Pacific Community
Communauté du Pacifique

KIRIBATI INTERNATIONAL WATERS
RIDGE TO REEF PROJECT

BONRIKI & BUOTA WATER RESERVES
WATER QUALITY SAMPLING/ MONITORING DATA
APRIL 2020 – JULY 2021

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ABBREVIATIONS

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
DLT	Dry Litter Technology
DO	Dissolved Oxygen
EC	Electrical Conductivity
ECD	Environment and Conservation Division
EPA	Environmental Protection Agency
IW	International Waters
KI	Kiribati
MELAD	Ministry of Environment, Lands and Agricultural Development
MHMS	Ministry of Health and Medical Services
MISE	Ministry of Infrastructure and Sustainable Energy
MPN	Most Probable Number
R2R	Ridge to Reef
RPCU	Regional Programme Coordination Unit
TN	Total Nitrogen
USP	The University of the South Pacific

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1. INTRODUCTION

The Kiribati International Waters Ridge to Reef (IW R2R) Project Bonriki & Buota Water Quality Monitoring Plan aims at measuring the health of the Bonriki/ Buota Water Reserve by monitoring levels of contamination. A copy of the monitoring plan can be accessed on https://www.pacific-r2r.org/sites/default/files/2020-08/IWR2R_Water_Quality_Monitoring_Plan_Kiribati.pdf.

The first baseline study and collection of data was carried out in February 2020 after a training on water quality and the use of water test kits delivered by the SPC Regional R2R Project. The results and report on that study can be accessed on https://www.pacific-r2r.org/sites/default/files/2020-06/Kiribati_Water_Quality_Training_Report.pdf

The Kiribati IW R2R Project is mainly focused on addressing the municipal waste problem and its impact on the underground water lenses. The project is investing resources to construct at least 30 dried litter piggery units for use by the communities living around the Water Reserve. The aim is to contain the pigs' wastes and use the dry leaves with wastes in the pig pens for garden composting.

As required under the R2R Pacific Regional Program, all interventions, research, and work undertaken under this program must be gender and socially inclusive. Thus, there were efforts to include women and youth in water quality testing and monitoring, and pig waste management.

Consequently, the project builds capacity for men, women, youths, and all sectors of the communities for sustainable piggery waste management, improved information management, and reduced pathogen and nutrient offload into the receiving environment of aquifers and underground water in the Reserves. The project target is a 5% reduction in total nitrogen from nutrient and pathogen loads from pig effluent discharging directly into the receiving environment. This is equivalent to 955 kg TN per year and to be achieved through construction of 30 DLT (dry litter technology) piggeries in demonstration sites (Table 1) by end of the KI R2R Project. The DLT piggeries are in the peripheries of the communities.

Table 1: Outcome and targets of the construction of 30 DLT (dry litter technology) piggeries.

Country	Outcome	Targets
Kiribati **(i) Bonriki demo site** **(ii) Buota demo site**	Improved domestic pig pen operations catalysed via piloting of locally appropriate methods and affordable materials for on-site pig waste management 30 household designed pig pens to demonstrate/trial the dry litter technology. Any reference to households, include the participation of men, women, youth, and children. Use as the control site	Sustainable pig waste management approaches demonstrated through conversion of 10% of households from near shore wash-down pig pens to dry-litter composting systems. Demonstration work included women, youth, and all community members. 70% household piggeries converted to dry-litter composting systems 70% household piggeries converted to dry-litter composting systems

Country	Outcome	Targets
	Improved options for sustainable on-site waste management of domestic pig pens	Reduction of TN through adoption of dry litter serving over 50 houses in demonstration site of Bonriki water reserve, and over 20 houses in Buota water reserve.
	Environmental and public health safeguarded via targeted reductions in nutrient and pathogen contamination of coastal areas	Nutrient and pathogen loads from pig pen effluent discharging directly into the receiving environment reduced by 10% through demonstration of dry-litter composting systems
	National uptake of sustainable pig waste management methods stimulated through community awareness and training	Proportion of target community members with awareness of and technical skills to successfully implement sustainable pig-waste management methods increased to 30% through innovative participatory techniques. Awareness and skill building work included men women, youth, and other members of the communities.

There is also an opportunity to maintain the level of skills of relevant line ministries such as MISE (Ministry of Infrastructure and Sustainable Energy), the MHMS, MELAD (ECD) and entities such as USP (The University of the South Pacific) through collaboration and coordinated efforts in the monitoring of water quality of boreholes and wells in the water reserves. This water quality monitoring program concurrently runs in conjunction with similar water quality monitoring programs such as the ones overseen by the Ministry of Health and Medical Services (MHMS) and MISE.

In 1999, the UNESCO reports on a case study at the Bonriki reserve on ground water recharge in low coral islands which identifies issues and conflicts on water resource management with such also reference to increasing houses of more than 30 households living edge to the reserve. Lack of the government intervention to protect the water reserve resulted with increase of houses in 2007 as reported on the Kiribati hot spot analysis with a count of households within the Bonriki area at the edge of the land to the water reserve area of 150 households (Government of Kiribati 2007). This study does not conduct survey on the number of households in the water reserve.

The prolonged actions of the Government to address eviction of settlements within the reserve area resulted with increasing number of encroachments to the water reserve area posing a number of concerns with contamination of the groundwater.

2. SAMPLING STRATEGY

2.1 Scope

The water quality sampling was conducted and confined to the Bonriki Water Reserve and the Buota Water Reserve from April 2020 – July 2021. This sampling is confined to boreholes and selected wells and does not extend to quality of water after it has been treated and transported to households on the island.

2.2 Frequency/Schedule/Duration

The sampling and water quality assessment was done quarterly in the months of April 2020, July 2020, April 2021, and July 2021. Each sampling and assessment of all the 22 sites are expected to occur within four (4 weeks) noting unforeseen circumstances that may delay work. Details of sampling are set out in Sauni et al., (2020).

2.3 Sampling Sites and Design

The Bonriki and Buota Water Reserves are geographically separated but in relative proximity to each other. The Bonriki Water Reserve is in South Tarawa, and Buota Reserve in North Tarawa. A narrow channel that provides for the exchange of water mass between the lagoon and the ocean side, separates South and North Tarawa. While similar in most respects, the two reserves do not necessarily share the same characteristics of aquifers and underground water lenses. The communities living in the periphery or close to both reserves are also different. In terms of land use it is more intense in Bonriki than Buota. However, in terms of vegetation cover, Buota is denser than Bonriki. The construction of 30 DLT (dry litter technology) piggeries is on South Tarawa, in proximity to the Bonriki Water Reserve. On this basis, the Bonriki Water Reserve will be treated as the target site, and the Buota Water Reserve as the control site. Accordingly, water samples will be collected from 22 sites[1] and 2-replicate water samples per site, as follows (Table 2, Figures 1 & 2): -

i. 10 boreholes and 4 wells in Bonriki; and,

ii. 4 boreholes and 6 wells in Buota

[1] Note that there are 9 boreholes in Buota and 25 in Bonriki Water Reserve, and not all are functional or operational in terms of ability to extract water samples through the monitoring tubes; 5 boreholes in Buota are not functional

Table 2: Water quality monitoring sites

Site location	#	Code	Site Type (borehole or well)	Brief Description of the site location	GPS Coordinates	
Buota	1	BU2	Borehole	North side of reserve toward Abatao	1° 23' 46.3”	173° 7' 41.1''
	2	BU4	Borehole	South side of reserve close to residential area	1° 23' 35.3”	173° 7' 45.1''
	3	BU12	Borehole	Close to residential area toward the Buota Bridge	1° 23' 41.1”	173° 7' 36.0''
	4	BU13	Borehole	Middle of reserve to Abatao side	1° 23' 36.4”	173° 7' 56.9''
	5	TBC	Well	TBC	TBC	TBC
	6	TBC	Well	TBC	TBC	TBC
	7	TBC	Well	TBC	TBC	TBC
	8	TBC	Well	TBC	TBC	TBC
Bonriki	1	BN1	Borehole	North side of North reserve near intersection of ocean road and northfrom PUB compoun	1° 23' 12.7”	173° 8' 48.2''
	2	BN2	Borehole	≈ 1-2 meters from small cemetery, close to few houses	1° 23' 9.0”	173° 8' 43.6''
	3	BN7	Borehole	≈2 meters from road, near residential area		
	4	BN11	Borehole	≈ 1 meter from house	1° 23' 16.8”	173° 8' 24.3”
	5	BN13	Borehole	≈40meters from >7 houses	1° 22' 57.8”	173° 8' 59.6”
	6	BN15	Borehole	≈4 meters from houses	1° 23' 4.7”	173° 8' 51.0”
	7	BN19	Borehole	≈4-5 meters from few houses, close to pond		
	8	BN20	Borehole	Close to few houses >4		
	9	NB23	Borehole	≈ 10 meters from cemetery		
	10	BN24	Borehole	≈ 50 meters from cemetery	1° 23' 1.3”	173° 8' 56.1''
	11	W1	Well	Well at BN15	1° 23' 4.7”	173° 8' 51.0”
	12	W2	Well	Well at BN20	TBC	TBC
	13	W3	Well	Well at BN19	TBC	TBC
	14	W4	Well	Well near BN1	TBC	TBC
	15	W5	Well	Well near house ≈ 1-2 meters away from water reserve mark	TBC	TBC
	16	W6	Well	Well		

