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OBJECT-BASED LAND COVER CLASSIFICATION AND FOREST MONITORING IN THE MOUNTAINOUS REGIONS OF UZBEKISTAN: A CASE STUDY OF DEKHKANABAD FORESTRY

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Abstract. *Uzbekistan's forest ecosystems, which cover approximately 6.7% of the national territory, face increasing threats from overgrazing, unsustainable land use, and climate-related adversities. Accurate mapping and monitoring are essential for the sustainable management of these vital resources, particularly in diverse terrains like the Dekhkanabad forestry region in the Gissar Range. This study employs an Object-Based Image Analysis (OBIA) approach to classify land cover by integrating multi-source remote sensing data, including Sentinel-2 and Kompsat-3 imagery, complemented by an ALOS PALSAR-derived Digital Terrain Model (DTM).*

To ensure rigorous validation, ground truth data were collected from 1,980 plots using the FAO's Collect Earth tool, categorized according to IPCC and Forest Resources Assessment (FRA) guidelines. The methodology utilized multi-resolution segmentation and supervised classification to overcome the limitations of traditional pixel-based methods, specifically addressing spectral overlaps in complex mountainous landscapes.

The results demonstrate high classification accuracy for dominant land cover types: pasture (91%), cropland (89%), and forest (80%). However, challenges remained for human settlements (53%) and wetlands due to spectral similarities and smaller sample sizes. The findings underscore the effectiveness of the OBIA framework and high-resolution satellite fusion in providing precise thematic maps. These spatial datasets offer critical insights for policymakers and forestry managers in Uzbekistan to support biodiversity conservation, resource allocation, and long-term environmental planning.

Keywords: *Object-Based Image Analysis (OBIA), Uzbekistan Forestry, Sentinel-2, Collect Earth, Remote Sensing, Land Cover Mapping, Dekhkanabad, Sustainable Forest Management.*

1. Introduction

In Uzbekistan, a notable proportion of the forested areas is characterized by natural regeneration, although the majority comprises planted forests, illustrating a diverse approach to forestry management within the nation. However, these vital ecosystems are increasingly threatened by a confluence of detrimental factors, including overgrazing practices that lead to habitat degradation, the surging demand for fuelwood and other forest-derived products that place immense pressure on resource sustainability, the repercussions of unsustainable land use practices, and a spectrum of climate-related adversities that exacerbate existing vulnerabilities.

Forest-covered lands total 3.03 million ha, resulting in a forest cover of 6.7%. The majority of state forests are located in Karakalpakstan, Bukhara, and Navoi provinces, with smaller areas in Fergana Valley, Samarqand, and Syrdaria provinces. The state forest stock includes sandy (7.78 million ha), mountainous (1.5 million ha), floodplain (0.10 million ha), and valley (0.18 million ha) lands, classified under the 1st group of forest functions. About 200 species of trees and shrubs are found, with key desert species including saxaul black (Haloxylon aphyllum) and white (Haloxylon persicum), as well as shrubs like cherkez, kandim, and tamarisk. Mountainous areas feature juniper (Juniperus), thuja (Thuja), walnut (Juglans regia), pistachio (Pistacia vera), almond (Amugdalus sp.), hawthorn (Crataégus), and others like Berberis sp. and Rosa sp. Floodplain forests are dominated by endemic poplars and broadleaved trees (Populus pruinosa, P. diversifolia, Elaeagnus sp., and Salix sp.), while valleys have a mix of deciduous and fruit trees.

In Uzbekistan, forests are state property and form a unified forest stock, which includes national forests and those managed by government forestry bodies but utilized by other sectors. Natural resource utilization can be general or special; general use is free and limited to subsistence needs while special use requires permits. Forest users may be permanent (forestry enterprises and organizations) or temporary (local communities). Forest management may be short-term (up to 3 years) or long-term (up to 10 years), with regulations set by relevant government agencies. Fees and collection procedures are established by the Cabinet of Ministers. To enhance forest cover, the Ministry of Forestry focuses on biodiversity conservation. Key indicators of MFD activities for 2010-2011 are summarized in Table 1-3. Annually, forest farms in Uzbekistan conduct forest seeding (43,000 ha), planting (20,000 ha), and facilitate

natural reforestation (16,000 ha), including 16,000-17,000 ha on the exposed bed of the Aral Sea (Botman, 2009).

