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Groundwater flow paths on the Reykjanes peninsula, Iceland – The mapping of flow paths using elemental tracers and development of new mobile electric pump

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INTRODUCTION

In 2020, a new volcanic episode began on the Reykjanes Peninsula, Iceland. These eruptions pose a significant threat to local water resources, including drinking water supplies, water supplies to produce hot water for district heating in the Svartsengi Geothermal Plant, and the distribution of hot and cold water in the area. In order to locate alternative water sources, should current ones be contaminated or inundated by lava flows or volcanic emissions, it is essential to map the peninsula's groundwater flow paths and characteristics. This is especially critical if specific flow paths become compromised by volcanic constituents such as fluoride or heavy metals.

The objectives of this study are twofold. Firstly, the research aims to trace and map groundwater flow paths across the peninsula by measuring conductivity and elemental tracers in groundwater samples collected from boreholes. A similar study was conducted in 1985 by Freysteinn Sigurðsson; since then, numerous boreholes have been drilled, providing the opportunity to update and refine the existing hydrogeological model.

Secondly, the study will test the performance of a newly developed electric pump by ÍSOR (Iceland Geosurvey), designed for sampling groundwater from narrow boreholes where the use of conventional mobile pumps is impractical. The reliability of this new pump will be assessed by comparing the quality and consistency of the samples it collects against those obtained using standard sampling methods.

1 SAMPLING METHODS

25 groundwater samples were collected during this study. All samples, except one, were taken at a maximum of 30 meters depth from the surface from shallow freshwater boreholes, the one exception was taken from a small surface stream south of lake Kleifarvatn. The different methods used in this study were collecting samples straight from sampling taps on wells with installed pumps, a bailer, and a newly developed electric pump. Multiple aspects were considered when choosing sampling locations. Ideally, samples needed to be collected all around the peninsula, allowing for the most accurate rendering of groundwater flow paths. Multiple locations were visited during the process, but many of the boreholes intended to be sampled from were lost, damaged, or inaccessible for other reasons. In the end, samples were collected where possible from the most convenient borehole in a given area. Sampling began on June 19th in 2025, lasting throughout August. By lucky chance, a volcanic eruption began near Sundhnúkagígar on July 16th, ending on August 5th. Ten samples were collected before the eruption, twelve during, and three after.

A small mobile electric pump recently developed at Iceland Geosurvey was tested and used for sampling during the study. It is made up of six Rule Inline Pump iL280 Plus - 12V pumps from CH Marine, connected to an approximately 30 m hose pipe. It has been nicknamed "Perlufestin" in Icelandic, or "the Pearl Necklace", due to the resemblance. It is compact and portable, and therefore ideal for sampling in narrow and remote boreholes that are inaccessible with traditional mobile pumps, which run on bulky generators that cannot be transported on foot. The Pearl Necklace also has many advantages over bailers, since it allows for continuous flushing which gives clearer, more representative samples. However, the Pearl Necklace has many limitations which require attention. It is vulnerable to pump failure, since each of the six pumps operate on their own, and if one pump malfunctions, no water is returned to the sampling end. It is also vulnerable to hose kinking and twisting, which can prevent flow. For these reasons, it is vital to carry tools and spare parts in the field when sampling. Despite these limitations, the Pearl Necklace is an extremely practical tool for fieldwork and has strong potential for further development and refinement.

In three suitable boreholes with different qualities, samples were collected using both a bailer and the Pearl Necklace, and the results and method suitability compared. In deep boreholes with little change in temperature and conductivity with depth both methods are equally suitable and give nearly identical results. In deep

boreholes where temperature and conductivity vary greatly with depth, each method is suitable for different purposes. If the purpose is to study the characteristics of the water derived through pumping in the area, the Pearl Necklace is more suitable, but if the purpose is to study the variation between water layers within the borehole, using a bailer is more suitable since it can be positioned very accurately at certain depths. In shallow boreholes where the water table lies close to the bottom, using a bailer risks disturbing sediments at the bottom of the borehole, which causes murky samples that can affect results. In those cases, the Pearl necklace is more suitable, since it can pump water from the borehole until it runs clear, yielding fresher samples.

