Journal of Hydrology 562 (2018) 40–49

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Hydrogeochemistry in the coastal area during construction of geological repository

Youn-Tae Kim[a,*], Seung Gyu Hyun[b], Jae-Yeol Cheong[c], Nam C. Woo[d], Sangdeok Lee[e]

[a] Institute of Earth Atmosphere Astronomy, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, Republic of Korea
[b] Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon 34142, Republic of Korea
[c] Korea Radioactive Waste Agency, 89 Bukseong-ro, Gyeongju-si, Gyeongsangbuk-do 38140, Republic of Korea
[d] Department of Earth System Sciences, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, Republic of Korea
[e] HYUNDAI Engineering Co., Ltd., 75, Yulgok-ro, Jongno-gu, Seoul 03058, Republic of Korea

ARTICLE INFO

This manuscript was handled by C. Corradini, Editor-in-Chief, with the assistance of Corrado Corradini, Associate Editor

Keywords:
Radioactive waste disposal
Underground construction
Seawater intrusion
Cation exchange
Fractured aquifer

ABSTRACT

A geological repository for low and intermediate radioactive waste (bottom at −130 m a.s.l.) was constructed from 2008 to 2014 in the southeastern coastal area in Korea. This research aimed to evaluate the hydrogeochemistry in this area during the construction period and to determine the characteristics that should be monitored during the operational period. During construction, the groundwater level decreased up to 136 m and the upper groundwater flow in the southeastern area reversed. After the groundwater level dropped below the sea level, the electrical conductivity (EC) in several wells along the coastal line started to increase; 23.2% of the measured water was classified as brackish water and the highest EC observed in groundwater was 18.9 mS/cm, nearly 38% of EC in seawater. The response time of the groundwater chemistry differs depending on the depth, even in wells, because of fracture networks. Among locations that showed drastic changes in EC, only the shallow depth of GM-4 showed a peak pattern in EC, but other locations showed increasing EC patterns or patterns with initial increase and sustained high till the end of the construction period. Based on the Cl/Br ratio, the source of the groundwater salinity was seawater intrusion, and ion exchange played an important role. Compared to Cl concentration, sodium was depleted and calcium was in excess in brackish water; however, the SO_4/Cl ratio remained constant at a level similar to seawater. Ca and Fe concentrations showed distinguishable characteristics depending on the location, suggesting differences in geological media. During the operational period, periodical evaluation of the groundwater chemistry in the mixing zone and continuous monitoring of EC patterns and seawater fractions are required.

1. Introduction

Nuclear energy and radioactive materials have many beneficial uses for human life, such as high electric power and development of the imaging technology, but the associated radioactive waste becomes intractable. Underground isolation of radioactive waste is considered a safe and reliable method, and therefore, it was adopted in several countries (Rempe, 2007). However, there are several hydrologic issues based on the host rock type (Tsang et al., 2015). Flow and transport are the main issues in fractured crystalline rocks, in which Sweden and Finland excavated repositories. Therefore, the Äspö Hard Rock Laboratory (Sweden) published many articles on hydrological processes and reactions within the fracture zone (Banwart et al., 1999; Molinero and Samper, 2006).

Facilities related to radioactive waste require a site monitoring program at different periods during its lifetime according to the International Atomic Energy Agency (IAEA, 2011) and Nuclear Safety Act (NSSC, 2014):

1) during the preoperational period to obtain baseline data to characterize the site,
2) during the operational period to obtain data to verify the characterization of the site, safety evaluation, and design, and
3) during the post-closure period to acquire data for the early warning with respect to radionuclide releases from the disposal site and to verify the characterization of the site and safety evaluation.

In Korea, the geological repository for low and intermediate radioactive waste (LILRW) is located in the southeastern coastal area. The site is currently in the operational stage; the monitoring program of this

* Corresponding author.
E-mail address: yountae@yonsei.ac.kr (Y.-T. Kim).

https://doi.org/10.1016/j.jhydrol.2018.04.071
Received 19 June 2017; Received in revised form 27 April 2018; Accepted 27 April 2018
Available online 30 April 2018
0022-1694/

