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ORIGINAL ARTICLE

Geo-ecological Values and Sustainable Geotourism Potential of the İğneada Floodplain Forests and Lagoon Lakes, NW Türkiye

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Abstract
The İğneada Floodplain Forests, located in Demirköy District of Kırklareli Province, are among the most significant natural heritage areas of Türkiye due to their ecological, hydrographic, and biological values. This study identifies the geomorphological, ecological, and socio-cultural heritage components of the İğneada Floodplain Forests and evaluates the geotourism potential of the region. A qualitative research design was adopted, employing field observations and document analysis methods. The findings indicate that İğneada possesses considerable geoheritage value with its unique lagoon lakes and dune systems, exceptionally high ecological heritage potential with its rich floral and faunal diversity, and a notable socio-cultural heritage dimension shaped by local cultural characteristics. It is understood that geotourism and ecotourism activities in İğneada could contribute both to the conservation of natural heritage and to local development. However, due to the sensitivity of the floodplain ecosystem to external pressures, sustainable management and planning approaches are of vital importance. The study concludes by offering integrated recommendations for conserving the region's values while promoting their assessment within the framework of geotourism.

Keywords Geoheritage · Geotourism · Ecological heritage · Floodplain forests · Erikli Lake · Mert Lake

Introduction

Natural heritage sites are areas that possess both scientific and aesthetic value due to their geological formations, landforms, ecosystems, and elements of biological diversity, and thus must be preserved and passed on to future generations. The concept of geoheritage refers to the identification, assessment, conservation, and sustainable management of geological and geomorphological features that illustrate the evolution of the Earth and contribute to scientific, educational, cultural, and tourism values (Wimbledon 1996a; Gray 2013; Kazancı 2010; Brilha 2016; Turoğlu 2025).

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Beyond protecting rare or highly representative elements, geoheritage emphasizes their responsible use and interpretation for society. Geotourism, as a heritage-based form of tourism, focuses on experiencing geological features within their broader natural and cultural context for education and enjoyment, while also promoting community well-being and the active conservation of geoheritage assets (Arouca Declaration 2011; Dowling and Newsome 2018). *Ecological heritage* emphasizes the holistic value of ecosystems and species within a region, highlighting the significance of biodiversity for humanity.

In this study, we adopt internationally recognized definitions to ensure conceptual clarity. Geoheritage refers to geological and geomorphological features of scientific, educational, cultural, and aesthetic value that require conservation and sustainable management (Wimbledon 1996b; Brilha 2016). Geodiversity encompasses the natural variety of geological materials (rocks, minerals, fossils, soils, water), geomorphological (landforms) properties, and processes that form the abiotic foundation of ecosystems and landscapes (Gray 2013). Geotourism is defined as tourism activities that focus on geological heritage and landforms as primary attractions, while promoting education, conservation, and local community benefits (Dowling and Newsome 2018). By distinguishing these concepts and applying them consistently, the present study aims to avoid conceptual overlap and to provide a clear theoretical framework for evaluating the geoheritage and ecological heritage values of the İğneada Floodplain Forests.

Türkiye is a country rich in geological, geomorphological, and biological diversity, and therefore many regions possess both geoheritage and ecological heritage value (Şaroğlu et al. 2009; Kazancı et al. 2015; Keskin Citiroglu et al. 2017; Turoğlu 2020; Canpolat et al. 2020; Şengün et al. 2023; Özdemir and Kaymak 2024; Köroğlu 2024; Güngör 2024; Aytaç et al. 2025; Kazancı and Boyraz-Aslan 2025). However, the promotion and tourism potential of these values, in accordance with a conservation–utilization balance, have not yet been fully realized. The İğneada Floodplain Forests (Demirköy District, Kırklareli Province), located on the Black Sea coast at the westernmost end of Türkiye, represent a unique area that hosts one of Europe's largest floodplain (longoz) forests (Yeni 2005; Özyavuz 2008). Declared a national park in 2007, the region encompasses extensive floodplain forests, as well as the Erikli and Mert lagoon lakes that form integral parts of this ecosystem. Geomorphologically, the İğneada floodplain is a rare coastal ecosystem consisting of a sand barrier approximately 10 km in length and a series of lagoons, marshes, and floodplain forests located behind it in low-lying drainage areas (Uludağ 2018). This environment is remarkable both for its geological formation and for the diversity of habitats it supports.

Ecologically, İğneada stands out for its rich flora and fauna (Kavgacı et al. 2007; Yılmaz Dağdeviren and Karlıoğlu Kılıç 2023). Floodplain (longoz) forests are rare ecosystems in Türkiye, characterized by seasonal flooding and confined to limited areas (Göksel and Bozkaya Karip 2017; Toker and Sunar 2018). The longoz forests of İğneada are dominated by ash (*Fraxinus*), alder (*Alnus*), and oak (*Quercus*) species, and represent one of the few forest types that can survive under flooded conditions. The wetlands and lakes in the area are vital habitats for aquatic birds and plants; for instance, Erikli and Mert Lakes are among the rare sites in Türkiye where Euro-Siberian freshwater flora elements can be found (Güler 2015). İğneada is also situated along major bird migration routes and is recognized as one of Türkiye's most important bird areas, hosting between 219 and 227 bird species according to different sources (Eken et al. 2006; Kaya 2015). Sensitive species such as the black stork (*Ciconia nigra*), white-tailed eagle (*Haliaeetus albicilla*), and bittern (*Botaurus stellaris*) breed in the area, while thousands of migratory waterbirds rest in the lakes during migration seasons. Around 310 insect species have been identified in the surrounding area, including *Cerambyx cerdo* (great capricorn beetle) and *Lycaena dispar* (large copper butterfly), which are listed in IUCN conservation categories. Furthermore, 34% of mammal species found in Türkiye and 57% of mammals found only in the Thrace region inhabit the İğneada Floodplain Forests and their surroundings (Bozkaya 2013; Dumlu 2023). Mert and Saka Lakes, as well as the coastal and wetland areas, host around 30 fish species (Bozkaya 2013; Dumlu 2023). The ecosystem also supports 6 amphibian and 11 reptile species, 5 of which (*Bufo viridis*, *Ophisaurus apodus*, *Triturus karelini*, *Lacerta viridis*, *Ablepharus kitaibelii*) are strictly protected under the Bern Convention (Bozkaya 2013).

