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Effect of site conditions on peak ground acceleration in alluvial sediments of Kabul city using DEEPSOIL

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Abstract

In this paper, the effect of site conditions is estimated on the peak ground motion acceleration in the alluvium of Kabul. Kabul is located on soft deposits near the Chaman-Mukur Fault system with a slip rate of 10 mm per year and Study the history of earthquakes shows that local geological conditions such as sedimentation history, soil texture and density, basin shape, etc. have a high influence on intensifying of ground motion and generally, seismic damage has been reported on soft alluvial sediments larger than rock outcrops. Seismic hazard analysis was performed by one-dimensional linear equivalent analysis by Deepsoil software. Finally, the results are presented in the form of zonation maps of peak ground acceleration at the ground surface in two conditions of elastic half-space bedrock and rigid half-space bedrock with a probability of exceedance of 10% in 50 years (equivalent to a return period of 475 years). The results show that the peak acceleration from west to east of Kabul city has a decreasing trend.

Keywords: Site effect, seismic zonation, peak ground acceleration (PGA), SPT, Kabul

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1. INTRODUCTION

Study the history of earthquakes shows that local geological conditions such as sedimentation history, soil texture and density, basin shape, etc. have a high influence on intensifying of ground motion and generally, seismic damage has been reported on soft alluvial sediments larger than rock outcrops [1]. Today, with the expansion of cities and the increase of building structures, the construction of high-rise residential complexes, the development of urban and industrial facilities, earthquake risks have increased significantly. Kabul is located on soft deposits near the Chaman-Mukur Fault system with a slip rate of 10 mm per year [2]. The left-lateral Paghman fault and northern Chaman fault on the western margin of the basin and the right-lateral Sarobi fault on the northeastern margin of the Kabul basin show geomorphic evidence for late Quaternary activity. Based on their lengths, these faults may be capable for producing earthquakes as large as Mw 7.8 [3]. Kabul metropolitan area is located in the northern part of the tectonically active Kabul block and has a high risk of damaging earthquake and related hazards. Kabul with a population of more than 4 million, is the capital city of the country. It is the most rapidly growing cities in the world due to the influx of refugees and people from the countryside. The rapid growth and development of the city show the need to study and use ways to prevent or reduce earthquake damage.

There are numerous studies in worldwide which evaluate effect of site condition on seismic characteristics of ground in urban area. Site-specific ground response analysis is a usual practice to predict the local site condition effects in an urban area. Grasso and Maugeri (2009) carried out the seismic response analysis on the Italian site conditions to develop a seismic microzoning map for Catania City [4]. Kumar and Boominathan (2010) carried out site specific analysis for a deep stiff soil site located near Ahmedabad, India [5]. In their study, 1D ground response analysis carried out using SHAKE 2000 and DEEPSOIL reveals an amplification of the ground with a surface PGA of 0.52g and 0.43g respectively. Naik and Choudhury (2013) conducted the 1-D EQL site response analysis for Goa City in India using the data of the Bhuj earthquake 2001 [6]. Shylamoni et al. (2014) performed the site-specific one-dimensional (1-D) equivalent linear (EQL) site response analysis for the nuclear power plants in Japan [7]. Mahmood et al. (2016) implemented the 1-D EQL site response analysis for sites in Islamabad, Pakistan [8]. Recently, Aaqib et al. (2018) performed 1-D nonlinear site response analyses for the Korean sites to investigate the effect of strength correction on the seismic site coefficients [9]. Nguyen et al. (2020) performed a series of one-dimensional (1-D) site response analyses using the nonlinear (NL) and equivalent linear (EQL) approaches to assess the applicability of the Vietnamese earthquake-resistance design code TCVN 9386: 2012 [10]. This study showed that the peak ground accelerations at the surface from EQL analyses are greater than those of the NL method because the latter generates a higher amount of nonlinearity.

The objective of this study is the evaluation of peck ground acceleration of alluvium deposits around Kabul city concerning the site condition and one-dimensional analysis

using Deepsoil software for seismic micro-zonation of the study area.

