Int Aquat Res (2023) 15:65–74
https://doi.org/10.22034/IAR.2023.1963612.1304

SHORT COMMUNICATION

Coastal groundwater salinization due to saltwater intrusion – new insights from a preliminary in-situ assessment

Thomas D. Kishore . Alvin Lal

Received: 21 July 2022 / Accepted: 20 March 2023 / Published online: 28 March 2023

Abstract Access to clean water is a major problem for many countries including low-lying volcanic Island nations. Many of these volcanic Island nations are therefore heavily dependent on groundwater resources for their freshwater supplies. Saltwater intrusion compounded by rising sea levels, excessive abstraction, and anthropogenic activities often contaminates limited fresh groundwater resources. For the first time, available coastal groundwater salinity data obtained from an in-situ assessment is used to determine groundwater salinity levels in a low-lying volcanic atoll in Aitutaki, a major urban centre in the Cook Islands. The study examines groundwater quality data obtained during three different periods i.e., at the end of the rainy season in 1996, at the end of the dry season in 2015, and at the end of the rainy season in 2018. Also, groundwater salinity levels at different depths of monitoring wells were analysed to establish a groundwater salinity-depth trend. The results suggest that climatic conditions play a crucial role in the variation of the groundwater salinity levels in aquifers. It is observed that at the end of the dry season, the salinity levels are higher at lower aquifer depths. However, at the end of the rainy season, salinity levels increase with increasing depth. In addition, the study also reveals that the location of the groundwater pumping wells has a direct correlation with groundwater salinity levels. Groundwater pumping wells closer to the shoreline were observed to have high salt concentrations when compared to those sampling points that were further inland. Overall, the key findings suggest that groundwater salinity levels in the Aitutaki aquifer are increasing and there is an urgent need for saltwater intrusion protection and management interventions.

Keywords Low-lying volcanic Islands . Saltwater intrusion . Coastal aquifers . Coastal groundwater quality . Climate change

Introduction

Increased industrialization, agriculture, isolation, wide distances between neighbouring atolls and/or islands, urbanization, increased tourism activities, and the unpredictable rainfall create distinct issues in water resource management in several Pacific Island Developing Countries (PIDC) (WHO 2018). Since 2010, diarrhoea related illnesses have claimed up to 3.4 million lives in PIDC (WHO 2016). Water Scarcity and poor environmental sanitation is an increasing issue that is seen to be a direct cause of the disproportionate increase in population, global climatic change, drought cycles, deforestation, and desertification (Gleick 2002). Water challengers on PIDCs are impaired by natural and anthropogenic factors. Rapid urbanization

Thomas D. Kishore
Discipline of Civil Engineering, School of Information Technology, Engineering, Mathematics & Physics, University of the South Pacific, Suva, Fiji

Alvin Lal (✉)
Global Centre for Environmental Remediation (GCER), College of Engineering, Science and Environment, The University of Newcastle, Callaghan, NSW 2308, Australia
e-mail: alvin.lal@newcastle.edu.au

Alvin Lal
crcCARE, The University of Newcastle, Callaghan, NSW 2308, Australia

in many PIDCs has resulted in a substantial increase in pollutants over the past few decades, including nutrients, suspended solids, and microbial pollution (Burns 2010). Half of the population in the PIDC region has access to improved drinking water sources whilst a third of the population use improved sanitary (WHO 2016). Therefore, two-thirds of the region's population depends on unprotected sources of water and unsanitary means of waste disposal, which pose a serious health risk. Furthermore, it is also established that the Pacific region has the lowest access to improved drinking water than anywhere else in the world. A 6% increase in the coverage of improved drinking water in the Pacific region was observed in 1990. Piped water coverage remains the lowest in the world at just 20%. In the region, 34% of the population relies on water taken directly from rivers, ponds, and lakes (WHO 2016).

