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MULTI-HAZARD ANALYSIS AND MAPPING OF COASTAL TAURANGA IN SUPPORT OF RESILIENCE PLANNING

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ABSTRACT

High growth is increasingly forcing development of hazard prone land in the coastal city of Tauranga. A multi-hazard mapping tool developed to guide strategic growth planning in this natural hazard rich environment gives direct comparison of total hazard levels across the city. By aggregating individual hazards into a summative multi-hazard rating for each part of the city, urban planners and engineers have a decision support tool to aid city planning over the next 100 years.

Tauranga growth requires 40,000 new homes over the next four decades in addition to the existing 57,000 homes. This 70% growth must squeeze within tight geographic constraints as Tauranga's 137,000 residents nestle around a harbour and are bound by open coast to the north and steep terrain to the south.

This research quantifies Tauranga's natural hazards of sea level rise, storm surge, coastal erosion, tsunami, earthquake shaking, liquefaction, landslides volcanic ashfall and flooding. Each hazard is spatially represented through hazard maps. Individual hazards are combined into a multi-hazard model to represent the aggregated hazard exposure of each point of the city. The multi-hazard exposure is spatially mapped using GIS allowing an area with tsunami, liquefaction and storm surge as dominant hazards to be directly compared with an area of different hazards such as flooding and landslides. Mapping of these hazards provides strategic input for building city resilience through land use planning and mitigation design. A pilot study area of 25 km^2 selected from the Tauranga City Council total area of 135 km^2 demonstrates the accumulated mapping approach. The pilot area contains a thorough representation of geology, elevation, landform and hazards that occur throughout the city.

Our findings showed the highest aggregated hazard areas in Tauranga are along the coast. As is common with many beach resort towns this corresponds with the most popular living areas. The lower hazard areas suitable for urban growth are distributed mostly away from the open coast in the slightly elevated topography.

INTRODUCTION

Tauranga – A Growing Coastal City

Good climate, easy beach access and proximity to recreational opportunities makes Tauranga a popular home and the fastest growing city in New Zealand (see Figure 1). This high growth is increasingly forcing development of hazard prone land for accommodation and industry. Growth projections require 40,000 new homes over the next four decades in addition to the current 57,000 homes. This 70% growth must squeeze within tight geographic constraints as Tauranga's 137,000 residents nestle around the harbour and are bound by open coast to the north and steep terrain to the south.

Typical for a coastal city a significant feature is the shoreline. This includes 26 km of open coast forming roughly the northern boundary of the city and the harbour coast which comprises multiple headlands, inlets and islands. Half of the inner harbour's 62 km of shoreline is characterized by 25 m high cliffs these are typically near-vertical faces which suffer constant erosion.

Tauranga Natural Hazard-Scape

The predominant sources of natural hazards in Tauranga arise from New Zealand's high level of seismic activity, the Taupo Volcanic Zone (TVZ) to the south and east, Auckland volcanic fields to the west and global sea level rise (SLR).

Figure 1: Tauranga is a popular and rapidly growing coastal city in the Bay of Plenty region of New Zealand.

New Zealand is a nation on the move, straddling the Pacific and Australian continental plates. This tectonic interface extends thousands of kilometres north and south of Tauranga and generates hundreds of earthquakes from its annual movement of around 60 mm. The Kermadec and Hikurangi trenches are to the north and east and major seismic movement on these plate interfaces is likely to generate earthquake shaking, liquefaction and tsunami hazards in Tauranga.

The TVZ is one of the most productive on earth in the last 20,000 years. The most recent eruption exceeding 1.0 km^3 of ejecta was in 1886 in which Tauranga received a substantial ashfall, however the volcanic sources are far enough away that

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proximal effects such as lava or pyroclastic flows are unlikely. Several of the volcanic cones are constantly active and monitored. White Island was the most recent eruption in December 2019. Multiple fatalities as a result of this eruption highlight the need for natural hazard awareness and education.

As a coastal city with 88 km of coastline and many low-lying areas the impact of sea level rise will be directly felt by the residents and the infrastructure. The most popular parts of the city are coastal due to their recreational and aesthetic value. A nationwide assessment in 2019 identified $200 million of Tauranga assets at risk in just 1.0 m of sea level rise including 13 km of road and 175 km of water pipes [1].

