

Comprehensive Report

Second Capacity Development Workshop on "Spatial Insights: Empowering Decision-Making and Transforming Knowledge into Action with Geospatial Intelligence"

Workshop Duration: 2-27 February 2026 (Four Weeks)

Location: Asmara, Eritrea

Organized by: United Nations Economic Commission for Africa (UNECA), African Centre for Statistics, Data Capacity and Integrated Geospatial Knowledge (DCIGK) Section

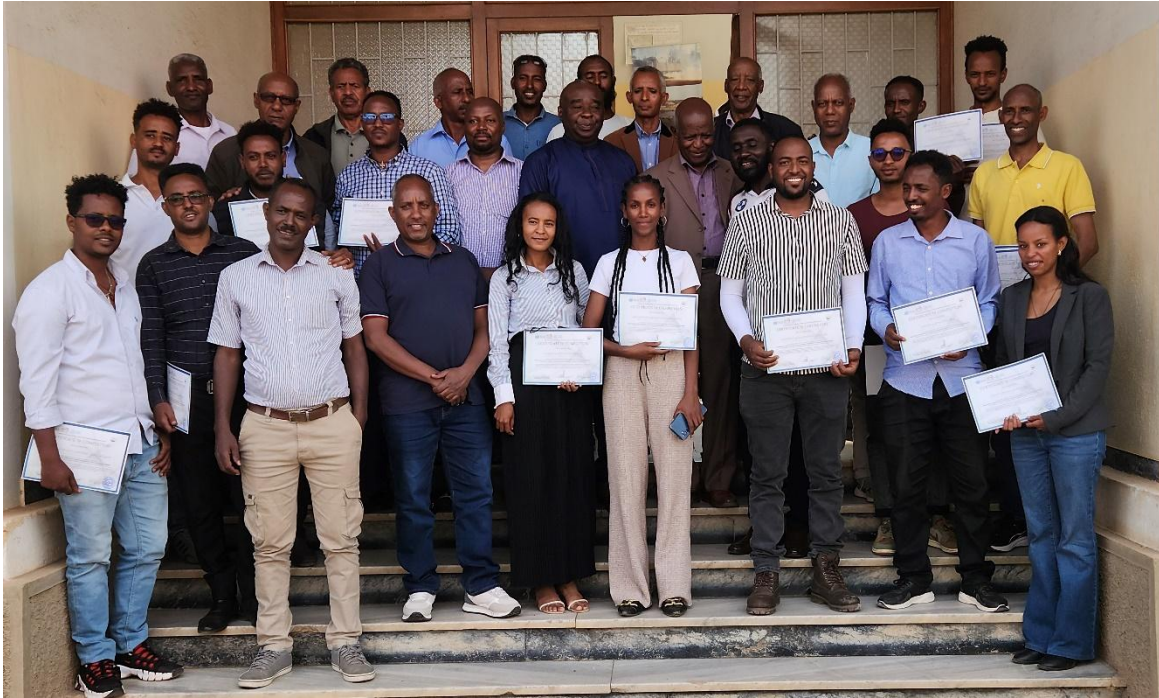
In Collaboration with: Ministry of Lands, Water and the Environment (MLWE), Eritrea

Report Prepared: March 2026



His Excellency Mr Tesfai Ghebreselassie Sebhata, the current Eritrean Minister of Land, Water and Environment, was present during the teams' project presentations and handed over certificates to trainees at the end of the workshop.

- **UNECA Team: Data Capacity and Integrated Geospatial Knowledge (DCIGK) Representatives:** [Ayenika Godheart, Statistician], [Peter Njagi, Geospatial Information Officer]
- **Consultant Lead GIS Trainer:** [Mbinkar Kenneth, ECA Consultant]
- **MLWE Coordination:** [Tedros Kubrom <ktedros70@gmail.com, workshop local coordinator]



Executive Summary

1. The United Nations Economic Commission for Africa (UNECA), through its African Centre for Statistics (ACS) and Data Capacity and Integrated Geospatial Knowledge (DCIGK) Section, have successfully undertook and delivered a comprehensive four-week capacity development workshop in Asmara, Eritrea, from February 2-27, 2026. This intensive training program brought together technical staff from the Ministry of Lands, Water and the Environment (MLWE) to build institutional capacity in geospatial technologies, remote sensing, land administration, and integrated geospatial information management systems.
2. Invariably, the workshop represented a strategic investment in Eritrea's geospatial and statistical infrastructure development, aligning with continental frameworks including the African Action Plan on Global Geospatial Information Management 2016 - 2030 and UN-GGIM Africa priorities. Training over 25 participants within 25 training days, participants engaged in structured learning combining theoretical foundations with extensive hands-on practice using both ArcGIS Pro and QGIS platforms.
3. Key achievements included successful skill development across fundamental GIS operations, remote sensing applications, land use/land cover (LULC) classification, watershed analysis, cadastral data management, and institutional geospatial information management systems (GIIMS) design. Participants demonstrated competency through daily practical exercises and culminated their learning with capstone project presentations showcasing integrated geospatial solutions for real-world MLWE challenges.
4. This report documents the workshop structure, methodology, daily activities, participant engagement, key outcomes, challenges encountered, and recommendations for sustaining and expanding geospatial capacity within Eritrean government institutions.

1. Introduction

1.1 Background and Context

5. Geospatial information has become critical for effective decision-making across diverse sectors including land administration, water resource management, environmental monitoring, agriculture, urban planning, and disaster risk management. Recognizing this critical need, UNECA's African Centre for Statistics has prioritized strengthening geospatial-statistical integration across African member states through targeted capacity development initiatives.
6. Eritrea, through the Ministry of Lands, Water and the Environment, has demonstrated strong commitment to modernizing its geospatial data infrastructure and enhancing technical capacity among government personnel. The ministry officially requested the ECA to build the institutions capacity in geospatial intelligence in areas including but not limited to land, water and the environment. This training workshop represents the second phase of a multi-year capacity development partnership designed to establish sustainable geospatial technical expertise within national institutions in Eritrea, ECA had already built the capacity of the Ministry of Lands, Water and the Environment in the first training.

1.2 Workshop Objectives

7. The primary objectives of this capacity development workshop were to:
 - Build foundational to intermediate competencies in Geographic Information Systems (GIS) and Remote Sensing (RS) technologies among MLWE technical staff
 - Develop practical skills in geospatial data acquisition, management, analysis, and visualization relevant to land, water, and environmental applications
 - Strengthen capacity in land use/land cover classification, change detection, and multi-temporal analysis using satellite imagery
 - Introduce modern cadastral GIS concepts, parcel data models, and field data collection methodologies
 - Establish understanding of Geospatial Institutional Information Management Systems (GIIMS) architecture, geodatabase design, and data governance frameworks
 - Foster cross-sectoral integration approaches connecting land, water, cadastral, and environmental geospatial datasets
 - Empower participants to independently design, implement, and manage geospatial projects addressing MLWE operational priorities

1.3 Target Participants

8. The workshop targeted technical and professional staff from various departments within the Ministry of Lands, Water and the Environment, and other sectoral ministries including:
 - GIS and mapping specialists
 - Land administration and cadastral officers
 - Water resource management professionals
 - Environmental monitoring and planning staff
 - Survey and cartography technicians
 - Database and IT specialists
 - Etc.
9. Participants represented diverse educational backgrounds ranging from diploma to master's degree levels, with varying levels of prior GIS exposure from novice to intermediate users. This diversity necessitated a carefully structured pedagogical approach balancing foundational concepts with advanced applications.

2. Workshop Structure and Methodology

2.1 Overall Design

10. The workshop was structured as an intensive four-week program comprising 25 full training days organized into thematic weekly modules. Each day followed a consistent schedule from 8:30 AM to 5:30 PM with morning and afternoon coffee breaks and a midday lunch period, providing approximately 8 hours of contact time per day.

The pedagogical approach combined:

- Theoretical presentations introducing concepts, frameworks, and methodologies
- Live demonstrations of software workflows and analytical techniques
- Extensive hands-on practice sessions with guided exercises
- Group discussions and collaborative problem-solving activities
- Daily recap sessions reinforcing previous learning
- Quizzes and knowledge checks assessing comprehension
- Individual and group project work applying skills to real scenarios

2.2 Software Platforms

11. A distinctive feature of this training was the dual-platform approach providing parallel instruction in both:
 - **ArcGIS Pro:** Industry-standard commercial GIS platform from Esri, widely used in government and enterprise environments
 - **QGIS:** Leading open-source GIS platform offering robust functionality without licensing costs, ensuring long-term sustainability
12. This approach ensured participants could apply learned concepts regardless of institutional software availability and licensing constraints, while comparing workflows across platforms to deepen conceptual understanding.

2.3 Training Materials

13. Comprehensive training materials were provided to all participants including:
 - PowerPoint presentation decks for each topic module
 - Detailed hands-on training manuals with step-by-step instructions for both ArcGIS Pro and QGIS
 - Sample datasets representing Eritrean geographic contexts (administrative boundaries, satellite imagery, elevation data, sample cadastral parcels)
 - Reference documents (over 60 technical manuals) on best practices, standards, and frameworks
 - Exercise templates and worksheets for practical sessions
14. Materials were designed to serve as ongoing reference resources for participants beyond the workshop duration, supporting continued learning and independent practice.

3. Week-by-Week Implementation

3.1 Week 1: GIS and Remote Sensing Fundamentals (February 2-6, 2026)

3.1.1 Week Overview

15. The opening week established foundational knowledge in GIS and remote sensing technologies, ensuring all participants regardless of prior experience, shared common conceptual understanding and basic operational skills.

3.1.2 Monday, February 2: GIS Basics and Mapping

16. The workshop commenced with formal opening ceremonies attended by senior MLWE leadership and UNECA representatives. Following introductions and expectation-setting exercises, the training team launched into fundamental GIS concepts including spatial data representation, components of GIS (hardware, software, data, people, procedures), and practical applications relevant to land administration, water management, and environmental monitoring.
17. Participants received thorough introduction to coordinate systems and map projections, with particular emphasis on understanding why spatial reference systems matter for accurate analysis and decision-making. The Eritrean national coordinate system and appropriate UTM zones for regional work were highlighted.
18. Afternoon sessions focused on cartographic principles including map layout design, essential map elements (scale bars, north arrows, legends, titles, metadata), and the communication purpose of maps. Hands-on exercises guided participants through navigating GIS software interfaces, loading base layers (administrative boundaries, roads, settlements), and creating simple overview maps of Eritrea.

3.1.3 Tuesday, February 3: Data Sources and Management

19. Day two addressed the critical question of where geospatial data originates. Presentations covered diverse data sources including national mapping agencies, open data repositories (OpenStreetMap, Natural Earth, DIVA-GIS), satellite imagery archives, and survey/field data collection. Participants learned about spatial data formats including shapefiles, geo-packages, and file geodatabases, understanding the advantages and limitations of each.
20. Extensive time was devoted to attribute tables as the foundation of spatial data management. Participants practiced creating and editing attribute fields, understanding data types (text, numeric, date), and performing basic attribute queries using "Select by Attribute" operations to isolate features meeting specific criteria.
21. Group discussions explored current data availability and identified gaps within MLWE operations, fostering reflection on how enhanced data management could improve organizational effectiveness.

3.1.4 Wednesday, February 4: Digitization and Editing

22. With foundational concepts established, participants progressed to spatial data creation and editing. Sessions covered digitizing principles, editing tool functionality, snapping settings for precision, and creating new features (points, lines, polygons). Topology concepts were introduced emphasizing the importance of clean spatial datasets without gaps, overlaps, or dangling edges.
23. Hands-on exercises challenged participants to digitize sample land parcels and land-use polygons from high-resolution satellite imagery, applying topology rules to ensure data quality. This practical work highlighted the precision and attention to detail required for cadastral and land administration applications.
24. Discussions addressed establishing editing standards and quality control procedures for MLWE datasets, considering institutional workflows and data maintenance responsibilities.

3.1.5 Thursday, February 5: Remote Sensing Basics

25. The fourth day introduced remote sensing fundamentals including electromagnetic spectrum principles, spectral signatures of different land cover types, and key resolution concepts (spatial, spectral, temporal, radiometric). Participants gained understanding of major satellite platforms including Landsat (30m resolution, 30+ year archive), Sentinel-2 (10m resolution, frequent revisit), and MODIS (coarse resolution, daily coverage).
26. Practical sessions demonstrated accessing and downloading free satellite imagery for Eritrea through platforms including USGS Earth Explorer, Copernicus Open Access Hub, and Google Earth Engine.

- Participants practiced loading multi-spectral bands, creating true-color and false-color composites (highlighting vegetation, water, urban features), and interpreting land cover characteristics from spectral response.
27. The day concluded linking remote sensing capabilities to MLWE operational needs including land cover monitoring, vegetation health assessment, water body mapping, and change detection.

3.1.6 Friday, February 6: Land Resources and Visual Interpretation

28. Week one concluded focusing on land resource concepts and visual image interpretation techniques. Presentations introduced land use versus land cover distinctions, land capability classification systems, and land degradation indicators observable through remote sensing.
29. Participants learned systematic image interpretation using elements including tone, texture, pattern, shape, size, shadow, and association. Demonstrations showcased interpreting satellite imagery to identify key LULC classes including agricultural areas, forests, grasslands, barren land, water bodies, and built-up areas.
30. Hands-on exercises engaged participants in interpreting Eritrean satellite imagery and assigning preliminary LULC classes to sample regions. Group work facilitated defining an MLWE-relevant LULC classification legend reflecting national land resource priorities and existing classification systems.
31. A plenary session explored practical applications of LULC information for environmental monitoring, land use planning, agricultural statistics, and natural resource management. Weekly wrap-up activities included knowledge assessment quizzes and participant feedback collection.

3.2 Week 2: Land and Water Applications (February 9-13, 2026)

3.2.1 Week Overview

32. Building upon foundational skills, week two advanced participants into applied geospatial analysis focused on land and water resource assessment using remote sensing and GIS techniques.

3.2.2 Monday, February 9: LULC Classification

33. The second week opened with automated land use/land cover classification methodologies. Participants learned distinctions between supervised classification (analyst-defined training samples) and unsupervised classification (algorithm-driven clustering), understanding appropriate applications and limitations of each approach.
34. Detailed coverage of the supervised classification workflow included training sample collection, spectral signature evaluation, classification algorithm selection (maximum likelihood, random forest, support vector machine), and output generation. Accuracy assessment concepts were introduced including confusion matrices, overall accuracy, producer's accuracy, user's accuracy, and kappa coefficient.
35. Hands-on exercises guided participants through performing basic supervised classification on Sentinel-2 imagery, creating LULC maps for sample regions, computing area statistics by class, and conducting rapid accuracy checks using reference points. Reflection sessions addressed classification limitations including mixed pixels, spectral confusion between classes, and the importance of ground-truth data.

3.2.3 Tuesday, February 10: Change Detection

36. Multi-temporal analysis and land-use change detection formed the focus of day two. Presentations explained change detection concepts, appropriate temporal intervals for different phenomena, and dataset selection criteria ensuring consistency across time periods.

37. Participants learned multiple change detection approaches including post-classification comparison (comparing two classified images), image differencing (subtracting spectral values), and vegetation index differencing (e.g., NDVI change). Emphasis was placed on practical considerations including seasonal variation, atmospheric correction, and change interpretation.
38. Practical sessions challenged participants to compare LULC maps from different years, build change matrices quantifying transitions between classes (e.g., forest to agriculture, grassland to barren), and visualize change patterns spatially. Group presentations showcased findings and discussed implications for land management policy.

3.2.4 Wednesday, February 11: Watershed and DEM Analysis

39. Midweek sessions introduced Digital Elevation Models (DEMs) and terrain analysis capabilities. Participants learned about DEM data sources including SRTM (90m), ASTER (30m), and emerging higher-resolution products. Fundamental terrain derivatives including slope, aspect, hill shade, and curvature were demonstrated with interpretations for land use planning and erosion risk assessment.
40. Watershed delineation and hydrological modeling formed major practical components. Participants worked through workflows including DEM conditioning (filling sinks), flow direction calculation, flow accumulation mapping, stream network extraction, and watershed boundary delineation. Exercises focused on delineating watersheds for specific stream gauges or water resource management zones within Eritrea.
41. Discussions connected watershed analysis to water resource planning, soil conservation prioritization, flood risk mapping, and irrigation scheme design all relevant to MLWE mandates.

3.2.5 Thursday, February 12: Water and Vegetation Monitoring

42. Advanced applications of spectral indices for environmental monitoring comprised day four content. Detailed exploration of Normalized Difference Vegetation Index (NDVI) covered calculation methodology, interpretation of values (-1 to +1), seasonal patterns, and applications for vegetation health monitoring, drought assessment, and agricultural productivity estimation.
43. Similarly, water-focused indices including Normalized Difference Water Index (NDWI) and Modified NDWI (MNDWI) were introduced for water body mapping, wetland monitoring, and flood extent delineation. Participants practiced calculating these indices, interpreting results, and tracking changes over time.
44. Case studies demonstrated operational applications including monitoring seasonal vegetation dynamics in agricultural zones, mapping ephemeral water bodies during rainy seasons, and detecting vegetation stress during drought periods.

3.2.6 Friday, February 13: Integration and Week Wrap-Up

45. Week two concluded with synthesis sessions emphasizing integration of geospatial products into decision workflows. Participants worked in small groups to design conceptual projects combining LULC classification, change detection, terrain analysis, and vegetation/water monitoring to address specific MLWE challenges such as:
 - Mapping agricultural expansion and monitoring productivity
 - Watershed prioritization for soil conservation interventions
 - Water resource mapping for irrigation planning
 - Environmental monitoring in protected areas
46. Group presentations allowed peer learning and trainer feedback. Knowledge assessment activities evaluated skill retention and identified areas requiring reinforcement. Week two concluded with

participants demonstrating solid competency in applied land and water geospatial analysis techniques.