In terms of plant diversity, the İğneada Floodplain ecosystem is also remarkably rich. Rare endemic species such as *Silene sangaria* and *Verbascum degenii*, listed in Appendix I of the Bern Convention, are found here (Eken et al. 2006). The dune zones host species like *Centaurea arenaria*, observed only in the İğneada area and nowhere else in Türkiye (Bozkaya 2013; Dumlu 2023). Other endemic plants in this ecosystem include *Silene sangaria* (Karadeniz catchfly), *Centaurea kilaea* (Kilyos cornflower), and *Crepis macropus* (Kanak). Additionally, rare species such as *Aurinia uechtritziana* (sand pearl), *Centaurea arenaria* (cornflower), *Crambe maritima* (sea kale), and *Pancratium maritimum* (sea daffodil) are under protection according to the Bern Convention (Bozkaya 2013; Dumlu 2023). These characteristics make İğneada a natural heritage site of international significance, both geomorphologically and biologically (Eken et al. 2006).

From a socio-cultural perspective, İğneada has developed a distinctive cultural identity due to its long-standing isolation (Çakır 2011; Tan 2012). The local population has traditionally depended on forestry, fishing, and crop production for their livelihoods; however, the depletion of forest resources and fish stocks has led to economic challenges in recent years. Consequently, ecotourism and alternative tourism activities have increasingly been viewed as potential solutions for local development. Various festivals, traditional handicrafts, local cuisine, and historical remains in and around İğneada constitute important socio-cultural heritage components (Çakır 2011; Tan 2012). The region also contains significant archaeological and historical structures such as Thracian dolmens and tumuli, and the Ottoman-era Demirköy Foundry (Çakır 2011). These elements, when considered together with natural heritage, offer visitors a rich and multifaceted experience.

With all these characteristics, the İğneada Floodplain Forests represent a region where geoheritage and ecological heritage values coexist, offering promising potential for geotourism development. The aim of this study is to identify the geomorphological, ecological, and socio-cultural heritage components of the İğneada Floodplain Forests particularly focusing on Erikli and Mert Lakes and to qualitatively evaluate their suitability within a geotourism framework. The study is based on a qualitative research approach supported by literature review and field observations.

Materials and Methods

Study Area

This study was conducted in the vicinity of Erikli and Mert Lakes, located within the İğneada Floodplain Forests National Park in the Demirköy District of Kırklareli Province, Türkiye. The research area represents one of the rare lagoon ecosystems along the Black Sea coast of Türkiye, encompassing a variety of habitats such as coastal dunes, reed beds, forested zones, and freshwater lakes. The surroundings of Erikli Lake (41°49′N, 27°58′E) and Mert Lake (41°50′N, 28°00′E) were selected as sampling sites due to their geomorphological diversity and biological richness (Fig. 1).

