
Photo Credit: European Space Agency

Classifying Urban Land in Indonesia Using Convolutional Neural Networks

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MUSA 6500 Geospatial Machine Learning in Remote Sensing
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April 2023

Introduction

Problem Statement

- Between 2000 and 2014, Indonesian cities expanded by 3.9%, or 6,904 km^2—more than the land area of Bali
- Compact and transit-oriented development in secondary cities—especially in developing countries—are important policy levers to maximize climate action and economic development
- **Benchmark datasets for land cover often do not include spatial patterns of developing countries and require high computational resources to manipulate, creating challenges to tracking urban expansion in rapidly urbanizing areas**

Study Design

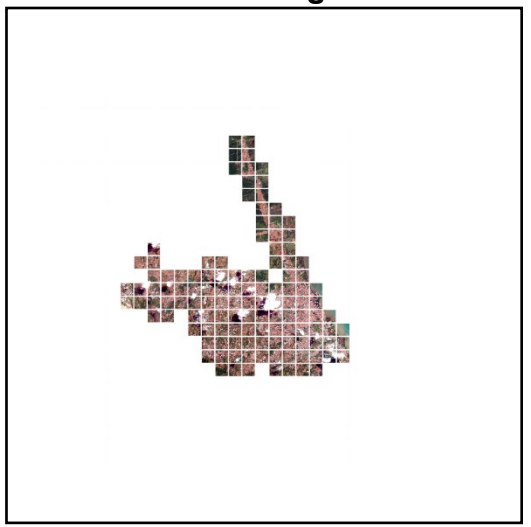
- We create a novel dataset of 1,424 tiles using Sentinel-2 satellite imagery georeferenced to Cirebon
- We pilot three CNN algorithms to classify urban land and visualize urban expansion