Hazard Research and Mapping to Guide Growth Planning

Managers of growth cities like Tauranga are in immediate need of knowledge and tools to guide development. They are now faced with climate change, sea level rise and intensified storms in addition to the already familiar natural hazards such as floods, volcanoes and earthquakes. From designers to councillors, all need certainty as they make decisions on growth and its attendant investment. These decisions depend on resilience considerations of preparing the city to survive natural hazards, recovering from major events and planning for sea level rise. A deficiency of existing Tauranga hazard data is that it does not fully incorporate sea level rise or forecast sufficiently far into the future to inform decisions that will impact 100 years into the future.

A key tool in evaluating and comparing potential growth areas is the quantification and spatial mapping of the natural hazards. This research has developed an aggregated multi-hazard mapping approach that will contribute to confident strategic growth decisions in Tauranga.

NATURAL HAZARD IDENTIFICATION AND QUANTIFICATION

This research seeks to accurately quantify and map the major natural hazards Tauranga is exposed to. This will inform city planning and be a pivotal input into building resilience into physical city infrastructure.

Hazards included in this study are sea level rise, coastal inundation from storm surge, coastal erosion, earthquakes, tsunami, liquefaction, landslides, volcanic ashfall and flooding. Hazard research is ongoing with tsunami, flooding and inundation at the open coast due for completion after publication of this paper.

Establishing a Consistent Methodology for All Hazard Studies

This research established a consistent approach to time horizons, event scenarios and spatial mapping of each natural hazard to enable effective summation into the multi-hazard representation. Time horizons adopted were current, 50-year and 100-year projections. These reflect planning horizons mandated nationally and common infrastructure design return periods.

Geomorphology and sea level rise were identified as key components to several hazard studies and were quantified early and applied consistently across all hazards. Geomorphology was a valuable informant to likely ground behaviour in earthquake shaking, liquefaction and landslip studies. Sea level rise projections informed inundation, erosion, flooding, tsunami and liquefaction studies.

Sea Level Rise

Mean sea level (MSL) calibration was carried out as a foundational baseline for all future sea level rise measurements and established a rise of 60 mm since 1995 [2].

Historical sea levels provide confidence in the establishment of the MSL of 0.13 m (Moturiki 1953 datum) in 2020. The rate of SLR has been analysed by NIWA at nominally 2 mm/year prior to 2000 and 3 mm/year since.

Sea level rise in Tauranga is projected from this baseline and adopts four scenarios of global temperature rise out of three greenhouse gas representative concentration pathways (RCP) as determined by Ackerley and Bell in 2013 [3]. Table 1 lists these projections and values adopted for hazard studies following adjustment for timelines appropriate to city planning and rounding for the benefit of community users.

Table 1: Sea level projections showing calculated and adopted values for Tauranga.

Purpose	Year	Projection Scenarios based on IPCC 5			
		RCP 2.6	RC 4.5	RCP 8.5	RCP 8.5H+
Baseline	1986-2005	0.07	0.07	0.07	0.07
Current	2020	0.13	0.13	0.13	0.13
Calculated	2070	0.39	0.43	0.52	0.68
Adopted	2080		0.4	0.6	
Calculated	2130	0.67	0.81	1.25	1.59
Adopted	2130		0.8	1.25	1.6

Coastal Inundation

Coastal inundation is land covered by sea water through a combination of storm effects, tide and wave setup plus any allowance for future sea-level rise. Coastal inundation due to these storm and atmospheric effects has been modelled by NIWA in 2019 [4]. This mapped the overland extent of coastal inundation for the whole Tauranga Harbour coastline of which Tauranga City occupies a small section of the eastern end. Land covered by water in each scenario is mapped using a four colour code to represent depth of inundation with the blue colours representing divisions less than one metre and orange representing anything over one metre depth from existing ground level to water surface. A sample mapping of three separate inundation scenarios is shown for the same location in Figure 2.

