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Flood risk susceptibility and evaluation by AHP technique in Denizli, Turkiye

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Abstract

Flood remains one of the most devastating natural calamities worldwide, inflicting irreparable damage upon society, the environment, and critical infrastructure. The compounding effects of climate change have only deepened the complexity of this challenge. Hence, a comprehensive exploration of the flood phenomenon from diverse perspectives becomes imperative, necessitating interdisciplinary collaboration with specialists from various fields of study. In this vein, the present study endeavors to evaluate eleven influential factors utilizing advanced technologies such as Google Earth Engine (GEE), Geographic Information System (GIS), and the Analytical Hierarchy Process (AHP). The outcome of this concerted effort is the development of a Flood Hazard Map (FHM), which accuracy was verified through a rigorous comparison with historical events. This model proves highly effective in discerning flood-prone regions, garnering substantial acceptance from rational perspectives. The ensuing results reveal that nearly half of the region under scrutiny is characterized by high and very high hazard levels, underscoring the urgent need for further in-depth investigations in this domain. Moreover, it is of paramount importance to acknowledge the profound impact of the June 2023 flood, a pivotal and well-documented factor influencing the outcomes of this study. Overlooking this critical aspect could portend irreversible consequences for the future. Therefore, it is imperative to recognize the significance of interdisciplinary cooperation, the potential ramifications of climate change, and the crucial historical events that shape our understanding of floods. Effective strategies to mitigate flood risks, safeguard lives, and protect irreplaceable resources can be developed by adopting a holistic strategy.

1. Introduction

Globally, floods continue to be a great natural hazard (Kreibich et al., 2022), causing over 4,000 fatalities in 2021 (Global Natural Disaster Assessment Report, 2021). Meanwhile, according to (Statista, 2023), 146 people died in the 2021 flash and river floods in the USA. This is the greatest amount between 1995 and 2021, after its peak in 2015 with 176 deaths. Floods can potentially destroy infrastructure, interrupt vital services, relocate populations, and threaten lives and livelihoods. Considering population expansion and climate change, this issue gets progressively more complicated. Flash floods and river floods are classified as two main types of floods. The first group generally leads to greater loss of life, and the latter issues damage to properties (USGS, 2023).

Flash floods (or Pluvial floods) are destructive floods that occur in a short period, generally caused by heavy rainfall or the unexpected release of water from either natural or artificial sources. Heavy rains in June 2019 caused flash floods in Denizli, a southwestern province of Turkiye. The flood destroyed infrastructure, residences, and agricultural fields in various regions, including Pamukkale. Flash floods immediately overwhelmed the region, causing fatalities and disrupting routines. Meanwhile, flooding in June 2022 affected the agricultural areas of the province.

River floods (or Fluvial floods) occur when rivers overflow their banks and inundate adjacent areas with

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water. The Büyük Menderes River in Denizli experienced a flood with spring run-off between March 10 and March 15, 2006.

Besides, addressing the impacts of floods in the era of climate change requires a comprehensive approach based on scientific understanding. Mitigation efforts to reduce greenhouse gas emissions are crucial in slowing down the pace of climate change and limiting its long-term impacts on flood patterns (IPCC, 2018). Despite the global concerns resulting from Covid-19, (Vafa et al. 2021, 2022) showed that mandatory quarantines reduced air pollution in Khuzestan province and Istanbul city, which are among the most polluted regions in Iran and Turkiye. Tackle the multidisciplinary issue, which is directly and indirectly affected or related to the trend of expanding urbanization, loss of agricultural land, changes in rain patterns, droughts, and depletion of water supplies needs the attention of numerous world specialists and international collaboration. This subject may be investigated from several perspectives. One of the most critical challenges is the availability of a Flood Map (FM) or flood-prone areas to make wise decisions to protect human, natural, and financial resources.

Despite the numerous floods that occurred in Turkiye and their financial and human losses, Haltas et al., (2021) discovered a significant disparity in the number of flood records and their accuracy between agencies. This study fills that gap by providing valuable flood event inventories. It should be mentioned that both the population and the number of floods depicted an increasing pattern. According to this research, floods killed over a thousand people (human resources), damaged nearly two thousand square kilometers of agricultural land (food scarcity and economic loss) and resulted in the loss of approximately two thousand million TL (financial resources) between 1930 to 2020 years. Meanwhile, Denizli province has taken fourth place in terms of floods, trailing only Istanbul, Antalya, and Rize. Due to the limited number of studies conducted in Denizli province, this area has been selected as a case study.

