Machine Learning Aided LiDAR Sinkhole Mapping

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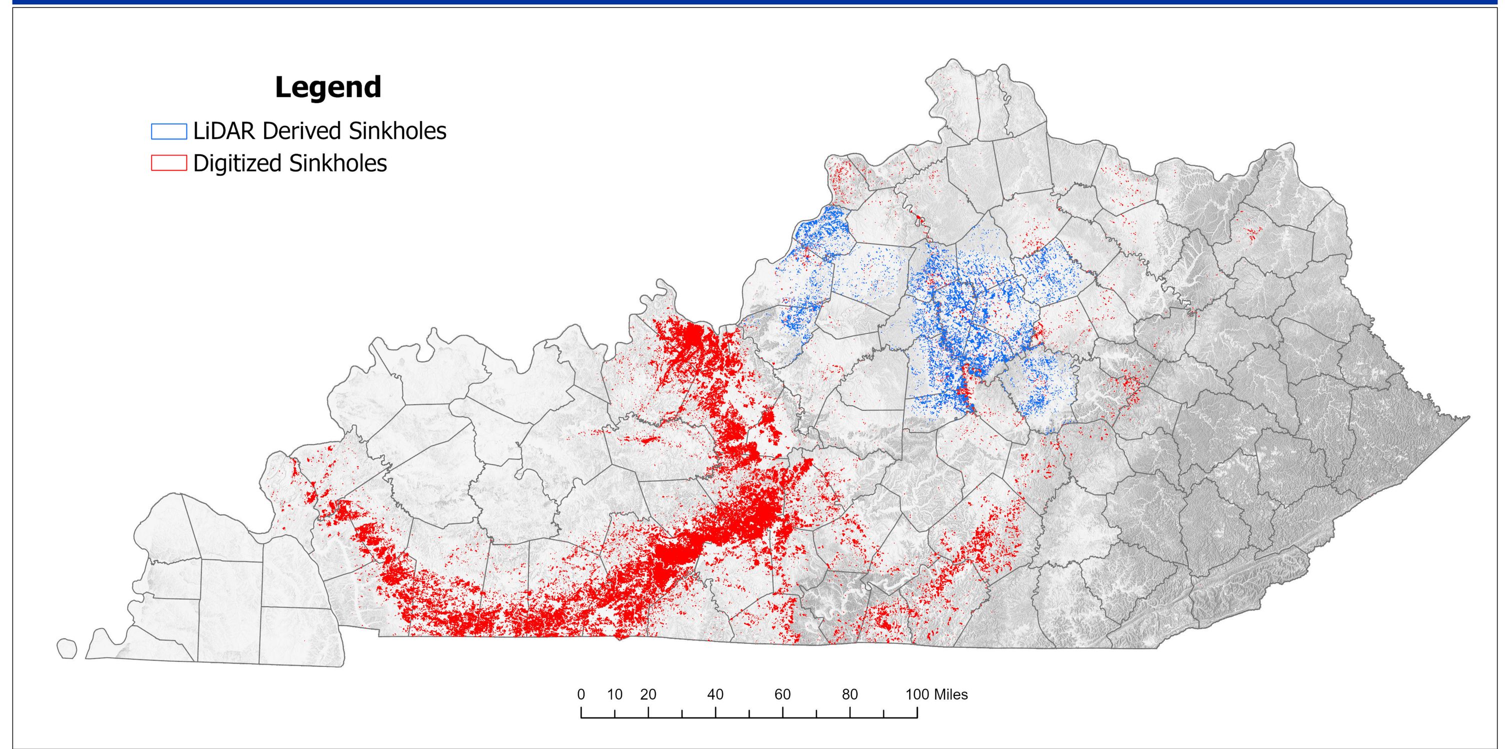
Introduction



All published sinkhole data available at https://kgs.uky.edu/kygeode/geomap/

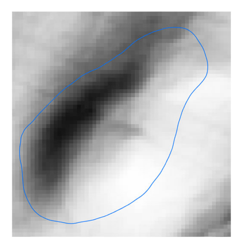
- The purpose of this project is to add to the LiDAR derived sinkhole database for Kentucky.
- An existing statewide sinkhole database was created from digitizing 1: 24,000 topographic maps and was not field checked. High resolution and high accuracy LiDAR data allow us to map sinkholes more accurately.
- The new counties I mapped were Clark County, Montgomery County, Garrard County, and Harrison County.

