Remote Identification of Sinkholes in Central Kentucky: An Application of Big Earth Data

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Content Explanation

Big Earth datasets are implemented to map existing depressions and delineate sinkholes to better assess sinkhole and karst hazard. Sinkholes are remotely classified with applications of big Earth data, specifically LiDAR derived Digital Elevation Models (DEMs) and their derivates as well as aerial photography. Manual classification with use of the big Earth data sources will eventually lead to machine learning classifications of sinkholes for adjacent counties, but the input data will remain consistent.

What is a Sinkhole? How do Big Earth Data Apply?

Sinkholes are internally drained surface depressions, typically circular in shape. Sinkholes develop where soil subsides or collapses into subsurface voids – in Kentucky's case subsurface voids typically created in the karst. Around 50-60% of Kentucky has karst or the potential for karst. Sinkholes, and other karst features, are not present in all areas of karst in Kentucky. Sinkholes can vary in size, from a few feet to hundreds, and overall shape, from more circular to elongated or complex. Sinkholes are broadly divided into two groups, subsidence and collapse. Subsidence sinkholes are gradual where collapse sinkholes are sudden ground failures and typically occur without any warning and do not depend on extreme weather events. Collapse sinkholes specifically are a hazard concern.

Karst and sinkholes are recognized geologic hazards in Kentucky, and this hazard is assessed for the State Hazard Mitigation Plans. By identifying sinkholes remotely with big Earth data, the hazard assessment efforts are strengthened with increased accuracy and efficiency.

Sinkholes can also be made by human actions, such as groundwater withdrawal, subsurface mining or other soil alterations related to construction. This study focuses on naturally forming karst sinkholes, however.

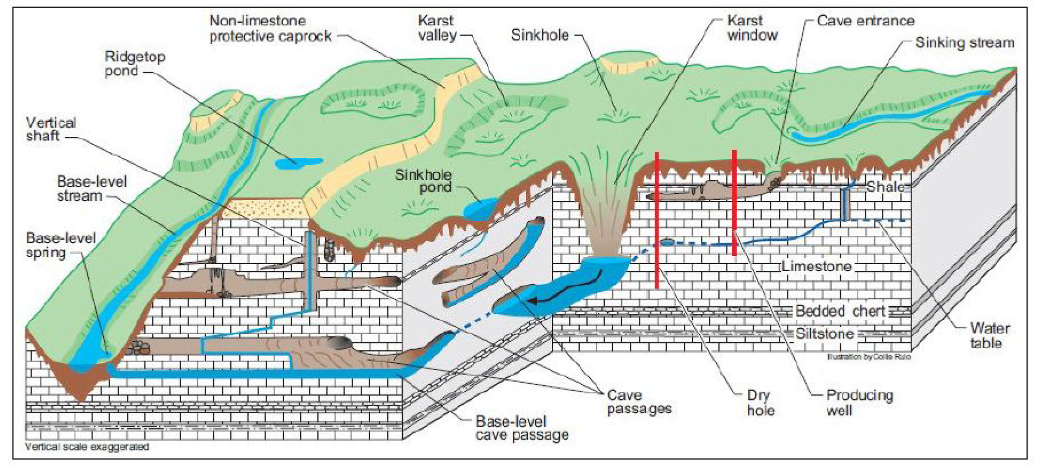
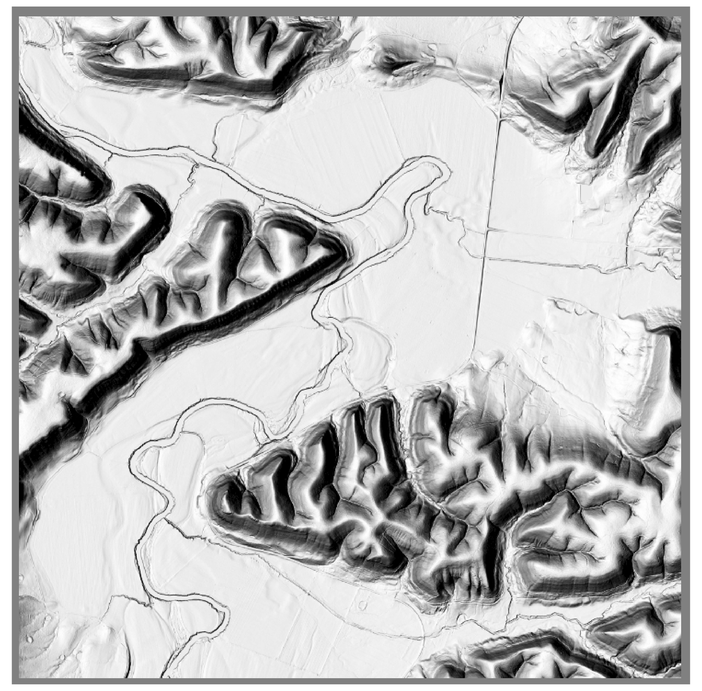