3.3 Week 3: Cadastral GIS and Integration (February 16-25, 2026)

3.3.1 Week Overview

47. The third week shifted focus toward land administration and cadastral applications, introducing specialized data models, field data collection workflows, and cross-domain data integration approaches.

3.3.2 Monday, February 16: Land Administration and Cadastral Systems

48. Week three opened with comprehensive coverage of land administration fundamentals including land tenure systems, cadastral concepts (parcels, rights, restrictions, responsibilities), and the role of spatial information in land governance. International frameworks including the Land Administration Domain Model (LADM) were introduced as conceptual foundations for designing cadastral information systems.
49. Presentations highlighted distinctions between fiscal cadastre, legal cadastre, and multipurpose cadastre, with discussions on Eritrea's current land administration framework and modernization priorities. The importance of unique parcel identifiers, attribute standards, and quality assurance procedures was emphasized.

3.3.3 Tuesday, February 17: Cadastral Data Models

50. Day two delved into technical aspects of cadastral spatial data design. Participants learned parcel-based data models including feature classes for parcels, boundaries, control points, and associated attribute tables capturing ownership, land use, valuation, and administrative information.
51. Topology rules specific to cadastral datasets received detailed attention including requirements that parcels must not overlap, gaps between parcels indicate public/unregistered land, and boundaries must align precisely. Hands-on exercises engaged participants in building sample cadastral geodatabases with appropriate feature classes, relationship classes linking spatial and tabular data, and domains enforcing attribute consistency.

3.3.4 Wednesday, February 18: Field Data Collection

52. Midweek sessions focused on modern field data collection technologies. Presentations covered Global Navigation Satellite Systems (GNSS) principles, GPS receivers (recreational vs. survey-grade accuracy), and mobile GIS applications for field mapping (ArcGIS Field Maps, QField, Mergin Maps).
53. Practical demonstrations showcased configuring mobile data collection forms, establishing attribute domains and validation rules, collecting features with GPS locations, and synchronizing field data back to central databases. Where equipment permitted, participants practiced outdoor GPS data collection and accuracy assessment.
54. Discussions addressed practical considerations including positional accuracy requirements for different applications, cost-benefit analysis of survey-grade equipment, and workflows integrating field data with office-based digitization.

3.3.5 Thursday, February 19: Cadastral Analysis and Reporting

55. Analytical capabilities specific to land administration formed day four focus. Participants learned spatial queries for identifying parcels meeting specific criteria (ownership, size, land use, zoning), buffer analysis for setback and easement enforcement, and overlay analysis for land use compliance checking.
56. Report generation workflows were demonstrated including producing parcel certificates with maps and attribute information, generating statistical summaries (total area by ownership type, number of parcels by size class), and creating thematic maps for planning and taxation purposes.
57. Exercises challenged participants to perform cadastral queries, generate ownership reports, and create map books for administrative regions all realistic tasks supporting MLWE land administration functions.

3.3.6 Friday, February 25: Cross-Domain Integration

58. Week three culminated in integration exercises connecting cadastral data with LULC, water, and environmental datasets. Participants explored analytical questions requiring multi-source integration such as:
 - Identifying parcels within watershed protection zones
 - Overlaying actual land use (from classification) with registered land use (from cadastre) to detect non-compliance
 - Assessing parcels at risk from flood zones or erosion-prone slopes
 - Supporting agricultural census by linking farm parcels to cropping patterns from satellite imagery
59. These exercises demonstrated the power of integrated geospatial information systems supporting evidence-based policy and operational decision-making across MLWE mandates.

3.4 Week 4: IIMS, Web GIS, Governance, and Capstone (February 23-27, 2026)

3.4.1 Week Overview

60. The final week elevated focus to enterprise-level considerations including Institutional Information Management Systems architecture, web-based geospatial platforms, data governance frameworks, and culminated in capstone project presentations demonstrating comprehensive skill integration.

3.4.2 Monday, February 23: IIMS Architecture

61. Week four commenced with enterprise GIS and Institutional Information Management Systems (IIMS) concepts. Presentations introduced IIMS as integrated frameworks connecting geospatial data, statistical data, administrative records, and field observations within unified institutional platforms supporting cross-departmental collaboration.
62. Architecture components covered included central geodatabase servers, data warehouses, metadata catalogs, web services (WMS, WFS), and client applications (desktop GIS, web viewers, mobile

- apps). Discussions addressed implementation considerations including infrastructure requirements, data migration strategies, user access management, and change management processes.
63. Case examples from African national statistical offices and land agencies illustrated successful IIMS implementations, challenges encountered, and lessons learned.

3.4.3 Tuesday, February 24: Geodatabase Design

64. Day two provided practical training in enterprise geodatabase design principles. Participants learned conceptual, logical, and physical database design stages, entity-relationship modeling, normalization principles, and translating organizational requirements into database schemas.
65. Hands-on exercises engaged participants in designing geodatabases for specific MLWE departments, defining feature datasets, feature classes, relationship classes, domains, and subtypes. Quality control mechanisms including topology rules, attribute validation, and geometric constraints were incorporated into designs.
66. Group work facilitated designing integrated MLWE geodatabases accommodating land administration, water resources, environmental monitoring, and planning datasets within coherent structures supporting institutional workflows.

3.4.4 Wednesday, February 25: Web GIS and Dashboards

67. Midweek sessions introduced web-based geospatial platforms enabling broader data access and visualization. Participants explored web mapping concepts, cloud-hosted GIS platforms (ArcGIS Online, Mapbox), and open-source alternatives (GeoServer, Leaflet).
68. Demonstrations showcased creating web maps, configuring pop-up windows displaying attribute information, setting symbology and scale-dependent rendering, and publishing maps for public or restricted organizational access. Dashboard concepts were introduced using ArcGIS Dashboards and similar tools for real-time monitoring and KPI visualization.
69. Discussions explored strategic considerations for deploying web GIS within MLWE including user needs assessment, security and access control, mobile responsiveness, and bandwidth considerations in resource-constrained environments.

3.4.5 Thursday, February 26: Data Governance and SOPs

70. Day four addressed critical institutional considerations including data governance frameworks, standard operating procedures (SOPs), metadata standards, and data quality assurance protocols.
71. Participants learned the importance of formal governance structures defining data ownership, update responsibilities, quality standards, access policies, and archiving procedures. Metadata standards aligned with ISO 19115 and national/regional frameworks were introduced as essential for data discoverability, evaluation, and appropriate use. Practical exercises engaged participants in creating metadata records for sample datasets using metadata editors.
72. Workflow documentation and SOP development methodologies were covered, with groups drafting sample procedures for common MLWE geospatial workflows such as updating administrative boundaries, processing new satellite imagery, or responding to map requests.

3.4.6 Friday, February 27: Capstone Presentations and Closing Ceremony

73. The workshop culminated in capstone project presentations where participant groups showcased integrated geospatial solutions addressing real MLWE operational challenges. Projects combined skills from all four weeks including data acquisition, processing, analysis, visualization, and decision support recommendations.

4. Capstone Project Demonstrations

74. The capstone presentations on the final day represented the culmination of participants' learning journey, demonstrating their ability to integrate multiple geospatial concepts, technologies, and analytical approaches to address real-world challenges facing the Ministry of Lands, Water and the Environment. Three exemplary projects are documented below, each showcasing different application domains and technical competencies.

4.1 Project 1: LULC Classification and Change Detection of Prosopis Juliflora in Lower Barka River Strip

Team Members: Awet Issak, Eyob Yemane, Ghirmay Abrha, Samuel Fishatsion, Tekelweyni Sele, Osman Mohamedhasen, Aman Tezare, Merhawi Amanuel, Sinit Simon

4.1.1 Project Background

75. Prosopis juliflora is a deciduous invasive plant species that can grow 10-15 meters tall and live up to 100 years. It can outcompete native vegetation, disrupt ecological balance, and alter soil chemistry. Prosopis juliflora was introduced to Eritrea from Sudan in the 1970s accidentally by animals (cattle) to Tessenei, Tamarat, and Qarora. Within one or two decades, the species invaded agricultural areas, riverine vegetation, encroached on pastures, and limited access of both humans and animals to River Gash. In the semi-arid areas of western Eritrea, Prosopis is widely viewed as a threat to natural resources and rural community livelihoods.

4.1.2 Study Area

76. The study area is a strip of the lower part of Barka River covering 67,582 hectares situated in the Gash Barka province. This region represents critical agricultural and grazing lands for local communities.

4.1.3 Problem Statement

77. Prosopis juliflora around Barka River creates problems by hindering communities in achieving food security. It aggressively invades grazing land and reduces grazing potential of rangelands by suppressing native trees and grasses. In addition, it competes for and reduces the productivity of croplands and impairs mobility while causing injuries to people and livestock.

4.1.4 Project Objectives

78. The overall objective was to identify and monitor land cover/land use along the Barka River strip using GIS application, and to assess the spatial distribution of Prosopis juliflora from 2015-2025.

Specific objectives included:

- To assess and quantify LULC change from 2015 to 2025 in the area colonized by Prosopis juliflora using satellite imageries
- To reveal the current land use and land cover of the study area
- To map the spatial distribution of Prosopis juliflora from 2015 to 2025

4.1.5 Methodology

79. The team utilized:

- **Data sources:** Landsat images from 2015 and 2025
- **Software:** ArcGIS Pro (offline application) and Microsoft Office Excel
- **Methods:**
 - a. Conversion of multi-band raster imagery into single-band raster
 - b. Digitizing categorical classes relating to different types of land cover
 - c. LULC classification via supervised classification
 - d. Random sampling method for accuracy assessment
 - e. Intersecting data from two different time periods (2015 to 2025)

4.1.6 Results and Findings

Overall LULC Area Changes (2015-2025):

LULC Class	Area 2015 (ha)	Area 2025 (ha)	Difference (ha)
Water	1,504	2,447	+943
Irrigated land	3,984	3,097	-887
Rocky area	8,311	8,300	-11
Riverine tree (Prosopis)	7,245	8,001	+756
River	5,658	8,670	+3,012
Bare land	40,878	40,243	-636
Total	67,581	70,758	+4,973

Prosopis Juliflora Change Detection Details:

80. The detailed analysis revealed complex transition patterns totaling 10,712 hectares of Prosopis-related changes:

Transition Type	Area (ha)	Percentage
Bare land → Riverine tree (expansion)	1,979.59	18%
Irrigated land → Riverine tree (invasion)	1,072.39	10%
Riverine tree → Riverine tree (persistence)	4,192.32	38%
Riverine tree → Irrigated land (clearing)	1,042.54	15%
Riverine tree → Bare land (clearing)	1,048.78	5%
River → Riverine tree (colonization)	401.07	5%
Riverine tree → River (flooding)	395.95	2%

Riverine tree → Rocky area	376.47	4%
Riverine tree → Water	187.59	2%
Water → Riverine tree	15.42	<1%

4.1.7 Key Findings

- Prosopis juliflora showed **net expansion of 756 hectares** (10.4% increase) over the 10-year period
- **38% of Prosopis areas remained stable**, indicating well-established populations
- **Invasion of productive lands:** 1,072 hectares of irrigated agricultural land converted to Prosopis
- **Expansion into bare lands:** 1,980 hectares of bare land colonized
- **Some management success:** 2,091 hectares cleared from Prosopis back to productive uses (irrigated land + bare land)

4.1.8 Challenges

81. The team identified several technical challenges:

- Satellite image resolution was limited to 30 meters (Landsat)
- Images were acquired in different months, affecting spectral consistency
- Difficulty separating bare land from uncultivated commercial agriculture when images were taken off-season

4.1.9 Conclusions and Recommendations

Conclusions:

- ArcGIS Pro application was effective and efficient to identify and map the invasive species problem
- Prosopis juliflora is actively invading the lower Barka region including commercial agricultural areas, rangelands, and riverine strips
- The expansion is limiting the growth of indigenous trees in the area

Recommendations:

- Decision makers should take measures to manage or eradicate the Prosopis juliflora species
- Higher resolution satellite imagery is needed to more accurately identify and classify land resources
- Additional technical capacity development is required for advanced mapping techniques

4.1.10 Evaluation Commentary

82. This project demonstrated excellent integration of remote sensing classification, multi-temporal analysis, and change detection methodologies. The team successfully applied supervised classification techniques learned in Week 2, produced quantitative change matrices, and interpreted results within the context of environmental management priorities. The project addresses a critical environmental and livelihood issue with clear policy relevance for MLWE decision-making.

4.2 Project 2: Gergera Dam Site Selection Alternative Analysis

Team Members: Abdelqadir Jemal, Daniel Kaleab, Diana Tekeste, Ersanos Berhe, Kibrom Tuum, Romodan Salh Musa, Simon Elma, Tekle Yemane

4.2.1 Project Background

83. The proposed Gergera dam site is located in the southern part of the Upper-Mereb River Basin. The Gergera River catchment covers an area of 547 km² and is located in the northern portion of the Debub region (coordinates: 37° 49' 17.80" E, 16° 58' 8.38" N). The dam site is surrounded by Gergera, Ghedele, and Feqeyh villages.
84. The Gergera River catchment is part of the Mereb River Basin which rises in the northwestern part and flows in a southeasterly direction, flowing through Dubarwa, east of Tera-Imni and Mendefera, and west of Dekemhare. Elevations in the basin range from about 1,395 m near the Hazemo Plain to nearly 2,600 m along the northwestern rim and more than 2,700 m at the northeastern corner, east of Segeneiti and north of Adi-Keih. The rainy season from June to September provides the area with mean annual rainfall of approximately 530 mm.

4.2.2 Problem Identification

85. The project aimed to evaluate the economic and social costs of two different dam options using ArcGIS Pro, comparing the existing planned Gergera Dam site with an alternative location.

4.2.3 Project Objectives

- Application of ArcGIS Pro for optimum site selection in dam construction, seeking higher volume of water availability with minimum negative impact on land use/land cover
- To solve water scarcity in the southern region
- To increase agricultural productivity
- To enrich ecological areas

4.2.4 Data Used

S.N	Data	Data Type
1	Eritrea Digital Elevation Model (DEM)	Raster
2	Eritrean villages	Vector
3	Southern subzoba boundaries	Vector
4	Eritrea roads	Vector

5	Eritrea Landsat 8 imagery	Raster
6	QuickBird high-resolution imagery	Raster

4.2.5 Methodology

86. The comprehensive hydrological modeling workflow included:

1. DEM Preprocessing:

- Fill DEM (sink removal)
- Flow direction calculation
- Flow accumulation analysis

2. Hydrological Network Extraction:

- Raster calculator for stream definition
- Stream link generation
- Stream ordering (Strahler method)
- Stream to feature conversion

3. Watershed Delineation:

- Pour point definition
- Snap pour point to high accumulation
- Watershed boundary delineation

4. Topographic Analysis:

- Contour generation (before and after watershed)
- Hillshade for visualization
- Watershed overlay on hillshade

5. Reservoir Design:

- Dam axis digitization
- Feature to polygon conversion for reservoir area
- Storage capacity calculation at different elevations
- Dam structure design

6. Impact Assessment:

- LULC classification of reservoir areas
- Agricultural land coverage comparison
- Settlement mobilization assessment
- Forest land coverage comparison

4.2.6 Studies Conducted

The team conducted comprehensive comparative analyses:

- Watershed delineation for both sites
- Dam storage capacity comparison
- Land use/land cover analysis for inundation areas
- Agricultural land coverage comparison
- Settlement mobilization requirements comparison
- Forest land coverage comparison

4.2.7 Results and Comparison

Reservoir Characteristics Comparison:

S.N	Parameter	Units	Existing Gergera Dam	Proposed Alternative Dam
1	Area of Reservoir	m ²	3,069,011	4,584,443
2	Volume of Reservoir	Million m ³	46.2	139.8
3	Dam Axis Length	m	692.27	292.80

Key Finding: The alternative site offers **3 times the storage capacity** (139.8 vs 46.2 million m³) with a **shorter dam axis** (293m vs 692m), suggesting significant construction cost advantages.

Land Use/Land Cover Impact Comparison:

S.N	LULC Type	Unit	Existing Dam	Proposed Dam	% Existing	% Proposed
1	Gravel road	km	6.73	7.96	<0.01%	<0.01%
2	Grazing land	m ²	1,592,830	3,235,598	54%	72%
3	High potential agricultural land	m ²	138,912	7,034	5%	1.44%
4	Low potential agricultural land	m ²	554,981	881,526	19%	25%
5	Moderate potential agricultural land	m ²	443,669	87,385	15%	2%
6	Plantation	m ²	6,373	5,593	0.2%	0.1%
7	River bed	m ²	254,678	268,168	7%	6%
8	Seasonal wetland	m ²	0	858	0%	0.02%
Total			2,941,441	4,486,162		

4.2.8 Key Findings and Trade-offs

87. Advantages of Proposed Alternative Site:

- **Substantially larger storage capacity:** 139.8 million m³ vs 46.2 million m³ (253% increase)
- **Shorter dam axis:** 293m vs 692m (58% reduction) - significant construction cost savings
- **Reduced impact on high-value agricultural land:** Only 7,034 m² vs 138,912 m² affected (95% reduction)
- **Reduced moderate agricultural land impact:** 87,385 m² vs 443,669 m² (80% reduction)

Considerations:

- **Larger overall inundation area:** 4.49 km² vs 2.94 km² (52% larger)
- **More grazing land affected:** 3.24 km² vs 1.59 km² (but proportionally similar at 72% vs 54% of total inundation)
- **Higher reservoir area for greater storage** suggests better reservoir morphology and depth

4.2.9 Conclusion

88. The team concluded that:

- ArcGIS Pro is highly effective and efficient in watershed delineation modeling and related land use/land cover impact assessment
- ArcGIS Pro has the potential to provide valuable insights and support for dam site selection
- The proposed alternative site offers significant advantages in storage capacity and construction efficiency while minimizing impact on high-value agricultural lands

4.2.10 Evaluation Commentary

89. This project exemplified sophisticated integration of multiple geospatial analysis techniques including DEM processing, hydrological modeling, watershed delineation, storage volume calculation, and multi-criteria impact assessment. The team successfully applied advanced terrain analysis skills from Week 2, combined with spatial overlay analysis from Week 3, to produce decision-relevant comparative analysis with clear implications for infrastructure investment planning. The systematic methodology and quantitative comparison framework demonstrated strong analytical thinking and practical problem-solving capabilities.

