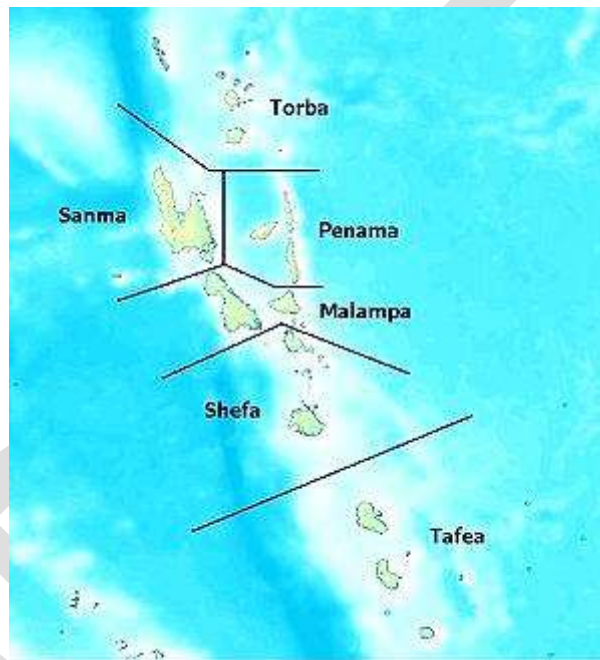


Profile of risks from climate change and geohazards in Vanuatu

Draft Report



October/November 2013

Dr Peter Kouwenhoven
CLIMsystems
Hamilton, New Zealand

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.

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. Currently there is no single, up-to-date and easily accessible document that summarises the major studies of risk undertaken to date.

This 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	<ul style="list-style-type: none">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	<ul style="list-style-type: none">this reporta 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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, what do these mean, what consequences for the bigger picture, what needs to be done for a more complete assessment?

2. Definitions and scope

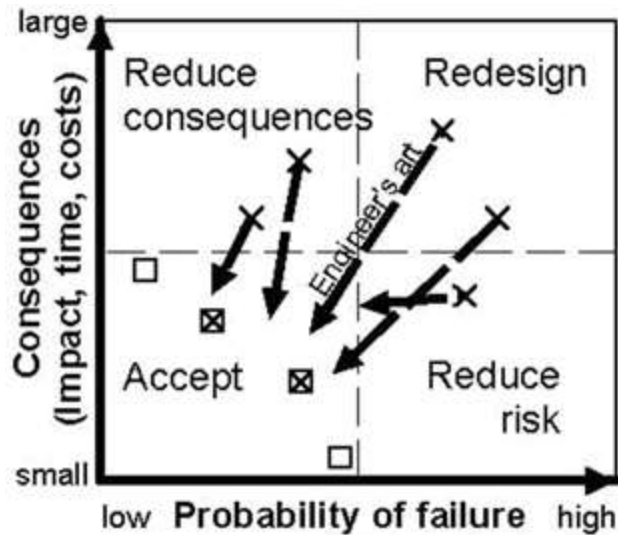
NDMO (National Disaster Management Office) in the Government of Vanuatu produced a working glossary for DRR (Disaster Risk Reduction) and DM (Disaster Management) [Final DRR Terminology.docx]. Here is a list of the definitions relevant to this report:

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

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

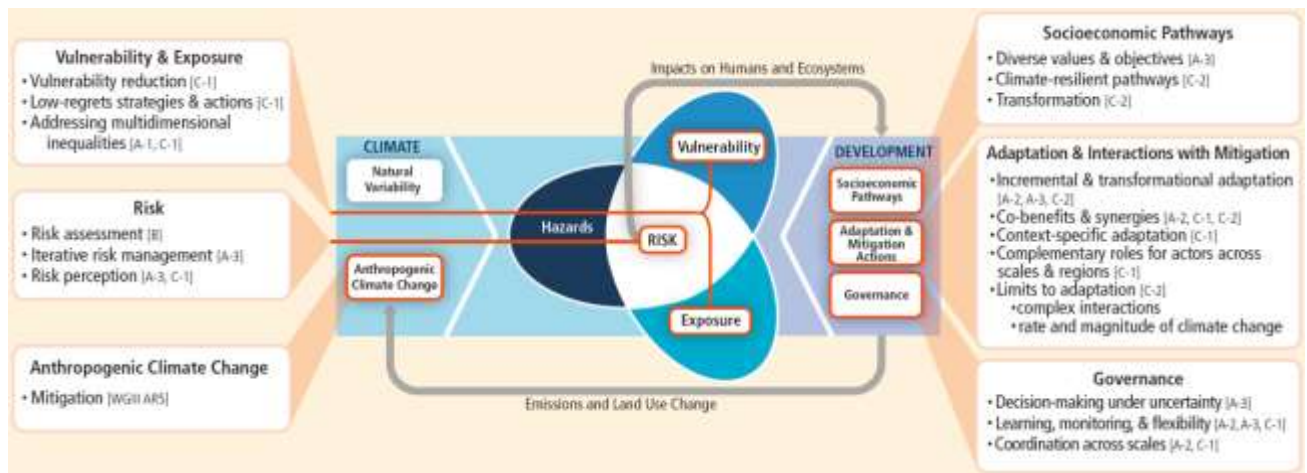
Quantitative vs. qualitative risk

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 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, 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

As the results of the fifth assessment report (AR5) by IPCC are becoming available (which are based on the CMIP5 model outputs), this risk profile uses outputs are taken from SimCLIM 3.0 for the

climate change projections, which implements these 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 3 locations, at the northern part of Vanuatu (Torba), in the middle (Shefa), and for the south (Tafea).

Risks from geohazards

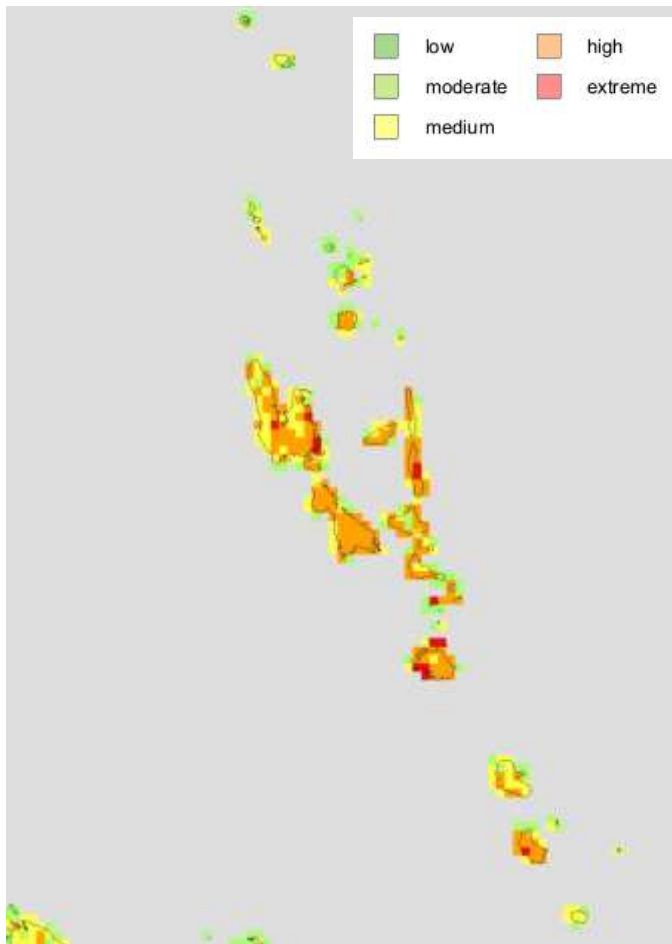
Other than the risks from climate change, the risks from geohazards are not known to change over time. As their trigger-mechanisms are still not well understood, estimates of future risks are solely based on past events (frequency, magnitude, location). New events will change these estimates.