Methodology

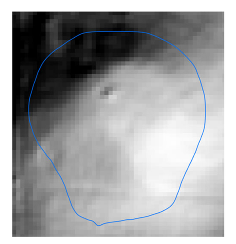
1. Use the Depression Evaluation tool (ArcHydro) in ArcGIS Pro to identify all possible depressions from the LiDAR-derived 5ft DEM (KyFromAbove, n.d.) within a particular county.
2. Eliminate depressions with less than 0.5 ft in depth and less than 500 ft^2 in area.
3. Classify polygons using a shaded relief map, KYAPED 2019 aerial imagery, machine learning identified sinkholes, and deep learning identified sinkholes. Depressions are classified as a sinkhole, or a non-sinkhole.

Sinkhole Identifiers: (Zhu et al. 2014)

- Shape: Polygon should be circular or elliptical. The bottom should be rounded, not flat.
- Drainage: Sinkholes should be internally drained. This can show up as a hole or a sinking stream.
- Depth: Most sinkholes are at least one foot deep and are deepest towards the center.



Clark County sinkhole, 9ft deep



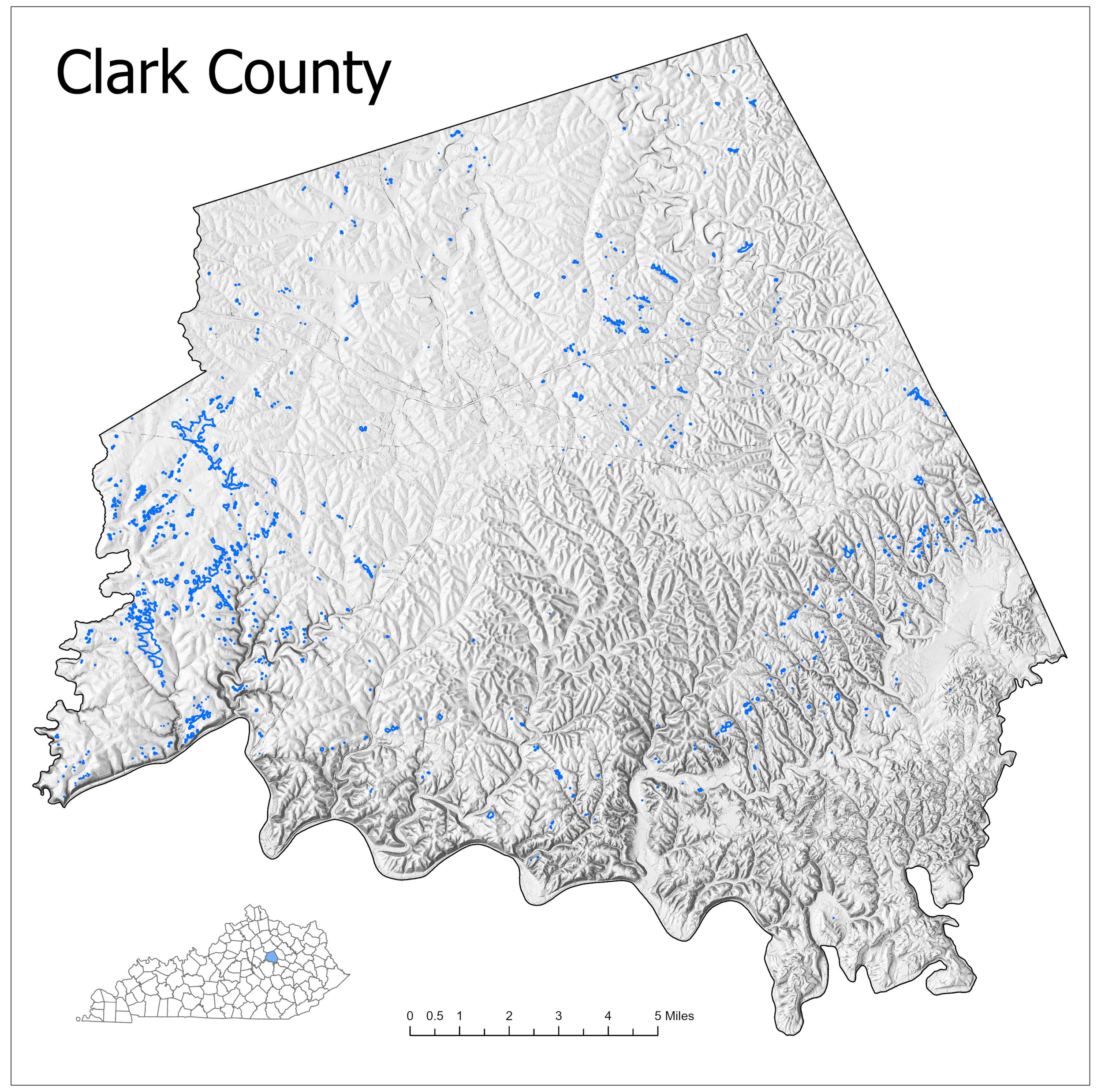
Clark County sinkhole, 10 ft deep with hole