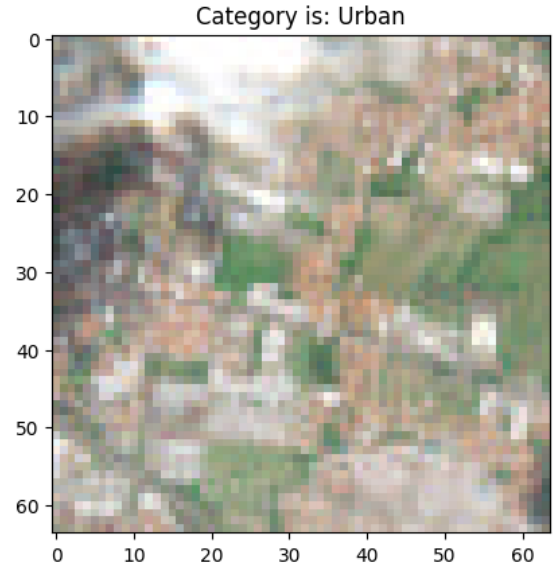
Data: Tile Creation and Labeling

2022 Sentinel-2 image of Cirebon

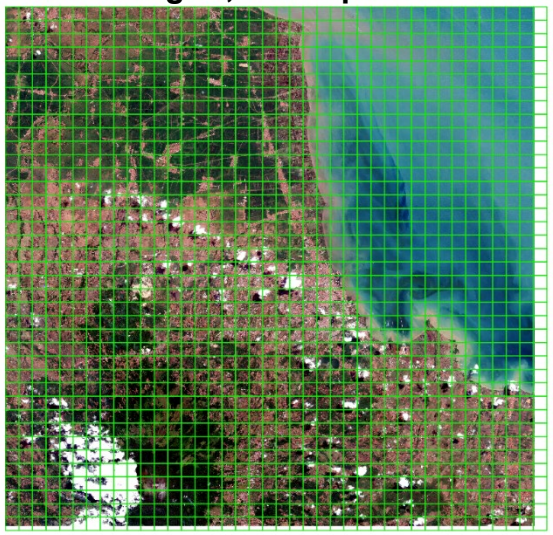
2014 urban boundary of Cirebon

114 urban image tiles

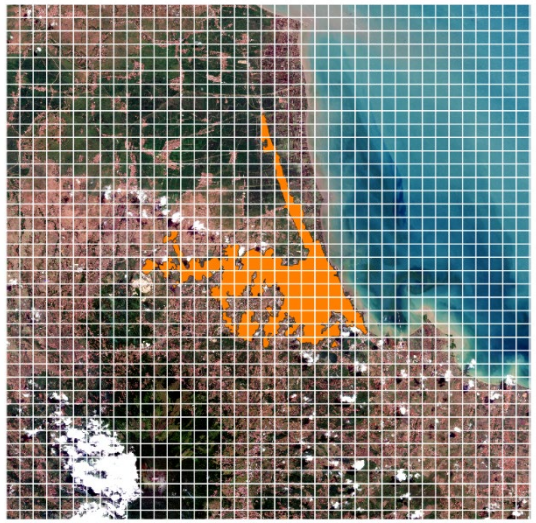




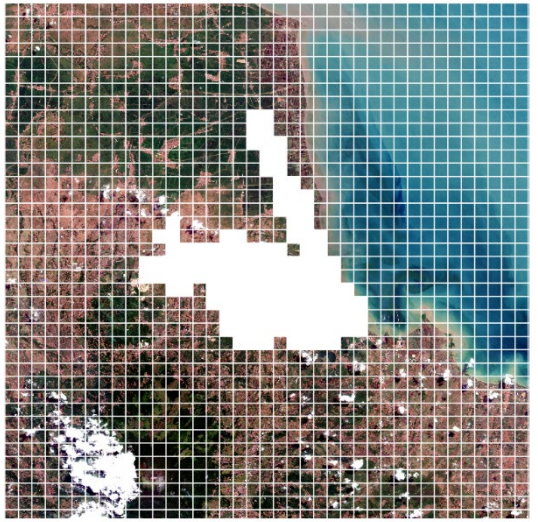
Tile grid, 64x64 pixels

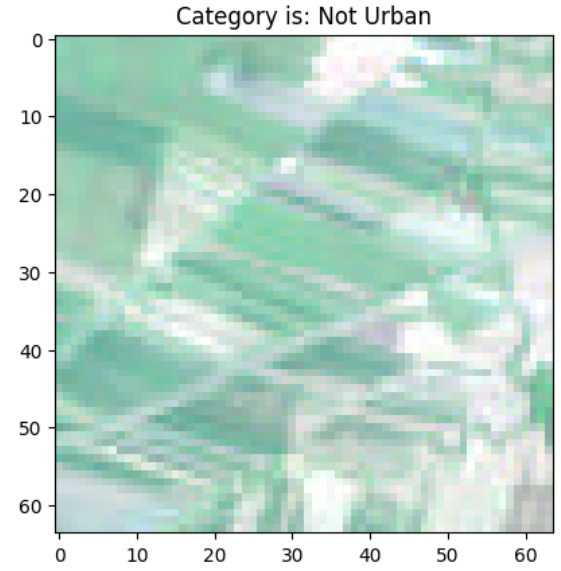


