CLIMATE RISK, VULNERABILITY AND RISK ASSESSMENT IN THE MADANG PROVINCE IN PAPUA NEW GUINEA

COLOPHON

Project:
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LIST OF ABBREVIATIONS

ANU	Australia National University
CCDA	Climate Change and Development Authority
CDD	Continuous dry days
DRM	Disaster Risk Management
IPA	Investment promotion authority
IPCC	Intergovernmental Panel on Climate Change
LLG	Local Level Government
LULC	Land Use / Land Cover
MASP	Mapping Agricultural Systems of PNG
NSO	National Statistical Office
PCRAFI	Pacific Catastrophe Risk Financing and Insurance Initiative
PIC	Pacific Island Countries
PNG	Papua New Guinea
PNGRIS	PNG Resource Information System
PSI	Physical sensitivity index
RC	Replacement cost
UNDP	United Nations Development Program
UNISDR	United Nations International Strategy for Disaster Reduction
WB	World Bank
WFP	World Food program

0. EXECUTIVE SUMMARY

Background

Papua New Guinea is prone to natural disasters induced by climate change, climate variability, and sea-level rise, including tsunamis, cyclones, inland and coastal flooding, landslides, and droughts.

UNDP is supporting a four year project, implemented by the Climate Change and Development Authority (CCDA), titled "Enhancing Adaptive Capacity of Communities to Climate Change-related Floods in the North Coast and Islands Region of Papua New Guinea," financed by the Adaptation Fund. The project seeks to build community resilience to coastal and inland flooding through improved awareness, risk management, and institutional capacity to implement appropriate adaptation measures.

Within this context, Antea Group, Hydroc & World Vision have conducted a climate risk, vulnerability and risk assessment in five provinces in Papua New Guinea (East Sepik, Madang, Morobe, Northern, and New Ireland).

Objective

The objective of the study was to identify climate risks, exposure, and vulnerability to principal climate hazards affecting five pilot provinces (East Sepik, Madang, Morobe, Northern, and New Ireland) and to prepare a Composite Risk Atlas and Maps/Indexes for the hazards at the district level.

Methodology

The methodology to identify and map current and future climate hazards, vulnerability and risks has been developed by the project team based on internationally accepted definitions and approaches found in the Disaster Risk Reduction and Climate Change Adaptation literature and customised based on data availability and quality for the five pilot province provinces in Papua New Guinea (East Sepik, Madang, Morobe, Northern, and New Ireland).

Data has been collected from leading institutions in Papua New Guinea and form international sources. Following a careful review and quality check of the available data, hazard maps, vulnerability indices and maps, and risk maps were produced for the following climate hazards:

- Inland flooding
- Coastal flooding
- Drought
- Extreme weather events (tropical cyclones)
- Increase of precipitation intensity and variability

The assessment was done for the current situation and a future situation based on projects climate data. The overall procedure followed involved the following steps:

<u>(i) Data collection and quality control</u>

Data has been collected from leading institutions in Papua New Guinea and international sources.

<u>(ii) Analysis of the existent climate data and climate change projections & hazard maps</u>

The available observation data from weather stations in PNG is too scarce for the purposes of this study. To overcome this issue, the project team took on a significant effort to downscale General Circulation Model (GCM) data and create climate time series that could be used for modelling and mapping the hydro-meteorological hazards for this study.

In order to cope with the limited availability of qualitative historic observation data, the main strategy followed by this study was to reanalyse hindcasted and forecasted outputs from downscaled model data to derive actual and projected patterns for parameters like temperature, precipitation and wind speed. These parameters are subsequently utilized to compute hazard parameters for risk mapping.

All analyses are based on climate model output from the 5th Coupled Model Intercomparison Project (CMIP5) , which informed the Intergovernmental Panel on Climate Change (IPCC) fifth assessment reports (IPCC 2013) .

A simple downscaling correction for spatial variability was applied, which adjusted the rainfall intensity and temperature value but does not affect the variability, including seasonal.

Under low, medium and high emissions scenarios, PNG is projected to get significantly hotter and slightly wetter. No significant change in mean or extreme wind speed is projected.

Increases in rainfall intensity are projected throughout the region. Further work (beyond the scope of this report) may ascertain the potential impact on flash and riverine flood risk.

The risk of seasonal drought is projected to decrease because of the increase in rainfall. However, increases in the lengths of dry spells and increased risk of extreme rainfall may have negative consequences for agriculture.

Based on various analysis as published under IPCC, cyclone frequency is expected to decrease in the southwest Pacific and hence in the waters around PNG, while some indications exist that intensities may increase . This report has used coarse data as available from previous study. For a more detailed assessment of future cyclone risk detailed regional cyclone modelling considering changes to cyclone drivers would need to be conducted.

Sea level rise along PNGs coastline is in line with global developments. To understand coastal flooding a combined analysis of sea level rise, the respective tidal signals, potential storm surges and aspects of increased wave energy resulting from increasing water depth would be required using coastal modelling tools. For the modelling detailed bathymetrical and topographical data, beyond the details that are currently provided by the SRTM data would be needed.

The hazard **(1) Drought** is characterised as a normal, recurrent feature of climate, temporarily deviating from normal climatic conditions for a specific location. In technical settings, a climatic hazard should represent the probability with which climatic events of various intensity are to occur. Drought hazard could therefore be defined as the frequency of abnormal precipitation deficits at some level of intensity in a particular region.

In order to describe the evolution of drought over time in the context of climate change, several metrics were considered relative to mean climate variables (temperature, precipitation and surface wind speed), duration statistics (continuous dry/wet days) and water balance indicators (precipitation minus evapotranspiration). These metrics were computed at a 0.5° grid over the area of interest in current and future climate conditions.

None of these metrics can be interpreted in the probabilistic manner necessary to quantify drought hazard. The most suited indicator selected for drought hazard is the annual maximum dry spell length i.e. the expected maximum number of continuous dry days (CDD) within a year. Using this indicator to quantify the level of drought hazard makes the assumption that regions which experience longer drought events are also the more likely to experience drought in terms of frequency. Also, because the expected duration of drought events is critical to evaluate the related consequences and the associated risk for crop production, this choice is consistent for a risk assessment: higher expected CDD will lead to higher levels of risk.

The hazard **(2) precipitation intensity and variability** is defined in terms of increased rainfall intensity and variability. Rainfall variability as a hazard cannot be easily predicted and is even more difficult to map. We consider the risks associated with rainfall increase relative to (i) agricultural system tolerance to a rainfall regime change, and (ii) communities sensitivity to intense rainfall events, extreme runoff and flash floods in urban areas.

To account for these two components, we consider two hazard indicators: (i) cumulative annual rainfall, and (ii) the total annual rainfall when the daily rainfall exceeds the 95th percentile. The underlying hypothesis is that heavy, intense rainfall is more likely to happen in overall wetter areas.

The mapping of **(3) extreme weather events** around Papua New Guinea, more specifically tropical cyclones, requires the analysis of historic cyclone path databases and damage reports, as well as observed meteocean parameters, like sea surface temperature. A review of past events was undertaken to understand the relation between driving factors, cyclone occurrence and damage potential occurring in the waters around the studied area. A projected future cyclone occurrence map was derived based on compiled data in the IPCC Fifth Assessment Report (AR5 report), summarized and averaged for the southwest Pacific.

Given the lack of hydro-meteorological data, topo-bathymetric data, gauged data, soil type and land use data, a pragmatic approach to develop **(4) inland flood hazard** maps has been customized for the purposes of this study. The method is based on limited available information and GIS routing techniques. Rainfall derived from the climate models were used to compute intensity duration frequency relations (IDF) for the current and the projected situations. The intensities are subsequently transported into run-off by means of the 'rational method'. These steps allow deriving maximum flood discharges at any location within the considered river reach. Combining the discharge with an estimated reach geometry allow to derive water levels and subsequently flood maps.

Potential changes in flood hazard are assessed by comparing the estimated flood maps generated for a specific frequency and intensity of precipitation of current climate data versus maps derived using future climate projections.

The mapping of **(5) Coastal flood** is one of the most important climate change related hazards in this area because most settlements in the North coast and islands of Papua New Guinea are located along its coast. Climate change is expected to lead to global sea level rise that would increase the coastal flooding areas. In order to identify the current coastal flooding extension, hourly tidal levels and wave height data are assessed. The projected sea level rise is extracted from global sea level projections and local oceanographic particularities for PNG. Then, the projected coastal flooding extension is estimated by adding the sea level rise to the total level of the current scenario.

<u>(iii) Developing social, infrastructure and economic vulnerability indices & vulnerability maps</u>

Vulnerability is defined as a 'set of conditions and processes resulting from physical, social and economic factors, which increase the susceptibility of a community to the impact of the hazard'. This includes intrinsic characteristics that predispose the asset or the community to suffer from a hazard, but also the potential loss that can result from it.

The general procedure for producing vulnerability and maps for each hazard follows these main steps:

(1) Identification of elements (sensitive assets) that are potentially exposed to the hazard: Maps showing communities, infrastructure and land use are combined with the hazard maps to identify the elements exposed to each of the hazards.

(2) Sensitivity of the elements potentially damaged by the effect of hazards are assessed using various indicators that are then combined into indices. Three separate indices are constructed to express physical, economic and social sensitivity to each of the hazards considered in this study. Each sensitivity index is derived from a set of indicators reflecting the various constituents of physical, social and economic sensitivity respectively.

(3) Vulnerability is interpreted here as the potential damage of the hazard. Potential damaging effects of a hazard are estimated as the product of the maximum potential loss (exposure) and sensitivity. To this end, sensitivity is expressed as an index (1 to 5) or a percentage (loss fraction). For

physical, economic and agricultural vulnerability assessment, the maximum loss associated to the exposed assets is estimated by their replacement cost. In the case of social vulnerability, maximum loss is the estimated number of exposed people. In order for vulnerability to be mapped and allow visual interpretation, it is scaled into five categories: very low, low, medium, high and extreme.

(iv) Risk mapping

Once the three vulnerability components (physical, economic and social) computed and mapped, risk is calculated as the product of the hazard index and the vulnerability index. A risk matrix allows consistent reclassification of the product operation between hazard and vulnerability.

(v) Composite risk

Finally, in order to map only one risk synthetic value, it was decided to use the maximum value of the three risk components to produce a "composite risk map". Risk maps can also be displayed for each vulnerability component separately for visualising potential damage to population, buildings and crops separately.

Key findings

Climate of Papua New Guinea

Based on observations carried out in Port Moresby since 1950, it can be concluded that a steady warming, averaging ~0.1 °C/decade,[1] is taking place. Over the next decades, **temperature** is projected to continue to increase, with a projected warming of 0.4-1 °C by 2030 under a business-as-usual emissions scenario. By 2050, under such a scenario, a 1.1 – 1.9 °C warming is projected. Over the next 30-50 years, increases in the average temperature will result in more very hot days, with potentially severe impacts on agriculture and human health.

The limited available information on precipitation reveals that there is no clear long-term historical change in rainfall in Port Moresby, although elsewhere there has been a slight decrease. In line with expectations globally, precipitation is projected to increase in response to the warming of the atmosphere. More extreme **rainfall** days are expected, likely contributing to increasing frequency of inland flooding. The regional pattern and magnitude of the increase is, however, highly uncertain.

Overall, trends in both rainfall and temperature are dwarfed by year-to-year variability.

On a global scale, the frequency of **tropical cyclones** is projected to decrease overall, but the frequency of high intensity cyclones is projected to increase. The projections for PNG are consistent with global projections, with fewer but more intense storm events expected.

Sea level rise is a serious consequence of climate change for Papua New Guinea. Under a business-as-usual scenario, by 2030, sea level in PNG is expected to rise[1] by 4-15 cm. Combined with natural variability, such a rise would increase the impact of storm surges and the risks of coastal flooding. It is notable that these projections could be underestimations, due to uncertainties in projections of ice sheet melt.

In addition to changes in climate, changes in land use may affect flood risk, for example through changes to catchment scale runoff and patterns of inundation. Since 1990, there has been a small degree of deforestation (reduction of forests from 31,523 KHa in 1990 to 29,159 KHa in 2007)[2] and an

[1] Climate Change in the Pacific: Scientific Assessment and New Research | Volume 2: Country Reports; Chapter 11: Papua New Guinea
[2] ITS consulting, 2009, downloaded from www.unredd.net

increase in land used for agriculture (877,000 Ha in 1990 to 1,040,000 Ha in 2007). Changes in coastal land use may affect the risk and impacts of tidal flooding.

Conclusions and recommendations

The risks are predictable. Disasters occur through lack of preparedness for likely occurrences. The immediate steps should be to set in place an adequate mechanism to respond to the kinds of emergencies that are likely to occur: principally flooding, landslide, some storm effects, and occasional drought. The disaster response team in Morobe is one of the best we have seen, and could be the model for other provinces like this one: adequately provisioned with boats to access difficult coastal areas, such as Tufi, 4x4 vehicles to reach inland, and standing arrangements with the air force and police, to reach populated areas not served by roads. This needs to be backed up with meteorological and early warning information, and a network that allows this information to reach areas likely to be affected. Emergency preparation, at the district and LLG level is essential, to know in advance how to cope with rescue and care of displaced people. In many places, local level organisation is the only way to ensure some buffer of security.

Invest in risk knowledge. Stakeholders can become more resilient by understanding the current and projected hydro climatological risks. Current initiatives in community-based disaster risk reduction could be enhanced to incorporate customized information related to the present risk mapping.

Incorporate adaptation strategies at various levels (community, district, province and national) to cope with changing climate. This should include institutional, physical, and structural measures. Integrating disaster management into school curriculum would be helpful.

Focus on urban flooding and the damage to infrastructure around major cities. This could imply the maintenance of drainage systems and clean-up of drainage infrastructure, bridges, and culverts before the rainy season begins. These measures should allow that the road network remains operational during the rainy season and that the urban damages are reduced.

Lowland flooding is a recognised feature of the rural ecology in this province that people have experienced for generations. Flooding in upland areas is likely to be exacerbated with greater intensities of rainfall. The practice of terracing could be introduced in the hilly regions of the Province to reduce soil deterioration, erosion and flash floods.

The traditional crop mix is well established to distribute risk, and to cover for most eventualities. As the frequencies of hazards change, the relative importance of one crop may change with respect to others. For example, longer dry spells is likely to increase the importance of cassava.

In rural zones, the focus should be on revising cropping practices and strategies for controlling and managing flash floods and bank erosion within an integrated approach.

Adequate measures for coping with drought risk should be defined. These could include reforestation plans for upper catchments to increase infiltration (positive for ground water recharge and effective reducing surface runoff). Additionally, communities should be trained on digging and maintaining superficial wells to improve their resilience to drought. For urban areas, a master plan on water supply, taking in account population increase and climate change, should be developed.

Papua New Guinea's Agricultural Research Institute considers drought to be the major climatic threat to agriculture in the country and is breeding crops for drought resistance. This research should be tested as quickly as possible at the local level, to give local people the chance to adapt local practices.

Protecting against drought requires the same measures as protecting against flash floods, using land and water management to restrain water and allow it to permeate the soil.

Community based DRR actions should be furtherly developed, especially in the most critical communities. Actions should include shelters and evacuation plans in place and communicated to residents. Early warning systems should be put in place focussing on alerting the population by alerts broadcast on TV and radio and sent by text to cell phones in advance.

Local government officials, hospital staff, the Red Cross, NGOs, and community, school and religious leaders should be further trained in emergency response to disasters. Emergency supplies, clothes, food, medical items, etc. should be procured and stored in strategic locations, ready for rapid distribution by emergency management personnel.

Organization of chapters

The report is organised in four chapters starting with this executive summary. Chapter 1 describes the objectives and methodology in greater detail and provides an overview of the baseline situation in the Northern Province. Chapter 2 describes the hazard assessment for inland flooding, coastal flooding, drought, extreme weather events and increase in precipitation intensity and variability, for the current and future scenario's. In chapter 3 we discuss the selection of exposed assets and their characteristics to compute sensitivity indices and to map social, infrastructure and economic vulnerability for the province. In chapter 4 we present the resulting risk maps and the composite risk map is presented in chapter 5. We conclude with recommendations in chapter 6.

1. INTRODUCTION

Papua New Guinea is prone to natural disasters induced by climate change, climate variability, and sea-level rise, including tsunamis, cyclones, inland and coastal flooding, landslides, and droughts.

UNDP is supporting a four year project, implemented by the Climate Change and Development Authority (CCDA), titled “Enhancing Adaptive Capacity of Communities to Climate Change-related Floods in the North Coast and Islands Region of Papua New Guinea,” financed by the Adaptation Fund. The project seeks to build community resilience to coastal and inland flooding through improved awareness, risk management, and institutional capacity to implement appropriate adaptation measures.

Within this context, Antea Group, Hydroc & World Vision have conducted a climate risk, vulnerability and risk assessment in five provinces in Papua New Guinea (East Sepik, Madang, Morobe, Northern, and New Ireland) .

This report describes the hazard, vulnerability and risk assessment for the Madang Province in Papua New Guinea.

1.1. *Objectives*

The objective of this study is to identify climate risks, exposure, and vulnerability to principal climate hazards affecting five pilot provinces (East Sepik, Madang, Morobe, Northern, and New Ireland) and to prepare Composite risk maps at the province and district level for (i) inland flooding, (ii) coastal flooding, (iii) drought, (iv) extreme weather events, and (v) increase in precipitation intensity and variability.

This requires:

- the assessment and mapping of major climate hazards in each of the 5 provinces in terms of their nature, geographical distribution, severity and frequency. Document the changing patterns induced by projected changes in the future climate.
- the assessment and mapping of physical, social and economic vulnerabilities and prepare district wise vulnerability profiles/maps for climatic hazards.
- the assessment of risks maps for the five hazards and a composite risk map, as a result of hazard and vulnerability assessments.

1.2. *Methodology*

The methodology to identify and map current and future climate hazards, vulnerability and risks has been developed by the project team based on definitions and approaches found in the Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) literature, and customisation taking into account data availability and quality for the five pilot province provinces in Papua New Guinea (East Sepik, Madang, Morobe, Northern, and New Ireland).

Data has been collected from leading institutions in Papua New Guinea and international sources. Data used and sources are listed in Annex 2. Following a careful review and quality check of the available data, hazard maps, vulnerability indices and maps, and risk maps were produced for the following climate hazards:

- Inland flooding
- Coastal flooding
- Drought

- Extreme weather events (tropical cyclones)
- Increase of precipitation intensity and variability

The assessment was done for the current situation and a future situation based on projects climate data. The overall procedure followed involved the following steps (shown in Figure 1) and explained in the following pages.

Vulnerability and risk maps were made for three sectors:

- Social
- Physical (or infrastructure)
- Economic

The overall process is shown in Figure 1, and is explained in the following sections.

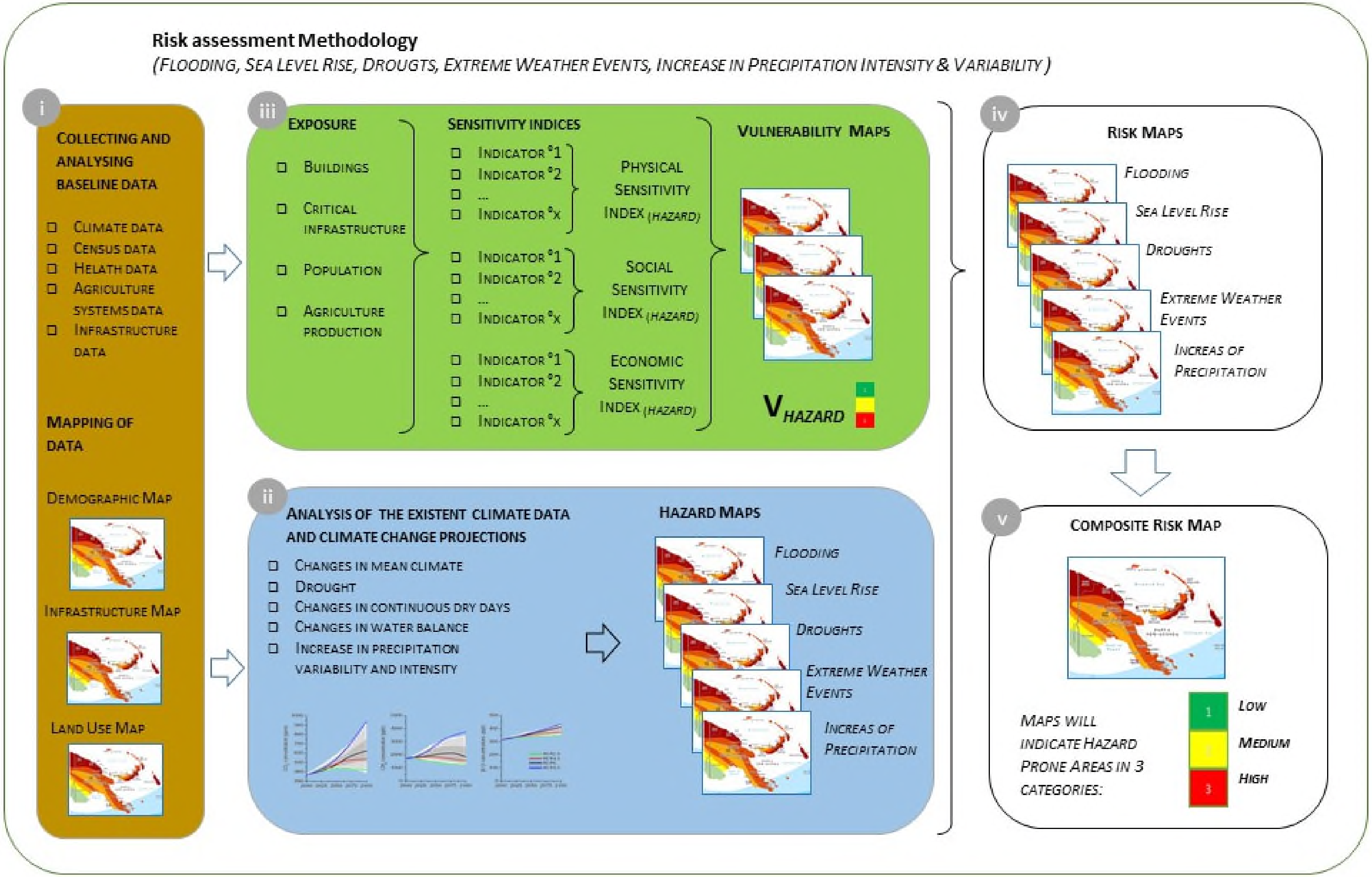

Figure 1. Risk mapping methodology

1.2.1. *Hazard assessment*

The definition of hazard used throughout this study is consistent with the UNISDR (2009)[3] definition: 'Dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage'.

Moreover, the hydrometeorological hazards, which are the focus of this study, are defined as the "process or phenomenon of atmospheric, hydrological or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage."

In order to produce maps for climate induced hazards, data on current climate and projected climate were collected from national and international sources for analysis of the climate metrics.

The available observation data from weather stations in PNG is too scarce for the purposes of this study.

In order to cope with the limited availability of qualitative historic observation data, the main strategy followed by this study was to reanalyse hindcasted and forecasted outputs from downscaled General Circulation Model (GCM) data to derive actual and projected patterns for parameters like temperature, precipitation and wind speed. These parameters were subsequently utilized to compute hazard parameters for risk mapping.

All analyses are based on climate model output from the 5th Coupled Model Intercomparison Project (CMIP5) , which informed the Intergovernmental Panel on Climate Change (IPCC) fifth assessment reports (IPCC 2013) .

A simple downscaling correction for spatial variability was applied, which adjusted the rainfall intensity and temperature value but does not affect the variability, including seasonal.

Following the analysis of the current and projected climate, a series of maps were produced for the hazards listed above and this under the current climate conditions and the forecasted climate. The result are show in chapter 2 of this report.

1.2.1.1. Drought

Drought is characterised as a normal, recurrent feature of climate, temporarily deviating from normal climatic conditions for a specific location. In technical settings, a climatic hazard should represent the probability with which climatic events of various intensity are to occur. Drought hazard could therefore be defined as the frequency of abnormal precipitation deficits at some level of intensity in a particular region.

In order to describe the evolution of drought over time in the context of climate change, several metrics were considered relative to mean climate variables (temperature, precipitation and surface wind speed), duration statistics (continuous dry/wet days) and water balance indicators (precipitation minus evapotranspiration). These metrics were computed at a 0.5° grid over the area of interest in current and future climate conditions.

None of these metrics can be interpreted in the probabilistic manner necessary to quantify drought hazard. The most suited indicator selected for drought hazard is the annual maximum dry spell length i.e. the expected maximum number of continuous dry days (CDD) within a year. Using this indicator to quantify the level of drought hazard makes the assumption that regions which experience longer drought events are also the more likely to experience drought in terms of frequency. Also, because the expected duration of drought events is critical to evaluate the related consequences and the

[3] UNISDR (2009) Terminology on Disaster Risk Reduction
http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf

associated risk for crop production, this choice is consistent for a risk assessment: higher expected CDD will lead to higher levels of risk.

CDD was computed for a large extent encompassing Papua New Guinea: 140-160° longitude, -15-0° latitude, with values ranging from 11 to 90 days. Looking exclusively at the provinces under study, CDD ranges from a minimum of 13 days and the maximum values of 28 days. There is a slight, however not dramatic, change between the current and future climate conditions. While drought shows an increasing trend, overall

1.2.1.2. Precipitation intensity and variability

The hazard precipitation intensity and variability is defined in terms of increased rainfall intensity and variability. Rainfall variability as a hazard cannot be easily predicted and is even more difficult to map. We consider the risks associated with rainfall increase relative to (i) agricultural system tolerance to a rainfall regime change, and (ii) communities sensitivity to intense rainfall events, extreme runoff and flash floods in urban areas.

To account for these two components, we consider two hazard indicators: (i) cumulative annual rainfall, and (ii) the total annual rainfall when the daily rainfall exceeds the 95th percentile. The underlying hypothesis is that heavy, intense rainfall is more likely to happen in overall wetter areas.

The indicator of Total Annual Rainfall (pr) was computed for a large extent encompassing Papua New Guinea: 140-160° longitude, -15-0° latitude, with values ranging from 1 100 mm to 3 800 mm. Strictly for the fives provinces under study, classes and contours of 100 mm are shown between a minimum of 2 300 mm and a maximum of 3 800 mm for the study area.

For the indicator of Total Rainfall in Wet Days (r95p), the larger extent of 140-160° longitude, -15-0° latitude includes values from 250 mm to 910 mm. Strictly for the fives provinces under study, classes and contours of 20 mm are shown between a minimum of 430 mm and a maximum of 840 mm.

1.2.1.3. Extreme weather events (cyclones)

The mapping of extreme weather events around Papua New Guinea, more specifically tropical cyclones, requires the analysis of historic cyclone path databases and damage reports, as well as observed meteocean parameters, like sea surface temperature. A review of past events was undertaken to understand the relation between driving factors, cyclone occurrence and damage potential occurring in the waters around the studied area.

Using data acquired from the Bureau Of Meteorology of Australia (BOM), all cyclone tracks that occurred from 1970 until 2016 and that passed within 200 km of Papua New Guinea were analysed. In the absence of measured cyclone width data the assumed average diameter of cyclones with destructive wind speeds is assumed as 2 degrees, based on observations of historic cyclones.

The number of times that a cyclone crossed over each grid of the area of interest was counted and converted into a historic cyclone occurrence map.

A projected future cyclone occurrence map for the southwest Pacific was derived based on compiled data in the IPCC Fifth Assessment Report (AR5 report), summarized and averaged for the southwest Pacific. This analysis resulted in a projected decrease of cyclone intensity of 44%. Therefore, each count per grid in historic cyclone occurrence map is multiplied by a factor of 0.56 in order to obtain the respective projected cyclone occurrence map.

The occurrence maps are re-classified into 5 classes of hazard level, required to later calculate the extreme weather risk maps. Two sets of hazard maps are assessed, one for the current scenario and another for the projected scenario.

1.2.1.4. Inland floods

Papua New Guinea suffers regular flooding events. Changes in flooding patterns in PNG are expected to arise as consequences of meteorological changes resulting from climate change. Specifically, changes in the intensity and frequency of rainfall events may lead to changed runoff patterns. Changes in anthropogenic influence are also expected to play a large role in future flooding, including catchment deterioration through unsustainable development practices as well as river engineering works that alter the hydraulic regime.

The risk of inland flooding can be inferred from changes in the climate and in the daily statistics of the weather. Metrics of particular relevance for assessment of flood risk are: maximum five day cumulative precipitation, total annual rainfall when the daily rainfall exceeds the 95th percentile and the simple precipitation intensity index.

Given the lack of hydro-meteorological data, topo-bathymetric data, gauged data, soil type and land use data, a pragmatic approach to develop inland flood hazard maps has been customized for the purposes of this study. The method is based on limited available information and GIS routing techniques. Rainfall derived from the climate models were used to compute intensity duration frequency relations (IDF) for the current and the projected situations. The intensities are subsequently transported into run-off by means of the 'rational method'. These steps allow deriving maximum flood discharges at any location within the considered river reach. Combining the discharge with an estimated reach geometry allow to derive water levels and subsequently flood maps.

There is no detailed information on digital terrain models nor river and floodplain for all the province. The flood maps in this report are estimated based in SRTM-3 data. This is the main input that defines the surface slope, and whether there is or not flooding.

Runoff coefficients are estimated from a soil map obtained from the National Mapping Bureau of Papua New Guinea (NMB), land cover map (Globalcover 2009), and a slope map (created using SRTM-3 data).

Runoff coefficients are estimated at pixel level allowing to create a map for runoff coefficients with a resolution of 90x90 meters. This runoff coefficient map is constant for the existing and future flood maps, as it is beyond the scope of this study to estimate future changes due to land use from anthropogenic activities.

The contributing area (the effective surface of a catchment contributing to runoff at the outlet) is derived from the DTM using GIS techniques. The flow accumulation map shows the number of pixels contributing flow to each downstream channel pixel and is derived from a digital elevation model. The stream channel network is derived from the flow accumulation map.

The analysis is carried out at province scale using a resolution of 90x90 m. The accumulated area at each point in a stream network is calculated. This computation indicates how many pixels contributed runoff to a specified location along the stream in km^2. A filtering step is applied to remove any creeks where the contributing watershed area (independent of the runoff coefficient) is less than a specified amount (30 km^2). This is necessary to prevent nearly every pixel being part of the stream network.

The time of concentration Tc is estimated for each pixel in the stream network by using the Kirpich regression equation (described in USDA NRCS 2010).

Potential changes in flood hazard are assessed by comparing the estimated flood maps generated for a specific frequency and intensity of precipitation of current climate data versus maps derived using future climate projections.

The flood elevation along the stream network is interpolated to generate flood elevation surface over the entire watershed. The flood elevation surface is then compared to the digital elevation model to identify where, and how deep, flooding occurs (i.e. where the flood elevation map is higher than the digital elevation model). A natural neighbour interpolation is used (ESRI 2010). This type of interpolation is local, uses only samples surrounding the query point, and interpolated elevations are guaranteed to be within the range of the surrounding samples. It will not produce peaks, ridges, or valleys that do not already exist in the input data. While computationally expensive, this method gives very smooth and reasonable water surface elevation surfaces.

As a last step, areas that are shown to be flooded in the flood map but that are not hydraulically connected to the stream network are removed. The result is a flood depth raster depicting only areas that are hydraulically connected to the stream network.

1.2.1.5. Coastal floods

Coastal flood is one of the most important climate change related hazards in this area because most settlements in the North coast and islands of Papua New Guinea are located along its coast. Climate change is expected to lead to global sea level rise that would increase the coastal flooding areas. In order to identify the current coastal flooding extension, hourly tidal levels and wave height data are assessed. The projected sea level rise is extracted from global sea level projections and local oceanographic particularities for PNG. Then, the projected coastal flooding extension is estimated by adding the sea level rise to the total level of the current scenario.

Sea level rise along PNGs coastline is in line with global developments. To understand coastal flooding a combined analysis of sea level rise, the respective tidal signals, potential storm surges and aspects of increased wave energy resulting from increasing water depth would be required using coastal modelling tools. For the modelling detailed bathymetrical and topographical data, beyond the details that are currently provided by the SRTM data would be needed.

1.2.2. Vulnerability assessment

Vulnerability is defined by the UNISDR as a "set of conditions and processes resulting from physical, social and economic factors, which increase the susceptibility of a community to the impact of the hazard". This includes intrinsic characteristics that predispose the asset or the community to suffer from a hazard, but also the potential loss that can result from it (UNISDR 2009).

Vulnerability is interpreted in this study as the potential damage (potential negative effects) of the hazard.

The general procedure for producing vulnerability maps for each hazard follows these steps:

1.2.2.1. Exposure

The first step is to identify the elements (sensitive assets) that are potentially exposed to the hazard: maps showing communities, infrastructure and land use are combined with the hazard maps using GIS techniques to identify the elements exposed to each of the hazards.

The 'elements' considered in this study are:

- Communities (demographic maps)
- Buildings (infrastructure maps)
- Agricultural land use (land use maps) /agricultural systems (agriculture survey)

1.2.2.2. Sensitivity indices

Where sensitivity refers to "the physical predisposition of human beings, infrastructure , and environment to be affected by a dangerous phenomenon due to lack of resistance and […] intrinsic and context conditions making it plausible that such systems once impacted will collapse or experience major harm and damage" (IPCC 2012).

Sensitivity of the elements potentially damaged by the effect of hazards is assessed using various indicators that are subsequently combined into sensitivity indices. Three separate indices are constructed to express respectively physical, economic and social sensitivity to each of the hazards considered in this study. General steps for the construction of a composite sensitivity index are:

- Inventory of data sources
- Assessment of data quality
- Selection of indicators
- Describing indicators and their relation to physical, social and economic sensitivity for each hazard
- Valuing indicators
- Normalisation of indicators, to allow operations (multiplications…) between them. One step further is standardization, transforming indicators into a consistent ordinal or unit-less scale to make them comparable to one another
- Assigning weights to indicators
- Calculating cumulative scores: the normalized or standardized indicators are averaged or added together to obtain a synthetic sensitivity score
- Defining categories for sensitivity reclassification (normalisation).

An overview of the indicators selected to constitute physical, social and economic sensitivities is given in the following paragraphs.

