Dose rate assessment at the submarine spring of Anavalos using ERICA Tool, Greece

F.K. Pappa, G. Eleftheriou, N. Maragos, C. Tsabaris

Institute of Oceanography, Hellenic Centre for Marine Research, Anavyssos, 19013, Greece
Keywords: submarine groundwater discharges, gamma-spectrometry, in-situ monitoring, radon daughters
Presenting author, e-mail: Filothei Pappa (fkpappa@hcmr.gr)

According to Burnett et al., (2003) and Moore (2010) as submarine groundwater discharge (SGD) can be defined the terrestrial groundwater discharging to the coastal area. Thus, groundwater serves as a pathway of nutrients from land to coastal regions, playing a significant role in coastal ecosystems and governing the coastal benthic environment. Although studies regarding the SGD influence in bacteria and biota were held by Vollberg et al. (2019) and Sugimoto et al. (2017), respectively, very little are known of the SGD radiological input. It is well known that good indicators of SGD areas are the natural radionuclides of ^{222}Rn and ^{220}Rn for the freshwater inflow and ^{40}K for the marine input (Tsabaris et al., 2012).
The main objective of this work was the radiological risk assessment in biota at an SGD site of Anavalos. Additionally, the hypothesis of utilizing the freshwater of this SGD spring taking into account the radiological assessment for aquaculture reasons was tested.

Study Area
Anavalos submarine underwater discharge (SGD) spring is one of the major springs of Nafplion city located at the coastal area of Argos, NE Peloponnese Peninsula in Greece. The spring is used for irrigation purposes and as an alternative water resource for Nafplio city. The groundwater originates from karst formations of the area and it is characterized by high levels of conductivity (low threshold) that indicates saline conditions. This saline environment can be attributed to either overexploitation of the water or leakage of the dam (Figure 1).

Figure 1. The dam surrounding the SGD spring of Anavalos. The main three "eyes" of the freshwater discharges are mentioned with blue. The aquatic plants grown in the dam are shown with green.

Methodology
In this work the activity concentrations in water (in Bq m^{-3}) and sediment (in Bq Kg^{-1}) of ^{40}K, ^{226}Ra, radon (^{214}Pb, ^{214}Bi), ^{228}Ra and thoron (^{208}Tl) progenies were utilized for the estimation of the dose rates receiving by marine biota.

Water
The activity concentrations in the water of ^{40}K, radon and thoron progenies were measured directly via in situ detectors of low (KATERINA) and medium (GeoMAREA) resolution. The average activity concentrations of the aforementioned radionuclides were utilized in the radiological assessment, takin into account the five-month measuring period. On the other hand, the activity concentrations of ^{226}Ra and ^{228}Ra in the water were determined by a well-established method in the laboratory, utilizing MnO_2 fibers (Wurl, 2009). The radionuclides of ^{226}Ra and ^{228}Ra, are characteristic of the coastal area, while the radon and thoron progenies represent an extra input due to freshwater discharge. Thus, through this methodology the supported radon and thoron, due to ^{226}Ra and ^{228}Ra presence, respectively, as well as the unsupported radon and thoron due to the freshwater input can be determined and taken into account.

Sediment
Similar approach was performed in the sediment measurements. The activity concentrations of ^{226}Ra and ^{228}Ra were calculated indirectly in the lab via their progenies ^{214}Pb / ^{214}Bi and ^{228}Ac, respectively assuming secular equilibrium (supported radon and thoron). In addition, the unsupported radon activity concentrations were estimated via the excess portion of ^{210}Pb. In brief the excess portion of ^{210}Pb was calculated by subtracting the supported portion of ^{210}Pb (^{226}Ra presence) from the total ^{210}Pb measured activity concentration in the sediment. Similarly, was calculated the unsupported thoron activity concentration (excess portion of ^{208}Tl).
Thus, the measured activity concentrations of natural radionuclides in the water and sediment were utilized, without using the default values of water-sediment distribution coefficient (Kd) provided by ERICA Tool. Alternatively, for the estimation of the activity concentration in the biota the default concentration ratios (CRs) were used, due to the absence of radioactivity measurements in the biota. Applying the aforementioned activity concentrations in all media, the dose rate calculation and assessment was performed via ERICA Assessment Tool. The radiological risk determination was performed for the biota inhabiting – or that are possibly inhabiting - in the freshwater of the SGD (fish, zooplankton, phytoplankton and vascular plant).

The ERICA Tool takes into consideration the progenies of a radionuclide if their half-lives are less than 10 days (Brown et al., 2008). However, the tool lacks in the estimation of dose rates due to the presence of noble gases (Vives i Battle at al., 2015) and little progress has been made regarding Rn, focusing only in air (Vives i Batlle et al., 2012). To the authors' knowledge the radiologic contribution of inert gases in the aquatic environment using ERICA, or other dose rate estimation models, is deficient. To overcome this problem two approaches were realized regarding the parent nuclides of radon and thoron progenies in the water. The first approach assumes that the parent nuclides are ^{222}Rn and ^{220}Rn, which are determined by the measured concentrations of ^{214}Pb / ^{214}Bi and ^{228}Ac, respectively. On the other hand, the second one considers ^{218}Po and ^{216}Po as the parent nuclides. With the first approach the CRs of the element Xe (IAEA, 2004) were utilized in order to describe Rn in the tool, as CRs for Rn are absent and Xe can be considered a good representative due to the fact that these elements have similar chemical characteristics. According to the second approach, the CRs of Po were inserted, which is a well-studied element for environmental radioactivity investigations.