2. Methods and Materials

For many years, remote sensing imagery has played an essential role in forest inventory and mapping practices, especially in numerous developed nations. The information gleaned from these images has become indispensable for understanding and managing forest resources. The application of automated processing techniques to these images offers the potential for considerable cost reductions, particularly within the increasingly digital data interpretation environment that is becoming standard practice. As data analysis shifts toward digital platforms, the efficiency and economy provided by automation become increasingly significant. Reference [9] highlights the importance of these cost savings and their connection to the growing digitalization of data interpretation workflows.

However, automated procedures that rely solely on analyzing individual pixels often fall short of achieving the desired level of accuracy. This limitation stems from their failure to account for the spatial arrangement and textural characteristics of the landscape. While spectral information is important, the context provided by spatial relationships and textural patterns is equally crucial for accurate classification. To achieve effective automated classification of landscape structures, it is necessary to identify and incorporate the spectral, textural, and geometric features that characterize different land cover classes. The unique combination of these features allows for better differentiation between various land cover types.

One of the challenges in this process is the potential for overlapping spectral curves between different land cover classes. This spectral similarity can make it difficult to distinguish accurately between these classes based solely on their spectral signatures. Differentiating between species or forest types based on spectral signature can be particularly challenging. Nevertheless, with a well-defined, confident methodology, coupled with the appropriate level of experience and expertise, this problem can be effectively addressed and overcome. Careful analysis and nuanced approaches are required to leverage spectral information effectively in the face of these challenges.

The creation of meaningful objects within the image analysis process fundamentally involves identifying and analyzing changes in the heterogeneity or homogeneity of the image features. By detecting shifts in these characteristics, it becomes possible to delineate distinct objects and extract valuable information. Over time, several sophisticated segmentation methods have been developed to facilitate this process [1, 10]. Common approaches within these segmentation methods typically

involve techniques such as thresholding, which separates pixels based on intensity values, or area enhancement algorithms, which highlight regions of similar characteristics. Different types of texture segmentation algorithms are also frequently employed, leveraging the patterns and variations in image texture to delineate objects.

Beyond these automated techniques, knowledge-based approaches also play a vital role in operational applications. These approaches incorporate expert knowledge and contextual information to guide the segmentation and classification processes. Baatz and Schepe [1] introduced a multi-resolution segmentation algorithm, a key innovation in the field. This algorithm was first implemented in the commercial object-oriented image analysis software known as eCognition [11, 12], showcasing its practical application and impact. The object classification procedure implemented in this software considers not only the spectral and texture properties of image objects, but also their size and behavior across different scale levels. This multi-scale analysis allows for a more comprehensive and robust classification process.

The core principle of the algorithm is to build image objects in a stepwise manner, systematically minimizing their weighted heterogeneity. This ensures that the resulting objects are as internally consistent as possible. Current object-based approaches are typically based on the creation of initial object primitives. These primitives are then subjected to a step-by-step reconstruction process, utilizing region-specific supervised methods at multiple levels. This iterative refinement process allows for the creation of highly accurate and meaningful image objects.

The supervised object-based classification approach leverages several key data sources. These include spectral information derived from Sentinel-2 and Compsat 3 imagery, elevation data obtained from a digital terrain model (DTM) generated from ALOS PalSAR data, and auxiliary GIS data, which provides additional contextual information. Combining these diverse data sources enables a more comprehensive and accurate classification process.

High spatial resolution satellite imagery, particularly that with four bands in the near-infrared electromagnetic region and two additional bands in the shortwave infrared region, can serve as a sufficient data source for automated forest boundary delineation. The level of detail captured by these images allows for precise identification of forest boundaries. To demonstrate this capability, several Sentinel-2 scenes from the summers of 2018-2020, encompassing the territory of Dehkanabad forestry, were processed and analyzed. These images provided valuable data for mapping and monitoring forest resources in the region.

