

1 Article

# 2 Deterministic Seismic Hazard Analysis (DSHA) for Herat 3 University

4 Qasim Aqbali <sup>1</sup>, Faheem Butt <sup>2</sup>5 <sup>1</sup> Structural Engineering Master Program, Department of Civil Engineering, University of Engineering and  
6 Technology Taxila, Pakistan; qasimaqbali571@gmail.com7 <sup>2</sup> Professor, Department of Civil Engineering, University of Engineering and Technology Taxila, Pakistan,  
8 faheem.butt@uetaxila.edu.pk

9 \* Correspondence: qasimaqbali571@gmail.com; Phone number: +923285277428

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## Abstract

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This result represents a deterministic seismic hazard analysis (DSHA) of Herat University, a university in the western part of Afghanistan, in an active tectonic area due to the collision of the Indian and the Eurasian plate. Local strike-slip faults, such as the Hari Rud Fault System and the Kaj Rud Fault, which are located in the area around the site at a distance of about 50 km, control the area. Empirical relationships were used to find maximum credible magnitudes, giving an Mw 7.4 to Hari Rud system and Mw 6.0 to Kaj Rud Fault. Findings indicate that Hari Rud system is the most dominant seismic hazard in Herat University which generates the highest values of ground acceleration (PGA) around 0.41-0.44 g, with the fault as Kaj Rud contributing to the moderate yet significant shaking. The recent devastating 2023 Herat earthquake sequence highlights the importance of site-specific hazard analysis to aid earthquake-resistant design, disaster preparation, and resilient urban development. The findings are not essential only in the protection of the Herat University but also in the enhancement of the seismic safety in the region at large

Keywords: Deterministic seismic hazard analysis (DSHA), Seismic hazard, Active tectonic

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## 27 1. Introduction

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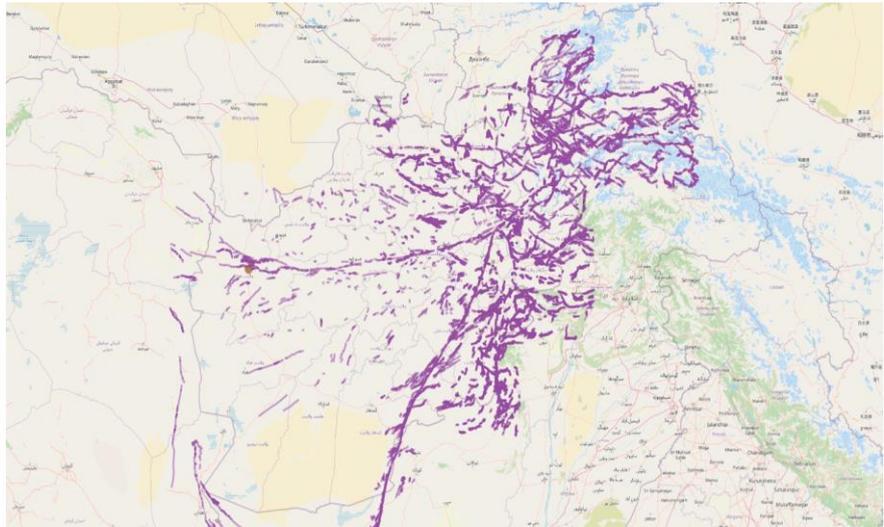
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28 In Western Afghanistan there are numerous earthquakes due to the collision of the Indian and the Eurasian plates. Strong earthquakes have had severe negative effects on humanity and buildings in the last several decades. The city of Herat, which is one of the largest and most critical cities in the region, is near to active strike-slip faults and thus is highly prone to earthquakes Herat university is located in Herat city and it is one of the most important universities in Afghanistan. This makes its earthquake safety very significant.



36  
37 **Figure 1.** Fault lines of Afghanistan extracted from QGIS, including the location of the study site.

38 Herat university is located in Herat city and it is one of the most important universi-  
39 ties in Afghanistan. This makes its earthquake safety very significant.



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41 **Figure 2.** A satellite view of Herat University campus, highlighting the Administrative Office build-  
42 ing, which is the focus of the DSHA calculations in this research.

