**NASA DEVELOP National Program**



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Georgia Disasters and Water Resources

Utilizing NASA Earth Observations to Monitor Sinkhole Development and Identify Risk Areas

 **Technical Report**

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# I. Abstract

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Sinkhole, Dougherty County, Georgia, Automated Sinkhole Detection, Time Series Analysis, Sinkhole Formation, Geospatial Statistics

# II. Introduction

Dougherty County, Georgia, is located within the Dougherty Plain of Southwest Georgia, an extensive karst region that experiences active sinkhole development—a problem that creates significant environmental and engineering hazards. These include difficulties for land use management, groundwater contamination, and infrastructure damage to roads and buildings. Thus, assessing the spatiotemporal distribution of sinkhole formation is an important step in addressing these problems within Dougherty County, Georgia, and other karst areas.

Dougherty County has a growing populace in an agricultural region that relies on groundwater resources from the Upper Floridan Aquifer and the Flint River and its tributaries. Albany is the county’s largest metropolitan area with a population of approximately 80,000 residents. The land surface is generally flat and underlain by the Ocala Limestone. This area is considered a covered karst region, as it is normally mantled by 0 -100 feet of unconsolidated sediment (Beck and Arden, 1984). Large-scale cover-subsidence and small-scale cover-collapse sinkholes form in this covered karst region.

Sinkholes are formed from interactions on the surface and in the subsurface between geologic, hydrologic, anthropogenic, geomorphologic, climatic, biologic, and hydrogeologic factors. Because sinkholes are initiated underground and develop over long periods of time, the processes are difficult to observe and quantify for useful purposes (Doctor and Doctor, 2012). Therefore, surface characteristics of sinkholes, which include spatial distribution, dimensions, and morphology, are useful in assessing sinkhole development and subsequent growth (Hyatt and Jacobs, 1996). By taking these variables into account, spatial and statistical analytical approaches are used to model sinkhole susceptibility.

Improving the understanding of sinkhole formation is a critical step towards alleviating concerns that many groups of people have related to land use, infrastructure, and water resource management in Dougherty County, Georgia. Farmers, city planners, water resource managers, and other organized groups can use this research to benefit their own respective projects and help reduce risks associated with sinkholes. Additionally, this research can be applicable to other urban and rural areas underlain by karst aquifer systems that exhibit active sinkhole formation.

An objective of this project is to assess the probability and risk of sinkhole occurrence by examining correlations between sinkhole distribution and geologic (i.e., distance to fractures), anthropogenic (i.e. land use), hydrologic (i.e., surface water interactions), geomorphologic (i.e., slope and aspect), and hydrogeologic (i.e., Upper Floridan Aquifer fluctuations) variables through time and space. This assessment was made by first producing an inventory of sinkhole maps from 1999 - 2011 for Dougherty County, Georgia. These maps were then used to produce temporal difference maps to identify newly formed sinkholes and sinkholes that have enlarged. Finally, the sinkhole inventory and temporal difference maps were used to produce sinkhole density maps to serve as inputs for the project’s geospatial analysis and to produce a sinkhole susceptibility map for Dougherty County, Georgia.

The project utilized a combination of NASA Shuttle Radar Topography Mission (SRTM), NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and European Remote Sensing -1 and 2 (ERS-1 and 2) satellite imagery for elevation data ranging from 1999 - 2011. The ancillary datasets obtained were United States Geological Survey (USGS) groundwater data for the Upper Floridan Aquifer, Parameter-elevation Relationships on Independent Slopes Model (PRISM) annual precipitation products, National Land Cover Database (NLCD) for 2001, 2006, and 2011, linear hydrography from the USGS National Hydrography Dataset (NHD), wetland extents from the United States Fish and Wildlife Service (USFWS) National Wetland Inventory (NWI), U.S. Census Bureau road locations, National Agriculture Imagery Program (NAIP) imagery, and USGS borehole log and cross-section data. Further, previously mapped fracture traces and lineaments from Brook and Allison, 1986 assisted with the analysis.

This project addressed the disasters national application area by providing ample information to the project partners in identifying areas susceptible to sinkhole formation as a means of disaster relief and prediction. By doing so, this will help reduce risks posed to human safety and other infrastructure damages that can occur from sinkholes. Additionally, this project addressed the water resources national application area since sinkholes can quickly introduce contaminants to karst aquifer systems with characteristically high transmissivities. The results of this project can be utilized to assist project partners in their decision making to prevent contamination and sustainably manage water resources within Dougherty County, Georgia, and surrounding areas.

The project partner for the Georgia Disasters and Water Resources team is Randy Weathersby, a member of the project’s end-user groups: the Southwest Georgia Water Resources Task Force and the City of Albany and Dougherty County Planning and Development Services. Mr. Weathersby was responsible for providing team members with relevant data for Dougherty County and general project overview. Additionally, he will assist the team by disseminating the results to improve decision-making capacity for end-users.

