Rapid Urbanization in Bali's Tourism Hotspots (2017-2024) Using AI-based Satellite Embedding Analysis

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ABSTRACT

Bali's rapid tourism-driven growth has transformed its landscapes at an unprecedented pace. Tourism contributes approximately 44% of the province's regional income, with development concentrated in coastal hotspots such as Canggu, Seminyak, and Kuta. While this growth sustains the local economy, it also accelerates the conversion of agricultural land and green spaces into built-up areas, raising concerns about sustainability, cultural preservation, and environmental resilience. Conventional urbanization studies often rely on optical remote sensing approaches that are highly sensitive to cloud cover, seasonal variation, and sensor noise. Moreover, land cover data has not been easily accessible in developing countries, making it difficult to do consistent long-term monitoring. Recent advances in artificial intelligence offer an alternative: AI-based satellite embeddings provide a multi-dimensional representation of surface conditions that is less affected by these limitations and can detect subtle land cover changes over time (Brown et al. 2025).

To this end, we propose an AI-based embeddings approach to analyse agricultural land conversion in Bali tourism hotspots between 2017 and 2024. It aims to answer how agricultural land has changed over this period, to what extent farmland has been converted into built-up areas compared to other land cover transitions, and whether AI-based satellite embeddings can serve as an effective tool for monitoring land cover change. Furthermore, the development of such an accessible tool is particularly important in the Indonesian context. Official government land cover data, known as *Data Tutupan Lahan* is often complicated to access for the public. This creates a significant challenge for those who need information on land use trends. Our study shows the potential of this embedding-based model to be a helpful tool that can act as a quick substitute. It could empower groups like local journalists, small environmental NGOs, or independent researchers to conduct their own analysis of terrain changes without being dependent on slow bureaucratic processes.

This study applies Google DeepMind's Satellite Embedding V1 dataset to quantify urban expansion in six village administrative districts in Bali: Ubud, Pererenan, Munggu, Cemagi, Tibubeneng, and Canggu from 2017 to 2024 (Brown et al. 2025). These areas were selected due to their varying degrees of tourism development and rapid land use changes. For detecting land cover changes, the embeddings allow a robust comparison across years while minimizing false changes from seasonal effects or sensor noise. The land cover was classified into four categories, agriculture, built, water, and others. Agriculture refers to rice fields, plantations, and other cultivated land. Built refers to built-up area such as housing, commercial area, tourism facilities and other supporting infrastructures. Water includes river, lakes and other permanent water bodies. Others encompass non-agricultural open land and vegetation, such as dry fields, grasslands, shrubs and bare soil. For each class, we select around 100 samples as training data.

We used a supervised k-Nearest Neighbours (kNN) classifier, where labeled examples are used to cluster the embedding space, assigning a label for each pixel based on the label of its closest neighbor in the embeddings space. A key advantage of the embeddings dataset is its suitability for low-shot learning, allowing high-quality classification with only a small number of labelled samples. The trained classifier was applied to satellite image embeddings from 2017 and 2024 in Google Earth Engine to produce consistent land cover maps. By comparing the classified maps, changes over seven years period were identified through pixel-level transitions, conducted in ArcGIS Pro. This process allows us to determine not only the extent of land cover transformation but also the specific transitions between categories (agriculture to built, agriculture to others). Overall, this approach provides a cost-effective

and accessible method for monitoring urban expansion, particularly valuable in developing country contexts.

The land cover classification achieved high reliability, with an overall accuracy of 92.4% and a Kappa coefficient of 0.89, indicating strong agreement between the predicted and reference data. This performance was achieved with a relatively small training dataset of only 100 samples per class, showing the effectiveness of the embedding-based classification approach. The confusion matrix shows that most misclassifications occurred between the agriculture and built categories, as well as between built and others, which is expected in a rapidly urbanizing landscape where land use boundaries are often blurred. Despite these overlaps, the classifier performed consistently well across all four categories, providing a robust basis for subsequent change detection analysis.

The land cover analysis between 2017 and 2024 reveals distinct spatial patterns across the seven study villages, as can be seen in Table 1 and figure 1. The land conversion from agricultural to built-up area experiences the largest change, particularly in Pererenan (18.74%), Canggu (15.50%), and Tibubeneng (14.51%). These findings highlight the strong development pressure in the tourism-driven southern coastal belt. By contrast, Ubud recorded a more modest agriculture-to-built conversion with 5.85% of its total area. Conversion from agriculture “other” land cover types (e.g., non-productive land) was also notable, especially in Pererenan (10.27%) and Munggu (8.83%), suggesting that agricultural land abandonment is not always followed directly by construction, but may remain as transitional or underutilized space.

By comparing our results to a relevant study (Yasada et al. 2024), we observed both similarities and important differences in Canggu Village. Their study, which used visual interpretation of Landsat images, also confirmed the major trend of land conversion to settlements. Our figure for the total settlement area is very close to theirs, with only a 1.96% difference, which reinforces the conclusion of rapid urban development in Canggu. However, a significant discrepancy appears in the classification of non-built-up land. Our model identified 32.15% less area as rice fields. In contrast, it classified a considerably larger area (+318.69%) as 'Village Forest & Open Land'.