Machine Learning

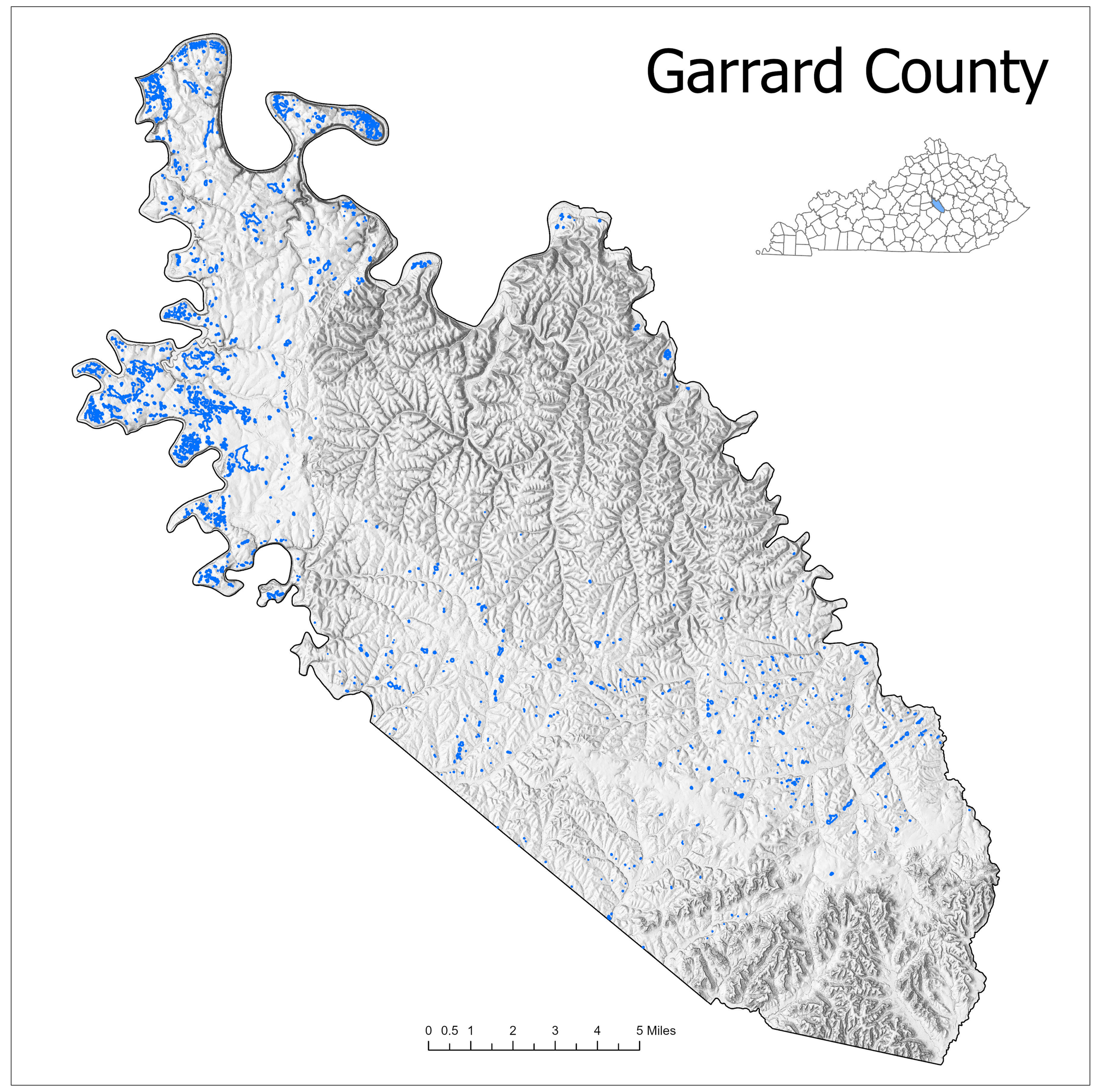
- A shallow neural network model that uses 10 morphometric characteristics about each polygon to be processed (Zhu et al. 2020)
- The output is a probability of a polygon being a sinkhole or non-sinkhole.
- Polygons with a probability greater than 0.5 are accepted as sinkholes.

