Bonriki Inundation Vulnerability Assessment

Topographic Survey Report

Zulfikar Begg, Hervé Damlamian, Amrit Raj, Jens Krüger

Australian Government

SPC Secretariat of the Pacific Community

Australian Aid

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SPC
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Table of Contents

List of Tables

List of Figures

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)

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

List of Abbreviations

AusAID	Australian Government Overseas Aid Program
BM	benchmark
BoM	Bureau of Meteorology, Australian Government
GPS	Global Positioning System
MELAD	Ministry of Environment, Lands and Agricultural Development
MFMRD	Ministry of Fisheries and Marine Resources Development
MPWU	Ministry of Public Works & Utilities
MSL	mean sea level
RTK	real-time kinematic
SOPAC	Secretariat of the Pacific Community's Geoscience Division
SPC	Secretariat of the Pacific Community
TBC	Trimble Business Center software
UAS	unmanned aerial system

Executive summary

The impact of climate change and variability on the coastal zone is one of the major constraints on coastal development in small island developing states. Geospatial information is necessary to adequately address infrastructure development. One of the more basic but critical datasets needed is that of topography, or a digital model of the terrain, which provides a baseline and underpins most of the development aspirations of the state and local communities. As a result, both dense and good topography data are equally important for coastal zone development and management.

The Bonriki Inundation Vulnerability Assessment project was established to study the probability of the freshwater lens being inundated with saltwater. One of the core objectives of the project is to produce a hydrodynamic model and a groundwater model, which both require topographic data.

Topographic data were collected using Trimble global navigation satellite system (GNSS) instruments across a survey area in Bonriki. Surveys were completed using 12 benchmarks; and 36,626 data points were measured. Geomorphological features such as vegetation line, beach berms, toe of beach, reef flats, sand flats, lakes and reef crests were captured during the survey.

In addition, an unmanned aerial system (UAS) – the Trimble UX5 aerial imaging solution –was used to compare and complement topography data. This was probably the first time a fixed-wing UAS was deployed in Kiribati, and provided an innovative solution to address the lack of coverage inherent with a ground-based survey such as the Trimble GNSS system.

The Kiribati tide gauge datum was investigated to verify and document the appropriate vertical reference level. Past survey results from Geoscience Australia, BECA International and Lal (2009) were compared. As a result of this, the topography data collected were referenced to tide gauge zero, which is 4.6301 m below the Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) sensor benchmark established by the Australian Bureau of Meteorology. The data were then processed using Trimble Business Center software, and a digital elevation model was created.

Having established ground control points and dense topography, this survey will be of use to future projects related to coastal zone management in the Bonriki area.

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 used 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.

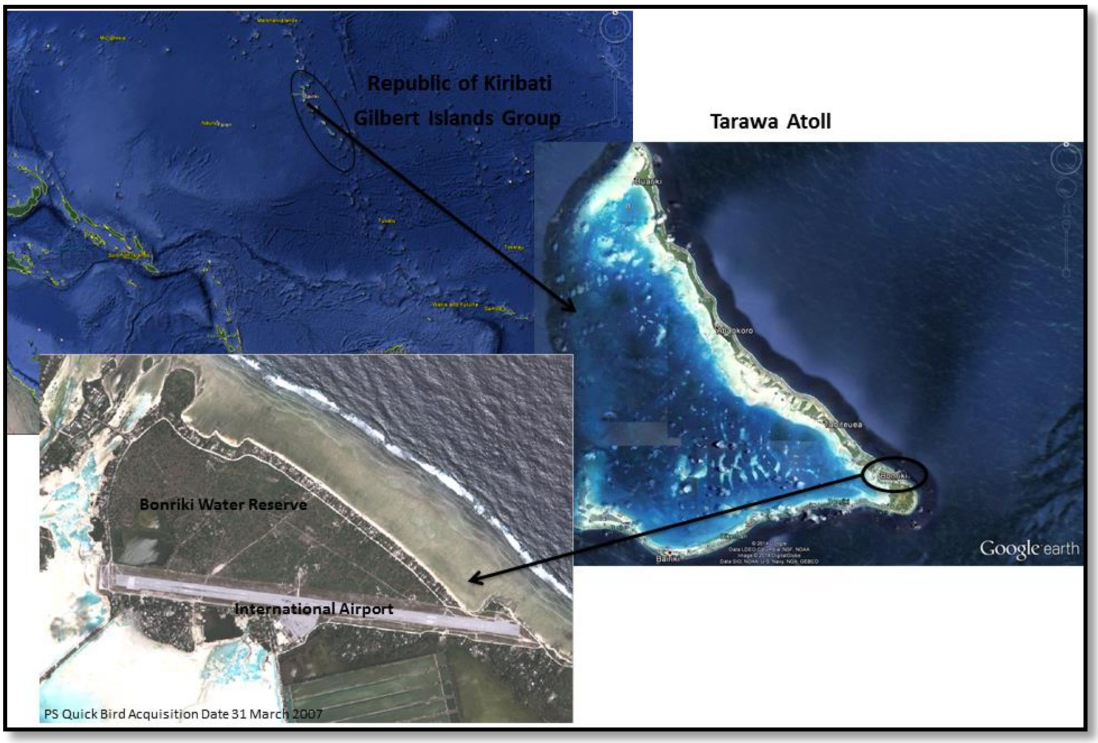

Figure 1. *Bonriki Water Reserve Location.*

1.2. Purpose and scope of the report

The ultimate goal of the coastal phase of the project was to develop a hydrodynamic model for Bonriki. However, before a hydrodynamic model can be developed, a coastal terrain model derived from topographical data is needed.

The first part of the report investigates/reports previous benchmarks used in the collection of topographical data. The remainder of the report provides a summary of topographical surveys of Bonriki, using real-time kinematic (RTK) survey and unmanned aerial system (UAS) methods, to obtain data for the development of a coastal terrain model. It also compares data collected from the two methods.

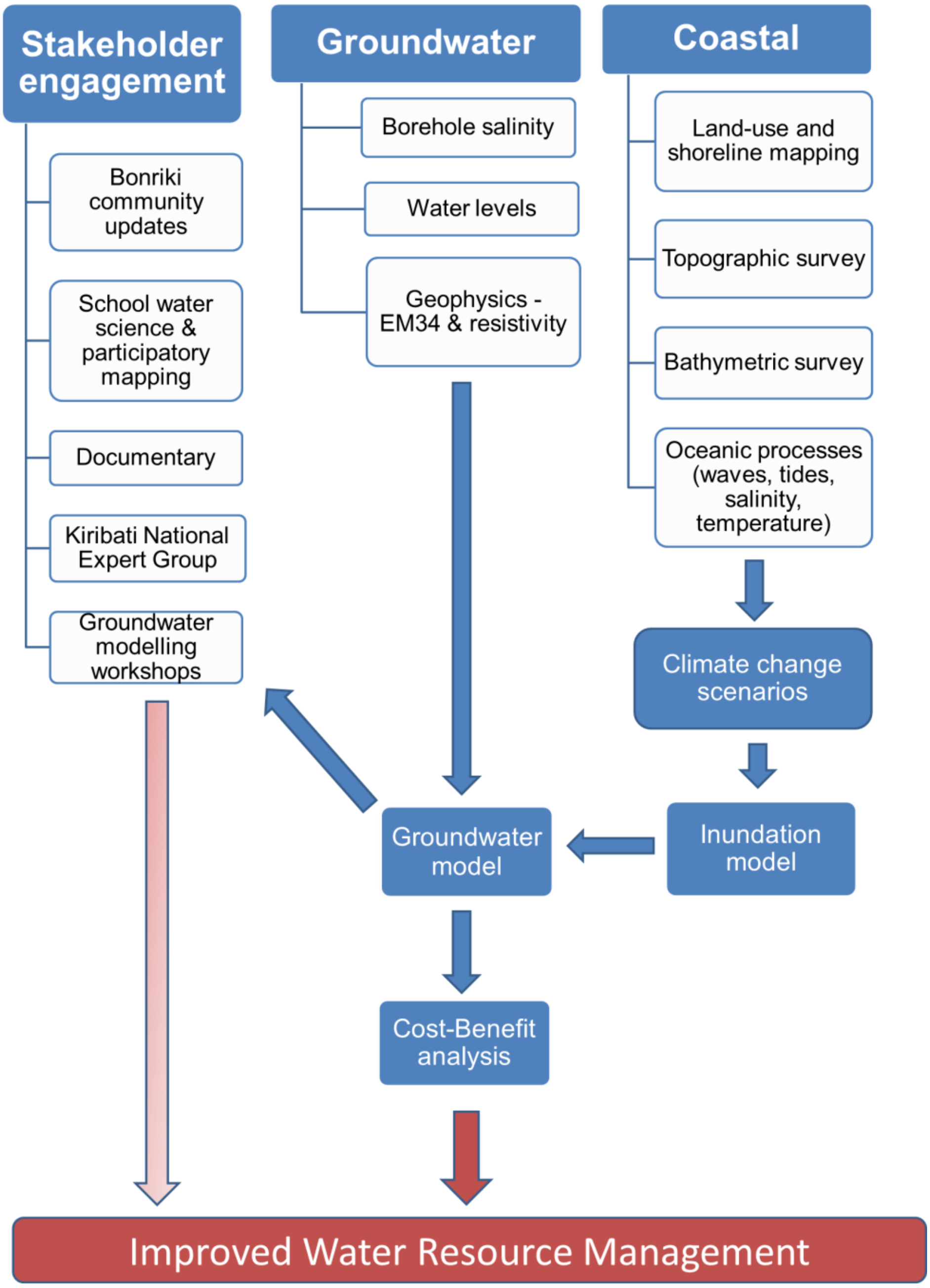

Figure 2. *Bonriki Inundation Vulnerability Assessment project components.*

2. Methods and results

2.1. SEAFRAME Datum

2.2. Global Navigation System survey

Vertical datum

In 1992, a Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) gauge was installed in Betio, South Tarawa, as part of the South Pacific Sea Level and Climate Monitoring Project. This tide gauge supplanted an older tide gauge operated by the University of Hawaii. The SEAFRAME gauge records sea level, air and water temperature, atmospheric pressure, wind speed and direction. The SEAFRAME sensor benchmark (SSBM) is referenced to tide gauge zero, which is equivalent to the University of Hawaii tide gauge zero (AMSAT et al. 2004; Yates and Lal 2012), where tide gauge zero is 4.6301m below SSBM (Figure 3).

Previous researchers (Ramsay et al. 2008) reported an inconsistency with the vertical datum of the SEAFRAME tide gauge, and how it relates to the older Hawaii tide gauge zero. The datum for the SEAFRAME tide gauge was therefore reviewed to check its suitability as a consistent reference point and for comparison with benchmarks surveyed by Lal (2009) and Beca International (2011).

The Kiribati datum was comprehensively analysed by Ramsay et al. (2008). Ramsay et al. (2008) identified a shift of 419 mm in the datum on the SEAFRAME gauge installed in Betio. Heights derived under the GPS control network survey by Lal (2009) is referenced to tide gauge zero (SSBM). These heights were used as the origin for this topography survey.

A comparison of topography data with water level statistics collected as part of the BIVA project produced a discrepancy of 420 mm, reconfirming the shift identified by Ramsay et al. (2008). Similarly, comparison of benchmark data from Yates and Lal (2012), Beca International (2011) and Lal (2009) revealed similarities in some locations and variation in the others, reconfirming the inconsistencies between vertical datums. Because of these inconsistencies, a survey was required to determine to what degree the values differed. Hence, static global navigation satellite system (GNSS) observations were made on a number of benchmarks surveyed by Yates and Lal (2013), Beca International (2011) and Lal (2009).