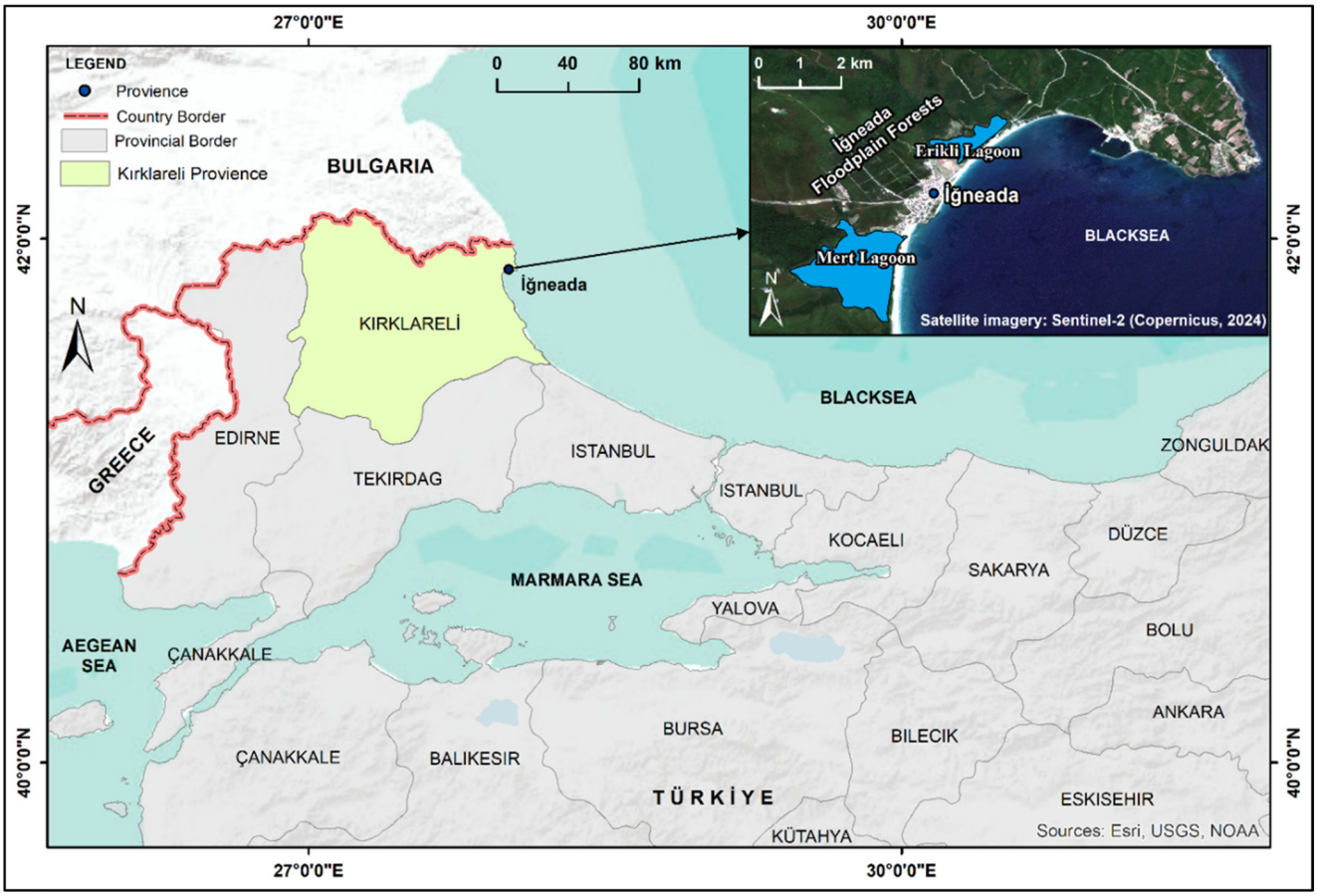

Fig. 1 Location map of study area

Methodological Approach

The research was carried out using a qualitative research design within the framework of a case study approach. This method allows for a contextual evaluation of the natural and cultural heritage components of the İğneada Floodplain Forests. The data collection process was conducted during May and September 2024, involving a total of 12 days of field observations. In this study, geoheritage elements were conceptually evaluated based on the criteria commonly used in geoheritage and geotourism literature, such as scientific relevance, educational potential, and tourism suitability (Hose 2012; Gray 2013; Brilha 2016). These criteria were used as interpretive guidelines during field observations and document review, allowing for a qualitative assessment of the geoheritage significance of the features within the study area.

During the fieldwork, an unstructured observation technique was employed. In-situ examinations were conducted around Erikli and Mert Lakes to document geomorphological formations (lagoon structures, coastal dunes, sediment accumulations), habitat types (reed beds, forests, open water surfaces), flora and fauna components, and land use patterns. More than 150 photographs were taken, and detailed field notes were systematically recorded. The morphology of the lake basins, water levels, shoreline dynamics, and human impacts were qualitatively assessed.

Comprehensive analysis of existing written sources related to the study area was undertaken. The review included flora and fauna reports, scientific articles, theses, official planning documents, and ecological assessment studies. In particular, key references such as the Yıldız Mountains Biosphere Project Flora Report (Özhatay et al. 2010; Kavgacı 2010), the Floodplain Forests Flora Study Report, the bird fauna study by Kaya and Kurtonur (1994), Important Natural Areas Reports by Doğa Derneği, as well as works by Eken et al. (2006), Bozkaya (2013), and Dumlu (2023) formed the main basis of the document analysis. The region's socio-economic structure and tourism potential were evaluated using studies by Çakır (2011) and Tan (2012), while land cover change dynamics were examined through Uludağ (2018). Ecological risk levels were assessed using sediment analysis studies conducted by Uludağ et al. (2018)d krer et al. (2024).

A qualitative content analysis technique was used during the document analysis phase. Data obtained from the relevant texts were coded and thematically categorized. The coding process was carried out manually, and the findings were grouped under three main themes: (1) Geomorphological Dimension, (2) Ecological Dimension, and (3) Socio-Cultural Dimension. These themes constituted the sub-sections of the study's findings chapter. To ensure transparency, the subthemes and codes used in the analysis are presented in Table 1.

Evaluation Framework

In this study, ecosystem values were assessed through a qualitative content analysis approach. The coding process was structured under three main dimensions: (1) Geomorphological, (2) Ecological, and (3) Socio-Cultural. This thematic categorization and subcodes are presented in Table 1. For the ecological dimension, the framework proposed by De Groot et al. (2002) was adopted, focusing on five criteria: integrity, resistance, resilience, rarity, and pollution. The evaluation ratings were derived through an expert judgment process involving five independent specialists, based on field observations and document analysis. Each criterion was scored using the qualitative scale of Low–Moderate–Moderate/High–High, and any differences in judgment were reconciled through consensus during panel sessions. The final results are presented in Table 2, and this expert-based approach was designed to enhance the transparency and reproducibility of the assessment process.

Dimension-specific Evaluation Criteria

The dimension-specific evaluation results are presented in Table 2. Each criterion was rated using the qualitative scale (Low–Moderate–Moderate/High–High) through expert consensus, as explained in the Evaluation Framework.

