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Bridging the national data gap with Google earth engine and landsat imagery by developing annual land cover for Afghanistan

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ABSTRACT

The national-level land cover database is essential to sustainable landscape management, environmental protection, and food security. In Afghanistan, the existing national-level land cover data from 1972, 1993, and 2010 relied on satellite data from diverse sensors adopted three different land cover classification systems. This inconsistent land cover map across the various years leads to the challenge of assessing landscape changes that are crucial for management efforts. To address this challenge, a 19-year national-level land cover dataset from 2000 to 2018 was developed for the first time to aid policy development, settlement planning, and

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the monitoring of forests and agriculture across time. In the development of the 19 year span of land cover data products, a state-of-the-art remote sensing approach, employing a harmonized classification scheme was implemented through the utilization of Google Earth Engine (GEE). Publicly accessible Landsat imagery and additional geospatial covariates were integrated to produce an annual land cover database for Afghanistan. The generated dataset bridges historical data gaps and facilitates robust land cover change information. The annual land cover database is now accessible through https://rds.icimod.org/. This repository ensures that the annual land cover data is readily available to all users interested in comprehending the dynamic land cover changes happening in Afghanistan.

Specifications Table

Subject	National land cover data, geospatial information, Landsat image processing, remote sensing technologies, geographical information systems (GIS), Machine Learning, Monte Carlo simulations, landcover primitives, National Landcover Monitoring System
Specific subject area	Afghanistan's new 19-year land cover database accessible at Regional Database System (RDS)
Type of data	The GEO Tag Image File Format (TIFF) and land cover table
Data collection	Land cover data generation begins by establishing a classification system and its typology. Reference training samples were collected using Collect Earth Online (CEO). Landsat satellite images were pre-processed to create annual image composites, and covariates were chosen for classification. The Random Forest machine learning algorithm was employed to generate land cover primitives, which were then assembled with a Monte Carlo simulation approach into a comprehensive land cover dataset and validated for accuracy.
Data source location	Regional Database System (RDS) Institution: International Centre for Integrated Mountain Development • City/Town/Region: Khumaltar, Lalitpur, Kathmandu • Country: Nepal • Web: www.icimod.org, https://rds.icimod.org
Data accessibility	Repository name: Land cover of Afghanistan Country: Entire Afghanistan Data identification number: doi.org/10.26066/rds.1973187 Direct URL to data: https://rds.icimod.org/DatasetMasters/Download/1973187 Instructions for accessing these data: The land cover data for Afghanistan is available for download from the RDS (https://rds.icimod.org). To access the data, users are required to register on the Regional Database System website, providing minimal basic information. The downloaded land cover information for Afghanistan is provided in GeoTIFF format, accompanied by a metadata file containing essential details such as land cover grid codes and class names. This user-friendly approach ensures easy access to valuable land cover information, facilitating research, analysis, and informed decision-making related to landscapes of Afghanistan.

1. Value of the Data

- Production of the first-ever 19-year national land cover dataset for Afghanistan, offering a comprehensive historical spatial status of evolving landscapes.
- Leveraged GEE for efficient Landsat satellite image analysis, enhancing accuracy in assessing spatial and temporal changes.

- The study conducted a diverse land cover changes across Afghanistan.
- Ensured widespread accessibility of the land cover data, enabling informed decisions by policymakers, researchers, and the public.
- Facilitated extensive dataset use across diverse applications, research, and environmental management efforts, aiding in informed policy decisions and sustainable development initiatives.

2. Background

Land cover, comprising the physical and biological elements of Earth's surface, has continuously evolved since the planet's formation [1]. This dynamic process, extensively studied by researchers, involves spatial changes such as shifts in vegetation cover across landscapes. Driven primarily by human activities, particularly notable in regions like Afghanistan, land use change has accelerated due to population growth and settlement expansion.

In Afghanistan, extensive changes in land cover have been observed, across arable lands, grasslands, forests, and other territories. Around 12% of the land in Afghanistan was arable, with a mere 6% of this being under cultivation, while grasslands covered approximately 45%, and forests constituted just 2%. The diverse ecosystems of Afghanistan are vital for supporting livelihoods, with over 80% of the population depended directly or indirectly on agriculture and ecosystem services. Political influences, natural shifts, and emerging water scarcity continue to heighten the risk to Afghanistan's land cover dynamics [2–4]. The absence of reliable historical land cover data further complicated effective land management, as previous national-level assessments lacked harmonization and standardization. Although national-level land cover assessments using data from various satellite sensors were conducted in 1972, 1993, and 2010, no subsequent annual assessments using a secure and standardized classification system have been conducted. The Food and Agriculture Organization (FAO) produced a 2010 land cover map, yet analyzing change detection is challenging because the 1972, 1993 and 2010 data were derived from different satellite images, classification schemes and methods.