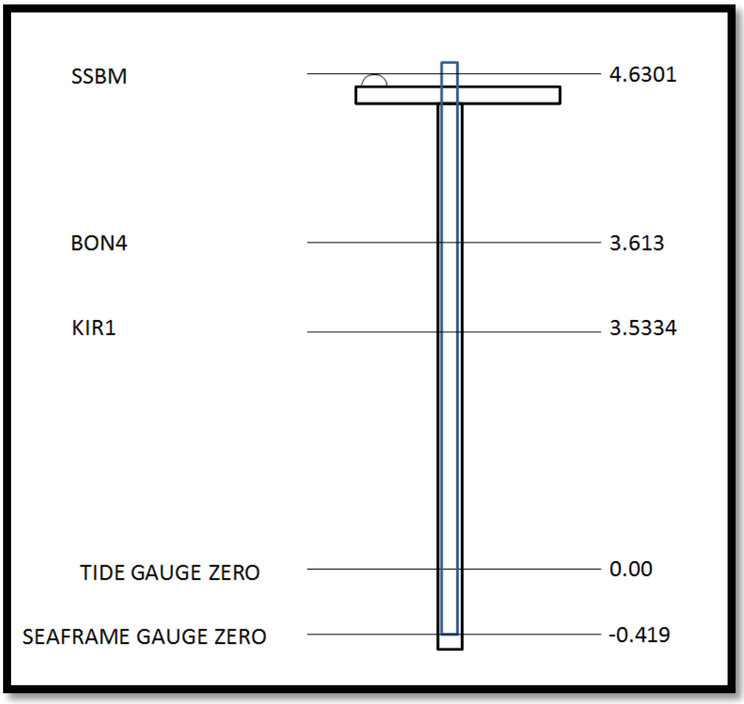

Figure 3. *Datum definition for the control and RTK survey in Bonriki. All the topography and control points are referenced to tide gauge zero (former University of Hawaii gauge zero) which is 4.6301 m below the SEAFRAME sensor benchmark (SSBM) established by the Australian Bureau of Meteorology. The SEAFRAME Tide Gauge Zero value is –0.419 m below SSBM. The 2013 annual mean level of the sea (not shown in the diagram above) is 1.26 m above tide gauge zero.*

Figure 4. *Locations of surveyed benchmarks for the datum investigation plotted on a Google satellite backdrop.*

2.3. Real-time kinematic topographic survey

The real-time kinematic (RTK) method was used to collect topographical data using Trimble R8 models 2 and 3. Twelve benchmarks were established in Bonriki (**Error! Reference source not found.**), with benchmark BON4 used as the control to correct heights for all other points as it is included in the Tarawa control network.

Two GPS receivers were used – a reference (base) receiver set up on a known point and one roving receiver set up on a pick-up truck. The reference receiver takes measurements from the satellites in view, with a minimum of 10 satellites, and transmits them with the position of the reference receiver via two Trimble radios to the roving receivers in real time.

The roving receivers also take measurements from the satellites in view, with a minimum of 10 satellites, and process them in real time with the measurement data and location from the reference receiver. The result is measurement vectors in the WGS84 datum from the reference receiver to the rover receiver. Using these measurement vectors, coordinates for the points occupied by the rover can be computed.

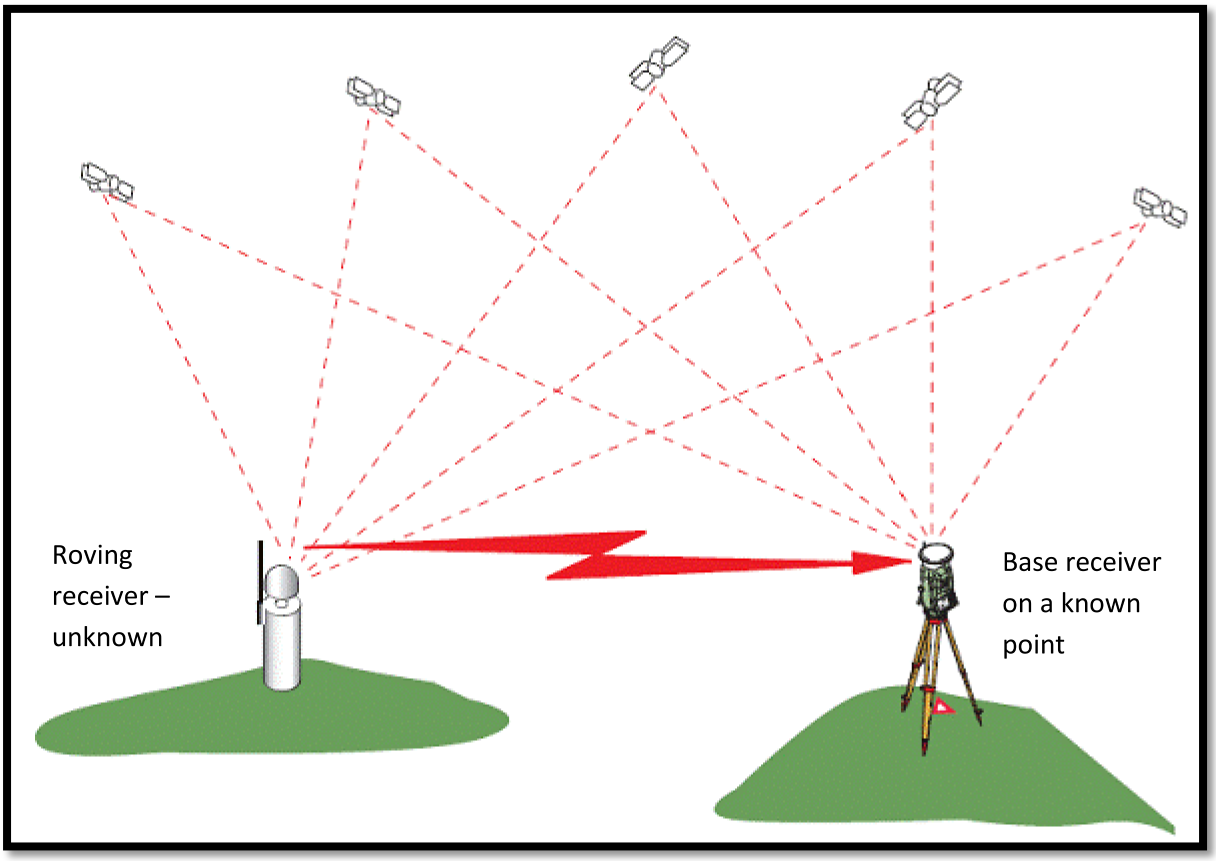

Figure 5. *Principle of a real-time kinematic GPS survey.*

The local coordinate system established before the survey was:

- map projection: UTM Zone 59 North
- horizontal datum: WGS84
- vertical datum: tide gauge zero

The survey also recorded all geomorphological features, such as vegetation line, beach berm, reef flats, and reef crest, which were processed using the Trimble Business Center software.

4× Trimble RTK R8s with their controllers

2× Trimble HPB 450 radios

2× Trimble Omni antennas

2× antenna cables: 30 m and 4 m long

Figure 6. *Main equipment used during the topography data acquisition survey*.

2.3.1. Capacity building

Local staff from the Ministry of Fisheries and Marine Resources Development (MFMRD); the Ministry of Public Works & Utilities (MPWU); and the Ministry of Environment, Lands and Agricultural Development (MELAD) were trained to use the Trimble GPS systems over two days of theory and three weeks of field surveys (Table 1). The field surveys involved learning the basics and set up of a GPS and practising different survey styles with the GPS system. Software such as the Trimble Business Centre and Quantum GIS were then used to show how to download and process field data.

Table 1. *Participants in GPS training from the Kiribati Government.*

Participant	Division	Ministry
Tiuere Torua	Lands	MELAD
Tentao Takaio	Lands	MELAD
Taie Nikora	Lands	MELAD
Romano Reo	Lands	MELAD
Tokabai Bauro	Mineral Unit	MFMRD
Bwenaate Rabunimango	Mineral Unit	MFMRD
Teebete England	Mineral Unit	MFMRD
Rateiti Uateraoi	Fisheries	MFMRD
Naomi Atauea	Mineral Unit	MFMRD
Tion Uriam	Mineral	MFMRD
Taina Temwakei	Water	MPWU

Upon completion of this training, the government departments, particularly Lands and Minerals, were able to initiate RTK surveys as part of their respective programme projects. One such project is coastline monitoring of Tarawa, where the shoreline is being repeatedly surveyed from Betio to Bonriki.

2.4. Field procedure

Figure 7. *Setting up the base station at the BON4 benchmark.*

Figure 8. *To increase radio coverage, the radio antenna was mounted on top of the Public Utilities water tower.*

Figure 9. *Capturing data on a reef crest during the RTK survey.*

Figure 10. *GPS receiver mounted on a government pick-up truck. The rover (receiver) and its pole are mounted at the back of the truck. The controller is mounted inside the car to allow a real-time check of data.*

Figure 11. *A Trimble R8 was mounted on a quad bike to help collect data from the sand flats as well as the water reserve.*

Figure 12. *A canoe was used in the RTK survey in the lakes and salt water marshes.*

2.4.1. Unmanned aerial system survey

Part of the funding received for the BIVA project was used to purchase and test the latest Trimble Unmanned Aircraft System – the Trimble UX5 (**Error! Reference source not found.**). Three SPC staff and one representative of the Kiribati Government participated in a one-week training course on the surveying and processing components of the UX5. A Trimble UX5 remote pilot licence was issued to the three SPC staff upon successful completion of the practical and theoretical exams. SPC is now able to undertake UAS surveys in all of its member countries.

The two main components of the UX5 are the plane (**Error! Reference source not found.**) and the launching ramp (**Error! Reference source not found.**).

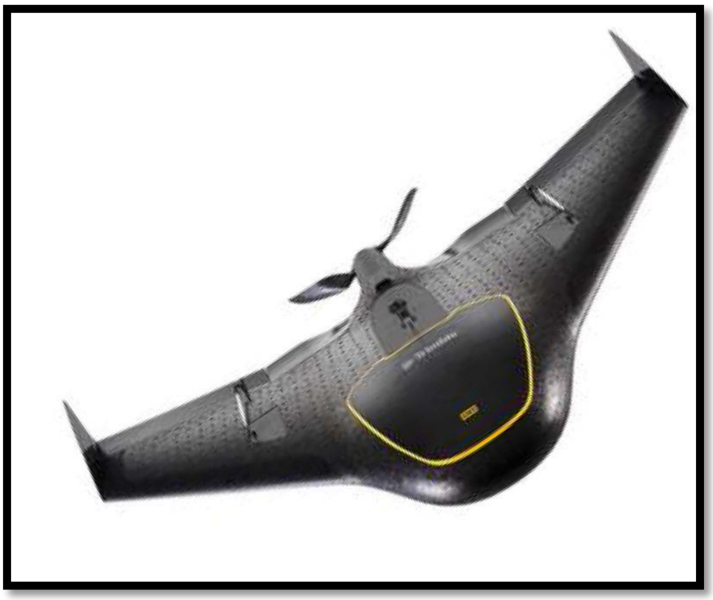

Figure 13. *Trimble UX5 unmanned aerial systems (UAS). The wind span is approximately 1m.*

Figure 14. *Trimble UX5 launching ramp used to propel the UAS into the air at high speed.*

After the training, the team conducted a UAS survey over the study site, which included four components: flight planning, establishment of control points, flights and data processing.

Ground control points

Ground control points (GCP) are essential to georeference the imagery taken by the UX5. A minimum of five well-distributed GCPs are usually recommended to constrain the 2D planar surface of the cloud point, or digital surface model (DSM) derived during data processing phase.

In this survey, 12 GCPs where used, including three GCPs (BK5, BK6 and BK7) newly surveyed using the RTK GPS system. Unfortunately, during the survey, two ground markers (BK3 and TH27) were removed.

Figure 15. *Ground marker seen in the centre of the image deployed on a ground control point, captured by the UAS flying at 315 m Height above Ground.*

Parameter settings

The survey included two 40 minute flights. To maximise the data coverage of each flight, the Height above Ground (HaG) of the UX5 was set at 750 m – the maximum allowed by the system. HaG and coverage are proportional, but are inversely proportional to the data resolution or the pixel size of the aerial imagery. A lower flight altitude results in higher resolution imagery and DSM.

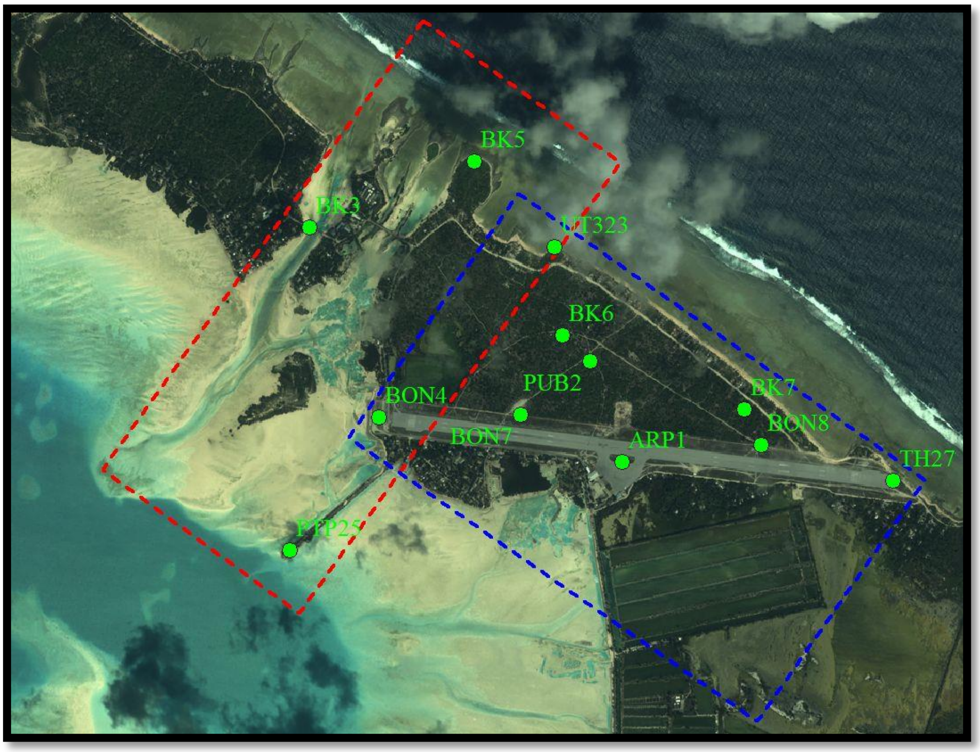

Figure 16. *Coverage of the UAS survey; flight 1 covered an area of 2.4 km^2 (the red zone), and flight 2 covered an area of 2.6 km^2 (the blue zone)*.