Table 1 Coding structure of the qualitative content analysis

Theme	Subthemes	Codes / Subcodes
Geomorphological Dimension	Landforms, Processes	Lagoon formation, Sand barrier (10 km), Floodplain dynamics, Coastal geomorphology, Marsh development
Ecological Dimension	Flora	Endemic plants (*Silene sangaria*, *Centaurea arenaria*, *Verbascum degenii*), Dune vegetation (*Crambe maritima*, *Pancratium maritimum*), Rare species under Bern Convention
	Fauna	Migratory birds (black stork, white-tailed eagle, bittern), Aquatic birds (Erikli & Mert Lakes), Mammals (34% of Türkiye's species, 57% of Thrace mammals), Insects (*Cerambyx cerdo*, *Lycaena dispar*), Amphibians & reptiles (*Bufo viridis*, *Lacerta viridis*, etc.)
	Ecosystem functions	Integrity, Resistance, Resilience, Rarity, Pollution (adapted from De Groot et al. 2002)
Socio-Cultural Dimension	Local practices	Traditional fishing, Forestry, Agriculture, Local cuisine

Table 2 Dimension-Specific Evaluation Criteria for the İğneada Floodplain Forests

Dimension	Criterion / Subtheme	Description (İğneada Floodplain Forests)	Evaluation
Geomorphological	Landforms & Processes	Lagoon formation, sand-barrier dynamics, floodplain morphology, coastal geomorphology	Moderate/High
	Flora	Endemic dune vegetation, rare species under Bern Convention	High
Ecological	Integrity	Marine–lake–forest system integrity, partially undermined by construction and agriculture	Moderate/High
	Resistance	Tourism pressure and groundwater use reduce resistance	Moderate
	Resilience	Habitat fragmentation and pollution pressures increase vulnerability	Low
	Rarity	Rare combination of soil, water, and forest integrity in Europe	High
	Pollution	Agricultural and residential pollutants accumulated in lake sediments	Moderate
Socio-Cultural	Local Practices	Traditional fishing, forestry, agriculture, local cuisine	Moderate
	Educational & Tourism Potential	Accessibility, documentation, storytelling, geotourism opportunities	Moderate/High

Ethical Principles and Limitations

During the research process, the necessary permits for fieldwork were obtained, and no direct interaction was established with local residents. Observations were conducted exclusively in publicly accessible areas. Seasonal variability, the limited duration of field observations, and restricted access to certain sources are among the primary limitations of the study. Since fieldwork was conducted only within a single seasonal period, the findings may not fully represent interseasonal biodiversity patterns. Therefore, future studies should incorporate multi-seasonal field observations to provide a more comprehensive assessment of ecological diversity in the floodplain ecosystem. Additionally, restricted access to certain sources and the limited duration of field observations are among the other constraints encountered during the study.

Fig. 2 A view of Mert Lagoon and İğneada

Results

Geomorphological Dimension

The geomorphology of İğneada is shaped by a unique lagoon and coastal dunes system along the Black Sea coast (Turoğlu and Uludağ 2006; Uludağ 2018). Erikli and Mert Lakes are lagoonal formations that developed behind a natural coastal sand barrier. This sandbar, approximately 10 km in length and 200–300 m in width, blocks the streams descending from the Istranca Mountains into the Black Sea, thereby enabling the development of freshwater and brackish water ecosystems behind it (Figs. 2, 3, 4 and 5). As a result of these geomorphological processes, five closely situated lakes have formed in the region: Mert (approximately 266 ha), Erikli (43 ha), Saka (5–7 ha), Hamam (19 ha), and Pedina (10 ha). Among these, Mert Lake is the largest and

Fig. 3 The coastal dunes and dune plants that form the Mert Lagoon

Fig. 4 Erikli Lake and its Floodplain

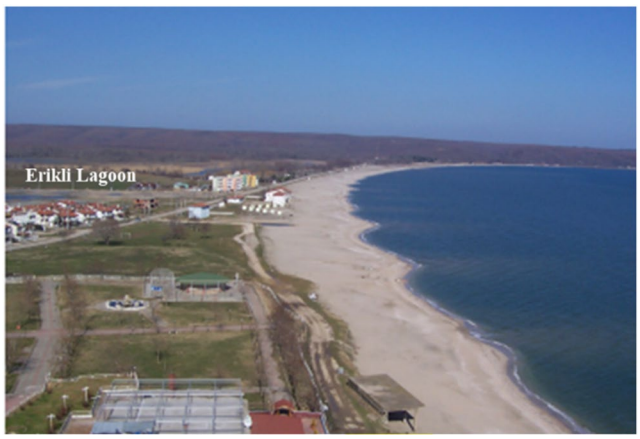

Fig. 5 Erikli Lagoon and beach

Fig. 6 The connection between Mert Lagoon and the sea

Fig. 7 The connection between Erikli Lagoon and the sea

one of the shallowest, with a maximum depth of about 1.5–2 m and extensive reed-covered areas (Uludağ 2018). Erikli Lake, located just north of the İğneada settlement, is a smaller lagoon covering about 59 hectares of marshland (Uludağ 2018). Although the hydrological connection between these lakes and the sea has been partially interrupted over time, temporary connections with the Black Sea still occur during certain periods (particularly during floods or severe storms). This intermittent exchange influences the water levels and salinity of the lagoons, reflecting directly on their geochemical cycles (Uludağ 2018). As shown in Figs. 6 and 7, variations in hydrological connectivity lead to seasonal changes in lagoon dynamics.

The coastal dunes and the geomorphological formations atop them constitute an essential component of the region's geoheritage value. Along the İğneada coastline, several beach ridges, strandlines, and dune hills formed during different coastal phases can be observed on the seaward side of the dunes. In the inland areas, low-lying plains with poor drainage have developed through the accumulation of alluvial deposits carried by rivers. This combination of dune and alluvial topography has provided the foundational conditions for the formation of the floodplain (longoz) forests.