# III. Methodology

The Georgia Disasters and Water Resources project utilized a time-series of digital elevation models (DEM’s) to complete the first objective of compiling sinkhole inventory maps for the study period (1999– 2011). A high density of DEM’s for our study period were acquired for a thorough analysis of the spatiotemporal distribution of cover-subsidence (large-scale) and cover-collapse (small-scale) sinkhole development. DEM data from NASA’s Flagship Earth Observing Satellite, Terra (ASTER sensor), and the SRTM were utilized to detect cover-subsidence sinkhole development. To complement and extend NASA Earth observations, DEM’s were generated using satellite data from the European Space Agency’s two ERS satellites, ERS-1 and ERS-2. The DEM extraction tool in ENVI’s SARscape program was used to generate high-resolution (5 meter) DEM’s from ERS-1 and 2 data for cover-collapse sinkhole detection.

NASA’s SRTM global 30 meter resolution DEM from the year 2000 and the 2011 ASTER global DEM Version 2, also 30 meter resolution, were purposed for cover-subsidence sinkhole mapping. Cover-subsidence sinkholes form gradually and over large areas. Thus, these two DEM’s were chosen for their spatial and temporal resolution suitable to fulfill that objective. These data were gathered from two sources. The 2000 SRTM DEM was acquired from the USGS Earth Explorer data download platform. The 2011 ASTER DEM was acquired as part of an application for ASTER L1A Reconstructed Unprocessed Instrument Data. These data were then converted to DEM’s throughout our study period. This application and subsequent ASTER data download was completed within NASA’s Land Processes Distributed Active Archive Center (LPDAAC).

Cover-collapse sinkholes tend to form abruptly over small areas. Thus, they can be difficult to detect without high-resolution data. ENVI’s SARscape program has the capability to extract DEM’s of high resolution from SAR data. ERS-1 and 2 SAR archived products were used to generate 5 meter resolution DEM’s for cover-collapse sinkhole detection for the years 1999, 2002, 2004, 2005, and 2009. The combination of two 30 meter NASA Earth observation DEM’s and five 5 meter SAR generated DEM’s allow for a thorough analysis of the spatiotemporal distribution of past and newly formed sinkholes between 1999 and 2011, which will ultimately benefit the project’s capabilities in building capacity for the end-users.

The project’s first objective was to develop sinkhole inventory maps from the aforementioned 7 DEM’s between 1999 and 2011 for Dougherty County, Georgia. These maps served as input data for all further analyses. Thus, implementing an efficient, accurate data processing procedure to create sinkhole inventories was vital to the project’s detailed analysis. The Georgia Disasters and Water Resources team produced a sinkhole delineation algorithm using ArcGIS ModelBuilder and Python code. This algorithm may serve as an end-product for project end-users and scientists, land use planners, engineers, and water resource managers in other active karst areas. This algorithm was developed from and tested for accuracy using a previous sinkhole mapping procedure developed by Cahalan and Milewski, 2014.

The sinkhole delineation algorithm employed three different steps. First, the Sink Evaluation tool in the Arc Hydro Geoprocessing toolset was applied to the DEM’s. Sinkholes act as surface runoff collection areas, and this tool allows for characterization of sinkholes by delineating areas that collect surface runoff within the DEM grid. The tool generates sink polygon and sink drainage area files, and characterizes the sink features with attributes that allow the user to decide which sinks to preserve for further analyses (ESRI Water Resources Team, 2011). The following two steps addressed DEM uncertainties that affect the use of DEM’s for hydrologic applications (Wechsler, 2007).

The next steps in producing accurate sinkhole inventory maps were to eliminate sinkholes that overlapped or were within 20 meters of roads and 5 meters of streams. A Dougherty County roads layout polyline file from the U.S. Census Bureau and a linear hydrography polyline file from the USGS National Hydrography Dataset were utilized for these steps. Within the study area, most roads have steep ditches on either side. This presents an issue because these ditches are identified as sinks during the first step of the algorithm. To resolve this issue of initial false sinkhole identification, the team input a buffered polygon file that represented the area within 20 meters of either side of the center road line. Similarly, a buffered polygon file that represented the area within 5 meters of either side of the center stream line was created. Sinkholes that had more than half of their area within these buffered polygon files were eliminated to decrease the probability of mapping false sinkholes, while also allowing for correct identification of sinkholes that formed close to roads and streams.

Upon production of the initial sinkhole polygon maps, a validation step was undertaken to check for accuracy and eliminate any falsely identified sinkholes from the sinkhole delineation algorithm. To complete this step, the team utilized aerial imagery, previous sinkhole maps for the area (Gordon et al., 2012; Hyatt and Jacobs, 1996), and locations of lakes and ponds within Dougherty County. Any sinkhole polygons that covered buildings’ roofs or were located within the boundaries of lakes/reservoirs and human-constructed ponds (as evidenced by dams) were eliminated. The sinkhole inventory maps were completed and prepared for further analyses upon the conclusion of the validation step.

