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Research Article

Integrating Certainty Factor (CF) Model and ROC/AUC Evaluation for Susceptibility Mapping

*Sh. Khamidullaev [1], R. Oymatov [2], N. Bakhriddinova [3]

[1,2,3] "Tashkent institute of irrigation and agricultural mechanization engineers" National Research University

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***Corresponding author:** *Sh. Khamidullaev*
"Tashkent institute of irrigation and agricultural mechanization engineers" National Research University

Abstract
Mudflows and debris flows represent significant natural hazards in mountainous and foothill regions of Uzbekistan, especially in the Surkhandarya basin. This study focuses on the application of the Certainty Factor (CF) model to assess flood susceptibility using GIS and remote sensing technologies. A dataset of 115 historical flood points was integrated with nine conditioning factors including Stream Power Index (SPI), Topographic Wetness Index (TWI), precipitation, drainage density, geology, land use/land cover (LULC), NDVI, elevation, and aspect. The CF model provided susceptibility values between –1 and +1, representing the decrease or increase in flood probability. Results demonstrated that LULC and elevation were the most influential factors, while NDVI and aspect had a negative impact on flood occurrence. The ROC/AUC analysis confirmed the robustness of the CF model with an AUC value of 0.889, outperforming other statistical models like Frequency Ratio (FR) and Statistical Index (SI). These findings highlight the CF model's reliability and practical application for disaster risk reduction and land-use planning.

Keywords: *Mudflow susceptibility, Certainty Factor, GIS, Surkhandarya basin, ROC/AUC, susceptibility mapping.*

1. Introduction

Mudflows and debris flows are among the most dangerous hydrogeological hazards in mountainous and foothill regions across the world [1]. In Uzbekistan, floods have caused numerous casualties and significant economic damage over the last decades. The Surkhandarya basin, located in the southern part of Uzbekistan, is particularly vulnerable to flash floods due to its steep topography, climatic variability, and intensive human activities [2]. Previous studies have widely applied statistical models such as Frequency Ratio (FR) and Statistical Index (SI) to map flood susceptibility [3]. However, these models often face limitations in reflecting the uncertainty and variability of influencing factors. The Certainty Factor (CF) model has recently emerged as a promising alternative that allows a probabilistic interpretation of susceptibility values [4].

The CF approach provides results in the range of –1 to +1, where negative values indicate a decrease in flood likelihood, while positive values indicate an increase [5]. This flexible interpretation makes the CF model more suitable for hazard studies in data-scarce regions. Moreover, the CF model enables a more realistic spatial distribution of susceptibility zones, which is essential for effective disaster risk management and land-use planning [6]. This paper aims to assess flood susceptibility in the Surkhandarya basin using the CF model and to evaluate its predictive performance through ROC/AUC analysis [7]. The study contributes to advancing scientific knowledge in natural hazard assessment while offering practical insights for local authorities.

The main objective of this study is to assess mudflow susceptibility in the Surkhandarya basin using the Certainty Factor (CF) model and to evaluate its predictive performance through ROC/AUC analysis.

2. Study Area

The Surkhandarya basin is located in the southernmost part of Uzbekistan, covering an area of approximately 13,500 km². It is bounded by the Hissar mountain range in the north and characterized by steep slopes, valleys, and foothill plains. The elevation in the basin ranges from 300 m in the lowlands to 3500 m in the mountainous areas, creating strong climatic and geomorphological contrasts. The region experiences a continental climate, with hot and dry summers and relatively cold winters. Average annual precipitation ranges between 250 mm and 400 mm, but localized heavy rainfall events often trigger floods and debris flows. Agricultural activities are widespread in the river valleys, making these areas particularly vulnerable to flood hazards. Deforestation, unplanned urbanization, and unsustainable land use practices have further exacerbated the risk of floods in the region. The Surkhandarya River is the main drainage system, supported by numerous tributaries that contribute to high drainage density in some areas. Historical flood records indicate that floods frequently affect settlements, infrastructure, and farmlands. The combination of natural and anthropogenic factors makes the Surkhandarya basin an ideal case study area for applying the Certainty Factor model in flood susceptibility mapping.

