

# Bonriki Inundation Vulnerability Assessment

## Shoreline Change Mapping



Amrit Raj, Herve Damlamian, Jens Kruger



Australian Government



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Community



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# Bonriki Inundation Vulnerability Assessment (BIVA)

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Amrit Raj

Herve Damlamian

Jens Kruger



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## Acknowledgements

The BIVA project is part of the Australian Government's Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP), within the International Climate Change Adaptation Initiative. The project was developed by the Secretariat of the Pacific Community's (SPC) Geoscience Division (GSD) in partnership with the Australian Government and the Government of Kiribati (GoK).

Key GoK stakeholders that contributed to the implementation of the project were:

- Ministry of Public Works and Utilities (MPWU), in particular the Water Engineering Unit with the MPWU
- The Public Utilities Board (PUB), in particular the Water and Sanitation Division and the Customer Relations Division within the PUB
- The Office of the President, in particular the Disaster Management Office
- The Ministry of Environment, Lands and Agricultural Development (MELAD) Lands Division
- The Ministry of Fisheries and Marine Resources Development (MFMRD) Minerals Division
- Members of the Kiribati National Expert Group on climate change and disaster risk management (KNEG)
- Ministry of Civil Aviation, CCA Kiribati

The Bonriki Village community members also played a key role in the implementation of the project. Community members participated in the school water science and mapping program, assisted with construction of new piezometers and data collection for the groundwater component, and shared their knowledge and experiences with regards to historical inundation events and coastal processes.

Key technical advisors involved with implementation of the project included:

- Flinders University, Adelaide, Australia
- University of Western Australia, Perth, Australia
- The University of Auckland, Auckland, New Zealand
- United Nations Educational, Scientific and Cultural Organization, Institute for Water Education (UNESCO-IHE), Delft, the Netherlands
- Technical advisors Tony Falkland and Ian White

## Executive Summary

Analyses of shoreline changes provide vital information on which most coastal zone management and policies are implemented. This shoreline mapping activity, based on historical aerial photos and satellite imagery, investigates changes in the position of the shoreline around Bonriki since 1943. Erosion or accretion of the shoreline can be driven by natural processes such as wave events or by human activities (e.g. sand mining, reef rock extraction, sea wall construction).

Eight shoreline positions were extracted for 1943, 1968, 1984, 1998, 2003, 2007, 2012 and 2014 covering a 71-year period. In this study, the estimated rate of shoreline change is based on the Digital Shoreline Analysis System software. Rates of change statistics were calculated using the shoreline change envelope, net shoreline movement, and weighted linear regression (WLR) methods. 32 transects on Bonriki's ocean side and 19 transects on the lagoon side were cast at right angles along the coast at 100-m intervals. Uncertainties attributed to the historical images were quantified for the digitised shorelines, ranging from  $\pm 10.01$  m to  $\pm 1.42$  m, and were used to perform the WLR. The outcome of the WLR shows an overall rate (from 1943 to 2014) on the ocean side ranging from -0.3 m/year to 2.5 m/year. Erosion dominates the ocean side shoreline with evidence of erosion seen at 70% of the cast transect. On the lagoon side, the rate ranges from -0.17 m/year to 1.85 m/year. Accretion dominates the lagoon shoreline with 60% of the cast transect recorded as accretion.

The analysis showed two distinct trends in shoreline positions, with significant changes taking place around the year 1984. Trends for 1943 to 1984 on the ocean side show an accretion rate ranging from 0.08 m/year to 0.63 m/year. This trend suggests that the island shoreline is recovering after being significantly reshaped during World War II. On the lagoon side, the accretion rates ranged from 0.29 m/year to 0.38 m/year and erosion rates ranged from -0.35 m/year to -2.10m/year. This trend is the result of the major reclamation project on Bonriki–Taborio.

Ocean side trends for 1984–2014 shows erosion rates ranging from -0.23 m/year to -0.49 m/year, with accretion only evident on the northern tip of the shoreline. On the lagoon side, the accretion rates range from 0.00 m/year to 1.18 m/year and erosion rates range from -0.22 m/year to -0.32 m/year. This is due to reclamation from 1984 onwards, and increases in the extent of mangroves, which are known to attenuate wave energy and trap sediments.



## 1. Introduction

### 1.1. Background

The Bonriki Inundation Vulnerability Assessment (BIVA) project is part of the Australian government's Pacific–Australia Climate Change Science and Adaptation Planning Program (PACCSAP), within the International Climate Change Adaptation Initiative. The objectives of PACCSAP are to:

- improve scientific understanding of climate change in the Pacific;
- increase awareness of climate science, impacts and adaptation options; and
- improve adaptation planning to build resilience to climate change impacts.

The BIVA project was developed by the Geoscience Division (GSD) of the Secretariat of the Pacific Community (SPC) in partnership with the Australian government and the Government of Kiribati (GoK).

#### 1.1.1. *Project objective and outcomes*

The BIVA project aims to improve our understanding of the vulnerability of the Bonriki freshwater reserve to coastal hazards and climate variability and change. Improving our knowledge of risks to this freshwater resource will enable better adaptation planning by the GoK.

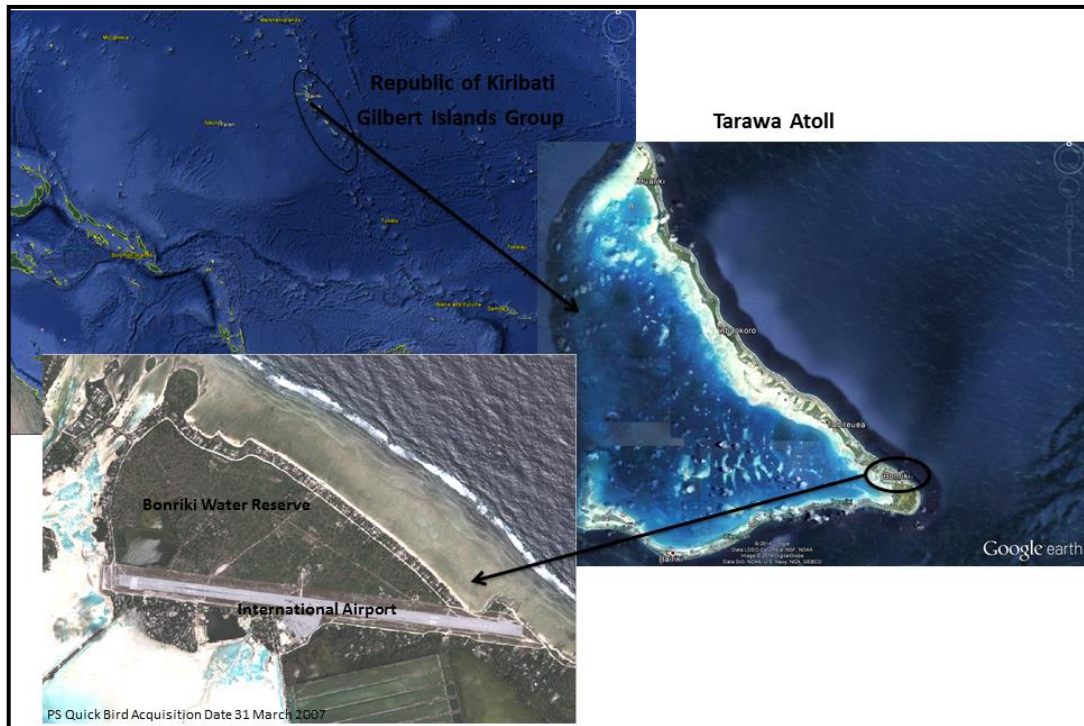
More specifically, the project has sought to use this knowledge to support adaptation planning through the following outcomes:

- Improved understanding and ability to model the role of reef systems in the dissipation of ocean surface waves and the generation of longer-period motions that contribute to coastal hazards.
- Improved understanding of freshwater lens systems in atoll environments with respect to seawater overtopping and infiltration, as well as current and future abstraction demands, recharge scenarios and land-use activities.
- Enhanced data to inform a risk-based approach in the design, construction and protection of the Bonriki water reserve.
- Increased knowledge provided to the GoK and the community of the risks associated with the impact of coastal hazards on freshwater resources in response to climate change, variability and sea-level rise.

#### 1.1.2. *Context*

The Republic of Kiribati is located in the Central Pacific and comprises 33 atolls in three principal island groups. The islands are scattered within an area of about 5 million square kilometres. The BIVA project focuses on the Kiribati National Water Reserve of Bonriki. Bonriki is located on Tarawa atoll within the Gilbert group of islands in Western Kiribati (Figure 1). South Tarawa is the main urban area in Kiribati, with the 2010 census recording 50,182 people of the more than 103,058 total population (KNSO and SPC 2012). Impacts to the Bonriki water resource from climate change, inundation, abstraction and other anthropogenic influences have potential for severe impacts on

people's livelihood of South Tarawa. The Bonriki water reserve is used as the primary raw water supply for the Public Utilities Board (PUB) reticulated water system. PUB water is the source of potable water use by at least 67% of the more than 50,182 people of South Tarawa (KNSO and SPC 2012). Key infrastructure including the PUB Water Treatment Plant and Bonriki International Airport and residential houses are also located on Bonriki, above the freshwater lens, making it an important economic, social and cultural area for the Republic of Kiribati.



**Figure 1.** *Bonriki Water Reserve Location*

## 1.2. Purpose of this report

The purpose of this report is to analyse historical shoreline changes using the Digital Shoreline Analysis System (DSAS) software. Understanding historical shoreline changes and what may have caused them is crucial to enhancing future coastal development planning.