Low-lying volcanic Islands in the pacific have limited or no surface water and are heavily dependent on rainwater and groundwater sources (Lal and Datta 2017). The volume of freshwater lenses is proportional to the width and surface area of an island (Burns 2010). The availability of freshwater from groundwater sources is dependent on the recharge of the aquifer, salt-water intrusion, and the extraction for use (Antoniou et al. 2019). Storm surges which are a common occurrence in these islands also complicate the balance, during which the mixing of saline water and freshwater occurs since the fresh groundwater, which occurs in lenses floats on saline groundwater (Huang and Cai 2009). The thickness of freshwater lenses varies depending on the sizes of the islands. While lenses may be as thick as twenty meters, most low-lying islands have aquifers only 10-20 cm thick (Mirti and Davies 2005). Most of these lenses are sensitive to rainfall variability, shrinking due to low rainfall periods, and vulnerable to salination due to over-pumping (Falkland 1993). The high recharge rate of the freshwater lenses is attributed to the highly porous nature of the sandy, cancerous, and volcanic soils, which are commonly found in low-lying atolls. However, this also makes the groundwater susceptible to pollution from agriculture and sanitation systems (Huang and Cai 2009). Poor sanitation systems, such as pit toilet allows direct contamination of freshwater lenses as typically the pits are dug into the water table. Leaking septic tanks due to poor construction also results in the contamination of freshwater lenses. High levels of fecal contamination were noted in surveys in Tarawa in the 1980s. High levels of bacterial contamination were also found in wells in islands in the Federated States of Micronesia (Detay et al. 1989). The quality of freshwater in the aquifers is dependent on the atoll width, recharge rate and the ease of transpiration through the aquifers (White et al. 2004). Groundwater in low coral atolls is vulnerable to both anthropogenic and natural processes. The quality and quantity of groundwater are severely impacted by droughts, storms, and climate effects. Inundations by waves during storms increase the salinity level of shallow groundwater. Furthermore, climate change impacts especially that of sea level rise excessively salinize groundwater on small island states (Alam and Falkland 1997).

Several studies have reported that groundwater salinization is one of the most critical threats to groundwater systems in PIDC (Lal and Datta 2019). White et al. (2004) reviewed the nature of shallow water aquifers and the impacts of seawater intrusion in small islands within the Pacific Ocean. The study used a simple steady-state approximation to understand the key climatic, hydrogeological, physiographic, and management factors that influent the quality of saline intrusion into freshwater lenses. The study found that the long dry period strongly coupled to sea surface temperatures impacts the quantity and salinize the fresh groundwater. Furthermore, the study suggests that careful assessment, vigilant monitoring, and appropriate development and astute management are needed to avoid excessing deterioration of fresh groundwater (White and Falkland 2009). Also, Sharan et al. (2021) identified the water sources in PIDC and discussed the major challenges and solutions or strategies for monitoring, management, and prevention of groundwater. The study revealed that salt-water intrusion is a highly common PIDC and there is a need for more detailed investigations to be conducted in this region. Furthermore, the study emphasizes the need to use technologies, artificial intelligence, simulation, and the presence of regulation to assist in the monitoring, managing, and preventing of saltwater intrusion and other ways of contamination in coastal aquifers for PIDC (Sharan et al. 2021). In addition, Oberle et al. (2017) evaluated the effects of short-term and long terms changes in rainfall, wave climate, and sea level rise on groundwater resources in Roi- Namur in the Republic of Marshall Islands. The study recorded the island over wash event that occurred and measured the island aquifer's response. The results showed that a small-scale over wash event caused an increase in the salinity of the freshwater lens. Furthermore, the study concluded that climate-related local sea level change would degrade freshwater resources and concluded that climate related local sea level change would degrade freshwater resources (Oberle et al. 2017). Furthermore, Chaudhari et al. (2021) evaluated the groundwater quality index using the weighted arithmetic method in the South-West zone of Surat city. The study analyzed the effects of seawater intrusion using MODFLOW and found that various factors contributed to the deterioration of water quality in Surat City. A higher salinity level was observed in areas with less rainfall. In addition, the study observed salt producing process at shallow depths (Chaudhari et al. 2021).

Previous studies have demonstrated that climatic changes significantly influence saltwater intrusion in the groundwater aquifer, therefore, contaminating the freshwater lenses. While there is a lot of literature available on groundwater salinization issues in PIDC, very few have discussed or investigated groundwater salinity levels in the Cook Islands. Hence, the major goal of this study was to analyze the groundwater salinity fluctuations in the low-lying volcanic island of Aitutaki, situated in the Cooks Islands. A major focus of the work was to highlight the current trends in freshwater depletion according to the different seasons using available data obtained in preexisting monitoring wells over a period of 23 years. It was envisioned that real field-scale in-situ monitoring data would help in establishing the status of groundwater in Aitutaki and enable a greater understanding of the groundwater salinization issues on the island.

In general, the significance of this study is three-fold. First, this study focuses on establishing groundwater salinity fluctuation patterns by analyzing groundwater quality data over a span of 23 years. It provides a stronger understanding of the saltwater intrusion phenomenon affecting groundwater resources in Aitutaki, Cook Islands. Having a comprehensive understanding of the status of groundwater system can help stakeholders better plan and manage the vital water resources and ensure groundwater retains its beneficial uses and stays usable for generations to come. Second, this study opens pathways for further scientific studies focusing on groundwater salinity to be conducted for similar low-lying aquifer in the Cook Islands as well as the pacific region. Lastly, the study presents the current status of groundwater salinity in the Aitutaki aquifer, which can aid policymakers in the Cook Islands to plan, develop and implement robust yet sustainable groundwater monitoring and management strategies. A robust groundwater monitoring and management system means a more efficient treatment process and an optimal response time when problems arise. This, in turn, improves water quality and simultaneously saves money. Overall, the importance of this study is to improve reliable groundwater planning and management in Aitutaki and protecting the aquifer from groundwater salinity problems in the future.

