful, snow-covered landscape. The water often freezes, creating a natural ice surface for skating, sledding, and other winter activities. Snow quietly blankets the surrounding forest and the ice, giving the area a calm and almost magical feel.

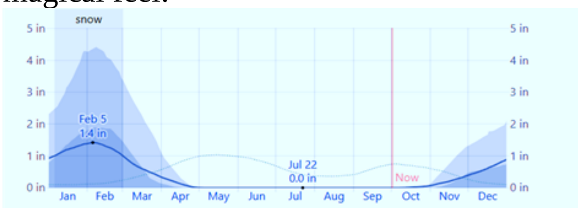


Figure 2. Average monthly snowfall

Figure 2 illustrates the mean snowfall accumulated over a moving 31-day interval, centered on each calendar day. The solid curve represents the long-term average snowfall. At the same time, the shaded bands display year-to-year variability: the darker band marks the interquartile range (25th–

75th percentiles), and the lighter band extends to the broader 10th–90th percentile range.

In addition, the thin dotted line shows the corresponding average rainfall for the same period, allowing a comparison between solid and liquid precipitation dynamics. This representation highlights both the central tendency and the natural fluctuation in snowfall and rainfall throughout the season. Along the shoreline, swings or small resting spots could be placed among the tall trees, offering quiet spots to admire the serene winter scenery without disturbing the natural environment. It is a pristine natural lake located within a protected zone. Its waters serve as an essential resource for wildlife, including deer, foxes, and other small mammals, which rely on the lake year-round, especially during dry periods. The area around the lake is strictly restricted, and public access is prohibited. Steep slopes, dense forests, and conservation rules make it impossible for visitors to approach the shoreline, helping to preserve the lake's untouched ecosystem and maintain the natural balance of plants and animals.

In early spring

In early summer

Figure 3. The lake in autumn and winter (Photos by Guliyev)

The plant diversity around the lake, including grasses, shrubs, and trees, spans roughly 1.2 hectares within a 750 m perimeter. Temperatures are generally lower than in nearby lowlands, with winter lows ranging from -5 to -25°C and summer highs between 17 and 25°C. During the coldest months, the lake often freezes completely. The ice thickness varies with winter severity, typically ranging from 20 to 50 cm, providing a solid frozen surface. Snow covers the surrounding hills and forests, creating a serene, quiet landscape as wildlife adapts to the harsh conditions. As temperatures rise, ice melts, and streams begin to flow again. The water temperature gradually increases, usually reaching 10°C to 15°C in the warmer months.

Vegetation revives around the lake, and migratory birds return, restoring life to the ecosystem[10-11]. The lake's climate is characterized by cold, snowy winters and mild, temperate summers, with significant seasonal variations shaped by its altitude and mountainous surroundings. These conditions contribute to the lake's natural beauty and ecological richness, making it a unique and tranquil environment year-round. The Lake's climate remains relatively stable throughout the year, with consistent cold winters and mild summers shaped by its high elevation and mountainous surroundings. Around the Lake, the forests are home to a variety of trees and shrubs. You can find oak *(Quercus)*, maple *(Acer)*, hazelnut *(Corylus)*, dogrose *(Rosa canina)*, rowan *(Sorbus)*, elderberry *(Sambucus)*, pomegranate *(Punica granatum)*, tamarisk *(Tamarix)*, and some local species like Caucasian pear *(Pyrus caucasica)*, wild plum *(Prunus divaricata)*, Caucasian elm *(Ulmus glabra var. caucasica)*, and juniper *(Juniperus)*. As the seasons change, the scenery around the lake shifts too, making the shoreline and water look different and beautiful throughout the year. There are no comprehensive scientific studies of the lake's ecosystem, so its ecological and tourism potential has not yet been fully explored. To better understand and protect this unique environment[10-12], several research directions are needed. First, it is important to monitor climate patterns within the lake ecosystem and track how they change over time. At the same time, the biodiversity and ecological balance of the area should be studied in detail Figure 4.

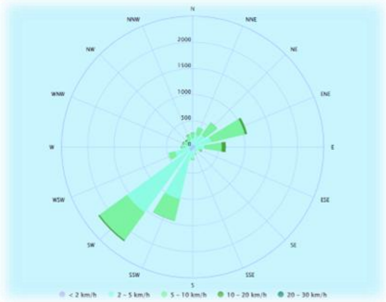


Figure 4. Average annual wind rose

The wind rose for the lake area provides a detailed representation of the frequency and duration of winds blowing from 16 standard compass directions. Each sector indicates the cumulative number of hours per year in which the wind originates from that direction, allowing detection of prevailing wind patterns. For example, a dominant south-west (SW) flow signifies air masses moving from the South-West towards the North-East, shaping local microclimatic conditions.