Social sensitivity

The social sensitivity Index is an aggregate view of a suite of variables that provides a sense of a community's overall sensitivity to climate change induced hazards. An appropriate suite of indicators is chosen based on the literature, taking in account the particularities of PNG and consistently with the available data. This is show in Table 1.

Social sensitivity of a community is assumed to be the same regardless of the hazard at hand. This is to say that a community in poor health or lack of education will increase equally the impact of the damage caused by a potential disaster, whichever it is.

Table 1. Overview of social sensitivity indicators and data

	Sensitivity Indicators (hazard dependent or not)	Geographic data	Format
Social Sensitivity	- Child and maternal health - Malaria incidence - Population density - Population dependency (age) ratio - Literacy rate	Population spread, according to census and building distribution.	- Health centre points - Census unit points - 2 x 2 km grid

Demographic indicators were calculated based on demographic statistics at census unit level received from the National Statistical Office (Census 2011). Following indicators were used:

- Population density (people/km2)
- Age dependency ratio: population below 15 and above 65 years old, divided by the population between 15 and 65.
- Literacy in at least one language (% of population over 10 years old)

Health indicators are calculated based on health performance data provided by the Department of Health. Data are collected for each health centre and summary statistics of the various health indicators are available at district and provincial level. Following indicators were used:

- Percentage of Children Weighed at Clinics Less than 80% Weight for Age 0 to 4 years old (%)
- Percentage of Facility Births that are Low Birth Weight (<2500 grams) (%)
- Incidence of Diarrhoea in Children under 5 years old (/1000 pop. < 5yr)
- Incidence of Malaria (per 1000 pop.)

The two indicators regarding weight of infants and children were selected because they can serve as sensitive proxy indicators for nutritional status, food availability, variety and intake in a human population.

The two indicators concerning the incidence of disease (childhood diarrhoea and malaria) were selected because they can be considered as sensitive proxy indicators for the general health status of a human population. The incidence of malaria can also serve as a proxy indicator of lost productivity in a population.

Physical sensitivity

To assess the physical sensitivity of infrastructure and buildings, the study focuses on buildings, infrastructure, and critical facilities. Infrastructure includes transport systems (roads, bridges, airports, port facilities, etc.), utilities (water and electricity), and critical facilities (including hospitals and health centres, emergency services, key transport and communications systems, essential services).

Factors influencing physical sensitivity of the exposed elements include both generic factors and hazard-specific factors. The infrastructure sensitivity index is therefore assessed for each of the five hazards separately and expressed as a hazard-dependent sensitivity index.

Table 2. Overview of infrastructure sensitivity indicators and data

	Sensitivity Indicators (hazard dependent or not)	Geographic data	Format
Infrastructure Sensitivity	- Building characteristics - Infrastructure characteristics	Buildings (PCRAFI 2013) Special infrastructure (PCRAFI 2013)	Points (buildings and punctual infrastructure) Lines (roads)

Physical characteristics influencing building resistance to each hazard are first selected as sensitivity indicators. Table 3 below lists building characteristics affecting (decreasing or increasing) the potential impact of each hazard.

Table 3. Indicators influencing building sensitivity

N°	Indicator	Inland flooding	Coastal flooding	Cyclonic wind
1	Building defect	x	x	x
2	Foundation type			
3	Foundation bracing type			
4	Roof shape			x
5	Roof pitch			x

6	Roof material			x
7	Shutter type			x
8	Wall opening type			x
9	Wall material	x	x	x
10	Minimum floor height	x	x	

Temperature changes, drought and annual rainfall variations are considered without significant physical damage on buildings and infrastructure.

Information describing special infrastructure is limited. Only for roads and bridges, secondary modifiers were used that affect sensitivity to flooding and cyclonic wind hazards (Table 4). By default, other infrastructures without descriptive information were considered to have a constant sensitivity to the mentioned hazards, irrespective of their size or other particularities. Sensitivity is considered null for temperature changes, drought and annual rainfall variations.

Table 4 Indicators influencing road and bridge vulnerability

Indicator	Inland flooding	Coastal flooding	Cyclonic wind
Road surface (dirt, gravel, sealed)	x	x	x
Road condition (good, fair, poor)	x	x	x
Bridge type (ford, steel, wooden, concrete…)	x	x	

For building, each indicator is given a score corresponding to the building characteristics. These indicators are valued according to interview/surveys and literature (Table 5). Indicators are then aggregated for each building, taking into consideration its different characteristics.

Table 5 Building sensitivity indicators scores

Attribute name	Description	Value	Legend	Sensitivity Inland Flooding	Sensitivity Coastal Flooding	Sensitivity Cyclonic Wind
Defect	Describes defects in the building structure that may compromise its strength	1	Minor	0	0	0
		2	Major or Uninhabitable/poor construction	1	1	1
		8	None or under construction	2	2	2
WallMat	Material used to clad the walls of the buildings occupied levels	2	timber & masonry/concrete	1	1	1
		7	traditional	2	2	2
		8	none	2	2	2
		9	complex/other	1	1	1
		10	masonry	0	0	0
		30	plywood sheet	2	2	2
		40	timber board	1	1	1
		50	fibre-cement sheet	2	2	2

Attribute name	Description	Value	Legend	Sensitivity Inland Flooding	Sensitivity Coastal Flooding	Sensitivity Cyclonic Wind
		60	metal sheet	1	1	1
		80	concrete	0	0	0
Roof Shape	Roof shape	1	MONOPITCH	-	-	2
		5	ARCH	-	-	0
		20	GABLE	-	-	2
		30	HIP	-	-	1
		40	COMPLEX	-	-	1
Roof Pitch	Angle of the roof	1	FLAT (0§)	-	-	2
		2	LOW (1§-25§)	-	-	2
		3	MODERATE (25§-45§)	-	-	0
		4	STEEP (>45§)	-	-	2
		9	COMPLEX	-	-	1
Roof Mat	Roof material	1	metal	-	-	0
		2	concrete	-	-	0
		7	traditional	-	-	2
		9	complex/other	-	-	1
Shutter	Describes whether the windows have cyclone protection	10	none/partial/unknown	-	-	2
		20	present	-	-	0
		21	grill	-	-	1
Min FloorH	Minimum floor height of the lowest living level above ground (meters)	1	0-0.1m	2	2	-
		2	0.2-0.3m	2	2	-
		3	0,4-1,0m	2	2	-
		4	1.1-3m	1	1	-
		5	>3m	0	0	-
Wall Open	Describes the amount of windows or if the structure is open (wall opening type)	10	<75% of wall is windows	-	-	1
		11	>75% of wall is windows	-	-	2
		20	Open space	-	-	2
		21	No windows	-	-	0

For special infrastructure Indicators are valued for bridges and roads in relation with their characteristics (Table 6 and Table 7).

Table 6 Bridge sensitivity indicators scores

Type	Sensitivity to Flood	Sensitivity to Wind
Causeway	0	0
Concrete	1	0
Culvert	0	0
Ford	0	0
Steel	1	1
Wooden	2	1

Table 7 Road sensitivity indicators scores

Condition	Surface	Sensitivity to Flood	Sensitivity to Wind
Good	Dirt	1	0
Good	Gravel	1	0
Good	Sealed	0	0
Fair	Dirt	2	0
Fair	Gravel	1	0
Fair	Sealed	1	0
Poor	Dirt	2	0
Poor	Gravel	2	0
Poor	Sealed	2	0

For other special infrastructures, we assume maximum sensitivity index by default (=2). We make the assumption that the size of the infrastructures (small, medium or large airport/mine etc) does not influence the sensitivity factor.

However, some infrastructure are intrinsically less sensitive than common buildings. For example, a mine does not lose all value in the event of a flood or a storm, even a strong one. Therefore, a sensitivity index of 2 will not mean a loss fraction of 100%. Also, roads or airstrips are intrinsically less sensitive than buildings, in the sense that, in most scenarios, they do not risk total destruction. This is taken into account when estimating potential damage.

Indicators for the sensitivity of buildings and of special infrastructure where aggregated into a composite physical sensitivity index for each hazard.

The composite building physical sensitivity index (PSI) is calculated as a weighted average that gives more importance to the "defect" indicator, which is assumed to be the most critical secondary modifier to affect the vulnerability to disaster. Physical sensitivity is calculated as the average between the index associated to defect and the average of all other indexes associated to other indicators.

Economic sensitivity

The aim of an economic sensitivity assessment is to unveil the economic consequences associated with natural disasters and the potential extend of damage to economic assets and related aspects in key economic sectors. According to Papua New Guinea investment promotion authority (IPA), the main "economic sectors in Papua New Guinea are agriculture and livestock, forestry, mining and petroleum, tourism and hospitality, fisheries and marine resources, manufacturing, retailing and wholesaling, building and construction, transport and telecommunications, and finance and business trade" (IPA 2017).

The economic sensitivity assessment depends strongly on the availability and refinement of the data. Identifying national databases with economic parameters for the country on provincial level (or lower) has been difficult. Because of this, and because agriculture is the main economic activity and since most of the population rely on their own production for their livelihood, the economic sensitivity analysis focuses on the agricultural sector. Sensitivity of the commercial and the industrial sectors, including mining, are already assessed by the physical sensitivity component and double counting should be avoided. Indirect damage to the different economic sectors is not taken into consideration here, because of the lack information on the disruption or inactivity duration caused by the different hazards. Such indirect damage includes for example economic losses due to transport disruption, market change or destruction of the means of production. Given the fact that duration information is essential for such economic loss calculations, indirect damage cannot be quantified in the framework of this project.

The main crops and agricultural activities in the province were identified. The potential impact of climate change induced hazards on these crops was assessed based on information gathered in the framework of interviews and literature reviews.

Data sources used for this task include land use data (PNG Resource Information System (PNGRIS) and Mapping Agricultural Systems of PNG (MASP). Crop replacement costs are also necessary for the vulnerability assessment and were collected from the PCRAFI study (PCRAFI 2013).

Factors influencing economic sensitivity of the exposed elements include both generic factors and hazard-specific factors. Those sensitivity indexes are therefore assessed for each of the five hazards separately and expressed as a hazard-dependent sensitivity index.

Table 8. Overview of economic sensitivity indicators and data

	Sensitivity Indicators (hazard dependent or not)	Geographic data	Format
ECONOMIC Sensitivity	- Crop tolerance to climatic changes - Plantation tolerance	Agricultural survey (Australian National University) PCRAFI-PacRIS Land Use/Land Cover (agricultural area)	Agricultural system and plantation polygons

Crop information was retrieved for each agricultural system described in the MASP surveys. Some areas were designated as plantations without crop specification. Intersecting with land use information from PNGRIS, these zones were assigned a plantation type (e.g. Palm Oil, Coconut, Banana…). Where those two sources of information did not match, surveyed “plantation” systems (according to MASP) were labelled as forest or open spaces on the land use map. For these areas, no assumptions could be made for a specific crop.

Tolerance of each plant variety to characteristic ranges of climate conditions was evaluated by means of expert knowledge, literature and data review. The selected climate variables corresponding to the hazard understudy are listed in Table 9.

Table 9. Indicators for crop tolerance assessment

Temperature ranges (∘c)	–0 1–10 10–20 20–30 30–40
Inland flood depth (m.) *(without flow)*	<0.5 0.5–5 5–10 >10
Sea level rise (m) *(assumes salinisation of groundwater)*	<0.5 0.5–5 5–10 >10
Annual rainfall (mm.) *(assumes relatively even distribution)*	0–500 500 – 1000 1000 – 3500 3500 – 5000
Max. Consecutive drought (days)	0–14 14–30 >30

Cyclonic winds (km/hr)	0–60 60–120 >120

In order to simplify the weighing system and the aggregation procedure of crop indicators in each agricultural system, these indicators were reduced to a reduced selection (Table 10).

Table 10. Selection of indicators for crop tolerance assessment

Indicator	Critical range/threshold
Inland flood depth (without flow)	> 0.5 m
Sea level rise (assumes salinization of groundwater)	> 0.5 m
High annual rainfall (mm.)	3500 – 5000
Max. Consecutive drought (days)	14–30
Cyclonic winds (km/hr)	60–120

Crop tolerance was evaluated for the major crops listed in the MASP database, for each hazard, on a scale from 0 to 2 (0 = Tolerant; 1 = Moderately tolerant; 2 = Intolerant). Based on their characteristics, the key crops were attributed low, medium or high tolerance scores taking into account their hazard-dependency and based on available literature.

Table 11 gives the tolerance scores for critical ranges of 8 climate hazards for staple crops. Tolerance of other crops, fruit, vegetable, nut types was also assessed and scored. The complete table of tolerance scores can be found in Annex 3.

Table 11. Tolerance score for staple crops

	INLAND FLOOD DEPTH (m.) ***(without flow)***	**SEA LEVEL RISE (m)** ***(assumes salinisation of groundwater)***	**LOW ANNUAL RAINFALL (mm.)** ***(assumes relatively even distribution)***	**HIGH ANNUAL RAINFALL (mm.)** ***(assumes relatively even distribution)***	**MAX. CONSECUTIVE DROUGHT (days)**	**CYCLONIC WINDS (km/hr)**
Critical range	*0.5–5*	*0.5–5*	*0–500*	*3500 – 5000*	*14–30*	*60–120*
Banana (Musa cvs)	1	2	2	1	2	2
Cassava (Manihot esculenta)	2	2	0	1	0	2
Chinese taro (Xanthosoma sagittifolium) also Cocoyam/Tannia	2	2	2	1	2	2
Coconut (Cocos nucifera)	2	0	2	1	1	2
Sago (Metroxylon sagu)	1	2	2	1	1	2
Sweet potato (Ipomoea batatas)	2	2	2	1	2	0
Taro (Colocasia esculenta)/ dasheen	1	2	2	1	2	2
Yam (Dioscorea alata)	2	2	2	0	0	2
Yam (Dioscorea esculenta)	2	2	2	0	0	2

The objective of this step of the methodology was to assign a sensitivity (or tolerance) score to each crop in all agricultural systems. Each crop has a different relative importance inside the system and a different replacement cost. Therefore, sensitivity was not aggregated at grid cell level at this stage. When computing the vulnerability index of each grid cell (see Part 3), vulnerability has to be aggregated for all crops according to (1) their predominance in the system (proportional to the surface area), (2) their replacement cost (value associated to a total loss), (3) in the case of flooding, whether or not they are exposed.

To give a notion of the most represented crops, the relative importance of each staple crop is show in Figure 2 as the proportion of agricultural systems where the crop is present.

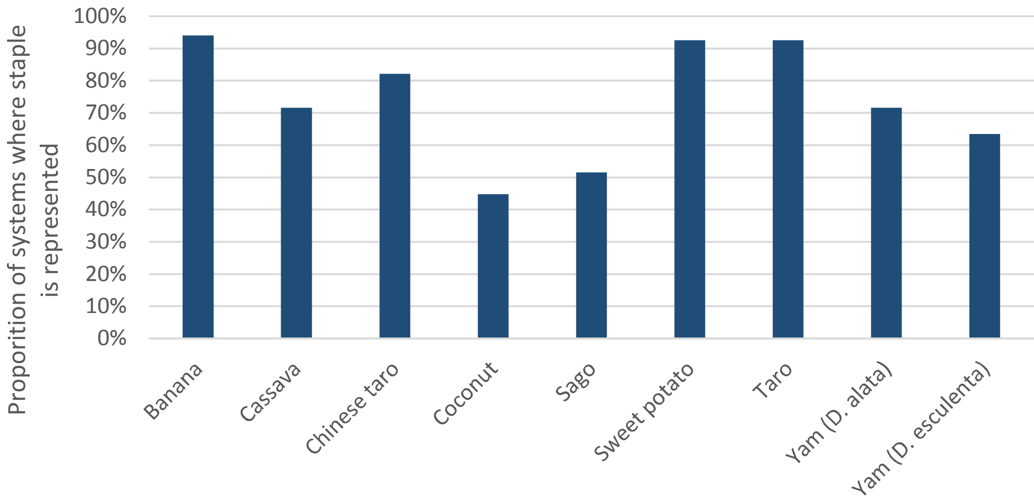

Figure 2. Representativeness of each staple crop across all systems

Some general comments on the chosen indicators are given in Table 12.

Table 12. General comments of crop tolerance scores

Indicator	Comment
Temperature ranges (∘c)	Temperature and altitude are related. In PNG, the temperature difference per 1,000m of altitude is 5.2∘C. The temperature tolerance of crops determines the altitudes at which they can be grown. For most of these crops, except notably coffee, a rise in temperature will extend the area at which they can be grown, as long as the supply of water is adequate..
Inland flood depth (m.)	The effects of flood on crops are functions of depth, the period of inundation and the velocity of flow. Most crops, for example, can withstand a day under 50 cm of water, if it drains away rapidly thereafter. With flowing water, even 10 cm can flatten a crop and remove the soil. Since most inland flood is caused by rivers breaking their banks, the effect of velocity is the most critical, but also the least studied. Trees can withstand deeper floods, but still only for very short periods in most cases.
Sea level rise (m)	Most of the tolerance scores relates to a crop's tolerance to salinity in the soil. Tidal surges, due to storms, will have immediate effects similar to river floods (lodging of plants, erosion of soil). They will also leave behind salt residues in the soil, which may last for a considerable time before rain leaches it out. The longer term problem is the effect that mean sea-level rise has on subterranean water reserves. This excludes salt-intolerant crops from being grown on that land for the future. This is a growing problem on the coasts. Certain important crops (e.g. cocoa, papaya, banana) can be adversely affected even by salt born on the wind)
Annual rainfall	Average annual rainfall requirement is a very rough measure. Its distribution through the

(mm.)	year is important. Most tropical crops benefit from an even distribution of rain throughout the growing season.
Max. Consecutive drought	For annual crops, this vulnerability data relates to the growing season. Many perennials are accustomed to a dry season. Even for annuals, the period at which a drought occurs can determine its resistance. Some crops (e.g. coffee) require a dry spell at certain stages of development (such as flowering); others can tolerate drought except at critical periods in their development (e.g. just after planting).
Cyclonic winds	A wind speed of about 60 km/h seems to be a dividing line between a tolerable wind and a destructive one. Lowe, ground-covering plants, such as sweet potato, are less susceptible to high wind. Trees offer more resistance and are more prone to breaking branches or uprooting. Nonetheless, tall, native coconut palms, which have evolved under cyclonic conditions, are more resistant than recently developed dwarf varieties. Breadfruit may be uprooted but has an outstanding capacity or regenerate. Cyclones are often followed by periods of drought, which can be more damaging to many crops than the storm itself.

Tolerance scores can only take index values of 0, 1 or 2. Normalisation is therefore not needed.

1.2.2.3. Vulnerability maps

Vulnerability is interpreted here as the potential damage of the hazard. Potential damaging effects of a hazard are estimated as the product of the maximum potential loss (exposure) and sensitivity. To this end, sensitivity is expressed as an index (1 to 5) or a percentage (loss fraction).

For physical, economic and agricultural vulnerability assessment, the maximum loss associated to the exposed assets (buildings, crops, …) is estimated by their replacement cost. In the case of social vulnerability, maximum loss is the estimated number of exposed people. In order for vulnerability to be mapped and allow visual interpretation, it is scaled into five categories: very low, low, medium, high and extreme.

Finally, vulnerability should be divided by a factor accounting for the coping capacity (C) of the community at large. For physical and agricultural aspects, vulnerability (V) can be expressed as a function of sensitivity (S) (Equation 1).

$$\boldsymbol{V_{PHY\ or\ ECO}} = \frac{\boldsymbol{Maximum\ damage} \times \boldsymbol{S_{PHY\ or\ ECO}}}{\boldsymbol{Capacity}}$$

Equation 1 Expression of physical/economic vulnerability

Social vulnerability is proportional to exposed population (Equation 2).

$$\boldsymbol{V_{SOC}} = \frac{\boldsymbol{Number\ of\ exposed\ people} \times \boldsymbol{S_{SOC}}}{\boldsymbol{Capacity}}$$

Equation 2 Expression of social vulnerability

Capacity was not computed at this stage and vulnerability was mapped with a homogeneous capacity of 1 which could be adjusted in the future when more information becomes available.

For each hazard, a set of maps depict the respective vulnerability index for each relevant components: physical, social and economic. Social vulnerability is assumed not hazard-dependant, so the same social vulnerability map is considered for all hazards. Buildings are considered not vulnerable to drought: drought is primarily relevant for the economic damage caused to crops. Physical and social vulnerabilities were thus not assessed for drought hazard. In the case of intense rainfall, building physical sensitivity and population social sensitivity were not assessed but a single indicator reflecting population density is used to account for the damage caused by heavy rainfall in urban areas ("urban vulnerability"). Conceptually, this indicator should reflect damage to both buildings and human lives.

Table 13. Relevant risk components per hazard

	Physical vulnerability	Social vulnerability	Economic vulnerability
Drought		x	x
Intense rainfall		x	x
Inland flooding	x	x	x
Coastal flooding	x	x	x
Extreme Weather	x	x	x

Social vulnerability

The social component of vulnerability focuses on the exposure of social groups or individuals to stress as a result of environmental change, where stress refers to unexpected changes and disruption to livelihoods. This definition emphasizes the social dimensions of vulnerability following the tradition of analysis of vulnerability to hazards.

Social Sensitivity is associated with the population exposed to hazard, and how the people's characteristics and conditions will affect their resiliency to the hazard. Social sensitivity and vulnerability mapping is therefore based on the distribution of communities and population. Census data is associated to so-called census units. GPS coordinates are available for these census units but they offer poor visualization because they represent communities various sizes (rural vs urban).

In order to map the social sensitivity, the social indicators were linked to the census units located on the map. The 7 social indicators described above are expressed in different units (number of cases per 1000 people, percentage of births, percentage of young children etc.). In order to aggregate them into a single index, they were normalised, though simple ranking.

In order to represent a more realistic spread of the population on the territory, population density was associated with location of buildings and population was subsequently reaggregated per grid cell (2 by 2 kilometres).

The results for each grid cell finally were reclassified into 5 social vulnerability classes for mapping.

Physical vulnerability

To calculate vulnerability, we estimate the potential damage to each building (or building cluster) *b* by multiplying their sensitivity index (S) - ranging from 0 to 2 - by their replacement cost (RC). Sensitivity is hazard specific, and so is the potential damage to each building.

Vulnerability is proportional to the potential damage associated to a certain hazard and is expressed in monetary value as to make it comparable (and additive) with infrastructure vulnerability. Because the sensitivity index is not expressed as a percentage, and because replacement cost is only but a gross estimation of damage loss, this calculated "potential damage" value has little monetary meaning but, scaling the index so, allows us to express building and infrastructure vulnerabilities in the same units.

Vulnerability is computed for exposed buildings only. For cyclones, all buildings are considered exposed, but for flooding, it reduces considerably the number of buildings taken into consideration.

To calculate infrastructure vulnerability, interpreted here as the potential damage to a structure, the sensitivity index of each infrastructure type is multiplied with their value, or replacement cost.

Roads are intrinsically less sensitive than buildings: a maximum sensitivity score of 2 does not mean total loss of the road whereas it can be the case for a building or a minor infrastructure. Therefore, road sensitivity was divided by 4 in order to balance more realistically their influence in the aggregated vulnerability index.

For the computation, linear and punctual infrastructure need be distinguished because the replacement cost of linear infrastructure such as roads is expressed in $/km (Table 14), whereas the replacement costs of punctual infrastructures are absolute values ($)(Table 15, Table 16 and

Table 17).

Table 14. Replacement cost for roads

Surface	Replacement cost ($/km)
Dirt	100,000
Gravel	250,000
Sealed	500,000

Table 15. Replacement cost for bridges

Type	Replacement cost ($)
Concrete/Steel	10,000
Steel	10,000
Wooden	1,000
Causeway/Ford/Culvert (insensitive)	-

Table 16. Replacement cost for airstrips

Type	Replacement cost ($)
Airstrip	10,000

Table 17. Replacement cost for special infrastructure

	Maximum loss fraction	Replacement cost ($)	Equivalent PCRAFI
AIRPORT	0.5	100,000	Small airport
CHEMICAL	1	10,000	Storage tank
CROP	0	-	Counted in economic vulnerability
ELECTRICITY - Generator	1	1,000	
ELECTRICITY - Substation	1	500,000	
FUEL	1	20,000	
MINE	0,5	10,000	Small mine

OTHER TRANSPORT	1	30,000	Bus station
PORT	0,5	5,000	Small port
PRODUCE	1	10,000	Storage tank
TELECOMMUNICATION	1	5,000	communication
UNKNOWN	0	-	
WASTE WATER - Treatment ponds	1	2,000,000	Water Treatment
WASTE WATER - Others	1	10,000	Storage tank
WATER - Treatment plant	1	2,000,000	Water Treatment
WATER - Pump station	1	40,000	Water intake
WATER - Others	1	10,000	Storage tank

For visualization, physical vulnerability is finally aggregated at the 2 x 2 km grid cell level, summing up potential damage for all buildings and infrastructures in it.

Since potential damage of a building/infrastructure is the product of sensitivity and replacement cost of this building/infrastructure, we can see this aggregation method as a weighted sum of sensitivity, using replacement costs as weights. Vulnerability depicted in a grid cell will naturally also depend on the number of buildings and infrastructures located in it.

This physical vulnerability index accounts only for the value of physical property and not for societal value or indirect damage that can be caused by the destruction of buildings. In particular, no weight is currently given to the different types of infrastructure other than their sensitivity factors and replacement cost. We might think that damage to some special infrastructure will generate bigger loss than the direct damage to the buildings and installations. More weight could be attributed to schools, aid posts, hospitals and police station that have a societal value that might exceed their replacement cost. This is not accounted for at the moment. Note as well that such buildings are likely to be reported in both the building and the special infrastructure databases.

It should be kept in mind that some infrastructures might overlap with economic indicators (mines, power plants, communications…). To avoid double counting, we assume that their economic sensitivity is approximated by their replacement cost and therefore already accounted for in the physical vulnerability. Economic sensitivity considers agricultural activities only. Doing so, indirect costs associated with the loss of commercial, social, communication and industrial infrastructure are ignored.

To produce an index easy to visualize, we can convert potential damage monetary estimates into an ordinal index. This vulnerability index can be obtained by reclassification, using a certain number of classes, and quantile, natural jenks or other bins.

In agreement with the uncertainty associated with the index and for good visual results, we choose to produce 5 classes (1 to 5).

Physical vulnerability is computed and shown only for a selection of pixels which contain exposed buildings or special infrastructures, or both. Vulnerability for the empty pixels is therefore considered as “no data” and does not appear on the map. Cells containing assets but with vulnerability equal to zero will, however, appear in blue shade (“very low vulnerability”).

To ensure consistency between cyclone and flood risk maps, classification is based on the same bins for flood and cyclone risk, using the flood layer quintiles as baseline.

Economic vulnerability

In order to include potential damage of a hazard to agricultural systems in the vulnerability index, the theoretical value of agricultural activities must be estimated. Replacement cost of each individual crop in the system are estimated based on the results of the PCRAFI study (PCRAFI 2013), using average values. The vulnerability of a crop towards a certain hazard is obtained by combining their value and sensitivity (i.e. tolerance score). The overall average vulnerability of the system is the weighted average of all vulnerabilities of represented crops, according to their relative importance.

For each crop in an agricultural system, vulnerability towards a hazard is described as the potential damage caused by the hazard to the crop, in $/ha.

Replacement costs considered for staple crops, vegetable, fruit, nuts and narcotics in agricultural systems are the estimates for subsistence agriculture. Replacement costs for cash crops in each system and for plantation crops are the estimates for commercial agriculture.

Crop vulnerability has then to be aggregated for each agricultural system, making assumptions on the importance of each crop in the system. The aggregation is additional, using a weighted sum of the represented varieties.

There is some subjectivity in the weights as no precise information about the surface area effectively covered by each crop in the system was available. According to the significance of the “dominant” and “sub-dominant” descriptors, we assume the following hypotheses in order to determine the weights:

- Weights for dominant crops should have a minimum of 0.33 (one-third)
- Weights for subdominant crops should have a minimum of 0,1 and maximum of 0.33 (one-third)
- Weights for other present crops should be below 0.1

In order to give each system the same total weighting, regardless of the number of varieties represented in it, weights were adjusted as to reach a total of 100 %, with as consequences that:

- Weight for one dominant crop will be higher if it’s the only dominant crop (with other crops being equal)
- Weight for one subdominant crop will be higher if it’s the only subdominant crop
- The sum of weights for all represented crops should be equal to 100%, whenever possible given the other assumptions

Additionally, certain cash crops are mentioned as part of some agricultural systems (Cocoa, Coffee Arabica, Coffee Robusta, Oil Palm, Rubber, Chillies and Coconut), with only qualitative information on their importance: “none”, “minor or insignificant”, “significant”, “very significant”. These cash crops are taken into consideration only for significant and very significant cash crops in the system. When weighting the composite index, significant and very significant are assumed equivalent to subdominant staple crops (in terms of importance), with a weight between 10 and 33 %.

Based on these assumptions, weights are determined for dominant, sub-dominant (and cash crops) and other crops in each system.

Table 18. Weighting of crops in agricultural systems

	Weight dominant crops	Weight subdominant (and cash) crops	Weight other crops
Average (all systems)	0.43	0.15	0.01
Minimum	0.28	0.1	0.003
Maximum	86	0.33	0.023

It is not always possible to fulfil both the conditions of minimum 1/3 weigh for dominant staple crops and 100 % total of weights. Therefore, the weight for dominant crops is sometimes as low as 0.28 (instead of 0.33) in some cases (Table 18).

For the special case of plantations, only one variety is determined based on the Land Use/Land Cover layer, and a unique sensitivity is given for the whole area (w = 100%). Zones designated as plantation in the MASP but where no crop could be associated were ignored.

For drought, high rainfall and extreme weather, risk can be computed based on the vulnerability of each system/plantation as whole. The economic vulnerability of a grid cell is the one associated with the system with the largest surface area, if more than one.

In the case of inland flooding, because the flood zone resolution is much higher than 2km, only the vulnerability of the flooded portion of the agricultural system inside each grid cell is taken into account: MASP systems and plantations are intersected with flood zones to determine exposure of the agricultural areas.

The resulting vulnerability index can be expressed in $/ha but does not represent total potential monetary loss because no information was available about the exact surface area covered by each crop : the surface area of each system/plantation does not mean effective “garden surface area”. The MASP layer is an approximate representation of the zones where the described agricultural systems are the most representative. As a consequence, the vulnerability indexes only have a relative meaning.

The vulnerability value calculated above is expressed in $/h but has no meaningful monetary units because there is not enough information on crop and garden area, rotations etc. It is therefore reclassified into 5 manually-defined categories to allow a contrasting visualization. Categories are the same across all provinces and for all hazards (Table 19).

Table 19. Economic vulnerability reclassification

Potential damage class ($/ha)	Economic vulnerability
< 1000	Very low
1000 - 1500	Low
1500 - 2000	Medium
2000 - 3000	High
> 3000	Extreme

Figure 3 shows the distribution of MASP polygons in the five categories. The maximum at 12,037 $/ha in Figure 3 corresponds to the oil palm plantations and appears as considerably more sensitive than other systems because of the high replacement cost of commercial oil palm plantations (in opposition to subsistence replacement cost).

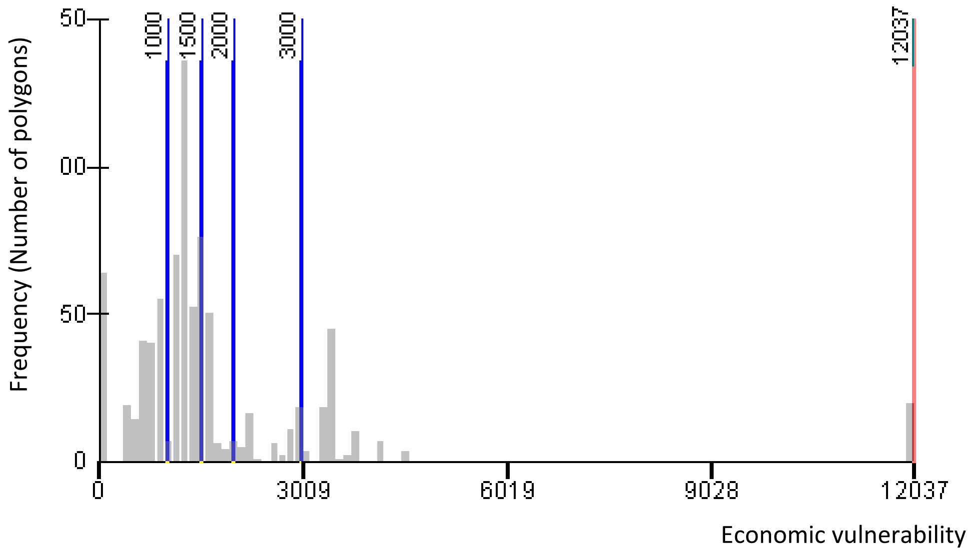

Figure 3. Frequency distribution of agricultural systems (MASP) and plantations vulnerability to extreme weather

This reclassified composite agro-economic vulnerability index can then be mapped based on the agricultural and plantation polygon of the MASP geo-database. Indexes are reclassified the same way for agricultural systems and for plantations in all the provinces, and for all hazards.

Because the polygons are much bigger than 2 x 2 km pixels, it was not deemed necessary to rasterise them at this stage. Agro-economic vulnerability values will however be associated to grid cells in the following steps, in order to compute the total vulnerability index combining physical, social and economic dimensions

Symbology

All mapped indices can be expressed qualitatively in terms of a hazard-dependent index scaled into three or more classes. Vulnerability and risk indices are classified according to 5 categories: very low, low, medium, high and extreme (Figure 4).

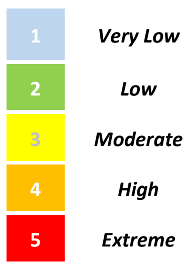

Figure 4. Vulnerability and risk classes

1.2.3. Risk assessment

Risk is defined by the United Nations International Strategy for Disaster Reduction as the combination of the probability of a hazardous event and its negative consequences which result from interactions(s) between natural or man-made hazard(s), vulnerability, exposure and capacity (UNISDR 2009).

Once the three vulnerability components (physical, economic and social) computed and mapped, risk is calculated as the product of the hazard index and the vulnerability index (Equation 3).

$$Risk = Hazard\ x\ Vulnerability$$

Equation 3. Risk calculation

Once the three vulnerability components (physical, economic and social) computed and mapped, risk is calculated as the product of the hazard index and the vulnerability index. A risk matrix allows consistent reclassification of the product operation between hazard and vulnerability.