This study aims to investigate the flood hazard by producing a flood hazard map (FHM) for the region using the AHP method and validating it by overlaying the results with a layer of historical events (archive data).

2. Method

2.1. Study Area

Denizli province is in the southwest of Turkiye, between longitudes 28.55° E and 30.04° E and latitudes 36.87° N to 38.45° N, and covers an area of around 11,000 km^2 with a population of around 1,061,000 people. There are currently 36 meteorological stations in the region. Based on the stations' coordinates, monthly rainfall information was extracted from the (NASA power data access viewer) for eight of these stations. The maximum slope of the region is approximately 70 degrees with an average of 11. Meanwhile, the average elevation is approximately 962 meters above sea level, ranging from 105 to 2531 meters "Figure 1".

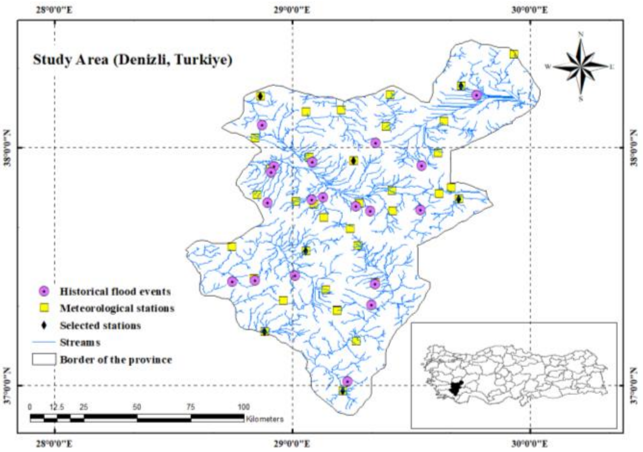

Figure 1. Study Area

2.2. Data

Shuttle Radar Topography Mission (SRTM) data was utilized to ascertain the Digital Elevation Model (DEM), as well as elevation (ELV), slope (SLP), curvature (CRV), distance to stream (DtS), drainage density (DD), flow accumulation (FA), and topographic wetness index (TWI) from the DEM.

The monthly precipitation data from the chosen stations between 1981 and 2021 are used in the equation (1), Modified Fournier Index (MFI) to generate the rainfall intensity map (Chen, 2022):

$$MFI = \sum_{1}^{12} \frac{{p_n}^2}{P} \quad \textbf{(1)}$$

Where P and p_n are the average annual and monthly rainfall, respectively.

Corine 2018 was used to generate the LULC map. Remote Sensing (RS) indices such as NDVI, MNDWI, and NDBI were derived from Landsat images with the aid of Google Earth Engine (GEE). Also, the soil type (ST) layer of the region has been obtained according to the layer provided by the Food and Agriculture Organization of the United Nations (FAO).

Then, using the Jenk algorithm, the 8 parameters ELV, SLP, DtS, DD, TWI, NDVI, FA, and MFI were divided into 5 categories. CRV, ST, and LULC are also classified as 1 to 5 based on expert's opinions and previous researches (Ozay and Orhan, 2023; Talukdar et al., 2020; Khosravi et al., 2019; Tehrany et al., 2014). Curvature was classified as concave, flat, and convex which were 5, 3, and 1, respectively. LULC has been classified as 5 for built-up and water bodies. Barren, agriculture, sparse vegetation, and forest were assigned 4 to 1, respectively. Also, ST had been classified as Calcic and Eutric Cambisols, Calcaric Fluvisol, Lithosols, Calcic Xerosols, and water as one, three, four, and five.

2.3. Analytic Hierarchy Process

The analytic hierarchy process (AHP) is a mathematical technique for evaluating complex decision problems with multiple criteria (Saaty, 1988). So, the weight values of each GIS layer were determined utilizing the AHP. The initial step is identifying the decision dilemma. Then using a pairwise comparison matrix in which all detected important properties of the GIS layer are compared with preference factors, AHP calculates the necessary significant weighting factors for each GIS layer (Yuan et al., 2022). In the pairwise comparison matrix of the AHP, ratings range continuously from 1 (least significant) to 9 (most significant). The importance rating of each criterion was introduced by Saaty (1977).