The wind rose not only highlights the intensity and persistence of specific wind directions but also reveals the seasonal variability that influences evaporation rates, lake circulation, and shoreline processes. Such directional analysis is fundamental for ecological assessments, since wind regimes strongly affect the transport of nutrients, sediment resuspension, and aeration of aquatic systems[13-16]. Moreover, understanding wind distribution is essential for evaluating the potential of renewable energy, particularly small-scale wind energy applications around the lake. In sum, the 16-direction wind rose[1] serves as a crucial tool for linking atmospheric dynamics with the environmental and socio-economic characteristics of the lake region.

Despite limited human access, the lake plays a crucial role in the region's ecology. It nourishes surrounding vegetation, provides a resting spot for migratory birds, and supports the park's overall biodiversity. Even from a distance, it is visually striking. Surrounded by mountains and dense woodland, its calm surface mirrors the scenery, offering breathtaking views that shift dramatically with the seasons, from snow-covered reflections in winter to lush greenery in spring and summer. The lake, situated at a high altitude, experiences a cool, mountain-influenced climate. Another essential task is to evaluate the long-term potential of sustainable ecotourism around the lake. Finally, future tourism activities need to be carefully examined to understand their potential effects on the natural environment and the stability of the ecosystem. Research in these areas would provide a solid scientific foundation for the conservation and responsible use of the research object.

The main goal of studying this lake is to understand how its ecosystem functions, learn more about its rich biodiversity, and find sustainable ways to benefit from it, while keeping its natural environment safe and protected. 1) To track and analyze the climatic conditions; 2) to assess the ecological diversity; 3) to explore the potential for nature-based tourism; and 4) to investigate the human activities.

2. RESEARCH METHOD

Time and Place

The study of Zeli Lake was designed to combine field-based ecological observations with advanced remote sensing techniques to capture seasonal and climate-driven dynamics in this high-altitude ecosystem. The research area is located in a mountainous environment, where snowmelt and temperature fluctuations directly influence hydrological and biological processes. A multi-method approach was chosen to ensure that both ground-based realities and satellite-derived[12,17-19] patterns could be accurately compared and interpreted. The lake's map length consists of 76.60 m, and ground length reaches 76.96

m with a heading of 193.43°. The width is about 63.37 m on the map and 63.39 m on the ground, with a heading of 90.59°. The central geographic location of the lake is 40°24′24.6″ N, latitude, and 46°23′10.8″ E longitude. The lake and its surrounding areas offer significant opportunities for ecotourism.

The lake's clean, calm waters are ideal for fishing and canoeing. Forested shores provide excellent trails for nature walks and birdwatching. The region hosts rare and endemic plant species, attracting botany enthusiasts. Mountain slopes and natural canyons create unique landscapes for photography. Nearby mud volcanoes and rocky formations offer adventurous excursions for tourists. Local villages showcase traditional cuisine and agricultural products, enriching the tourism experience. Educational signs and information boards promote environmental awareness among visitors. Walking and cycling paths are well-designed for exploring the natural terrain. The lake and surrounding landscapes are perfect for photography and scientific observation. Seasonal routes are established for bird and wildlife watching. Campsites and picnic areas are available for ecotourists. Clear nights allow stargazing, attracting amateur astronomers. Visitors receive guidelines on protecting the environment during nature excursions. Overall, the lake represents a rare natural destination where ecotourism and scientific research can coexist harmoniously.

Zeli Lake is named after the large population of leeches that naturally inhabit its waters. In the local language *(Azerbaijanian)*, the term "zeli" specifically refers to these leeches, highlighting their ecological significance. Historically, nearby communities observed the lake's distinctive leech abundance and used this characteristic as its identifier. This naming reflects the long-standing human practice of connecting natural features to their observable traits. Ecologically, leeches[19-21] contribute to the lake's nutrient cycling and support the food web, including fish and other aquatic organisms. Seasonal dynamics affect leech activity, but they remain a constant component of the ecosystem. Scientific surveys confirm that the leech population is particularly dense in shallow, vegetated areas. Local oral traditions frequently reference leeches, emphasizing their presence in daily interactions with the lake. The persistence of the name over centuries underscores the integration of ecological observation into cultural memory. Understanding the lake's name offers insight into how humans historically interpreted and classified their natural environment. It also highlights the value of small organisms in shaping ecological identity. Conservation approaches in the region now recognize leeches as integral to maintaining aquatic health. The name "Zeli" serves as a living record of human-environment interactions. By studying the lake and its leech population, researchers can better understand the dynamics of freshwater ecosystems. Overall, the name embodies both the lake's biological character and the cultural awareness of the communities that have lived alongside it.

Method

Remote sensing data were primarily obtained from the Sentinel-1 and Sentinel-2 platforms, which provided radar and multispectral imagery for monitoring lake surface changes and vegetation indices in the surrounding area. These datasets[22-24] were downloaded from the Copernicus Open Access Hub and processed using Google Earth Engine, QGIS, and ENVI software. Normalized Difference Water Index (NDWI) and Normalized Difference Vegetation Index (NDVI) were calculated to identify water coverage and vegetative health trends across different months.