4.3 Project 3: The Role of GIS in Modern Cadastral System

Team Members: Group B (specific names not recorded in presentation)

4.3.1 Project Background and Context

90. This project addressed the fundamental transformation of cadastral management through GIS technology. The team articulated that Geographic Information Systems represent a broad concept as tools and software, GIS enables spatial data for display, visualization, and information retrieval. Cadastre, traditionally, deals with parcel-based ownership and property rights as tabular data.

91. The project emphasized that in modern practice, GIS has fundamentally transformed cadastral management from paper-based record-keeping to dynamic, integrated digital systems that serve as the spatial backbone of modern land administration.

4.3.2 Conceptual Framework

92. The team presented a clear conceptual framework showing how:

- **ArcGIS Pro enables cadastral information** to become the coordinating platform linking parcels with pertinent information through common parcel-level geographic and ownership data
- **Cadastral data exists as tabular information** (attribute tables) linked to geographical features (parcel polygons)
- **Each parcel record contains multiple attributes** organized in columns, with rows representing individual properties
- **GIS-enabled cadastral systems support** everything from property transactions and taxation to urban planning and infrastructure development

4.3.3 Problem Statement

93. The team conducted a detailed assessment of current cadastral operations in the MLWE Cadastral Office, which is responsible for registering property rights throughout the country. They identified critical operational inefficiencies:

Current System Limitations:

- **Physical access requirements:** Accessing information and registration require physical visits to cadastral offices
- **Manual processes:** Searching through paper map sheets and cross-referencing handwritten records
- **Time-consuming updates:** Updating boundaries involves redrawing paper maps
- **Error-prone analysis:** Analyzing land patterns is labor-intensive and prone to errors
- **Limited accessibility:** Information retrieval is slow and geographically constrained

4.3.4 Project Objective

94. To introduce and establish a GIS-based spatial geodatabase cadaster in the Cadastral Office of the MLWE to transform cadastral management from paper-based record-keeping to dynamic and integrated digital systems that serve as the spatial backbone of modern land administration.

4.3.5 Methodology

95. The team implemented a pilot cadastral GIS system using the following approach:

Mapping Process:

1. **Geodatabase establishment:** A parcel-based cadastral geodatabase for targeted buildings was established in ArcCatalog of ArcGIS Pro
2. **High-precision digitization:** Each parcel was digitized using high-resolution imagery at 15cm resolution in the ArcGIS Pro environment

3. **Attribute population:** Pertinent information for each parcel was populated in the attribute table of each parcel feature
4. **Report generation:** Final reports were produced in both map and tabular formats in ArcGIS Pro

4.3.6 Study Area: Mai Chihot

96. The pilot project focused on Mai Chihot area, where a sample of buildings and associated parcels were mapped and registered in the digital cadastral system.

4.3.7 Results

The team successfully produced:

1. Property Map:

- Visual cartographic representation showing parcel boundaries, building footprints, and parcel identifiers
- Professional map layout with proper scale, north arrow, legend, and metadata
- Clear spatial relationships between parcels and surrounding infrastructure

2. Tabular Data (Attribute Table):

- Comprehensive parcel database linking spatial features to ownership and property attributes
- Structured information including parcel ID, owner name, parcel area, land use, registration date
- Queryable database enabling rapid information retrieval

3. Integrated System:

- Demonstration of seamless integration between spatial visualization (map) and alphanumeric data (tables)
- Capability for spatial queries (e.g., "select all parcels larger than 500 m²")
- Capability for attribute queries (e.g., "find all parcels owned by specific owner")

4.3.8 Recommendations

97. The team provided strategic recommendations for institutional transformation:

Urgent Priority: GIS-Based Cadastral Infrastructure

The cadastral office urgently needs to establish a GIS-based Cadastral Geospatial Infrastructure unit to migrate from tedious and time-consuming paperwork to a digital system.

Inter-Departmental Integration

Currently, multiple departments handle sequential processes:

- **Department of Land:** Allocates land for end users for different purposes
- **Technical Office in Municipality:** Prepares architectural designs

- **Cadastral Office:** Registers owner property rights

Critical Need: Interconnection through network infrastructure between these sections is essentially crucial for efficient workflow and data consistency.

Capacity and Infrastructure Requirements

To handle and manage these activities effectively, the cadastral office should be:

- **Equipped with GIS software** such as ArcGIS Pro
- **Staffed with trained personnel** possessing cadastral GIS competencies
- **Supported with appropriate hardware** and network infrastructure
- **Provided with ongoing capacity development** and technical support

4.3.9 Evaluation Commentary

98. This project demonstrated comprehensive understanding of cadastral GIS principles introduced in Week 3, including parcel data models, topology requirements, attribute management, and the critical link between spatial and legal dimensions of land administration. The team successfully:

- Articulated clear conceptual understanding of GIS role in modern cadastre
- Identified specific operational problems in current systems through institutional analysis
- Implemented a functional pilot demonstrating feasibility
- Produced both cartographic and database outputs meeting professional standards
- Developed strategic recommendations addressing institutional transformation needs

99. The project showcases strong grasp of enterprise GIS concepts from Week 4, particularly regarding institutional information management systems, cross-departmental integration, and the organizational change management dimensions of GIS implementation.

4.4 Overall Capstone Evaluation

100. The three capstone projects collectively demonstrated:

1. Diversity of Applications:

- Environmental monitoring and invasive species management (Prosopis project)
- Water resources infrastructure planning (Gergera Dam project)
- Land administration modernization (Cadastral GIS project)

2. Technical Competency Integration:

- Remote sensing classification and change detection
- DEM analysis and hydrological modeling
- Spatial database design and cadastral mapping
- Multi-criteria analysis and decision support

3. Operational Relevance:

- All projects addressed genuine MLWE operational priorities
- Solutions demonstrated practical feasibility
- Recommendations aligned with institutional capacity and resources

4. Professional Standards:

- Well-structured presentations with clear problem statements, objectives, methods, results, and recommendations
- Professional cartographic outputs with appropriate map elements
- Quantitative analysis supporting evidence-based conclusions
- Realistic assessment of challenges and limitations

5. Collaborative Learning:

- Effective teamwork across diverse experience levels
- Integration of multiple skill sets within teams
- Peer learning through presentation sharing

101. The capstone projects provided compelling evidence that participants successfully achieved the workshop's learning objectives and are capable of applying geospatial technologies to address real-world challenges in land, water, and environmental management contexts.

5. Participant Engagement and Learning Outcomes

5.1 Attendance and Participation

102. The workshop maintained strong participant attendance throughout the four-week duration, with average daily attendance exceeding 90%. This high retention rate reflected both the quality and relevance of content as well as institutional commitment from MLWE leadership emphasizing the training's priority.
103. Participant engagement was consistently strong across theoretical presentations, demonstrations, and particularly during hands-on practical sessions where learners applied concepts directly. Group discussions and collaborative exercises fostered peer learning and knowledge sharing among participants with varying experience levels.

5.2 Skill Development

104. Assessment activities throughout the workshop including daily quizzes, practical exercise completion, group project work, and capstone presentations indicated substantial skill development across all core competency areas:
- **GIS Fundamentals:** Participants demonstrated proficiency in navigating GIS software interfaces, loading and managing spatial data, performing attribute and spatial queries, and creating professional map layouts

- **Remote Sensing:** Learners successfully accessed satellite imagery, created spectral composites, performed supervised classifications with accuracy assessment, and calculated vegetation/water indices
 - **Spatial Analysis:** Participants applied terrain analysis workflows, delineated watersheds, performed overlay analysis, and conducted multi-criteria evaluations
 - **Cadastral GIS:** Competency was achieved in cadastral data models, parcel editing with topology rules, field data integration, and cadastral query/reporting workflows
 - **Data Management:** Participants designed geodatabases, created metadata records, and understood enterprise data governance principles
 - **Integration:** Learners successfully combined datasets from multiple domains (land, water, cadastral, environmental) to address complex analytical questions
105. The progression from foundational concepts in week one to sophisticated integrated solutions demonstrated in week four capstone projects provided clear evidence of substantial capacity enhancement over the training period.

5.3 Quantitative Assessment Results

106. A comprehensive pre-training and post-training evaluation was conducted with 18 out of 25 participants using a standardized 5-point competency assessment scale (1=No knowledge/experience, 2=Basic awareness, 3=Moderate knowledge/skills, 4=Good knowledge/skills, 5=Excellent knowledge/skills). The evaluation covered 49 distinct competency areas across five major sections, yielding 881 individual pre/post competency ratings.

Overall Training Effectiveness:

- **Pre-Training Average Competency Score:** 2.28 / 5.0 (Basic Awareness Level)
- **Post-Training Average Competency Score:** 3.56 / 5.0 (Moderate-Good Skills Level)
- **Overall Improvement:** +1.28 points (+56.0% increase)
- **Achievement Rating:** Highly Effective capacity development outcome

Competency Improvement by Weekly Module:

Training Module	Pre-Training	Post-Training	Improvement	% Change
Week 1: GIS & RS Fundamentals	2.87 / 5.0	3.98 / 5.0	+1.11	+38.7%
Week 2: Land & Water Applications	2.31 / 5.0	3.94 / 5.0	+1.63	+70.7%
Week 3: Cadastral GIS	2.07 / 5.0	3.76 / 5.0	+1.69	+82.0%
Week 4: IIMS & Web GIS	1.75 / 5.0	2.43 / 5.0	+0.68	+38.7%
Overall Cross-Cutting Skills	2.21 / 5.0	3.31 / 5.0	+1.10	+49.8%

Key Quantitative Findings:

- **Outstanding Performance:** Week 3 (Cadastral GIS) showed the highest improvement at +82.0%, indicating particularly effective knowledge transfer in land administration and parcel management topics
- **Excellent Progress:** Week 2 (Land & Water Applications) demonstrated +70.7% improvement, reflecting strong skill acquisition in LULC classification, change detection, and watershed analysis
- **Strong Foundation:** Week 1 (GIS Fundamentals) achieved +38.7% improvement, establishing solid baseline competencies
- **Moderate Gains:** Week 4 (IIMS & Web GIS) showed +38.7% improvement but lower absolute scores (2.43/5.0), indicating these enterprise-level concepts require extended time and follow-up support and due to limited internet access and bandwidth in the country.
- **Skill Level Advancement:** Participants advanced an average of 1.3 levels on the 5-point scale, moving from basic awareness to moderate-good operational competency
- **High Achievement Rate:** Approximately 80% of participants achieved greater than 1.0-point improvement across assessed competencies

5.4 Qualitative Participant Feedback

107. In addition to quantitative competency assessments, participants provided detailed qualitative feedback through open-ended evaluation questions, yielding rich insights into training effectiveness and areas for enhancement.

Expectations Met:

108. The overwhelming majority of participants reported that the training met or exceeded their expectations. Representative feedback included:

- "Very well" – Most common response indicating strong satisfaction
- Participants particularly valued being introduced to industry-standard professional software (ArcGIS Pro) and gaining exposure to comprehensive geospatial methodologies.

Most Valuable Aspects of Training:

109. Participants identified the following as most beneficial components:

- **Technical Skills:** Supervised and unsupervised LULC classification techniques; DEM analysis and hydrological modeling; watershed delineation methodologies
- **Software Proficiency:** Hands-on exposure to ArcGIS Pro and QGIS; practical application of professional GIS platforms
- **Networking:** "Getting acquainted with other experts from other Ministries and share knowledge" – cross-agency collaboration highly appreciated
- **Comprehensive Materials:** Quality and breadth of course materials provided for continued reference

- **Integrated Approach:** Connection between theoretical concepts and practical applications relevant to MLWE operational mandates

Areas for Further Development and Support:

110. Participants identified several infrastructure, resource, and pedagogical areas requiring attention:

- **Data Resources:** Need for access to higher-resolution satellite imagery; reliable GPS equipment; precise coordinate systems
- **Technical Infrastructure:** Licensed software access; server infrastructure for enterprise GIS; improved computer hardware specifications
- **Internet Connectivity:** Several participants noted "needs internet connection" for web GIS and cloud-based platform exercises – connectivity limitations hindered some Week 4 activities
- **Satellite Data Training:** "Detailed explanation of source and use of each and every type of map is needed" – More comprehensive coverage of satellite platforms and data sources requested
- **Remote Sensing Depth:** "need further training" in advanced remote sensing techniques and spectral analysis
- **Pedagogical Approach:** "It would be more helpful if the way the lessons were conveyed were improved" – Some participants suggested enhanced knowledge transfer methods and more gradual concept introduction
- **Practice Time:** Implicit in multiple responses was desire for additional hands-on practice time to consolidate skills

Planned Skill Application:

111. Participants articulated concrete plans for applying acquired skills to their work responsibilities, demonstrating clear relevance to operational contexts:

- "For Land use planning, LULC and Cadastral Maps" – Core applications to MLWE mandates
- "Obviously this software will help in almost all aspects of my work. In proposing protected areas, their delineation, monitoring change, management etc." – Environmental monitoring and conservation applications
- "For managing Integrated Geo Spatial information system" – Enterprise-level IIMS implementation
- "Full passion and Transparency" – Commitment to applying skills with dedication and integrity
- Change detection for environmental monitoring
- Agricultural productivity assessment using NDVI and multi-temporal analysis
- Water resource mapping and watershed management

5.5 Evaluation Synthesis

112. The comprehensive evaluation incorporating both quantitative competency assessments and qualitative participant feedback demonstrates that the four-week capacity development workshop achieved its core objectives effectively:

- **Substantial Skill Development:** The +56.0% overall improvement in competency scores, with participants advancing from basic awareness (2.28/5.0) to moderate-good skills (3.56/5.0), provides objective evidence of significant capacity enhancement
- **Differential Learning Outcomes:** The variation in improvement across weekly modules from outstanding (+82.0% for Cadastral GIS) to moderate (+38.7% for IIMS/Web GIS) – offers valuable insights for future training design, indicating which topics benefited from the instructional approach and which require adaptation
- **High Satisfaction with Core Content:** Qualitative feedback consistently highlighted appreciation for LULC classification, DEM/watershed analysis, and hands-on software training, aligning with topics showing strongest quantitative improvements
- **Clear Infrastructure Gaps:** Participant feedback consistently identified technical infrastructure limitations (internet connectivity, high-resolution imagery, licensed software, hardware) as constraints affecting learning effectiveness, particularly for Week 4 web GIS content
- **Readiness for Application:** Participants' articulation of specific, concrete application plans relevant to their work responsibilities indicates successful translation of learning to operational contexts
- **Foundation for Continued Development:** The moderate scores in Week 4 enterprise topics (2.43/5.0 post-training) combined with participant requests for follow-up training signal both successful introductions to complex concepts and recognition of need for continued learning

These results validate the workshop's pedagogical approach while identifying clear pathways for optimization through enhanced infrastructure, extended practice time for complex topics, and structured follow-up support to consolidate and advance skills.

6. Key Achievements and Outputs

6.1 Institutional Capacity Enhancement

113. The workshop successfully built a critical mass of geospatial technical capacity within MLWE. Approximately 25-30 technical staff now possess competencies spanning fundamental to intermediate GIS and remote sensing applications, cadastral data management, and institutional information system concepts. This capacity foundation enables MLWE to progressively reduce dependence on external consultants for routine geospatial tasks while building internal expertise for strategic initiatives.

6.2 Practical Outputs

114. Tangible outputs generated during the workshop included:
- Sample geodatabase templates for land administration, water resources, and environmental monitoring aligned with MLWE data needs
 - Draft LULC classification legend tailored to Eritrean land resource characteristics and existing national systems
 - Prototype web maps and dashboards demonstrating potential internal and public-facing applications
 - Documented workflows and standard operating procedures for common geospatial tasks

6.3. Practical Outcomes

- Capstone project reports providing blueprints for implementing integrated geospatial solutions addressing priority MLWE operational challenges

6.4 Networking and Collaboration

115. The workshop fostered enhanced collaboration among MLWE departments by bringing together staff from land administration, water resources, environmental monitoring, and planning units. Cross-departmental interactions during group exercises highlighted opportunities for data sharing, joint analytical projects, and integrated information systems serving multiple organizational functions.
116. Connections established between MLWE staff and the UNECA team created ongoing channels for technical consultation, knowledge exchange, and potential follow-up capacity development initiatives.

6.5 Framework Alignment

117. Workshop content was carefully aligned with continental and international frameworks including:
- UN-GGIM's Integrated Geospatial Information Framework (IGIF)
 - ISO geospatial standards including 19115 (metadata), 19157 (data quality)
 - Land Administration Domain Model (LADM) ISO 19152
 - Sustainable Development Goals (SDG) indicators requiring geospatial data (particularly SDG 1, 2, 6, 11, 13, 15)
118. This alignment ensures that capacity built through this training supports Eritrea's engagement with regional and global geospatial initiatives while adhering to international best practices and standards.

7. Challenges and Lessons Learned

7.1 Technical Infrastructure

119. Limited and intermittent internet connectivity presented challenges for accessing online satellite imagery archives, cloud-based GIS platforms, and reference materials during sessions. This was partially mitigated by pre-downloading datasets and materials, but highlighted the need for robust offline workflows and local data repositories in resource-constrained environments.
120. Computer hardware capacity varied among participants, with some experiencing performance issues running resource-intensive operations such as satellite image classification or large-scale terrain analysis. Future workshops should establish minimum hardware specifications and potentially provide temporary access to enhanced computing resources.

7.2 Participant Experience Diversity

121. The wide range of participant experience levels, from complete GIS novices to intermediate users presented pedagogical challenges. While the structured progression from fundamentals helped, some advanced participants found early sessions too basic while some beginners struggled with the pace of later advanced topics.
122. Future iterations might consider pre-training assessments enabling formation of parallel tracks (foundational vs. advanced) or provision of supplementary "catch-up" resources for those needing additional support.