Intersects join polygon to grid



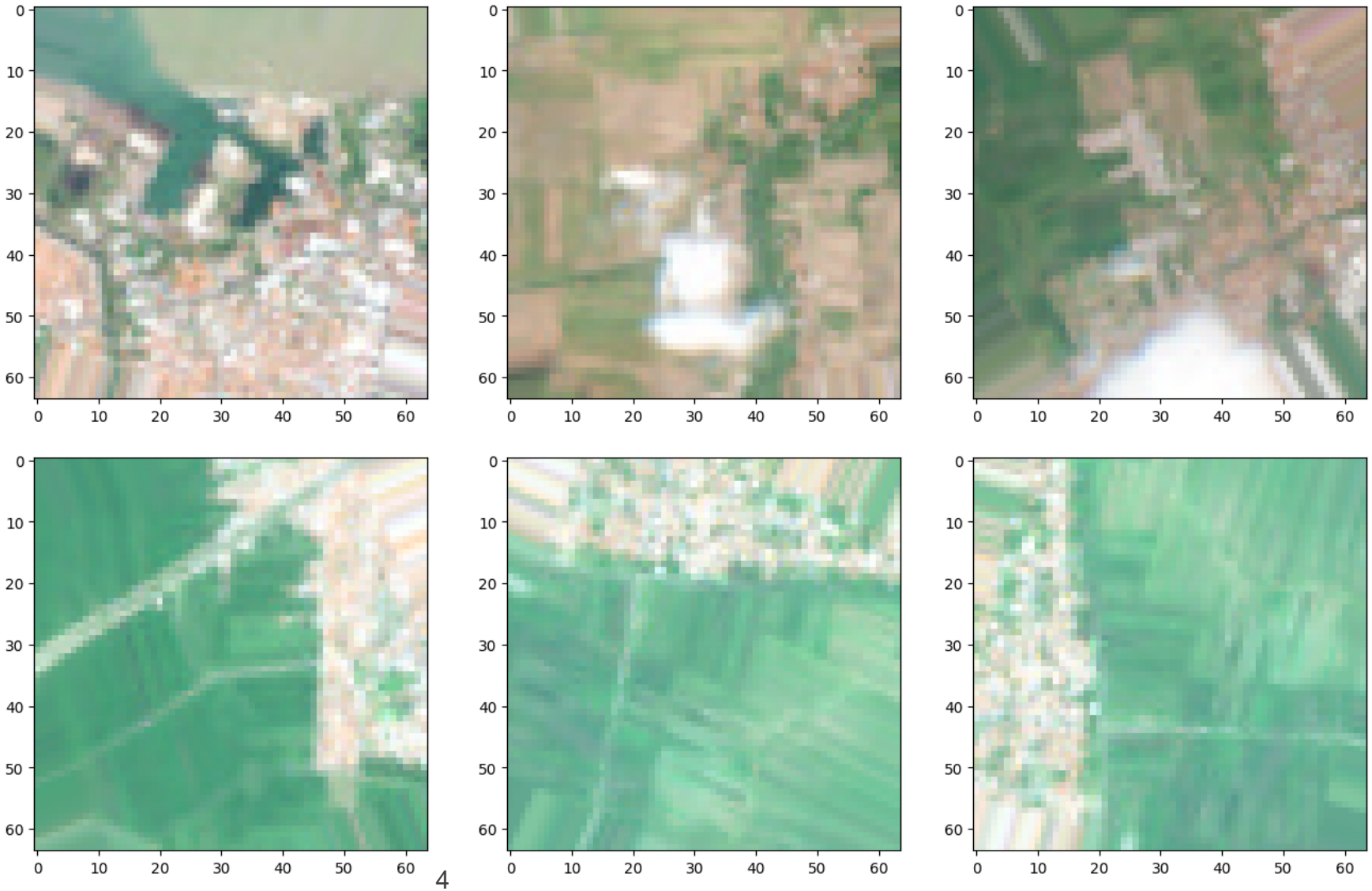
1,310 non-urban image tiles





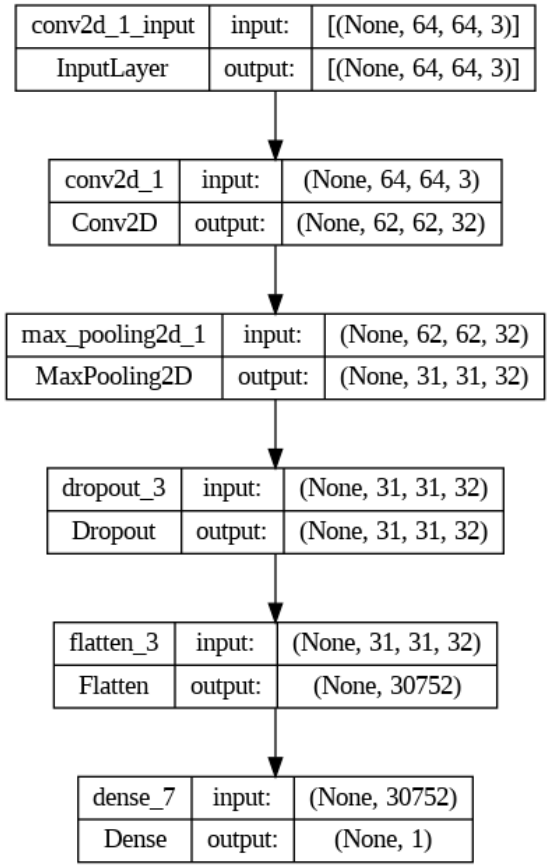
Data: Data Augmentation

- **Balanced dataset of 228 total image tiles**
  - 114 urban
  - 114 non-urban (randomly selected)
- **Data augmentation of both urban and non-urban image tiles**

