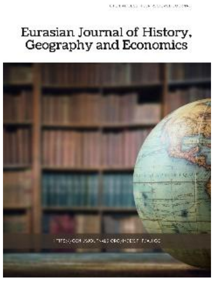


# Integration Of Geographical And Gis Methods In The Study Of Hydrogeological Processes In The Balikesir Region


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| **Azizkhon Marupov[1],** | *Fergana State Technical University, Uzbekistan, Fergana[1]* |
| **Abdullah KÖSE[2]** | *Balikesir University, Turkey, Balikesir[2]* |
| **Alper UZUN[2]** | *Balikesir University, Turkey, Balikesir[2]* |
| **Erdal GÜMÜŞ[2]** | *Balikesir University, Turkey, Balikesir[2]* |



**ABSTRACT**

This study investigates the integration of geographical and GIS-based methods for analyzing hydrogeological processes in the Balıkesir region of Türkiye. The research combines digital elevation modeling, remote sensing, and spatial hydrogeological data to identify groundwater recharge zones, aquifer systems, and the influence of topography on subsurface water movement. GIS tools such as ArcGIS and QGIS were used to process topographic, geological, and satellite datasets, while interpolation and overlay analyses were performed to visualize groundwater depth and flow dynamics. The results show that topography, lithology, and land cover significantly influence groundwater distribution. The study demonstrates that GIS provides an effective framework for integrating multi-source data to support sustainable groundwater management and environmental planning.


**Keywords:** GIS, hydrogeology, Balıkesir, geography, topographic maps, groundwater, spatial analysis

**Introduction**. The study of hydrogeological processes is a fundamental aspect of regional geography and environmental management, especially in areas characterized by complex geological and geomorphological structures. The Balıkesir region of Türkiye represents one of the most hydrologically diverse territories in western Anatolia, where groundwater resources play a critical role in agriculture, urban development, and ecological balance. In this context, the integration of Geographic Information Systems (GIS) with traditional geographical and hydrogeological methods provides powerful tools for spatial analysis, mapping, and modeling of water-related processes.

Recent advancements in GIS technology have made it possible to visualize and analyze hydrogeological data with high spatial accuracy, enabling researchers to assess groundwater distribution, aquifer recharge zones, and the influence of topography on subsurface flow. Topographic and thematic maps, combined with remote sensing data, allow for a multidimensional understanding of how geological formations and landforms influence the movement and storage of groundwater.

This study aims to integrate GIS-based approaches with hydrogeological and geographical analysis to investigate the spatial characteristics of water-bearing formations, drainage networks, and relief patterns within the Balıkesir province. The research focuses on developing a comprehensive spatial database, generating hydrogeological maps, and performing geostatistical analyses to identify the relationships between geological structure, topography, and groundwater dynamics.

**Materials and Methods.**

**Study Area.** The Balıkesir province is located in the western part of Türkiye, extending between the Marmara and Aegean regions. The area is characterized by a combination of coastal plains, hilly terrain, and mountainous landscapes, forming a complex hydrogeological system.

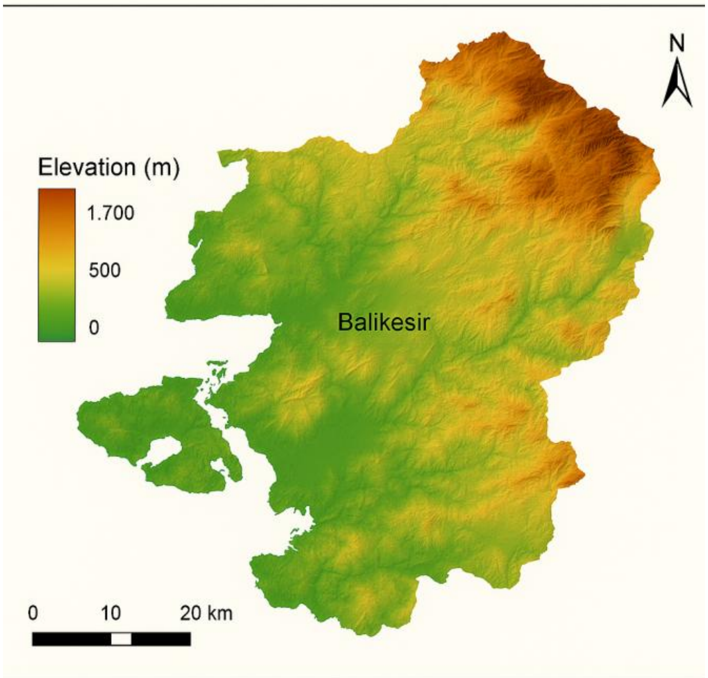


**Figure-1. Digital Elevation Model (DEM) of the Balıkesir region.**

The region experiences a Mediterranean climate with distinct wet and dry seasons, which significantly influences groundwater recharge and surface water flow. Balıkesir's geological structure includes sedimentary, metamorphic, and volcanic formations that host several aquifer systems with varying permeability and water-holding capacities Figure-1.

