

The 10<sup>th</sup> JPTM 2025

# Optimization of Demography and Spatial Data to Calculate Population Exposure using Google Earth Engine

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# The Critical Gap in Flood Detection

## The Optical Sensor "Full of Cloud"

Heavy rainfall creates high cloud cover, rendering optical sensors like Sentinel-2 and Landsat completely ineffective precisely when flooding occurs. This creates a critical visibility gap during the most crucial moments of disaster response.

Mapping delays cascade into inefficient aid distribution, leaving vulnerable populations without timely assistance. Emergency managers lack real-time situational awareness when decisions matter most.

Often, floods are time-sensitive. They can occur quickly, then disappear in less than a day. Except, debris flood



# Why Active Sensors? The Power of SAR

## All-Weather Capability

Synthetic Aperture Radar (SAR) penetrates clouds, smoke, and atmospheric interference. Unlike optical systems, SAR operates effectively at night and through severe weather conditions, providing continuous monitoring regardless of environmental constraints.

## Water Detection Sensitivity

Radar backscatter is highly sensitive to water's unique dielectric constant and surface roughness characteristics. Smooth water surfaces create specular reflection, resulting in low backscatter values that clearly distinguish inundated areas from dry land in SAR imagery.

# The Integrated Dataset on Google Earth Engine



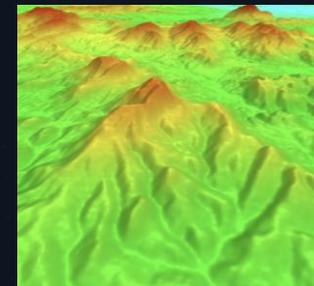
## Sentinel-1 GRD

10-meter resolution SAR imagery utilizing VH polarization for optimal water-land contrast and flood boundary delineation.



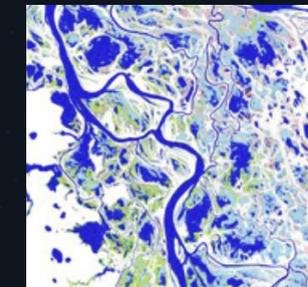
## WorldPop Demographics

100-meter resolution population density with age and sex disaggregation for vulnerability assessment and exposure calculation.



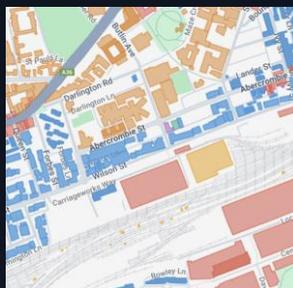
## NASADEM Elevation

High-resolution elevation data enabling slope correction, shadow masking, and topographic refinement of flood extent mapping.



## JRC Global Surface Water

Historical permanent water body database for seasonality masking, ensuring new flood areas are distinguished from existing watercourses.



## OpenBuildingMap

Merged infrastructure footprints combining multiple sources for comprehensive structural exposure and damage assessment capabilities.

```
var collection= ee.ImageCollection('COPERNICUS/S1_GRD')
  .filter(ee.Filter.eq('instrumentMode','IW'))
  .filter(ee.Filter.listContains('transmitterReceiverPolarisation', polarization))
  .filter(ee.Filter.eq('orbitProperties_pass',pass_direction))
  .filter(ee.Filter.eq('resolution_meters',10))
var swater = ee.Image('JRC/GSW1_4/GlobalSurfaceWater').select('seasonality');
var dem = ee.Image('NASA/NASADEM_HGT/001')
var popDataset = ee.ImageCollection("WorldPop/GP/100m/pop_age_sex_cons_unadj")
  .filterBounds(aoi)
  .filter(ee.Filter.eq('year', 2020)).mosaic();
var buildings = ee.FeatureCollection('projects/sat-io/open-datasets/OPEN-BUILDING-MAPS/tiles/building_132223')
```

# Flood Detection: Change Detection Simple Algorithm

## The Detection Approach

Change detection compares pre-event baseline imagery with post-flood acquisitions, isolating areas where backscatter has decreased significantly due to water accumulation.

$$\text{Flood} = \frac{\text{Post-Event}_{\text{VH}}}{\text{Pre-Event}_{\text{VH}}} < \text{Threshold}$$

Ratio-based detection quantifies relative backscatter changes, with threshold values typically set around 1.1 to isolate significant drops caused by surface inundation while minimizing false positives.

Before Flood



After Flood



# Refining Result

This is necessary because the object values detected from the threshold consist of:

