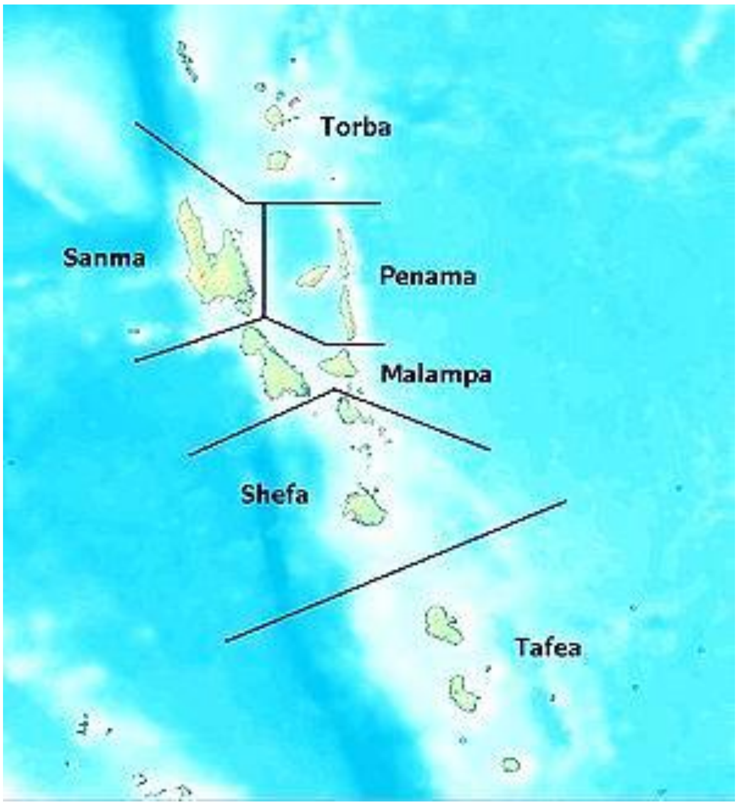
FINAL

Profile of Risks from Climate Change and Geohazards in Vanuatu



November 2013

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Acknowledgements

Creating a risk profile for a country requires the collection, amalgamation, synthesis and analysis of a lot of information, form literature, datasets and people. Moreover it requires a proper understanding of the local viewpoints and considerations as to what risks are deemed to be relevant and how the information needs to be presented. Therefore many people were consulted during the production of this document. They contributed information directly (through documents and datasets), indirectly (by pointing to other contacts or data-sources) and shared viewpoints and observations on the issue.

I would like to thank them all. This report would not have been possible without them. I would especially like to thank the PMU team (Peta, Malcolm and Dora), the RGA-team (Ian, Bikash, Flora and Bob) and GIZ (Chris) for their inputs and contributions.

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November 2013

Executive Summary

The Government of Vanuatu recognises that effective institutions and the inter-relationships between them are at the heart of its ability to respond to growing climate and disaster risks. To this end, a comprehensive analysis of climate and disaster risk governance is undertaken.

A critical precursor is the development of a risk profile for Vanuatu that identifies the key risks and vulnerabilities that Vanuatu's risk governance institutions must address. Currently there is no single, up-to-date and easily accessible document that summarises the major studies of risk undertaken to date.

This "Profile of risks from climate change and geohazards in Vanuatu" report describes the activities and results of the risk profiling.

The ***overall objective*** is to compile a summary analysis of Vanuatu climate, climate change and disaster risks. The outputs are as follows:

output description	**output format**
library of Vanuatu risk assessment reports from completed geohazards, climate, climate change and disaster risks and vulnerability analyses undertaken by the Government of Vanuatu, development partners, projects and academics	• digital files of the relevant documents (pdf, docx and xlsx) • summary documents (**Library list.xlsx, Library overview.docx**)
a geohazards, climate change and disaster risk profile for Vanuatu to inform the Risk Governance Assessment, Second National Communication and national climate change and disaster risk reduction policy	• the risk profile report • a digital database with all identified spatial information
a list of current and planned risk mapping activities in Vanuatu that can be used for coordination purposes	• digital files of the relevant documents (pdf, docx and xlsx) • summary document (**Future Risk Mapping Activities.docx**)
identified data and analysis gaps and a set of priority risk mapping, data collection or analysis actions and recommendations required to improve information on Vanuatu climate and disaster risks	• the risk profile report

The assessment followed these steps:

1. Compilation of documents and information through: collection of social and natural scientific research reports undertaken on geohazards, climate, climate-change and disaster risks in Vanuatu; collection of key national and provincial level vulnerability identification and assessments or any other published risk reports; identification and listing in a database of current and planned risk mapping activities in Vanuatu; identification, location and listing of datasets for Vanuatu that could be useful. These include all geophysical/climate/oceanographic datasets both locally and overseas.

2. Synthesise and analyse through: summarise and synthesise the key findings into a single document covering geological risks (volcanic, seismic hazards and tsunami-genic hazards), climate variability, climate change to date, climate projections, disaster risk; create basic visual risk maps of Vanuatu climate and disaster risks, showing in broad terms the level of risk for each island.
3. Identify gaps and options for future work through: identification of gaps in data, information and analysis; identification of research required to downscale analysis and further identify the level of risk for each province or island; identification of the most important meteorological variable that needs research to determine the level of risk for each island; listing of options for further research and recommendations for priority projects.

The following table lists the effects of climate change that are considered in the assessment.

climate change	**long term effects (climate)**	**short term effects (weather)**
temperature increase	higher Tmin, Tmean, Tmax	heat waves, cold spells
precipitation change	less or more annual rainfall	floods, droughts
sea level rise (NB. vertical land movement)	higher sea levels, compounded by higher wave-setups	higher flood extremes
ocean acidification	increase with atmospheric CO_2 levels	
sea surface temperature increase	higher min, mean and max SST	more and longer episodic high temperatures

For tropical cyclones, IPCC in its 5th Assessment Report concludes the following: "*Projections for the 21st century indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rain rates. The influence of future climate change on tropical cyclones is likely to vary by region, but there is low confidence in region-specific projections.*"

Therefore tropical cyclones have been excluded as a component in the risks from climate change. However, observations on current risks from cyclones are included in the report.

Some findings for the risks from climate change:

- Increase in daily temperatures is the same for the whole of Vanuatu, for minimum, mean and maximum daily temperatures. Compared to 1995, by 2040 it is 1.2°C (global 1.9°C), by 2070 2.3°C (global 3.6°C)
- Increase in sea surface temperatures will bring the whole of Vanuatu in a zone where coral bleaching will be frequent (above 29.5°C)
- The change in precipitation is unclear: half the models project a change of less than 10% by 2040, while the other half projects a stronger change. This will pose challenges to planning and policy development. This uncertainty is much higher than the differences over the islands.
- The wetter periods are getting slightly drier, while the dry periods are getting slightly wetter.
- Sea level rise will continue and accelerate. Information on local vertical land movement is crucial. For Port Vila, an increase of 159cm is projected for 2100, when the observed sinking of 4.8mm/year is taken into account.

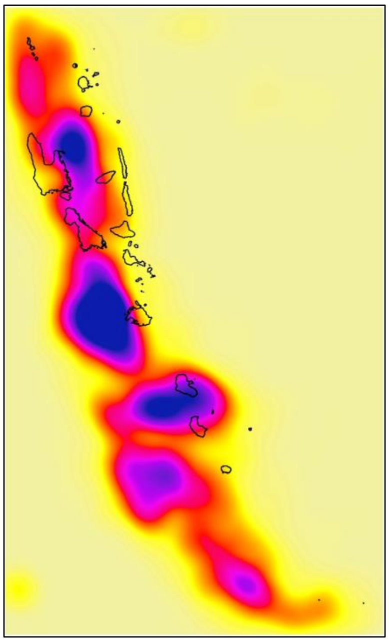
- In 20 years from now, ocean acidification will have damaged 80% of the coral reefs around the world, including those in Vanuatu. Considering there crucial role for coastal protection, food security and tourism, this makes it the most significant impact of climate change for Vanuatu.
- The extreme temperatures (including heatwaves) will reach higher levels and become more frequent. By 2040, the current 1-day maximum occurring once every 20 years, will occur every other year.
- The duration of dry periods will become longer. The 1 in 5 year event will lengthen from just under 19 days to 28 days.
- Extreme rainfall will become more frequent and intense. By 2040 the magnitude of the 1 in 100 year event will have increased by about 10%. This change is the same over all islands. Frequencies of current events will increase 1.2-2.5 times.
- Episodic high sea surface temperatures will increase from about 10% of the time currently to 25% of the time by 2040 (in Efate). This is different for different islands.

The following geohazards are present in Vanuatu:

hazard	**data/information sources**
Earthquakes	A global database with all recorded earthquakes (location of epicentre as well as the magnitude [from 1950]) is used to produce a density map of earthquakes around Vanuatu
Volcanoes	The location of the volcanoes is known, and risk-zones are mapped around these, identifying the areas at risk
Land/mud slides	Land/mud slides are happening when a certain slope is exceeded for specific soil compositions, when triggered by rainfall or earthquakes
Floods	Floods from extreme rainfall events or coastal inundation (from high-tide, storm-surges, tsunamis, waves, aggravated by sea level rise)
Tsunamis/storm-surges	Coastal areas prone to inundation from elevated sea levels (tsunamis, storm-surges, high-tides / combinations)are mapped
Liquefaction	Liquefaction occurs in soil with a high moisture content (usually reclaimed land) when shaken by an earthquake

Some findings for the risks from geohazards:

- The risks are well understood, with known properties regarding location and frequency and expected to not change in frequency or intensity over time.
- Given the rarity of the disasters, there is a lot of uncertainty in the frequency/intensity distribution. This is not going to improve.
- Inferring impacts from events requires information that is currently not available: for flooding (both coastal inundation and flooding from extreme rainfall) a high resolution Digital Elevation Model with high vertical precision is needed. The same is true for landslides.
- The map shows the epicentres of all earthquakes in the Vanuatu area, weighted with the magnitude: earthquakes are concentrated offshore, potentially causing tsunamis.



- Storms are nn important trigger for flood disasters. There is a 10% chance that the southern half of Vanuatu (Efate and below) will be hit by a category 5 storm (wind speeds over 250 km/h) in the next 10 years. For the northern half (above Efate) it will be a category 4 storm (210-250 km/h).

The report finishes with observations and recommendations:

Observation	**Recommendation**
No disaster database exists	Set up a database shared and used by the ministries and other stakeholders
Vanuatu has not produced its Second National Communication yet	Finalize the SNC asap and share with stakeholders
Climate change projections are solely dependent on the PCCSP information	Use other tools (i.e. SimCLIM 3.0) as well, to increase flexibility, assess additional functionality and use more and more detailed information
No high-resolution Digital Elevation Model exists for Vanuatu as a whole	As this information is crucial for assessing flood risks and risks from landslides, creating a better DEM should be prioritized
The change in future precipitation is highly uncertain	Closely monitor rainfall on the different islands to build a database that will improve projections of extreme weather
Current development projects seem to focus on areas that have a lower risk profile	Focus development projects on areas where the risks are high; this is the only way to lower Vanuatu's global profile as the most "risky" country

Lastly, these follow-up projects are recommended:

aspect	research needed
DEM+soil	A Digital Elevation Model is required for modelling the impacts of flooding, both from sea and from heavy rainfall, as well as landslides. The global DEM has a horizontal resolution of 30x30 meters with a vertical (interpolated) resolution of 1 meter, which is insufficient for the modelling. The LIDAR DEM that is being handover to Vanuatu Government has a horizontal resolution of 1x1 meter, with 0.3 meter vertical resolution, but does only cover some coastal areas in Vanuatu. This area needs to be extended. Furthermore, the modelling of landslides also needs soil information, including moisture content.
coral reefs	Coral reefs are crucial for the livelihoods of the people in Vanuatu. They are part of the protection against coastal flooding, home to fish that feeds the communities, and an attraction for tourists. The pressures on the coral reef from higher sea surface temperatures and ocean acidification, acerbated by sea level rise (health coral reef can grow with up to 5 mm/year, SLR could become larger than that), is causing a severe deterioration. Coral reef management (focussing on removal of garbage, prohibiting artificial beaches and digging trenches as well as removal of coral) would aim at giving the coral the best chance of survival while the international community is getting their act together.

VLM/SLR	Vertical land movement is a process that has the same order of magnitude as sea level rise, but can either off-set it or make it worse. Only for Port Vila information on VLM is available. Given the fact that Vanuatu is in a tectonic active area, it is to be expected that there is variation between the islands. Estimating the VLM in these locations is essential for assessing the risks from sea level rise. This is possible directly (i.e. from continuous GPS) or indirectly (from tidal records).
precipitation	Precipitation is a more complex issue than might seem from a first glance. There is significant variation in time (about 30%) and space (from just over 1100mm to just under 4600mm) in annual precipitation, while there is a strong disagreement between climate models over how precipitation is going to develop under climate change. As extreme events (floods and draughts) are being impacted by climate change quicker and more pronounced than the annual average, efforts should be made to build a detailed, complete, reliable precipitation record in all provinces or even islands in Vanuatu.
streamlining risk information into decision making	The availability of risk information as generated through this assessment (in this report, but also in the extensive electronic library and spatial datasets) does not guarantee a proper streamlining of this information in Vanuatu decision making and disaster risk reduction. Hands-on application and support in pilot projects would highlight the barriers that prevent the streamlining and allow for the development of better interaction between the policy and the science.

1. Introduction

The Government of Vanuatu has a newly established National Advisory Board (NAB) on Climate Change and Disaster Risk Reduction designed to improve coordination and governance surrounding the threats climate change and disasters pose to its people, environment and assets. One of the key functions of the NAB is to improve access to and the management of human, financial and technical resources to effectively respond to the priority adaptation needs of the people of Vanuatu.

The Government of Vanuatu recognises that effective institutions and the inter-relationships between them are at the heart of its ability to respond to growing climate and disaster risks. The NAB is undertaking a comprehensive analysis of climate and disaster risk governance in Vanuatu to: a) better understand the specific capacities and needs of various national provincial and local stakeholders; b) evaluate national institutions' performance of key functions critical to adaptation and preparedness; and c) identify specific gaps in capacity that can be filled through investment and action to improve governance.

A multidisciplinary team combining experts on climate change and disaster risk management governance, public financial management and local institutional knowledge has been assembled to perform the analyses. Each expert is allocated a specific set of tasks, with the team leader undertaking overarching analysis and ensuring consistency of the assessment and its output documents. The expert team is been steered and guided by the NAB and its Project Management Unit (PMU) within the Vanuatu Meteorological and Geo-hazards Department (VMGD).

The Assessment is supported by the Pacific Risk Resilience (PRR) Programme, implemented by UNDP, which will focus on strengthening governance mechanisms for DRM and CCA at the national, sub-national and local levels in Vanuatu (and in the Solomon Islands, Fiji and Tonga). The PRR programme will be centred on two components that will be implemented under one coordinated and integrated programme: 1) risk governance: supporting mainstreaming of DRM and CCA into development planning and budgeting at all levels of government; and 2) community level risk management and integration of risk management into local level governance mechanisms. This assignment is supported under component one of UNDP's PRR programme.

Currently there is no single, up-to-date and easily accessible document that summarises the major studies of risk. Therefore, a critical precursor to this overarching governance assessment is the development of a risk profile for Vanuatu that identifies the key risks and vulnerabilities that Vanuatu's risk governance institutions must address.

This report describes the activities and results of the risk profiling activity.

The overall objective is to compile a summary analysis of Vanuatu climate, climate change and disaster risks. The outputs are as follows:

output description	**output format**
library of Vanuatu risk assessment reports from completed geohazards, climate, climate change and disaster risks and vulnerability analyses undertaken by the Government of Vanuatu, development partners, projects and academics	• digital files of the relevant documents (pdf, docx and xlsx) • summary documents (**Library list.xlsx, Library overview.docx**)
a geohazards, climate change and disaster risk profile for Vanuatu **t**o inform the Risk Governance Assessment, Second National Communication and national climate change	• this report • a digital database with all identified spatial information

and disaster risk reduction policy	
a list of current and planned risk mapping activities in Vanuatu that can be used for coordination purposes	• digital files of the relevant documents (pdf, docx and xlsx) • summary document (**Future Risk Mapping Activities.docx**)
identified data and analysis gaps and a set of priority risk mapping, data collection or analysis actions and recommendations required to improve information on Vanuatu climate and disaster risks	• this report

This report contains the following chapters.

“Definitions and scope” introduces the important concepts and bounds the assessment as to what is looked into and what is not. “Approach” explains how the work was executed, which steps were taken and who was consulted. “Risks from Climate Change” and “Risks from Geohazards” pinpoints the risks that are analysed, with an introduction and description of each category followed by the outputs, some observation and a first-order assessment of the impacts for various sectors. “Other risk factors” presents information on population density and cyclones. "Current and planned risk mapping activities" deals with the uncovering of other on-going or planned activities to map the risks from natural hazards in Vanuatu. The two remaining chapters "Conclusions" and "Discussion, recommendations and gaps" deal with the findings of this assessment i.e. what do these mean, what are the potential consequences for the bigger picture and what needs to be done for a more complete assessment?

2. Definitions and scope

NDMO (National Disaster Management Office) in the Government of Vanuatu produced a working glossary for DRR (Disaster Risk Reduction) and DM (Disaster Management) [Final DRR Terminology.docx]. Here is a list of the definitions relevant to this report:

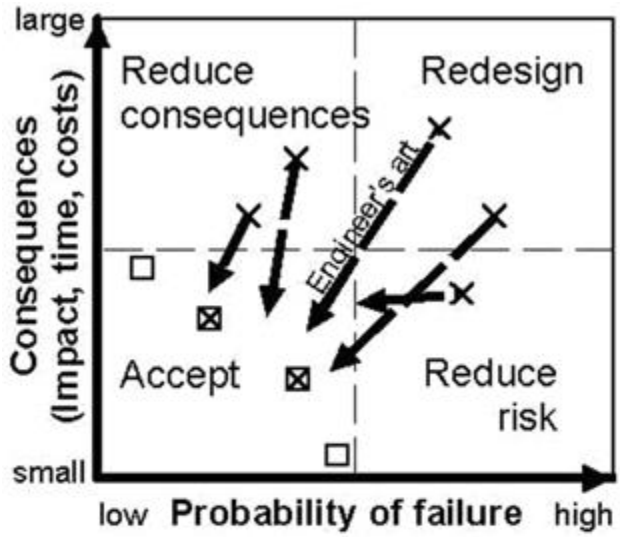
TERM	**DEFINITION**
HAZARD	Something natural or man-made that *may cause* disruption or damage to life, property and/or environment.
DISASTER	When a hazard strikes a community and the result level of impact *exceeds the affected* community's *ability* to respond and allow the community to get *back to normal*.
DISASTER RISK	Impacts that *could happen* to life, property and or environment if a hazard strikes a community.
VULNERABILITY	Vulnerability is the *degree* to which life, property and/or environment is open to being *affected* by, or *unable to cope with*, adverse effects of hazard impacts.
DISASTER MANAGEMENT	All aspects of *planning for and responding* to emergencies and disasters, including both *pre-and post-event activities*.
DISASTER RISK REDUCTION	*Prevention, Mitigation, Preparedness and Response Activities* that a community may decide to undertake *to reduce* present and future *hazard impact*.

(NB. The "Risk Governance Assessment Report" points out (page 12) that there are some discrepancies in the NDMO definitions and the more widely accepted ones)

The following is modified from http://www.ngi.no/en/Geohazards/Content/Shortcuts/Research-and-development/Vulnerability-and-risk-assessment/ and gives a good introduction in risk assessment.

Risk assessment framework

Most risk assessment frameworks contain the following steps: danger identification, hazard assessment, consequence assessment (or vulnerability assessment and elements at risk identification), risk quantification/estimation, risk evaluation and risk management. Risk management is an integrated process containing scientific and political decisions with several levels and countless back-steps and iterative loops. The final goal is to reduce the societal risk; either by reducing the probability of failure or by reducing the consequences.