2. GEOLOGY OF STUDY AREA

The Kabul sedimentary basin is located in the central-northern part of Kabul Massif, Kabul block surrounded by Altimur fault and Chaman mukur fault system that the Kabul block is separated from the heights of Paghman Mountains in the west and the Safi Mountains in the east. The Kabul Basin is formed by the tectonic faulting of crystalline rocks and then weathering and erosion. The fault processes have been elevated the surrounding mountains and hills of the sub-basins, and the sequences of erosion of these heights and sedimentation in the grabens have led to the creation of the current appearance of this region. The formation of graben structures began in the late Miocene at the same time as the formation of the Kabul River valley. Therefore, the sedimentary basin of Kabul can be considered as a valley filled with mountains, the valleys are filled with Tertiary and Quaternary sediments and debris and the mountain range is composed of sedimentary and crystalline rocks. In a general view, this area has appeared as a typical area of mountain slopes or foothills and the mountain range has turned it into semi-closed slopes in different directions. The morphological and geological features of this region are similar to those of Arizona and Nevada in the United States [11]. Tertiary and Quaternary sediments of Kabul Basin are divided into two categories of older and younger deposits. The younger deposits of the loess, gravelly, sandy, and pebble series are present age, and the older sediments include the Lataband series, the Kabul series, and the Botkhak series [12]. Figure (1) shows the sequence of these sediments.

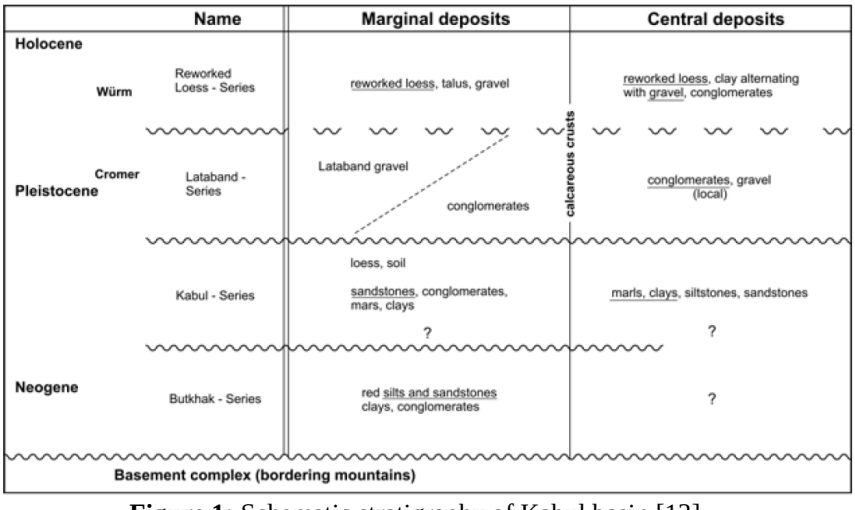


Figure 1: Schematic stratigraphy of Kabul basin [13]

3. Methodology

Modeling the effect of materials on the surface seismic waves caused by seismic waves of bedrock is called site effect analysis. Thus, the earth's response is determining the response spectrum of the soil mass to the motion of the bedrock beneath it. Waves are intensified or attenuated by passing through soil layers depending on damping, geometrical characteristics, and geotechnical properties. Dynamic response of geological materials or analysis of response spectrum can be done by one, two, and three-dimensional modeling. These methods differ in their ability to modeling the waves geometry and their theory for modeling the ground response, as well as is different in the analytical methods that they use to solve motion equations.

In this study, the equivalent one-dimensional linear method is used to analyze the ground response. In the one-dimensional method, it is assumed that the ground surface and the boundaries of the layers are horizontal and the amplification of seismic waves passing through alluvial sediments is due to the propagation of S waves that propagate vertically from the bedrock.