1. Floods = the main objectives
2. Water body expansion : corrected with seasonal water data from Global Surface Water. Water inundation in locations that are frequently inundated for 10 months in a year, not floods
3. Shadows due to steep slopes : Corrected with DEM. Flood often occur in flat area (<5 % slope)
4. Speckle noise, which produces scattered but small flood areas : Flooding occurs in a wide area. It rarely occurs in small spots. Each pixel that is not connected to each other is at least 8 pixels, not flooded. The number of pixel, depend on the location

```
// Refine flood result using additional datasets
// Include JRC layer on surface water seasonality to mask flood pixels from areas
// of "permanent" water (where there is water > 10 months of the year)
var swater = ee.Image('JRC/GSW1_4/GlobalSurfaceWater').select('seasonality');
var swater_mask = swater.gte(10).updateMask(swater.gte(10));

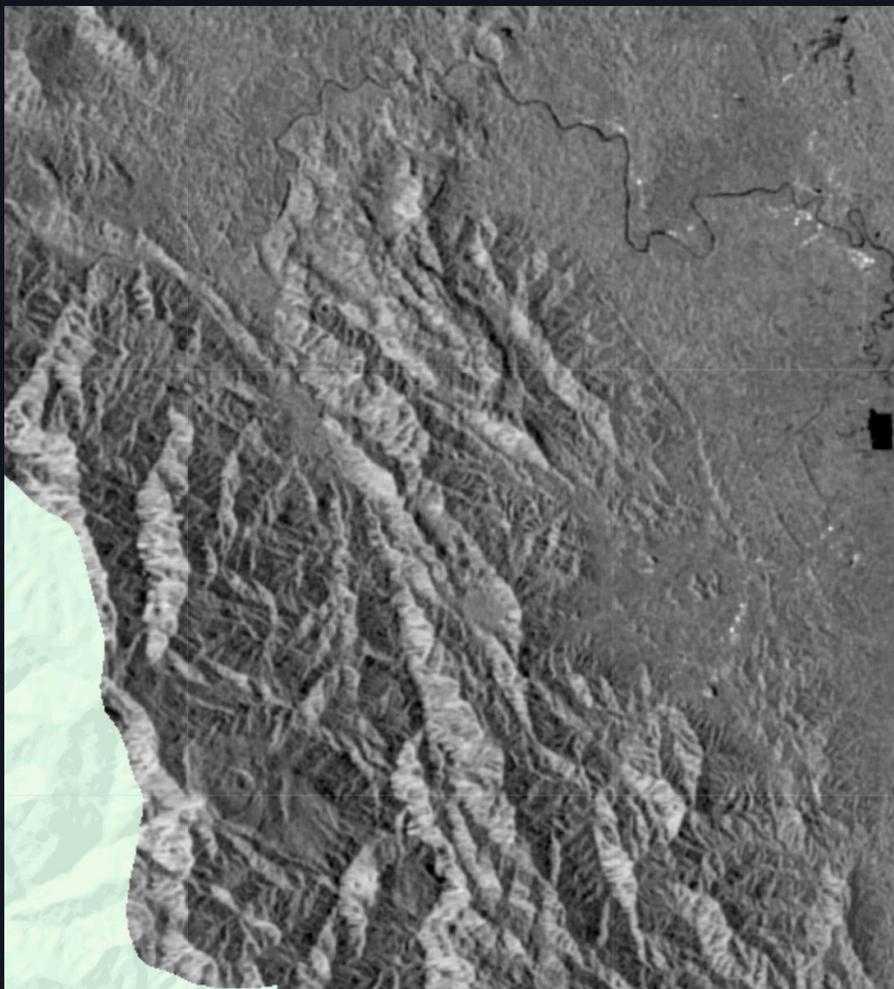
//Flooded layer where perennial water bodies (water > 10 mo/yr) is assigned a 0 value
var flooded_mask = difference_binary.where(swater_mask,0);
// final flooded area without pixels in perennial waterbodies
var flooded = flooded_mask.updateMask(flooded_mask);

// Compute connectivity of pixels to eliminate those connected to 8 or fewer neighbours.
// This operation reduces noise of the flood extent product
var connections = flooded.connectedPixelCount();
var flooded = flooded.updateMask(connections.gte(8));

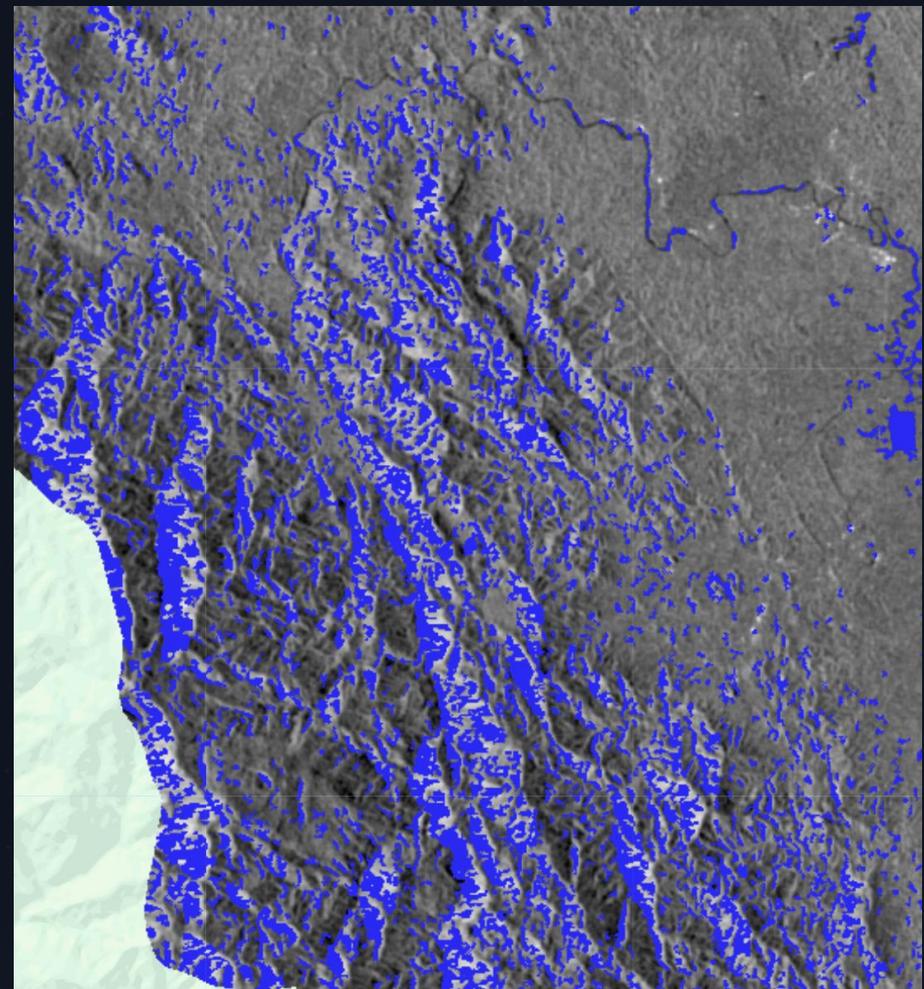
// Mask out areas with more than 5 percent slope using a Digital Elevation Model
var dem = ee.Image('NASA/NASADEM_HGT/001')
    .select('elevation')
    .clip(aoi);
var slope = ee.Terrain.slope(dem);
var floodSAR = flooded.updateMask(slope.lt(5));
```