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 in the world. Zoomed in on Vanuatu shows the following picture:



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 precipitations). 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), 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 works on 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 a slow change in average values. The change in weather expresses itself as a much faster change in extreme events.

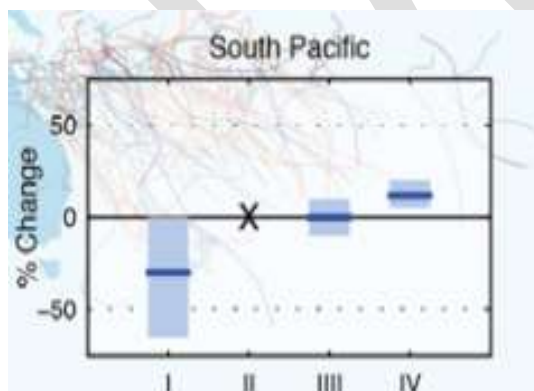
The following table lists the effects of climate change that are considered in this assessment.

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 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 IPCC are used, either through an offline tool (SiimCLIM 2.5) or through the PCCSP website.

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 3.0 (as used here) to produce these (and other) results. The PCCSP website is announced 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 3.0)

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

IMPACTS:

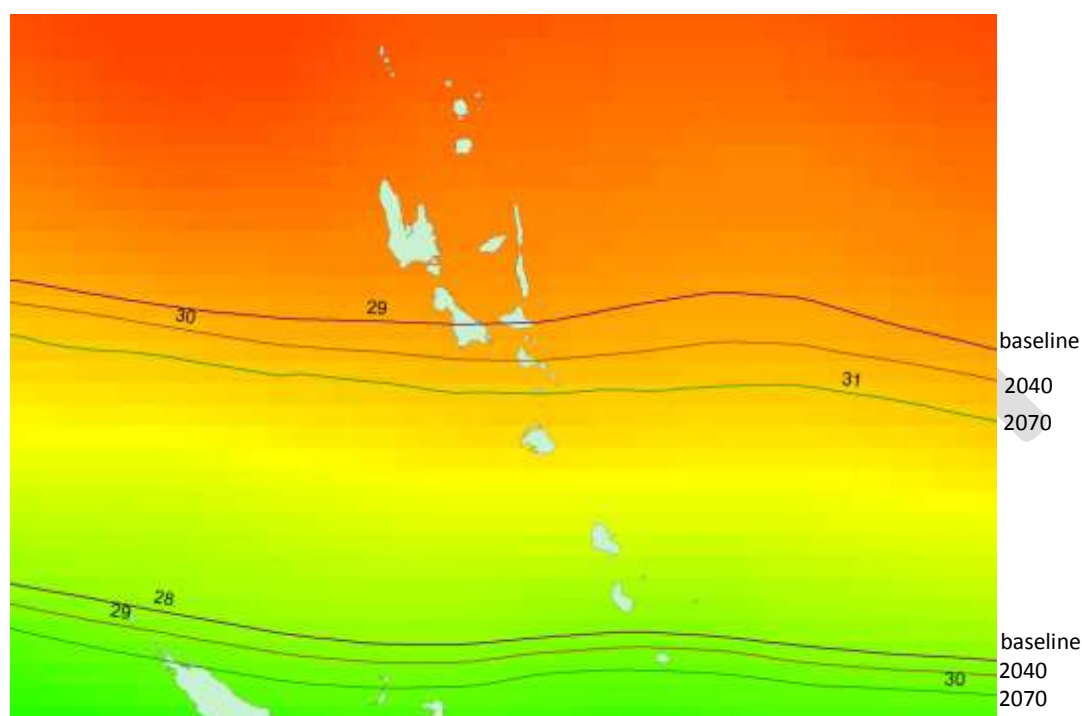
Sector	Potential direct impacts
Agriculture	Shifts in crop-seasons: all phases will happen earlier and faster Increase in water demand, both for irrigation and cattle Potentially new pests with new temperature regimes
Fisheries	May impact aquaculture (faster growth, but also quicker oxygen depletion)
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 regarding this aspect

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

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

CLIMATE CHANGE: SST will increase, both average and maximum. 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 (bottom-middle) contour-lines. The other contour-lines are for 2040 (29°C, bottom-middle and 30°C, middle-middle), and current (28°C, bottom-top and 29°C middle-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.

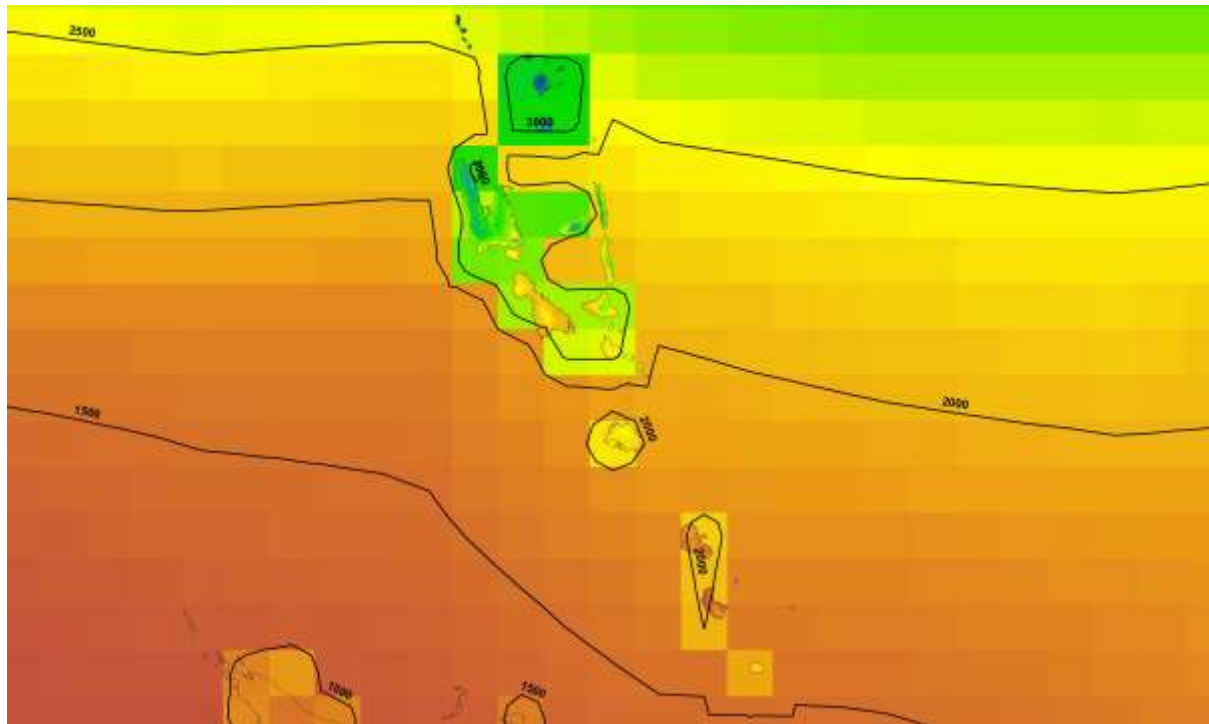
IMPACTS:

Sector	Potential direct impacts
Agriculture	Increased food demand, as fisheries is impacted negatively
Fisheries	Negative Impact from coral reef deterioration (including spawning, breeding, hiding)
Forestry	No major impacts
Transport	No major impacts
Infrastructure	No major impacts
Health	Food security issues
Tourism	Tourist 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.