Figure 1: Locations of water quality monitoring sites at Bonriki, Tarawa

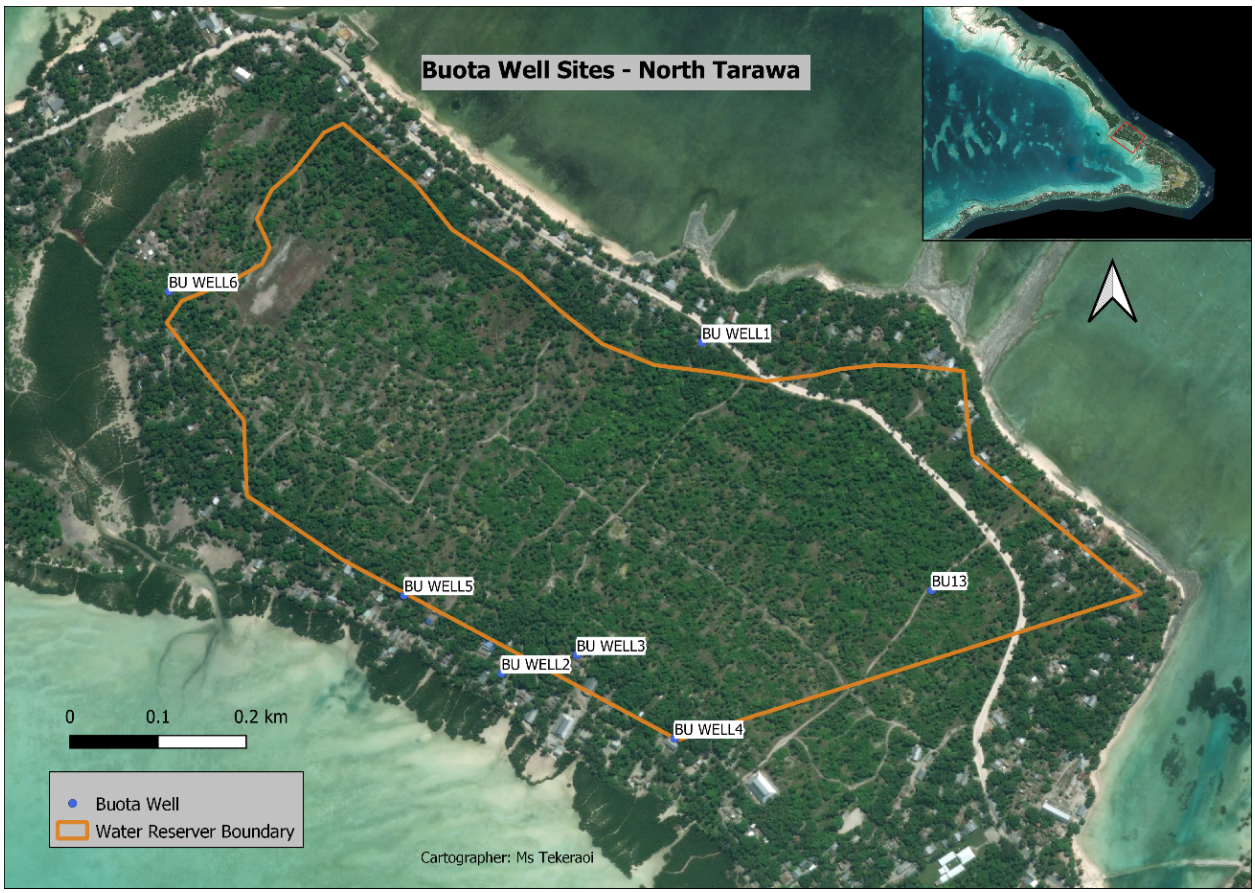

Figure 2: Locations of water quality monitoring sites at Buota, Tarawa

2.4 Water Quality Parameters[2]

- pH.
- Conductivity (salinity).
- Dissolved Oxygen (DO)/Oxygen-Reduction Potential (ORP)[3].
- Temperature.
- Nutrients (nitrate, nitrite, phosphate, and ammonia).
- Biological Oxygen Demand (BOD).
- Microbiology (faecal coliforms, *Escherichia coli*).

3. MATERIALS AND METHODS

3.1 Field Measurements

The following measurements were undertaken at project sites including – pH, conductivity, Dissolved Oxygen (DO), ORP, temperature. These tests are conducted using the YSI professional multi-meter and test kits. The methods are as follows (also see details in Anon., 2019): -

The MISE (Ministry of Infrastructure and Sustainable Energy) method was followed to extract the water from the boreholes and wells (Sauni et al., 2020).

Approximately 500mL of water was attained into site labelled bottle, for microbial testing and put in the cooler box. The MHMS (laboratory department) sampling protocol was followed to collect the sample.

The YSI multimeter was placed into the remaining sample water. It was ensured that all the probes were fully submerged, and samples being tested were catalogued and programmed correctly into the multimeter. The numbers on the YSI multimeter screen were allowed to stabilize and then the test was run, and the readings were recorded.

- The multimeter was removed from the sample water and dried out before placing back in carry bag.

3.2 Equipment (checklist)

- YSI, sample bottles, labels & pens, sampling form.
- Consult the list in Attachment 1.

3.3 Micro-sampling and Laboratory Measurements

The measurements were undertaken in laboratory which included the microbial test – *E. coli* and faecal coliform, nitrate, nitrite, phosphate, and ammonia. The method was as follows.

- A sample of 500 ml of water was poured out into a labeled storage bottle for microbiology, and nutrient (phosphate, nitrate, ammonia, and nitrite) [Attachment 2, 3, 4, 5 respectively] test, and were placed directly in a cooler.

[2] As reported in the Kiribati Water Quality Training Report (2020)

[3] Pacific IW Ridge to Reef Project Water Quality Monitoring Guide (2019)

- For microbiology test – sterilized sampling bottles were prepared by MHMS (Ministry of Health and Medical Health Services) laboratory and collected prior sampling collection. (Note: the laboratory was informed 1 day prior the sampling day).
- For nutrient test, refer to Attachment 2, 3, 4 and 5.
- The YSI multimeter was placed into the remaining sample (in the basket), and it was ensured that all probes were fully submerged. Numbers were allowed to stabilize and before running the test.
- The reading was recorded and at the same time it was saved on the multimeter.

3.4 Guidelines/Standards/Evaluation Criteria

Use existing standard accessible and available at the WHO & ANZECC, or local standards where such standards have been approved and gazette for use by the Kiribati Government.

Table 3: Guideline values for determinands/physical or chemical stressors for ecosystems like underground water lenses or aquifers.

Determinands	Guideline Value (GV)	Max. acceptable value (MAV)	Unit	Remarks	Source
Ammonia (NH_4)	0.1		mg/ L	aesthetic	(ANZECC & ARMCANZ, 2000)
	10.0		µg/ L		ANZECC & ARMCANZ (2018)
pH	7.0 – 8.5			< 8 preferred; aesthetic	ANZECC & ARMCANZ. (2000)
	6.0 – 8.0			upper & lower limit	ANZECC & ARMCANZ (2018)
Turbidity	2.5		NTU		(ANZECC & ARMCANZ, 2000)
[4]Nitrate, short-term		50	mg/ L	Inorganic	ANZECC & ARMCANZ (2018)
Nitrite, short-term		0.2	mg/ L	Inorganic	ANZECC & ARMCANZ (2018)
Nitrite, long-term		3.0	mg/ L	Inorganic	ANZECC & ARMCANZ (2018)
Nitrite	10		µg/ L	Default trigger value	ANZECC & ARMCANZ (2018)

[4] Results of nutrient analyses can be reported in two ways – as the whole compound or as the principal element in the compound. For example, nitrate may be reported as nitrate (NO3) or nitrate as nitrogen (NO3-N). When assessing results against guidelines and standards, or when comparing data from different sources, it is important to compare like with like and convert the results if needed.

Determinands	Guideline Value (GV)	Max. acceptable value (MAV)	Unit	Remarks	Source
[5]Salinity	90 - 900		mg/ L	Lakes, reservoirs wetlands; nutrient concentration	ANZECC & ARMCANZ (2018)
Phosphate	<0.1		mg/ L	Freshwater farm species	ANZECC & ARMCANZ (2000)

Table 4: Biochemical reactions and corresponding ORP values

Biochemical Reaction	ORP, mV
Nitrification	+100 to +350
cBOD degradation with free molecular oxygen	+50 to +250
Biological phosphorus removal	+25 to +250
Denitrification	+50 to -50
Sulfide (H_2S) formation	-50 to -250
Biological phosphorus release	-100 to -250
Acid formation (fermentation)	-100 to – 225
Methane production	-175 to - 400

Source: (https://www.ysi.com/parameters/orp-redox)

[5] Default trigger value for electrical conductivity of water that increases/ decreases with salinity (EC, salinity) varies between places. The unit of measurement for conductivity is siemens (S) per unit of length of water that the current is passed through. The Kiribati DC (Development Coordination) adopted a salinity threshold of 1,500 micro siemens per centimetre (µS/cm) as the acceptable upper limit for portable use of water. Higher values than the threshold is considered unacceptable for potable use of water pumped from the Bonriki Water Reserve Treatment/ Storage facility.

4. RESULTS

As per the Kiribati Water Quality Training Report (Sauni et al., 2020), the initial preliminary baseline sampling found that water samples could be taken at any depth for testing. The report concluded that there was no significant difference in readings between depths.

4.1 Assessing Physical Parameters Against Guidelines & Standards

The dissolved oxygen (DO) measured in the monitoring boreholes and wells were mostly within the range 0.38 mg/L and 3.975 mg/L across most of the boreholes and wells except for Bonriki borehole BN13 which recorded a reading of 29.465 mg/L (Figure 3). This trend was also observed in the preliminary baseline readings in March 2020 with regards to BN13 (Attachment 6A). All the boreholes and wells were not within the threshold DO (6 mg/L) where all boreholes (except for BN13) had DO readings less than 6 mg/L.

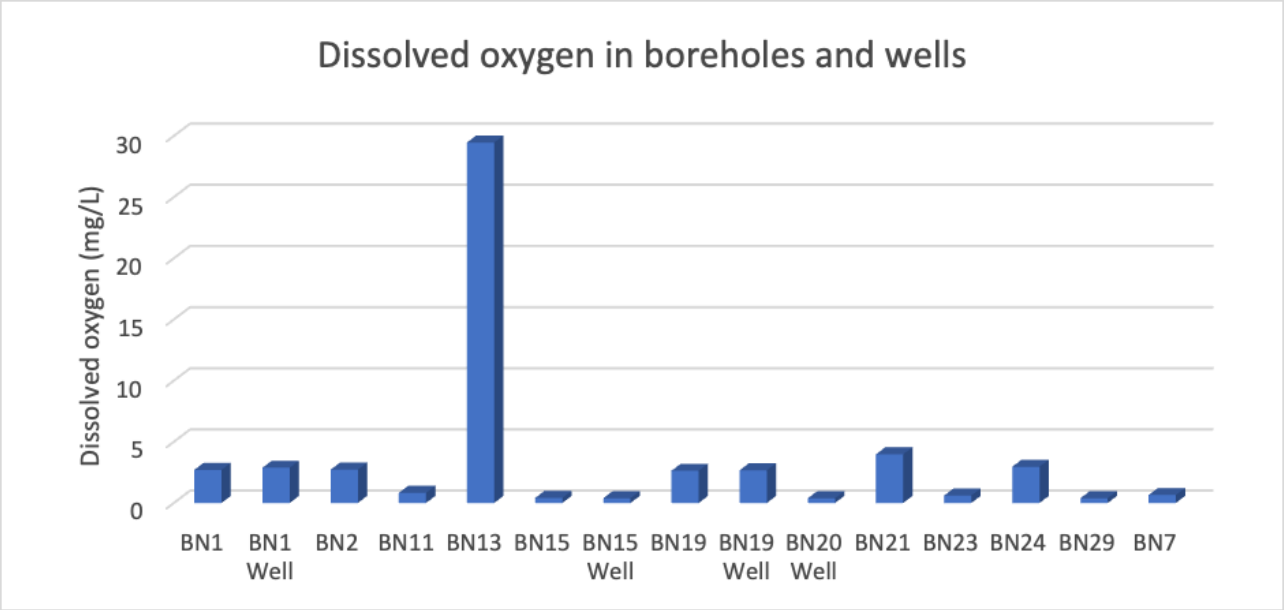

Figure 3: Dissolved oxygen in boreholes and wells.