Although only two flights were needed to cover Bonriki (**Error! Reference source not found.**), data accuracy and resolution were compromised. At a HaG of 750 m, the UX5 was able to capture imagery at a resolution of 24 cm. At a 75 m HaG, the minimum allowed by the system, the UX5 can capture imagery at a resolution of 2.4 cm. While this setting would give much higher accuracy, it would also require a large number of flights to compensate for the relatively small data coverage obtained on each flight.

Moreover, the UAS allows the user to define a percentage of overlap in the aerial imagery. The overlap controls the accuracy of the data; however, higher overlap leads to smaller coverage, which requires more flights to complete the survey. The percentage of overlap commonly used ranges from 70% to 90%, giving low to high accuracy (relatively to the HaG chosen), respectively. An overlap of 80% was used in the test survey.

Flight

Wind parameters are essential for flight planning. During the flight there was south westerly wind in Tarawa with a speed of 5 m/s to 10 m/s. The flight path was adjusted to make the survey lines perpendicular to the wind direction. The flight path for flight 1 can be seen in **Error! Reference source not found.**.

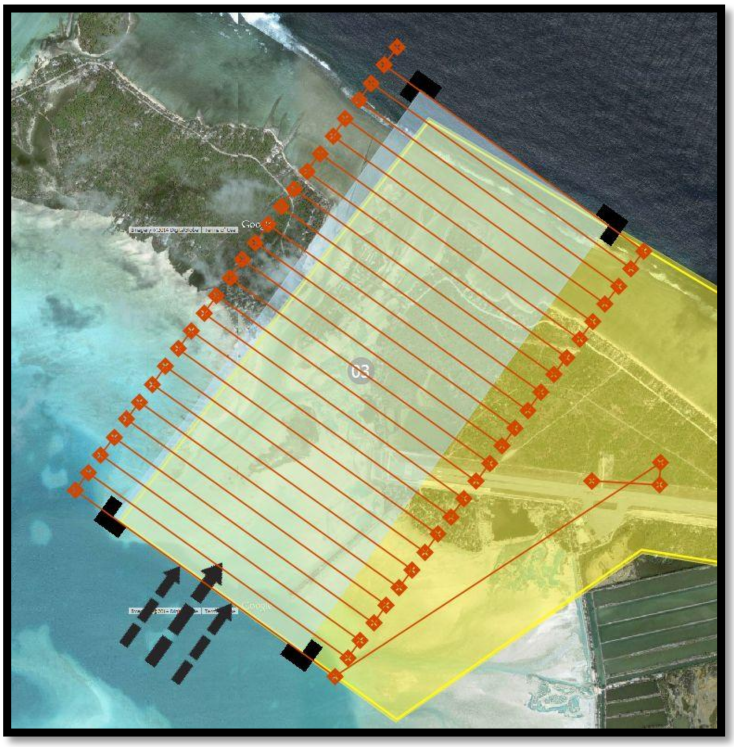

Figure 17. *Designed flight path for flight 1, using Trimble Aerial Imaging Software; black arrows show the wind direction.*

3. Results

3.1. Global Navigation System Survey

3.1.1. Vertical datum

Evaluation of data from the survey suggests that the vertical component (elevation) values concur with the data from Lal (2009). Variations between 0 to 9mm (**Error! Reference source not found.**) were discerned but these are considered to be negligible in this situation as these surveys were accomplished with the GNSS system which has an uncertainty of up to 20mm for values in the vertical. The discrepancy of 420mm produced in comparison of water level data to topography was due to variation in reference points. The water level derived from the SEAFRAME gauge is referenced to the SEAFRAME datum whereas topography data is referenced to tide gauge zero. This also confirms the datum definition by Ramsay et al. (2008) which states, the SEAFRAME datum is 419mm below the tide gauge zero (Figure 3).

3.1.2. Real-time kinematic topographic survey

All the benchmarks were networked with BON4 (**Error! Reference source not found.**, Figure 19, and **Error! Reference source not found.**), which has a known coordinate and is connected to the KIR1 benchmark. KIR1 is referenced to the SEAFRAME station installed by the Australian Bureau of Meteorology, and all heights are therefore relative to tide gauge zero (Figure 3). A total of 36,626 data points were measured during the survey (**Error! Reference source not found.**). The topography data collected show a range of elevations between about –0.918 m across the sand flat on the lagoon side to 5.679 m inland at the water reserve. Various features on the either side of water reserve such as reef crest, reef flat, base of beach, high tide level, vegetation line, sand flat etc. were recorded during the RTK survey as shown in **Error! Reference source not found.**. This was done in order to be able to separate and compare elevations between the various regions such as inland on the islet, lagoon, and on the reef flat (**Error! Reference source not found.** to **Error! Reference source not found.**) which contributes towards a more detailed understanding of the geomorphology and also improves the calibration of the inundation model for which the topography was used.

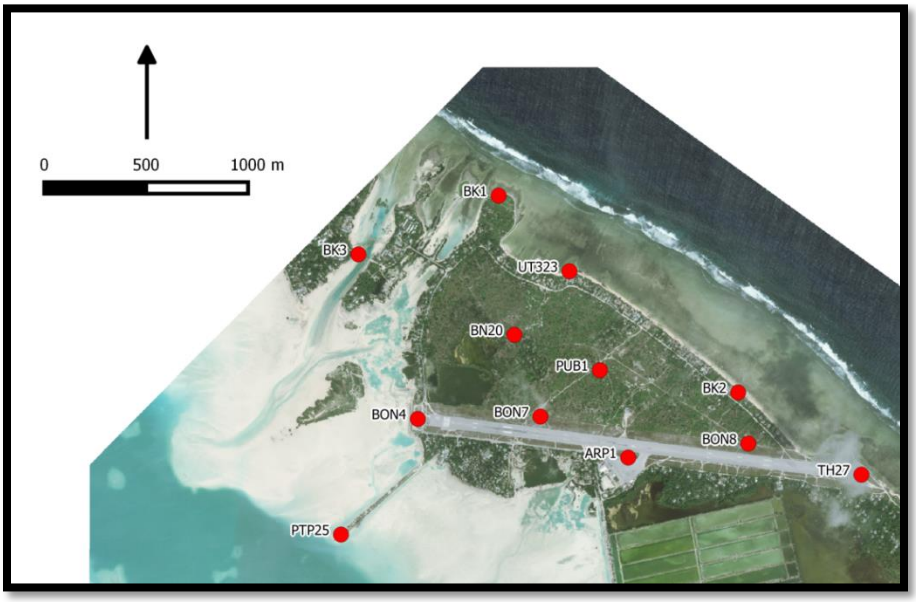

Figure 18. *Map showing locations of benchmarks in Bonriki.*

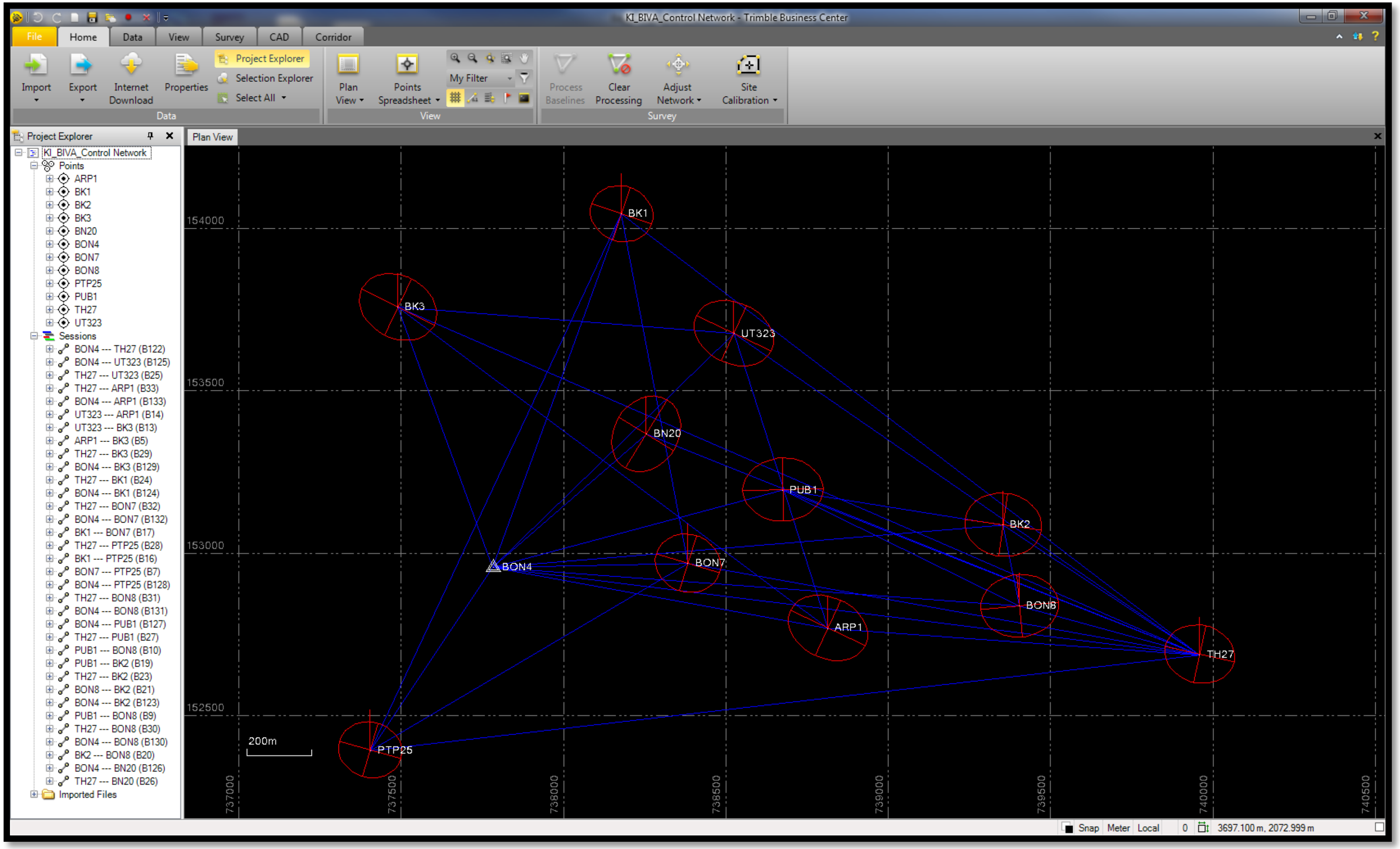

Figure 19. *Screen capture of Trimble Business Center software, v2.81, showing the control network of benchmarks established in Bonriki.*

Table 2. *Height comparison of benchmarks for the various surveys in Kiribati. The results from this survey are in agreement with the survey by Lal (2009).*

				Elevation			Differences between surveys		
Point ID	Easting	Northing	BIVA project	Yates & Lal (2013)	BECA (2011)	SOPAC (2009)	Y&L–BIVA	BECA–BIVA	SOPAC–BIVA
7032	738907.7	152764.8	2.984						
7033	739959.9	152713	3.844						
BON4	737781.6	152955.3	3.613			3.613			0
KIR3	713946.7	149822.8	3.569	4.6316		3.565	1.0626		–0.004
KIR12	715063.2	150964.2	4.357	4.2188	4.22		–0.1382	–0.137	
KIR102	714863.2	150237.4	4.085	4.0096	4.01		–0.0754	–0.075	
KIRI	713951.3	149807.1	5.356	5.3576			0.0016		
PIN103	726937.6	149285.2	3.637		3.559			–0.078	
TH09	737843	152951.2	3.605		3.983			0.378	
TH27	739959.1	152685.1	4.129		4.641			0.512	
UT179A	719711	147125.4	4.236		4.145	4.237		–0.091	0.001
UT348	721890.9	147086.2	3.591		3.482	3.596		–0.109	0.005
UT407	728523.2	149931.1	3.054			3.063			0.009