Schematic illustration of risk management

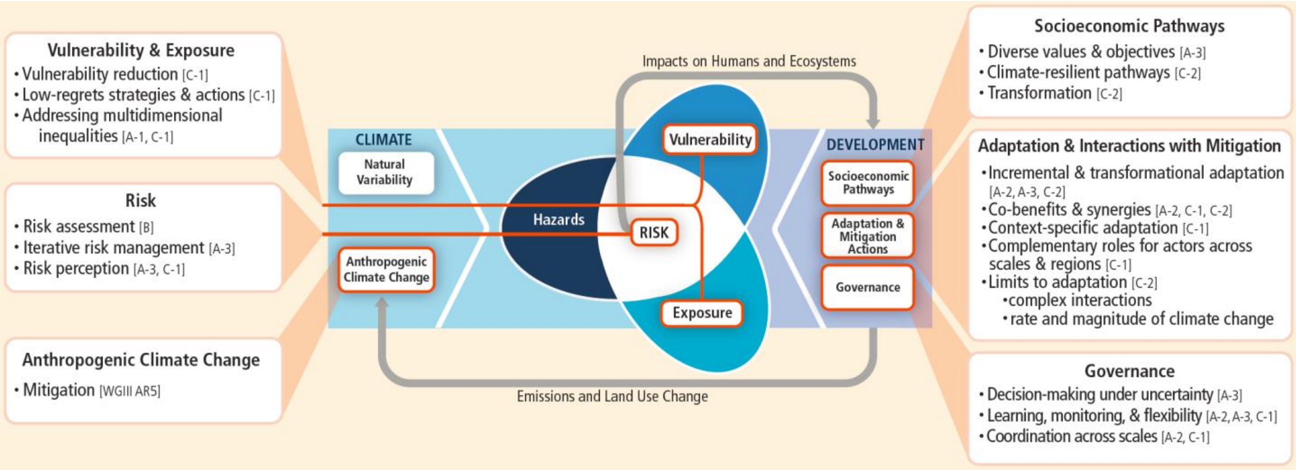
Quantitative vs. qualitative risk

There are two approaches to risk assessment, a qualitative and a quantitative approach. In qualitative risk assessment, the components of risk, which are basically hazard, elements at risk and vulnerability, are expressed verbally and the final result is in terms of ranked or verbal risk levels. Qualitative risk assessment is subjective in nature: what is a “low” risk?

Quantitative risk assessment involves quantification of risk components and computation of risk from these components. The purpose of quantitative risk assessment is to calculate a mathematical value for the risk which enables improved risk communication and systematic decision making, usually thru answering the following questions:

1. Danger identification: what are the probable dangers/problems?
2. Hazard assessment: what would be the magnitude of dangers/problems?
3. Identification of risk: what are the consequences and/or elements at risk?
4. Vulnerability assessment: what might be the degree of damage in elements at risk?
5. Risk quantification and estimation: what is the probability of damage?
6. Risk evaluation: what is the significance of estimated risk?
7. Risk Management: what should be done?

The draft report (as part of AR5) from WGII in IPCC contains the following figure that captures all the important aspects beautifully:



The scope of the assessment of risks of climate change and geo-hazards for Vanuatu is:

- only risks from climate change and geo-hazards are assessed: other risks, like from industrial activities, or the operations from the airport or harbour, are not considered
- only direct risks (first-order) are assessed: the risks from flooding on the operations of the airport are not considered
- focus is put on the consequences for policy and planning
- assessing information (content) and information-flow (process)
- considering within (intra) and between (inter) sectors

The sectors considered in the first order assessment of the impacts of the identified risks are:

- Agriculture (crops, cattle, sustenance)
- Fisheries (freshwater, coastal, deep sea, aquaculture)
- Forestry (including mangroves and production forest)
- Tourism (cruise-ships, hotels)
- Transport (road, ferries, air)
- Infrastructure (utilities [energy, water, sanitation], houses, offices, industry)
- Health (food-security, water-security, safety, well-being)

3. Approach

The assessment followed these steps:

1. Compilation of documents and information:

- Collection of social and natural scientific research reports undertaken on geohazards, climate, climate-change and disaster risks in Vanuatu.
- Collection of key national and provincial level vulnerability identification and assessments or any other published risk reports.
- Identification and listing in a database of current and planned risk mapping activities in Vanuatu.
- Identification, location and listing of datasets for Vanuatu that could be useful. These include all geophysical/climate/oceanographic datasets both locally and overseas.

To this end, key persons (in NDMO, VMGD, Lands Department, Statistics Bureau, NAB, PMU and GIZ) were interviewed and materials collected. Supervised access was granted to NDMO, VMGD and NAB servers to browse through digital material. Internet searches were performed for the various data-elements and results were collected, catalogued and archived in a structured way.

2. Synthesise and analyse

- Summarise and synthesise the key findings into a single document covering geological risks (volcanic, seismic hazards and tsunami-genic hazards), climate variability, climate change to date, climate projections, and disaster risk.
- Create basic visual risk maps of Vanuatu climate and disaster risks, showing in broad terms the level of risk for each island.

The relevant electronic documents were summarized in a separate report, while risk maps are included in this report under the Risk Profiles per hazard.

3. Identify gaps and options for future work

- Identification of gaps in data, information and analysis
- Identification of research required to downscale analysis and further identify the level of risk for each province or island
- Identification of the most important meteorological variable that needs research to determine the level of risk for each island
- Listing of options for further research and recommendations for priority projects.

The last part of this report discusses findings (as observations + recommendations), including gaps (in the observations) and further research (in the recommendations).

Risks from climate change

The results of the fifth assessment report (AR5) of the IPCC (which are based on the CMIP5 model outputs) are becoming available. This risk profile report uses outputs derived from SimCLIM 2013 for the climate change projections, which applies AR5 model results. It is currently the only source available for such an analysis.

Results are from an ensemble of climate change models, using the median from all models available. The number of available models varies with the climate variable. Changes are expressed against the new climate baseline for 1981-2010, as defined in AR5.

RCP8.5 is selected as the worst case emission scenario, combined with a high climate-sensitivity.

Depending on the risk factor focussing on the long term (slow change of climate) or the shorter term (faster change in weather characteristics), time-horizons are set differently.

Where relevant, results are presented for three locations, at the northern part of Vanuatu (Torba), in the middle (Shefa), and for the south (Tafea).

Risks from geohazards

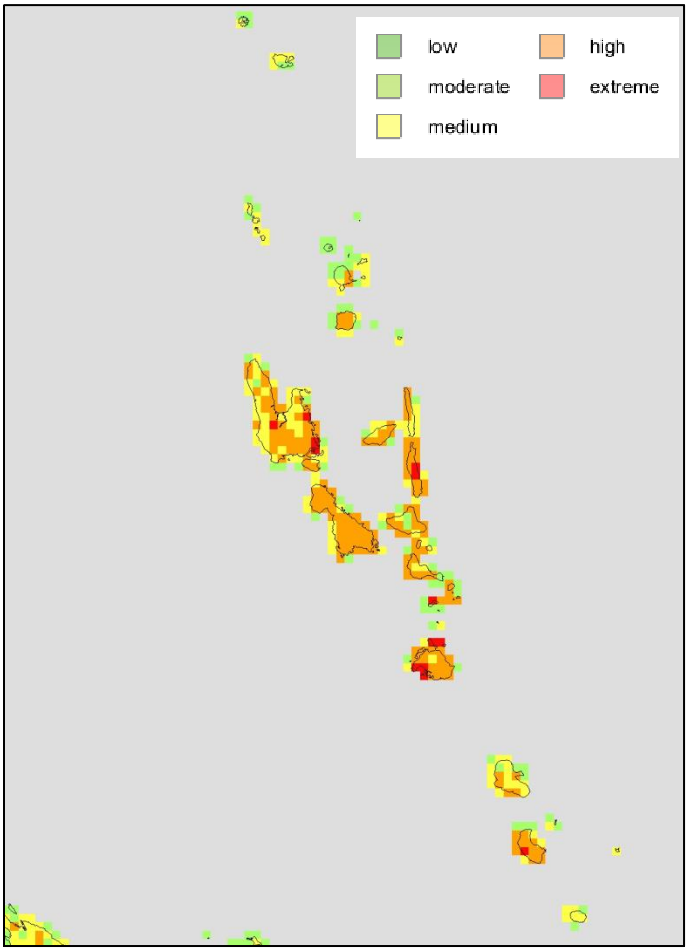
Other than the risks from climate change, the risks from geohazards are not known to change over time. As their trigger-mechanisms are still not well understood, estimates of future risks are solely based on past events (frequency, magnitude, location). New events will change these estimates.

The information presented in this assessment for geohazards is based on past events.

Multi-hazards

The exposure to different hazards in one location can be combined in a multi-hazard analysis.

The World Risk Index report contains information on the mortality risk from multiple hazards for all countries of the world. By zooming in on Vanuatu the following picture can be presented:



The map shows the spatial distribution of mortality risk from multi-hazards. It is taken from the World Risk Index report (2012), and zoomed in on Vanuatu.

The dataset is based on an estimate of the global risk induced by multiple hazards (tropical cyclone, flood and landslide induced by precipitation). The unit used is the estimated risk index from 1 (low) to 5 (extreme). This product was designed by UNEP/GRID-Europe for the Global Assessment Report on Risk Reduction (GAR), with a dataset courtesy of the PREVIEW Global Risk Data Platform. It was modelled using global data.

(source: UNEP/GRID-Europe.)

The annex “Statistics on natural disasters in Vanuatu” contains factual information (number of deaths, number of affected people and economic costs) for major disasters that occurred in Vanuatu since 1900.

4. Risks from climate change

Climate change influences both the climate and the weather. Climate can be seen as the long-term average weather: "Climate is what you expect, weather is what you get". The change in climate expresses itself as a slow change in average values. The change in weather expresses itself as a much faster change in extreme events.

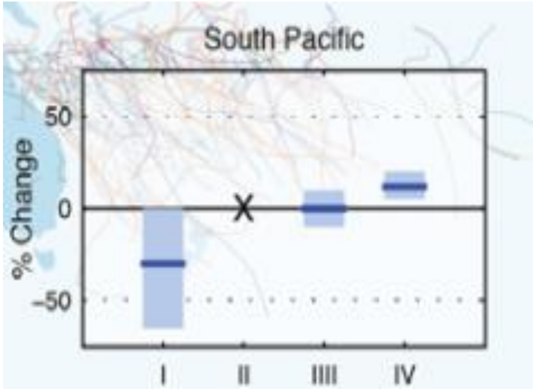
The following table lists the effects of climate change that are considered in this assessment.

climate change	**long term effects (climate)**	**short term effects (weather)**
temperature increase	higher Tmin, Tmean, Tmax	heat waves, cold spells
precipitation change	less or more annual rainfall	floods, droughts
sea level rise (NB. vertical land movement)	higher sea levels, compounded by higher wave-setups	higher flood extremes
ocean acidification	increase with atmospheric CO2 levels	
sea surface temperature increase	higher min, mean and max SST	more and longer episodic high temperatures

The glaring "omission" in this table is "tropical cyclones". The reason is the following statement in the 5th Assessment Report (AR5) from the IPCC:

"Confidence remains low for long-term (centennial) changes in tropical cyclone activity, after accounting for past changes in observing capabilities. … There is low confidence of large-scale trends in storminess over the last century and there is still insufficient evidence to determine whether robust trends exist in small-scale severe weather events such as hail or thunder storms."

"Projections for the 21st century indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rain rates. The influence of future climate change on tropical cyclones is likely to vary by region, but there is low confidence in region-specific projections."



Four metrics are shown: the percent change in I) the total annual frequency of tropical storms, II) the annual frequency of Category 4 and 5 storms, III) the mean Lifetime Maximum Intensity (LMI; the maximum intensity achieved during a storm's lifetime), and IV) the precipitation rate within 200 km of storm centre at the time of LMI. For each metric plotted, the solid blue line is the best guess of the expected percent change, and the coloured bar provides the 67% (likely) confidence interval for this value.

In current assessments by the responsible department in Vanuatu, the results of the 4th Assessment Report (AR4) from the IPCC are used, either through an offline tool (SimCLIM 2.5) or through the PCCSP website (see Annex "Summary from PCCSP report on Vanuatu's future climate").

However, the results of AR5 are now available, and used in this assessment. If the licence is current, SimCLIM 2.5 can be upgraded to SimCLIM 2013 (as used here) to produce these (and other) results. The PCCSP website is expected to be updated at the end of the year.

RISK FACTOR: Climate Change, Climate: Average minimum, mean and maximum daily temperatures will increase

DEFINITION: Longer term average (20 years) for daily minimum, mean and maximum temperatures.

CLIMATE CHANGE: All temperatures will increase with marginally different values. The increases are lower than the global averages (2040: 1.88°C, 2070: 3.56°C), which is due to the fact that Vanuatu is surrounded by ocean, tempering the changes.

Temperature increase compared to baseline climate (1981-2010):

	2040			2070		
Location	**Tmin**	**Tmean**	**Tmax**	**Tmin**	**Tmean**	**Tmax**
North	1.22°C	1.22°C	1.23°C	2.32°C	2.33°C	2.33°C
Efate	1.20°C	1.21°C	1.20°C	2.28°C	2.30°C	2.28°C
South	1.21°C	1.22°C	1.20°C	2.29°C	2.30°C	2.28°C

(source: SimCLIM 2013)

The table shows that the differences between the islands are very small, and well within the uncertainty of the climate change projections.

IMPACTS:

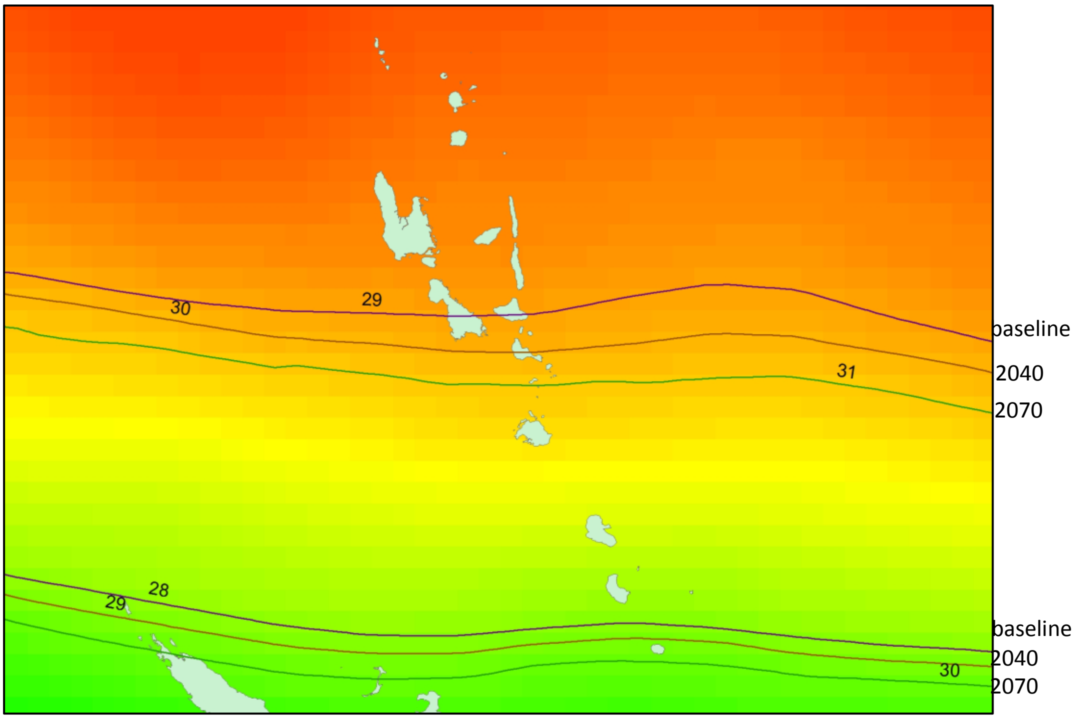
Sector	Potential direct impacts
Agriculture	Shifts in crop-seasons: all phases will happen earlier and faster Increase in water demand, both for irrigation and cattle Potentially new pests with new temperature regimes
Fisheries	May impact aquaculture (faster growth, but also quicker oxygen depletion) Fish migration routes might shift
Forestry	Increased fire-risk, increased evapotranspiration (increasing water-demand) New pests
Transport	No major impacts
Infrastructure	Decrease in efficiency of power generation and distribution (higher temperatures increase the resistance in the network) Increase in power-demand for air-conditioning
Health	Increase in temperature related diseases and conditions
Tourism	As temperature increase are lower than global, Vanuatu is likely to remain a favourite tourist destination in spite of modest changes in climate

RISK FACTOR: Climate Change, Climate: Average and high sea surface temperatures will increase

DEFINITION: Average and maximum temperatures at the surface of the sea are determined by solar radiation, ambient air temperature and mixing with deeper (cooler) water. High SST's (above 29.5°C) will increase the likelihood of coral bleaching.

CLIMATE CHANGE: Both the average and the maximum SST will increase. This will impact coral reef health.

Spatial distribution of Sea Surface Temperatures during February/March:



(source: SimCLIM for ArcGIS/Marine)

The image shows the situation in 2070, with the corresponding 30°C (bottom-bottom) and 31°C (top-bottom) contour-lines. The other contour-lines are for 2040 (29°C, bottom-middle and 30°C, top-middle), and current (28°C, bottom-top and 29°C top-top). This shows that the temperatures increase well over 29°C (by 2040) and 30°C (by 2070) for all islands. This will cause regular and prolonged coral bleaching.

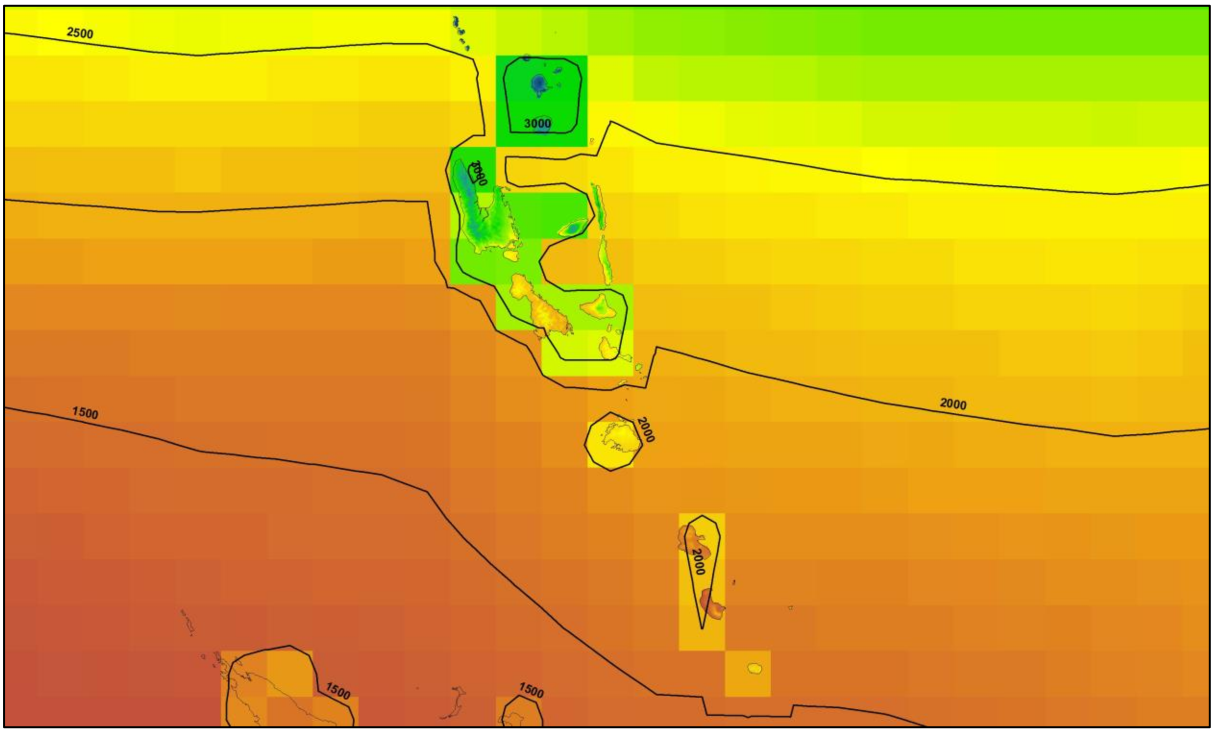
IMPACTS:

Sector	**Potential direct impacts**
Agriculture	Increased food demand, as fisheries is impacted negatively
Fisheries	Negative impacts through coral reef deterioration from coral bleaching (including spawning, breeding, proving hiding places)
Forestry	No major impacts
Transport	No major impacts
Infrastructure	No major impacts
Health	Food security issues
Tourism	Tourists coming (also) for coral reefs and fish/fishing experience might switch to alternatives

RISK FACTOR: Climate Change, Climate: Change in precipitation is unclear

DEFINITION: Long term average annual rainfall, as well as the total rainfall in the drier (July till October) and wetter (January till March) periods of the year.

Annual precipitation varies considerably between the islands:



(source: SimCLIM for ArcGIS/Climate)

The picture also shows that the islands create their own climate, as they are wetter than the surrounding areas.