In this method, which is based on the viscoelastic behavior of the soil, along with changes in soil properties, linear analysis is repeated step by step until the problem is solved in the state of strain compatibility. The software used (DeepSoil) is based on the direct and continuous solution of the wave propagation equation, which calculates the responses of a system consisting of homogeneous and viscoelastic layers against shear waves. The linear model is equivalent to only an approximation of the actual nonlinear soil behavior that is used in the frequency domain. For a description of the soil behavior in equivalent linear analysis, the shear modulus and the damping coefficient are used as equivalent linear parameters of materials. The parameters of shear modulus and damping coefficient for each soil layer are constant during the earthquake and are determined according to the strain generated in each layer. In this paper, the following parameters have been used for equivalent linear analysis by the software: the maximum bedrock acceleration, depth of bedrock, 12 seismographs from 6 earthquakes in Iran, shear wave velocity, thickness and unit weight of soil, the ratio of shear modulus and damping changes to shear strain based on the proposed relationships of Seed and Idriss (1991), and Vucetic and Dobry (1991), for coarse and fine grains, respectively [14] [15].

4. Data and material

The geotechnical data used in this study include 44 geotechnical reports of civil engineering and construction projects in Kabul. A total of 237 boreholes with a minimum depth of 3 and a maximum depth of 32 meters. The total length of the boring is 2367 meters. Also drilled 18 boreholes with deeper depth and with the target of exploring groundwater resources have been used by Böckh (1971) [16]. From these boreholes, 11 boreholes are located in the study area, and their data have been used to determine the geological condition of the area.

In each project, from the drilled boreholes, the borehole that has more depth and contains maximum information is selected. Figure (2) shows the study area and the location of

completed projects. As can be seen, the drilled boreholes are not well distributed in the area and are more concentrated in the central and northern areas.
In these drilled boreholes, there are no measured values of shear wave velocity and therefore this parameter is obtained by empirical equations of Hafezi and Ghezi (2006), from N-SPT value data [17]:

$V_s=105.01N^{0.4485}$ Fine grain Soils (1)

$V_s=83.62N^{0.4964}$ Coarse grain soils (2)

4.1. Input seismic data

From the year 1933 onwards, the seismograph was installed in the United States to record the strong movement of the earth, and to the year 1986, more than 4000 records were collected from various earthquakes. Currently the networks of seismic data record station have been established in most seismic countries, but due to lack of attention and political instability in recent decades, an accelerometer has not been installed in Afghanistan yet. In this study, seismographs of earthquakes inside Iran have been used. Because they are both geographically close and both regions are located in the Alpine-Himalayan seismic belt. Also, in terms of earthquake focal mechanism, in the both regions have a similar mechanism and most of the seismic faults in Iran and Afghanistan are reverse fault, strike-slip fault or reverse fault with strike-slip component.
In this study, seismographs of 6 Iranian earthquakes including Bam (2003), Baladeh (2004), Changureh (2002), Naghan (1977), Tabas (1978), and Vendic (1976) earthquakes, and each earthquake with two horizontal acceleration component was used. In this way, a total of 12 seismographs were used. Table (1) shows the characteristics of the earthquakes used for this study.

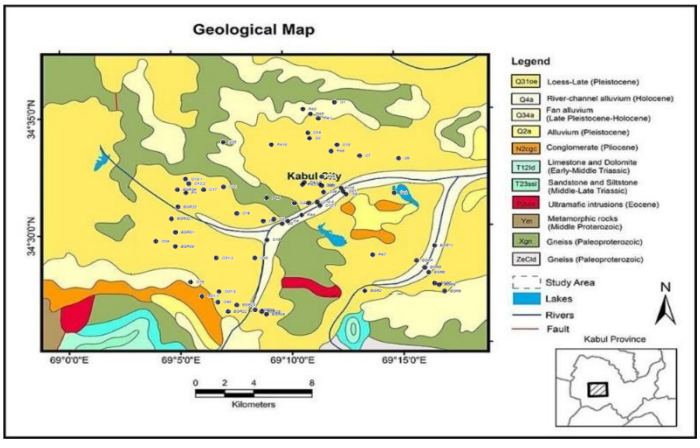


Figure 2: Geological map of the study area and location of boreholes

Table 1: Specifications of seismographs used in this research (International Institute of Earthquake Engineering and Seismology, Iran)

