



The last urban frontier:
Assessing drivers of
urbanization and
tradeoffs among social
and ecosystems services
associated with LCLUC
in Africa


Jody C. Vogeler^{1,2},
Shahriar Shah Heydari¹,
Orion Cardenas-Ritzert²,
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Multi-tiered urban
mapping for characterizing
urbanization patterns,
identifying hotspots of
LCLUC, and informing UN
Sustainable Development
Goal Indicators in Africa

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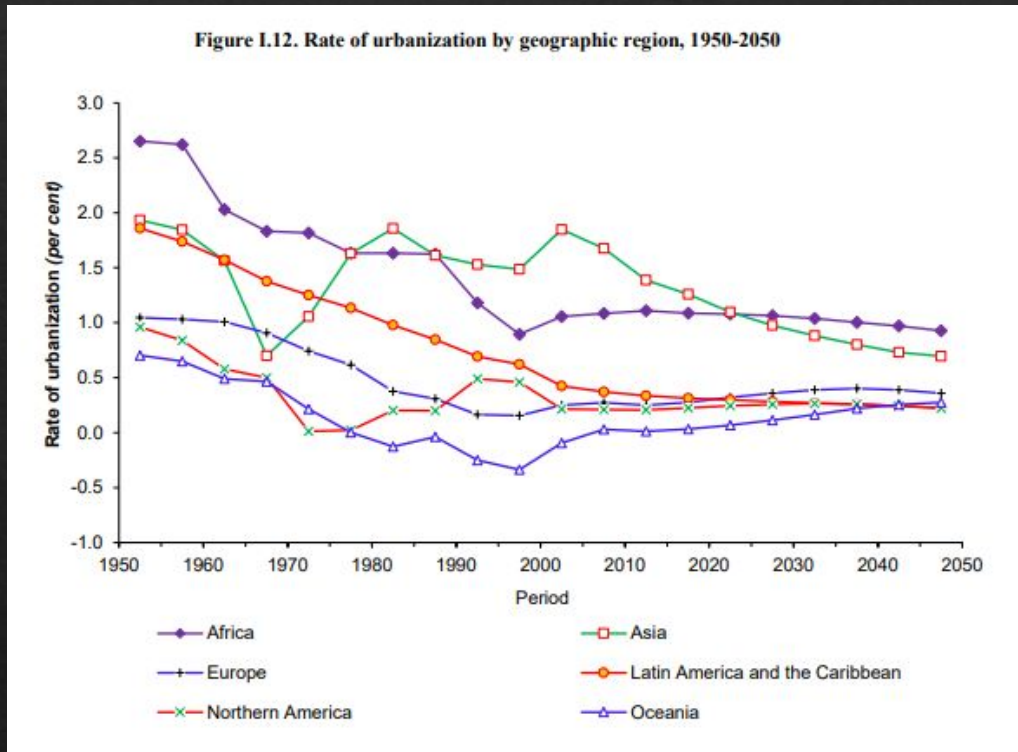
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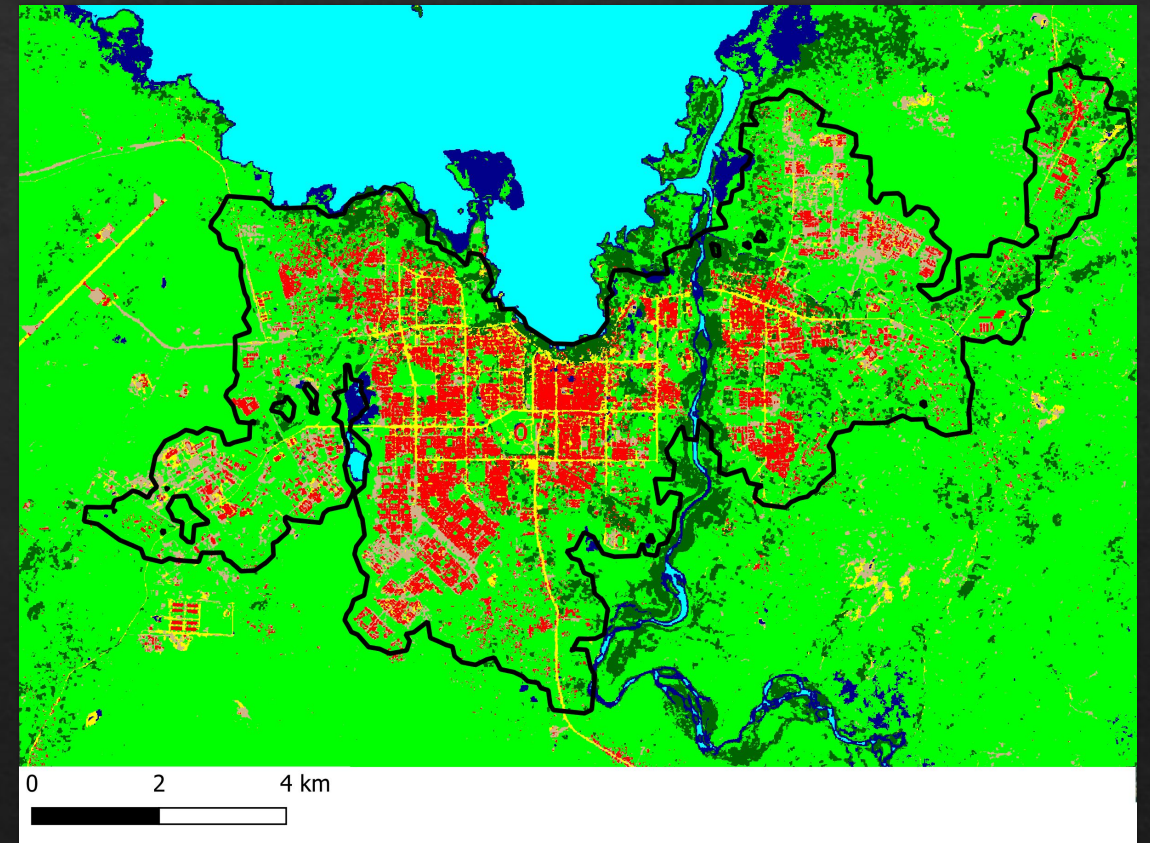
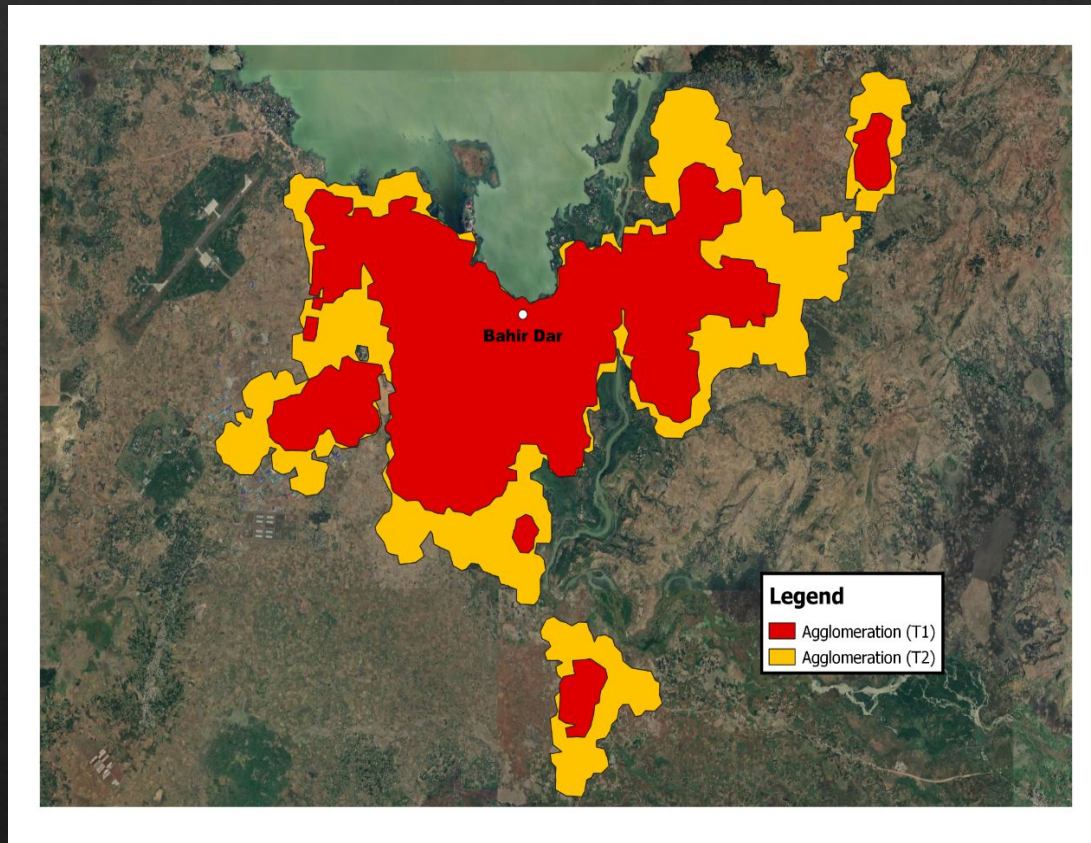
Background – Africa Urbanization Trends

Mitigating implications of rapid unplanned



23% of sub-Saharan Africa's urban population living in slums or informal settlements as of 2018

Background – Multi-Tier Urban Mapping



Characterizing urbanization/LCLUC patterns *AND* heterogenous urban landscapes!

Background – SDG Monitoring

WorldPop

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| | |
|------------------|---------------------|
| Burnt Area | NDVI |
| Dry Matter Prod. | Soil Water Index |
| FAPAR | Surf. Soil Moisture |
| FCOVER | VCI |
| Leaf Area Index | VPI |
| Land Cover | |

Sustainable Development Goal 11:

Make cities and human settlements inclusive, safe, resilient and sustainable.

Target 11.3: *By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management by all countries.*

Indicator 11.3.1 – *Ratio of land consumption rate (LCR) to population growth rate (PGR).*

Formulas:

$$LCR = \frac{\ln(\text{Area of urban extent } t1 / \text{Area of urban extent } t2)}{\text{Years between } t1 \text{ and } t2}$$

$$PGR = \frac{\ln(\text{Total population } t1 / \text{Total population } t2)}{\text{Years between } t1 \text{ and } t2}$$

$$11.3.1 \text{ Ratio} = \frac{LCR}{PGR}$$

Target 11.7: *By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.*

Indicator 11.7.1 – *Average share of the built-up area of cities that is open space for public use for all, by sex, age, and persons with disabilities.*

Formulas:

$$11.7.1 \text{ Ratio} = \frac{(\text{Public open space area} + \text{area of streets})}{\text{Total area of urban agglomeration}}$$



Crowd sourced



Open source



Humanit.