Responding to this gap in harmonized land cover data, Landsat satellite data was leveraged to address this gap, with the primary goal of developing the first comprehensive 19-year national-level land cover dataset for Afghanistan. This effort utilized GEE to analyze spatial and temporal changes across diverse land cover and emphasize the significance of landscape information for understanding patterns. This 19 year data product has laid the foundation for informing policy-making and sustainable land management in Afghanistan.

3. Data Description

As presented in this article, the comprehensive analysis of land cover in Afghanistan offers comprehensive land cover statistics and a detailed land cover map of Afghanistan, with 13 distinct classes as represented in Figs. 1 and 2.

The analysis reveals that Rangeland constitutes the primary land cover in the country, covering 44.58% of the total area in 2018, primarily located in the northern and eastern regions. Barren land follows as the second-largest land cover, predominantly found in the central and southern areas, covering 34.82% of the country. Notably, irrigated agriculture has exhibited a steady increase, expanding from 2.81% in 2000 to 3.30% in 2018, particularly concentrated in the south and southwest. This is likely due to the development of new irrigation systems and increased demand for food crops. Rainfed agriculture is another important type of land cover in Afghanistan. It is particularly important in rural areas, where it is often the only source of livelihood. Rainfed agriculture fluctuates, but generally encompasses around 3% of the land area across the 19 year timeframe. Forest cover has seen a slight increase from 2.88% in 2000 to 3.08% in 2018, predominantly situated in the eastern mountains and along the border with Pakistan.

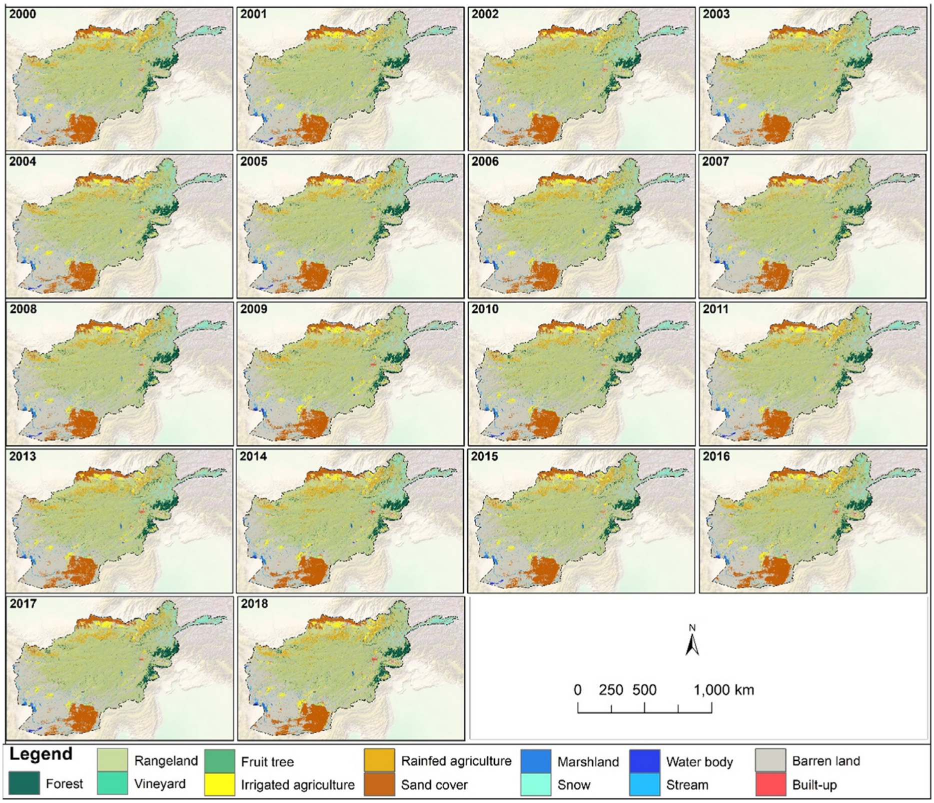

Fig. 1. Land cover maps of Afghanistan spanning the years 2000 to 2018.