Continuous hazard indicators are reclassified into five classes whenever possible, for consistency with vulnerability classes, and to smooth a bit more of the spatial variability of hazard levels (using only three classes, all provinces sometimes end up in the same category). The risk matrix becomes thereafter:

Hazard Potential damage	Vulnerability	Rare (1)	Unlikely (2)	Possible (3)	Likely (4)	Very likely (5)
Insignificant (1)	Very Low	1	2	3	4	5
Minor (2)	Low	2	4	6	8	10
Moderate (3)	Medium	3	6	9	12	15
Major (4)	High	4	8	12	16	20
Severe (5)	Very High	5	10	15	20	25

1.2.4. Composite risk

The overall composite risk map for the province has been derived from the risk maps for the respective hazards as presented in the previous chapter.

The map indicated areas that are exposed to multiple risks. To count the number of risks per pixel on the map, risks occurrence with values moderate, high or very high were counted. This results in the following categories. The area that are exposed to some very low of low risks for one or more hazards have received a value '0', areas that are not coloured on the map have not been characterised at risk for any of the considered hazards. All areas with a values 1 to 5 are have been identified as having a moderate (or higher) risk for 1 to 5 hazards. An example is shown in Figure 5.

Note: the maps in this report will be updated to count for coastal risk, at the moment this is not included and the maximum value on the map therefore is 4 and not 5.

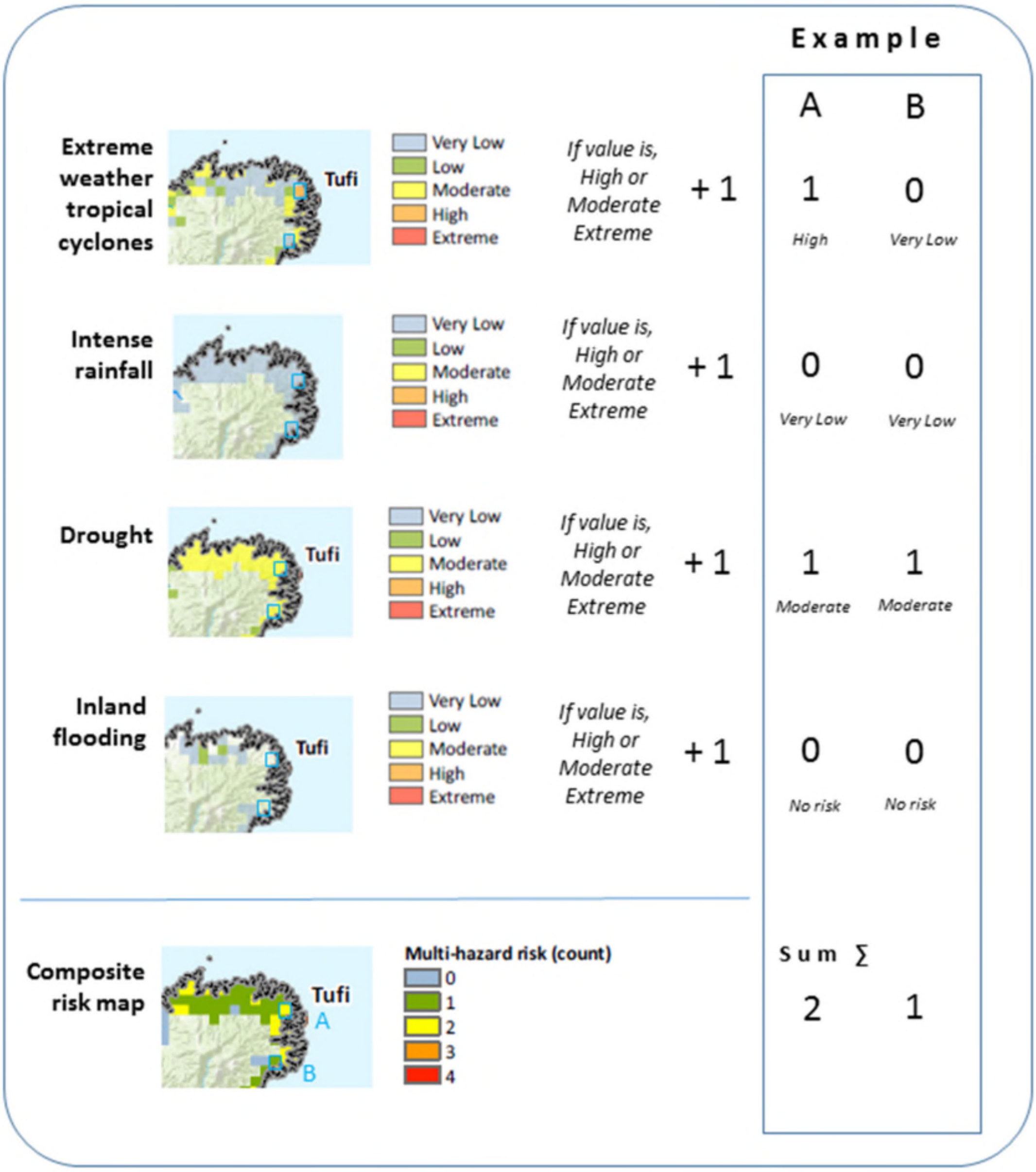

Figure 5. Example calculation of composite risk

1.3. Baseline information of Madang Province

1.3.1. Administrative

The Madang Province is located in north central Papua New Guinea along its northern coast and has the city of Madang as its provincial headquarters. It belongs to the Momase Region and it is composed from a total of six districts: Bogia, Madang, Middle Ramu, Rai Coast, Sumkar and Usino Bundi. Each district is in turn divided into Local-Level Government Areas (LLGs). There are a total of 19 LLGs in Madang Province.

Table 20. Number of wards per LLG

District	LLG	Number of wards	
Bogia District	Almani Rural	37	91
	Iabu Rural	15	
	Yawar Rural	39	
Madang District	Ambenob Rural	22	39
	Madang Urban	1	
	Transgogol Rural	16	
Middle Ramu District	Arabaka Rural	34	93
	Kovon	15	
	Josephstaal Rural	26	
	Simbai Rural	18	
Rai Coat District	Astrolabe Bay Rural	15	89
	Naho Rawa Rural	20	
	Rai Coast Rural	40	
	Nayudo Rural	14	
Sumkar District	Karkar Rural	33	64
	Sumgilbar Rural	31	
Usino Bundi District	Bundi Rural	22	66
	Gama Rural	13	
	Usino Rural	31	

Figure 6. Administrative map Madang Province

1.3.2. Topography

Madang province is located in north central Papua New Guinea along the northern coast. As described in the National Research Institute's *Papua New Guinea: District and Provincial Profiles* (2007), the Madang Province runs from the head of the Ramu River south to Saidor. Going inland, it covers the

Ruboni, Adelbert, Schrader, Bismarck and Finisterre Ranges, and the Ramu, Sogeram and Golgol Valleys.

Figure 8 shows the main rivers flowing through Madang Province. The most important rivers are Ramu, Sogeram, Gogol and Malas, that flow into the Bismarck Sea.

Figure 9 show the slope map for Madang Province. The slopes map is obtained by classifying the digital elevation model into three classes as presented in Table 21.

Table 21. Slope classes an occurrence in Madang Province

Slope (%)	Code
0-5	1
5-10	2
>10	3

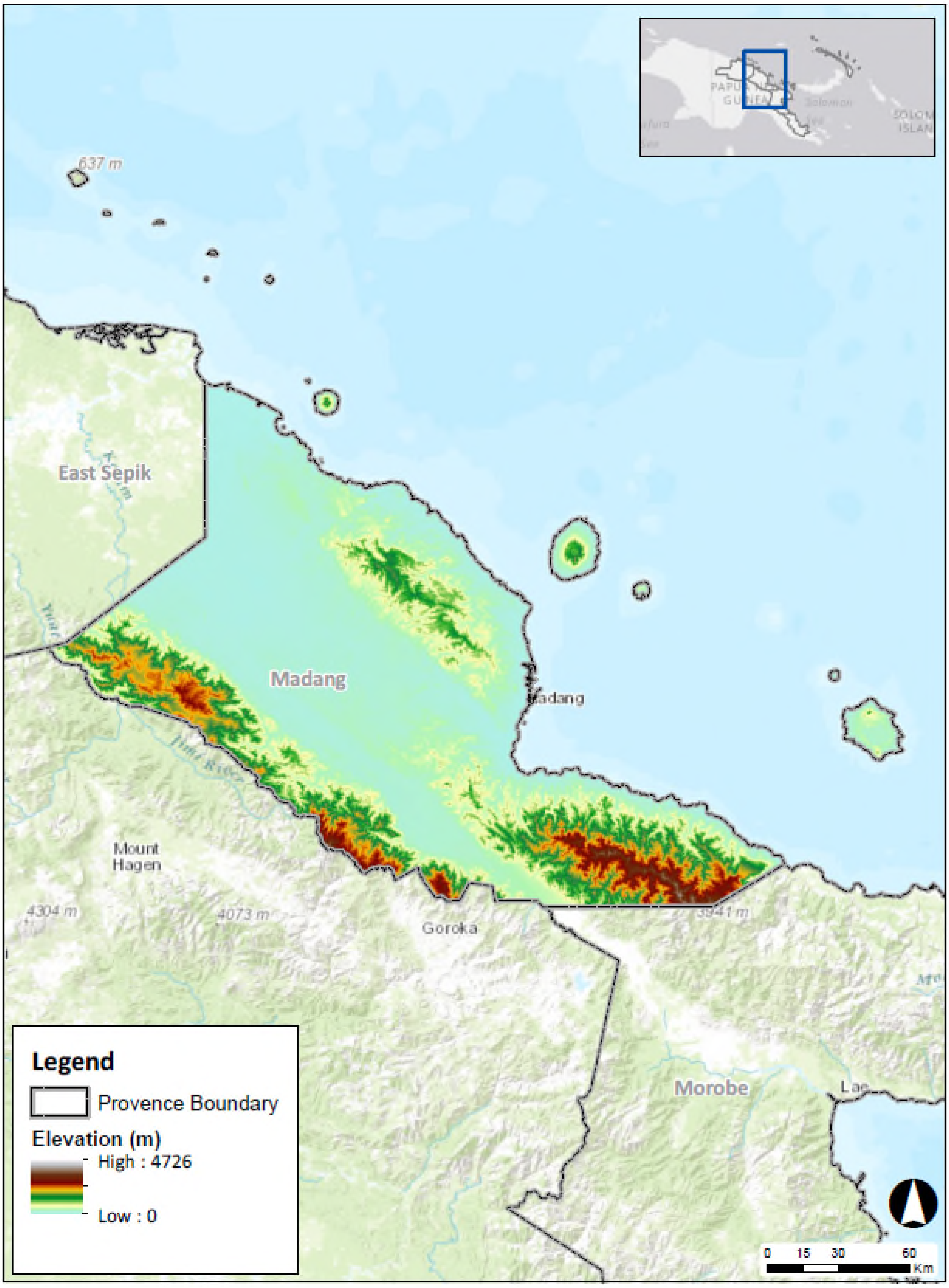

Figure 7. Elevation map of Madang Province

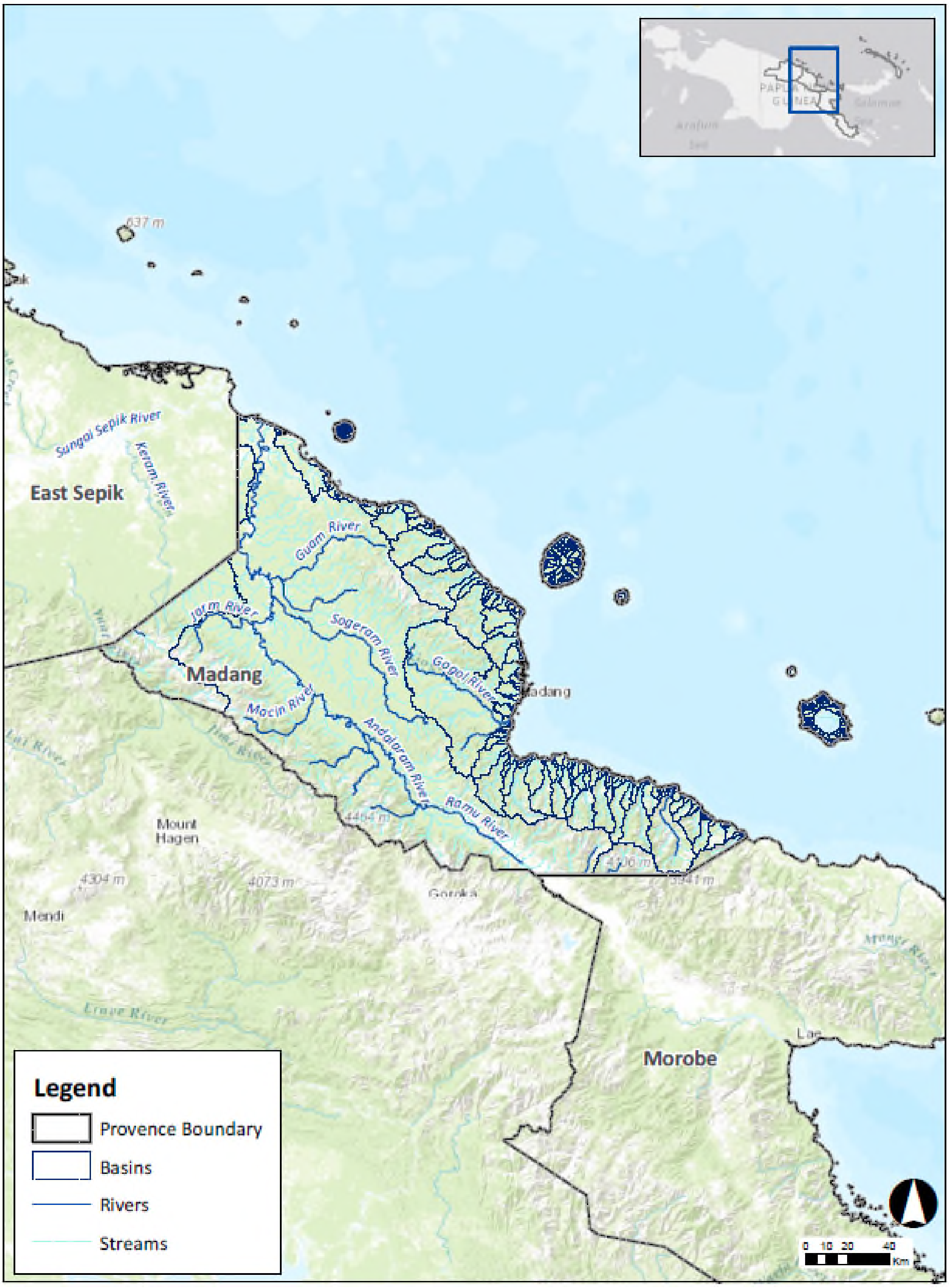

Figure 8. Main rivers in Madang Province

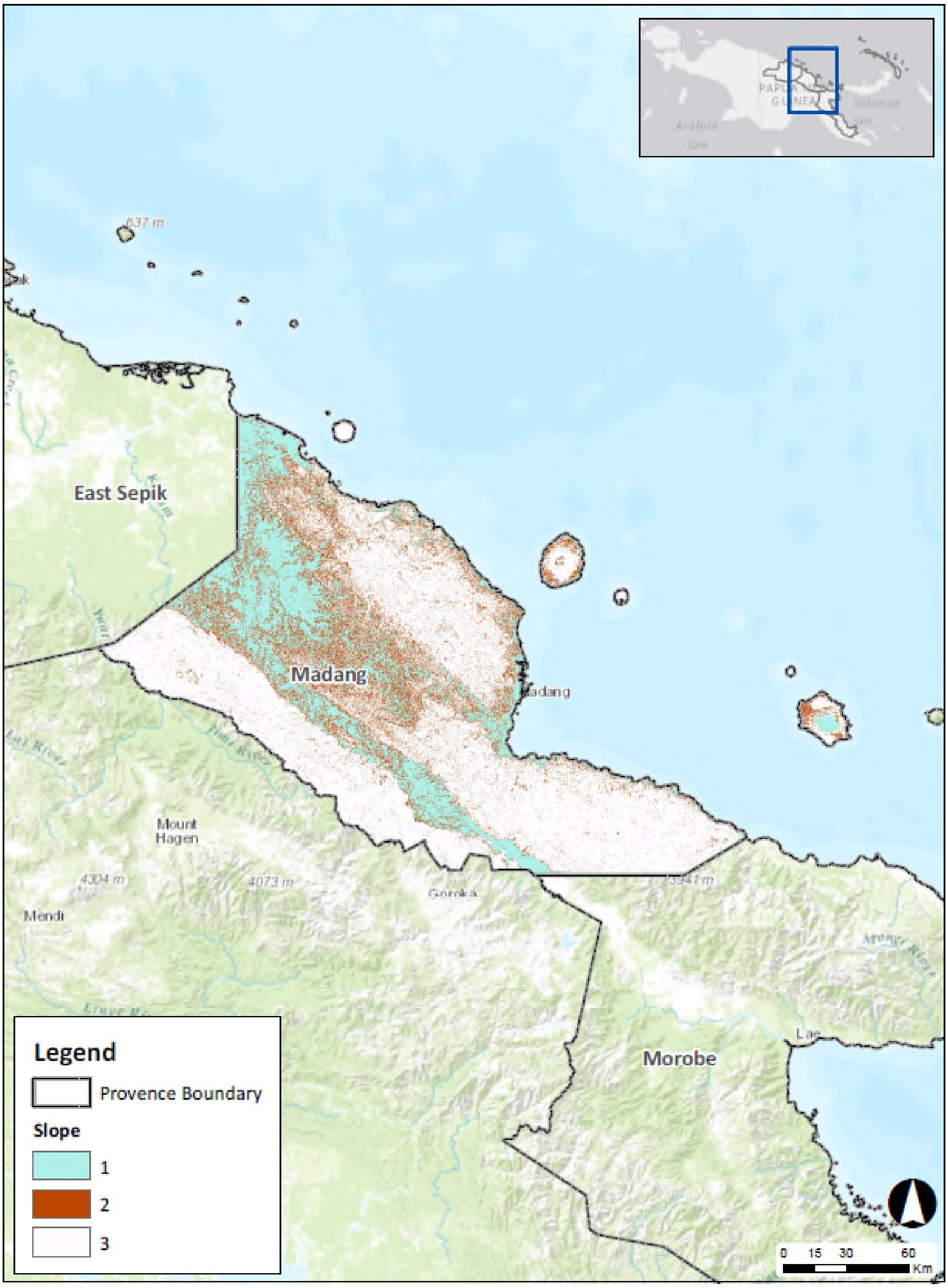

Figure 9. Slopes classification map for Madang province (from DTM, from SRTM-3, 90m).

1.3.3. Land use / land cover

Figure 10 show the soil cover map for Madang Province. About 56% of the province is marked as agriculture and just 1% for plantations. 43% of the province is classified as 'other' which is mostly forest or other uncultivated land. Economy in Madang Province, similarly to other provinces in Papua New Guinea, is strongly characterized by its agriculture production.

Figure 10. Land Use map Madang Province

1.3.4. Population and health

The Madang Province has a total of 493.906 inhabitants and 86.140 households according to the 2011 national census. It comprises the 6,8% of PNG's total population and has an annual growth rate of 2,7% for the period 2000-2011.

The Province consists of six districts, Madang District is found to have the highest population (110,978), which accounts for 22.5% of the total population of Morobe Province, whereas Usino Bundi District had the lowest population with approximately 12.3% (60,807).

The population density is 17 inhabitants per km^2, somewhat higher than the national average of 11. The average household size in the province is 5.7 persons.

Table 22. Population numbers per age group and per district

District	Age Group				
	Age not stated	0 - 4 yr	< 15 Yrs	15-64 yrs	> 65 yrs
Bogia District	927	56,271	157,612	215,947	8,436
Madang District	698	56,959	161,169	222,911	8,443
Middle Ramu District	830	51,954	145,854	200,500	7,801
Rai Coat District	577	45,692	129,129	178,727	6,913
Sumkar District	987	59,426	166,487	227,161	8,729
Usino Bundi District	448	47,163	134,528	177,595	6,794

The more densely populated LLGs are Madang Urban and Karkar Rural, followed by Ambenob Rural which is situated along the coast in the vicinity of Madang. This can be seen in Figure 11.

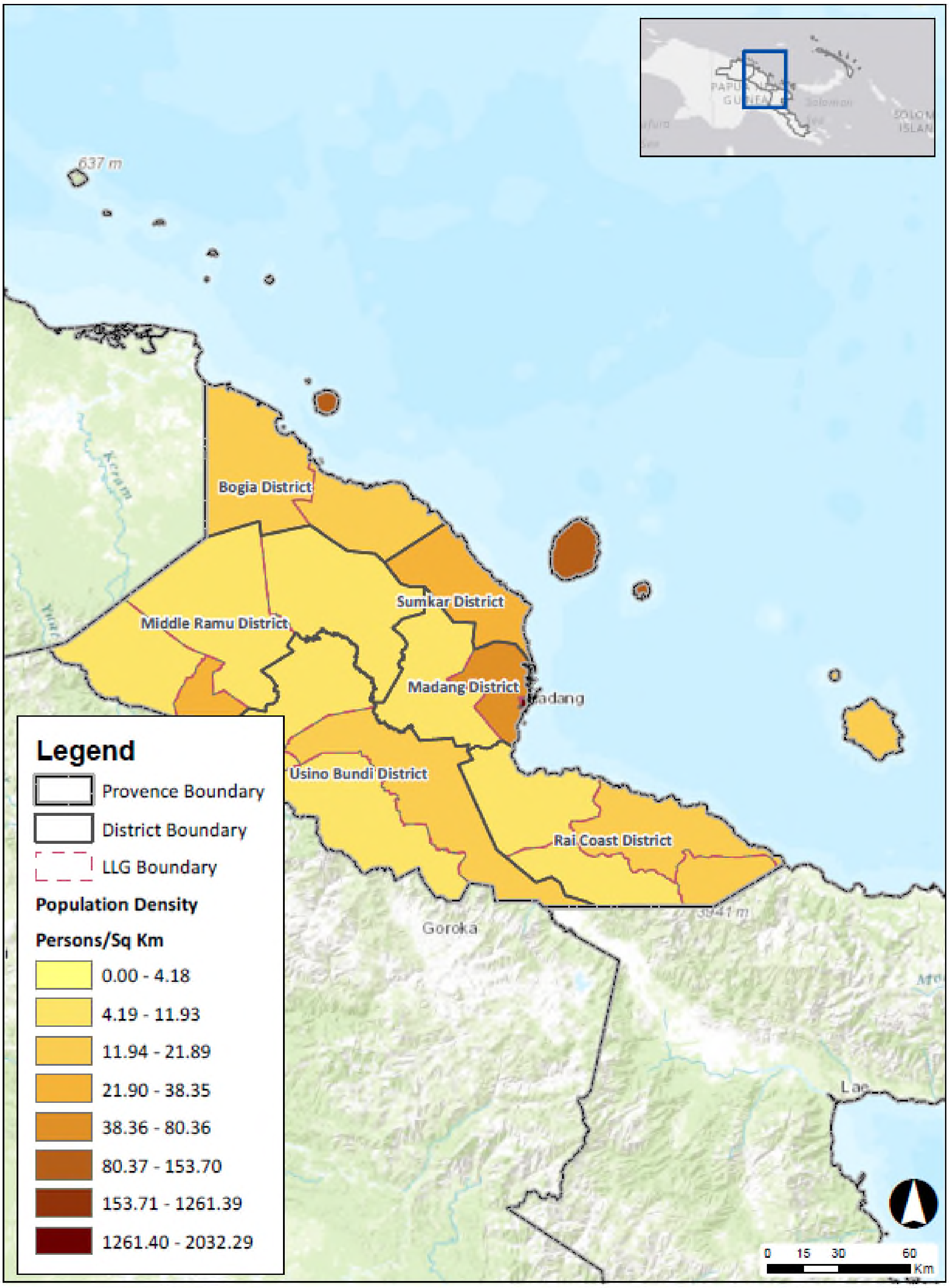

Figure 11. Population density map of Madang Province

Selected health indicators taken from the health performance report 2010-2014 for the province and its respective districts are shown in the Table 23, together with the national average.

Table 23. Selected Health Indicators for Madang Province (2014)

	Low Weight for Age < 5 years old (%)[4]	Low Birth Weight (%)[5]	Incidence of Malaria (1,000 population)[6]	Incidence of Diarrhoea (<5 years/1,000 pop.)[7]
Bogia District	38	14.5	153	126
Madang District	26	12.2	110	183
Middle Ramu District	49	6.3	112	88
Rai Coat District	32	8.1	79	75
Sumkar District	40	1.9	94	92
Usino Bundi District	37	4.5	284	246
Madang Province	**34**	**10.8**	**132**	**137**
National	**24.2**	**7.6**	**108**	**291**

Figure 12 shows the locations of health centers and aid posts in the province. There are a total of 180 aid posts and 47 health centres in the province. The percentage of children weighed at clinics is less than 80% of the normal weight for their age for districts in Madang Province during the period 2010 - 2014.

In 2014, Middle-Ramu District had the highest percentage of low weight for age children (49%), followed by Sumkar District (40%). Which are higher than the provincial and national averages of 34% and 24%, respectively. Usino-Bundi District had by far the highest reported incidence of diarrhoea in children under 5 years old and number of recorded cases of malaria. The Table 24 shows that, in Madang Province, Bogia and Usino-Bundi districts exhibit the highest sensitivity on health indicators.

Table 24. Number of Healthcare facilities per LLG

District	Aid posts	Health centres
Bogia District	29	8
Madang District	23	9
Middle Ramu District	35	8
Rai Coat District	41	7
Sumkar District	36	7
Usino Bundi District	16	8

[4] The indicator measures total number of children under 5 who have attended MCH clinic and weight less than 60% or 60% - 80% weight for age

[5] The indicator measures the proportion of those children that are born in health centres and hospitals and weigh less than 2500 gm.

[6] The indicator measures the total number of presentations to health centre/hospitals in the districts during the year, expressed as a ratio for every 1000 people in that district. The number is based upon clinical diagnosis, not RDT or microscopy

[7] The indicator measures the number of children under 5 yrs who seek care for diarrhoeal illness as a proportion of all children under five years. Diarrhoeal illness serves as an indicator of water quality,

food hygiene and personal hygiene.

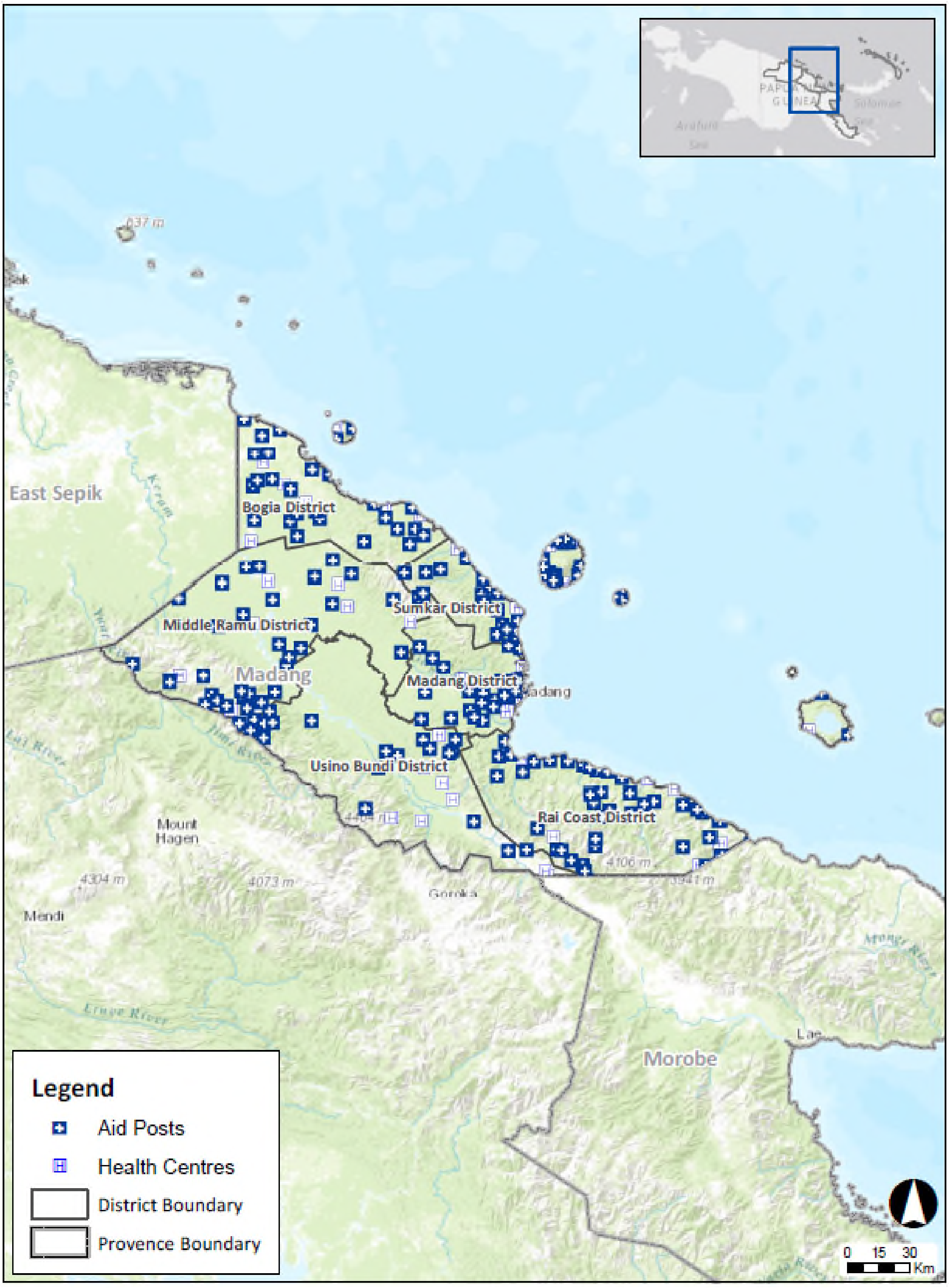

Figure 12. Location of health centers and aid posts in Madang Province

1.3.5. *Infrastructure*

Figure 13 shows the main road network in the province. The main roads classified as highway of national roads are connecting Usino Bundi District to Madang District, and Madang to Morobe Province. A large part of the province is not easy accessible by road.

Table 25 Kilometers of roads in Madang

	Highway	National Road	Provincial road
Km of roads in Madang	154.46	798.2	918.64

Table 26 Number of bridges in Madang

District	Number of bridges
Bogia District	21
Madang District	52
Middle Ramu District	0
Rai Coat District	18
Sumkar District	52
Usino Bundi District	34

Table 27 Total of public establishment

District	Aid posts	Health centres	Police stations	Airports	Schools	Religion	Government	Public facility
Bogia District	29	8	1	0	56	91	116	36
Madang District	23	9	4	1	45	160	234	77
Middle Ramu District	35	8	2	2	29	102	127	25
Rai Coat District	41	7	1	0	36	83	111	31
Sumkar District	36	7	2	0	39	100	133	34
Usino Bundi District	16	8	3	0	19	99	58	20

Figure 13. Road infrastructure in Madang Province

1.3.6. *Agriculture and livelihoods*

Economy in Madang Province, similarly to other provinces in Papua New Guinea, is strongly characterized by its agrarian nature. As an agrarian society, 80% of the people in PNG grow the food they eat while also growing cash crops. This means trade is also an important part of PNGs agrarian culture. Different varieties of crops from the Eastern Highlands are sold for lowland coastal residents and vice versa. Most popular cash crops are coffee, cocoa, coconut, banana and spices. There are 60.000 hectares coconuts in Madang Province and 71% of PNG's cattle are in Morobe and Madang Provinces, particularly in the Ramu Valley (Macfarlane, 2000/2006/2009).

Nonetheless, more than just agriculture moves the economy in Madang Province. There are currently, for example, two significant projects that play important roles in the economy of the province. These are the Ramu Nickel Joint Venture by the Chinese company Ramu Nico Management Limited, and the sugar plantation and factory project by the state-founded Ramu Sugar Limited company.

2. PROVINCE RISK PROFILE

2.1. Hazard Assessment

In this chapter we discuss the results of the analysis of climate data and projected climate, and we discuss the hazard maps produced for Madang Province for the five climate hazards considered in this study:

- Inland flooding (as a function of precipitation)
- Coastal flooding due to sea level rise
- Drought (as function of temperature and precipitation)
- Extreme weather events (tropical cyclones)
- Increase of precipitation intensities and variability

Hazard maps for each of the five hazards listed above indicate the areas likely to be affected by the hazard and provide an indication of its relative intensity.

2.1.1. Current and future climate

A brief review on Papua New Guinea's current climate and future prospections is available in the regional overview publication from International Climate Change Adaptation Initiative (ICCAI) (2011)[8]. The content of the publication is the result of a collaborative effort between the Papua New Guinea National Weather Service (NWS) and the Pacific Climate Change Science Program – a component of the Australian Government's International Climate Change Adaptation Initiative.

The key conclusions of the report are:

- Observed air temperatures depict a steady increase; it is expected that they will continue to warm resulting in more very hot days in the future.
- Rainfall observations since 1950 at Port Moresby do not show a clear trend, but observations at Kavieng seem to show a decrease in wet season. Projections on rainfall patterns, show an increase over this century with more extreme rainfall days expected.
- Tropical cyclones are not very frequent in the country; projections depict a further decrease on number of tropical cyclones with a slight increase in their intensities.
- Sea level observations have shown a clear rise in the recent past. This tendency will continue throughout this century.

Furthermore, the analysis of existing climate data and projected climate change reveals the following information:

- Based on observations carried out in Port Moresby since 1950, it can be concluded that a steady warming, averaging ~0.1 °C/decade, is taking place. Over the next decades, temperature is projected to continue to increase, with a projected warming of 0.4-1 °C by 2030 under a business-as-usual emissions scenario. By 2050, under such a scenario, a 1.1 – 1.9 °C warming is projected. Over the next 30-50 years, increases in the average temperature will result in more very hot days, with potentially severe impacts on agriculture and human health.