The upper and lower limit for the pH threshold is 6.0 – 8.0. The pH level in boreholes BN1, BN2, BN13 and BN19 averaged a pH value of 7.66 whereas boreholes BN7, BN11, BN15, BN21, BN23, BN24 and BN29 averaged a pH value of 3.68 (Figure 4). The wells in Bonriki namely BN1, BN15 and BN19 showed similar readings as their respective boreholes (i.e., boreholes BN1, BN15 and BN19) and BN20 (well), had a reading of 3.49. This shows that 9 out of the 15 readings were below the threshold and were acidic in nature. Compared to the preliminary baseline findings (Attachment 6A), BN21 is the only major difference in change between the current sampling and the preliminary baseline readings and had doubled the pH values (from pH of 4 to 8).

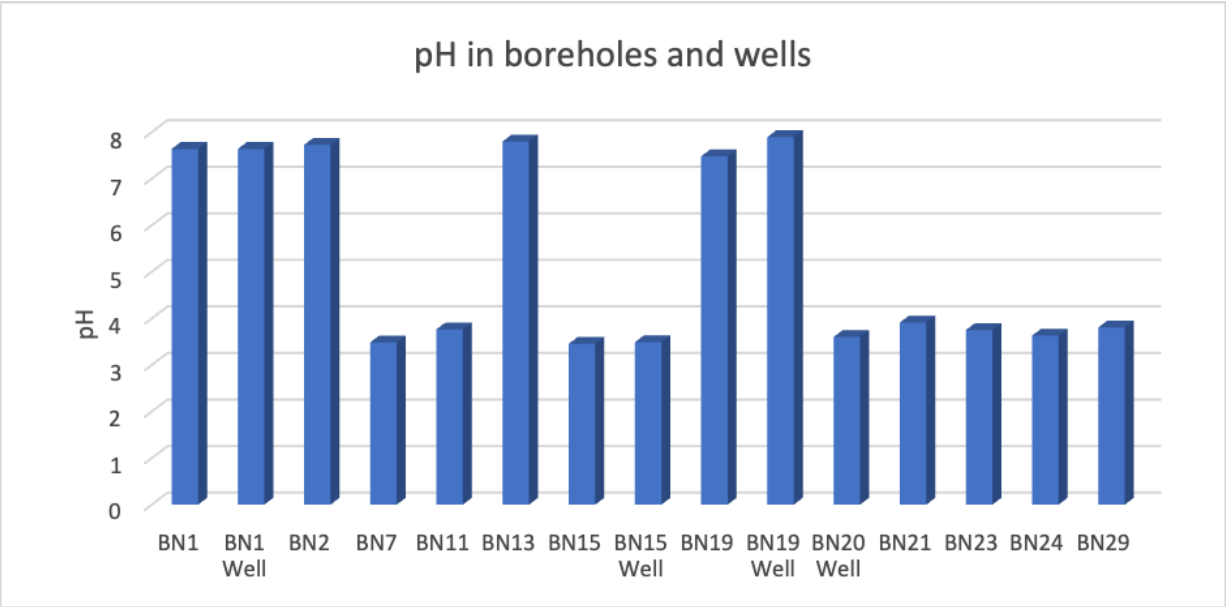

Figure 4: pH readings in boreholes and wells

The ORP readings consisted of positive and negative values. The ORP readings in the Bonriki boreholes were positive in BN23, BN24 and BN29. The negative values of ORP readings from boreholes in order from highest to lowest were BN19 followed by BN11, BN15, BN7, BN2, BN13 and BN1. The BN20 and BN21 boreholes did not have any readings.

The order from most negative to least negative ORP readings in Bonriki wells were BN1, BN19 and BN15. BN20 was the only well in Bonriki that was positive. The Buota well that was sampled (BU Well1) did not have any ORP readings (Figure 5).

The ORP readings were not lower than -100 mV and stayed within a range of -11.55 mV to -94.6 mV. Referring to Table 4, BN1, BN2, BN7, BN13, BN23, BN15 Well, BN19 Well and BN20 Well fall within the biochemical reaction of denitrification (+50 mV to -50 mV). BN11, BN19 and BN1 Well had higher values which fall within the biochemical reaction of sulfide (H_2S) formation. BN24 and BN29 fall within the biochemical reaction of biological phosphorus removal (+25 mV to +250 mV).

In order of number of sites, majority of the sites sampled for ORP were undergoing denitrification, followed by sulfide (H_2S) formation and then phosphorus removal.

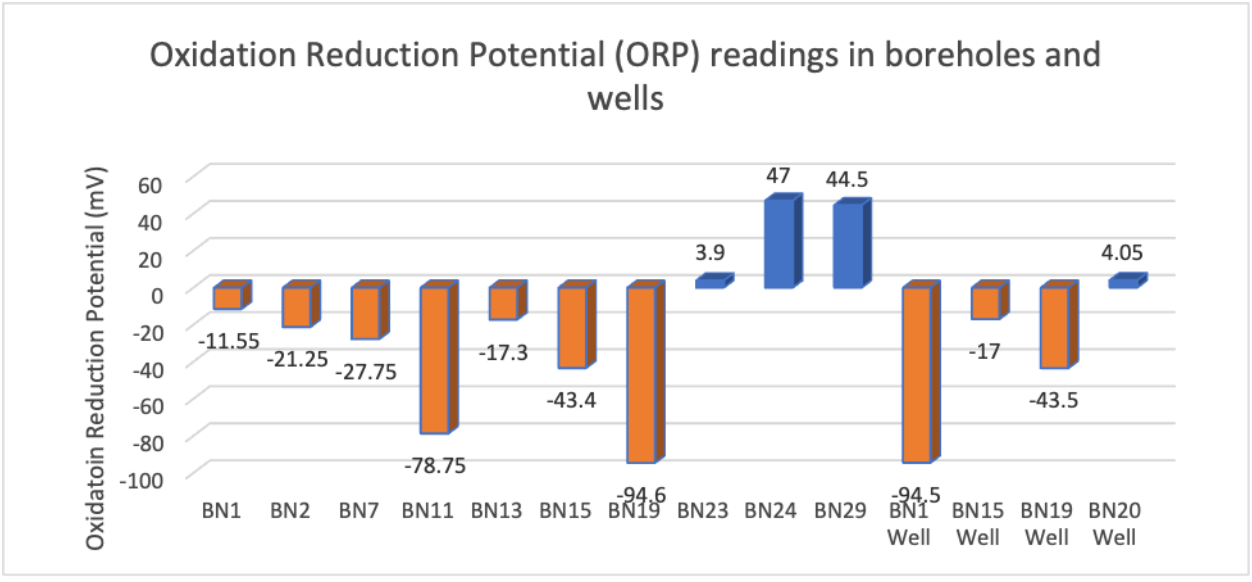

Figure 5: Oxidation Reduction Potential (ORP) readings in boreholes and wells.

There was no clear trend seen regarding conductivity borehole and well readings (Figure 6). The highest recorded conductivities were 845.5 µS/cm and 893 µS/cm for well BN19 and borehole BN19 respectively while the lowest reading was 177.45 µS/cm at borehole BN29. The conductivity readings vary between those values across all sampled boreholes and wells with no clear trend, except that boreholes have similar conductivity readings with their respective wells (i.e., borehole BN19 will have similar readings to well BN19). The Kiribati DC-adopted salinity threshold of 1500 µS/cm is the acceptable upper limit for potable use of water and the reading in the current sampling falls below that (it is also noted that the typical value for potable water is 50-500 µS/cm and freshwater is <1500 µS/cm). In terms of conductivity, it is suggested to continue monitoring during the dry and rainy season to ascertain any important and useful changes/trends (Attachment 6B).

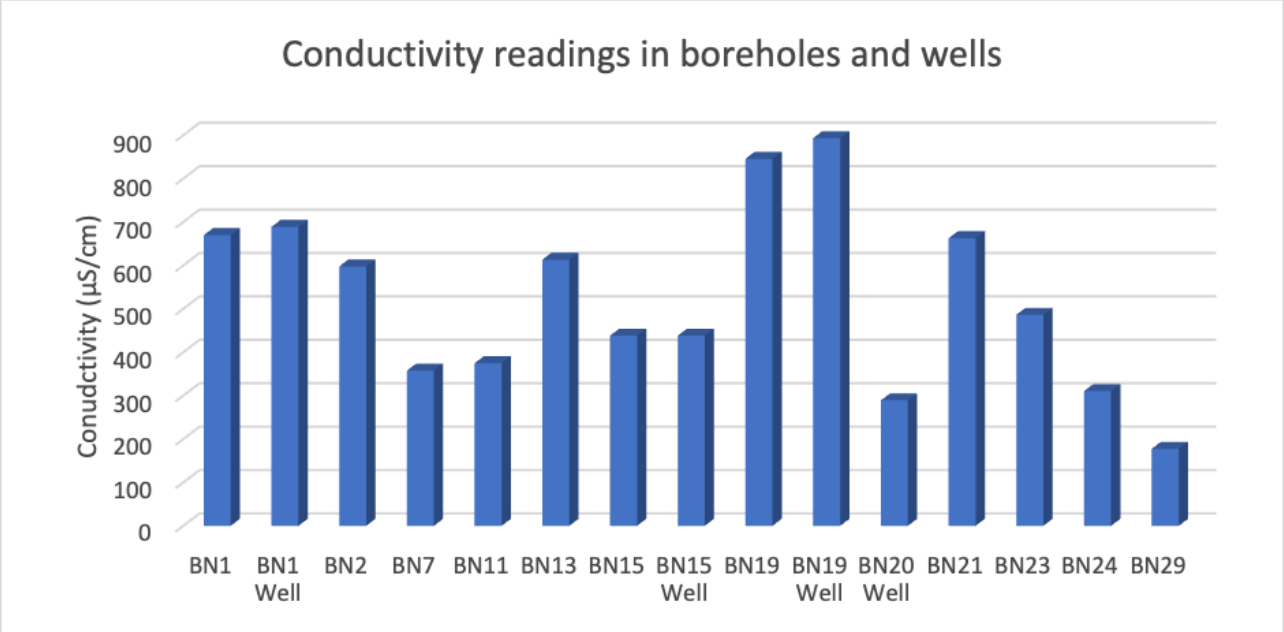

Figure 6: Conductivity readings in boreholes and wells

4.2 Assessing Nutrients (Nitrites, Nitrates, Ammonium and Phosphates) Against Guidelines and Standards

All the nitrite readings, compared to ammonium readings, across all boreholes either recorded lower readings or recorded 0 mg/L. BN7, BN11, BN23 and BN29 recorded 0 mg/L of nitrites. There was no evidence to suggest that lower or 0 mg/L of nitrite affected ammonium readings (e.g., nitrite to ammonium ratio of BN2 compared to BN7) (Figure 7). The nitrite readings in the boreholes in the current report have decreased on average compared to the preliminary baseline readings in March 2020 (Attachment 6C). The common source of nutrient pollution sources identified around the water reserve include human (open defections) and animal waste, inputs from phosphate from washing, and from the garden (organic compost).