The study used a calibrated hydrodynamic model operating in 2D to simulate water levels. Boundary conditions applied were tidal levels and annual average river flows. Physical processes were input as parameters for wind, barometric pressure, surface conditions and bottom conditions and overland roughness conditions for the actual inundation. Table 2 lists specific input details. The model was calibrated for tidal elevations from 26 gauging sites and the output was validated against a storm event in January 2018.

Table 2: Inputs and outputs for inundation modelling.

Input parameter	Description
Base tidal scenario	Mean High water springs 7 (MHWS7) - The elevation exceeded only by the highest 7% of all high tides.
Storm scenarios	2%, 1% and 0.2% AEP
SLR	Scenarios as described in table 1

Legend: Water depth in metres above existing ground ● 0.10-0.25 m ● 0.25-0.50 m ● 0.50-1.00 m ● Above 1 m

Figure 2: Inundation model output 2% AEP storm 2020, 1% storm with 0.6m SLR in 2080 (centre), 1% storm with 1.25 m SLR 2130.

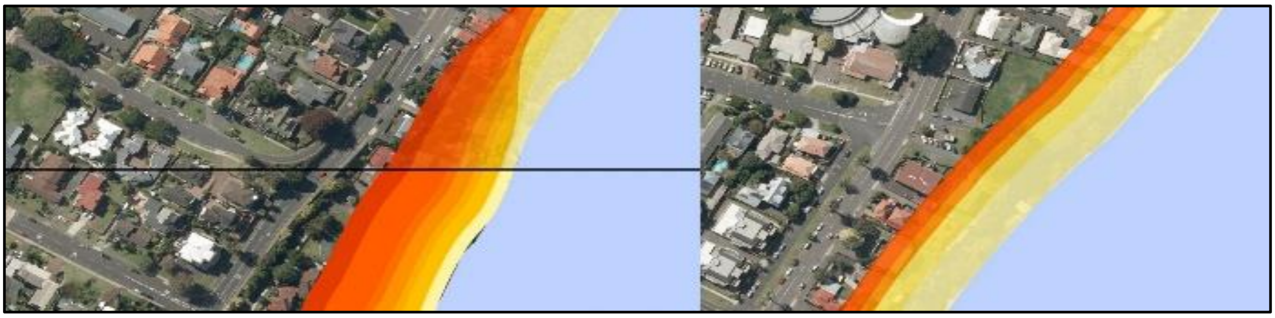

Figure 3: Erosion mapping of low-lying (left) and high cliff (right) coastline showing time and probability. Refer to Table 3 for legend.

Coastal Erosion

Tauranga's 88 km coastline includes 26 km of north facing coast open to the Pacific Ocean and 62 km of harbour coast. Inner harbour shores can be classified into 31 km of cliffs and 31 km of unconsolidated low-lying margins (see Figure 3). This creates three different erosion mechanisms which were modelled separately due to very different environmental drivers.

Table 1: Inputs to the coastal erosion modelling.

Input parameter	Inner Harbour		Probabilities Mapped
Coastline	Historical aerial photos 1943		
SLR	Scenarios as per section 2.2		
Mapped Scenarios	Current	Current MSL	Likely
			Very unlikely
	2080	0.4 m SLR	Likely
		0.6 m	Likely
		0.6 m	Very unlikely
		0.8 m	Likely
	2130	1.25 m	Likely
			Very unlikely
		1.6 m	Very unlikely

Inner harbour erosion zones were defined by combining component parameters of slope stability, long term erosion rate, retreat due to sea level rise and short-term changes from storm erosion. Probabilities used for mapping erosion were adopted to reflect levels of confidence of "likely" and "very unlikely". Numerical probability for "likely" meaning there is a 66% probability that the line indicated on the map will be reached or exceeded. In the case of "very unlikely" there is a 5% probability, but it is still possible. The "very unlikely" line is always further landward than the "likely" case.

Table 3 provides the input data for erosion projection.

Tsunami

Coastal cities like Tauranga are particularly exposed to tsunami hazard as a large proportion of the population and much of the proposed growth is along the open coast. Tauranga is susceptible to both far-field and regional sources, with the Kermadec Trench to the north-east identified as the most likely source of a large tsunami which would pose a significant hazard.