However, the geomorphological diversity of the region extends beyond these features. To the southwest of the floodplain forests, the extensions of the Yıldız (Istranca) Mountains rise sharply, reaching elevations of 100–150 m above sea level within a short distance (Fig. 8). The seaward slopes of these uplands are characterized by steep coastal cliffs, and the town of İğneada itself is situated atop one such cliff. In addition, small-scale karstic limestone formations, coastal caves, and remnants of ancient river valleys have been identified in the area (Turoğlu and Uludağ 2006). Each of these geomorphological elements represents a site of natural interest for geotourism and could be integrated into educational excursions or nature trails designed to enhance visitors' understanding and appreciation of the landscape (Figs. 11 and 12).

When evaluated in terms of its geoheritage potential, the geomorphological structure of İğneada possesses several unique values.

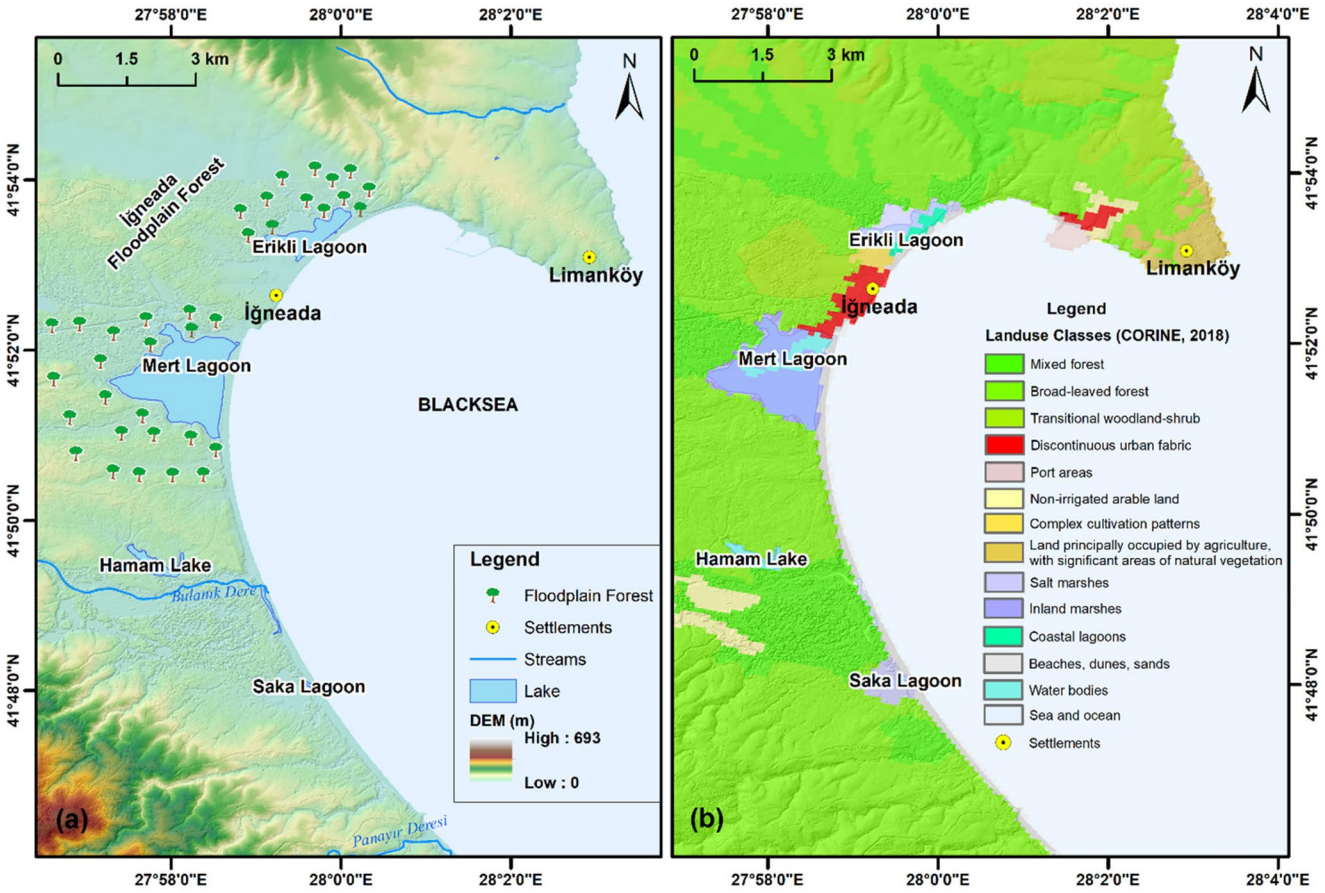

Fig. 8 Elevation levels map of study area (**a**) Land use map of study area (**b**)

First, the lagoon and dune system constitutes a natural laboratory rarely found in Türkiye. The formation of coastal lagoons is closely related to geomorphological processes such as sea-level fluctuations, fluvial sedimentation, and aeolian deposition. The İğneada lagoons represent a dynamic environment where these processes are still actively operating.

Second, the geomorphology of the floodplain (longoz) forests—characterized by seasonal inundation across alluvial plains—holds significant hydromorphological importance. These floodplain forests function as natural barriers that regulate the flow regime within the basin and mitigate flooding events (Yeler et al. 2023). In this sense, they exemplify a rare interaction between geomorphological processes and ecosystem functions. Third, the coastal cliffs and dune–delta complexes can be regarded as significant geosites, both in terms of geological timescales and ongoing geomorphic activity (Figs. 2, 3, 4, 5, 9 10, 11 and 12). Coastal erosion and cliff retreat processes are clearly observable in the area; large blocks detached from the cliffs are visible along the shoreline, and measurable shoreline retreat has been documented in certain sections. Such processes possess substantial educational value, offering insight into the monitoring and understanding of geoheritage dynamics.