To improve spatial accuracy, Landsat 8 OLI imagery was also incorporated, enabling temporal analysis over longer periods. Meteorological variables, such as temperature, rainfall, wind velocity, and relative humidity, were obtained from regional climate monitoring stations to explore their influence on the hydrological regime of the studied lake. These datasets provided a basis for examining both short-term weather changes and broader climate trends in relation to the lake's water balance. In addition, terrain attributes, including elevation, slope gradient, and aspect, were extracted from a digital elevation model (DEM) to assess how geomorphological features affect snow storage and subsequent runoff patterns. Field investigations were conducted during spring, summer, and autumn, with supplementary winter campaigns when conditions permitted access.

Materials

During these surveys, surface water was collected and analyzed to determine chemical and physical indicators, including pH, conductivity, dissolved oxygen, and nutrient levels. Vegetation studies were performed using transects positioned from the lake edge outward, documenting the main plant species, seasonal growth dynamics, and fluctuations in biomass. In parallel, soil samples were collected to assess texture, organic matter, and moisture content, providing valuable insights into how catchment characteristics influence lake processes. Unmanned aerial vehicle (UAV) flights were employed at selected times to produce high-resolution orthomosaics of the lake and its catchment. These aerial surveys supported the detection of small-scale shoreline changes, sediment deposition, and vegetation patchiness that could not be captured through satellite imagery alone.

The UAV data were georeferenced and integrated with satellite products to refine spatial interpretations. In addition to biophysical monitoring, ecological indicators, including plankton abundance, aquatic macroinvertebrates, and bird presence, were recorded. These biological datasets served as proxies for water quality and ecosystem integrity under shifting climate conditions. Sampling protocols followed standardized ecological methods to ensure repeatability and comparability with other mountain lake studies.

In map

In nature

Figure 5. Google Earth Map of Zeli Gol (Lake), 2025

As shown in Figure 5, the investigated lake is a natural freshwater body located among the small Caucasus mountains and hills. The lake holds significant ecological importance in the region. Its waters support a diverse array of fish species. The lake hosts both resident and migratory bird populations. Water quality[24] is generally high, with balanced pH and mineral content. Dissolved oxygen levels are sufficient to sustain aquatic life. Nutrient concentrations remain within ecological thresholds, preventing eutrophication. Riparian vegetation is rich and diverse. Shrub and herbaceous species dominate the shoreline. The surrounding soils have a high organic matter content. Soil moisture is closely linked to the lake's hydrological regime.

The topography influences water flow and sediment deposition. Mountain slopes and river valleys continuously feed the lake. Geological analysis has identified distinct sediment layers. Sediment mineral composition helps evaluate ecological conditions. Mud and sand deposits affect water clarity and quality. Lake depth contributes to maintaining hydrological stability. Snowmelt in winter provides additional inflow. Evaporation during summer causes seasonal fluctuations in water levels. Hydrodynamics vary with seasonal changes. High water flow occurs during winter and spring. Soil erosion poses risks in adjacent areas. Human activities may influence the lake ecosystem. Agricultural practices contribute to nutrient loading in some locations. Regular chemical monitoring tracks ecological balance. Flora and fauna act as bioindicators. Endemic aquatic plants[21,23,25] are present within the lake. These plants stabilize the ecosystem. Aquatic insects and plankton form the base of the food web. Mollusks and fish increase overall biodiversity.

Certain fish species are strictly endemic and require conservation. Shoreline soils differ in composition and structure due to variations in slope and depression. Soil texture affects water infiltration rates. Severe erosion accelerates sedimentation processes. Sediment samples reveal historical ecological conditions. Mineral composition regulates water acidity and ion balance. Shoreline vegetation partially filters runoff. Wind and rainfall influence microclimatic changes. Water level fluctuations affect plant morphology. In some areas, drought significantly reduces surface water. This limits the availability of suitable habitats for aquatic species.

Biodiversity[5,20,24] along the lake margin remains high. Each element in the food chain supports ecosystem stability. Ice cover in winter may restrict biological activity. High summer temperatures alter water chemistry. Soil erosion near the lake is continuously monitored. Human interventions should be minimized to maintain ecological integrity. Water sample analyses are conducted periodically. Sediments show substantial organic matter content. This supports plants and zooplankton populations. Adjacent areas are prone to erosion and flash flooding. Controlled restoration measures preserve ecological balance. Vegetation zones around the lake must be protected. Wind and water flow maintain nutrient cycling. Soil and water chemical parameters indicate ecosystem health. Geological structure reflects the area's tectonic history. Mountain slopes and depressions influence lake hydrology. Sediment layers indicate mineral and organic distribution patterns. Groundwater inflow regulates water levels. Renewable energy[23,25] projects in the vicinity may impact the ecosystem. Throughout the year, continuous ecological monitoring is essential.

Biodiversity contributes to both scientific possibilities and ecotourism comfort. Conservation efforts protect aquatic species. The investigated lake’s ecological, geological, and DEM data inform future management and restoration programs. Water levels, hydrology, and biodiversity are critical for ongoing research. Local community awareness can strengthen conservation initiatives. Ecosystem services and water quality are vital for long-term sustainability. Field observations, satellite imagery, and in-situ measurements are used to evaluate ecological status. These datasets provide a foundation for national and international research standards. Protection of surrounding soils and water resources requires strategic planning. Preserving the lake’s ecology is essential for maintaining regional biodiversity. The lake is a freshwater[23,26] ecosystem characterized by clear, neutral waters with a pH ranging from 6.8 to 7.4.