3. Materials and Methods

This study utilized 115 flood inventory points obtained from the national hydrometeorological service for the period 2022–2024. These points were integrated into a geodatabase using ArcGIS Pro. Nine flood conditioning factors were selected based on previous research and their relevance to flood processes: Stream Power Index (SPI), Topographic Wetness Index (TWI), precipitation, drainage density, geology, land use/land cover (LULC), NDVI, elevation, and aspect. All datasets were processed at a spatial resolution of 30×30 m. Topographic data were derived from Shuttle Radar Topography Mission (SRTM), while NDVI and LULC were obtained from Landsat-9 and Sentinel-2 imagery. The CF model was applied to calculate the contribution of each factor to flood susceptibility. The model compares the conditional probability of flood occurrence within each class of a factor (PPa) to its spatial probability across the basin (PPb).

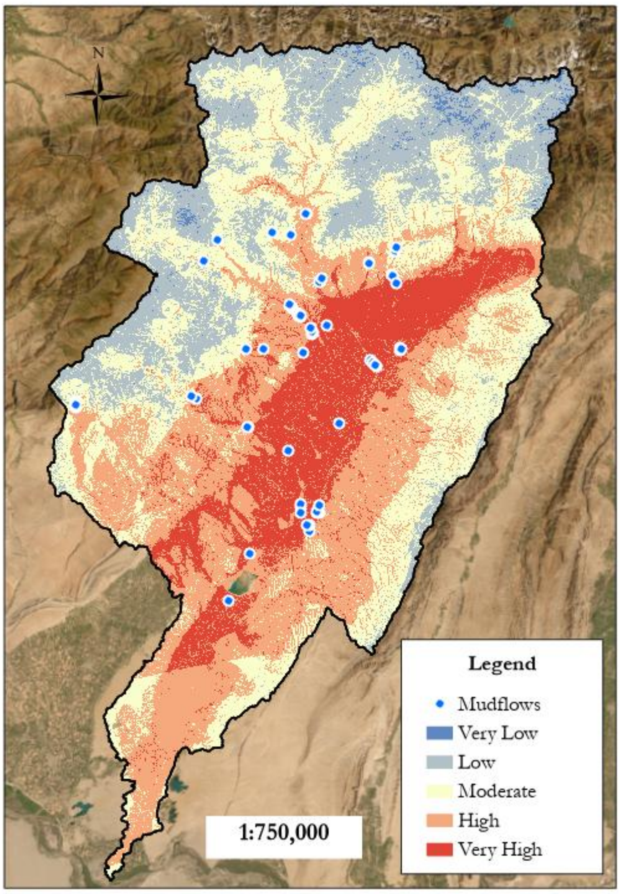

Figure 1: Mudflow susceptibility map obtained using the CF model

Positive CF values indicate a higher likelihood of floods, while negative values suggest lower susceptibility. After calculating CF values for all factors, the results were combined to produce a composite susceptibility map (Fig.1). To validate the model, ROC (Receiver Operating Characteristic) curve analysis was employed using the ArcSDM extension in ArcGIS. The AUC (Area Under the Curve) value was used as the primary performance metric. An AUC value greater than 0.8 is considered to represent high predictive accuracy. This methodology ensured a systematic and quantitative evaluation of flood-prone zones in the Surkhandarya basin.

4. Results and Discussion

The CF model successfully identified areas with varying degrees of flood susceptibility in the Surkhandarya basin. Among the conditioning factors, land use/land cover (LULC) and elevation demonstrated the highest positive CF values, indicating their strong influence on flood occurrence [8]. Agricultural lands and bare soil areas were found to be the most flood-prone zones, while forested areas showed significantly lower susceptibility [9]. Elevation analysis revealed that steep slopes and high-altitude zones were more vulnerable to flash floods due to intense rainfall accumulation and rapid runoff. In contrast, NDVI showed negative CF values, highlighting its protective role in reducing erosion and surface runoff. Aspect was also a less significant factor, although north- and east-facing slopes exhibited slightly higher flood likelihood [10].