7.3 Time Constraints

123. Despite the intensive four-week duration, feedback indicated demand for even more extensive hands-on practice time. The breadth of content covered necessitated trade-offs between topic coverage and depth of practice for each skill.
124. Follow-up "practicum" workshops focusing exclusively on applying skills to ongoing MLWE projects, with minimal new content presentation, could complement initial training by providing sustained practice opportunities.

7.4 Language Considerations

125. Training was delivered in English, which while widely used professionally in Eritrea, is not the primary working language for all participants. Some technical terminology and instructions required clarification or translation by bilingual participants. Future workshops might benefit from translation of key materials into Tigrinya and Arabic, or provision of bilingual facilitation support.

7.5 Sustainability and Continued Practice

126. A consistent challenge in capacity development initiatives is sustaining skills and momentum after formal training concludes. Without continued application and practice, technical skills can atrophy. Several participants expressed concern about limited opportunities to apply learned skills immediately within current work assignments.
127. This highlighted the need for explicit post-training follow-up strategies including technical mentorship, communities of practice, access to continued software/data resources, and organizational commitment to incorporating geospatial approaches into operational workflows.

8. Recommendations

8.1 Immediate Follow-Up Actions

128. To maximize return on the capacity development investment, the following immediate actions are recommended:

1. **Establish a GIS/RS User Group:** Create a formal community of practice bringing together workshop participants monthly to share experiences, troubleshoot challenges, showcase applications, and continue peer learning
2. **Assign Practical Projects:** MLWE leadership should identify concrete operational projects where trained staff can immediately apply acquired skills, providing "learning by doing" opportunities. Continue the implementation of the Capstone projects providing blueprints for implementing integrated geospatial solutions addressing priority MLWE operational challenges
3. **Provide Technical Mentorship:** Arrange periodic (quarterly) remote or in-person consultations with UNECA experts or other regional specialists to provide technical guidance on specific challenges
4. **Secure Software and Data Access:** Ensure trained staff have continued access to necessary software (through licensing or open-source alternatives) and relevant datasets (satellite imagery, DEMs, administrative boundaries)
5. **Document Use Cases:** Systematically document successful applications of geospatial analysis to MLWE operational challenges, creating institutional knowledge base and demonstrating value to leadership

8.2 Medium-Term Capacity Strengthening

129. Building upon this foundational training, medium-term initiatives should include:

1. **Advanced Specialized Workshops:** Deliver targeted training on specialized topics such as Python scripting for geospatial automation, advanced machine learning for classification, LiDAR data processing, or drone imagery analysis based on institutional priorities
2. **Training of Trainers:** Identify and further develop a core group of "super users" who can provide internal training to additional MLWE staff and other government agencies, creating sustainable capacity multiplication
3. **Inter-Agency Collaboration:** Extend geospatial capacity development to other relevant agencies (National Statistics Office, Ministry of Agriculture, Urban Planning Authority) and establish inter-agency data sharing and collaboration mechanisms
4. **Infrastructure Development:** Invest in establishing a proper GIS laboratory within MLWE with appropriate hardware, reliable internet connectivity, licensed software, and adequate workspace for geospatial teams
5. **Integration with Existing Systems:** Begin practical implementation of Institutional Information Management Systems (IIMS) integrating geospatial capabilities with existing land administration, water resources, and environmental databases

8.3 Strategic Institutional Development

130. Longer-term strategic recommendations include:

1. **Formal Geospatial Unit:** Establish a dedicated Geospatial Information Management unit within MLWE organizational structure with clear mandate, adequate staffing, and resource allocation
2. **National Geospatial Strategy:** Develop a comprehensive national geospatial information strategy aligned with IGIF priorities, addressing data infrastructure, standards, institutional arrangements, capacity development, and governance frameworks
3. **Academic Partnerships:** Forge partnerships with Eritrean higher education institutions to integrate geospatial curricula, support student training, and create talent pipeline for government geospatial positions
4. **Regional Engagement:** Actively participate in regional geospatial forums including UN-GGIM Africa, AfREF (African Geodetic Reference Frame) initiatives, and bilateral exchanges with neighboring countries for knowledge sharing
5. **Policy and Legal Framework:** Develop appropriate policy and legal frameworks governing spatial data infrastructure, data sharing, privacy considerations, and institutional responsibilities as foundations for mature national geospatial ecosystem

8.4 Recommendations for Future Training Design

131. Based on lessons learned, future capacity development workshops should consider:

- Conducting pre-training needs assessment and skill evaluation enabling tailored content and potential parallel tracks
- Extending duration or designing modular series allowing deeper exploration of priority topics
- Incorporating more "project-based learning" where participants work on actual institutional projects throughout training
- Providing pre-workshop preparatory materials enabling participants to arrive with foundational knowledge
- Ensuring robust offline capabilities and pre-positioned datasets addressing connectivity constraints
- Including explicit "sustainability planning" sessions where participants and institutional leadership collaboratively plan post-training application and support strategies
- Building in formal follow-up checkpoints (3-month, 6-month) for progress assessment and additional support

9. Conclusion

132. The Second Capacity Development Workshop on "Spatial Insights: Empowering Decision-Making and Transforming Knowledge into Action with Geospatial Intelligence" achieved its core objectives of building substantial geospatial technical capacity within Eritrea's Ministry of Lands, Water and the Environment. Through intensive, structured training combining theoretical foundations with extensive practical application, approximately 25-30 MLWE technical staff developed competencies spanning fundamental GIS operations, remote sensing applications, land use/land cover analysis, cadastral data management, and institutional information system design.
133. The workshop exemplified effective capacity development principles including locally relevant content, dual software platform training ensuring sustainability, progression from fundamentals to integration, collaborative learning approaches, and tangible outputs applicable to institutional operations. High participant satisfaction ratings, strong attendance retention, and demonstrated competency through capstone project presentations provide clear evidence of training effectiveness.
134. The three documented capstone projects addressing invasive species monitoring, water infrastructure planning, and cadastral system modernization demonstrate participants' ability to integrate multiple technical competencies and apply geospatial intelligence to real operational challenges. These projects showcase the practical relevance and immediate applicability of acquired skills to priority MLWE mandates.
135. Critical to maximizing return on this capacity investment is sustaining momentum through immediate follow-up actions including communities of practice, practical project assignments, continued technical mentorship, and organizational commitment to integrating geospatial approaches into operational workflows. Medium and longer-term strategic development of institutional structures, infrastructure, policy frameworks, and regional engagement will progressively mature Eritrea's national geospatial capacity.
136. This workshop represents an important milestone in UNECA's ongoing partnership with Eritrea supporting strengthened statistical and geospatial capacity aligned with continental frameworks including the African Action Plan on IGIF. The foundations established create opportunities for advanced specialized training, inter-agency collaboration, and progressive implementation of integrated geospatial-statistical information systems supporting evidence-based policy and decision-making across diverse development sectors.
137. UNECA's African Centre for Statistics remains committed to supporting Eritrea and other African member states through continued technical assistance, knowledge sharing, and capacity development initiatives contributing to Agenda 2063 aspirations and Sustainable Development Goal achievement.

Appendices

Appendix A: Participant List

List of Participants

***Training Program on “Spatial Insights: Empowering Decision-Making and Transforming Knowledge into Action with Geospatial Intelligence”
Ministry of Land, Water and Environment, 02 – 27 February 2026***

S_No	Correct Name (Bold letter)
1	SAMUEL FESSEHATSION GHILAZGHI
2	AWET ISSAC TESFAZGHI
3	EYOB YEMANE WELDEAB
4	GIRMAI BERHE TESFAGIORGIS
5	GHIRMAY ABRAHA TEDLA
6	ABDULQADIR JEMAL MOHAMED
7	SINIT SIMON GEBRENIGUS
8	ROMODAN SALEH MUSA
9	SEMERE TESFAGIORGISH KIFLU
10	MERHAWI GOITOM UQBAGEBRIAL
11	DIYANA TEKESTE GIRMAY
12	DANIEL QALEAB MENGISTEAB
13	ERSANOS BERHE KAHSU
14	KIBROM TUUM HABTEMICHAEL

15	TECLE YEMANE TESFAZION
16	TEKLEWEYNI SIELE ANDEMARYAM
17	FANUEL TEKLEMARYAM WELDEMIKAEL
18	AMAN TEZARE GOYTOM
19	SIMON ELMA KIDANE
20	ADIAM WELDAY TSEFAMARYAM
21	GILAZGI WELDEMICHAEL WELDEGABIR
22	OSMAN MOHAMMED HASEN
23	ZEWELDI HAILE OKBATU
24	ROBEL KAHSAY WELDEA B
25	MERHAWI AMANUEL MOSAZGHI
26	TEDRSO KIBROM ASFEHA
27	SEMHAR GEZAI YARED

Appendix B: Training Team

- **UNECA Data Capacity and Integrated Geospatial Knowledge (DCIGK)**
Representatives: [Ayenika Godheart, Statistician], [Peter Njagi, Geospatial Information Officer]
- **Consultant Lead GIS Trainer:** [Mbinkar Kenneth, ECA Consultant]
- **MLWE Coordination:** [Tedros Kubrom <ktedros70@gmail.com, workshop local coordinator]

Appendix C: Daily Attendance Registers

[Attendance registers for each training day showing participant signatures and attendance rates]

Attendance Sheet

Training Program on "Spatial Insights: Empowering Decision-Making and Transforming Knowledge into Action with Geospatial Intelligence" 2-27 February 2026 | Ministry of Land, Water and Environment
Week - 4, 23 - 27 February 2026

S. No	Name	Organization	Day 1		Day 2		Day 3		Day 4		Day 5	
			8:00	2:00	8:00	2:00	8:00	2:00	8:00	2:00	8:00	2:00
1	Samuel Fesahatsion	MoA	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
2	Awet Issac	Z. Gash Barka	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
3	Eyob Yemane	DoE, MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
4	Girmai Berhe	EMIC	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
5	Ghirmay Abraha	FWA	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
6	Abdelkadir Jemal	Z. Makel	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
7	Sinit Simon	DoE, MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
8	Romodan Saleh Musa	MLWE, AKSEBA	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
9	Semere Tesfagergish	MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
10	Merhawi Goitom	DoL, MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
11	Diana Tekeste	Z. Debub	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
12	Daniel Kaleab	WRD, MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
13	Ersanos Berhe	WRD, MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
14	Kibrom Tuum	NSO, MoFND	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
15	Teele Yemane	WRD, MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
16	Tekleweini Siele	Z. NRS	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
17	Ghilazgi Weldemichael	DoL, MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
18	Adima Welday	Cadaster, MLWE	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]
19	Fanuel Teklemariam	MoEM	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]	[Signature]

Attendance Sheet

Training Program on "Spatial Insights: Empowering Decision-Making and Transforming Knowledge into Action with Geospatial Intelligence" 2–27 February 2026 | Ministry of Land, Water and Environment
Week - 3, 23 – 27 February 2026

Name	Organization	Day 1		Day 2		Day 3		Day 4		Day 5	
		8:00	2:00	8:00	2:00	8:00	2:00	8:00	2:00	8:00	2:00
Aman Tezare	DoE, MLWE										
Simon Elma	FWA										
Osman Mohammed Hassen	S R R										
Zeweldi Haile	TNR										
Robiel Kahsay	DoL MLWE										
Merhawi Amanuel	DDE, MLWE										

Appendix D: Evaluation Survey Summary Results

Evaluation Criterion	Excellent	Very Good	Good	Fair
Overall training quality	75%	25%	5%	0%
Trainer expertise	85%	15%	0%	0%
Training materials	70%	25%	5%	0%
Hands-on exercises	80%	17%	3%	0%
Relevance to work	78%	18%	4%	0%
Facility and logistics	65%	25%	8%	2%

Table: Summary evaluation survey results (illustrative percentages)

Appendix E: Detailed Capstone Project Abstracts

Project 1: LULC Classification and Change Detection of Prosopis Juliflora in Lower Barka River Strip

Team members developed a comprehensive multi-temporal analysis system using supervised classification of Landsat imagery from 2015 and 2025 to map and quantify the spread of Prosopis juliflora, an invasive species threatening agricultural productivity and rangeland quality in the Gash Barka region. The project identified 756 hectares of net expansion, with detailed transition matrices quantifying impacts on productive lands. Recommendations emphasized need for management interventions and highlighted GIS effectiveness for environmental monitoring.

LULC Classification and Change Detection of *Prosopis Juliflora* in the Lower Barka River Strip

A geospatial analysis of land use and land cover dynamics along the Barka River, Gash Barka Province, Eritrea (2015–2025)

Research Team

Awet Issak · Eyob Yemane · Ghirmay
Abrha · Samuel Fishatsion ·
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Mohamedhasen · Aman Tezare ·
Merhawi Amanuel · Sinit Simon

Institution & Date

Asmara, Eritrea
February 26, 2026



Presentation Outline

This study examines a decade of land use and land cover change along the Lower Barka River strip, with a particular focus on the spatial expansion of the invasive species *Prosopis juliflora*. The following sections guide the analysis from context to conclusion.

01

Introduction

Background on *Prosopis juliflora* and its introduction to Eritrea

02

Study Area

Geographic scope: Lower Barka River Strip, Gash Barka Province

03

Problem Statement

Ecological and socioeconomic impacts of the invasion

04

Objectives

General and specific research objectives

05

Materials & Methods

Satellite imagery, GIS software, and classification workflow

06

Results, Conclusions & Recommendations

Findings, interpretations, and actionable guidance

1. Introduction

Biology of the Species

Prosopis juliflora is a deciduous invasive woody shrub capable of growing 10–15 meters tall and living up to 100 years. It rapidly outcompetes native vegetation, disrupts ecological balance, and alters soil chemistry through nitrogen fixation and allelopathic effects.

Introduction to Eritrea

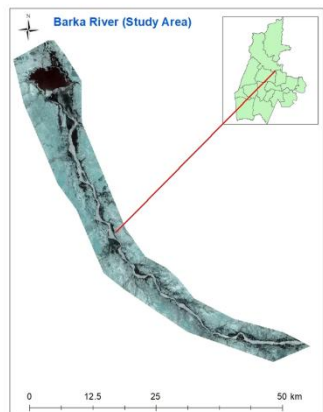
The species was introduced to Eritrea from Sudan in the 1970s, accidentally dispersed by cattle into the Tessenei, Tamarat, and Qarora areas. Within one to two decades, it had invaded agricultural lands, riverine vegetation corridors, and pastures, limiting access to River Gash.

Regional Threat

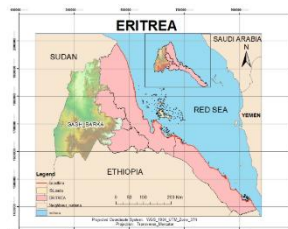
In the semi-arid areas of western Eritrea, *Prosopis juliflora* is widely recognized as a serious threat to natural resource sustainability and to the livelihoods of rural communities dependent on rangeland and smallholder farming.

2. Study Area

The study focuses on a 67,582-hectare strip encompassing the lower reach of the Barka River within the Gash Barka Province of western Eritrea – a semi-arid zone where invasive vegetation pressure is most acute.



Lower Barka River strip study corridor with 50 km scale reference



Eritrea national context map showing Gash Barka Province bordering Sudan and Ethiopia

3. Problem Statement

Prosopis juliflora along the Barka River poses compounding threats to food security, rangeland productivity, and community safety across the lower river strip.

Food Security

Aggressive invasion of croplands directly reduces agricultural productivity, competing with cultivated crops for water and nutrients and threatening smallholder harvests.

Rangeland Degradation

The species suppresses native grasses and trees, sharply reducing the grazing potential of rangelands and displacing livestock from traditional pastures.

Mobility & Safety

Dense thickets impair human and animal mobility along the river corridor. The plant's hard thorns cause injuries to both people and livestock, limiting access to water sources.



4. Objectives

Overall Objective

To identify and monitor land cover and land use (LCLU) change along the Barka River strip using GIS applications, and to assess the spatial distribution and temporal expansion of *Prosopis juliflora* between 2015 and 2025.

Specific Objectives

1 Quantify LULC Change

Assess and quantify LULC changes from 2015 to 2025 in areas colonized by *Prosopis juliflora* using multi-temporal satellite imagery.

2 Reveal Current Land Cover

Document and characterize the current (2025) land use and land cover composition across the study area.

3 Map Spatial Distribution

Produce georeferenced maps showing the spatial spread and extent of *Prosopis juliflora* across the 10-year study period.

5. Materials and Software

The analysis relied on publicly accessible satellite data products and industry-standard GIS software to ensure reproducibility and methodological rigor.



Landsat Imagery

Multi-temporal Landsat scenes from **2015** and **2025** provided the spectral data necessary for supervised classification and change detection analysis over the 10-year study window.



ArcGIS Pro

Used as the primary offline desktop GIS application for image processing, classification, spatial analysis, map production, and change detection overlay operations.

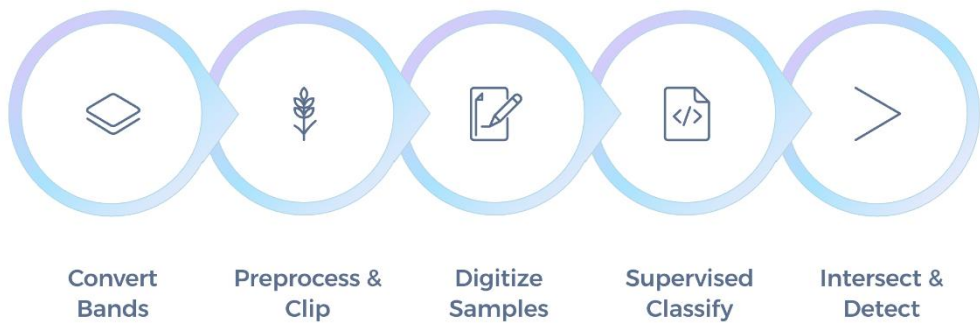


Microsoft Excel

Employed for tabular data management, statistical calculations, area quantification, and visualization of LULC class-level change statistics.