2.1. Study area

Dekhkanabad forestry, situated in the southeast of the Kashkadarya region within the Dekhkanabad district, extends across the slopes of the Gissar Range (Fig 1) . The forestry's mountainous terrain exhibits diverse altitudes and natural conditions, encompassing three morphological relief types: low-mountain (up to 1,500 meters, denudation-tectonic formations of dissected ridges and adyrs), mid-mountain (denudation-tectonic slopes), and high-mountain (alpine areas above 3,000 meters, occupying relatively small spaces). A vertical zonality characterizes the soil composition: brown carbonate soils in the foothill zone, brown typical and mountain-forest brown soils on the steeper slopes, and typical serozems in the lower zone. Brown carbonate soils, found at 1400-1900 meters, contain 3-5% humus in the upper horizon, decreasing to 1-1.5% below 25-30 cm.

The forestry lies within Uzbekistan's Surkhan-Gissar mountain district, belonging to the Hissar or Central Asian soil-climatic region. Average annual temperatures range from +14.8°C to +6.7°C, varying with altitude. January temperatures average -0.2°C in the foothills and -5.4°C in the mountains, while average temperatures in a warm month are +26.1°C and +14.5°C, respectively.

Forests cover 73.6% (55,689 ha) of the total forest area, with 36.3% (20,229.5 ha) being non-forested. Cultivated forests comprise 1.2% (671.7 ha) of the forested area. Overall, forest land constitutes 69.4% (75,916.6 ha) of the total forest land area, while deforestation accounts for 30.5% (33,467.7 ha). The forest-growing region favors the growth of juniper, walnut, hawthorn, and fruit species, enabling highly productive plantations. Pastures, primarily mountain and adyr types utilized for spring and summer grazing, occupy over 30% of the territory, alongside rocky terrains and stony scree.