Deep Learning

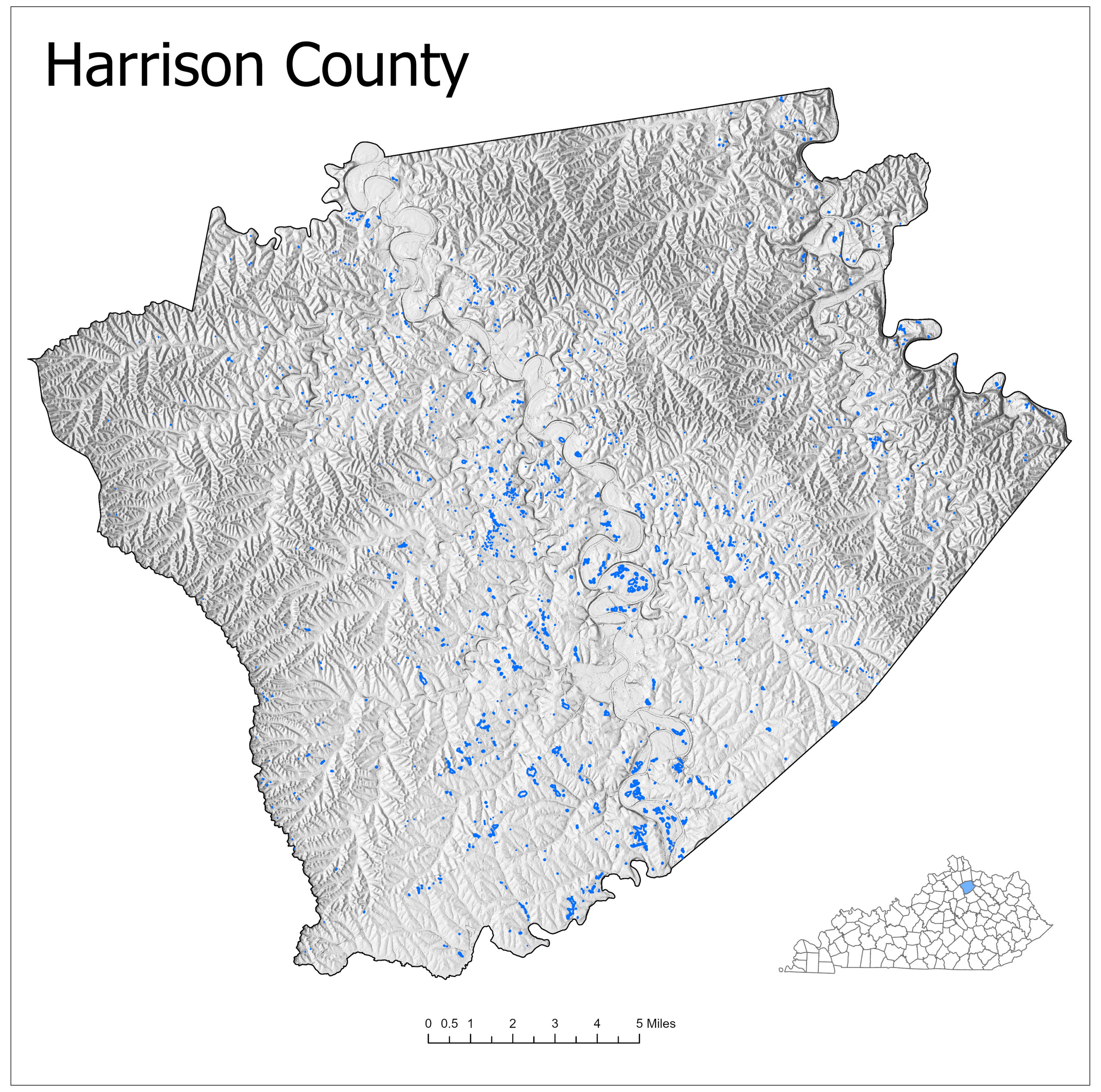
- A deep neural network model that uses image segmentation to classify each pixel (Rafique et al. 2022). It directly uses DEM images as inputs.
- This creates a sinkhole raster which is then converted to polygons.