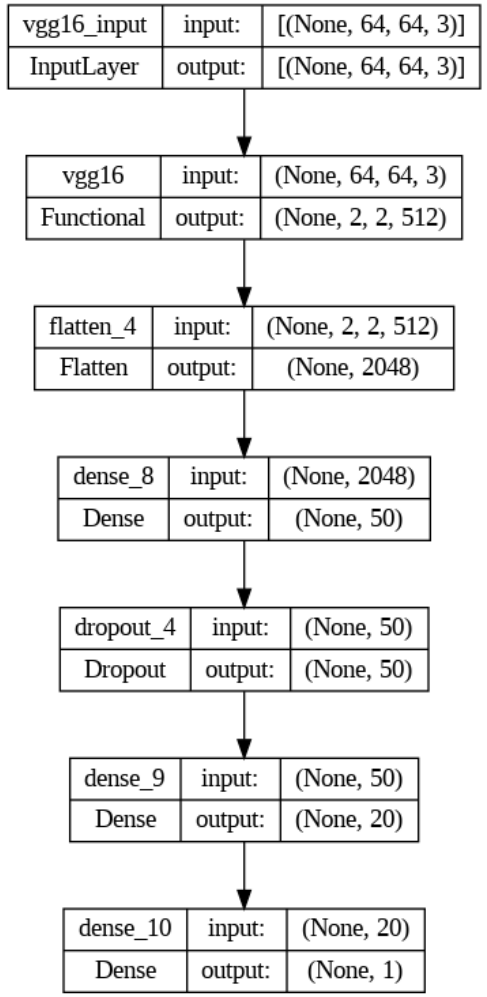


Methods

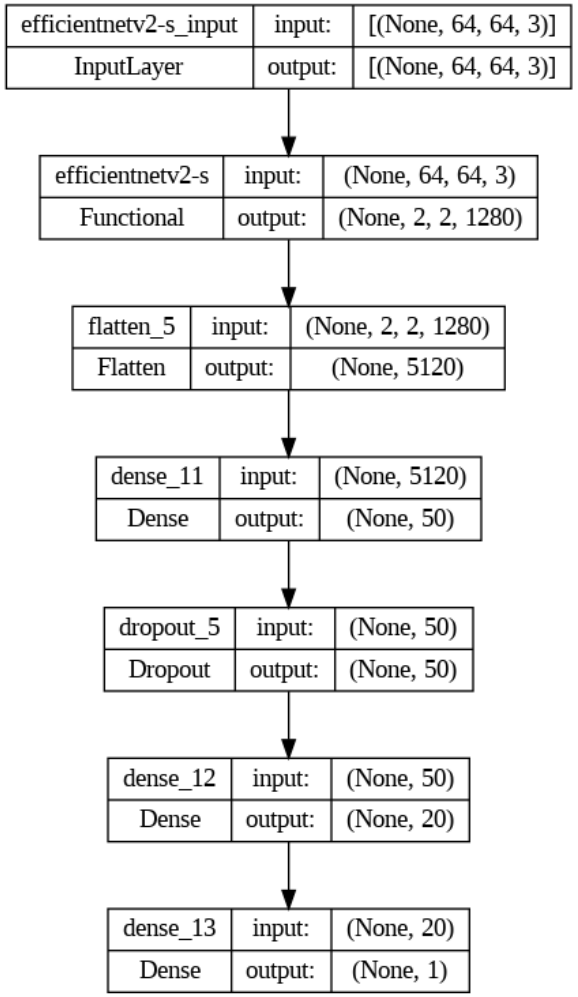
CNN



Customized VGG16



Customized EfficientNetV2

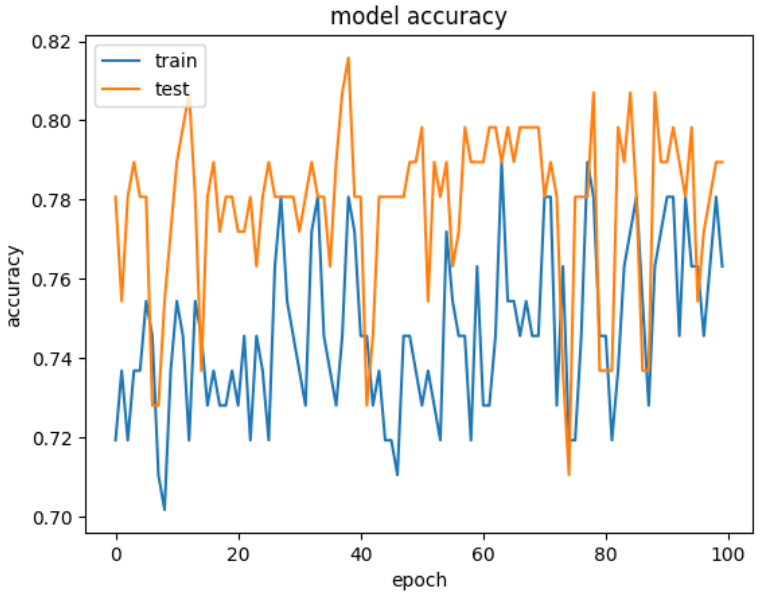


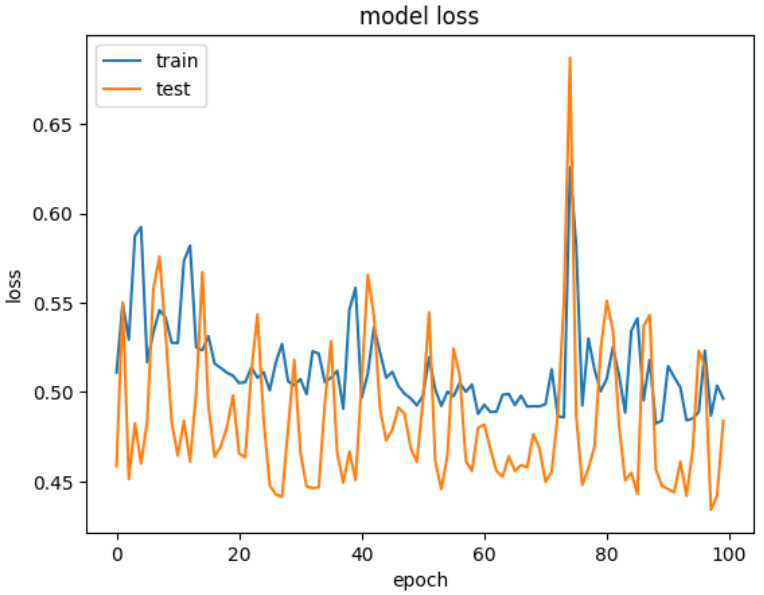
Results: Model Comparison

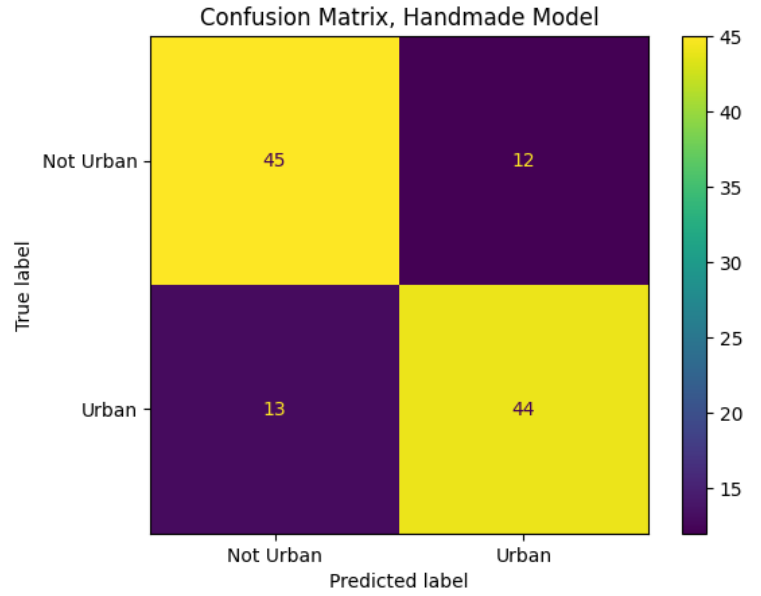