Methodology

Study area

The Cook Islands is a Polynesian group of islands located in the Pacific Ocean between latitudes 14° S and 22° S, and longitudes 159° W and 164° W (Fig. 1). The Cook Islands compromises of fifteen widely dispersed islands, surrounded by 1.8 million square kilometers of the Exclusive Economic Zone. The climatic condition in the Cook Islands is tropical in nature and is influenced by trade wind and two distinct seasons: the dry season from April to November and the wet season from December to March (International Groundwater Resources Assessment Centre 2016). Aitutaki is a low volcanic island with a total area of 16.8 km^2 and is the main island of Aitutaki Atoll in the southern Cook Islands, which is located approximately 250 km north of the country's capital Rarotonga. Aitutaki has a maximum elevation of 123 m and a total population of approximately two thousand people (Antoniou et al. 2018).

The average annual precipitation on Aitutaki in the past 66 years was 1877 mm. February is the wettest month of the year with 16 days on average over the last 29 years. July, August, and September had an average of 8 rainy days in the same period. The average annual temperature is 25°C (Antoniou et al. 2018) Aitutaki's coefficient of variation of rainfall is 23.8%, thus considering the average rainfall, the coral atoll lies within the low to moderate climate risk. Meteorological droughts periods on Aitutaki ranges from 2 to 28 months, with an average duration of 6 months and the frequency of occurrence is every 18 months on average (Antoniou et al. 2018).

Generally, Aitutaki is separated into three basic geological units. The majority of the basaltic volcanic lavas and pyroclastic are present in the northern hilly region (Binnes and Partners 1984). Coral fragments discovered in basaltic scoria show that this region was developed upon an earlier reef (Wood and Hay 1970). Nepheline basalt, tuff, scoria, and breccia exposures can be seen in the vicinity of Maunga Pu hill.

