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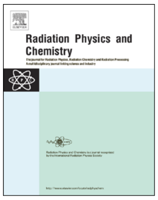

Radiological and chemical monitoring of Dikili geothermal waters, Western Turkey

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HIGHLIGHTS

- This paper analyses radiological and chemical contents of thermal waters located in Dikili geothermal area of Turkey.
- The quality of waters is evaluated according to national and international recommendations.
- The chemical–physical parameters do not exceed the maximum limit of contamination for analysed waters

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ABSTRACT

Naturally occurring Radionuclides such as ^{226}Ra and ^{222}Rn as well as the major dissolved ions were investigated in the four thermal springs from Dikili Geothermal Area, Western Turkey. It was observed that ^{222}Rn concentrations vary from 0.3 to 31 Bql^{-1} with an average value of 8.2 Bql^{-1}, while the ^{226}Ra activities range from 0.10 to 1.2 Bql^{-1} with a mean value of 0.495 Bql^{-1}. A direct correlation was determined between radon and radium activities which indicates their parent–child relationship. The annual effective doses ranged from 0.58 to 3.06 μSvy^{-1} with an average 1.75 for radon and vary from 4.88 to 8.58 μSvy^{-1} with an average value of 6.53 μSvy^{-1} for radium and all are well below 100 μSvy^{-1} recommended by WHO. The chemical analyses of water samples show that Na^{+} and Cl^{-} ions mainly dominate the chemistry of waters. Due to their chemical characteristics, the springs were placed in the Water Quality Class 1 or 2 according to Turkish Environmental Regulations for Water Pollution Control. On the other hand, no significant correlations was found between the physic–chemical parameters and investigated radionuclides.

1. Introduction

Radioactivity in hot spring systems has been recognised and documented for many decades (Duenas et al., 1998; Horvath et al., 2000; Vogiannis et al., 2004; Bertolo and Bigliotto, 2004; Song et al., 2005; Erees et al., 2006; Bolca et al., 2007; Beitollahi et al., 2007; Baba et al., 2008; Roba et al., 2010; 2012; Chaudhuri et al., 2010; Onishchenko et al., 2010; Gurler et al., 2010; Lin et al., 2011; Saç et al., 2011; Eross et al., 2012; Condomines et al., 2012; Tanaskovic et al., 2012). The most observable radionuclides in hot waters are ^{226}Ra and ^{222}Rn. ^{226}Ra is an α emitter with a long half-life of 1622 years and produced by the alpha decay of ^{230}Th in the uranium (^{238}U) decay series (Roba et al., 2012). Radon (^{222}Rn) is also an alpha emitting radioactive noble gas produced naturally in the environment by the decay of Radium (^{226}Ra) (Chauhan and Chakarvarti, 2002). It is colourless, odourless, and tasteless and its behaviour is not affected by chemical processes (Misdaq et al., 2010).

In order to understand the source of the radiation in thermal waters, we briefly remind the occurrence of them. The water falling to the earth with various meteorological events moves towards the lower layers. When they reach an impermeable rock on their pathways terminate and accumulate to form a reservoir. These rocks warmed by magma cause to heat of water and to reach again the surface with pressure using the faults (Kalinci, 2006). During its long passage within the earth's crust, thermal waters come in contact with large surfaces of radioactive eruptive rocks such as granites, quartz porphyry, basalt which contain radium (Chaudhuri et al., 2010). Therefore, the activity concentrations of ^{226}Ra and ^{222}Rn depend first on the geological structure of the aquifer and distribution of the parent element in the rock matrix (Roba et al., 2012; Chaudhuri et al., 2010). Secondly the solubility

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of the parent element and also the solubility of the radionuclide itself play important role on the concentrations of these radionuclides in hot waters (Szabo et al., 2012). However, the solubility of radionuclides is effected fluid characteristics (chemical and physical composition) of the aquifer (Roba et al., 2012). For example, the solubility of ^{222}Rn varies under the different physical conditions and decreases with increasing temperature (Toutain and Baubron, 1999). Contrary to radon the mobility and the absorption of radium vary depending on the chemical parameters including pH (Vinson et al., 2009). Besides high correlations were observed between ^{226}Ra concentrations and Chloride ions (Labidi et al., 2010; Eross et al., 2012). Thirdly, the release rate of the radionuclides by recoil relative to the rate of geochemical reactions controlling or limiting mobility effects the distribution of radionuclides in waters. The physical process known as alpha-recoil, during which the newly created progeny radionuclide recoils in the opposite direction of the ejected alpha particle may liberate Ra rapidly relative to leaching by the weathering process. The isotopes of Ra can be continuously released to ground water by alpha-recoil mechanisms from mineral surfaces (Szabo et al., 2012).