EQ-CODE	Earthquake Name	Mechanism	Magnitude	Distanse	PGA (g)
3	Vendic, Iran 1976/11/07	SS	6.4	10	0.17
4	Vendic, Iran 1976/11/07	SS	6.4	10	0.18
5	Naghan, Iran 1977/04/06	R	6.1	7	0.87
6	Naghan, Iran 1977/04/06	R	6.1	7	0.57
7	Tabas, Iran 1978/09/16	R	7.4	45	0.11
8	Tabas, Iran 1978/09/16	R	7.4	45	0.09
29	Changureh, Iran 2002/02/26	R	6.0	28	0.43
30	Changureh, Iran 2002/02/26	R	6.0	28	0.44
31	Bam, Iran 2003/12/26	SS	6.5	56	0.16
32	Bam, Iran 2003/12/26	SS	6.5	56	0.1
33	Baladeh, Iran 2004/05/28	R	6.3	20	0.29
34	Baladeh, Iran 2004/05/28	R	6.3	20	0.16

SS: strike-slip, R: reverse

4.2. Maximum acceleration of bedrock

Seismic bedrock was determined using the shear wave velocity value, that's mean, where the shear wave velocity reached 700 m/s for coarse-grained soils and 600 m/s for fine-grained soils, seismic bedrock was considered.

The maximum bedrock acceleration for the study area was extracted from the zoning maps of Afghanistan prepared by the US Geological Survey (USGS) in 2007. Figure (3) shows a map of the maximum ground motion acceleration distribution for the return period of 475 years (10% probability of exceedance in 50 years). As can be seen, in eastern Afghanistan and especially in the northeast, there is a higher number of faults and seismic potential than in other parts of Afghanistan. Among the important cities in Afghanistan, Kabul has the highest earthquake risk (Table 2), the main reason being its proximity to the Chaman fault and the high potential for fault movement [2].

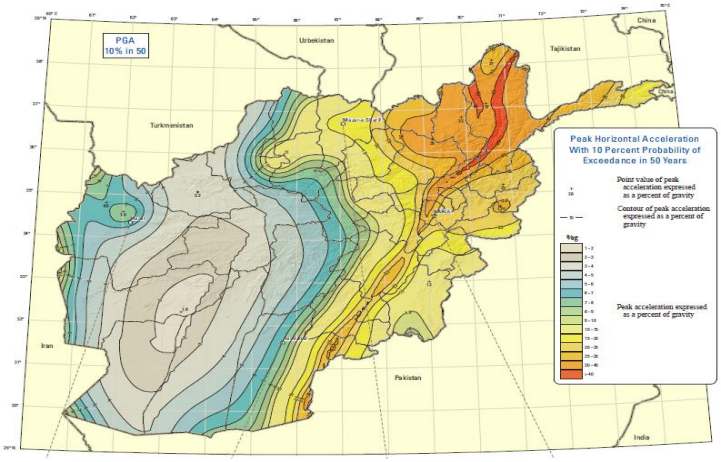


Figure 3: Peak Horizontal Acceleration Estimation Map (PGA), with 10 percent probability of Exceedance in 50 years (475 years return period), [18]

Table 2: Possible ground motion for selected cities [18]

			2%			10%		
			Probability of exceedance in 50 years					
City	Lat.	Long.	PGA (%g)	0.2 sec	1.0 sec	PGA	0.2 sec	1.0 sec
Kabul	34.53	69.17	48	113	53	25	57	22
Mazar-e Sharif	36.70	67.10	33	78	22	16	37	11
Herat	34.35	62.18	28	62	24	7	15	4
Kandahar	31.61	65.69	13	30	16	7	16	8

Figure (4) shows the maximum acceleration peak of the bedrock in the study area. As can be seen, the western regions have a higher acceleration than the eastern regions due to their proximity to the Chaman fault. Therefore, according to the proposed map, for zonation maps with a probability of exceedance of 10% in 50 years from west to east, the maximum input acceleration of seismic bedrock is 30% and 25% g, respectively. In this study, first, the input observed acceleration data were scaled by Deepsoil software according to the maximum bedrock accelerations, and then the scaled data is analyzed for each cell.