[8] Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview. Volume 2: Country Reports. Available from November 2011

- The limited available information on precipitation reveals that there is no clear long-term historical change in rainfall in Port Moresby, although elsewhere there has been a slight decrease. In line with expectations globally, precipitation is projected to increase in response to the warming of the atmosphere. More extreme rainfall days are expected, likely contributing to increasing frequency of inland flooding. The regional pattern and magnitude of the increase is, however, highly uncertain.
- Overall, trends in both rainfall and temperature are dwarfed by year-to-year variability.
- On a global scale, the frequency of tropical cyclones is projected to decrease overall, but the frequency of high intensity cyclones is projected to increase. The projections for PNG are consistent with global projections, with fewer but more intense storm events expected.
- Sea level rise is a serious consequence of climate change for Papua New Guinea. Under a business-as-usual scenario, by 2030, sea level in PNG is expected to rise2 by 4-15 cm. Combined with natural variability, such a rise would increase the impact of storm surges and the risks of coastal flooding. It is notable that these projections could be underestimations, due to uncertainties in projections of ice sheet melt.
- In addition to changes in climate, changes in land use may affect flood risk, for example through changes to catchment scale runoff and patterns of inundation. Since 1990, there has been a small degree of deforestation (reduction of forests from 31,523 KHa in 1990 to 29,159 KHa in 2007) and an increase in land used for agriculture (877,000 Ha in 1990 to 1,040,000 Ha in 2007). Changes in coastal land use may affect the risk and impacts of tidal flooding.

2.1.2. *Inland flooding*

The most relevant flooding features within the province are described in the following paragraphs. The description follows the river systems reaching the coastline from North to South.

The map for current inland flood hazard of the Province of Madang (Figure 14), shows that flood is expected along the northwest of the province, in the region around the boundary with East Sepik Province, in the floodplains of the Ramu and its tributaries like the Jarm, Amgurum, Guam and the Sogeram river that cross the Bogia, Middle Ramu and Usino Bundi District. In Madang Distric, the capital of the Province, flooded areas are expected along the downstream part of the Gongol river, which are areas with high population density.

The flood extensions produced by the projected scenario H40 are slightly larger than those produced by the current scenario HND (Figure 15). The limited variation in the flooded extensions between the current and the projected scenarios can be also due to the low horizontal (90m) and the vertical (1m) resolution of the SRTM model. In Madang Province, larger flooding areas are expected in some floodplains of the Sogeram and Ramu rivers that cross the Bogia, Middle Ramu and Usino Bundi District. In Madang Distric some larger flood area is expected in some tributary of the Gongol river.

The table below gives the flood areas (km²) for current and future climate conditions in the Madang province:

Table 28 Flood areas (km²) for current and future climate

Madang	HND	H40
T 0-5y	4157.3	4271.7
T 5-10y	64.6	75.3
T 10-50y	151.2	187.1
Total	4373.1	4534.1

During the community risk assessment (CRA[9]), 6 communities were visited in the Madang Province: Boroi, Butelgot, Aiome, Sepu, Boko, Wel-Sogeram, Lalok, Arenduk, Kumisanger and Koroba-Asas.

According to its CRA[10], the Boroi community, located in the north coast of the province (North of Bogia city), is exposed to inland flooding along the banks of the Boroi river, that drains from south to north towards the sea, parallel to the Ramu river (areas may remain flooded for days between December and Februari). However, the Boroi river is not accurately identified as part of the stream channel network derived from the flow accumulation map, this is caused by the low resolution of the SRTM (90m*90m, similar network obtained with 30*30m). The flooded area in the current or the projected scenario extends south east of the Boroi river, according to the risk map defined during the CRA.

According to their CRA, the Botelgot community (CRA[11]), located north of Madang city and the the Aiome community (CRA[12]), located north of Madang city, are affected by flash floods along the banks of the rivers and creeks. However, these rivers and creeks are no part of the stream channel network derived from the flow accumulation map, this is likely caused by the filtering step applied to remove any small river or creeks where the contributing watershed area is less than 30 km^2.

According to its CRA[13], the Sepu community, located in the north-east bank or the Ramu river, is exposed to inland flooding along the banks of this river (mainly flash floods between March and April). However, the estimated floodplains do not extend far from the river banks in the current or the projected scenario. This is probably caused by the low horizontal (90m) and the vertical (1m) resolution of the SRTM model.

The flooded areas around the Boko community are observed in this report, this is consistent with what is mentioned in its CRA[14] (along the Ramu, Mea and Boko river banks). However, the extension of these areas seem to be reduced.

The flooded areas around the Wel-Sogeram community are observed in this report, this is consistent with what is mentioned in its CRA[15] (along both banks of the Sogeram river). However, the extension of these areas seem to be reduced.

Limited flooded areas are observed around the Lalok community in this report, more extended flooded areas are expected along the banks of the Minzing and the Nambatu rivers, according to what is mentioned in its CRA[16].

Limited flooded areas are observed around the Arenduk community in this report, more extended flooded areas are expected along the banks of the Fufuruk and the Sagen rivers, according to what is mentioned in its CRA[17].

[9] Most communities are reported to suffer regular inland flooding events in their respective CRAs. While the estimated flood maps reported here are a good indication of their extension, they use a SRTM with resolution too coarse for ensuring the flood extensions at community level.

[10] Report Community Risk Assessment, Boroi Village, Bogia District, Madang Province, Papua New Guinea
[11] Report Community Risk Assessment, Botelgot Village, Madang District, Madang Province, Papua New Guinea
[12] Report Community Risk Assessment, Aiome Village, Middle Ramu District, Madang Province, Papua New Guinea
[13] Report Community Risk Assessment, Sepu Village, Usino-Bundi District, Madang Province, Papua New Guinea
[14] Report Community Risk Assessment, Boko Village, Usino-Bundi District, Madang Province, Papua New Guinea
[15] Report Community Risk Assessment, Wel-Sogeram Village, Madang District, Madang Province, Papua New Guinea
[16] Report Community Risk Assessment, Lalok Village, Rai Coast District, Madang Province, Papua New Guinea
[17] Report Community Risk Assessment, Arenduk Village, Sumkar District, Madang Province, Papua New Guinea

Flooded areas are observed around the Kumisanger community in this report, as expected along the banks of the Sadater River, Mburaskur Creek and Siduntugan Creek, according to what is mentioned in its CRA[18].

[18] Report Community Risk Assessment, Kumisanger Village, Rai Coast District, Madang Province, Papua New Guinea

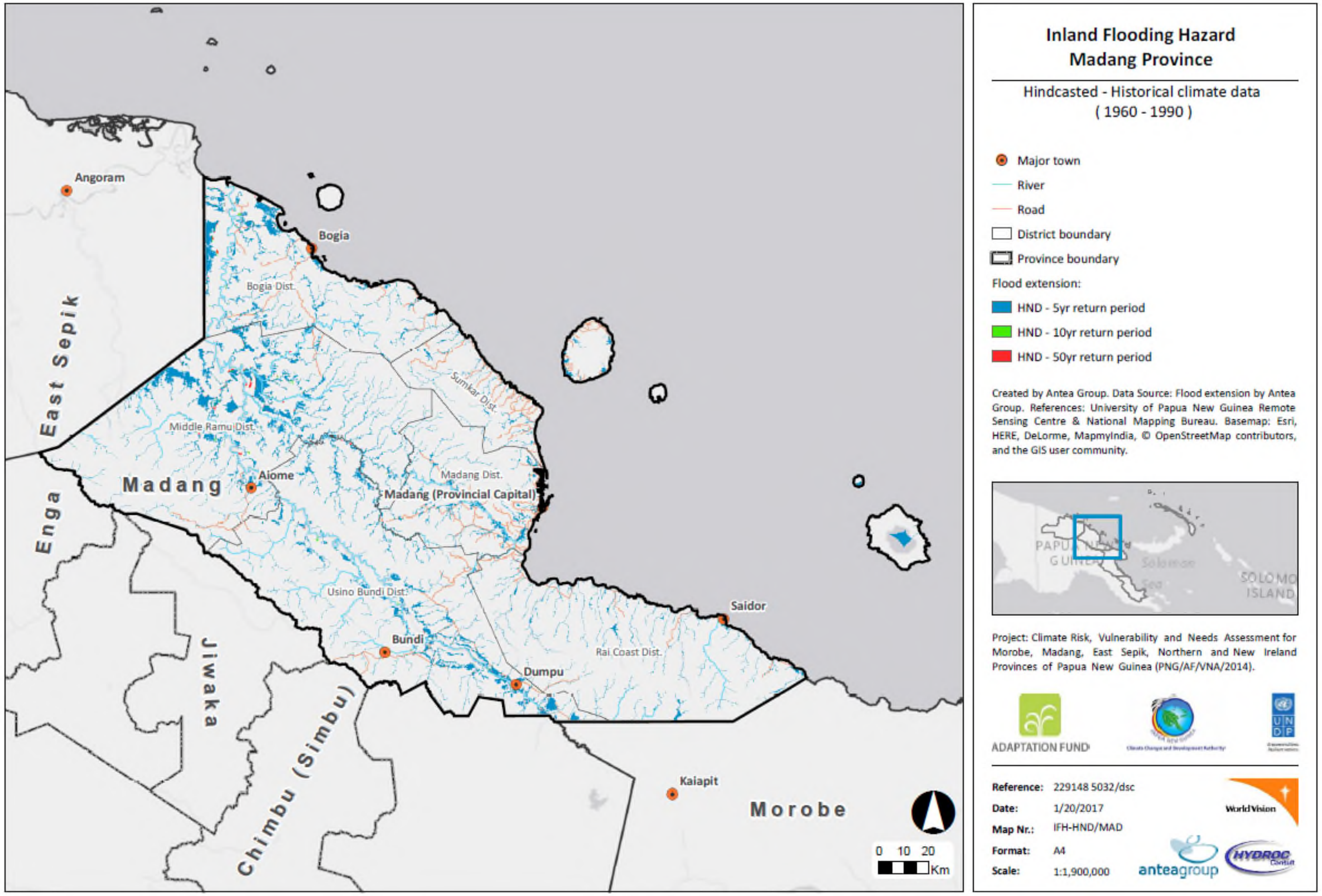

Figure 14. Inland flooding (current climate) ■ flooded

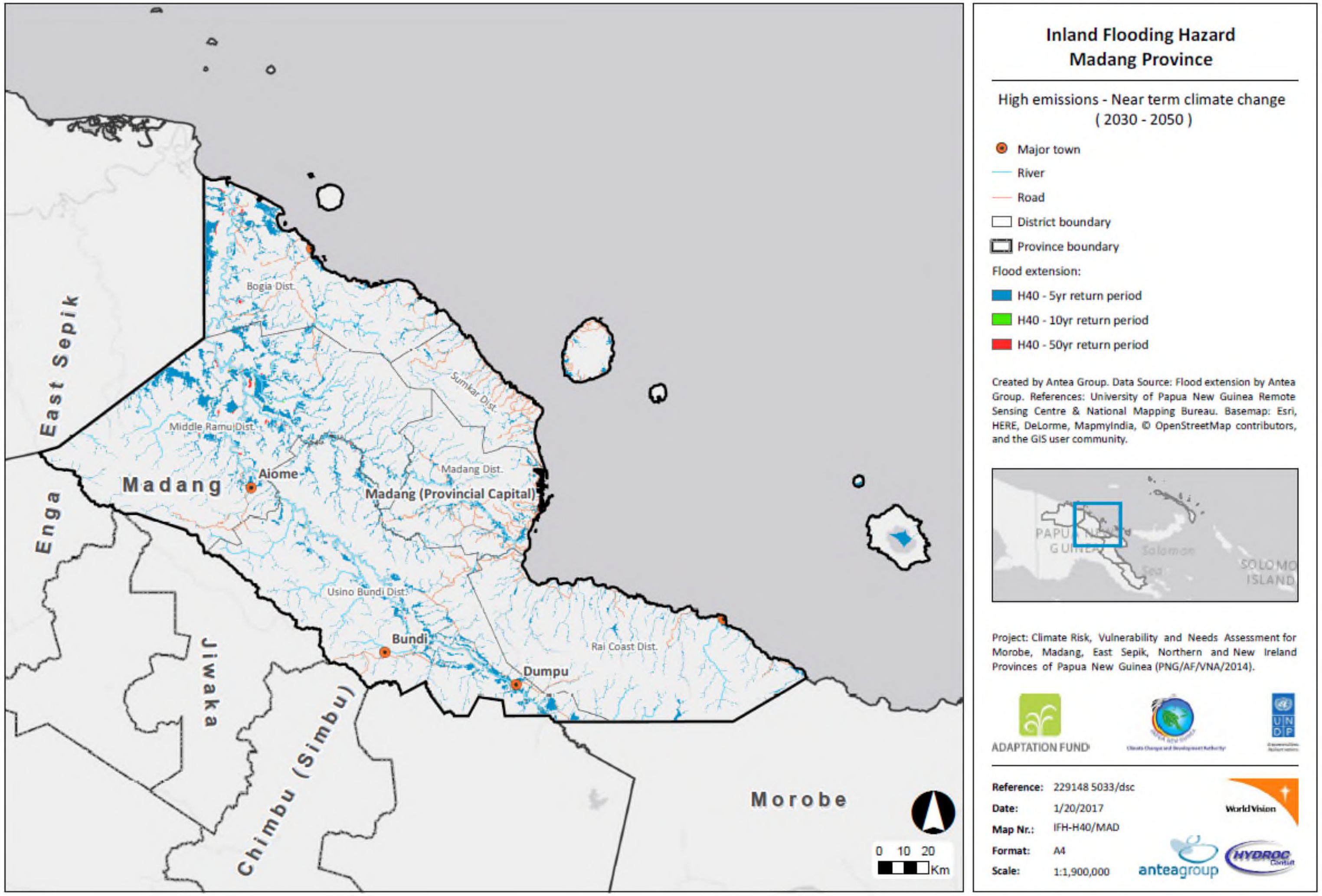

Figure 15 Inland flooding (projected climate) ■ flooded

2.1.3. *Coastal flooding*

The coastal flooding analysis estimated water levels for different return periods for the existing and projected sea level. The available coarse (20 x 20 m) topographic information (SRTM) did not allow to explicitly map the coastal flooding hazard for the province. In order to asses which coastal areas would be most prone to flooding a detailed survey of the coastal zone (LIDAR) is recommended; the survey would provide a reliable description of the topographical relieve.

Another major limitation is the lack of quality, long-term water level measurements tied to a consistent (known) vertical datum that is the same as the vertical datum of the DEM.

2.1.4. *Drought*

Current drought hazard follows a gradual increase towards the east of the province, with values that range from 16 continuous dry days in the westernmost point to 21 continuous dry days in the easternmost point, as can be seen in Figure 16.

Projections for the near future show that the tendency is to increase slightly, as can be seen in Figure 17.

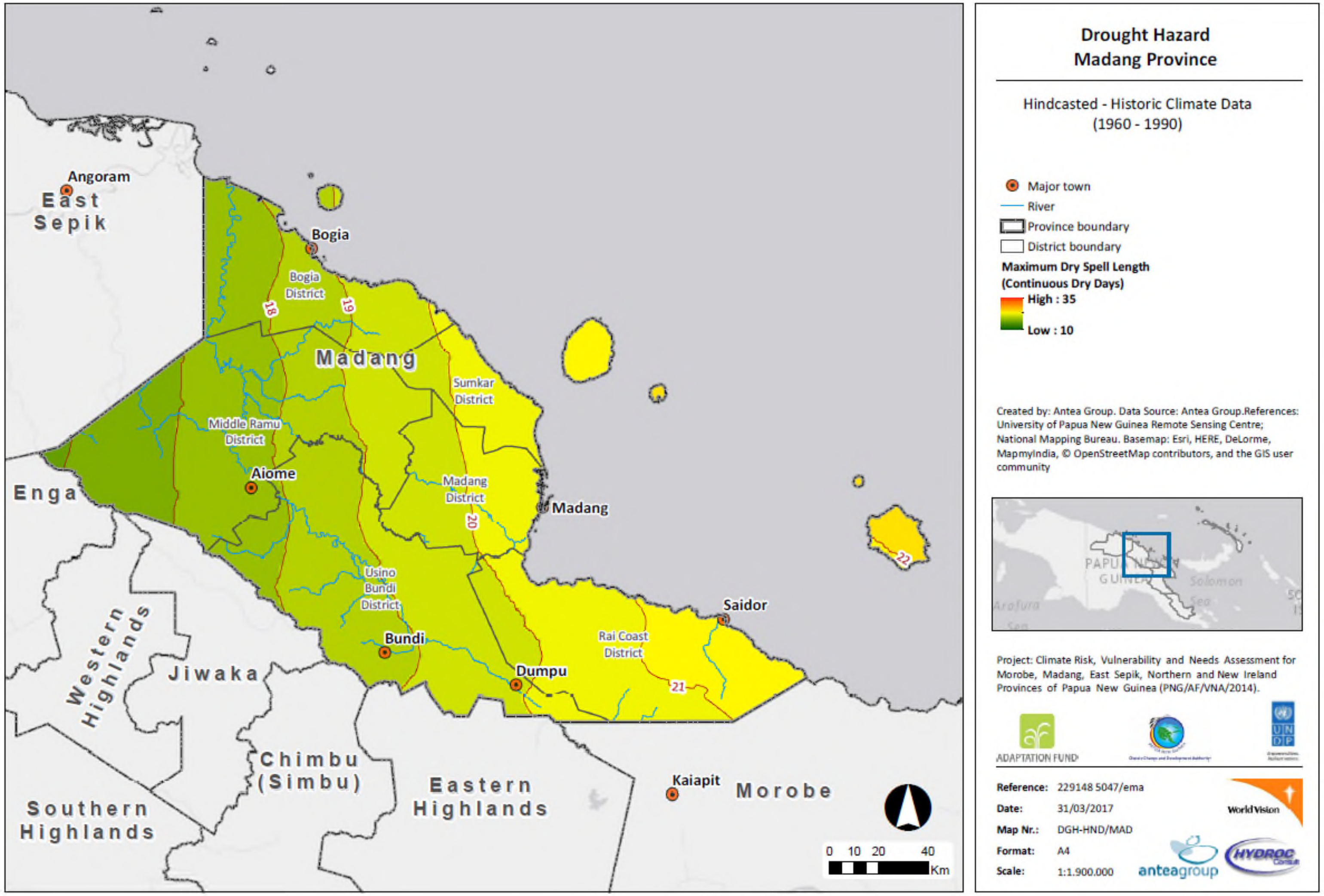

Figure 16. Drought (current climate) expressed as number of continuous dry days 10-16 16-21 21-24 24-29 >29

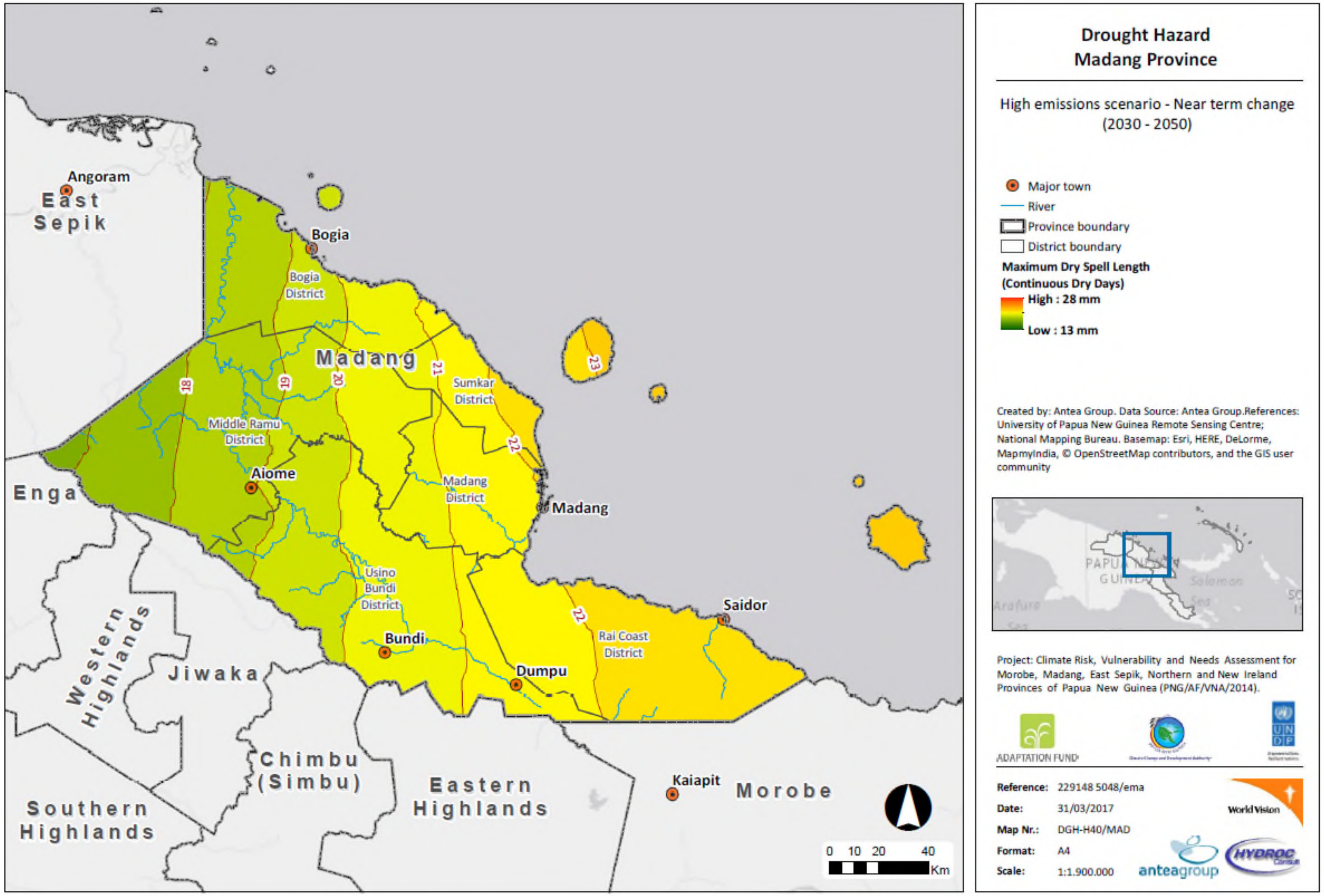

Figure 17. Drought (projected climate) expressed as number of continuous dry days 10-16 16-21 21-24 24-29 >29

2.1.5. *Extreme weather events (tropical cyclones)*

Madang Province is not prone to cyclones. This is illustrated in maps on the next pages.

Cyclone hazard is expressed as a number N which is the number of cyclone passes over a grid cell (0.5 degree grids) over a observed historical period 1970-present (the average diameter of cyclones with destructive wind speeds is assumed as 2 degrees).

Under existing climate conditions, there is no registered tropical cyclone event in this province during the observed period (count =0 in Figure 18) and neither is it foresee in the projections for the future scenario (Figure 19).

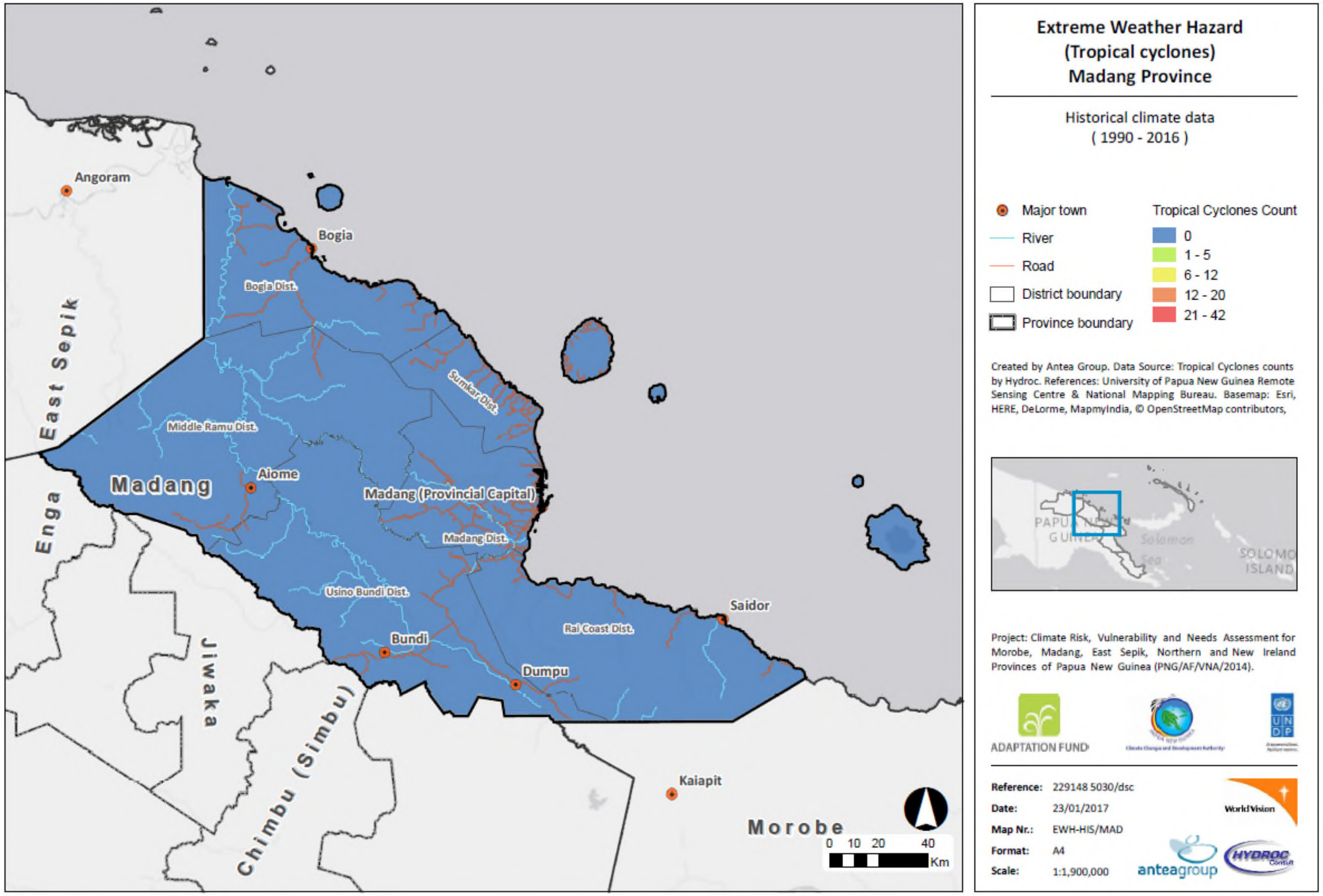

Figure 18. Tropical cyclones (current climate) as number of cyclones ■0 ■1-5 ■6-12 ■12-20 ■>21

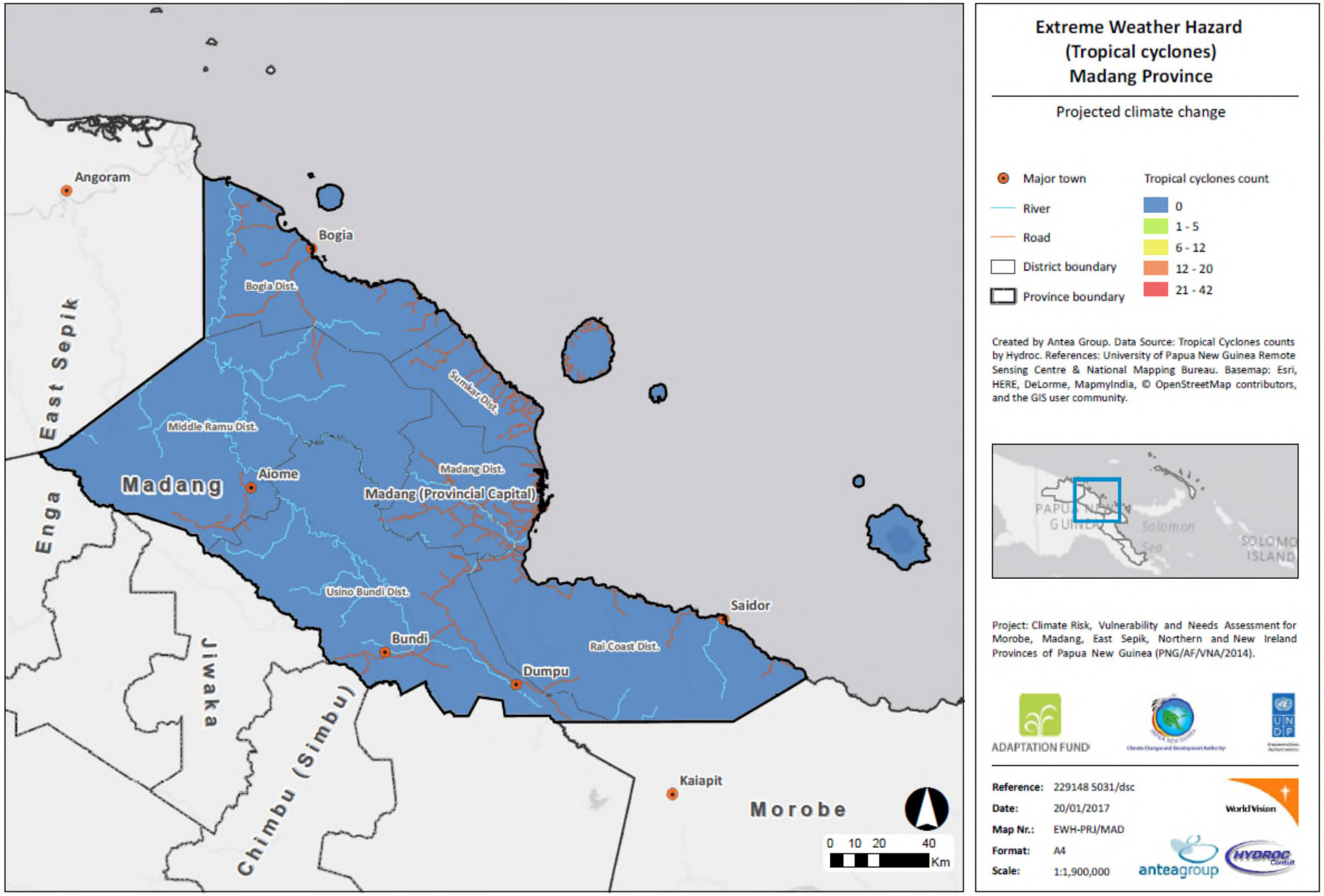

Figure 19. Tropical cyclones (projected climate) as number of cyclones 0 1-5 6-12 12-20 >21

2.1.6. *Increase of precipitation intensity and variability*

The map for total annual rainfall (Figure 20) shows a gradual decrease towards the east of the province, with values that range from 3300mm in the westernmost point to 2900mm in the easternmost point (Long Island).

Projections for the near future (Figure 21) show that the tendency is to increase slightly (3500 to 3100 respectively).

Regarding values for total rainfall on wet days, it can be seen (Figure 22) that the current trend is to decrease from west to east towards the coast, such that the higher values are found to the west (with 600 mm) and the lowest in the region of Saidor (560mm).

Projections for the near future (Figure 23) show a considerable increase in total rainfall on wet days, with values that range from 800mm in the west to 680mm in the region of Saidor and 660mm in Long Island.