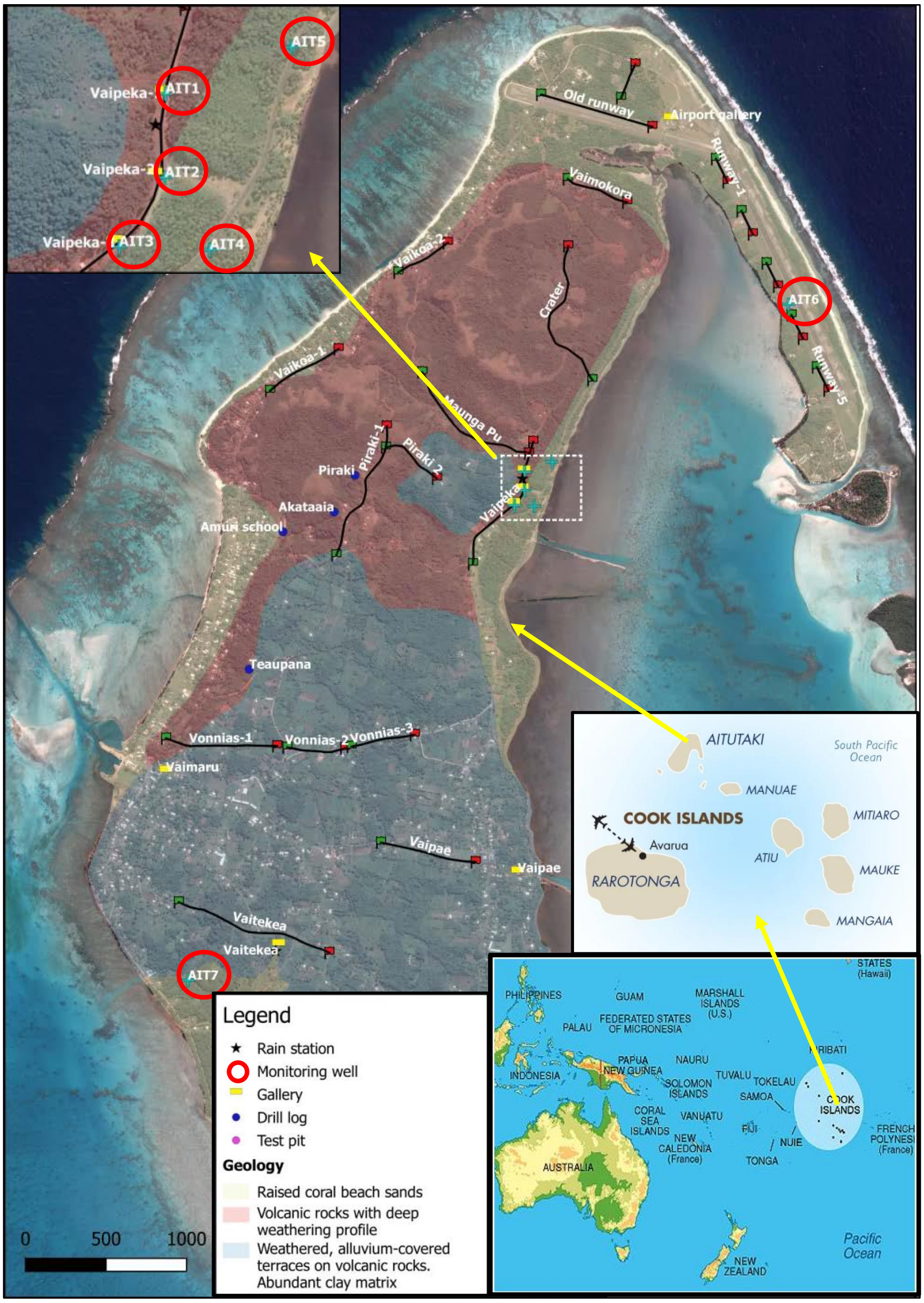

Fig. 1 Map of Aitutaki with location of monitoring wells

A worn profile comprising clay that extends up to 13 m in depth is described in the lithological logs from two boreholes drilled at Akataaia and Amuri School. The southern section of the island is where you'll find weathered alluvial volcanic strata that are primarily found. These strata have flat tops and form a succession of terraces (Waterhouse et al. 1978)

The presence of groundwater at depth in boreholes conducted in the northern hilly region suggests the existence of a basal aquifer where groundwater collects. There are coastal springs around the island, which means that groundwater from the basal aquifer empties into the ocean. Particularly in the region around the airfield, which resembles coral islands found in atolls, thin aquifers are found in the coral sands where fresh groundwater floats on top of seawater to create a shallow freshwater lens.

Current water supply in Aitutaki

Groundwater is the primary and most reliable source of freshwater in Aitutaki. Other sources of water include surface water and rainwater harvesting systems. Rainwater collected from household and community-buildings is stored in tanks to supplement their potable water needs. Some community building employs a secondary treatment system through Ultraviolet technology to improve the water quality of rainwater stored in the communal tanks (Antoniou et al. 2018)

Vaipeka, Vaipae, Tautau, Vaimaru, and Vaitekea are the six-groundwater infiltration galleries, which non-potable water resources are sourced from. The gallery locations are shown in Fig. 1. The Vaipeka gallery, which is operated by the Island Council, accounts for the biggest proportion of non-potable water sources on the Island. Two galleries exist in Vaipeka, Gallery 1 and Gallery 2. Both are located in proximity to each other. There are three pumping stations at the Vaipeka gallery, two of which are operational at the Vaipeka Gallery 1 whilst Vaipeka Gallery 2 is equipped with one pumping station. Water pumped from these three pumps is stored in water reservoirs (Piraki Tanks and Punganui Tank) before water is distributed to households via piped reticulation networks. The reticulated system is heavily dependent on weather conditions therefore, during dry seasons, communities suffer from a reduced water flow in their reticulated system (Antoniou et al. 2018).

Groundwater salinity data

Groundwater monitoring was conducted on existing monitoring wells, production galleries, and test pits known as AIT1, AIT2, AIT3, AIT4, AIT5, AIT6, and AIT 7. Electrical conductivity (EC) and temperature were measured through the sampling tubes installed on each monitoring well. A 12 V FLOWJET pump was used to pump groundwater to ensure that measurements were representative of depth.

Three Schlumberger Divers data loggers installed in selected production wells in Vaipeka Gallery 1 and 2 to record temperature, pressure, and conductivity changes in the groundwater over a 10-day period from 6 to 16 March 2018. Data obtained in 1996 and 2015 were obtained using similar method.

Using stainless steel wires, the data loggers were suspended at a depth below the water table. The loggers recorded data at 6 minutes interval. The water level and EC data were manually recorded at the beginning and at the end of the 10 days monitoring period to validate the reading from the loggers (Antoniou et al. 2018).