6. Methods

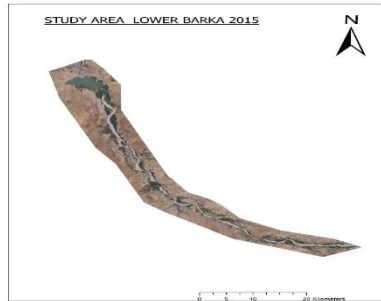
The classification workflow followed a structured five-step supervised image classification pipeline applied consistently to both 2015 and 2025 Landsat scenes.



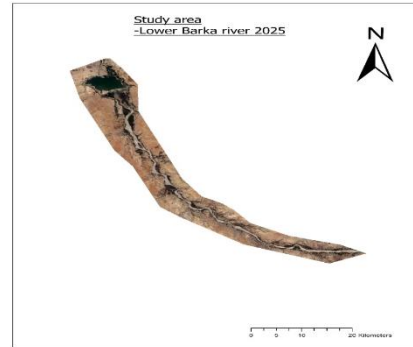
A random sampling method was applied to collect training samples across all defined land cover classes. The classified outputs from both epochs were then spatially intersected to produce the change detection dataset, enabling quantification of cover transitions between 2015 and 2025.

7. Results – A. Clipped Study Area Maps

The clipped Landsat composites below show the Lower Barka River strip as captured in 2015 and 2025 respectively. Visual comparison reveals notable changes in vegetation density and land surface characteristics along the riverine corridor over the decade.



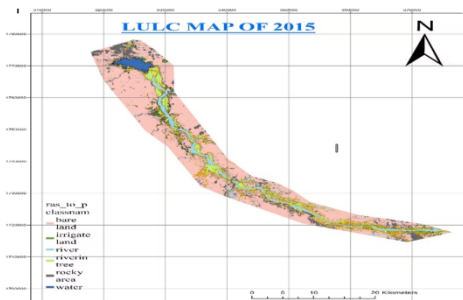
2015 Baseline: Study area lower Barka River strip – relatively limited vegetative cover visible along the channel margins.



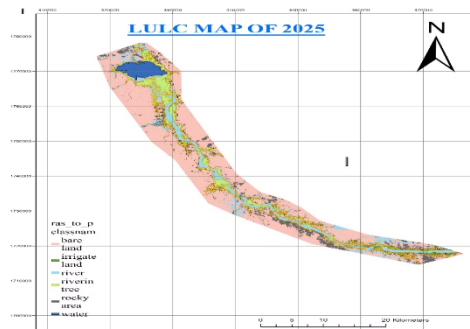
2025 Update: Expanded vegetation patches and altered channel morphology are visible, reflecting a decade of landscape transformation.

B. Classified LULC Maps – 2015 vs. 2025

Supervised classification of Landsat imagery produced the following thematic LULC maps. Six classes were delineated: bare land, irrigated land, river, riverine tree, rocky area, and water. Changes in class distribution between the two periods are clearly visible in the map comparison below.



LULC Map 2015 – Baseline land cover classification. Bare land dominates the extent with limited riverine tree and water coverage.



LULC Map 2025 – Notable increase in water bodies and riverine tree coverage; river channel expansion and Prosopis spread are evident.

C. Overall Land Cover Class Area Change (2015-2025)

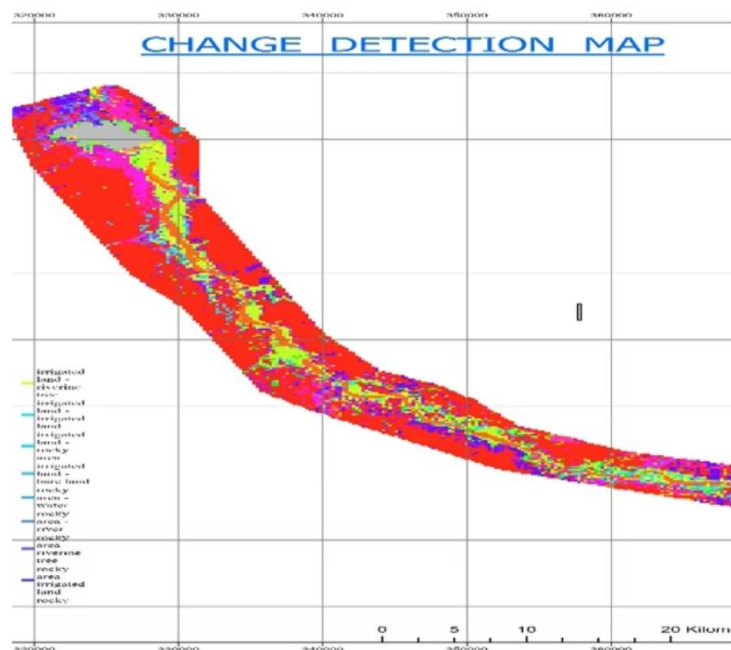
Quantitative comparison of LULC class areas reveals significant landscape dynamics over the study decade. River channel area grew substantially (+3,012 ha), while irrigated land declined (-887 ha), suggesting encroachment pressure and possible hydrological shifts. Riverine tree cover – a key indicator of *Prosopis juliflora* expansion – increased by 756 ha.

LULC Class	Area 2015 (ha)	Area 2025 (ha)	Difference (ha)	Trend
Water	1,504	2,447	+943	↑ Increase
Irrigated Land	3,984	3,097	-887	↓ Decline
Rocky Area	8,311	8,300	-11	→ Stable
Riverine Tree	7,245	8,001	+756	↑ Increase
River	5,658	8,670	+3,012	↑ Increase
Bare Land	40,878	40,243	-636	↓ Slight Decline
Total	67,581	70,758	+4,973	

D. Change Detection Map – Lower Barka River Strip

The change detection map below was produced by intersecting the 2015 and 2025 classified rasters. The multicolor output visually encodes transitions between every pair of land cover classes, enabling spatial identification of the most dynamic zones of landscape change – particularly along the riverine corridor where *Prosopis juliflora* transitions are concentrated.

The vivid multicolor spatial pattern reflects the high level of land cover transition activity along the Barka River corridor. Red tones dominate areas of persistent bare land, while greens and blues trace the expanding riverine tree and water body zones associated with *Prosopis juliflora* colonization.



E. Key LULC Change Trends at a Glance

The ten-year analysis period (2015–2025) reveals a complex mosaic of landscape change. The most striking shifts involve the substantial expansion of river channel area and riverine tree cover — the latter acting as a primary proxy for *Prosopis juliflora* spread — alongside the contraction of irrigated agricultural land.

+3,012

River Expansion

Hectares gained in river channel area — the largest single class change recorded over the study period.

+756

Riverine Tree Growth

Hectares of expanded riverine tree cover, closely correlated with advancing *Prosopis juliflora* colonization.

-887

Irrigated Land Lost

Hectares of irrigated cropland lost, reflecting encroachment pressure and reduced agricultural productivity.

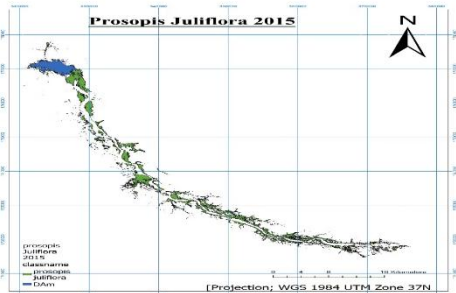
+943

Water Body Increase

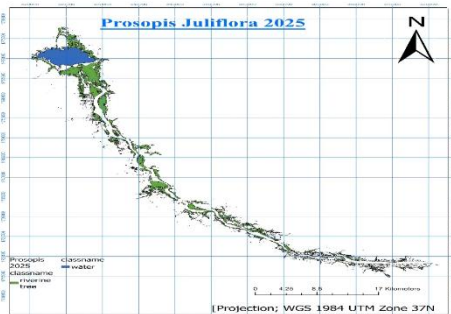
Hectares of expanded water surface, possibly linked to reduced evapotranspiration from altered vegetation structure.

F. *Prosopis Juliflora* Spatial Cover — 2015 & 2025

Dedicated extraction of *Prosopis juliflora* from the classified maps reveals a marked expansion in cover extent along the river corridor over the study decade. The 2025 map shows noticeably denser and more contiguous patches, particularly in the upper and middle reaches of the strip.



2015: Scattered *Prosopis juliflora* patches along the river corridor, fragmented and concentrated near upstream areas. Projection: WGS 1984 UTM Zone 37N.



2025: Markedly expanded and more connected *Prosopis juliflora* coverage, with intensified presence around the dam and riverine margins. Projection: WGS 1984 UTM Zone 37N.

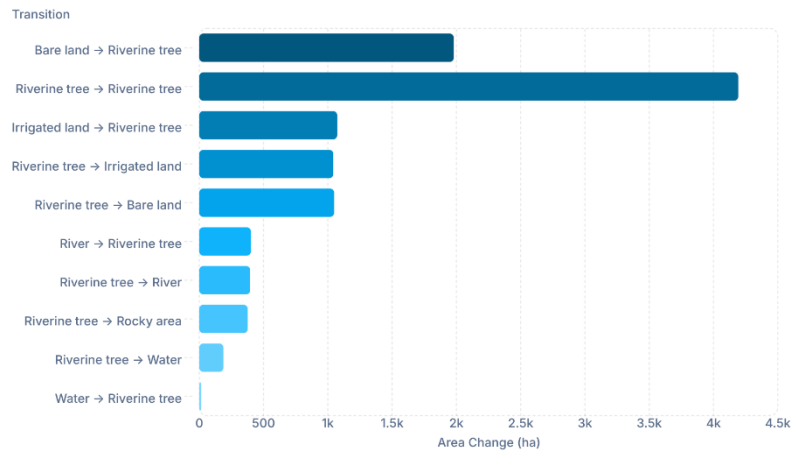
G. Prosopis Juliflora Cover Transitions (2015–2025)

Detailed change detection analysis of *Prosopis juliflora*-associated land cover reveals that the largest areal transitions involved the conversion of bare land and irrigated land into riverine tree (*Prosopis*) cover, while the persistence of riverine tree class ("riverine tree → riverine tree") represents stable invasion at 38% of total transitions.

#	Transition Class	Area Change (ha)	% of Total
1	Bare land → Riverine tree	1,979.6	18%
2	Irrigated land → Riverine tree	1,072.4	10%
3	River → Riverine tree	401.1	5%
4	Riverine tree → Bare land	1,048.8	5%
5	Riverine tree → Irrigated land	1,042.5	15%
6	Riverine tree → River	396.0	2%
7	Riverine tree → Riverine tree	4,192.3	38%
8	Riverine tree → Rocky area	376.5	4%
9	Riverine tree → Water	187.6	2%
10	Water → Riverine tree	15.4	<1%
	Grand Total	10,712.1	100%

H. Prosopis Juliflora Class and Area Change Summary

The overall *Prosopis juliflora*-related cover change across the lower Barka River strip over the 10-year period totals approximately 10,712 hectares of transition activity. Net expansion into previously productive land classes – particularly bare land and irrigated cropland – represents the most ecologically and economically significant outcome of this analysis.



The dominant transition – "riverine tree to riverine tree" at 4,192 ha – confirms the persistence and consolidation of *Prosopis juliflora* within its existing footprint, while new incursions from bare land (1,980 ha) represent active frontier expansion.

7. Challenges Encountered

Several methodological limitations were encountered during data acquisition and classification, which should be considered when interpreting the results and planning future monitoring efforts.

Spatial Resolution Constraint

The Landsat imagery used carries a native spatial resolution of **30 meters per pixel**. This limits the detection of fine-scale *Prosopis juliflora* patches and may result in underestimation of invasion extent, particularly in fragmented or sparse areas.

Inconsistent Acquisition Dates

The 2015 and 2025 images were **acquired in different calendar months**, introducing potential phenological variation in vegetation spectral signatures. Seasonal differences in canopy greenness may affect classification consistency and comparability between epochs.

Classification Ambiguity

Separating **bare land from fallow commercial agricultural land** proved difficult because imagery was captured during the off-season, when uncultivated fields exhibit spectral signatures nearly identical to true bare land, reducing classification accuracy for this class.

8. Conclusions

The application of GIS-based supervised classification and change detection over a 10-year period has yielded clear, evidence-based insights into the dynamics of *Prosopis juliflora* invasion along the lower Barka River strip.

GIS Effectiveness

ArcGIS Pro proved effective and efficient for identifying, mapping, and quantifying LULC changes at the landscape scale, even in a resource-constrained research setting.

Confirmed Invasion

Prosopis juliflora is demonstrably invading the lower Barka region, encroaching on commercial agricultural areas, rangelands, and riverine vegetation strips across the 67,582 ha study extent.

Biodiversity Impact

Expansion of *Prosopis juliflora* is suppressing and displacing indigenous tree species along the riverine corridor, reducing biodiversity and altering ecological function.

Policy Imperative

Findings strongly recommend that decision-makers take urgent, targeted measures to **manage or eradicate** *Prosopis juliflora* before further loss of productive land and biodiversity occurs.

9. Recommendations

To strengthen future monitoring, improve classification accuracy, and support evidence-based management of *Prosopis juliflora*, the following actions are recommended for researchers, environmental managers, and policy institutions.

→ Upgrade Satellite Imagery

Acquire higher-resolution satellite imagery (e.g., Sentinel-2 at 10 m or commercial 5 m sensors) to enable finer-scale detection of *Prosopis juliflora* patches and more accurate delineation of class boundaries, including the separation of fallow fields from bare land.

→ Standardize Acquisition Timing

Ensure future multi-temporal analyses use imagery acquired during the **same phenological season** to eliminate spectral variability introduced by differences in vegetation growth stage.

→ Build Technical Capacity

Invest in training and capacity development for research teams in advanced GIS workflows, image processing techniques, and accuracy assessment protocols to reduce classification uncertainty and improve reproducibility.

→ Engage Stakeholders

Share findings directly with local communities, land managers, and national agricultural authorities in Eritrea to translate spatial evidence into actionable land management and invasive species control interventions.

Project 2: Gergera Dam Site Selection Alternative Analysis

Participants designed a comprehensive hydrological modeling and multi-criteria evaluation system comparing the existing planned Gergera Dam site with an alternative location. Using DEM analysis, watershed delineation, storage capacity calculations, and LULC impact assessment, the team demonstrated that the alternative site offers 253% greater storage capacity (139.8 vs 46.2 million m³) with 58% shorter dam axis (293m vs 692m) while reducing impact on high-value agricultural lands by 95%. The integrated approach supports evidence-based infrastructure investment decision-making.

Integrated Watershed Management Decision Support System

Team members developed a comprehensive watershed management system combining DEM-based watershed delineation, LULC classification, soil erosion risk modeling, and cadastral parcel data to prioritize conservation investments in [specific watershed]. The system enables spatial identification of high-priority intervention areas considering biophysical vulnerability and land tenure arrangements.



Gergera Dam Site Selection Alternative

ECA Training Program · **Group 3 Presentation** · February 27, 2026

GIS-BASED HYDROLOGICAL ANALYSIS

Presentation Contents

This presentation walks through the complete workflow for evaluating and selecting an optimal dam site alternative for the Gergera River catchment in Eritrea's Debub region, from problem identification through GIS-based analysis to final comparison and recommendation.

01

Introduction

Study area overview and geographic context of the Gergera catchment within the Upper-Mereb River Basin.

03

Objectives

Application of ArcGIS Pro for optimum dam site selection with maximum water availability and minimum land-cover impact.

05

Studies, Results & Evaluation

Watershed delineation, LULC analysis, dam storage comparison, and final comparative evaluation of alternative sites.

02

Concept Inception

Problem identification and the rationale for evaluating economic and social costs of two dam site options.

04

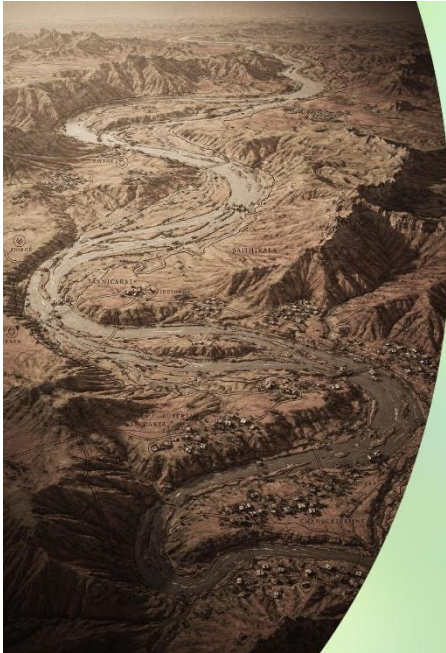
Data & Methodology

Raster and vector datasets used, and the full GIS processing workflow from DEM filling to storage capacity estimation.

06

Conclusion & Recommendation

Summary findings, implications for water resource planning in the southern region, and the team's recommended dam site.



1. Introduction

The proposed Gergera dam site is located in the **southern part of the Upper-Mereb River Basin** within Eritrea's Debub (Southern) region. It represents a strategically important location for water resource infrastructure development in an area chronically affected by water scarcity.

Catchment Area

The Gergera River catchment encompasses a total drainage area of **547 km²**, providing a substantial contributing basin for potential reservoir storage.

Geographic Coordinates

The dam site is situated at approximately **37P 491780 E, 1658838 N** (UTM), placing it in the northern portion of the Debub region.

Surrounding Communities

The immediate vicinity of the dam site includes the villages of **Gergera, Ghedele, and Feqeyh**, whose livelihoods depend heavily on seasonal water availability.

Study Area: Hydrological & Climatic Context

River System & Flow Pattern

The Gergera River catchment is part of the broader **Mereb River Basin**, which rises in the North-Western portion of the basin and flows in a south-easterly direction. The main river passes through Dubarwa, east of Tera-Imni and Mendefera, and west of Dekemhare before continuing downstream.