Tsunami hazard was studied in 2013 [5] for the purposes of establishing evacuation zones shown in Figure 4. Modelling inputs and output are detailed in Table 4. In this case establishing the impact of a very large, low probability event was the primary objective. The data from this study was used to establish the tsunami hazard for the multi-hazard mapping so described in Table 5.

Earthquake Shaking

A Tauranga specific earthquake shaking analysis was completed to underpin liquefaction analysis and contribute a baseline input [7].

This probabilistic seismic hazard analysis (PSHA) adopted a model of soil conditions represented by Vs30 seismic shear wave velocity [8] which reflected the continuous geotechnical variation across the city. An earthquake rupture forecast was developed, and the seismic hazards then calculated in terms of peak ground acceleration (PGA) which was spatially mapped for return periods of 25, 100, 500, 1,000 and 3,030 years. The mean earthquake magnitude ranges from M_w 6.1 to 6.3 across this spectrum.

Figure 2: Tsunami evacuation zones adopted as hazard zones for this study. Orange represents approx. 1000 - 2500-year return period. Yellow represents maximum credible event.

Table 2: Inputs and outputs for tsunami modelling.

Input parameter	Description
Generating source	M_W 9 at 4-6 km depth over 300 km of southern section of Kermadec Trench [6]
Water Levels	Tide of 0.8 m above MSL representing exceedance by 50% of high tides
SLR	SLR of 0.8 m was incorporated as alternate tidal at the time of the tsunami
Output	
Time	66 mins to shore from southern Kermadec source. Post impact estimation of 30 mins for majority of inundation, 3-6 hours to maximum inland extent after first arrival.
Wave characteristics	Approaches from approx. parallel to shore. Nearshore islands cause localized refraction and secondary wave focusing on middle third of the 26 km coast.

Table 3: Definition of hazard zones for model calibration.

Evacuation Zone	Description	Reference Tsunami scale
Red High Hazard	Evacuated during all scenarios regardless of size.	10 m buffer from the coastal edge
Orange Medium hazard	Evacuation in most if not all official warnings	Inundated under shoreline wave of 10 m. This equates to a return period of 1,000-2,500 years
Yellow Low Hazard	Likely extent of inundation under max credible event	Area inundated under maximum credible tsunami. Return period in excess of 2,500 years

Liquefaction

Liquefaction is an earthquake driven process where shaking increases the water pressure in some types of soil resulting in temporary loss of strength which causes significant land and building damage through settlement and horizontal ground movement. Liquefaction was mapped by ground damage projections based on soil type, water level and ground shaking. The damage map represented both free-field settlement and lateral spreading conditions showing three ground damage divisions of none-to-minor, minor-to-moderate and moderate-to-severe. Input parameters adopted for liquefaction are listed in Table 6.

Table 4: Parameters for the liquefaction study.

Input parameter	Description
Seismic hazard	A city specific seismic assessment PSHA was prepared
Ground water levels	Current ground water surface levels used in current liquefaction modelling Current +1.25 m used as ground water surface for 2130 scenarios
Earthquake return periods analysed	25-yr representing serviceability limit state requirements 100-yr and 250-yr showing interim liquefaction levels 500-yr representing ultimate limit state requirements 1,000-yr representing full liquefaction mobilization condition
Ground water levels analysed	Current water level at 50% probability 100-yr projection at +1.25m

Landslides

Tauranga is a city of two geomorphic halves. The western city is dominated by ignimbrite and volcanic ash ridges while the east is low lying sandy coastal plain. It is the western section that exhibits landslides. Studies carried out in 2001 [9] established a methodology for hazard rating according to the slope, and this forms the basis of Tauranga hazard mapping at present.

The 2001 study used aerial photos to identify more than 2,000 relic slip features and establish a register of 2,000 head scarps and 400 slope debris features. Analysis of typical landslide features provided a frequency distribution of slip and head scarp attributes that were translated into Tauranga city planning rules which are summarized in Table 7.

Table 5: Current parameters for the landslide hazard evaluation.