Ecological Dimension

In terms of ecological heritage potential, the İğneada Floodplain Forests constitute an exceptionally rich area. The region presents an ecosystem complex characterized by a mosaic of diverse habitats with high biological diversity values (Figs. 13 and 14). Floodplain forests, wetlands, lakes, marshes, meadows and pastures, coastal dunes, and the marine shoreline coexist in close spatial proximity. This diversity of habitats creates suitable living conditions for a wide range of plant and animal species, thereby reinforcing the area's overall biological richness.

Flora Due to its position at the intersection of the Black Sea and Balkan biogeographical regions, the flora of İğneada contains elements characteristic of both Euro-Siberian and Balkan endemism. In the arboreal layer of the floodplain forests, water-tolerant species dominate; the most common are elm (*Ulmus* sp.), narrow-leaved ash (*Fraxinus angustifolia*

Fig. 9 Narrow-high coastal type in the İğneada Region

Fig. 10 Coastal erosion around İğneada

Fig. 11 Dupnisa Cave and Karstic Formations

Fig. 12 Geosite Related to Orogeny in the İğneada Harbor

ssp. *oxycarpa*), alder (*Alnus glutinosa*), and several oak species, particularly pedunculate oak (*Quercus robur*) (Bozkaya 2013; Güler 2015; Dumlu 2023). The forest floor and shrub layers feature hydrophilic and hygrophilous plants such as water chestnut (*Trapa natans*), water violet (*Hottonia palustris*), water lilies, water hyacinths, reeds, and bulrushes, which are abundant along lake and marsh margins (Bozkaya 2013; Dumlu 2023).

The coastal dunes of İğneada host numerous specialized psammophilous species, including *Aurinia uechtritziana*, *Centaurea kilaea*, *Stachys maritima*, and *Silene dichotoma* ssp. *euxina* (Bozkaya 2013; Dumlu 2023). According to the inventory of the Directorate of Nature Conservation and National Parks, at least 600 plant species have been recorded in the region (Güler 2015), 24 of which are classified as endemic or rare (Özhatay et al. 2010). The İğneada Forests are listed among Türkiye's *Important Natural Areas (INA)* and host critical populations of globally threatened and narrowly distributed plants such as *Silene sangaria* and *Verbascum degenii*. The area also represents one of the few sites in Türkiye where several Balkan-origin plants (e.g., *Digitalis grandiflora*, *Sideritis scardica*) can be found (Özhatay et al. 2010; Bozkaya 2013; Dumlu 2023). This remarkable floristic diversity elevates the ecological heritage value of the area to an international level.

Fauna The faunal diversity of the region is equally remarkable. İğneada serves as a crucial refuge for many animal groups, especially birds (Figs. 15 and 16). The floodplain forests and reed-fringed lagoon lakes host 219 bird species, making İğneada one of the most attractive destinations for birdwatchers (Eken et al. 2006; Tan 2012; Bozkaya 2013; Dumlu 2023). Conservation-priority species such as the white-tailed eagle (*Haliaeetus albicilla*), lesser spotted eagle (*Clanga pomarina*), black stork (*Ciconia nigra*), and bittern (*Botaurus stellaris*) breed in the area (Eken et al. 2006). During late summer and spring migrations, thousands of storks and raptors pass over İğneada, resting on the lakes, while in winter, waterbirds such as the black-throated

Fig. 13 Erikli floodplain forest

Fig. 14 Mert floodplain forest

Fig. 15 Erikli Lake and pelicans

Fig. 16 Water Buffaloes in the İğneada Floodplain Forest

diver (*Gavia arctica*), which migrates inland from the Black Sea, are observed in significant numbers at Mert Lake (Eken et al. 2006).

Erikli and Mert Lakes also function as overwintering sites for waterbirds including ducks, geese, swans, herons, and other aquatic species, which feed and shelter in the area (Eken et al. 2006; Özkan 2007; Bozkaya 2013; Dumlu 2023). The extensive reed belts around the lakes provide breeding and nesting grounds for many bird species. However, uncontrolled and frequent reed cutting around Mert Lake negatively affects bird reproduction habitats by reducing suitable nesting areas (Eken et al. 2006).

The region is also rich in mammals. Large mammals such as deer, wild boar, jackal, fox, and roe deer inhabit the floodplain forests, while the Eurasian otter (*Lutra lutra*) occupies the wetlands. İğneada supports significant populations of small mammals in Thrace, including the Black Sea mole (*Talpa levantis*) (Eken et al. 2006; Bozkaya 2013; Dumlu 2023). The fish fauna includes both freshwater and brackish-water species; mullet, stone moroko, and rudd are common in lagoon lakes; trout and cyprinids occur in streams; and flounder and horse mackerel inhabit the nearby marine areas (Eken et al. 2006; Bozkaya 2013; Dumlu 2023). Because of the transitional nature of the lagoon waters—mixing fresh and saline inputs—both marine and freshwater fish coexist. Nine endemic fish species have been identified in the rivers and lakes of the region (Ministry of Agriculture and Forestry 2019).

Additionally, suitable habitats exist for reptiles and amphibians; aquatic frogs, tree frogs, and water snakes are widespread (Bozkaya 2013; Dumlu 2023). Small ponds and temporary pools within the floodplain forests provide essential breeding grounds for amphibians, further contributing to the ecological diversity and heritage value of İğneada.

All these flora and fauna elements add significant value to the region in terms of ecosystem services. The floodplain ecosystem performs essential ecological functions such as flood regulation, water quality maintenance, carbon storage, and climate regulation (Yeler et al. 2023). Moreover, the area serves as an important site for scientific research due to its role as a reservoir of genetic diversity.