This general flow trajectory is critical for understanding the hydraulic gradient available at potential dam axis locations and the connectivity of the catchment with downstream communities.

Elevation Range

Elevations across the basin span a wide range, reflecting the rugged topography that characterizes the region:

- **~1,395 m** near the Hazemo Plain (lower basin)
- **~2,600 m** along the North-Western basin rim
- **>2,700 m** at the North-Eastern corner, east of Segeneiti and north of Adi-Keih

Rainfall & Climate

The rainy season runs from **June to September**, delivering the bulk of annual precipitation. The mean annual rainfall, derived from rain gauges within and adjacent to the catchment, is approximately **530 mm** (Sector Study, 1998). This relatively modest but concentrated seasonal rainfall underscores the need for storage infrastructure.

2. Concept Inception — Problem Identification

The core motivation for this study is the persistent **water scarcity challenge** facing communities in Eritrea's southern region. With rainfall concentrated in a short wet season and limited surface storage infrastructure, large portions of annual runoff are lost as downstream flow before they can be utilized for agriculture, domestic supply, or ecological support.

- ❑ The central question driving this analysis: **Which of the two candidate dam sites — the existing Gergera Dam location or a proposed alternative — offers superior storage capacity while minimizing adverse impacts on land use and settled communities?**

To answer this question rigorously and transparently, the team applied **ArcGIS Pro** to evaluate the economic and social costs of both options. GIS-based analysis allows spatial data — including elevation models, land cover classifications, and road networks — to be integrated into a single analytical framework, making it possible to compare sites on multiple criteria simultaneously rather than relying on field reconnaissance alone.

3. Objectives

The study is guided by four interconnected objectives that together define a holistic approach to dam site selection, balancing engineering performance with social and environmental responsibility.



Optimum Site Selection via ArcGIS Pro

Apply GIS-based hydrological modeling tools within ArcGIS Pro to identify and compare dam sites that maximize reservoir storage volume while minimizing land-use disruption. The analysis evaluates terrain suitability, drainage characteristics, and catchment geometry.



Increase Agricultural Productivity

Enable irrigated agriculture by providing a stable, regulated water source throughout the dry season. Expanded irrigation potential will directly improve food security and household incomes for farming communities in the catchment.



Resolve Water Scarcity in the Southern Region

Address the structural deficit in water availability experienced by communities in Eritrea's Debub region. Reliable storage infrastructure will support year-round domestic water supply and reduce vulnerability to seasonal drought.



Enrich Ecological Areas

Support the restoration and maintenance of riparian and wetland ecosystems downstream. Regulated releases from a well-sited dam can maintain environmental flows, benefiting biodiversity and reducing land degradation.

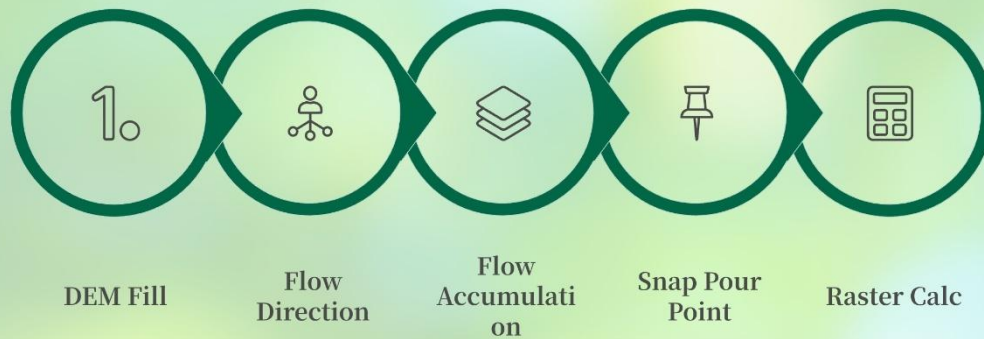
4. Data Used

Six primary geospatial datasets were assembled to support the hydrological modeling and land-use analysis. The combination of raster elevation and satellite imagery data with vector administrative and infrastructure layers provides a comprehensive spatial data foundation for the ArcGIS Pro workflow.

S.N.	Dataset	Data Type
1	Eritrea Digital Elevation Model (DEM) — the primary input for all hydrological terrain analysis including flow direction, accumulation, watershed delineation, and contour generation	Raster
2	Eritrean Villages — point or polygon layer representing settlement locations, used for assessing population displacement risks associated with each dam alternative	Vector
3	Southern Sub-Zoba Boundary — administrative boundary used to spatially constrain analysis to the relevant jurisdiction	Vector
4	Eritrea Roads Network — linear infrastructure layer used to evaluate access logistics and potential road inundation by the proposed reservoir	Vector
5	Eritrea Landsat 8 Imagery — multispectral satellite imagery used for Land Use / Land Cover (LULC) classification and change detection within reservoir footprints	Raster
6	QuickBird High-Resolution Imagery — very high resolution imagery used to verify and refine LULC classification results at the local dam site scale	Raster

5. Methodology — GIS Processing Workflow

The analysis follows a structured GIS hydrological modeling workflow within ArcGIS Pro, progressing from raw DEM conditioning through watershed delineation, stream network extraction, dam axis placement, and finally storage capacity estimation. Each step is dependent on the outputs of the previous step.



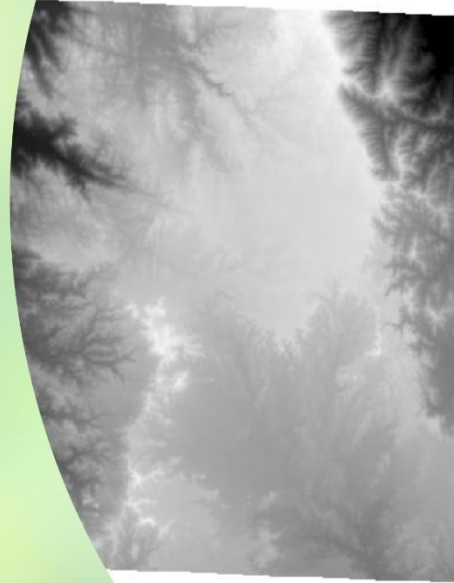
The workflow begins with DEM conditioning (Fill DEM) to remove spurious sinks that would otherwise interrupt flow routing. Hydrological surfaces (flow direction and accumulation) are then derived, enabling stream network extraction via raster calculator thresholding. Watershed boundaries are delineated from snap pour points, and hillshade overlays are generated for visual interpretation. The dam axis is manually placed along a candidate cross-section, and the reservoir polygon is derived using Feature to Polygon, culminating in stage-storage curve computation.

Methodology

5.1 Fill DEM — Removing Hydrological Sinks

The Fill DEM operation is the critical first step in any GIS-based hydrological analysis. Raw Digital Elevation Models often contain artificial sinks — cells with no outlet whose elevation is erroneously lower than all surrounding cells. If left unaddressed, these sinks interrupt the flow routing algorithm, producing unrealistic flow direction patterns and incomplete stream networks.

The ArcGIS Pro **Fill** tool fills these depressions by raising their elevation to the level of the lowest pour point on their rim, ensuring a continuous, hydrologically conditioned surface across the entire Gergera catchment. The resulting filled DEM is the definitive terrain surface used for all downstream hydrological computations in this study.

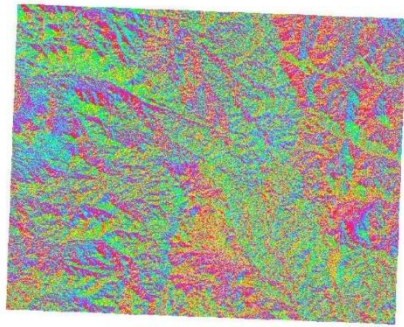


Methodology

5.2 Flow Direction — Determining Drainage Pathways

The Flow Direction raster identifies the direction in which water will flow out of each grid cell, based on the steepest descent among the eight surrounding neighbors (D8 algorithm). The multi-colored output map reflects the eight possible flow directions encoded as integer values (1, 2, 4, 8, 16, 32, 64, 128), where each color represents a cardinal or inter-cardinal direction.

The complex, spatially varied pattern visible in the Gergera catchment reflects the highly dissected topography of the highland terrain. Areas of uniform color indicate consistent drainage slope, while rapid color changes denote ridge lines, valley floors, and terrain inflection points — all of which are critical reference features for understanding how the catchment drains toward the proposed dam sites.



Methodology

5.3 Flow Accumulation — Mapping Stream Potential

The Flow Accumulation raster computes, for each cell, the total number of upstream cells that drain into it — effectively quantifying the relative contributing area at every point on the landscape. Cells with high accumulation values correspond to major channel locations, while low-accumulation cells represent hillslopes and ridgelines.

In the output image, the high-accumulation stream channels appear as bright lines against a near-black background, since the logarithmic range of values means that most hillslope cells have near-zero counts. These high-accumulation threads define the natural drainage network of the Gergera catchment and serve as the basis for stream extraction in the subsequent Raster Calculator step. The density and branching pattern of the network informs the catchment's hydrological responsiveness to rainfall events.

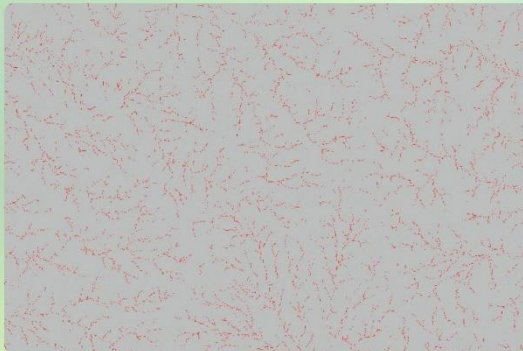


Methodology

5.4 Raster Calculator — Stream Network Extraction

The Raster Calculator applies a threshold condition to the flow accumulation surface to extract a binary stream network raster. By selecting only those cells whose accumulation value exceeds a defined minimum threshold (expressed as a conditional expression such as `Con("flow_acc" > threshold, 1)`), cells belonging to active stream channels are isolated from hillslope cells.

The resulting output, shown here as a red dot-pattern network on a neutral gray background, reveals the dendritic drainage pattern of the Gergera catchment. The choice of threshold value directly controls stream network density — a lower threshold yields a denser, more detailed network, while a higher threshold retains only major channels. For this study, the threshold was calibrated to match observable stream channel features identifiable in the QuickBird and Landsat imagery, ensuring the extracted network is hydrologically realistic.



Methodology

5.5 Contour — Terrain Analysis Before Watershed Delineation

Contour lines are derived directly from the filled DEM and provide an intuitive representation of the terrain's three-dimensional form. Generated at a specified contour interval, the lines connect points of equal elevation across the landscape, revealing ridgelines, valley bottoms, and slope gradients at a glance.

This contour map, generated **before** watershed delineation, serves two analytical purposes: first, it visually confirms the accuracy of the filled DEM by displaying a smooth, continuous elevation surface without artificial steps or discontinuities caused by unfilled sinks; second, it provides essential context for manually identifying plausible dam axis locations where the valley narrows and the topographic cross-section would minimize embankment volume while maximizing reservoir storage. The closely spaced contours in the western highlands confirm steep gradients suitable for high hydraulic head, while the broader spacing in the central basin indicates the relatively flat reservoir floor area.

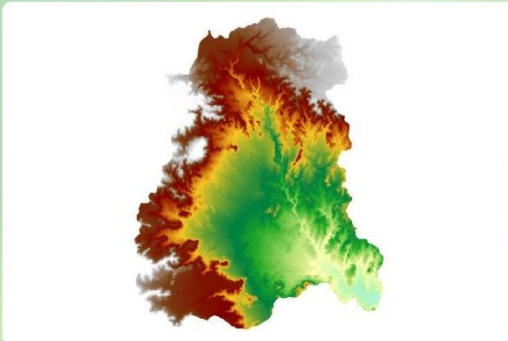


Methodology

5.6 Watershed Delineation — Defining the Catchment Boundary

Watershed delineation uses the ArcGIS Pro **Watershed** tool to identify all grid cells that drain to a designated pour point — the location on the stream network where the dam axis is proposed. The tool traces upstream from the pour point using the flow direction raster, classifying every contributing cell as part of the watershed.

The resulting watershed boundary, displayed here as a color-coded elevation map (red = high elevation, green/teal = low elevation), delineates the full 547 km² contributing area of the Gergera catchment. This boundary is the most important spatial output of the analysis, as it defines the land area whose rainfall directly contributes runoff to the proposed reservoir. The elevation gradient visible within the watershed — from high-elevation northwestern ridges to the lower southeastern basin — drives the dendritic stream network and determines the hydrological regime that the dam will regulate.

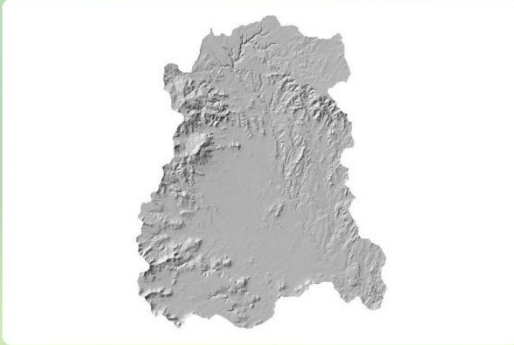


Methodology

5.7 Hillshade — Visualizing Terrain Relief

The Hillshade tool simulates the illumination of the terrain surface from a defined sun azimuth and altitude angle, producing a grayscale shaded relief image that makes landform features immediately perceptible to the human eye. Unlike the raw DEM — which encodes only numeric elevation values — the hillshade output renders slope, aspect, and curvature as light and shadow, making ridgelines, valleys, escarpments, and drainage divides visually intuitive.

For the Gergera watershed, the hillshade clearly differentiates the steep, dissected western highlands (strong shadow and highlight contrast) from the more gently sloping central basin (muted tones). This visualization was essential for qualitative validation of the watershed boundary, confirming that the delineated divide follows genuine topographic ridgelines rather than artefacts introduced by DEM processing. Hillshade layers are also used as base maps in subsequent overlays to provide geographic context for stream network and LULC results.

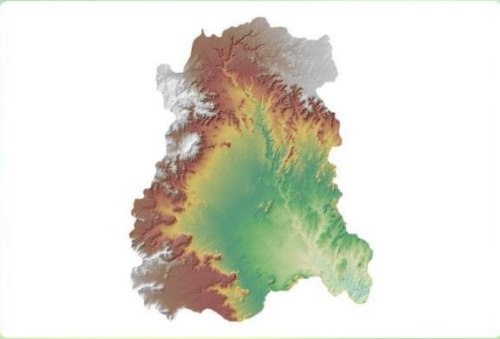


Methodology

5.8 Watershed Overlay on Hillshade — Integrated Terrain Visualization

Overlaying the color-coded watershed elevation raster onto the hillshade base map produces the most information-rich terrain visualization in the analysis workflow. This composite combines the perceptual depth cues of the hillshade (shadow and highlight) with the quantitative elevation information of the colored DEM, enabling simultaneous interpretation of both terrain shape and relative height.

In this overlay, the warm red and orange tones of the high-elevation western and northern ridges contrast sharply with the cool greens and teals of the lower central basin and valley floors. The three-dimensional relief effect makes it straightforward to identify the valley constrictions where dam construction would be most efficient — locations where the catchment narrows to a manageable cross-section at an elevation suitable for the proposed dam crest level. This composite map was used directly to guide the placement of dam axis lines for both the existing Gergera Dam site and the proposed alternative site.

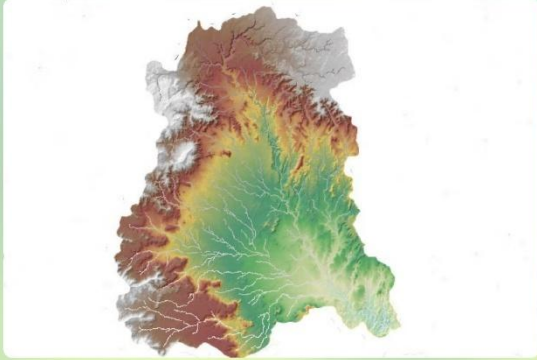


Methodology

5.9 Stream Link — Segmenting the Drainage Network

The Stream Link tool assigns a unique identifier to each segment of the stream network between junctions. Unlike the continuous flow accumulation raster, which encodes cumulative upstream area, stream link segments are discrete topological units — each one representing a branch of the drainage network between two confluences, or between a headwater source and the first downstream junction.

Stream links form the structural backbone for Stream Order classification and are used in the Watershed tool to define sub-watershed boundaries for each individual link. In the Gergera analysis, the stream link map — overlaid here on the watershed hillshade composite — reveals the complete bifurcating structure of the drainage network. High-order links (main stem channels) converge toward the proposed dam sites at the south-eastern portion of the catchment, confirming that both candidate sites are positioned on the primary drainage axis of the system.

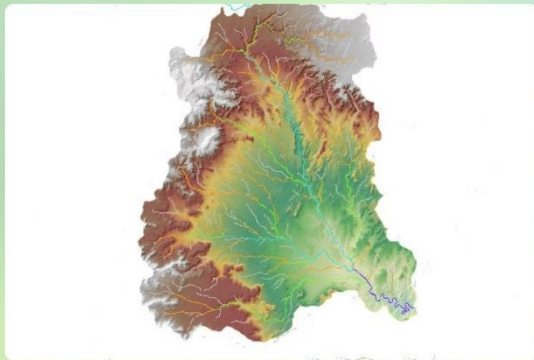


Methodology

5.10 Stream Order — Classifying Channel Hierarchy

Stream Order quantifies the hierarchical position of each stream segment within the drainage network using the **Strahler method** — the standard classification scheme in hydrological analysis. Under this scheme, fingertip tributaries with no upstream tributaries are designated Order 1. Where two Order 1 streams join, an Order 2 stream begins; where two Order 2 streams join, an Order 3 stream begins, and so on. A higher order number indicates greater drainage area, discharge, and channel dimension.