43 Previous research revealed that local hazard assessment is significant in Afghanistan.  
44 To give example, Bakhshi Hossein and others (2025) conducted Seismic Hazard Evalua-  
45 tion and Accelerated Curves for Kunduz City These publications demonstrate that the  
46 examination of certain locations contributes to preserving the critical infrastructure. Nev-  
47 ertheless, there is no determined seismic hazard analysis of Herat University as it is sig-  
48 nificant and close to the active faults. Two approaches are commonly used in seismic haz-  
49 ard assessment. Probabilistic Seismic Hazard Analysis (PSHA) is a method used to esti-  
50 mate the probability that ground motion at a site will exceed a specified level within a

51 given time period, considering the contributions and uncertainties of all possible earth-  
52 quake sources. Deterministic Seismic Hazard Analysis (DSHA) analyses the impact of the  
53 largest potential earthquake caused by nearby faults. Both are important, yet DSHA is  
54 most suitable when it comes to investigating significant locations where the worst case  
55 scenario should be prepared. In this we apply DSHA to Herat University. We determine  
56 the principal sources of seismic, estimate the maximum magnitudes of these sources with  
57 empirical equations and predict the site-specific ground motion with ground-motion pre-  
58 diction equations. The findings provide important statistics to ensure that Herat Univer-  
59 sity is more resilient to earthquakes and also assist in enhancing safety in the bigger urban  
60 region.

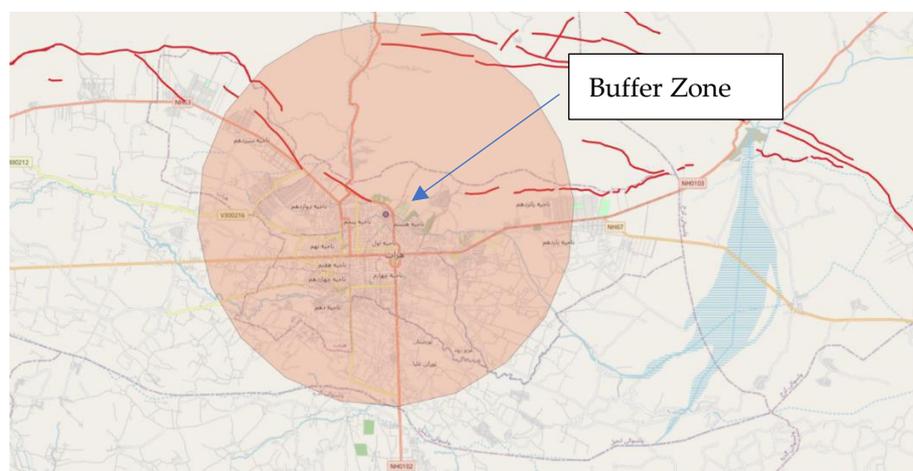
## 61 2. Methodology

62 Deterministic Seismic Hazard Assessment (DSHA) methodology was developed to  
63 assess the possibility of ground shaking within Herat University, which is situated in  
64 western Afghanistan. The method follows the standard DSHA model:

- 65 1: Identification of active faults that can affect the study site
- 66 2: Site to Source Distance.
- 67 3: Estimation of their maximum earthquake potential.
- 68 4: Prediction of ground motion levels at the site using well established Ground Mo-  
69 tion Prediction Equations (GMPEs).

### 70 2.1 Seismic Identification of Source

71 The first step of the Deterministic Seismic Hazard Assessment (DSHA) is identi-  
72 fication of seismic sources that may affect the study site. In this context, active and situa-  
73 tional faults were mapped and described in a 100 km radius around Herat University. The  
74 selection of this buffer was based on the fact that faults that are located beyond 100 Kilo-  
75 metres usually have a minor impact when it comes to local ground motions when per-  
76 forming a deterministic analysis. The coordinates of Herat University ( $X = 6925328.37$ ,  $Y$   
77  $= 4078281.3$ ) were taken from QGIS. These data sets enabled visualization of the active  
78 faults and their paths as well as spatial proximity to the site of interest with accuracy. Two  
79 significant strike-slip fault systems existed in the 100-kilometre buffer as shown in the  
80 analysis. Hari Rud Fault System is one of the most notable and active fault systems in  
81 western Afghanistan and it has a history of causing devastating earthquakes. Another ac-  
82 tive system is the Kaj Rod Fault System, which has the potential of generating a moderate  
83 to a strong seismic event. Based on this, the two fault systems were declared as the main  
84 seismic sources to the DSHA of Herat University.



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86 **Figure 3.** The study site and surrounding fault lines in QGIS.

