An Interactive Earthquake Impact Visualization Tool

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Abstract

This project presents an interactive dashboard for visualizing and analyzing earthquake data, integrating geospatial population data to estimate the human impact of seismic events. Using Ground Motion Prediction Equations (GMPEs), the tool calculates the radius of significant ground motion and visualizes it alongside population density data. The dashboard employs various visualization techniques, including scatter plots, heatmaps, and 3D terrain maps, to provide insights into earthquake patterns and their potential impact. This work aims to assist researchers, policymakers, and emergency responders in understanding and mitigating earthquake risks.

1 Introduction

Earthquakes are unpredictable geological events that frequently result in extensive damage to infrastructure and pose a serious threat to human life. Despite advancements in seismic monitoring, there is a lack of accessible tools that combine earthquake data with population impact analysis. This project addresses this gap by developing an interactive dashboard that visualizes earthquake data and estimates the affected population using geospatial data. The tool leverages GMPEs to calculate shockwave radii and integrates population data to provide actionable insights.

2 Problem Formulation

Earthquakes pose a significant threat to human life, infrastructure, causing widespread destruction and loss. Despite advancements in seismic monitoring and data collection, existing tools often fail to provide a comprehensive analysis of their impact on populations. Most tools focus on seismic parameters such as magnitude, depth, and location, but lack integration with population data to assess the human impact effectively. This gap limits the ability of researchers, policymakers, and emergency responders to prioritize resources and plan disaster mitigation strategies. A more holistic approach is needed to combine earthquake data with population analysis, enabling better risk assessment and decision-making.

3 Related Works

Several existing works have influenced the development of this project, including tools, methodologies, and research papers addressing earthquake visualization, population impact analysis, and ground motion prediction.

- **USGS Earthquake Hazards Program:** Provides a comprehensive earthquake catalog and hazard maps but lacks integration with population data for impact analysis. *Reference:* `https://earthquake.usgs.gov/`

33rd Conference on Neural Information Processing Systems (NeurIPS 2019), Vancouver, Canada.

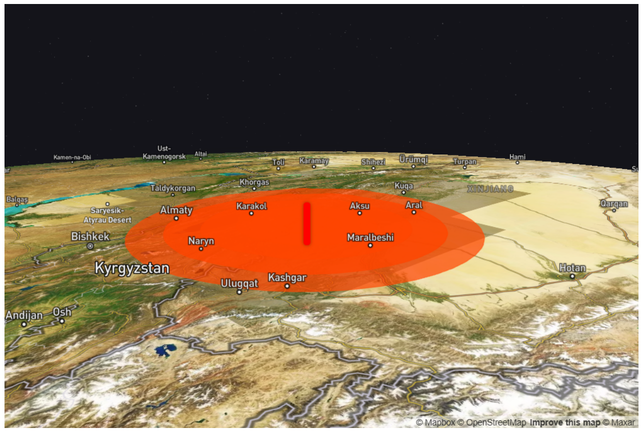


Figure 1: Shockwave Effect Visualization. This figure shows the concentric rings representing the shockwave radius around the earthquake epicenter.

- **WorldPop Population Data:** Offers high-resolution population data widely used in disaster risk assessment, leveraged here to estimate populations affected by earthquakes. *Reference:* `https://www.worldpop.org/`
- **OpenQuake Engine:** An open-source tool for seismic hazard assessment, providing GMPE models like BooreEtAl2014 for radius estimation. *Reference:* `https://github.com/gem/oq-engine`
- **ShakeMap by USGS:** Generates maps of ground motion intensity, extended in this project to include population impact analysis. *Reference:* `https://earthquake.usgs.gov/data/shakemap/`
- **Turf.js for Geospatial Analysis:** A geospatial library for geographic calculations, used here for shockwave radius visualization. *Reference:* `https://turfjs.org/`
- **BooreEtAl2014 GMPE Model:** Widely used for predicting ground motion intensity, applied here to estimate the radius of significant ground motion. *Reference:* Boore, D. M., Stewart, J. P., Seyhan, E., & Atkinson, G. M. (2014) *Earthquake Spectra* **30**(3):1057-1085. DOI: 10.1193/070113EQS184M.
- **PAGER System by USGS:** Integrates population data with seismic hazard analysis, aligning with this project's goals. *Reference:* Wald, D. J., Lin, K., Porter, K., & Turner, L. (2008) *Seismological Research Letters* **79**(3):318-323. DOI: 10.1785/gssrl.79.3.318.