2 GROUNDWATER CHARACTERISTICS

The conductivity of the samples was measured using a conductivity meter, and anions were analyzed using Ion chromatography. The results are shown in table 1.

Table 1. The results of conductivity measurements and anion analysis in samples collected on Reykjanes peninsula during summer 2025. The samples highlighted in grey were taken during the volcanic eruption in Sundhnúkagígar that lasted from July 16th to August 5th. The sampling location can be seen on fig. 1.

Sampling locations	Sampling method	Conductivity (µS/cm)	Br^- (mg/L)	Cl^- (mg/L)	F^- (mg/L)	SO_4^{2-} (mg/L)
Nesbú egg	Sampling tap	1081	0,942	291	0,05	39,7
VS-21	Pearl Necklace	381	0,141	40,5	0,03	13,4
ÖH-07	Pearl Necklace	418	0,291	76,4	0,03	15,6
VH-03	Pearl Necklace	470	0,375	114	0,09	15,7
SF-01	Pearl Necklace	164,7	0,093	33,1	0,04	4,57
GS-02	Sampling tap	180,3	0,055	18,2	0,07	13,2
VS-02	Pearl Necklace	410	0,070	33,3	0,03	9,27
KAL-16	Pearl Necklace	629	0,514	161	0,04	22,3
SL-01	Pearl Necklace	3630	3,48	1080	0,13	147
AR-02	Sampling tap	210	0,093	38,0	0,06	5,35
VH-03	Pearl Necklace	469	0,386	114	0,09	15,6
HSK-18	Sampling tap	512	0,344	110	0,06	164
Gjá í Lágum	Sampling tap	302	0,215	70,7	0,07	9,88
HSK-09	Sampling tap	333	0,234	77,9	0,08	10,7
HSK-10	Sampling tap	185,6	0,121	41,3	0,06	5,99
SY-02	Sampling tap	444	0,347	110	0,05	14,8
VG-02	Pearl Necklace	295	0,120	59,1	0,04	6,08
VL-05B	Pearl Necklace	1057	0,859	276	0,07	41,0
Baðstofugjá	Sampling tap	3770	3,78	1380	0,06	73,2
Lækur	Surface water	89,9	0,03	16,5	0,02	3,05
SL-01	Bailer	2800	2,44	752	0,10	98,5
SF-01	Bailer	168	0,09	31,6	0,04	4,49
VH-03	Bailer	451	0,365	118	0,08	11,3

The results suggest similar divisions between groundwater bodies on Reykjanes peninsula as suggested by Sigurðsson (1985). A clear distinction is between groundwater bodies in the Lágar area, where freshwater is

currently sourced. Eastern Lágar has higher conductivity and anion concentrations than western Lágar, where the chemistry of the groundwater is more similar to that in Miðnes. There is also a distinct boundary between groundwater properties near Vogar, where samples taken only a few hundred meters apart had different chemical properties. These distinctions between waterbodies are likely caused by the different bedrocks where the wells are located: higher chemical values can be attributed to bedrock made up of young, post-glacial lava flows, while lower values can be attributed to older, quaternary bedrock (Sæmundsson et al., 2016). Samples taken near the coast around the peninsula have higher conductivity than those taken further inland, presumably due to seawater mixing. Fig. 1 shows a map of the sampling locations and methods used to collect each sample, the measured conductivity of each sample, and the estimated distribution of groundwater conductivity on the peninsula based on the result. In locations where no data is available, due to a lack of boreholes and surface water, the estimated distribution is unreliable. The volcanic fissures and lava extent from the eruptive events in 2021 until August 2025 are included to show the proximity of the volcanic activity to the sampling locations.