Slope	Associated Hazard
2H:1V or steeper	High slip hazard
4H:1V from head-scarp location	Debris runout zone hazard
3H:1V from toe location	Head-scarp collapse hazard

Flooding

Flooding due to heavy rainfall is a regular occurrence in Tauranga. The city is characterized by 24 catchments that are predominantly residential. Portions of the lower catchments are also used for water management, passive recreation and conservation. The upper portion of large catchments are frequently outside of the Tauranga boundary and undeveloped.

Modelling these catchments was carried out from 2014 to 2020 using coupled models to simulate the multiple environments present in the catchment. The input parameters are shown in Table 8 and the combined output of all catchments is mapped on the TCC GIS [10]. The model was validated using flood incident reports for a storm event that occurred in April 2013 [11].

Table 6: Parameters for the flood modelling.

Input parameter	Description
City catchments	24 total ranging 2 km^2 to 56 km^2 Total area183 km^2 Highest elevation 930 m
Rainfall scenarios	10, 50, 100-year storm. Present climate and development 10 and 50-year storm. Projected 2055 climate conditions 50, 100 and 500-year storm. Projected 2130 climate conditions

MULTI-HAZARD EXPOSURE MAPPING IN GIS

Hazard Aggregation

The aggregated hazard at each point of the city was achieved by combining output from each individual hazard into a summative multi-hazard model. Each point is rated according to the accumulated number and scale of individual hazards, effectively providing a multi-hazard exposure for that point. The resultant map provides a visual interpretation of the accumulated hazard. This research appears unique in the large number of hazards aggregated into this multi-hazard map. Steps in this process:-

1. Complete probabilistic hazard assessments adopting consistent probabilities and timescales to enable direct aggregation ($H_1 – H_n$ and H_{SLR})
2. Define exposure levels to each hazard and apply a 10-point scale to be adopted as a hazard schema (HS_1-HS_n and HS_{SLR}). Application of an additional schema factor will be necessary for hazards mapped with different return periods and timescales ($SF_1 – SF_n$ and SF_{SLR})
3. Define weighting coefficient to normalize individual hazards for balanced aggregation ($N_1 – N_n$ and N_{SLR})
4. Sum normalized schema to obtain numerical representation of aggregated exposure (E_{HM})
5. Geospatially map multi-hazard ratings in GIS

$$E_{HM} = \sum_{H_1}^{H_n} HS \times SF \times N \qquad (1)$$

where, E_{HM} = Exposure sum for all hazards
HS = Hazard Schema
SF = Schema Factor
N = Normalisation
H_n = Individual hazard (specific hazard represented by the subscript; e.g. hazard due to SLR is shown as H_{SLR})

Identification of Pilot Zone for the Study

A sub-area of Tauranga city has been adopted as a pilot area for this study (see Figure 5). This 25 km^2 area represents the full suite of hazards, landforms, infrastructure and population applicable to Tauranga's total of 135 km^2. The area consists of the central business district (CBD) and extends southward through the areas being considered for future residential intensification. It is this southern area that is prone to landslides. The area extends northwards far enough to represent both open coast and inner harbour erosion. Mt. Maunganui itself is not included in the mapping at the time of publication.

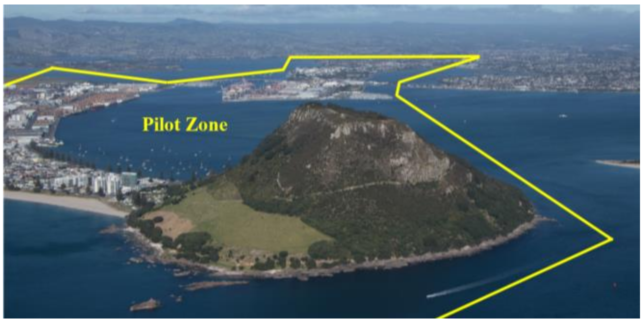

Figure 3: Plan of the pilot study area.

Table 7: Hazard Schema for each hazard showing defining events.