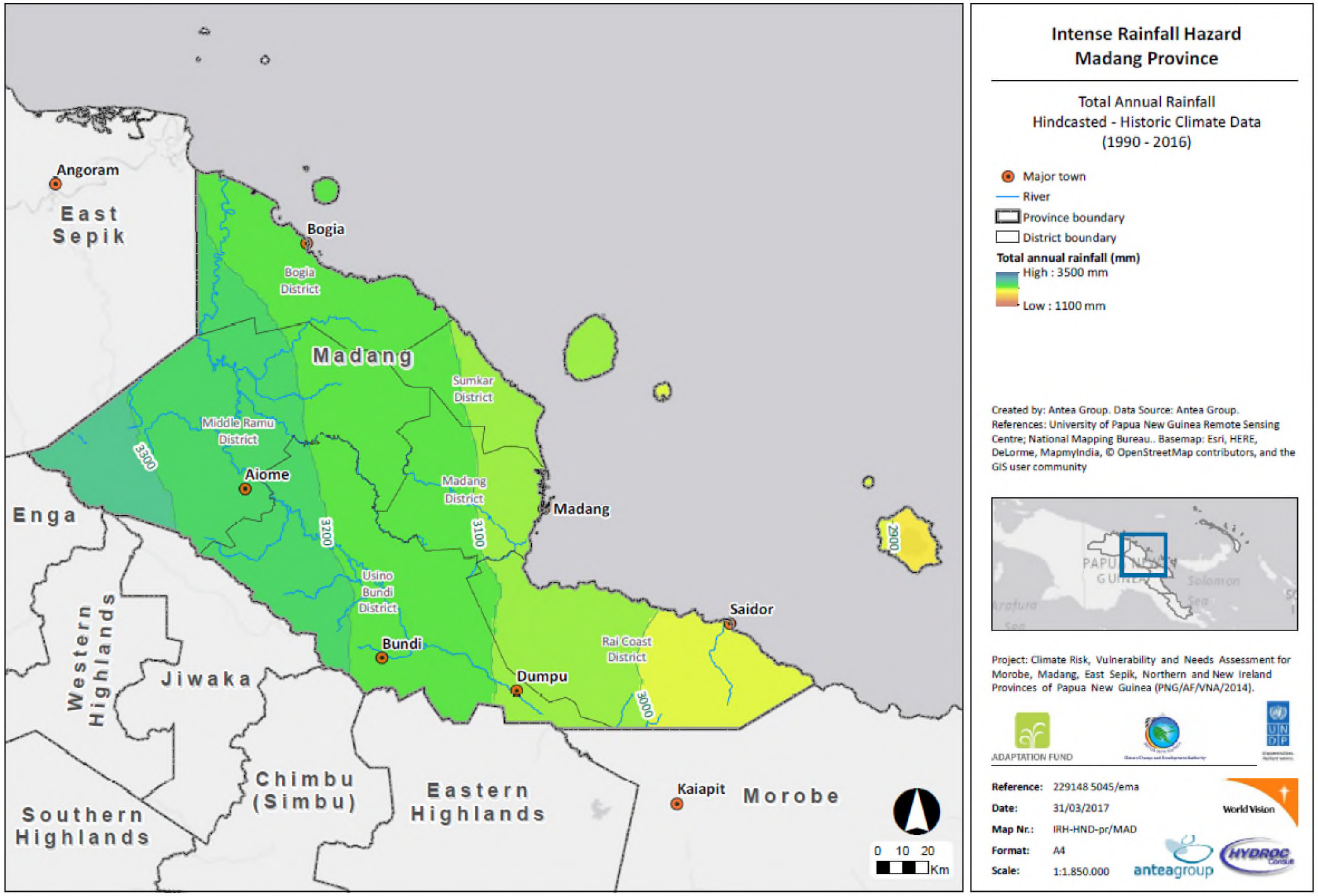

Figure 20. Total annual rainfall in mm (current climate) 1135-2078 2079-2710 2711-2979 2980-3280 3281-3777

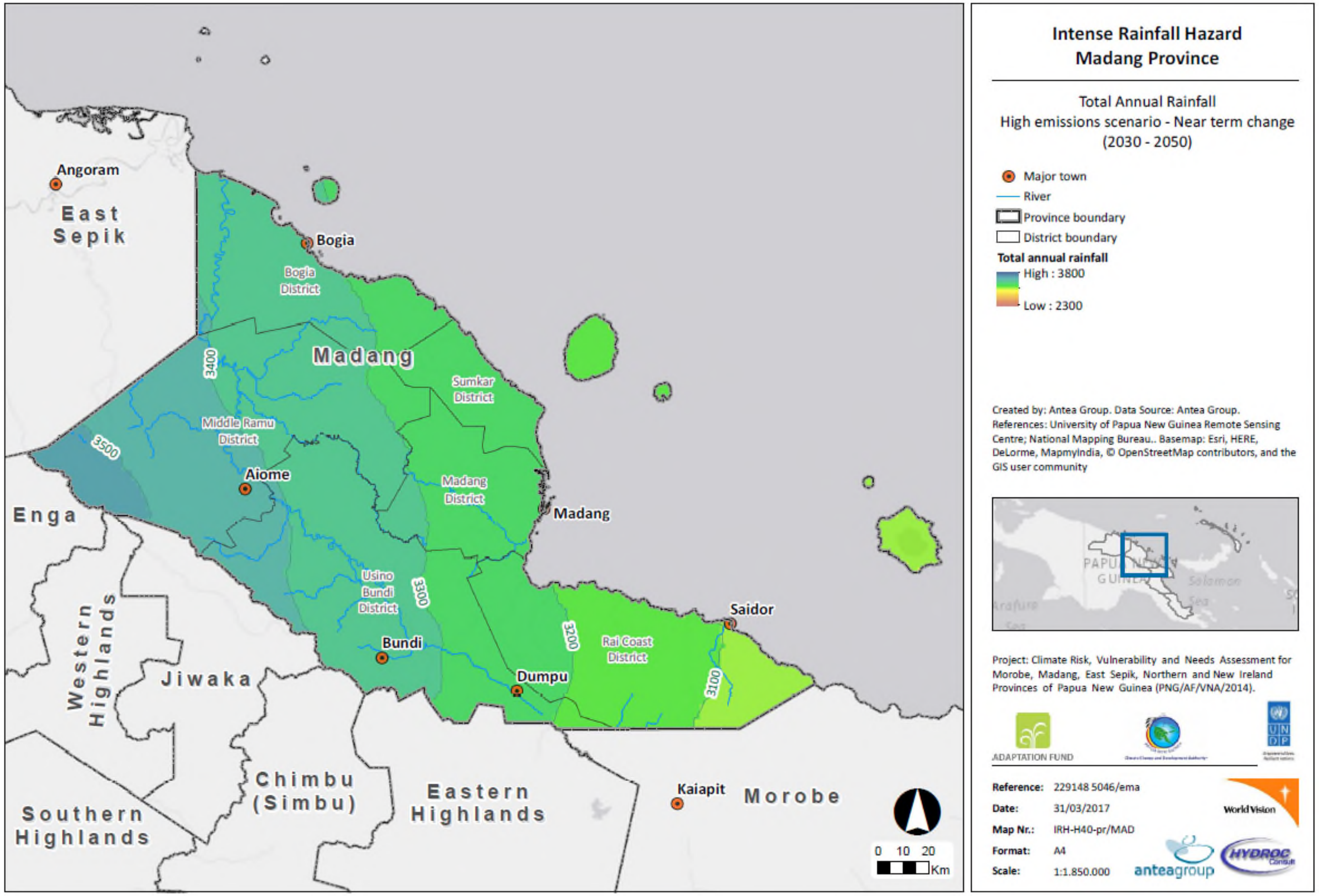

Figure 21. Total annual rainfall in mm (projected climate) 1135-2078 2079-2710 2711-2979 2980-3280 3281-3777

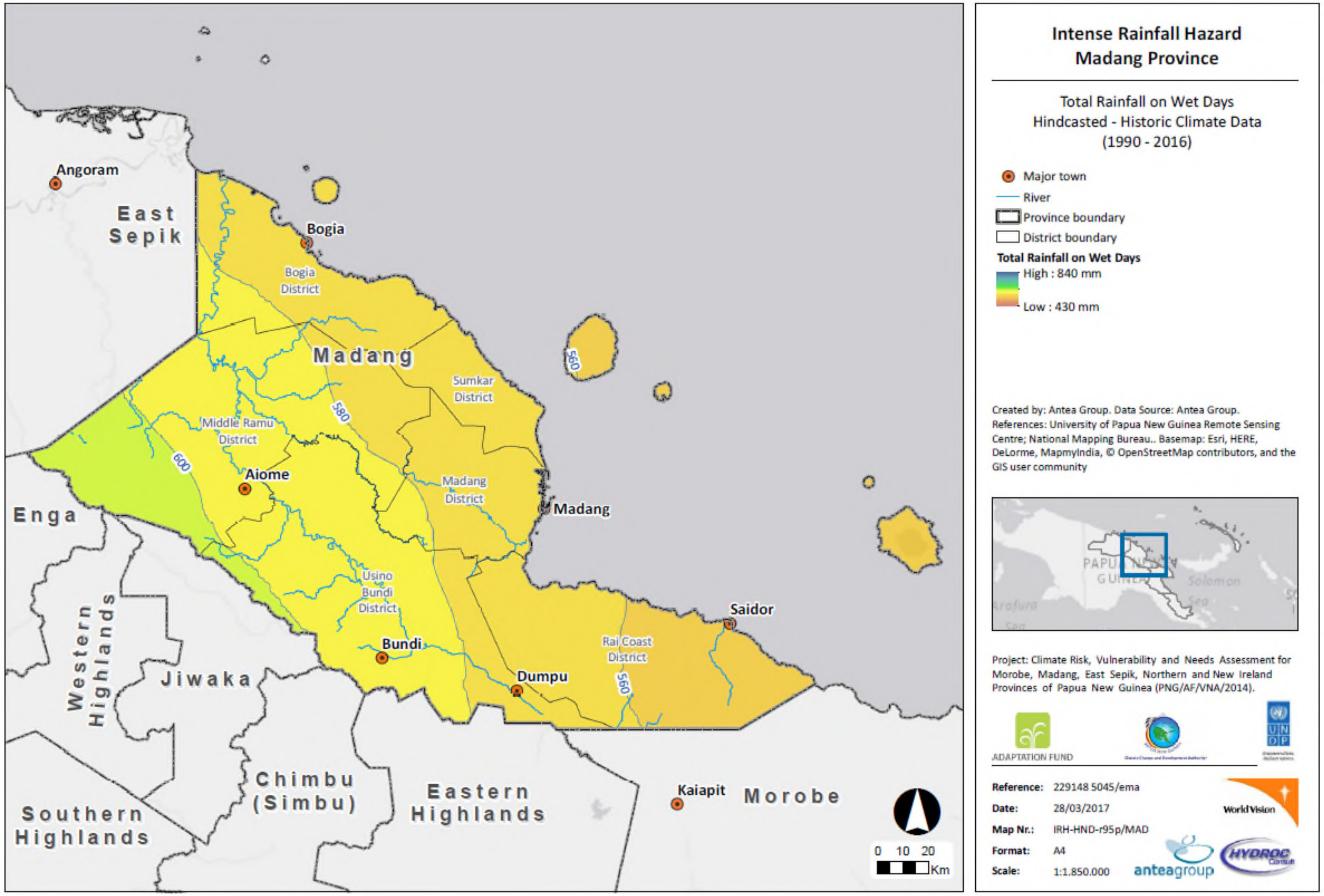

Figure 22. Rainfall on wet days in mm (current climate) 250-500 501-600 601-700 701-800 801-900

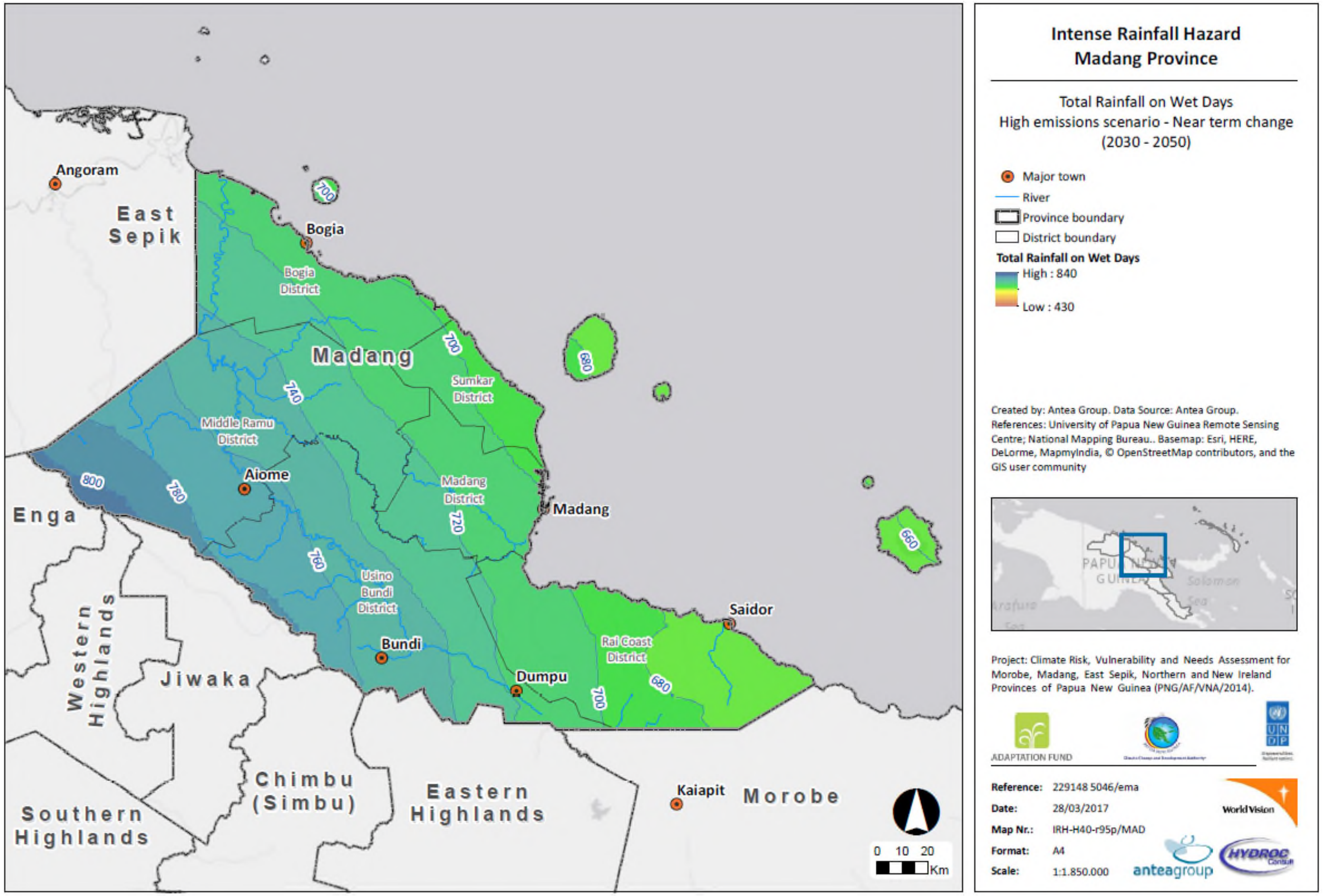

Figure 23. Rainfall on wet days in mm (projected climate) 250-500 501-600 601-700 701-800 801-900

2.2. Vulnerability Assessment

In this chapter we discuss the vulnerability maps for Madang Province. The vulnerability assessment for the five climate induced hazards discussed in the previous chapter, was conducted for three of its components:

- Social vulnerability
- Physical vulnerability (infrastructure)
- Economic vulnerability

2.2.1. Vulnerability to inland flooding

Social vulnerability

As can be seen from Figure 24, the highest social vulnerability to inland flooding is to be found in five larger clusters and in a number of smaller areas scattered throughout the province. The five clusters are located; (1) along the coast north and south of Madang City and including Madang City itself; (2) Along the Ramu River valley northwest of Madang City in Madang District; (3) along the Ramu River valley in Usino Rural District; (4) around and north of the town of Aiome and including the town of Aiome, and parts of Arabaka Rural District, and (5) Along the Songaram River valley running north-south inland from Bogia Town in Yawar Rural District.

The factors used to determine social vulnerability include population size and density, the presence of important social infrastructure such as health facilities, schools and markets, access points linking more remote areas to main roads and the presence of social and kinship networks. Seen from the perspective of reducing social vulnerability to disasters in the province, emergency staging, supply and evacuation centres should be established in Madang City, Aiome, Bogia City, Bundi or Usino and Saidor, as well as on the southern coast of Karkar Island off the east coast of the province.

Additional details can be provided from the Community Risk Assessment carried out by the study team. The following is the experience of the Koroba Abas community located in Ward 10, Usino Rural LLG, in Usnino-Bundi District.

Flooding is a constant hazard in Koroba Asas. Over the years the village gets inundated by floodwaters rushing from the mountains particularly from the Finisterre mountain range. The village sits in between two big rivers which makes it highly susceptible to flooding that mostly happened during the wet season. Both Asas and Aumia Rivers are highly susceptible flooding because of sedimentation and siltation. The carrying capacity of both rivers is very low as it becomes very shallow. Every time big flooding happen the river changes its course and landscape.

The village has seen three major destructive floodas in recent years The flooding that took place in 1960, 1972 and 2015 were the most destructive to hit the village. In terms of impact the flood in 2015 was massive. By this time the village has more people and structures, and livelihood assets exposed to the impacts of natural hazards. The condition of the environment and ecosystem is more susceptible to impacts of intense rain and extreme precipitation. The denuded mountains and heavy silted waterways are some of the reasons why the recent floods have become more destructive. The flooding caused the destruction of roads and bridges located along the main provincial road between Madang and Morobe. This has cut off travel of people and goods as the road was not passable. Several houses along the banks of the rivers were swept away, food gardens and cash crop plantations destroyed, assets damaged including vehicles owned by local people, and livestock perished.

Physical vulnerability

The map for inland flooding physical vulnerability (Figure 25) shows some scattered hotspots throughout the province, whereas the biggest concentration around the area of Madang City, where there is more infrastructure and in higher concentration than the rest of the province. Other hotspots include the areas of Arabaka Rural, Usino Rural, Yawar Rural and Karkar Island.

Economic vulnerability

Figure 26 shows that the highest economic vulnerabilities in the province are in the area of Dumpu, where there are many plantations and agricultural land, and in the region of the Gogol river up to Madang Provincial Capital.

Composite vulnerability to inland flooding

The composite map for vulnerability to inland flooding of the Province of Madang (Figure 27) shows scattered hotspots, to be found in higher concentrations along the Gogol river and the area of Madang City, Arabaka Rural, Yawar Rural and Usino Rural. In the region of Madang-Gogol the vulnerability comes from the high population and infrastructure density, joined to the agricultural land exposed in the area. In the remaining areas, which are more rural, vulnerability comes more from the social perspective.

The districts that accumulate a higher % of composite vulnerability (3+4+5) are Madang, Bogia and Middle Ramu, as can be seen in the table below:

Table 29. Distribution of vulnerability classes for inland flooding in Madang Province (combined social, economic and physical)

	HAZARD : INLAND FLOODING						
	COMPOSITE VULNERABILITY %						
District	1	2	3	4	5		(3+4+5)
Bogia District	19,0	11,2	4,1	0,9	9,5	55,3	14,5
Madang District	32,6	12,4	2,7	3,4	10,6	38,3	16,7
Middle Ramu District	31,5	7,8	2,3	0,9	8,3	49,1	11,5
Rai Coast District	25,5	2,4	0,9	1,7	5,5	63,9	8,1
Sumkar District	29,4	8,6	3,1	2,3	4,9	51,7	10,3
Usino Bundi District	24,8	6,1	2,0	2,8	3,9	60,5	8,7

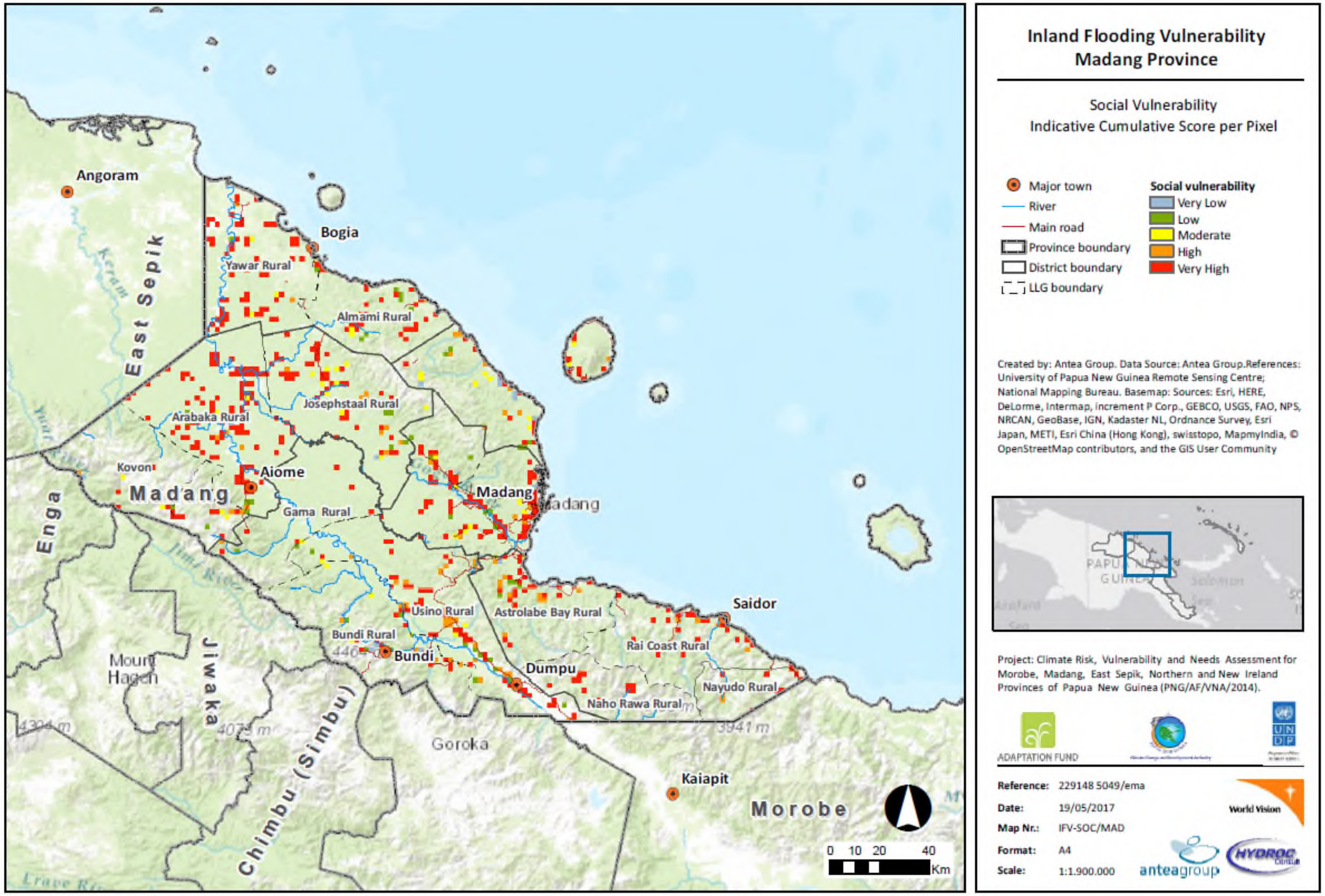

Figure 24. Social vulnerability to inland flooding in Madang Province

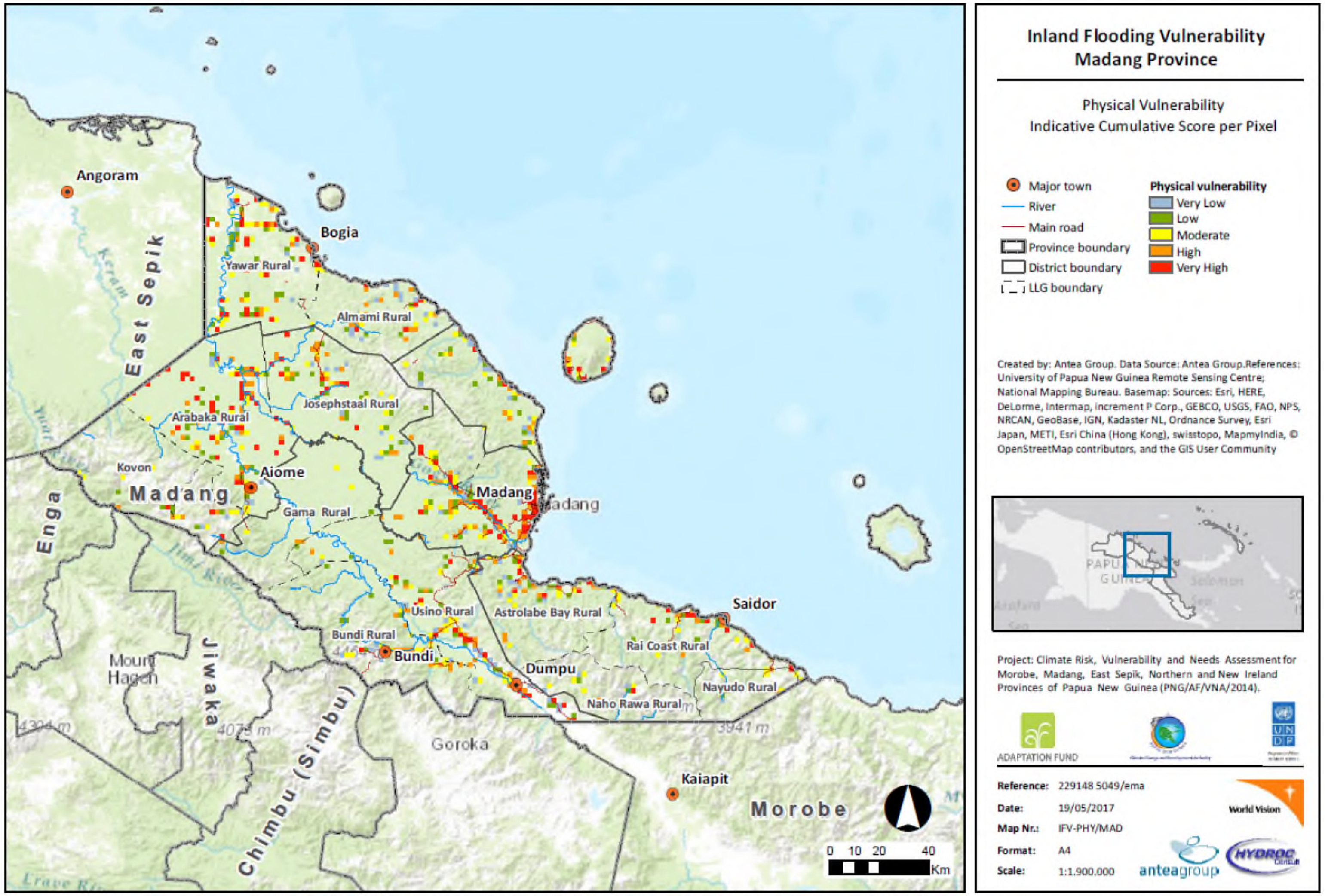

Figure 25. Physical vulnerability to inland flooding in Madang Province

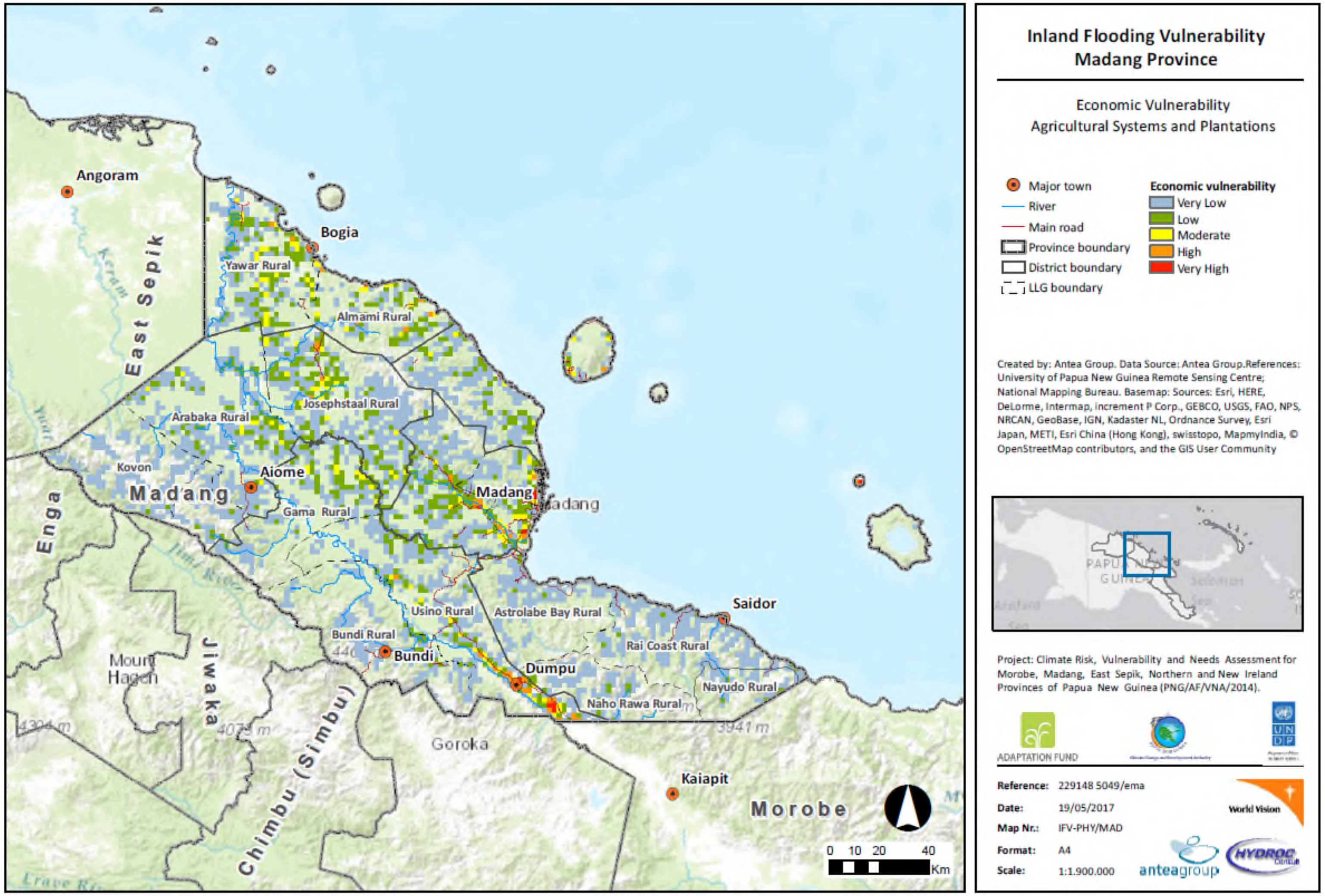

Figure 26. Economic vulnerability to inland flooding in Madang Province

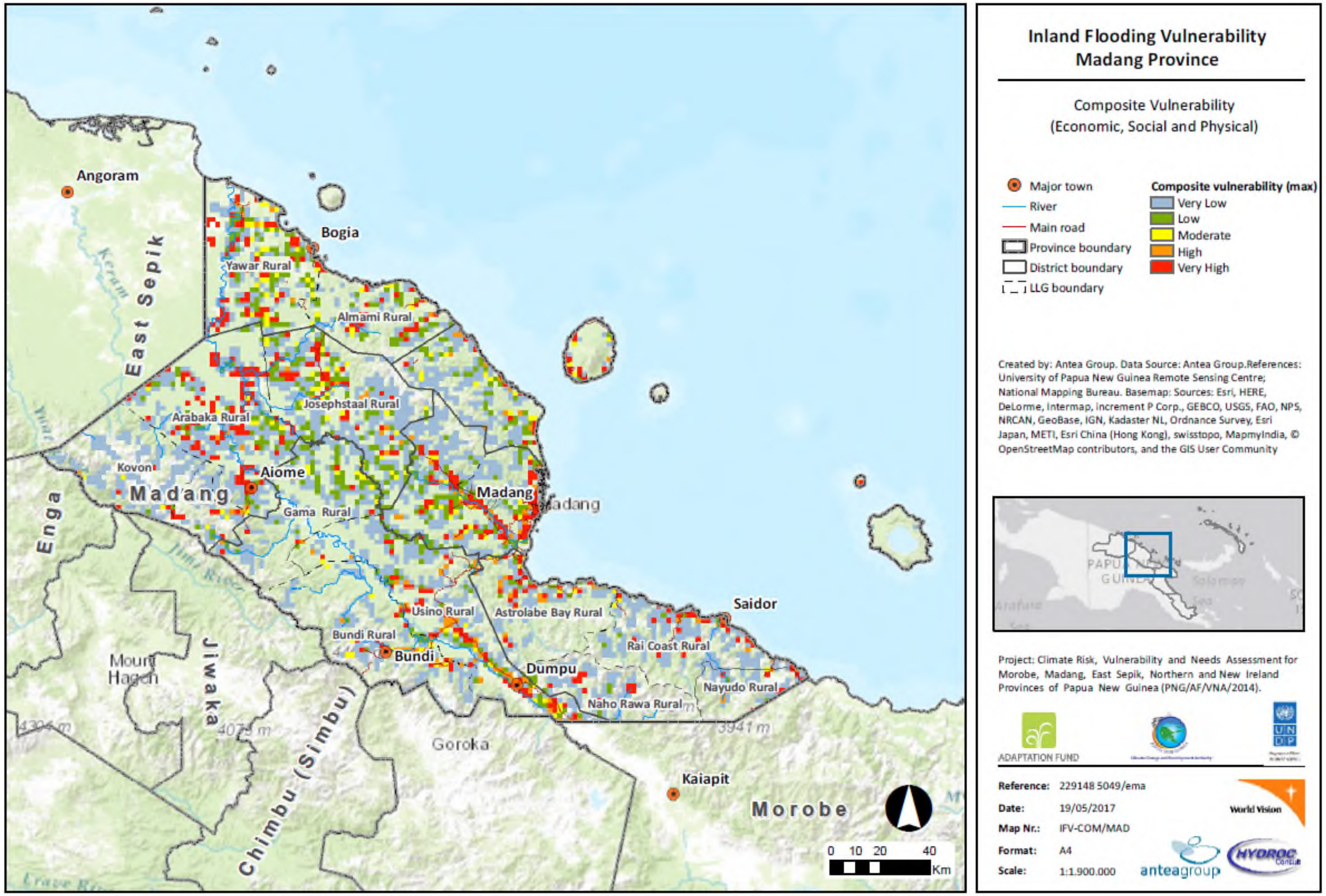

Figure 27. Combined inland flood vulnerability map for Madang Province

2.2.2. *Vulnerability to coastal flooding*

<maps not available>

2.2.3. *Vulnerability to drought*

Social vulnerability

The areas with highest social vulnerability to drought in the province are found around Madang town, in Ambenob LLG, and along the western coast of Karkar Island in Madang District and Karkar LLG. Since the impacts of droughts are relatively slow to develop, there is more time for the population to take adaptive measures such as obtaining food assistance from kin in other areas, increased planting of drought resistant crops such as cassava and sago and trade of goods for food.

Excerpts from the CRA in Arenduk Village, Ward 2, Sumgilbar LLG, Sumkar District:

Droughts have occurred four times in the recent history of Arenduk Village in 1990, 1994, 1997 and 2015. People in the village have suffered from the impacts of the extreme heat and dry conditions. None however, were worse than the droughts; in 1997 and 2015. The drought has dried up most of the water sources of people in the village. Many food gardens and cocoa plantation were severely affected. Sweet potato, taro, yam and cassava all have withered. Taro weevil destroyed most of the taro stocks in the village. Cocoa pod borer ravaged the cocoa plantation in the area. The drought has dried up or reduced the capacity of the village' water sources. Fufuruk and Sagen Rivers which are the main sources of water for the village have stopped flowing. This prompted people to look for water from other sources. Others have no choice but to rely on the stagnant contaminated water sources. There were series of outbreak of water-borne diseases that have taken place during the drought incidents in the area. The 2015 drought had several of the villagers especially children suffered from diarrhea and dysentery. People get drinking water from rivers and creeks without boiling it. Respiratory and other health ailments due to dry conditions have spiked putting additional burden to families' finances.

A main source of drinking water in Arenduk Village

As a coping strategy extended families and clans support each other to help ease the impact of droughts and other disasters. They rely on local knowledge/skills in dealing with the effects of droughts, trade goods with other areas for food, seek wild foods (e.g. wild yam, breadfruit, wild animals, etc.), delay setting bush fires, and drink coconut water.

Economic vulnerability

Figure 29 shows that the province has a relatively low profile to economic vulnerability to drought, with the exception of the agricultural areas around Dumpu, Madang City and to the southwest of Aiome.

Composite vulnerability to drought

The composite map of drought vulnerability for the Povince of Madang (Figure 30) shows a rather low profile to this type of vulnerability, except for the area around Madang City and the upper stretch of River Ramu around Dumpu. Maybe also worth mentioning the areas of Simbai Rural and Karkar Island.

