Determining the endmember values of Ra and nutrients in seeping groundwater

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Submarine groundwater discharge (SGD) and SGD-driven nutrients fluxes based on a radium (Ra) tracer are dependent on the endmember values of Ra and nutrients in groundwater. However, it is extremely difficult to determine the endmember values owing to a variable nature of chemical species in coastal groundwater depending on hydrogeological and oceanographic conditions. In this study, we show that the geographical bias of data distributions on determining the endmember values of Ra and nutrients is less than 20%. However, groundwater endmember values of Ra and dissolved inorganic nitrogen (DIN), phosphorus (DIP), and silicon (DSi) are dependent significantly on salinity for the data (n >500) obtained from global coastal aquifers. The activity of ^{228}Ra and concentration of DIP are much higher in saline groundwater, whereas the concentrations of DIN and DSi are higher in lower salinity groundwater (salinity <10). To avoid overestimation and offer a conservative estimate of SGD and associated nutrient fluxes, data from fresh groundwater (salinity <10) are excluded from the dataset. The results show that the previous estimates of SGD for the global ocean were overestimated twofold to threefold. Our conservative estimation of global net nutrient fluxes to the global ocean via SGD by combining a global compilation of nutrient concentrations in groundwater and ^{228}Ra-derived SGD shows that SGD-driven fluxes of DIN, DIP, and DSi are comparable to the river-driven fluxes to the global ocean. This study highlights that the groundwater endmember should be carefully considered in order to estimate more accurate SGD and associated fluxes of chemical species into the ocean.