Hazard	Events defining schema points assignment			
	High (10)	Medium	Low (1)	Max. extent
Sea level rise (HS_{SLR})	Up to 0.4m SLR	50-year projection 0.4-0.8 m	100-yr projection 1.25-1.6 m	100-yr projection 1.6m SLR
Inundation from Storm Surge (HS_I)	10-yr projection 0.0m SLR 1% AEP storm	50-yr projection 0.6m SLR 1% AEP storm	100-yr projection 1.25m SLR 1% AEP storm	100-yr projection 1.25m SLR 1% AEP storm
Coastal erosion (HS_C)	10-yr projection 0.0m SLR 5% AEP (Highly unlikely)	50-yr projection 0.6m SLR 66% AEP (Likely)	100-yr projection 1.25m SLR 66% AEP (Likely)	100-yr projection 1.25m SLR 66% AEP (Likely)
Tsunami (HS_T)	Red evacuation zone	Orange evacuation zone	Yellow evacuation zone	Yellow zone inland extreme
Liquefaction (HS_L)	Moderate-severe ground damage 0.0m SLR 0.2% AEP	Minor - moderate ground damage 0.0m SLR 0.2% AEP	100-yr projection Minor - moderate 1.25m SLR 0.2% AEP	100-yr projection Extent of minor-mod 1.25m SLR 0.2% AEP
Landslide (HS_{LS})	Within slope zone 2h:1v	Outside 2h:1v zone *and* inside 3h:1v upslope *or* inside 4h:1v runout side		Outside of defined zones
Flooding (HS_F)	Current 1m depth 0.0m SLR 1% AEP storm	Current max 0.0m SLR 1% AEP storm	100-yr projection 1.25m SLR 1% AEP storm	100-yr projection 1.25mSLR 1% AEP storm

Define Hazard Schema (HS)

It is necessary to assign a numerical score representing the exposure level at each spatial point to each hazard. A 10-point scale adequately represented the full range of exposure while enabling considered variations based on the local conditions and parameters of the hazard quantification study. Schema assignments are detailed in Table 9. Areas already exposed to the hazard at a low return period event were considered high exposure. Areas at the outer extents of exposure under a hazard scenario of 1% AEP and 1.25 m SLR were considered low exposure. An example using the inundation shown in Figure 2 would assign a high hazard exposure value (9-10) to all areas inundated in a 2% AEP storm in a 2020 event, shown in dark blue. A low value would be assigned at the 1% storm with 1.25 m SLR 2130. Graduation of the exposure value between one and ten can be assigned according to intermediate depths of inundation, intermediate event magnitudes and SLR.

Earthquake shaking and volcanic ashfall were not individually mapped as there was minimal variation across the city and so did not provide differentiation in the multi-hazard map.

Define Schema Factor (SF) for Probability Variations

Calculation of adjustment factors to the HS to account for different return periods where these were not aligned adequately from the hazard quantification study. In this study two hazards incorporated probabilities that required a schema factor. Tsunami exposure was obtained from low frequency event estimates and liquefaction adopted a 0.2% AEP event to better represent the spatial potential of liquefaction in an earthquake. These are shown in Table 10.

Table 8: Schema factors (SF) for return period adjustment.

Hazard	Schema Factor (SF)	Hazard study return period	Basis of adjustment calculation
Tsunami (SF_T)	0.5	1,000 to 2,500-year Orange >2,500-year Yellow zone	Available data is based on long return period high magnitude events established for evacuation purposes. Factor was derived from ratio of PGA established for Tauranga through the PSHA
Liquefaction (SF_L)	0.75	500-year	500-year adopted to give extent of liquefaction in post-activation condition. Factor was derived from ratio of PGA established through the PSHA

Determine Hazard Normalization (N) for Aggregation

Seven factors have been recognised as important aspects of events in regard to their potential hazard [12]. These are magnitude, frequency, duration, areal extent, speed of onset, spatial dispersion and temporal spacing. For each hazard these factors are assessed and weighted and shown in Table 11 with the exclusion of magnitude, frequency and temporal spacing which are already included in the specific hazard mapping quantification.