As illustrated in Figure 2, the project consisted of three interlinked components, stakeholder engagement, groundwater investigations and analysis, and coastal investigations and analysis.

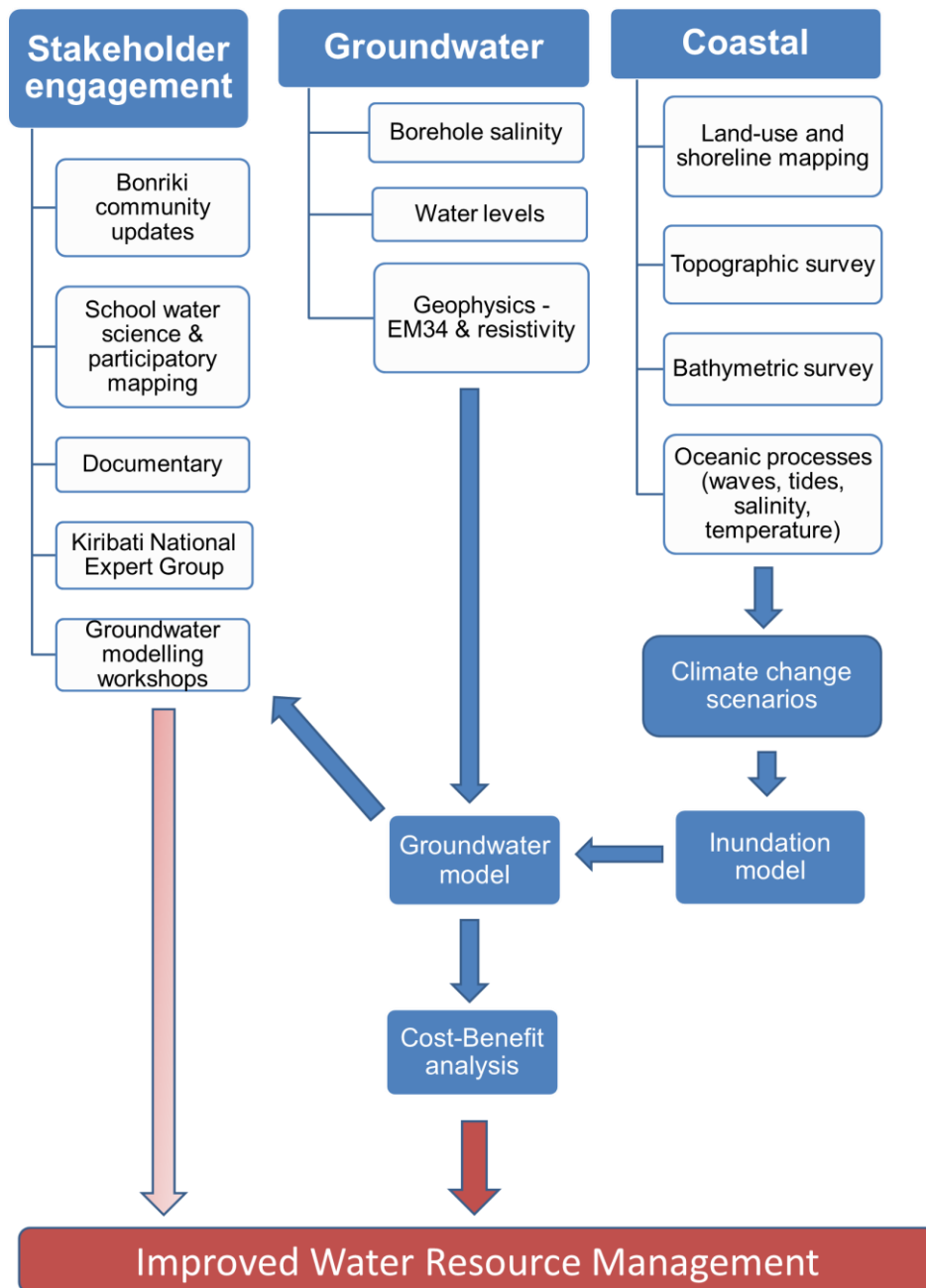


Figure 2. Bonriki Inundation Vulnerability Assessment project components

### 1.3. Scope of this report

It is well known that there are large-scale natural geographic variations in coastal landforms, and these reflect major differences in geomorphic processes and evolution, and that shoreline position and changes are the integrative products of these geomorphic variations (Davies 1972). The shoreline is therefore considered a dynamic feature, subject to erosion as well as accretion, and can be defined as the position of the land–water interface at one instant in time (Gens 2010).

Historical shorelines can be derived from several reference features, such as the toe or base of the beach, high water line, or vegetation line. In the case of Bonriki, the vegetation line was digitised from historical aerial photos and satellite, and a historical shoreline change analysis was carried out using DSAS in order to improve our understanding on how the shoreline of Bonriki has varied

through recent decades. This report provides technical details of the shoreline change analysis and its structures as below:

- Section 2 provides a detailed methodology on the image processing and shoreline mapping
- Section 3 provides results from the shoreline change analysis
- Section 4 provides a conclusion

## 2. Methodology

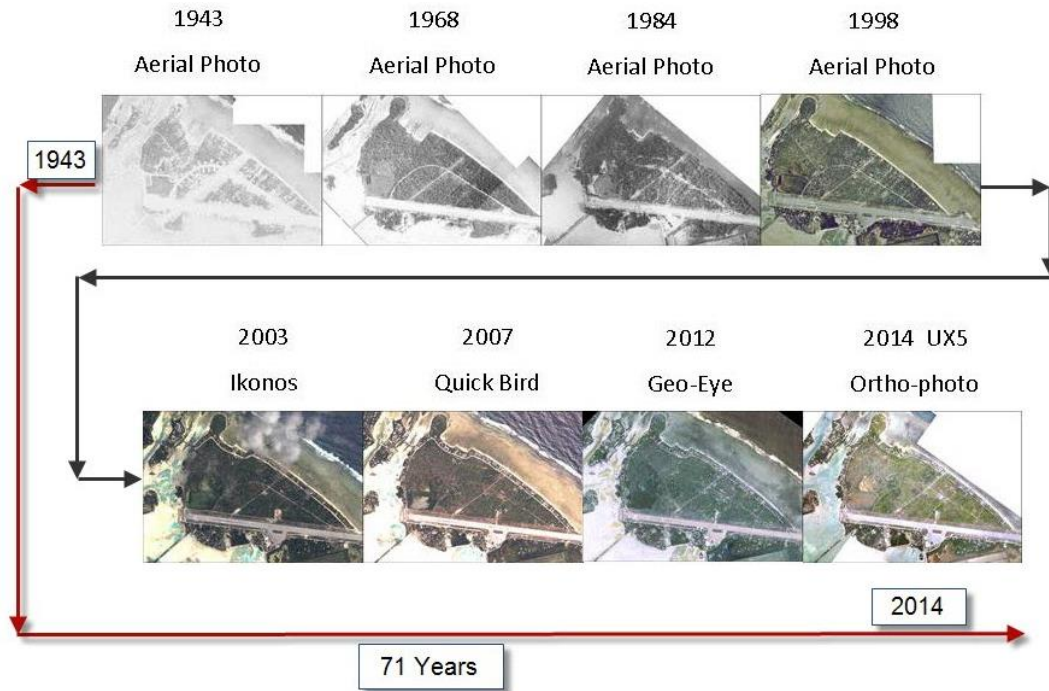
### 2.1. Image processing

For this project, available historical aerial photos and satellite images for Bonriki were compiled, including historical aerial photos for years 1943, 1968, 1984 and 1998, and satellite images Ikonos for 2003, PS Quick Bird for 2007, and Geo-Eye for 2012. Finally, in August 2014, the team conducted an unmanned aircraft system (UAS) survey (TRIMBLE UX5) over the site to expand the database with the latest possible imagery (Table 1 and Figure 3).

All aerial photos were georectified. Georectification is the process of georeferencing an image to a particular coordinate system and then electronically manipulating the historical photograph so that it can be compared with current georeferenced satellite images. The common projection used for all datasets is Universal Transverse Mercator Zone 59 North. The image manipulation was undertaken using ERDAS Imagine and GIS software ESRI Arc Map 10.

**Table 1:** Imagery used for shoreline mapping

Imagery type	Year of acquisition	Resolution (m)
Aerial photo	1943	1.0
Aerial photo	1968	0.30
Aerial photo	1984	0.60
Aerial photo	1998	0.25
IKONOs	2003	4.0
Quick Bird PS	2007	0.60
Geo-Eye	2012	0.50
UAS ortho-photo	2014	0.10



**Figure 3:** The eight sets of imagery used in the shoreline change analysis were 1943, 1968 and 1984 black and white and 1998 colour aerial photo; 2003 Ikonos; 2007 Quick Bird (QB2) imagery; 2012 Geo-Eye; and 2014 Ortho-photo image that was taken using UAS (Trimble UX5) under the project

## 2.2. Detection of shoreline changes using DSAS

After digitising the vegetation line for each georeferenced image, an historical shoreline change analysis was carried out using DSAS v4.3 (<http://www.csc.noaa.gov/digitalcoast/tools/dsas>). DSAS is a computer software application that computes rate-of-change statistics from multiple historic shoreline positions residing in a geographic information system. DSAS was freely available from the NOAA Coastal Services Center website as an ArcGIS Desktop 10 plugin. DSAS is now a web application called DSAS web, which can be found online at <http://cida.usgs.gov/DSASweb/>.

The analysis provides the shoreline change envelope (SCE), net shoreline movement (NSM), and the weighted linear regression (WLR). SCE is defined as the distance between the farthest and the closest shoreline to the baseline of each transect. NSM is the distance between the oldest and most recent shorelines for each transect.