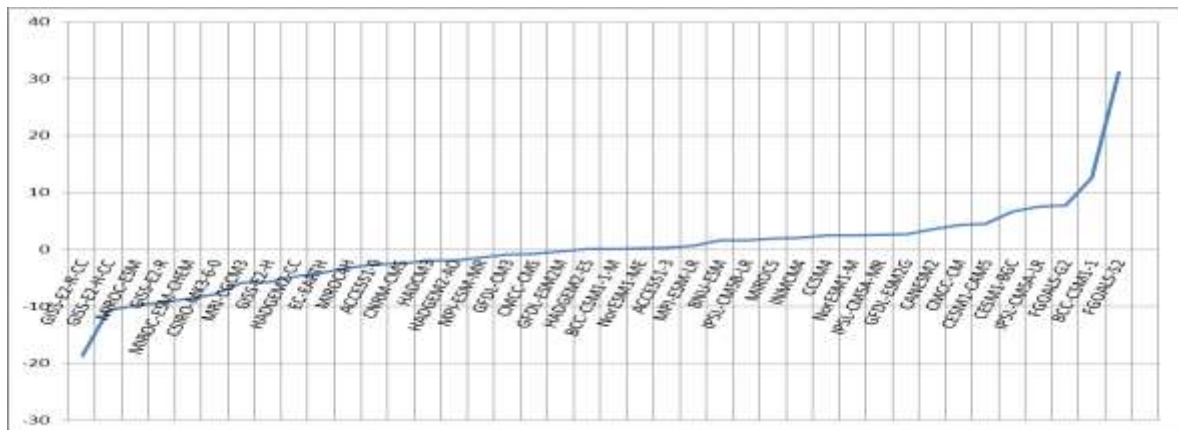
CLIMATE CHANGE: The median result from the model ensemble shows a very small change in Precipitation, from slightly positive in the North to slightly negative in the South. However, there are big differences between the models, suggesting a large uncertainty in the model-outputs. This is challenging 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	-13.1	-1.6	+11.1	-24.9	-3.0	+21.1
South	-14.8	-2.9	+12..8	-28.0	-5.4	+24.3

(source: SimCLIM 3.0)

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 $^{\circ}\text{C}$ of global warming) sorted for the different models:



(source: SimCLIM 3.0)

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.

Sector	Impacts of lower average rainfall	Impacts of 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 melt of land-ice (glaciers, Greenland, Antarctic) and changes in local ocean water temperatures (from increasing air temperatures), local air-pressure and ocean currents, the average sea level will 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 CO₂-concentrations and temperature stabilize (with the current values, sea level will continue to rise for more than 500 years, with up to 5m 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 geophysical active location, significant vertical land changes are to be expected, and 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).

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 3.0)

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	No major impacts
Forestry	Impact on mangrove areas, shifting more inland (were possible)
Transport	Coastal roads need to be relocated or change in layout
Infrastructure	Coastal operations (power plants, sewage treatment plants, sewage pipes) need redesign and possibly relocation Coastal defences needed in places
Health	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

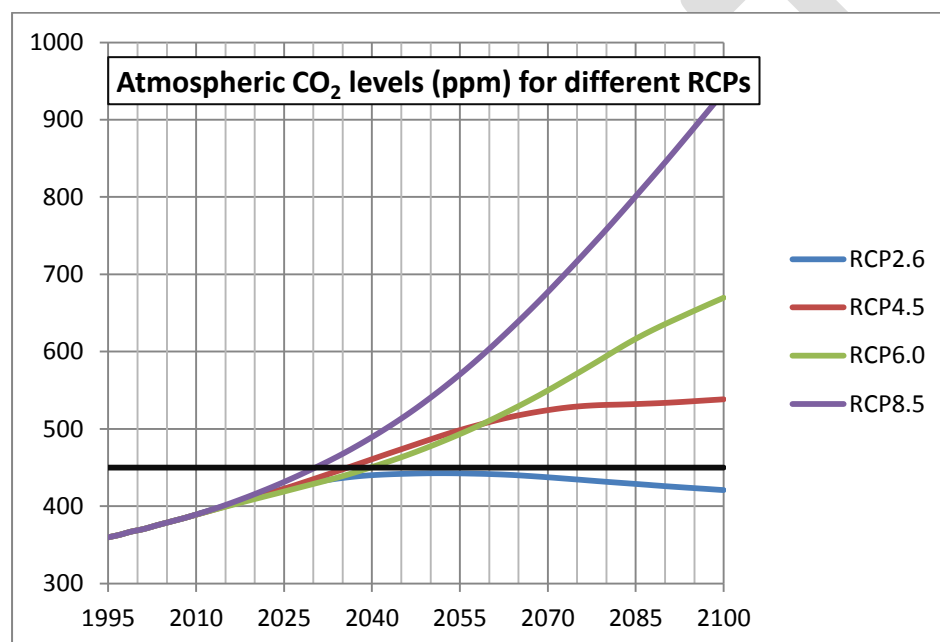
DEFINITION: Ocean acidification is the process whereby the oceans become slightly more acidic as about one-third of the CO₂ emitted in the atmosphere dissolves in the oceans. The additional

dissolved CO₂ 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 CO₂. A report of WRI (Reefs at risk revisited, Burke & Reytar, 2011), lists 450 ppm CO₂ 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

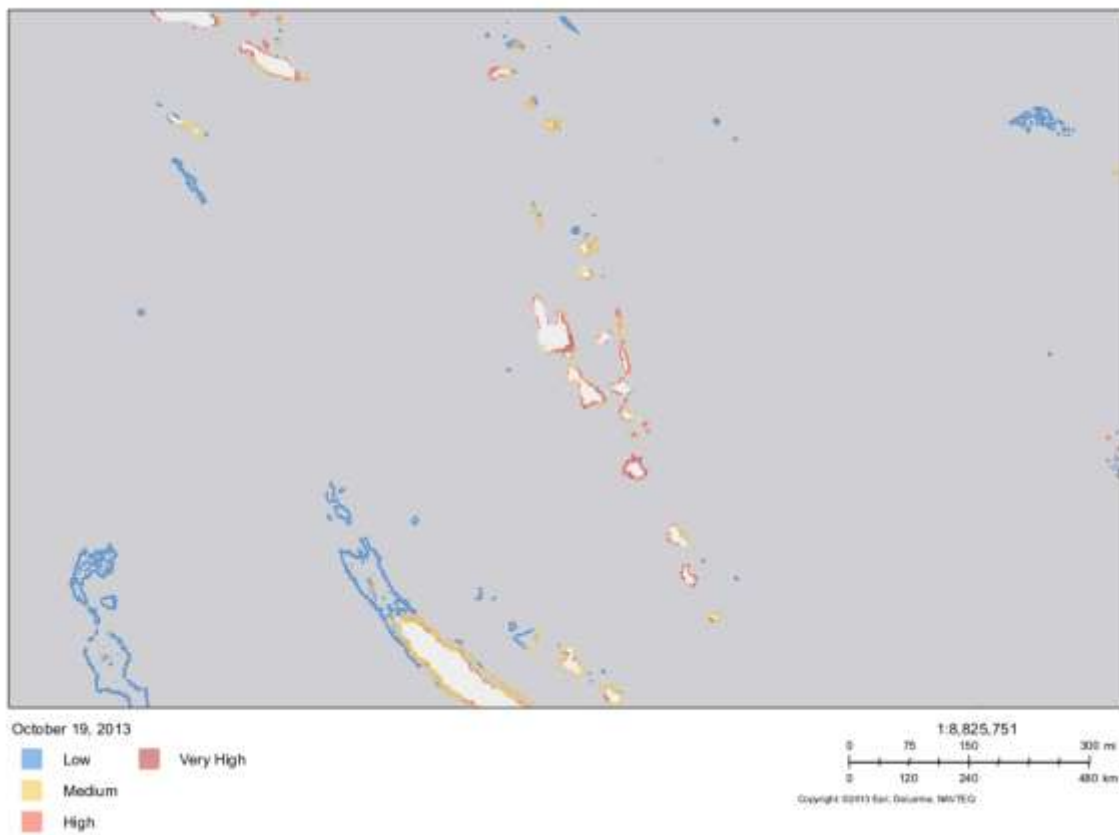
(source: SimCLIM 3.0)



