Addressing UHI Effects in Arizona through the Strategic Urban Greening using AI-Driven Semantic Segmentation of Satellite Imagery

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Problem Statement

- **Urban Heat Island Effects:** Elevated temperatures in urban areas, increased energy consumption, environmental impacts. [1]
- **Inefficiency in Existing Approach:** Time-consuming and inaccurate land identification for afforestation.
- **Limited Land Availability:** High land costs and rapid urbanization restrict potential green spaces.
- **Need for Technological Solutions:** There is a crucial need for innovative, technology-driven approaches to accurately and efficiently identify optimal sites for urban forests, taking into account factors such as land availability, temperature patterns, and population density.

Our Approach

- **Vacant Land Identification**: Employ U-Net architectures for high-precision semantic segmentation to detect vacant urban lands.
- **Optimal Size Selection**: Utilize a sophisticated algorithm that considers land temperature profiles and population density to prioritize afforestation in areas where it would provide maximum environmental relief and human benefit.
- **Study Area** : Rapidly urbanizing areas across Arizona, USA – Phoenix, Mesa, Paradise Valley.

Vacant Land Identification

- **Data Collection** : 500 patches dataset derived from 1m resolution NAIP [3] satellite imagery from Gilbert city.
- Manual two class (vacant and occupied) pixelwise annotation.

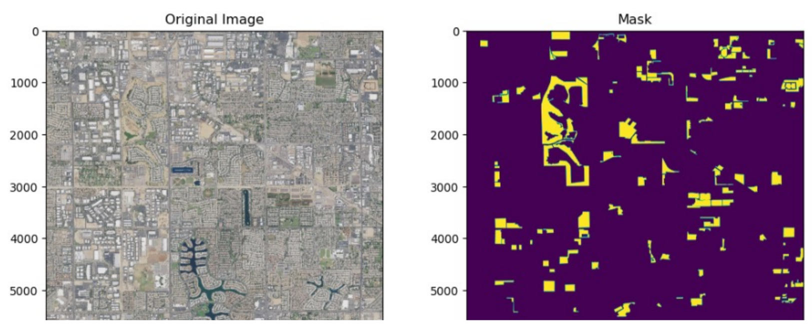


Figure 1. Contains figure showing original high-resolution RGB image from Gilbert city(left) and annotated image showing vacant (yellow) and occupied (purple) areas (right)

- **Model Structure:** U-Net architecture with contracting path for context capture and symmetric expanding path for precise localization; includes skip connections for effective feature propagation and minimal information loss. [2]
- **Model variants**: U-Net1 with ~50,000 parameters and U-Net2 with ~4 million parameters.
- Data augmentation for improved generalizability, Adam optimizer, BCE as loss function, Intersection over Union as evaluation metric.

$$\mathrm{IoU} = \frac{\text{Area of Overlap}}{\text{Area of Union}}$$

- Models evaluated on Phoenix, Mesa and Paradise Valley to test capability in correctly identifying vacant spaces suitable for forestation.
- Post-processing via erosion, dilation and area based selection of vacant lands (1 to 10 hectare).

Cooling Intensity Model

- Cooling intensity as a function of size of urban forest, current temperature and distance from the forest. [4]

$$CI(x,S,d) = \left(\frac{6}{1+e^{-k\cdot(x-x_0+\alpha\cdot\ln(S))}}\right)(5.76-0.847\ln(d))$$

- For up to 900m from forest boundary.
- Only logistic term for within forest region

