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19 September 2022

Gisborne District Council
PO Box 747
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Attention: Murry Cave

Dear Murry,

Rapid landslide and flooding assessment of Gisborne Storm, 23–27 March 2022

1.0 INTRODUCTION

This letter report is submitted by the Institute of Geological & Nuclear Sciences Limited (GNS Science) in response to a request from Murry Cave, Principal Scientist of Gisborne District Council (GDC), for a rapid assessment of landslide and flood damage from the March 23–27 storm event in the Gisborne region.

From the 23rd to 27th of March, 2022, the Gisborne region received extreme rainfall that caused significant flooding and triggered extensive landsliding across the region. Rainfall totals of >500 mm were recorded over 48 hours at Te Puia and Tokomaru Bay, which have annual return intervals (ARIs) of 100–250+ years, and up to 648 mm in eight days in the Wharerata Ranges (ARI ~250 years). The scale of landsliding in some of the northern coastal towns (Figure 1.1), and in the southern part of the region, was significant and has not been seen since Cyclone Bola in 1988. A state of emergency was declared in the region on March 23 due to the extent of flooding, which resulted in damage to bridges and evacuations from many towns such as Te Karaka, on the Waipaoa River, and Tokomaru Bay.

Figure 1.1 Example of extreme landsliding near Kaiaua Bay triggered by the 23–27 March 2022 storm (Photo: Dougal Townsend / GNS Science).

GDC requested that GNS Science undertake a rapid landslide and flooding extent assessment using Sentinel imagery (10 m resolution) to better target recovery work and to determine areas where higher-resolution satellite imagery is required to map landslide and flooding extent in greater detail.

The objectives of the project are as follows:

1. Identify areas in Gisborne Region that received the highest rainfall during the March 23–27 storm event.
2. Identify areas in Gisborne Region that experienced severe landsliding during the March 23–27 storm event and the extent of overbank flooding because of the rainfall. These areas may be targeted for acquisition of higher-resolution satellite imagery to map landslides and flooding extent in greater detail.
3. Determine if 10 m resolution Sentinel imagery is sufficient to identify areas affected by severe flooding and landslides during the event.

2.0 METHODOLOGY

2.1 Data Sources

A rapid regional-scale assessment of landslide severity was undertaken by comparing satellite imagery taken before and after the storm to identify and map new landslides. For this study, the pre- and post-storm images from the European Space Agency's (ESA) Sentinel satellites were used. Sentinel-2 Level-2A and Level-1C data was downloaded from the ESA Sentinel data hub (https://scihub.copernicus.eu). Images were selected with minimal cloud cover but encapsulating immediate post-event damage. These images were already converted to display surface reflectance. Four bands in the visible/near-infra-red (VNIR) range were captured at 10 m spatial resolution and used here for landslide analysis. We mosaiced images from two different orbits to cover the entire GDC region (Figure 2.1). The mosaics contain un-altered reflectance values of the main image covering the majority GDC region (primary image), whereas the small, uncovered part of the image is added from the secondary images. The mosaics were cropped to the Land Information New Zealand (LINZ) 1:50,000-scale GDC boundary (Figure 2.2). Mosaic details are described in Table 2.1.