Results and Discussion

The results of the total dose rates and the internal and external fraction for each approach are presented below. The results of the first methodology, where Rn (^{222}Rn, ^{220}Rn) is the parent nuclide are shown in Figure 2 a, b.

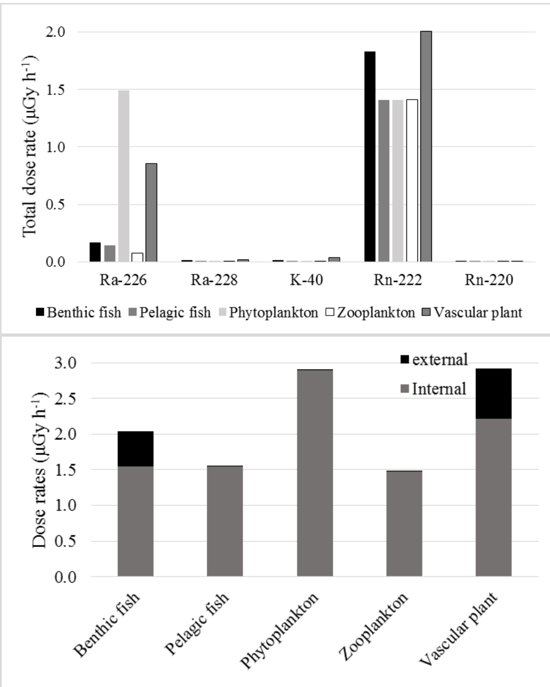

Figure 2. The total dose rates (a) and the internal and external fraction (b) estimated for freshwater biota at a submarine groundwater discharge, utilizing in situ gamma-ray measurements of KATERINA and GeoMAREA detectors. First approach results, where the noble gases (^{222}Rn and ^{220}Rn) are considered the parent nuclides for the dose rate estimation.

The total dose rates revealed that the highest dose rates can be attributed to ^{226}Ra and ^{222}Rn due to the high water-sediment distribution coefficient and the high activity concentrations, respectively describing these radionuclides. Additionally, the greatest fraction in the total dose rate can be attributed to the internal dose rate, as all the before mentioned radionuclides (^{226}Ra, ^{222}Rn, ^{228}Ra and ^{220}Rn) and their progenies, are mainly alpha emitters. Therefore, the dose rate input of a pure gamma-ray emitter (^{40}K) is negligible. The estimated dose rates were found well below the screening values (400 μGy h^{-1}) adopted by the ERICA Tool and proposed by IAEA (1992) and UNSCEAR (1996). For concentrations below the screening values (for chronic exposure situations) no measurable population effects would occur, thus the radiological risk is negligible.
The results of the second methodology, where Po (^{218}Po, ^{216}Po) is the parent nuclide are shown in Figure 3 a, b.

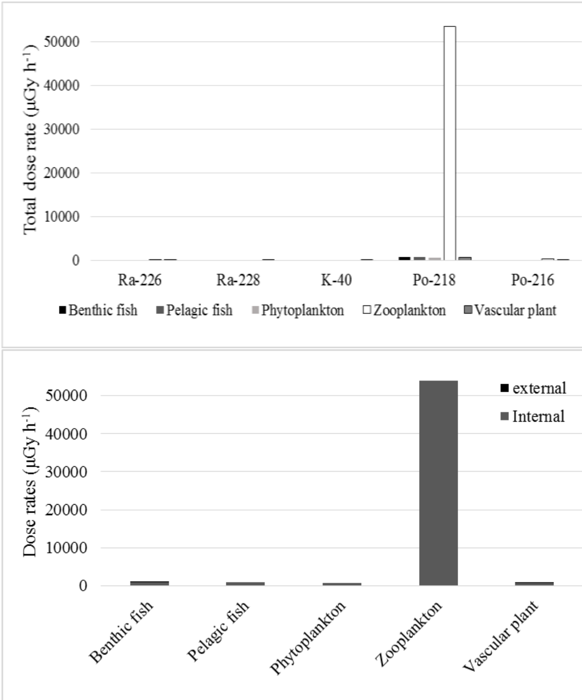

Figure 3. The total dose rates (a) and the internal and external fraction (b) estimated for freshwater biota at a submarine groundwater discharge, utilizing in situ gamma-ray measurements of KATERINA and GeoMAREA detectors. Second approach results, where the ^{218}Po and ^{216}Po are considered the parent nuclides for the dose rate estimation.