Ammonium was recorded in all boreholes and on average was significantly higher in content than nitrites. Contrast to the corresponding nitrite readings, ammonium was at its highest readings in BN11 and BN19.

BN7, BN11, BN23 and BN29 had zero readings for nitrite and BN15, BN20 and BN24 showed readings that were below the default guideline values of 0.2 mg/L (ANZECC & ARMCANZ, 2000; ANZECC & ARMCANZ, 2018). However, all boreholes had readings that exceeded the 0.1 mg/L threshold value for ammonium (ANZECC & ARMCANZ, 2000; ANZECC & ARMCANZ, 2018).

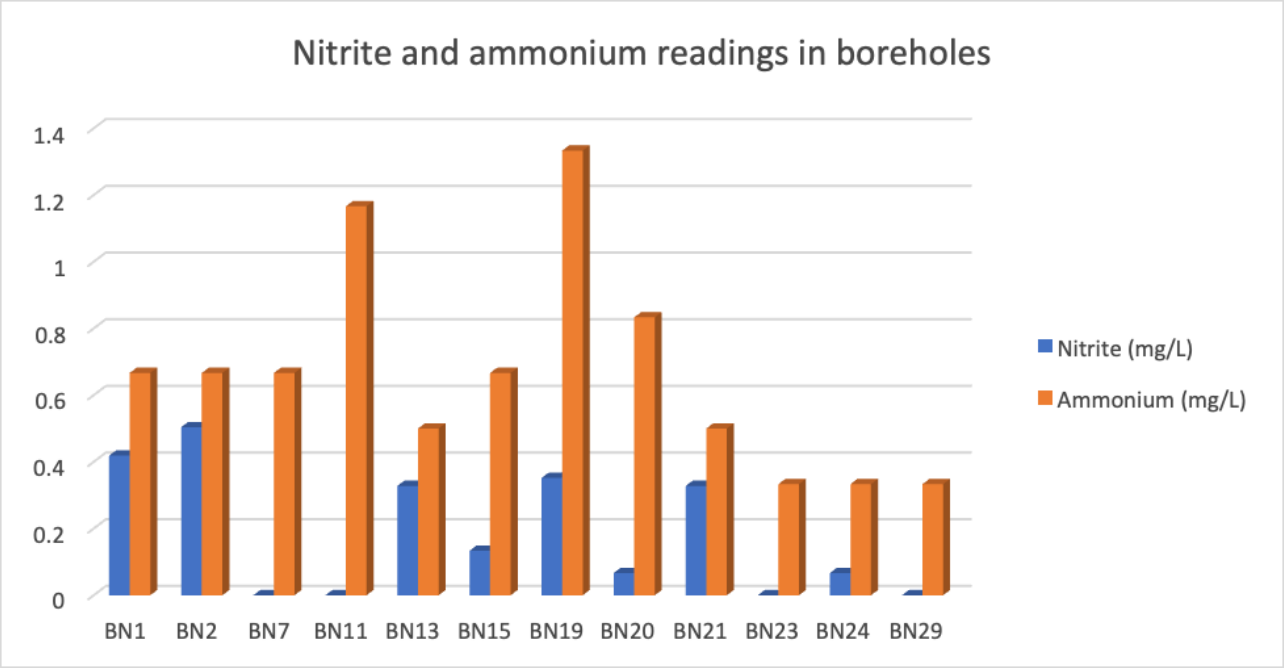

Figure 7: Nitrite and ammonium readings in boreholes

As seen in the Bonriki boreholes (except for the well at BN15 which was not that much of a difference between nitrite and ammonium readings), the corresponding wells had the same trend of having a significantly higher amount of ammonium readings compared to the nitrite readings.

The only data collected for Buota was a well that recorded more than twice the amount of nitrites in the other wells in Bonriki (i.e., BU Well1 in Buota had twice the amount of nitrites as wells in BN1, BN15, BN19 and BN20). The ammonium reading however was the 4th highest amongst the total wells sampled (Figure 8). Compared to the preliminary baseline study in March 2020, there was an increase in nitrate readings in the current sampling but no apparent difference in ammonium readings in the well in BN20 (Attachment 6C).

The well in BN15 did not exceed the nitrite default guideline value of 0.2 mg/L. For the rest of the wells, however, the nitrite and ammonium threshold values were exceeded.

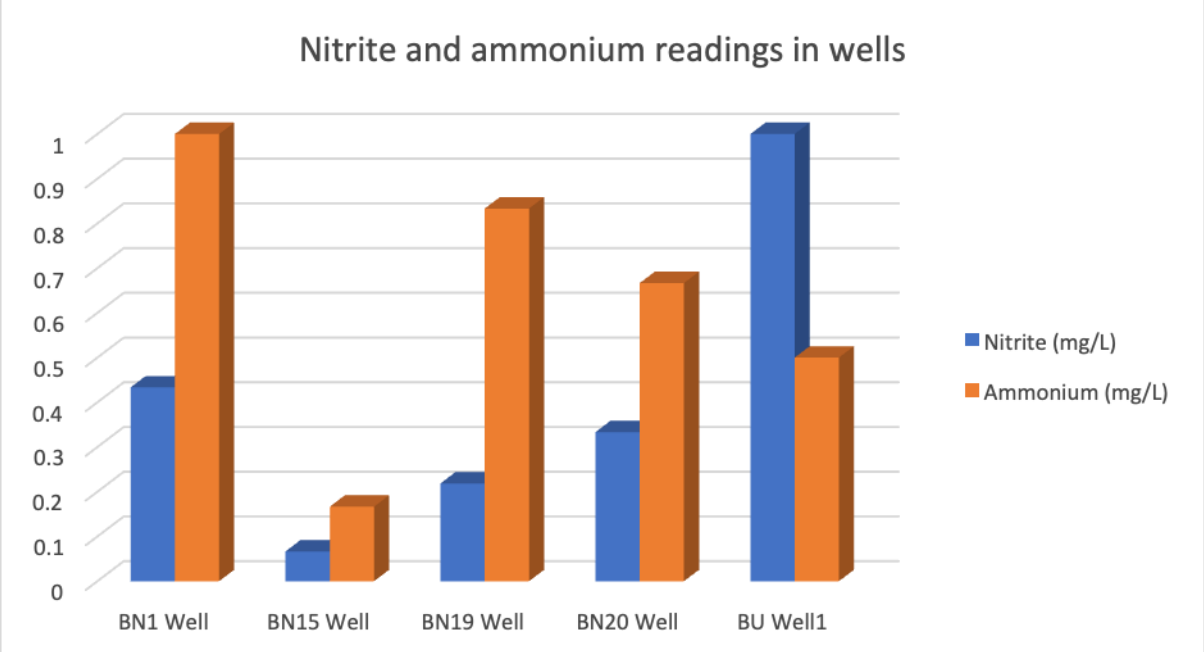

Figure 8: Nitrite and ammonium readings in wells

The BN13 borehole had the highest phosphate reading of 2.5 mg/L. The boreholes at BN1, BN2, BN23 and BN24 recorded the second highest phosphate levels with a collective reading of 1.77 mg/L followed by BN15 at 1.47 mg/L and BN7, BN11, BN19 and BN29 having an average reading of 0.7 mg/L. BN20 had the second lowest reading at 0.1 mg/L and BN21 was the only borehole with 0 mg/L of phosphate recorded (Figure 9). The default guideline value of 0.005 mg/L of phosphate (ANZECC & ARMCANZ, 2000; ANZECC & ARMCANZ, 2018) was far exceeded in all boreholes sampled. There is a notable link of the nutrient level with the land used (settlement, household pigs, gardening) however further sampling is required to monitor the impact of the encroachment into the future.