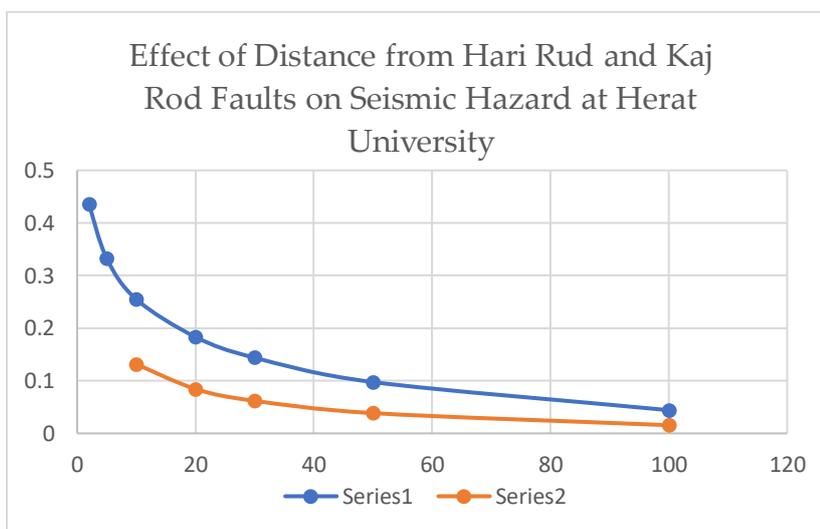
## 2.2 Site-to-Source Distance

In QGIS, the measuring tool was used to measure the minimum distances between Herat University and each identified fault segment. The results show that the nearest one, Hari Rud Fault System, has the most seismic impact, while the Kaj Rod Fault System the more distant one, can still produce moderate shaking. The measurements are an important contribution to the next phase of deterministic seismic hazard assessment (DSHA), whereby, they make a direct impact on predicted ground motion.

All GIS operations, including distance calculations and buffer creation, were carried out using QGIS 3.36 (QGIS Development Team, 2023).

**Table 1.** The distance of the study site to seismic sources (in kilometers).

Parameter	Hari Rud Fault	Kaj Rud Fault
Fault type	Strike- slip	Strike-slip
Location	1,76km from Herat university	31.89km from Herat university
Fault length(km)	120	5.61
Maximum magnitude(Mw)	7.4	6
Coordinate of closest point	X=6924361.62,Y=4079120.41	X=6993985.66,Y=4055731.44
Seismic activity	Active	Active



**Figure 4.** Effect of distance from the Hari Rud and Kaj Rod faults on peak ground acceleration (PGA) at Herat University, showing a clear decrease in PGA values as distance increases.

## 2.3 The Maximum Magnitude Estimation

The maximum credible earthquake of the key faults was calculated by combining seismic catalogue, historical records and empirical correlation of fault-magnitude. The USGS and ISC Earthquake records were compiled on events with moment magnitude (Mw) of at least 4.5 or larger within a 100km radius of Herat University. These data were complemented by published regional studies especially the scaling relationships of Wells and Coppersmith (1994) which correlate rupture length with potential magnitude. Based on these inputs: The Hari Rud Fault System, which has a rupture length of over 120km, has the ability to cause earthquakes of magnitude up to Mw 7.4. The Kaj Rod Fault System,

which is estimated to be about 5.6 km long in rupture, is associated with the largest possible magnitude of Mw 6.0 - 6.2. In the DSHA, the Mw 7.4 scenario at Hari Rud Fault was determined to be the controlling case, as it was nearest to the study location and had greater energy potential, compared to the Kaj Rod Fault.

### 2.4 Ground Motion Estimation Using GMPE

In order to evaluate ground motion at Herat University, it was important to determine ground motion prediction equations (GMPEs) that will fit the tectonic environment. Two NGA-West GMPEs were used in this study; Boore and Atkinson (2008) (BA08) and Abrahamson and Silva (2008) (AS08). The models have wide usage on active shallow crustal earthquakes and can provide a good forecast of maximum ground motion. The use of two complementary equations helps improve the trust of the outcomes and allows measuring the epistemic uncertainty. The seismicity of western Afghanistan (notably the 2023 Herat earthquake sequence) is dominated by shallow events (depths less than 20km) on active strike-slip faults like the Hari Rud and Kaj Rod systems. Therefore, GMPEs designed to be used in deep subduction or stable areas on continents (e.g., Cornell et al.) cannot be applied. BA08 and AS08 were selected due to the calibration of both in shallow active crustal settings that are considered analogous to the conditions in Iran and Turkey which are considered regional analogues of the setting of the Herat tectonic.