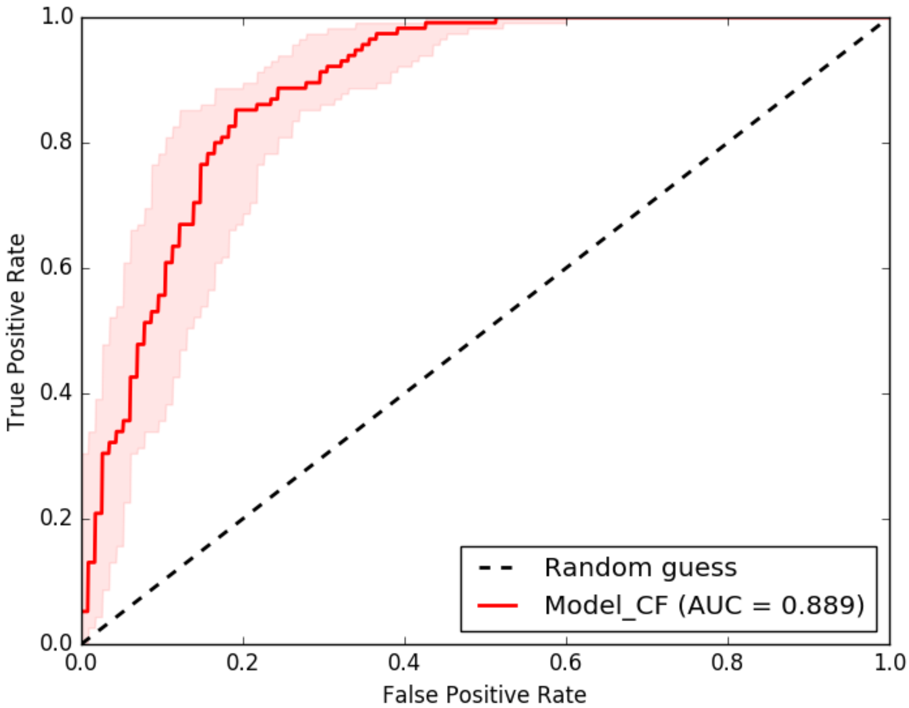

Figure 2: ROC/AUC

The composite CF-based susceptibility map categorized the basin into five zones: very low, low, moderate, high, and very high susceptibility [11]. Approximately 16.1% of the basin fell under very high susceptibility, while 31.8% and 31.1% were classified as high and moderate, respectively. Validation using ROC analysis confirmed the reliability of the CF model, with an AUC value of 0.889, which is considered highly accurate (Fig.2). Overall, the CF model provided a balanced and realistic representation of flood hazard zones, aligning closely with historical flood occurrences [12].

5. Conclusion

This study demonstrated the effectiveness of the Certainty Factor (CF) model in flood susceptibility mapping of the Surkhandarya basin. The integration of flood inventory data with nine geo-environmental factors allowed a comprehensive analysis of hazard distribution. The CF model highlighted the critical role of land use/land cover and elevation in driving flood processes, while vegetation cover acted as a mitigating factor. The susceptibility map produced through the CF approach provided detailed insights into areas of very high and high risk, which together covered nearly half of the basin. Validation through ROC/AUC analysis confirmed the robustness of the CF model with a high predictive accuracy (AUC=0.889). These results underscore the CF model's potential for application in other mountainous and foothill regions of Uzbekistan and beyond. The findings can serve as a valuable tool for disaster risk management, guiding urban planning, infrastructure development, and environmental protection strategies. By adopting CF-based flood susceptibility mapping, local authorities can enhance resilience and reduce the impacts of future flood events. Further research could explore integrating CF with advanced machine learning algorithms to enhance predictive performance even more.

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