**Data Sources.** To analyze hydrogeological processes, several types of spatial and thematic data were utilized:

- **Topographic maps** at scales of 1:25,000 and 1:50,000 obtained from the General Directorate of Mapping (Harita Genel Müdürlüğü).
- **Satellite imagery** from Landsat 8 and Sentinel-2 missions, used for land cover classification and surface drainage mapping.
- **Digital Elevation Models (DEMs)** with a 30-meter resolution (SRTM and ASTER) to extract slope, aspect, and elevation parameters.
- **Hydrogeological data** including well locations, groundwater depth, and aquifer parameters collected from the Turkish State Hydraulic Works (DSİ).
- **Geological and soil maps** from the MTA (General Directorate of Mineral Research and Exploration).

All spatial datasets were standardized to a common coordinate system (UTM Zone 35N, WGS 84) and integrated into a unified GIS database.

**GIS Processing and Analysis.** Geospatial analysis was carried out using **ArcGIS 10.8** and **QGIS 3.34** software. The following methods were applied (Table-1):

1. **Topographic Analysis**
   - ✓ Derivation of slope, aspect, and elevation maps from the DEM.
   - ✓ Identification of drainage basins and sub-basins using the *Hydrology* toolset.

- ✓ Delineation of flow accumulation and flow direction to assess potential recharge areas.

2. **Geological and Hydrogeological Mapping**
   - ✓ Overlay of geological formations and fault lines to define aquifer boundaries.
   - ✓ Interpolation of groundwater depth using *Kriging* and *Inverse Distance Weighting (IDW)* methods.
   - ✓ Zonal statistics to relate groundwater levels with elevation and land use.
3. **Land Cover and Surface Water Interaction**
   - ✓ Classification of land cover types using supervised classification (maximum likelihood method) based on Sentinel-2 imagery.
   - ✓ Buffer analysis around rivers and lakes to assess their influence on groundwater recharge zones.
4. **Map Production and Visualization**
   - ✓ Generation of thematic maps showing aquifer distribution, recharge zones, drainage networks, and groundwater potential.
   - ✓ Integration of 3D terrain visualization for improved interpretation of the relationship between relief and hydrogeological conditions.

**Table-1. Data sources and their characteristics used in GIS analysis.**

| Data Type | Source | Format / Scale | Purpose |
|---|---|---|---|
| Topographic maps | General Directorate of Mapping | 1:25,000 – 1:50,000 | Elevation, drainage, contours |
| DEM (SRTM, ASTER) | NASA / METI | 30 m resolution | Slope, aspect, relief modeling |
| Satellite imagery | Landsat 8, Sentinel-2 | 10–30 m resolution | Land-cover classification |
| Geological maps | MTA (Turkey) | 1:100,000 | Lithology, structural mapping |
| Groundwater data | DSİ (Balıkesir region) | Point data (wells) | Groundwater depth, aquifer type |
| Soil maps | MTA / FAO | 1:100,000 | Infiltration capacity, recharge potential |

**Validation.** To ensure the reliability of spatial analyses, results were validated through field observations and comparison with hydrogeological measurements from DSİ monitoring wells. Cross-validation of interpolation methods was conducted to minimize errors in groundwater depth estimation.

**Results.**

**Topographic and Morphometric Characteristics**

The Digital Elevation Model (DEM) analysis revealed that the elevation of the Balıkesir province ranges from **sea level along the Aegean coast to over 1,700 meters** in the mountainous eastern and northern regions. The general slope direction follows a **northwest–southeast gradient**, determining the direction of surface water flow and potential groundwater movement. Areas with moderate slopes (5–15°) were found to be the most favorable for groundwater recharge due to slower surface runoff and higher infiltration capacity (Figure-2).