The districts that accumulate a higher % of composite vulnerability (3+4+5) are Sumkar and Madang as can be seen in the table below:

Table 30. Distribution of vulnerability classes for drought in Madang Province (combined social and economic)

	HAZARD : DROUGHT						
	COMPOSITE VULNERABILITY %						
District	1	2	3	4	5		(3+4+5)
Bogia District	16,5	43,3	4,1	0,3	1,3	34,5	5,7
Madang District	0,3	84,8	6,2	1,9	6,0	0,8	14,1
Middle Ramu District	11,7	39,6	7,5	0,5	0,2	40,5	8,2
Rai Coast District	13,4	29,5	8,5	0,1	0,2	48,3	8,8
Sumkar District	0,6	70,7	12,5	5,3	1,9	8,9	19,7
Usino Bundi District	7,2	41,1	3,4	1,2	2,3	44,9	6,9

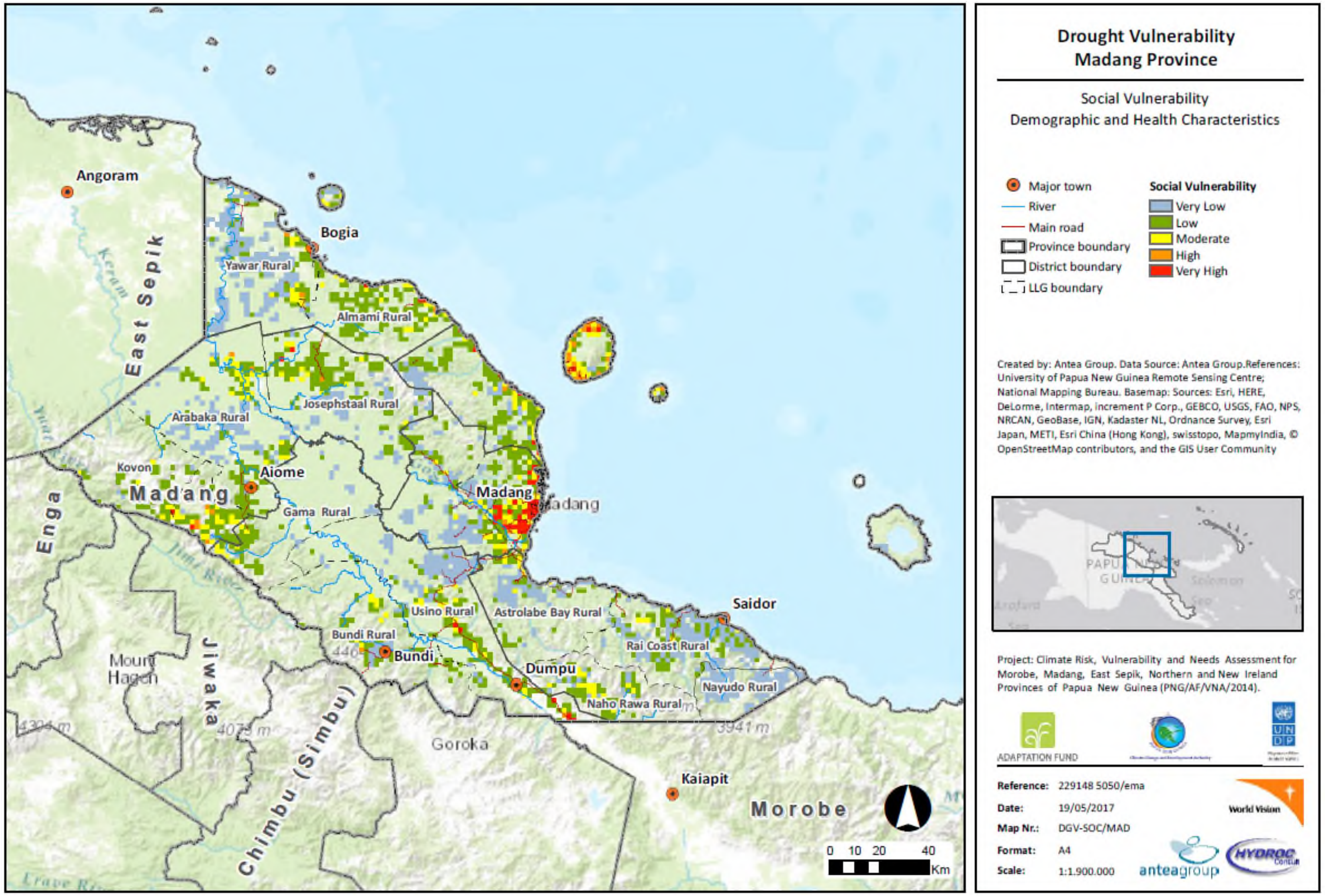

Figure 28. Social vulnerability to drought in Madang Province

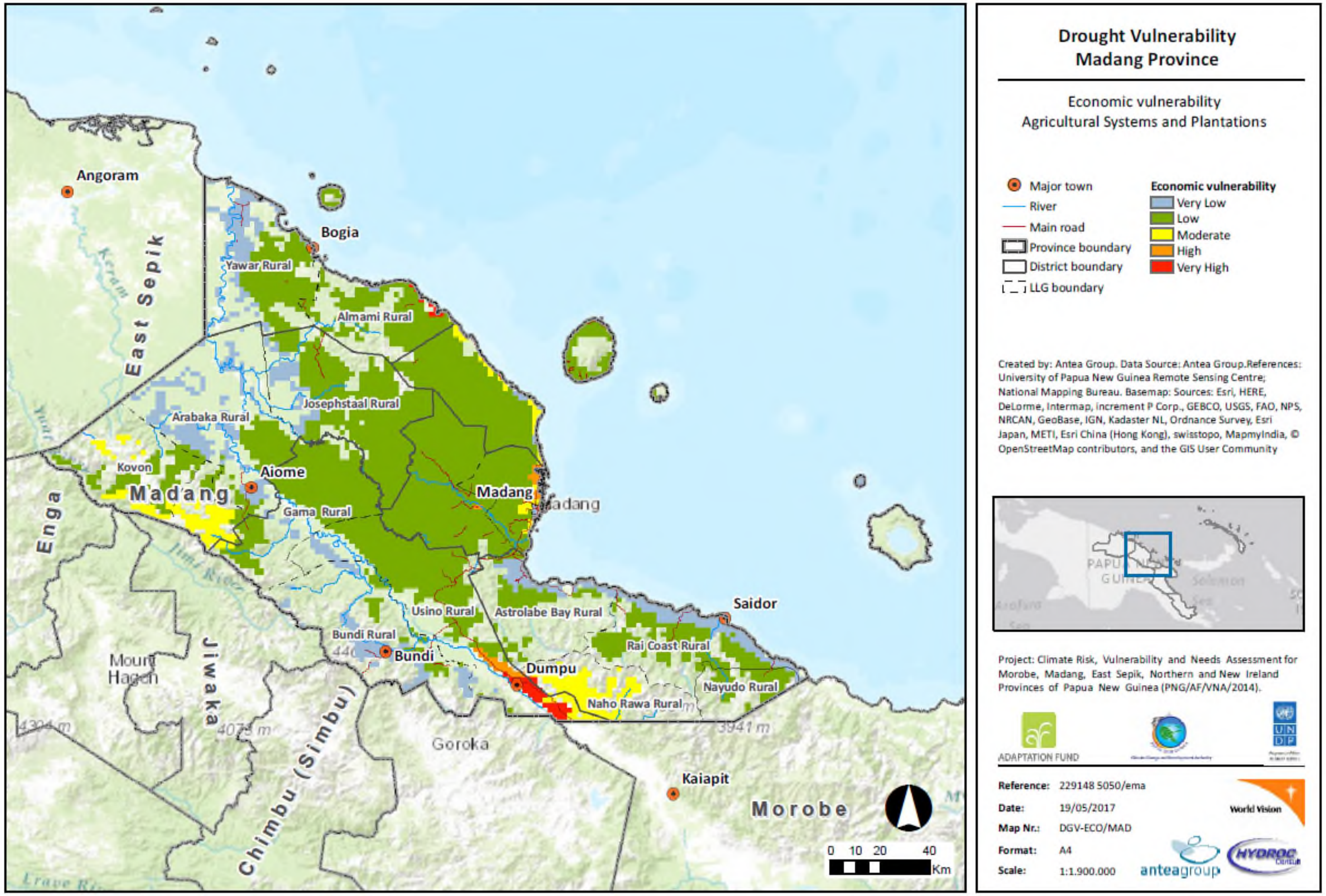

Figure 29. Economic vulnerability to drought in Madang Province

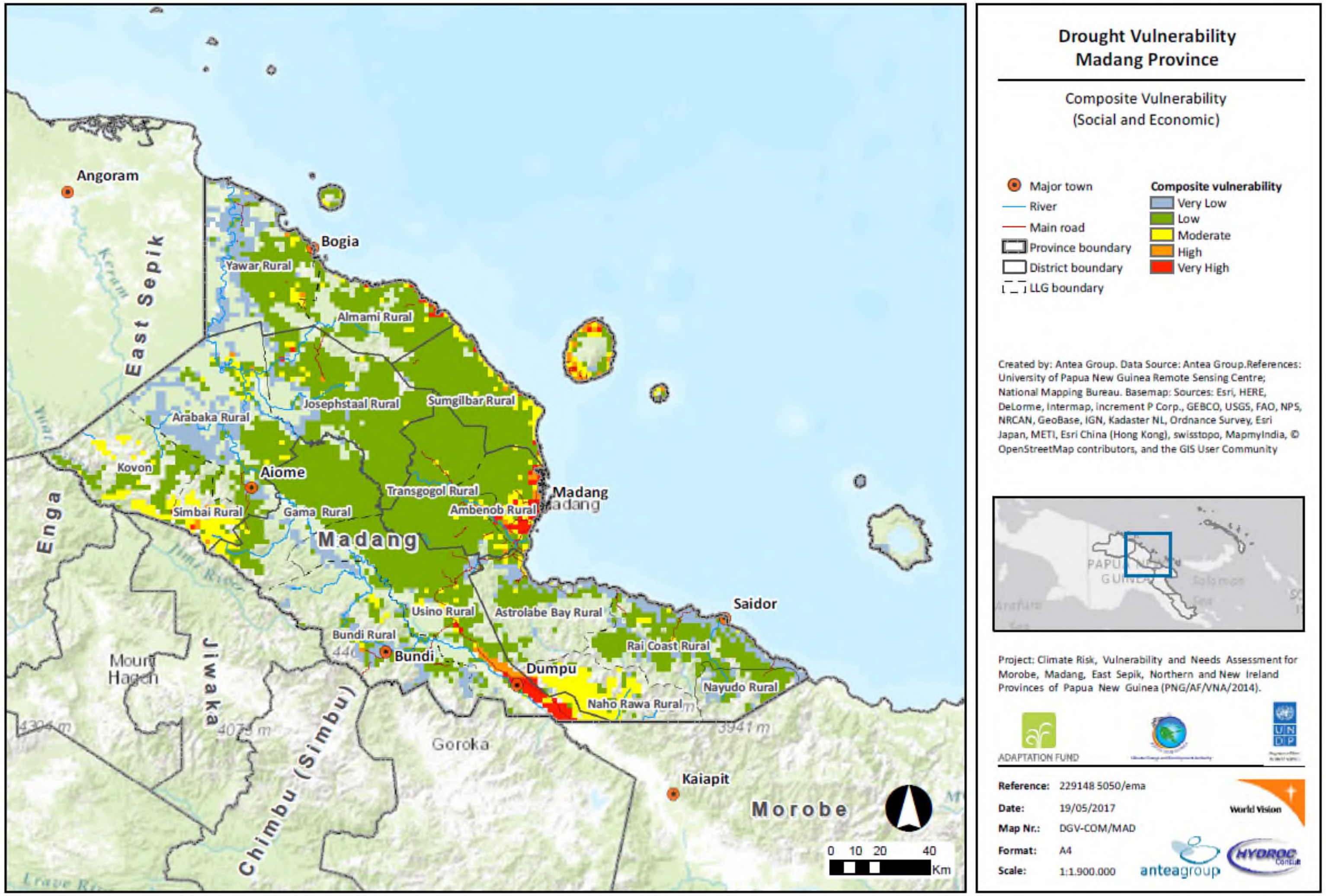

Figure 30. Combined drought vulnerability map for Madang Province

2.2.4. *Vulnerability to extreme weather (cyclones)*

Social vulnerability

The areas with the highest social vulnerability to extreme weather events such as cyclones in the province are found in areas with high population density and with social infrastructure such as health centres, schools and markets in and around Madang town, in Ambenob LLG, and along the western coast of Karkar Island in Madang District and Karkar Island (Figure 31).

Physical risk

The map for extreme weather physical risk of the Province of Madang (Figure 32) shows big hotspots around Madang City and Karkar Island. Other hotspots can be found in the southern part of Middle Ramu District, in the coastal area in front of Karkar Island around Mirap and in Borgia District.

Economic vulnerability

Figure 33 shows a varied picture regarding economic vulnerability in the Province of Madang: on the one hand, there is very high vulnerability along the central part of the coast in front of Karkar Island down to Madang City. On the other hand, there is a big extension that covers 2/3rds of Yawar Rural, the whole of Almani Rural and a part of Josephstaal Rural, with a high vulnerability profile. Additionally, there are three big regions with a moderate profile: Simbai Rural, the region around Dumpu – Naho Rawa Rural, the coastal areas around Karkar Island and finally a big extension that covers Transgogol Rural, Ambenob Rural and Sumgilbar Rural.

Composite vulnerability to extreme weather

The composite map for vulnerability to extreme weather events in the province of Madang (Figure 34) shows hotspots around Madang City, the coast of Karkar Island and a region in Simbai Rural. Additionally, there is a region that covers part of Yawar Rural, the whole of Almani Rural and a part of Josephstaal Rural, with a high vulnerability profile. Finally, there is a long stretch of high vulnerability along Ramu River downstream of Dumpu.

The districts that accumulate a higher % of composite vulnerability (3+4+5) are Sumkar, Madang and Bogia, as can be seen in the table below:

Table 31. Distribution of vulnerability classes for extreme weather (cyclones) in Madang Province (combined social, economic and physical)

	HAZARD : CYCLONE						
	COMPOSITE VULNERABILITY %						
District	1	2	3	4	5		(3+4+5)
Bogia District	6,7	11,4	4,9	36,4	7,8	32,7	49,1
Madang District	0,1	49,6	25,7	10,5	13,2	0,8	49,4
Middle Ramu District	7,4	30,9	6,3	12,0	3,4	40,0	21,7
Rai Coast District	16,0	11,4	13,8	7,5	3,7	47,6	25
Sumkar District	0,4	37,2	28,0	8,0	17,9	8,5	53,9
Usino Bundi District	5,9	35,9	7,2	4,6	2,5	43,8	14,3

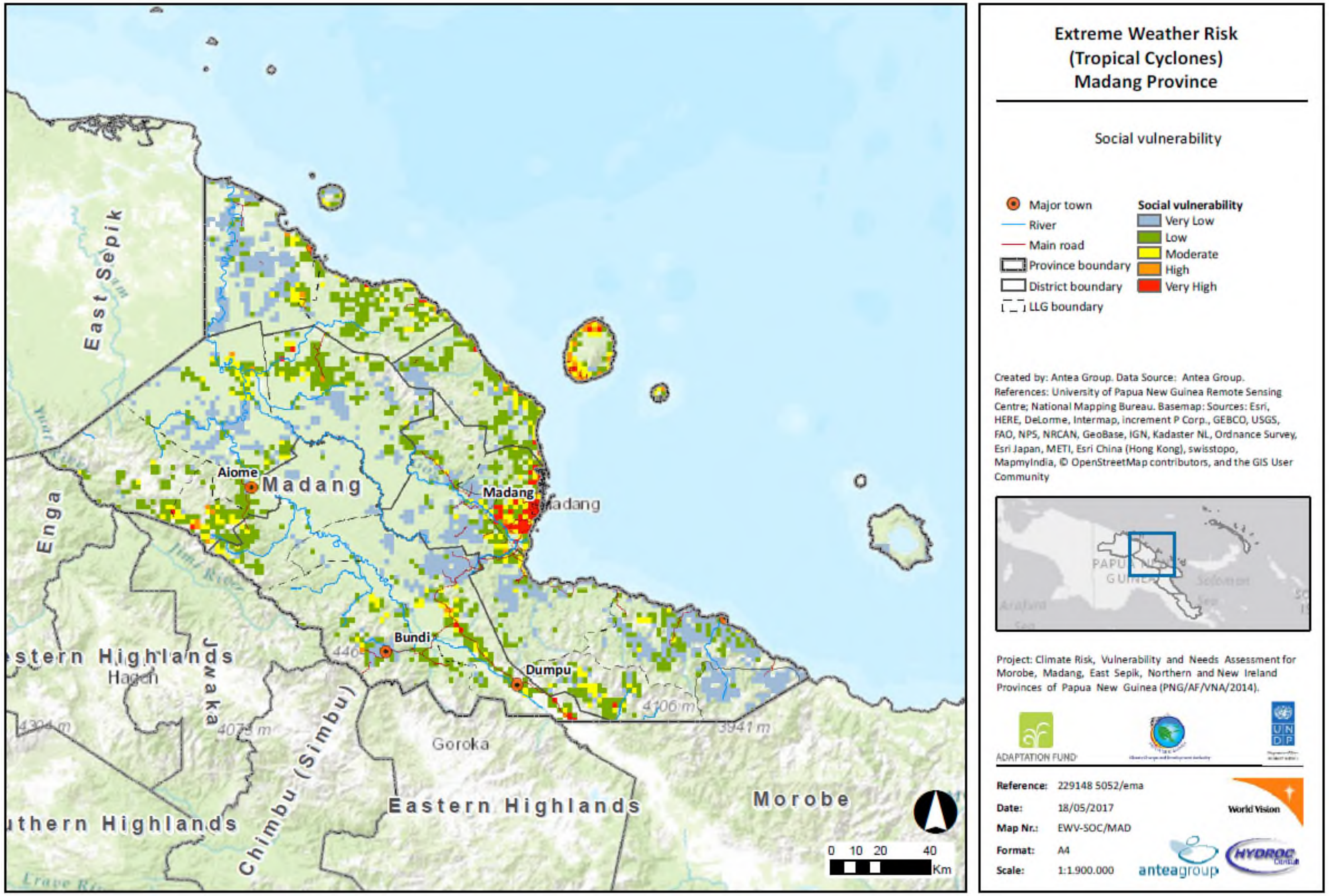

Figure 31. Social vulnerability to cyclones in Madang Province

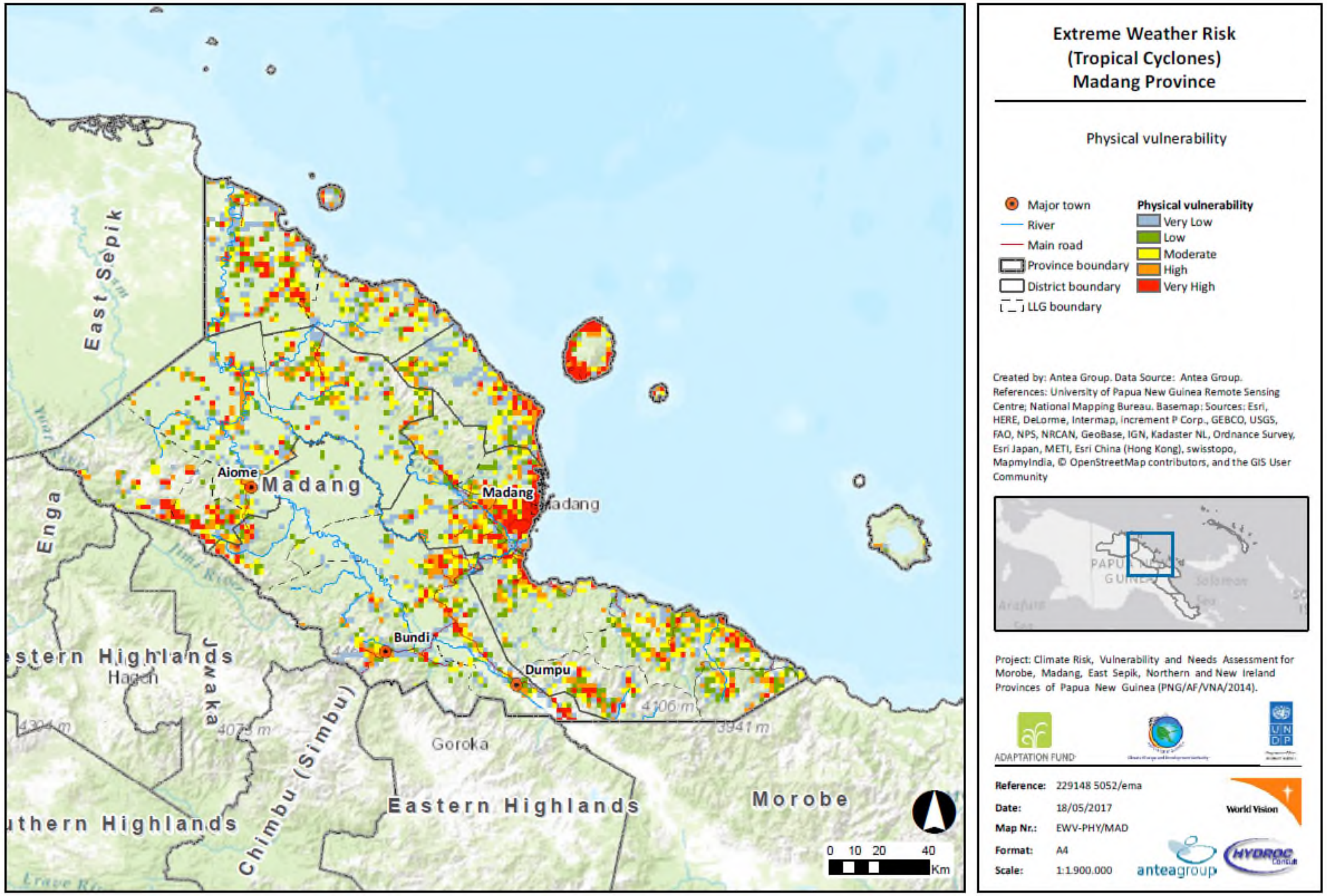

Figure 32. Physical vulnerability to cyclones in Madang Province

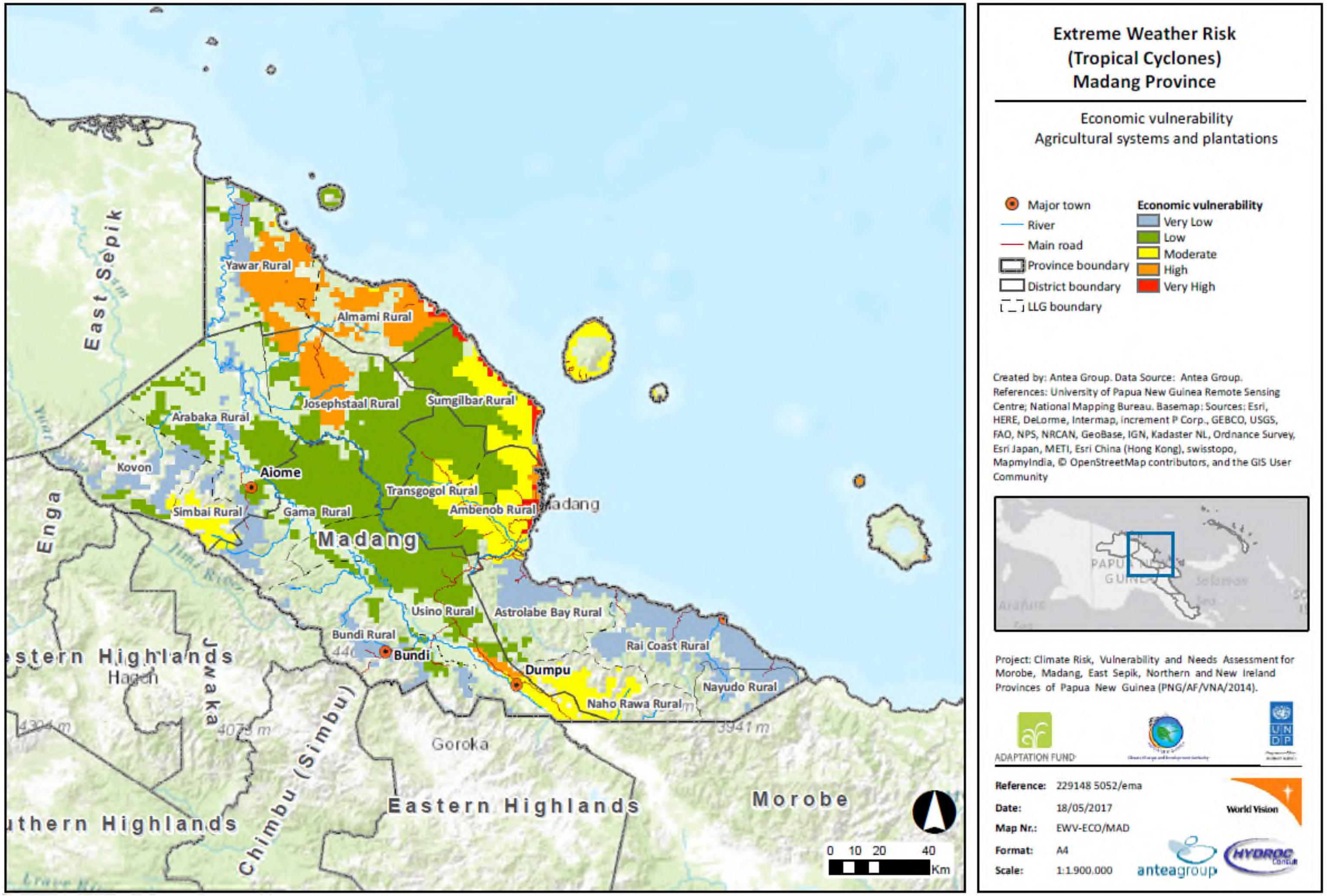

Figure 33. Economic vulnerability to cyclones in Madang Province

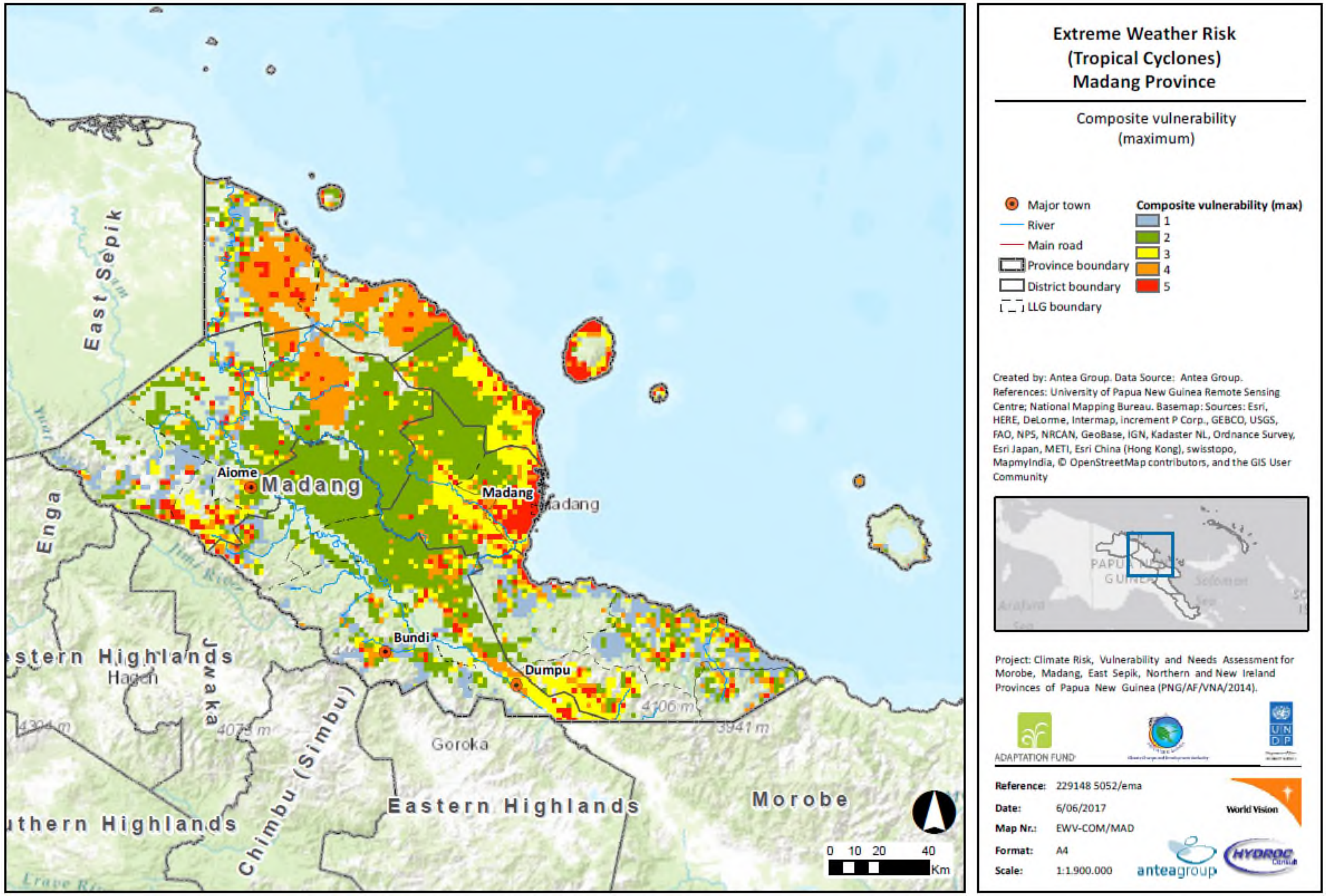

Figure 34. Combined vulnerability to cyclones in Madang Province

2.2.5. *Vulnerability to precipitation intensity and variability*

Social vulnerability

The areas with the highest social vulnerability to high precipitation intensity and variability in the province are found in areas with high population density and with social infrastructure such as health centres, schools and markets in and around Madang town, in Ambenob LLG, and along the western coast in front of Karkar Island in Madang District and Karkar Island (see Figure 35).

Economic vulnerability

The map for economic vulnerability to intense rainfall (Figure 36) shows a very low profile except in the north of Madang City, where the vulnerability is very high. Additionally, the regions around Dumpu and Simbai Rural, where there are extensive plantations and agricultural land, show a moderate to high vulnerability to rainfall intensity.

Composite vulnerability to intense rainfall

The composite map for vulnerability to intense rainfall for the Province of Madang (Figure 37) shows a very low profile in general, with just one major hotspot in the area of coastal Madang District. Other incipient hotspots can be seen in the upper stretch of River Ramu, Sambai Rural and along the coastal areas of Karkar Island.