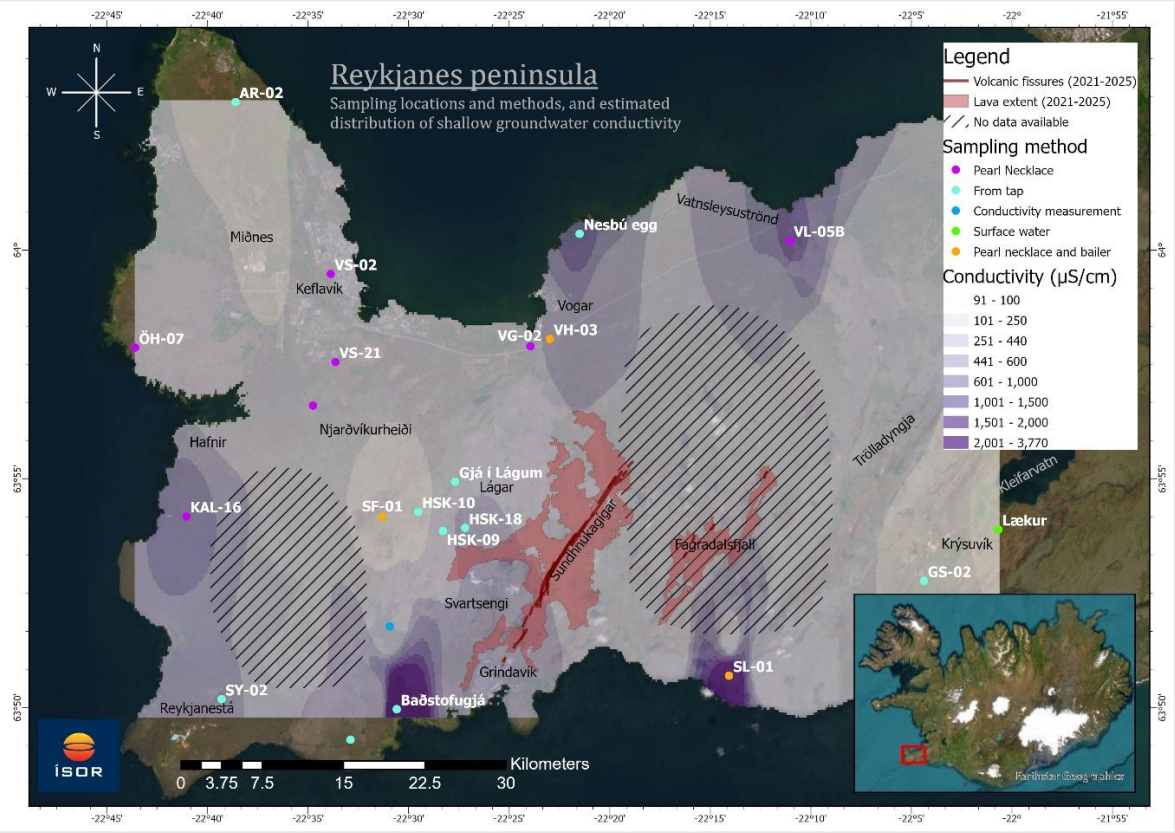


Figure 1. The conductivity of each sample taken during the study in µS/cm, and the estimated distribution of groundwater conductivity on Reykjanes Peninsula based on those results. Includes sample locations and sample methods. The black lines indicate areas where no data is available due to the absence of boreholes and surface water. The volcanic fissures and lava extent from the eruptive events in 2021 until August 2025 are shown in red.

Multiple samples were taken near the eruptive vents and resulting lava flow during the Sundhnúkagígar volcanic eruption in July 2025. Because fluoride contamination in groundwater is often associated with volcanic activity (e.g. D'Alessandro, 2006; Shaji et al., 2024; Fridriksson, 1983; Steingrímsson, 1998), particular interest was in analyzing the fluoride content of the shallow groundwater close to the active area. The fluoride content of the groundwater samples taken in Lágar during the July 2025 eruption show particularly low values, measuring from 0.04-0.07 mg/L. For context, the maximum amount of fluoride permissible in drinking water according to The World Health Organization and Icelandic regulations (Matvælaráðuneytið, 2018) is 1.5 mg/L. The results of this study greatly resemble those from analysis done in the same wells during the last 50 years. As seen in fig. 2, the fluoride content in four wells close to Sundhnúkagígar has remained remarkably stable over the last decades, with the volcanic events of 2021 – 2025 having seemingly no effect. As of now, there is no evidence that the volcanic activity on the Reykjanes peninsula has any impact on the chemistry of the shallow groundwater in the area.