4 Methodology

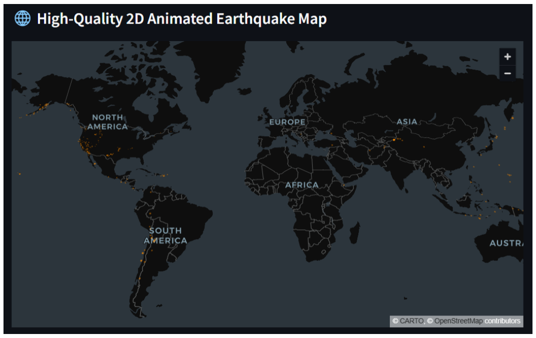
4.1 Data Sources:

The earthquake data for this project was sourced from the USGS Earthquake Catalog, providing details such as time, location, depth, magnitude, and type. The data was cleaned and preprocessed for analysis, with additional attributes like fault and plate distances calculated. Population data from WorldPop GeoTIFF files, offering high-resolution density estimates, was used to assess populations affected within the shockwave radius. Geospatial libraries were employed to process raster data and extract population values for relevant regions.

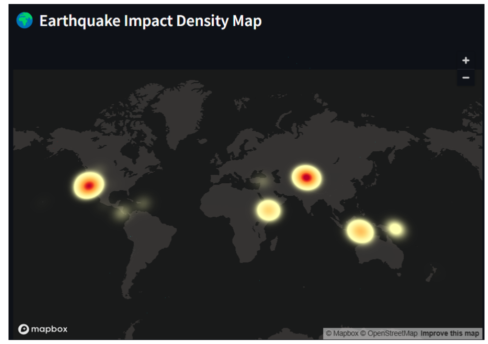
4.2 Radius Calculation:

The radius of significant ground motion was calculated using the BooreEtAl2014 GMPE model, a widely used Ground Motion Prediction Equation. The GMPE model estimates the Peak Ground Acceleration (PGA) based on earthquake magnitude, distance from the epicenter, and other parameters. The formula used is:

$$\ln(PGA) = f(M, R, siteconditions, otherparameters)$$



(a) 2D Animated earthquake map. This map visualizes earthquake epicenters with markers sized by magnitude, allowing users to explore spatial patterns interactively.



(b) Earthquake Impact Density Map. This map highlights population density near earthquake epicenters, identifying high-risk regions.

Figure 2: Population Impact Analysis Visualizations. The 2D animated earthquake map provides an interactive view of earthquake epicenters, while the density map highlights areas with significant population exposure to seismic activity.

Where M is the earthquake magnitude, R is the distance from the epicenter (in km), and site conditions and other parameters are specific to the GMPE model.

An iterative approach was used to calculate PGA at various distances, ranging from 1 km to 300 km from the epicenter. The radius was determined as the distance where PGA dropped below a threshold value, such as 0.05g. This process is expressed as:

$$PGA(R) < Threshold(e.g., 0.05g)$$

The implementation was carried out using the OpenQuake library, which provides a robust framework for GMPE calculations. The calculated radius was then used to define the area of significant ground motion for further analysis.

