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学 位 論 文 題 名

An environmental assessment of gully erosion susceptibility in Chambal ravines of India: Geospatial and machine learning based approach

（インド・チャンバル渓谷におけるガリー侵食の起こりやすさの環境評価：地理空間情報および機械学習によるアプローチ）

Gully erosion is the most hazardous form of land degradation, characterized by deep cut into the soil bed by dynamic of water current and results into ravine formation. It affects the ecology, economy, and human life of many nations including India, where 3.97-million-hectare of total cultivated land is affected by gully erosion. Chambal ravine is one of the most extreme and is the biggest ravine topography in India. Gully erosion in this area significantly damaging the agriculture and livelihood, hence it is highly concerned area for ravine reclamation programs by the national and international governments. Despite this, the area is lacking basic studies of gully erosion assessment such as gully erosion susceptibility mapping, gully development rate, and erosion-fill volume change, for any land restoration program.

For this purpose, the traditional methods or only field surveying are not enough and are very time-consuming and expensive. High-resolution multi-temporal digital elevation models (DEM) are key to an accurate mapping of gully erosion volume change studies. Owing to the lack of multi-temporal DEMs at a high spatial resolution, gully development rate, and gully erosion-fill volume change estimates of Indian badlands are poorly studied. This study explored the use of a 5 m spatial resolution multi-temporal TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X) derived elevation models to quantify the erosion volume and gully susceptibility mapping of Chambal ravine in Central India. The average gully erosion volume based on the DEM subtraction method in the study area was found to be 135×10^5 m^3, and the estimated annual rate of soil erosion was ~284 t hr^{-1} y^{-1}. Machine learning models were used to train the data for gully erosion susceptibilities and volume prediction for a larger study region and validated the results with independent samples. The accuracy of the model in terms of area under the receiver operating curve (AUC) value has come up to 0.85 for training a

nd 0.87 for validation, indicating satisfactory model performance. After validation, the model was implemented onto a testing site (no multi-temporal DEM available) in order to predict erosion zones and erosion volume esti mation. The model predicted about 40% of the area is highly affected by gully erosion with the maximum gul lying process in north-central and lowest in the west-south location of the testing area. The framework presente d in this study can be useful in gully erosion rate estimation and to monitor the change in volume of area due to gully erosion.

Toward the importance of DEM (Digital Elevation Model) in getting topographic information, in the f urther attempt, this study has tried to reveal the unexplored effect of the DEM resolution scale on the accuracy of gully erosion susceptibility mapping (GESM). The six different DEMs has been considered for this analysis are TanDEM-X (5m), SRTM (30m), ALOS PALSAR (12.5m), ASTER GDEM(30m), AW3D (30m), MERIT (90m). The training model for this study has been constructed with DEM-derived gully controlling variables a nd the average volume value of the area calculated by the DEM subtraction method. There was six separate tr aining model was prepared from all six DEMs separately and were tested on Random Forest model (RF). The accuracy of these models was analyzed by Receiver operating characteristics curve indicator (ROC value), kap pa index, and Root mean square error value (RMSE). The highest accuracy was confirmed by the 5m TanDE M-X and predicted that 40% area is suffering from gully erosion. However, the order of accuracy with respect to DEM resolution is TanDEM-X (5m)> AW3D (30m) > SRTM (30m)> ALOS PALSAR (12.5m)> MERIT (90m)> ASTER GDEM (30m). This trend is indicating that the finer resolution DEM data favor to attend hig h accuracy in making GESM but not necessarily because of the type of sensors and other satellite features are also influential in gaining good quality topographic data. Very low-resolution topographic data also failed to gi ve a robust model because a large grid is unable to predict the finer processes like gully erosion on the land s urface. This research contributes to understand the selection of suitable DEM for gully erosion susceptibility. Th is study is useful in gully erosion assessment and environmental monitoring of Chambal ravines and can be uti lized effectively in the ravine reclamation projects.

The outcomes of this thesis are policy-relevant and aligned well with the ongoing National Initiative o n Climate Resilient Agriculture (NICRA) project by the Government of India. This research is demonstrating th e importance of DEM data in erosion volume estimation in ravines, which can help to provide scientific infor mation to support ravine reclamation program. This research can also provide essential knowledge to implement SDGs goal number 15 (life on land) and United Nations Convention to Combat Desertification (UNCCD).

The examination committee recognized that this thesis presents important findings in the monitoring of ravines using advanced geospatial techniques. In addition to the excellent academic knowledge in the research, her academic records throughout the Ph. D. course was good. Based on these evidences, the committee reache d to the conclusion that Raveena Raj is eligible for the degree of Doctor of Philosophy (Environmental Scienc e).