5. Result and Discussion

As previously presented, the nonlinear one-dimensional seismic analysis was performed by Deepsoil software. The city of Kabul is networked with 2*2 km cells and analyzed for each cell (51 cells) in two modes of Elastic Half-space and Rigid Half-space, as well as for 10% probability of exceedance in 50 years (475 years return period), 12 input accelerations were performed using a total of 1224 analyzes. For example, Figure (5) shows the curve of response spectra of 12 input acceleration for cell No. I-8, where the average of which is indicated by a thicker line curve.

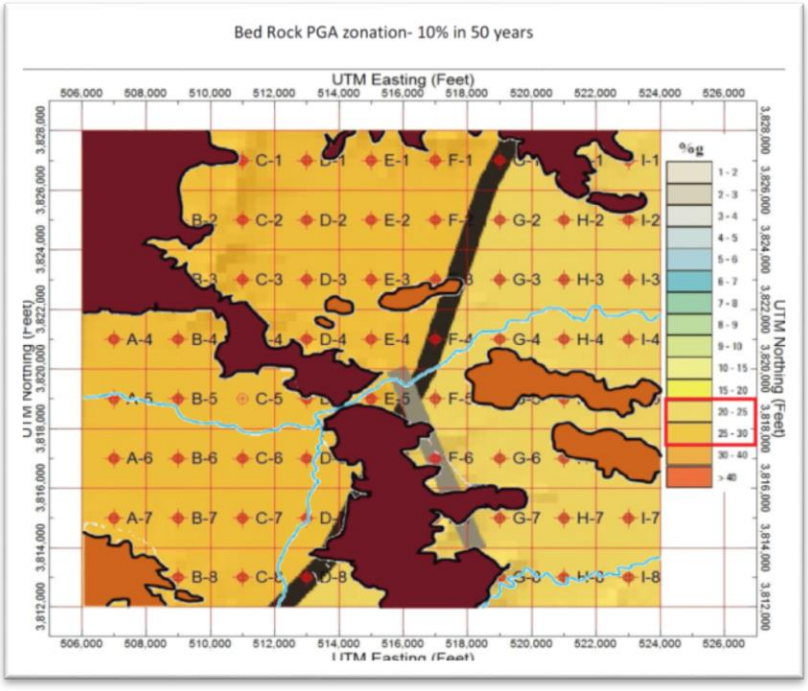


Figure 4: Peak Horizontal Acceleration Estimation Map (PGA), with 10 percent probability of Exceedance in 50 years (475 years return period)

The most common parameters in strong ground motion are the peak horizontal ground motion acceleration amplitude PHGA and the peak vertical acceleration amplitude PVGA. Horizontal accelerations are usually used to describe the strong motion of the earth due to their natural relationship with inertial forces and In fact, seismic dynamic effects in structures are closely related to the peak ground motion acceleration (PGA).
Figure (5) shows the peak ground motion acceleration for an elastic half-space bedrock with a 10% probability of exceedance in 50 years. As can be seen, the maximum value of peak ground motion acceleration is 56% g and the lowest value is 15% g, and most cells show the peak ground motion acceleration values between 30- 40 % g. In the western parts, the zonation map shows the peak ground motion acceleration in greater values.