(source: SimCLIM 3.0)

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

Coral reefs at risk



(source: World Risk Index)

IMPACTS:

Sector	Potential direct impacts
Agriculture	Impacts on food demand as fisheries is impacted
Fisheries	Impact on fish availability as coral reef is impacted
Forestry	No major impacts
Transport	Coral aggregate no longer available 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 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

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

IMPACTS:

Sector	Potential direct impacts
Agriculture	Heat waves negatively impact crop yields
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

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%, taking that away 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 to 0, turning it in a dry day).

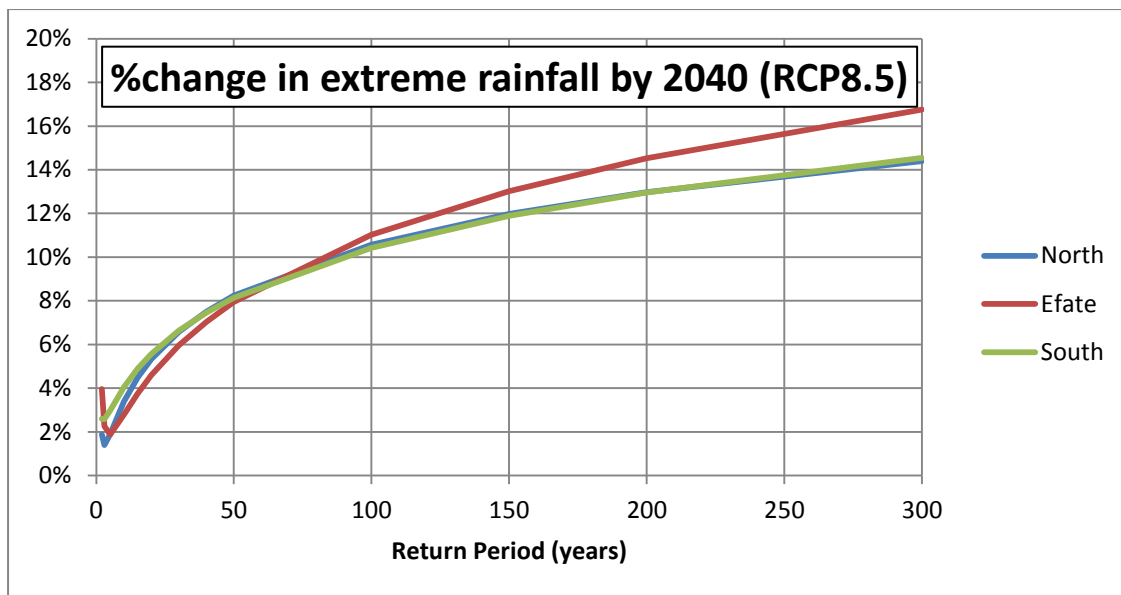
IMPACTS:

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.

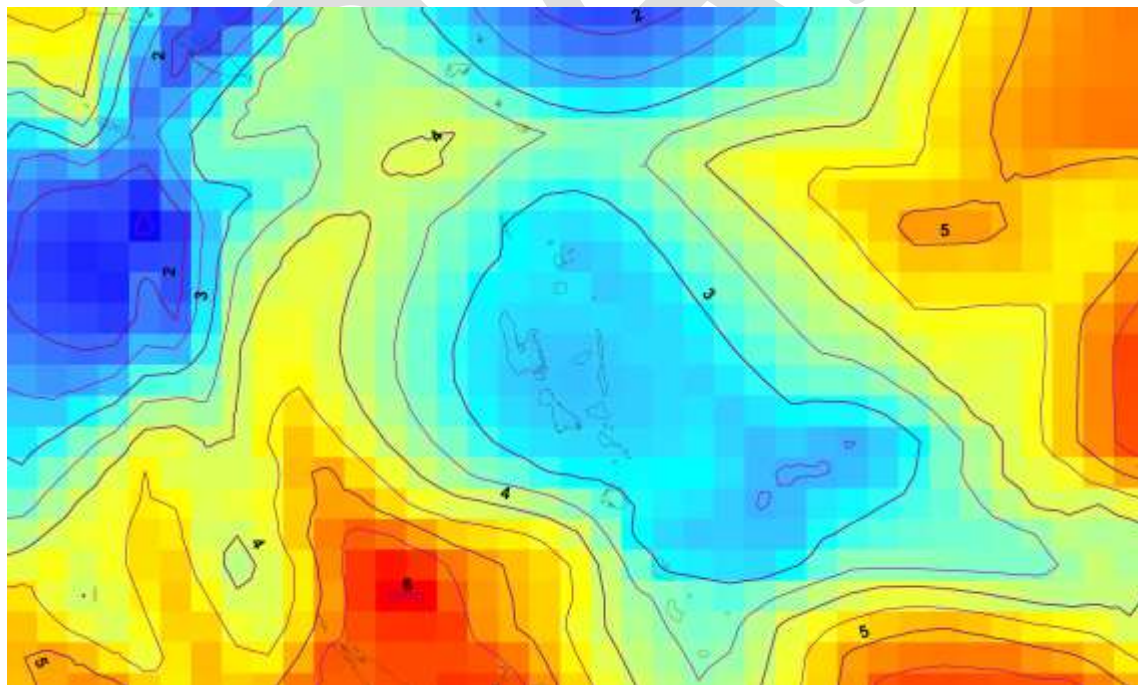
Climate change: Climate change intensifies the weather extremes, both low and high. Even in locations where average precipitation decreases, short-duration rainfall events can still become stronger ("its rains less frequent, but when it rains, it pours"). From an ensemble of 40 AR5 models, the median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



(source: SimCLIM 3.0)

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 change in the 1 in 20 year extreme, expressed as a percentage change per degree of global warming (from a 22-model ensemble):



(source: SimCLIM 3.0)

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 now, will be more frequent in the future. The table list 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

Thus the 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).

