BD Open LULC Map: High-resolution land use land cover mapping & benchmarking for urban development in Dhaka, Bangladesh

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Introduction & Motivation

Importance of LULC Mapping: Significantly enhances reliability, aids understanding of geography, socio-economic conditions, poverty, and urban sprawl.

Challenges in Developing Countries:

- **Scarcity of annotated satellite data:** Due to limited funding, diverse infrastructures, and dense populations.
- **Low-resolution imagery:** Inadequate for dense, unstructured urban areas.
- **Domain shift:** Models trained on developed regions fail due to differences in building materials, landscapes, etc.
- **Coarse annotations:** Existing datasets for Bangladesh have coarse annotations, leading to misclassified pixels.

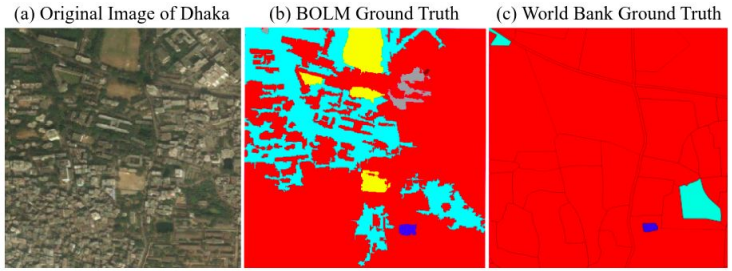

Fig. 1: Comparison between World Bank and BOLM Ground Truth

Existing Datasets and Limitations

- **Limitations of High-Quality Datasets:**
  - Datasets from developed countries (e.g., Potsdam, Vaihingen, GID) often fail when applied to developing countries due to domain shift.
  - UAV-based datasets (e.g., OpenEarthMap) are costly and limited in developing regions.
- **Limitations of Regional Datasets:**
  - Most datasets from this region (e.g., IndiaSat, Hanoi) use low-resolution imagery (10-30m), which is insufficient for dense urban areas.
  - Datasets like the World Bank's urban mapping of Dhaka have coarse annotations, merge key categories, and are often not publicly available.

Our Contribution: BD Open LULC Map (BOLM)

- **Introduction of BOLM:** A novel dataset providing pixel-wise LULC annotations.
- **Key Features:**
  - Covers Dhaka metropolitan city and surroundings, spanning 4,392 km^2 (891 million pixels).
  - Uses high-resolution Bing satellite imagery (2.22 m/pixel).
  - Includes eleven LULC classes (e.g., Farmland, Water, Forest, Urban Structure, Rural Built-Up).
  - Ground truth validated through a rigorous three-stage process involving GIS experts.

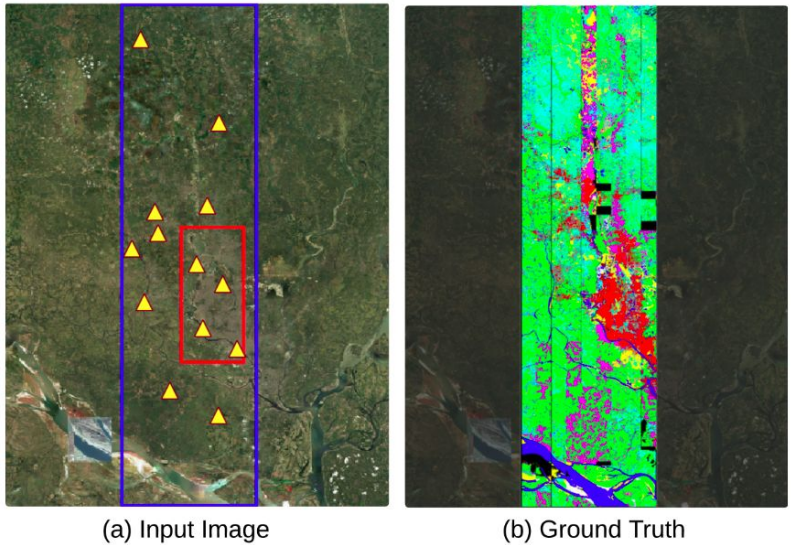

Fig. 2: Example of the Bing input image and its corresponding high-resolution ground truth created for the BOLM dataset.