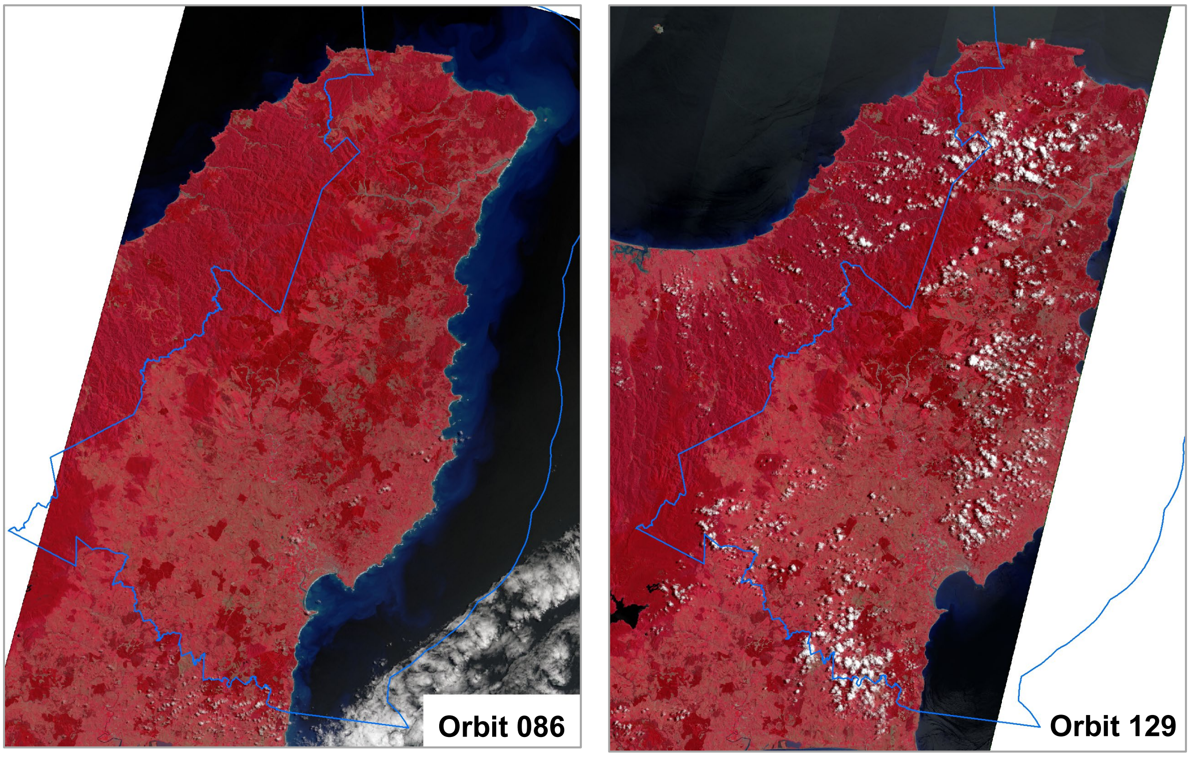

Figure 2.1 Extents of Sentinel-2a images from orbits 086 (primary image) and 129 (secondary image) that were mosaiced to form the pre- and post-event imagery. The vegetation appears red in these images because the NIR, red and green spectral bands are shown as red, green and blue.

Table 2.1 Image information used to generate mosaics for pre- and post-event analysis. The March 11/23 mosaic was only used for verification.

Mosaics	Satellite/Sensor	Acquisition Date and Time (in UTC)	Orbit Number	Usage
Pre-event	Sentinel-2B	10 Jan 2022; 22:16	129	Secondary
	Sentinel-2B	17 Jan 2022; 22:16	086	Primary
Pre-event	Sentinel-2B	11 Mar 2022; 22:16	129	Secondary
	Sentinel-2A	23 Mar 2022; 22:06	086	Primary
Post-event	Sentinel-2B	7 Apr 2022; 22:06	086	Primary
	Sentinel-2A	25 Apr 2022; 22:16	129	Secondary

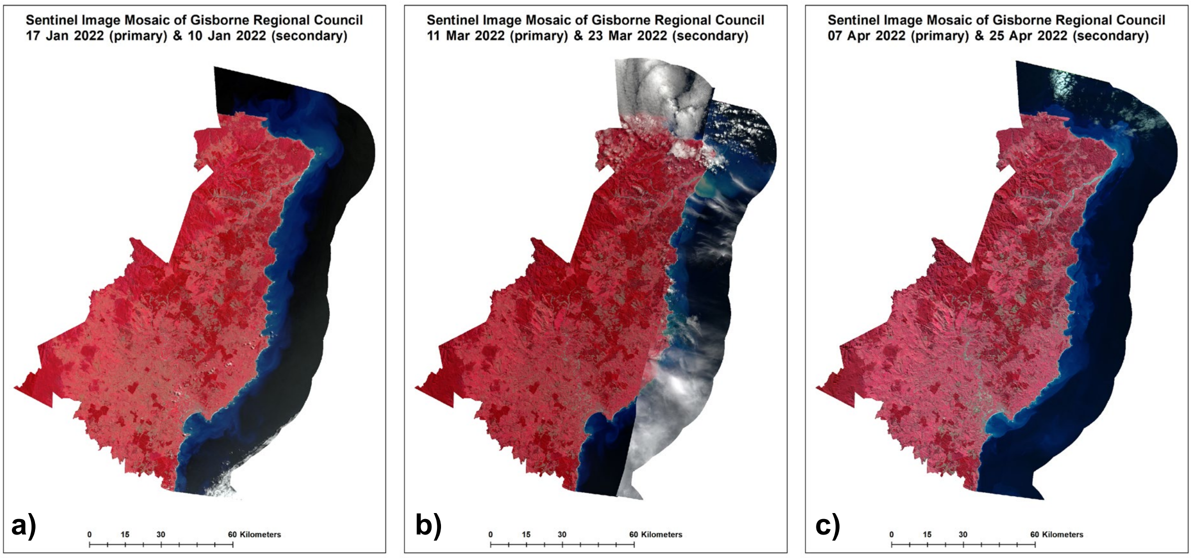

Figure 2.2 The Sentinel 2a mosaics generated for the analysis shown as False Colour Composite images: (a) 17 and 10 January 2022, (b) 11 and 23 March 2022, (c) 7 and 25 April 2022.

