Geophysical investigation to improve the landslide susceptibility analysis in Kerala, India.

Geoscientists Without Borders Application:
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FollowUp Form

Basic Information

Project Name*

Name of Project

Geophysical investigation to improve the landslide susceptibility analysis in Kerala, India.

Project Start Date*

Select the date when your project was started.

03/15/2020

Project End Date*

Select the date when the project ended.

07/15/2023

Report Author(s)*

List the names of the primary author(s) of this final report.

Vishnu Chakrapani Lekha, Thomas Oommen, Snehamoy Chatterjee, Sajinkumar K.S.

Executive Summary

The Executive Summary section of the report should succintly, yet comprehensively, summarize the project and its outcomes. Greater detail on the project will be provided as outlined in the additional sections of the report.

Introduction*

Provide a brief, focused introduction to the project and its need.

This project focus on developing a landslide nowcasting system in Idukki, Kerala, India, using regional scale subsurface characterization and rainfall modeling.

Project Goals and Objectives*

Describe the project goal(s) and objectives as they were outlined in the Phase II application or subsequent project revisions approved by the GWB Committee.

Utilize geophysical investigation to characterize the geotechnical and groundwater properties of the landslide-prone terrains in the study area.

A rain gauge network will be developed in the study area of Idukki that can be integrated with the satellite-based rainfall forecast system to obtain accurate rainfall estimates.

Develop a landslide hazard nowcasting system utilizing the improved geotechnical, groundwater, and rainfall characteristics that can be utilized for reducing landslide.

Project Participants*

List all project participants, with title and affiliation.

PI – Dr. Thomas Oommen, Professor, Michigan Technological University
Co-PI - Snehamoy Chatterjee, Ph.D., Associate Professor, Michigan Technological University
Collaborator Sajinkumar K.S., Assistant Professor, University of Kerala (UoK), Thiruvananthapuram, India
Vishnu Chakrapani Lekha, Graduate Student, Michigan Technological University
A. Rajaneesh, Graduate Student, University of Kerala(UoK), Thiruvananthapuram, India
A. Arya, Graduate Student, University of Kerala(UoK), Thiruvananthapuram, India

Methods Used*

List all methods used, including application and specific instrumentation.

Conditional Merging for calibrating satellite precipitation.

Sequential optimization for installing new rain gauges.

2D - Electrical Resistivity Tomography (ERT) – geophysical sub-surface estimation of soil electrical resistivity, using a CRM Auto C.

Developing rainfall thresholds for predicting landslide initiation.

Regression modeling – Estimation of regional subsurface resistivity from 2D ERT and topographic proxies.

Web based Landslide Early Warning System using Google Earth Engine.

Summary of Results and Key Findings*

Provide a summary of the project's results and key findings.

8 new rain gauges were installed in the study area, in corporation with the Kerala State Disaster Management Authority (KSDMA), expanding the original network to 13 rain gauges. (Vishnu et al., 2023a)

GPM IMERG satellite observations were calibrated using rain gauge measurement through a process called conditional merging to produce spatially continuous rainfall observations for the study area. (Vishnu et al., 2022).

2-D ERT profiles of 21 locations were surveyed and these results were used to develop a regional sub-surface resistivity model for the study area. Regression modeling with topographic proxies like slope, elevation and Height Above Nearest Drainage (HAND) was used to develop this model. The subsurface model was used to derive improved geotechnical properties of the area for slope stability analysis. The improved geotechnical properties were also validated with field observations of Cohesion and Angle of Internal Friction.

GIS-TISSA (Escobar-Wolf et al., 2021), a GIS based slope stability model, was used to derive a regional scale slope stability map of the area using geotechnical and vegetation parameters.

A web based Landslide Early Warning System was created using the cloud computing platform Google Earth Engine. This platform predicts landslide occurrences in the study area utilizing GPM (Global Precipitation Measurement) rainfall observations, GFS (Global Forecast System) rainfall forecast and the GIS-TISSA model.

Conclusion and Implications*

List the conclusions that the project team derived and the implications those conclusions have.