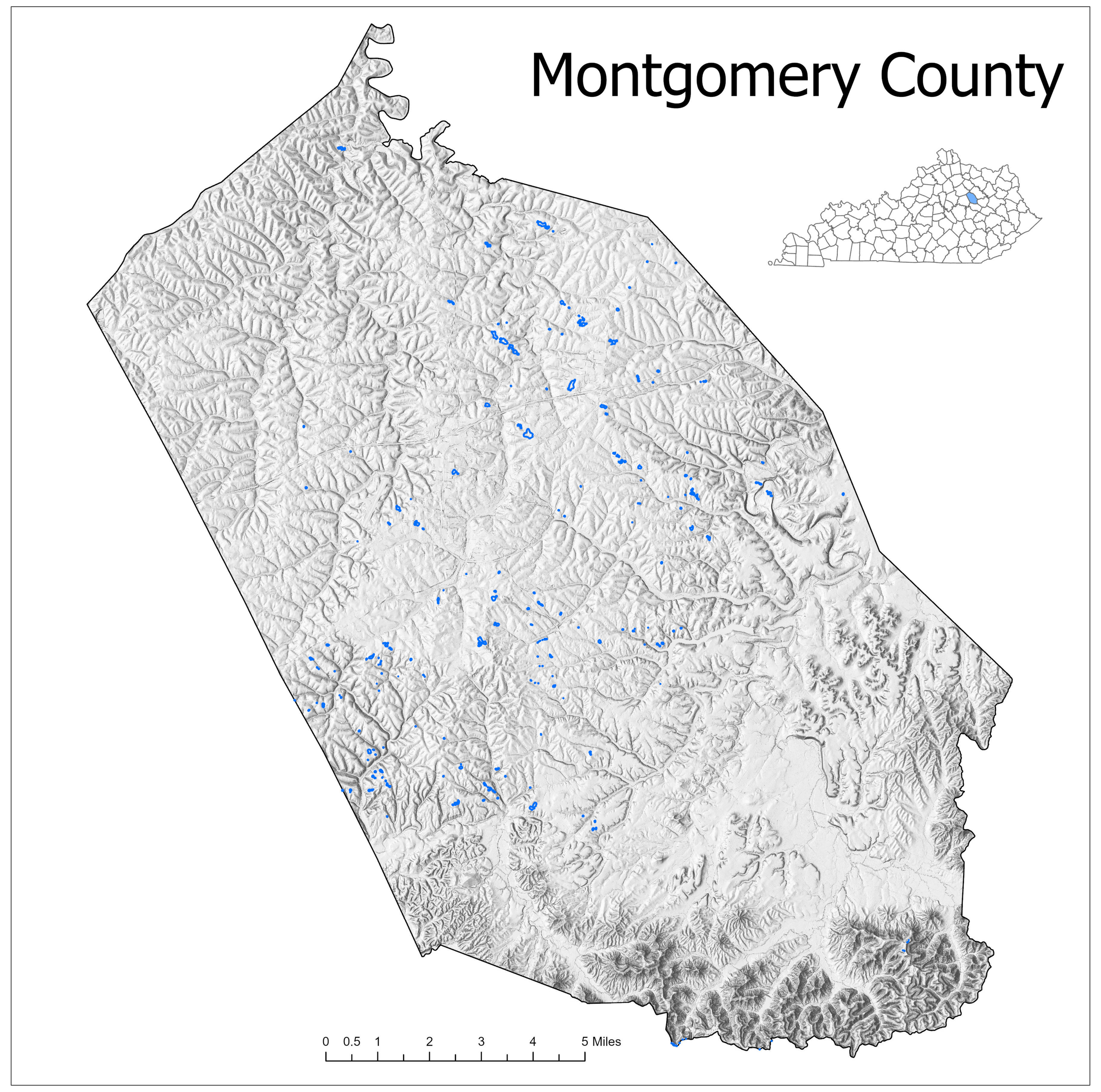
LiDAR Derived Sinkholes in Clark County, KY