Further analysis included generation of temporal difference and sinkhole density maps, which are primary inputs for the project’s second objective of producing a sinkhole susceptibility map. To produce the temporal difference maps, the finalized sinkhole polygon maps from the various years were converted into point files. Then, newly formed sinkholes between the years were identified through comparisons of the maps. The 30 meter and 5 meter derived sinkhole maps were compared separately. Two temporal difference maps were created: one that showed the newly formed or expanded cover-subsidence sinkholes between 2000 and 2011 from NASA 30 meter data, and one that showed the newly formed or expanded cover-collapse sinkholes between 1999 and 2011. The latter is a compilation of temporal difference maps from 1999 – 2002, 2002 – 2004, 2004 – 2005, and 2005 – 2009- each color coded to show the newly formed sinkholes between the respective periods.

From the point files, sinkhole density maps could be created. First, however, a cluster analysis was completed to examine the spatial distribution of sinkholes. The cluster analysis showed the distance at which sinkholes, which are clustered at some maximum distance, exhibit a statistically significant dispersed pattern. This distance was the search radius input for the sinkhole density maps.

Ordinary least squares (OLS) and geographically weighted regression (GWR) geostatistical techniques were utilized to improve the understanding of and predictive capabilities for sinkhole development, as well as building a more robust sinkhole susceptibility map. The dependent variable for both of these geostatistical models was sinkhole density. Independent variables included precipitation from PRISM datasets, Upper Floridan Aquifer fluctuation levels, distance to roads, distance to streams, distance to lakes and ponds, distance to fractures/lineaments, land use type, land use change, slope, aspect, distance to wetlands, and overburden thickness. The dependent variable and independent variables were spatially assigned to each sinkhole point generated from the temporal distance maps.

# IV. Results & Discussion

Insert images, graphs, maps, charts, etc. here. Choose the most important results to highlight here. No word cap, but two to six pages is a good range.

Things to discuss:

* Analysis of Results: What can you tell from your graphs, images, etc? What does this mean for your project?
* Errors & Uncertainty: What factors could you not account for, what things didn’t work out like you expected they would, etc.
* Future Work: If this project was to be selected for another term, what would be the focus? What other areas would be of interest?

# V. Conclusions

Final conclusions. Word count: 200-600 (~a page).

# VI. Acknowledgments

The Georgia Disasters and Water Resources team would like to thank the NASA DEVELOP National Program Office and community for supporting this project. This work could not have been completed without the knowledge, direction, and resources provided by our science advisor, Dr. Adam Milewski. We would also like to thank our partner organizations, the City of Albany and Dougherty County Planning and Development Services and the Southwest Georgia Water Resources Task Force, for working with us in building capacity for future decision making. Our point-of-contact for both organizations, Randy Weathersby, was instrumental in dissemination of results.

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# VII. References

Beck, B.F. and Arden, D.D., 1984. Karst Hydrogeology and Geomorphology of the Dougherty Plain, Southwest Georgia. *In* Southeastern Geological Society Guidebook No. 26. 59 p.

Brook, G.A., Allison, T.L., 1986. Fracture Mapping and Ground Subsidence Susceptibility Modeling in Covered Karst Terrain: The Example of Dougherty County, Georgia. In: Land subsidence, IAHS-AISH Publication, 151: 595 - 606.

Cahalan, M. and Milewski, A., 2014. Spatiotemporal Analysis of Sinkhole Development in the Covered Karst Terrain of Dougherty County, Georgia, Geological Society of America Annual Meeting Abstracts with Programs, Vol. 46.

Doctor, D.H. and Doctor, K.Z., 2012. Spatial analysis of geologic and hydrologic features relating to sinkhole occurrence in Jefferson County, West Virginia. Carbonates Evaporites, 27: 143 - 152

ESRI Water Resources Team, 2011. Arc Hydro Tools Overview Version 2.0. 15 p.

Gordon, D.W., Painter, J.A., McCranie, J.M., 2012. Hydrologic Conditions, Groundwater Quality, and Analysis of Sinkhole Formation in the Albany Area of Dougherty County, Georgia, 2009. USGS-SIR 2012-5018: pg. 1-60.

Hyatt, J. A. and Jacobs, P.M. 1996. Distribution and Morphology of Sinkholes Triggered by Flooding following Tropical Storm Alberto at Albany, Georgia, USA. Geomorphology: 305-16.

Wechsler, S. P., 2007. Uncertainties Associated with Digital Elevation Models for Hydrologic Applications: A Review. Hydrology and Earth System Sciences Hydrol. Earth Syst. Sci.: 1481-500.

# VIII. Content Innovation

Potential content innovation choices:

1. Multimedia- audio slides feature to present research in team’s own words.
2. Open Data - data profile feature to present a structured summary of data.
3. Computer Code- executable papers to embed executable code for sinkhole delineation algorithm in ArcGIS ModelBuilder and/or Python.
4. Contextual References - glossary viewer feature to help readers comprehend terminology.
5. Interactive Data Visualization - interactive map viewer feature to allow readers to see the sinkhole maps.

In preparation for DEVELOP’s coming microjournal, please select two content innovation features to support your paper. For each item, please list the name of the feature, and include the tool itself if possible (eg. glossary terms and definitions). If the tool does not work in Microsoft Word (eg. Interactive MATLAB Figure Viewer), please list the file name and upload the related file to the microjournal folder on the DEVELOP Exchange. If you choose to use Inline Supplementary Material, please also include where the material should appear in the text.

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# IV. Appendices

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