The study area had a deficit of rain gauges at the beginning of the study that impeded the development of robust landslide models. This problem was solved by installing new rain gauges in locations optimized within landslide hotspots. An increase in rain gauge network improved the landslide detection capabilities in the study area (Vishnu et al., 2023) and further addition of rain gauges is recommended to increase the accuracy of the current landslide forecast model.

Satellite precipitation measures, calibrated using corresponding rain gauge observations is found to capture the spatial variability of rainfall better than rain gauges alone. Thus, the landslide early warning system developed as part of this project utilizes calibrated satellite precipitation for rainfall modeling.

It was found that the study area had two distinct intra-seasonal monsoon rainfall waves with different contributions to landslide occurrence (Vishnu et al., 2023). Thus, separate rainfall thresholds were calculated for these monsoon waves.

2D-ERT surveys conducted across 21 profiles in the study area showed a linear relationship between sub-surface resistivity and topographic proxies. This relationship was used to develop a regional resistivity model for Idukki and regional scale cohesion and angle of internal friction were developed from this model. These parameters were used to develop a slope stability model for Idukki.

The slope stability model and the rainfall threshold model was combined to develop a landslide early warning system (LEWS). This LEWS was hosted in the cloud computing platform Google Earth Engine (GEE). GEE was chosen due to the near real time availability of rainfall and weather forecast data and its easy accessibility.

The newly developed system is maintained by the University of Kerala in coordination with the Kerala State Disaster Management Authority (KSDMA).

Deliverables*

List all deliverables that will be discussed in the final report, including those that were given to the in-country partners and participants.

The landslide early warning system (LEWS) web portal in Google Earth Engine (GEE) (Vishnu et al., 2023 c).

Inverted resistivity profiles derived from the 2-D ERT survey, processed using the EarthImager 2D software. (The processed images are provided in the document: field_report.docx).

8 new Automatic Weather Stations (AWS) installed in Kerala state government premises in the study area. The data is readily available through a Amazon cloud service.

Improved regional scale geotechnical properties (subsurface resistivity, cohesion and angle of internal friction) and slope stability model for the study area.

Improved rainfall threshold calculations for the study area (Vishnu et al., 2023b).

Improved methodology for calibrating satellite precipitation for the study area (Vishnu et al., 2022).

Final Report

The final report should be comprehensive and provide enough information for assessment of whether the project has accomplished the technical, humanitarian, educational, and sustainability goals outlined in the Phase II application. You are expected to write the report with the care and attention to detail that a published paper requires. Reports are published (with confidential information removed, including financial data) on the GWB website to help educate the public on the program and its impact. Reports should be proofread to ensure accuracy of language and data.

Figures and pictures should be original, high quality graphics and must include captions and appropriate scales. All maps should be oriented with north at the top. All field data and interpretations should be shown on logs, maps, and sections within the same georeferenced projection system, datum, and scale. All maps and sections are to have distance scales in the same unit system. Include color legends, if appropriate.

If you would like additional guidelines to help you prepare your report, please email us at withoutborders@seg.org and ask for more specific instructions.

Reports that have not been written with the highest attention to detail and accuracy will be returned to draft status for editing and any pending payments will be delayed until an acceptable report is received.

Project Location and Geologic Setting*

In the space below, provide a description of the project's location, including its geologic setting. Using the upload button, attach a Word document, pdf, jpeg or preferrably, a geotiff with a map of the area where the team is working. Include a bounded polygon around the area where studies are being conducted. Include the title "Project Location" at the top of the document.

StudyArea.docx

Idukki is a district in the state of Kerala, India, with a preponderance of monsoon rainfall, begetting annual average of about 3000 mm. Idukki is a hotspot for rain-induced shallow landslides due to change in local climate (Vijaykumar et al. 2021) and human influences on vulnerable slopes, like land clearance and slope modifications accentuating the frequency and intensity of landslides. Figure 1 shows the location map of Idukki. For details refer excerpts from Vishnu et al., 2022 uploaded.

Project Location continued*

Upload a Google Earth kmz file that outlines the boundaries of the project location. This file will be used to display the project location on a master map of GWB projects, including the project map on the GWB website.