Table 3. *Benchmarks used for the RTK survey. Coordinates are referenced as UTM WGS84 Zone 59 North.*

Point ID	Easting	Northing	Elevation
ARP1	738814.3	152767.5	2.641
BK1	738177.4	154044.2	3.423
BK2	739353.4	153085.6	4.644
BK3	737489.4	153757.1	6.138
BN20	738255.3	153365.7	3.143
BON4	737781.6	152955.3	3.613
BON7	738383.1	152967.3	2.709
BON8	739403.8	152836.4	3.221
PTP25	737404.9	152390.8	3.266
PUB1	738675.1	153193.5	7.57
TH27	739959.1	152685.1	4.137
UT323	738525.2	153675.5	3.857

Table 4. *Example of RTK survey data exported from Trimble Business Center software.*

Point ID	Easting	Northing	Elevation	Feature Co	Point ID	Easting	Northing	Elevation	Feature Co
A0001	737784	152899.8	3.106	TOPO	**BRA246**	739958.1	152743.5	2.19	BEACH ROCK
A0002	737782.8	152891.5	3.034	TOPO	**BRA247**	739960.5	152741.5	1.998	BEACH ROCK
A0003	737780.8	152877.5	2.933	TOPO	**BRA248**	739959.8	152739.8	2.132	BEACH ROCK
A0004	737778.2	152868.9	2.798	TOPO	**BRA249**	739962.8	152737.2	2.43	BEACH ROCK
A0005	737792.6	152860.9	2.421	TOPO	**BRA25**	739787.3	152810	2.087	BEACH ROCK
A0006	737802.6	152888.6	3.011	TOPO	**BRA250**	739964.3	152738.4	2.131	BEACH ROCK
A0007	737913.7	152873.6	2.983	TOPO	**BRA251**	739967.6	152736.2	2.118	BEACH ROCK
A0008	737902.4	152851.1	2.876	TOPO	**BRA252**	739966.9	152734.8	2.313	BEACH ROCK
A0009	737885.3	152801	2.841	TOPO	**BRA253**	739970.7	152733.9	2.114	BEACH ROCK
A0010	737873.7	152775.4	2.548	TOPO	**BRA254**	739969.8	152732.4	2.385	BEACH ROCK
A0011	737870.5	152739	2.761	TOPO	**BRA255**	739973.8	152729.5	2.301	BEACH ROCK
A0012	737879.3	152753.3	2.678	TOPO	**BRA256**	739975.2	152730.4	2.1	BEACH ROCK
A0013	737893.3	152773	2.969	TOPO	**BRA257**	739978.4	152728.5	1.813	BEACH ROCK
A0014	737899.6	152728.2	2.823	TOPO	**BRA258**	739977.7	152727	2.27	BEACH ROCK
A0015	737909.8	152749.6	2.986	TOPO	**BRA259**	739980.7	152724.7	2.245	BEACH ROCK
A0016	737934.4	152792.8	2.94	TOPO	**BRA26**	739785.3	152813.5	2.026	BEACH ROCK
A0017	737959.7	152869.2	3.142	TOPO	**BRA260**	739982	152725.8	1.864	BEACH ROCK
A0018	737958.4	152859.4	3.252	TOPO	**BRA261**	739985.7	152723.3	1.839	BEACH ROCK
A0019	737957.8	152849.9	.771	TOPO	**BRA262**	739984.4	152721.9	2.053	BEACH ROCK
A0020	737942.6	152824.1	2.996	TOPO	**BRA263**	739987.6	152718.9	2.048	BEACH ROCK
A0021	737935.1	152805	2.745	TOPO	**BRA264**	739989.4	152719.9	1.808	BEACH ROCK
A0022	737931.3	152795.6	2.942	TOPO	**BRA265**	739991.9	152717.6	1.831	BEACH ROCK
A0023	737940.1	152721.8	2.242	TOPO	**BRA266**	739990.8	152716	2.119	BEACH ROCK

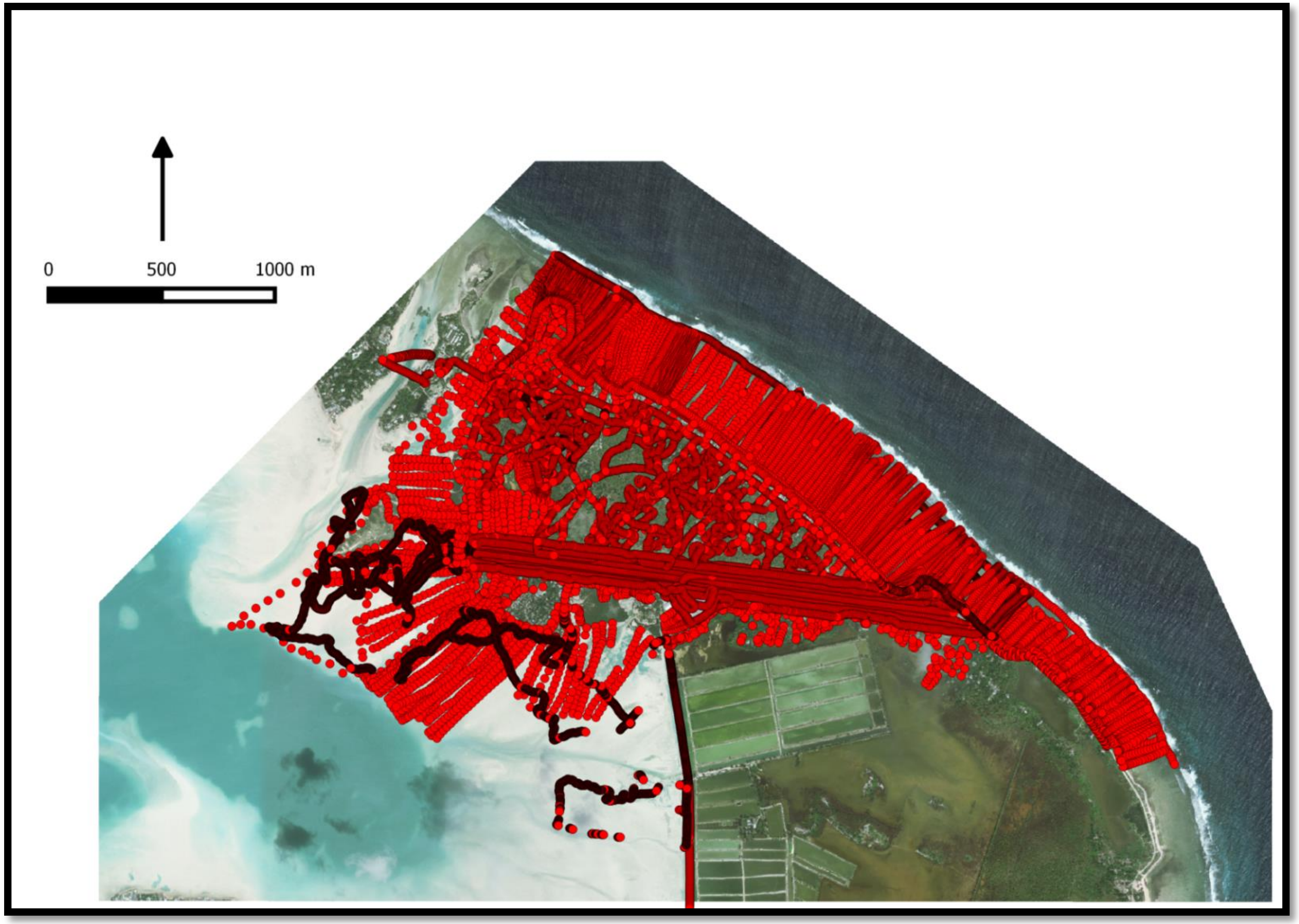

Figure 20. *Map of the Bonriki study site, showing the area covered during the RTK survey. Darker points show the dense collection of point along the tracks of RTK collected using the quadbike.*

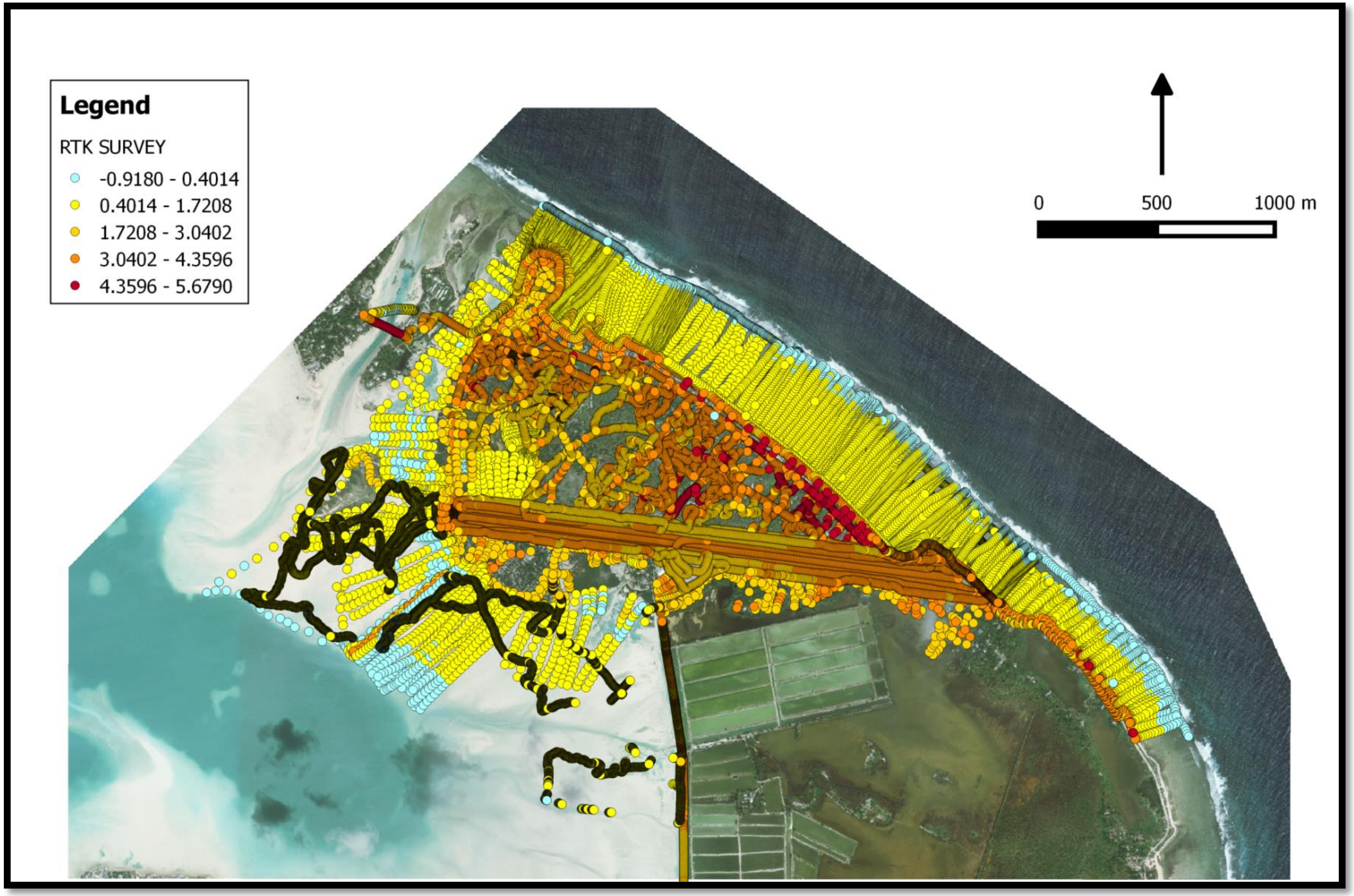

Figure 21. *Map of the Bonriki study site, showing the RTK coverage with graduated colours representing elevation in metres.*