This study's proposed methodology suggests an 11 by 11 pairwise comparison matrix. The criteria are arranged hierarchically. Each row's values characterize the relative importance between the two factors. So, a pairwise comparison matrix was developed based on Saaty's rating, literature review, and expert opinions. Table 1 represents the normalized comparison matrix.

The obtained weight for each layer is given in Table 2.

Table 1. Normalized pairwise comparison matrix

Factor	DtS	SLP	DD	ELV	FA	NDVI	MFI	LULC	TWI	ST	CRV
DtS	0.29	0.35	0.28	0.34	0.32	0.23	0.21	0.20	0.17	0.17	0.16
SLP	0.15	0.17	0.28	0.11	0.19	0.23	0.21	0.20	0.17	0.17	0.16
DD	0.15	0.09	0.14	0.23	0.19	0.14	0.13	0.14	0.12	0.13	0.12
ELV	0.10	0.17	0.07	0.11	0.13	0.14	0.13	0.14	0.12	0.13	0.12
FA	0.06	0.06	0.05	0.06	0.06	0.14	0.13	0.09	0.12	0.09	0.09
NDVI	0.06	0.03	0.05	0.04	0.02	0.05	0.13	0.09	0.07	0.09	0.09
MFI	0.06	0.03	0.05	0.04	0.02	0.02	0.04	0.09	0.12	0.09	0.09
LULC	0.04	0.02	0.03	0.02	0.02	0.02	0.01	0.03	0.07	0.06	0.09
TWI	0.04	0.02	0.03	0.02	0.01	0.02	0.01	0.01	0.02	0.06	0.05
ST	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03
CRV	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02

Table 2. Factors' weight by AHP method

Factor	DtS	SLP	DD	ELV	FA	NDVI	MFI	LULC	TWI	ST	CRV
Weight	0.25	0.19	0.14	0.12	0.08	0.06	0.06	0.04	0.03	0.02	0.01

And finally, the hazard map of the area was generated by Equation (2) in the raster calculator.

$$FHI = \sum_{i=1}^{n} W_i F_i = W_{Dts}Dts + W_{SLP}SLP + W_{DD}DD + W_{ELV}ELV + W_{FA}FA + W_{NDVI}NDVI + W_{MFI}MFI + W_{LULC}LULC + W_{TWI}TWI + W_{ST}ST + W_{CRV}CRV \quad (2)$$

Where;
FHI: Flood Hazard Index
W_i: Weights derived via the AHP
F_i: Flood factor's raster layers

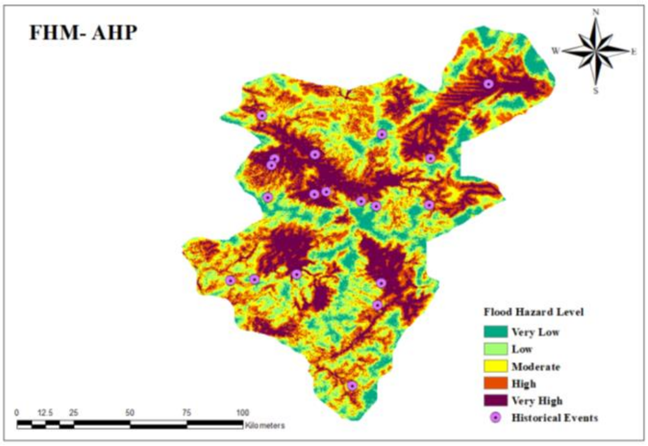

Figure 2. Flood Hazard Map

3. Results

To demonstrate the reliability of the flood hazard map, the results were validated using historical flood events "Figure 2".

4. Discussions

AHP was able to classify the previously selected events as having a hazard level between 2 and 5, except for a single point that is classified as having a very low hazard level. On this basis, the implementation of the AHP method to generate the area's flood hazard map was deemed effective.

Accordingly, approximately 26% and 22% of the region are at high and very high inundation hazard levels, respectively.

5. Conclusions

In this study, the AHP method was used to develop a map of the region's flood hazard, and nearly fifty percent of the region was classified as having a high or very high flood hazard level. Due to the presence of agricultural lands and gardens, urban areas, mines, construction and industrial spots in the region, it is essential to develop a comprehensive crisis management plan.

Acknowledgment

This research represents the preliminary phase of a master's thesis currently being finalized at Istanbul Technical University. It is anticipated that this endeavor will serve as a foundation for defining additional multidisciplinary initiatives to reduce the province's vulnerability and devising effective action plan scenarios.

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