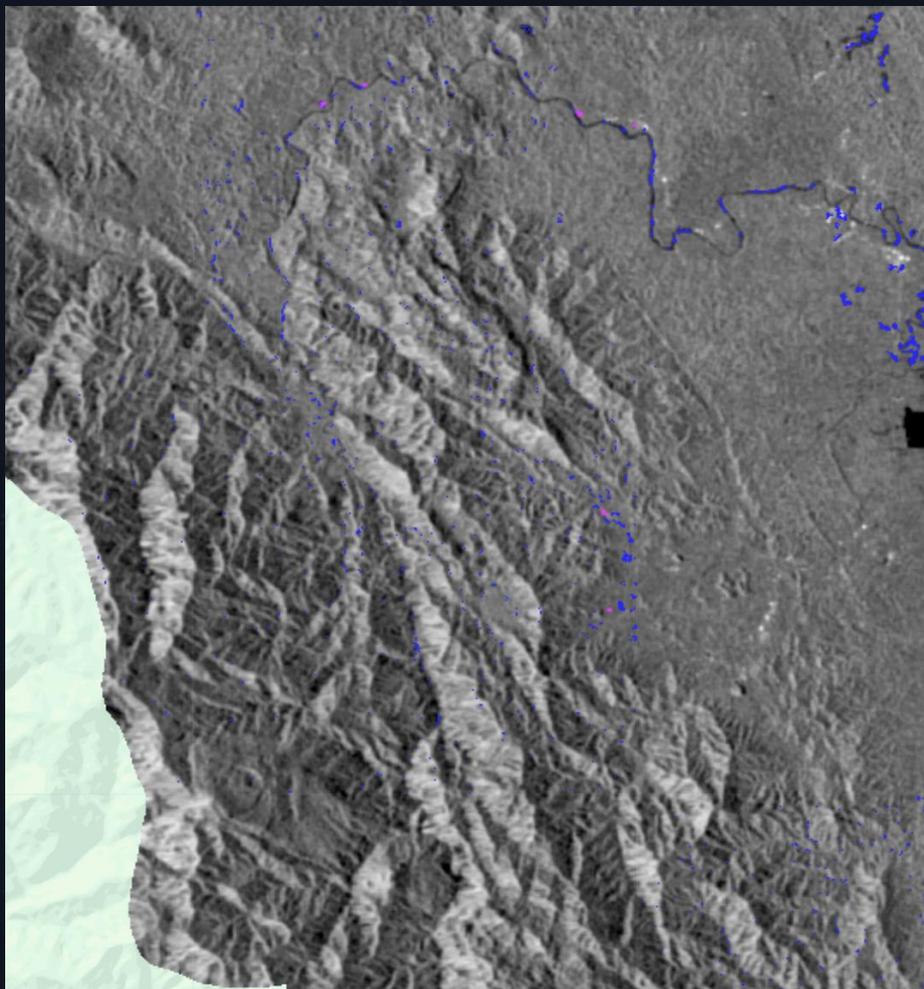
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**S-1 After Flood**



**Before refined with Slope**



**After refined with Slope**

# Limitations of Radar Data

## Urban Area

Flooding in urban areas is difficult to detect using backscatter differences due to the double bounce characteristic of built-up areas.