Dataset Creation: Data Sources

- **Bing Imagery:**
  - High-resolution aerial imagery (2.22 m/pixel) from 17 zoom levels.
  - Acquired April 20, 2019.
  - Serves as high-quality ground truth for accurate LULC segmentation.
- **Sentinel-2A Data:**
  - Acquired April 11, 2019.
  - Includes 12 spectral bands with resolutions from 10m to 60m per pixel.
  - Used for experiments with various band combinations and index images.
  - Channels like NIR and SWIR enhance LULC mapping.

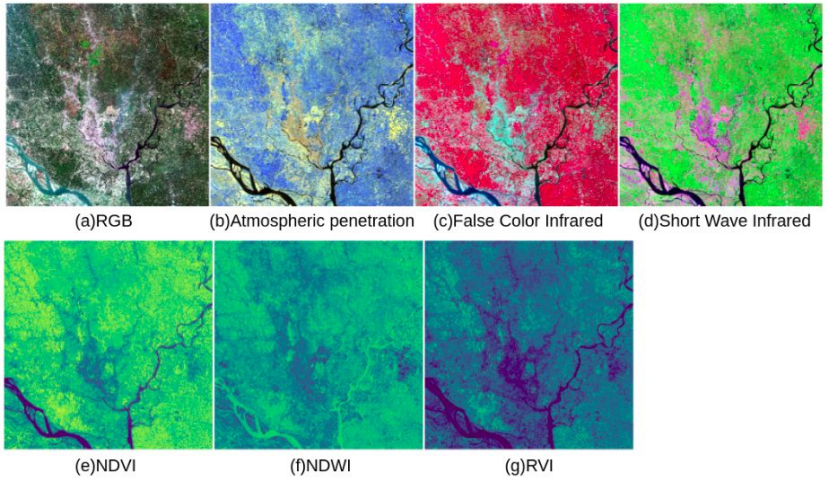

Fig. 3: Combination and Index images generated from Sentinel-2 multispectral bands

Dataset Creation: Ground Truth Annotation

- **Annotation Process:**
  - The large Bing image (48,906 x 47,256 pixels) divided into 1,089 sub-images (1,500 x 1,500 pixels).
  - 24 annotators classified polygons using eCognition software and a rule-based approach.
  - Multi-resolution segmentation and merging of adjacent polygons applied.
  - Annotators received training and expert clarification.

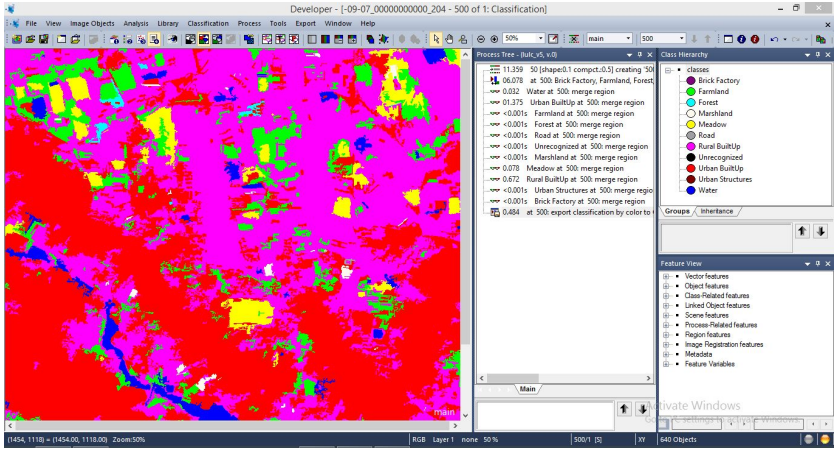

Fig. 5: A screenshot of the eCognition software showing the polygon-based ground truth annotation process.

Dataset Creation: Validation & Data Reliability

- **Three-Stage Validation Process:**
  - Stage 1: Two annotator groups independently labeled, with pixel-wise agreement highlighting disagreements.
  - Stage 2: Refined disagreement regions through manual corrections.
  - Stage 3: GIS experts validated the dataset, achieving over 99% agreement for most classes.
- **In Situ Visual Assessment:** On-site validation conducted in Dhaka Division, visiting 13 diverse locations.

Fig. 6: Various Regions on the Dhaka Division.