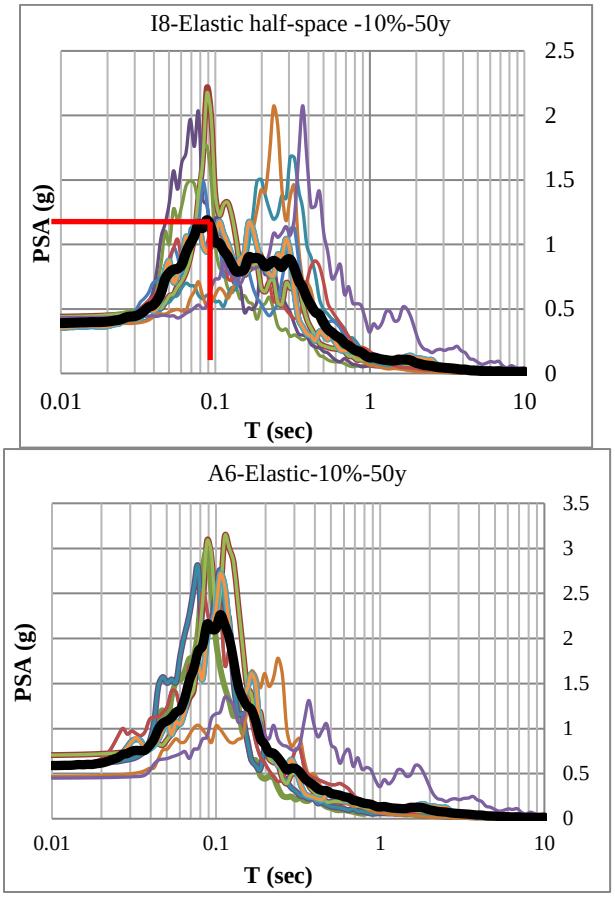


Figure 4: Graph of average peak acceleration of the response spectrum (thicker line curve) and its equivalent period for cell A-6 and I-8 for elastic half- space bedrock, with 2 percent probability of Exceedance in 50 years (475 years return period).

Figure (6) shows the peak ground motion acceleration for a rigid half-space bedrock with a 10% probability of exceedance in 50 years. The values of peak ground motion acceleration are varied between 39 and 131% g and are strongly influenced by the depth of the seismic bedrock and the size of sediment particles. In places where the seismic bedrock is shallower and the upper sediments are coarse, the peak ground motion acceleration shows greater values. Mostly the maximum of peak ground motion acceleration values is in the central and western areas. In the eastern parts, the peak ground motion acceleration values are varied between 50 and 70%.

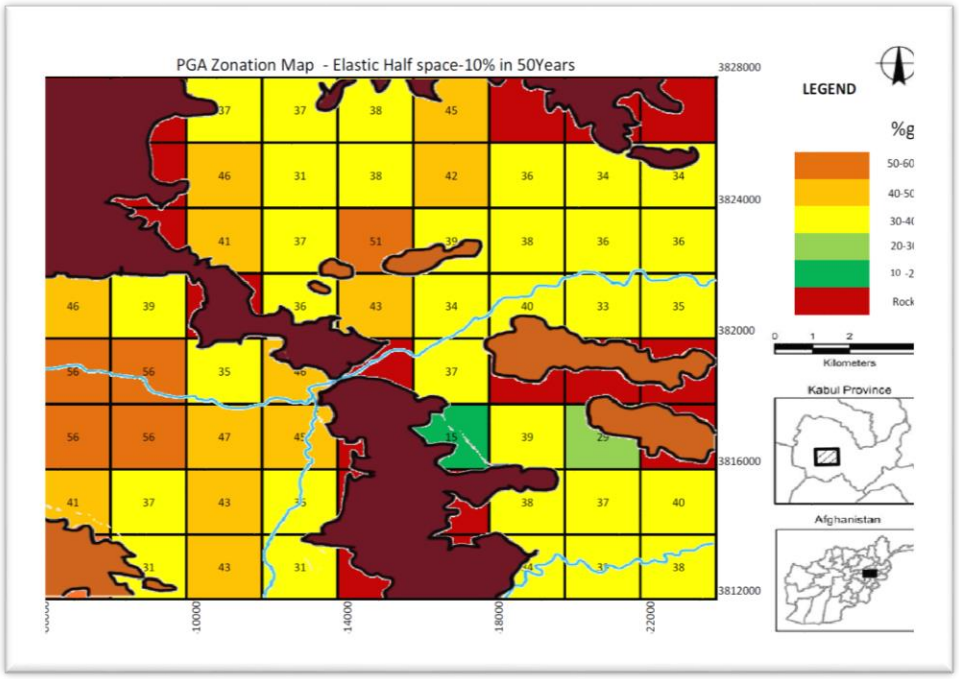


Figure 5: peak ground motion acceleration for elastic half- space bedrock with a probability of exceedance 10% in 50 years