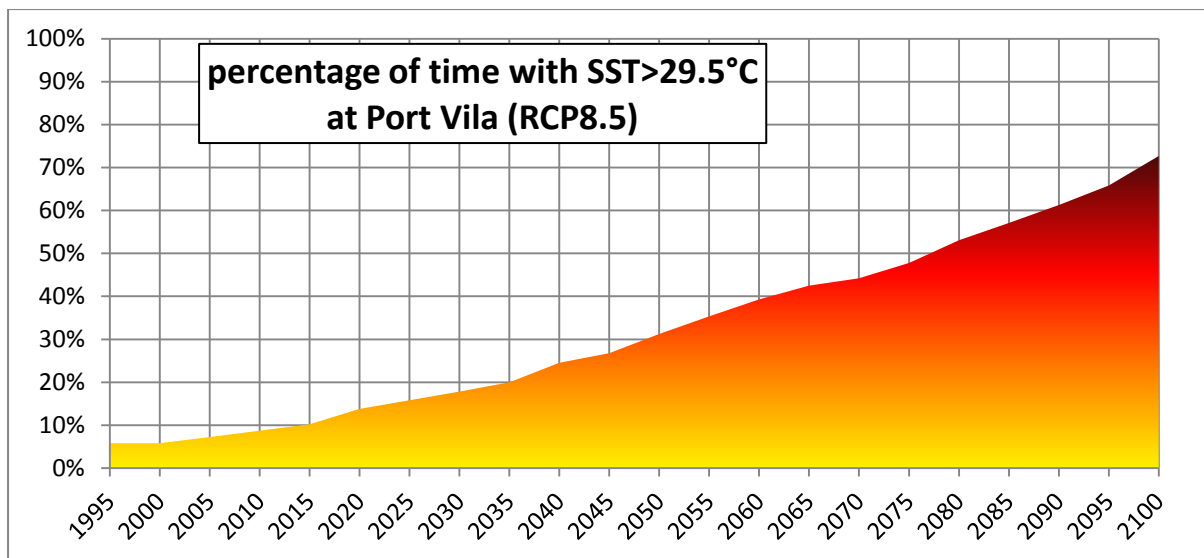
IMPACTS:

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
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 3.0)

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 fisheries is impact through 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]) can be used to produce a density map of earthquakes around Vanuatu
Volcanoes	The location of the volcanoes is known, and risk-zones can be 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) can be mapped
Liquefaction	Liquefaction occurs in soil with a high moisture content (usually reclaimed land) when shaken by an earthquake

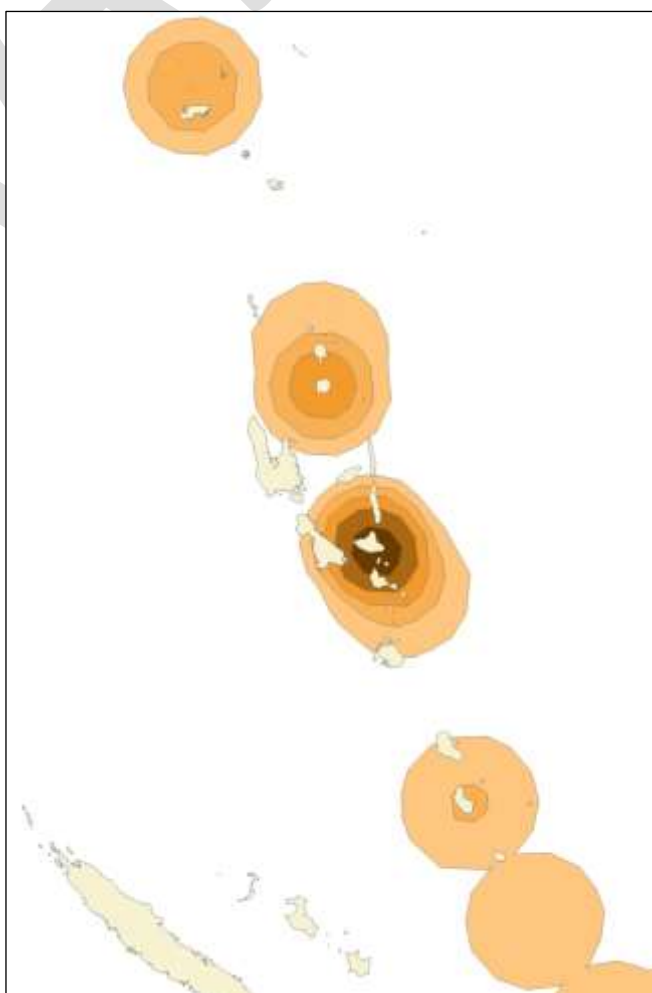
All data on location and severity of past events were retrieved from internet sources. The past events form a good predictor of future disaster locations.

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 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 point source to indicate areas that could be affected by volcanic emissions or ground shaking.

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



IMPACTS:

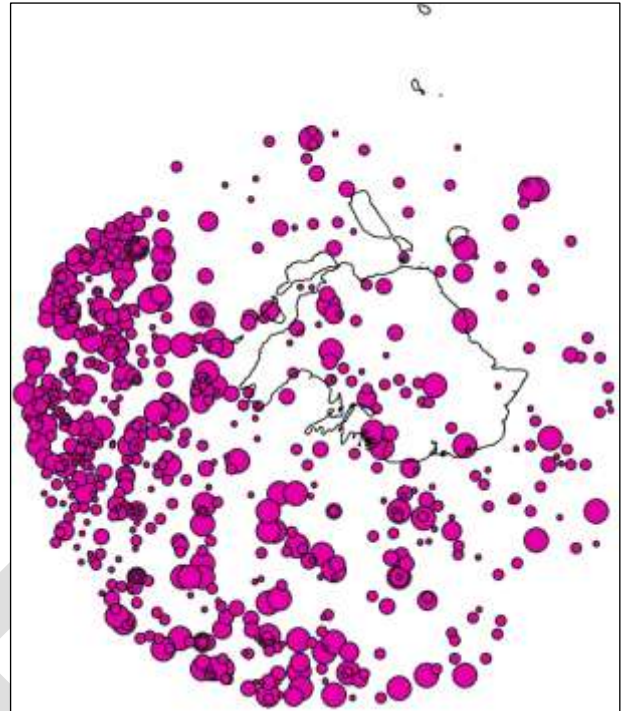
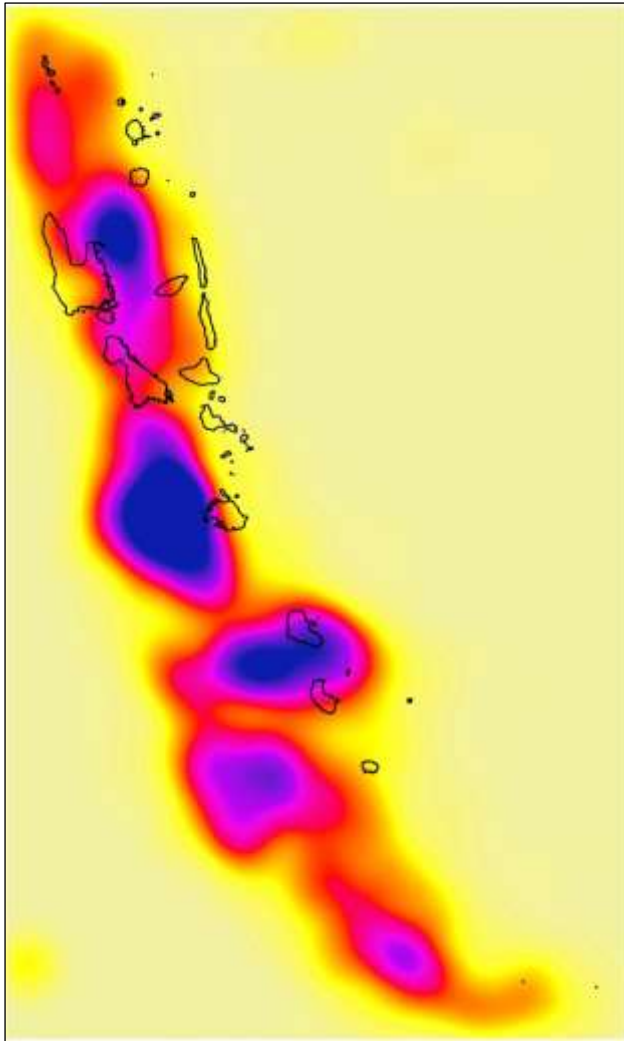
From the image it is clear that the effects of a volcano eruption are fairly localized, with some islands not being vulnerable at all, while others are highly vulnerable. The table below thus describes the local more extreme impacts.