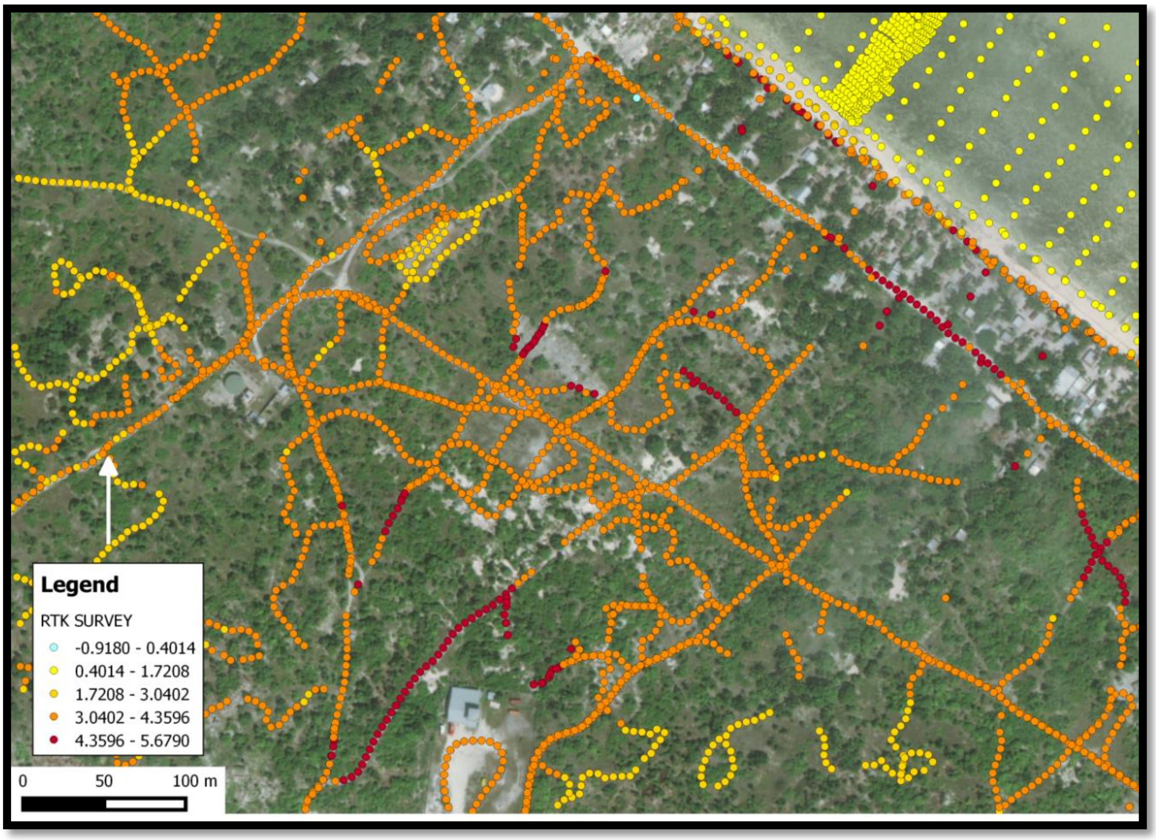

Figure 22. *Detail of the RTK survey results showing higher elevation areas, which mainly includes roads and the water reserve area.*

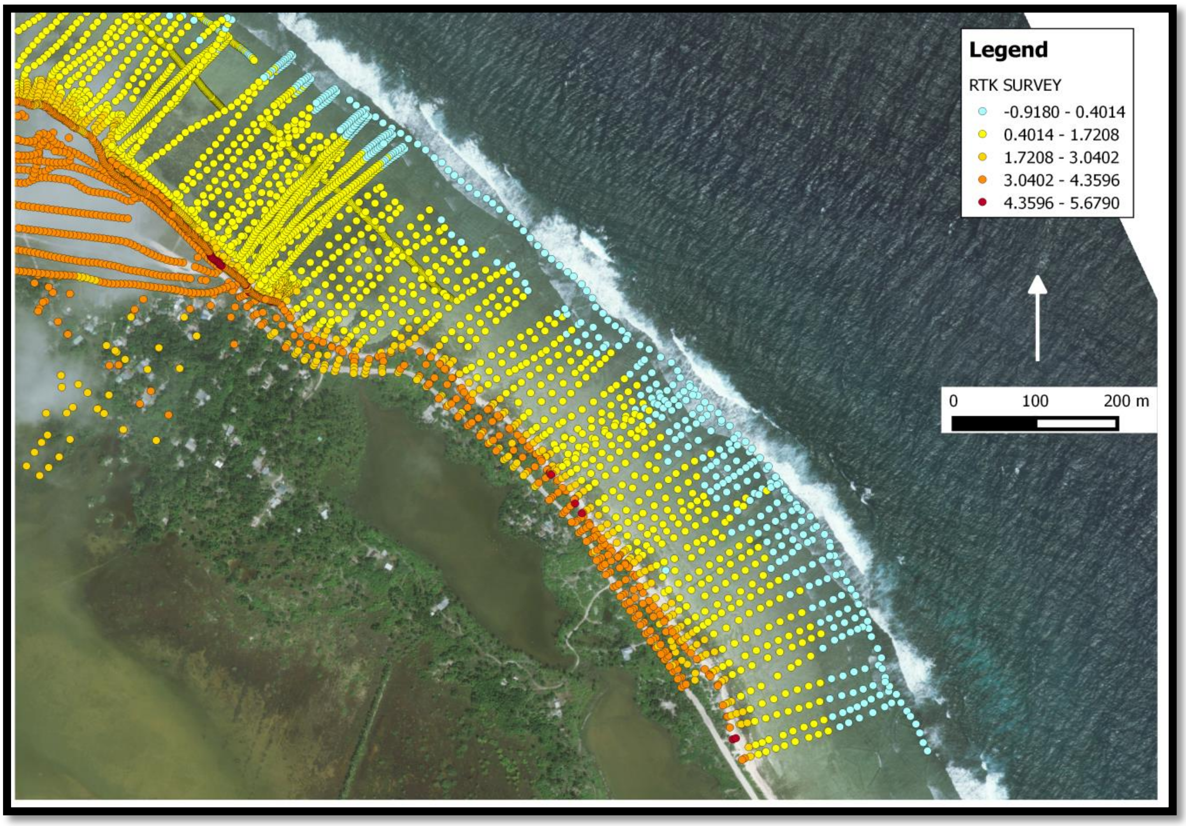

Figure 23. *RTK survey of Bonriki showing low areas such as sand flats, reef flats and reef crests.*

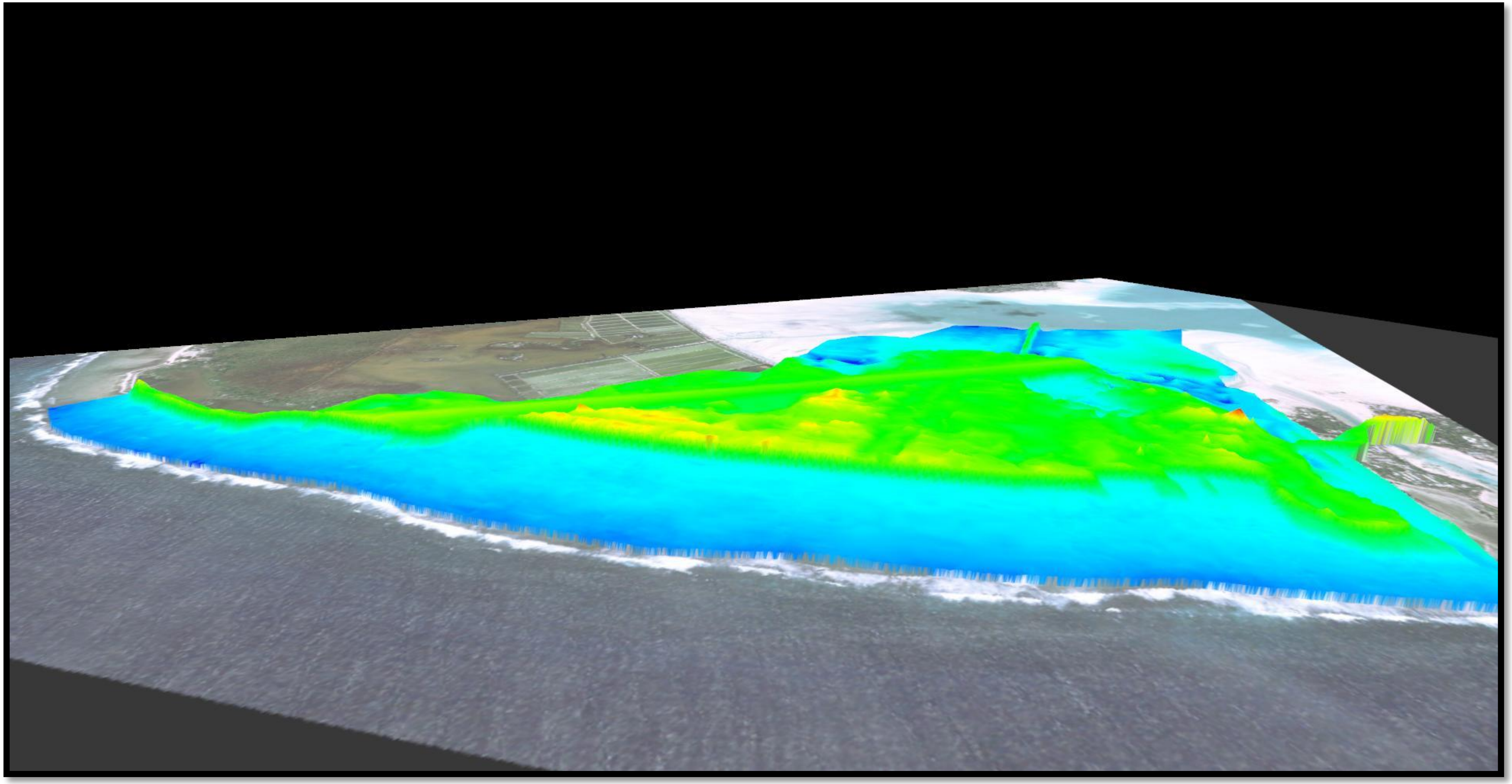

Figure 24. *Digital terrain model generated from elevation points collected from the RTK survey.Image looking toward the southwest.*

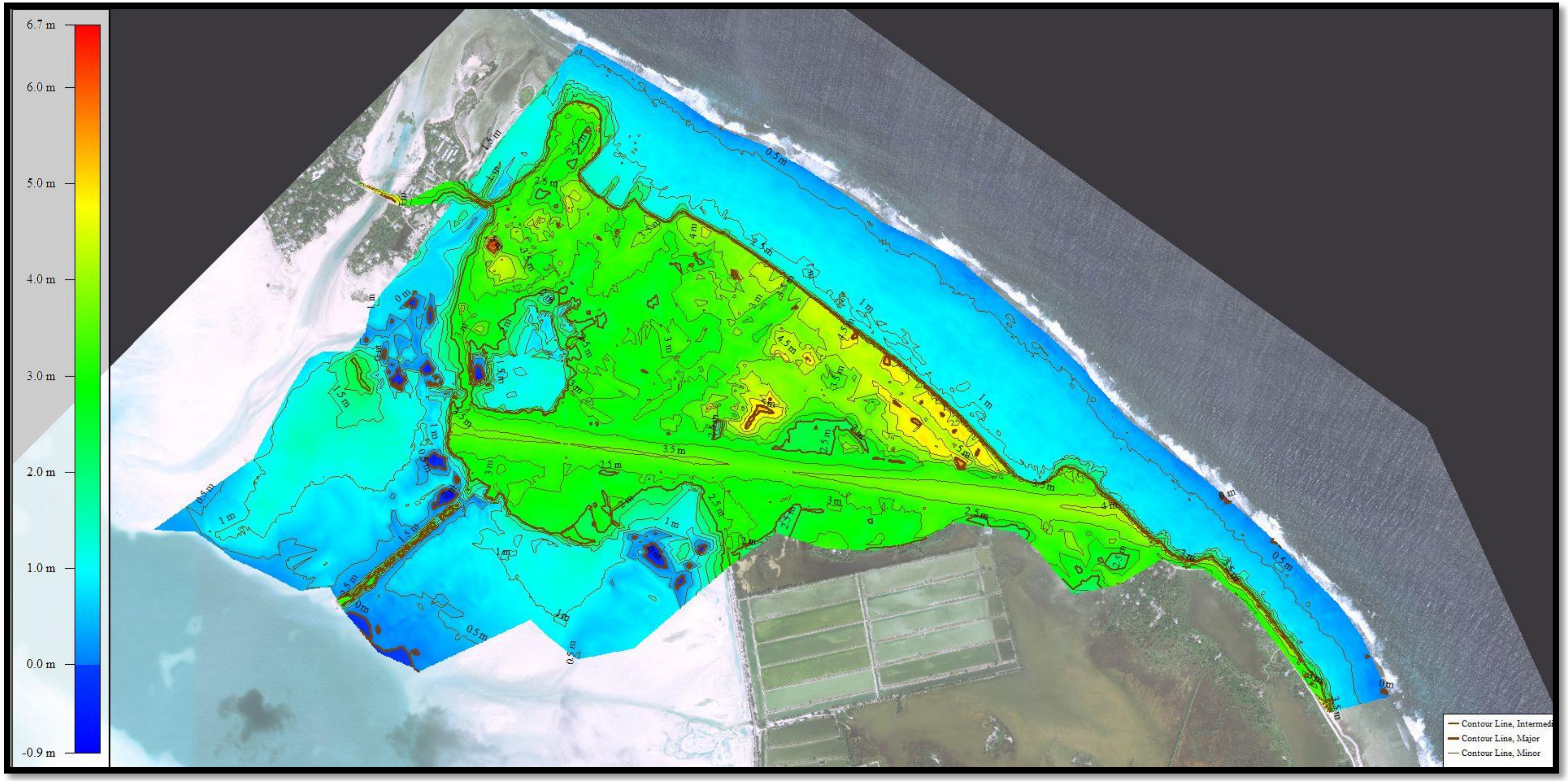

Figure 25. *0.5-m contours generated from the digital terrain model.*

3.2. Unmanned aerial system

The photogrammetry module of the Trimble Business Center software was used to process the data obtained from the UAS survey. The software provides four outputs: an orthophoto (**Error! Reference source not found.** and **Error! Reference source not found.**), a point cloud (**Error! Reference source not found.** and **Error! Reference source not found.**). The point clouds were interpolated into a 25 cm grid over the study site. The resulting digital surface model is shown in Figure 30 and Figure 31.