In the color-coded stream order map of the Gergera catchment, first-order streams (typically shown in yellow/orange) dominate the upper hillslopes, while the highest-order channels (blue tones) occupy the main valley axis. The maximum stream order observed in the catchment reflects the overall basin complexity and is consistent with the 547 km² drainage area. Understanding stream order is important for engineering design as it informs expected flood magnitudes, channel stability, and the hydrological behavior of the reservoir inlet zone.

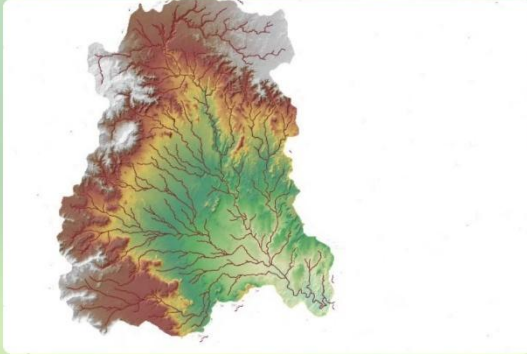


Methodology

5.11 Stream Line — Converting Raster Network to Vector Features

The Stream to Feature (Stream Line) tool converts the raster-based stream network — derived from the flow accumulation threshold — into a vector polyline feature class. This conversion is a pivotal step in the workflow because it transitions the analysis from raster processing into the vector domain, where stream segments can be attributed, queried spatially, and used as reference geometry for dam axis placement.

The vector stream network inherits the connectivity and hierarchy established in the stream link and stream order steps, with each polyline segment carrying attributes including its Strahler order value and grid code. In ArcGIS Pro, this vector layer is overlaid on the hillshade-watershed composite to produce the final integrated map of the Gergera drainage system — the definitive spatial product used to guide the selection and positioning of candidate dam axis lines across the main channel.

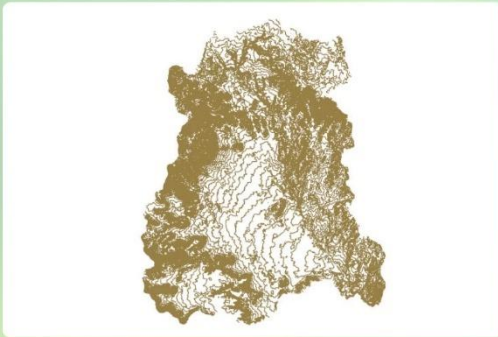


Methodology

5.12 Contour After Watershed — Elevation Detail Within the Delineated Basin

Following watershed delineation, contour lines are regenerated — this time clipped to the confirmed watershed boundary. This post-delineation contour map serves a distinctly different analytical purpose from the pre-delineation version: it provides the precise elevation geometry needed to compute reservoir surface area and storage volume at any given water surface elevation.

By analyzing contour lines within the watershed boundary in combination with the Feature to Polygon tool, the team can estimate the planimetric area enclosed between successive contour intervals. Integrating these areas over the vertical distance between contours (the prismoidal or average-end-area method) yields the stage-area and stage-volume (storage capacity) curves for each candidate dam site. The spatial density and shape of contour lines near the proposed dam axis location directly determines the sensitivity of reservoir storage to changes in dam crest elevation — a key design trade-off in dam siting.

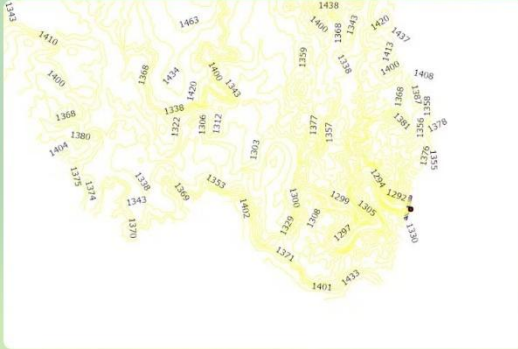


Methodology

5.13 Dam Axis — Positioning the Embankment Centerline

The dam axis is manually digitized as a polyline feature across the main channel at the most favorable topographic cross-section identified through contour and hillshade analysis. The ideal dam axis location minimizes embankment length (and therefore construction cost and material volume) while being positioned to impound the maximum possible reservoir storage volume upstream.

For both the existing Gergera Dam site and the proposed alternative, the dam axis line was drawn perpendicular to the principal flow direction of the main channel, spanning between the valley walls at the selected elevation. The length of the axis line directly influences embankment design — a shorter axis (as seen at the proposed alternative site with a length of 292.8 m) generally implies lower embankment material requirements, reduced construction cost, and a narrower valley cross-section offering better foundation conditions. The existing dam axis, at 692.3 m, represents a significantly wider cross-section with correspondingly greater embankment demands.

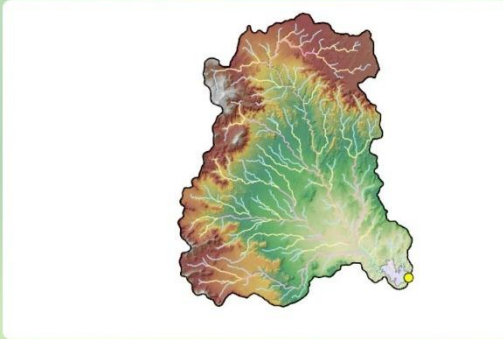


Methodology

5.14 Feature to Polygon — Defining the Reservoir Footprint

The Feature to Polygon tool converts the dam axis line and the surrounding topographic boundary (defined by the intersection of a horizontal water surface plane with the terrain) into a closed polygon representing the reservoir inundation area. This polygon is the fundamental spatial unit for quantifying all downstream reservoir characteristics.

In practice, the reservoir polygon is constructed by combining the dam axis line with the contour line at the proposed dam crest elevation, enclosing the area between the two features. The resulting polygon's planar area gives the reservoir surface area at full supply level. This polygon is also used as the spatial mask for the LULC analysis, enabling precise quantification of which land cover classes fall within the inundation zone of each candidate site — a critical input to the social and environmental cost comparison. The stark difference in polygon area between the two sites (3.07 km² for the existing site vs. 4.58 km² for the proposed alternative) directly reflects their differing storage capacities and inundation extents.

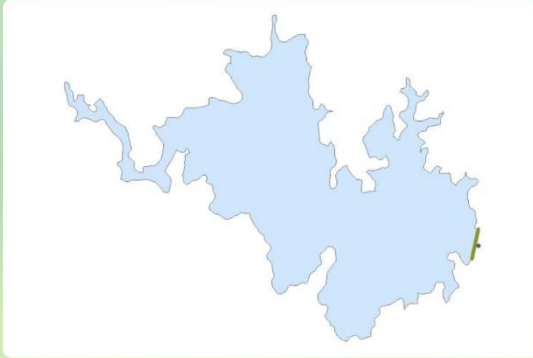


Methodology

5.15 Dam Structure — 3D Visualization of the Proposed Embankment

Following the definition of the dam axis and reservoir polygon, a three-dimensional structural visualization of the proposed dam embankment is generated in ArcGIS Pro using the hillshade-watershed composite as the base terrain. This visualization integrates the dam axis geometry, the reservoir polygon footprint, and the surrounding terrain relief to produce a spatially accurate representation of what the constructed dam and impounded reservoir would look like on the landscape.

This visualization is particularly valuable for stakeholder communication, allowing non-technical audiences — including local community members, regional planners, and policy makers — to understand the spatial scale and physical character of the proposed infrastructure. It also serves as a cross-check on the engineering plausibility of the selected axis location: the apparent relationship between the embankment height, valley width, and reservoir extent should be consistent with the computed storage volume and dam axis length derived from the GIS analysis.

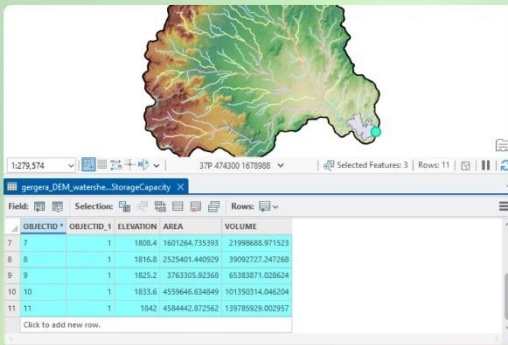


Methodology

5.16 Storage Capacity — Stage-Volume Curve Computation

The storage capacity analysis is the culminating quantitative output of the methodology. Using the reservoir polygon and the underlying DEM, a stage-storage curve is computed by calculating the volume of water that would be impounded at successive water surface elevations (stages) above the minimum reservoir floor elevation. The volume at each stage is determined by integrating the planimetric area of successive contour intervals using the average-end-area or prismatic formula.

The resulting stage-volume curve provides engineers with the fundamental design relationship for the dam: it defines how much water can be stored for any given dam crest elevation, directly informing decisions about spillway design, dam height, and operational rule curves. For the Gergera study, this computation revealed a substantial difference in storage capacity between the two candidate sites — the proposed alternative site stores approximately **139.8 million m³** compared to only **46.2 million m³** at the existing site — a factor of three difference that is the central finding of the comparative analysis.

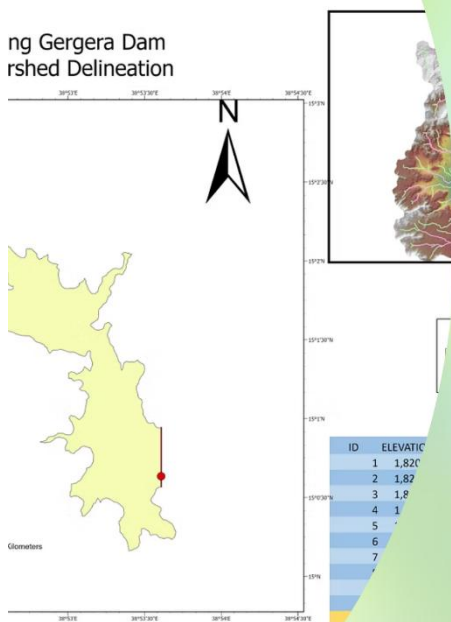


6. Studies Conducted

Six interrelated studies were carried out within the GIS analytical framework to provide a comprehensive multi-criteria evaluation of the two candidate dam sites. Together, these studies address both the engineering performance of each site (storage capacity) and its social and environmental footprint (land use impacts).

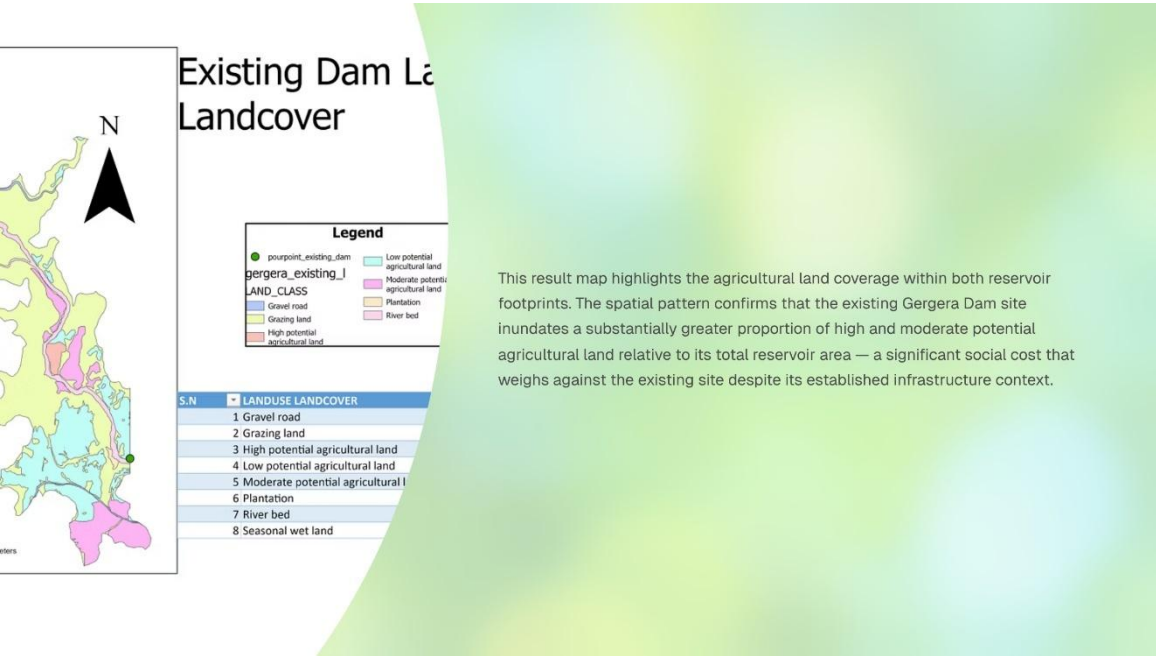
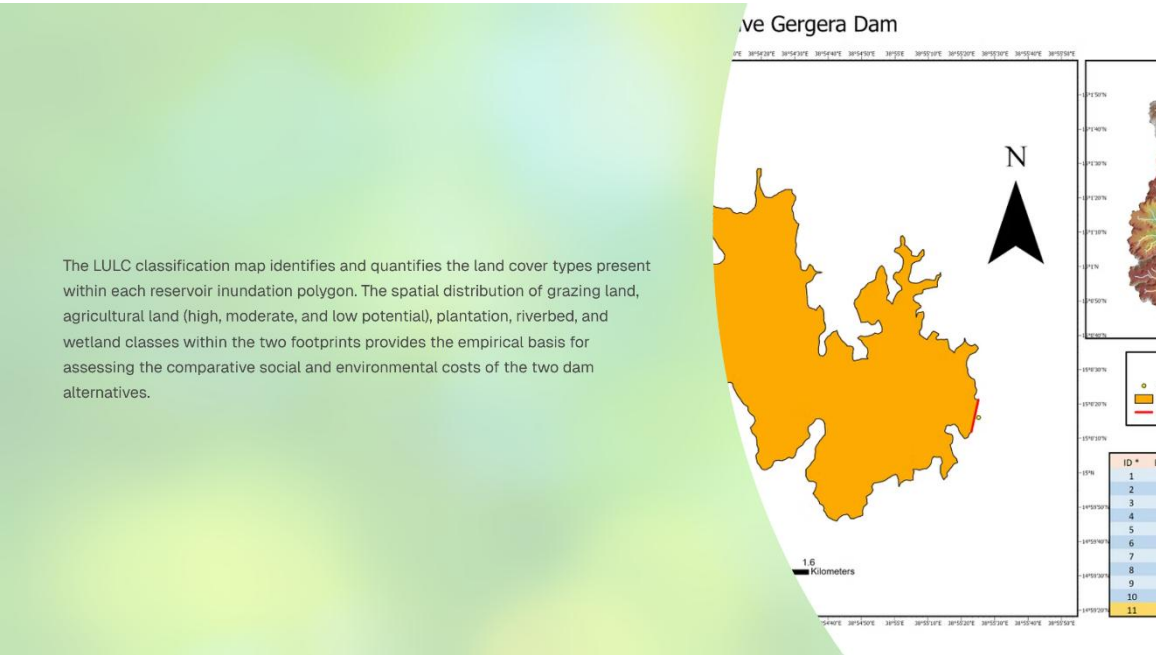
- 1 **Watershed Delineation**
Full delineation of the Gergera River catchment boundary (547 km²) using the DEM-based flow direction and accumulation workflow, confirming the contributing area for both candidate dam sites.
- 2 **Dam Storage Capacity Comparison**
Stage-volume computation for both sites using contour-based area integration, producing storage curves that allow direct comparison of reservoir yield potential at equivalent dam crest elevations.
- 3 **Land Use / Land Cover Analysis**
LULC classification of the reservoir inundation zones using Landsat 8 and QuickBird imagery, identifying the area and type of land cover affected by each alternative reservoir footprint.
- 4 **Agricultural Land Coverage Comparison**
Quantification of high, moderate, and low potential agricultural land within each reservoir polygon, assessing the extent to which productive farmland would be lost under inundation.
- 5 **Settlement Mobilization Comparison**
Spatial analysis of the overlap between reservoir footprints and mapped village locations and road infrastructure, estimating the population displacement and infrastructure relocation burden of each alternative.
- 6 **Forest Land Coverage Comparison**
Assessment of plantation and natural vegetation cover within each inundation zone, providing an indicator of ecological impact and carbon stock loss associated with reservoir filling.

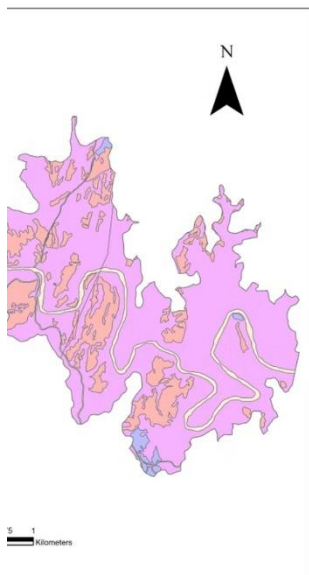
Gergera Dam Watershed Delineation



7. Results and Discussions

The following maps and analytical outputs present the spatial results of the GIS-based watershed delineation, stream network extraction, and reservoir footprint analysis for both the existing Gergera Dam site and the proposed alternative. These results form the evidentiary basis for the comparative evaluation in Section 8.





NEW CO LAND US

The final comparative results map integrates the stream network, watershed boundary, both dam axis locations, and reservoir polygons into a single spatial product. This composite view allows direct visual comparison of the relative size, position, and catchment context of the two candidate sites, confirming the substantially larger inundation footprint and storage potential of the proposed alternative site.

8. Comparison and Evaluation

Three primary engineering parameters — reservoir area, storage volume, and dam axis length — were computed for both sites and are summarized in the table below. The results reveal a striking difference in storage performance between the existing Gergera Dam site and the proposed comparative alternative.

S. N.	Parameter	Units	Existing Gergera Dam	Proposed Alternative Dam
1	Area of Reservoir	m ²	3,069,011.26	4,584,442.87
2	Volume of Reservoir	million m ³	46.20	139.79
3	Dam Axis Length	m	692.27	292.80

+49% Larger Reservoir Surface

The proposed alternative's reservoir covers 4.58 km² compared to 3.07 km² for the existing site — a 49% increase in surface area, enabling greater evaporative losses to be tolerated while still delivering superior net yield.