4.3 Population Impact Analysis:

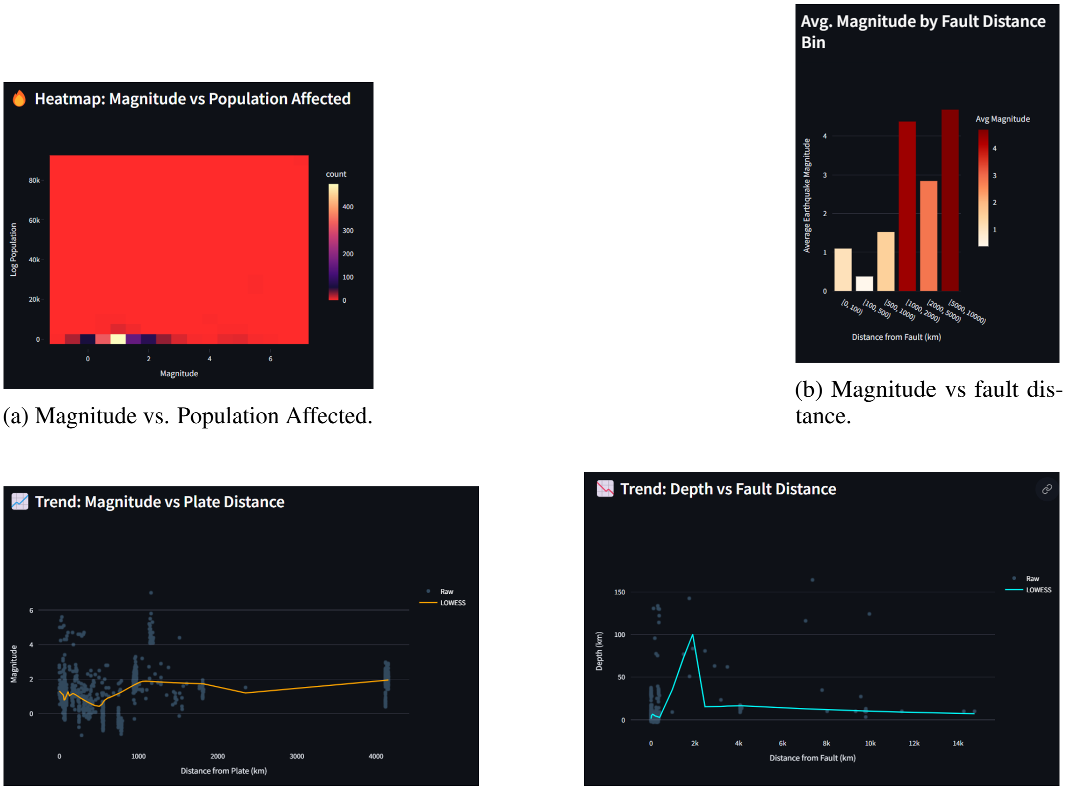
The calculated shockwave radius was used to create a buffer around the earthquake epicenter. This buffer was applied to the population raster data to extract population density values within the affected area. The total population within the buffer was estimated using the formula:

$$TotalPopulation = \sum_{i=1}^{n} PopulationDensity_i \cdot Area_i$$

Geospatial operations, such as masking and cropping, were performed using Rasterio and GeoPandas to isolate the relevant population data. The total population within the buffer was summed to estimate the number of people affected by the earthquake. This analysis provided valuable insights into the human impact of earthquakes, particularly in densely populated regions.

4.4 Visualization Techniques:

Various visualization techniques were employed to communicate results effectively. Scatter plots revealed relationships like magnitude versus depth and population impact versus magnitude, highlighting patterns such as shallow, high-magnitude earthquakes near tectonic boundaries. Heatmaps showcased fault distance versus magnitude and population density near epicenters, providing spatial risk insights. 3D terrain maps with concentric rings, created using Mapbox, visualized the geographical spread of ground motion. Interactive 2D maps using Pydeck allowed spatial exploration of earthquake data, with markers sized and colored by magnitude.



(a) Magnitude vs. Population Affected.

(b) Magnitude vs fault distance.

(c) Magnitude vs fault distance

(d) Earthquake depth vs fault distance.

Figure 3: Population Impact Analysis Visualizations. These plots highlight the relationship between earthquake magnitude, fault distance, and population exposure, as well as the geographical distribution of affected populations.

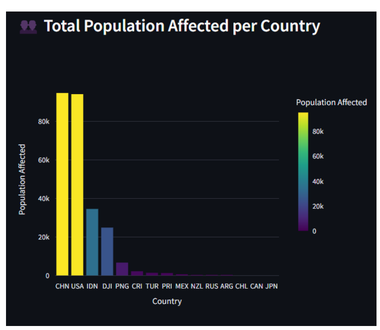


Figure 4: total population affected per country.

4.5 Tools and Libraries:

The project utilized a range of tools and libraries to achieve its objectives. For distance calculations, the Euclidean distance formula was used to compute the distance between the earthquake epicenter and known fault or plate boundaries:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

This calculation was implemented using geospatial libraries such as GeoPandas and Shapely.