Background – Project Goals



Overarching goals:

- Create multi-tier spatial products to better characterize spatial heterogeneity of urban landscapes in three rapidly developing African countries

Background – Project Goals



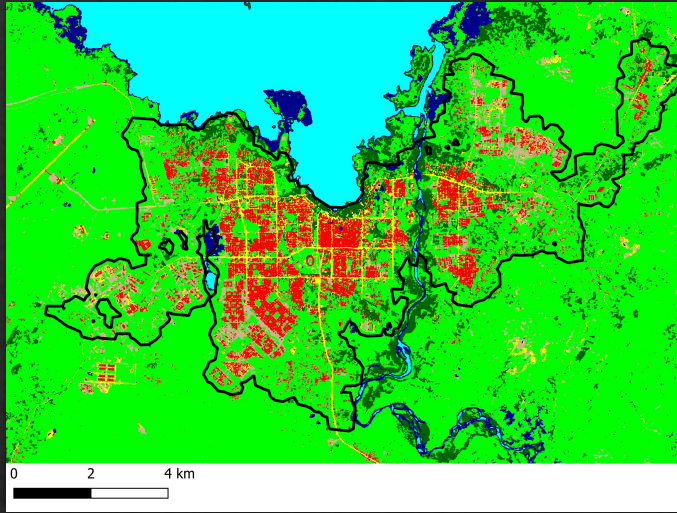
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Tier 1:

Country-level annual land use maps, moderate 30m resolution

Background – Project Goals



Overarching goals:

- Create multi-tier spatial products to better characterize spatial heterogeneity of urban landscapes in three rapidly developing African countries

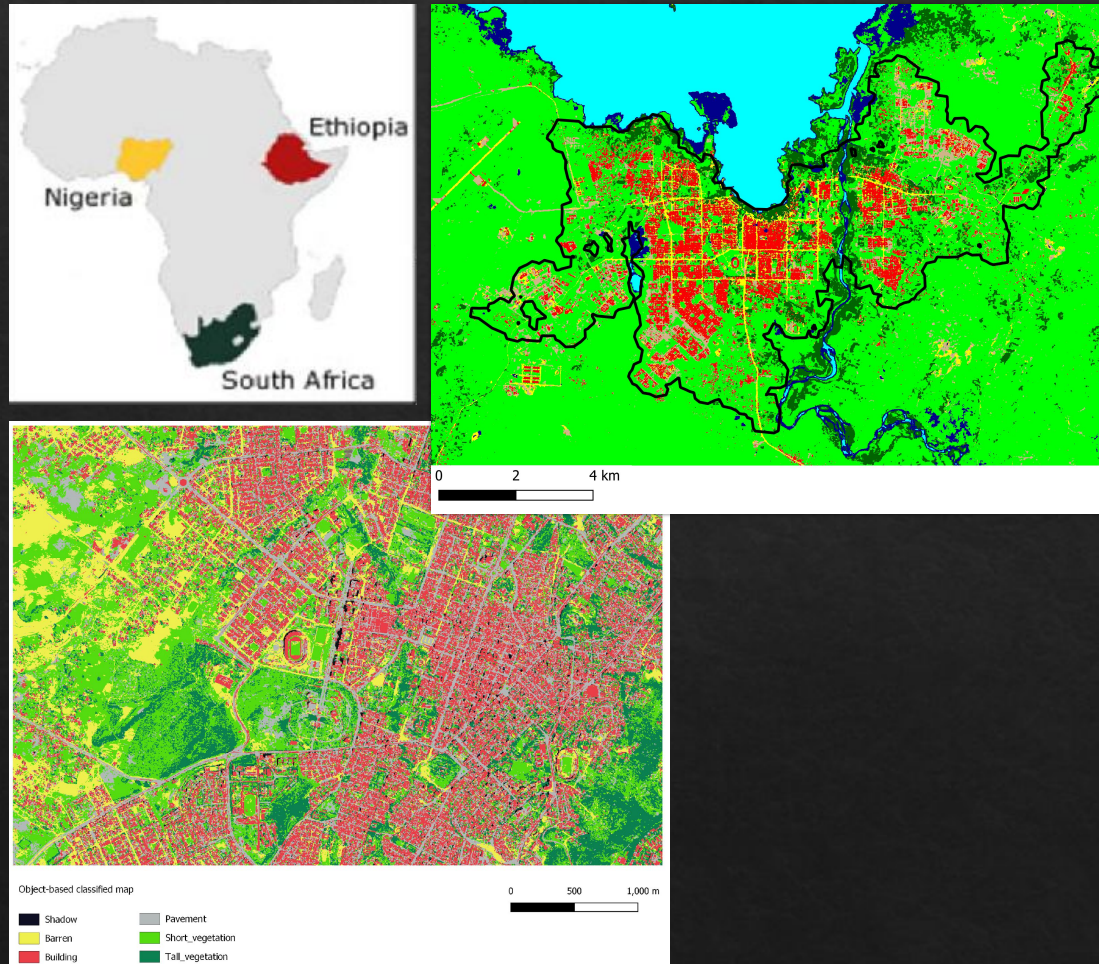
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Country-level annual land use maps, moderate 30m resolution

Tier 2:

Urban agglomeration annual land cover map, 10m resolution

Background – Project Goals



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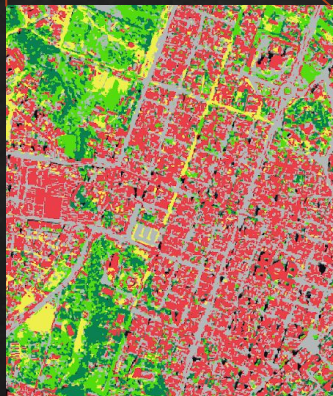
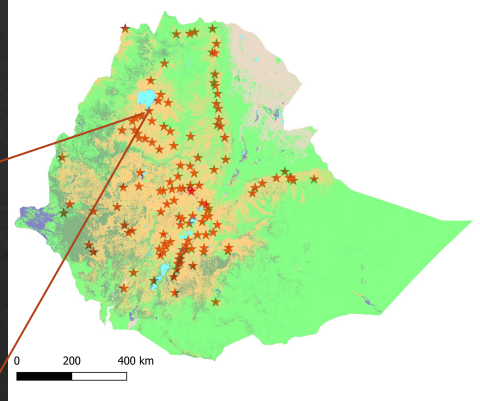
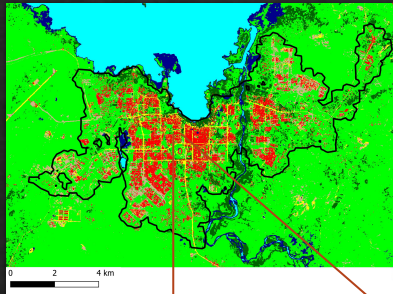
Tier 2:

Urban agglomeration annual land cover map, 10m resolution

Tier 3:

Temporal object-level and map refining, very high resolution

Background – Project Goals



Overarching goals:

- Create multi-tier spatial products to better characterize spatial heterogeneity of urban landscapes in three rapidly developing African countries
- Identify hotspots of urbanization-driven LCLUC and better dissect within city functional land uses and change patterns

Background – Project Goals

FIGURE 3.3:
The urban clusters in the study area of Addis Ababa, Ethiopia in 1986, with open space within the study area differentiated into fringe open space (light green), captured open space (bright green), rural open space (dark green).

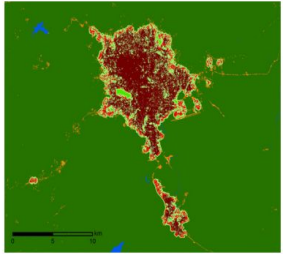
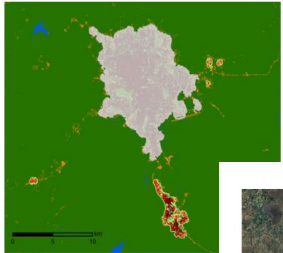
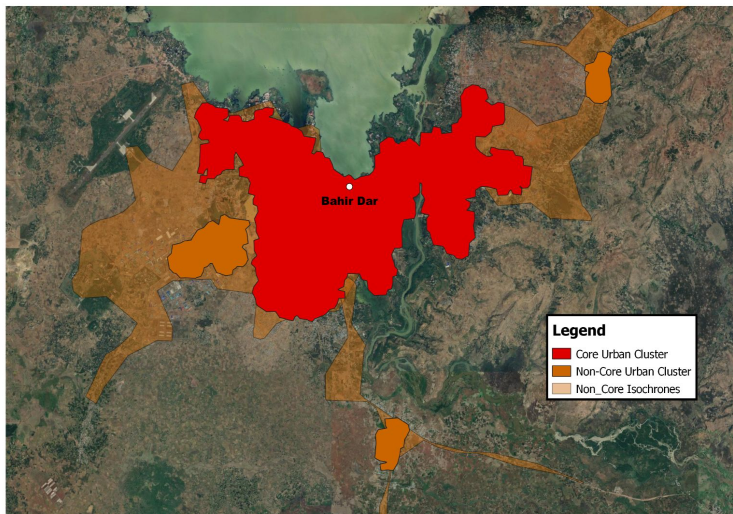


FIGURE 3.4:
The urban extent (grey) of Addis Ababa, Ethiopia in 1986 and the ex-urban areas within its study area.



Angel et al. 2016



Overarching goals:

- Create multi-tier spatial products to better characterize spatial heterogeneity of urban landscapes in three rapidly developing African countries
- Identify hotspots of urbanization-driven LCLUC and better dissect within city functional land uses and change patterns
- Contribute to the comprehension of SDG Indicator 11.3.1 (and others) and build on methods to improve its role within large extent urbanization monitoring efforts.

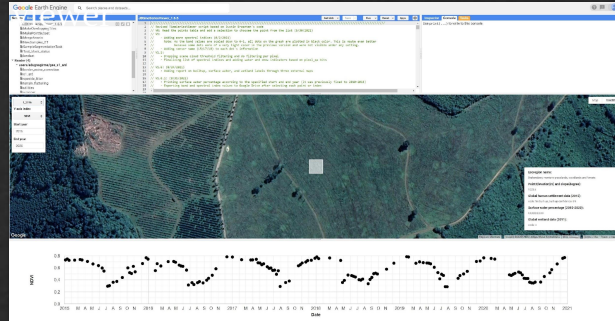
Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)

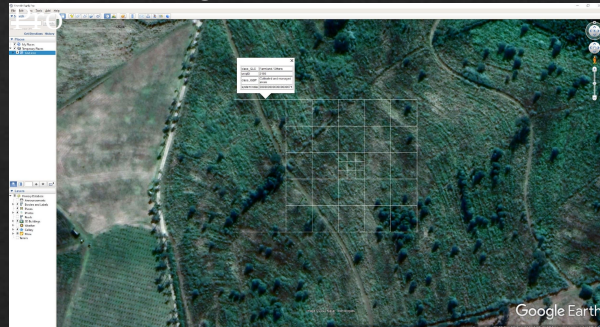
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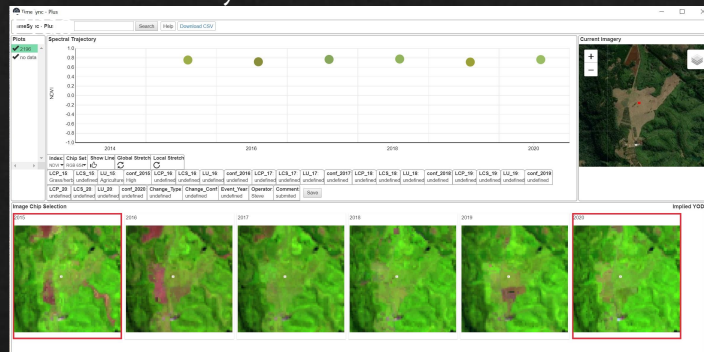
Tool#1: Landsat/Sentinel time series