~3× Greater Storage Volume

The proposed alternative stores approximately **139.8 million m³** versus only **46.2 million m³** at the existing site. This three-fold difference fundamentally changes the water supply security and irrigation potential of the project.

57% Shorter Dam Axis

At 292.8 m versus 692.3 m, the proposed alternative requires a significantly shorter embankment. A shorter dam axis implies lower construction cost, reduced material volumes, and typically a more favorable valley cross-section with better foundation rock exposure.

8.1 Land Use / Land Cover Comparison

The LULC analysis quantifies the types and extents of land cover classes within the inundation footprint of each dam alternative. This comparison is essential for assessing the social and environmental cost of each option beyond purely hydraulic metrics.

S.N.	Land Use / Land Cover Class	Unit	Existing Dam	Proposed Dam	% Existing	% Proposed
1	Gravel Road	km	6.73	7.96	—	—
2	Grazing Land	m ²	1,592,829.58	3,235,597.55	54%	72%
3	High Potential Agricultural Land	m ²	138,911.60	7,034.00	5%	1.4%
4	Low Potential Agricultural Land	m ²	554,980.64	881,526.42	19%	20%
5	Moderate Potential Agricultural Land	m ²	443,668.62	87,384.98	15%	2%
6	Plantation	m ²	6,373.07	5,592.98	0.2%	0.1%
7	River Bed	m ²	204,677.64	268,168.34	7%	6%
8	Seasonal Wetland	m ²	—	857.51	0%	0.02%
9	Total	m ²	2,941,441.15	4,486,161.76	—	—

Key finding: The existing Gergera Dam site inundates 20% moderate and 5% high potential agricultural land — a combined 25% of productive farmland within its footprint. The proposed alternative reduces this combined figure to just 3.4%, representing a dramatic reduction in the agricultural displacement burden despite its larger overall reservoir area.

9. Conclusion

The GIS-based analysis conducted through ArcGIS Pro demonstrates convincingly that **the proposed alternative dam site outperforms the existing Gergera Dam site** across every key criterion evaluated in this study.

→ ArcGIS Pro as an Effective Dam Siting Tool

The study confirms that ArcGIS Pro is highly effective and efficient for watershed delineation, hydrological modeling, and land use impact assessment in dam site selection. The integrated workflow — from DEM conditioning through storage capacity computation — delivers quantitative, spatially explicit outputs that are directly actionable for engineering design and planning decisions.

→ Lower Social and Agricultural Impact

Despite its larger reservoir footprint, the proposed alternative inundates far less productive agricultural land. Combined high and moderate potential agricultural land loss is reduced from 20% to just 3.4% of the reservoir area, substantially lowering the social cost of resettlement and the long-term agricultural productivity impact on affected communities.

→ Superior Engineering Performance at the Alternative Site

The proposed comparative dam site stores approximately **three times the volume** of the existing Gergera site (139.8 vs. 46.2 million m³) at a shorter dam axis length (292.8 vs. 692.3 m), indicating both greater water resource yield and lower embankment construction costs. This combination of higher capacity and lower structural complexity represents a clear engineering advantage.

→ GIS as a Transferable Planning Framework

Beyond the specific Gergera case, this study demonstrates that ArcGIS Pro's spatial analysis capabilities have strong potential to provide valuable insights and rigorous, evidence-based support for dam site selection across the broader Eritrean water resources planning context — particularly in data-sparse highland environments where field investigation is logistically challenging.

Team Members

This analysis was conducted as part of the **ECA Training Program** by Group 3, whose members contributed to data collection, GIS processing, analysis, and presentation preparation.

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ECA TRAINING PROGRAM - GROUP 3 - FEBRUARY 27, 2026

Project 3: The Role of GIS in Modern Cadastral System

This team created a pilot cadastral GIS system for Mai Chihot area, establishing parcel-based geodatabase with high-precision digitization from 15cm resolution imagery. The system integrates spatial parcel data with attribute information on ownership, area, and land use, enabling both cartographic visualization and database queries. The project articulated clear institutional transformation roadmap including GIS infrastructure unit establishment, inter-departmental network integration, and capacity development for transitioning from paper-based to digital cadastral management.



Group-B

A comprehensive study on the integration of Geographic Information Systems into modern cadastral management — transforming land administration from paper-based records to dynamic, spatially-enabled digital infrastructure.

CADASTRAL GIS STUDY

LAND ADMINISTRATION

The Role of GIS in Modern Cadastral Systems

Introduction

Geographic Information Systems (GIS) represent a broad and powerful concept in spatial data management. As both a tool and a software environment, GIS enables the display, visualization, and retrieval of spatially referenced information. Cadastre, by contrast, deals primarily with parcel-based ownership records and property rights maintained as tabular data — defining who owns what land, and under what legal conditions.

In recent decades, GIS has fundamentally transformed cadastral management, moving the field away from cumbersome paper-based record-keeping toward dynamic, integrated digital systems. Today, GIS serves as the **spatial backbone of modern land administration**, enabling governments and cadastral agencies to manage, query, and analyze land-related information with unprecedented speed and accuracy. The convergence of spatial technology with legal property records marks a watershed moment for land governance worldwide.

GIS as the Coordinating Platform for Cadastral Data

Linking Parcels to Information

ArcGIS Pro serves as the enabling platform that transforms raw cadastral information into a coordinated, spatially referenced system. It links each parcel polygon to its pertinent ownership, legal, and descriptive data through a common parcel-level geographic identifier — creating a seamless bridge between spatial geometry and administrative records.

This integration means that every polygon on the map corresponds directly to a row of attributes in a database table, ensuring that spatial queries and administrative lookups are always synchronized.

Structure of Cadastral Data in GIS

Cadastral data typically exists as **tabular information (attribute tables)** linked directly to geographic features — specifically, parcel polygons. Each parcel record contains multiple attributes organized in columns, with individual rows representing distinct properties. Key attributes typically include owner name, parcel area, land use type, block and plot numbers, and legal status.

This structure enables GIS-based cadastral systems to support a wide spectrum of functions, including:

- Property transactions and title transfers
- Land taxation and revenue assessment
- Urban planning and zoning decisions
- Infrastructure development and utility routing

Problem Statement

The Cadastral Office of the Ministry of Land, Water, and Environment (MLWE) currently bears responsibility for registering and maintaining property rights across the entire country. While this mandate is critical to land governance, the existing operational framework is severely constrained by outdated, paper-based processes that limit efficiency, accuracy, and public accessibility.

Physical Access Requirement

Accessing cadastral information and initiating property registration requires citizens to make **physical visits to cadastral offices** — a significant barrier in terms of time, cost, and geographic distance, particularly for rural landholders.

Manual Search Processes

Records retrieval is carried out by **searching through physical map sheets** and cross-referencing handwritten ledgers. This process is slow, inconsistent, and highly dependent on the institutional knowledge of individual staff members.

Boundary Update Limitations

Any change to parcel boundaries requires **physically redrawing paper maps** — a labor-intensive task prone to drafting errors, version conflicts, and loss of historical accuracy over time.

Error-Prone Land Analysis

Analyzing land use patterns, detecting overlaps, or generating statistical reports is **extremely labor-intensive and error-prone** when conducted manually, severely limiting the office's capacity to support planning and policy decisions.

Project Objective

Core Goal

To introduce and establish a **GIS-based spatial geodatabase cadastre** within the Cadastral Office of the Ministry of Land, Water, and Environment (MLWE), fundamentally transforming the cadastral management framework from paper-based record-keeping to a dynamic, integrated digital system.

This digital system is intended to serve as the **spatial backbone of modern land administration** — enabling efficient, accurate, and accessible property registration and land information services throughout the country.

Expected Outcomes

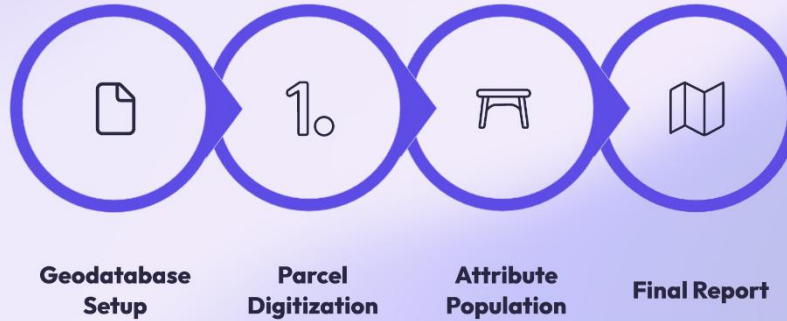
- Establishment of a structured, parcel-based GIS geodatabase within ArcGIS Pro
- Transition from manual paper records to a fully digital cadastral registry
- Improved speed and accuracy of property registration and retrieval
- Elimination of redundant manual map-drafting tasks
- Enhanced capacity for spatial analysis and land pattern reporting
- A replicable model for scaling GIS-based cadastral systems to additional areas

By achieving these outcomes, the MLWE Cadastral Office will be positioned to deliver modern, reliable land administration services that align with international best practices in cadastral management.

Methodology

Mapping & Geodatabase Development

The methodology followed a systematic, GIS-driven workflow designed to produce both spatial and tabular cadastral outputs with a high degree of accuracy and completeness. The process was carried out within the ArcGIS Pro environment, leveraging high-resolution imagery and structured geodatabase design principles.

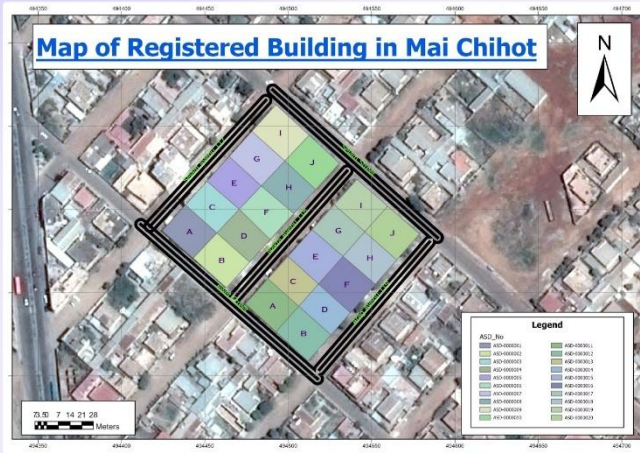


Each step was carefully executed to ensure that the resulting cadastral geodatabase accurately reflects real-world parcel boundaries and ownership data. High-resolution imagery at **15 cm pixel resolution** provided the spatial precision necessary for reliable parcel delineation, while ArcCatalog's geodatabase structure ensured data integrity and scalability. Final outputs were delivered in both **map format** (visual property maps) and **tabular format** (attribute-based reports), supporting a range of administrative and planning use cases.

Result: Property Map

Map of Registered Buildings in Mai Chihot

The spatial output of the GIS-based cadastral mapping exercise is presented below. Each parcel polygon is uniquely identified and color-coded according to its assigned **ASD**. No attribute, enabling quick visual distinction between adjacent properties. The map was produced in the ArcGIS Pro environment using high-resolution aerial imagery at 15 cm resolution as the base layer, ensuring precise boundary delineation.



The map clearly displays the spatial arrangement of registered building parcels within the Mai Chihot study area, organized into distinct blocks and plots. Each parcel is linked to a corresponding record in the attribute table, establishing the spatial-tabular integration that is the hallmark of a functional GIS-based cadastral system. The legend on the right side identifies each parcel by its unique ASD number, supporting traceability and administrative reference.

Result: Tabular Data

Map of Buildings Registered in Mai Chihot — Attribute Table

In addition to the spatial map output, the GIS geodatabase produced a comprehensive attribute table capturing the key descriptive and ownership data for each registered parcel. The table below represents the populated attribute records linked to each digitized parcel polygon, with a total count of **20 registered properties** as reflected in the report totals.

ASD_No	Shape_Length	Shape_Area	Owner_Name	House_Type	Plot	Parcel
ASD-0000001	91.592645	520.004985	Semere	Villa	Block_1	A
ASD-0000002	94.766064	553.027926	Gilazgi	Service	Block_1	B
ASD-0000003	89.543132	491.688124	Bereket Tekie	Service	Block_1	C
ASD-0000004	90.195479	495.101104	Asmerom Yemane	Service	Block_1	D
ASD-0000005	91.018383	507.831682	Hana Kidane	Villa	Block_1	E
ASD-0000006	92.067864	521.545346	Habtom Hagos	G+4	Block_1	F
ASD-0000007	93.615073	539.01076	Adiyam Welday	Villa	Block_1	G
ASD-0000008	90.937985	509.311106	Kifle Solomon	Villa	Block_1	H
ASD-0000009	96.472213	574.227013	Tesfay Tesfay	Service	Block_1	I
ASD-0000010	92.526681	531.422568	Merhawi Goitom	G+2	Block_1	J
ASD-0000011	90.37151	505.484467	Samuel Araya	G+4	Block_2	A
ASD-0000012	93.552519	540.206806	Robel Kahsay	Service	Block_2	B
ASD-0000013	85.318335	443.461904	Bereket Tesfay	G+2	Block_2	C
ASD-0000014	87.258003	459.524515	Gidey Hadigu	Service	Block_2	D
ASD-0000015	93.103641	539.91121	Genet Habtom	Service	Block_2	E
ASD-0000016	96.384415	577.925545	Samsom Haile	Villa	Block_2	F
ASD-0000017	88.764424	486.959795	Solomon Embaye	Villa	Block_2	G
ASD-0000018	90.332125	500.929803	Merhawit Haile	Service	Block_2	H
ASD-0000019	90.006852	502.588756	Adhanom Habte	Villa	Block_2	I
ASD-0000020	92.295735	526.692407	Asmeret Gebray	Service	Block_2	J

Report Totals

Count: 20

Each row in the attribute table corresponds to one registered parcel, with columns capturing the **ASD No** (unique parcel identifier), **Shape_Length**, **Shape_Area**, **Owner_Name**, **House_Type** (Service or Villa), **Plot**, and **Parcel** (sub-block designation). This structured data model enables efficient querying, reporting, and future updates — demonstrating the core advantage of GIS-based cadastral management over manual paper records.

Recommendations

Establishing a GIS-Based Cadastral Geospatial Infrastructure

Based on the findings and outcomes of this study, the following recommendations are put forward to the Cadastral Office and the Ministry of Land, Water, and Environment (MLWE) for immediate and near-term action:

1 Establish a Dedicated GIS Cadastral Unit

The Cadastral Office urgently needs to establish a formal **GIS-based Cadastral Geospatial Infrastructure Unit** with clearly defined staffing, equipment, and operational mandates. This unit will be responsible for migrating existing paper-based records into digital format and maintaining the geodatabase on an ongoing basis. Continued reliance on manual workflows is no longer sustainable given the volume, complexity, and accuracy demands of modern land administration.

2 Integrate Workflows Across Departments

Currently, the Department of Land, the Technical Office in the Municipality, and the Cadastral Office each operate in relative isolation — allocating land, preparing architectural and engineering plans, and registering ownership rights respectively. **Interconnecting these sections through a shared network and common geospatial platform** is essentially crucial. A networked GIS infrastructure will eliminate duplicated effort, reduce registration delays, and ensure that spatial and legal records remain synchronized across all responsible agencies.

Implementation Requirements

Equipping the Cadastral Office for Digital Transformation

To effectively handle and manage the full range of cadastral activities within a modern GIS framework, the Cadastral Office must be equipped with the appropriate technology and human capacity. This investment is not optional — it is a foundational prerequisite for any sustainable transition from paper-based to digital land administration.

GIS Software

The office must be licensed and deployed with professional-grade GIS software such as **ArcGIS Pro**, which supports advanced geodatabase management, high-resolution digitization, spatial analysis, and report generation in both map and tabular formats.

Hardware Infrastructure

Adequate computing hardware — including workstations, large-format plotters, and network servers — must be procured and configured to support geodatabase hosting, multi-user access, and reliable data backup and recovery.

Trained Personnel

Skilled and **trained GIS professionals** must be recruited or developed within the existing workforce. Capacity-building programs should cover geodatabase design, parcel digitization, attribute management, spatial analysis, and system administration.

Network Connectivity

A reliable internal network connecting the Cadastral Office, Municipality Technical Office, and Department of Land will enable real-time data sharing, coordinated land allocation workflows, and centralized access to the cadastral geodatabase across all relevant stakeholders.

Thank You

This study was conducted by **Group-B** as part of an applied research initiative on GIS integration in cadastral management. We appreciate the time and attention of all cadastral officials, land administration stakeholders, and GIS practitioners who engaged with this work.

Key Takeaway

GIS-based cadastral systems are no longer a future aspiration — they are an operational necessity for modern, efficient, and equitable land administration.

Next Step

Establishment of a dedicated GIS Cadastral Infrastructure Unit within the MLWE, equipped with ArcGIS Pro and supported by trained personnel and inter-departmental network integration.

GROUP-B PRESENTATION

MLWE CADASTRAL OFFICE



Appendix F: Training Materials List

- PowerPoint presentations (125+ slides per day, 25 days = 2400+ slides total)
- Hands-on training manuals for ArcGIS Pro/QGIS (60 + Manuals)
- Sample datasets: Eritrea administrative boundaries, DEM, Landsat/Sentinel-2 imagery, sample cadastral parcels
- Reference documents: IGIF framework, FELA, ISO standards summaries, metadata guidelines
- Exercise worksheets and templates

- Quiz and assessment materials

Appendix G: Workshop Photographs

[Collection of photographs documenting opening ceremony, training sessions in progress, hands-on practical work, group activities, capstone presentations, and closing ceremony]















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Report Prepared By:

United Nations Economic Commission for Africa
African Centre for Statistics
Data Capacity and Integrated Geospatial Knowledge (DCIGK) Section

In Collaboration with:

Ministry of Lands, Water and the Environment
Government of Eritrea

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