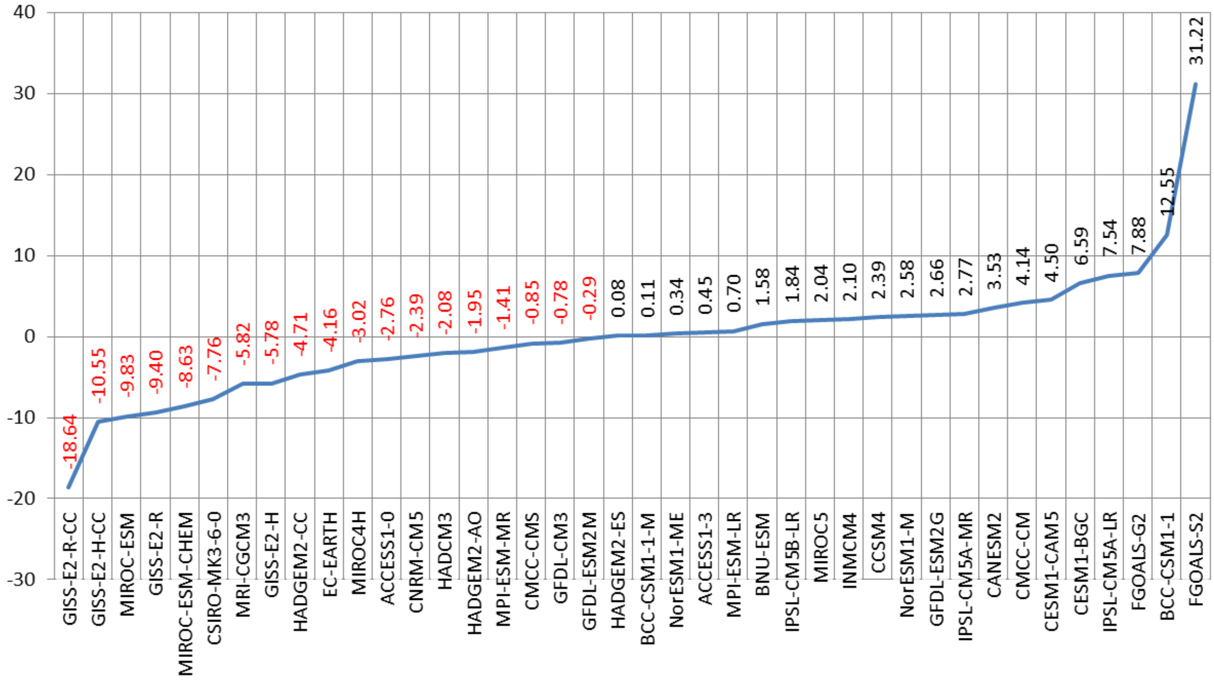
CLIMATE CHANGE: The median result from the model ensemble shows a very small change in precipitation, from slightly positive in the North to slightly negative in the South. However, there are considerable differences between the models, suggesting a large uncertainty in the model-outputs. This is challenging for planning and adapting to climate change.

Per cent change in annual rainfall for 25-percentile (25 per cent of the models have a lower value), median and 75-percentile (a different 25 per cent of the models have a higher value):

	2040			**2070**		
Location	**25-%**	**median**	**75-%**	**25-%**	**median**	**75-%**
North	-14.2	+0.1	+11.2	-26.9	+0.2	+21.3
Efate	-13.2	-1.5	+11.3	-24.9	-3.0	+21.1
South	-14.7	-2.8	+12..9	-28.0	-5.4	+24.3

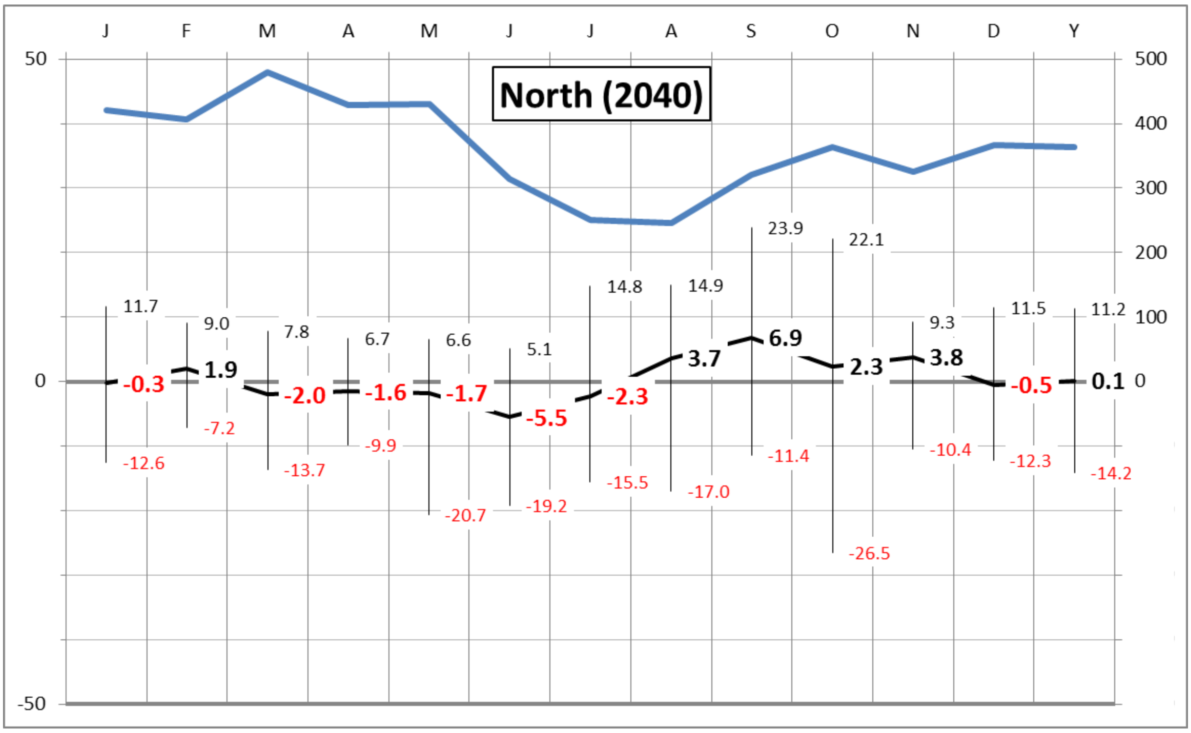
(source: SimCLIM 2013)

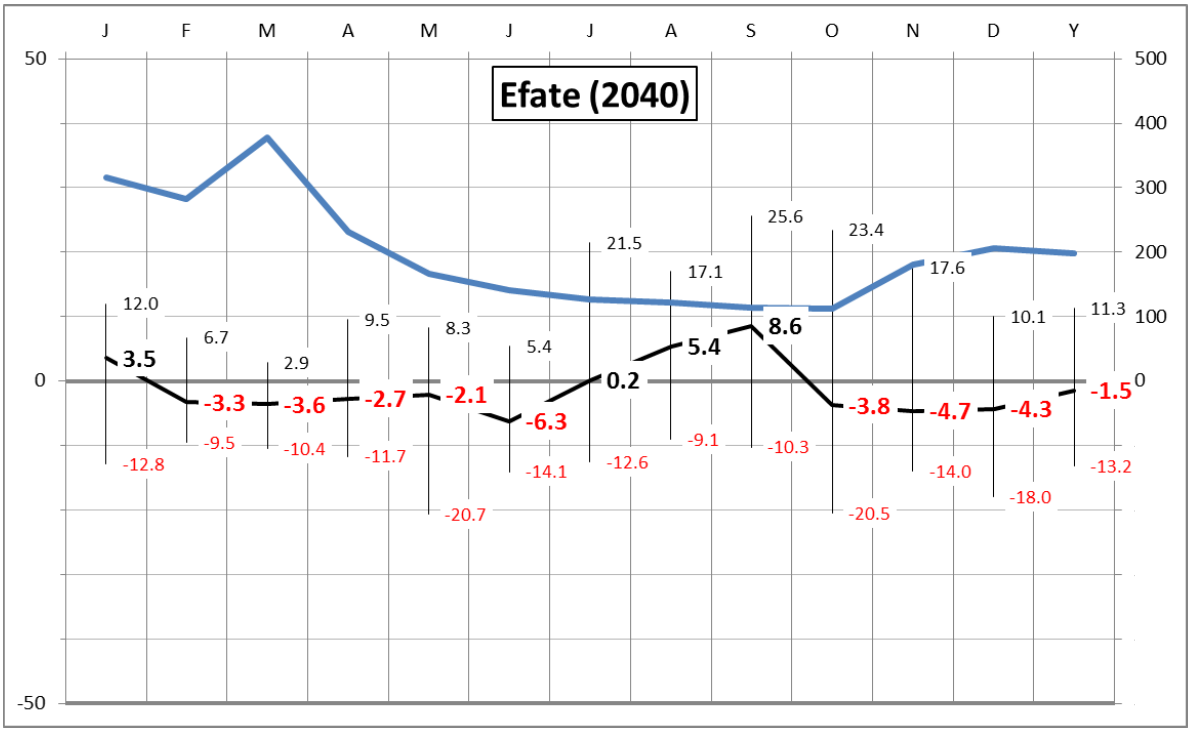
The variation in the model results is much bigger than the differences between the islands. The significant variation in model-outputs for Efate is presented in the following graph, showing normalized values (%Δ-precipitation per °C of global warming) sorted for the different models:

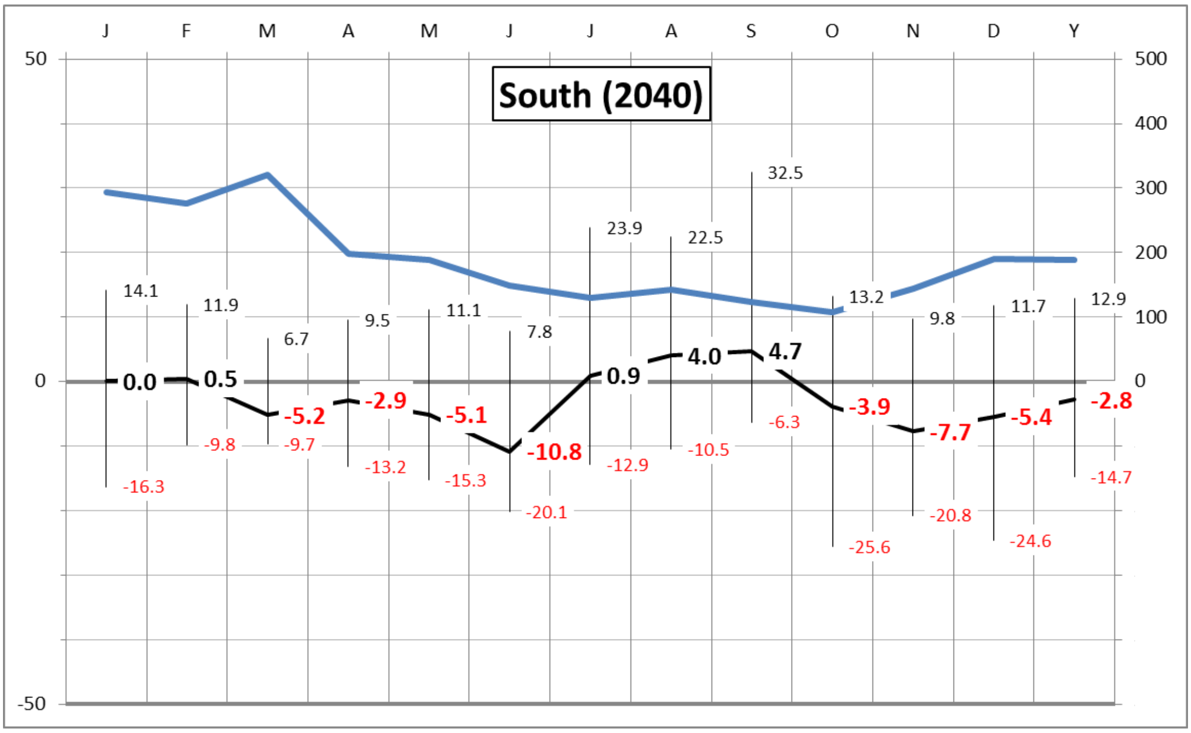


(source: SimCLIM 2013)

To illustrate the variation of the projected percentage change in precipitation throughout the year, the following images show the monthly 25-percentile, median and 75-percentile change in precipitation by 2040 (%, left axis), as well as the monthly baseline precipitation (in mm, right axis) for North, Efate and South:







IMPACTS:

The assessment is done in light of the high spatial and temporal variation in precipitation, which means that the impacted sectors are already seeing (much) higher and lower rainfall in some years, compared to the long-term average. The focus is on the impacts from the change in average weather (climate), as the impacts of the change in extremes are discussed later on.

Sector	Impacts of 10% lower average rainfall	Impacts of 10% higher average rainfall
Agriculture	More irrigation needed for crops More water supply to cattle Change in best crops More stress on crops and cattle	Some crops impacted
Fisheries	No major impacts	No major impacts
Forestry	Some species might suffer	No major impacts
Transport	No major impacts	No major impacts
Infrastructure	Drinking water utility impacted	Drainage needs to be improved
Health	Water-security issues	No major impacts
Tourism	No major impacts	No major impacts

RISK FACTOR: Climate Change, Climate: Sea level rise will continue and accelerate

DEFINITION: Due to the melting of land-ice (glaciers, Greenland, Antarctic) and changes in local ocean water temperatures from increasing air temperatures (causing thermal expansion), local air-pressure and ocean currents, the average sea level has been rising and will continue to rise.

CLIMATE CHANGE: The increase in sea level is slow (current global average is 3.2 mm/year), but will continue for a long time, even when atmospheric CO_2-concentrations and temperature stabilize (with the current values, sea level will continue to rise for more than 500 years, with up to 5 meter rise for the global mean). Sea level rise rates are projected to accelerate under the RCP6.0 and RCP8.5 scenarios. Local vertical land movement can either (partly) compensate for sea level rise (when land is rising), or aggravate the problem. As Vanuatu is a tectonically active area, significant vertical land movements are to be expected, which also might change over time.

The SONEL data-set (www.sonel.org) which uses continuous GPS to estimate land movement, shows -4.1 (±0.7) mm/year of vertical land movement at Port Vila (sinking)[1].

SLR (in cm) at Port Vila for RCP8.5-high scenario (compared to 1995):

Year	global	local*	with VLM**
2040	23	26	48
2060	42	47	78
2080	66	74	115
2100	97	108	159

* local sea level rise takes into account local factors

**-4.8mm/year was used for VLM as worst estimate

(source: SimCLIM 2013)

[1] A Torres GPS station showed twice this rate (Ballu et all., 2011)subsiding 117±30 mm from 1997 to early 2009 (9.4± 2.5 mm ⁄year).

IMPACTS:

Sector	Potential direct impacts
Agriculture	Some operations close to the coast might need relocation as inundation might happen more frequently, while the groundwater table (fresh water lens) is impacted
Fisheries	Loss of deeper coral habitats
Forestry	Impact on mangrove areas, shifting more inland (where opportune)
Transport	Coastal roads need to relocated or a change in road level will be required
Infrastructure	Coastal operations (power plants, sewage treatment plants, sewage pipes, wharves, landings) might need redesign and possibly relocation. Water intakes may need to be shifted inland Coastal defences needed in places
Health	Water insecurity (impact on groundwater) Some villages might need to relocate
Tourism	A lot of tourist resources (hotels, resorts, recreation, beaches) are on or very close to the coast line. Potentially extensive relocation or defence measures might need to be taken

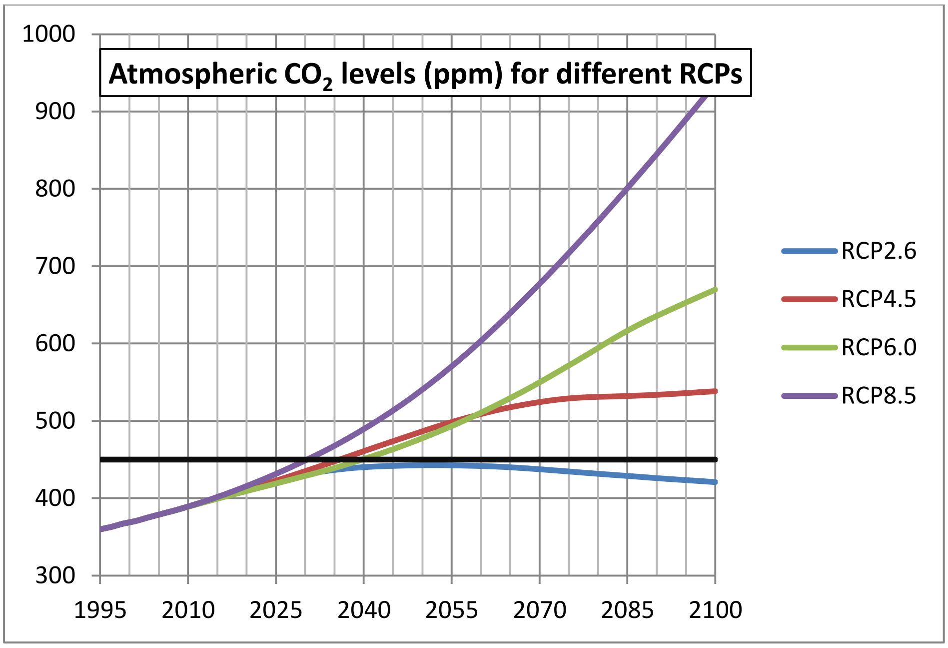
RISK FACTOR: Climate Change, Climate: Ocean acidification will reach damaging levels

DEFINITION: Ocean acidification is the process whereby the oceans become slightly more acidic as about 30% of the CO_2 emitted in the atmosphere dissolves in the oceans. The resulting increase in dissolved CO_2 makes the water slightly more acidic and shifts certain chemical equilibriums including the one that involves calcium-carbonate, a building block for coral reefs.

CLIMATE CHANGE: The rate of ocean acidification is directly linked with the concentrations of atmospheric CO_2. A report of WRI (Reefs at risk revisited, Burke & Reytar, 2011), lists 450 ppm CO_2 as the level at which 80% of the coral reefs worldwide will be dying. This level is reached at different moments for the different RCP's:

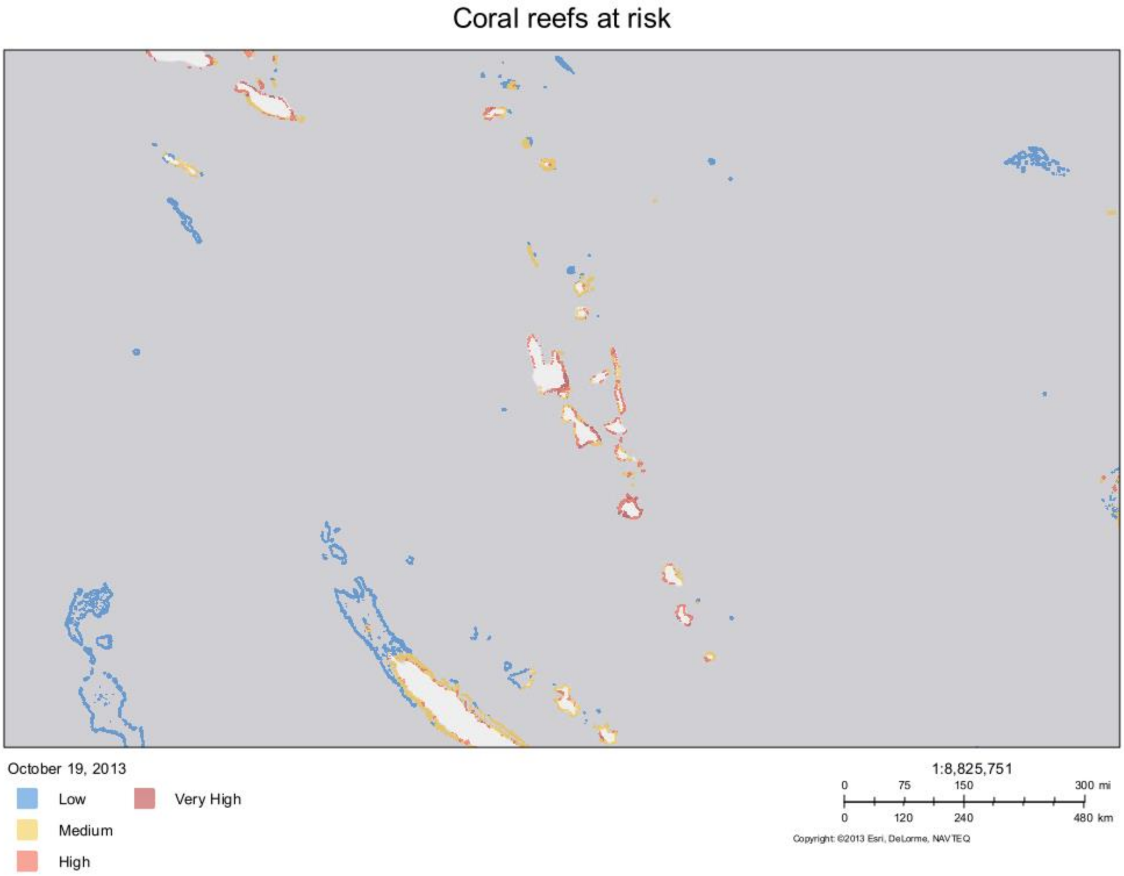
Emission pathway	450 ppm CO_2 reached by	CO_2 by 2070 (ppm)
RCP2.6	not reached	437
RCP4.5	2036	524
RCP6.0	2040	550
RCP8.5	2031	677

(source: SimCLIM 2013)



(source: SimCLIM 2013, 450ppm level highlighted)

The following image shows how the reefs around Vanuatu are estimated to be at risk.