## Agriculture Area

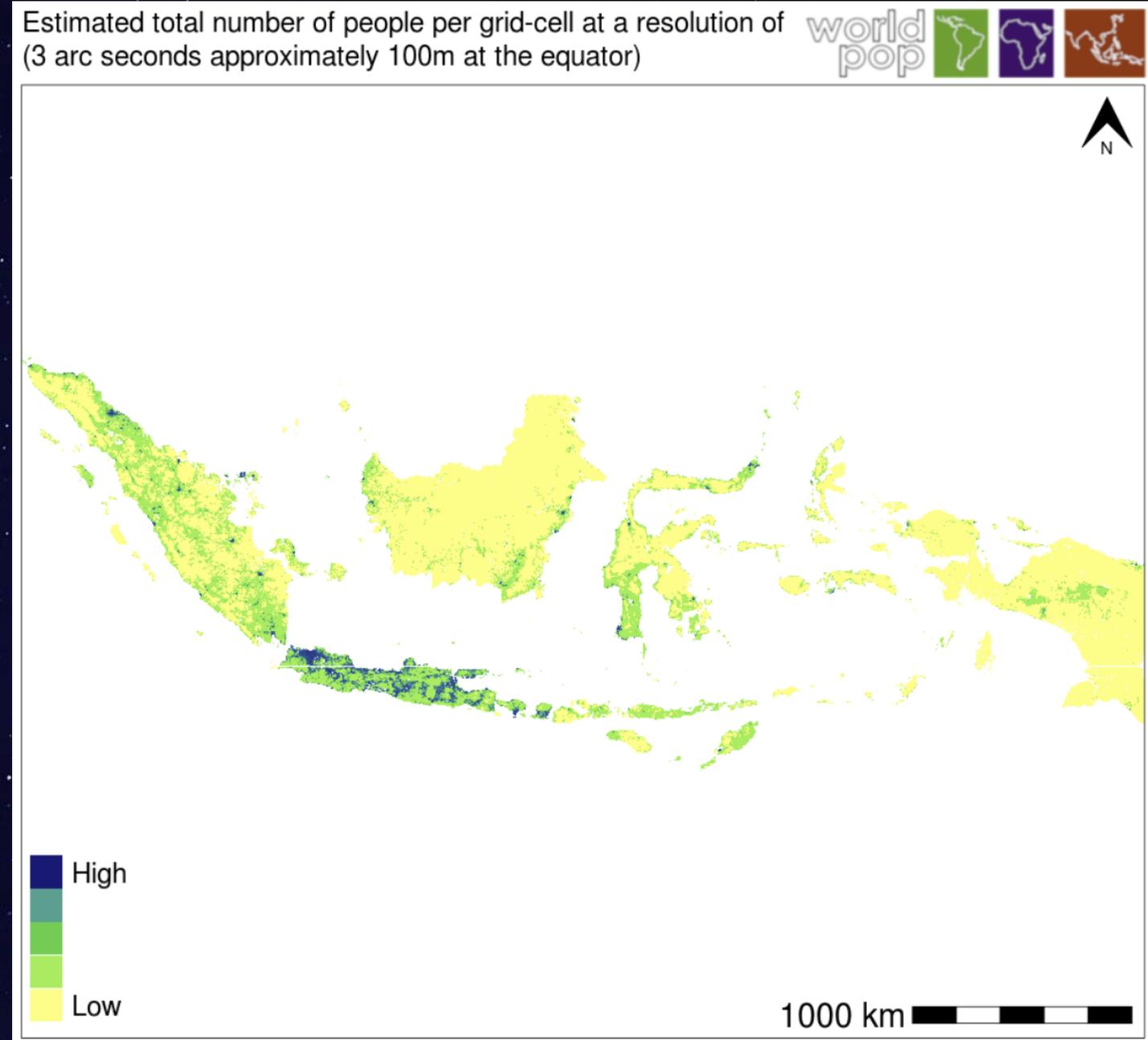
Agricultural areas that were already inundated before the flood were not detected as flooded because there was no difference in backscatter.