#### 1. Boore & Atkinson (2008) – BA08 (PGA form)

For PGA the BA08 log-mean form used here is:

$$\ln Y = FM(M) + (c1 + c2(M - Mref)) \ln(\sqrt{RJB^2 + h^2}) + c3(\sqrt{RJB^2 + h^2} - 1) + Fs(Vs30) \tag{1}$$

where Y is PGA (g), M is moment magnitude, RJB is Joyner-Boore distance (km), Mref = 4.5, FM(M) is the BA08 magnitude term (hinged at Mh), and FS(VS30) is the site term (zero for BA08 reference rock VS30 = 760m/s). Coefficients are taken from Boore & Atkinson (2008).

#### 2. Abrahamson & Silva (2008) – AS08 (compact form)

AS08 is the second GMPE used to quantify model uncertainty. Its compact PGA form is:

$$\ln Y = \ln Yref(M, Rrup, RJB, \dots, Ztor, \dots) + Fsite(VS30, PGAref) \tag{2}$$

where lnYref is the magnitude–distance reference motion (with rupture distance Rrup as a primary predictor) and Fsite (depends on VS30 and the reference PGA).

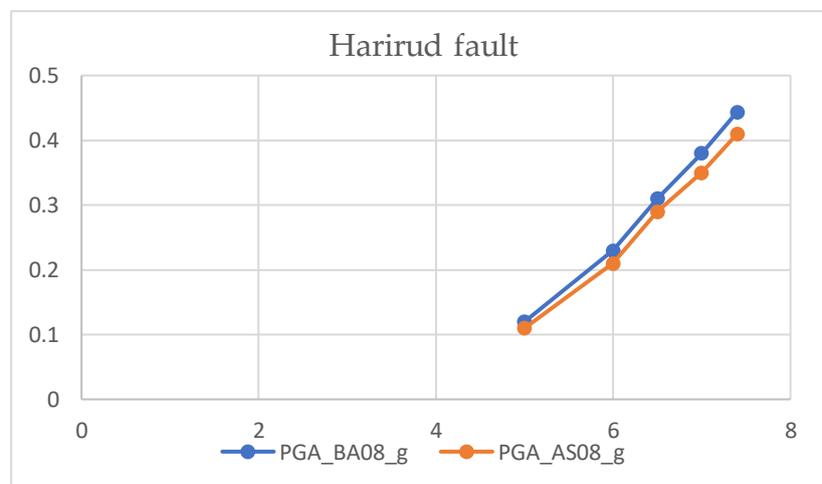


Figure 5. Comparison of PGA (g) predicted by Equation (1) (BA08) and Equation (2) (AS08) for varying earthquake magnitudes along the Harirud fault.

### 3. Discussion and Results

According to deterministic seismic hazard analyses, Herat University is exposed to high-level seismic hazards, which are mainly controlled by the proximate Hari Rud Fault System. The analysis indicates that a peak ground acceleration (PGA) of about 0.44 g in the worst credible event can shake the university, which is a level of shaking that is associated with intense ground shaking. On the contrary, the Kaj Rud Fault plays a secondary role in the site-specific hazard since it is further and its magnitude is lower. Although it has regional significance, its influence on the university campus is not so high. The results confirm that Hari Rud system is the major cause of seismic hazard at Herat University, which requires the application of design-level PGA of 0.44 g to structural engineering practices and risk mitigation measures. This parameter will significantly increase the resilience of university infrastructure when incorporated into the local seismic design codes.

### 4. Conclusions

The present research used a deterministic seismic hazard analysis to determine the risk of the earthquake in Herat University. The analysis has determined the Hari Rud Fault as the main seismic source, which could produce up to Mw 7.4 and produce maximum ground accelerations of about 0.44 g at the site of analysis. Despite the fact that the Kaj Rod Fault is also operative, it does not pose the significant risk, which could be explained by its being more distant to the site, as well as the fact that its magnitude potential is relatively low. The resultant site specific seismic input parameters can be directly used in the structural design, retrofitting, and risk management at Herat University. The use of these hazard estimates within the engineering practice will make the campus resilient and will make available the continuation of important educational activities following future earthquakes.

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