It is well known that some geothermal waters can have high concentrations of ^{226}Ra and ^{222}Rn which may cause health damage (Rodenas et al., 2008; Vogiannis, et al., 2004). Radon and its non-gaseous short-lived daughters namely, ^{218}Po and ^{214}Po, cause a half of the radiation dose of origin in humans (Durrani and Ilic, 1997; Somlai et al., 2007). Exposure of person to high concentration of radon and its short-lived progeny for a long period leads to health problems, particularly lung cancer, resulting from inhalation of radon (Ramola et al., 2008; Sen et al., 2013; UNSCEAR, 2000). However, a very high level of radon in ingested drinking water can also leads to a significant risk of stomach cancer (Binesh et al., 2010). ^{226}Ra follows the calcium metabolism in human body and deposited in bones. This may lead to enrichment of ^{222}Rn and its daughters, causing potential health implications and high degree of radio toxicity due to long exposure hazards (Lasheen et al., 2007). Also, ^{226}Ra causes bone, cranial and nasal tumours (Ramasamy et al., 2011).

On the other hand, due to their excellent resolving properties, geothermal waters contain soluble salts in addition to radioactive elements depending on the chemical contents of the rocks where the aquifers originate (Bolca et al., 2007). So, they cause the groundwater and environmental pollution and also the health problems for the people who use them to believe health benefits. Therefore, radiological and chemical monitoring of thermal waters is necessary for both radiation protection and water quality purposes.

In the present study, radiological and chemical contents of thermal waters located in Dikili Geothermal Area (Turkey) were investigated. The quality of waters was evaluated in terms of radiological and chemical according to national and international recommendations. Also, the relationship between the radioactivity and chemical contents of water was examined.

2. Material and methods

2.1. Geological settings of the research area

Western Turkey lies at east of the Aegean Sea, which is actively extending in roughly the north–south direction, and south of the North Anatolian Fault Zone, a major east–west trending dextral strike-slip fault zone. The latter resulted from the relative movement between the Eurasian plate to the north and the central Turkey microplate to the south. Western Turkey forms one of the most rapidly deforming continental regions of the world. It displays several related concentrated seismic and volcanic activity, high heat flow, intense faulting and folding (Erees et al., 2006; Papazachous, 1990). The collision of the Arabian and Anatolian blocks during the middle Miocene forced Anatolian microplate to the west and resulted in an east–west compression in Western Turkey, which began to be relieved by north–south extension. The most prominent structural and morphological features of the Western Turkey extensional province are east–west trending normal faults system. These faults dip steeply to form the boundaries of the Büyük Menderes, the Küçük Menderes, the Gediz and Bergama Graben Systems (Erees et al., 2006).

Dikili geothermal area lie on Bergama Graben System located in Northwest of İzmir. It is one of the important geothermal fields in Western Turkey. The thermal springs and wells in the region use for spa facilities. Additionally, the district heating project of some residences of Dikili is planned. Electricity generation, greenhouse heating, thermal tourism can be the other potential uses of these thermal sources. The Dikili Geothermal Area is characterised by NE–SW extensional horst-graben systems (Özen et al., 2005). There are three kinds of faults NW–SE, NE–SW, WNW–ESE and also many thermal springs whose distribution is controlled by these fracture patterns (Akyürek and Soysal, 1983). Zeytindali, Nebiler, Camur and Bademli which constitute the Dikili geothermal area were selected as study sites (Fig. 1).

The area has complex magmatic and volcanic geological structures (Ercan et al., 1984; Seyitoğlu and Scott, 1992; Jeckelmann, 1996; Yılmaz et al., 2000). A large part of the investigation area is covered with volcanic material, known as Yuntdağ volcanic and some residual rock formations cover a small part of the area in the east (Akyürek and Soysal, 1983). The Yuntdağ volcanics were divided into three groups: Yuntdağ volcanic-I (Tyu1), Yuntdağ volcanic-II (Tyu2) and Yuntdağ volcanic-III (Tyu3). The oldest Yuntdağ volcanic-I consists of widely altered andesite. Tertiary Demirtaş pyroclastics mainly made up of felsic pyroclastics cover the Yuntdağ volcanic-I. Overlying Yuntdağ volcanic-II is restricted to the western of the study area. The rock consists of dark compact basalt and pyroxene andesite lava. In the rocks, a few small hydrothermal veins are found. This unit is covered with the youngest Yuntdağ volcanic-III. The rock that consists of biotite, hornblende and andesite is dome shaped volcano type (Özen et al., 2005).

2.2. Measurements of radon and radium in geothermal waters

The radon and radium measurements in geothermal waters were performed by the collector chamber method (Fig. 2) (Kumru, 1992; Kumru and Öznur, 1994; Erees et al., 2006; Bolca et al., 2007; Saç et al., 2012). The method is based on the measurement of the alpha particles emitted by the radon daughters (Kumru, 1992). A copper plate with a diameter of 4.5 cm, a collector chamber having a volume of 2.47 L and an applied voltage of 600 V are optimal conditions for the collector chamber method (Kumru and Öznur, 1994).

The water samples were taken from the geothermal sources into 100 ml bubbler bottles and the valves of the bottles were tightly closed to prevent radon gas leakage. The bottles were designed to ensure to remove the radon gas from the media with the help of a carrier gas. In this system, ripe air was used as the carrier gas. In the laboratory, the outlet of a gas regulator (containing ripe air) was connected to the inlet of the radon bubbler bottle and the outlet of the bottle was connected to the inlet of the collector chamber. Collector chamber is a steel container which has a collector plate in the middle. When the bottle valves were in closed position, the collector chamber valve was opened and the system vacuumed at the pressure of −0.6 mb. The outlet valve of the bubbler bottle connected to the collector