The uncertainty field of the shoreline feature class is used to calculate a weight. Genz et al. (2007) discussed the various statistical methods to derive shoreline change rates and noted that most researchers prefer to use a linear regression method. For Bonriki, we decided to use the WLR method so that the best-fit line would be determined, placing more emphasis on overall shoreline certainty. Hence, in a WLR, a greater emphasis or weight is given to the more reliable data towards determining a best-fit line.

The weight ( $w$ ) is defined as a function of the variance in the uncertainty of the measurement ( $e$ ) (Genz et al. 2007):

$$w = 1 / (e^2)$$

where:

$e$  = shoreline uncertainty value (Table 2)

The WLR rate was determined by plotting shoreline positions with respect to time; these data are exactly the same as in the linear regression example. The shoreline measurement points with smaller positional-uncertainty values had more influence in the regression calculation because of the weighting component in the algorithm.

Transects for the shoreline analysis were at 100-m intervals as shown in Figure 4. Further analysis on DSAS output was done using the Matlab software package to compute and plot the WLR graphs for each cast on the ocean side and lagoon side.

**Table 2:** *Shoreline uncertainty sources for Bonriki. RMS = the root mean square. Note: For this Digital Shoreline Analysis System analysis, the vegetation line was used and not shoreline. This was due to the poor contrast of some of the earlier black and white aerial photography, which did not permit the delineation of the a geomorphic feature such as the base of the beach.*

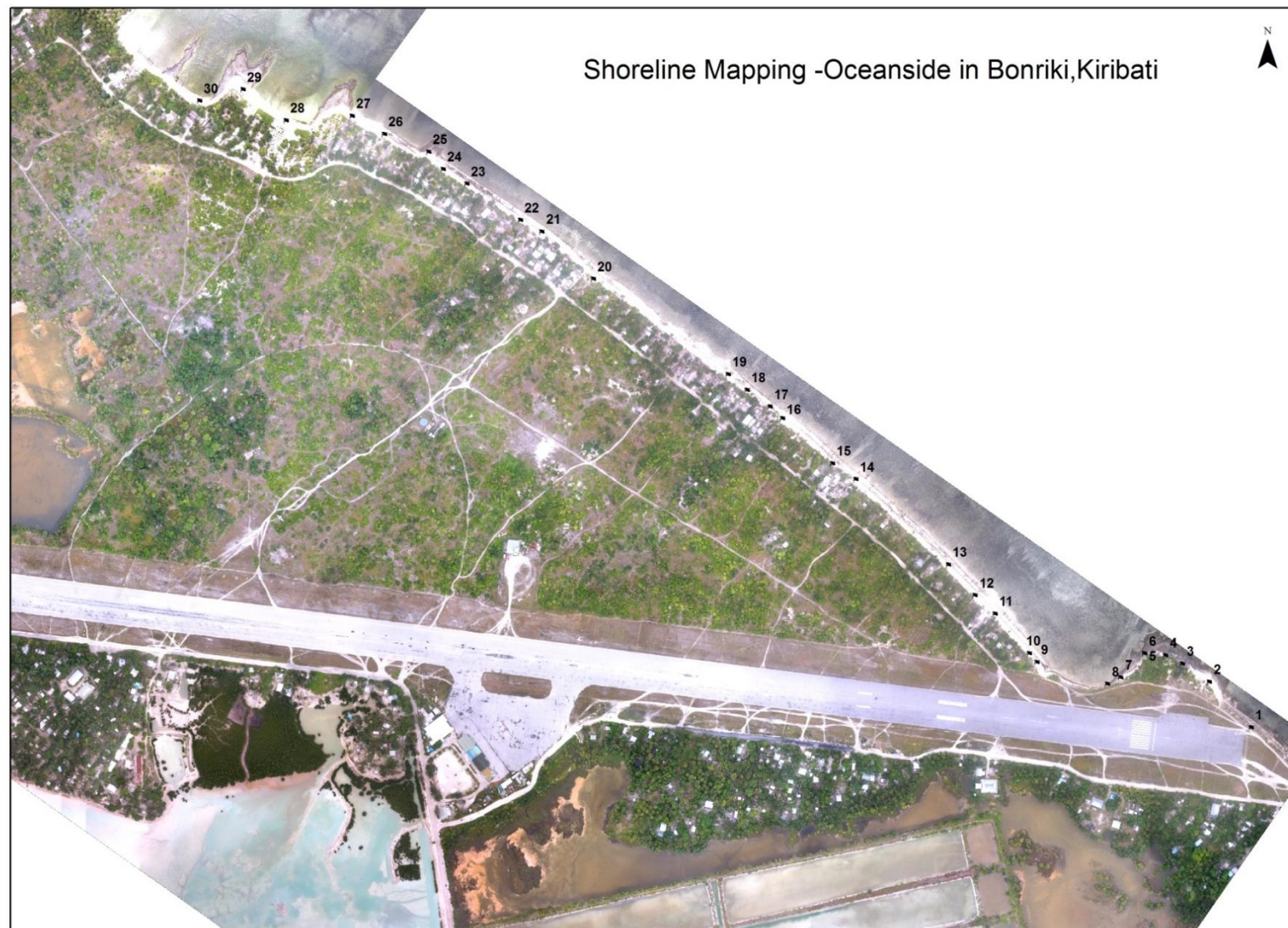
Uncertainty source	1943 Aerial Photo	1968 Aerial Photo	1984 Aerial Photo	1998 Aerial Photo	IKONO`s 2003	Quick Bird 2007	Geo-Eye 2012	UAV Ortho-photo 2014
<b>Digitising error (m)</b>	3	2	10	1	4	2	2	1
<b>Pixel error (m)</b>	1	0.3	0.6	0.25	4	0.6	0.5	0.1
<b>Rectification error (m)</b>	1	1	1	1	1	1	1	1
<b>Total error (m)</b>	11	5.09	101.36	2.06	33	5.36	5.25	2.01
<b>RMS error (m)</b>	3.31	2.26	10.07	1.44	5.74	2.32	2.29	1.42

### 2.3. Shoreline mapping

As part of the project, a shoreline mapping exercise was carried out along the ocean side shoreline using a handheld global positioning system (GPS) and digital camera, effectively geocoding each photo. Evidence of coastal erosion was visible in most parts. Notes were taken in terms of formation of erosional scarps as well as accretion features. The locations of photos are shown in Figure 5 and photos are shown in Appendix 1 and observations are summarised in Table 3.



**Figure 4:** Transect cast used for Digital Shoreline Analysis System analysis for vegetation line from 1943 to 2014 at Bonriki



**Figure 5:** Shoreline mapping survey at Bonriki



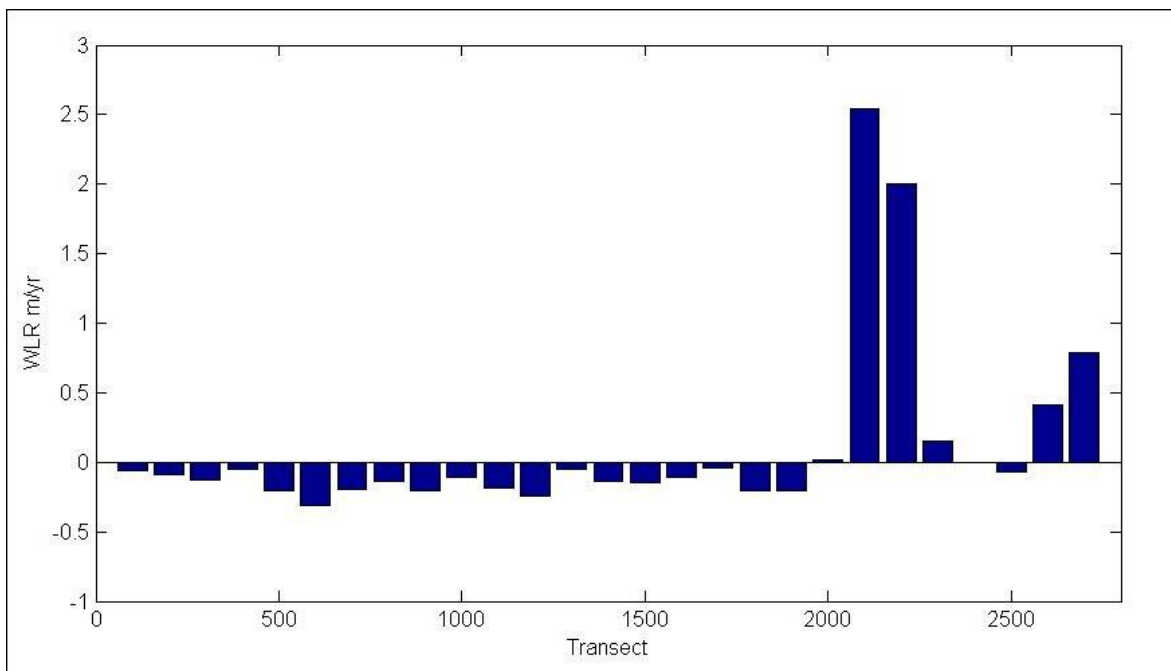
### 3. Results

#### 3.1. General trend from 1943 to 2014

In this study, eight historical shoreline positions were extracted to investigate shoreline change. Change rates were calculated for the period between 1943 and 2014 for the ocean side and lagoon side. The results show that there have been significant changes along the entire shoreline for the 71-year period. Change in shoreline positions were determined by creating 32 transects on the ocean side and 19 transects on the lagoon side, all of which are oriented perpendicular to the baseline at 100-m spacing alongshore by using DSAS software (Figure 4).