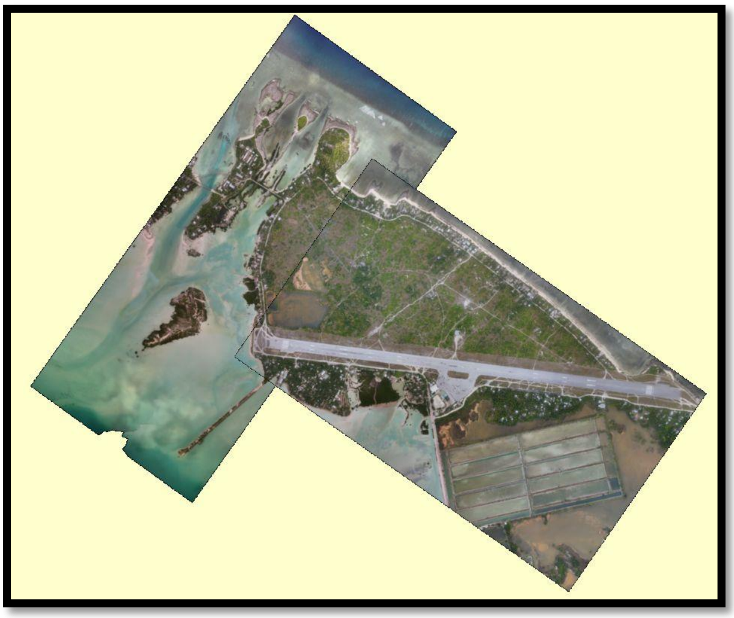

Figure 26. *Combined orthophotos from flight 1 and flight 2; 10 cm image resolutions.*

Figure 27. *Orthophoto, zoomed in on the Control Tower; 10 cm resolution.*

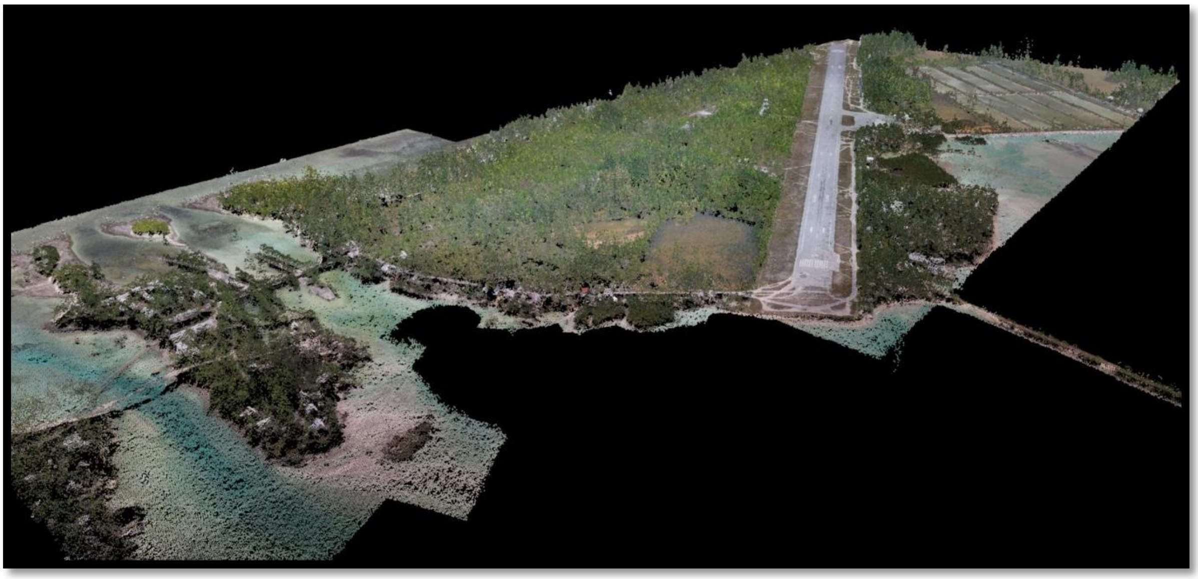

Figure 28. *Point clouds generated from the aerial imagery over Bonriki.Image looking toward the southeast.*

Figure 29. *Zoomed in view of the point cloud generated from aerial imagery over Bonriki.*

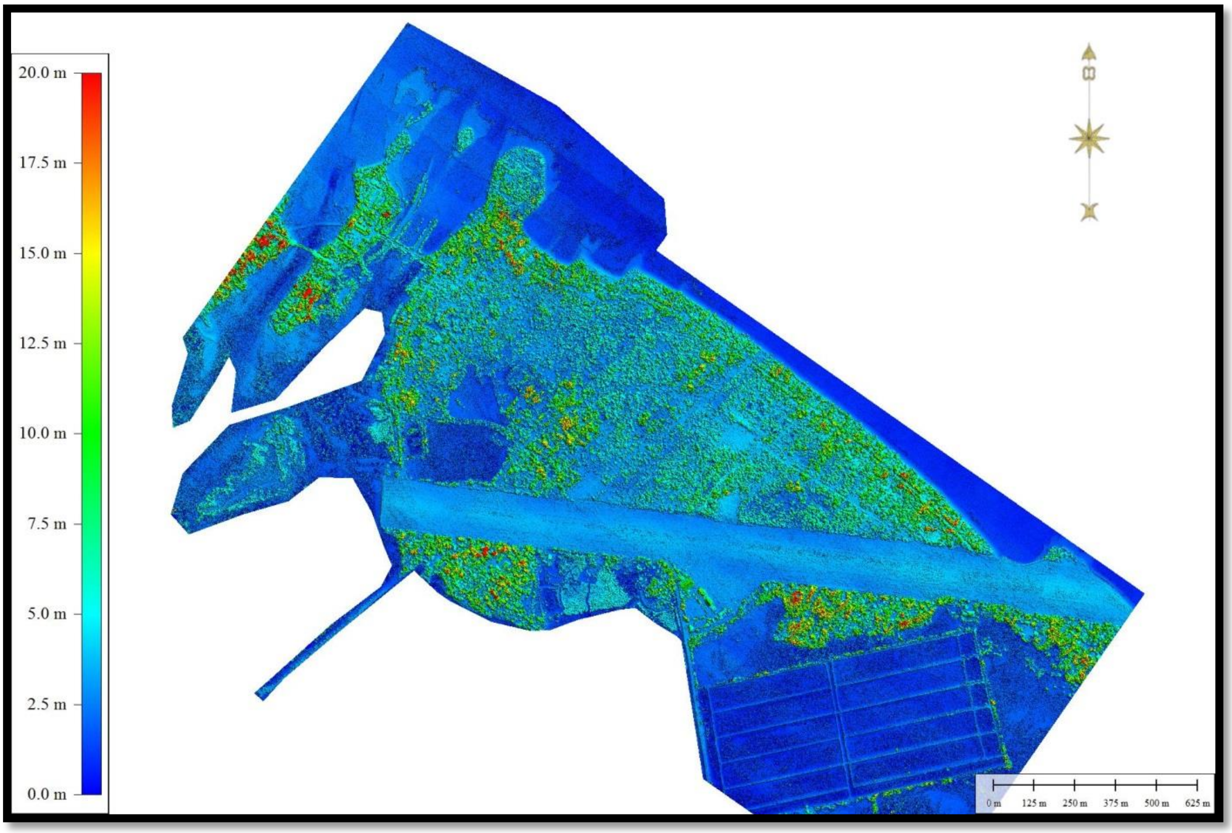

Figure 30. *25 cm digital surface model generated from cloud points.*

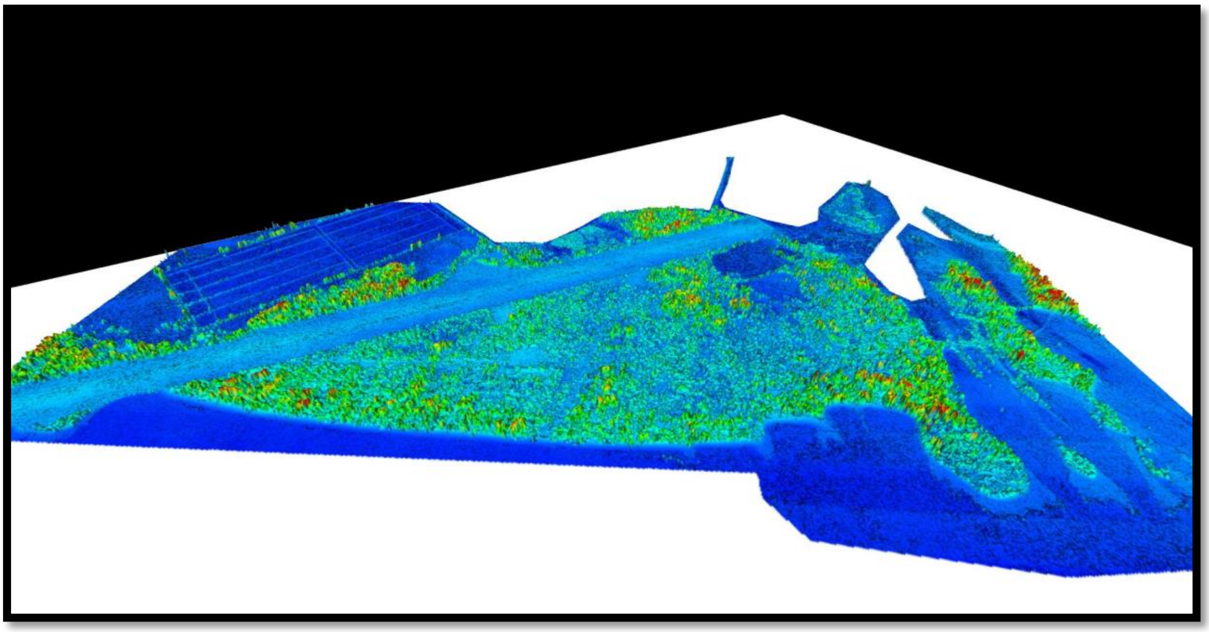

Figure 31. *3D image of the digital surface model of Bonriki, using the same colour scale as Figure 300. Image is looking toward the southwest.*

In order to progress to an elevation model that shows bare earth only (DTM), buildings and vegetation have to be removed from the surface model (DSM). The automated processing to generate the DTM successfully removed buildings and a reasonable number of trees. However, the resulting elevation is still highly influenced by vegetation, with large areas showing elevation higher than 7 m and up to 18 m above tide gauge zero (Figure 32).