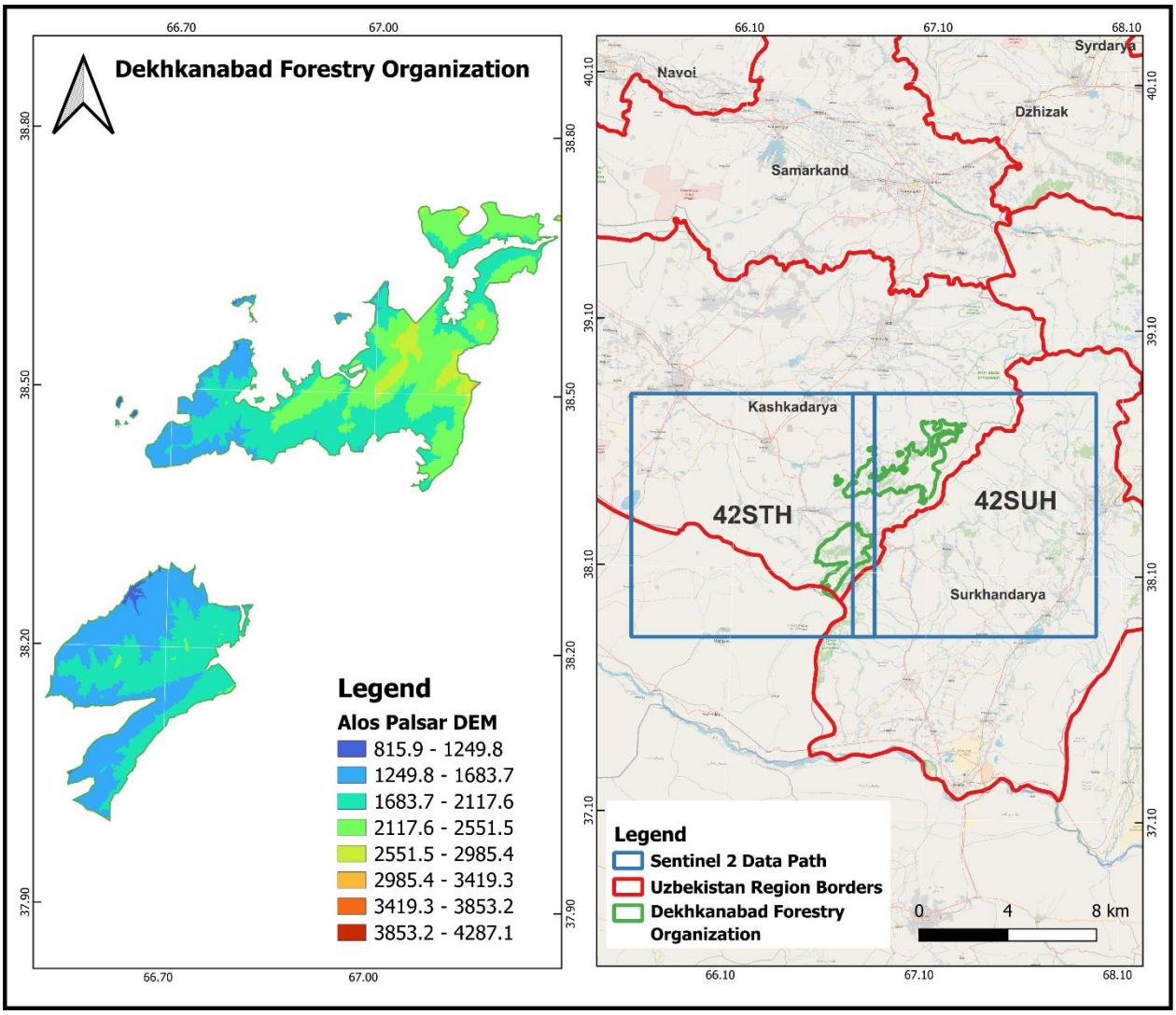


Fig 2. Location of the area of interest and Sentinel 2 data path

2.2. Satellite data

Effective use of remote sensing data from multiple sources relies on rigorous pre-processing methodologies to ensure data quality, geometric accuracy, and spectral consistency, thereby optimizing their usefulness for subsequent analysis. In this study, Sentinel-2 and Kompsat-3 imagery, augmented with an ALOS PALSAR-derived digital elevation model (DTM) and auxiliary GIS data, underwent a series of specialized pre-processing steps. Sentinel-2 Level-2A data, already atmospherically corrected, were initially subjected to an atmospheric correction check through visual inspection and comparison with ground truth data; where inconsistencies were detected, the FLAASH module in ENVI was used for re-calibration. Subsequent refinement of the geometric correction involved the use of ground control points (GCPs) derived from high-resolution orthorectified imagery and GIS layers, achieving a root mean square error (RMSE) below 0.5 pixels to ensure accurate spatial alignment.

The corresponding spectral bands were then stacked to create a multispectral image, after which all bands were resampled to a uniform 10-meter spatial resolution using the nearest neighbor method to preserve the original spectral values. Complementing Sentinel-2, Kompsat-3 images, offering improved spatial resolution, were processed using rigorous geometric correction, again aiming for an RMSE below 0.5 pixels, after which atmospheric correction was performed using the FLAASH module to obtain surface reflectivity values. In addition, the Gram-Schmidt pan-sharpening technique was applied to merge the multispectral and panchromatic bands, resulting in a high-resolution multispectral image. The ALOS PALSAR L1.1 data, critical for obtaining topographic information, are radiometrically calibrated and geometrically corrected using Range-Doppler terrain correction, followed by interferometric processing to create an interferogram and a wrapped phase image. The phase unwrapping resolves phase ambiguities, and the wrapped phase image is geocoded to create a georeferenced DEM. This original DEM is then filtered to reduce noise, smoothed to minimize artifacts, and void filled using interpolation techniques to ensure a complete and accurate representation of the terrain. The culmination of these pre-processing steps is a carefully prepared dataset ready for subsequent feature extraction, image classification, and spatial analysis.