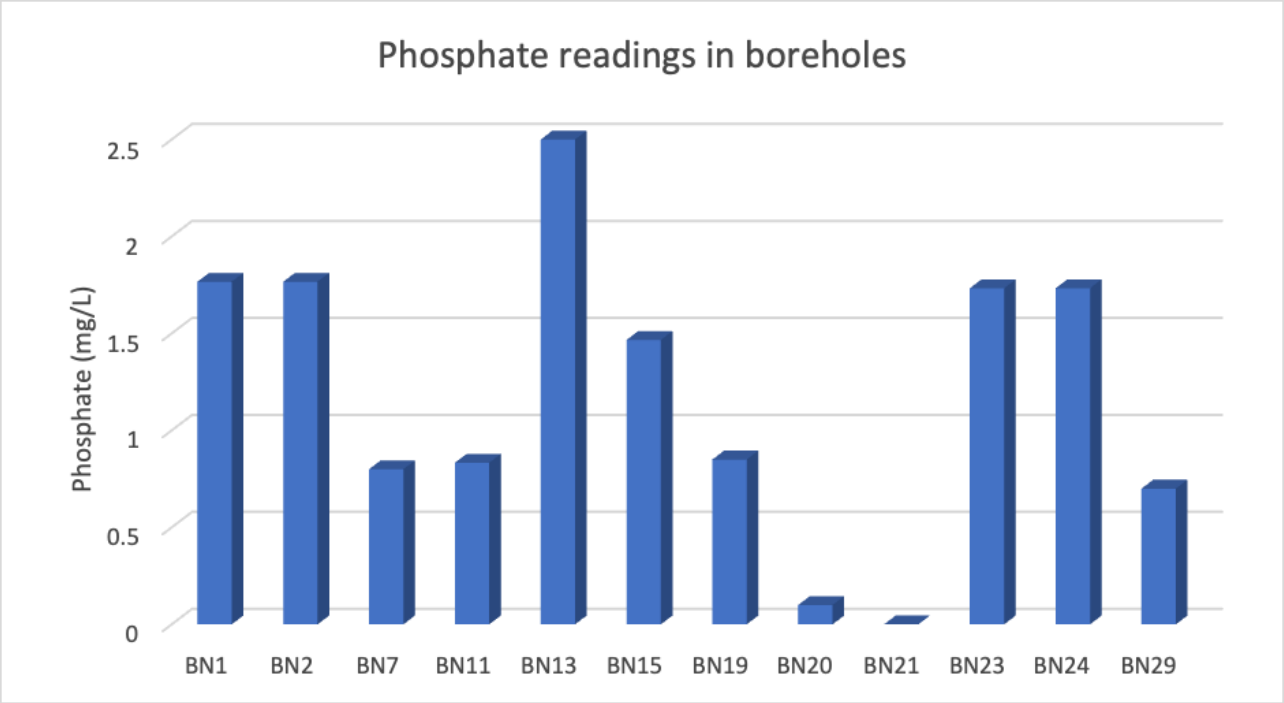

Figure 9: Phosphate readings in boreholes

The highest readings of phosphate in wells were 2 mg/L in the BU Well1 located in Buota. The second highest reading were wells BN1 and BN19 which both recorded 1.73 mg/L of phosphate. The well in BN20 had a reading of 0.5 mg/L while the well in BN15 had a reading of 0.33 (Figure 10). The phosphate default guideline value of 0.005 mg/L (ANZECC & ARMCANZ, 2000; ANZECC & ARMCANZ, 2018) was far exceeded in all boreholes sampled. It is important to note that the preliminary baseline readings in March 2020 had no phosphate readings.

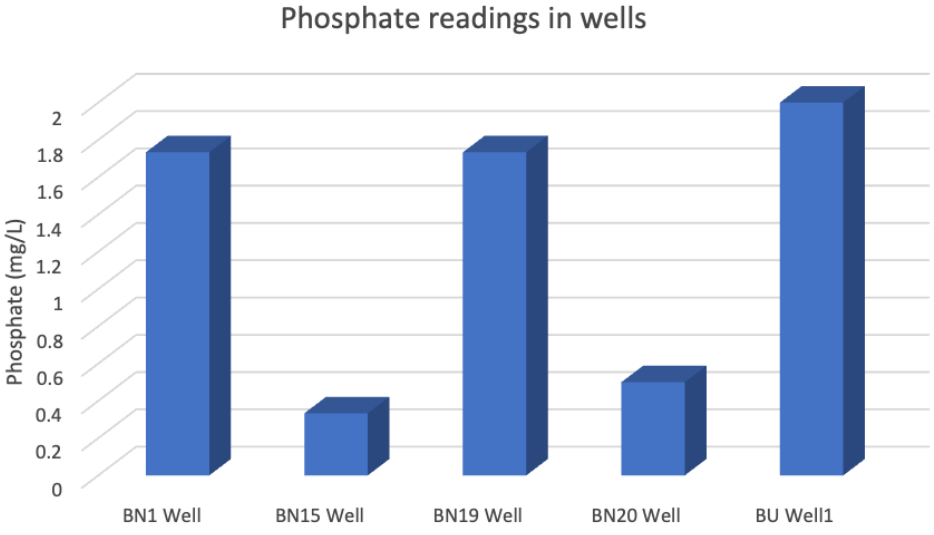

Figure 10: Phosphate readings in wells

Trends on nitrates in the boreholes and wells were not evident as most of the nitrate readings read 0 mg/L, hence the graphical representation of the data was provided as an attachment appended to this report. The data recorded included the borehole in BN1 which had the highest reading of 6.67 mg/L while the rest of the readings were from boreholes BN19 and BN23 which both had readings of 3.33 mg/L. The Bonriki well which was sampled (BU Well1) also had the same reading of 3.33 mg/L.

4.3 Assessing Coliforms and *Escherichia coli* Against Guidelines and Standards

The *E.coli* and coliform bacteria sampling in Bonriki occurred in April 2020, July 2020, April 2021, and July 2021. Boreholes and wells in Bonriki were not sampled for *E.coli* and coliform bacteria in July 2020. There were 5 new wells in Buota (near and around the water reserve area) which were tested for *E.coli* and coliform bacteria in July 2021.

Boreholes BN1, BN15, BN20, BN21, BN23, BN29 and well at BN20 had consistently tested positive for both E. coli and coliforms throughout the sampling period in this report (April 2020 and July 2021). All but three boreholes in Buota tested positive for E. coli and coliform bacteria in April 2020. The borehole at BN24 tested negative for both E. coli and coliforms in April 2021 although they had tested positive in April 2020. The borehole at BN19 and well at BN19 tested positive for coliform bacteria but not E. coli. In July 2021, the level of E.coli in wells BU2 and BU5 in Buota were reported as too numerous to count (TNC). Wells BU1, BU3, BU4, and BU6 were found to have E.coli greater than 100 counts/100ml. The well in Buota (BU Well 1) tested negative in July 2020 for both E. coli and coliforms but were found to have E.coli greater than 100 counts/100ml in July 2021. Previous studies have confirmed the presence of bacteriology contamination at a greater extent at the monitoring bore holes within the Bonriki water reserve area (SPC 2015).

It is important to note, however, that except for BN24 and BU Well 1, the boreholes and wells tested at least once for both *E. coli* and coliforms for the duration of this sampling period in this report. The well at BN15 has been abandoned and covered with sand as of April 2021 and therefore may no longer be used for future sampling (Table 5).

While the maximum acceptable value is <1 MPN/100ml for similar ecosystems in Australia and New Zealand (ANZECC & ARMCANZ, 2018) and 2.2 MPN/10mL according to the WHO standard for drinking water (Addo *et al.,* 2009), the data collected in this sampling period indicated whether the boreholes and wells tested for positive or negative presence of *E. coli* and coliform bacteria for majority of the sampling, as only the water sampling in April 2020 and July 2021 have values for MPN/100ml.

Table 5: Sampling sites tested for E. coli and coliform bacteria.

	Apr-20			Jul-20		Apr-21		Jul-21	
Site ID	**E.coli**	**Coliform bacteria**	**MPN/100ml**	**E.coli**	**Coliform bacteria**	**E.coli**	**Coliform bacteria**	**Coliforms/100ml**	**E.coli/100ml**
BN1	**positive**	**positive**	100	No data	No data	**positive**	**positive**	**-**	**-**
BN2	negative	negative	0	No data	No data	negative	negative	-	-
BN7	negative	negative	0	No data	No data	**positive**	negative	-	-
BN11	negative	negative	0	No data	No data	negative	**positive**	**-**	**-**
BN13	**positive**	**positive**	100	No data	No data	No data	No data	-	-
BN15	**positive**	**positive**	100	No data	No data	**positive**	**positive**	**-**	**-**
BN19	**positive**	**positive**	100	No data	No data	negative	**positive**	**-**	**-**
BN20	**positive**	**positive**	100	No data	No data	**positive**	**positive**	**-**	**-**
BN21	**positive**	**positive**	5.2	No data	No data	No data	No data	-	-
BN23	**positive**	**positive**	100	No data	No data	**positive**	**positive**	**-**	**-**
BN24	**positive**	**positive**	1.5	No data	No data	negative	negative	-	-
BN29	**positive**	**positive**	100	No data	No data	**positive**	**positive**	**-**	**-**
BN1 (well)	**positive**	**positive**	22.75	No data	No data	**positive**	**positive**	**-**	**-**
BN15 (well)	**positive**	**positive**	100	No data	No data	abandoned & covered with sand		-	-
BN19 (well)	**positive**	**positive**	100	No data	No data	negative	**positive**	**-**	**-**
BN20 (well)	**positive**	**positive**	9.1	No data	No data	**positive**	**positive**	**-**	**-**
BU Well1	No data	No data	-	negative	negative	No data	No data	366	16
BU 2 well	-	-	-	-	-	-	-	TNC	1
BU3 well	-	-	-	-	-	-	-	232	16
BU4 well	-	-	-	-	-	-	-	150	0
BU5 well	-	-	-	-	-	-	-	TNC	22
BU6 well	-	-	-	-	-	-	-	240	18

5. DISCUSSION

The physical parameters, nutrients, *E. coli* and coliform bacteria data are discussed below. It is noted that in the April 2021 sampling, it was not possible to obtain data on physical parameters due to a non-functional multimeter (this has been addressed and sampling can continue). The boreholes BU2, BU4, BU12 and BU13 in Buota were not operational, therefore water quality data was not collected. Instead, there are 6 new wells namely Well 2, Well 3, Well 4, Well 5, Well 6 sampled in July 2021 in Buota to give a representative of the quality of the water in Buota.

5.1 Physical Parameters

The DO measured in the boreholes and wells was dependent on the atmospheric pressure and the temperature and salinity of the water. As seen in the preliminary baseline data in March 2020, the results suggested decrease in turbid water and temperature with acceptable input levels of algal production and nutrients.

The levels of pH change with increase in DO, runoff and pollution may indicate land-based pollutants and point source pollution. The levels of pH observed in this sampling showed that 9 out 15 sample readings were below the threshold of 6.0 – 8.0 pH, which according to the Environmental Protection Agency (EPA, 2012), provides the conditions for higher toxicity and solubility of chemicals and heavy metals in the water.

Oxidation Reduction Potential (ORP) is a nonspecific measurement as the same values obtained (in mV) are subject to multiple interpretations. Table 4 shows corresponding ORP values with the respective biochemical reactions, noting that more than one biochemical reaction falls within the same ORP range of values. For example, the biochemical reaction of methane production falls within an ORP range of -175 mV to -400 mV. And the biochemical reaction of fermentation falls within an ORP range of -100 to -225 (YSI, n.d.). It is, therefore, important that the ORP readings during the current monitoring program are interpreted by users that have the knowledge and history of the sites.