Results

Groundwater salinity fluctuations over the monitoring period

The groundwater salinity variations at respective monitoring wells during the monitored period of 1996, 2015 and 2018 are shown in Fig. 2. In this Figure monitoring wells AIT1, AIT2, AIT3, AIT4, AIT5, and AIT6 were analysed. AIT7 was excluded from the analysis because of inconsistency in obtained datasets (dataset from large periods was missing). Furthermore, the salinity data for February 1996 and September 2015 period was not available for monitoring wells AIT4 and AIT6, respectively.

The preliminary results for AIT1 as indicated by Fig. 2 depicts an increase in salinity levels in September 2015 and March 2018 at all the monitored depths. However, there was a decrease in salinity levels from 2015 to 2018 for all the monitored depths except 3 m. The highest salinity level was observed in September 2015 at depth 25 m. The salinity level in February 1996 was observed to be the lowest for all the depths. A notable increase in EC values were noted at the end of the dry season (Sep-2015). However, the EC values went below 1000 µS/cm at the end of the rainy seasons. Furthermore, the graph depicts an increasing trend of EC values at depths higher than 9 meters.

For AIT2, the groundwater salinity values obtained during September 2015 are observed to be higher at all the monitoring depths. The EC values during the end of the dry season were significantly higher in comparison with values obtained at the end of the rainy season. During the end of the dry season, it was observed that the EC values were more than 1000 µS/cm at all depths. For the monitoring period 1996 and 2018, the salinity values fluctuated with values obtained in 1996 were seen to be slightly higher at monitoring depths 3m, 6m, and 9m when compared to salinity levels at similar depths obtained during 2018.

For AIT3, a similar trend was observed for the monitoring period in 2015. Like AIT1 and AIT2, groundwater salinity data obtained at all depths were higher than the corresponding data obtained for 1996 and 2018. For AIT3, it is also observed that groundwater salinity values increase with increasing depths. Is also seen that groundwater salinity levels in Aitutaki were the lowest in 1996. This indicates that groundwater salinity levels are increasing. In addition, the data obtained from monitoring well AIT3 reveals that the EC values are significantly higher when compared to AIT1 and AIT2. Also, during the end of the dry season (Sep 2015), the EC value was more than 2000 µS/cm. However, at the end of the wet season in both the1996 and 2018 monitoring periods, the EC values were noted to be more than 1000 µS/cm.

For AIT4, the groundwater salinity levels were higher during the 2015 monitoring period. When compared to AIT1, AIT2, and AIT3, a notable increase in salinity levels was observed during both sampling periods. Also, a decrease in salinity levels was observed at the end of the rainy season of 2018. A significant reduction in salinity values is observed at depths of 9m, 12m, and 15m. Also, at the end of the dry season in 2015 the maximum recorded salinity level was observed to be 17520 µS/cm at a depth of 15 m. The minimum-recorded salinity level were 1543 µS/cm at a depth of 3 m. Likewise, at the end of the rainy season of 2018, the maximum and the minimum salinity values recorded was observed to be 11020 µS/cm at a depth of 15 m and 693 µS/cm at a 3m depth, respectively. The 1996 groundwater quality monitoring data was not available and therefore it could not be analyzed.

For monitoring well AIT5, it was observed that groundwater salinity levels at all the monitoring depths were highest during the 1996 monitoring period and lowest during the 2018 monitoring period. Decreasing trend Also, it was observed that salinity levels obtained for AIT5 were higher when compared to the values obtained at corresponding depths of AIT1, AIT2, and AIT3. At the end of the dry season in 2015, the maximum salinity level was observed to be 3450 µS/cm at a depth of 3 m and the minimum EC value of 1050 µS/cm was observed at a depth of 9 m. For data obtained in March 2018, which was the end of the rainy season, the maximum and minimum salinity level was 1951 µS/cm at 3m and 883 µS/cm at 9 m depths, respectively. The 2005 groundwater quality monitoring data was not available and therefore it could not be analyzed.

For AIT6, salinity data was recorded for depths ranging from 3 m to 22 m. For AIT6, the salinity values obtained during the monitoring period in1996, increased with the increasing depths. For the 2018 monitoring period, the salinity values increased with increasing depths until a depth of 18 m was reached, after which the salinity level dropped to 27867 µS/cm recorded at 22m. Similar fluctuation patterns were observed when considering the seasonality effect. At the end of the rainy season of 1996, the maximum recorded EC value was 46400 µS/cm at a depth of 22 m and the minimum recorded EC value was 870 µS/cm at the depth of