Measure	CNN	Customized VGG16	Customized EfficientNetV2
Testing accuracy	78.1%	71.9%	81.6%
Sensitivity (TPR)	77.2%	96.5%	84.2%
Specificity	78.9%	47.4%	78.9%
AUC	0.80	0.828	0.861

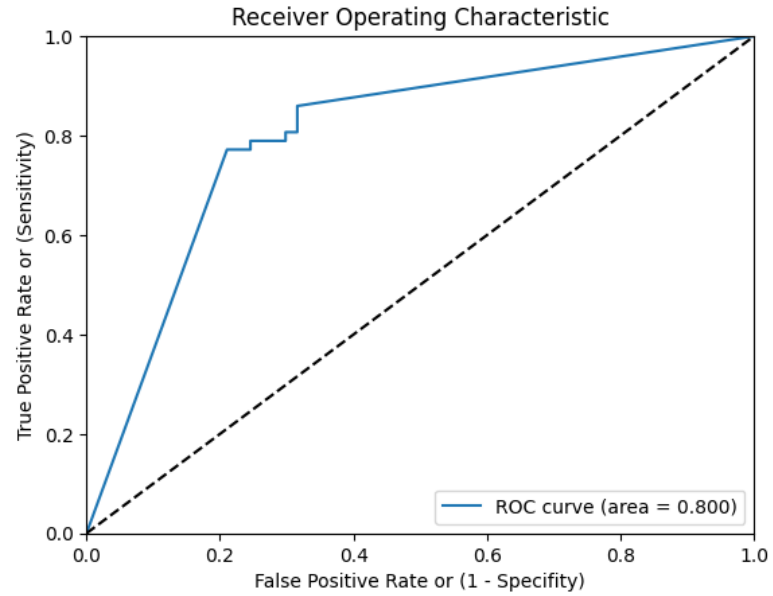
Results: CNN

- **Testing accuracy: 78.1%**
- **Sensitivity (TPR): 77.2%**
- **Specificity: 78.9%**
- **AUC: 0.80**