The interpretation of these ORP datasets can be used as an indicator over time and/or with other common parameters to develop a more complete picture and scientifically accurate narrative for decision making. It is unfortunate however, that ORP readings have also been previously reported to differ by a significant margin (50 – 100 mV) even though the same container of water was being tested by multiple equipment (McDermand, 2015). This further emphasizes that the history and context of the environment must be considered and ORP values must be supplemented with other water parameters before any conclusive decisions are made.

The conductivity of water in the sampled boreholes fell below the salinity threshold of 1500 µS/cm. Conductivity helps identify unacceptable levels of salinity and changes may indicate agricultural run, sewage leak or rising saltwater intrusion in groundwater. As seen in the preliminary results in March 2020, the excessive precipitation seems to help with the recharging of underground freshwater lenses and implication of seawater intrusion is not a cause of concern as of the current monitoring program.

5.2 Nutrients (Nitrites, Ammonium and Phosphates), *E. coli* and Coliform Bacteria

Nutrients have influence in aquatic primary production such as growth of phytoplankton, macroalgae, aquatic vascular plants, benthic microalgae, and photosynthetic bacteria. Recorded high levels and excess of nutrients and algae growth in underwater aquifers could be attributed to animal waste from piggeries and runoffs due to human waste. Thus, human activities on land substantially contributing to high levels and excess of nutrients and algal growth, highlighting the need for a concerted effort in inclusion of women and other sectors of the communities in this project and future planning for improved water sources to ensure behavior and attitude change.

The sampled boreholes and wells had concerning amounts of nitrites, ammonium and phosphates based on the exceeded threshold values. The *E. coli* and coliform bacteria tests had an overwhelming number of positive results and a majority of water sampled dangerously exceeding the threshold value of MRN/100ml in April 2020 and July 2021 which suggests contamination from human and animal waste and a possible influence from the nearby graveyard. Previous testing in May 2005 (Ian et al., 2005) suggests the same that *E. coli* contamination is associated with land uses on Bonriki Water reserve such as babai pits, gardens, squatter settlements, and the cemetery. This is based on the examination of the spatial extent of the *E. coli* on Bonriki.

The preliminary results from March 2020, also noted the problem of abandoned old vehicles and scrap metals which could contribute to the heavy metal contamination of the underground water lenses and aquifer. Due to the acidity (low pH) recorded in majority of the sampling sites, this may contribute to higher solubility of chemicals and heavy metals, however the Kiribati IW R2R project does not extend to cover these parameters.

However, it is important to note that all testing of water was carried out before the water being treated in Bonriki chlorination plant.

6 CONCLUSIONS AND RECOMMENDATIONS

The current monitoring program collected essential water quality data as well as how the current monitoring work fits into the overall workplan of those tasked to collect data. The direct contact with suppliers of equipment with MELAD was also established. This report outlines a major step forward in the continuation of this monitoring program that would provide robust scientific water quality data. The continuation from the successful water quality training in March 2020 and domestic efforts to upskill stakeholders in the various sectors and communities is critically important in this endeavor to provide scientific advice for informing important policy discussions. In stakeholder training and awareness work the importance of inclusion of women, who are mostly in charge of household wastes and oversee proper waste disposal by children and other members of the household is critical.

The monitoring of the reserves has shown concerning amounts of contamination that have exceeded established thresholds. There remains cause of concern of the high levels of contaminants in the underground water of Bonriki and Buota water reserves. The R2R investments to reduce nutrients by 5% is not occurring however, noting the combined monitoring work, awareness raising campaigns and DLT units' application would slowly assist lower nutrient levels into the future. It just requires close monitoring and commitments to use DLT composting to minimize or avoid nutrients discharge directly to groundwater.

The following are proposed recommendations for the consideration of the responsible agencies responsible for water quality monitoring in Kiribati. It is recommended:

i. That the Kiribati Water Quality Committee administered by MISE is revived to oversee all water quality activities including projects that include water quality monitoring. That water quality protection and improvement include regular awareness, training and capacity building by men, women, and all sectors of the communities.

ii. Boreholes in Bonriki and Buota water reserve are regularly maintained. In particular, Boreholes in Buota require fixing to allow water testing in future.

iii. The MHMS authority to develop a bacteriological monitoring program. Use MHMS Laboratory testing method to test the concentration of microorganisms in the groundwaters of both water reserve that would allow estimate of the level of contamination.

iv. That the sampling protocol developed by the project is reviewed by the National Water Quality Monitoring Committee administered by MISE. This is important to ensure the continuation of the sampling at the same location to be able to measure the trend over time.

v. That a cabinet paper includes the results of the water quality monitoring and seek additional funding support for the provision of the water quality testing equipment and kits.

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APPENDICES

1: Water Quality Packing List – Kiribati

Item	QTY	Pre-De-part	In country	Return
Black casing				
ProDSS-10 Meter 4 port Cable Assembly	1			
Black Backpack				
Stopwatch	2			
Ziplock bag	4			
Sample bottle	1			
Folding bucket	1			
Measuring tape	1			
Extech TISAB tablet	1			
EC standard solution – 400 mL	1			
Turbidity standard solution – 500 mL	2			
Blue Backpack				
pH buffer – 7.00 (1 litre)	1			
pH buffer – 4.00 (1 litre)	1			
pH buffer – 10.01 (1 litre)	1			
Conductivity standard solution (1 litre)	1			
Zobell's solution (250 mL)	2			
Secchi disk	1			
Hydrometer	1			
Fluoride meter	1			
Backpack lab manual	1			
Luggage Bag				
Carbon dioxide Test Kit	1			
Alkalinity Test Kit	1			
Salinity Test Kit	1			
DO Test Kit	1			
Acidity Test Kit	1			
Nitrate Reagent 2 Test Kit	1			
Nitrite Reagent 2 Test Kit	1			
Phosphate Reagent Test Kit	1			
Ammonia Reagent Test Kit	1			

YSI Pro Plus 4M	1			
YSI Pro Comm II Kit	1			
YSI polargraphic DO sensor	1			
Colorimetric	1			
Handheld colorimeter – phosphorus	1			
Waterproof tester	2			
Sodium sulphite for zero DO (50 g)	1			
Scissors	1			
	Batteries			
Idc battery	8			
CSi	4			
AA	6			
AAA	4			

2: Phosphate Test Manual

Instruction Manual

HI 3833
Phosphate Test Kit

www.hannainst.com

Dear Customer,

Thank you for choosing a Hanna Instruments Product.

Please read this instruction manual carefully before using the chemical test kit. It will provide you with the necessary information for correct use of the kit.

Remove the chemical test kit from the packing material and examine it carefully to make sure that no damage has occurred during shipping. If there is any noticeable damage, notify your Dealer or the nearest Hanna office immediately.

Each kit is supplied with:

- 1 plastic beaker (20 mL);
- 1 color comparator cube;
- **HI 3833-0** Phosphate Reagent (50 pcs.)

Note: Any damaged or defective item must be returned in its original packing materials.

Specifications

Range	0 to 5 mg/L (ppm) PO_4^{3-}
Smallest Increment	1 mg/L (ppm) PO_4^{3-}
Analysis Method	Colorimetric
Sample Size	10 mL
Number of Tests	50
Case Dimensions	220 x 145 x 55 mm (8.7 x 5.7 x 2.1")
Shipping Weight	160 g (6 oz.)

Significance and Use

Phosphates are widely introduced into the environment from such sources as agricultural fertilizers, cleaning and laundering products, boiler water conditioners, and drinking water treatment aids.

At high levels, phosphates stimulate the growth of photosynthetic organisms which may contribute to eutrophication of lakes, rivers, and ponds. This makes it important to monitor and control phosphate discharges into the environment.

Phosphates can be classified as ortho, condensed or organically bound. As with existing test kits on the market, the Hanna Phosphate Test Kit will only determine orthophosphate levels.

Note: mg/L is equivalent to ppm (parts per million).

Chemical Reaction

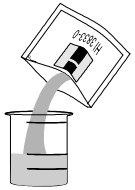
The orthophosphate level in mg/L (or ppm) is determined by a colorimetric method. Ammonium molybdate and potassium antimonyl tartrate react in acid medium with orthophosphate to form a phosphomolybdate complex, that is reduced to intensely colored molybdenum blue by ascorbic acid. The color intensity of the solution determines the phosphate concentration.

Instructions

READ THE ENTIRE INSTRUCTIONS BEFORE USING THE KIT

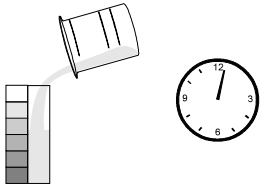
- Remove the cap from the plastic vessel. Rinse the plastic vessel with water sample, fill it to 10 mL mark.

- Add 1 packet of **HI 3833-0** Phosphate Reagent.

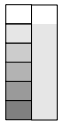


- Replace the cap and mix solution until solids dissolve.

- Remove the cap and transfer the solution into the color comparator cube. Let set for 1 minute.



- Determine which color matches the solution in the cube and record the result as mg/L (ppm) of phosphate (PO_4^{3-}).



References

- 1987 Annual Book of ASTM Standard, Volume 11.01 Water (1).
- Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998.

Accessories

HI 3833-050	Replacement kit (50 tests)
HI 740032P	Cap for 20 mL plastic beaker (10 pcs.)
HI 740037P	20 mL plastic beaker (10 pcs.)

Safety Data Sheets

The chemicals contained in this kit may be hazardous if improperly handled. Read the relevant Safety Data Sheet before performing this test.

3: Nitrate Test Manual

Instruction Manual

HI 3874
Nitrate
Test Kit

www.hannainst.com

Dear Customer,

Thank you for choosing a Hanna Instruments Product.

Please read the instructions carefully before using the chemical test kit. It will provide you with the necessary information for correct use of the kit.

Remove the chemical test kit from the packing material and examine it carefully to make sure that no damage has occurred during shipping. If there is any noticeable damage, notify your Dealer or the nearest Hanna office immediately.

Each kit is supplied with:

- **HI 3874-0** Nitrate Reagent, packets (100 pcs.);
- 1 glass cuvette;
- 1 color comparator cube.

Note: Any damaged or defective item must be returned in its original packing materials.

ISTR3874 07/13

Specifications

Range	0 to 50 mg/L (ppm) as NO_3^--N
Smallest Increment	10 mg/L (ppm) NO_3^--N
Analysis Method	Colorimetric
Sample Size	10 mL
Number of Tests	100
Case Dimensions	230 x 59 x 70 mm (9.0 x 2.3 x 2.8")
Shipping Weight	156 g (6.0 oz.)