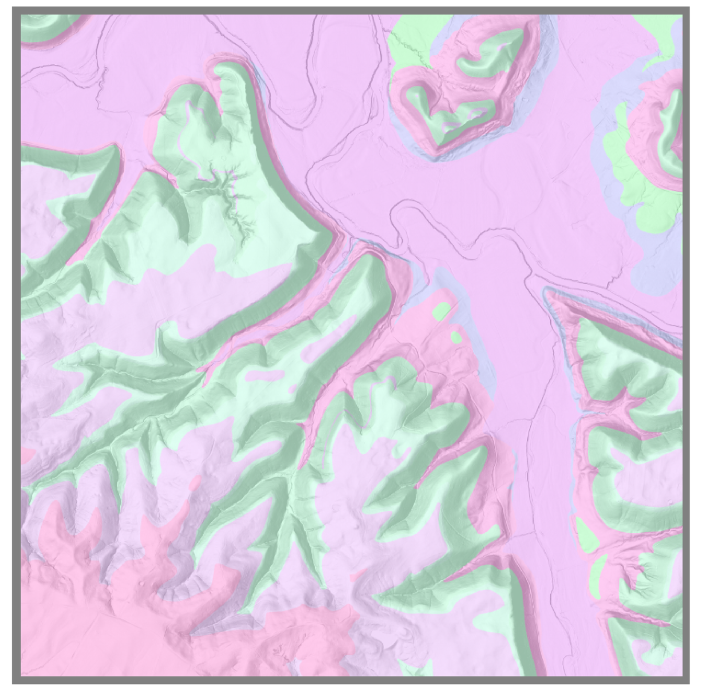
Figure 3-1. (b) from CK-EHMP 2018

Big Data Sources



LiDAR derived DEMs and their derivates such as multi-directional hillshades and depression rasters – from statewide coverage from KyFromAbove (Kentucky DGI).

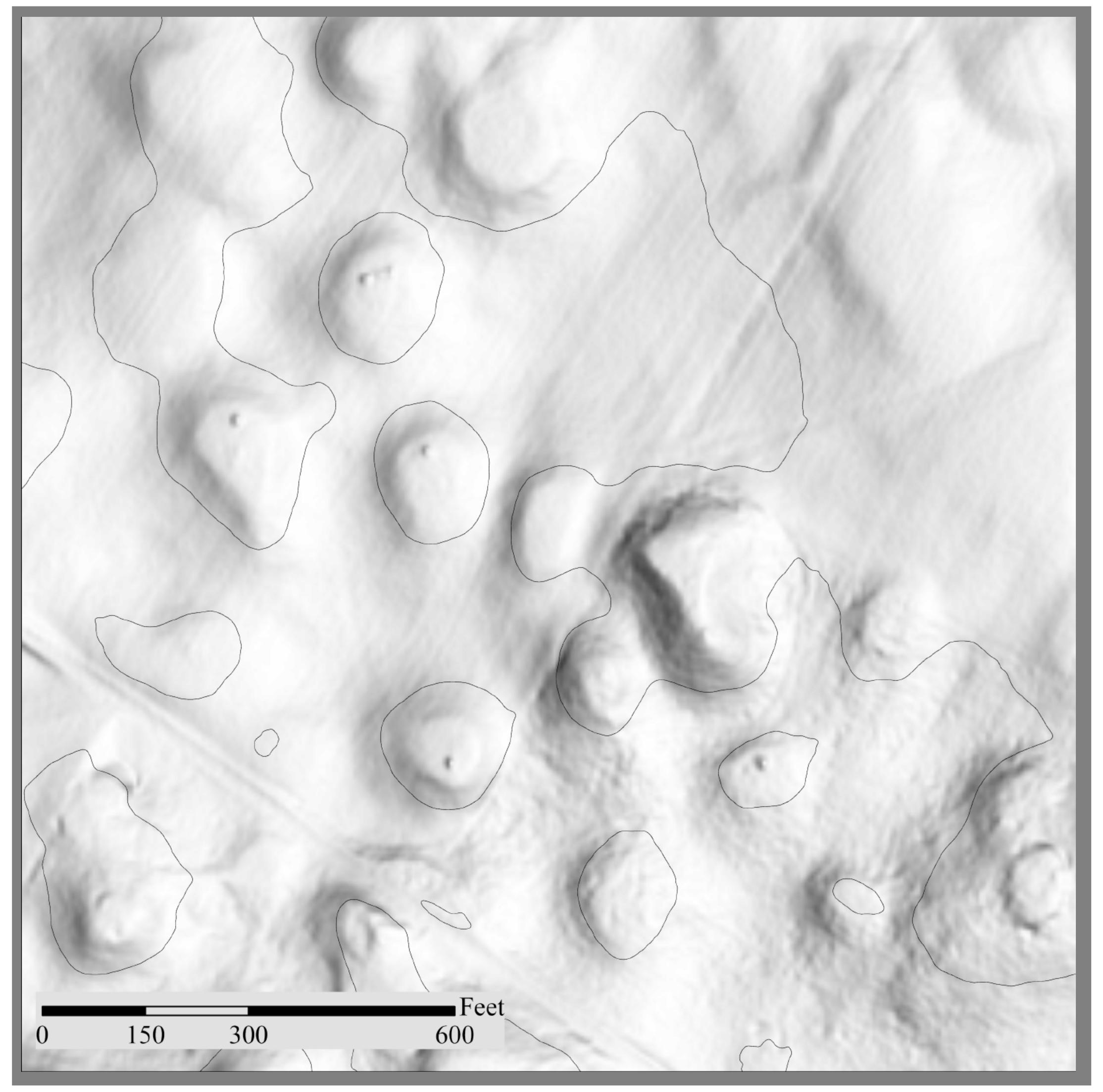
Aerial photography, from specifically KYAPED (2020, 6-inch resolution) where available otherwise NAIP or ESRI basemaps.