On the ocean side, rates of shoreline movement from 1943 to 2014 range from -0.3 m/year to 2.5 m/year, where negative values represent erosion and positive values represent accretion (Figure 6). Results revealed that erosion dominates the ocean side shoreline with 70% of the cast transect recorded as erosion and 30% as accretion. The result agrees with the shoreline mapping done for the ocean side as shown in Table 3. The shoreline mapping survey revealed a large erosion scarp on the ocean side, from 50 cm to 1 m in height as seen in

Figure 7.

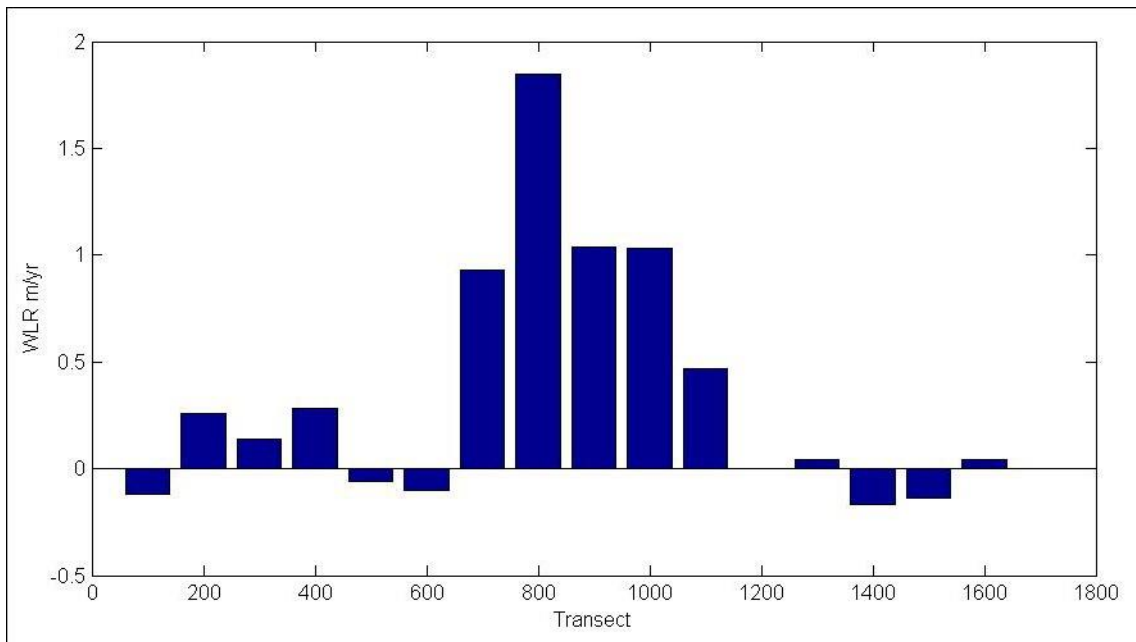


**Figure 6:** Erosion and accretion rates from 1943 to 2014 for the ocean side of Bonriki



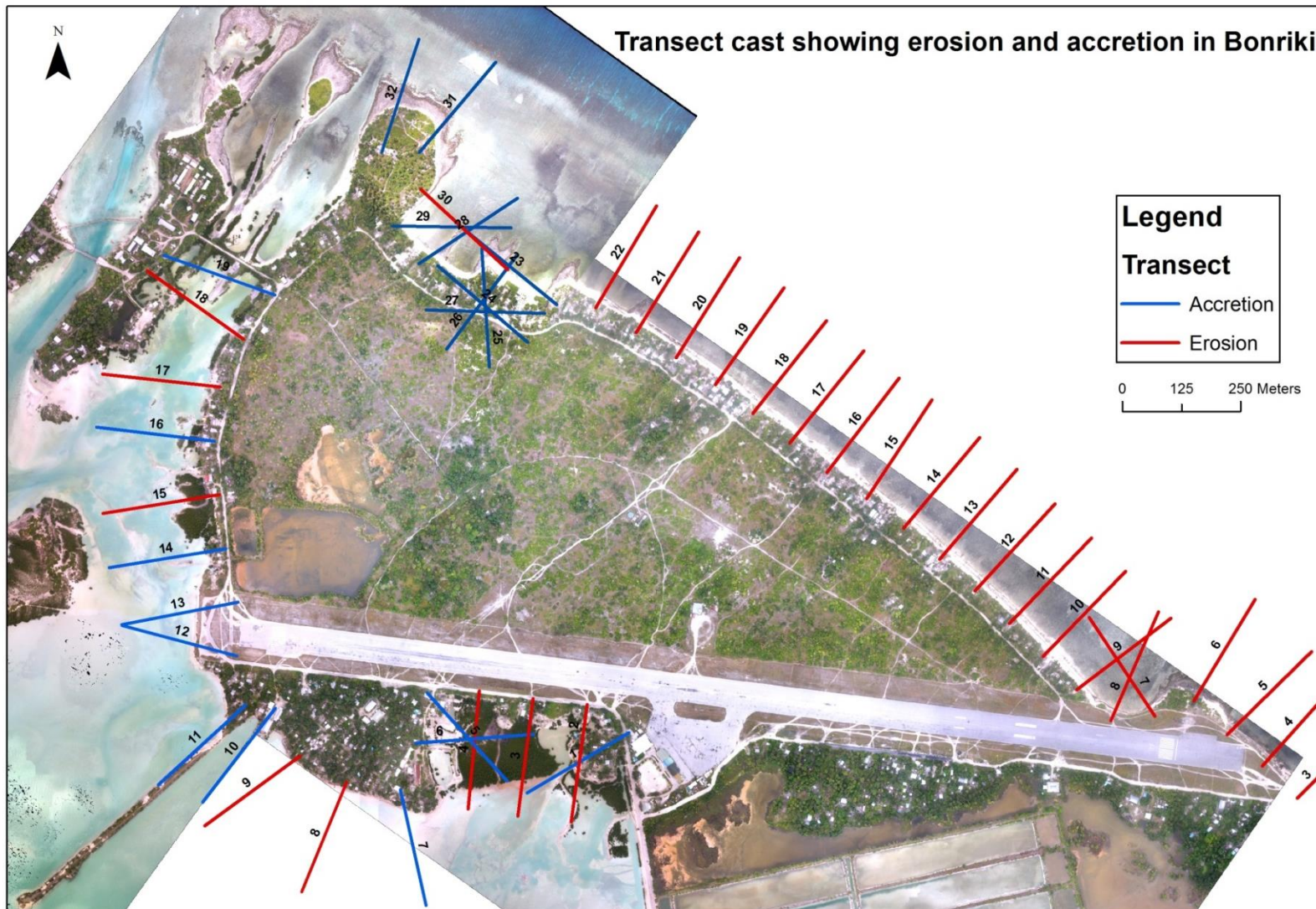
**Figure 7:** A one-meter high erosion scarp on the ocean side of Bonriki

On the lagoon side, the rates ranges from -0.17 m/year to 1.85 m/year. Where negative values represent erosion, and positive values represent accretion (Figure 8). The results revealed that accretion dominates the lagoon shoreline, with 60% of the cast transect recorded as accretion and 40% erosion. This is a result of the major reclamation project on Bonriki–Taborio, and closing of the causeway, which caused the land area to increase from 1968 to 1998.



**Figure 8:** Erosion and accretion rates from 1943 to 2014 for the lagoon side of Bonriki

Figure 9 shows the general trend of accretion and erosion in Bonriki. Note the continuous erosion along the shoreline on the ocean side, which was verified through shoreline mapping as shown in Table 3.



**Figure 9:** Transect cast showing accretion and erosion for the ocean side and lagoon side of Bonriki

### 3.2. Coastline change categories

The shore normal transects were categorised in four groups: accretion, erosion, mixed trend of erosion and accretion, and no trend, where the shoreline is highly unstable, so that no significant trend can fit the shoreline change.

#### 3.2.1. Accretion

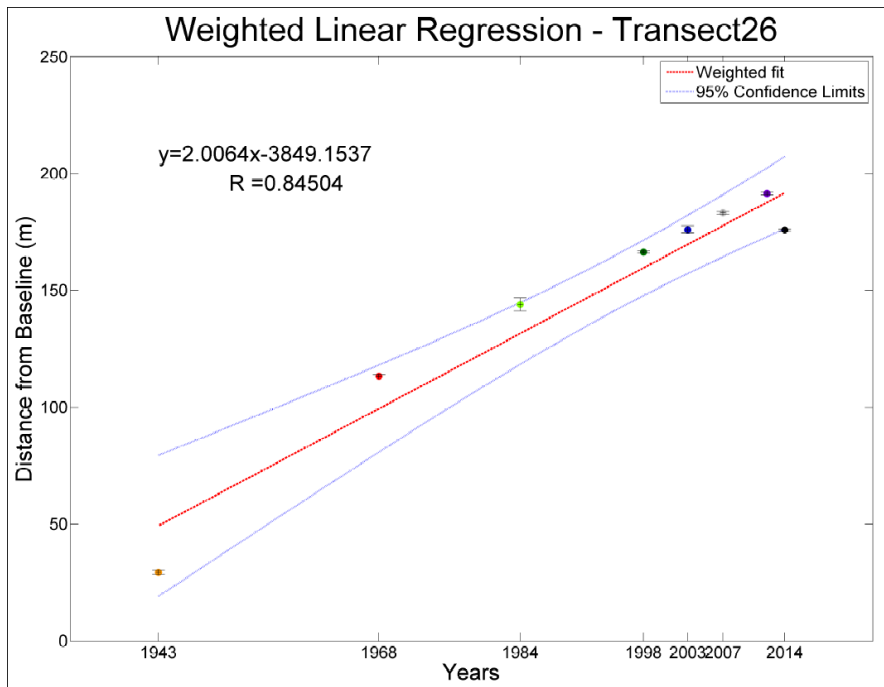
Transects that showed continuous accretion from 1943 to 2014, include transects 25 and 26, with an NSM of 147 m. The accretion rates ranged from 2.0 m/year to 2.54 m/year for these two transects.