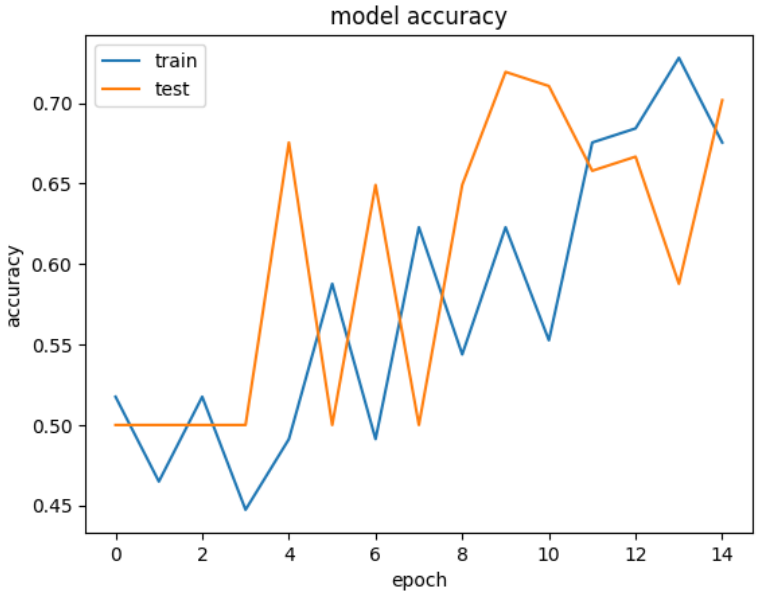


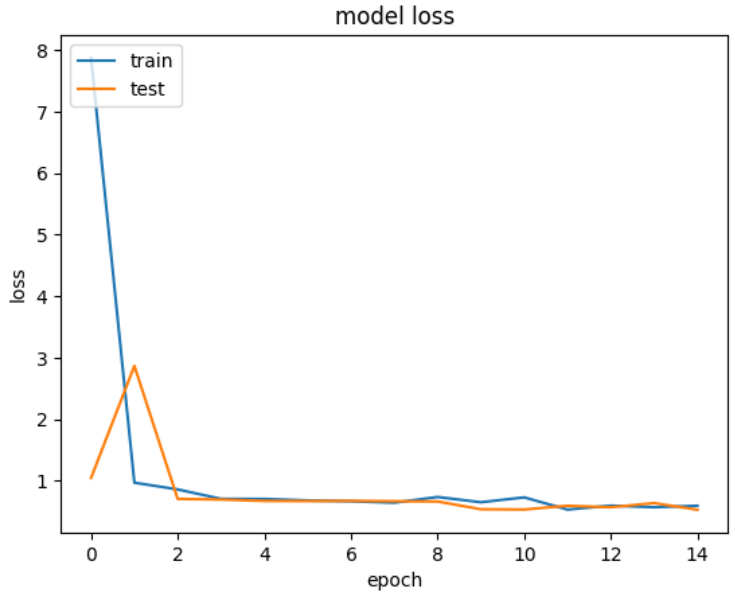


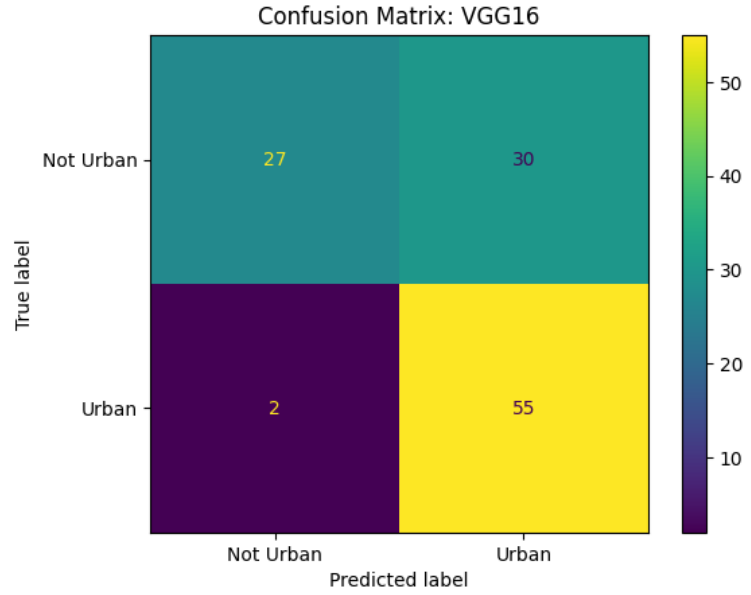


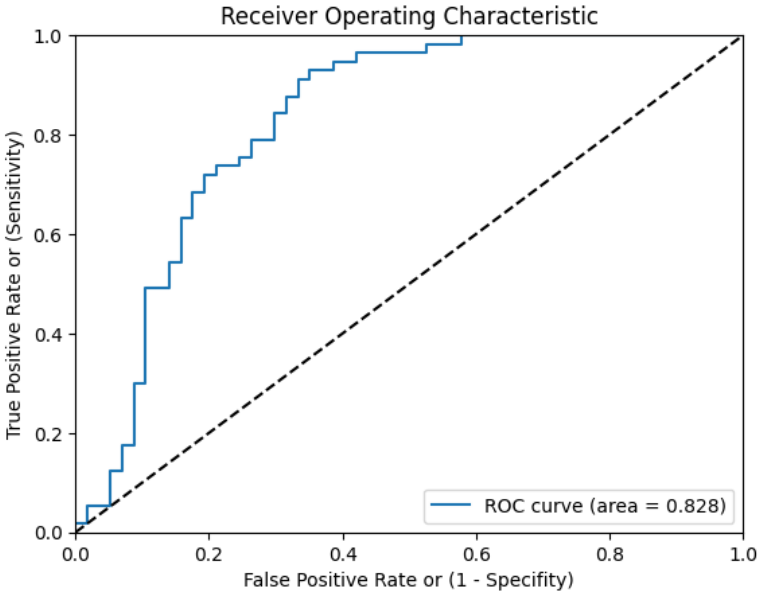
Results: VGG16

- **Testing accuracy: 71.9%**
- **Sensitivity (TPR): 96.5%**
- **Specificity: 47.4%**
- **AUC: 0.828**