Significance and Use

Nitrate ions are present in trace amounts in surface water and in higher levels in some groundwater. Nitrate is found only in small quantities in domestic wastewater but can reach higher concentration (up to 30 mg/L as nitrogen) in the outflow of nitrifying biological treatment plants. Excessive amounts can contribute to methaemoglobinemia: infant death and adult illness. In order to prevent this, a 10 mg/L limit (as nitrogen) has been imposed on drinking water.

Note: mg/L is equivalent to ppm (parts per million).

Chemical Reaction

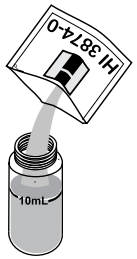
Nitrates are reduced to nitrites in the presence of Cadmium. The nitrites thus produced react with the reagent to yield an orange compound. The amount of color developed is proportional to the concentration of nitrate present in the aqueous sample.

Instructions

READ THE ENTIRE INSTRUCTIONS BEFORE USING THE KIT

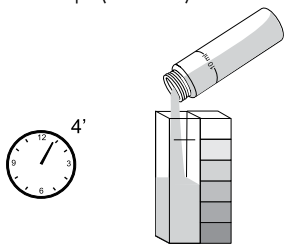
- Fill the glass cuvette with 10 mL of the sample, up to the mark.

- Add 1 packet of **HI 3874-0** Nitrate Reagent.

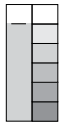


- Replace the cap and shake vigorously for exactly 1 minute. A deposit may remain, but it will not affect measurement. Time and manner of shaking can affect the results.

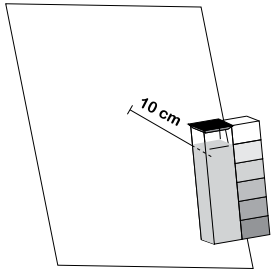
- Wait for 4 minutes to allow the color to develop. Remove the cap and fill the color comparator cube with 5 mL of the treated sample (to the mark).



- Determine which color matches the solution in the cube and record the result in mg/L (or ppm) of Nitrate-nitrogen.



- It is better to match the color with a white sheet at about 10 cm behind the comparator.



- To convert the reading to mg/L of Nitrate (NO_3^-), multiply the reading by a factor of 4.43.

References

Adaptation of the cadmium reduction method from Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998.

Accessories

HI 3874-100 Replacement kit (100 tests)

Safety Data Sheets

The chemicals contained in this kit may be hazardous if improperly handled. Read the relevant Safety Data Sheet before performing this test.

Attachment 4: Ammonia Test manual

Instruction Manual

HI 3826
Ammonia Test Kit for Sea Water

HANNA instruments

www.hannainst.com

Dear Customer,

Thank you for choosing a Hanna Instruments Product.

Please read this instruction manual carefully before using the chemical test kit. It will provide you with the necessary information for correct use of the kit.

Remove the chemical test kit from the packing material and examine it carefully to make sure that no damage has occurred during shipping. If there is any noticeable damage, notify your Dealer or the nearest Hanna office immediately.

Each kit is supplied with:

- 1 plastic beaker (20 mL) with cap;
- 1 color comparator cube;
- Ammonia Reagent 1 for Sea Water, 1 bottle with dropper (20 mL);
- Nessler Reagent, 1 bottle with dropper (20 mL).

Note: Any damaged or defective item must be returned in its original packing materials.

ISTR3826 04/13

Specifications

Range	0.0 to 2.5 mg/L NH_3-N
Smallest Increment	0.5 mg/L NH_3-N
Analysis Method	Colorimetric
Sample Size	10 mL
Number of Tests	25 (average)
Case Dimensions	220 x 145 x 55 mm (8.7 x 5.7 x 2.1")
Shipping Weight	180 g (6.8 oz.)

Significance and Use

In nature, the ammonia level in water can vary. Ground water normally contains ammonia due to bacterial decay of plants and animals. However, the presence of ammonia in surface water may be evidence of sanitary pollution due to waste discharges or natural causes.

The Hanna Ammonia Test Kit determines the ammonia concentration in water in several easy steps. The kit is portable and can be used in the field as well as in the laboratory.

* mg/l is equivalent to ppm (parts per million)

Chemical Reaction

The ammonia level in mg/L (or ppm), ammonia as nitrogen is determined by a colorimetric method.

The Nessler reagent reacts with ammonia, under strong alkaline conditions, to form a yellow colored complex (see equation below). An addition of Reagent 1 (EDTA solution) inhibits precipitation of calcium and magnesium ions due to the presence of the alkaline Nessler reagent.

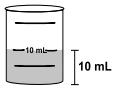
The color intensity of the solution determines the ammonia concentration.

$$2K_2HgI_4 + 2NH_3 \rightarrow NH_2Hg_2I_3 + NH_4I + 4KI$$

Instructions

READ THE ENTIRE INSTRUCTIONS BEFORE USING THE KIT

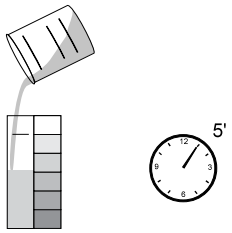
- Remove the cap from the plastic beaker. Rinse the plastic beaker with water sample before filling it up to the 10 mL mark.



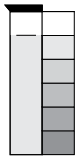
- Add 5 drops of Ammonia Reagent 1 for Sea Water, replace the cap and mix by carefully swirling the beaker in tight circles.

- Add 8 drops of Nessler Reagent, replace the cap and mix by carefully swirling the beaker.

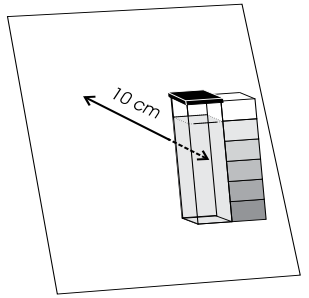
- Remove the cap and transfer the solution into the color comparator cube. Wait for 5 minutes to allow color to develop.



- Determine which color matches the solution in the cube, and record the results in mg/L (or ppm) NH_3-N.



- It is better to match the color with a white sheet at about 10 cm behind the comparator.



Accessories

HI 3826-025	replacement kit (25 tests average)
HI 3824-99	color cube for ammonia test kit
HI 740032P	cap for 20 mL plastic beaker (10 pcs.)
HI 740037P	20 mL plastic beaker (10 pcs.)

Bibliography

Standard Methods for the Examination of Water and Wastewater, 16th Edition, 1985, pages 379-382.

Health and Safety Data Sheets

The chemicals contained in this kit may be hazardous if improperly handled. Read Health and Safety Data Sheet before performing this test.

Attachment 5: Nitrite Test Manual

Instruction Manual

HI 3873
Nitrite
Test Kit

HANNA instruments

www.hannainst.com

Dear Customer,

Thank you for choosing a Hanna Product.

Please read the instructions carefully before using the chemical test kit. It will provide you with the necessary information for correct use of the kit.

Remove the chemical test kit from the packing material and examine it carefully to make sure that no damage has occurred during shipping. If there is any noticeable damage, notify your Dealer or the nearest Hanna office immediately.

Each kit is supplied with:

- HI 3873-0 Reagent, packets (100 pcs);
- 1 glass cuvet;
- 1 color comparator cube.

Note: Any damaged or defective item must be returned in its original packing materials.

ISTR3873R2 01/07

Specifications

Range	0.0 to 1.0 mg/L (ppm) as NO_2^--N
Smallest Increment	0.2 mg/L (ppm) NO_2^--N
Analysis Method	Colorimetric
Sample Size	10 mL
Number of Tests	100
Case Dimensions	230x59x70 mm (9.0x2.3x2.8")
Shipping Weight	169 g (6.0 oz.)

Significance and Use

Nitrites are intermediate oxidation state of nitrogen (in the oxidation of ammonia to nitrate or in the reduction of nitrate). Such oxidation/reduction may occur in wastewater of treatment plants and in natural waters during the biological decomposition of nitrogen-compounds. In small quantities it can cause methaemoglobinemia among infants. Conversely, high levels are used to inhibit corrosion in cooling towers. Nitrosation reactions of nitrites can yield organic nitrosamines, which are known to be carcinogenic.

Note: mg/L is equivalent to ppm (parts per million).

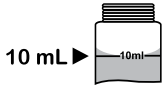
Chemical Reaction

Nitrites react with chromotropic acid reagent to form a pink tint in the sample. The amount of color developed is proportional to the concentration of nitrite present in the aqueous sample.

Instructions

READ THE ENTIRE INSTRUCTIONS BEFORE USING THE KIT

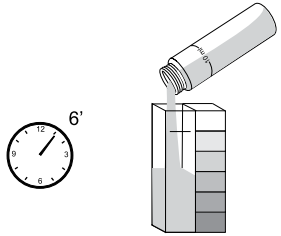
- Fill the glass cuvet with 10 mL of the sample, up to the mark.



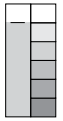
- Add 1 packet of HI 3873-0 Nitrite Reagent.

- Replace the cap  and shake gently for about 15 seconds.

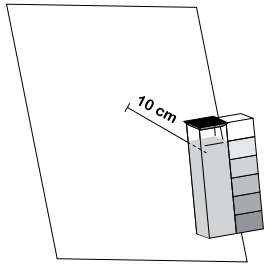
- Wait for 6 minutes to allow the color to develop. Remove the cap and fill the color comparator cube with 5 mL of the treated sample (to the mark).



- Determine which color matches the solution in the cube and record the result in mg/L (or ppm) of Nitrite-nitrogen.



- It is better to match the color with a white sheet at about 10 cm behind the comparator.



- To convert the reading to mg/L of Nitrite (NO_2^-), multiply the reading by a factor of 3.28.