LiDAR Derived Sinkholes in Garrard County, KY



LiDAR Derived Sinkholes in Harrison County, KY



LiDAR Derived Sinkholes in Montgomery County, KY

References

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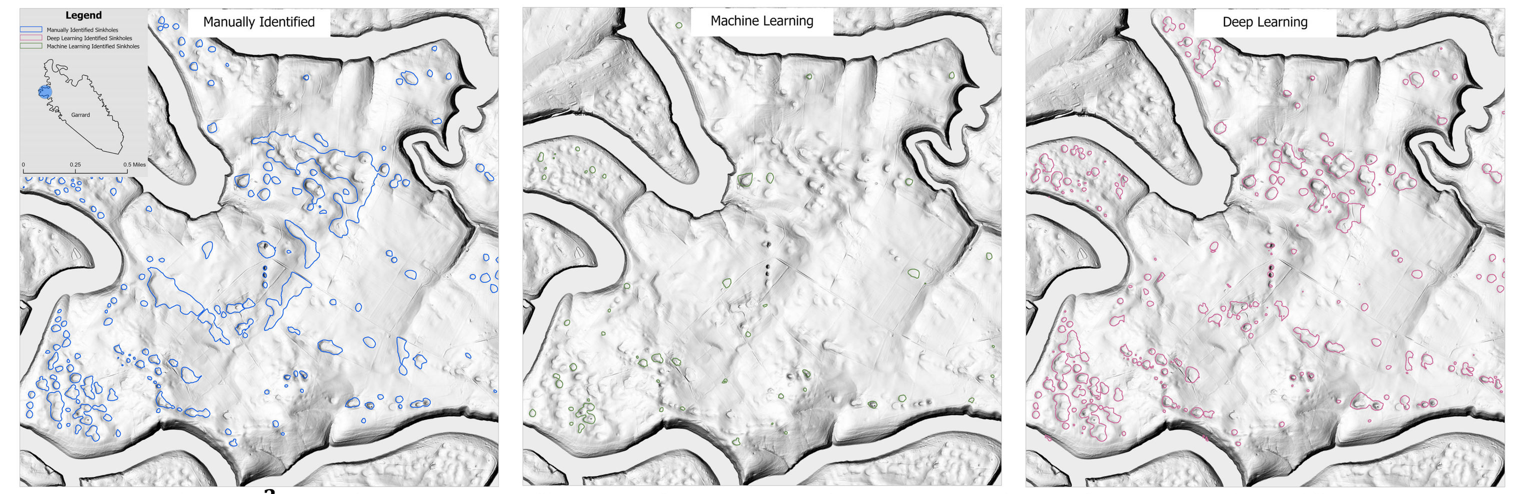
3. Zhu, J., Nolte, A. M., Jacobs, N., & Ye, M. (2020). Using machine learning to identify karst sinkholes from LiDAR-derived topographic depressions in the Bluegrass Region of Kentucky. Journal of Hydrology (Amsterdam), 588, 125049. https://doi.org/10.1016/j.jhydrol.2020.125049
4. Zhu, J., Taylor, T.P., Currens, J.C., & Crawford, M.M. (2014). Improved karst sinkhole mapping in Kentucky using LiDAR techniques: a pilot study in Floyds Fork Watershed. Journal of Cave and Karst Studies, v. 76, no. 3, p. 207–216. DOI: 10.4311/2013ES0135

Results

Count of Mapped Sinkholes by County		
County	LiDAR Derived Sinkholes	Previously Mapped Sinkholes
Clark County	954	396
Garrard County	1,758	641
Harrison County	1,670	173
Montgomery County	247	80

Machine Learning Model Observations



A 5 mi^2 area in northwest Garrard County showing a comparison of manually identified sinkholes, machine learning identified sinkholes, and deep learning identified sinkholes.

- The sinkholes mapped by the deep learning model are more consistent with visual inspection than the sinkholes mapped by the machine learning model.
- The deep learning model uses a DEM directly as inputs, likely utilizing more information than the 10 variables in the shallow machine learning model.
- One common error with the machine learning model is identifying ponds as sinkholes which is not common among sinkholes identified by the deep learning model.
- Another issue that arises in the machine learning model is missing smaller sinkholes within sinkhole clusters. The deep learning model, on the other hand, is capable of locating these sinkholes, as can be seen in the above maps.

Conclusion

- In total, I mapped 4,629 sinkholes across the four counties using this methodology in comparison to the 1,290 that were previously mapped.
- Visual inspection is the most accurate method for identifying sinkholes but using the machine learning model and the deep learning model aids in identification and expedites the process.
- The machine learning model can expedite the process of identification, but the deep learning model extracts more information to determine the location of sinkholes, which makes it more reliable during visual inspection.

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