Environmental Science & Technology

Correspondence/Rebuttal

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Response to Comment on "High Naturally Occurring Radioactivity in Fossil Groundwater from the Middle East"

In his comment to the paper "High Naturally Occurring Radioactivity in Fossil Groundwater from the Middle East"[1] Dababneh[2] argues that due to its current water crisis Jordan has no option but to allow the use of the Disi aquifer water in spite of the high annual radiation dose levels relative to the World Health Organization (WHO) guidelines. While we recognize that each nation should consider costs and risks in order to manage its water resources, in our response we highlight key health and epidemiological evidence that should be carefully weighed as part of the national assessment. We show higher radiation dose for children that demonstrates the potential negative health impact upon long-term consumption of the Disi aquifer water.

Dababneh[2] demonstrated that the annual dose from radium exposure in drinking water from the Disi Conveyance Project in Jordan will be about 10 times the value of WHO[3] recommended reference dose level (RDL) of 0.1 mSv/year. The WHO annual dose value represents the minimum lifetime risk of health effects (approximately 10^{-4}) upon prolonged exposure to radium in drinking water.[3] This RDL level had been adopted and is enforceable in both the EU[4] and U.S.[5] Yet Dababneh[2] argued that countries like Australia and Jordan chose higher annual dose values (1 and 0.5 mSv/year, respectively), and thus the radioactivity data of the Disi groundwater should be compared to these values. While countries may select different drinking water standards based on their own cost and benefit evaluation of the recommended WHO drinking water threshold, we argue that health benchmark such as the nominal radiation dose is universal, and exceeding this threshold would increase the cancer risk of the exposed population.

In addition to the risks posed by the annual radiation dose of the general population, we evaluate further factors that could increase health risk levels due to the differential effect of radium exposure on different subgroups of the population. We show that due to the high potency of radium[6] the dose from consuming the Disi groundwater will be much higher for vulnerable subgroups such as children (Figure 1). Based on reported radium dose coefficients,[6] the annual dose estimate for adults consuming drinking water from the confined Rum aquifer is 11-fold, while the doses for infants and children under 10 years old are 116-fold and 21 to 30-fold, respectively, relative to the RDL value. The estimated annual dose values are directly proportional to the radium levels in the Disi groundwater (Figure 1). The annual dose calculations were based on conservative drinking water consumption rates of 2 L for adults, 1 L for children, and 0.5 L for infants.[7−9] Higher rates of water consumption, which would result in increasing exposure, may occur in the dry and hot region of Jordan, particularly for poor communities without access to alternative water sources. While the radiation dose estimates were calculated for radium, other nuclides of the uranium-238 decay chain (e.g., ^{210}Po with the highest radiation dose coefficient[6]) might be present in the groundwater.[10] These other nuclides would increase the overall radiation dose and should be tested in further analysis.

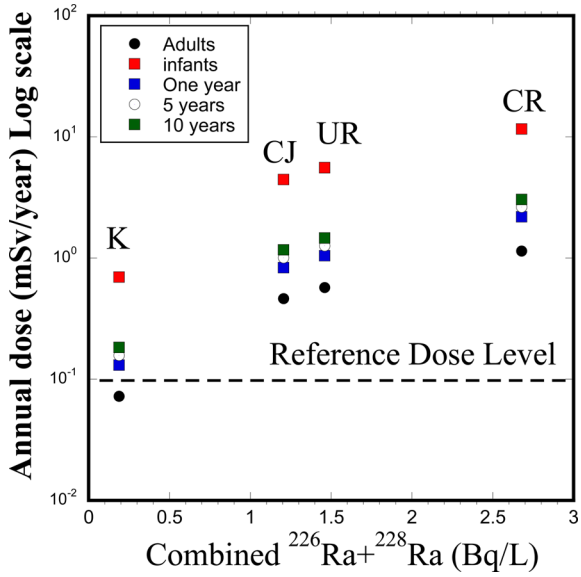

Figure 1. Annual dose calculations versus the mean combined ^{226}Ra +^{228}Ra activities in groundwater from the Khrein Formation (K), Central Jordan (CJ), Unconfined Rum Group (UR) and Confined Rum Group (CR) reported in Vengosh et al.[1] The annual dose values (mSv/year) were calculated from multiplying radium activities in the Disi groundwater (Bq/L) with differential dose coefficients for age groups (Sv/Bq)[6] and amount of water consume per year (L/year). For infant and one year old we assumed consumption of 0.5 L per day, children 1 L per day, and adults two liters per day. Note the high annual dose values relative to the WHO reference dose level (RDL).[3]

The higher dose of radium infers higher health risks on the populations no matter which annual dose value a country selects. The U.S. Environmental Protection Agency (USEPA) estimates that the lifetime cancer mortality risk (predominantly due to bone cancer) at the Maximum Contaminant Level (MCL) for combined radium isotopes (0.185 Bq/L) is $0.7-2 \times 10^{-4}$,[11,12] which is consistent with the WHO nominal RDL.[3] Based on the linear-no-threshold (LNT) concept,[13−15] the BEIR report[16] and USEPA[11] estimated that the radioactivity acts linearly with dose. Indeed, epidemiologic field-based studies in the U.S.,[17] Canada,[18,19] and Thailand[20] have demonstrated the validity of this approach and showed an increase of cancer prevalence among residents that consume radium above the MCL level.[16] In particular, it has been shown that there are higher bone cancer prevalence among children with incidence peaks particularly during mid- to late-adolescence,[18,19] as well as high cancer prevalence among males.[17] However, no increase in cancer rates was reported for females.[17]

dx.doi.org/10.1021/es501140b | Environ. Sci. Technol. XXXX, XXX, XXX−XXX

Finally, the blending of the Disi groundwater with external radium-free water under mixing ratios of 1:1 and 2:1 suggested by Dababneh[2] cannot mitigate the radiation risks and substantially larger proportions (~10:1) of radium-free water are needed to reduce the radiation to the WHO recommended RDL. Since the Disi conveyance project is expected to extract 100×10^6 m^3 per year,[2] at least similar volume of fresh water is needed to blend it to 1:1 mixing ratio. This amount of fresh water is currently not available in Jordan, and thus the blending option is not a feasible solution. Furthermore, blending of water does not reduce the overall cancer risk under the LNT model; it rather spreads the risk over a larger population. Instead, our original paper[1] suggested that water treatment could possibly mitigate the radiation risks. Future development of the Red-Dead Sea Water Conveyance Project that includes desalination of the Red Sea and transport of the desalinated water to Amman[21] could be part of a management plan. In this context, the Disi groundwater should consist of only ~10% of the blend in order to keep the radiation levels low and closer to RDL. In spite of the urgent water need and the important role the Disi Conveyance Project could play in Jordan for mitigating water scarcity, we argue that the health risks upon long-term consumption of the Disi groundwater are substantial and should be addressed during early stages of the project's implementation.

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Notes
The authors declare no competing financial interest.

ACKNOWLEDGMENTS

We thank the editor and three anonymous reviewers for evaluating and improving the quality of an earlier version of this Response.

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