Table 1. The result of land cover analysis.

Land cover change	Area (ha)						
	Canggu	Cemagi	Munggu	Pecatu	Pererenan	Tibubeneng	Ubud
Agriculture to built	86.73	66.14	81.35	0.46	48.64	98.13	38.64
Agriculture to others	44.90	27.28	59.30	6.05	26.66	55.58	29.61
Built to agriculture	0.32	0.57	0.50	0.33	0.06	0.42	14.09
Built to others	6.35	2.98	3.08	90.72	3.87	8.70	33.02
Others to agriculture	1.42	2.18	2.00	0.77	0.68	3.83	4.04
Others to built	59.33	11.44	11.30	528.39	40.58	71.17	20.21
Stable	360.29	357.38	513.18	1950.02	138.77	437.72	520.86
Total	559.34	467.98	670.70	2576.74	259.28	675.54	660.48

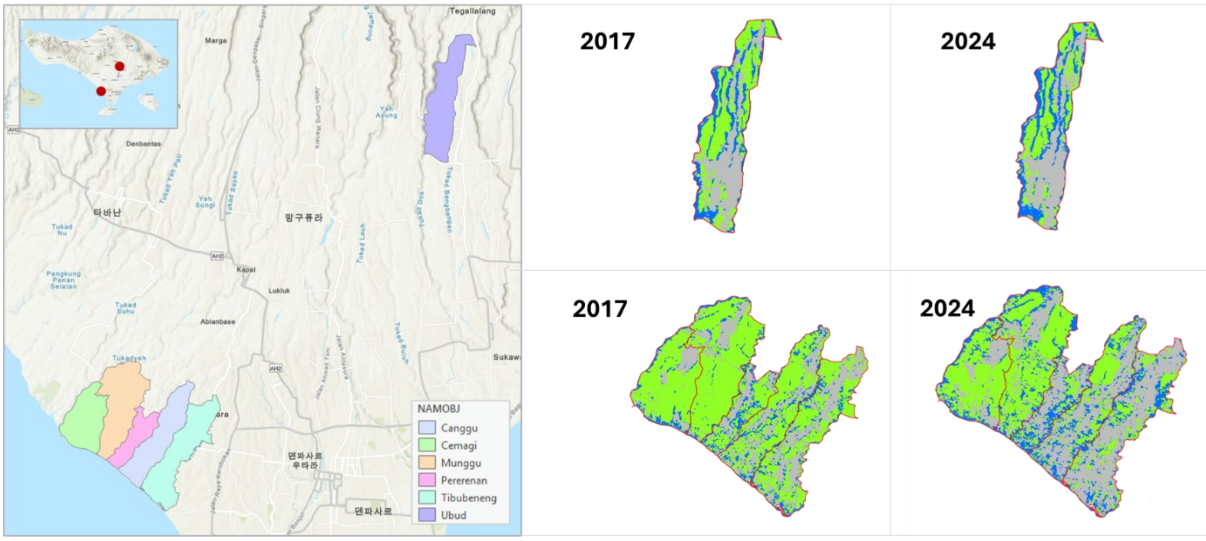

Figure 1. The land cover analysis.

Keywords: *Land cover change, urban expansion, spatial analysis, sustainability, land conversion*

References

Brown, Christopher F., Michal R. Kazmierski, Valerie J. Pasquarella, William J. Rucklidge, Masha Samsikova, Chenhui Zhang, Evan Shelhamer, Estefania Lahera, Olivia Wiles, Simon Ilyushchenko, Noel Gorelick, Lihui Lydia Zhang, Sophia Alj, Emily Schechter, Sean Askay, Oliver Guinan, Rebecca Moore, Alexis Boukouvalas, and Pushmeet Kohli. 2025. "AlphaEarth Foundations: An Embedding Field Model for Accurate and Efficient Global Mapping from Sparse Label Data."

Suyadnya, I. Wayan, Rusli Cahyadi, Luh Ayu Tirtayani, and Astrida Fitri Nuryani. 2025. "Overtourism Sensitivity and Tourism Development in Canggu, Bali." *Cogent Social Sciences* 11(1):2521364. doi:10.1080/23311886.2025.2521364.

Yasada, Gede, Evin Yudhi Setyono, Made Sudiarsa, and I. Made Tapa Yasa. 2024. "Analysis of Land Use Changes Based on Visual Interpretation Results of Satellite Images (Case Study: Canggu Village, North Kuta District, Badung Regency, Bali)." Pp. 153–62 in Proceedings of the International Conference on Sustainable Green Tourism Applied Science - Engineering Applied Science 2024 (ICoSTAS-EAS 2024). Vol. 249, Advances in Engineering Research, edited by A. A. N. G. Sapteka, I. G. L. M. Parwita, I. K. Wiratama, F. Moi, K. W. Widantha, E. Septevany, D. A. I. C. Dewi, W. E. Mariani, and R. N. Fakhrurozi. Dordrecht: Atlantis Press International BV.