2.3. Collect earth data

This study leverages Collect Earth, an open-source tool developed by the Food and Agriculture Organization (FAO) and Google, for collecting ground truth data within the Dekhkanabad forestry area. Collect Earth allows for efficient and systematic visual interpretation of high-resolution satellite imagery, facilitating the creation of a spatially explicit database of land cover types. A total of 1,980 Collect Earth plots were interpreted and classified according to a predefined classification scheme, aligning with both Intergovernmental Panel on Climate Change (IPCC) and FAO Forest Resources Assessment (FRA) guidelines (Fig 3). This robust dataset provides the necessary ground truth for training and validating the supervised object-based classification model.

The classification scheme used in Collect Earth incorporated the following land cover categories:

1. **Forest:** Land covered with forest, characterized by a dominance of tree vegetation.
2. **Cropland:** Land that is regularly cultivated (plowed) for the purpose of growing crops. This includes both annual and perennial crops.

3. **Pasture:** Areas of land covered with perennial grasses or forbs. Pastures and permanent pastures include both manicured and unmanicured areas used for grazing livestock.

4. **Wetlands:** Land covered or saturated with water in whole or in part throughout the year. This category encompasses marshes, swamps, bogs, and similar ecosystems.

5. **Settlement:** Land that is part of an urban or rural residential setting. This includes buildings, roads, and associated infrastructure within residential areas.

6. **Other Land:** Land not included in other categories. This residual category encompasses a diverse range of land cover types such as barren land, rock outcrops, and sparsely vegetated areas (Fig 4).

The use of Collect Earth enabled a systematic and consistent approach to ground truth data collection. The tool's ability to overlay high-resolution imagery (e.g., from Google Earth) with plot boundaries and pre-defined classification schemes ensured that the interpreter could accurately and efficiently assign land cover classes to each plot. Furthermore, the integration with Open Foris facilitates data management and analysis, streamlining the process of utilizing ground truth data for land cover mapping and monitoring. The reliance on the IPCC and FAO FRA classification types ensures the comparability of the results with international standards and reporting frameworks.

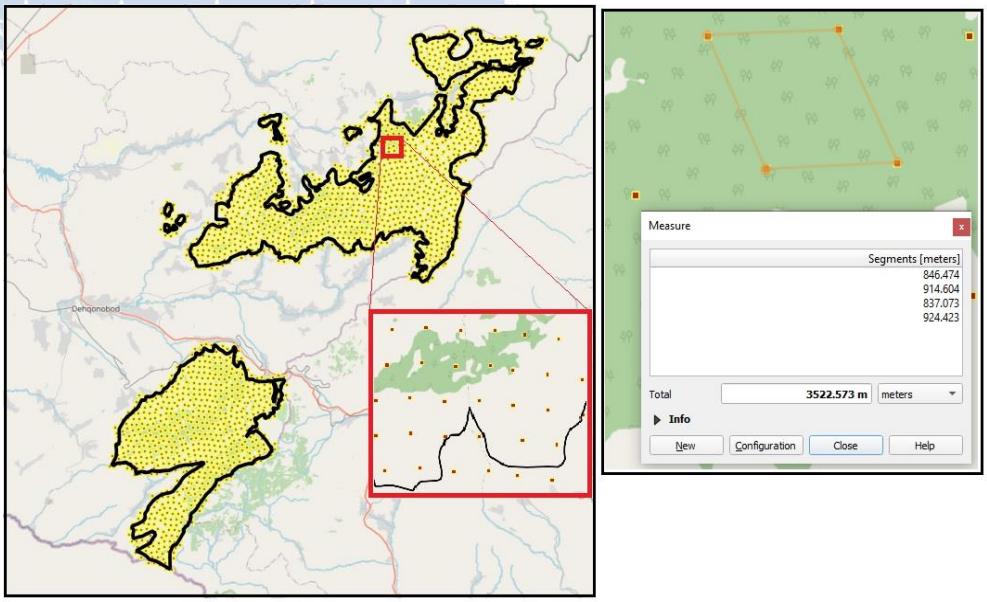


Fig. 3 Generated 0.8 by 0.8 km grid points to be used as Google Earth reference images based on sample area classification.