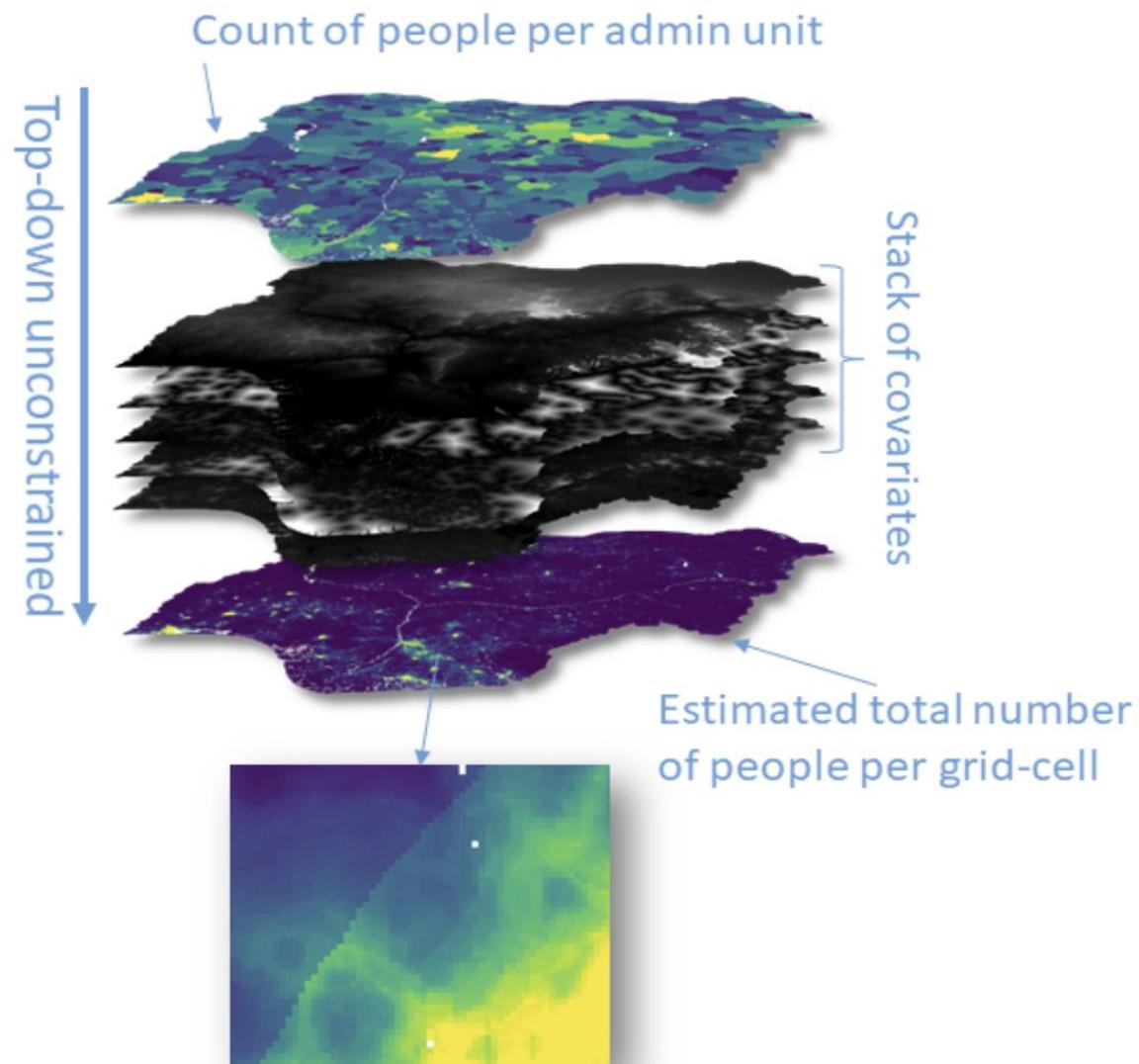


# Population Exposure: WorldPop Integration

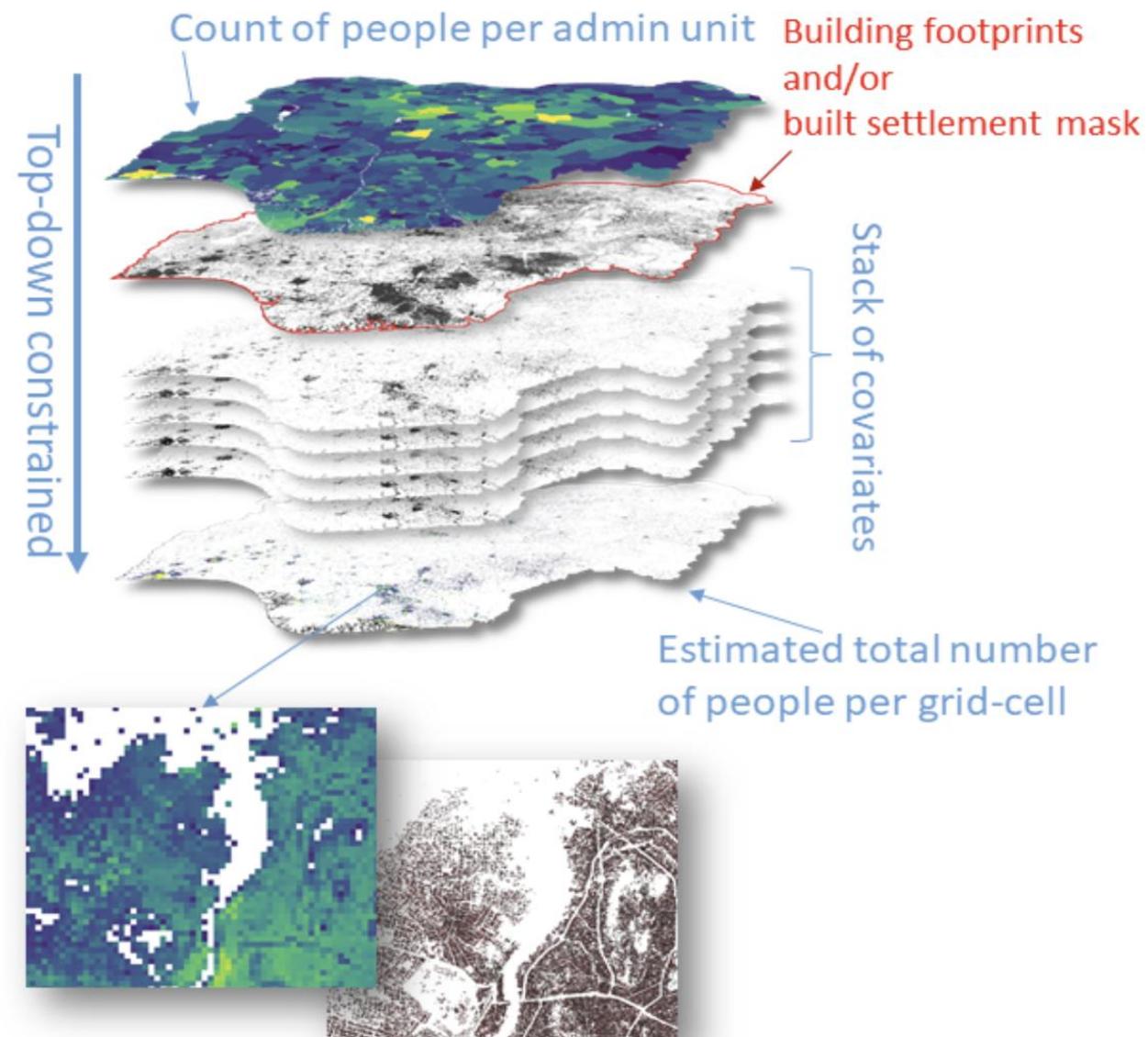
Demographic modeling redistributes census data into 100m grid cells using satellite-derived proxies like settlement patterns, land cover, and built-up density. This approach dramatically improves spatial precision over traditional administrative unit aggregation.