Similar observations with those of the first approach can be obtained, such as the external dose rate is negligible and the internal fraction is the main contributor to the total dose rate due to the high concentrations of ^{218}Po and the alpha-decay processes characterizing its progenies. Nevertheless, the total dose rates are orders of magnitude higher than those estimated with the first approach, as well as the adopted screening values (400 μGy h^{-1}) by ERICA. Therefore, the radiological risk is severe, and a more detailed assessment must follow based mainly on experimental data. The contradiction between the first and second approach reveal the importance of the inserted default parameters (in this case the CRs) of the tool, as they may differ from region to region due to biochemical and physicochemical characteristics of the biota and the environment where they reside, respectively or due to lack of experimental data. In such cases the radiological problem must be further cautiously analyzed.

On the other hand, the problem of utilizing the default or experimental water-sediment distribution coefficient (Kd) values, was overcome via the use of experimental obtained activity concentrations in the water and sediment media. In Table 1 are given the experimental and default Kd values only for comparison reasons and in order to show the significance of having experimental data. The experimental data can be considered representative of the area assuming equilibrium between the media (water and sediment) so as to be compared with the default values.

Table 1. The experimental and default values of the water-sediment distribution (Kd) in (L kg^{-1}).

	Activity concentrations				
	Water (Bq l^{-1})	Sediment (Bq kg^{-1})	Exper.	ERICA	ratio
^{226}Ra	0.0054	60	11111	14034	0.79
^{40}K	0.5386	315	585	-	-
^{218}Po	12.518	940	75	17848	0.004
^{222}Rn*	12.518	940	75	1	75

The Kd values of radon are those of Xe, because the information regarding Kd data for Rn is absent and Rn and Xe have similar chemical characteristics as they both are noble gases.

It is well known, and it is especially mentioned in ERICA Tool that the Kd values, as well as CRs, differ among regions and thus the dose rate estimation is performed conservatively. However, in this work emerged the lack of experimental data needed to determine the Kd and CR parameters for natural radionuclides of interest, e.g. ^{222}Rn, ^{220}Rn resulting in ambiguous radiological assessments. For the time being it is not clear the radiological situation of the SGD spring and the scenario of utilizing the freshwater for aquaculture purposes cannot be supported yet. Thus, in order to verify one of the two approaches and clarify the radiological risk, aquatic plants were collected from the SGD spring inside the dam and radioactivity measurements are held.

The authors would like to thank the Municipality of Argos-Mykines and the Prefecture of Peloponnese for the continuous support regarding the organizing deployment in the study area. This work was supported by the project ANAVALOS “Development of an in-situ method for the study of submarine groundwater discharges at the coastal zone using radio-tracers” (MIS 5005218) through the Operational Program “Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) 2014-2020 co-financed by Greece and the European Union (European Social Fund ESF).

Burnett, W.C., Bokuniewicz, H., Huettel, M., Moore, W.S., Taniguchi, M. 2003. Groundwater and pore water inputs to the coastal zone. *Biogeochemistry* 66, 3–33

Brown, J.E., Alfonso, B., Avila, R., Beresford, N.A., Copplestone, D., Prohl, G., Ulanovsky A., 2008. The ERICA Tool. *J Environ Radioact.* 99, 1371-1383.

International Atomic Energy Agency (IAEA) 1992 Effects of ionising radiation on plants and animals at levels implied by current radiation protection standards. Technical Reports Series No. 332, Vienna

International Atomic Energy Agency (IAEA) 2004 Sediment distribution coefficients and concentration factors for biota in the marine environment. IAEA Report 422.Vienna

Moore, W.S. 2010. The effect of submarine groundwater discharge on the ocean. *Annu. Rev. Mar. Sci.* 2, 59–88.

Sugimoto, R., Kitagawa, K., Nishi, S., Honda, H., Yamada, M., Kobayashi, S., Shoji, J., Ohsawa, S., Taniguchi, M., Tominaga, O., 2017. Phytoplankton primary productivity around submarine groundwater discharge in nearshore coasts, *Mar. Ecol. Prog. Ser.* 563, 25–33

Tsabaris, C., Patiris, D.L., Karageorgis, A.P., Eleftheriou, G., Papadopoulos, V.P., Georgopoulos, D., Papathanassiou, E., Povinec, P. 2012. In-situ radionuclide characterization of a submarine groundwater discharge site at Kalogria Bay, Stoupa, Greece. *J. of Environ. Radioact.* 108, 50-59.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1996 Effects of radiation on the environment. United Nations Scientific Committee on the effects of atomic radiation, report to the general assembly, annex I. United Nations, New York.

Vives i Batlle, J., Copplestone, D., Jones, S.R., 2012. Allometric methodology for the assessment of radon exposures to terrestrial wildlife, *Sci. Total Environ.* 427-428, 50-59.

Vives i Batlle, J., Jones, S.R., Copplestone, D., 2015. A method for estimating ^{41}Ar, ^{85,88}Kr and ^{131m,133}Xe doses to non-human biota, *J. of Environ. Radioact.* 144, 152-161.

Vollberg, F., Walther, M., Gardes, A., Moosdorf, N., 2019. Modeling the Potential of Submarine Groundwater Discharge to Facilitate Growth of Vibrio cholerae Bacteria, *Hydrology* 6, 1-15