Optimized Seismic Sensor Placement for Earthquake Early Warning in Kathmandu Valley Using Vs30-Adjusted Fault Criticality Analysis

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KTM GEO LAB

Abstract

Kathmandu Valley is highly vulnerable to seismic hazards due to active Himalayan tectonics and soft sedimentary basin deposits that amplify ground motion. This study presents a GIS-based framework for identifying critical fault corridors and optimizing seismic sensor placement for a prototype Earthquake Early Warning (EEW) system using ten sensors across the valley. Historical earthquake data, fault geometry, Vs30-based soil amplification, PGA amplification, and co-seismic Newmark displacement analyses were integrated to evaluate seismic criticality. A Vs30-adjusted buffer approach revealed that NW–SE trending central valley fault systems exhibit the strongest seismic influence and strongly correlate with zones of amplified ground motion and permanent displacement. Based on these results, strategic sensor deployment locations were proposed to improve P-wave detection, reduce warning latency, and strengthen real-time seismic monitoring capability. The framework provides a scalable foundation for future EEW implementation in Nepal.

Introduction

Nepal lies within the active Himalayan collision zone formed by convergence between the Indian and Eurasian tectonic plates. Seismic activity is primarily controlled by the Main Himalayan Thrust (MHT), which has generated several destructive earthquakes, including the 1934 Nepal–Bihar Earthquake and the 2015 Gorkha Earthquake.

Kathmandu Valley is particularly susceptible to earthquake damage because of its thick fluvio-lacustrine deposits, which significantly amplify seismic waves. Existing seismic monitoring coverage in Nepal remains sparse, limiting rapid earthquake detection and warning capability.

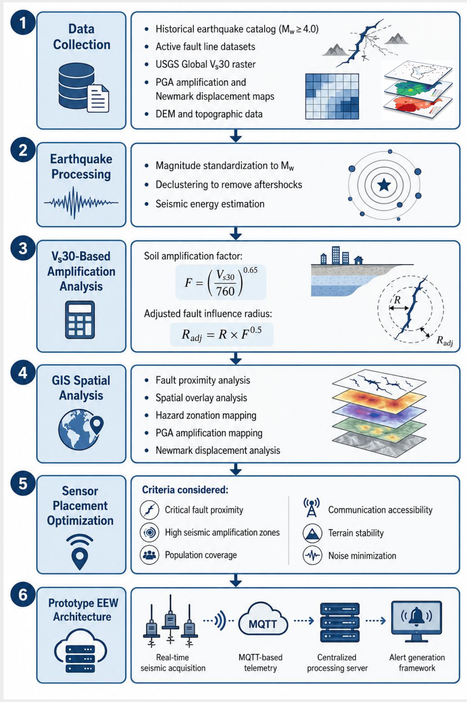
This study focuses on identifying critical fault corridors and optimizing seismic sensor placement using GIS-based seismic hazard analysis, soil amplification characteristics, and earthquake distribution patterns to support development of a prototype Earthquake Early Warning (EEW) system for Kathmandu Valley.

Methodology

A GIS-based seismic hazard assessment framework was developed to identify critical fault corridors and optimize seismic sensor placement for a prototype EEW system in Kathmandu Valley. Historical earthquake records ($M_w \geq 4.0$), active fault datasets, Vs30-based soil condition data, PGA amplification maps, and co-seismic Newmark displacement maps were integrated within a spatial analysis environment.

Earthquake magnitudes were standardized and declustered to retain independent seismic events. Fault influence zones were then adjusted using Vs30-derived soil amplification factors to account for local geological effects on seismic wave propagation. Spatial overlay analysis was subsequently performed to identify regions exhibiting high seismic amplification, elevated displacement potential, and concentrated earthquake activity.

The resulting critical fault corridors were used to determine optimal sensor deployment regions based on seismic hazard intensity, terrain suitability, communication accessibility, urban coverage, and network redundancy considerations. The final framework supports real-time seismic data acquisition and provides a scalable prototype architecture for future EEW implementation in Nepal.



Results

The Vs30-adjusted fault criticality analysis identified the central Kathmandu Valley as the most seismically critical region due to the combined influence of active fault systems and soft fluvio-lacustrine sediments. Critical and High fault categories were concentrated along NW–SE trending corridors characterized by clustered seismicity and elevated seismic energy accumulation.

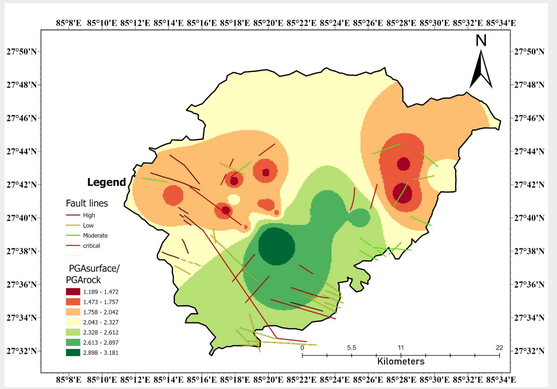


Fig. 1. Fault criticality overlay on mean PGA amplification across Kathmandu Valley.
Data: (Uttarkashi (1991), Kobe (1995), Chi-Chi (1999), Gorkha (2015)

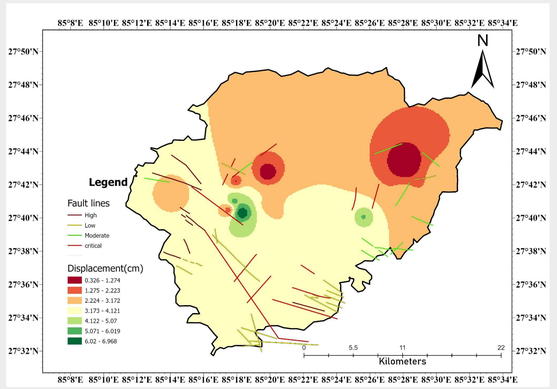


Fig. 2. Fault criticality overlay on mean co-seismic Newmark displacement across Kathmandu Valley.
Data: (Uttarkashi (1991), Kobe (1995), Chi-Chi (1999), Gorkha (2015)

Overlay analysis showed strong spatial agreement between critical fault corridors, high PGA amplification zones, and maximum co-seismic Newmark displacement regions, indicating increased ground shaking susceptibility and infrastructure vulnerability. These high-hazard zones were identified as priority regions for EEW sensor deployment.

Based on the integrated hazard assessment, Tokha, Nagarjun, Chandragiri, Kirtipur, Pharping, Changunarayan, Sankhu, Godawari, and Central Kathmandu were selected as optimal locations for prototype seismic sensors to improve real-time monitoring coverage and reduce earthquake warning latency.

Conclusions

This study demonstrates that integrating fault geometry, earthquake distribution, and Vs30-based soil amplification within a GIS framework provides an effective approach for identifying critical seismic corridors in Kathmandu Valley. The analysis revealed that central basin fault systems exhibit the highest seismic criticality and strongly correlate with amplified PGA response and co-seismic displacement zones.

The proposed prototype sensor network offers a practical framework for improving earthquake detection capability, reducing warning latency, and strengthening seismic preparedness in Nepal. The methodology also provides a scalable approach for future EEW expansion in other Himalayan urban basins.

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References

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