Idukki_location.kmz

Humanitarian Need and Benefit*

Summarize the reason, need(s) and benefit(s) of the project (humanitarian, community, environmental, etc.)

Changing global climate and increased anthropogenic stress is increasing the frequency and intensity of landslides in Idukki. Developing improved landslide prediction and a nowcasting systems would be essential to save lives in case of future extreme rain events. In addition, having improved landslide hazard characterization would be critical for the land use planning and community development. People in the highlands of Idukki are living at constant fear for landslides that killed their family and friends. They look up to the scientific community for help and answers. Moreover, this project addresses wide data gaps in the geophysical characterization of the subsurface which will be important contribution to future research.

Project Goals and Objectives*

Describe the project goal(s) and objectives as they were outlined in the Phase II application or subsequent project revisions approved by the GWB Committee and the methods used to accomplish the goal(s).

The project aims to develop a landslide forecasting model in Idukki, Kerala, India for developing an early warning system. This objective will be achieved through the following goals:

a) Conduct a geophysical survey to measure soil and groundwater properties (hydraulic conductivity, electrical resistivity)

b) Utilize satellite precipitation products, improve the spatial resolution

c) Develop a rain-triggered landslide forecasting model.

Previous Studies in the Project Area*

Provide a summary of the pertinent previous studies by others in the project area. Describe how the current project goals complemented previous work or filled a void.

Hao et al. (2020), reported the most exhaustive landslide database for Idukki with 2223 landslides in a single year (2018). However, this database lacked the recording of the date and time of occurrence of landslides which are important parameters for developing rainfall thresholds. To overcome this, we conducted a review of reports and news articles to develop a database of landslides with accurate dates.

Sajinkumar et al., (2020), performed a cluster analysis based approach to derive rainfall thresholds for landslides in Kerala. However, this study was performed on a relatively few number of landslide events and thus wasn't representative of the rainfall-landslide pattern of the study area. Other studies, like the one by Abraham et al., (2019), used duration-based approaches to define thresholds. However, a major gap in such studies what the utilization of the sparse rain gauge network in Idukki, comprising only of 5 rain gauges which is incapable of representing the spatial variations in rainfall over such a large area. This study overcame this problem by both considering satellite precipitation and by expanding the rain gauge network.

Sajinkumar and Oommen (2021), developed a landslide atlas for the region, which used gross approximations of geotechnical properties owing to the lack of availability of fine scaled properties. Such data gaps reduce the accuracy of any slope stability model developed for the region. To avoid this uncertainty, this study performed detailed subsurface characterization using 2D ERT surveys and developed regional scale geotechnical properties: cohesion and angle of internal friction.

FIeld Studies*

Using the space below, describe the field studies conducted during the course of the project. Be sure to include the following:

- Approach(es) used, including your rationale for the particular approach(es), the application mode applied, and instrumentation used (manufacturers and models, number of electrodes, etc.);
- Brief description of methods used;
- Who conducted the field work (professors, students, locals, professionals?)? Be sure to clearly indicate who did what;
- Provide maps of data acquisition and acquisition dates;
- Provide evaluation of data quality and usefulness;
- Describe inversions applied and software used;

- Provide field results, including pertinent samples with inversion residual error values)
- Describe any field challenges or problems and the actions taken to mitigate them.

Use the upload button to attach a Word document or pdf appendix with the maps and figures referenced in your summary, including captions. Include the title "Figures for Field Studies" at the top of the document.