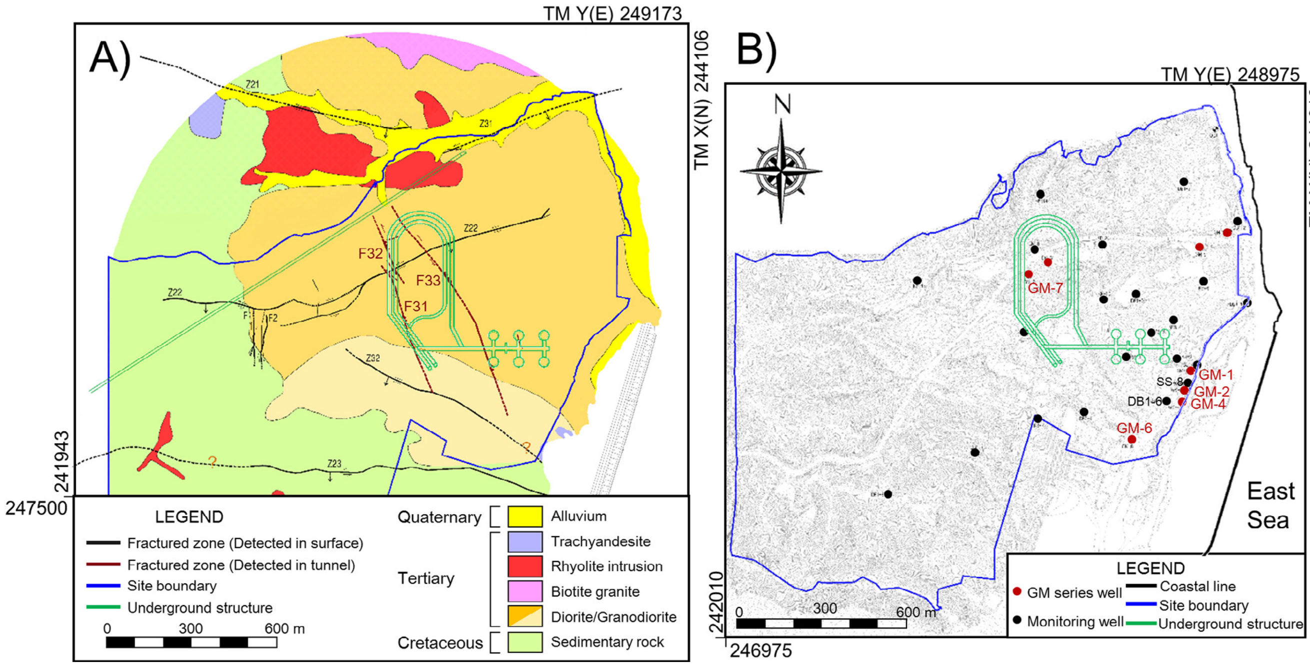

Fig. 1. Map of the study area showing the surface geology and geological structures (a) and monitoring well locations (b).

stage started in 2015. At least quarterly monitoring will be continued over 60 years until closure. Before starting construction, a detailed survey was conducted to assess the feasibility of the location for LILRW; several research papers were published (Kim et al., 2008a; Kim et al., 2008b). The groundwater in this area was fresh at that time. However, the electrical conductivity (EC) in several groundwater sampling locations started to increase during construction; fresh groundwater then changed to brackish groundwater. To estimate the status of seawater intrusion (SWI), monitoring wells equipped with a multi-packer were installed along the coastal line because the geology at the depth of dome bodies is characterized by fractured aquifers.

SWI is a worldwide issue, especially with respect to freshwater conservation because many coastal aquifers are threatened by SWI (Custodio and Bruggeman, 1987; Goswami and Clement, 2007; Werner et al., 2013a). Groundwater depletion caused by intensive pumping and increased water use is one of the reasons leading to SWI in coastal areas and changing fresh groundwater to brackish or saline water (USGS, 2000; Werner et al., 2013b). Underground structures in coastal areas also cause the decrease of the groundwater level leading to SWI because drainage of the groundwater inflow into underground structures is required (Fernandez and Moon, 2010; Attard et al., 2016). Additionally, construction activities, such as excavation, cutting the mountain, and building underground facilities, can affect the groundwater flow system (Ding et al., 2008; Hyun, 2013). Despite extensive studies on the SWI process, there are knowledge gaps, particularly with respect to the transient state; therefore, long-term, high-density monitoring of field-scale SWI is required (Werner et al., 2013a).

SWI dynamics have been studied with laboratory experiments and numerical simulations (Goswami and Clement, 2007; Lu and Werner, 2013). However, the distribution of saline water and the nature of the SWI in fractured coastal systems remain poorly understood (Werner et al., 2013a; Sebben et al., 2015). Numerical investigations of the effect of high permeability fractures are in the preliminary stage (Sebben et al., 2015). Modeling of heterogeneity effects reflecting stratified geological formations indicated that the difference in the permeability across layers causes broad mixing zones in low-permeability layers but narrower zones in higher-permeability layers (Dagan and Zeitoun, 1998; Lu et al., 2013; Kim et al., 2013). Based on several case studies of SWI in fractured aquifers (Lim et al., 2013; Park et al., 2012), it was concluded that fractures provide preferential flow and transport pathways.

The chemical process of SWI with time is usually investigated with laboratory experiments such as column tests and reactive transport modeling (Apple et al., 1990; Russak and Sivan, 2010; Russak et al., 2016; Boluda-Botella et al., 2008, Boluda-Botella et al., 2014). The groundwater chemistry in the area affected by SWI is controlled by conservative mixing between saline and fresh water and various water-rock interactions such as cation exchange and mineral dissolution/precipitation (Russak and Sivan, 2010). Because the constituents of seawater are different than that of fresh water, relative changes in constituents, such as Ca and Na and sometimes Sr, Li, and Mn, indicate a characteristic development of water types and chromatographic patterns (Appelo and Postma, 2005; Russak et al., 2016). Therefore, the ratio or patterns of these constituents are used as a reliable tool to characterize the SWI status.

However, unlike in lab experiments or modeling studies, many factors affect the major constituents during field observations. Preliminary source tracking of groundwater salinity is required because there may be various salinity sources (Richter and Kreitler, 1993; Alcalá and Custodio, 2008; Giambastiani et al., 2013). Fresh-saline water interfaces might fluctuate because of rainfall recharge, tides, global sea level rise, and changes of the artificial pumping rate, leading to complex SWI stages such as salinization or freshening (Russak and Sivan, 2010). Therefore, contour mapping of Cl or total dissolved solid (TDS) is usually adapted to estimate the region affected by SWI during field observations (Barlow, 2003; Han et al., 2014).

The purpose of this study was to understand the hydrology and hydrogeochemistry in the coastal area during the construction of the geological repository and determine characteristics that should be carefully monitored during the operational period of the geological repository for LILRW in Korea. Our study area is a good field site to study the SWI process in a fractured aquifer at the field scale because of great advantages with respect to obtaining long-term periodical groundwater data as a facility related to radioactive waste. We propose a conceptual model for this area that explains the hydrogeochemical evolution during the construction period and suggest characteristics to be monitored during the operational period.