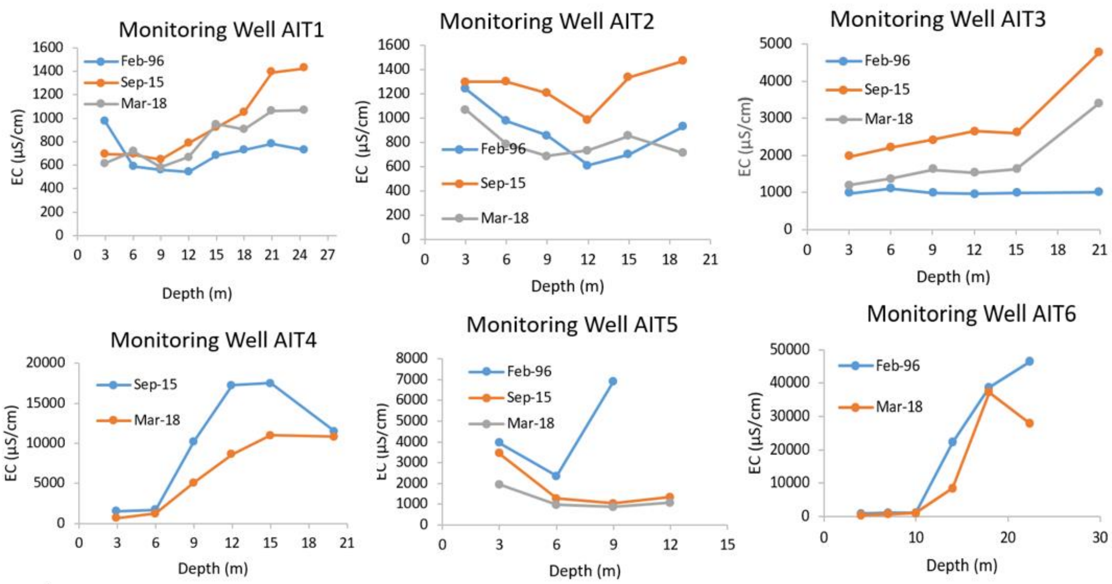

Fig. 2 Groundwater salinity variations at respective monitoring wells over the monitored period

4 m. Similarly, at the end of the rainy season of 2018, the maximum recorded EC value was 37167 µS/cm at a depth of 18 m and the minimum recorded EC values was 466 µS/cm at the depth of 4 m.

Groundwater salinity-depth analysis

Fig. 3 shows respective EC values obtained at different depths during the three-monitoring period. It is seen that at a depth of 3m, a higher salinity value for the monitoring period 2015 (end of dry period) is recorded in comparison with the end of rainy season results of 1996 and 2018. Monitoring well AIT5 shows significantly higher EC values as compared to other monitoring wells. Similarly, at a depth of 6m, the results obtained for the dry season show higher salinity values when compared to the two-monitoring period. However, at the monitoring well AIT5 data obtained at a depth of 6m from monitoring period 1996 shows a high EC value even during the end of the rainy season. As per Fig. 3, it is seen that at the depth of 9m, the EC values are significantly high at monitoring well AIT4. The highest EC value recorded at AIT4 is more than 10,000 µS/cm and it occurs during the end of the dry season i.e., September 2015. Similarly, at a depth of 12m, the maximum salinity level was observed to be more than 20000 µS/cm recorded at AIT6. This occurred at the end of the rainy season in 1996. Overall, high salinity values are observed at AIT4, AIT5, and AIT6 and this is observed at depths more than 15m. Monitoring wells AIT4 shows extremely high EC values when compared to other monitoring wells. At a depth of 15m, EC values obtained after the end of the dry season in 2015 are higher than that of the end of the rainy season data.

As depth increases the sampling or recording of data becomes undependable as observed at depth of 15 m. Results obtained at this depth only include that of AIT1, AIT2, AIT 3, and AIT4 which are located at the Vaipeka gallery. However, results from monitoring wells at AIT5, AIT6 and AIT 7 were not recorded and therefore excluded from the analysis. This may be attributed to the reliability of the sampling tools used and the depth of the groundwater aquifer.

Discussion

Seasonality effect on groundwater salinity

After the analysis of the preliminary data collected, it was observed that changing weather patterns or

