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Micro-zoning of the natural radioactivity levels and seismic velocities of potential residential areas in volcanic fields: The case of Isparta (Turkey)

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ABSTRACT

This study involved the analysis of the locations with the lowest earthquake risk in the Isparta province of Turkey and the radiological properties of these locations. The most convenient residential areas in the region in terms of radiology and earthquake risk were identified. The radiological characteristics of soil are an important factor in the evaluation of residential areas. Gamma ray spectrometry and multi-source seismic refraction methods were used to conduct radioactive and seismic measurements. The measured ^{238}U, ^{232}Th and ^{40}K activity concentrations were used to calculate the absorbed gamma dose rate, the annual effective dose rate, the radium equivalent and the external hazard index of the environment to estimate the radiological risk of natural radioactivity. The compressional and shear wave velocities were calculated based on the results of multi-source seismic refraction. The calculated parameters were used to generate micro-zone maps. The shear wave velocity was used to analyze the stiffness of looseness of the soil. The radiological risks of the area were determined. Both the seismic and radiological hazards were considered in determining the appropriate areas for residential development. In the results of this study, the best location for residential development was demonstrated to be on limestone, and the worst location was determined to be on alluvium.

1. Introduction

Micro-zoning is defined as the separation of smaller areas within a larger study region (Uyanık et al. 2006). Micro-zoning is used to map environmental risk factors on a micro-zone scale. Micro-zoning can be used to determine the radioactive properties of surface soils within a city or local area, to predict environmental radiological hazard and to determine appropriate residential areas. In this study, micro-zone maps of both the soil strength (generated using the seismic refraction method) and the natural radioactivity level in the soil (measured using a gamma-ray spectrometer) were used to identify suitable areas to construct residential units.

The seismic refraction method has been used to perform in-situ geophysical investigations in previous studies. Seismic waves passing through a medium are affected by the lithological, physical and elasticity characteristics of the soil. Seismic velocities have been previously used to address certain characteristics (e.g., Othman, 2005; Uyanık, 2010; O. Uyanık, 2011). A lower soil density indicates less soil compaction (Uyanık and Ulugergerli, 2008). Seismic velocity is used to interpret the behavior of soil during earthquakes in geotechnical studies. P-wave velocity (V_p) is primarily utilized to identify the structural properties of soil (e.g., faulting, inclination, porosity). S-wave velocity (V_S) is primarily used to determine the mechanical properties of soil (e.g., strength, consolidation, load-bearing capacity, permeability and stiffness). Geophysical engineers produce information regarding the static and dynamic properties of the soil. This information is used by civil engineers to determine suitable areas for settlement (Uyanık et al. 2006; Uyanık and Ulugergerli, 2008; Uyanık, 2010; O. Uyanık, 2011).

People are constantly exposed to natural radiation, which is primarily caused by the cosmic radiation from space and terrestrial radioelements, such as K, U and Th. In addition to natural radiation, there are also anthropogenic sources of radiation that result from the use of technological devices. The combination of natural and anthropogenic radiation in a location is known as background radiation. The level of background radiation is related to the geographical and geological conditions of a location, such as the amount of naturally occurring radioactive elements in the local soil or rock. Background radiation is naturally occurring and is inevitably present in our environment. For example, people living in areas that are composed of granite or mineralized sands receive more terrestrial radiation than others. Furthermore, people living or working at high altitudes receive more cosmic radiation. Therefore, it is important to determine the levels of natural radiation by geophysical studies. The average range of surface gamma radiation is 24 to 160 nGy/h according to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2000). Under normal circumstances, the maximum admissible dose rate from terrestrial gamma rays is 55 nGy/h (UNSCEAR, 2000).

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Due to their important effects on human health, natural radioactivity levels in settlement areas should be determined by conducting in-situ measurements. A radioactive micro-zone map of a settlement area will enable an evaluation of the area's risks. The natural radioactivity levels present in soil and rock are due to the presence of radioelements, including uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). Radiometry is one of the most powerful and rapid methods to obtain information about the distribution and concentration of radionuclides (eU, eTh and K (%)) at any location (Uyanık et al., 2011). Moreover, previous studies using this method indicate that it is also possible to perform radiological hazard, geological, geotechnical and geochemical mapping of a study area (e.g., Akkurt et al., 2009, 2010; Aydin et al., 2006; Durrance, 1986; Faheem et al., 2008; Ruffell et al., 2006; Uyanık and Akkurt, 2010; Uyanık et al., 2009; 2011; 2012). Bochiolo et al. (2012) performed a radiometric survey to evaluate the natural radioactivity and analyze the potential hazard level, both outdoor and indoor, in a mine tunnel. Ayres and Theilen (2001) investigated the use of natural gamma activity as a measure of geotechnical properties of near-surface marine sediments, such as density, porosity, water content and shear strength. Gautam et al. (2000) measured the electrical resistivity and the natural gamma ray intensity over karst features in the Pokhara Valley of central Nepal. Chiozzi et al. (1998) determined the distribution of radioactive elements using in situ gamma-ray spectrometric measurements from key locations throughout the island of Lipari.