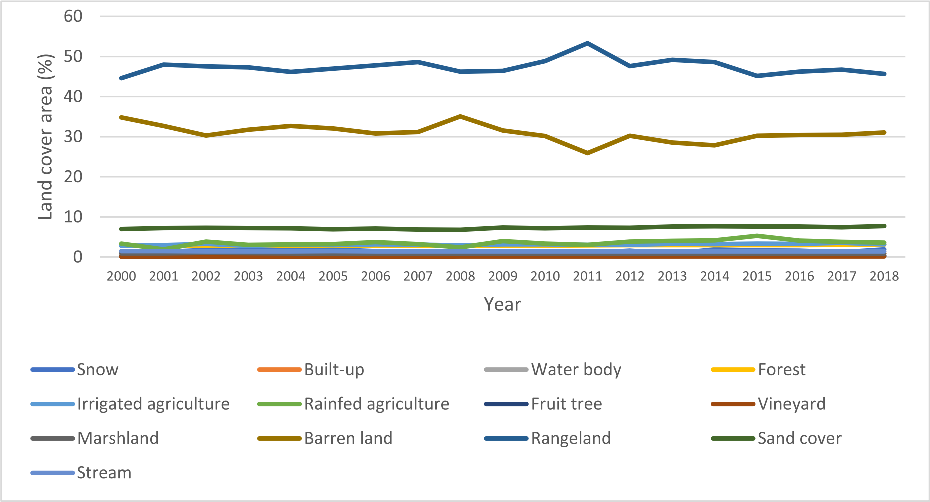

Fig. 2. The land cover between 2000 and 2018 in various categories of Afghanistan.

Other categories, such as snow, built-up areas, water bodies, fruit trees, vineyards, marshland, sand cover, and streams, collectively contribute to the overall land cover composition, despite constituting a smaller percentage.

The change matrix in Table 1 provides further insights. Notably, the forest area remained relatively stable between 2000 and 2018, indicating a balance between deforestation and afforestation. However, the built-up area experienced a significant expansion, increasing from 1841 km^2 in 2000 to 12397 km^2 in 2018, a built-up growth of nearly 570%. This surge in built-up areas suggests factors such as population growth, economic development, infrastructure expansion. The conversion of land from various land cover, including irrigated agriculture, rainfed agriculture, and barren land, underscores the dynamic changes in land use for urban development in Afghanistan.

An accuracy assessment is considered a mandatory step to ensure the reliability and credibility of land cover maps for Afghanistan. In this regard, the most appropriate method is to validate the land cover map using the ground truth data, considered a more authentic reference. High-resolution satellite images were used to collect 6487 samples randomly using Collect Earth Online (CEO). Using 924 reference points, an accuracy assessment of the 2018 land cover was conducted. Data indicates an overall accuracy of 83.89% with a Kappa Statistics of 0.81 (as shown in Table 2). Notably, Rangeland exhibits high user accuracy (93.18%) but comparatively lower producer's accuracy (78.9%), highlighting the precision of classification but potential for misidentification.

4. Experimental Design, Materials and Methods

The land cover data produced methodology utilized for Afghanistan follows an eight-step approach adapted from the Regional Land Cover Monitoring System (RLCMS) developed for the Hindu Kush Himalaya (HKH) region. The process is detailed below:

I) Developed land cover classification system: The land cover data produced process begins with defining a harmonized land cover classification system, involving consultations with relevant government departments to agree upon 13 land cover classes. These classes include snow, water bodies, marshland, forest, rangeland, fruit trees, irrigated agriculture, rainfed agriculture, vineyards, barren land, sand, and built-up areas. All the land cover classed definitions were adopted following the FAO-developed land cover classification system (LCCS).

II) Training sample collection: A total of 41166 reference samples were collected, primarily utilizing a systematic sampling approach with a five km resolution grid. Additionally, 150 points were randomly chosen from small, representative classes to ensure inclusivity and thorough coverage across diverse land cover types. This methodological framework aimed to secure at least 150 sample points for each land cover category. The primary reference data spanned from 2000 to 2018, with particular attention given to recent years. For instance, in 2000, 38048 references were meticulously collected, nearly reaching high-resolution standards, while in 2017, 1467 reference points were found, reflecting the dynamic nature of land cover changes over time. High-resolution satellite images, facilitated by Collect Earth Desktop or Collect Earth Online (CEO), were employed to gather samples from earlier years. CEO's capability to systematically collect reference samples using various satellite images ensured the project's diverse temporal requirements.

