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A Local Snow-Ice Hazard Model Using Weighted Overlay Analysis: Predictive Spatial Decision Support System for Hazard Mitigation

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ABSTRACT

In this study, a local snow-ice hazard model was developed using a weighted overlay analysis approach based on three factors: elevation, slope, and aspect. The model assigns values between 0 and 1 to each input factor using appropriate functions and weights and then combines them into an overall Hazard Index, which represents the relative spatial risk of snow and ice hazards and can be used to identify areas with high or low hazard potential before or during extreme snow-ice events. This study demonstrates the effectiveness of weighted overlay analysis for local snow-ice hazard modeling and highlights the importance of considering multiple factors in hazard assessment. This model can be used for hazard mapping, risk assessment, and decision-making in planning and emergency management.

Keywords- snow-ice hazard, weighted overlay, GIS, risk assessment, emergency management.

I. INTRODUCTION

Snow and ice hazards pose significant risks to transportation, infrastructure, and public safety in various regions of the world. However, cities with lower historical snowfall experience a greater struggle owing to inadequate awareness, preparedness, and infrastructure to deal with hazards. Climate change has caused changes in snow and ice patterns, complicating predicting and managing these hazards (IPCC, 2018). Therefore, there is an increasing need for efficient snow and ice hazard assessments and management tools.

Geographic Information Systems (GIS) is a preferred tool used for snow and ice hazard assessments. GIS allows the integration and analysis of diverse spatial data, including topography, climate, and land cover, to identify high or low snow and ice hazard potentials. Several studies have been conducted to develop models for snow and ice hazard assessment. For instance, Li et al. (2017) developed a snow disaster risk assessment system based on GIS and a backpropagation (BP) neural network. The model utilizes snow depth, snow cover duration, terrain features, and meteorological data to assess snow hazard risks in Inner Mongolia, China. Maity et al. (2019) used remote sensing and GIS to develop a snow avalanche risk zonation model for the Indian Himalayas. The model incorporates a slope, aspect, terrain ruggedness, and land use parameters to predict avalanche hazards. Gurung et al. (2020) employed a machine-learning approach to predict the occurrence of snow avalanches in western China using meteorological and topographical data.

Despite the development of these models, several limitations still need to be addressed. One major limitation is the availability and quality of data. Many models require extensive and high-quality data that may be limited in some regions. Another limitation is the complexity of some models, making them difficult to use and interpret by non-experts. Additionally, some models may need to be more specific to a particular region or terrain, limiting their generalizability. Finally, the changing climate and its impact on snow and ice patterns may require constant model updates and recalibration. This study presents a preliminary snow-ice hazard (SIH) model that can be utilized for the spatial assessment of local snow-ice hazards. The aim of this study is to

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provide a technical baseline that can be enhanced with higher-quality data in the future.

II. SNOW-ICE HAZARD MODEL

Data

The proposed baseline SIH model was developed using a geographic information system (GIS) technique called weighted overlay analysis. Elevation, slope, and aspect were identified as critical variables in determining the level of snow-ice hazard at a given location. Elevation, slope, and aspect have been widely used in snow-ice hazard modeling because of their strong influence on snow accumulation and distribution (Hernandez-Henriquez et al., 2017; Wang et al., 2019). The elevation is an important factor, as it directly affects temperature and precipitation, which are the critical drivers of snow accumulation and melting (Dingman, 2015). The slope is another crucial factor as it determines the amount of solar radiation received by the surface, which affects the temperature and melting rate of the snow (Wang et al., 2019). Aspect also plays a significant role, as it determines the direction in which the surface faces, which affects the amount and duration of solar radiation received, and hence the snow distribution and melting rate (Hernandez-Henriquez et al., 2017).

High-resolution LiDAR DEM (Digital Elevation Model) data is preferred for this model. LiDAR is a remote sensing technology that uses laser pulses to measure the distance between a sensor and the ground surface. It provides accurate and detailed information about topography and surface features (Pallathadka et al., 2021). The high resolution of LiDAR data allows for a more accurate representation of the terrain, which is essential for snow and ice hazard modeling. Additionally, LiDAR data is available for many regions, including urban areas, making it a suitable choice for local hazard modeling.

III. METHOD

After obtaining the Lidar DEM data, the slope and aspect are derived using ArcGIS Pro software's spatial analyst toolkit (ESRI). The slope is calculated as the angle between the horizontal plane and the terrain surface and is expressed as degrees or percent rise. Aspect is the direction in which a slope faces and is measured in degrees clockwise from north. After calculating the slope and aspect, the next step is to reclassify each independent layer (elevation, slope, and aspect) into values ranging from 0 to 1, which can be performed using the "Reclassify" tool on ArcGIS Pro. Reclassification is the process of grouping or categorizing data into classes based on their values. Elevation and slope are grouped into classes based on their range of values, and each class is assigned a value between 0 and 1 based on its significance in snow-ice hazard assessment. The aspect layer is also reclassified into classes based on its range of directions, and each class of direction is assigned a value between 0 and 1 based on its influence on the snow-ice hazard.