(source: World Risk Index 2012)

IMPACTS:

Sector	Potential direct impacts
Agriculture	Impacts on food demand as fishery is impacted
Fisheries	Impact on fish availability as coral reef is impacted Impact of shell-building organisms (trochus, clams, crustaceans)
Forestry	No major impacts
Transport	Coral aggregate availability greatly reduced for road construction
Infrastructure	Threats to coastal infrastructure with loss of coastal defence from coral reef
Health	Food-security and impacts on safety for coastal communities
Tourism	Impacts through coral reefs (quality and coastal defence)

RISK FACTOR: Climate Change, Weather: Maximum temperature extremes will rise

DEFINITION: Higher than “normal” daily maximum temperatures, for one or more days (heat-waves). “Normal” is defined by the historic observed daily maximum temperatures, which give a distribution of the daily extremes vs. a return period. High extremes are episodic.

CLIMATE CHANGE: Will both increase the maximum temperatures for a given return period, as well as shorten the return period for a given maximum. These changes in weather occur faster and are more prominent than the slow climate change evident in the average temperature values.

Current extremes as well as by 2040 (from an ensemble of 40 AR5 models), for 1 and 5-day period and a 20 year return period are:

	current		**2040**	
Location	**1-day RP20**	**5-day RP20**	**1-day RP20**	**5-day RP20**
North	33.4°C	32.5°C	34.7°C	33.8°C
Efate	34.7°C	33.6°C	35.9°C	34.8°C
South	33.6°C	32.9°C	34.8°C	34.1°C

(source: SimCLIM 2013)

The changes for the 20 year return period under climate change by 2040 are:

Location	1-day RP20	5-day RP20
North	1:1.1 year	1:1.1 year
Efate	1:2.3 year	1:2.0 year
South	1:1.7 year	1:2.1 year

(source: SimCLIM 2013)

IMPACTS:

Sector	Potential direct impacts
Agriculture	Heat waves negatively impact crop yields Higher vulnerability to pests and disease outbreaks
Fisheries	Aquaculture (land base) impacted through higher water temperatures
Forestry	Increase in fire-risk
Transport	Potential road damage (sealed roads)

Infrastructure	Higher power demand for air-conditioning Power-generation disrupted by higher demand and higher temperatures (as these will lower the efficiency of the power plant and increase the resistance in the distribution network)
Health	Heat stroke related diseases will increase
Tourism	Heat waves might deter tourists coming to Vanuatu Impacts on outdoor activities

RISK FACTOR: Climate Change, Weather: Droughts will become more frequent and intense

DEFINITION: From the many definitions of drought, the one chosen here is the situation where there is no rainfall for an extended period.

CLIMATE CHANGE: Climate change intensifies the weather extremes, both high and low. Longer periods with less rainfall are to be expected even when the total (annual or seasonal) rainfall is increasing.

There are no good methods available to project changes in drought extremes. One approach is to analyse what will happen when the total amount of rainfall is lowered by 10%, removing it from the lowest rainfall days. This will lengthen the dry periods:

Return Period	**longest consecutive number of dry days (baseline)**	**longest consecutive number of dry days (-10% rain)***	**percentage increase**
2	12.6 days	20.1 days	60%
5	18.6 days	28.0 days	51%
10	23.4 days	33.5 days	43%
20	28.7 days	38.8 days	35%
50	36.8 days	46.0 days	25%
100	44.0 days	51.5 days	17%

* for the Bauerfield data used in the analysis, this corresponds to 1.3mm less rain on the days that it rains (when the rain is less than 1.3mm, it is lowered it to 0, turning it in a dry day).
(source: SimCLIM 2013)

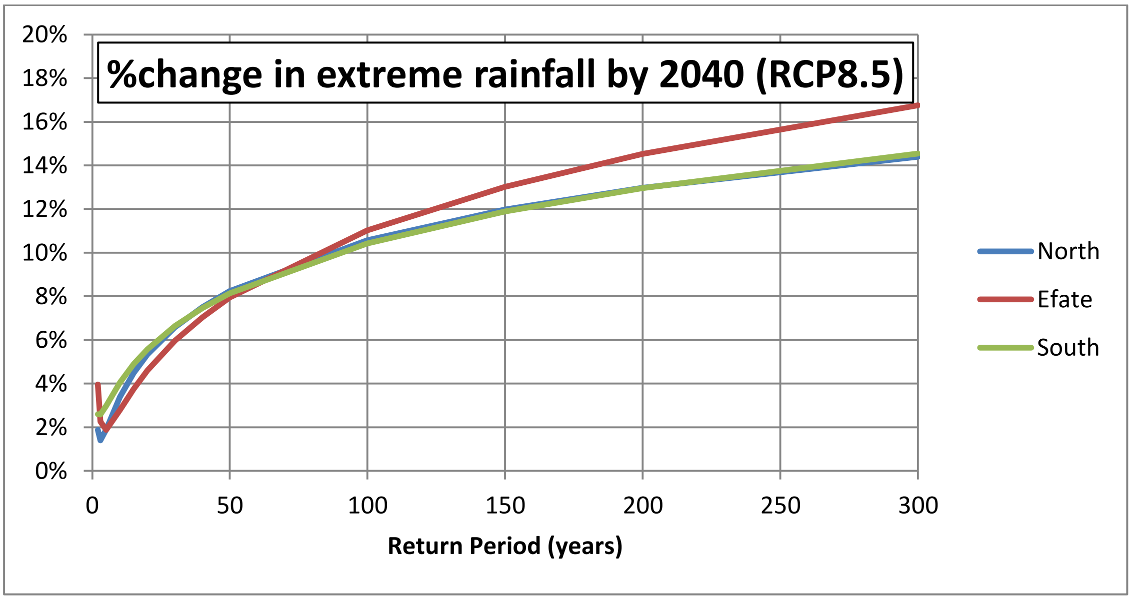
IMPACTS:

Sector	**Potential direct impacts**
Agriculture	Prolonged periods of drought impacts irrigation requirements and water needed for cattle; shifts to different crops might be necessary
Fisheries	Increased demand because of lower agricultural production
Forestry	Impacts might be strongly negative, leading to leaf-loss or killing trees Increased risk of forest fires
Transport	No major impacts
Infrastructure	Impact on drinking water supply
Health	Water-security issues (especially where dependent on rainwater collection) Food-security issues
Tourism	Environmental stress might deter tourists

RISK FACTOR: Climate Change, Weather: Extreme high rainfall will become more frequent and intense

DEFINITION: Episodic higher than normal rainfall events, over a few hours to days. “Normal” defined by historic events.

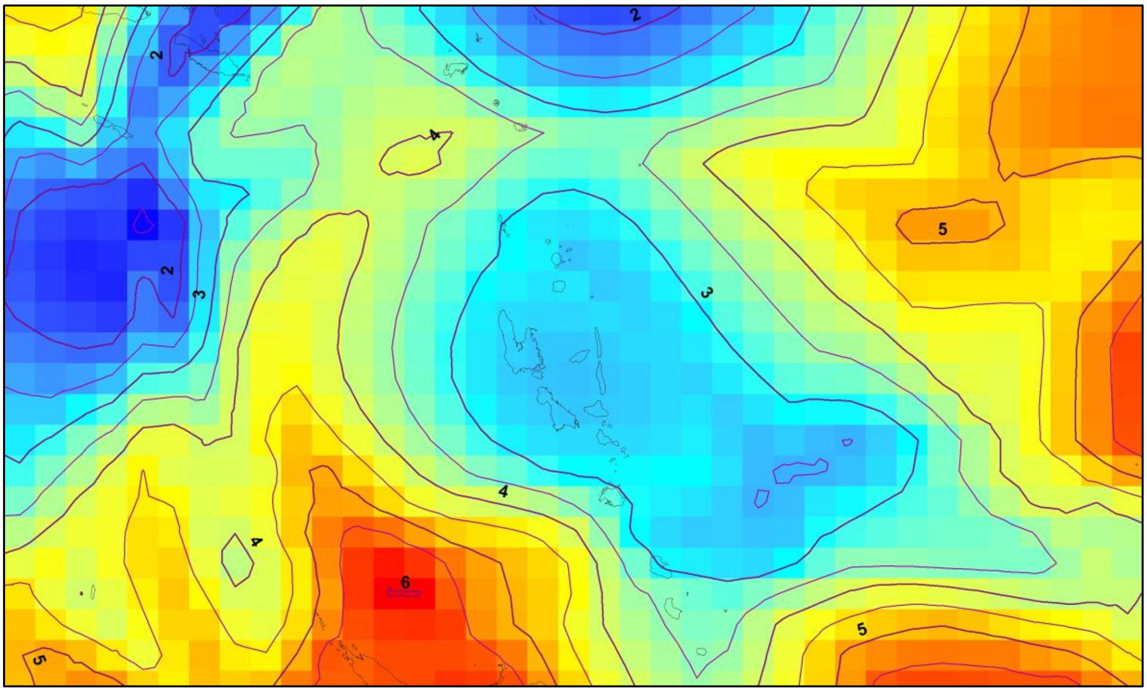
Climate change: Climate change intensifies the weather extremes, both low and high. Even in locations where average precipitation decreases, short-duration rainfall events can still become stronger (“its rains less frequently, but when it rains, it pours”). From an ensemble of 40 AR5 models, the median changes in extreme rainfall are presented below:



(source: SimCLIM 2013)

The percentages in this graph can be applied to multi-day rainfall extremes as well. For instance, the 1 in 100 year extreme rainfall event, will have increased in 2040 by 11%, both for the 1-day total, as for the more-day totals.

The following map shows the spatial distribution of the increasee in the 1 in 20 year extreme, expressed as a percentage change per degree of global warming (from a 22-model ensemble):



(source: SimCLIM for ArcGIS/Climate)

Most of Vanuatu is within the 3%/Δ°C contour-line.

The effect of climate change can also be expressed in the change in frequency (the return period) from current. A 1 in 100 year extreme event experienced now, will be more frequent in the future. The table lists how more frequent the 1-day and 5-day events in Efate will have become by 2040:

RP(year)	15	20	30	40	50	100	150	200	300
1d	1.12x	1.16x	1.21x	1.27x	1.31x	1.47x	1.59x	1.69x	1.84x
5d	1.23x	1.31x	1.44x	1.57x	1.68x	2.14x	2.51x	2.83x	3.40x

(source: SimCLIM 2013)

Thus the current 1 in 100 year, 5-day extreme rainfall event will have become 2.14 times more frequent (1 in 46.8 years) by 2040 (RCP8.5).

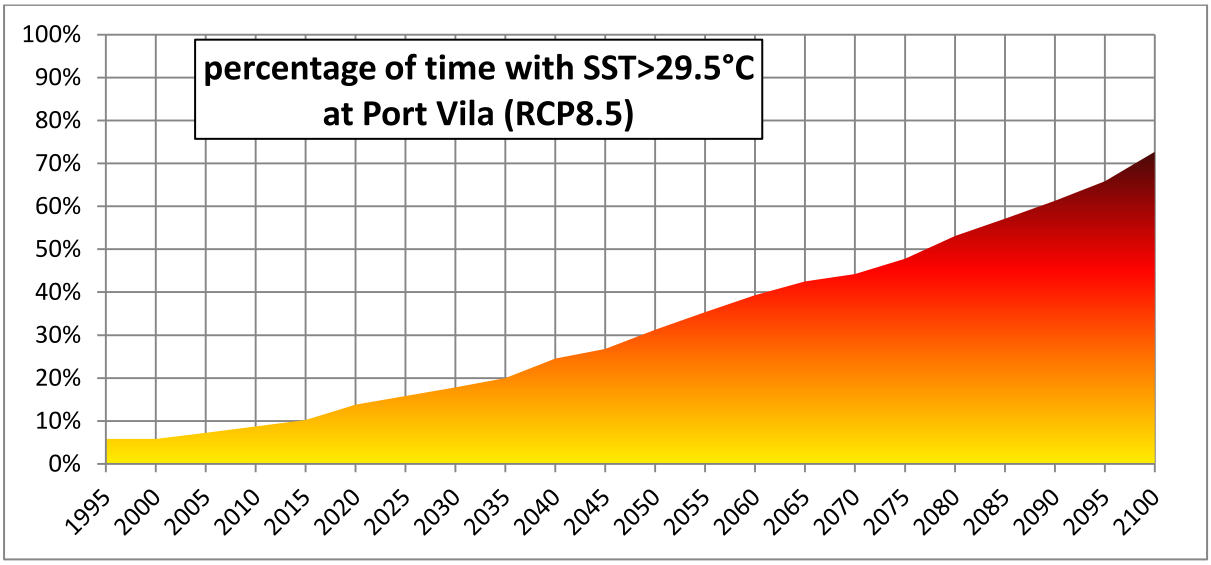
IMPACTS:

Sector	Potential direct impacts
Agriculture	Crops might be destroyed from heavy rainfall
Fisheries	Demand might increase because of impact on agriculture
Forestry	No major impacts
Transport	Roads might get flooded and/or damaged
Infrastructure	Potential increase in damage to infrastructure Higher drainage requirements Higher bridge/culvert design requirements Flooding of buildings Flooding of essential infrastructure (power, telecom, water-supply)
Health	Safety and food-security impacted Water-security (interaction of septic and drinking water systems)
Tourism	Frequent high rainfall events (or impacts thereof) might deter tourist

RISK FACTOR: Climate Change, Weather: episodic high sea surface temperatures will become more frequent

DEFINITION: El Niño/la Niña events as well as weather can cause episodic periods with higher than normal sea surface temperatures. If a period with temperatures above 29.5 is long enough, coral bleaching might occur.

CLIMATE CHANGE: Climate change is likely to increase the length of the episodes with high sea surface temperatures, making coral bleaching events much more likely. As there are no daily SST projections available, a different approach was used for the analysis. BOM observations of SST in Port Vila were perturbed for climate change, and analysed for their temperature frequency characteristics.



(source: SimCLIM 2013)

By 2040 the frequency that SST is above 29.5°C will have shifted from 5.8% to 24.5% of the time (or more than 4x more frequent). By 2070 this has risen to 44.2% of the time.

IMPACTS:

Sector	**Potential direct impacts**
Agriculture	Demand for food might increase because of the impact on the fishery through deterioration of coral reef health
Fisheries	Potential impacts from coral reef deterioration
Forestry	No major impacts
Transport	No major impacts
Infrastructure	No major impacts
Health	Food-security issues through impacted fisheries
Tourism	Tourist coming for coral might be deterred because of the poor quality of the reefs

5. Risks from geohazards

The following geohazards are present in Vanuatu:

hazard	data/information sources
Earthquakes	A global database with all recorded earthquakes (location of epicentre as well as the magnitude [from 1950]) is used to produce a density map of earthquakes around Vanuatu
Volcanoes	The location of the volcanoes is known, and risk-zones are mapped around these, identifying the areas at risk
Land/mud slides	Land/mud slides are happening when a certain slope is exceeded for specific soil compositions, when triggered by rainfall or earthquakes
Floods	Floods from extreme rainfall events or coastal inundation (from high-tide, storm-surges, tsunamis, waves, aggravated by sea level rise)
Tsunamis/storm-surges	Coastal areas prone to inundation from elevated sea levels (tsunamis, storm-surges, high-tides / combinations) are mapped
Liquefaction	Liquefaction occurs in soil with a high moisture content (usually reclaimed land) when shaken by an earthquake

Data on location and severity of past events were retrieved from various internet sources (listed per hazard). The past events form a good predictor of future disaster locations.

RISK FACTOR: Geohazard: Volcanoes

DESCRIPTION: Vanuatu has several active volcanoes. Impacts are related to the magnitude of an eruption, as well as the type (lava flows, lava bombs, ash, pyroclastic flows) and duration. Some eruptions can trigger mud- and landslides, change water flows and cause pollution of catchments (from the ash fall-out).

The map shows density of volcanic eruptions based on the explosivity index (VEI) for each eruption and the time period of the eruption. VEI is a simple 0-8 index of increasing explosivity, with each successive integer representing about an order of magnitude increase. Eruption information is spread to 100km beyond the point source to indicate areas that could be affected by either volcanic emissions or ground shaking.

(source: \Site Data\GIS\PRCC\Volcanoes)

IMPACTS:

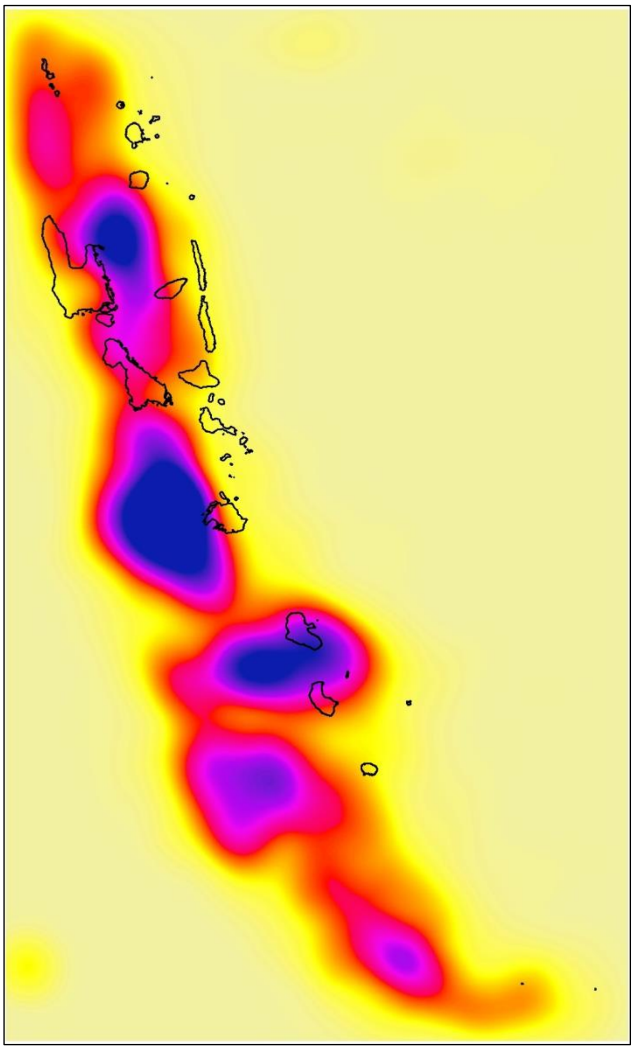
From the image it is clear that the effects of a volcano eruption are fairly localized, with some islands not being vulnerable at all, while others are highly vulnerable. The table below thus describes the local more extreme impacts.

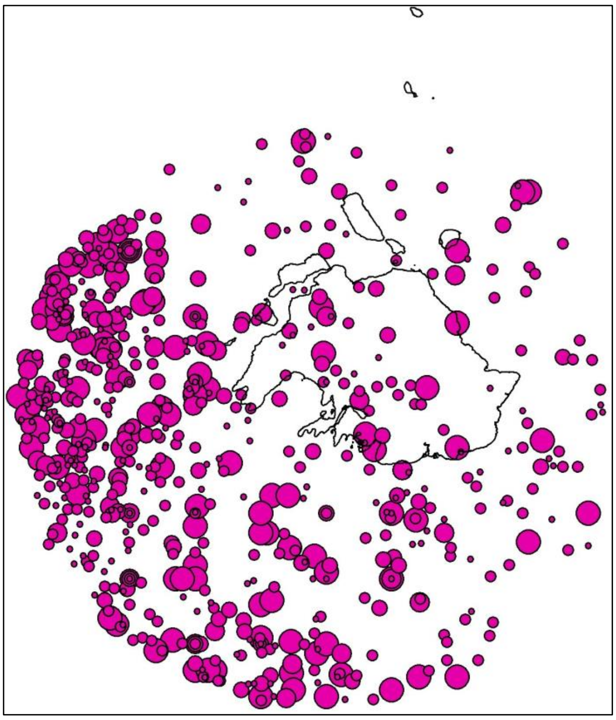
Sector	Potential direct impacts
Agriculture	Loss of crops Cattle might be impacted
Fisheries	Potential poisoning in close by areas
Forestry	Forest fires
Transport	Air traffic impacted
Infrastructure	Possible destruction of infrastructure
Health	Loss of life, water- and food security, safety (from ash clouds, lava-bombs, pyroclastic clouds, poisonous gasses, water pollution)
Tourism	Might go either way: attracted by activity, deterred by danger

RISK FACTOR: Earthquakes

DESCRIPTION: Vanuatu is positioned in a very active earthquake zone. On average, the country is hit monthly by an earthquake of at least magnitude 4. Earthquakes can trigger tsunamis, land/mudslides and liquefaction.

