Delineating Agricultural and Water Surfaces in Ergani (Diyarbakır) via Maximum Likehood Classification: A Remote Sensing-Based Approach for Sustainable Agriculture

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Abstract. The manageability of agricultural lands is linked to spatiotemporal monitoring of water–soil resources, evidence-based planning of cropping patterns, and improvements in irrigation efficiency. Within the semi-arid Tigris Basin, Ergani district (Diyarbakır, Türkiye) combines high agricultural potential with water-scarcity risk. This study integrates remote sensing with supervised classification to delineate the spatial distribution of agricultural lands and open-water surfaces. Landsat 8 OLI/TIRS scenes from January 2025 under low cloud cover were processed using reflectance-based band combinations and water- and vegetation-sensitive indices, and a Maximum Likelihood Classification (MLC) was implemented with 90 training samples. MLC models class-specific covariance structures and assigns each pixel to the class with the highest likelihood. The study area was partitioned into five classes: water, agriculture, urban/settlement, mountainous/rocky terrain, and grassland. Agricultural land accounts for 42% of the area, whereas water surfaces cover 3%, confirming the dominant role of agriculture and limited surface-water presence. In this context, groundwater emerges as a strategic buffer for drought resilience, baseflow support, and seasonal irrigation supply. Conjunctive use of surface water and aquifers, adherence to sustainable abstraction thresholds, and protection of recharge zones are critical. Integrating MLC-derived land-cover maps with piezometric head observations, baseflow metrics, and well-abstraction records can help close the water balance and guide demand management through deficit irrigation and pressurized/drip systems, providing a robust spatial basis for integrated water-resources strategies in Ergani.

Keywords: Maximum Likehood Classification, Remote Sensing, Sustainable Agriculture.

1 Introduction

The sustainability of agricultural production in semi-arid regions increasingly depends on integrated water-resources management approaches that jointly consider surface water and groundwater components [1–5]. At the global scale, irrigated agriculture

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accounts for the largest share of freshwater withdrawals, while intensifying climatic pressures, hydroclimatic variability, and irregular rainfall regimes are pushing basin-scale water budgets towards a fragile equilibrium [6–13]. The Tigris Basin is a hydrologically vulnerable system due to its semi-arid climate, high evaporative demand, and seasonally varying flow regime. Forward-looking climate projections for the Upper Tigris indicate decreasing trends in precipitation and streamflow accompanied by rising air temperatures, implying heightened risks for aquifer recharge, baseflow contributions, and environmental flow regimes [14].

Within this setting, the Ergani district represents a piedmont–plain system with high agricultural potential but limited surface-water extent, leading to increased groundwater abstraction for irrigation and additional stress on aquifer storage. Remote sensing helps bridge observational gaps in such data-scarce basins, enabling analysis of agriculture–water interactions at high spatial and temporal resolution and supporting conjunctive surface water–groundwater assessments [6–8,11,15–17]. Landsat imagery, combined with vegetation- and water-sensitive indices (e.g., NDVI, NDWI/MNDWI) and supervised methods such as Maximum Likelihood Classification (MLC), has proven effective for mapping irrigated and rainfed croplands as well as water bodies in semi-arid landscapes [11,18–26].

Against this background, the present study uses recent Landsat 8 OLI/TIRS data and MLC to quantitatively delineate agricultural land and open-water surfaces in Ergani, generating thematic land-cover maps to support interpretation of key water-budget components (surface runoff, baseflow, recharge) and irrigation demand, and to provide a spatial framework compatible with future integration of piezometric, baseflow, and well-abstraction data [3,4,6–8,11,15–17].

2 Materials and Methods

2.1 Study Area

The study focuses on the Ergani district of Diyarbakır Province in southeastern Türkiye, in the semi-arid upper reaches of the Tigris River Basin. The area is characterized by hot, dry summers and cool, relatively wet winters, with most precipitation concentrated between late autumn and spring and long rainless periods during the irrigation season. Average annual precipitation on the order of ~450–500 mm, with only a small fraction falling in summer months, underscores a structurally water-limited hydroclimatic regime [14].

Topographically, Ergani forms a typical plain–foothill system in the transition between the Diyarbakır Plain and the Southeastern Taurus foothills (Figure 1). Alluvial deposits along ephemeral and seasonal streams support intensive agriculture, while surrounding uplands consist of rocky and shallow-soil units with lower water-storage capacity. Under these conditions, surface-water resources (small reservoirs, ponds, and short river reaches) are spatially restricted, and groundwater functions as a critical buffer for sustaining baseflow, maintaining environmental flows, and meeting peak irrigation demand during dry periods, similar to other semi-arid irrigated basins [1–

4,6–8,11,15–17]. Regionally, satellite-based assessments have documented strong links between land-use change, irrigation development, and surface water–groundwater stress in Diyarbakır and surrounding areas as well as in comparable semi-arid basins.

Fig. 1. The boundaries of Ergani district in Diyarbakır province.

2.2 Satelite Data and Pre-processing

Land-cover and water-surface delineation used Landsat 8 OLI/TIRS Level-2 surface reflectance products (Collection 2) from the USGS (Figure 2). These data offer 30 m multispectral and 15 m panchromatic resolution with 12-bit radiometry in the visible, near-infrared, and shortwave infrared bands, allowing reliable separation of vegetation, bare land, and water bodies in semi-arid areas [18,21,23–26].

For this study, near-cloud-free Landsat 8 scenes from January 2025 (low-vegetation period with partially filled reservoirs and ponds) were selected to maximize contrast between open water and surrounding agricultural/rangeland areas. Using surface reflectance instead of top-of-atmosphere radiance improves image consistency and reduces atmospheric artifacts that could affect spectral indices and supervised classification[18].