Tool#2: Google Earth



Tool#3: TimeSync



Reference data generation

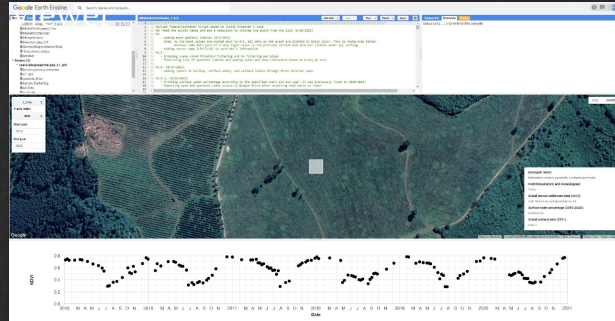
| Tier-1 Land Cover / Land Use classes | Tier-2 Land cover classes |
|---|---|
| <p>Land Cover (over pixel per year):</p> <ul style="list-style-type: none"> - Barren - Grass/herb - Impervious - Shrub - Tree - Water <p>Land Use (over pixel neighborhood per 3-year epoch):</p> <ul style="list-style-type: none"> - Agriculture - Bare - Developed - Forest - Rangeland <ul style="list-style-type: none"> - Grassland - Shrubland - Woodland - Wetland - Water | <p>Land Cover (over pixel per year):</p> <ul style="list-style-type: none"> - Barren - Impervious_Building - Impervious_Pavement - Short vegetation - Tall vegetation - Wetland - Water |

| Country | LU Training | LU Validation | LC Training | LC Validation |
|--------------|-------------|---------------|-------------|---------------|
| Ethiopia | 926 | 550 | 2526 | 700 |
| South Africa | 1285 | 1000 | 3182 | 1000 |
| Nigeria | 695 | 700 | TBD | TBD |

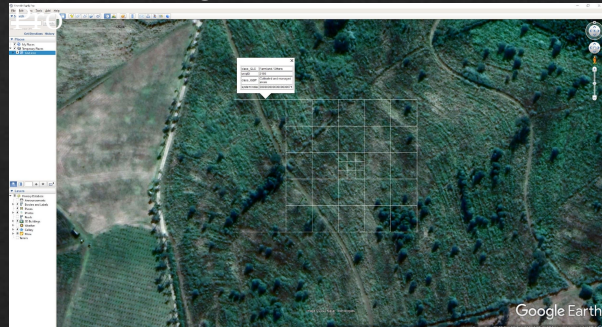
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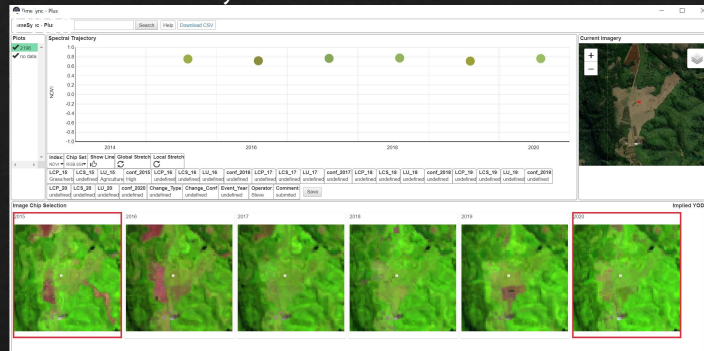
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Legend

- Agriculture
- Barren
- Developed
- Forest
- Rangeland
- Water
- Wetland

Legend

- Bare
- Impervious - Building
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30m resolution
land use maps
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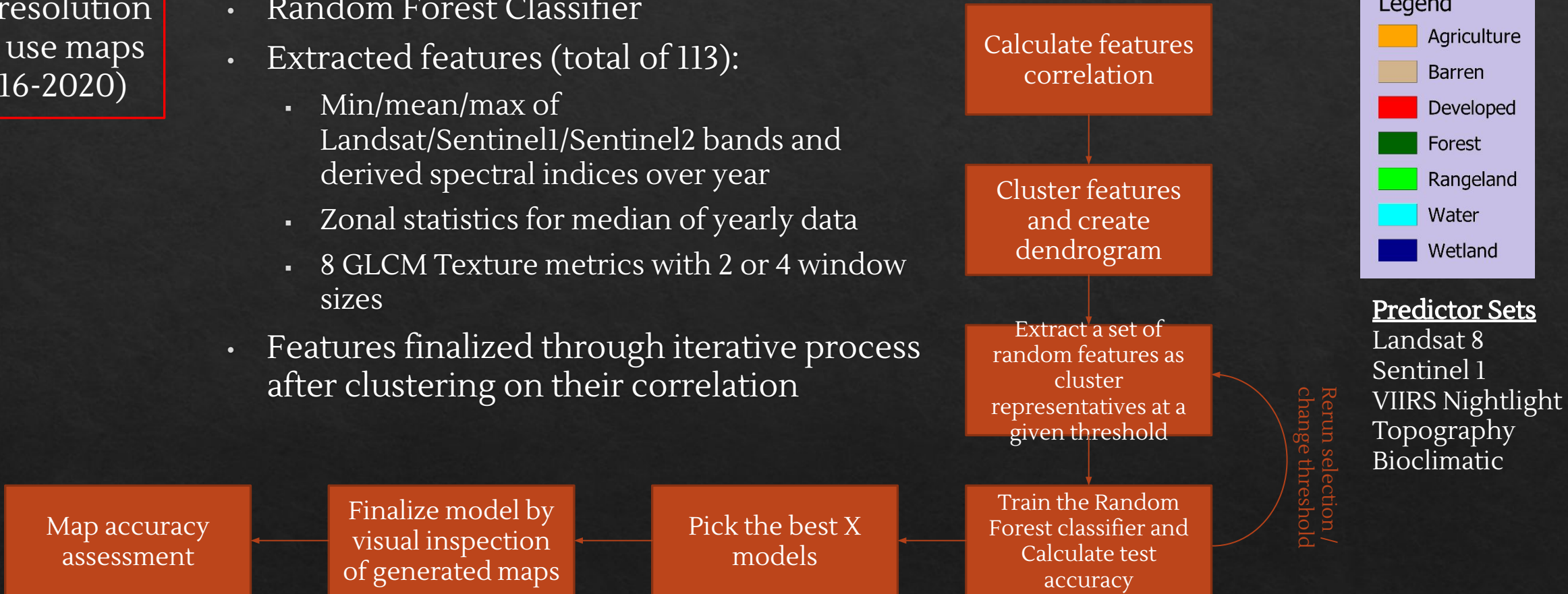
Predictor Sets

Landsat 8
Sentinel 1
VIIRS Nightlight
Topography
Bioclimatic

Africa Urbanization Patterns & Hotspots

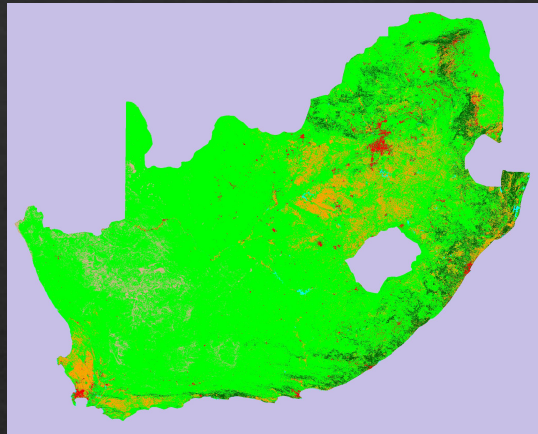
30m resolution
land use maps
(2016-2020)

- Random Forest Classifier
- Extracted features (total of 113):
 - Min/mean/max of Landsat/Sentinel1/Sentinel2 bands and derived spectral indices over year
 - Zonal statistics for median of yearly data
 - 8 GLCM Texture metrics with 2 or 4 window sizes
- Features finalized through iterative process after clustering on their correlation

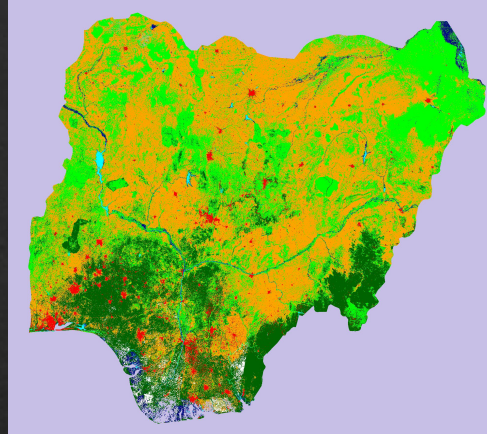


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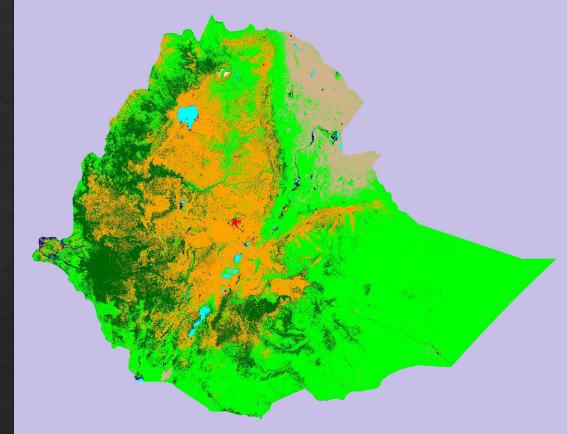
30m resolution
land use maps
(2016-2020)



South Africa,
2019



Nigeria,
2019



Ethiopia,
2019



Map accuracy assessment for Ethiopia model (other countries

| (Olofsson, 2014 method) | | | | |
|-----------------------------|-------------------|-----------------|---------------|----------------|
| <i>Weighted proportions</i> | Producer Accuracy | 95% conf. int. | User Accuracy | 95% conf. int. |
| Agriculture | 73.4% | 10.2% | 64.6% | 10.6% |
| Bare | 75.7% | 3.8% | 72.5% | 10.6% |
| Developed | 10.0% | 1.5% | 68.9% | 11.7% |
| Forest | 61.3% | 5.1% | 75.4% | 10.9% |
| Range | 82.0% | 19.4% | 75.0% | 7.3% |
| Water | 100.0% | 0.0% | 98.3% | 3.4% |
| Wetland | 14.3% | 14.3% | 45.9% | 10.7% |
| Overall accuracy: | 72.1% | 95% conf. int.: | 5.1% | |

Predictor Sets

Landsat 8
Sentinel 1
VIIRS Nightlight
Topography
Bioclimatic

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
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Figure 7: High density, cells, urban centre and city of Graz, Austria