The image shows a density map of past earthquakes, combining location and intensity of the earthquakes. There are several major hotspots, all offshore, contributing to the risk of tsunamis.





(source: \Site Data\GIS\EQ)

Selecting all earthquake epicentres within a 50km radius around Port Vila, over the past 50 years, finds 600 earthquakes with a magnitude of 4 or more, or on average 1 every month.

IMPACTS:

The impacts of an earthquake can be diverse (i.e. triggering other hazards like landslides and tsunamis). Here only the potential direct impacts are considered (as the impacts from landslides and tsunamis are listed in their respective paragraphs).

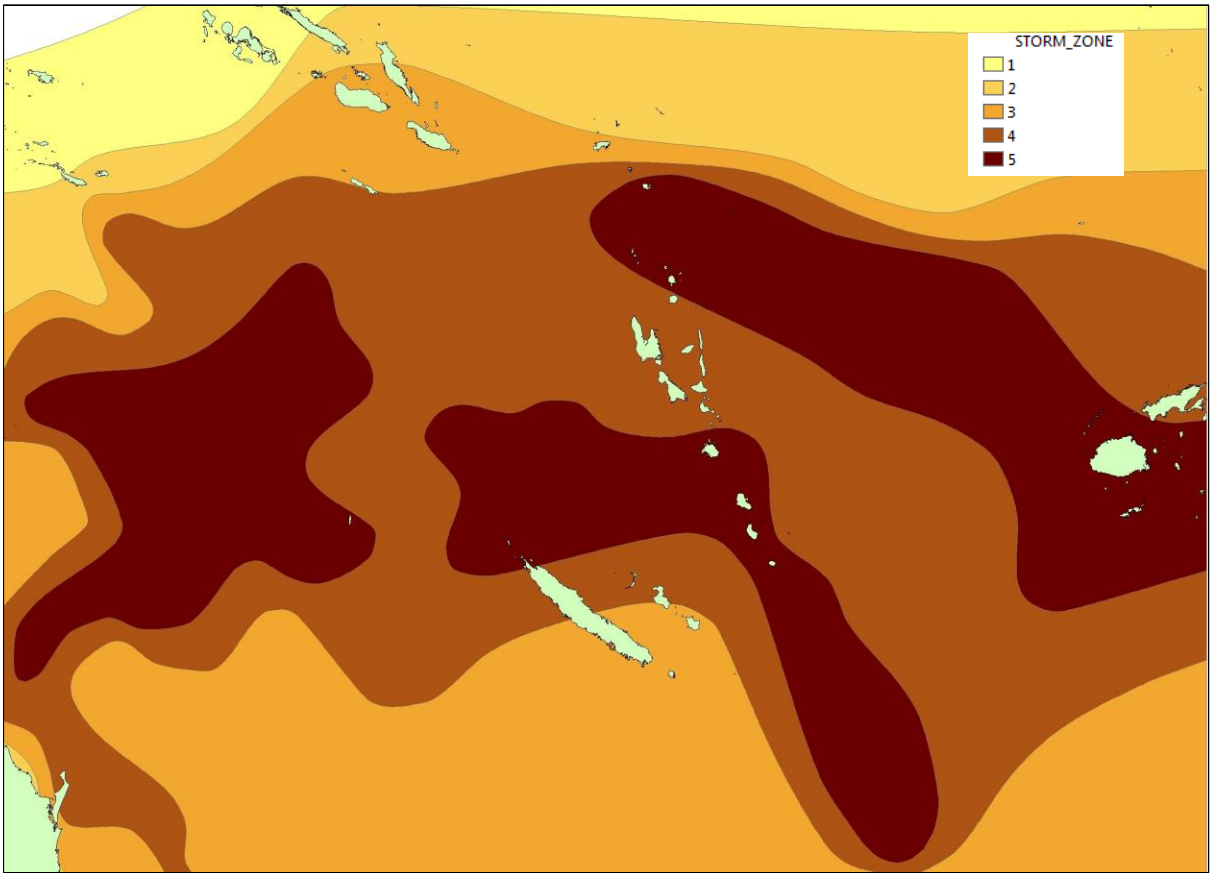
Sector	**Potential direct impacts**
Agriculture	Cattle might be impacted
Fisheries	Aquaculture may be impacted (tank breaches)
Forestry	No major impacts
Transport	Damage to road, airport and harbour infrastructure Accidents
Infrastructure	Damage to infrastructure (visible and invisible) including power- and power-distribution, as well as telecommunications
Health	Direct casualties, safety
Tourism	Might deter tourists, especially when essential infrastructure is damaged

RISK FACTOR: Flooding from coastal inundation

DESCRIPTION: Coastal flooding from sea is driven by storms/cyclones, possible combined with high tide events. The major aspects determining the inundation risk of a location is its elevation and proximity to the sea.

As there is no properly detailed digital elevation model available to model coastal inundation, only an analysis of the most important driver (storm surges) will be presented here.

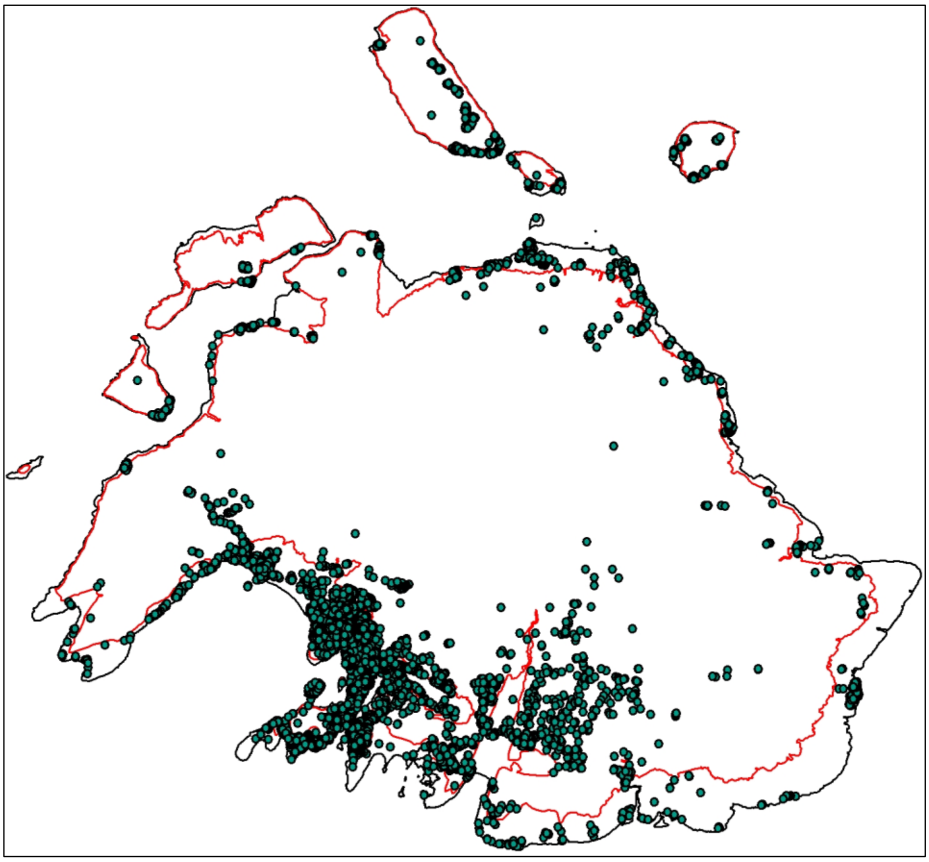
The image shows the tropical storm intensity coverage around Vanuatu.



(source: \Site Data\GIS\PRCC\Storms)

This dataset is derived from the Munich Reinsurance Company's (Munich Re) World Map of Natural Hazards. This data layer shows tropical storm intensity zones based on the five different wind speeds of the Saffir-Simpson Hurricane Scale. The Saffir-Simpson Scale is used to give public safety officials an assessment of a tropical storm's potential for wind and storm surge damage. The scale indicates probable property damage for each of the following five wind speed categories: 1) 118-153 km/h, 2) 154-177 km/h, 3) 178-209 km/h, 4) 210-249 km/h, 5) 250+ km/h (mean wind-speed over a 1 minute interval). The Storm Intensity Zone layer shows that there is a 10% probability of a storm of this intensity striking in the next 10 years (which is equivalent to a return period of 100 years).

The potential impacts from coastal flooding (regardless of the source, being tsunami, high tide, storm surge, and compounded by sea level rise), are taking place in a zone with low elevation. The current datasets are insufficient for a robust analysis, but a first order assessment can be done by identifying the zone between the 20 meter contour line (the lowest contour available) and the coastline. The image shows Efate, with properties indicated, highlighting the high risk of Port Vila. The coastline is coloured black, while the 20 meter contour is red. The area in between is potentially vulnerable for coastal inundation.



(sources: \Site Data\GIS\LANDS, \Site Data\GIS\VNSO)

IMPACTS:

As the impacts occur in the coastal zone (by definition), only the activities located in that area are considered in the table below. The floodwater will be saline.

Sector	**Potential direct local impacts**
Agriculture	Flooding with saline water will destroy many crops Cattle can be evacuated
Fisheries	Aquaculture ponds might be destroyed
Forestry	Brief periods of inundation should not cause a problem; prolonged inundation will kill trees (except for mangroves)
Transport	Coastal roads might be flooded and damaged; airports and ports might be damaged
Infrastructure	Coastal infrastructure (power plant, desalinisation plant) might be damaged
Health	Safety Food-security Water-security
Tourism	Many resorts, vacation-homes, hotels are built on the coast and are likely to be impacted

RIKS FACTOR: Flooding from extreme rainfall

DESCRIPTION: Flooding from extreme rainfall occurs from a combination of factors, where a rapid collection of water in one point (i.e. because of steep slopes) is not compensated with an equally fast (or faster) run-off and absorption of that water.

Hydrological modelling is necessary to identify the areas at risk. The model would combine (precise) elevation information (calculating slopes and overland flow paths) with extreme rainfall conditions. There is no such elevation information available.

IMPACTS:

The impacts are from fresh-water flooding, focussing on areas that are impacted, both from being submerged and from the forces of the flooding.

Sector	**Potential direct local impacts**
Agriculture	Submerging of crops with possible destruction Eroding crop areas
Fisheries	Potential impact on aquaculture (large freshwater inflow in saline areas, high sediment loads in flood waters)
Forestry	Sudden localized erosion might undermine trees (on slopes)
Transport	Damage to roads
Infrastructure	Damage to infrastructure
Health	Safety Water security (from contamination) Food security
Tourism	Negative impressions from situation

RISK FACTOR: Geohazards: Tsunamis

DESCRIPTION: Tsunamis can be generated by various events but most commonly by certain sea-floor earthquakes, which precede the tsunami event. Depending on the distance the tsunami-waves travel, there is a varying lead time, impacting the response time for people potentially affected. As Vanuatu is in an active earthquake zone, some tsunamis are generated close by, giving little time to react. When a tsunami is generated elsewhere, Vanuatu receives a warning.

Currently, there is no signage in place (to point people where to go in case of an alert), and an alarm-system (giving sound/light signals in threatened places) is also missing. This is a concern given the large numbers of short-term tourists that visit Vanuatu, who are usually not aware of any danger.

Tsunami events registered for Vanuatu since 1900:

year	month	day	location	latitude	longitude	distance	height
1901	8	9	VANUATU ISLANDS	-14.0740	167.8280	911	0
1905	3	19	MALO PASS	-15.6330	167.1830	0	0.6
1909	7	8	MALO	-15.6330	167.1830	15	0
1910	11	9	TANMAETO	-15.0830	168.0670	207	0
1961	7	23	FORARI	-17.6670	168.5170	93	1.5
1965	8	11	TONGOA ISLAND	-17.0000	168.0000	158	2.43
1965	8	13	ESPIRITU SANTO ISLAND	-15.2500	168.8300	229	2
1987	7	6	VANUATU ISLANDS	-14.0740	167.8280	0	0.1
1997	4	21	LINUA	-13.3100	166.6100	81	0
1999	11	26	AMBRYM ISLAND	-16.1200	168.1900	34	3.6
1999	11	26	EFATE ISLAND	-17.5300	168.4900	127	2.6
2009	9	29	LUGANVILLE	-15.5150	167.1880	2220	0.17
2009	10	7	LUGANVILLE	-15.5150	167.1880	288	0.1
2010	1	3	LUGANVILLE	-15.5150	167.1880	1304	0.05
2011	3	11	LUGANVILLE	-15.5150	167.1880	6521	0.54
2011	3	11	VANUATU ISLANDS	-17.7553	168.3077	6797	0.85
2011	8	20	LUGANVILLE	-15.5150	167.1880	319	0.09

Some observations:

- 17 Tsunami events in 110 years (from 1901-2011; likely incomplete records for first half of the century); 13 in 50 years (from 1961-2011) (NB. some events could be the same: 1965/8, 1999/11 and 2011/3) (NB. the 1997 event is the only one with a recorded dead-toll: 100 people were killed). Thus on average there is 1 event in every 4 to 6 years
- highest water level setup +2.43 meters

IMPACTS:

The impacts are the same as for coastal inundation from flooding, but as energy is released in a very short period, a tsunami event is likely to be more destructive.

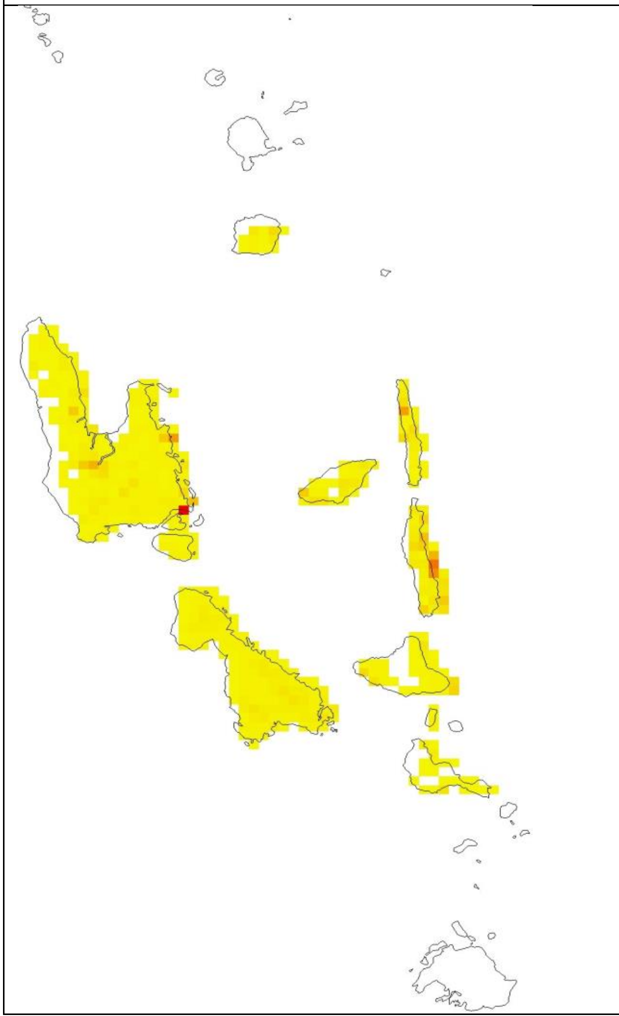
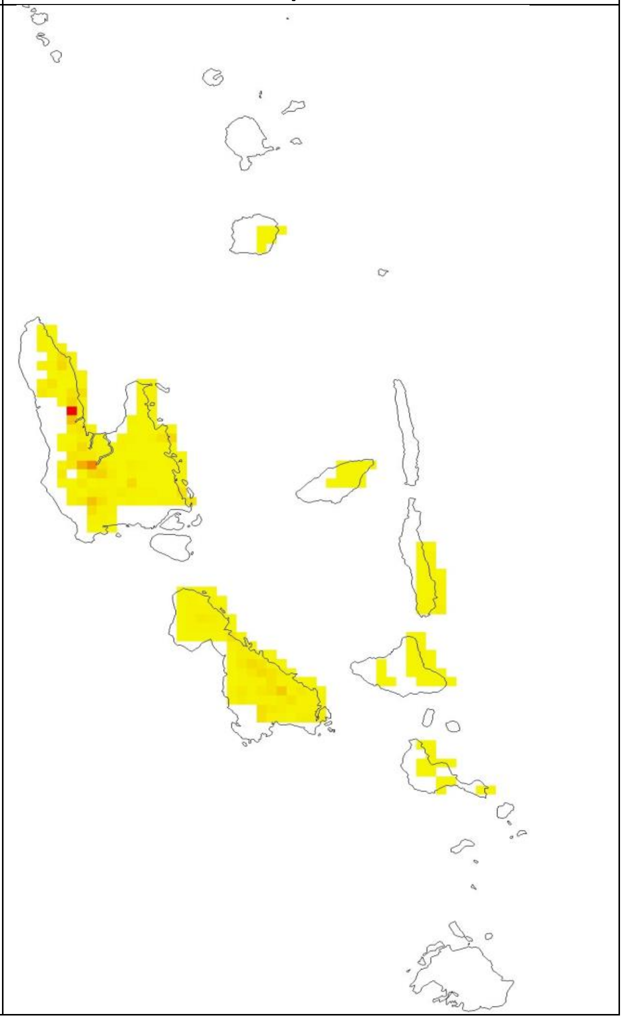
Sector	**Potential direct local impacts**
Agriculture	Crop destruction Soil erosion Soil quality issues (salinity)
Fisheries	Aquaculture impacted
Forestry	Trees uprooted
Transport	Destruction of coastal roads and ports
Infrastructure	Coastal infrastructure damaged / destroyed
Health	Safety Food-security Water-security
Tourism	High risk to day- / short-term tourists (unfamiliar with the risk, the area and the escape-routes); negative impact on image

RISK FACTOR: Geohazards: land- and mud slides

DESCRIPTION: Land- and mud slides are caused in terrain with certain combinations of slope, soil-composition and moisture content. A mudslide is only different in the material that is sliding (much higher water content). A lahar is a large-scale landslide, often caused by a building crater-lake from which one of the walls collapses. Lahars can also be initiated by loose and friable volcanic material being mobilized on the slopes of a volcano by an extreme rainfall event. These can occur on Vanuatu.

Landslide modelling is necessary to find potentially impacted areas, using slope and soil information, as well as information on trigger-events (rainfall, earthquakes). This is outside the scope of the study.

The GRID dataset contains physical exposure areas on a global scale, split between landslides caused by rainfall and landslides cause by earthquakes. Zooming in on Vanuatu provides the following images:

Landslides from Rainfall	**Landslides from Earthquakes**
	

(source: \Site data\GIS\GRID\Landslides\)

The images suggest that there is a misalignment between the data-grids and the coastal boundaries, as the west coast of Santo seems to be “safe” while it experiences regular landslides (pers. comm. C. Bartlett).

IMPACTS:

Landslide effects are very localized. The following impacts could occur at the landslide location.

Sector	**Potential direct local impacts**
Agriculture	Loss of crops Soil erosion
Fisheries	Reef systems impacted by sediments from mud and debris
Forestry	Uprooting of trees
Transport	Roads can be covered/damaged; potential casualties
Infrastructure	Less likely to be in areas with slopes, but vulnerable when it is
Health	Safety i.e. injuries or loss of life
Tourism	Negative impact on image; potential casualties

RISK FACTOR: Geohazards: liquefaction

DESCRIPTION: Liquefaction is the process whereby the water in a soil separates from the particles by vigorous shaking from an earthquake. This dramatically lowers the soils capacity to support infrastructure, like buildings or roads.

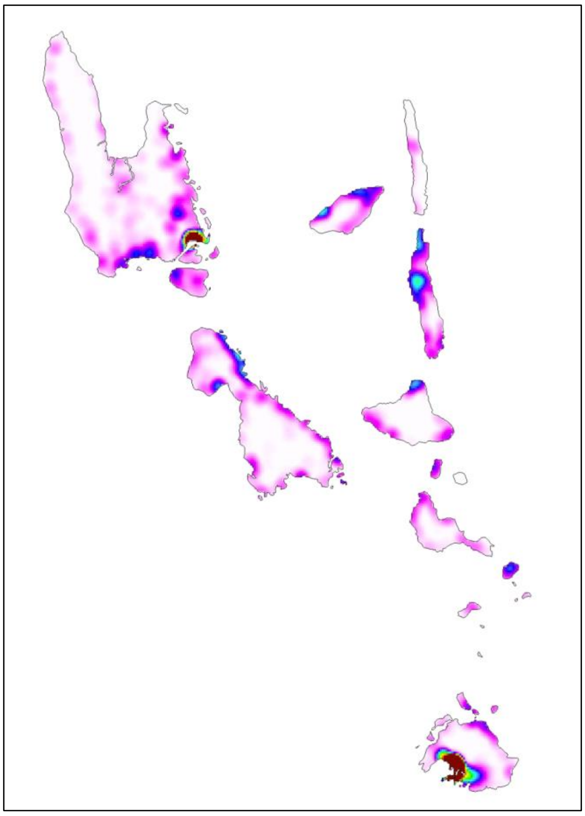
There is no data available that identifies locations in Vanuatu that are vulnerable for liquefaction.