III) High-quality training samples, totalling 36843 reference samples, are collected using Collect Earth Online for robust validation through high-resolution satellite imagery [5]. These samples were utilized for both primitive generation and accuracy assessment, ensuring robust validation using high-resolution satellite imagery and various indices.

IV) Image preprocessing: Landsat 5, 7, and 8 satellite images were selected for land cover classification. Image preprocessing involves the selection of Landsat 5, 7, and 8 satellite

Table 1
Land cover change matrix between 2000 and 2018.

Land cover sk^2	Snow	Built-up area	Water body	Forest	Irrigated agriculture	Rainfed agriculture	Fruit trees	Vineyards	Marsh-land	Barren land	Range-land	Sand cover	Stream	Total (2000)
Snow	7485	2	10	0	2	0	0	0	62	918	1005	0	11	9496
Built-up area	0	1587	1	0	137	49	14	20	1	17	11	2	1	1841
Water body	45	3	602	0	27	0	0	0	154	809	6	0	60	1706
Forest	0	3	0	18,134	2	3	1	0	0	57	347	0	1	18,548
Irrigated agriculture	3	448	45	5	10,702	149	331	125	239	5027	815	71	125	18,084
Rainfed agriculture	1	175	1	6	161	10,190	1	1	11	2703	8008	71	29	21,360
Fruit trees	0	2	0	0	14	0	928	0	4	4	1	0	4	958
Vineyards	0	0	0	0	18	0	1	553	0	1	0	0	0	573
Marshland	46	3	447	1	346	16	1	1	4661	152	16	30	34	5753
Barren land	2155	2395	219	313	7412	3402	699	294	133	169,448	30,291	7379	60	224,199
Rangeland	2645	1052	21	1377	1312	9196	15	4	31	17,196	252,531	1666	20	287,067
Sand cover	0	28	6	0	93	8	0	0	3	3450	966	40,398	0	44,953
Stream	17	5	340	3	204	21	2	1	134	28	25	1	8616	9395
Total (2018)	12,397	5703	1692	19,839	20,429	23,033	1992	999	5432	199,811	294,024	49,619	8961	643,932

Table 2
Accuracy assessment report of Afghanistan land cover.

Land Cover	Snow	Built-up area	Water body	Forest	Irrigated agriculture	Rainfed agriculture	Fruit trees	Vineyards	Marsh-land	Barren land	Range-land	Sand cover	Stream	Total	User Accuracy (%)
Snow	126	0	0	1	0	0	0	0	0	7	3	0	0	137	91.97
Built-up area	0	427	0	2	32	15	10	2	1	46	32	0	0	567	75.31
Water body	0	0	61	0	0	0	0	0	11	1	0	0	2	75	81.33
Forest	0	0	0	933	1	3	0	0	0	46	116	0	0	1099	84.90
Irrigated agriculture	0	0	0	0	424	3	7	7	11	70	13	0	0	535	79.25
Rainfed agriculture	0	0	0	0	1	238	0	0	1	37	106	0	0	383	62.14
Fruit trees	0	1	0	0	25	0	270	11	1	73	2	0	0	383	70.50
Vineyards	0	0	0	0	15	0	8	203	0	58	0	0	0	284	71.48
Marshland	4	0	8	0	8	0	2	0	309	0	2	0	0	333	92.79
Barren land	8	0	0	0	2	0	0	0	0	851	63	0	0	924	92.10
Rangeland	2	0	0	4	0	7	1	0	1	80	1297	0	0	1392	93.18
Sand cover	0	0	0	0	1	1	0	0	0	61	9	294	0	366	80.33
Stream	0	0	0	0	0	0	0	0	0	0	0	0	9	9	100
Total	140	428	69	940	509	267	298	223	335	1330	1643	294	11	6487	
Producer Accuracy	90.00	99.77	88.41	99.26	83.30	89.14	90.60	91.03	92.24	63.98	78.94	100	81.82		

images, with various steps like cloud masking, shadow masking, and topographic correction applied to enhance data quality [6,7].