Overlaying flood extent polygons with WorldPop layers enables direct calculation of **exposed population counts** disaggregated by age and sex 4critical information for targeting evacuation efforts toward vulnerable groups including children and elderly residents.





Top-down unconstrained



Top-down constrained

# WorldPop Dataset

population	0*	21171*	meters	Estimated number of people residing in each grid cell
M_0			meters	Estimated number of men between 0 and 1 years old residing in each grid cell
M_1			meters	Estimated number of men between 1 and 4 years old residing in each grid cell
M_5			meters	Estimated number of men between 5 and 9 years old residing in each grid cell
M_10			meters	Estimated number of men between 10 and 14 years old residing in each grid cell
M_15			meters	Estimated number of men between 15 and 19 years old residing in each grid cell
M_20			meters	Estimated number of men between 20 and 24 years old residing in each grid cell
M_25			meters	Estimated number of men between 25 and 29 years old residing in each grid cell
M_30			meters	Estimated number of men between 30 and 34 years old residing in each grid cell
M_35			meters	Estimated number of men between 35 and 39 years old residing in each grid cell
M_40			meters	Estimated number of men between 40 and 44 years old residing in each grid cell
M_45			meters	Estimated number of men between 45 and 49 years old residing in each grid cell
M_50			meters	Estimated number of men between 50 and 54 years old residing in each grid cell
M_55			meters	Estimated number of men between 55 and 59 years old residing in each grid cell
M_60			meters	Estimated number of men between 60 and 64 years old residing in each grid cell
M_65			meters	Estimated number of men between 65 and 69 years old residing in each grid cell
M_70			meters	Estimated number of men between 70 and 74 years old residing in each grid cell
M_75			meters	Estimated number of men between 75 and 79 years old residing in each grid cell
M_80			meters	Estimated number of men 80 years old or above residing in each grid cell

F_1	meters	Estimated number of women between 1 and 4 years old residing in each grid cell
F_5	meters	Estimated number of women between 5 and 9 years old residing in each grid cell
F_10	meters	Estimated number of women between 10 and 14 years old residing in each grid cell
F_15	meters	Estimated number of women between 15 and 19 years old residing in each grid cell
F_20	meters	Estimated number of women between 20 and 24 years old residing in each grid cell
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F_55	meters	Estimated number of women between 55 and 59 years old residing in each grid cell
F_60	meters	Estimated number of women between 60 and 64 years old residing in each grid cell
F_65	meters	Estimated number of women between 65 and 69 years old residing in each grid cell
F_70	meters	Estimated number of women between 70 and 74 years old residing in each grid cell
F_75	meters	Estimated number of women between 75 and 79 years old residing in each grid cell
F_80	meters	Estimated number of women 80 years old or above residing in each grid cell

```
var popDataset = ee.ImageCollection("WorldPop/GP/100m/pop_age_sex_cons_unadj")
    .filterBounds(aoi)
    .filter(ee.Filter.eq('year', 2020)).mosaic();
```

```
var total_pop = popDataset.select('population');
var female_pop = popDataset.select('F.*').reduce(ee.Reducer.sum());
var male_pop = popDataset.select('M.*').reduce(ee.Reducer.sum());
var baby_toddler = popDataset.select(['F_0', 'M_0', 'F_1', 'M_1']).reduce(ee.Reducer.sum());
var elderly_pop = popDataset.select(['F_65', 'M_65', 'F_70', 'M_70', 'F_75', 'M_75', 'F_80', 'M_80',]).reduce(ee.Reducer.sum());
```