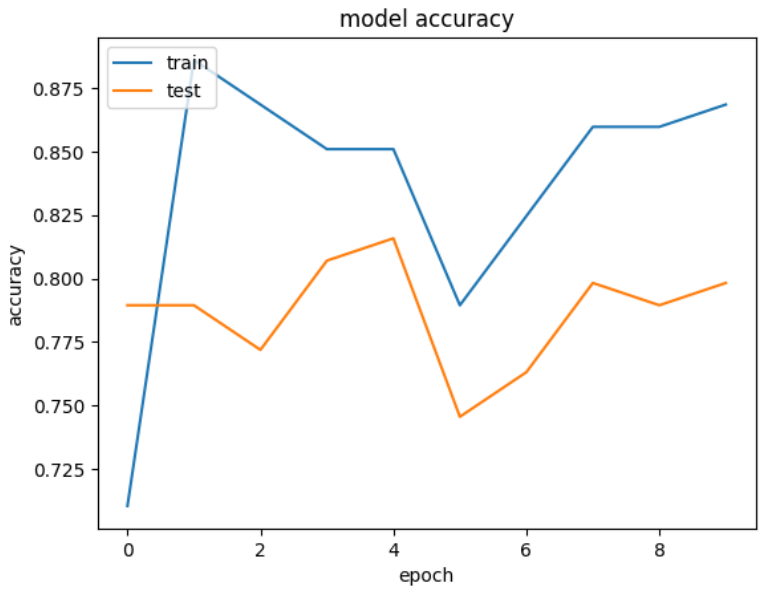


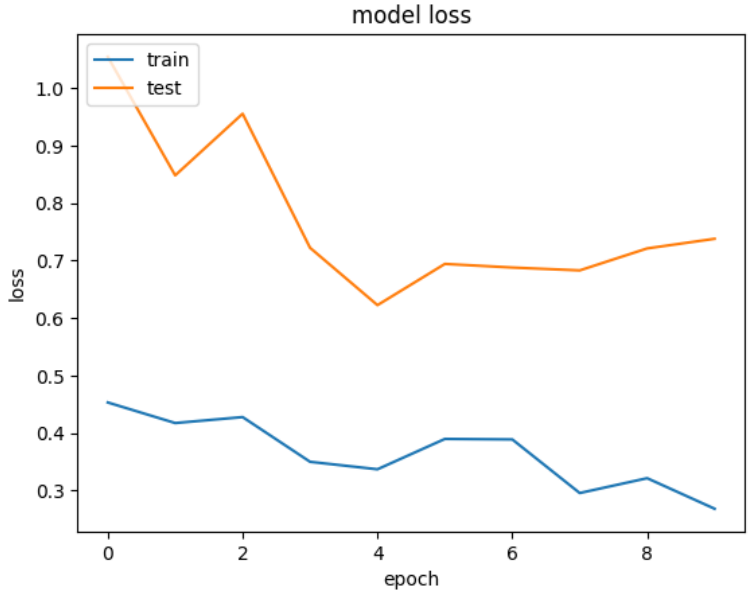


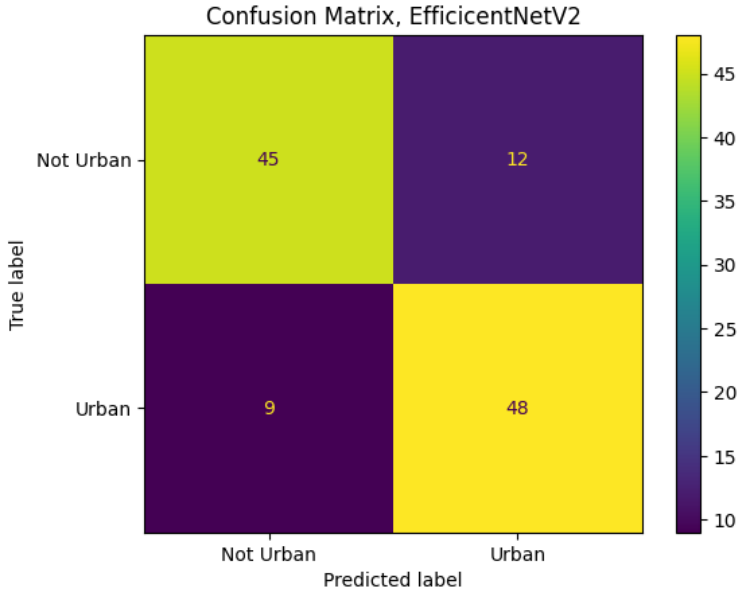


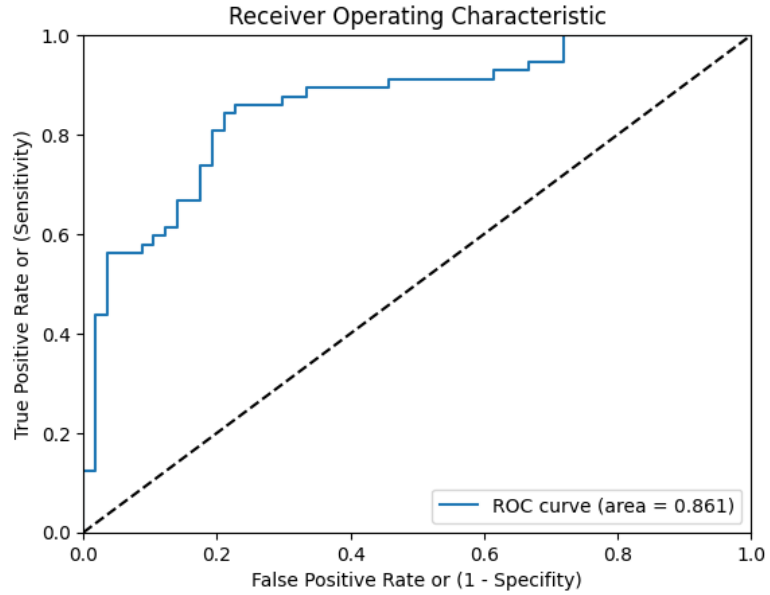
Results: EfficientNetV2

- **Testing accuracy: 81.6%**
- **Sensitivity (TPR): 84.2%**
- **Specificity: 78.9%**
- **AUC: 0.861**



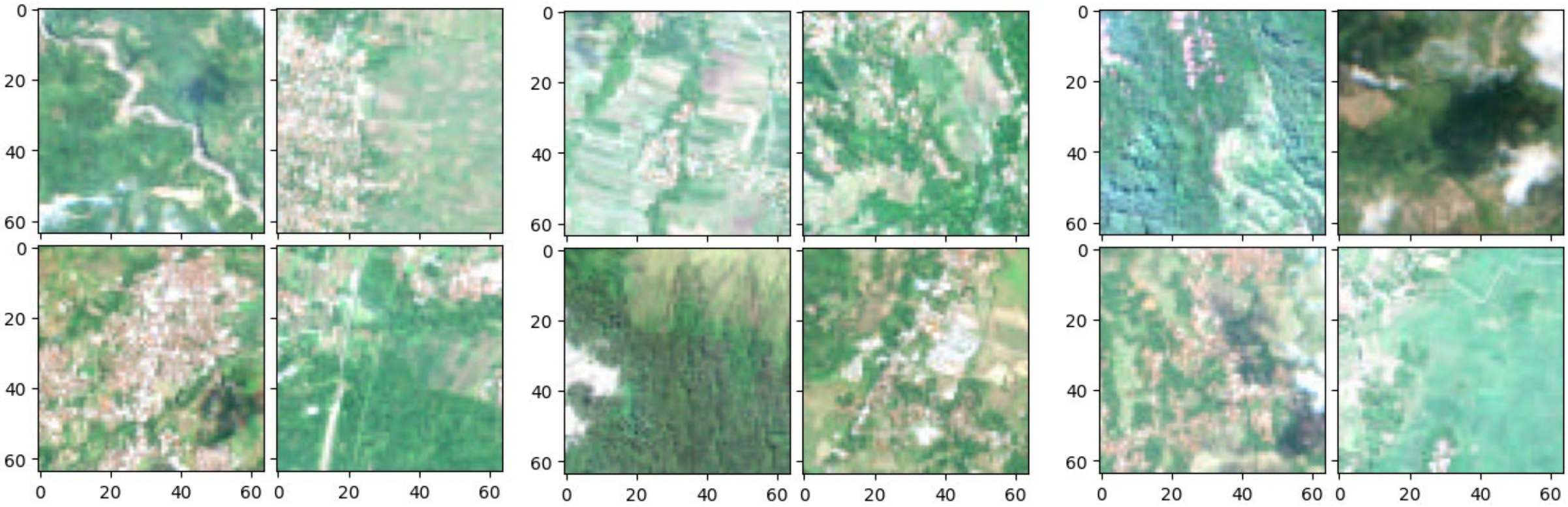






Results: Examples of False Positives (Predicted = Urban)

CNN	Customized VGG16	Customized EfficientNetV2



- **Potential areas of new urban expansion since 2014**

Discussion

Key Findings

- Customized EfficientNetV2 model outperforms the others across all performance measures, with a testing accuracy of 81.6% and AUC of 0.861
- Custom CNN likely needed further training to compete with the pre-trained models
- VGG16 took the longest time to compile
- False Positives provide a feasible way to identify areas of potential urban expansion in Indonesia

Limitations

- Some tiles labeled as urban may actually be mostly non-urban, contributing to a higher misclassification error
- Urban expansion polygon boundary is based on 2014 urban extents of the city and likely underestimates urban land because of urban expansion within the past decade, contributing to lower testing accuracy scores

Research Directions

- Expand dataset size by gathering data from additional cities
- Use zonal statistics and object detection to calculate the actual proportion of urban land within each tile
- Map current urban extents of the city would improve model training and performance
- Remove tiles classified as "urban" that are in fact only partially crossing the urban boundary
- Remove more clouds
- Try urban identification with multispectral imagery