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硕 士 学 位 论 文

基于氡-222 的胶州湾海底地下水排泄研究  
Tracing Submarine Groundwater Discharge into  
Jiaozhou Bay by Radon-222

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## 摘要

本文依托国家自然科学基金项目“多种方法研究胶州湾海底地下水排泄(41072174)”,通过运用天然存在的氡同位素( $^{222}\text{Rn}$ )示踪技术,对胶州湾的海底地下水排泄(SGD)进行评价,并对其输送的营养盐通量进行估算。

本研究利用 RAD7(电子测氡仪)对胶州湾周边的地下水、河水和海水进行 $^{222}\text{Rn}$ 活度测量。测得 2011 年 9~10 月胶州湾周边地下水中 $^{222}\text{Rn}$ 的平均活度为 $16706\text{Bq/m}^3$ ,河水中 $^{222}\text{Rn}$ 的平均活度为 $1970\text{Bq/m}^3$ ,湾内海水中 $^{222}\text{Rn}$ 的平均活度为 $221\text{Bq/m}^3$ ;2012 年 4~5 月地下水中 $^{222}\text{Rn}$ 的平均活度为 $17855\text{Bq/m}^3$ ,河水中 $^{222}\text{Rn}$ 的平均活度为 $393\text{Bq/m}^3$ ,海水中 $^{222}\text{Rn}$ 的平均活度为 $111\text{Bq/m}^3$ 。研究显示地下水中 $^{222}\text{Rn}$ 活度的空间分布主要受控于地质环境因素(岩性),且受降水影响。

2011 年 10 月和 2012 年 5 月在胶州湾北岸东大洋码头附近对海水中的 $^{222}\text{Rn}$ 进行了 48 小时连续测量。海水中 $^{222}\text{Rn}$ 活度的时间分布显示与潮高近似呈负相关关系,推测是潮汐泵效应影响到海底地下水的排泄所致。将测得的结果经过大气逃逸、潮汐涨落、混合损失、沉积物扩散等校正,计算得海底地下水排泄通量平均值分别为 $0.064\text{m}^3/(\text{m}^2\cdot\text{d})$ (2011 年 10 月)和 $0.083\text{m}^3/(\text{m}^2\cdot\text{d})$ (2012 年 5 月)。实际观测到的海底地下水排泄速率动态变化较大,主要控制因素是降水、潮汐和波浪。

通过分析和识别胶州湾 $^{222}\text{Rn}$ 的源汇项,认为 $^{222}\text{Rn}$ 的源项主要有:SGD 输入的 $^{222}\text{Rn}$ ,河流输入的 $^{222}\text{Rn}$ ,沉积物扩散输入的 $^{222}\text{Rn}$ , $^{226}\text{Ra}$ 支持的 $^{222}\text{Rn}$ ,城市废水输入的 $^{222}\text{Rn}$ 。 $^{222}\text{Rn}$ 的汇项主要有放射性衰变损失的 $^{222}\text{Rn}$ 、逸散损失的 $^{222}\text{Rn}$ 和混合损失的 $^{222}\text{Rn}$ 。

通过构建整个胶州湾 $^{222}\text{Rn}$ 的质量平衡模型,量化各个源汇项,计算得全湾海底地下水排泄量 2011 年 10 月为 $10.62\times 10^6\text{m}^3/\text{d}$ ,约为同期周边河流径流入海量的 38.8%;2012 年 5 月为 $3.72\times 10^6\text{m}^3/\text{d}$ ,约为同时期河流径流入海量的 29.7%。计算的 SGD 通量既包括陆源淡水,也包括再循环海水。

如果把再循环海水考虑在内,且认为营养盐在滨海含水层中的化学行为是保守的,近似估算 SGD 输入胶州湾的营养盐通量,则得 2011 年 9 月 SGD 输送的

DIN、 $SiO_3^{2-}-Si$ 、 $PO_4^{3-}-P$  通量分别为  $665.90 \times 10^4 \text{mol/d}$ 、 $163.11 \times 10^4 \text{mol/d}$ 、 $0.12 \times 10^4 \text{mol/d}$ ；2012 年 5 月输送的 DIN、 $SiO_3^{2-}-Si$ 、 $PO_4^{3-}-P$  通量分别为  $209.25 \times 10^4 \text{mol/d}$ 、 $85.96 \times 10^4 \text{mol/d}$ 、 $3.60 \times 10^4 \text{mol/d}$ 。

关键词： $^{222}\text{Rn}$ ；海水；地下水；SGD；胶州湾

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## Abstract

This paper, supported by the project of Using multi-methods research submarine groundwater discharge (SGD) in Jiaozhou Bay (41072174), which belongs to the National Natural Science Foundation of China. Calculate flux of SGD in Jiaozhou Bay by using naturally-occurring radon isotopes ( $^{222}\text{Rn}$ ) trace technique and estimates flux of nutrients through SGD.