# Pros and Cons of WorldPop

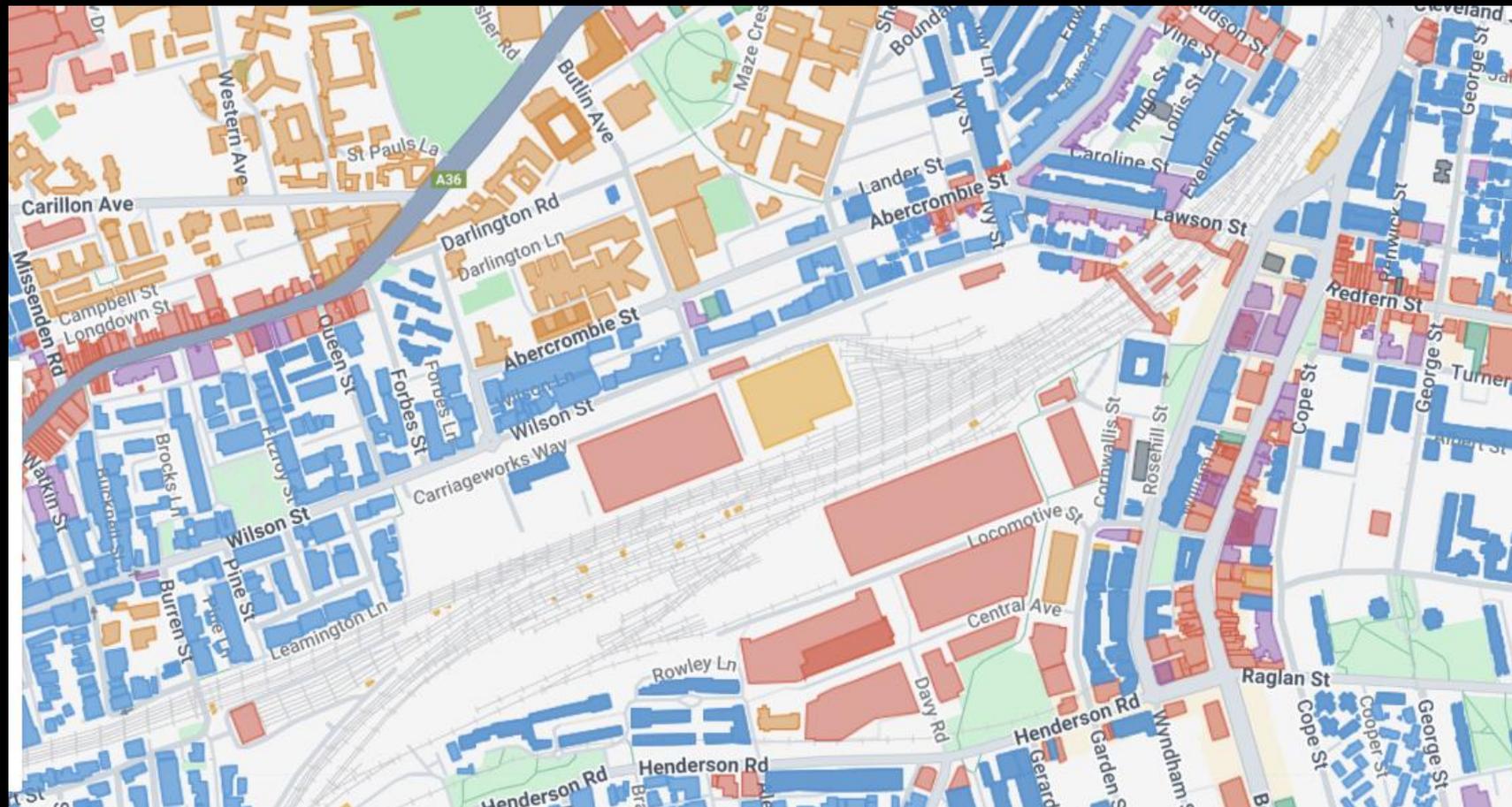
## Advantages

- **Age/Sex Disaggregation:** Enables targeted vulnerability assessment for children, elderly, and reproductive-age women
- **Global Consistency:** Standardized methodology facilitates cross-border disaster response coordination
- **High-Resolution Availability:** 100m grids provide actionable spatial detail for neighborhood-scale planning

## Limitations

- **Commercial Zone Overestimation:** Allocating population to non-residential areas inflates exposure counts
- **Slum Underestimation:** Extreme density informal settlements often exceed model capacity, undercounting vulnerable populations
- **Temporal Dynamic:** Multi-year lags reduce accuracy in rapidly urbanizing regions

# Infrastructure Impact: Building Dataset



AI-derived building footprints provide unprecedented infrastructure exposure detail. The dataset enables calculation of both building count and total structural area in flooded zone.

This dual metric approach supports damage assessment by distinguishing between scenarios affecting many small structures versus fewer large facilities. Critical infrastructure like hospitals, schools, and emergency facilities can be rapidly identified and response.



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# OpenBuildingMap Global Footprints