**Figure 10:** Shoreline change envelope for Transect 26, which was on the ocean side of Bonriki

The SCE for Transect 26, calculated as the distance between the 2012 and 1943 shorelines, is 162.16 m. This distance is not associated with the age of the shorelines.

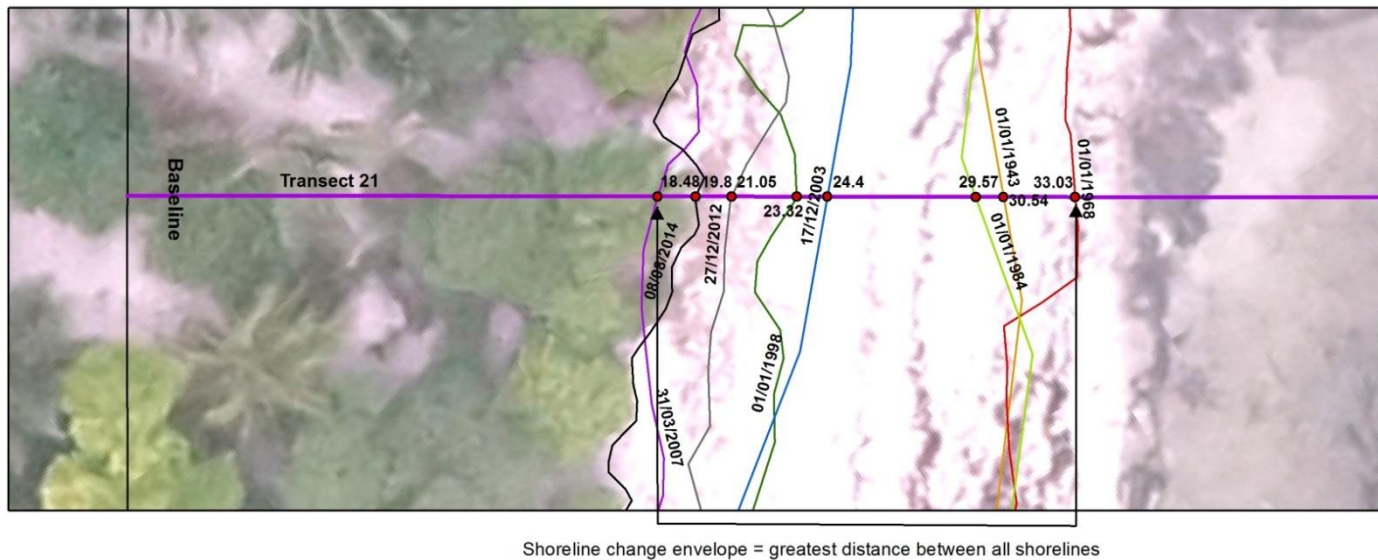
For Transect 26, an NSM of 146.57 m is calculated as the distance between the most recent shoreline from 2014 and the oldest shoreline from 1943.



**Figure 11:** An example of continuous accretion on the ocean side of Bonriki

### 3.2.2. Erosion

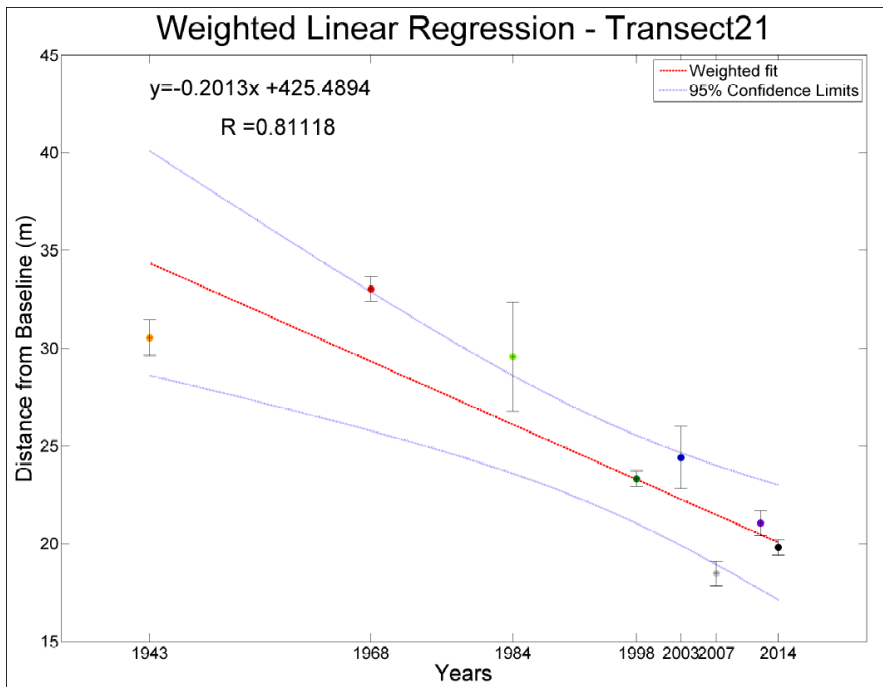
Only Transect 21 showed persistent erosion from 1943 to 2014, with an NSM of 12 m. The erosion rate was -0.2 m/year.



**Figure 12:** Weighted linear regression showing continuous erosion on the ocean side of Bonriki

The SCE for Transect 21 is the distance between the 1984 and 2014 shorelines of 14.55 m. This distance is not associated with the age of the shorelines.

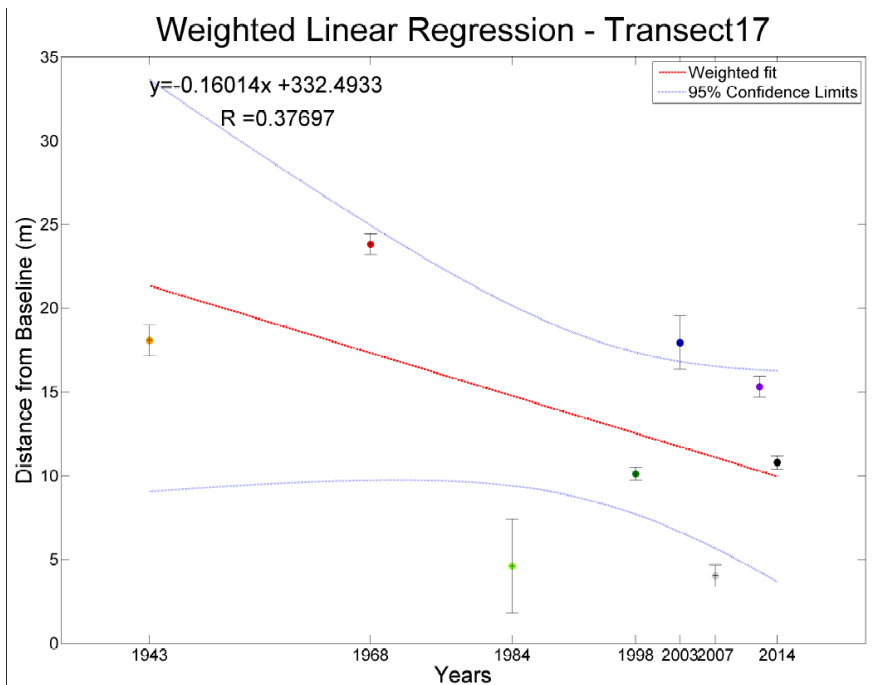
The NSM for Transect 21 is the distance of 12.06 m between the most recent shoreline from 2014 and the oldest shoreline from 1943.



**Figure 13:** An example of continuous erosion on the ocean side of Bonriki.

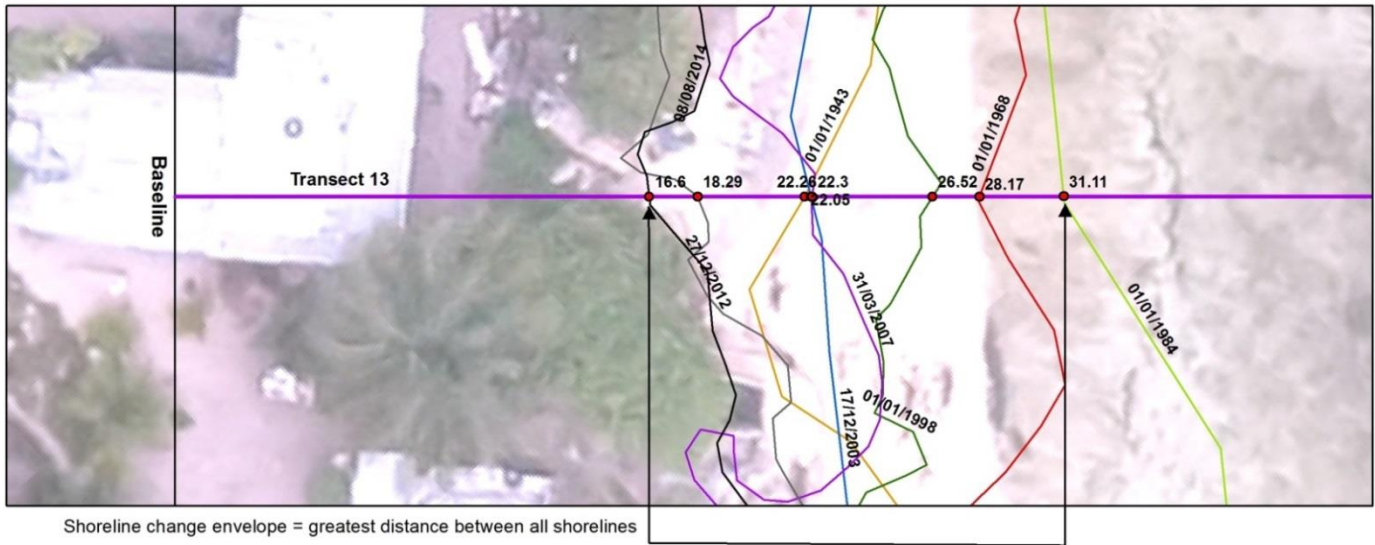
### 3.2.3. No trends

For ocean side transects 4, 5, 20, 23 and 29, and for lagoon side transects 6, 9, 11, 15, 17, 18 and 19, there were no trends in accretion and erosion and no patterns of change could be extracted. Details for Transect 17 are shown in Figure 14 below.