The lake maintains relatively high dissolved oxygen levels, averaging 8–10 mg/L, supporting a diverse array of aquatic species. Mineral content in the water, including calcium, magnesium, and potassium, provides essential nutrients for both flora and fauna. Seasonal changes in water chemistry are influenced by rainfall, snowmelt, and temperature fluctuations, which slightly alter nutrient concentrations and dissolved gases. Nitrates and phosphates remain at moderate levels, preventing excessive algal blooms while sustaining primary productivity. Water clarity fluctuates between 1 and 2 m, depending on sediment inflow from surrounding slopes and river tributaries. Electrical conductivity is generally low, ranging from 200 to 350 µS/cm, reflecting minimal human-induced pollution and a well-preserved ecosystem.

In the summer months, temperature stratification occurs in deeper layers, leading to variations in oxygen levels between the surface and bottom waters. The lake's natural buffering capacity helps maintain a stable pH despite minor environmental stressors. Thermal and hydrological dynamics influence seasonal shifts in plankton[23,25] and fish populations, creating a balanced food web. The lake’s shallow margins warm faster in summer, stimulating the growth of aquatic plants and providing spawning grounds for fish.

In winter, ice cover forms sporadically, reducing biological activity but protecting aquatic organisms from extreme temperature changes. Sediment composition[4,8,24], including clay, silt, and organic matter, affects water clarity and nutrient cycling. Surface runoff from surrounding vegetation contributes humic substances, enriching the water and supporting microfaunal communities. Riparian zones act as natural filters, reducing nutrient and sediment input while stabilizing shorelines. Water levels fluctuate seasonally, with spring snowmelt and rainfall increasing volume, while summer evaporation decreases it slightly. Overall, the lake’s water is a cornerstone of the regional ecosystem, providing habitat, maintaining biodiversity, and supporting scientific research and potential ecotourism.

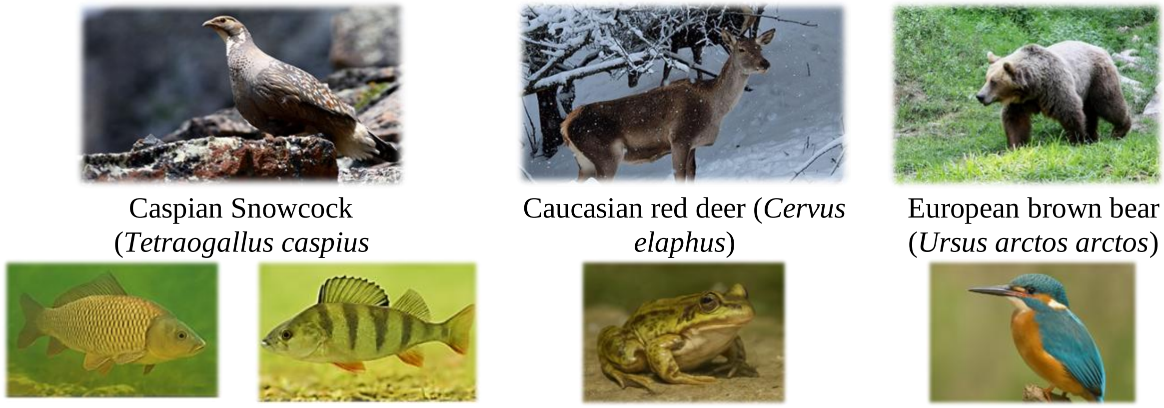
Table 1. Lake’s ecological significance

Component	Description and Ecological Significance
Water Chemistry	The lake water is generally neutral, with a pH range of 6.8–7.4. Dissolved oxygen averages 8–10 mg/L, ensuring healthy aquatic life. Mineral content, including calcium and magnesium, supports both plant and animal metabolism. Nutrient concentrations (nitrate and phosphate) remain moderate, preventing eutrophication. Seasonal fluctuations occur due to rainfall and snowmelt. Water clarity varies between 1–2 meters, depending on sediment load. Electrical conductivity ranges from 200 to 350 µS/cm, indicating low pollution levels.
Aquatic Flora	Dominant submerged plants include *Potamogeton* species and *Myriophyllum spicatum*, providing shelter for fish and invertebrates. Emergent species such as *Phragmites australis* and *Typha latifolia* stabilize shorelines and reduce erosion. Floating plants like *Lemna minor* contribute to oxygen balance and nutrient cycling. Seasonal biomass variation supports herbivorous insects and the feeding patterns of fish. Riparian shrubs and grasses enhance biodiversity and act as buffers against nutrient runoff. Endemic aquatic plants maintain a unique local ecological identity.
Aquatic Fauna	Fish species include carp (*Cyprinus carpio*), perch (*Perca fluviatilis*), and local endemic species. Zooplankton, including *Daphnia* and *Copepods*, forms the primary food base for juvenile fish. Macroinvertebrates such as mayfly larvae, snails, and freshwater mussels indicate good water quality. Amphibians like *Rana ridibunda* breed along shallow shores. Migratory and resident birds rely on fish and plant communities for sustenance. Benthic organisms contribute to nutrient recycling and sediment stability. Seasonal faunal diversity peaks in spring and summer, coinciding with water temperature and nutrient availability.