24k Kentucky geological maps from the Kentucky Geological Survey, used for reference of possible underlying karst features.

Applying Big Data

Extracted Depressions



Follow the procedure set by Zhu et. al., 2014 surface depressions are extracted from the DEM, then are further processed. Depressions below 500-sqft are omitted and noise such as small parts and jagged edges are removed.

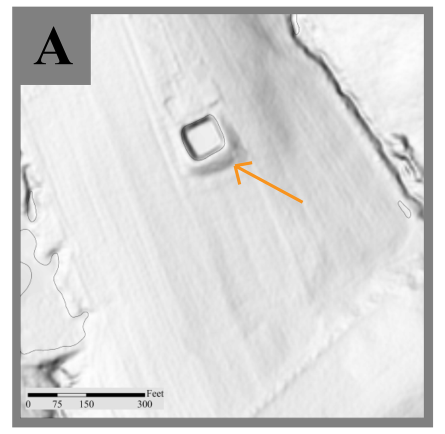
The processed depressions are manually inspected with aerial photography, while considering the geological setting.

Depressions are assessed for internal drainage (and therefore a lack of water retention), no berm features, and an otherwise clear absence of human interference. If the depression meets the described characteristics it is classified as a sinkhole.

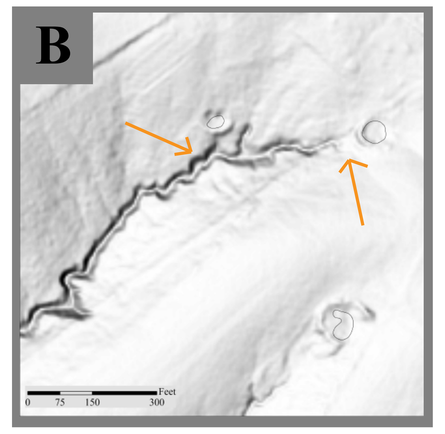
For example, this depression has a clear hole with no berm features surrounding the depression. It is drained, has a depth of greater than half a foot, and likely not created by human actions. This is considered a sinkhole.

6-inch Aerial Photograhpy from KYAPED

Hillshade Identifiers

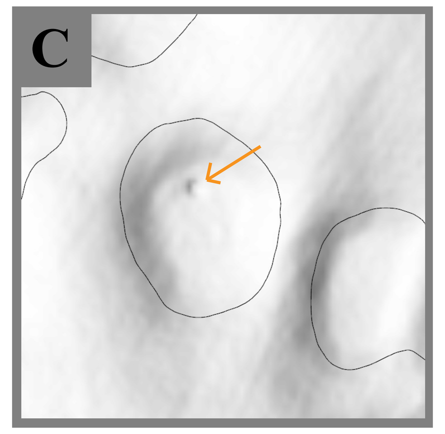


a.) **"Berm" features** refer to mounding around the outsides of the depressions. Typically, berms are not naturally occurring and the presence of them indicates that the depression is a farm pond or other human made feature. The flat, cleanly smooth bottom of this depression also indicates standing water, therefore no drainage.



b.) **Drainage** can be seen in these depressions, which are benched above this stream feature. External drainage indicates that depressions are not sinkholes. External drainage can be seen as *direct drainage* – where the stream connects to an opening in the side of the depression, or *inferred drainage* – where the stream originates underneath a benched depression.