Several studies have been performed in the present study area, which primarily analyzed the geology (Gutnic et al., 1979; Koçyiğit and Deveci, 2007; Plateovet et al., 2008; Yağmurlu et al., 1997) and seismic microzonation of the region (Uyanık and Yeşil, 2012). However, there is no report in the literature on a microzonation study to obtain regional radiometric data in the present study area. Turkey has experienced frequent neotectonic volcanism, often in the form of alkaline volcanism, which can cause high levels of natural radioactivity. There are a wide range of volcanic structures and materials in the Isparta region. These volcanic structures generally include dikes, domes, irregular volcanic extrusions and pyroclastics that are composed of trachyte, trachyandesite and basaltic trachyandesite. In addition, limestone and flysch are also observed in this region (Bozcu et al., 2003; Yağmurlu et al., 1997).

This study used multi-source seismic refraction and gamma-ray spectrometry methods. The average seismic velocities for the trachyandesite, limestone, flysch and alluvium (agricultural soils that are rich in volcanic products) were identified for a depth of 30 m. In addition, "in situ" natural gamma radiation (% K, ppm Th and ppm U) was measured for trachyandesite, alluvium, flysch and limestone. The results of seismic and radioactivity studies were presented as the respective microzoning maps.

2. Study area and geology

Isparta province is located at 37°45′53″N 30°33′24″E (Figs. 1 and 2). Çünür Hill is located in the center of the study area, at an elevation of approximately 1090 m. The location of Isparta province and the

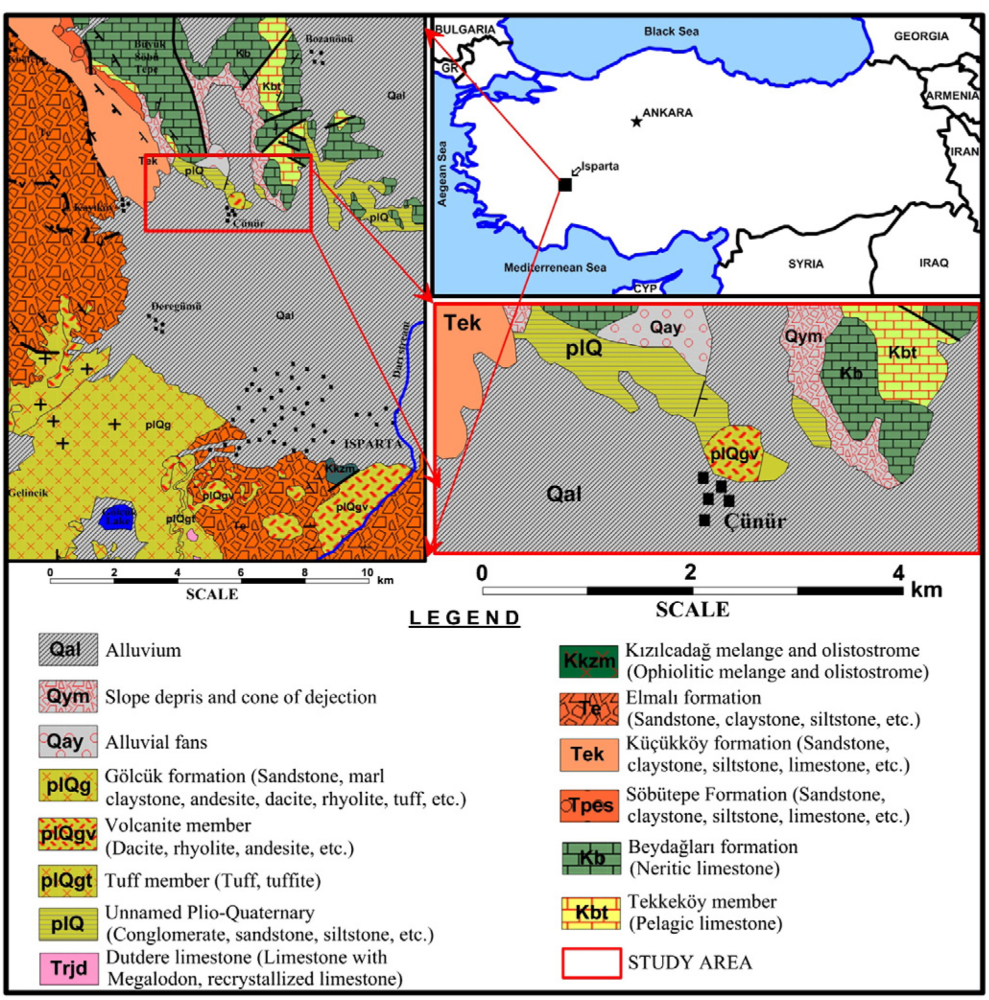

Fig. 1. Geological map of Isparta (adopted from MTA 1997) and the study area (modified from Uyanık et al., 2011).