2.1 Landslide Mapping

Landslide polygons were extracted using a semi-automated approach by comparing pre- and post-event images to identify pixels with visual changes. An automated extraction of potential landslide scars as polygon features using GIS was then undertaken to rapidly determine potential landslides. Given that fresh landslide scars, debris tails and the presence of fine sediment on the floodplain appears bright and highly reflective when viewing the true-colour image, we used strong spectral differences between the pre- and post-event imagery to indicate recent landslide scars. By calculating the change in pixel value across a single band (B04 Red), and extracting the pixels with highest variance, a set of polygons representing new landslides (scar plus debris tail) were generated. Due to the scale of the satellite imagery (10 m resolution), it was not possible to differentiate between landslide source areas (scars) and deposits (debris tails).

The difference image (I_d) represents pixel-value difference in the form of a simple digital number, the radiance or the reflectance value. The change in the difference image can be extracted by a simple thresholding. There are numerous ways to determine the threshold value either empirically or statistically; often empirical methods (such as linear- or percentile-based threshold values) generate better results (Singh 1989). For Sentinel datasets, a difference image was computed using only the red band because it is less sensitive to changes in vegetation. Three different threshold-based change images were generated, which showed both negative and positive change. For Sentinel images, we used change thresholds that were empirically derived after visual interpretation of landslides that occurred on mainly pasture hillslopes. Post-event Planet imagery was used to refine the thresholds so that the landslide areas were best represented by the red-band difference model.

It is important to note that there are other factors that can also influence the image difference (I_d) values, such as differences in atmospheric conditions, sun angle and soil moisture (Jenson 1983). Differences may also be introduced due to incorrect image registration, resulting in a shift in the location of features in pre- and post-event imagery. Other factors influencing the detection of new landslides for this event included seasonal changes or poisoning of vegetation, e.g. manuka/kanuka, and the brightness or saturation of the images.

This dataset was manually checked to remove potential errors (e.g. cloud cover, dead vegetation, vegetation clearance / logging). The result was a set of fresh bare-ground polygons, representing the change between 17 January and 7 April 2022 (Figure 2.3). To identify areas with the greatest density of landsliding (bare ground/km^2), points were derived for each polygon in ArcGIS, and the Point Density function was used using a search radius of 4 km and an output cell size of 1 km.

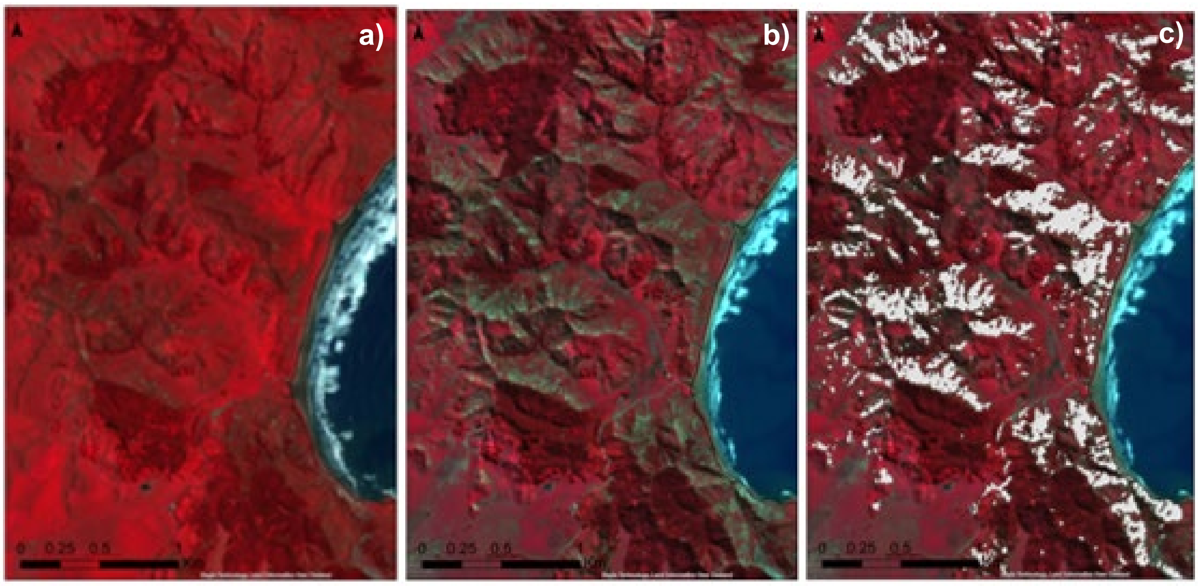

Figure 2.3 Sentinel-2a 10 m false-colour image tiles captured on (a) 17 January 2022 and (b) 7 April 2022, following the March 2022 storm. Landslide damage in the Kaiaua Bay area is clearly visible in (b). (c) Landslide polygons (in white) derived from the red-band differencing (Copernicus Sentinel data 2018, processed by ESA).