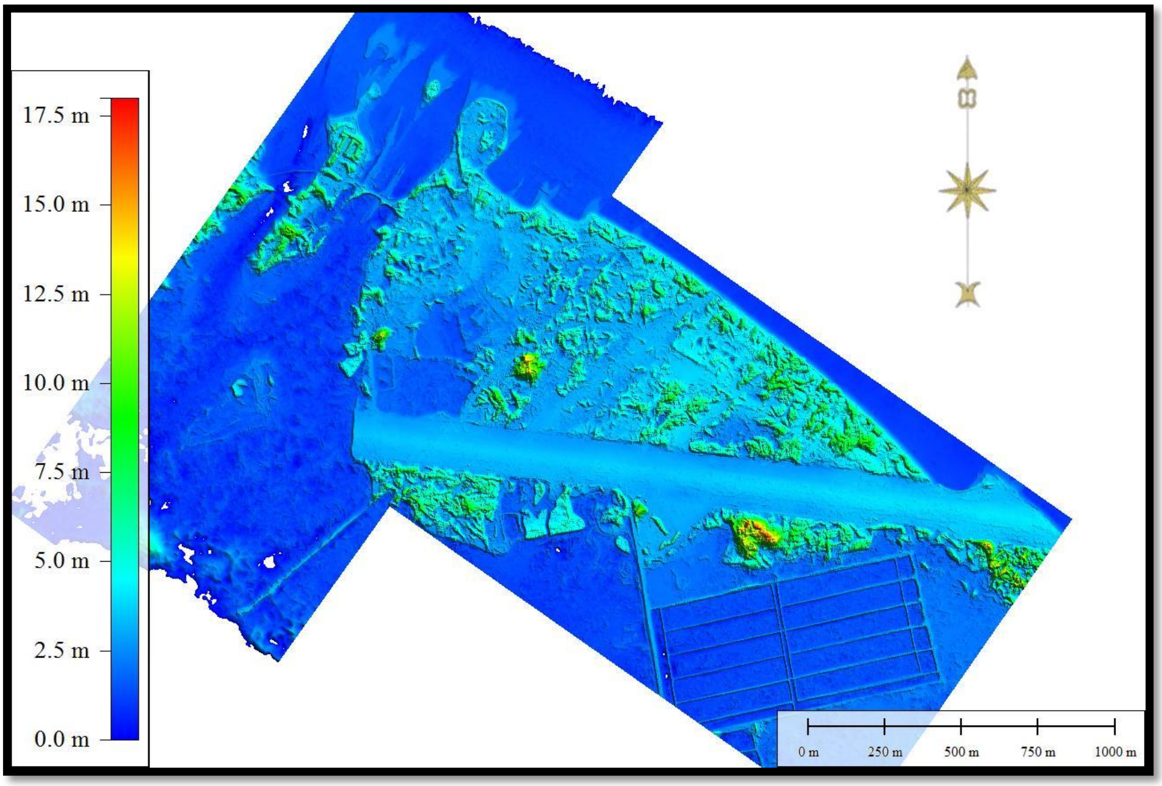

Figure 32. *50 cm digital terrain model (generated by the Trimble Business Center software).*

To remove all the outliers, the orthophoto was clustered into six groups (Vegetation, Grassland, Bare land, Buildings, Runway and Saltwater Marsh, as shown in Figure 33) using standard image classification techniques. The 50 cm DTM grid was converted into xyz points.

A script was developed to select points falling on pixels categorised as 'bare land' and 'runway' (Figure 34). Finally, the selected points were used to generate a 5-m grid DTM (Figure 35).

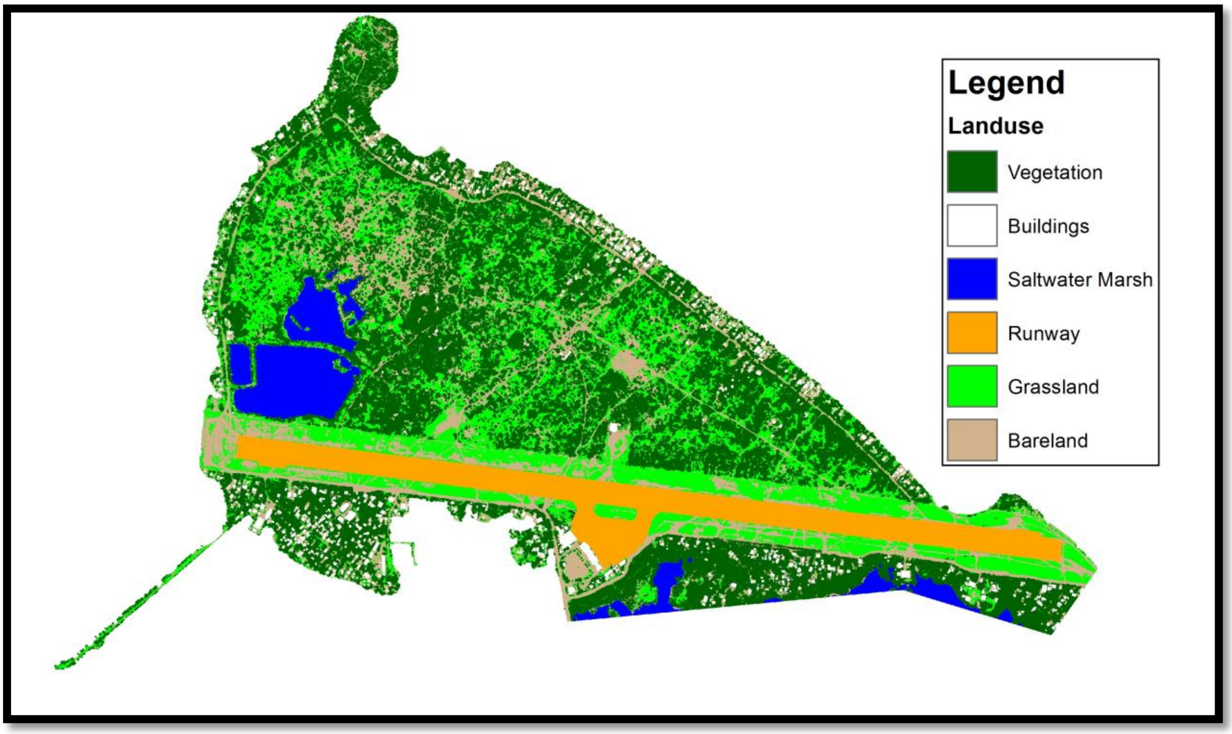

Figure 33. *Land use map derived from spectral analysis of the orthophoto imagery. The land use map is based on three categories: bare land (brown), vegetation (dark green) and grassland (light green). Buildings were manually cropped out (white). Image clustering is only used on land.*

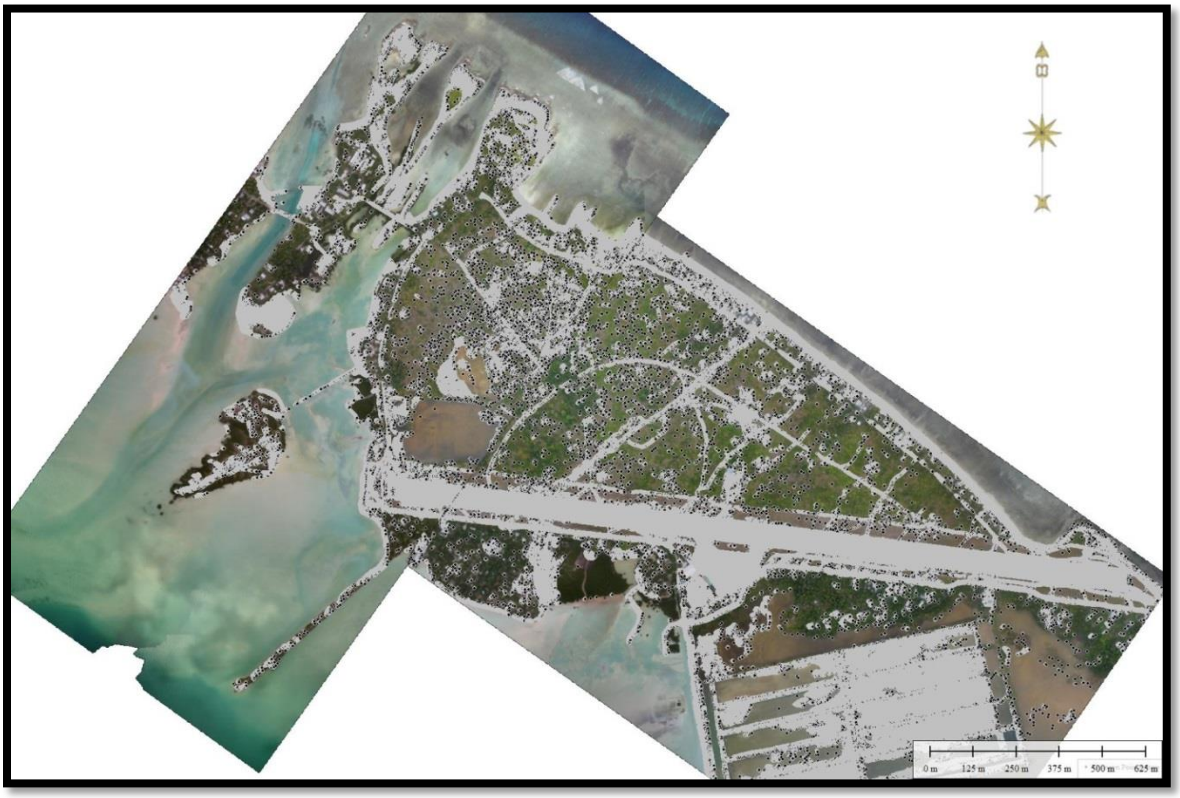

Figure 34. *Topographic points selected to generate a digital terrain model.*

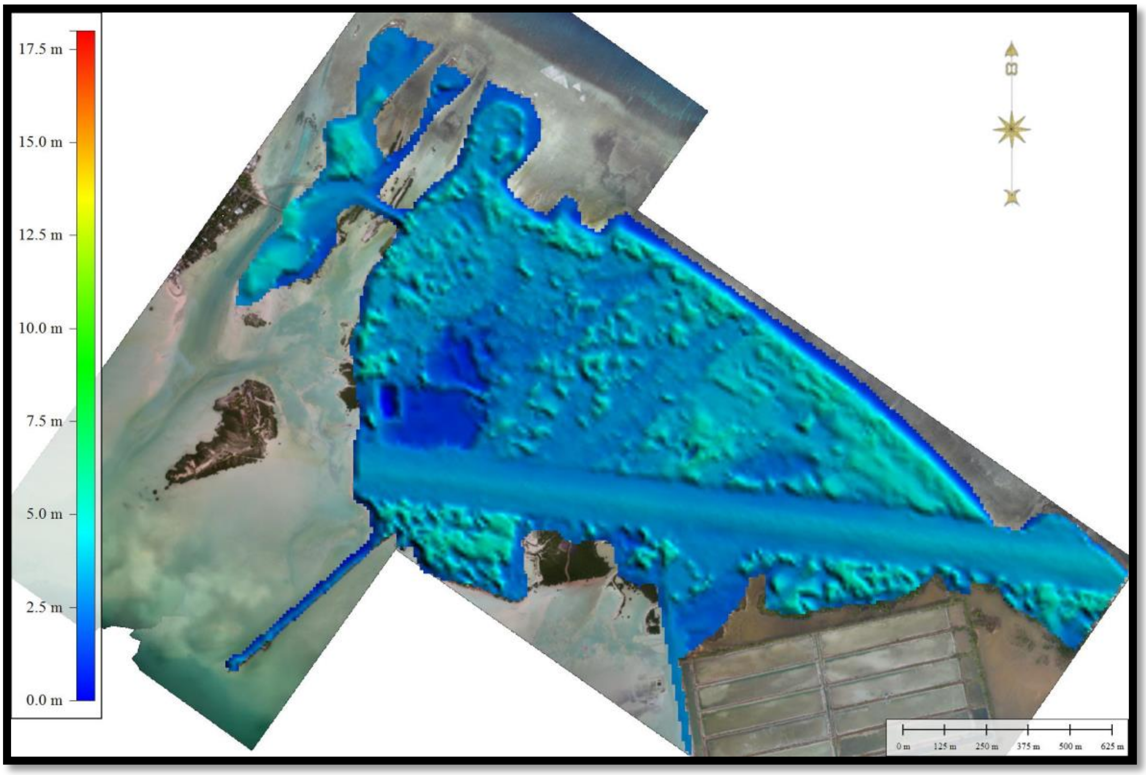

Figure 35. *Digital terrain model after using image classification technique; 10 m resolution.*

3.3. Discussion

In this section we compare topography data measured from RTK GPS and topography data derived from the Trimble UX5.

The point cloud generated by the UAS was reduced to only keep data on bare land.

A script was developed to compute the height difference between each RTK data point and its closest UX5 data point, as long as they were less than 50 cm apart.

To quantify the difference between the RTK and UAS topography data, two statistical measurements were computed: the root mean square (RMS) and a goodness-of-fit of the two datasets to the 1-to-1 line (R^2) (Figure 36).

The RMS of 0.29 m was calculated as follows

$$\text{RMS} = \sqrt{(mean((Z_{RTK} - Z_{UAS})^2))}$$

where *Z* is the elevation referenced to tide gauge zero

The R^2 of 0.88 was calculated as follows

$$R^2 = mean(\,(Z_{RTK} - mean(Z_{RTK})) \times \frac{(Z_{UAS} - mean(Z_{UAS}))}{Std(Z_{UAS}) \times Std(Z_{RTK})})$$

where Z is the elevation referenced to tide gauge zero and Std is the standard deviation.