Class Consolidation

- **Conversion from 11 to 6 Classes:** Due to class imbalance, 11 initial classes were merged into 6 broader categories.
- **Final Class Distribution:**
  - Farmland (39%)
  - Water (6%)
  - Forest (21%)
  - Built-up (19%) (merged Urban Structure, Rural Built-up, Urban Built-up, Brick Factory)
  - Meadow (11%) (merged Meadow and Marshland)
  - Unrecognized (4%)

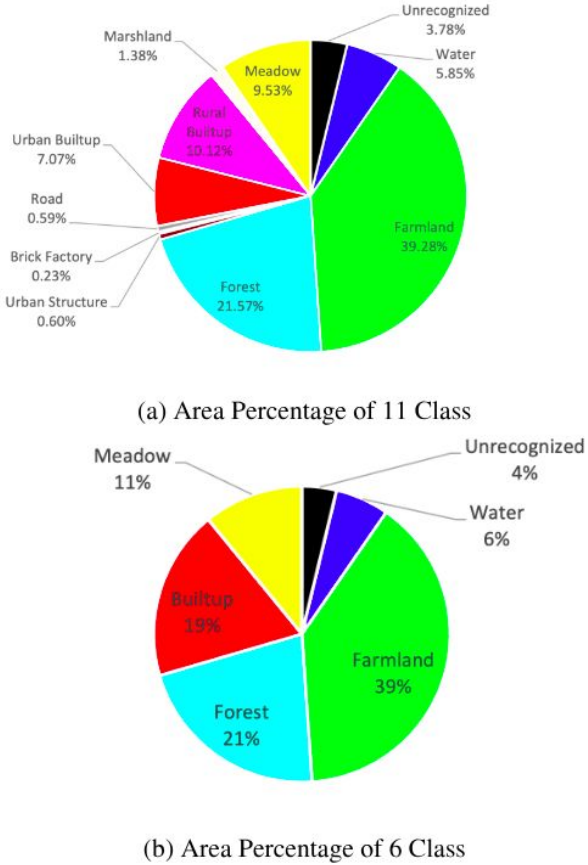

Fig. 6: Area Percentage of the 11 class and 6 class dataset.

Image Processing for Satellite Data

- **Sentinel-2A Index and Combination Images:**
  - 12 spectral bands combined for segmentation.
  - Index images (NDVI, NDWI, RVI) and various combinations generated (e.g., ATM, FCI, SWI).
  - Channels upsampled to 10m/pixel using bilinear interpolation.
- **Bing RGB Image Processing:**
  - High-quality ground truth for accurate LULC segmentation.
  - High resolution (2.22m/pixel) enables precise annotation but increases processing time.

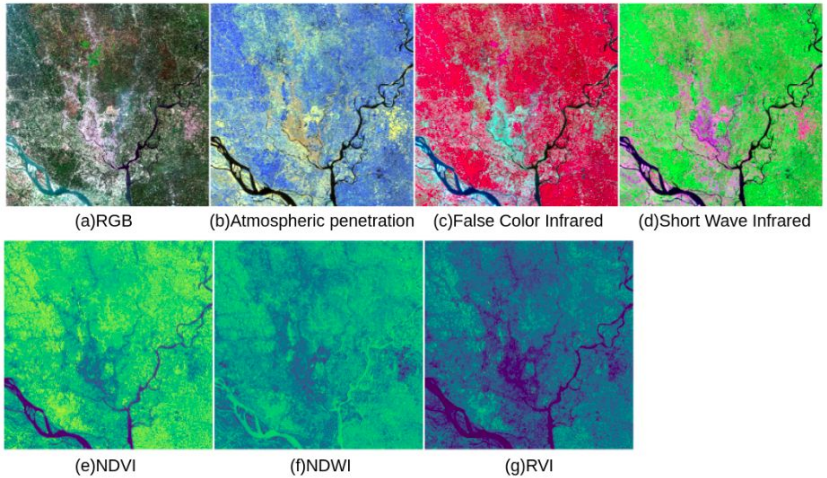

Fig. 7: Combination and Index images generated from Sentinel-2 multispectral bands

Experimental Setup

- **Model:** DeepLabV3+, an advanced encoder-decoder with atrous convolution for semantic segmentation.
  - Input & Patching:
  - Images split into 513x513 patches.
- Training uses a sliding window with 75% overlap; testing uses non-overlapping patches.
- **Training/Testing Regions:** Dhaka city region (red rectangle) for test set; surrounding areas (blue rectangle) for training.
- **Experimental Settings (per image type):**
  - Batch size: 8.
  - Epochs: 25.
- **Evaluation Metrics:** IoU and F1 scores (accuracy not used due to class imbalance bias).