This study using RAD7 (Durriage Company Inc) measure the activity of radon-in-waterbody, including groundwater, river water and seawater in Jiaozhou Bay area. The results show that during September to October, 2011, the average of  $^{222}\text{Rn}$  activity in groundwater, river water and seawater was  $16706\text{Bq/m}^3$ ,  $1970\text{Bq/m}^3$ , and  $2216\text{Bq/m}^3$ , respectively; during April to May, 2012, the average of  $^{222}\text{Rn}$  activity in groundwater, river water and seawater was  $17855\text{Bq/m}^3$ ,  $393\text{Bq/m}^3$ , and  $111\text{Bq/m}^3$ , respectively. Study shows that spatial distribution of  $^{222}\text{Rn}$  activity in groundwater and river water mainly controlled by the geological environmental (lithology) and affected by precipitation.

At Dongdayang Dock, which located at the north shoreline of Jiaozhou Bay, we deployed an in-situ 48h continuous experiment on measuring  $^{222}\text{Rn}$  activity in seawater in October 2011 and May 2012, respectively. Temporal distributions of  $^{222}\text{Rn}$  show an inverse relationship with the tidal height, which reflect the tidal effects on SGD obviously. Through establishing continuous  $^{222}\text{Rn}$  model, which was corrected for tidal effects, atmospheric loss, sediment diffusion and mixing loss, etc, the average of SGD flux are assessed to be  $0.064\text{m}^3/(\text{m}^2\cdot\text{d})$  and  $0.083\text{m}^3/(\text{m}^2\cdot\text{d})$  in October 2011 and May 2012, respectively. In fact, the SGD rate fluctuate greatly, daily and seasonally, which are mainly controlled by precipitation, tidal pump and wave oscillation.

By identifying the total  $^{222}\text{Rn}$  resources and sinks of Jiaozhou Bay, we found the resources of  $^{222}\text{Rn}$  contain SGD transport, river transport, sediment diffusion,  $^{226}\text{Ra}$  support and municipal wastewater, while the sinks include radioactive decay,

atmospheric loss and mixing loss.

Through constructing the  $^{222}\text{Rn}$  mass balance model of Jiaozhou Bay, qualitatively all kinds of sources and sinks terms, estimated that the SGD flux is  $10.62 \times 10^6 \text{m}^3/\text{d}$  in September 2011, approximately 38.84% of the river flux in the same period;  $3.72 \times 10^6 \text{m}^3/\text{d}$  in May 2012, approximately 29.72% of the river flux in the same period. SGD was higher in September than in May due to the high level of precipitation in Jiaozhou Bay area.

Nutrients' Concentration in groundwater around Jiaozhou Bay were measured. The inputs of nutrients through SGD were calculated by multiplying the average concentrations of nutrients in coastal groundwater by total SGD. Estimates of nutrients loading through the pathy way of SGD is  $665.90 \times 10^4 \text{mol}/\text{d}$ ,  $163.11 \times 10^4 \text{mol}/\text{d}$ , and  $0.12 \times 10^4 \text{mol}/\text{d}$  for DIN,  $\text{SiO}_3^{2-} - \text{Si}$ , and  $\text{PO}_4^{3-} - \text{P}$  during September 2011, respectively;  $209.25 \times 10^4 \text{mol}/\text{d}$ ,  $85.96 \times 10^4 \text{mol}/\text{d}$ , and  $3.60 \times 10^4 \text{mol}/\text{d}$  for DIN,  $\text{SiO}_3^{2-} - \text{Si}$ , and  $\text{PO}_4^{3-} - \text{P}$  during May 2012, respectively.

Keywords:  $^{222}\text{Rn}$ ; Seawate; Groundwater; SGD; Jiaozhou Bay



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