J. Ind. Geophys. Union, 29(4) (2025), 260-275
https://doi.org/10.71122/JIGU.29(4)2025.0025

Seismic risk assessment using analytic hierarchy process: An integrated approach for Varanasi city, India

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ABSTRACT

Seismic hazards present significant risks to urban areas, highlighting the need for a comprehensive earthquake risk assessment (ERA) to enhance disaster preparedness. This study utilizes the Analytic Hierarchy Process (AHP) methodology to construct an integrated ERA map using Geographic Information System (GIS) for Varanasi city, which is one of the most densely populated cities of Northern India, located in the Indo-Gangetic plain. The AHP framework created a pairwise comparison matrix to assess the relative significance of factors affecting seismic risk, such as peak ground acceleration, geology, geomorphology, building density, population density, literacy, transports and building typology. Weights were based on global studies with similar characteristics, expert advice and consistency checks to ensure coherence in comparisons. Integrated AHP model is used to generate seismic hazard index and vulnerability index which is then integrated to develop a comprehensive seismic risk map using GIS. As a result, Varanasi City is classified into five zones of seismic risk levels, ranging from very low to very high for the seismicity occurrence with a 10% probability of exceedance and a 2% probability of exceedance in 50 years. Our study finds that 6.92% of the area of Varanasi city lies in the very high seismic risk zone (Zone 5), followed by 23.88% in high risk, 21.32% moderate, 20.25% low, and 27.66% very low risk (zone 1) for the seismicity occurrence with 10% probability of exceedance in 50 years (DBE). For a 2% probability of exceedance in 50 years (MCE), the distribution slightly changes, with 26.14% in very low, 21.24% low, 23.31% moderate, 21.69% high, and 7.62% area lie in very high seismic risk zones (Zone 5).

Keywords: Seismic, hazard, vulnerability, risk, Varanasi city, Analytic Hierarchy Process (AHP).

INTRODUCTION

Varanasi, an ancient city in northern India, known for its rich cultural and religious heritage, is at significant seismic risk due to its location in the seismically active Gangetic Plain. As one of the most populated cities in northern India, Varanasi is vulnerable to potentially devastating earthquakes from nearby faults and tectonic features such as the Himalayan Frontal Thrust (HFT), ridges, and faults (Sahu and Saha, 2014; Singh et al., 2020). The city's aging infrastructure, with many buildings either very old and damaged or possessing specific structural weaknesses, further compounds its vulnerability to earthquake hazards (Jha and Bajwa, 2023). The presence of geological structures like the Faizabad Ridge, Allahabad Fault, Azamgarh Fault, Devoria Fault, Patna Fault, and the Siwan Fault, are capable of generating earthquakes or reactivating during large Himalayan seismic events, which is a matter of grave concern (Sahu and Saha, 2014; Singh et al., 2020). Notably, the HFT, the surface expression of the Main Himalayan Thrust, facilitates the northward movement of the Indian plate, often resulting in large earthquakes (Seeber and Armbruster, 1984). The thick quaternary alluvial deposits, ranging from clay to gravelly sand formations (Shukla and Raju, 2008), coupled with the low-lying terrain, heighten the city's susceptibility to seismic events and flooding hazards (Pandey et al., 2021). Geomorphological investigations have unveiled the intricate network of drainage systems and fluvial landforms that shape the Varanasi district, with the Varuna River basin serving as a focal point for comprehensive analysis (Prakash et al., 2016). These geological and geomorphological factors contribute to the region's complex hazard profile, necessitating a thorough understanding for effective risk assessment and mitigation strategies. The Varanasi city region chosen for the comprehensive risk assessment is shown in Figure 1.

Several studies have earlier assessed seismic hazard and risk in Varanasi and other regions using geological, geophysical, and geotechnical data (Nath et al., 2019; Singh, 2022; Tiwari et al., 2024). Using GIS and seismic hazard parameters, a seismic microzonation map for Delhi (India), has been developed by Mohanty et al. (2007). Anbazhagan et al. (2010) utilized probabilistic and deterministic approaches to assess seismic hazard and develop seismic risk maps for the Bangalore region. The Seismotectonic setup around Varanasi city is shown in Figure 1 (Bhukosh-GSI, 2023).

Various approaches have been employed for seismic risk assessment and hazard mapping in past. These include Probabilistic Seismic Hazard Analysis (PSHA), which incorporates the probability of seismic events, ground motion attenuation models, and site conditions to estimate ground motion levels (Kramer, 1996), and Deterministic Seismic Hazard Analysis (DSHA), which considers the worst-case scenario of a maximum credible earthquake (Rasool et al., 2024; Tilara et al., 2024).