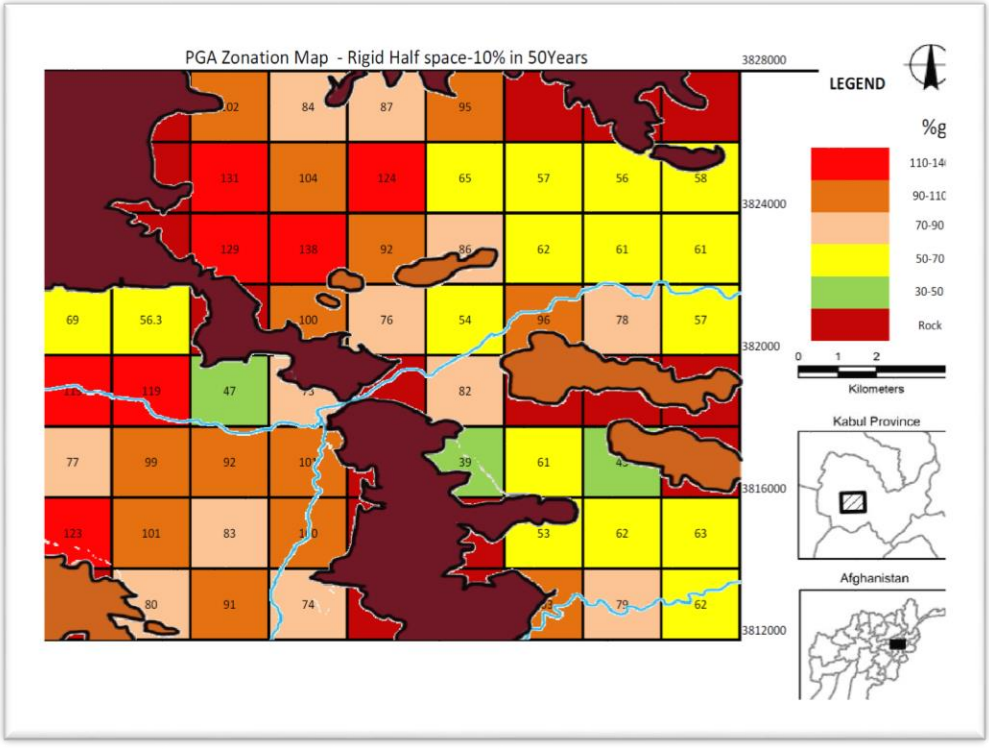


Figure 6: peak ground motion acceleration for rigid half- space bedrock with a 10% probability of exceedance in 50 years

6. CONCLUSION

The zonation maps of peak ground motion acceleration (PGA) show that the values of acceleration in the rigid half-space bed are observed much higher (up to twice) than in the elastic half-space bed because in the rigid half-space bedrock conditions all the energy of the return waves from the surface is reflected the surface again and again.

In the western areas, higher peak acceleration is seen than in the eastern areas, which can be due to the proximity to the fault, the decrease in the depth of the seismic bedrock, and the size of surface particles.

The thickness of fine-grained sediments has a relative increase from west to east and the peak ground motion acceleration is decreased from west to east. This subject indicates the failure of fine-grained soil structure at high stresses and nonlinear soil behavior.

The analysis results by Deep Soil software show that there is no linear relationship between elastic half- space bedrock and rigid half- apace bedrock, or in other words, it cannot be said that the rigid half- space state values are always twice the elastic half-space state, or the multiplication of a constant number. Other factors such as density, porosity, granularity and cohesion are effective in changing the earthquake frequency range.

In cells F6 and H6, sediments have weakened the range of seismic waves, which is probably due to its fine grain and the presence of lake sediments with high porosity in Heshmat Khan Area.

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