FieldStudies.pdf

A 2-D Electrical Resistivity Tomography (ERT) survey was conducted to assess the subsurface properties on shallow depths of 2-3 meters. A CRM Auto C resistivity meter was used to conduct 2-D ERT profiling. The CRM Auto C has four electrodes by default and is especially suited for 1-D (Vertical Electrical Sounding) VES. However, since the requirements of this study were more tuned toward 2-D profiles, more electrodes were needed to establish profile lines. 30 additional steel electrodes were manufactured for this purpose, and profiles typically of length ranging between 20 m to 50 m were surveyed. A Wenner array was used for the 2-D ERT profiling. A total of 21 such profiles with an average length of about 30 m were surveyed in selected locations across the study area. The locations were chosen such that they were close to known locations of landslide incidences to characterize the unstable slopes as much as possible. Most locations were on slopes with historical or existing landslide sites, while some profiles were chosen on locations without any recorded history of landslides. Care was taken to survey locations from the predominant land use types of Idukki, including cut slopes, agricultural plantations, and wasteland/grasslands. The profiles were collected from October 2021 to January 2022, coinciding with the wet season. Figure 2 shows the locations of the profiles mapped for the 2-D ERT survey. A Wenner array was used for the 2-D ERT profiling. The CRM Auto C lacks automation, and readings for every electrode point were acquired by manually moving the connections. Repeated observations were taken for every profile, and the average was taken to avoid ambiguity. The resistivity profiles were inverted using the EarthImager 2D software. Our interpretation scheme (details in next section) required converting the 2-D profile to 1-D representations and thus topographic corrections were not applied to the resistivity inversion.

The field work was a joint effort between the professors and students of University of Kerala and Michigan Technological University. The survey team coordinated with geophysical experts from V.O. Chidambaram College, Tamil Nadu, India, who had previous experience conducting such surveys in similar terrain. Prior to the 2D ERT survey a reconnaissance survey was conducted to identify potential 2D profiles. Overall our field work was significantly delayed due to Covid and restrictions on international travel. However, we were able to achieve the minimal field work required for the successful completion of the project.

A team of students from Amal Jyothi College of Engineering was involved in estimating the geotechnical properties of the soil in the study area as part of their undergraduate project. These samples were taken close to the ERT profiles and were tested in a laboratory were properties like cohesion, angle of internal friction, consistency etc. These properties were used to establish regional scale relationships between resistivity and geotechnical properties.

Interpretation of Data*

In the space below, describe the interpretation of data for the project. Be sure to include all of the following:

- Describe the interpretation process applied, including data integration, borehole comparisons, 2D surfaces developed, 3D interpretative images, fence diagrams, voxels, etc.;
- Povide examples of representative final interpretations including maps, sections, images, charts, tables, etc.;
- Provide an evaluation of the data quality and usefulness as application to interpretation;
- Include discussion on whether the data support the goals, objectives, and hypotheses and discuss what additional data would be useful.

Use the upload button to attach a Word document or pdf appendix with any figures or pictures referenced in your summary, including captions. Include the title "Figures for Interpretation of Data" at the top of the document.

The aim of this study was to develop a regional model of fine scale geotechnical properties for Idukki. For this, any potential relationship between subsurface resistivity and soil properties were investigated. For this investigation, the resistivity profiles had to be converted to point observations representative of their subsurface morphology. To achieve this, each profile was divided into horizontal layers of 1 m each. Three such layers were created, and within each layer, the resistivity value was aggregated to get the point representation of the corresponding horizontal layer.

Resistivity is a phenomenon that can have large local variations. However, in this study, we are concerned with developing a regional scale model that best approximates the general trend of resistivity. Aggregating the resistivity of a layer by computing the mean of resistivity would lead to unrealistic values if sections of large resistivity are present locally. To avoid these outliers, we chose to aggregate the resistivity over each 1 m depth by computing the median resistivity value in that profile. Since the median is the value corresponding to the middle point of data, outliers due to local variations can be avoided in the aggregate. Once the point samples corresponding to 2-D ERT profiles were developed, topographic proxies in corresponding locations were extracted and used to develop an empirical relationship with sub-surface resistivity.

A 30 m SRTM (Shuttle Radar Topography Mission) DEM was used to derive the topographic parameters. Elevation, a percentage rise in slope and Height Above the Nearest Drainage (HAND) layers were generated. HAND is a popular topographic derivative used to derive the relative height of terrain with respect to the water surface level of the nearest drainage (Nobre et al., 2011). Since soil with more moisture content has lower resistivity levels, we assumed it was logical to investigate a relationship between resistivity and its vertical distance from water bodies.