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	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).

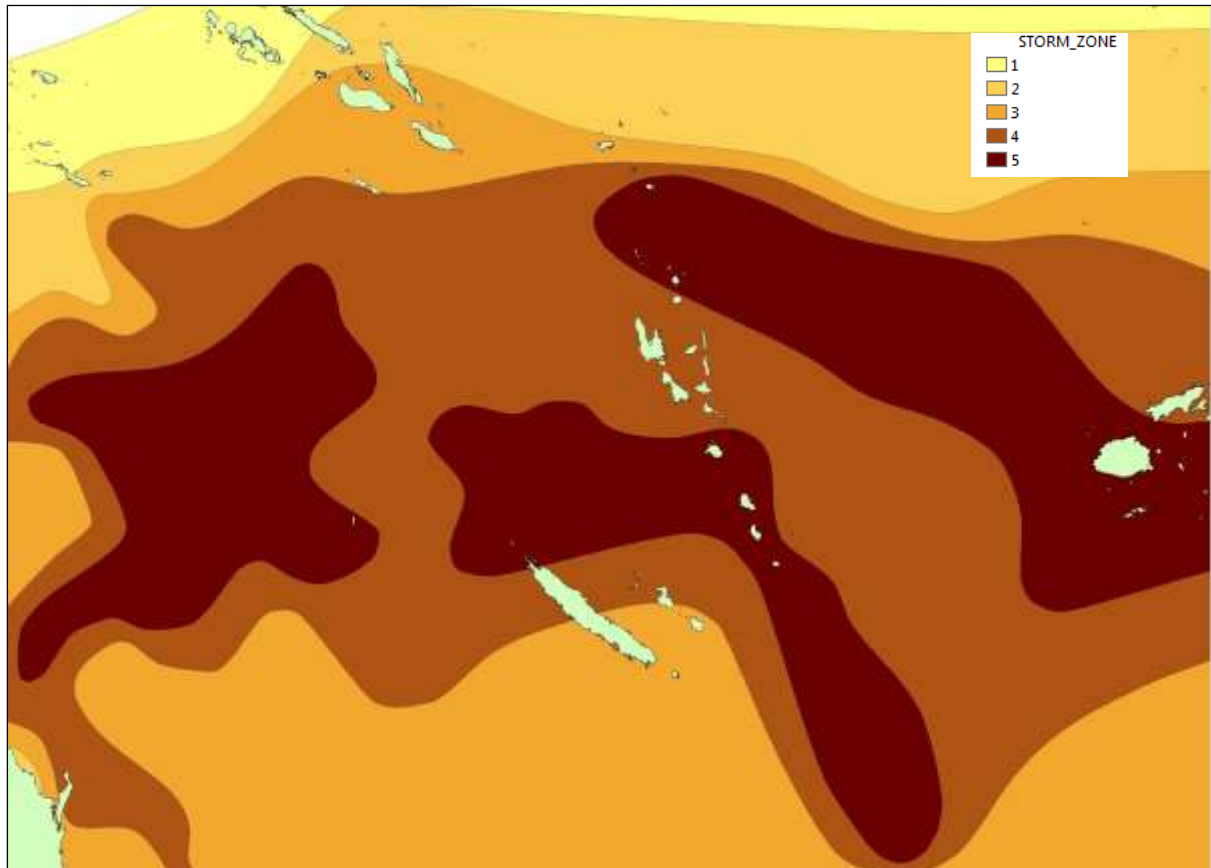
Sector	Potential direct impacts
Agriculture	Cattle might be impacted
Fisheries	Aquaculture may be impacted (tank breaches)
Forestry	No major impacts
Transport	Damage to road, airport and harbour infrastructure Accidents
Infrastructure	Damage to infrastructure (visible and invisible) including power-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

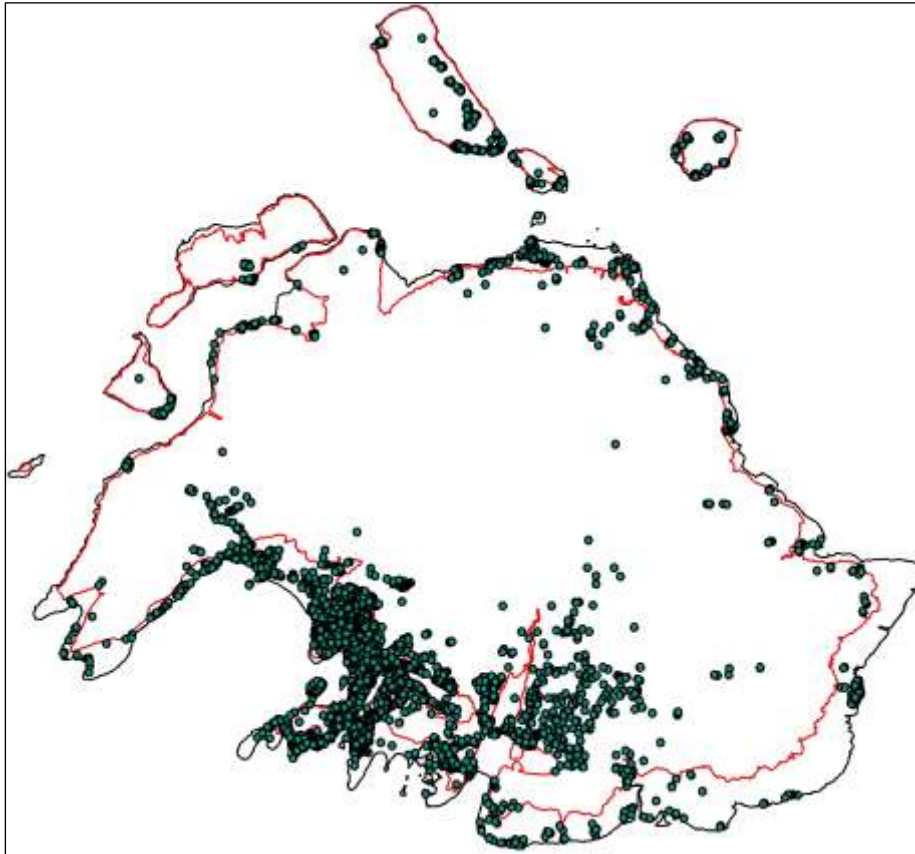


(source: \Site Data\GIS\PRCC\Storms)

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 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 take 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 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 contents)
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 are generated 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 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 is the only event with a recorded dead-toll: 100 people were killed) (on average 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.