**Figure 14:** An example showing no trend in accretion or erosion at Bonriki. Note that the data points are poorly constraint.

**3.2.4. Mixed trend**

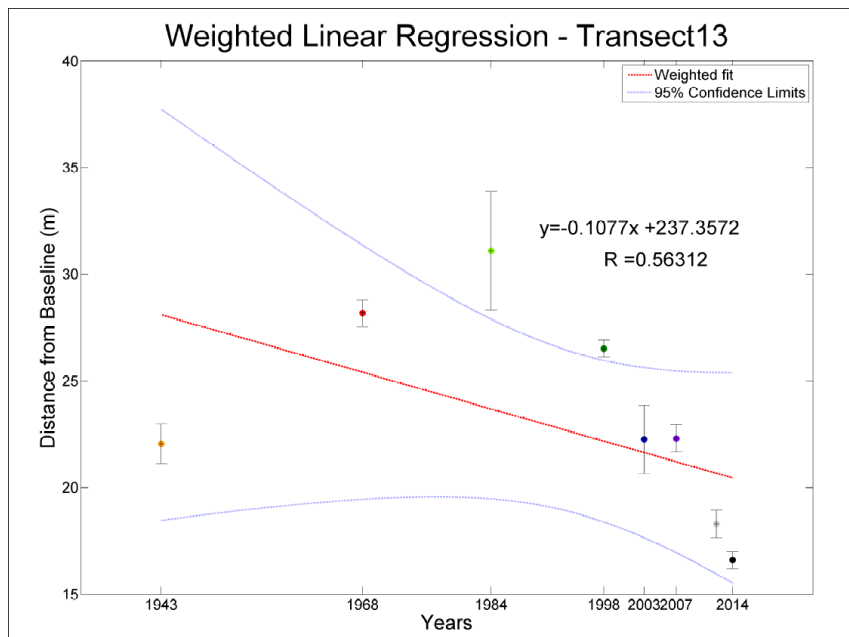


**Figure 15:** An example showing a mixed trend for transects at Bonriki

Ocean side transects 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19, and lagoon side transects 4, 5, 7, 12, 13 and 14 show two distinct trends of erosion and accretion from 1943 to 1984 and from 1984 to 2014. The mixed trend transects number 13 is discussed in more detail below by way of example.

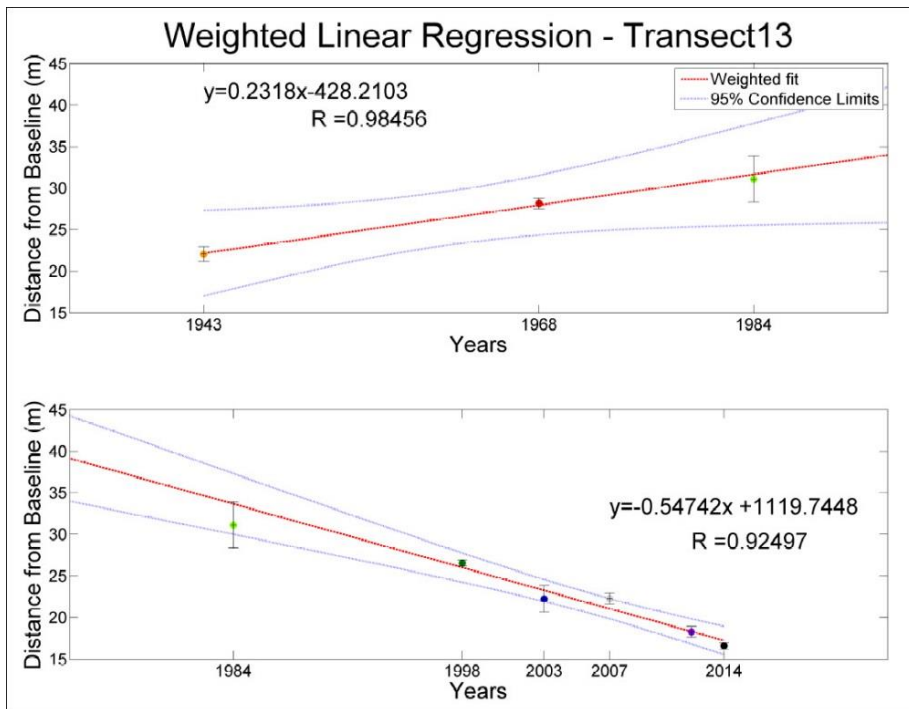
The SCE for Transect 13 is the distance between the 1984 and 2014 shorelines of 12.82 m, this distance is not associated with the age of the shorelines.

The NSM for Transect 13 is the distance of 5.45 m between the most recent shoreline from 2014 and the oldest shoreline from 1943.





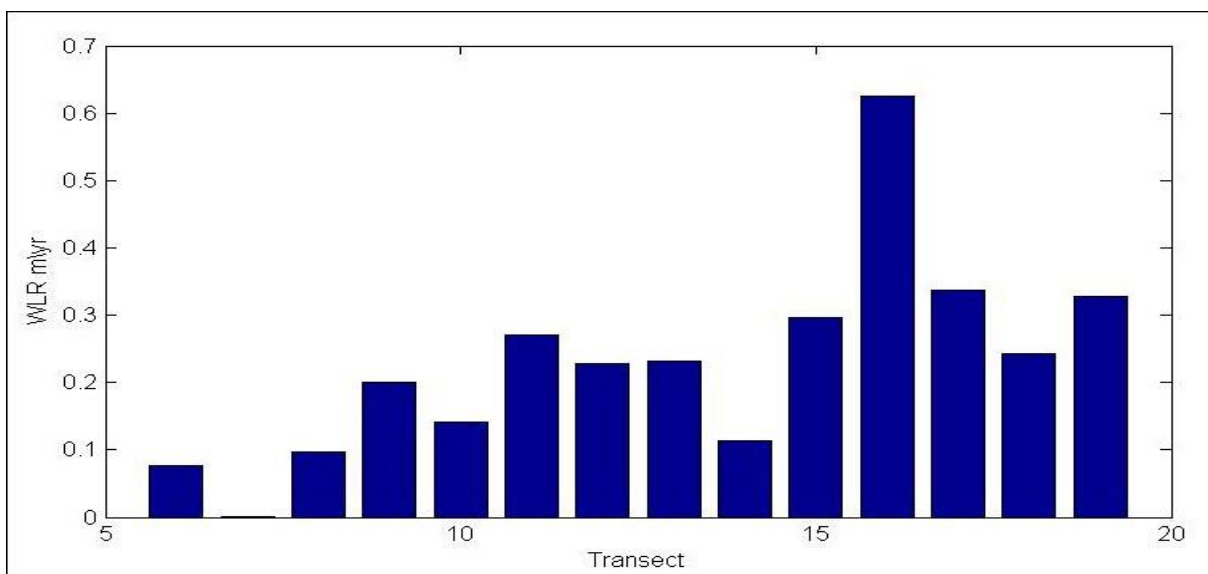
**Figure 16:** An example showing two different trends, one from accretion and the other erosion. The inflection point around 1984 can be clearly identified



**Figure 17:** Weighted linear regression for Transect 13 over two periods: 1943–1984 and 1984–2014.

### 3.2.5. Trends from 1943 to 1984

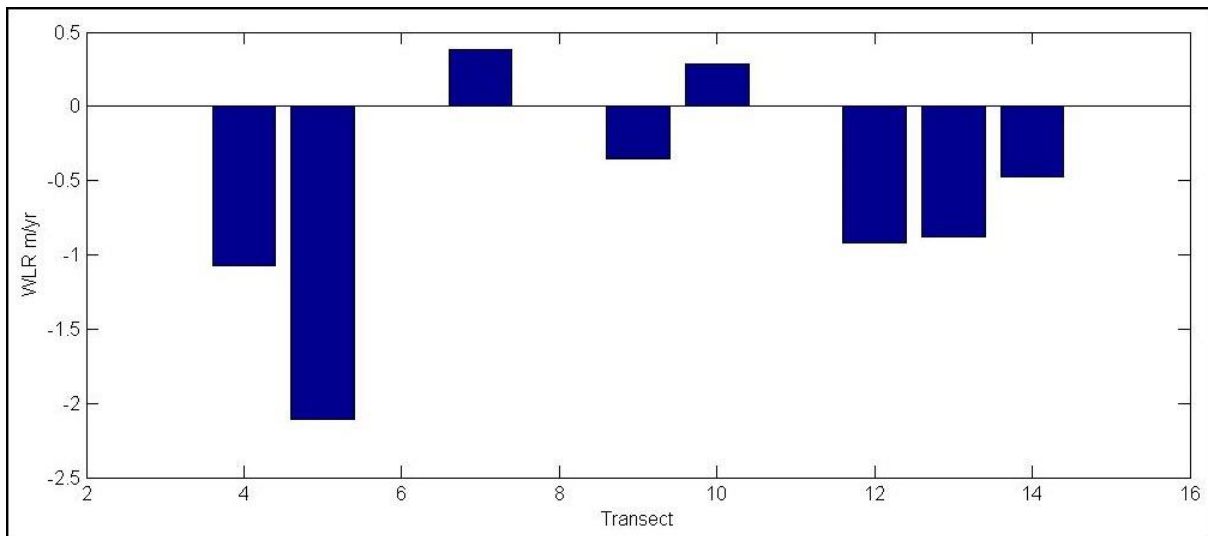
Change rates were calculated for the period 1943–1984 as seen in Figure 18. The results show that there has been significant accretion along the entire ocean coastline for the 41 year period. The average accretion rate was 0.23 m/year. The overall accretion rate ranges from 0.08 m/year to 0.63 m/year. Significant accretion from 1943 to 1984 suggests that the shoreline was recovering from heavy human impact on the island during World War II when Bonriki was an airbase for the US Navy. Two airstrips were built in addition to other infrastructure.