2.2 Overbank Flood/Deposition Mapping

To detect the extent of overbank deposition associated with flooding, we derived the Normalised Difference Water Index (NDWI) from pre- and post-event images. We used the following equation to determine NDWI from 10 m resolution Sentinel images:

$$NDWI = \frac{\rho_{green} - \rho_{nir}}{\rho_{green} + \rho_{nir}}$$

where ρ is the reflectance of corresponding spectral bands.

Pixel values of NDWI images range from -1 to +1, where positive values indicate water or higher soil moisture content (Figure 2.4). NDWI images do not fully remove the background soil reflectance effects. To overcome this limitation, we used four threshold values to delineate the overbank deposition extent. These NDWI-derived threshold values were empirically derived after visual interpretation of flooded areas. For this analysis, we have shown the full flooding extent, which includes the river channel and banks. The mapped areas of flooding were verified using 3 m resolution Planet imagery. The NDWI images were clipped to the floodplain area, which was identified using the 'Landform' classification from the New Zealand Erosion Terrains (Dymond 2010).

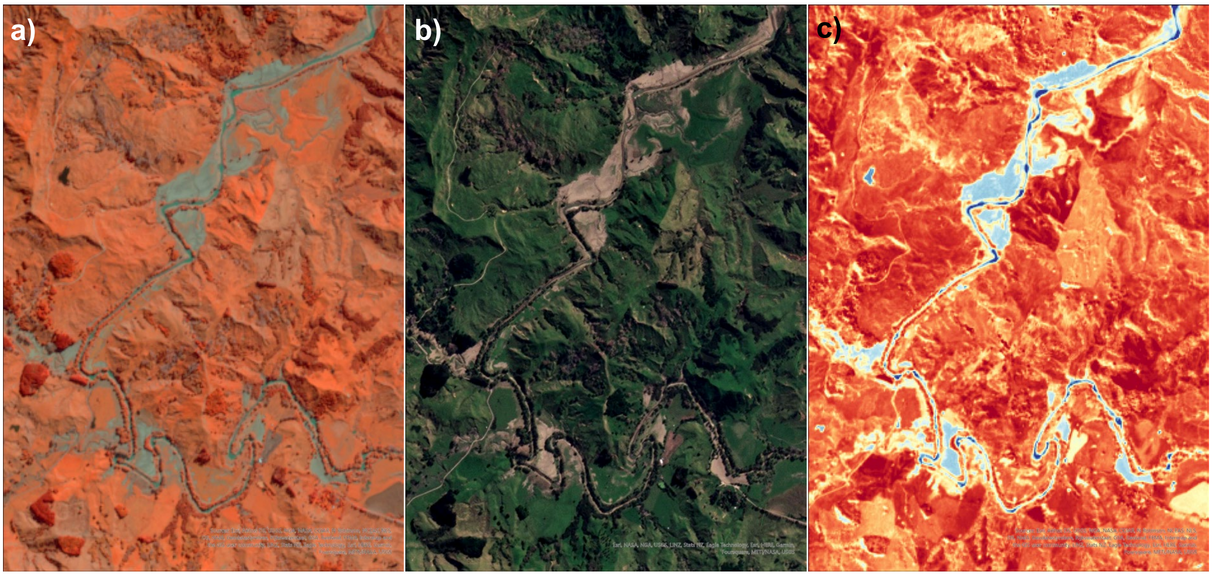

Figure 2.4 Example of the NDWI index model for the Pakarae River valley. (a) False-colour post-event Sentinel-2 (10 m) image showing silt-laden floodwater extent, appearing as a grey colour. (b) True-colour post-event (3 m) Planet imagery showing flood extent. (c) NDWI image (10 m), where non-water NDWI values appear in tones of red and water appears in blue tones.

2.3 Rainfall

Rainfall data for the March 2022 rainfall event was provided by GDC. Additional rainfall data were downloaded from the National Climate Database (NIWA) and Hawke's Bay Regional Council (HBRC) website (https://www.hbrc.govt.nz/environment/rainfall). Rainfall totals for the period March 23–27 are shown in Figure 2.5. It should be noted that the majority of the rainfall in the Tolaga Bay to Ruatoria area fell over a period of 48 hours, while the rainfall in the southern part of Gisborne District and Wairoa District (not part of this report) fell over five days.