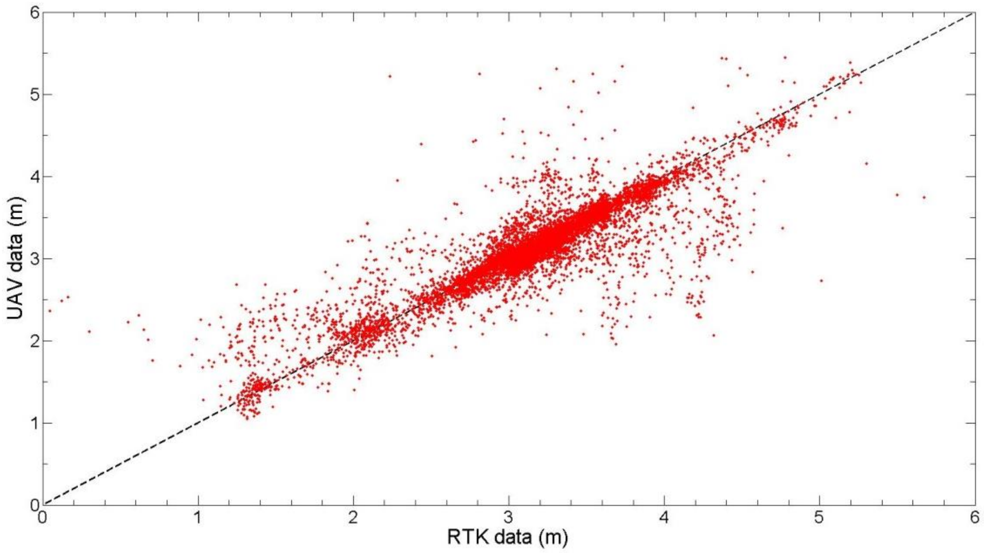

Figure 36. *Comparison between heights measured by the RTK GPS system and heights derived from the UAS. The dashed line is the line of best fit.*

To understand the height differences (Hd) between the two topographic datasets, the RTK dataset with Hd as the attribute was overlayed onto the orthophoto (Figure 37).

Figure 37. *Height difference (Hd) between RTK data and UAS data; blue is Hd < 0.1 m, green is Hd < 0.2 m, yellow is Hd < 0.5 m, orange is Hd < 1.0 m and red is Hd > 1.0 m.*

Acquiring topography data using RTK GPS or using UAS has advantages and disadvantages. Since new data were collected to produce a DTM of Bonriki, they can be qualitatively compared around two main factors: data accuracy and data coverage.

RTK GPS measurement can deliver topography data with a high vertical accuracy (<2 cm), depending on the methodology used during the survey. In this survey, data were either measured while on foot, while driving a quad bike or car, or while in a canoe. The data are expected to have a high vertical accuracy (decimetre range) when collected while on foot. However, the confidence in the vertical accuracy can decrease when the RTK GPS is mounted on vehicles, especially when surveying on bumpy tracks and terrain, as is often the case in Bonriki.

The vertical accuracy of the data derived from photogrammetry primarily depends on the pixel size of the imagery captured by the UX5. The manufacturer, Trimble, assumes the vertical accuracy to be less than three times the pixel size of the aerial imagery. For our survey in Bonriki, with a set of aerial imageries captured at 10 cm resolution, the vertical accuracy should therefore be less than 30 cm.

Thus, the vertical accuracy of the data collected by RTK GPS is expected to be much higher, i.e. better, than the accuracy of data derived from the UX5.

The calculated Hd can provide some indications on the vertical accuracy of the UAS data. Figure 37 gives much information on the possible improvements and the current limitation of the UAS survey. The Hd shows a much higher accuracy of the UAS data on the runway and tracks with little vegetation, with Hd < 10 cm. Low accuracy, indicated by a high Hd, is seen along the ocean side. Along the coastline, with a relative high number of buildings and trees, the land coverage is more complex, which led to a low vertical accuracy as indicated by the overall higher Hd. It seems that the 10 cm pixel size combined with an image overlap of 80% led to significant differences between RTK measurement and UAS data. We need to keep in mind however that RTK GPS and UAS points had to be co-located within 0.5 m for comparison and that this may have resulted in discrepancies in areas of complex morphology such as over erosional scarps in the nearshore area.

The northern and southern sides of Bonriki show low vertical accuracy. This is because the GCP markers in both regions were removed by an act of vandalism during the survey and so the UAS data could not be adequately orthorectified.

From Figure 37 it is clear that UAS data accuracy not only depends on the image pixel size but also on the number and distribution of the GCPs used in the survey and the complexity of the terrain and its coverage.

Finally, the major disadvantage of the RTK GPS survey is the relative sparseness of the resulting data. Using an RTK GPS survey to create a DTM on a relatively large scale is unpractical because it requires a dense cloud of points. In practice, sparse data are collected in areas such as along roads and remaining areas are filled by interpolation, potentially introducing large errors. In contrast, the UAS produces a dense cloud of points with a nearly complete coverage of the area with only two flights, whereas the RTK GPS survey took several weeks to complete.

To get the best DTM possible, a weighted interpolation was performed using both dataset. Weights of 0.75 and 0.25 were attributed to the RTK data and the UAS data, respectively. As a result, the

DTM generation is highly influenced by the RTK data where the data is available. The UAS data is used as an alternative to large interpolation where no RTK data is available.

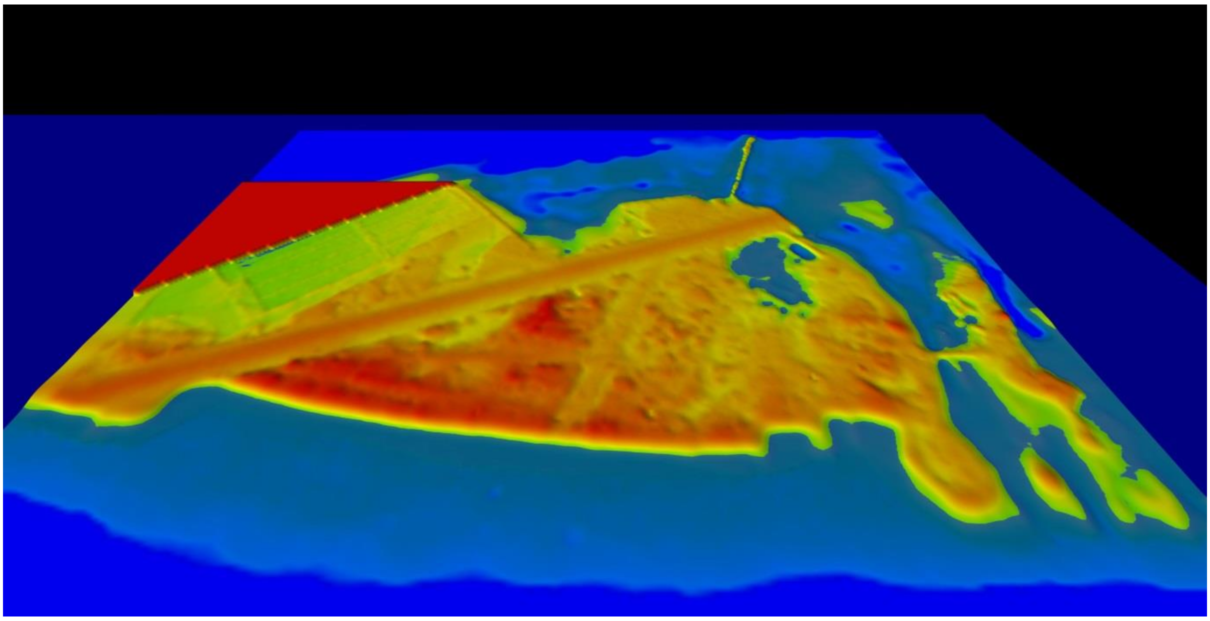

Figure 38. *DTM generated from a weighted interpolation between RTK data and UAS data. The image looks toward the southwest.*

4. Conclusion

The datum issue raised by Ramsey et al. (2008) was further investigated, and it was determined that all benchmarks derived and surveyed under the South Pacific Sea Level and Climate Monitoring Project project and by Lal (2009) are referenced to tide gauge zero. The heights derived under this project are consistent with Lal (2009).

Topography data was collected over Bonriki using two methods: RTK GNSS and UAS.

The RTK survey was successful and produced good quality data over the area surrounding the water reserve, along the coast and across the beach, on the lagoon intertidal areas and on the reef flat. To maximise data coverage and data density, the rover was mounted on various vehicles such as a quad bike, a truck and a canoe. Unfortunately, some parts of the site were not mapped because of dense vegetation and time constraints. The data produced a realistic DTM of Bonriki, accounting for all morphological features.

Co-funded between Australia through the BIVA project and supplemented with funds that New Zealand provides to SPC, SPC purchased the Trimble UX5. After a week of training, the team conducted a UAS survey, collecting aerial images at 10 cm resolution over Bonriki. The images were processed using the photogrammetry module of the Trimble Business Centre software. Outputs of the software were a high-resolution orthophoto of Bonriki, a dense point cloud, a 25 cm digital surface model and a DTM. To remove large discrepancies in the DTM, we developed a new method. Based on the high-resolution orthophoto, areas/pixels of bare land were extracted, and a new DTM was created by interpolating the topographic data on bare land onto a 10 m resolution grid over Bonriki.

The datasets from the RTK and UAS surveys were compared to assess the benefits of each to create a DTM. While RTK data provides a better accuracy in a survey time period measuring weeks, UAS data offers a full coverage of the area in a matter of days.

The height differences found between RTK and UAS data indicate the importance of establishing well-distributed GCPs over a survey site. By capturing 10 cm resolution images with 80% overlap, the photogrammetry algorithm was able to estimate heights of small areas between trees. However, there is low confidence in the resulting vertical accuracy, with points showing more than 50 cm height difference with RTK measurement. This contrasts with the good accuracy (less than a pixel size) delivered by the UAS in clear areas such as the airport runway.

It seems clear that more surveys are required to better estimate the optimal UAS setting, depending on the land cover and the complexity of the terrain. A new UAS survey is planned for London, the urban centre of Kiritimati atoll, in early 2015, providing a good opportunity to further test the system. The urban area will be surveyed using the Trimble UX5 maximised setting – capturing 2.4 cm resolution imagery with a 90% image overlap. This will provide the member countries with a better understanding of the new capabilities SPC can offer with their UAS.

This topography survey was also used as a training opportunity. A number of local staff from the Kiribati Government were trained in RTK surveying and data processing, and one government representative attended the one week training on UAS surveying and processing.

5. References

AMSAT, AusAID, NTF Australia. 2004. Pacific country report on sea level and climate: their present state. Kiribati, June 2002. Australian Agency for International Development. Australian Marine Science and Technology Limited. National Tidal Facility Australia, JC0163a.

Australian Government Bureau of Meteorology. 2010. Pacific country report, sea level & climate: Their present state Kiribati.
http://www.bom.gov.au/oceanography/projects/spslcmp/country_report.shtml accessed on February 2014.

Beca International. 2011. Coastal Monitoring Benchmark Network, Report for the Office of Te Beretitenti, Government of Kiribati, prepared under the KAP – II – FS6 Improving the Protection of Public Assets Project.

KNSO and SPC. 2012. Kiribati 2010 census. Volume 2, Analytical report. Kiribati National Statistics Office and the Secretariat of the Pacific Community Statistics for Development Program.

Lal A. 2009. Tarawa Secondary Photo Control Surveys Static and Kinematic Global Positioning Systems (GPS) Surveys,Tarawa, Kiribati. SOPAC Technical Report (unpublished), Suva, Fiji.

PASAP (Pacific-Australia Climate Change Science and Adaptation Planning Program). 2013. Pacific Australia Climate Change Science and Adaptation Planning Program, Bonriki Inundation Vulnerability Assessment (BIVA) Project, project proposal.

Ramsay, D.L., Stephens , S., Gorman , R., Oldman , J., Bell, R. 2008. Kiribati Adaptation Programme: Phase II: Information for climate risk management. Sea levels, waves, run-up and overtopping. NIWA draft client report HAM2008-022.

Yates S.J.K and Lal A. 2012. EDM Height Traversing Levelling Survey Report Tarawa, Kiribati, April 2012. Record 2014/17. Geoscience Australia.

Yates S.J.K. & Lal A. 2014. EDM Height Traversing Levelling Survey Report: Tarawa, Kiribati, August 2013. Record 2014/018. Geoscience Australia.

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