3. Results

Thematic maps derived from remote sensing images should provide measures of thematic classification accuracy. Commonly used metrics include overall accuracy and bias, errors of omission/commission, user accuracy, producer accuracy, and accuracy

statistics (e.g., Kappa). They are calculated based on a correlation (error) matrix that estimates the correspondence between map classes and validation points (Figure 5).

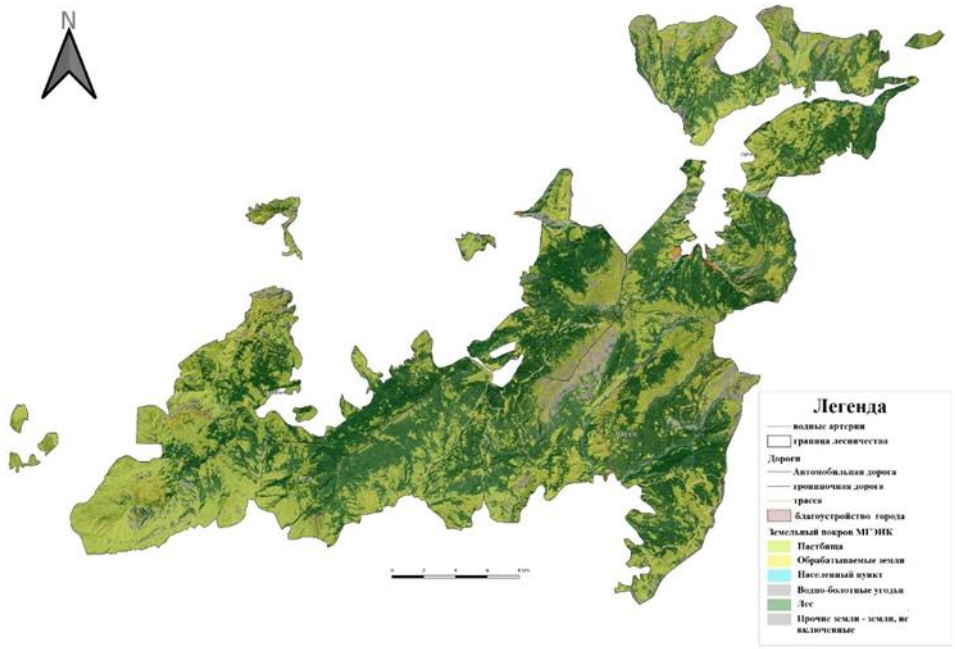


Fig. 5. Map of the land classes of Dekhkanabad forestry.

Table 1. Confusion Matrix for IPCC Land Cover Classification and CollectEarth Points

IPCC Land Cover Class	*Cropland*	*Forest*	*Pasture*	*Settlement*	*Otherland*	*Wetland*	*Classification Class Error*
Cropland	448	0	50	3	2	1	0.11
Forest	2	514	5	1	5	0	0.19
Pasture	33	7	1372	1	31	1	0.09
Settlement	21	2	3	13	1	0	0.73
Otherland	28	1	2	2	6	0	0.47
Wetland	4	1	7	2	1	0	1.00

4. Conclusion

The study demonstrates the effectiveness of OBIA for land cover mapping, achieving high accuracy for a variety of land cover classes, including pasture (91%), cropland (89%), forest (80%) and human settlements (53%). The resulting thematic maps provide valuable information for sustainable land management, forest conservation and environmental planning in Uzbekistan. The OBIA approach has proven particularly useful for accurately identifying land cover types across the diverse landscape of Uzbekistan. Detailed thematic maps produced using this method offer important information for policymakers, researchers and stakeholders involved in land use planning and conservation efforts across the region. The high classification accuracy achieved for key land cover classes highlights the potential of OBIA as a valuable tool to support sustainable development practices and informed decision-making processes in Uzbekistan.

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