Geospatial Mapping Multi-Hazard Ratings using GIS

Mapping of aggregated multi-hazards exposure values was carried out using GIS providing a spatially correct all-hazard exposure rating for all points of the pilot zone. The resultant map provides a visual interpretation of multi-hazard exposure. Numerical output of E_{HM} was represented through a five-level colour map. A maximum exposure value would identify a point impacted by all hazards at low return periods. These exposures were represented by hexagonal shapes of 250 m diameter in order to represent a defined area without being so detailed as to identify individual properties.

Table 9: Hazard normalization coefficient (N).

Hazard		Speed of onset	Duration	Areal extent	Spatial dispersion
		Speed event becomes hazard	How long event will persist	Spatial extent likely	Spatial predictability
	N	1-slow fast-5	1-short long-5	1-limited spread-5	1-diffuse conc-5
Sea level rise (N_{SLR})	0.16	1	5	5	5
Inundation (N_I)	0.11	2	5	2	3
Coastal erosion (N_C)	0.12	2	5	2	3
Tsunami (N_T)	0.15	4	2	4	5
Liquefaction (N_L)	0.16	5	1	5	5
Landslides (N_{LS})	0.14	5	5	2	2
Flooding (N_F)	0.13	3	3	3	4

Usability Objective of Mapping

Output that is easily usable and quickly understandable while maintaining appropriate levels of accuracy is key to this tool being adopted. Table 12 sets out elements that contribute and how they were achieved.

Table 10: Selected elements of usability showing objective and methodology.

Usability sub-objective	Method adopted
Visually uncluttered	Five colour rating system to produce a heatmap of exposure
Clear indication of relative exposures spatially	Limiting to five colours maintains clarity Vertical (3D) representation of exposure will also enhance readability
Easy location identification	Underlying City map visible through exposure heatmap 3D will aid location recognition through topographical features
More depth of data available on demand	Provide exposure chart for any space providing the percentage of impact each hazard applies to that location

Evaluation of Mapping

The output mapping as shown in Figure 6 is visibly simple and identification of various exposure areas in this pilot zone is straight forward. The single point exposure chart in Figure 7 provides excellent clarification and will be useful to develop for community education.

Verification of the multi-hazard mapping was carried out by comparison with historical mapping. City planning rules have established hazard zones for several decades and the exclusion zones and building restriction lines match well with the high and extreme hazard exposures identified in this multi-hazard mapping. Inspection of individual hazard mapping also confirms alignment of the multi-hazard exposure.