Results - Index and Channel-Combined Images

Key Finding:

- NDWI performs best for Forest and Water.
- NDVI outperforms for Built-up and Farmland.
- SWI generally achieves the highest average IoU and F1 score among Sentinel-2A combinations.

	Metric	Forest	Built-Up	Water	Farmland	Meadow	Avg
NDVI	IoU	0.17	**0.52**	**0.68**	**0.35**	**0.51**	**0.30**
	F1	0.17	**0.68**	0.27	**0.51**	0.50	**0.45**
NDWI	IoU	**0.20**	0.38	0.24	0.34	0.28	0.28
	F1	**0.32**	0.55	**0.38**	0.51	0.50	0.43
RVI	IoU	0.13	0.50	0.17	0.31	0.36	0.29
	F1	0.22	0.66	0.29	0.47	**0.52**	0.43
ATM	IoU	0.17	**0.56**	0.29	**0.48**	0.19	0.33
	F1	0.29	**0.72**	0.45	**0.64**	0.31	0.48
FCI	IoU	0.20	0.53	0.30	0.46	0.17	0.33
	F1	0.33	0.69	0.45	0.62	0.29	0.47
SWI	IoU	**0.22**	0.56	**0.32**	0.46	0.22	**0.35**
	F1	**0.35**	0.71	**0.48**	0.62	0.37	**0.50**
SentinelRGB	IoU	0.18	0.54	0.30	0.46	**0.25**	0.34
	F1	0.30	0.70	0.46	0.63	**0.40**	0.49
BingRGB	IoU	0.33	0.58	0.48	0.57	0.26	0.44
	F1	0.49	0.73	0.65	0.72	0.41	0.60

Tab. 1: Scores for 5 classes of all the image types

Results - Bing RGB Image & Overall Comparison

Key Finding:

- Model with full Bing RGB image significantly outperforms other models, achieving the highest average IoU and F1 score.
- A trade-off exists between precision (Bing) and accessibility/multi-channel data (Sentinel-2A).

	Metric	Forest	Built-Up	Water	Farmland	Meadow	Avg
NDVI	IoU	0.17	**0.52**	**0.68**	**0.35**	**0.51**	**0.30**
	F1	0.17	**0.68**	0.27	**0.51**	0.50	**0.45**
NDWI	IoU	**0.20**	0.38	0.24	0.34	0.28	0.28
	F1	**0.32**	0.55	**0.38**	0.51	0.50	0.43
RVI	IoU	0.13	0.50	0.17	0.31	0.36	0.29
	F1	0.22	0.66	0.29	0.47	**0.52**	0.43
ATM	IoU	0.17	**0.56**	0.29	**0.48**	0.19	0.33
	F1	0.29	**0.72**	0.45	**0.64**	0.31	0.48
FCI	IoU	0.20	0.53	0.30	0.46	0.17	0.33
	F1	0.33	0.69	0.45	0.62	0.29	0.47
SWI	IoU	**0.22**	0.56	**0.32**	0.46	0.22	**0.35**
	F1	**0.35**	0.71	**0.48**	0.62	0.37	**0.50**
SentinelRGB	IoU	0.18	0.54	0.30	0.46	**0.25**	0.34
	F1	0.30	0.70	0.46	0.63	**0.40**	0.49
BingRGB	IoU	0.33	0.58	0.48	0.57	0.26	0.44
	F1	0.49	0.73	0.65	0.72	0.41	0.60

Tab. 1: Scores for 5 classes of all the image types

Conclusion

- **Introduced BOLM Dataset:**
  - High-resolution, pixel-wise LULC ground truth for Dhaka (4,392 sq km), covering 11 classes.
- **Benchmarking Results:**
  - Bing's high-resolution imagery consistently outperforms Sentinel-2A for LULC classification.
- **Key Findings:**
  - Highlighted trade-offs between precision (Bing) and accessibility/multi-channel data (Sentinel-2A).

Thank You