## Multi-Source Fusion

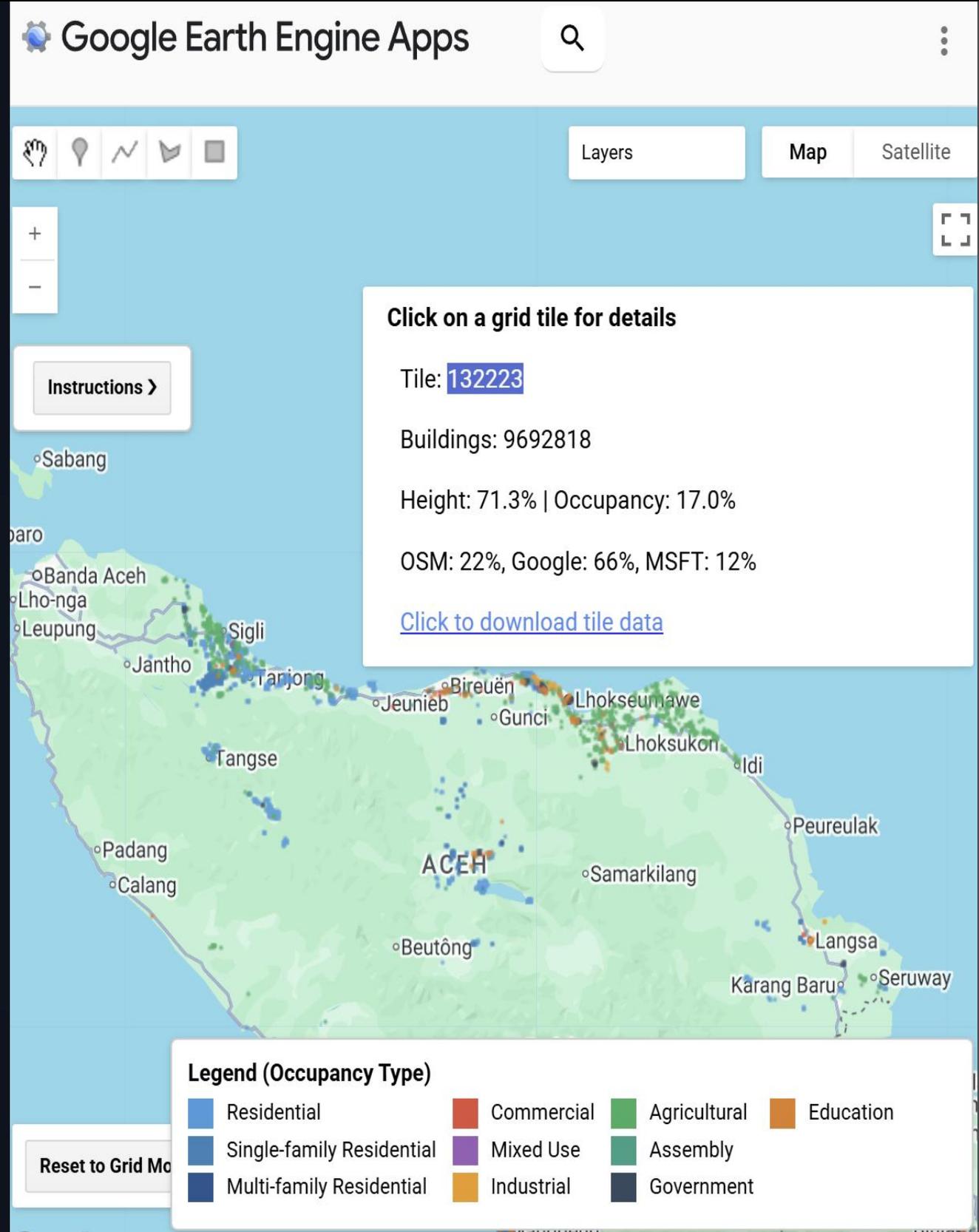
Combines Microsoft, Google, and OSM, building datasets into unified global coverage

## Filling Data Gaps

Community-sourced footprints complement commercial AI products in underrepresented regions

## Enhanced Accuracy

Cross-validation between sources improves baseline infrastructure assessment reliability





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Google Earth Engine

Search places and datasets...

ee-ucnugroho

Scripts Docs Assets

owner (1)

- users/ucnugroho/geogis
  - Banjir\_Sumatera
  - Coba\_Banjir
  - Coba\_Banjir\_Koreksi
  - DeteksiKolong\_Fungsi\_L7
  - DeteksiKolong\_Fungsi\_Landsat
  - Deteksi\_Kolong
  - FloodAndExposure
  - KoreksiS1\_Lee
  - Koreksi\_Sentinel1
  - LST\_L8\_TOA
  - MT Void

FloodAndExposure

```

158 // Display the result
159 print('Total Area of Flood (m²)', flood_area_ha);
160 print('Population Exposure (People)', popStats);
161 print('Number of Affected Building', count_buildings);
162 // Display S-1 Data Before Flood
163 Map.addLayer(ee.Image(before_filtered), {min: -25, max: 0}, 'Sentinel-1 Pre Event');
164 // Display S-1 Data After Flood
165 Map.addLayer(ee.Image(after_filtered), {min: -25, max: 0}, 'Sentinel-1 Post Event');
166 // Flooded areas
167 Map.addLayer(flooded, {palette: "0000FF"}, 'Flooded areas');
168 // Affected Building
169 Map.addLayer(buildings_flooded, {color: 'FF00FF'}, 'Affected Building');

```

Inspector Console Tasks

ImageCollection COPENNIC... JSON

Total Area of Flood (m²) JSON  
24081

Population Exposure (Peop... JSON

Object (5 properties) JSON

- baby: 5835.38474458456
- elderly: 1627.9907416515052
- female: 26050.23546789959
- male: 27663.118029870093
- total: 53713.353733062744

Layers Map Satellite

Google

Keyboard shortcuts Map data ©2026 Google 10 km Terms Report a map error

<https://code.earthengine.google.com/3c32bfc82e3f5079af55512a58048d59>

# GEE limitation for non-commercial user

## Memory Limitation

Heavy or complex operation frequently trigger "User Memory Limit Exceeded" errors. Server-side memory allocation remains strictly capped for interactive client-side tasks, forcing developers to constantly optimize their spatial analysis workflows.

## Timeout Constraints

Interactive computations hit a hard 5-minute ceiling. Large-scale analyses—such as calculating population exposure across entire provinces—must shift to Batch Exports, introducing significant delays that hamper real-time emergency response and decision-making capabilities.

## UI & API Restrictions

GEE Apps offer minimal widget customization and suffer performance degradation when rendering multiple high-resolution rasters with complex vector overlays. These limitations constrain the development of sophisticated user interfaces for stakeholder engagement.



# The Next....



## Integrate with Python

Logically, settlements with elevations lower than the flood zone should be flooded. The region growing method can be used to fill settlements not detected as flooded. However, it is limited to GEE and must be processed externally.



## Machine Learning Integration

Machine learning classifier potential to overcome the threshold method.



## Loss Damaged Assessment

Using the flood depth, tax price, and land cover approaches to calculate the loss value

## Coherence Change

Flood detection based on coherence change not in backscatter



# Terima Kasih