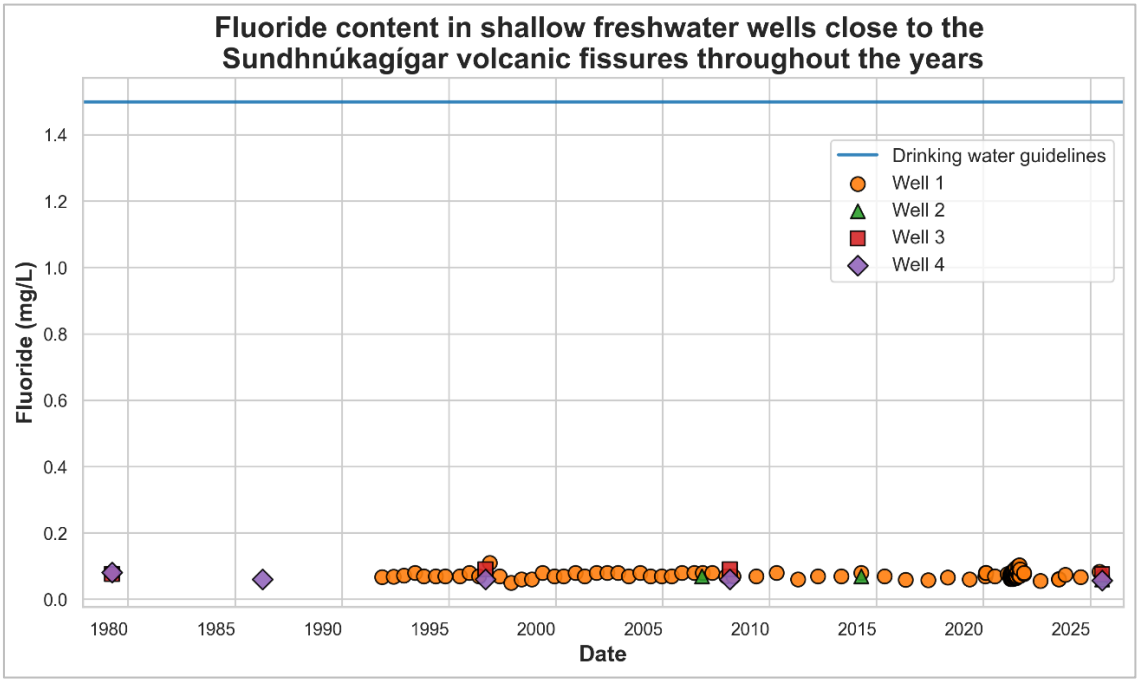


Figure 2. Fluoride content in samples taken over the past fifty years from four shallow freshwater wells in Lágar, close to the Sundhnúkagígar volcanic fissures. The blue line represents the maximum amount of fluoride in drinking water according to Icelandic regulations (Matvælaráðuneytið, 2018) and The World Health Organization (2011).

These result form the basis of understanding on the characteristics of groundwater bodies on Reykjanes peninsula. However, since this study only considered conductivity and anion content, even further insight into the groundwater characteristics can be gained through the study of other chemical tracers, such as dissolved inorganic carbon, major cations, trace metals, and isotopes of hydrogen, oxygen, and carbon. Further research into the chemical characteristics of the shallow groundwater on Reykjanes is essential to better define groundwater bodies and trace groundwater flow paths, which will aid in the search for an alternative water source on the peninsula.

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