Dijkstra et al. 2018

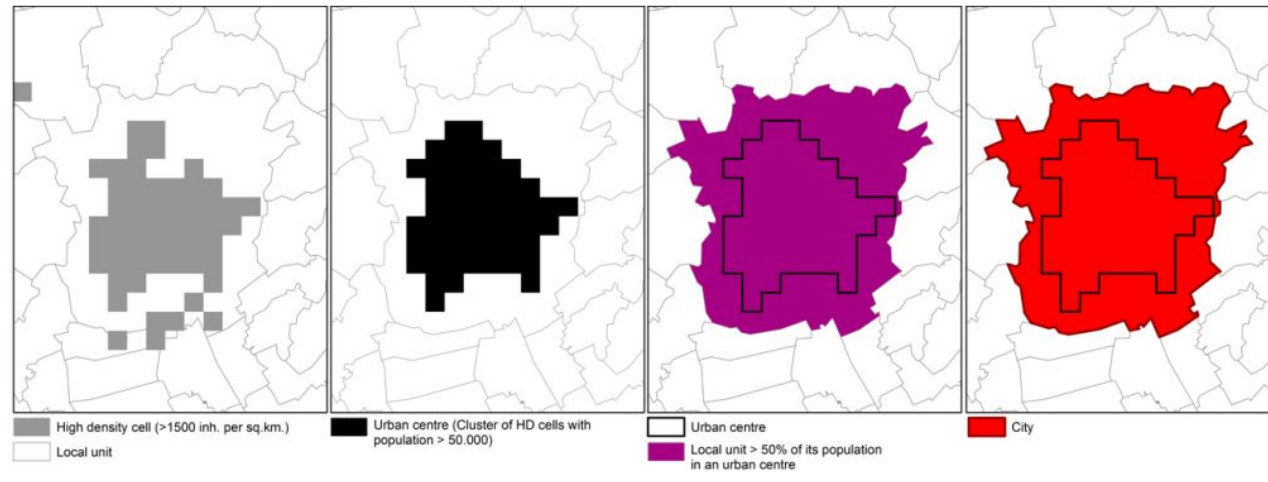


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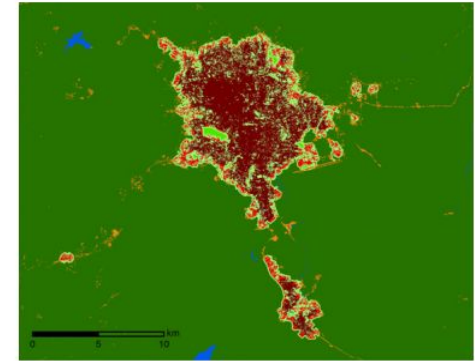
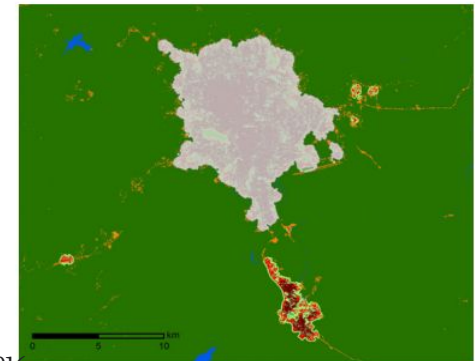


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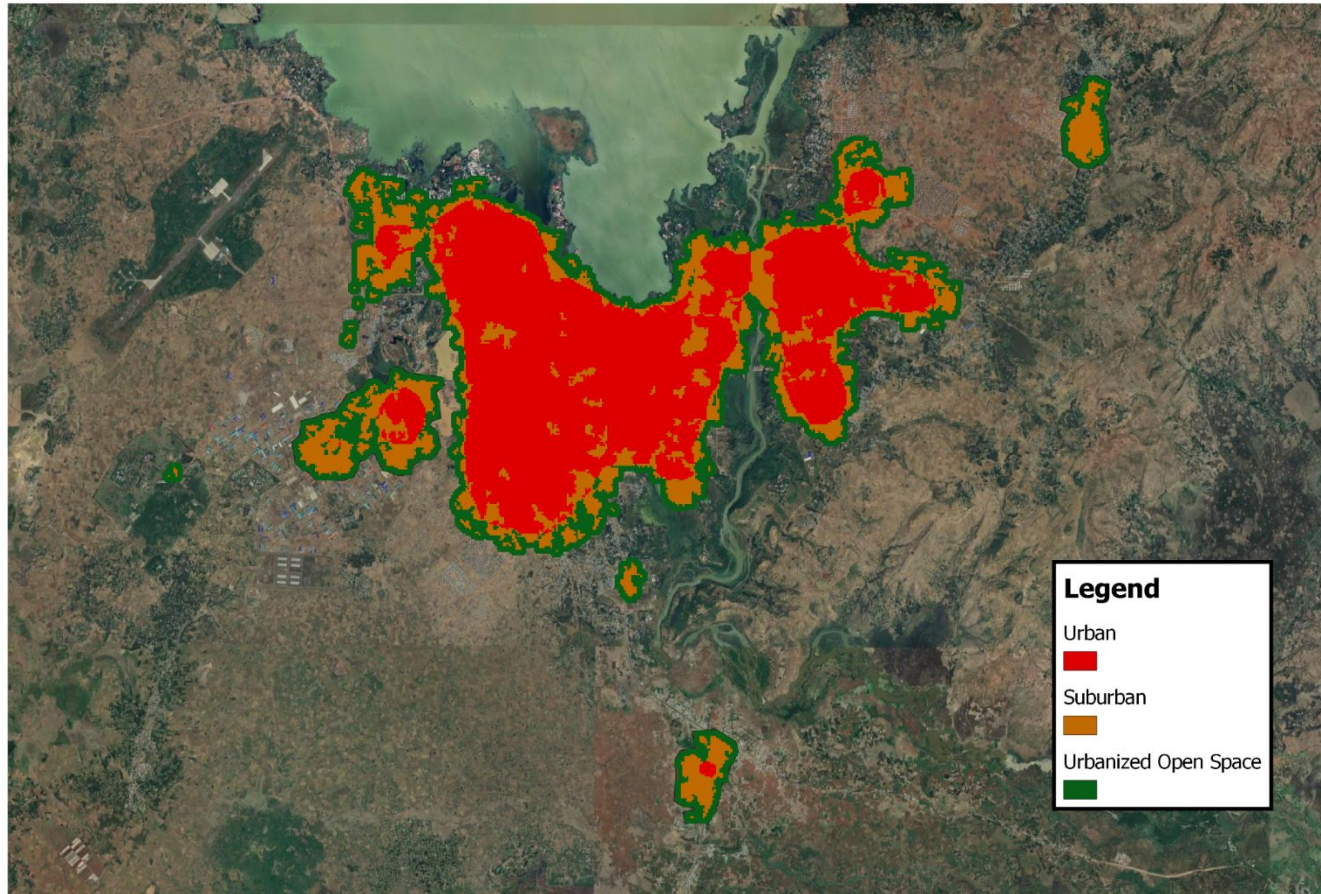
Angel et al. 2016

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30m resolution
land use maps
(2016-2020)



Urban
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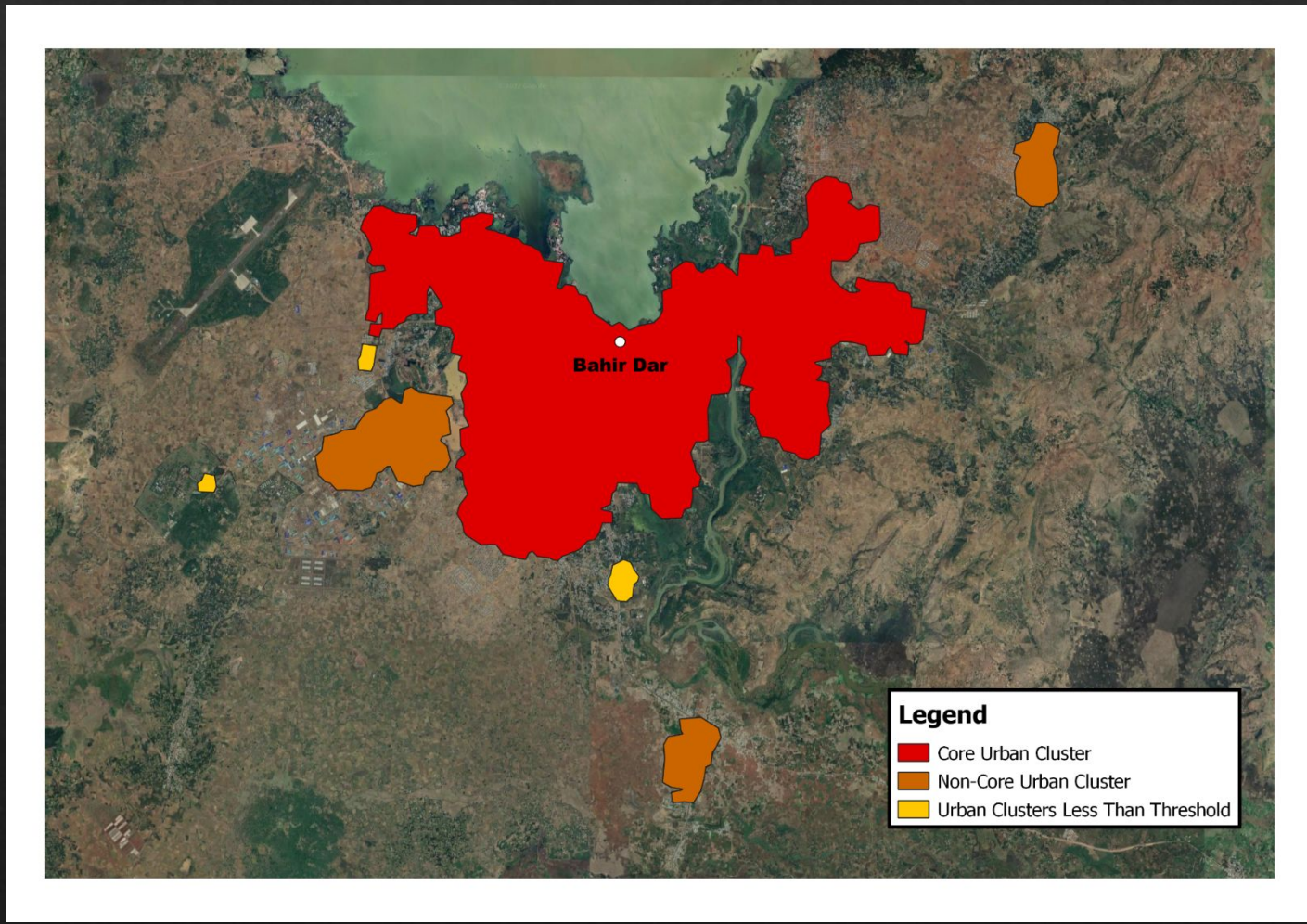


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(2016-2020)