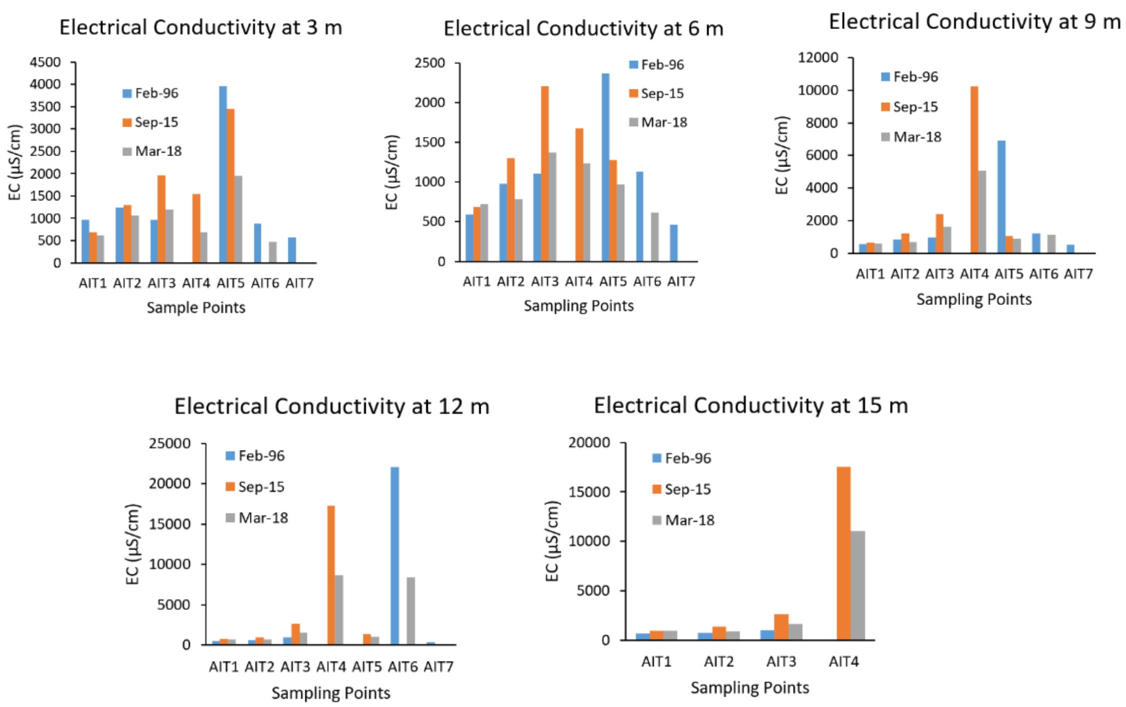

Fig. 3 EC values obtained at different depths during the three-monitoring period

changes in seasons have a direct impact on the salinity levels observed in Aitutaki. As shown in Table 1, the salinity level decreases at the end of each rainy season. However, it increases at the end of the dry season. This can be attributed to the fact that after the rainy season, the groundwater aquifer is replenished causing the water table to rise. Also, it is observed that during the dry season, salinity levels increase. This can be because of over pumping of the groundwater during this period. It is established that during groundwater pumping, the water table drops causing the hydraulic gradient between freshwater and seawater to shift towards the sea. This triggers the denser seawater to encroach inland and contaminate fresh groundwater.

The influence of the location of monitoring bores

The analyzed groundwater data also reveals that the location of the borehole is a vital factor to consider when installing groundwater quality monitoring bores. It is observed that all monitoring bores that are near to the shoreline have recorded high salinity values. For example, as shown in Fig. 1, AIT4, AIT5 and AIT6 are closest to the shoreline, thus the salinity levels are high in these wells when compared to AIT1, AIT2, and AIT3, which are located further inland. AIT4 and AIT5 had the highest salinity levels when compared to all the monitoring wells. This is attributed to their closeness to the shoreline in relative comparison to the location of other monitoring wells. As shown in Table 1, AIT4, and AIT5 groundwater recorded the highest EC values at all depths when compared to AIT1, AIT2, and AIT3. Based on the analysis, it could be stated that locations of monitoring wells play a critical role and should be carefully chosen during field investigations and assessments. It is highly likely that if a monitoring well is installed near the shoreline, the water quality at that site may be of higher salinity content. This information is especially important to island communities as they are mostly surrounded by ocean and deciding on a suitable location for installing a groundwater quality monitoring well is challenging.

The preliminary in-situ groundwater quality data analyzed in this study demonstrate that groundwater salinity levels in Aitutaki are fluctuating. The study indicates that climatic conditions and the location of aquifers play a significant role in determining groundwater salinity variations in low-lying pacific island countries. To further support the claim made in this study and to observe a more definite trend, robust groundwater quality monitoring and modeling efforts are needed needs for Aitutaki. In addition, the use of modern technology for data collection, management, and 3D groundwater modeling needs to be considered. Automatic data loggers and groundwater monitoring tools are needed to ensure high reliability in data collection. Also, sustainable management of groundwater resources must be made a priority in the Cook

Table 1 Maximum and minimum salinity (EC) values obtained during the monitoring period

