学 位 論 文 内 容 の 要 旨

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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）

Ravine and Gully erosion is an extreme form of land degradation hazard caused by water induce soil erosion process. It may impact ecosystem function, soil productivity, water quality, crop failure, and the quality of human life surrounding it. Generally, the gully erosion process is characterized by a deep channel on land created by the concentrated flow of water which remove the surface soil and parent material. Ravine is the final stage of the gully erosion process and, consists of a complex network of several gullies, it is a highly unproductive and unprotected ecosystem, well known as Badland. Gully erosion mapping and monitoring are essential for the implementation of land restoration or ravine reclamation projects. In India, 3.97-million-hectare of total cultivated land is affected by gully erosion. Chambal ravine in central India has been considered in this study, is one of the most extreme, and is the biggest ravine topography in India. Gully erosion in this area significantly damages agriculture and livelihood and hence it is a highly concerned area for ravine reclamation programs by the national and state governments. Despite this, owing to the lack of multi-temporal DEMs at a high spatial resolution the area lacks important scientific studies of gully erosion assessment especially gully erosion susceptibility mapping, gully development rate, and erosion-fill volume change.

For this purpose, the traditional methods or field surveying-based monitoring are not found as sufficient in getting accurate scientific and environmental information, plus these are very time-consuming, and limited to the accessibility of the area. Literatures from recent years reveal the advantages of using remote sensing data and machine learning technology for gully erosion assessment. Especially the high-resolution multi-temporal digital elevation models (DEM) are key to an accurate mapping of the gully erosion effect on the area. 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 ravines. 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}. Employing machine learning models with the above data of gully erosion volume and rate from the DEM subtraction method has been trained for gully erosion susceptibilities and volume prediction for a larger study region. The accuracy of the model in terms of area under the receiver operating curve (AUC) value has come up to 0.85 for training and 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 estimation. The study reveals the presence of active gully erosion and showing the gully erosion intensity in different zone. The model predicted Out of 131 km^2 areas, approximately 52.67 km^2, about 40% of the area is highly affected by gully erosion with the maximum gullying process in north-central and lowest in the west-south location of the testing area. The study estimates average soil erosion volume is 135×10^5 m^3, and the average soil erosion rate is ~284 t ha^{-1} yr^{-1} which is an alarm for the quick mitigation action.

The study has also observed the importance of DEM (Digital Elevation Model) in getting topographic information. In the further attempt, the study has tried to reveal the unexplored effect of the DEMs with different resolutions and from different sources on the accuracy of gully erosion susceptibility mapping (GESM) by machine learning model. 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 and the average volume value of the area calculated by the DEM subtraction method. There was six separate training model was prepared from all six DEMs separately and were tested on the Random Forest model (RF). The accuracy of these models was analyzed by Receiver operating characteristics curve indicator (ROC value), kappa index, and Root mean square error value (RMSE). The highest accuracy was confirmed by the 5m TanDEM-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 high accuracy in making GESM but not necessarily because 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 give a robust model because a large grid is unable to predict the finer processes like gully erosion on the land surface. This finding is a contribution toward making the understanding of the selection of suitable DEM for gully erosion susceptibility.

The overall study can be very significant as a first-hand source for the scientific information on gully erosion in the area to the researchers, geoscientists, agricultural advisors, policymakers, and local people involve in the ravine's reclamation program. The findings of this study are important to get the idea about the gully erosion rate, the location of active gully erosion with its intensity (low, medium, or high), and also the information about volume change in area due to the gully erosion process. The methodology constructed in this study can be utilized in the estimation of change in volume by gully erosion and its rate. It can be applied for geomorphological assessment of other ravine areas of Chambal badland by the researchers and geological survey officers. This scientific research can be helpful in making the decision for the division of land into zones for where to do labeling, where to grow vegetation, and which locations highly need mitigation action. The overall contribution of this study is significant in Land degradation mitigation and Land restoration projects.

Keywords: Gully erosion, Gully erosion Susceptibility mapping (GESM), soil erosion volume, Digital Elevation Model (DEM), Chambal ravines, Random Forest.