For instance, recent analyses of bottom sediments from the İğneada lakes have revealed accumulations of certain heavy metals originating from anthropogenic activities,

indicating the ecosystem's vulnerability (Kükrer et al. 2024). Elemental analyses of surface sediments from Erikli Lake demonstrated that the accumulation of Hg (mercury) and Cd (cadmium) is predominantly anthropogenic, and that the ecological risk level of these metals can reach a "moderate" degree. This finding underscores the area's sensitivity to external influences. The same studies point out that agricultural and domestic wastewater discharges, along with atmospheric transport, are the primary sources of these pollutants (Uludağ et al. 2018; Kükrer et al. 2024). This situation serves as a clear indication of the need to preserve the floodplain ecosystem.

In summary, the ecological dimension of the İğneada Floodplain Forests embodies an outstanding heritage value through the coexistence of endemic and rare species, the integration of diverse habitats, and the functional integrity of its ecosystem processes. This ecological richness offers not only exceptional scientific value but also remarkable potential for nature tourism and environmental education. However, the ecosystem's fragility highlights the vital importance of conservation measures.

Socio-cultural Dimension

The socio-cultural dimension encompasses the interaction between human life, economic activities, and cultural values in and around İğneada and its natural environment. The region has largely preserved its traditional way of life due to prolonged geographic isolation (Çakır 2011; Tan 2012). According to the the Turkish Statistical Institute (TURKSTAT 2024), there are two municipal settlements in Demirköy district, one of which is the district center: Demirköy and İğneada. The population of Demirköy Municipality is 3,434, while İğneada Municipality has a population of 2,660. In addition, a total of 5,536 people live in the rural villages of the district. Accordingly, approximately two-thirds of the district's population resides in urban areas, whereas one-third lives in rural areas. This distribution indicates that Demirköy district predominantly retains a rural character, although urban settlements also hold a notable share of the population. The majority of the population in İğneada and the surrounding villages lives in rural areas, where livelihoods are based primarily on forestry, fishing, animal husbandry, and, to a lesser extent, crop production. In the past, forest products (such as timber and resin) and fisheries formed the backbone of household economies; however, the depletion of these resources in recent decades has led to economic challenges. Nevertheless, ecotourism and alternative tourism activities have emerged as potential opportunities for creating new income sources for the local population.

Culturally, the local people maintain the distinctive folkloric traditions of the Thrace region (Çakır 2011). The traces of Rumelian culture are evident through traditional weddings, folk dances, culinary practices, and handicrafts passed down through generations (Çakır 2011). Various annual festivals—such as the İğneada Strawberry Festival and the Fish Festival—help preserve this cultural vibrancy while attracting visitors from outside the region. Moreover, the area contains historical remains and structures that form part of its socio-cultural heritage (Çakır 2011). The Demirköy Foundry (an Ottoman-era iron casting workshop) and nearby dolmens and tumuli belonging to the Thracian civilization are examples of culturally and archaeologically significant features (Çakır 2011). These historical elements, when combined with the region's natural heritage, offer visitors an enriched and multifaceted experience.

Within the socio-cultural context, the lifestyle and traditions of the local population also represent an important component of heritage. The villages in the region still exhibit traces of traditional rural Thracian life—cooperative working practices (imece), traditional wedding and festival celebrations, local cuisine, and distinctive clothing styles are still preserved (Çakır 2011). Annual events such as the İğneada Sea and Forest Festival celebrate both the region's natural beauty and its cultural heritage. Such activities provide visitors not only with nature-based experiences but also with the opportunity to engage with and learn about the local culture in the context of geotourism and ecotourism.

The socio-economic structure of the İğneada region is closely linked to its natural environment. Traditional economic activities based on natural resources are directly dependent on the conservation of these resources. For example, the sustainable management of floodplain forests is crucial for the continuity of livelihoods such as timber production, honey harvesting, and beekeeping (Çakır 2011). In recent years, tourism initiatives—such as accommodation facilities and local guiding services—have begun to create new income opportunities for residents. However, if tourism develops in an unplanned manner, there is a potential risk of degradation in both the natural and cultural fabric of the region.

Overall, the socio-cultural dimension of İğneada reflects a long-standing equilibrium between human and natural elements. Maintaining this balance in the future will depend on participatory management approaches and the implementation of sustainable tourism planning.

As shown in Table 2, while the İğneada Floodplain Forests have high rarity value and moderate-to-high integrity, their resistance and resilience levels are considerably weakened by increasing anthropogenic pressures, particularly around lake and coastal areas. The moderate pollution level further indicates growing environmental vulnerability, emphasizing the need for stronger conservation and management strategies.

In light of these five criteria, the ecological value of the İğneada Floodplain Forests was qualitatively evaluated from a holistic perspective. Based on the framework of De Groot et al. (2002), this assessment systematically reveals the strengths and weaknesses of the floodplain ecosystem, providing a scientific foundation for the conservation and sustainable use of the area.

Discussion

The findings confirm that the İğneada Floodplain Forests constitute an integrated natural heritage area, where geological, geomorphological, and biological values coexist within a single landscape. This coexistence enhances the region's geotourism potential by offering visitors the opportunity to observe geomorphological formations and biological diversity simultaneously, as emphasized in previous research (De Groot et al. 2002; Eken et al. 2006). In this regard, İğneada can be defined as a "living laboratory" where geological and ecological processes can be directly observed in the field.

Nevertheless, the floodplain forests and lagoon ecosystems are highly sensitive structures, and their conservation requires careful planning. The seasonal increase in population and tourism pressure intensifies the use of water resources and the accumulation of solid waste, thereby creating significant strain on the hydrological balance and ecological integrity of the area. The heavy metal accumulation observed in lake sediments (Kükrer et al. 2024) and the land-cover changes reported by Uludağ (2018) indicate that the ecosystem's capacity to resist external pressures is declining. These findings clearly demonstrate that geotourism initiatives must be guided by strong conservation policies.