V) Annual satellite image composites and covariate generation: Annual satellite image composites are prepared, incorporating band percentiles and around 80 covariates, essential for better differentiating land cover primitives.

VI) Generation of primitives and smoothing: Each land cover primitive, representing mappable biophysical elements, was generated using a Random Forest classifier for each year. Temporal Smoothing Algorithms are employed to prioritize covariates for each primitive layer. Temporal Smoothing Algorithms proposed by Khanal, Matin, Uddin, Poortinga, Chishtie, Tenneson and Saah [8] were implemented as a time series land cover data statistics often fluctuate abruptly due to seasonal impact and other noise in the input image.

VII) Incorporation of tree canopy cover, canopy height and other layers: Data on tree canopy cover and height were obtained from the Global Land Analysis and Discovery Lab (GLAD) and calibrated using tropical airborne lidar data. These annual dynamics of woody vegetation structure were integrated into the mapping process [9,10] along with external layers such as with external layers such as SRTM DEM [11], glacier data [12], Normalized Difference and Distance Built-up Index (NDDBI) [13], OpenStreetMap [14] and tree canopy cover and height [15] were used in the land cover assemblage process.

VIII) Land cover assemblage: Generated primitives and external layers were used in the land cover assemblage process. A decision tree classifier was applied to classify each pixel and generate the final land cover map.

IX) Accuracy assessment: In remote sensing-based land cover mapping, the accuracy evaluation process can be defined as evaluating the agreement between the reference sample and the classified image. Classification error occurs when a pixel (or feature) belonging to one category is assigned to another category. Accuracy can be assessed using qualitative methods through visual interpretation and quantitative evaluation based on statistical methods. For quantitative accuracy assessment, an error matrix method is widely used.

Limitations

Creating confidence with partner agencies for robust land cover mapping was challenging, requiring multiple consultations, and training to shift from traditional methods. Co-development and partnership were crucial, yet political complexities in Afghanistan hindered the official release of land cover data. Data is disseminated through the International Centre for Integrated Mountain Development’s regional database system (https://rds.icimod.org/). Challenges included obtaining spatially distributed training samples due to constraints like historical satellite image shortages, field data collection limitations, and the 30-meter resolution of Landsat images. Besides, the tendency of comparing 30-meter resolution land cover data with Google Earth images is common with many data users, it’s not always practical due to variations in image dates and scales. Additionally, Google Earth images are not a thematic layer for comparing different types of images with different resolutions of land cover data. Therefore, caution should be exercised when comparing the satellite image and land cover data sources, considering their limitations and potential discrepancies. The land cover mapping project aimed to generate annual data from 2000 to 2018, but the absence of sufficient Landsat imagery hindered the creation of a land cover map for 2012.

Ethics Statement

The study has not conducted human or animal experiments or collected social media data.

Declaration of Competing Interests

The views and interpretations in this publication are those of the authors. They are not necessarily attributable to ICIMOD and do not imply the expression of any opinion by ICIMOD concerning the legal status of any country, territory, city, or area of its authority, or concerning the delimitation of its frontiers or boundaries, or the endorsement of any product.

Data Availability

Land cover of Afghanistan (Original data) (Land cover of Afghanistan)

CRediT Author Statement

Kabir Uddin: Conceptualization, Methodology, Data curation, Formal analysis, Validation, Investigation, Supervision, Writing – review & editing; **Sayed Burhan Atal:** Data curation, Formal analysis, Validation, Writing – review & editing; **Sajana Maharjan:** Data curation, Formal analysis, Validation; **Birendra Bajracharya:** Conceptualization, Methodology, Project administration, Funding acquisition, Writing – review & editing; **Waheedullah Yousafi:** Conceptualization, Methodology, Writing – review & editing; **Timothy Mayer:** Project administration, Funding acquisition, Writing – review & editing; **Mir A. Matin:** Conceptualization, Methodology, Project administration, Funding acquisition, Supervision, Writing – review & editing; **Bandana Shakya:** Project administration, Funding acquisition, Writing – review & editing; **David Saah:** Conceptualization, Methodology, Writing – review & editing; **Peter Potapov:** Conceptualization, Methodology, Writing – review & editing; **Rajesh Bahadur Thapa:** Writing – review & editing; **Bikram Shakya:** Visualization, Data curation, Writing – review & editing.

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