Spectral bands were processed in a common cartographic framework (WGS84 / UTM Zone 37N) and resampled to 30 m. Besides standard false-color composites (red, near-infrared, shortwave infrared), water- and vegetation-sensitive indices were derived: NDVI for photosynthetically active vegetation, and NDWI/MNDWI to enhance open-water features relative to built-up and bare soil surfaces [19,20].

Fig. 2. Landsat 8 OLI/TIRS 4-3-2 band combination image of the study area.

For thematic mapping and hydrological analysis, Landsat scenes were clipped to the Ergani district boundary using national-scale administrative vectors [27]. Elevation and terrain structure were represented by a 30 m DEM consistent with the Landsat grid, helping distinguish plain from mountainous/rocky areas with contrasting runoff and infiltration behavior (Figure 3).

Fig. 3. DEM data of the study area.

2.3 Maximum Likehood Classification

Supervised land-cover mapping used the Maximum Likelihood Classification (MLC) algorithm, which assumes class-specific normal distributions in spectral space and assigns each pixel to the most probable class (Figure 4). MLC remains a widely used, statistically robust method for LULC mapping in agricultural and semi-arid basins, especially when training data are limited but spectrally distinct [22–26].

For this study, 90 training polygons were digitized from high-resolution imagery and local expert knowledge, evenly distributed across five classes: (i) open water (rivers, ponds, reservoirs), (ii) agriculture (irrigated and rainfed fields), (iii) urban/settlement, (iv) mountainous/rocky terrain, and (v) grassland/rangeland. These hydrologically meaningful classes reflect contrasts in evapotranspiration, runoff, soil–water storage, and recharge. The labeled dataset underpins the MLC-derived thematic maps, which link land-cover patterns to local water-balance components and support integrated surface water–groundwater assessment in the Ergani sub-basin.

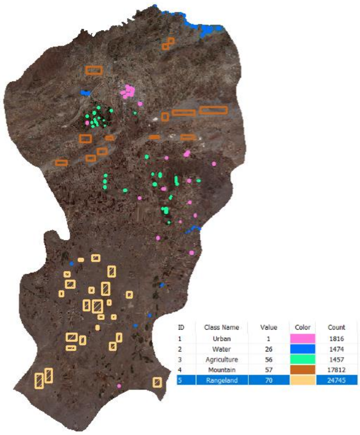

Fig. 4. Training classes for MLC in the study area.

3 Results

The Maximum Likelihood Classification produced a coherent land-cover map for Ergani, with the error matrix indicating strong agreement between mapped classes and reference data, especially for open water and urban/settlement. Misclassifications were mainly limited to agriculture–grassland/rangeland transitions, where mixed cropping–fallow patterns and sparse vegetation yield similar spectral responses. Overall, agriculture dominates (~42% of the district), open-water bodies (rivers, ponds, small reservoirs) cover ~3%, urban/peri-urban areas cluster along main corridors and the district center, mountainous/rocky terrain forms a discontinuous belt along the Southeastern Taurus foothills, and grassland/rangeland infills foothill slopes and residual patches within the agricultural matrix (Table 1).

Table 1. Spatial distribution of landuse classes within the study area.

Class Name	Area (%)
Urban	5
Water	3
Agriculture	42
Mountain	32
Rangeland	18

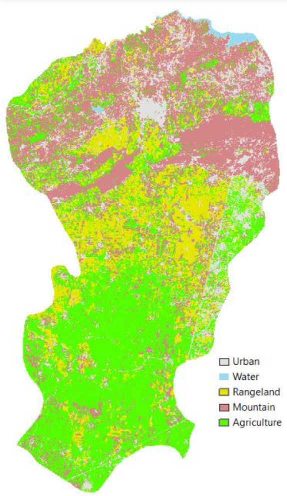

Fig. 5. Spatial distribution of landuse classes as a result of the MLC

Open-water features are strongly aligned with ephemeral and seasonal stream corridors, as well as with engineered water bodies such as irrigation ponds and small reservoirs. This spatial organization is typical of semi-arid basins in which surface-water storage is localized and closely tied to both topography and infrastructure (Figure 5).

4 Conclusion

This study showed that single-date Landsat 8 OLI/TIRS imagery combined with Maximum Likelihood Classification (MLC) can yield hydrologically meaningful land-cover information for a semi-arid, data-scarce basin such as Ergani in the upper Tigris. The MLC-derived map depicts a landscape dominated by agriculture (~42% of the area) and only a small fraction of open-water surfaces (~3%), confirming that intensive cultivation operates within a structurally water-limited regime. The spatial arrangement of classes—irrigated fields on permeable alluvium, small reservoirs and ponds clustered along ephemeral channels, and largely rocky uplands—indicates a strong dependence on conjunctive use of surface water and groundwater, with groundwater acting as a key hydrological buffer that sustains baseflow, environmental flows and peak irrigation demand during prolonged dry periods.

From a management perspective, the land-cover map provides a robust spatial basis for integrated surface water–groundwater assessment and for designing sustainable irrigation strategies. It can be combined with piezometric data, baseflow indices and well-abstraction records to identify critical recharge areas, over-abstracted zones and priority irrigation districts where measures such as deficit irrigation, pressurized and drip systems or cropping-pattern adjustments would deliver the greatest hydrological benefit. More broadly, the study underscores the operational potential of remote sensing - particularly the use of NDVI/MNDWI-enhanced, MLC-based products—for monitoring irrigated agriculture and water-related land-cover dynamics in semi-arid regions under increasing hydroclimatic variability. Although based on a single winter scene and thus not resolving seasonal or interannual dynamics, the work establishes a hydrologically oriented land-cover baseline for the Ergani sub-basin and illustrates the practical value of combining freely available satellite data with standard supervised classification for semi-arid water-resources management.

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