Another significant rainfall event occurred at East Cape on 6–7 February 2022, which also caused significant landsliding in that area and closed East Cape Road. A total of 265 mm of rain fell in 24 hours, with 215.5 falling in just 12 hours. This event was fairly isolated to the East Cape area and triggered around 100 landslides that GDC has previously mapped.

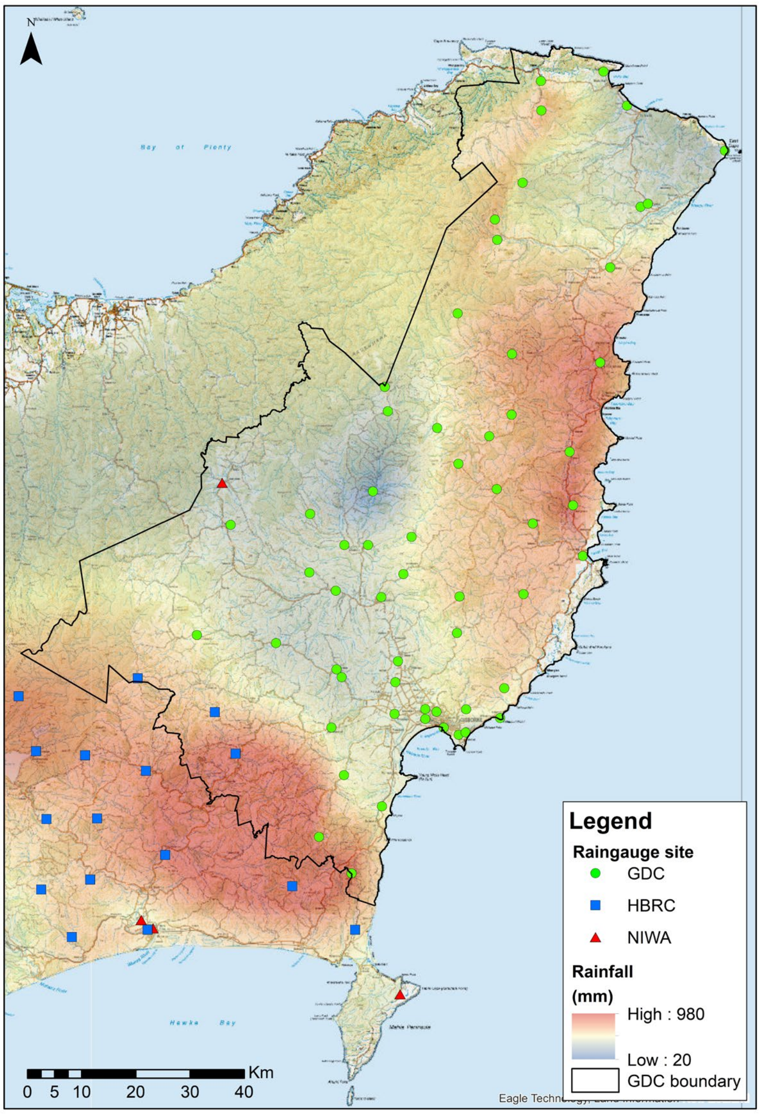

Figure 2.5 Rainfall distribution for the March 23–27 storm in the Gisborne region. Rainfall data was provided by GDC, HBRC and NIWA (https://cliflo.niwa.co.nz/).

3.0 RESULTS

The results include the landslide distribution and flooding extents caused by the March 23–27 storm in the Gisborne region. The results will be provided to GDC as two ArcGIS shapefiles representing landslides triggered by the storm and flood extent.

3.1 Landslide Severity Mapping

The satellite differencing identified >50,000 potential landslides that were triggered by the March 23–27 storm event in Gisborne District. The predominant landslide types were shallow (~1 m depth) translational soil slides, debris slides and debris flows. Due to the resolution of the satellite imagery (10 m) and inability to differentiate landslide source from deposit at this scale, several landslides may be represented by a single polygon, so this number represents a minimum. The distribution of landslides identified by satellite differencing is shown in relation to event rainfall in Figure 3.1. The landslide distribution broadly follows the distribution of the highest rainfall during the storm event. No analysis of the controlling landslide susceptibility factors have been undertaken as part of this report.