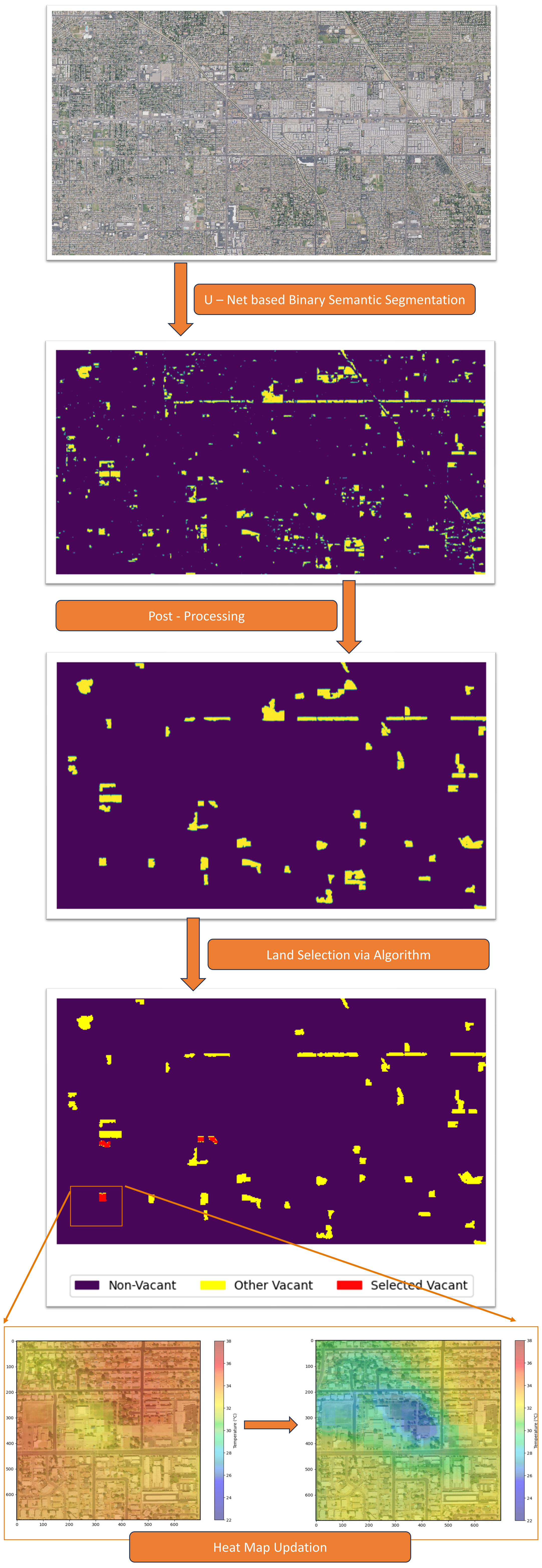
Site Selection Algorithm

- **Data collection**: 30m resolution temperature data from Landsat-9 and 100m resolution population density data from WorldPop Global dataset.
- Optimal defined as being worst hit by UHI effect for a substantial population.
- Compares vacant lands over score where M and P are the mean temperature and mean population density of region within 900m from the boundary of selected landmass.

$$\text{score} = \mathrm{M} \times \mathrm{P}$$

- **Input**: Land cover, heat, and population density maps.
- **Output**: Updated heat map and selected vacant lands for urban forests.
- **Workflow**: Initialize data, score and select lands, apply cooling model, and update maps iteratively.

Implementation Workflow



Evaluation

U-Net Models: IoU obtained for vacant class by UNet1 is 79.7% and UNet2 is 84.6%.

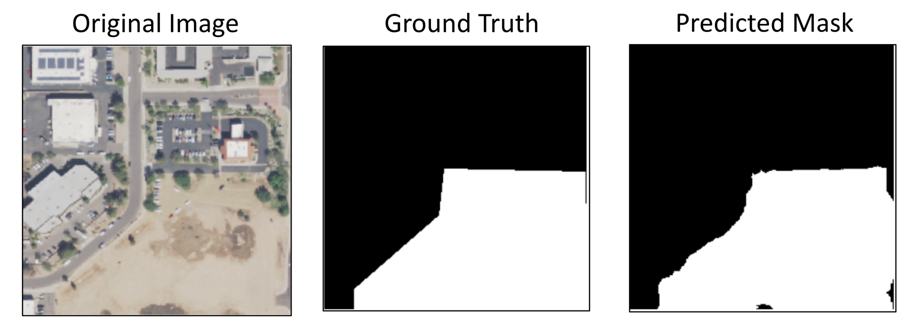


Figure 2: Performance of U-Net2

Practical Application:

Model	Metric	Mesa	Phoenix	Paradise Valley
U-Net1	Ground Truth Vacant Lands	61	50	28
	Correctly Identified Vacant Lands	38	41	24
	Incorrectly Identified Areas	7	31	4
U-Net2	Ground Truth Vacant Lands	61	50	28
	Correctly Identified Vacant Lands	52	47	27
	Incorrectly Identified Areas	9	28	4

Table 1: Performance metrics across cities for different U-Net models.

For the U-net2 model-

- On average 92% of the vacant lands are identified.
- If we exclude the anomaly in Phoenix, percentage of incorrectly identified areas is 14.5%

Impact On UHI Mitigation

- Evaluation based on mean temperature decrease, area affected corresponding to this temperature decrease and the total number of people impacted **per hectare** of urban forestation in each of the three cities.

Places	Mean Temp. Difference (°C)	Area Affected (ha)	Population Affected
Mesa	1.69	44.3	1343
Phoenix	3.19	21.6	1524
Paradise Valley	2	33.7	494

Table 2: Impact per hectare algorithm based forestation

- Compared to random allocation, algorithm results in 53% higher cooling effect and 43% more people affected.
- The process is approximately 10 times faster and more accurate compared to traditional approach (due to manual vacant land identification). [5]

Discussion

- **Enhanced Cooling and Community Impact**: Validates strategic urban forest placements for maximum cooling and social benefits.
- **Efficient Use of Urban Spaces**: Demonstrates effective resource management and space optimization in urban environments.
- **Model Scalability Limitation**: High incorrect identification rate in Phoenix highlights need for city level stratification.

Future Aspects

- **Real-Time Data Integration**: Explore real-time monitoring for adaptive response in urban forest planning.
- **Algorithm Enhancement**: Develop advanced algorithms incorporating more environmental variables for precision.
- **Broader Application**: Extend research to additional cities and climates to refine and universalize the model.

References

1. Environmental Protection Agency (EPA) et al., "Reduce Urban Heat Island Effect"
2. O. Ronneberger, P. Fischer, and T. Brox et al., "U-Net: Convolutional Networks for Biomedical Image Segmentation"
3. USDA National Agriculture Imagery Program et al., "NAIP - USDA Aerial Imagery"
4. I. Gallay, B. Olah, V. Murtinová, and Z. Gallayová et al., "Quantification of the Cooling Effect and Cooling Distance of Urban Green Spaces Based on Their Vegetation Structure and Size as a Basis for Management Tools for Mitigating Urban Climate"
5. L. Mao, Z. Zheng, X. Meng, Y. Zhou, P. Zhao, Z. Yang, and Y. Long et al., "Large-scale automatic identification of urban vacant land using semantic segmentation of high-resolution remote sensing images"