Higher elevation values should correspond to values closer to 1 because higher elevations generally correlate with more significant snow accumulation and distribution. Higher slope values should also correspond to values closer to 1, as steeper slopes tend to accumulate more snow owing to less solar radiation received. The aspect layer is reclassified based on the direction that should receive the most solar radiation and hence has the highest snow accumulation potential, with values close to 1 assigned to those directions. The direction in which the most solar radiation is received depends on the location and time of the year. In the northern hemisphere, surfaces facing south receive the most solar radiation during the winter months, whereas surfaces facing north receive the most radiation during the summer months. The opposite is true in the southern hemisphere, where surfaces facing north receive the most solar radiation during the winter months, whereas surfaces facing south receive the most radiation during the summer months. The exact direction also depends on the latitude and local topography. The weighted overlay analysis can be expressed as follows (Eq. 1):

Hazard Index = (w1 * Elevation Index) + (w2 * Slope Index) + (w3 * Aspect Index) …………. (Eq. 1)

Where,

Hazard Index represents the overall snow-ice hazard index for a given location Elevation Index represents the contribution of elevation to the hazard index and is calculated as a function of elevation using a threshold or other method. For example, you could use a linear or nonlinear function to assign a value between 0 and 1 to each elevation class based on its snow risk.

Slope Index represents the contribution of slope to the hazard index and is calculated as a function of slope angle or other slope-related factors. For example, you could use a linear or nonlinear function to assign a value between 0 and 1 to each slope class based on its ice risk.

Aspect Index represents the relative influence of the direction that a location faces on snow-ice hazard, with values close to 1 indicating that the location faces the direction that receives the most solar radiation.

The weights (w1, w2, w3) are used to adjust the relative importance of each input factor to the overall hazard index. These weights could be based on expert judgment or on quantitative data, such as the relative importance of each factor to snow and ice hazards.

Once the Hazard Index has been calculated for each location, the resulting layer may be used to identify areas with high or low snow-ice hazard potential. The output layer classifies the index into hazard zones using

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threshold values or other methods and then maps the zones to visualize the spatial distribution of snow-ice hazards in the study area. The model's ability to provide a preliminary assessment of snow-ice hazards at a local level makes it a valuable tool for communities with limited resources for hazard assessment and management.

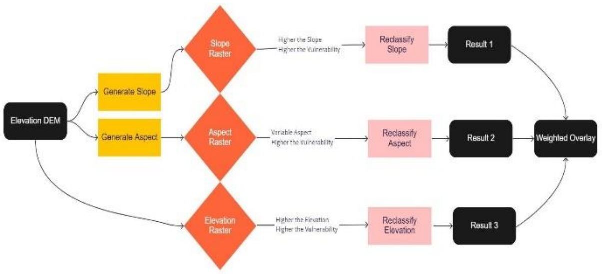

Figure 1: ArcGIS workflow for SIH model

IV. APPLICATIONS

The proposed SIH model has several potential applications for hazard management and planning. It can be used for hazard mapping, which helps identify areas with high or low hazard potentials and provides a spatial understanding of the risks associated with snow and ice hazards. The model can also aid in risk assessment by allowing decision-makers to understand the potential impacts of snow and ice hazards on transportation, infrastructure, and public safety. Additionally, the model can be used to develop emergency management plans by identifying high-risk areas that require targeted mitigation. The model can also be used to optimize the allocation of resources for snow and ice removal operations, such as prioritizing certain areas for snow plowing or de-icing.

V. CONCLUSIONS

In conclusion, the proposed baseline snow-ice hazard model utilizing elevation, slope, and aspect has been demonstrated to assess local snow-ice hazards spatially and effectively. The model is easily implementable and provides a preliminary assessment that can be improved as high-quality data become available. The use of elevation, slope, and aspect as input factors in snow-ice hazard modeling has been widely accepted in the literature because of their strong influence on snow accumulation and distribution. The methodology presented in this study, utilizing high-resolution Lidar DEM and ArcGIS Pro, can be helpful for researchers and practitioners in snow-ice hazard modeling. This model may have potential applications in risk assessment and decision-making processes for various activities in snow and ice-prone regions. Further research should be conducted to investigate the applicability of the model in other areas and to improve its accuracy.

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