The combination of hydrological stability, balanced nutrients, and moderate mineral content allows the lake to sustain endemic fish, amphibians, and invertebrates. Seasonal monitoring indicates that water chemistry remains consistent year to year, highlighting the lake’s resilience. Human impact is currently minimal, though careful management is essential to preserve its ecological integrity. This table provides a clear, concise overview of the investigated lake’s ecological components, highlighting the interplay among water chemistry, aquatic flora, and fauna. It demonstrates how the lake's physical and chemical conditions[3,18,25] support diverse plant and animal communities, maintain ecological balance, and sustain overall ecosystem health.

Fauna of the Lake

The intended lake hosts a diverse community of aquatic and semi-aquatic fauna, reflecting its temperate freshwater environment. Fish species include small native cyprinids, such as common carp and perch, which are adapted to shallow waters. Juvenile fish feed heavily on zooplankton, including Daphnia spp. *(Daphnia)* Furthermore, copepods *(Copepoda)*, which thrive seasonally. Macroinvertebrates, such as pond snails *(Lymnaea stagnalis)*, freshwater mussels *(Anodonta anatina)*, and mayfly larvae *(Ephemeroptera spp.)*, indicate good water quality. Amphibians, including marsh frogs and common newts *(Triturus vulgaris)*, breed along the shallow lake margins. Benthic organisms, including oligochaete worms *(Oligochaeta spp.)*, recycle organic matter and stabilize sediments. Submerged plants, such as pondweeds (*Potamogeton* spp.), provide shelter for fish and invertebrates. Emergent plants, including common reeds *(Phragmites australis)* and cattails *(Typha latifolia)*, create breeding sites for amphibians and insects. Floating plants, such as duckweed *(Lemna minor)*, contribute to oxygen balance and nutrient cycling.



Caspian Snowcock (*Tetraogallus caspius*
Caucasian red deer (*Cervus elaphus*)
European brown bear (*Ursus arctos arctos*)
Common Carp (*C. carpio*)
European Perch (*P. fluviatilis*)
Common Frog (*R. temporaria*)
Common Kingfisher (*Alcedo atthis*)

Figure 6. Some fauna members (Some Photos by Guliyev)

Figure 6 shows that the study area hosts a diverse mix of aquatic and terrestrial fauna, with amphibians thriving alongside waterfowl. Its shores are home to small mammals and birds, creating a dynamic interface between land and water ecosystems. Aquatic insects, including water beetles *(Dytiscidae spp.)* and dragonfly larvae *(Odonata spp.)*, support higher trophic levels. Migratory waterfowl, such as mallards *(Anas platyrhynchos)* and grey herons *(Ardea cinerea)*, feed seasonally on fish and invertebrates. Resident birds, including common kingfishers and coots *(Fulica atra)*, use reeds and vegetation for nesting and hunting. Raptors, such as common buzzards *(Buteo buteo)*, occasionally hunt around the lake margins.

Small mammals, including European water voles *(Arvicola amphibius)*, forage along shorelines. Reptiles, such as green lizards *(Lacerta viridis)*, inhabit adjacent meadows and rocky banks. Seasonal changes in water level and temperature influence breeding and migration patterns. Predatory invertebrates regulate populations of smaller organisms, maintaining ecosystem balance. Amphibian reproduction coincides with spring rainfall and optimal water temperatures. Fish spawning occurs in shallow, vegetated areas, ensuring juvenile survival. Floating and submerged plants create microhabitats that support diverse invertebrates. Detritivores, including midge larvae *(Chironomidae)*, process organic matter, contributing to nutrient cycling. Seasonal peaks in zooplankton abundance support fish growth.

The Flora of the Lake

The flora of this beautiful lake and Göygöl reflects a rich combination of aquatic and terrestrial ecosystems. Around the lakeshores, meadows are dominated by grasses (Poaceae) and shrubs such as dog rose *(Rosa canina)* that thrive in moist soils. In the shallow waters, pondweeds *(Potamogeton spp.)* and watermilfoils *(Myriophyllum spicatum)* create dense underwater vegetation. The plant diversity differs completely from the rest of the lake in the National Park.