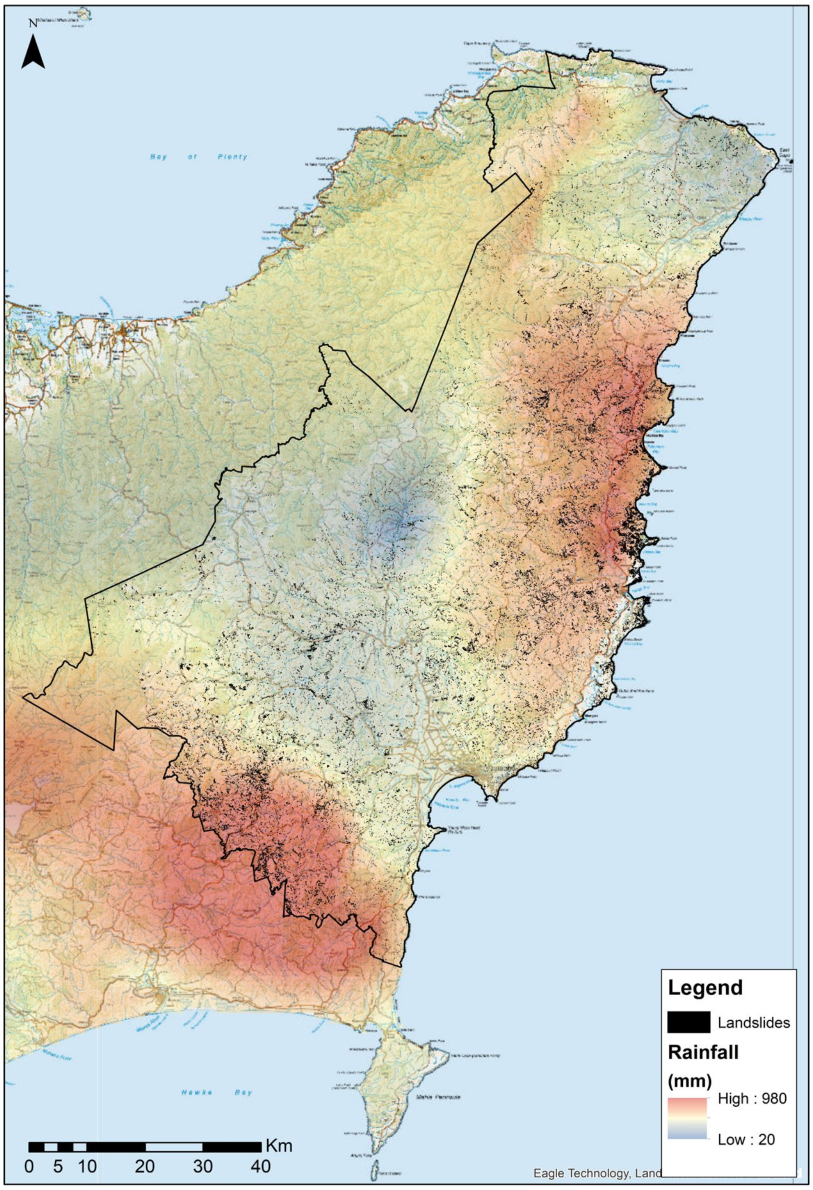

Figure 3.1 Distribution of landslides triggered by the March 23–27 storm event, identified by satellite image differencing and shown in relation to storm rainfall.

Landslides were triggered over most parts of the region, but the greatest density of landslides (landslides/km^2) were identified in the areas from Te Reinga to Pehiri in the south of the district, in the area from Tolaga Bay north to Te Puia Springs, and inland as far as Ihungia in the north (Figure 3.2). The highest density of mapped landslides of >45 landslides/km^2 was identified between Tolaga Bay and Anaura Bay; however, this landslide density is also a minimum for the reasons outlined above and may be as high as 90–100 landslides/km^2 in the area between Tolaga Bay and Anaura Bay.

There were also notable areas of landsliding in the following areas:

- In the lower reaches of the Wharekopae, Waihuka and Waikohu catchments, between Rere and Puha.
- In the Waihora and Waimata catchments near Waimata.
- Inland from Tolaga Bay in the Pakarae catchment near Takapau.
- In the Mata catchment from Aorangi to Ihungia.