**Figure 18:** Accretion rates from 1943 to 1984 for the ocean side of Bonriki

On the lagoon side, there was both accretion and erosion from 1943 to 1984. The accretion rate ranged from 0.29 m/year to 0.38 m/year and the erosion rate ranged from -0.35 m/year to -2.10 m/year as shown in Figure 19. This trend is the result of the major reclamation project on Bonriki–Taborio and the causeway closure from 1968 to 1998, which resulted in an increase in total land area.

Figure 20 shows the overall accretion and erosion on Bonriki from 1943 to 1984 in map format.



**Figure 19:** Erosion and accretion rates from 1943 to 1984 for the lagoon side of Bonriki

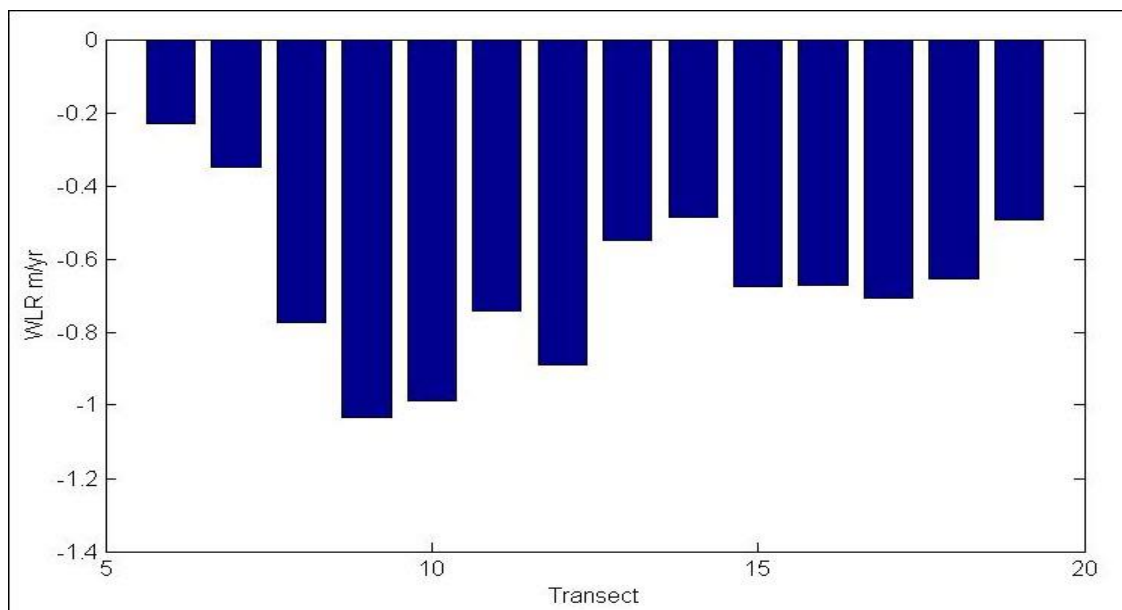


### 3.2.6. Trends from 1984 to 2014

The trend from 1984 to 2014 shows an opposite trend than that for 1943 to 1984 for transects 6–19. The results show that there has been erosion along the ocean coastline for the past 30 years as shown in Figure 21 and Figure 25. The average erosion rate was -0.68 m/year. The overall erosion rate ranged from -0.23 m/year to -0.49 m/year.

As Biribo and Smith (1994) conservatively estimated in 1993, “private” aggregate extraction (meaning individuals selling or using aggregate, of which practically 100% would be sourced from the beach environment) was 4100 m<sup>3</sup> of sand and 8800 m<sup>3</sup> of gravel.

This erosion trend is mainly due to increasing population and development, leading to more encroachment onto the active beach, which is resulting in further interruptions to longshore sediment transport (Figure 22). As reported by Webb (2005), “this is evident everywhere on this coast and is not only hastening the disintegration of this already disturbed beach system but the excavation pits which lay just behind the beach scarp, greatly weaken the beach structure and it is likely that a large storm will result in the loss of many meters of land and flooding”. Another factor is the presence of ad hoc seawalls, which were built by the local communities. These hard structures can lead to further erosion, rather than protection of the coast (Figure 23).



**Figure 21:** Erosion rates from 1984 to 2014 for the ocean side of Bonriki

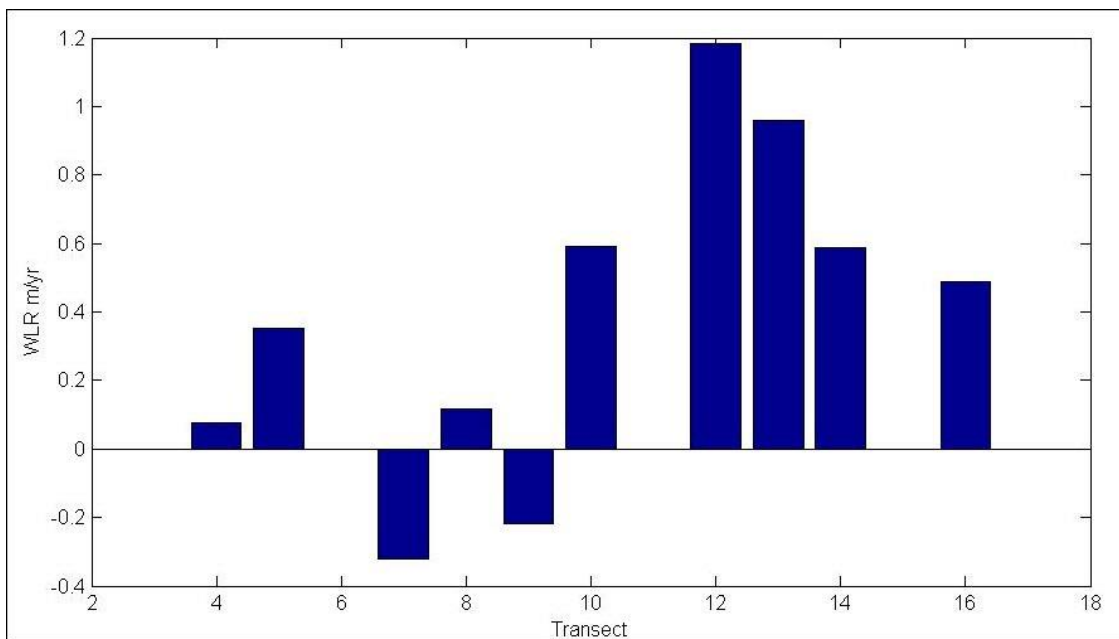


**Figure 22:** Beach mining on the ocean side of Bonriki. Note the bags containing beach material (aggregate) ready for sale and/or transport



**Figure 23:** A seawall structure at Bonriki. Vertical hard structures such as these can lead to scour of the beach and interrupt longshore sediment transport, which can lead to erosion along the adjacent shoreline

For the lagoon side there was both accretion and erosion from 1984 to 2014. The rate ranged from 0.00 m/year to 1.18 m/year and the erosion rate ranged from -0.22 m/year to -0.32 m/year as shown in Figure 24. This trend is due to reclamation towards lagoon side from 1984 onwards. Secondly the increase in mangroves coverage on the lagoon side provides a natural sediment trapping system potentially leading to accretion.