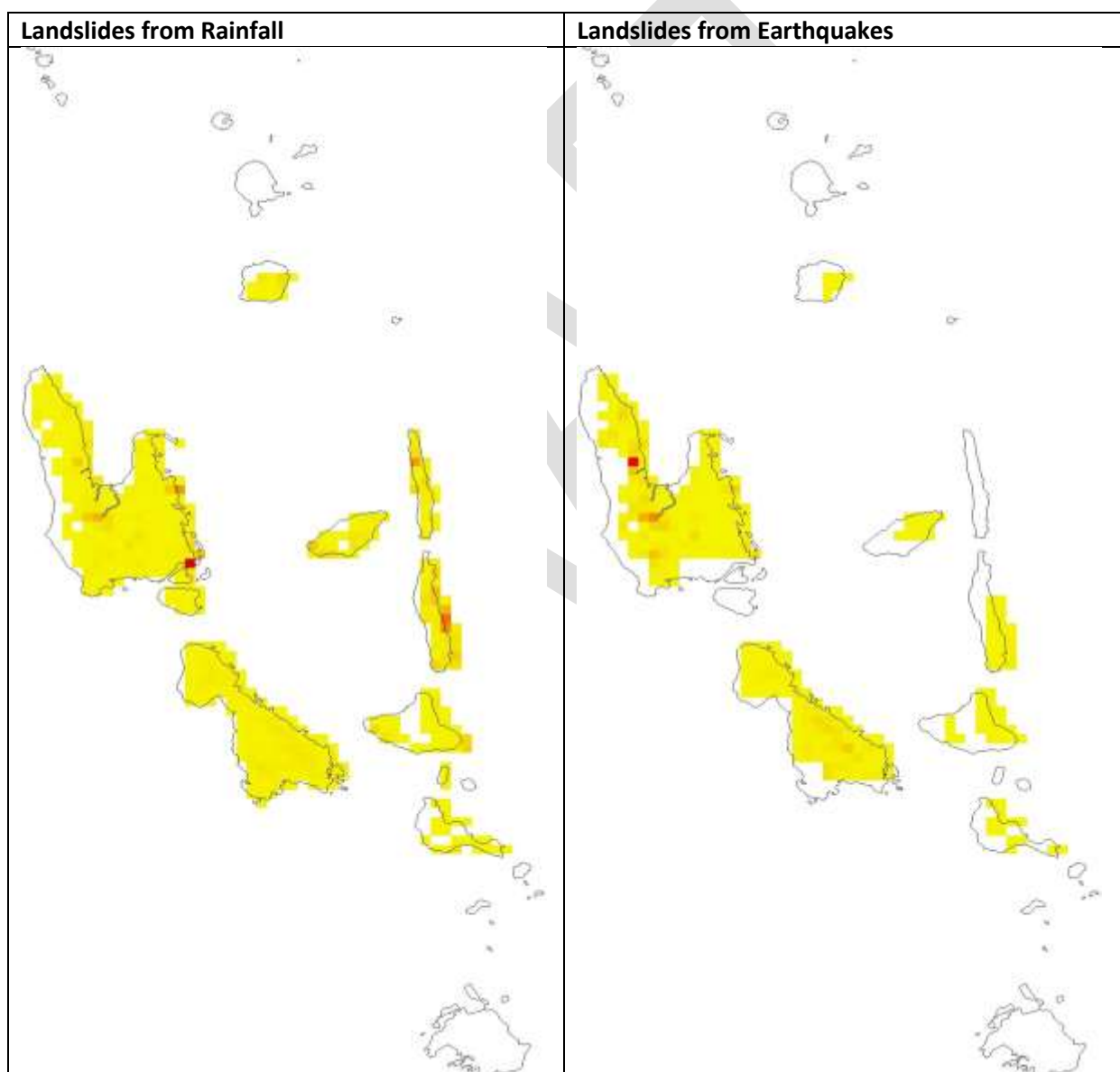
Sector	Potential direct local impacts
Agriculture	Crop destruction Soil erosion Soil quality issues (salinity)
Fisheries	Aquaculture impacted
Forestry	Trees uprooted
Transport	Destruction of coastal roads
Infrastructure	Coastal infrastructure damaged / destroyed
Health	Safety Food-security Water-security
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. These do not 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 caused by earthquakes. Zooming in on Vanuatu gives the following images:



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

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	No major impacts
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
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 carry anything, like buildings or roads.

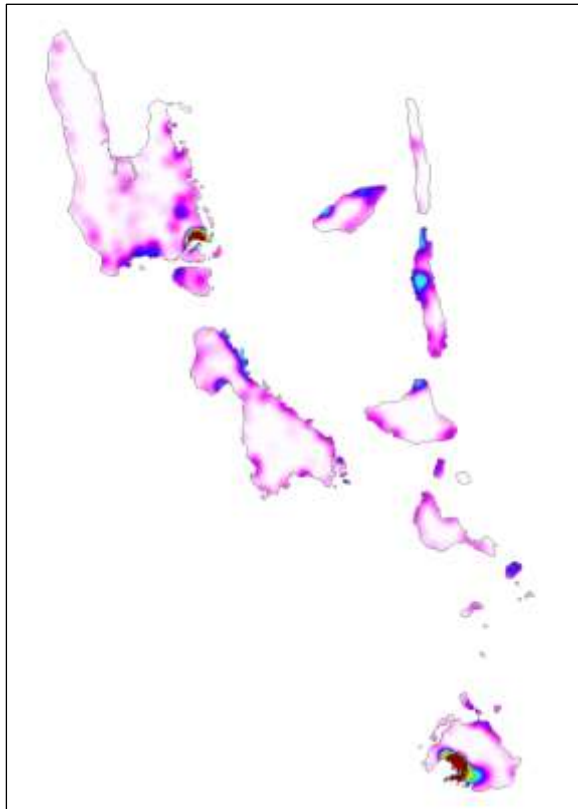
There is no data available that identifies locations in Vanuatu that are vulnerable for liquefaction.

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 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:

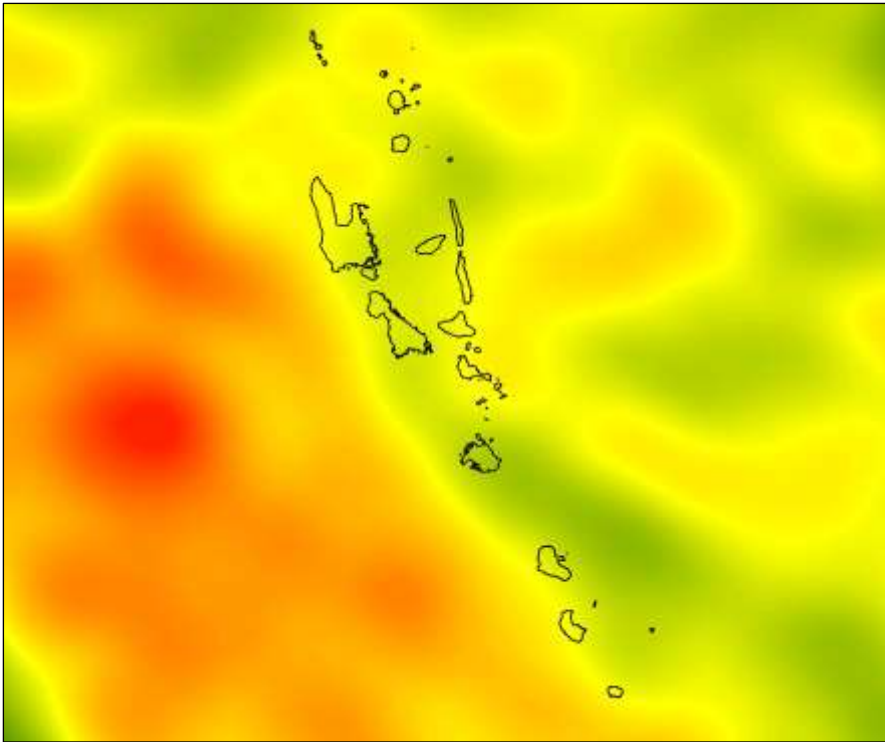
Two major population centres are visible. Most people are also clearly living close to the coast, making them more vulnerable to tsunamis and coastal flood events, as well as sea level rise.