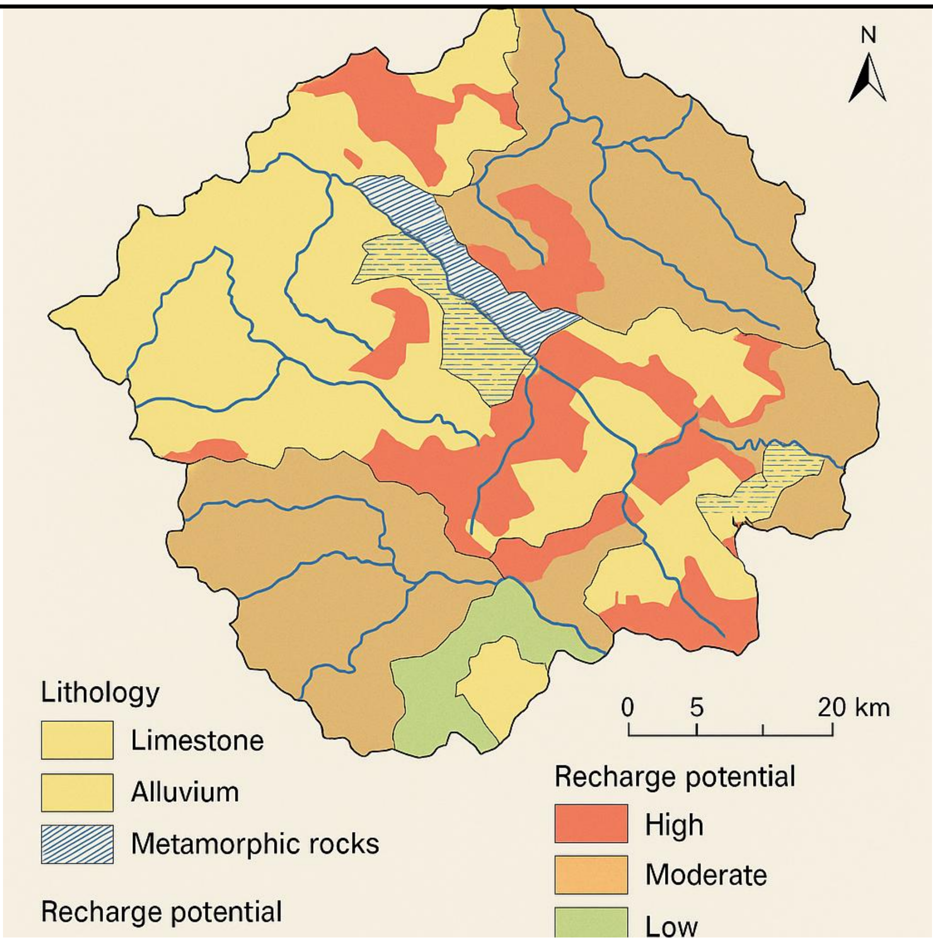


**Figure-2. Hydrogeological map of Balıkesir province.**

The morphometric analysis identified **five major drainage basins**, including the Susurluk, Gönen, and Manyas systems, which are hydrologically connected to the Marmara Sea. Flow accumulation and direction models derived from the DEM indicated that surface water convergence zones correspond closely with groundwater recharge areas.

**Geological and Hydrogeological Mapping.** Geological and hydrogeological overlays showed that the Balıkesir region is composed predominantly of **limestone, sandstone, and alluvial deposits**, which form the principal aquifer systems. The **limestone formations**, distributed mainly in the southern and central parts of the region, exhibit high permeability, allowing intensive groundwater storage and movement. Conversely, **metamorphic and volcanic rocks** in the northern mountainous areas act as aquitards, restricting groundwater flow.

Interpolation of well data using the Kriging method resulted in a **groundwater depth map** showing significant spatial variability. Groundwater levels are shallow (less than 10 meters) in alluvial plains near the Gönen and Manyas rivers but exceed 60 meters in upland areas. These differences indicate strong topographic and lithological control over subsurface hydrodynamics.

**Hydrological Network and Drainage Pattern.** The derived drainage network, based on flow direction and accumulation models, revealed a **dendritic pattern** dominating the lowlands and a **subparallel pattern** along the slopes of elevated areas. River buffering analysis indicated that **zones within 500 meters of major rivers** exhibit higher groundwater recharge potential, supported by coarse-grained sediments and shallow water tables (Table-1).

**Table-2. Hydrogeological zonation of the Balıkesir region.**

| Zone | Dominant Lithology | Groundwater Depth | Recharge Potential | Remarks |
| --- | --- | --- | --- | --- |

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|---|---|---|---|---|
| Northern Lowlands (Manyas–Gönen) | Alluvium, limestone | 5–15 m | High | High-yield unconfined aquifers |
| Central Plateau (Balıkesir–Sındırgı) | Mixed sedimentary–metamorphic | 20–40 m | Moderate | Semi-confined aquifers |
| Southern Highlands (Dursunbey) | Metamorphic, volcanic | 40–60 m | Low | Deep confined aquifers |

Several perennial streams, such as the Simav and Kocadere Rivers, play a key role in maintaining base flow and groundwater replenishment during the dry season. Integration of surface and subsurface data demonstrated that the majority of aquifer recharge occurs along **valley bottoms and contact zones between permeable and impermeable strata**.