Validation of the regional scale resistivity model was performed using the cohesion and angle of internal friction samples collected by students of Amal Jyothi College of Engineering, Kerala. The sample observations were used to develop a linear regression model with the sub-surface resistivity derived above. The regression model was used to develop continuous, gridded layers of cohesion and angle of internal friction for Idukki.

Using these soil parameters a slope stability model was developed for Idukki. GIS TISSA, slope stability model that characterizes slope stability in terms of a Factor of Safety (FOS) was used for this purpose. The model input soil parameters include moist soil weight, soil depth, saturated soil weight, cohesion, angle of internal friction, vegetation parameters, which include root cohesion and surcharge, and slope. The output is in the form of a FOS layer. In this study, we use the resistivity-derived cohesion and angle of internal friction while the remaining soil parameters are derived from a soil classification map of Idukki, and vegetation parameters are derived using an NDVI-derived vegetation map.

Human Element*

Describe the involvement of participants. Include all participants, such as college professors, professional consultants, students (either local or from outside the local region), local residents, local governments, and others.

PI – Dr. Thomas Oommen, Professor, Michigan Technological University
Co-PI - Snehamoy Chatterjee, Ph.D., Associate Professor, Michigan Technological University
Collaborator Sajinkumar K.S., Assistant Professor, University of Kerala (UoK), Thiruvananthapuram, India
Vishnu Chakrapani Lekha, Graduate Student, Michigan Technological University
A. Rajaneesh, Graduate Student, University of Kerala(UoK), Thiruvananthapuram, India
A. Arya, Graduate Student, University of Kerala(UoK), Thiruvananthapuram, India
Kerala State Disaster Management Authority (KSDMA)
Students from Amal Jyothi College of Engineering, Kerala.
Anthony Ravindran, Professor, V.O. Chidambaram College, Tamil Nadu.

Project Sustainability*

It is a goal of GWB that funded projects continue sustainably after their end dates. To receive GWB funding and achieve that goal, funded projects proposed sustainability goals and objectives to achieve them. Describe measures taken to ensure the sustainability of the project beyond the end date. What methods did you use and what objectives were accomplished to ensure project sustainability?

The project team coordinated with the Kerala State Government for the sustainability of the project and have developed a memorandum of understanding with Kerala State Disaster Management Authority (KSDMA) for the long term sustainability of the project. The rain gauges are installed in the government premises for its continuous maintenance by the agency. The University of Kerala, is actively involved in disaster management projects in the state and play a crucial role in the sustainability of the project deliverables. The landslide early warning system developed as part of this project is hosted in the open source Google Earth Engine (GEE) cloud server, ensuring its wider accessibility.

Education*

What educational institutions within the host country have been involved in the project? What other educational institutions have been involved? Describe any specific educational opportunities that have been provided during the project to any stakeholders (local residents, professionals, students, government officials, etc.) within the host country.

A student from Michigan Tech worked in this project towards the fulfillment of his Ph.D. degree. He also spent a year in Kerala, as part of the field work.

The field work was conducted in collaboration with graduate students from the University of Kerala and undergraduate students from Amal Jyothi College of Engineering, Kerala.

A professor from V.O. Chidambaram College, Tamil Nadu lent his expertise in geophysical survey in mountainous terrain, for equipping the students with practical knowledge for performing field work in Idukki.

Lessons Learned*

Describe the positive and negative lessons learned while conducting the project. What you recommend to do and not to do during future projects?

Students from different Universities worked towards the completion of this project. These students varied in discipline from geological engineering & geology to civil engineering. This collaboration of students from various disciplines brought about the mixing of different perspectives to a single problem. Overall, in excess of 10 students were able to get hands on experience of advanced geotechnical and geophysical investigation procedures.

This project was also able to develop an early warning system that directly impacts the community. Moreover, we were able to improve the existing infrastructure in the study area using the project funding.

Perhaps the most difficulties surrounding this project were a result of the then ongoing covid pandemic. Everything from travel to procurement of new rain gauges were delayed by the pandemic induced complexities.

Field Pics