IMPACTS:

The extent of the impacts of liquefaction is determined by the type of area that is prone to the phenomenon.

Sector	**Potential direct local impacts**
Agriculture	Crops might be damaged
Fisheries	No major impacts
Forestry	No major impacts
Transport	Roads might be damaged
Infrastructure	Infrastructure in the area might be damaged
Health	Safety
Tourism	No major impacts

6. Other risk factors



RISK FACTOR: Socio-economic: population distribution

DESCRIPTION: Risks from climate change and geo-hazards express themselves most where people live. A database of all properties, location and number of inhabitants is available and used to create a density map. The map can be used in combination with the other hazard maps to identify hotspots.

The map shows the relative population density for some of the islands.

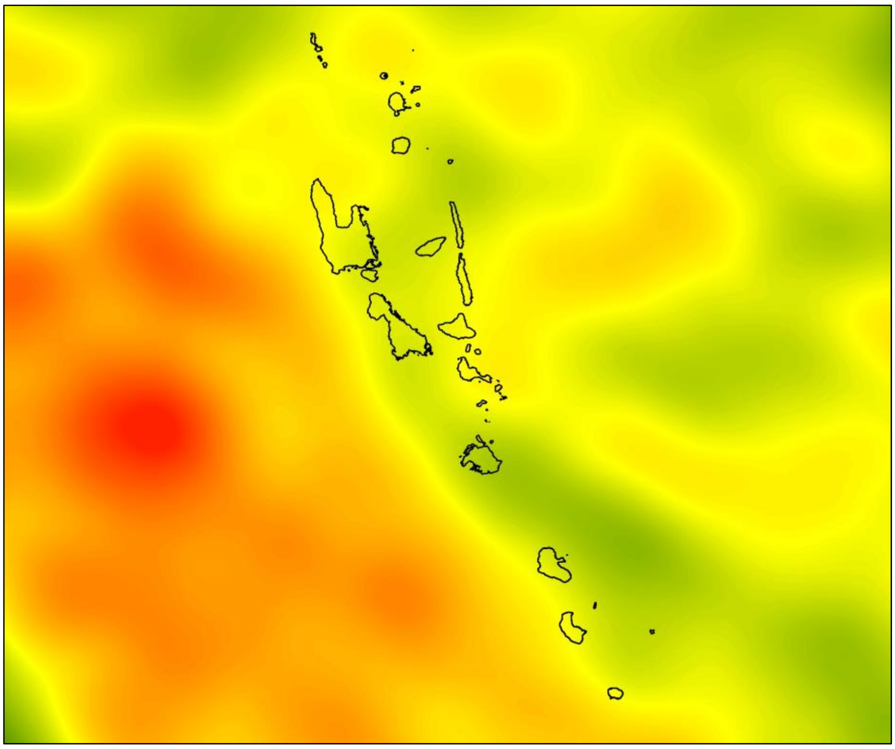
Two major population centres are visible. Most people are also clearly living close to the coast, making them more vulnerable to tsunamis and coastal flood events, as well as sea level rise.

(source \Site Data\GIS\VNSO)

RISK FACTOR: **Tropical cyclones**

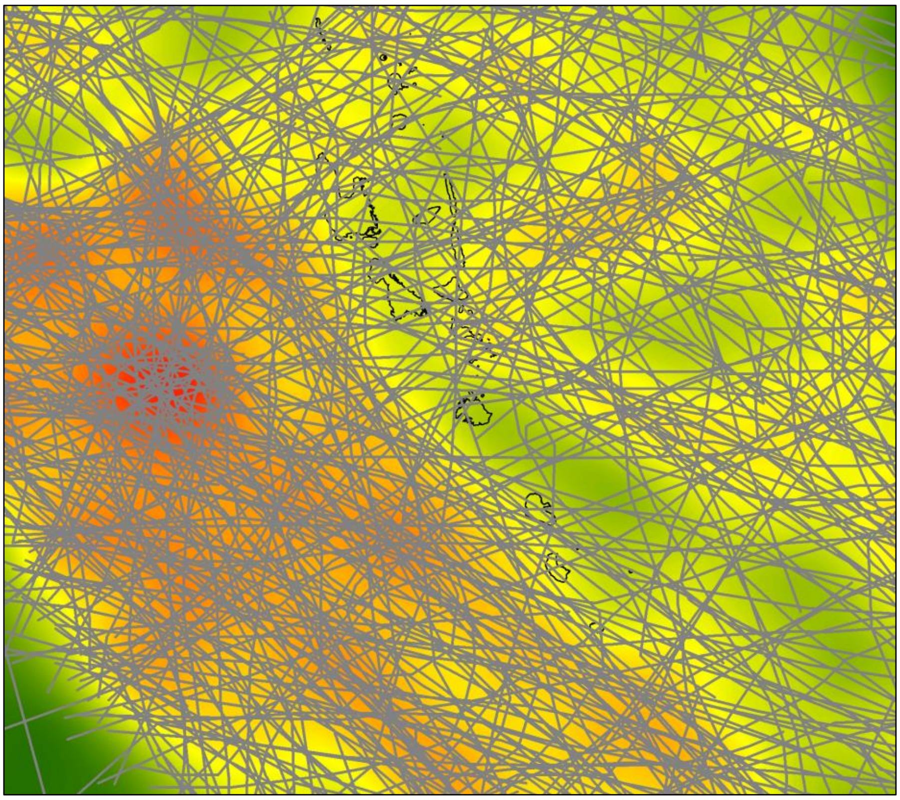
DESCRIPTION: Tropical cyclones are a major risk factor for Vanuatu, but not impacted by climate change, and also not a geo-hazard, so technically not part of this analysis. Nevertheless, data on cyclones has been collected during this assessment, and is presented here.

The image shows the track-density of storms (weighed with the wind speeds) in the area around Vanuatu. The highest track density is west of Vanuatu. The cyclone-eyes seem to avoid the land areas, but as cyclones extend quite a bit from their eye, this does not mean that the impacts would be lower on Vanuatu than in the surrounding area.



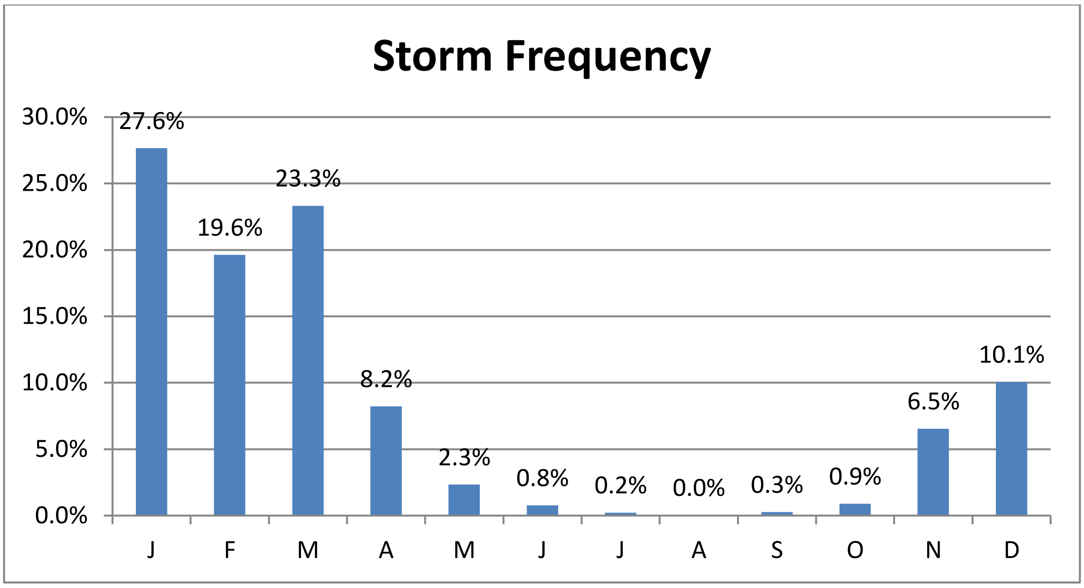
(source: \Site Data\GIS\PRCC)

To show how the cyclones “avoid” the islands, the same picture is presented with the tracks overlaid:



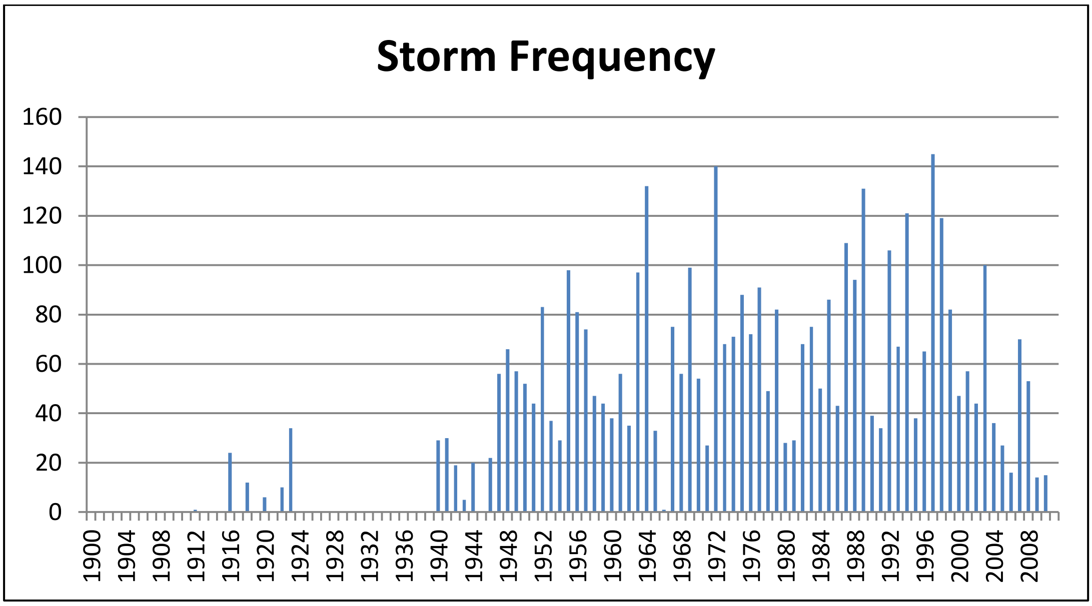
(source: \Site Data\GIS\PRCC)

The following statistics were generated from the selected cyclone tracks, showing occurrence frequency over the months (this if for are all storms occurring in an area 5 degrees around Vanuatu):



Most storms (~70%) occur between January and March.

The trend over the years looks like:



Records before 1960 contain significant gaps. There does not seem to be a trend in the storm frequency, supporting the current view that climate change is unlikely to change the frequency of storms in the South Pacific.

7. Conclusions

The risk profiling reveals important insights in the relative priority of the various risks from climate change and geo-hazards. The risks from the geo-hazards are well-defined, and their extent and impacts are known. Moreover, as these risks will not change over time, existing coping mechanisms only need to adjust for aspects like changes in land use and population.

The situation with the risks from climate change is different. Data and science is developing continuously and uncertainties in some areas are still quite high. This places some challenges on policy development and planning.

The following three results from the risk profiling are the most important:

a) The change in annual precipitation is close to 0 (no change) but carries a large uncertainty

By 2040, only half the models project a change between ca. -10 to 10%, while the other half is outside this range. For 2070 the range has increase to ca. -25 to 20%. As the adaptation strategies for less rain differ from those that plan for more rain this presents a challenge to the planners.

However, this uncertainty should be put into perspective with the yearly variation in total rainfall: the long term average rainfall for Efate is 2400 mm/year with a standard deviation of 675mm/year, or almost 30%. The seasonal changes suggest that the wet season will become slightly drier, while the dry season becomes slightly wetter. The differences of the climate change effect between the islands are much smaller than the variation over the year or between the various climate models.

b) Coral reefs are double hit by ocean acidification and coral bleaching

Because of the unresponsiveness of the global community, ocean acidification is not going to stop or reverse in the foreseeable future, putting a huge strain on the health of the reefs. Moreover, Vanuatu is already in an area where the SST is hovering close to the trigger-temperature for coral-bleaching (29.5°C), and coral-bleaching episodes are highly likely to be extended dramatically because of the increases in sea surface temperatures. This is going to deteriorate the existing reefs, decreasing their attractiveness for tourism, their ability to be a niche for fish as well as their contribution to Vanuatu's coastal defence.

The lack of management of the coral reefs, causing degradation and over-use from human activities is exacerbating the impacts from climate change.

c) Local sea level rise is dramatically higher than previous projections

Projections from PCCSP for Vanuatu yield 63cm by 2090 under the worst scenario. This is based on results from the 4th Assessment Report (IPCC) and does not take into account local effects, including vertical land-movement. When using information from AR5, combined with local effects, including a sinking of -4.8 mm/year, the projection for 2100 is 159cm for the worst scenario (RCP8.5 with high climate sensitivity) for Port Vila.

What is important to remember is that SLR does not stop at the time horizon (2090 or 2100), but will continue, even if atmospheric CO_2 levels stabilize, as the heat-exchange between atmosphere and ocean is delayed significantly. Thus planning for an extreme increase of sea level now, avoids a continued updating and changing of any adaptation put in place later.

8. Discussion, recommendations and gaps

During this assessment several observations were made that warrant a response. The observations are listed below, each with a recommendation.

Observation: No disaster database exists

An important aspect of disaster risk reduction and management is the discrepancy between the probabilistic theory of an event happening at some location sometime in the future, versus how often the events actually happen and what impacts they have. The theoretical estimates are partly improved by better understanding and modelling of what makes these events happen, and partly by using past events as predictors of future events.

Especially the step from disaster event to impacts (how many casualties from an earthquake), will benefit from a proper recording of all disaster impacts. At the moment there is no single database or data-kiosk where this information is monitored, maintained or stored.

Recommendation: Create a disaster database

DESINVENTAR (http://www.desinventar.net/) is free software that comes with training, and supports the recording, reporting and analysis of disaster events. It has been developed from a user's perspective and is in use by more than 40 countries. By mainstreaming DESINVENTAR in the various ministries, Vanuatu would get a powerful tool to guide disaster risk reduction and management, and support for the policy and planning development.

Observation: There is no Second National Communication

Under the Kyoto protocol agreement, all non-annex 1 countries are required to produce a National Communication. The document reports on the greenhouse gas emissions of a nation and what has been or is going to be done to reduce these. It also reports on the climate change that is already being experienced, the climate change that is expected and the impacts both have, or will have on the various sectors. Last but not least it includes adaptation options being implemented, or are expected to be needed to be implemented. The document is invaluable for planning and development with respect to climate change.

Vanuatu's Second NC should have been published but it is not yet completed. If the document had been available it would have greatly supported the analysis of sectorial impacts of the risks from climate change.

The delay in the production of the SNC now also creates an issue of no longer being up-to-date with the current science: a finished SNC would be based on the 4th Assessment Report by the IPCC, but the 5th report is just being published, and new results for climate projections are now available. NAB will have easy access to this if it updates its current licences for SimCLIM 2.5 to that of SimCLIM 2013.

Recommendation: Prioritize the finalization of the Second National Communication

Finalization of the SNC will still drive some of the analysis and development for disaster risk reduction and management. Although this report cannot benefit from the SNC, some information in the report can be put to good use in the finalization of the SNC, like the climate change results based on AR5 outputs.

Observation: Climate change projections for Vanuatu solely use the PCCSP information

The Australian PCCSP project created downscaled patterns (to 25 km resolution) for Pacific countries. Access to the results of this effort is enabled through a dedicated website. The website allows for a limited selection of emission scenarios, climate variables and time-horizons. Results are presented for a country as a whole. Countries have no other way to access the information behind the website. Currently the results are based on AR4. Plans are to release an update to AR5 outputs at the end of the year.

This setup limits the usability of the information for Vanuatu (and probably others): it would benefit from more variables, emissions and climate variables. More importantly, given the climate differences between the north and the south, Vanuatu definitely needs outputs on a provincial level, and higher resolution than 25km.

Recommendation: Use other tools as well for projecting climate change in Vanuatu

In the preparation of Vanuatu's Second National Communication, the country team was trained in the use of SimCLIM, a tool for assessing the effects and risks of climate change on a very local level. SimCLIM is still in use in some departments, and has recently been updated to the AR5 results. Vanuatu is represented on a 1km scale, and the different provinces are available as different areas. SimCLIM can also be used to analyse extreme events. It is recommended to renew the current licences, so the AR5 update can be used, and have a refresher training for a wider group in how SimCLIM 2013 can be used for policy planning and development work that is needed for the disaster risk reduction and management.

Observation: No high-resolution Digital Elevation Model exists for Vanuatu as a whole

Elevation is crucial information to properly assess the risks from flooding, both coastal inundation and from extreme rainfall. Although recently a LIDAR-dataset has been created, it 1) has not yet been released (so it is impossible to judge how well it suits the demands) and 2) only covers part of Vanuatu (probably the coastal areas with higher than average population densities). Requirements for a DEM in order to be suitable for flood-modelling are pretty stringent: high horizontal resolution (10x10 meters) and very high vertical resolution (better than 0.1 meters). Although a detailed contour-map exists, the lowest elevation is 20 meters, thus only the area between 0 and 20 meters elevation (potentially partly prone to coastal inundation) can be identified, while overland flow-paths from rain runoff cannot be determined with any precision.

Recommendation: Prioritize the creation of DEM covering the whole of Vanuatu

The creation of this DEM can be done in steps, where the first focus would be in areas with higher population densities and vulnerable infrastructure, and gradually extending this to other parts of the country. The annex “Developing a high resolution DEM” explores alternative approaches to DEM generation for specific sites and development requirements.

Observation: The change in future precipitation is highly uncertain

There is a strong model disagreement about the way future precipitation if Vanuatu will develop. Although half the models project a change by 2040 of between ca. -10 to 10%, the other half projects changes that are outside this range. This presents a challenge to planners, as adaptation strategies will be different for a drier compared to a wetter situation. Even though the inter-annual variation is about 30%, an on-going change in precipitation in either direction (up or down) will push the nation in new territory considering the amount of rainfall to expect.

Recommendation: Closely monitor rainfall on the different islands.

By keeping taps on how rainfall is developing over time, in different locations, some early warning may become available as to which direction future precipitation is going to develop. The fact that the spatial variation in rainfall across the country in very high (1140 to 4580 mm per year), means that some areas are already experiencing the amount of rainfall that other areas are going to experience in the future, and are likely to have already adapted to these amount, offering adaptation potential for other areas.

Observation: Current development projects seem to focus on areas that have a lower risk profile

With the exception of the risks from the volcanoes, all other risks identified in this assessment have impacts anywhere in Vanuatu. The impacts of the disasters linked with these risks are mostly determined by the population density and infrastructure involved, which is the more developed area. Nevertheless, most (externally funded) projects seem to focus on the least developing areas. This will not improve Vanuatu’s position as the “most risky” country in the world.

Recommendation: Focus development projects on areas where the risks are high

As the highest density of population and infrastructure is be found in just a few locations on Santo, Efate and Tanna it makes sense to focus the risk reduction and disaster management activities there. This is where it will make the biggest difference. It also allows for continuing the proven traditional ways to deal with many of these disasters in the more remote areas, most importantly those that are linked with tropical cyclones.

The terms of reference for this assessment included three specific questions that can only be answered at its completion:

What research is required to downscale the analysis and further identify the level of risk for each province or island?

> The best resolution of all information that is available (and accessible in the database resulting from this assessment) and for which that spatial delineation is relevant, is already at the level of provinces and even islands. The exception is the Digital Elevation Model, that even with the LIDAR results being released now, will not be available for all islands. An observation/recommendation to that extend can be found above.
>
> For sea level rise and for sea surface temperatures, the level of resolution is still quite coarse, but the lack of spatial diversity does not require any improvements at this time.

What is the most important meteorological variable that needs research to determine the level of risk for each island?

> The most important meteorological variable is precipitation. As is outlined in the conclusions, the uncertainty about future trends in rainfall (increase or decrease), poses a planning challenge. In addition to that, new extreme precipitation events (both for flooding and for drought) are likely to change the distribution that is based on observations, and thus projected extreme events under climate change. Given the spatial range in climate for precipitation over Vanuatu (from 1140 in Tafea to 4580mm per year in Torba), it is to be expected that there are significant local differences. Furthermore, precipitation affects the flooding hazard, further warranting additional research.

What are the options for further research and recommendations for priority projects?