The districts that accumulate a higher % of composite vulnerability (3+4+5) are Sumkar and Madang, as can be seen in the table below:

Table 32. Distribution of vulnerability classes for precipitation intensity and variability in Madang Province (combined social and economic)

	HAZARD : PRECIPITATION						
	COMPOSITE VULNERABILITY %						
District	1	2	3	4	5		(3+4+5)
Bogia District	41,5	18,3	4,1	0,3	1,1	34,7	5,5
Madang District	60,6	25,0	5,8	0,4	7,5	0,8	13,7
Middle Ramu District	38,3	15,4	5,6	0,5	0,2	40,0	6,3
Rai Coast District	33,0	9,8	8,5	0,1	0,1	48,5	8,7
Sumkar District	36,8	38,5	8,8	5,3	1,9	8,7	16
Usino Bundi District	37,0	12,4	3,0	2,1	0,3	45,1	5,4

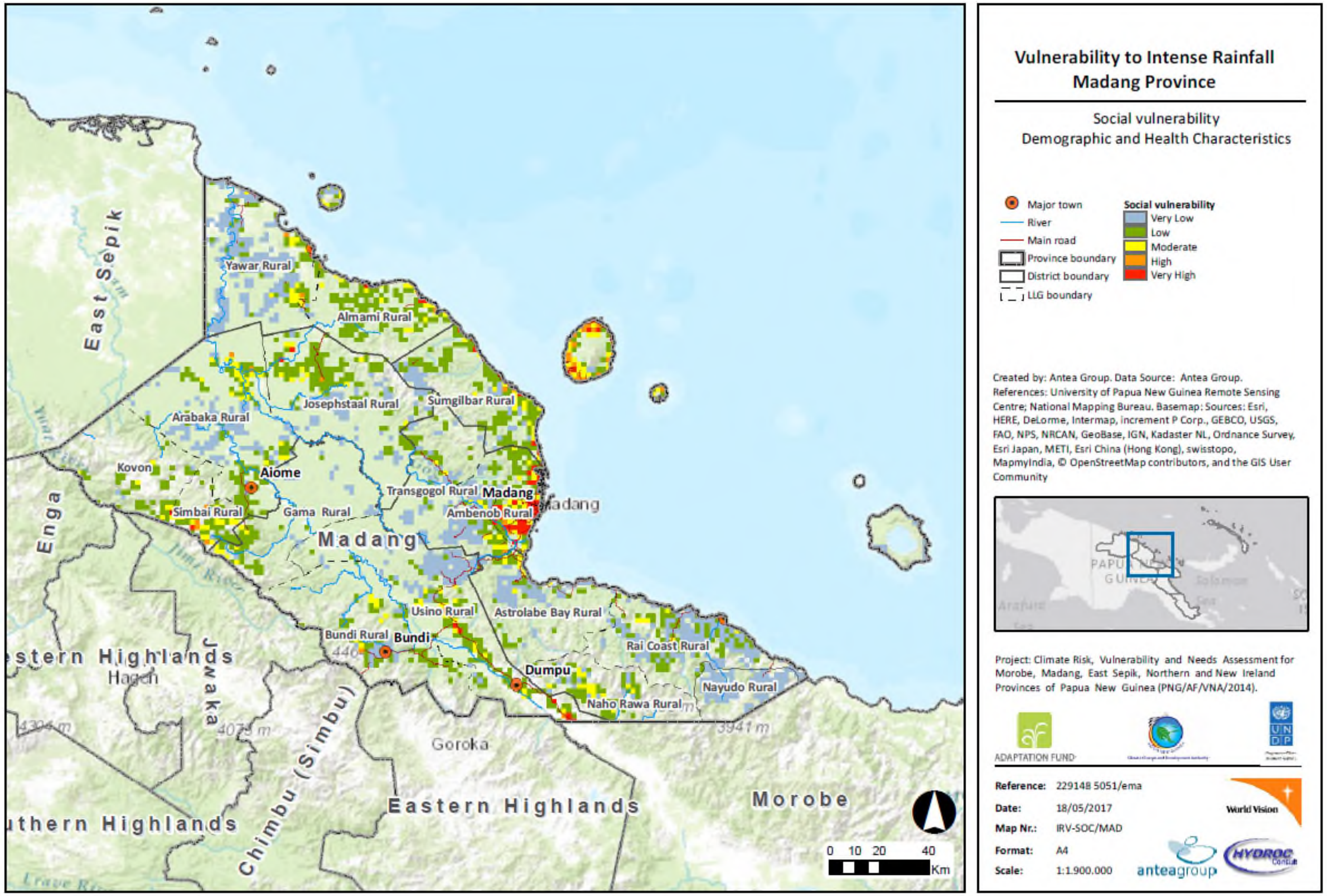

Figure 35. Social vulnerability to precipitation intensity and variability (intense rainfall) in Madang Province

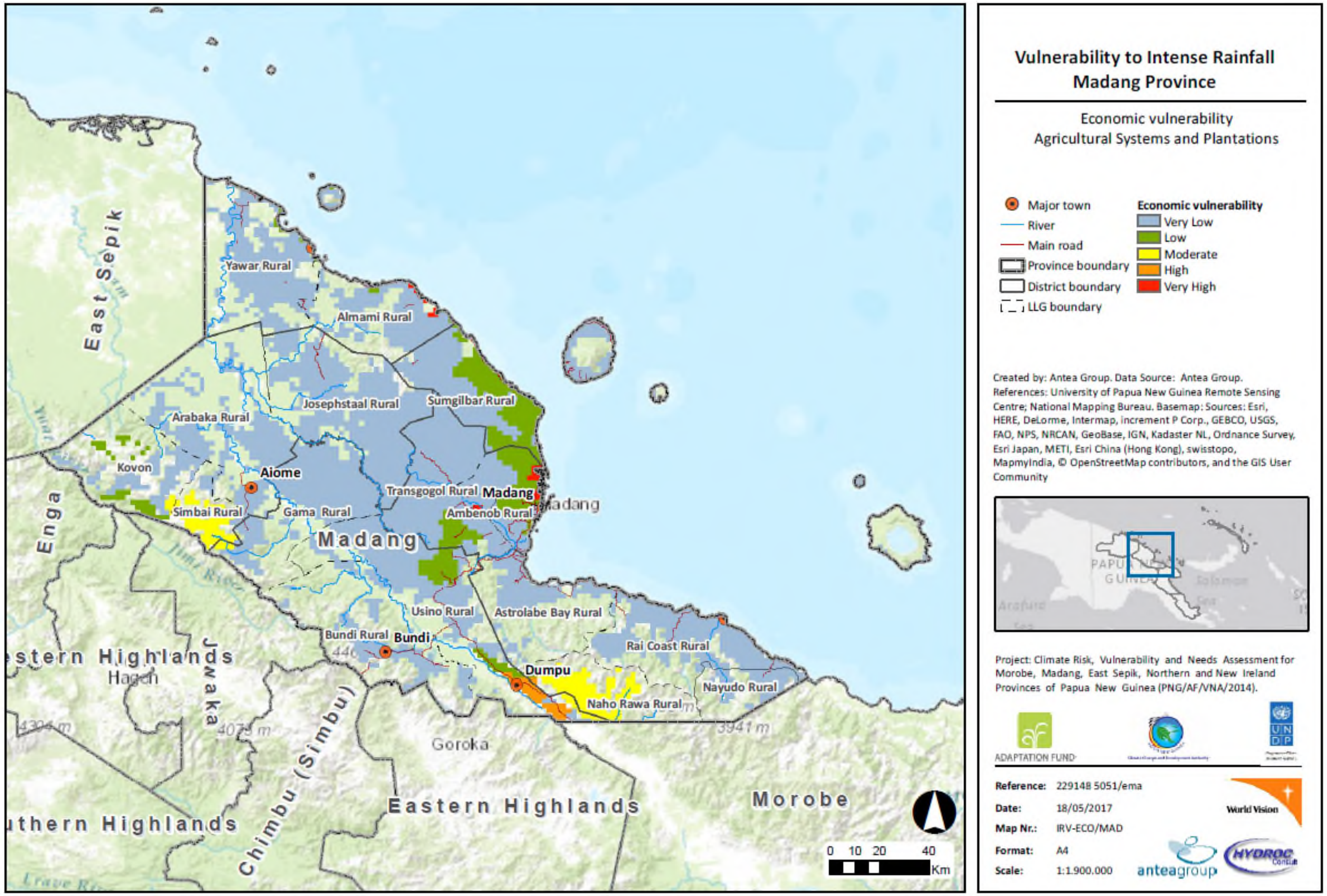

Figure 36. Economic vulnerability to precipitation intensity and variability (intense rainfall) in Madang Province

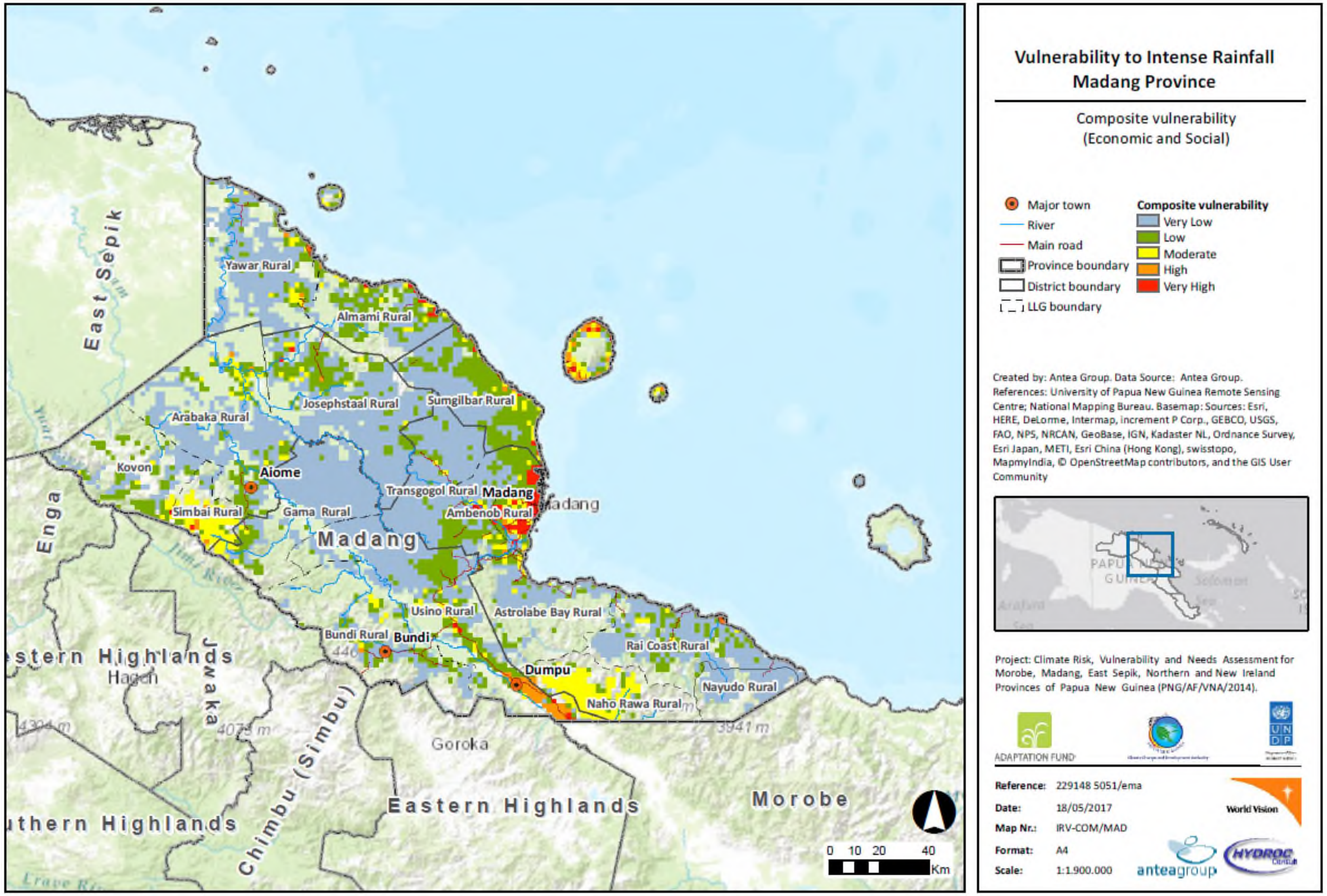

Figure 37. Combined vulnerability to precipitation intensity and variability (intense rainfall) in Madang Province

2.3. Risk Assessment

In this chapter we discuss the risk maps produced for Madang Province and this for each of the five hazards considered in the study. Risk maps were produced for each of the three components:

- Social vulnerability
- Physical vulnerability (infrastructure)
- Economic vulnerability

More over the risk maps were produced each time under the current climate and under a projected climate scenario.

2.3.1. Inland Flood Risk

There are a few scattered areas with moderate to high social risk for inland flooding in the province, located mainly in Middle Ramu District north of Aiome town and smaller areas in the vicinity of Boko and Bundi in Usino-Bundi District in the southwestern part of the province, as can be seen in Figure 38.

Projections for the future show a slight increase in the profile for social risk in the regions of Middle Ramu and Bogia Districts.

Excerpt from the CRA in Boko Vilage, Ward 31, Usino LLG, Usino-Bundi District

Flooding is the main hazard in Boko village. Located along the banks of Mea and Boko Rivers, the village is highly vulnerable to flooding. Added to this is that the village is located in a floodplain and a waterlogged area. Boko village typically experiences regular flooding during the year, but the biggest floods occured in 2004 and 2013. At this time, a number of houses and food gardens were washed away. The village was isolated for days as they were cut off from the main Usino highway. It took several days before the flood waters subsided.

The flood destroyed many of the crops in the village which significantly affected the economic activities of people. Apart from the destruction of houses, property and the loss of livelihoods and income, flooding has also made the situation of families in the area worst. Without safe drinking water, they have no choice but to use unsafe flood water for drinking, washing and bathing. This led to the increase of water-borne diseases in the village. Also, stagnant water and water logged areas become breeding grounds for mosquitoes after the floods and an increase in the incidence of malaria.

The inland flooding physical risk map of the Province of Madang shows only a few hotspots along the coastal area of Madang District and scattered throughout Middle Ramu District (Figure 39).

Projections for the near future do not show much change (Figure 43).

The map for economic risk shows a few hotspots around Madang District, the southeast of Dumpu and Karkar Island. Otherwise, incipient risk in mostly concentrated in the northern half of the province.

Projections for the near future (2030-2050) show a very slight increase.

The composite map for inland flooding risk for the Province of Madang shows a few hotspots mostly along the coastal area of Madang District, the upper strech of Ramu River, and scattered throughout Middle Ramu District (Figure 41).

Projections for under a high emission scenario show a slight risk increase in the provinces of Bogia, Madang and Middle Ramu and a slight decrease in the district of Usino Bundi, as shown in the table below:

Table 33. Distribution of inland flood risk classes in Madang Province

		HAZARD : INLAND FLOODING												
	RISK 1960-1990 %							RISK 2030-2050 %						
District	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**
Bogia District	21,4	13,5	6,0	1,6	2,0	55,5	9,6	20,5	13,8	6,5	1,7	2,1	55,3	10,3
Madang District	34,4	16,2	4,7	3,2	3,1	38,3	11	34,4	16,1	4,9	3,2	3,1	38,3	11,2
Middle Ramu District	33,0	10,5	3,6	1,7	1,5	49,6	6,8	32,9	10,7	3,5	2,0	1,7	49,1	7,2
Rai Coast District	28,2	4,2	2,0	1,1	0,6	63,9	3,7	28,2	4,2	2,0	1,1	0,6	63,9	3,7
Sumkar District	32,7	9,9	3,5	2,1	0,2	51,7	5,8	32,7	9,9	3,5	2,1	0,2	51,7	5,8
Usino Bundi District	26,9	7,8	2,5	1,2	0,9	60,6	4,6	26,7	8,1	2,6	1,2	0,9	60,5	4

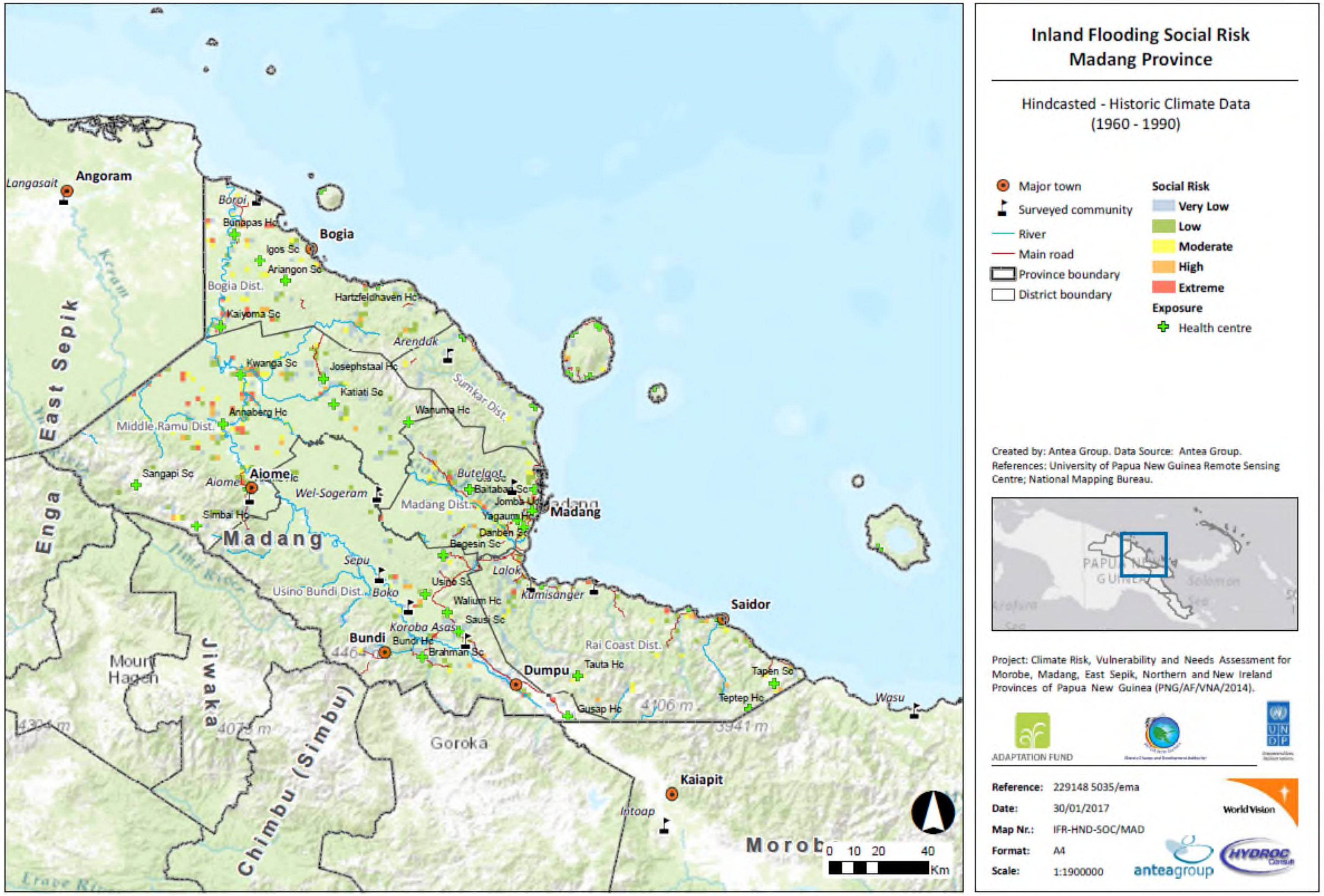

Figure 38. Inland Flooding Social Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

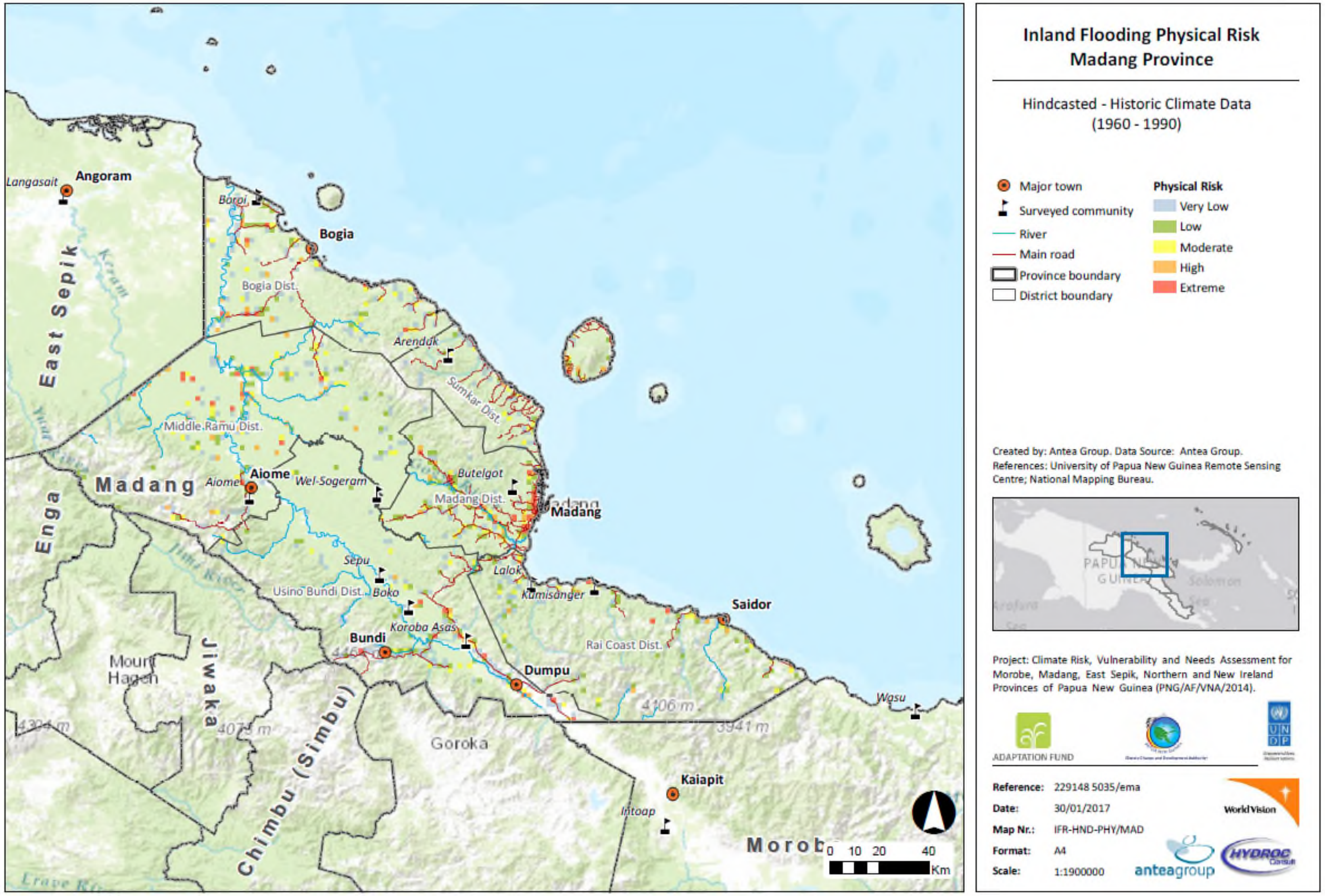

Figure 39. Inland Flooding Infrastructure Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

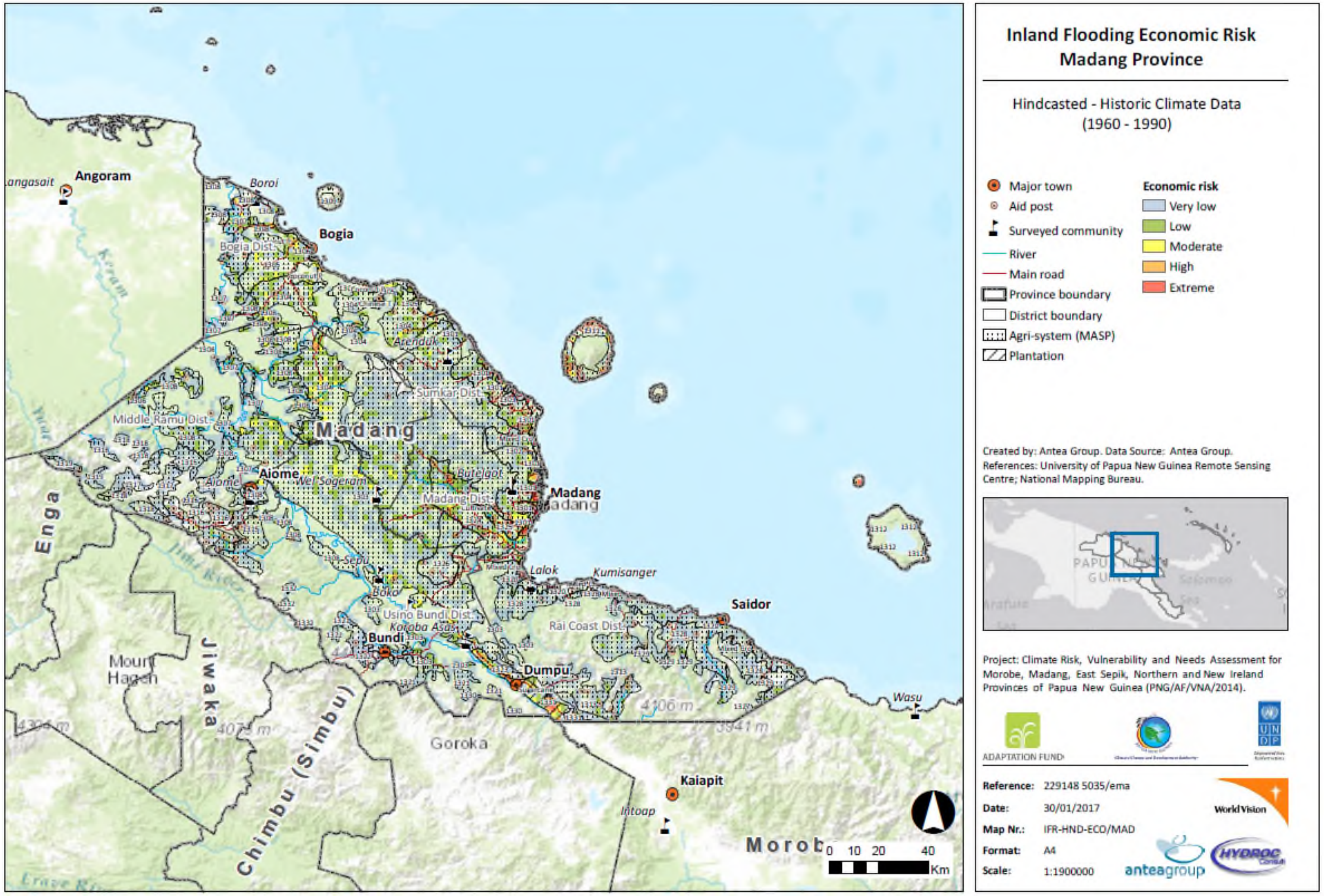

Figure 40. Inland Flooding Economic Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

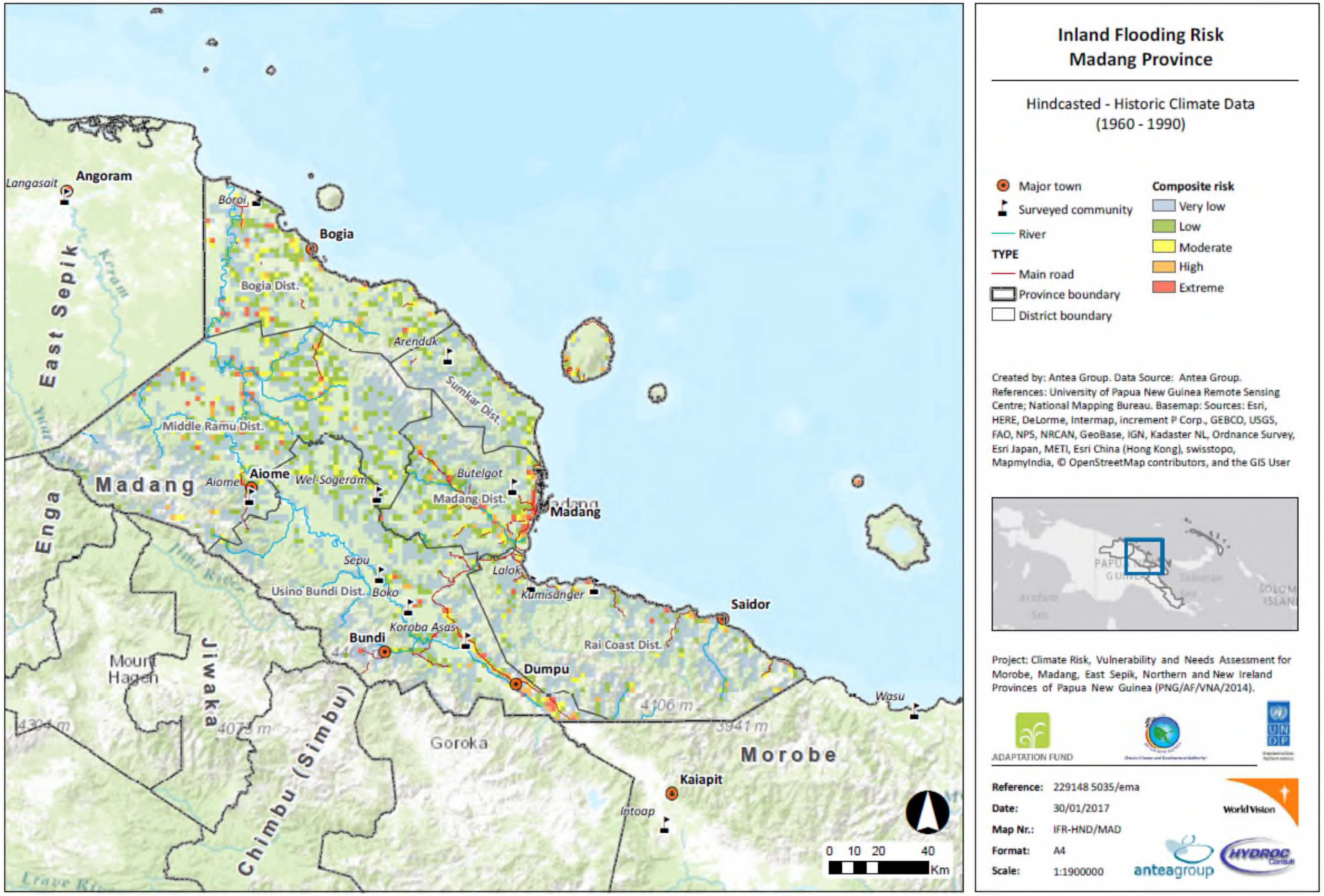

Figure 41. Inland Flooding Composite Risk (current climate) Very Low Low Moderate High Extreme

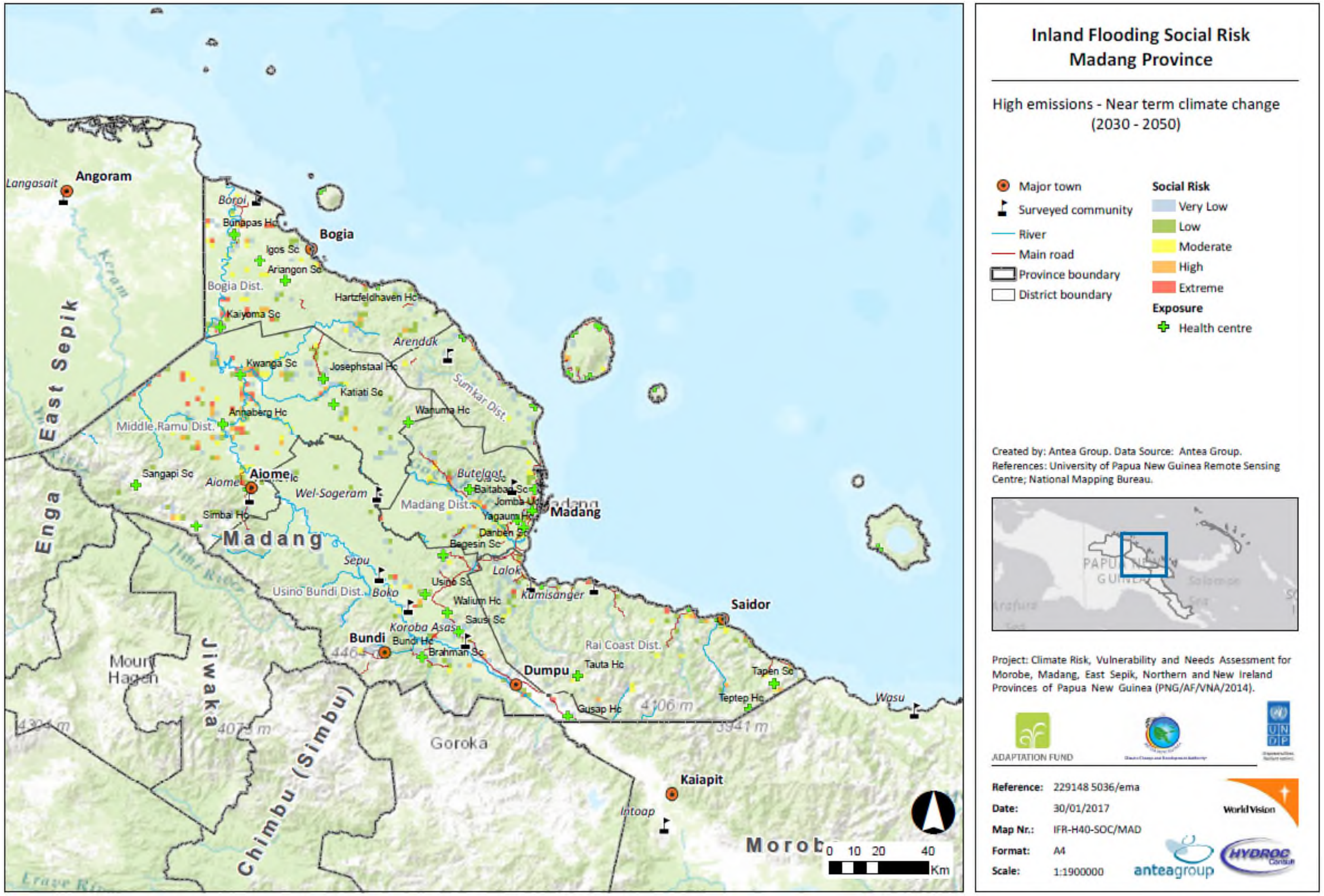

Figure 42. Inland Flooding Social Risk (projected climate) Very Low Low Moderate High Extreme

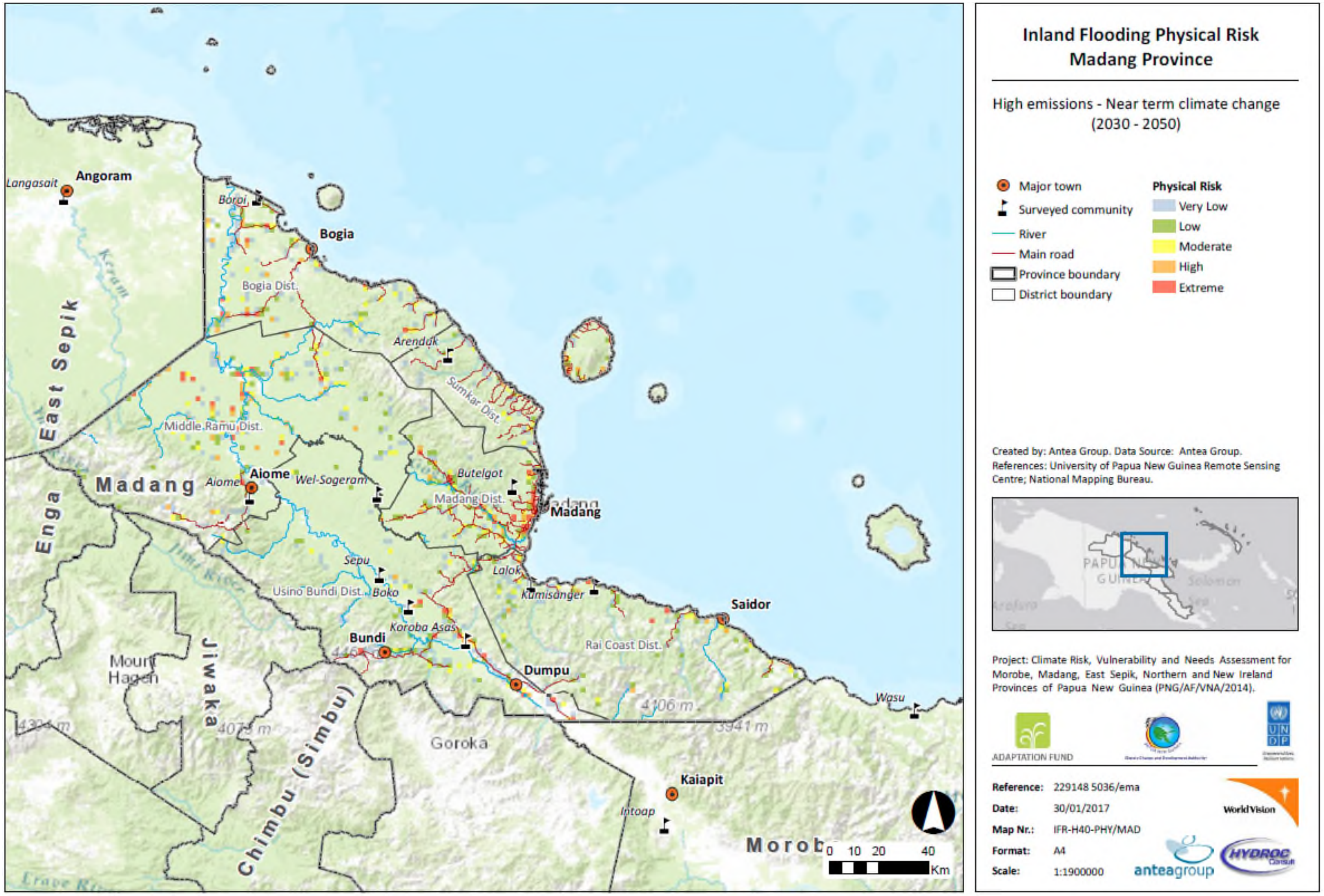

Figure 43. Inland Flooding Physical Risk (projected climate) Very Low Low Moderate High Extreme