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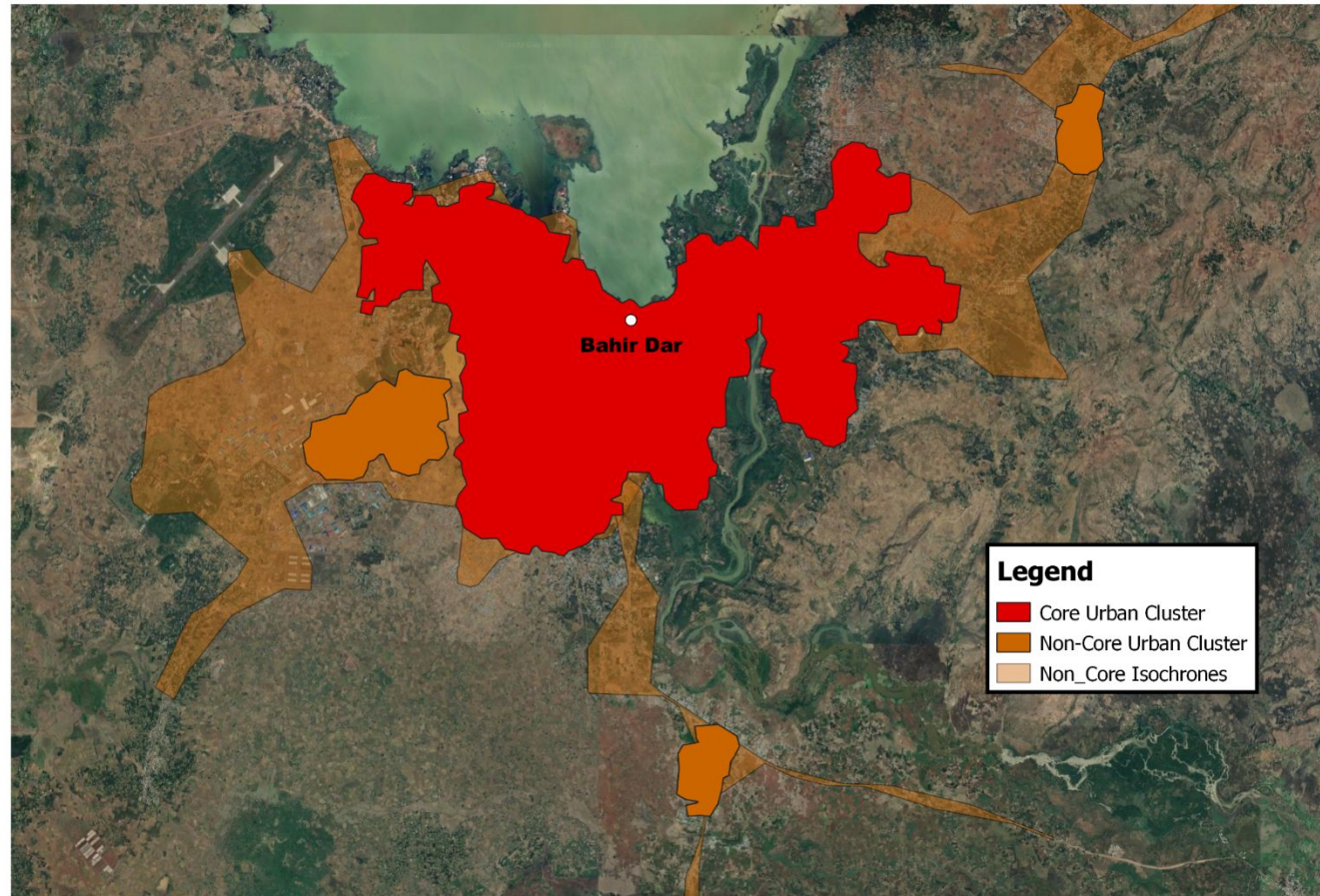


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30m resolution
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Urban
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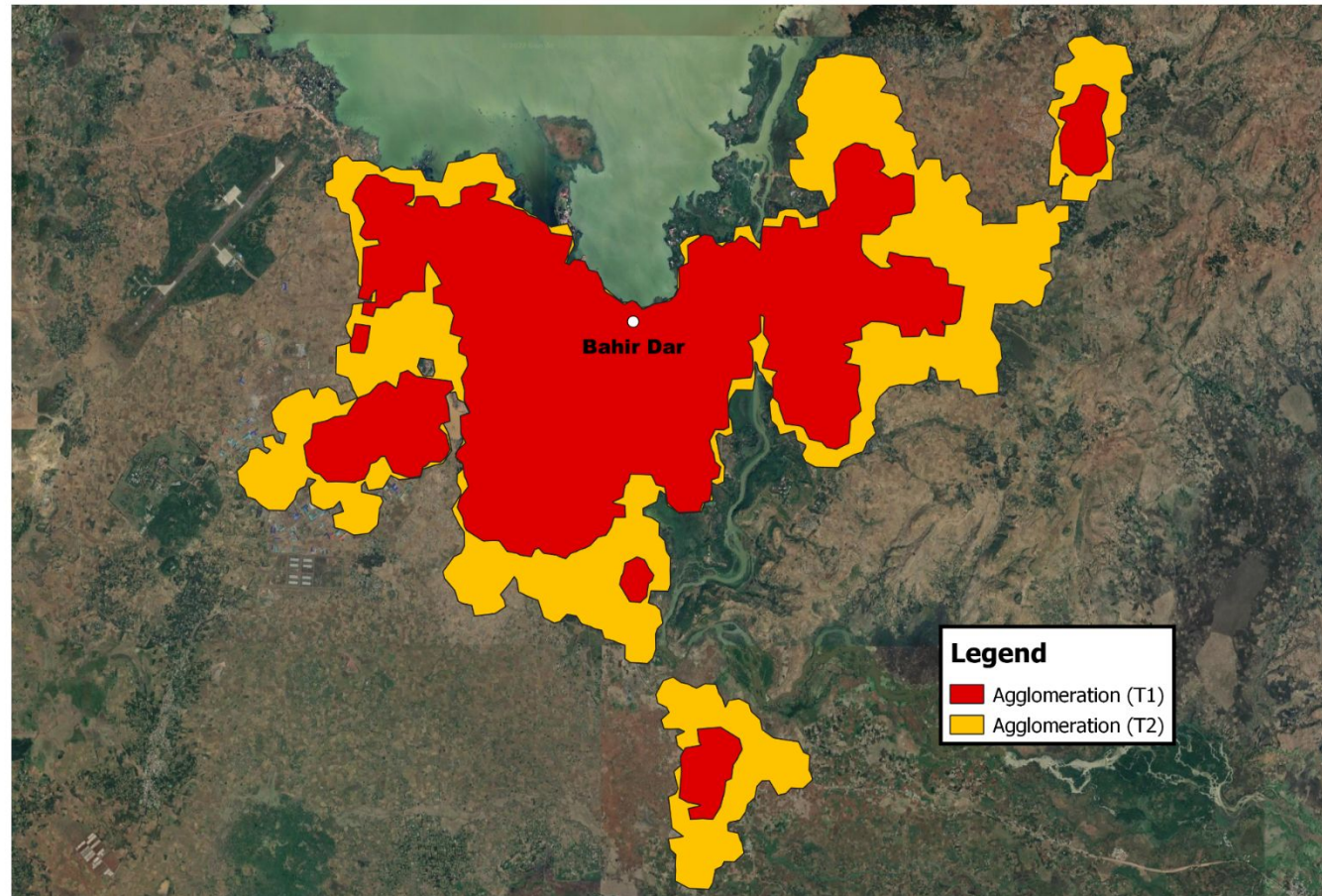


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30m resolution
land use maps
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Land Consumption Rate =
0.15
Pop Growth Rate = 0.024
SDG 11.3.1 Ratio = 6.3

Africa Urbanization Patterns & Hotspots

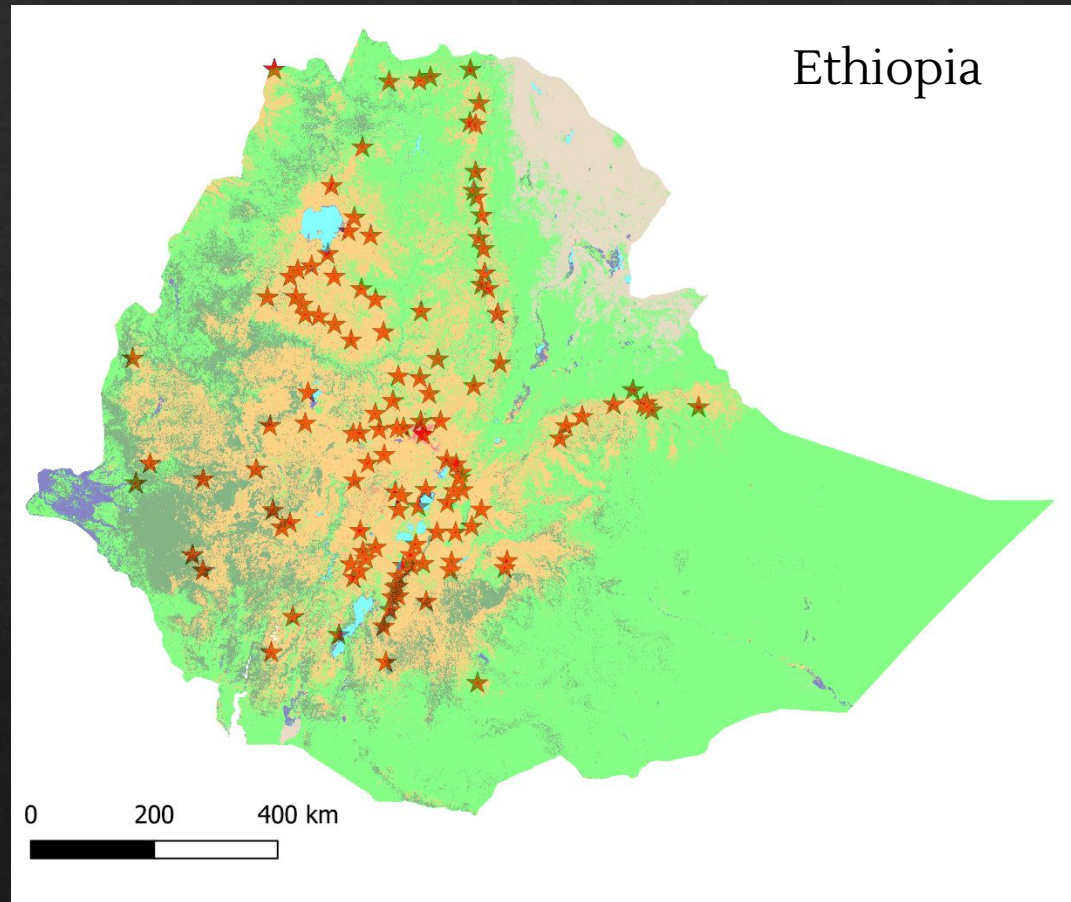
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(2016-2020)