**Figure 24:** Erosion and accretion rates from 1984 to 2014 for the lagoon side of Bonriki

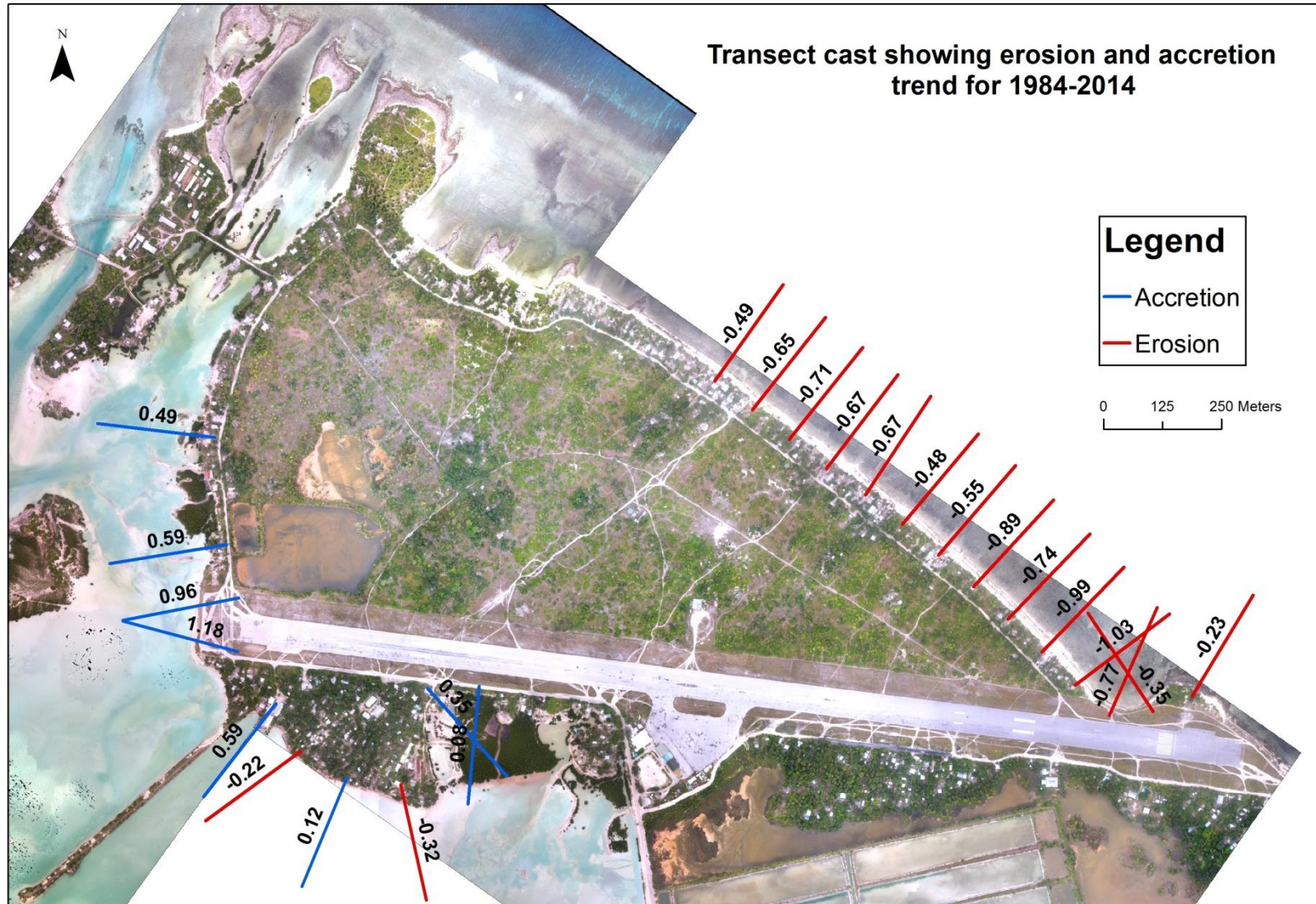


Figure 25: Transect cast showing accretion and erosion at Bonriki from 1984 to 2014

**Table 3:** Detailed comments on each site from the shoreline mapping exercise. Please see appendix 1 for photos of these locations

Site	Latitude	Longitude	Comments
1	1.380689	173.156663	Seawall at runway. Spring high tide – little wave Hs <0.5 m – Observing overtopping of seawall
2	1.381339	173.156072	Erosion beside seawall and beach mining
3	1.381597	173.155692	WWII tank and tar dumping on about 20-m stretch
4	1.381719	173.155453	Erosion scarp visible
5	1.381743	173.155156	Erosion up to the seawall for about 30 m
6			
7	1.381402	173.154819	Start of seawall
8	1.381308	173.15463	Issues in seawall construction – large erosion behind seawall causing a hole in the seawall.
9	1.381623	173.153629	1-m erosion scarp adjacent to seawall
10	1.381748	173.15352	House only 5 m from the erosion scarp
11	1.38231	173.153037	Privately constructed seawall 1 m in height
12	1.382572	173.152756	Extensive erosion scarp
13	1.383011	173.152379	Rubbish on the beach berm and erosion
14	1.384228	173.151064	Seawall start at approximately 1.5 m in height
15	1.384456	173.150735	End of seawall – 1 m erosion scarp – 75 m of a 1 m erosion scarp and rubbish
16	1.385099	173.150028	Start of seawall
17	1.385263	173.149852	End of seawall – 1 m erosion scarp starts again from here
18	1.385501	173.149526	Low beach berm; sand mining – piles of sand for construction purposes; erosion goes to the house. Seawall is at knee height (~ 50 cm)
19	1.385724	173.149257	
20	1.387083	173.147348	Possible pathway for inundation – looks like sand washed over the berm. Gentle slope from tide level (~17:30) to top beach berm with length of 16 m.
21	1.38776	173.146623	No more beach berm
22	1.387924	173.146317	Water mark < 5 m away from the top of the beach, ~1 m lower with small wave (~Hs < 0.5 m)
23	1.388441	173.14556	Erosion
24	1.388651	173.145226	Accumulation of algae due to natural groyne. Suggest longshore current northward
25	1.388898	173.145018	Natural groyne. Stop sediment to move northward. Erosion scarp about 30 cm height
26	1.38915	173.144389	No more erosion
27	1.38941	173.143937	Accumulation of algae – natural groyne – its north side shows large shore retrieval – but very healthy beach – with no erosion
28	1.389347	173.142998	No erosion
29	1.389788	173.142391	Natural groyne – no more algae accumulation. Behind it is very healthy
30	1.389628	173.141773	Healthy shore – lots of clothing on beach (rubbish)



## 4. Conclusion

Mapping changes in shoreline position is vital to our understanding of the dynamics of the coastal system and underpins sound coastal and resource management. The mapping of the Bonriki reserve was achieved by using remotely sensed imagery in the form of aerial photography and satellite imagery in a Geographic Information System. It has been shown that the methodology applied under this mapping activity lends itself for long-term (decadal) quantitative monitoring of shoreline erosion and accretion patterns.

Ocean side and lagoon side rates of shoreline change show that Bonriki has been heavily impacted by ongoing human activity since 1943. The recent shoreline trend (1984–2014) shows an increasing rate of erosion, especially on the ocean side of the islet. As mentioned in Biribo and Woodroffe (2013), “evidence shows that widespread erosion along the ocean and lagoon shorelines is primarily due to human activities and further encroachment onto the active beach will disrupt longshore sediment transport, increasing erosion and susceptibility of the reef islands to anticipated sea-level rise.”

It is recommended to use the information generated under the BIVA Project to support the design of a comprehensive and integrated coastal zone management plan for the Bonriki reserve, with a view to build the resilience of the shoreline against climate change and variability as well as human impacts.

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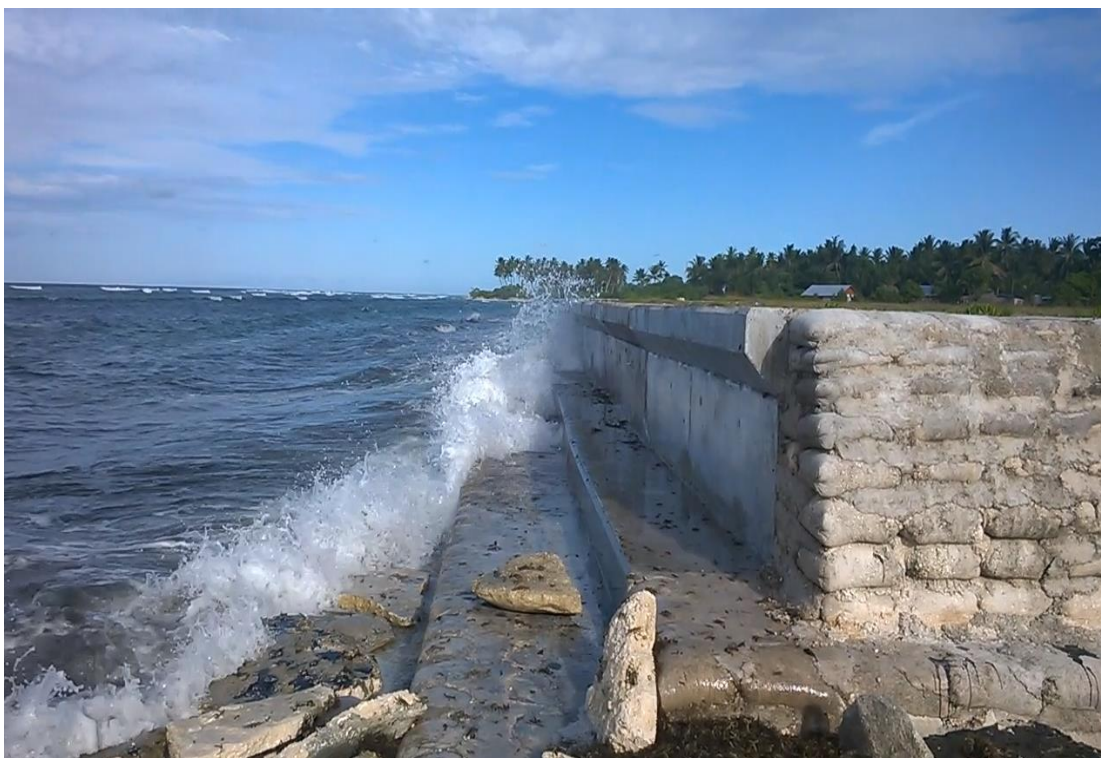
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## Appendix 1: Shoreline mapping photos

### Site 1



Site 2



Site 3



Site 4



Sites 5-6



Site 7



Site 8





Site 9



Site 10



Site 11



Site 12



Site 13



Site 14



Site 15





Site 16



Site 17



Sites 18–19



Site 20





Site 21



Site 22



Site 23



Site 24



Site 25



Site 26



Site 27



Site 28



Site 29



Site 30





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