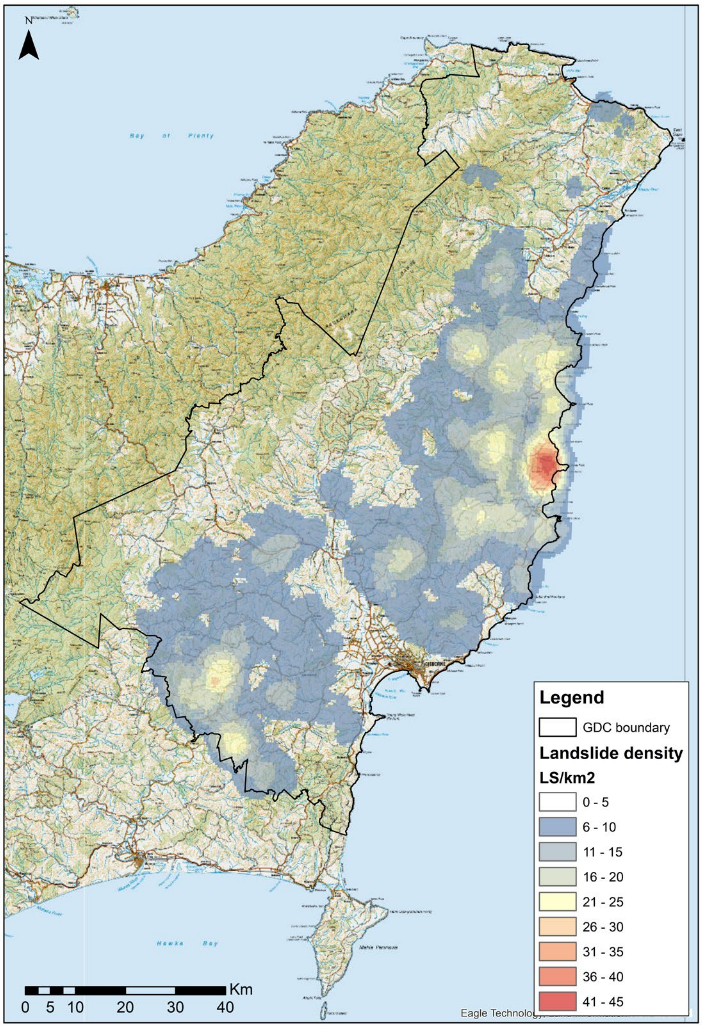

Figure 3.2 Landslide density (in landslides/km^2) for the 23–27 March 2022 storm event in the Gisborne region.

3.2 Overbank Flood Extent

Areas of flooding and sediment deposition were identified by satellite differencing as described in Section 2.3. Examples of the flood extent mapping are shown in Figure 3.3. Extensive flooding typically occurred in the same areas identified as having high landslide occurrence, including the following areas:

In the Waiapu catchment:

- Mata River and Makarika Stream from Aorangi to Ruatoria (worst hit area).
- Ihunugia River.
- The lower reaches of the Tapuaeroa River.

In the Uawa catchment:

- Mangatokerau River.
- Mangahauini River at Tokomaru Bay.
- Hikuwai River near Hikuwai and downstream from Three Bridges.
- Kotingatahata and Raponga Streams near Anaura Bay.
- Lower reaches of the Mangahaia River near Takapau.

In the Waipaoa catchment:

- Waipaoa River downstream from Whatatutu.
- The lower reaches of the Waingaromia River.
- The lower reaches of the Te Arai, Waimata and Waikura rivers.

In the Wairoa River catchment:

- Mangarangiora Stream.
- Mangapoike River.