Location	Season	Salinity Level (µS/cm)		Depth (m)	
		Minimum	Maximum	Minimum	Maximum
AIT1	Feb 1996 - Rain Season	545	970	12	3
	Sep 2015 – Dry Season	689	1425	6	25
	Mar 2018 – Rain Season	589	1068	9	25
AIT2	Feb 1996 - Rain Season	610	1240	12	3
	Sep 2015 – Dry Season	987	1468	12	19
	Mar 2018 – Rain Season	686	11068	9	3
AIT3	Feb 1996 - Rain Season	960	1110	12	6
	Sep 2015 – Dry Season	1959	4760	3	25
	Mar 2018 – Rain Season	1372	3403	6	25
AIT4	Sep 2015 – Dry Season	1543	17520	3	15
	Mar 2018 – Rain Season	693	11020	3	15
AIT5	Sep 2015 – Dry Season	1050	3450	9	3
	Mar 2018 – Rain Season	883	1951	9	3
AIT6	Feb 1996 - Rain Season	870	4640	4	22
	Mar 2018 – Rain Season	460	37167	4	18

Islands. The island is highly dependent on the groundwater and therefore, careful groundwater abstraction strategies and policies are needed. Awareness on water utilization is needed especially during the dry season. Regulatory authorities need to employ proper water management plans to maintain a consistent water supply and good water quality all year round.

In the future, the authors have planned to further develop this research project and conduct a robust groundwater salinity monitoring assessment by including data from more boreholes within the aquifer. The authors have also planned to investigate water salinity contents in nearby atolls in the Cook Islands to establish a correlation between water quality parameters with locations. Moreover, a 3-dimensional groundwater flow and transport simulation models for the Aitutaki groundwater system will be developed. This will function as a digital twin and help in simulating, forecasting, and developing robust groundwater management tools and strategies. Furthermore, machine learning-based forecasting model can also be developed using available datasets for groundwater salinity predictions. In recent years, machine learning- based groundwater quality forecasting models have been used in several water resources management applications such as (Lal and Datta 2018-19) and have proven to be important. Similar studies can be conducted for the Aitutaki region to ensure reliable and efficient monitoring, planning, and management of the groundwater resources.

There are also a few limitations involved in the present work. Firstly, the study has been conducted over the span of 23 years at various sampling points within Aitutaki. The reliability of the datasets used in this study is dependent on the reliability of the sensors and data loggers used. Malfunctioning of the sensors and data loggers are common in hydrogeological studies. Secondly, natural disasters, bad weather patterns, flooding, and storm inundation were a few factors that made the collection of groundwater quality parameter datasets difficult. Lastly, the conclusion drawn in this study is from the analysis of limited number of datasets obtained. To get a robust and thorough insights into the groundwater salinization process in coastal low-lying islands, there is an urgent to have more in-depth field assessment, data analysis, and saltwater intrusion modeling investigations.

Conclusion

This study examines the fluctuation in groundwater salinity levels at various depths of six boreholes located in Aitutaki, Cook Island. Aitutaki aquifer (located in the Cooks Islands) was chosen for this study due to several reasons. Firstly, Aitutaki atoll has been highlighted to experience water supply challenges due to its geological location and isolation. In addition, Aitutaki is a low-lying atoll whose primary water source is derived from groundwater, which is threatened by saltwater intrusion. Secondly, there has been a limited number of scientific studies on groundwater salinity conditions in the Cook Islands. To fill this research gap, we undertook this study to find out about the current status of the Aitutaki aquifer, which serves as a major source of freshwater for the people of the Cook Islands. It was also envisioned that findings from this study could be used by policymakers and researchers for small pacific islands sharing similar challenges.

In-situ water quality monitoring was conducted at various monitoring wells at the end of the rainy season of February 1996, at the end of the dry season of September 2015, and at the end of the rainy season of March 2018. The study found that climatic condition plays crucial in the variation of salinity levels. At the end of the dry season, salinity levels are higher at lower depths. However, at the end of the rainy season, the salinity level increases as depth increases. In addition, the study validates that the location of the groundwater abstraction well, or boreholes is also vital as it is seen that those wells that were situated closer to the shoreline experienced increased salinity levels when compared to those sampling points that were further inland. The most alarming conclusion drawn from this study is that groundwater salinity is increasing in the Aitutaki aquifer, and there is an urgent need for proper saltwater intrusion mitigation measures, robust groundwater abstraction policies and overall sustainable management. This study provides baseline information on the status of groundwater salinity levels in Aitutaki. This information could be used as a reference when planning further groundwater monitoring and management investigations in the area.

Competing interest This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors declare that they have no competing interests.

Authors contributions TDK is responsible for data analysis, drafting, and reporting. AL is responsible for report drafting, final draft checking, and proof reading.

Acknowledgments The Authors are grateful to the Pacific Community (SPC) for allowing the partial use of the report titled "Strengthening water security of vulnerable island groundwater investigation Aitutaki, Cook Islands."

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