**Land Cover and Recharge Zones.** The land cover classification identified **forest (34%)**, **agricultural land (42%)**, **urban areas (9%)**, and **bare or rocky surfaces (15%)**. The spatial overlay between land cover and groundwater depth showed that agricultural and forested zones coincide with high recharge areas, whereas urbanized regions display limited infiltration due to impervious surfaces.

Recharge zone mapping based on slope, land cover, and geology highlighted three categories:

- **High recharge potential:** alluvial plains and limestone plateaus (mainly in Gönen and Sındırgı districts).
- **Moderate recharge potential:** areas with mixed lithology and moderate slopes.
- **Low recharge potential:** steep terrain with metamorphic rocks and urban development.

**Hydrogeological Zonation**

The integration of all thematic layers resulted in the delineation of **three hydrogeological zones** within Balıkesir province:

1. **Northern Lowlands (Manyas–Gönen Zone):** shallow groundwater table, alluvial aquifers, high recharge.
2. **Central Plateau (Balıkesir–Sındırgı Zone):** mixed lithology, medium recharge, moderate aquifer potential.
3. **Southern Highlands (Dursunbey Zone):** deep groundwater, low recharge, confined aquifers.

These spatial relationships clearly demonstrate that GIS-based analysis enables the identification of hydrogeological structures and recharge patterns with high precision.

**Discussion.** The integration of geographical and GIS-based methods in the study of hydrogeological processes in the Balıkesir region has demonstrated the high potential of spatial analysis for identifying patterns in groundwater distribution and recharge dynamics. The results confirm that **topography and lithology are the primary controlling factors** influencing groundwater occurrence, with slope and elevation exerting direct effects on infiltration and subsurface flow direction.

The hydrogeological zoning produced through GIS overlay analysis corresponds well with the known regional geology and hydrology reported in previous studies conducted in western Anatolia. For instance, the alluvial plains of Gönen and Manyas, characterized by highly permeable sediments, show similar recharge potential to that of the Gediz Basin, while the metamorphic terrains in Dursunbey exhibit confined aquifers with limited recharge—analogous to conditions found in the Kazdağları massif.

By integrating Digital Elevation Models, satellite data, and hydrogeological field measurements, the study demonstrates that **GIS serves as a unifying platform** that links geological, hydrological, and land cover information. This multi-layered spatial approach allows for the identification of groundwater recharge zones, flow directions, and vulnerable areas more accurately than traditional methods alone.

Furthermore, the comparison between interpolated groundwater levels and field data validates the use of **Kriging interpolation** as a reliable tool for hydrogeological mapping in areas with sparse monitoring wells. The correlation between drainage networks and shallow groundwater zones underscores the importance of incorporating fluvial geomorphology in aquifer assessments.

**Conclusion.** This study highlights the effectiveness of integrating geographical analysis and GIS technology in understanding and mapping hydrogeological processes in the Balıkesir region. The main conclusions can be summarized as follows:

1. **Topography and geological structure** exert a dominant influence on groundwater occurrence and recharge distribution.
2. **GIS-based spatial modeling** enables accurate delineation of hydrogeological zones and recharge areas using multiple thematic layers.
3. **Alluvial plains and limestone formations** represent the highest groundwater potential zones, whereas metamorphic terrains act as natural barriers to recharge.
4. **Remote sensing data** combined with DEM analysis enhances the detection of drainage patterns and recharge pathways.
5. The integrated GIS framework developed in this study can serve as a **decision-support tool** for sustainable water resource management, agricultural planning, and environmental protection in the Balıkesir province and other similar regions of Türkiye.
6. **Hydrogeological zonation of Balıkesir:**
   The region can be divided into three main hydrogeological zones:

**- Northern Lowlands:** shallow groundwater, high recharge, alluvial aquifers.

**- Central Plateau:** mixed lithology, medium recharge, moderate aquifer productivity.

**- Southern Highlands:** deep groundwater, confined aquifers, low recharge potential.

7. GIS as an integrative analytical tool: GIS technology proved essential for merging diverse datasets—geological, hydrological, and topographical—into a coherent analytical framework. This integration enhances the precision of hydrogeological mapping and supports advanced spatial modeling.

Future research should focus on dynamic modeling of groundwater flow using time-series data and climate projections to evaluate the long-term sustainability of aquifer systems under changing climatic conditions.

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