These follow-up projects are recommended:

aspect	research needed
DEM+soil	A Digital Elevation Model is required for modelling the impacts of flooding, both from sea and from heavy rainfall, as well as landslides. The global DEM has a horizontal resolution of 30x30 meters with a vertical (interpolated) resolution of 1 meter, which is insufficient for most modelling. The LIDAR DEM that is being handed over to Vanuatu Government has a horizontal resolution of 1x1 meter, with 0.3 meter vertical resolution, but only covers some selected coastal areas in Vanuatu. This area needs to be extended. Furthermore, the modelling of landslides also needs soil information, including moisture content.
coral reefs	Coral reefs are crucial for the livelihoods of the people in Vanuatu. They are part of the protection against coastal flooding, home to fish that feed the communities, and an attraction for tourists. The pressures on the coral reef from higher sea surface temperatures and ocean acidification, exacerbated by

	sea level rise (health coral reef can grow with up to 5 mm/year, SLR could become larger than that), is already causing a severe deterioration. Coral reef management (focussing on removal of garbage, prohibiting artificial beaches and digging trenches as well as removal of coral) would aim at giving the coral the best chance of survival while the international community focuses on reducing and sequestering greenhouse gasses.
VLM/SLR	Vertical land movement is a process that has the same order of magnitude as sea level rise, but can either off-set or accentuate the process. Information on VLM is only available for Port Vila. Given the fact that Vanuatu is in a tectonically active area, it is to be expected that there is variation between the islands. Estimating the VLM in these locations is essential for assessing the risks from sea level rise. This is possible directly (i.e. from continuous GPS) or indirectly (from tidal records).
precipitation	Precipitation is a more complex issue than might seem from a first glance. There is significant variation in time (about 30%) and space (from just over 1100mm to just under 4600mm) in annual precipitation, while there is a strong disagreement between climate models over how precipitation is going to develop under climate change. As extreme events (floods and droughts) are being impacted by climate change more quickly and more profoundly than the annual average, efforts should be made to build a detailed, complete, reliable precipitation record in all provinces and major islands in Vanuatu.
streamlining risk information into decision making	The availability of risk information as generated through this assessment (in this report, but also in the extensive electronic library and spatial datasets) does not guarantee a proper streamlining of this information in Vanuatu decision making and disaster risk reduction. Hands-on application and support in pilot projects would highlight the barriers that prevent the streamlining and allow for the development of better interaction between the policy and the science.

Annex: Summary from PCCSP report on Vanuatu's future climate

To enable a comparison between the new results for climate change in this risk profile report (using the results from AR5 and the RCP emission pathways, downscaled to individual islands), and the ones that are produced by PCCSP for Vanuatu (using the older AR4 results and the SRES emission scenarios, for Vanuatu as a whole), a summary of the PCSSP results is given here:

1) Temperature:

	2030 (°C)	2055 (°C)	2090 (°C)
Low emissions scenario	0.2–0.6	0.3–0.7	0.5–1.3
Medium emissions scenario	0.4–1.1	0.7–1.7	1.2–2.8
High emissions scenario	0.4–1.1	0.7–1.9	1.7–4.1

The emission scenarios correspond to B1 (low), A1B (medium) and A2 (high).

For B1, by 2055, a hot day with a current return period of 20 years, will occur every year.

For A2, by 2090, a hot day with a current return period of 20 years, will occur 6 times a year.

2) Rainfall:

Average annual and wet season rainfall during the wet season is likely to increase, due to the expected intensification of the South Pacific Convergence Zone. Projections for dry season rainfall suggest a general decrease, however the model results are not consistent.

Model projections show extreme rainfall days are likely to occur more often. Under A2, by 2090, a rainfall event with a current return period of 20 years, will occur once every five years.

3) Tropical cyclones:

On a global scale, the projections indicate there is likely to be a decrease in the number of tropical cyclones by the end of the 21st century. But there is likely to be an increase in the average maximum wind speed of cyclones by between 2% and 11% and an increase in rainfall intensity of about 20% within 100 km of the cyclone centre.

In the Vanuatu region, projections also show a decrease in the frequency of tropical cyclones by the late 21st century and an increase in the proportion of the more intense storms.

4) Sea level:

	2030 (cm)	2055 (cm)	2090 (cm)
Low emissions scenario	5–16	10–27	17–47
Medium emissions scenario	5–16	8–31	20–59
High emissions scenario	3–17	7–31	21–63

5) Ocean acidification:

Under all three emissions scenarios (low, medium and high) the acidity levels of waters in the Vanuatu region will continue to increase over the 21st century, with the greatest change under the high emissions scenario. The impact of increased acidification on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure.

Annex: Statistics on hazard events in Vanuatu

Source: "EM-DAT: The OFDA/CRED International Disaster Database, www.emdat.be - Université catholique de Louvain - Brussels - Belgium"

Top 10 natural disasters in Vanuatu for 1900-2013, ranked for #Deaths.

Disaster	Date	#Deaths
Storm	24-Dec-51	100
Earthquake	21-Apr-97	100
Storm	7-Feb-87	48
Storm	8-May-99	32
Earthquake	27-Nov-99	12
Storm	16-Jan-85	9
Storm	2-Feb-72	4
Storm	30-Mar-93	4
Storm	9-Jan-92	2
Storm	25-Feb-04	2

ranked for #deaths

Disaster	Date	#Affected
Storm	16-Jan-85	117,500
Storm	25-Feb-04	54,008
Storm	7-Feb-87	48,000
Earthquake	27-Nov-99	14,100
Storm	30-Mar-93	12,005
Volcano	Dec-08	9,000
Volcano	27-Nov-05	5,000
Storm	11-Jan-88	4,700
Volcano	8-Jun-01	4,500
Flood	21-Dec-02	3,001

ranked for #affected

Natural disasters in Vanuatu for 1900-2013, sorted by damage costs.

Disaster	Date	Damage (000 US$)
Storm	16-Jan-85	173,000
Storm	7-Feb-87	25,000
Storm	30-Mar-93	6,000
Storm	12-Dec-81	1,000
Storm	24-Dec-51	250

Summary of natural disasters in Vanuatu from 1900 to 2013

		#events	Killed	#affected	Damage 000 US$)
Earthquake	ground shaking	8	12	15,105	-
	per event		2	1,888	-
	tsunami	1	100	-	-
	per event		100	-	-
Flood	general flood	2	-	3,951	-
	per event		-	1,976	-
Mass movement	landslide	1	1	3,000	-
	per event		1	3,000	-
Storm	unspecified	2	32	-	-
	per event		16	-	-
	tropical cyclone	23	171	242,573	205,250
	per event		7	10,547	8,924
Volcano	eruption	5	-	18,900	-
	per event		-	3,780	-

Source: GRID: Risks for Vanuatu:

	Tropical Cyclones	**Earthquakes**	**Landslides (EQ)**	**Landslides (Rain)**
Average modelled physical exposure per year (total x 1000)	69	136	<1	<1
Average modelled physical exposure per year (per million inhabitants)	284551	604064	311	80
Average modelled physical exposure per year (% population)	28.5	60.4	0.031	0.008
Mortality risk class (absolute)	4	3	...	3
Mortality risk class (relative)	7	7	...	6
Combined mortality risk class	6	5	...	5
Economic risk class (absolute)		3		
Economic risk class (relative)		8		
Combined economic risk class		6		
Human vulnerability class	5	4	...	10

Annex: Developing a high resolution DEM

Introduction

This annex describes additional work that has been done to investigate the possibilities to create a high resolution DEM from existing datasets. Although this is outside the terms of reference for the Risk Profiling, the fact that such a DEM is essential for assessing flood risks (from 1) coastal inundation from cyclones, sea level rise, high tides and tsunamis and 2) extreme rainfall) as well as landslides (from earthquakes and extreme rainfall) warrants this exercise.

Output examples are presented for Efate.

Current status

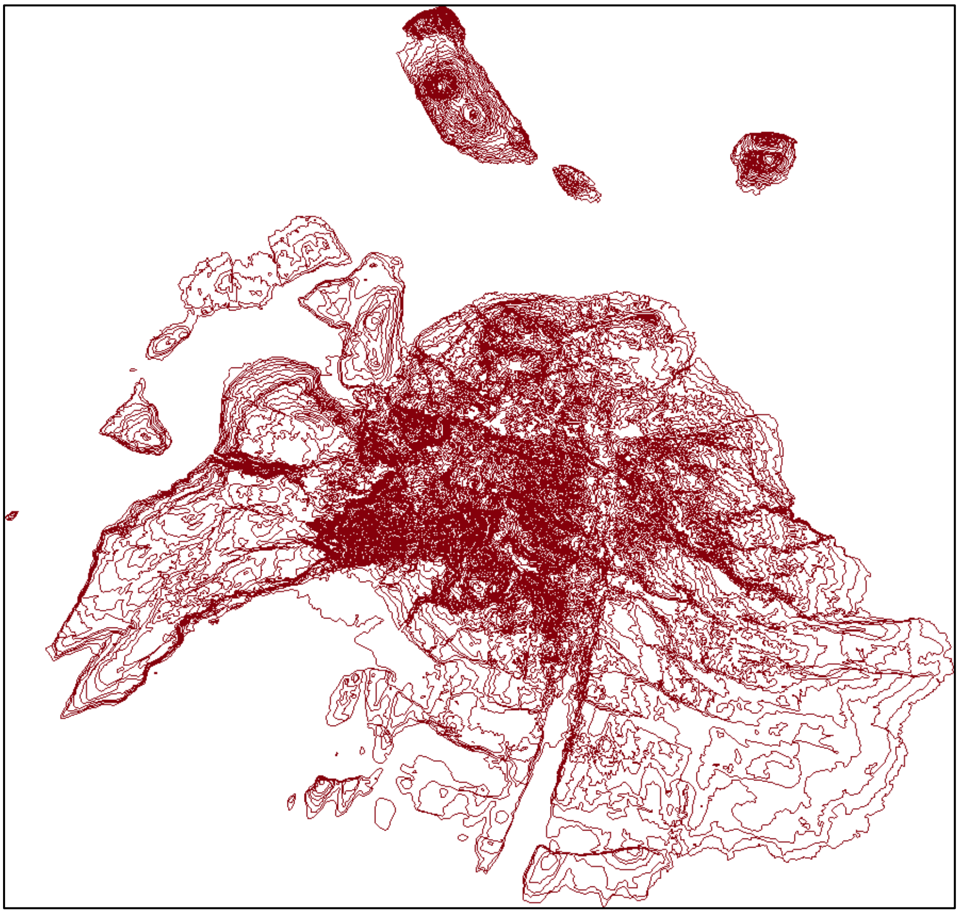
There is a DEM for the whole of Vanuatu created from a global DEM, with a horizontal resolution of 30x30 meters, and a vertical resolution of 1 meter. The absolute accuracy of the vertical resolution is much less, about 10 meters, while the relative accuracy is about 5 meters. This is insufficient for the application described above. For some coastal areas, a LIDAR generated DEM will become available in 2014, with a 1x1 meter horizontal resolution and a 20 cm absolute accuracy for the vertical resolution, and 10 cm relative. This will not deal with the landslide areas.

Option to do better

ArcMAP (from ESRI) has a tool (Topo to Raster) that can generate a DEM from topographic information. Moreover, this DEM is guaranteed to be hydrologically correct (all the waterways will drain correctly, taking into account lakes).

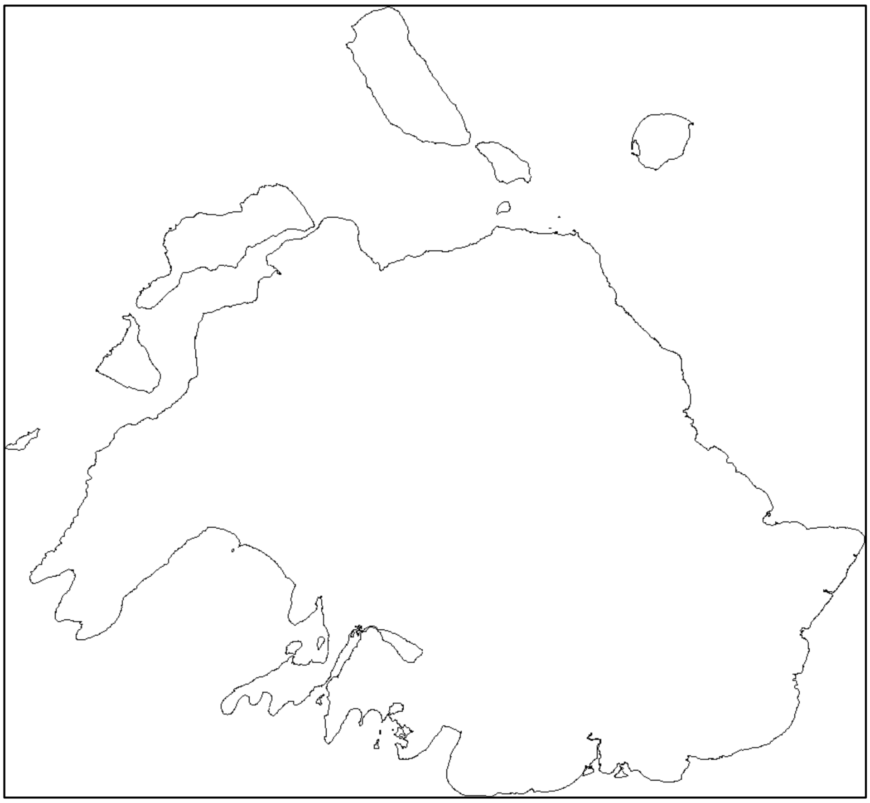
The following information that is available from LANDS (and included in the Site data-directory) can be used to build the DEM with the ArcMAP tool.

Contours:



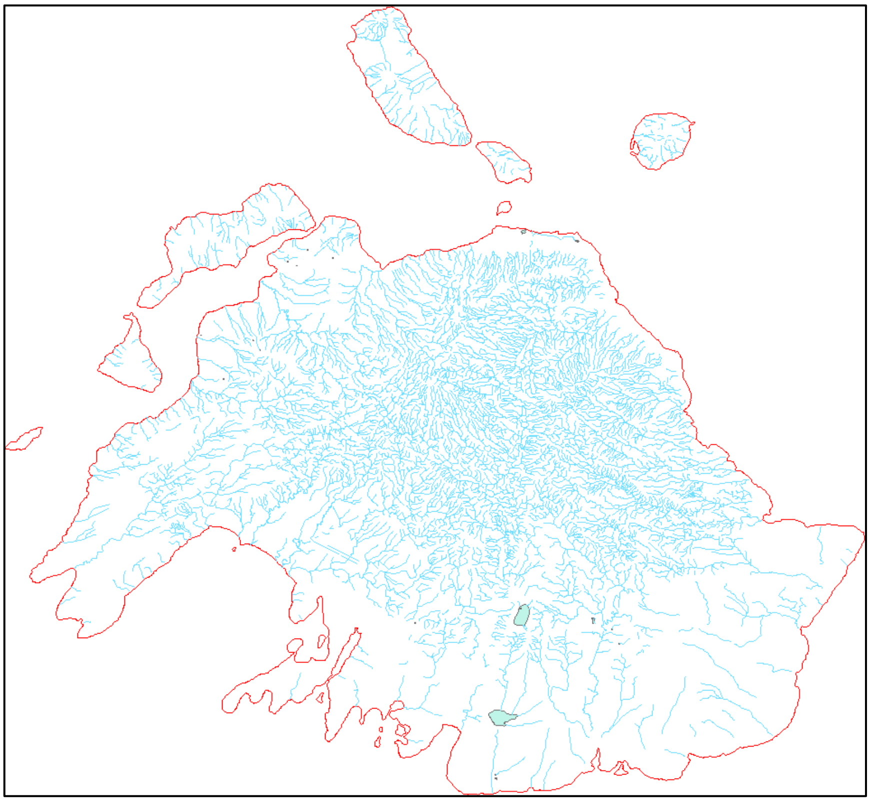
The contour set is too complex for ArcGIS to handle (too many intermediary points), so a different program (Q-GIS) was used to create a "simplified" contour-line set. The contour lines are specified for different elevations in the "zv2" attribute (0, 20, 40, 60, 80, 90, 100, …). The set also includes "29999" values, and contours with this value were excluded.

Coastline:



Although the conversion-tool accepts a "coastline" definition, the feature needs to be a "polygon" (which is a continuous, non-crossing, closed line). The coastline feature in the data-set is a "polyline" and thus cannot be used. However, it also contains elevation information, and can thus be added as another contour line (using the "slt" attribute).

Streams, lakes and boarder:



The location of streams and lakes are crucial information for the identification of steep slope areas, which are usually where streams are at the higher elevation.

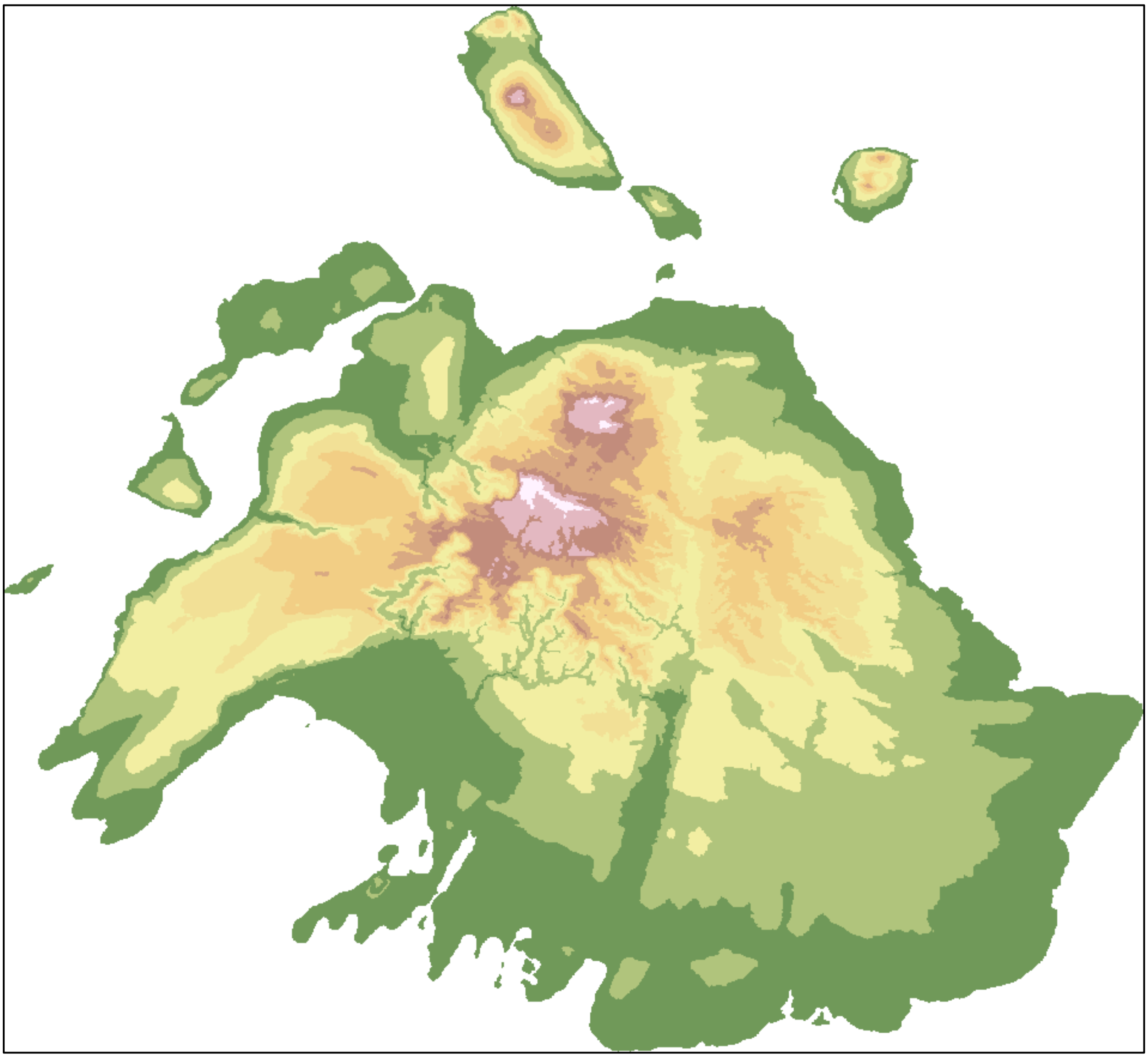
Finally the boarder information (which is a real polygon) can be used to both specify the coastline (where all the water eventually goes) and the "boarder", which stops the tool from generating values outside the island.