Accessories

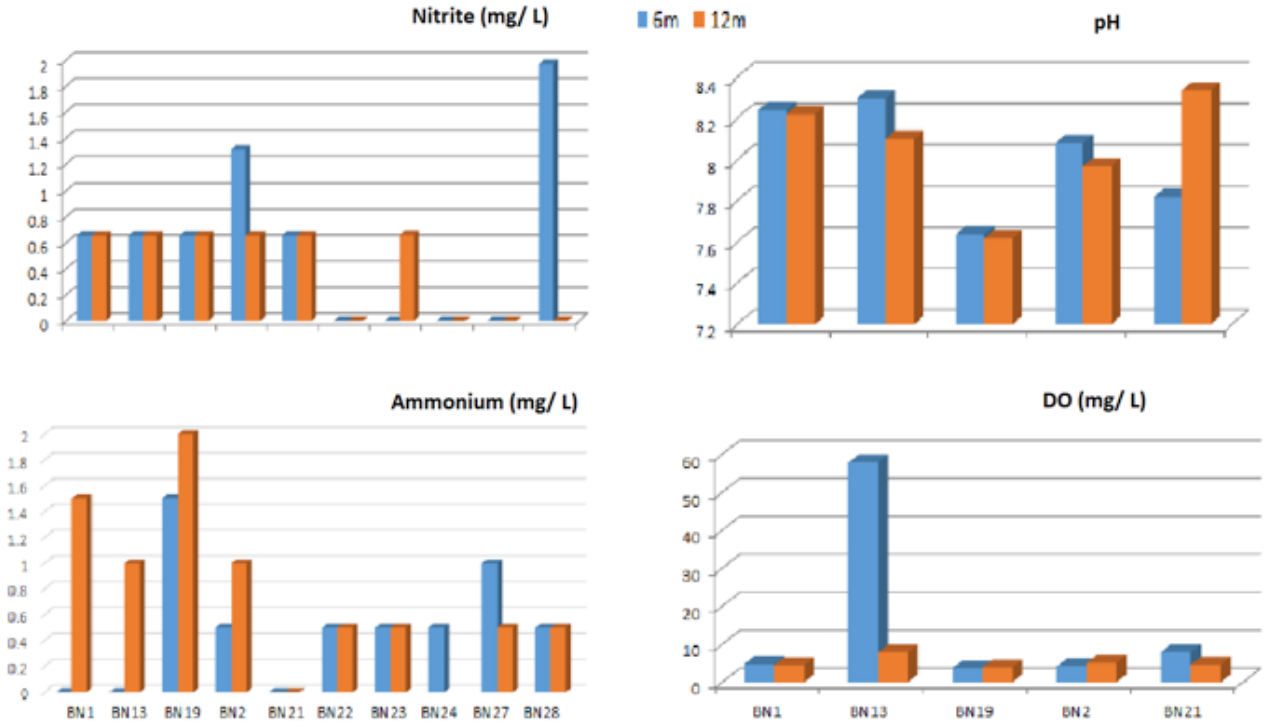
HI 3873-100	replacement kit (100 tests)
HI 740032P	cap for 20 ml plastic beaker (10 pcs)
HI 740037P	20 ml plastic beaker (10 pcs)

Safety Data Sheets

The chemicals contained in this kit may be hazardous if improperly handled. Read the relevant Safety Data Sheet before performing this test.

Attachment 6: Water quality results in Kiribati Water Quality Training Report - 2020

A



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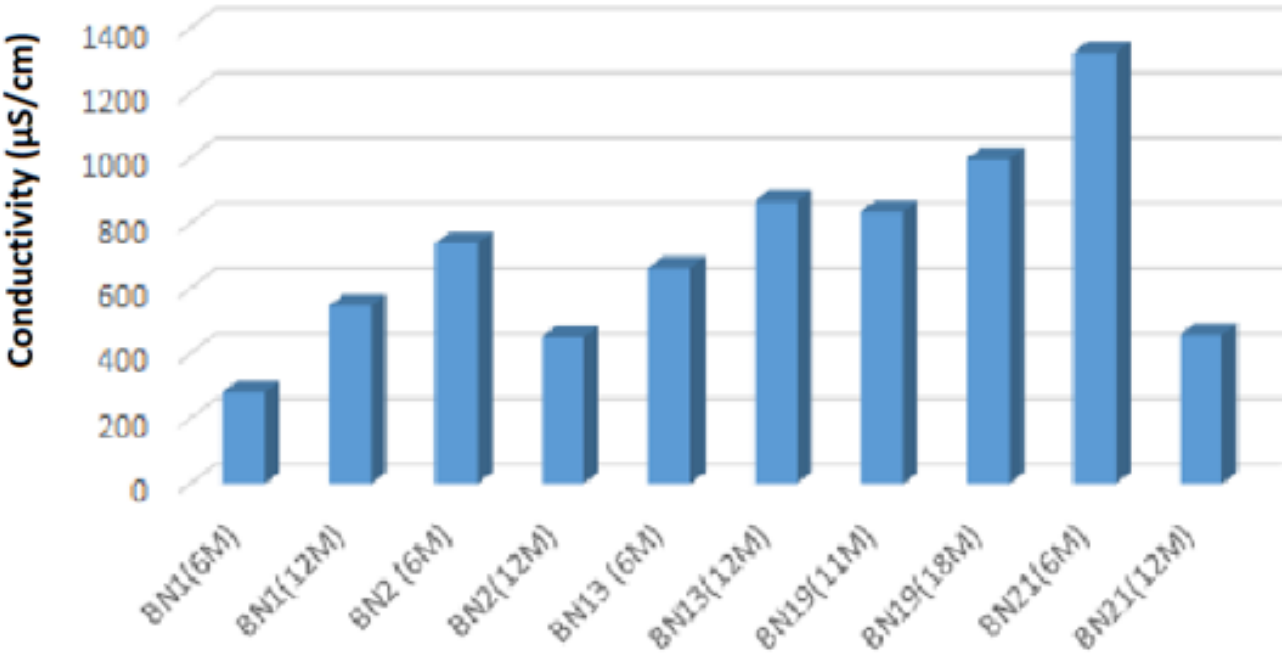

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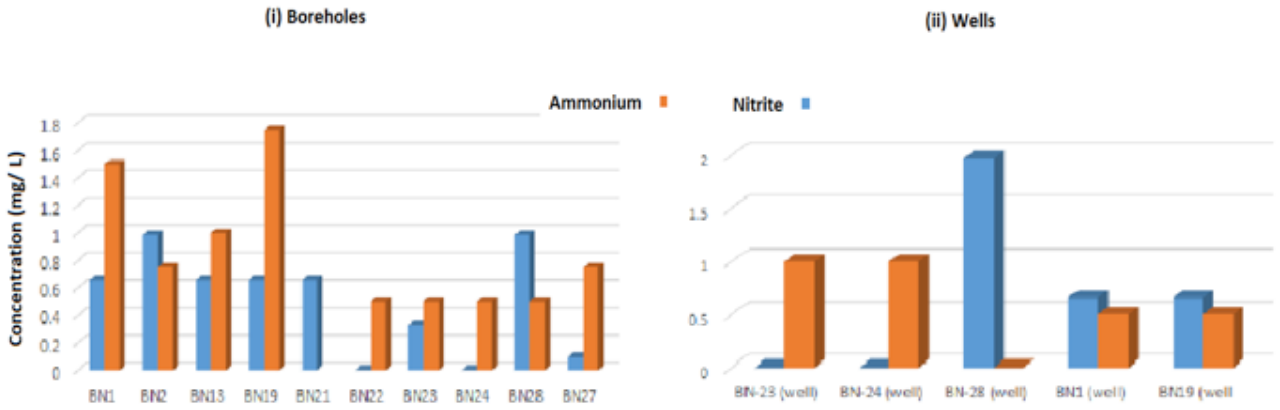
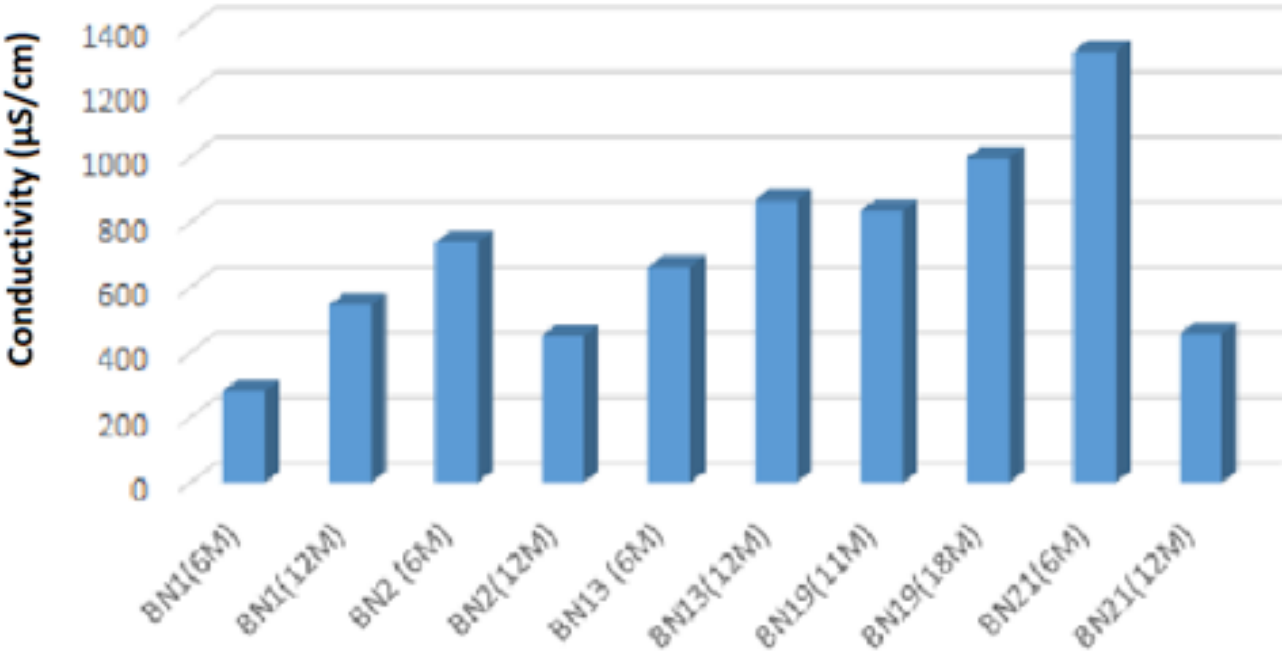

(i) Boreholes
(ii) Wells
Ammonium
Nitrite
Concentration (mg/ L)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
BN1
BN2
BN13
BN19
BN21
BN22
BN23
BN24
BN28
BN27
2
1.5
1
0.5
0
BN-23 (well)
BN-24 (well)
BN-28 (well)
BN1 (well)
BN19 (well

D


Conductivity (µS/cm)
1400
1200
1000
800
600
400
200
0
BN1(6M)
BN1(12M)
BN2 (6M)
BN2(12M)
BN13 (6M)
BN13(12M)
BN19(11M)
BN19(18M)
BN21(6M)
BN21(12M)

Attachment 7: Nitrate readings in boreholes and wells (April 2020 – April 2021)