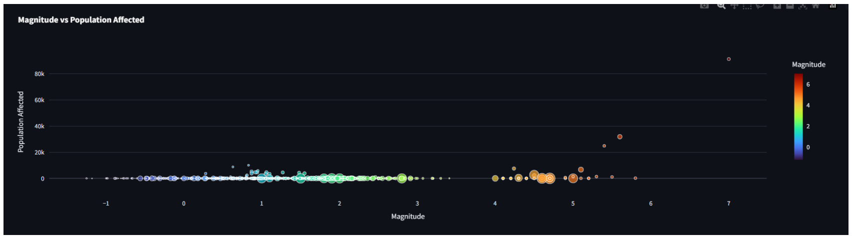


Figure 5: Magnitude vs Population Affected

5 Results

5.1 Radius Estimation:

The shockwave radii for earthquakes were successfully calculated using the BooreEtAl2014 GMPE model. The results demonstrated that larger magnitude earthquakes produced wider radii, as expected, due to their higher energy release and ground motion intensity. For example, earthquakes with magnitudes above 6.0 exhibited significantly larger radii compared to smaller events, highlighting the scalability of the GMPE-based approach. The iterative calculation of PGA at various distances ensured accurate determination of the radius where ground motion intensity dropped below the threshold (e.g., 0.05g). These radii were visualized using concentric rings on 3D terrain maps, as shown in Figure 1 (shockwave effect.png), which dynamically illustrates the geographical spread of ground motion.

5.2 Population Impact:

Using the calculated shockwave radii, the population affected by each earthquake was estimated by integrating geospatial population data. The analysis identified high-risk regions with dense populations near tectonic boundaries, such as urban areas along the Pacific Ring of Fire. For instance, earthquakes occurring near densely populated cities had a disproportionately higher estimated population impact compared to those in rural or sparsely populated regions. The Earthquake Impact Density Map (earthquake impact density map.png) visualizes the population density near earthquake epicenters, highlighting areas with the greatest exposure to seismic activity. Additionally, Figure 2 (total population affected per country.png) shows the total population affected by earthquakes in each country, emphasizing the regions most vulnerable to seismic events.

Top 5 Earthquakes by Population Affected

	country_iso3	place	mag	time	estimated_population
483	CHN	129 km WNW of Aykol, China	7.0	2024-01-22 18:09:04	91,238
132	IDN	80 km ENE of Ruteng, Indonesia	5.6	2024-01-25 12:24:13	31,867
92	DJI	26 km SSE of Obock, Djibouti	5.4	2024-01-25 17:00:43	24,844
541	USA	3 km SE of Fontana, CA	0.8	2024-01-21 04:52:11	10,020
167	USA	3 km SE of Fontana, CA	0.6	2024-01-25 09:37:56	8,764

Figure 6: Top 5 Earthquakes by Population Affected

5.3 Visualization:

The visualizations created as part of this project effectively communicated the results and provided deeper insights into earthquake patterns and their impacts. Scatter plots, such as Magnitude vs. Depth (depth vs fault dist.png), revealed clear relationships between earthquake magnitude and depth, showing that shallow earthquakes tend to have higher magnitudes and greater surface impact. Magnitude vs. Population Affected (mag vs pop affected.png) highlighted how larger magnitude earthquakes tend to affect more people, especially in urban areas. Heatmaps, such as Fault Distance vs. Population Affected (fault dist vs population affecred Hexbin.png), provided a spatial representation of risk by showing the relationship between fault proximity and population exposure.

The 3D terrain maps, created using Mapbox, displayed earthquake epicenters with concentric rings representing the shockwave radius, offering a dynamic visualization of the geographical spread of ground motion. These maps are complemented by interactive 2D maps, such as the 2D Animated Earthquake Map (2d Animated earthquake map.png), which allows users to explore earthquake data spatially and intuitively. Together, these visualizations provide a comprehensive understanding of earthquake patterns, their geographical spread, and their human impact.

6 Analysis

6.1 Strengths:

- Combines earthquake data with population analysis for actionable insights.
- Provides multiple visualization techniques for different use cases.
- Interactive and user-friendly dashboard for real-time exploration.

6.2 Limitations:

- Population data resolution may not capture small-scale variations.
- GMPE-based radius estimation assumes uniform ground conditions, which may not always be accurate.

7 Conclusion

The visualization tool effectively combines earthquake and population data to estimate impact zones and inform mitigation strategies. The interactive dashboard offers a comprehensive tool for researchers and policymakers to understand and mitigate earthquake risks.

8 Future Work

Future work includes:

Incorporating real-time earthquake data from APIs. Improving population impact estimation using finer-resolution data. Expanding the tool to include tsunami and aftershock analysis. Integrating machine learning models for earthquake risk prediction.

References

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