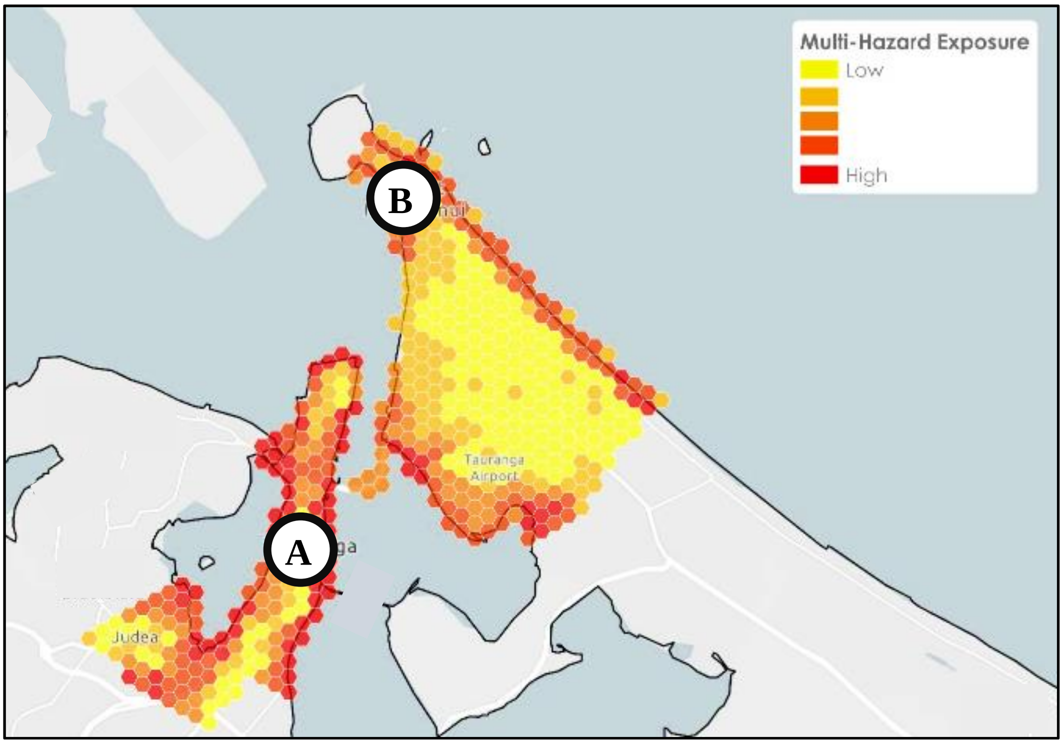

Figure 4: Multi-hazard exposure map for the pilot zone.

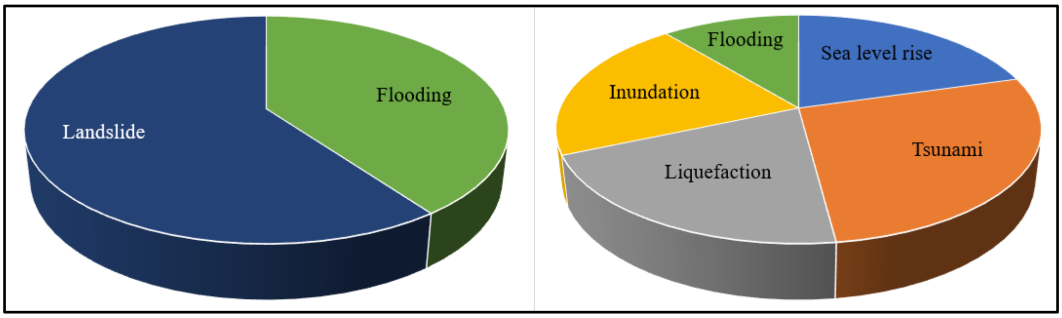

Figure 5: Single point exposure contribution chart from points A (left) and B in Figure 6.

The successfully achieved visual output, substantiated by the integrated hazard data supports the continuation of research to include the entire city in the multi-hazard mapping and to incorporate a 3D visualization option.

Areas for Further Research

Completion and incorporation of new hazard data will enhance the hazard representation accuracy. A new probabilistic landslide mapping is due for completion in 2021 which will remove the application of a hazard schema factor (SF) to the landslide hazard. Hazards with a longer return period but higher consequential damage could be factored into the hazard mapping and subsequent growth planning.

CONCLUSIONS

Multi-hazard mapping effectively identified hazard exposures to support urban growth planning in the coastal city of Tauranga. Each part of the city was rated according to the overall number and scale of individual hazards and spatially mapped to provide a clear visual interpretation of the exposure at any part of the city. Direct comparisons across the city are a critical informant to city growth planning and targeted investment in infrastructure resilience building. This research provides evidence that multi-hazard mapping will fulfil that need.

The mapping showed that the highest aggregated hazard exposure areas in Tauranga are along the coast. As is common with many beach resort towns this corresponds with the most popular living areas. Lower hazard areas suitable for urban growth are on the slightly elevated peninsulas. It can also be seen that landslide potential increases exposure further from the coast and along the peninsular margins, thus constraining Tauranga’s growth on all sides.

A key to effective mapping was high-resolution quantification of the many natural hazards. As this is a coastal city, sea level rise projections impact every hazard except landslides. A common calibration point across all hazards was established at 1% AEP event projected 100 years to 2130 incorporating 1.25m sea level rise provided for reliable aggregation. Aggregated mapping of seven natural hazard appears unique in the number of hazards represented.

The resultant map provides a reliable visual interpretation of the aggregated hazard levels to help decision makers and aide in communicating risks to the public. The graphic representation is a powerful tool that can also be used for building community resilience through education and extended to asset exposure to enable infrastructure strengthening for resilience. Based on this successful pilot it is proposed to expand the map to the whole city and incorporate improved 3D graphic visualization.

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