(source \Site Data\GIS\VNSO)

RISK FACTOR: Tropical cyclones

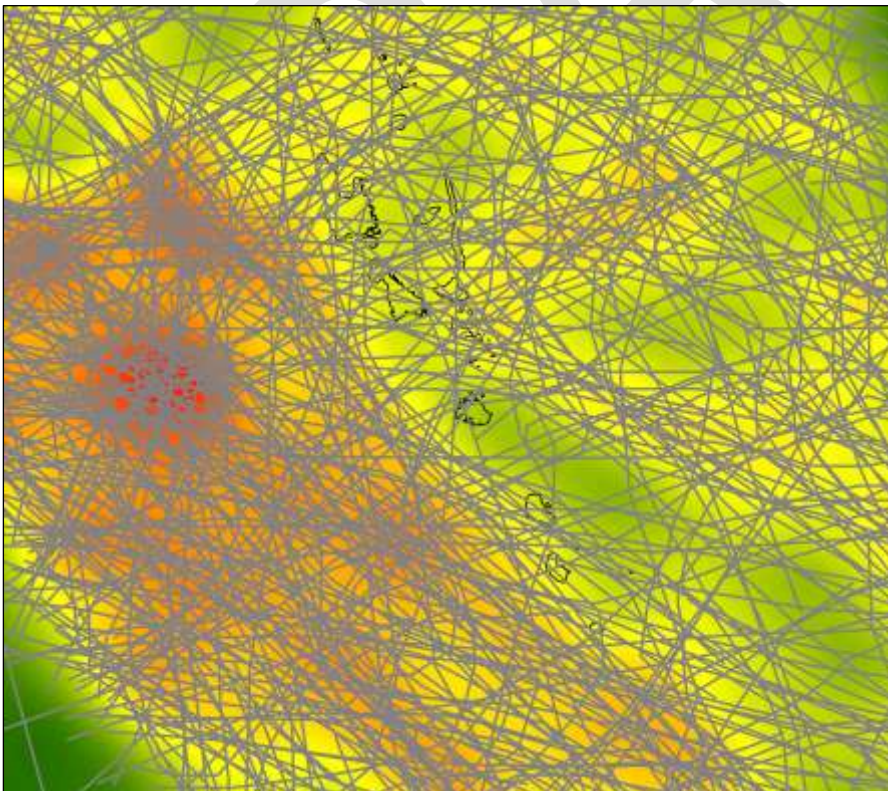
DESCRIPTION: Tropical cyclones are a major risk factor for Vanuatu, but neither changing from climate change, nor a geo-hazard, so technically not part of this analysis. Nevertheless, data on cyclones has been collected during this assessment, and is presented here.

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 around.



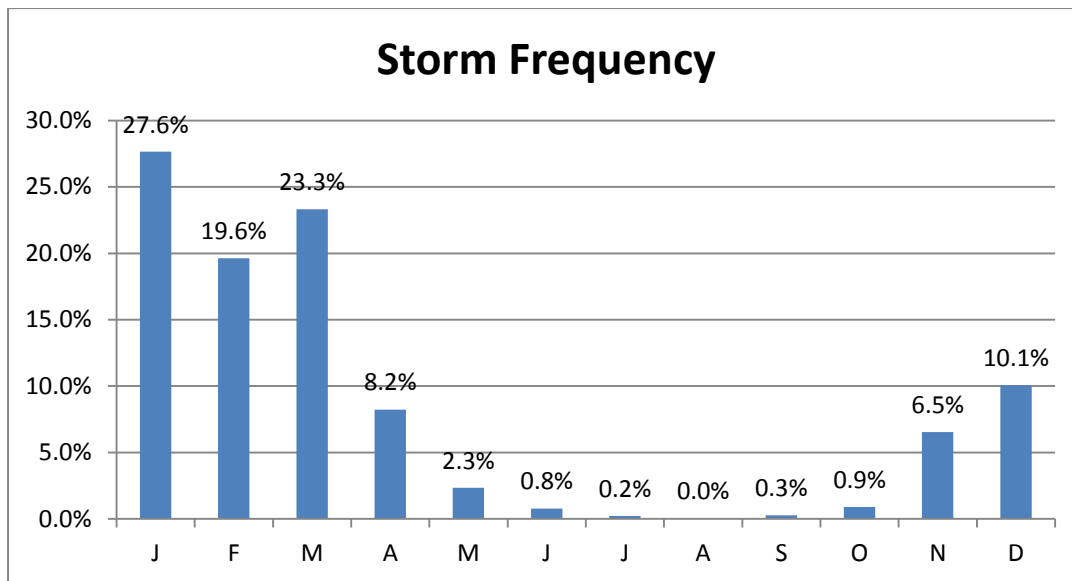
(source: \Site Data\GIS\PRCC)

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



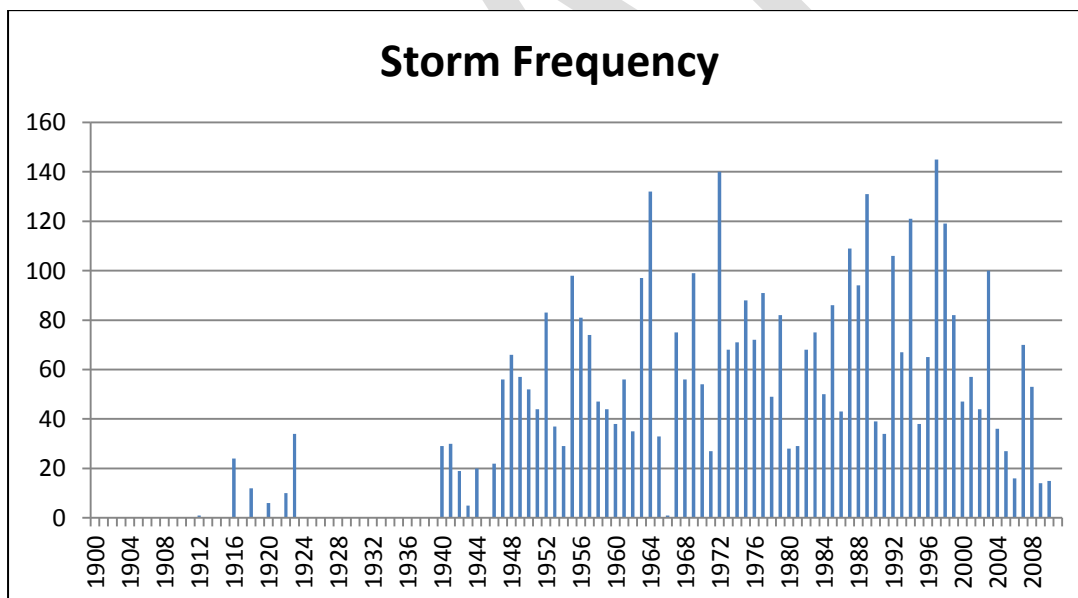
(source: \Site Data\GIS\PRCC)

The following statistics were generated from the selected cyclone tracks, showing occurrence frequency over the months (this is for 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 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 puts some challenges on the policy development and planning.

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

a) The change in precipitation averages 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 increased to ca. -25 to 20%. As the adaptation strategies for less rain differ from the ones that plan for more rain this sets a challenge for 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%.

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 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 going to be extended dramatically because of the increase of 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.

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).

What is important to remember is that SLR does not stop at the time horizon (2090 or 2100), but will continue, even if atmospheric CO₂ levels stabilize, as the heat-exchange between atmosphere and ocean is delayed a lot. 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 the events actually happen. The theoretic 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.

Currently Vanuatu's Second NC should have been published but it has not done this yet. 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 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 3.0.

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 greater detail 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 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 to use SimCLIM for the 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 been released yet (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.

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 the 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 tabs 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 is 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 amounts, offering adaptation potential for the 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 density of the people 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 to 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 could 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 there.

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?

The following research projects are recommended according to their priority:

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.

Annex: Statistics on natural disasters 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