Urban
Delineations &
Change



Identify Hotspots
of Urbanization



Africa Urbanization Patterns & Hotspots

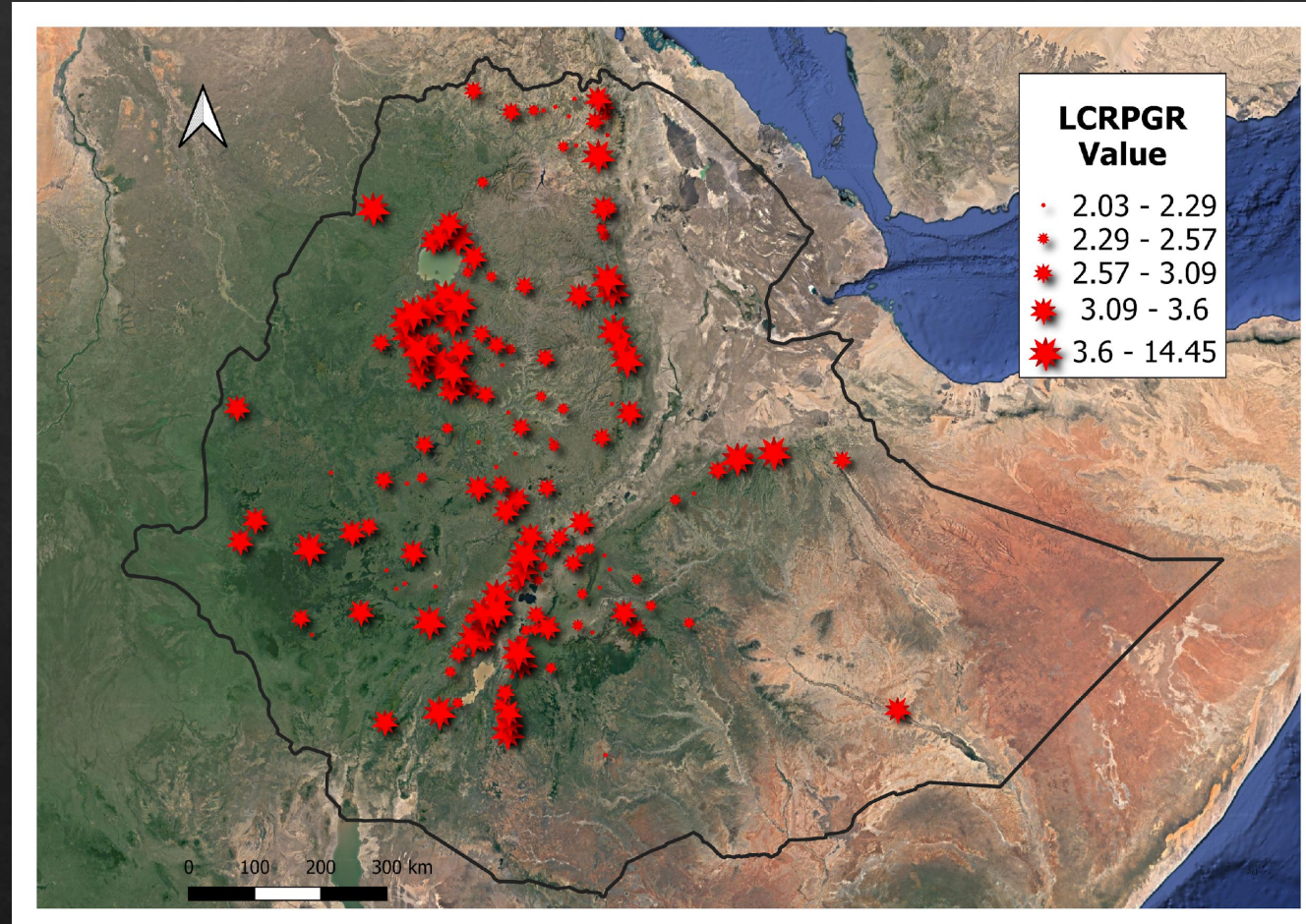
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Identify Hotspots
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Africa Urbanization Patterns & Hotspots

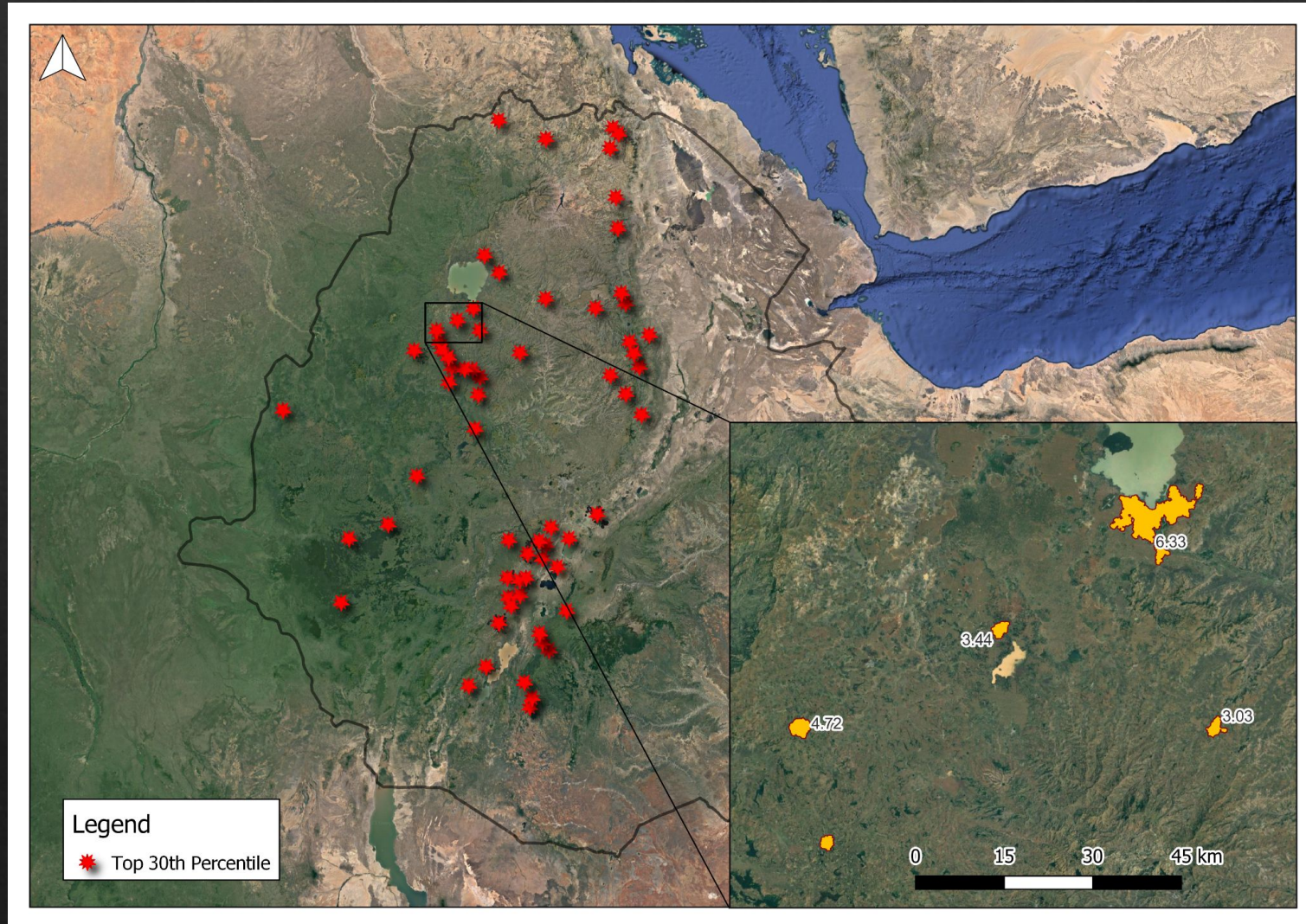
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Africa Urbanization Patterns & Hotspots

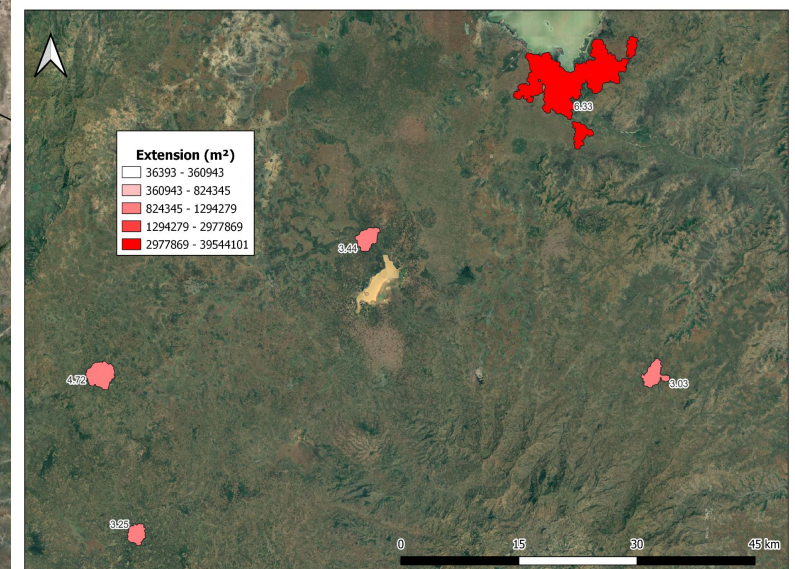
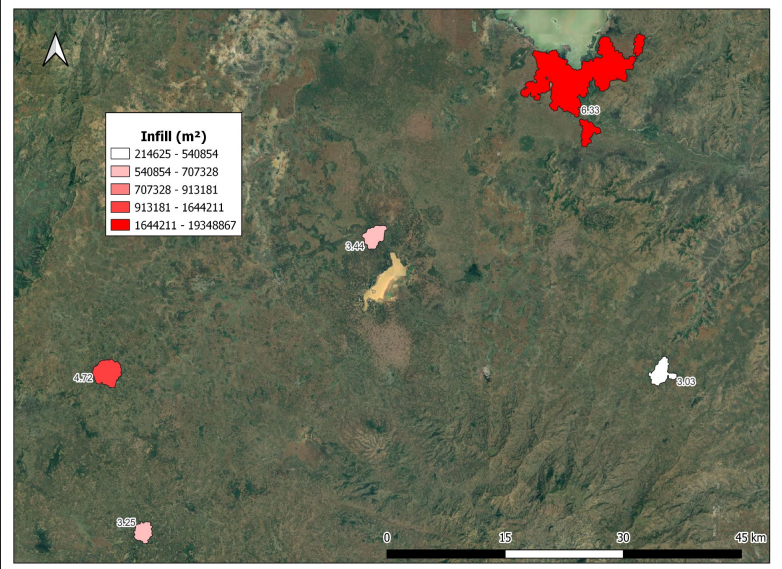
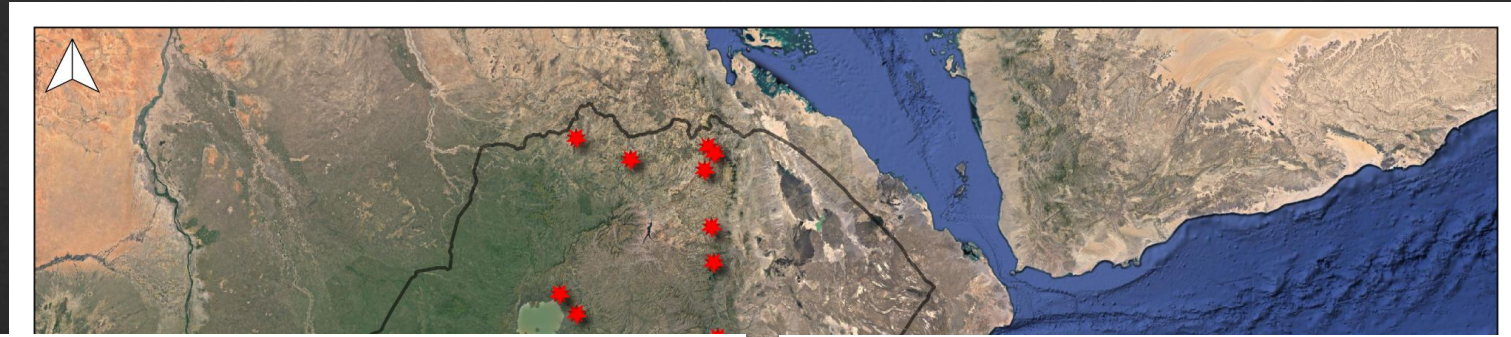
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Urban
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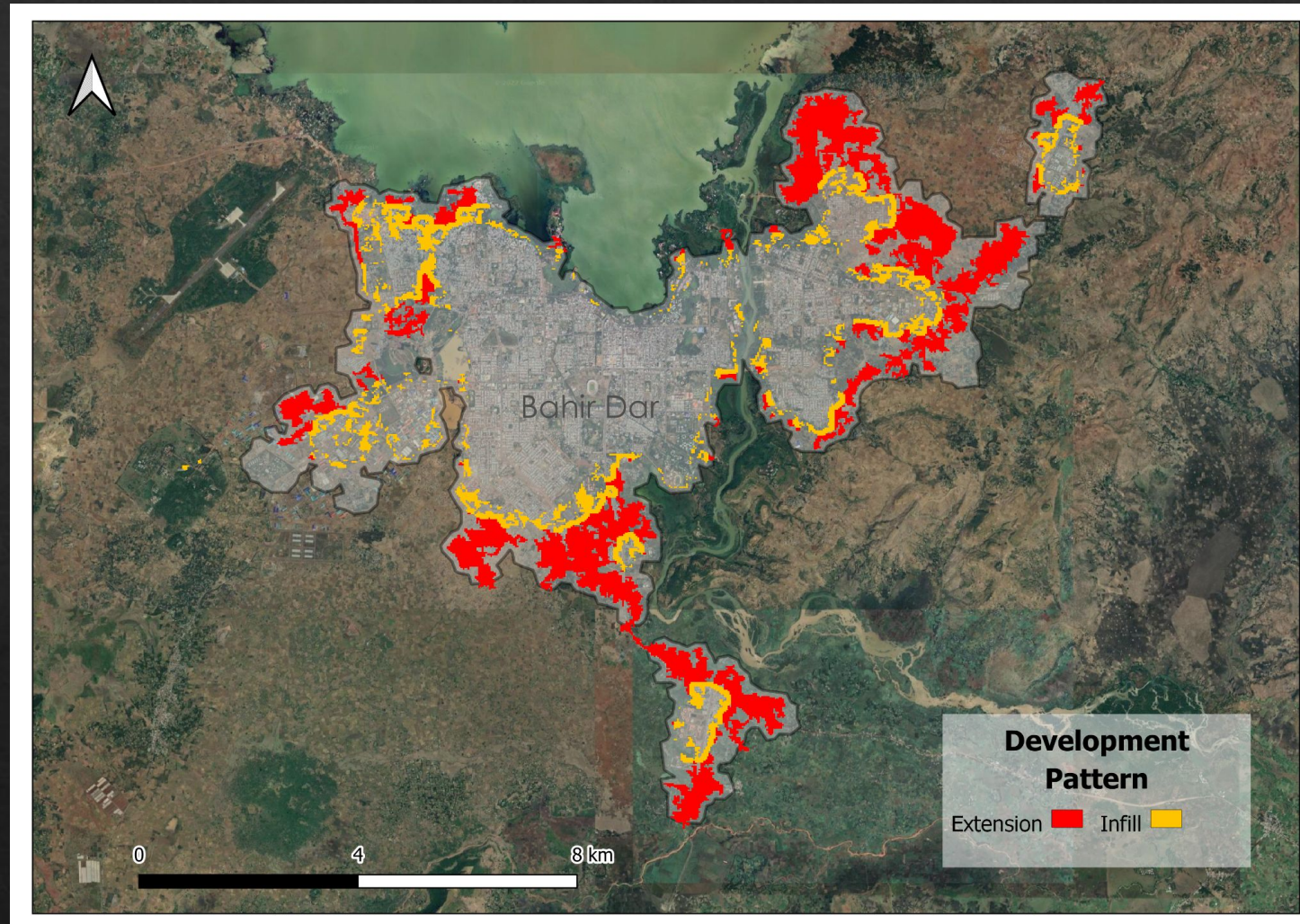
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Urban
Delineations &
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Identify Hotspots
of Urbanization



Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change

Identify Hotspots
of Urbanization

- Examined metrics by population size classes to identify urban agglomerations with the highest SDG 11.3.1 values in each class

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change

Identify Hotspots
of Urbanization

- Examined metrics by population size classes to identify urban agglomerations with the highest SDG 11.3.1 values in each class
- Evaluated different patterns between size classes as well as across the different countries

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change

Identify Hotspots
of Urbanization

- Examined metrics by population size classes to identify urban agglomerations with the highest SDG 11.3.1 values in each class
- Evaluated different patterns between size classes as well as across the different countries
- Investigated impacts of spatial resolution on urbanization metrics when using our approach.
 - overall increase in the mean 11.3.1 value for small cities when using coarser resolution land use data
 - decrease in the mean values for larger cities when using coarser resolution land use data

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change



Identify Hotspots
of Urbanization

- Pair our findings with ground data to aid in the allocation of planning and development efforts

| Name | LCRPGR | LCR | PGR |
|--------------|--------|-------|-------|
| → Bahir Dar | 7.33 | 0.197 | 0.027 |
| → Mekelle | 3.63 | 0.196 | 0.054 |
| Adama | 3.46 | 0.161 | 0.047 |
| → Jijiga | 3.07 | 0.113 | 0.037 |
| Debre Markos | 2.86 | 0.199 | 0.070 |
| Debre Berhan | 2.62 | 0.141 | 0.054 |
| Hawassa | 2.32 | 0.099 | 0.043 |
| Jimma | 2.24 | 0.127 | 0.057 |
| Dilla | 2.12 | 0.152 | 0.072 |

LCRPGR is the ratio of Land Consumption Rate to Population Growth Rate, LCR is Land Consumption Rate, PGR is Population Growth Rate, and DA is Developed Area

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change



Identify Hotspots
of Urbanization



10m resolution
land cover maps
within all cities

| Legend | |
|---|-----------------------|
|  | Bare |
|  | Impervious - Building |
|  | Impervious - Pavement |
|  | Short Vegetation |
|  | Tall Vegetation |
|  | Water |
|  | Wetland |

Predictor Sets

Sentinel-2

Sentinel 1

Topography

Bioclimatic

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change

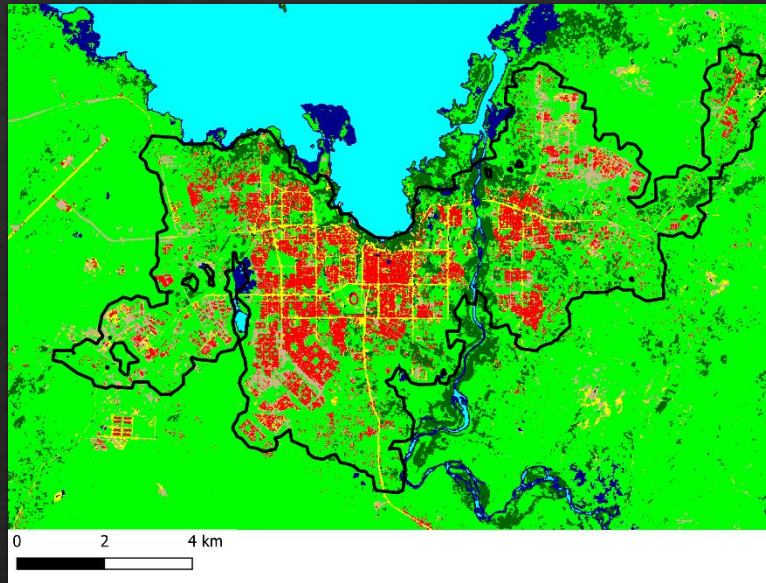


Identify Hotspots
of Urbanization

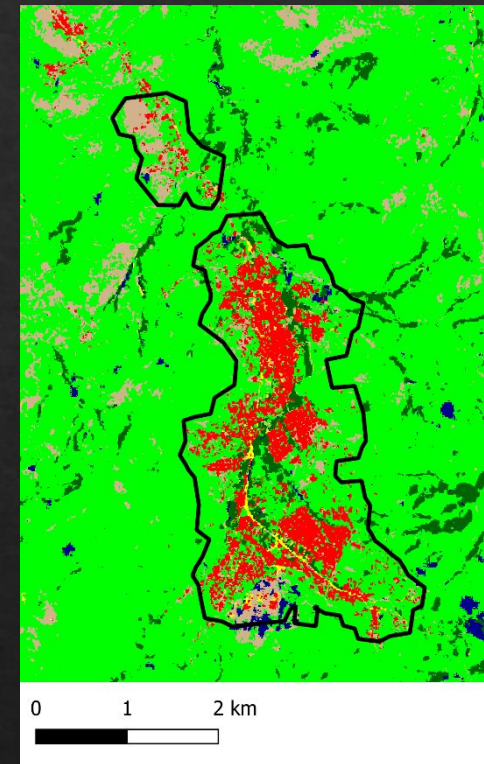


10m resolution
land cover maps
within all cities

Bahir Dar, Ethiopia (65.7 km²)



Chiro (8.5 km²)



| | precision | recall | F1-score |
|---------------------|-----------|--------|----------|
| Barren | 0.712 | 0.7 | 0.706 |
| Impervious_building | 0.76 | 0.736 | 0.748 |
| Impervious_Pavement | 0.531 | 0.573 | 0.551 |
| Short vegetation | 0.89 | 0.906 | 0.898 |
| Tall vegetation | 0.905 | 0.884 | 0.894 |
| Water | 0.4 | 1 | 0.571 |
| Wetland | 0.789 | 0.577 | 0.667 |
| Macro average | 0.713 | 0.768 | 0.719 |
| Accuracy | 0.775 | | |

Predictor Sets

- Sentinel-2
- Sentinel 1
- Topography
- Bioclimatic

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change



Identify Hotspots
of Urbanization



10m resolution
land cover maps
within all cities



High-resolution
urban object
classifications



Object-based classified map



0 500 1,000 m



Mekelle, Ethiopia
2020
(OBIA using Maxar
Imagery)

Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change



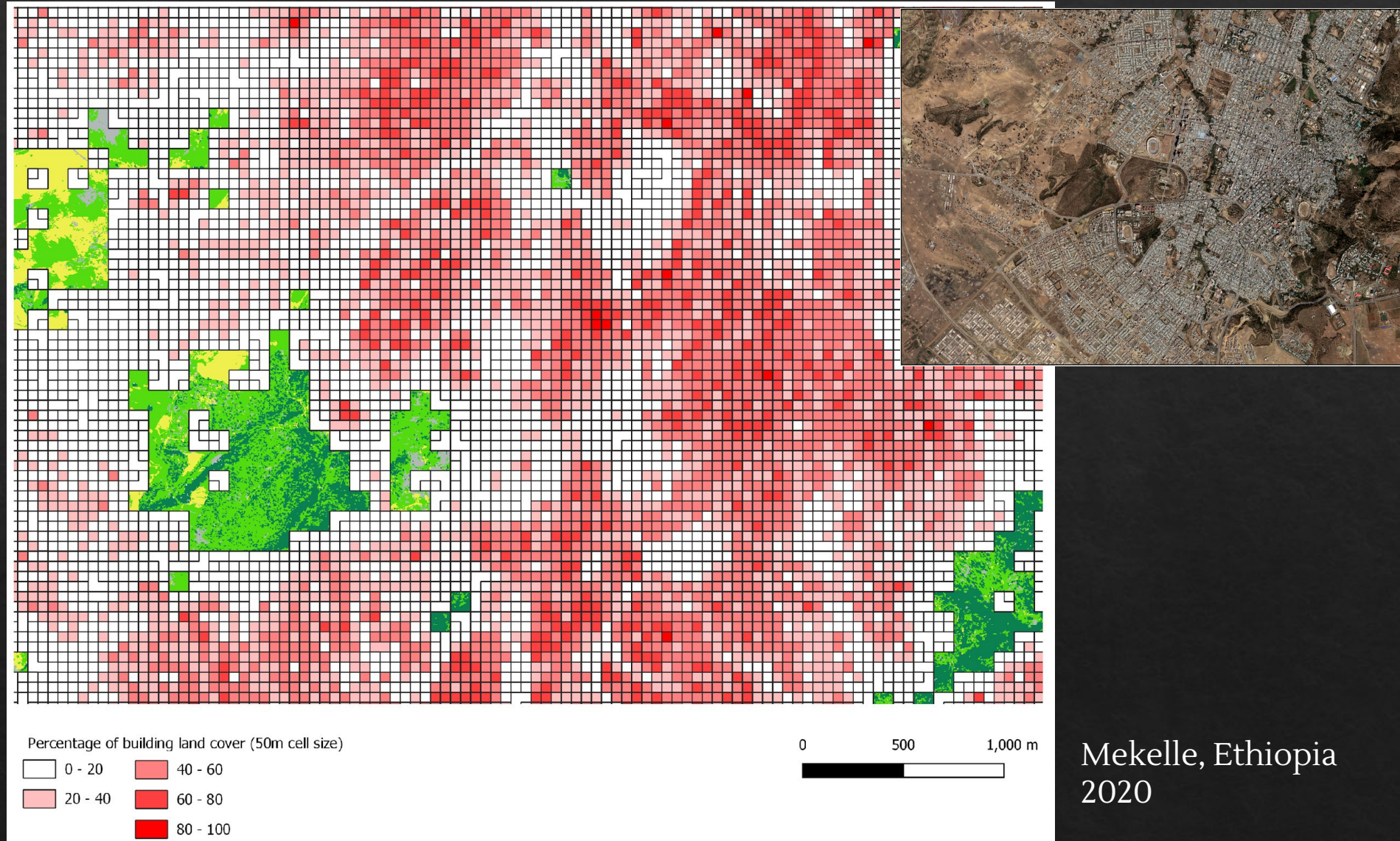
Identify Hotspots
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10m resolution
land cover maps
within all cities



High-resolution
urban object
classifications



Africa Urbanization Patterns & Hotspots

30m resolution
land use maps
(2016-2020)



Urban
Delineations &
Change



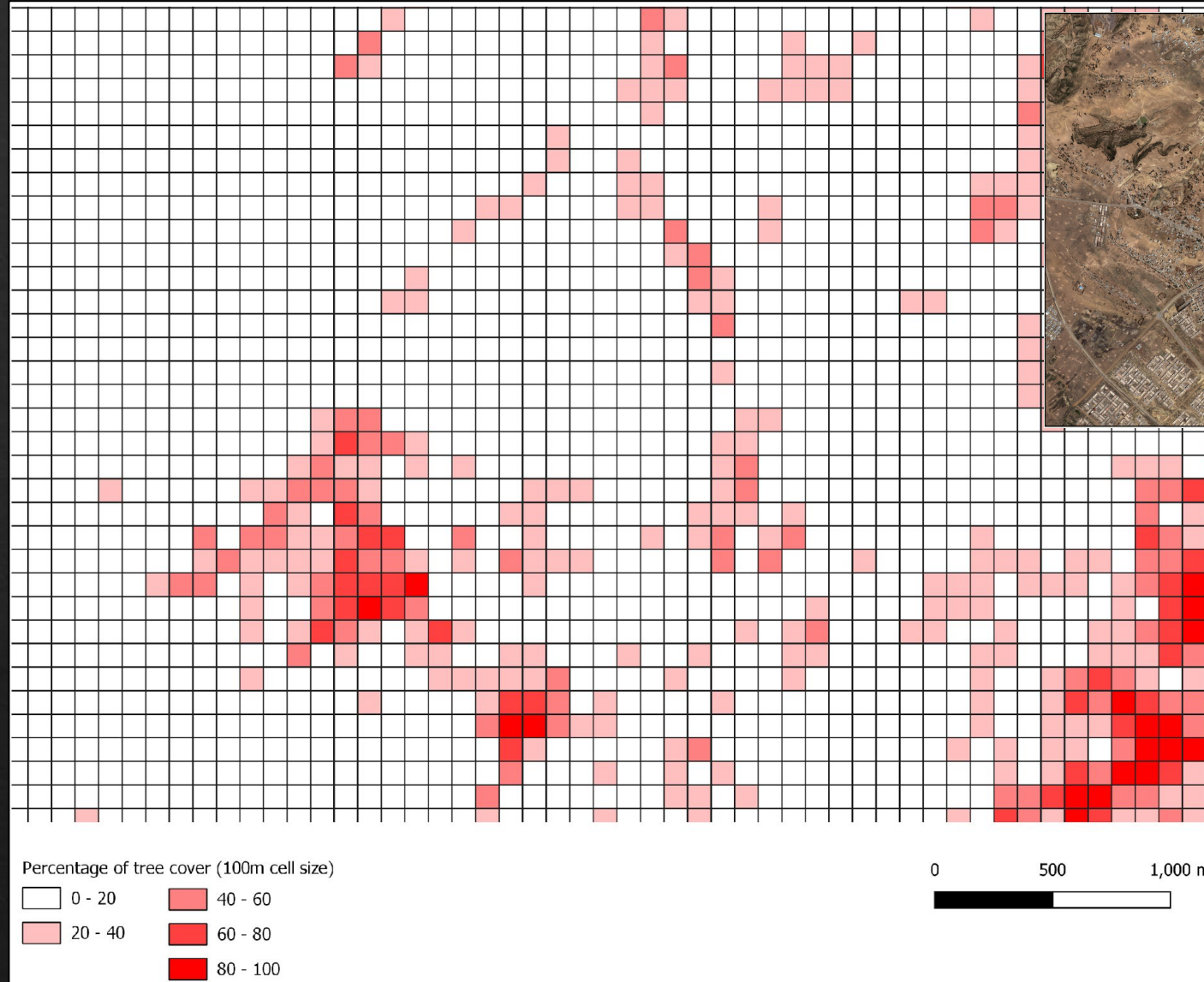
Identify Hotspots
of Urbanization



10m resolution
land cover maps
within all cities



High-resolution
urban object
classifications



Mekelle, Ethiopia
2020

Africa Urbanization Patterns & Hotspots

30m resolution
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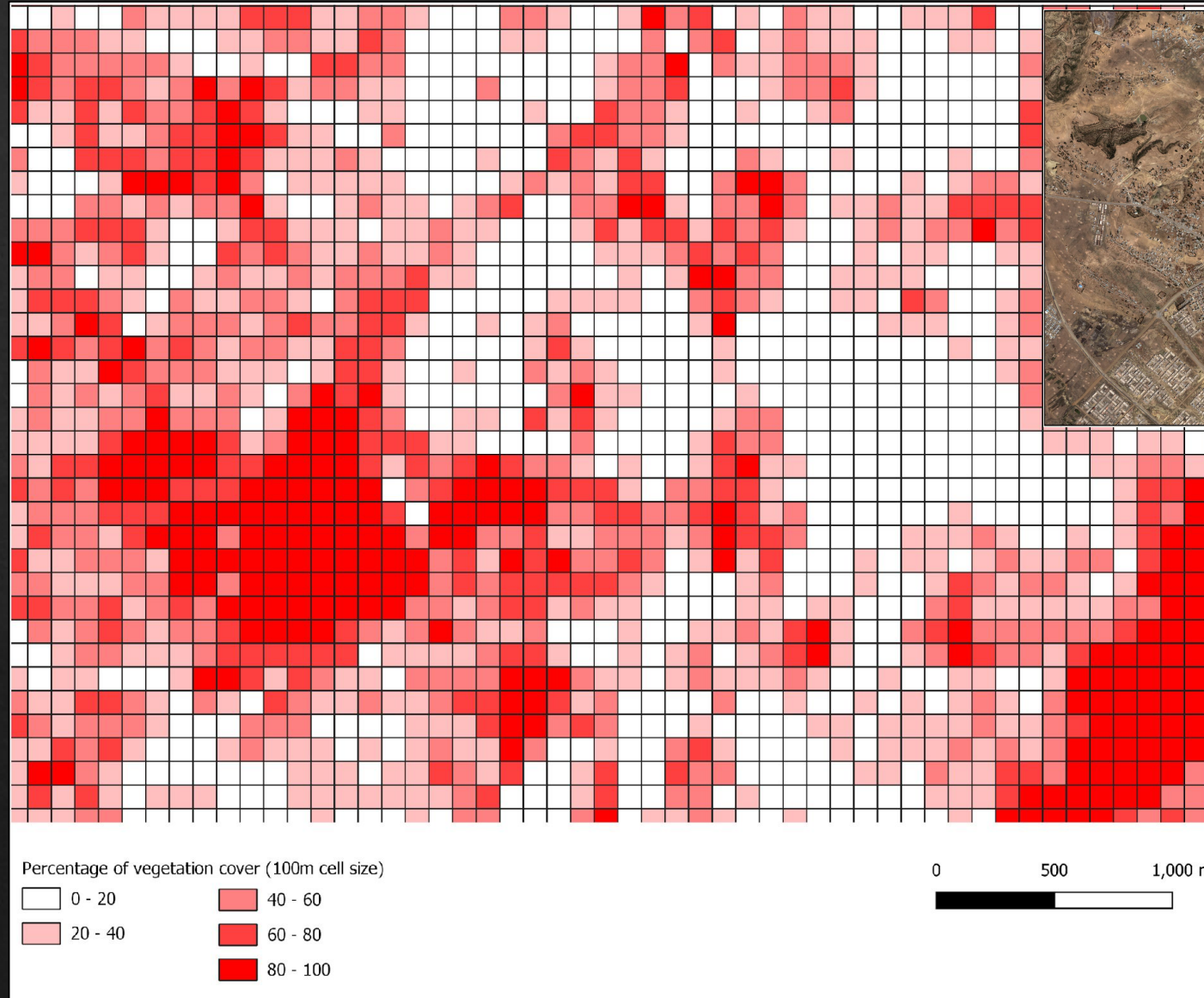
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Summary

- Multi-tier spatial products for better characterizing spatial heterogeneity of urban landscapes in three rapidly developing African countries

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Summary

- Multi-tier spatial products for better characterizing spatial heterogeneity of urban landscapes in three rapidly developing African countries
- Identified hotspots of urbanization-driven LCLUC and better dissected within city functional land uses and change patterns

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Summary

- Multi-tier spatial products for better characterizing spatial heterogeneity of urban landscapes in three rapidly developing African countries
- Identified hotspots of urbanization-driven LCLUC and better dissected within city functional land uses and change patterns
- Contributed to the comprehension of SDG Indicator 11.3.1 (and others) and built on methods to improve its role within large extent urbanization monitoring efforts



Thank You Project
Team!

QUESTIONS?

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