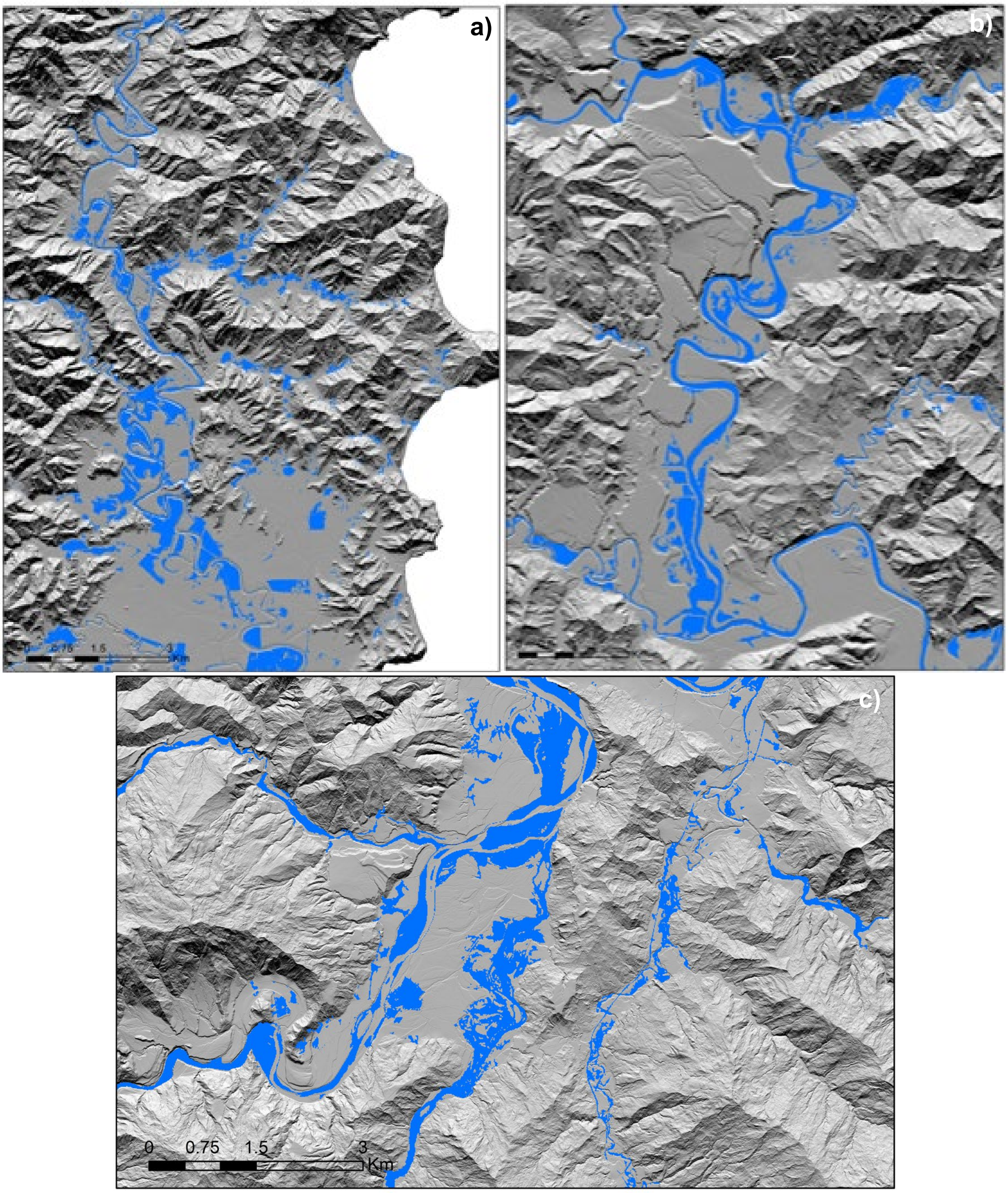

Figure 3.3 Examples of flood extent mapping for (a) Hikuwai River near Tolaga Bay; (b) Waipaoa River at Te Karaka and (c) Mata River and Makarika Stream at Makarika. Flooding (in blue) is overlaid on the regional LiDAR hillshade model.

4.0 SUMMARY AND CONCLUSIONS

- From the 23rd to 27th of March, 2022, the Gisborne region received extreme rainfall that caused significant flooding and triggered extensive landsliding across the region. Rainfall totals of >500 mm were recorded over 48 hrs at Te Puia and Tokomaru Bay (ARIs 100–250+ yrs) and up to 980 mm in seven days in in the Hangaroa and Tiniroto areas (ARI ~250 yrs).
- Landslides triggered by the March 23–27 storm event were mapped by a semi-automated classification using differencing of the red-band on pre- and post-event 10 m resolution Sentinel satellite imagery. While differencing did provide a very quick assessment of the likely locations of new landslides, as well as an assessment of the number and scale of landslides triggered during the storm, the resolution of the imagery did not allow detailed mapping of landslide morphology such as differentiating landslide source area from deposit or coalescing landslides/deposits. The small distances between landslides also meant that it was not possible to differentiate between individual landslides from the Sentinel imagery, and several landslides were often combined into a single polygon.
- The extreme rainfall triggered >50,000 potential landslides. The landslides occurred over all parts of Gisborne District but were concentrated in two main areas:
  - Tolaga Bay to Te Puia Springs
  - Hangaroa to Tiniroto.
- Other areas identified with significant landsliding were in the lower reaches of the Wharekopae, Waihuka and Waikohu catchments; in the Waihora and Waimata catchments near Waimata; inland from Tolaga Bay in the Pakarae catchment near Takapau; and in the Mata catchment from Aorangi to Ihungia.
- The NDWI index mapping from Sentinel imagery was sufficient to map the flooding extent; however, verification using higher-resolution Planet imagery was necessary to differentiate flooding on some areas of bare ground or where vegetation clearance had occurred (e.g. ploughed fields).
- Significant areas of overbank flooding were identified in the following catchments:
  - Mata River (particularly Makarika Stream).
  - Uawa and Hikuwai (particularly betweeen Tolaga Bay and Anaura Bay).
  - Waipaoa River downstream from Whatatutu.
  - Te Arai River.
  - Waimata River.
  - Waikura River.
  - Mangarangiora Stream.
  - Mangapoike River.

5.0 RECOMMENDATIONS

Red-band differencing of pre- and post-event Sentinel satellite imagery successfully identified the main areas affected by landsliding caused by the 23–27 March 2022 storm event; however, details of individual landslides were not able to be determined. If more detailed information on landslide size, type and runout distance are required (e.g. for landslide hazard and risk assessment), acquisition of higher-resolution satellite imagery or aerial photography is recommended.

Yours sincerely,

Brenda Rosser	Salman Ashraf
Geomorphologist	Remote Sensing Scientist

6.0 REFERENCES

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