In parallel, administrative and legal protection frameworks play a critical role in shaping sustainable tourism development. Although the İğneada Floodplain Forests were declared a national park in 2007, human activities continue to expand particularly in buffer zones. In this context, the biosphere reserve model proposed by Özyavuz (2008) offers an integrated conservation approach that balances strict protection with sustainable-use zones. This model would be highly suitable for İğneada, where natural and cultural values coexist within a shared landscape.

Recent literature also highlights the transition from geotourism to "geo-bio-tourism," which emphasizes the combined interpretation of geological and biological heritage (Şaroğlu et al. 2009). İğneada is a strong candidate for this approach: while dune structures, lagoon lake formation and granite exposures can be observed along the coast, the same route allows for birdwatching and the exploration of endemic plant species within the floodplain forest. Designing thematic routes integrating geomorphological and ecological stops would support environmental education and enhance visitor awareness.

Another key aspect of sustainable development in the region is the participation and socio-economic empowerment of the local community. Earlier studies have emphasized that tourism-oriented infrastructure investments and community involvement contribute both to conservation success and local development (Turoğlu and Uludağ 2006). Therefore, geotourism and ecotourism initiatives can encourage income diversification while ensuring the continuity of cultural heritage, provided that residents are actively integrated into planning and management processes.

Overall, the findings underline the importance of science-based conservation planning, multi-stakeholder cooperation, and awareness-raising activities to protect the outstanding natural and cultural values of the İğneada Floodplain Forests while enabling sustainable geotourism development.

Conclusion and Recommendations

This study, which examined the geoheritage, geotourism, and ecological heritage potential of the İğneada Floodplain Forests, revealed that the region possesses exceptional importance in terms of its natural and cultural values. The main conclusions are as follows:

- Geomorphological significance: İğneada's lagoon lakes, dune ridges, and floodplain systems form a rare coastal geomorphological complex within Türkiye. These landscape characteristics elevate the geoheritage value of the region and provide a natural setting suitable for geoscientific interpretation and geotourism development. The area contains numerous geosite candidates that can contribute to the visibility of Türkiye's geological heritage.
- Ecological significance: The floodplain forests function as a natural laboratory with rich biodiversity, endangered species, and diverse habitat structures. However, the ecosystem remains highly vulnerable to external pressures such as pollution and land-use change. Without evidence-based conservation actions, ecological degradation may become irreversible.
- Socio-cultural significance: Traditional livelihoods (forestry, fishing, beekeeping, reed harvesting) and cultural-historical elements enrich the region's identity. Sustainable tourism practices must therefore promote local culture while supporting economic diversification and community well-being.
- Geotourism potential: With its geological history, aesthetic landscapes, and biocultural diversity, the İğneada

Floodplain Forests National Park offers strong potential for sustainable tourism activities that simultaneously protect the environment and provide economic benefits to the local community.

Based on the research findings, the following recommendations are proposed:

- Integrated Management and Planning: The current national park plan should be revised to include geological heritage components. A participatory, multi-sectoral, and ecosystem-based management approach—such as the biosphere reserve model—should be adopted to ensure unified governance among zones with different conservation statuses.
- Low-impact Geotourism and Ecotourism Infrastructure: Observation points, interpretation panels, walking trails, and visitor centers should be installed in priority geosite and ecosite areas using environmentally sensitive design principles. Controlled access platforms around Erikli and Mert Lakes would allow visitors to experience nature without damaging sensitive habitats.
- Capacity Building and Guiding Services: Local communities should be trained in interpretation, guiding, and sustainable tourism services. Nature education programs and collaborative summer schools with universities could foster a new generation of environmental stewards.
- Promotion and Visibility: International recognition efforts such as UNESCO Biosphere Reserve or World Heritage candidacy should be supported. Communication strategies should highlight distinctive characteristics, including the region's large floodplain forests and avian richness.
- Strengthened Conservation Measures: Planned dam projects affecting the hydrological regime should undergo independent ecological assessments. Enforcement against illegal construction, logging, and poaching must be increased, alongside public awareness programs on the consequences of environmental disturbance.
- Inclusive Local Development: Economic returns from geotourism should be distributed equitably. Local product marketing and community-based tourism initiatives (e.g., cooperatives) should be supported. Continuous stakeholder engagement should ensure public participation in management decisions.

The İğneada Floodplain Forests and associated lagoon systems stand out as one of the limited regions where geological and ecological heritage coexist harmoniously. Ensuring that these values are preserved and transferred to future generations is not only a regional obligation but also a global responsibility. By adopting the strategies proposed here, İğneada can become a successful model where nature conservation and local development progress together. The study provides a scientific foundation for future research and detailed planning efforts aimed at building such a sustainable geotourism framework.

Author Contribution Dilek Aykır: Conceptualization, Fieldwork, Background Literature Survey, Geosite Evaluation, Data Collection and Analysis, Validation, Draft of The Manuscript, Writing – Review & Editing
Abdulkadir Duran: Data Compilation and Curation, Methodology, Conception, Design, Formal Analysis, Preparing Tables and Figures, Review & Editing
İsa Cürebal: Data Compilation and Curation, Methodology, Conception, Design, Formal Analysis, Preparing Tables and Figures, Review & Editing
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Serkan Kükrer: Fieldwork, Geosite, Conception, Evaluation, Writing – Review & Editing
Gülsen Erginal: Fieldwork, Geosite, Conception, Evaluation, Review & Editing
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Declarations

Competing interests The authors declare no competing interests related to the submitted work.

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