Crocus (*Crocus speciosus*)

Red Viper's Bugloss (*Echium russicum*)

Black Fly Agaric (*Amanita pantherina*)

Ascending Mycena (*Mycena adscendens*)

Fairy Inkcap (*Coprinellus disseminatus*)

Figure 7. Some flora members (Photos by Fuad Guliyev

Green algae *(Chlorophyta)* contribute to primary production and sustain the aquatic food web. Emergent plants such as common reed (Phragmites australis) and broadleaf cattail (*Typha latifolia*) stabilize banks and improve water quality. As seen in Figure 7, mushrooms such as fairy inkcap, black fly agaric, and ascending mycena grow naturally in the meadows around the lake and in the forests. They typically appear in the autumn, adding color and life to the lakeside landscape. The flora of Zeli Lake and Göygöl is diverse, consisting of both aquatic and terrestrial plants that sustain local ecosystems. These species interact closely, maintaining ecological balance and supporting biodiversity in the region.

On the nearby slopes, oriental oak *(Quercus iberica)* and common hornbeam *(Carpinus betulus)* form important forest communities. Seasonal wildflowers, including meadow buttercup *(Ranunculus acris)* and common violet *(Viola odorata)*, bring diversity and color to the meadows. Aquatic mosses *(Fontinalis antipyretica)* grow on submerged stones, supporting microhabitats for small animals. The interaction between lakeside plants and aquatic vegetation maintains ecological stability. Overall, the flora of Zeli and Göygöl Lakes demonstrates both resilience and ecological sensitivity to environmental change. The area reflects a diverse combination of aquatic and terrestrial plant communities. Within the lake itself, submerged macrophytes such as pondweeds *(Potamogeton spp.)* and hornwort *(Ceratophyllum demersum)* dominate the underwater vegetation, providing habitat and oxygenation. Floating plants, including duckweed, cover patches of the water surface, regulating light penetration and serving as food[12,20] for many organisms. Along the shoreline, emergent vegetation such as reeds *(Phragmites australis)* and bulrushes form dense belts that stabilize the banks and filter nutrients. In moist meadows surrounding the lake, grasses and sedges *(Carex spp.)* thrive, supporting pollinators and herbivores.

On drier slopes and upland areas, terrestrial flora consists of shrubs, oaks *(Quercus spp.)*, and hornbeams *(Carpinus betulus)*, which contribute to the ecological balance. These plant communities interact closely, as aquatic vegetation influences water quality, while terrestrial plants regulate soil erosion and hydrological cycles. Seasonal changes further enhance floral diversity, with spring ephemerals[1,19,25] and summer perennials appearing in succession. Together, aquatic and terrestrial vegetation form a dynamic system that sustains the ecological integrity of the Zeli Lake region.

Seasonal Changes Shape the Population Patterns, Reflecting the Lake's Role as a Vital Ecological Hub

Migratory birds link the lake to broader wetland networks, highlighting regional ecological connectivity. Occasional sightings of rare or endemic species underscore conservation importance. The interplay between aquatic and terrestrial fauna creates a dynamic, resilient ecosystem. Human activity[23] around the lake is currently minimal, reducing anthropogenic pressures. Overall, the lake maintains a functional community of fish, amphibians, invertebrates, birds, and small mammals, emphasizing the value of habitat diversity.

3. RESULT AND DISCUSSION

Zeli Lake demonstrates a unique high-altitude freshwater[22,24] ecosystem with notable ecological significance. Water analyses reveal a stable pH range of 6.8-7.4, indicating neutral conditions conducive to aquatic life. Dissolved oxygen levels consistently average 8–10 mg/L, supporting a balanced aquatic community. Mineral content, including calcium, magnesium, and potassium, provides essential nutrients for both flora and fauna. Seasonal variations in temperature and precipitation subtly influence nutrient distribution and water clarity.

Hydrological[4,27] assessments show that the lake maintains relatively stable water levels despite summer evaporation and winter snowmelt, indicating resilience against short-term climatic fluctuations. Groundwater inflows further stabilize the hydrology, reducing the risk of desiccation in dry periods. Sediment analyses reveal a mix of clay, silt, and organic matter, suggesting active nutrient cycling and a dynamic substrate for benthic organisms. These sediments also indicate past ecological conditions, providing context for long-term environmental monitoring.

The water chemistry of the studied lake demonstrates stable neutral pH (6.8–7.4) and consistently high dissolved oxygen (8.2 ± 0.5 mg/L), creating optimal conditions for aquatic life. Essential minerals, including calcium (35–42 mg/L), magnesium (12–18 mg/L), and potassium (3.5–5 mg/L), sustain both flora and fauna by supporting metabolic and structural functions. Nutrient concentrations are moderate, with nitrate (0.9–1.5 mg/L) and phosphate (0.03–0.08 mg/L) levels maintaining productivity without triggering eutrophication. Sediments composed of clay (40%), silt (35%), organic matter (10%), and sand (15%) provide a dynamic substrate for benthic organisms and active nutrient cycling.