The other parameters provided to the tool are:

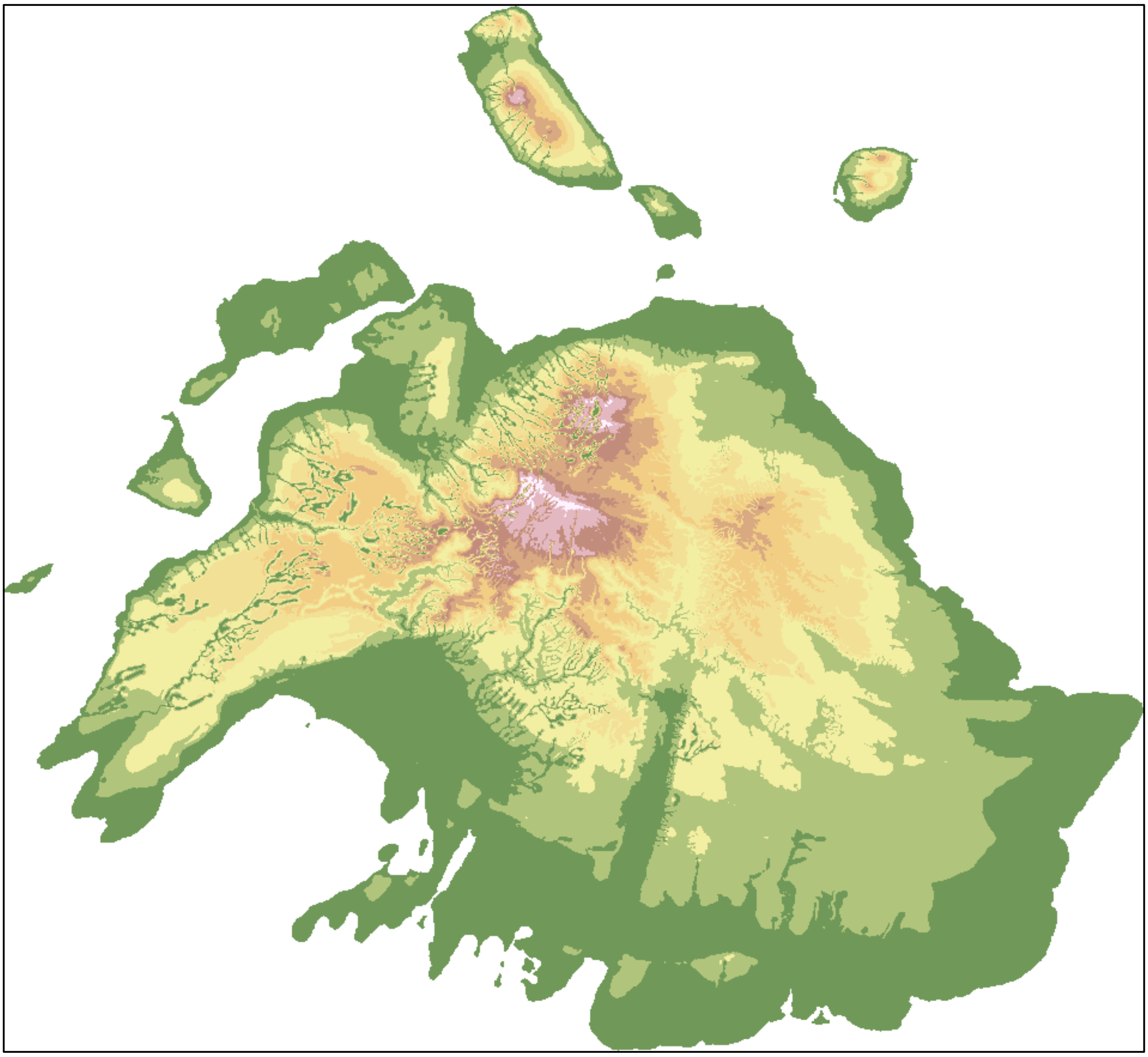
- resolution: set to 0.0001 degrees, which roughly equates to 10 meter
- lowest z-value used for interpolation: set to 0
- processing extend: set to display, when zoomed in to 1 island (as the tool cannot process the whole of Vanuatu in one go, because of the sheer amount of information)

Results

First the 30x30 meter DEM is shown in the following map:

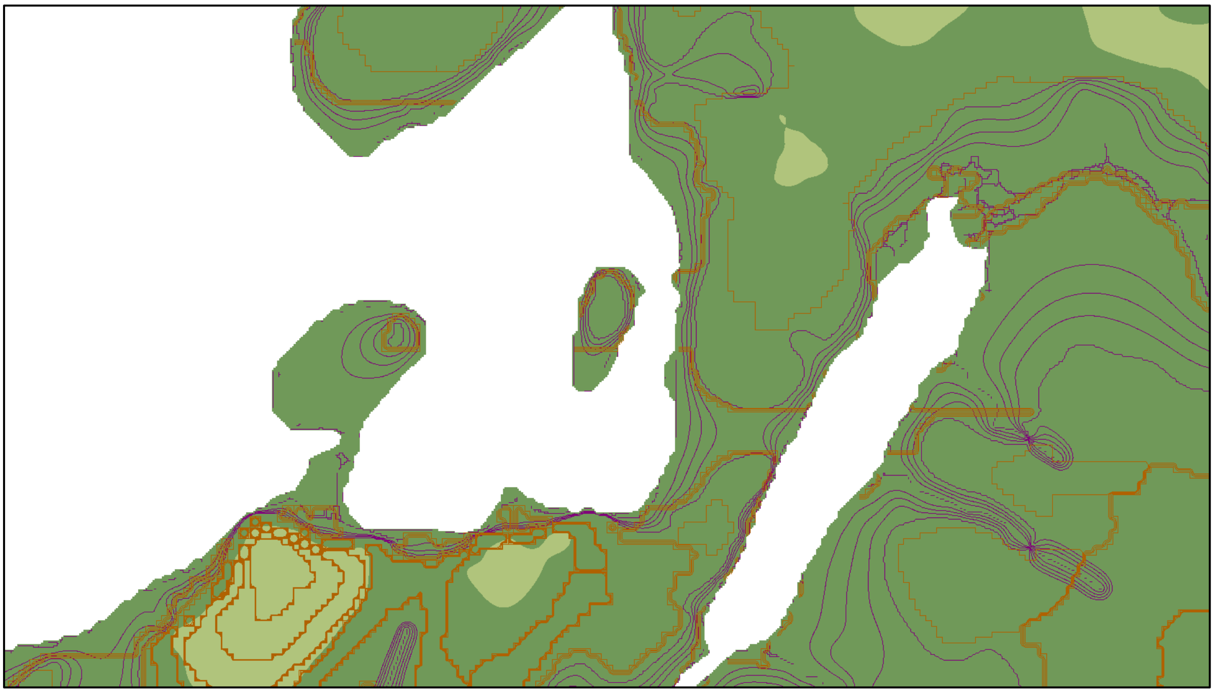


And here is the 10x10 meter DEM from the Topo to Raster tool:



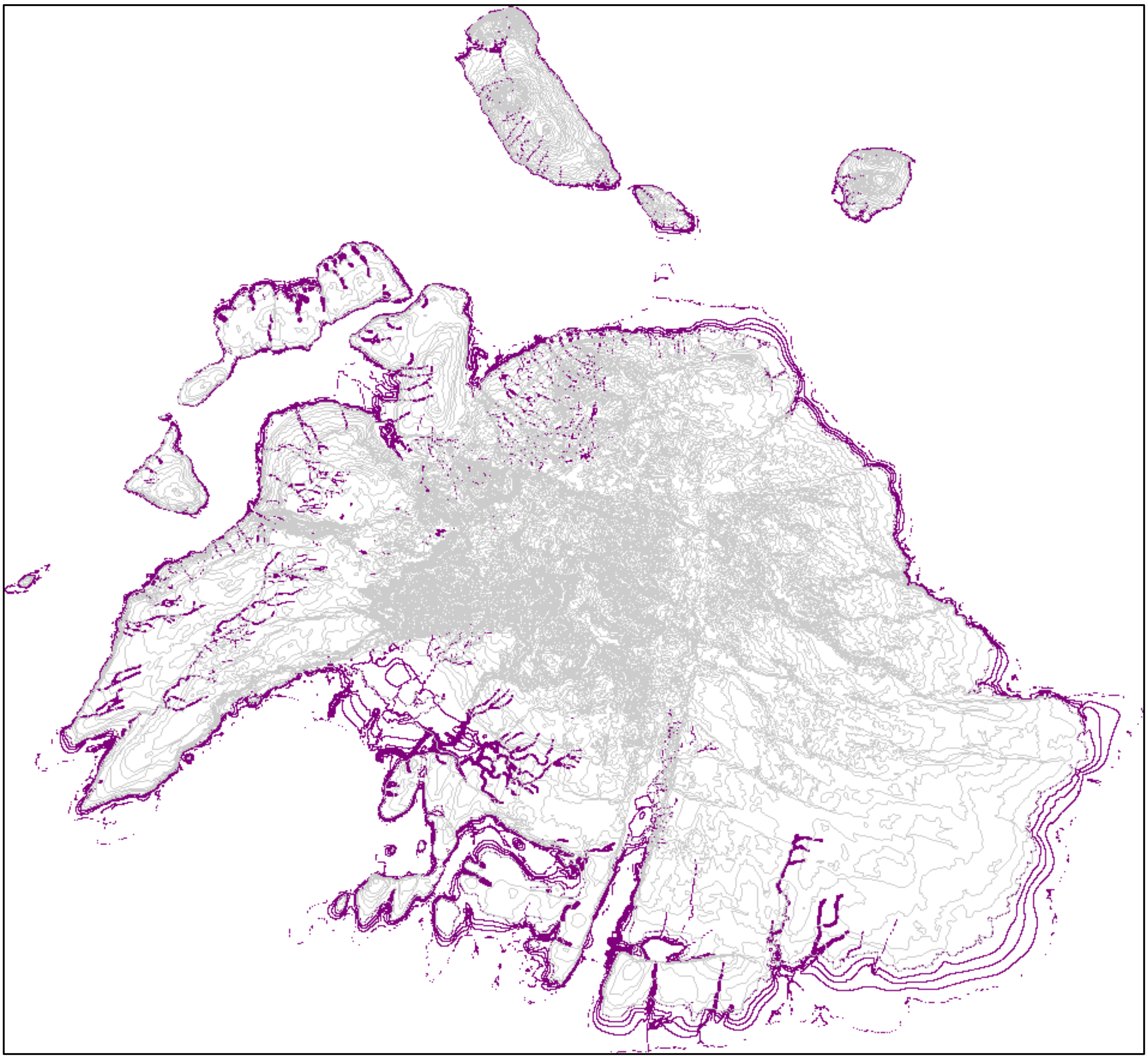
The latter shows clearly more detail especially from where the streams are.

The contour lines from the 2 DEM’s can also be compared. For this purpose the maps are zoomed in to Port Vila:



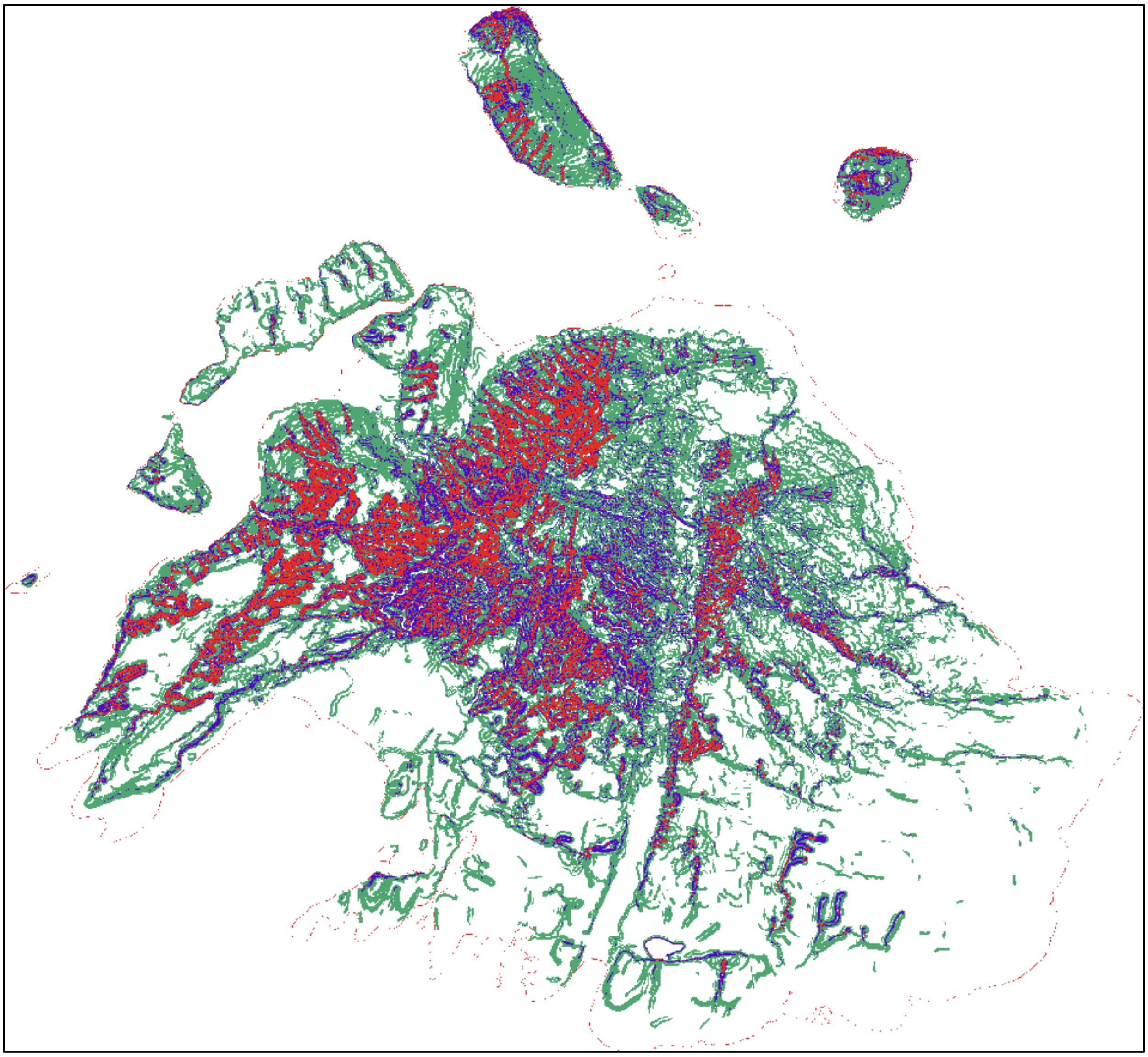
The red lines follow the 30x30 DEM, while the purple ones the new 10x10 DEM. The latter are much more realistic.

Showing the whole map of Efate, with the new 0, 5, 10 and 15 meter contour lines that were generated, combined with the existing contour lines for 20 meter and up shows the following:



This demonstrates that the new DEM contains additional information for the low-lying coastal areas as well as for some of the streams.

Applying the newly created DEM to generate slopes gives the following critical slope map:



(NB. The “vague” red outline is caused by a steep cut-off at the boundary, making the slope-calculation algorithm returning a 90° value)

Three classes are discerned:

colour	slope	landslide types (seen Annex Landslide types and classification)
red	45°-90°	falls, topples, transitional & rotational slides, spreads, rock flows & avalanches
purple	25°-45°	debris flows & avalanches, earth flows
green	5°-25°	mudflows

Annex: Landslide types and classification

The following table shows a schematic landslide classification adopting the classification of Varnes 1978 and taking into account the modifications made by Cruden and Varnes, in 1996. Some integration has been made by using the definitions of Hutchinson (1988) and Hungr et al. 2001.

<table>
<tr><td colspan="3" rowspan="3">Type of movement</td><td colspan="3">Type of material</td></tr>
<tr><td>Bedrock</td><td colspan="2">Engineering soils</td></tr>
<tr><td></td><td>Predominantly fine</td><td>Predominantly coarse</td></tr>
<tr><td colspan="3">Falls</td><td>Rock fall</td><td>Earth fall</td><td>Debris fall</td></tr>
<tr><td colspan="3">Topples</td><td>Rock topple</td><td>Earth topple</td><td>Debris topple</td></tr>
<tr><td rowspan="3">Slides</td><td>Rotational</td><td></td><td>Rock slump</td><td>Earth slump</td><td>Debris slump</td></tr>
<tr><td rowspan="2">Translational</td><td>Few units</td><td>Rock block slide</td><td>Earth block slide</td><td>Debris block slide</td></tr>
<tr><td>Many units</td><td>Rock slide</td><td>Earth slide</td><td>Debris slide</td></tr>
<tr><td colspan="3">Lateral spreads</td><td>Rock spread</td><td>Earth spread</td><td>Debris spread</td></tr>
<tr><td colspan="3" rowspan="3">Flows</td><td>Rock flow</td><td>Earth flow</td><td>Debris flow</td></tr>
<tr><td>Rock avalanche</td><td></td><td>Debris avalanche</td></tr>
<tr><td>(Deep creep)</td><td colspan="2">(Soil creep)</td></tr>
<tr><td colspan="3">Complex and compound</td><td colspan="3">Combination in time and/or space of two or more principal types of movement</td></tr>
</table>

Falls

description	"A fall starts with the detachment of soil or rock from a steep slope along a surface on which little or no shear displacement takes place. The material then descends mainly through the air by falling, bouncing, or rolling" (Varnes, 1996). Secondary falls: "Secondary falls involves rock bodies already physically detached from cliff and merely lodged upon it" (Hutchinson, 1988)
speed	from very to extremely rapid
slope angle	45-90 degrees
control factor	discontinuities
causes	vibration, undercutting, differential weathering, excavation, or stream erosion

Topples

description	"Topples is the forward rotation out of the slope of mass of soil or rock about a point or axis below the centre of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted by material upslope of the displaced mass and sometimes by water or ice in cracks in the mass" (Varnes, 1996)
speed	extremely slow to extremely rapid
slope angle	45-90 degrees
control factor	discontinuities, lithostratigraphy
causes	vibration, undercutting, differential weathering, excavation, or stream erosion

Slides

"A slide is a downslope movement of soil or rock mass occurring dominantly on the surface of rupture or on relatively thin zones of intense shear strain." (Varnes, 1996)

Translational slide

description	"In translational slides the mass displaces along a planar or undulating surface of rupture, sliding out over the original ground surface." (Varnes, 1996)
speed	extremely slow to extremely rapid (>5 m/s)
slope angle	45-90 degrees
control factor	discontinuities, geological setting
causes	vibration, undercutting, differential weathering, excavation, or stream erosion

Rotational slides

description	"Rotational slides move along a surface of rupture that is curved and concave" (Varnes, 1996)
speed	extremely slow to extremely rapid
slope angle	45-90 degrees
control factor	morphology and lithology
causes	vibration, undercutting, differential weathering, excavation, or stream erosion

Spreads

description	"Spread is defined as an extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying material." (Varnes, 1996). "In spread, the dominant mode of movement is lateral extension accommodated by shear or tensile fractures" (Varnes, 1978)
speed	extremely slow to extremely rapid (>5 m/s)
slope angle	45-90 degrees
control factor	discontinuities, lithostratigraphy
causes	Vibration, undercutting, differential weathering, excavation, or stream erosion

Flows

A flow is a spatially continuous movement in which surfaces of shear are short-lived, closely spaced, and usually not preserved. The distribution of velocities in the displacing mass resembles that in a viscous liquid. The lower boundary of displaced mass may be a surface along which appreciable differential movement has taken place or a thick zone of distributed shear (Cruden & Varnes, 1996)

Flows in rock

Rock Flow

description	"Flow movements in bedrock include deformations that are distributed among many large or small fractures, or even microfracture, without concentration of displacement along a through-going fracture" (Varnes, 1978)
speed	extremely slow
slope angle	45-90 degrees
control factor	
causes	vibration, undercutting, differential weathering, excavation, or stream erosion

Rock avalanche (Sturzstrom)

description	"Extremely rapid, massive, flow-like motion of fragmented rock from a large rock slide or rock fall" (Hungr, 2001)
speed	extremely rapid
slope angle	45-90 degrees
control factor	discontinuities, lithostratigraphy
causes	vibration, undercutting, differential weathering, excavation or stream erosion

Flows in soil

Debris flow

description	"Debris flow is a very rapid to extremely rapid flow of saturated non-plastic debris in a steep channel" (Hungr et al.,2001)
speed	very rapid to extremely rapid (>5 m/s)
slope angle	20-45 degrees
control factor	torrent sediments, water flows
causes	high intensity rainfall

Debris avalanche

description	"Debris avalanche is a very rapid to extremely rapid shallow flow of partially or fully saturated debris on a steep slope, without confinement in an established channel." (Hungr et al., 2001)
speed	very rapid to extremely rapid (>5 m/s)
slope angle	20-45 degrees
control factor	morphology, regolith
causes	high intensity rainfalls

Earth flow

description	"Earth flow is a rapid or slower, intermittent flow-like movement of plastic, clayey earth." (Hungr et al.,2001)
speed	slow to rapid (>1,8 m/h)
slope angle	5-25 degrees
control factor	lithology
causes	

Mudflow

description	"Mudflow is a very rapid to extremely rapid flow of saturated plastic debris in a channel, involving significantly greater water content relative to the source material (Plasticity index> 5%)." (Hungr et al.,2001)
speed	very rapid to extremely rapid (>5 m/s)
slope angle	20-45 degrees
control factor	torrent sediments, water flows
causes	high intensity rainfall

Complex movement

Description: Complex movement is a combination of falls, topples, slides, spreads and flows