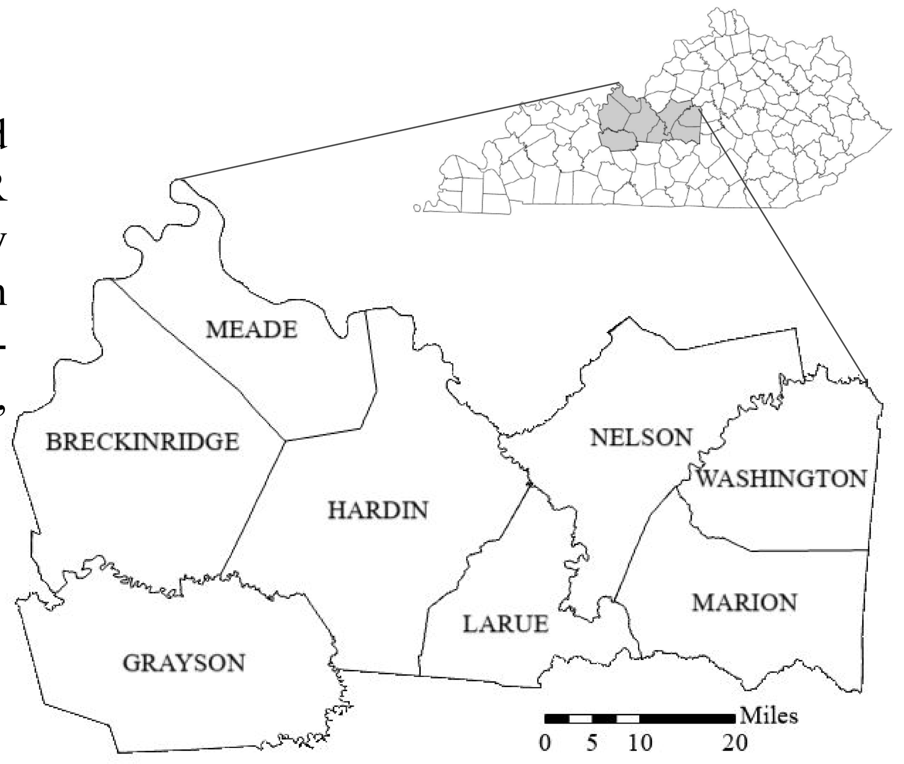
c.) This hillshade corresponds to the aerial photograph sinkhole example to the right, the sinkhole's **swallet feature** is visible on the hillshade as well as the aerial photograph. Notice the gentle gradient into the depression is more visible with the hillshade.



Continued Work

Depressions are to be assessed using the state wide LiDAR datasets and aerial photography for two counties in the Lincoln Trail Area Development District (LTADD) study area, LaRue and Grayson.

The identified sinkholes will then be the learning dataset for a machine learning approach that will ID sinkholes for the remaining counties of the study area.



Project study area, LTADD

Following the sinkhole identification, hazard assessment can be performed following the procedure set by the Kentucky Emergency Management (CK-EHMP 2018). Karst areas are determined from the 24k Kentucky geological maps, and these areas will be intersected with sinkhole density determined from the classification effort. The number of sinkholes per km2 in karst areas determines the hazard category.

To assign the categories numerical values for use in risk assessment a karst/sinkhole score will be used, following the equation:

Hazard Category	Definition
Low	Area of no potential for karst
Moderate	Karst area without sinkholes
High	Karst area with 1-9 sinkholes per km^2
Severe	Karst area with > 9 sinkholes per km^2

Table 3-4. from CK-EHMP 2018

$$\text{Karst/sinkhole score} = \log10[(\text{karst area percentage}) + (\text{sinkhole density}) + 1]$$

Equation 4 from CK-EHMP 2018

Acknowledgements

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References

J. Zhu, T.P. Taylor, J.C. Currens, and M.M. Crawford – 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

Kentucky Emergency Management, 2018, CK-EHMP 2018, S3-S6, Risk Assessment, Hazard Identification, 8, Karst, Original Submittal, in 2018 Kentucky Hazard Mitigation Plan, https://kyem.ky.gov/recovery/Pages/2018-Kentucky-Hazard-Mitigation-Plan-.aspx.