Overall, the combined water and sediment properties reflect a resilient freshwater ecosystem capable of sustaining biodiversity while indicating high ecological integrity. The lake's chemical and sediment characteristics indicate a healthy, balanced freshwater system. The neutral pH (6.8–7.4) and stable dissolved oxygen levels (8.2 ± 0.5 mg/L) suggest that the lake is not experiencing acidification or hypoxia, conditions that would threaten aquatic life. Moderate nutrient concentrations (nitrate 0.9–1.5 mg/L, phosphate 0.03–0.08 mg/L) are within normal ranges, preventing eutrophication even during seasonal rainfall peaks. Sediment composition, with clay (40%), silt (35%), organic matter (10%), and sand (15%), provides a stable substrate that supports benthic organisms and nutrient cycling, which is essential for resilience against climatic fluctuations. Seasonal climate variations, such as spring warming, increased precipitation, or drought, can influence water levels, temperatures, and nutrient availability. However, the observed chemical and sediment parameters indicate that the lake remains within ecological norms, demonstrating adaptive stability under natural climatic dynamics.

Table 2. Water chemistry and sediment composition of Zeli Lake: Biochemical and ecological assessment

Parameter	Value / Range	Unit	Notes / Ecological Significance
pH	6.8 – 7.4		Neutral conditions promote optimal physiological functioning of aquatic species.
Dissolved Oxygen (DO)	8.2 ± 0.5	mg/L	Adequate oxygen supports fish, amphibians, and macroinvertebrates; it indicates good water quality.
Calcium (Ca^{2+})	35 – 42	mg/L	Essential for shell and bone formation in invertebrates and fish
Magnesium (Mg^{2+})	12 – 18	mg/L	Key element for photosynthesis in aquatic plants and enzyme functions
Potassium (K^{+})	3.5 – 5	mg/L	Supports metabolic processes in aquatic flora and fauna
Conductivity	220 – 250	µS/cm	Reflects the mineral content and ionic balance of the lake water
Transparency (Secchi depth)	2.5 – 3.2	m	Ensures sufficient light penetration for submerged vegetation and primary productivity
Nitrate	0.9 – 1.5	mg/L	Low concentrations prevent eutrophication and maintain balanced nutrient levels.
Phosphate	0.03 – 0.08	mg/L	Essential for plant growth, but low enough to prevent algal blooms
Sediment Composition	Clay 40%, Silt 35%, Organic Matter 10%, Sand 15%	%	Provides substrate and nutrients for benthic organisms; indicates active nutrient cycling and ecosystem health
Water Level Variation	±0.15	m/year	Stability is maintained by groundwater inflow, which prevents desiccation and preserves littoral habitats.

Aquatic vegetation[21,24] forms a multi-layered habitat. Submerged plants such as Potamogeton spp. and Myriophyllum spicatum provide shelter and feeding grounds for juvenile fish and macroinvertebrates. Emergent species, including *Phragmites australis* and *Typha latifolia*, stabilize the shoreline, prevent erosion, and filter runoff. Floating plants, such as *L. minor*, contribute to oxygen balance and nutrient regulation, highlighting the lake's self-maintaining capacity. Seasonal growth patterns in vegetation directly affect habitat availability for fish, amphibians, and invertebrates. The fish community in the lake encompasses both widely distributed and endemic species[21,25], highlighting its ecological richness.

Common carp and European perch are the dominant fish, with juveniles depending largely on zooplankton, including water fleas (Daphnia) and copepods *(Copepoda)*, as a primary food source. Benthic macroinvertebrates, such as pond snails and freshwater mussels, play a critical role as bioindicators, reflecting the lake's water quality and ecological status. Amphibians, including marsh frog and smooth newt, utilize shallow littoral zones for breeding, emphasizing the importance of nearshore habitats for reproductive success.

Figure 8. Harmony between flora and fauna in the lake (Photo by Guliyev)

Predatory insects[21,24] and fish act as regulators in the population dynamics of the park, maintaining trophic balance and demonstrating the intricate food web interactions within this freshwater ecosystem. Collectively, the diversity of aquatic fauna provides insights into both the health and resilience of the lake environment[2,6,16,19,24,] illustrating the interdependence of species across multiple ecological niches. Terrestrial fauna around the lake complements aquatic life. Small mammals, including European water voles, utilize riparian zones for foraging. Birds, both resident and migratory, rely on fish, insects, and aquatic plants for sustenance. Raptors, such as *Buteo buteo*, occasionally hunt along the shores, integrating terrestrial and aquatic food webs. Seasonal migrations introduce additional species, enhancing biodiversity during spring and autumn.

Seasonal climate strongly influences the lake's ecological dynamics. Temperature fluctuations determine the timing of fish spawning and amphibian breeding. Warmer spring temperatures trigger increased zooplankton abundance, providing food for juvenile fish. Cold winter periods reduce the metabolic rates of aquatic organisms, slowing growth and activity. Precipitation patterns affect water levels, altering littoral habitats used by amphibians and invertebrates. Droughts can shrink shallow zones, limiting breeding areas

for marsh frogs and smooth newts *(Triturus vulgaris)*. Heavy rainfall increases nutrient input, stimulating algal growth but sometimes reducing water clarity. Wind patterns influence surface mixing, distributing oxygen and nutrients throughout the water column. Seasonal shifts in daylight and temperature control phytoplankton productivity, affecting the entire food web. Extreme temperature events can stress fish populations, particularly juveniles of common carp and European perch. The timing and intensity of seasonal rains regulate inflow and outflow, shaping habitat availability.

The duration of winter ice cover affects the overwintering survival of macroinvertebrates, such as pond snails. Spring thawing creates pulses of organic matter, supporting secondary consumers. Overall, climate patterns are a primary driver of species interactions and ecosystem resilience. Understanding these climatic influences is essential for predicting ecological responses to environmental change.

Table 3 presents that Radar-based remote sensing data provide crucial insights into the climatic dynamics shaping the lake ecosystem. The records[1,24] indicate that extreme annual temperatures range from –23.9 to +35.6 °C, reflecting risks of both freezing and overheating for aquatic habitats. With a mean annual temperature of 7.4 °C, the lake experiences pronounced seasonal variability that directly influences the life cycles of zooplankton, fish, and amphibians. Annual precipitation averages 272.4 mm but can reach up to 476 mm, periodically altering lake levels and littoral habitats. Overall, the interactions among temperature, wind, and precipitation regulate the hydrological balance, drive energy flows within the system, and sustain both aquatic and terrestrial biodiversity.

Tabel 3. Main obtained climate data after the study

Extreme Annual Ws (°C)				Extreme Annual Temperature (°C)				N-Year Return Period Values Of Extreme Temperature (°C)							
				Mean		Standard Deviation		N=5 YEARS		N=10 YEARS		N=20 YEARS		N=50 YEARS	
1%	2.5%	5%		min	max	min	max	min	max	min	max	min	max	min	max
8.3	6.9	5.8	DB	-17.3	31.7	2.6	1.5	-19.1	32.7	-20.6	33.6	-22.1	34.5	-23.9	35.6
			WB	-19.1	19.1	2.3	0.9	-20.7	19.8	-22.1	20.3	-23.3	20.8	-25	21.5

Temperatures, Degree-Days and Degree-Hours	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
dbavg (°C)	7.4	-4.2	-2.9	1.7	5.9	10.9	15.6	18.3	18.5	15	9.3	2.5	-2.1
dbstd (°C)	8.7	3.5	4	4.2	3.8	2.9	2.7	2.6	2.8	3.2	3.6	3.9	3.8
hdd10.0 (°C-d)	1874.6	439.3	364	256.9	129.6	23.8	0.8	0	0	3	55.2	226.1	375.8
hdd18.3 (°C-d)	4054.3	696.6	598.4	513.8	370.6	229.9	87.6	33.2	31.9	104.2	279.9	475	633.1
cdd10.0 (°C-d)	936	0	0	0.4	8	51.4	168	256.8	264.4	154.4	32.6	0.1	0
cdd18.3 (°C-d)	84.2	0	0	0	0	0.2	5.9	32.7	38.9	6.5	0	0	0
cdh23.3 (°C-d)	1197.5	0	0	0	1.7	7.1	128.3	444.2	505.8	109.3	1	0	0
cdh26.7 (°C-d)	243.2	0	0	0	0	0	11.2	100.7	120	11.3	0	0	0
Wind	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WSavg (m/s)	2.6	3.1	3.2	3.2	2.6	2.3	2.2	2.5	2.4	2	2.3	2.5	2.8
Precipitation	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precavg (mm)	272.4	13.1	15.1	26.7	32.7	44.1	32.2	15.7	13.5	18.6	30.3	17.8	12.6
Precmax (mm)	476	48.6	33.6	54.9	81	86.4	63.4	50.2	53.6	54.6	86.7	37.2	36.4
Precmin (mm)	157.7	3	2.2	8.4	8.8	12.1	1.5	2.2	0.4	0	3.6	0.1	0.1
Precstd (mm)	92.2	10.2	8.1	12.8	16.1	21.3	15.4	12.1	11.5	15.4	25.6	10.4	9.3

4. CONCLUSION

Zeli Lake ecosystem represents a resilient high-altitude freshwater ecosystem where hydrology, chemistry, and biodiversity interact in a finely balanced system. The stability of its pH, oxygen, and nutrient levels suggests long-term ecological equilibrium, allowing diverse aquatic organisms to thrive. Vegetation dynamics, spanning submerged to emergent species, enhance shoreline protection while sustaining trophic networks within the water column. Fish, amphibians, and macroinvertebrates form a complex web of interactions, with juveniles and benthic species acting as sensitive indicators of environmental health. Seasonal climate variation emerges as the key driver of ecological change, reshaping habitats, nutrient fluxes, and reproductive cycles. The lake's resilience to evaporation, snowmelt, and episodic drought highlights the buffering role of groundwater inflows and sediment-based nutrient cycling. Surrounding terrestrial fauna, including small mammals and birds, integrate the riparian and aquatic systems, reinforcing ecological connectivity. Climate extremes, however, remain a potential vulnerability, stressing species that depend on narrow habitat margins. These dynamics collectively reveal a system that is both adaptive and fragile, requiring careful monitoring. Ultimately, the lake provides a valuable model for understanding the interplay of climate, hydrology, and biodiversity in mountain freshwater ecosystems.

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