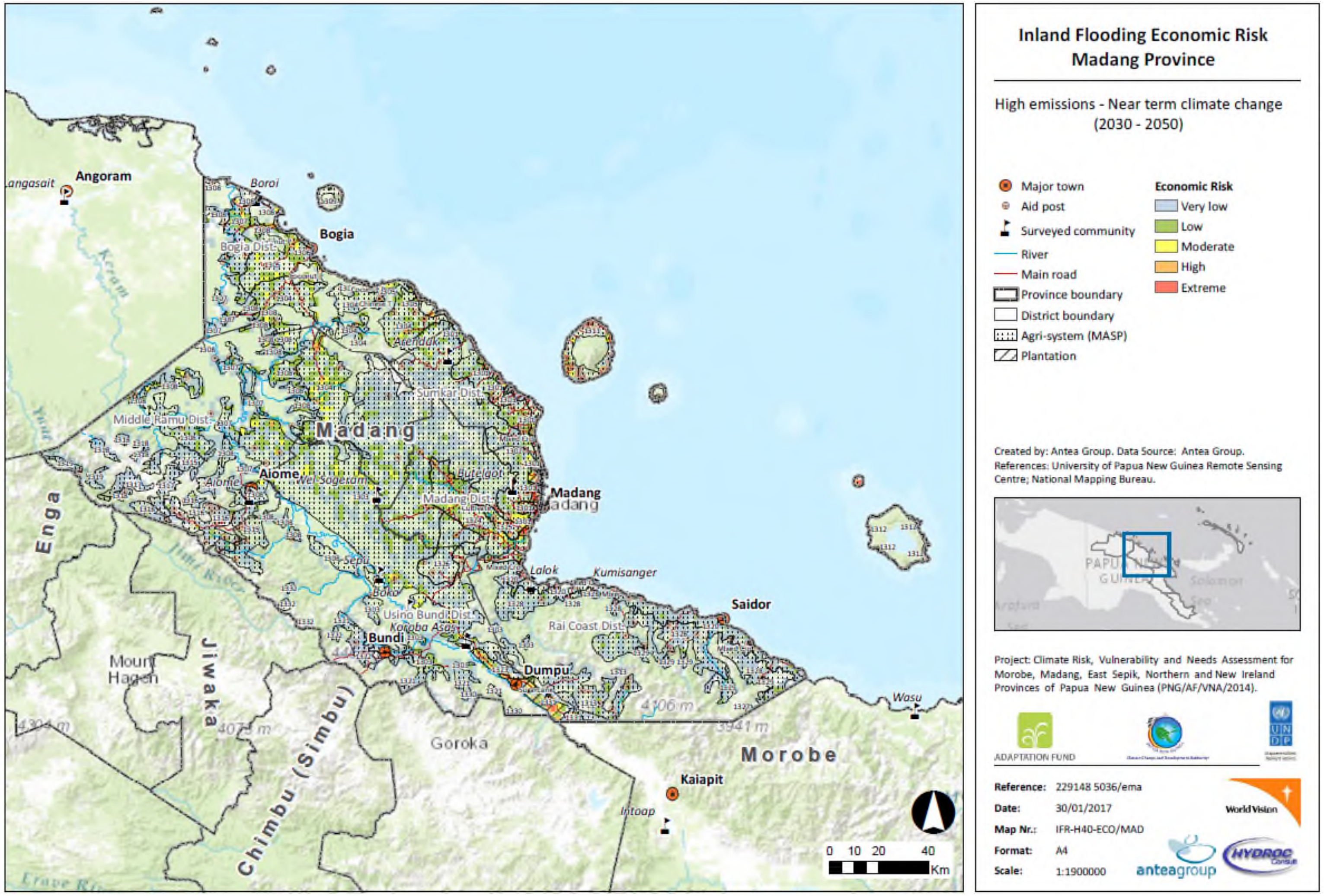

Figure 44. Inland Flooding Economic Risk (projected climate) Very Low Low Moderate High Extreme

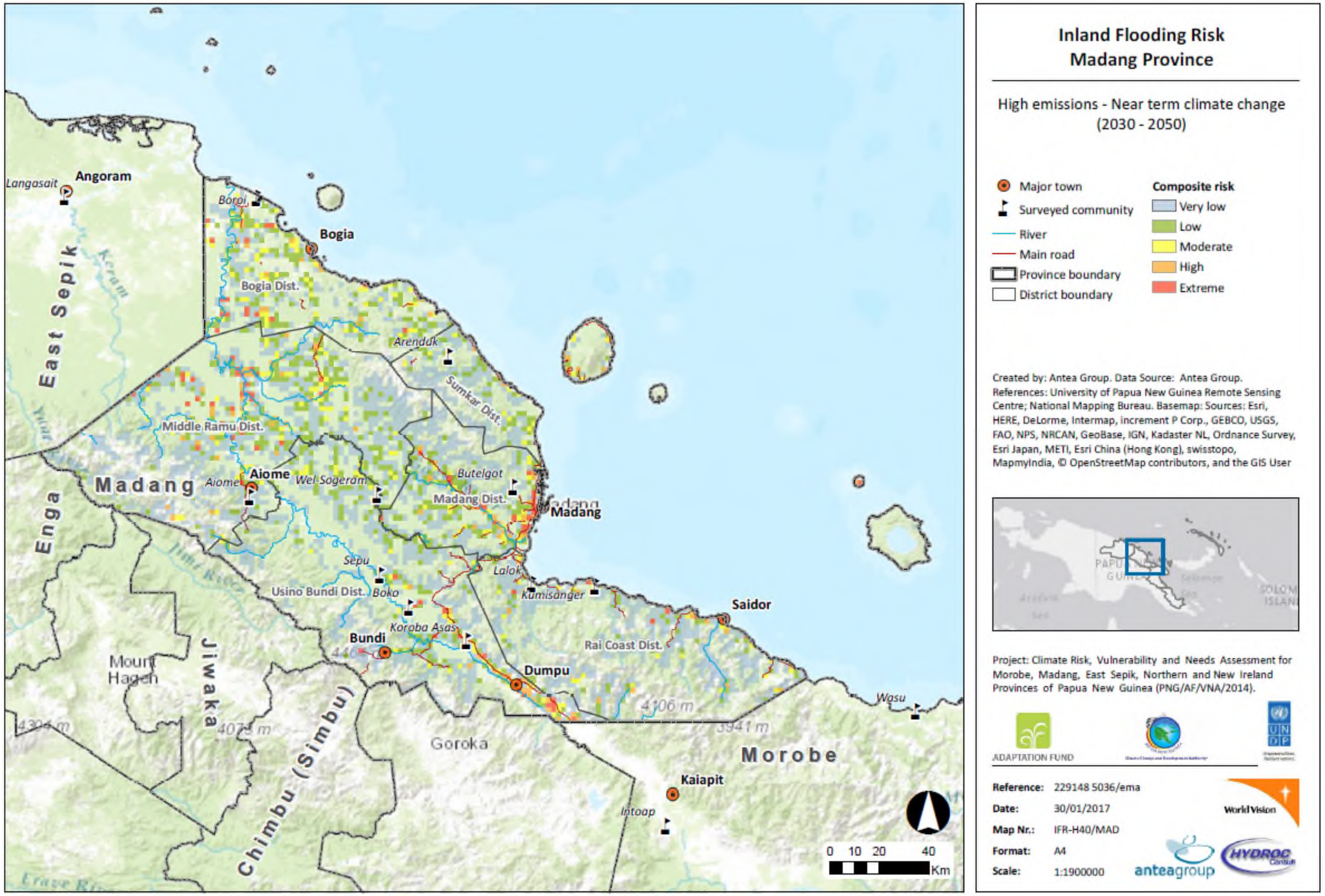

Figure 45. Inland Flooding Composite Risk (projected climate) **Very Low** **Low** **Moderate** **High** **Extreme**

2.3.2. Coastal Flood Risk

The lack of available topographic information prevented mapping coastal flood risk for the province.

2.3.3. *Drought Risk*

Areas with the highest social risk for droughts are found on Karkar Island off the east coast of the province and around Madang town, with areas of moderate risk for droughts found in several other areas, including an area southwest of Aiome town, around and inland from Saidor town in the in Rai Coast District in the south eastern part of the province and in the vicinity of Dumpu in the Usino-Bundi District in the southwestern part of the province (see Figure 46). It is expected that the social risk from droughts will be correlated with areas with economic risk as well, since the effect of droughts on food crops and food availability and water sources will also have social and health impacts.

Projections for the future show a general increase in the social risk to droughts as can be seen in Figure 49. The areas that are foreseen to have a higher risk are around Madang City and Karkar Island, but there are four other regions that show an incipient moderate risk: the stretch of coast of Sumkar District, the region to the southwest of Aiome, a big section of the area around the road that goes from Dumpu to Madang and Rai Coast District.

The map for economic risk to drought (Figure 47) shows a low profile in general, except in the region southeast and east of Dumpu, in inland north and east of Rai Coast District, in the region southwest of Aiome and in Karkar Island.

Projections for the future show a big increase in the extension of the moderate risk, extending to most of Madang, Sumkar and Rai Coast Districts, and specially high in the region southeast of Dumpu (see Figure 50).

The map for composite risk for drought in the province of Madang (Figure 48) shows a low to moderate profile with hotspots along the upper stretch of Ramu River, along the east of Madang District and around the coastal areas of Karkar Island. Other areas worth mentioning given the big extension they cover are the south of Middle Ramu District and Rai Coast District.

Projections for the near future (Figure 51) show an increase of this risk, especially in the eastern half of the province, with hotspots around Madang City, and the upper stretch of Ramu River, as well as in the coastal areas of Karkar Island. The table below shows more detail on the magnitude:

Table 34. Distribution of drought risk classes in Madang Province

	HAZARD : DROUGHT													
	RISK 1960-1990 %							RISK 2030-2050 %						
District	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**
Bogia District	16,5	43,3	4,4	1,3	0,0	34,5	5,7	16,5	40,9	6,8	0,6	0,6	34,5	8,0
Madang District	0,3	84,8	8,1	6,0	0,0	0,8	14,1	0,0	34,4	56,9	1,9	6,0	0,8	64,8
Middle Ramu District	11,7	39,4	8,0	0,2	0,0	40,8	8,2	11,7	39,6	8,0	0,2	0,0	40,5	8,2
Rai Coast District	5,3	21,7	24,5	0,2	0,0	48,3	24,7	0,0	13,4	38,0	0,1	0,2	48,3	24,7
Sumkar District	0,2	66,2	18,1	5,8	0,0	9,7	23,1	0,2	12,8	71,0	5,3	1,9	8,9	78,2
Usino Bundi District	7,2	41,1	4,5	2,3	0,0	44,9	5,8	6,0	37,9	7,9	1,1	2,2	44,9	11,2

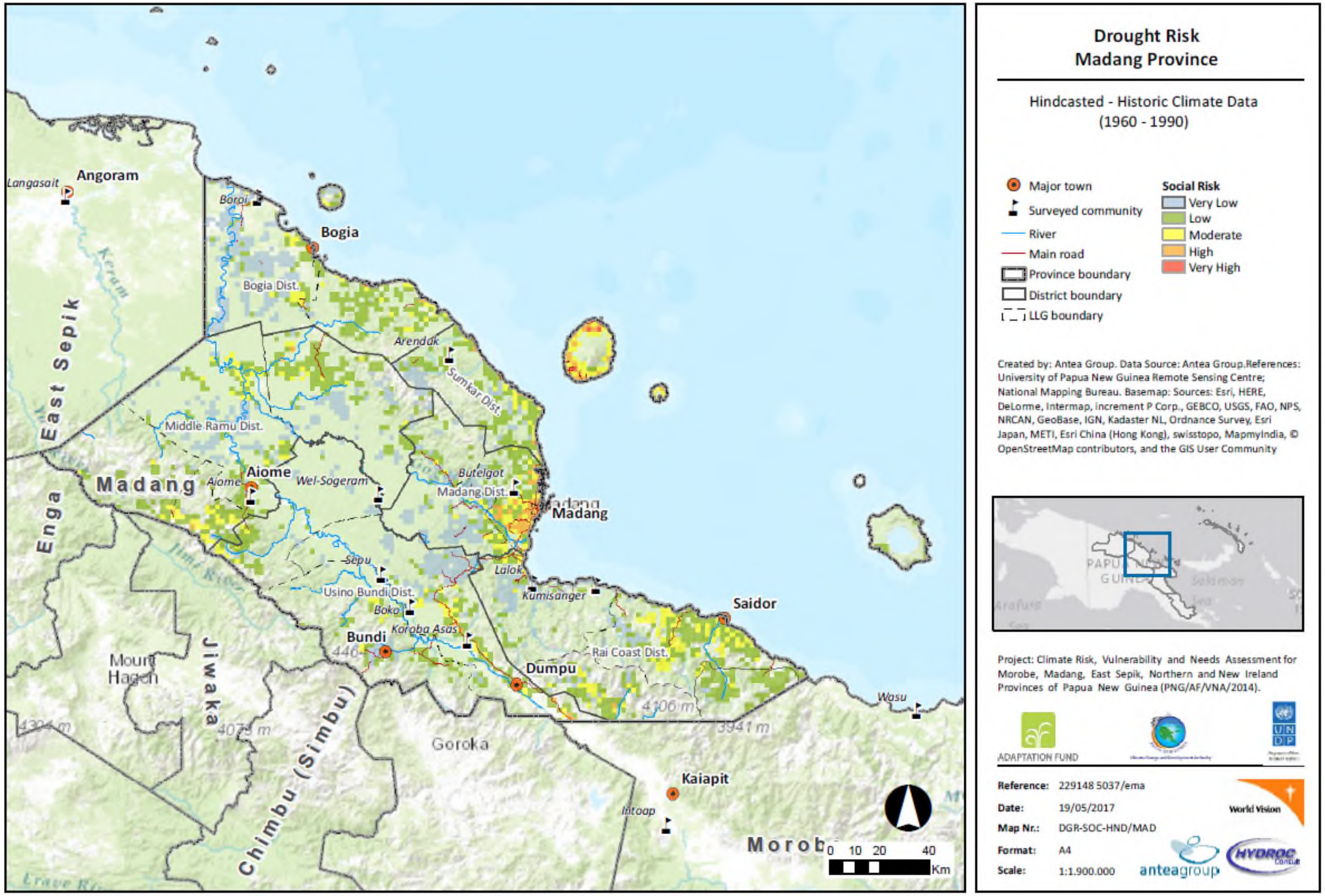

Figure 46. Drought Social Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

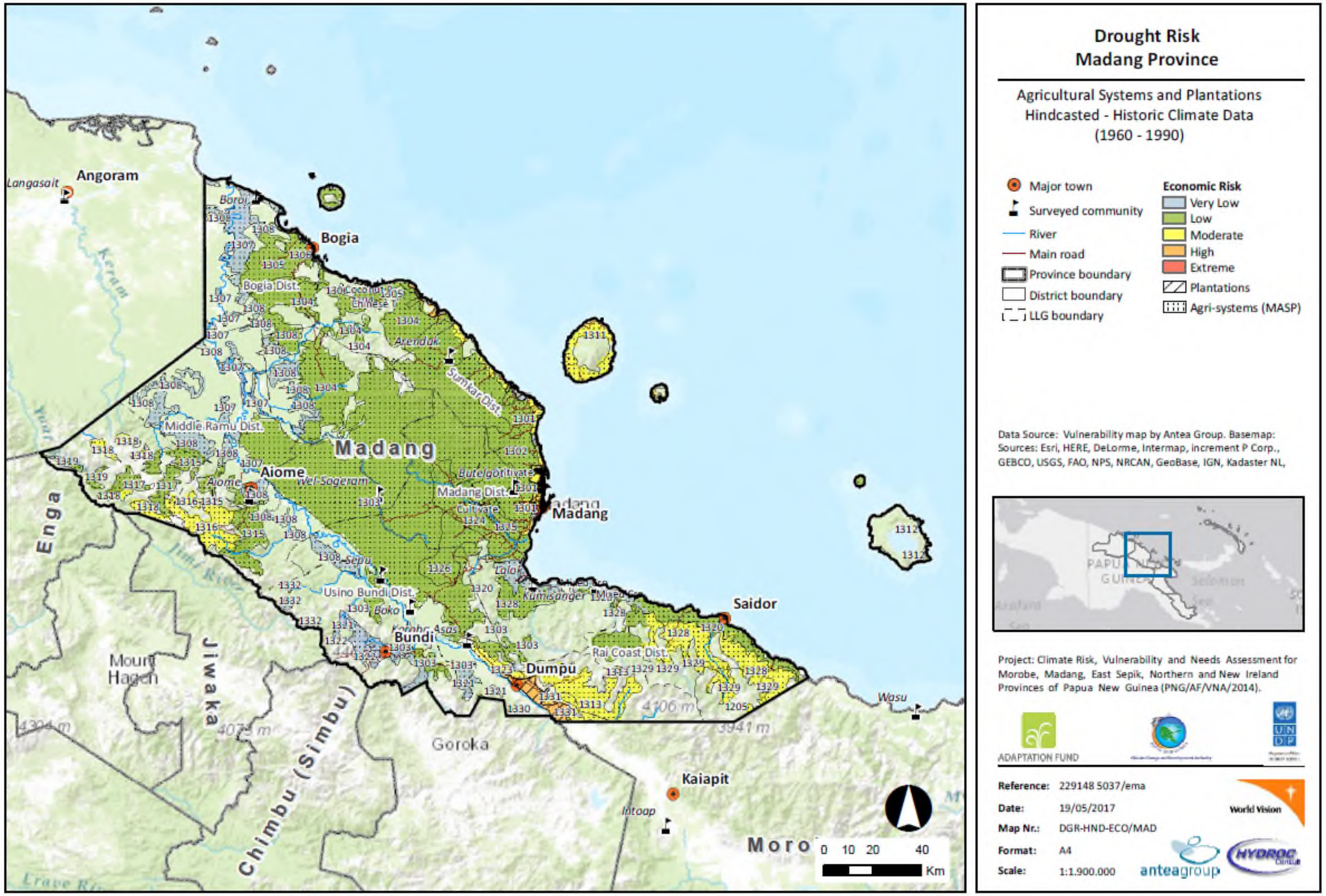

Figure 47. Drought Economic Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

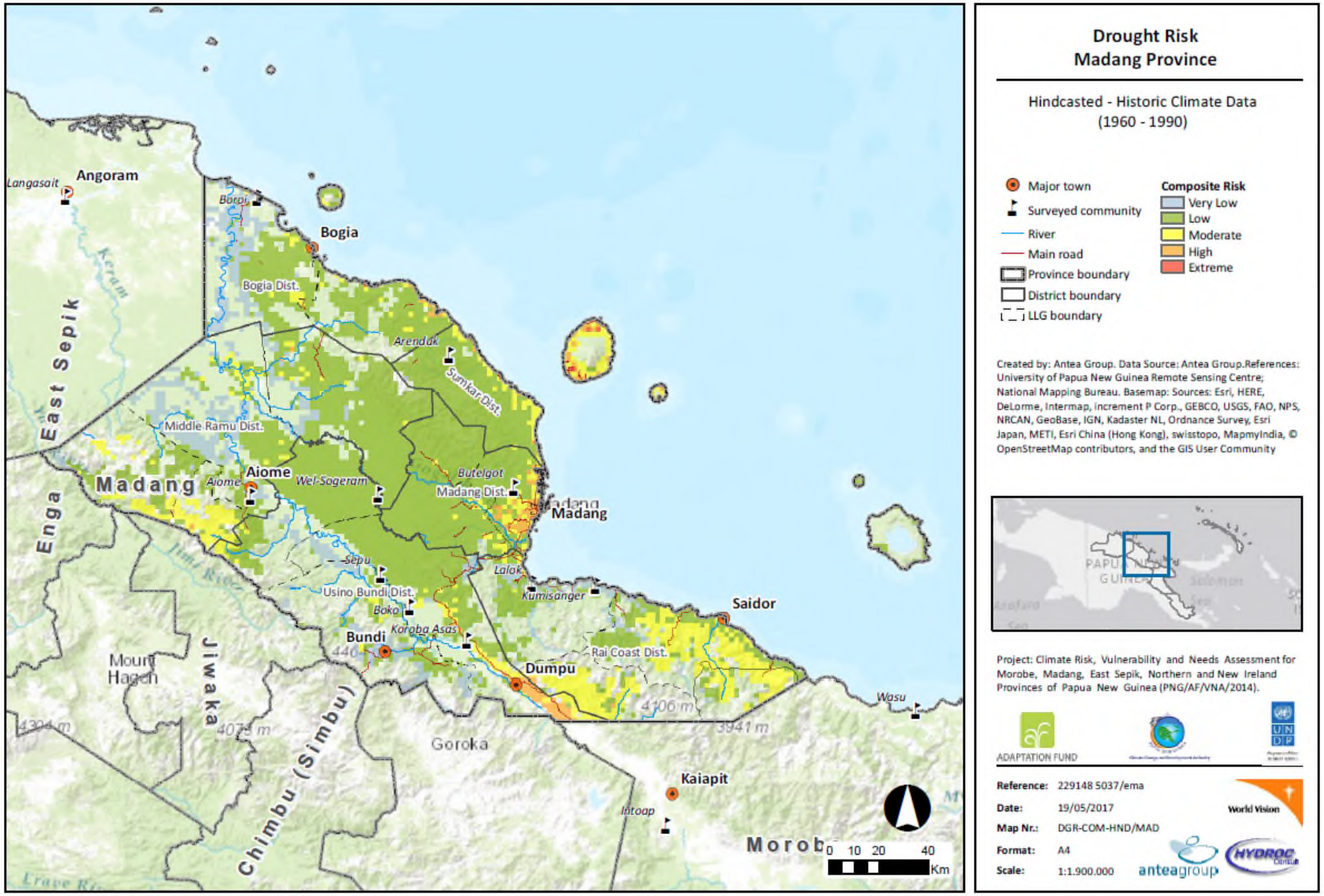

Figure 48. Combined Drought Risk (current climate) Very Low Low Moderate High Extreme

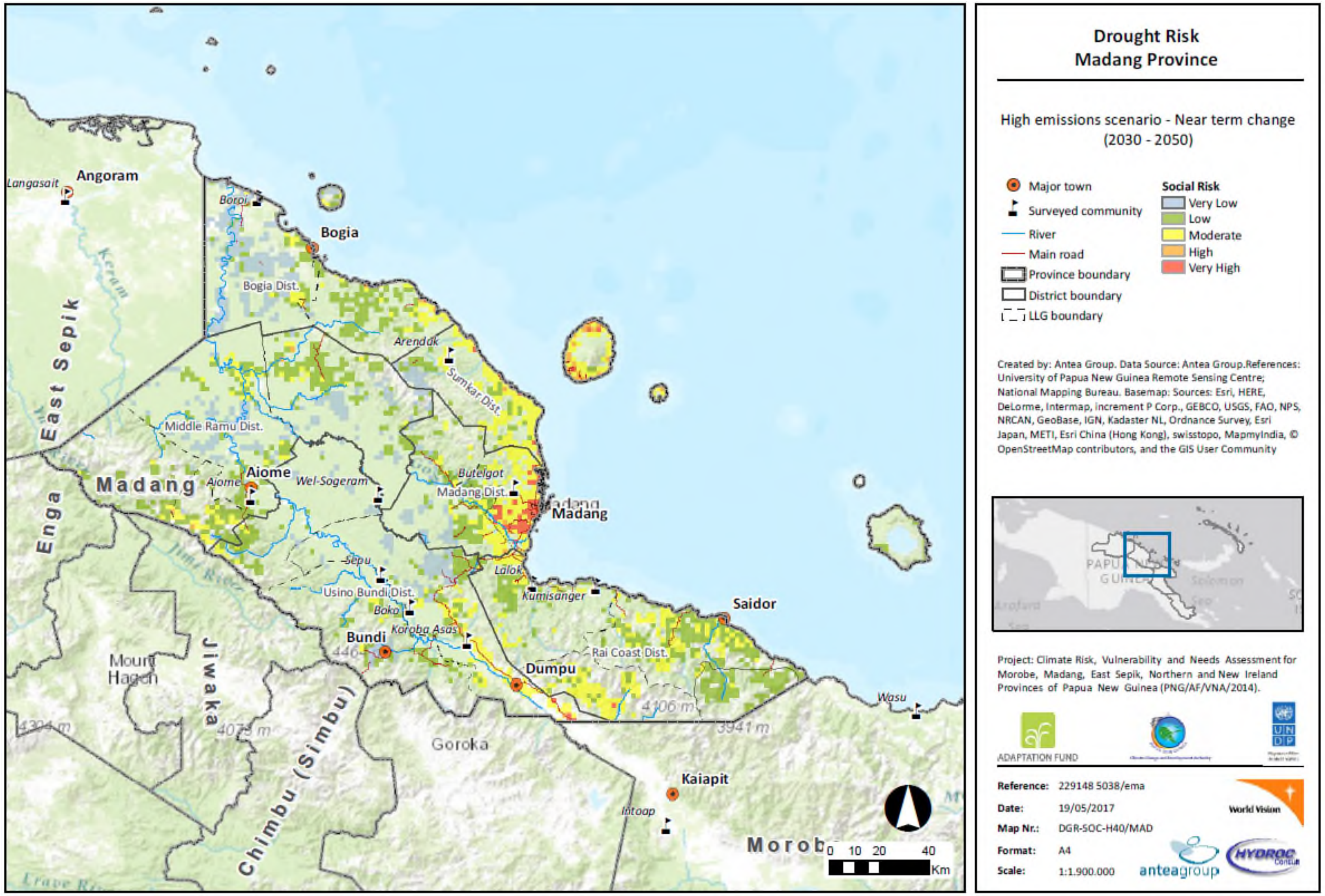

Figure 49. Drought Social Risk (projected climate) Very Low Low Moderate High Extreme

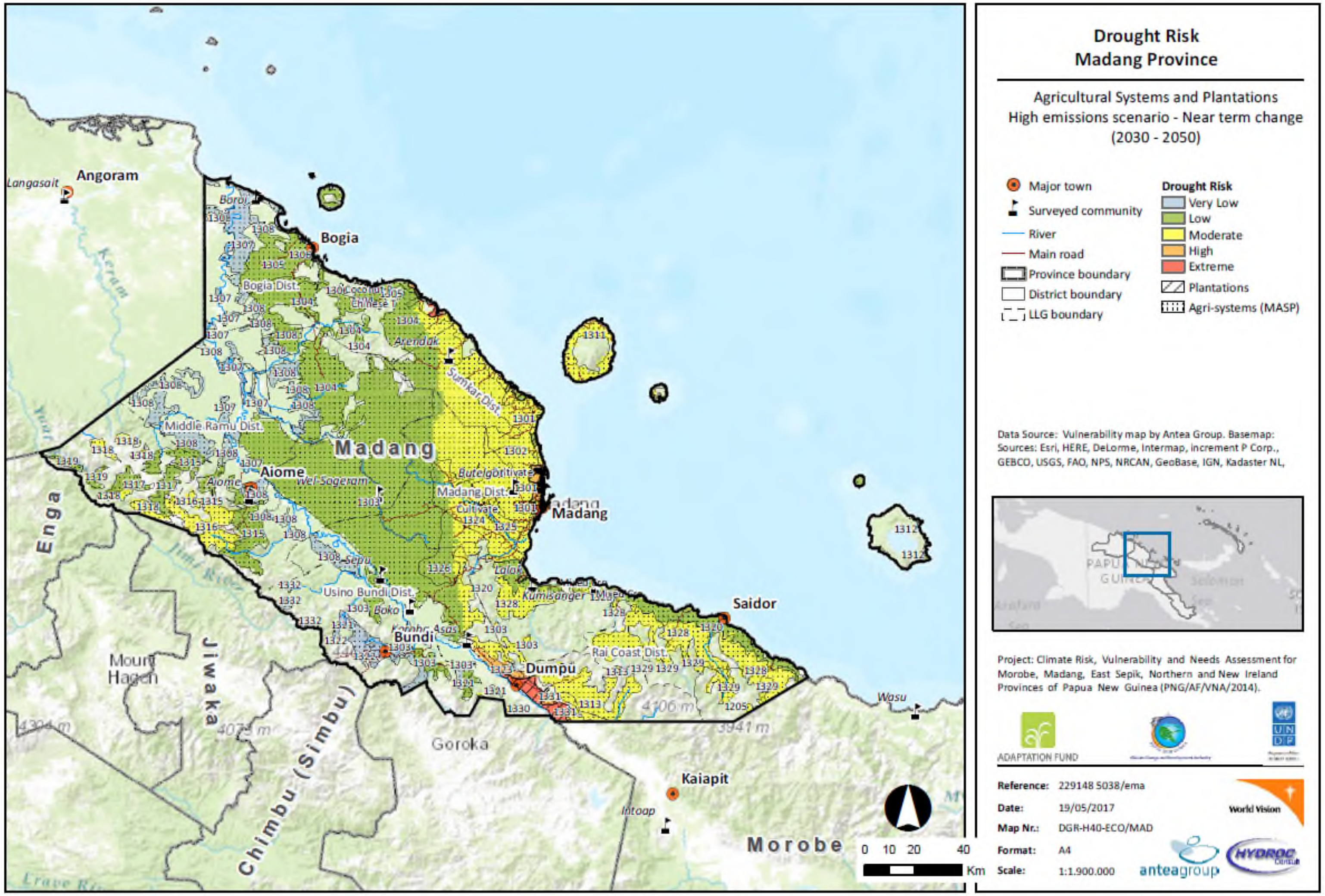

Figure 50. Drought Economic Risk (projected climate) ■Very Low ■Low ■Moderate ■High ■Extreme

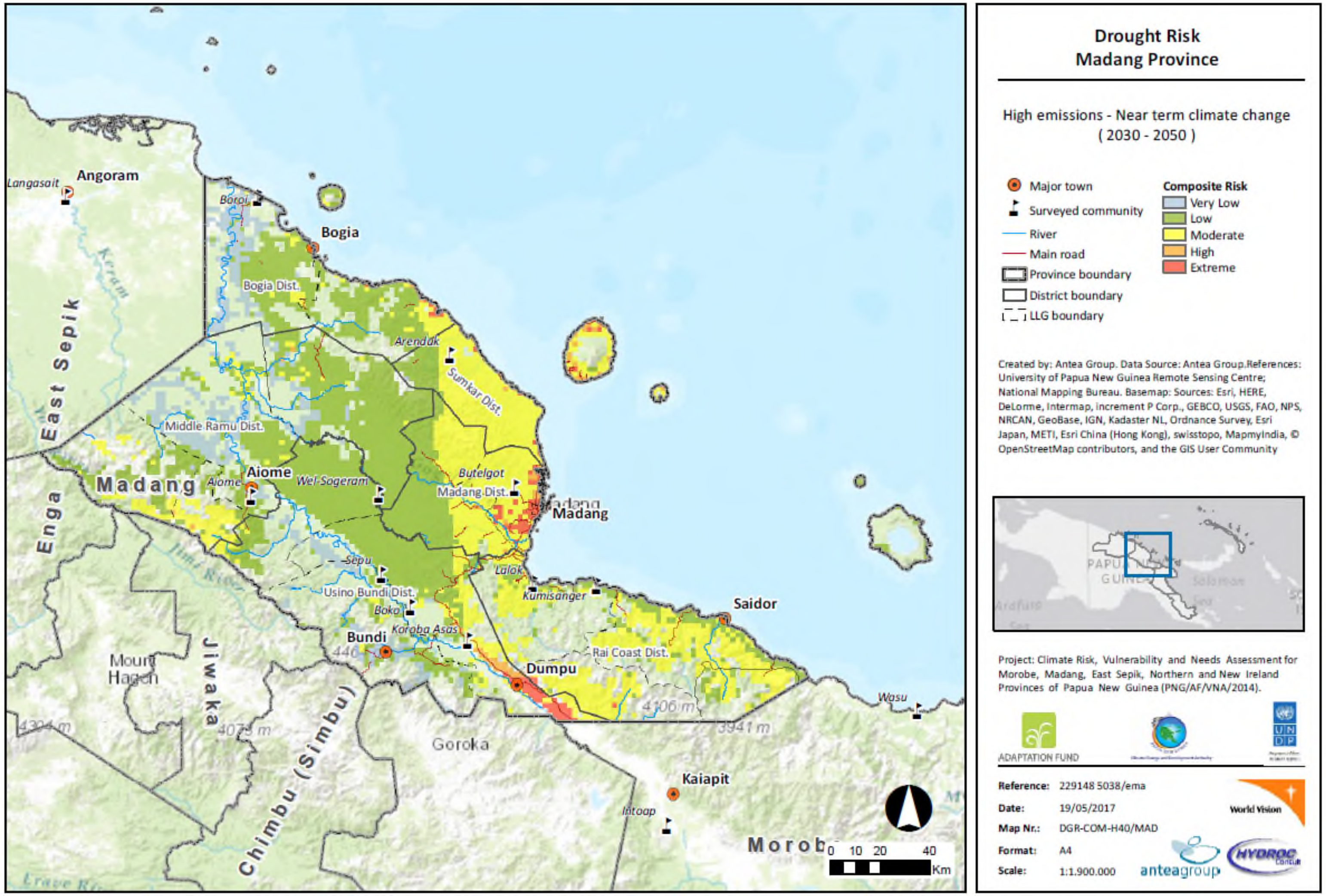

Figure 51. Combined Drought Risk (projected climate) Very Low Low Moderate High Extreme

2.3.4. *Extreme weather (tropical cyclone) Risk*

The social risk from extreme weather is generally low throughout the province, with a slightly higher concentration of low risk around Madang town and along the coast of Karkar Island (see Figure 52).

As can be seen in Figure 56, projections for the future do not show much change.

The map for physical risk to extreme weather episodes shows that the province has a rather low profile, and projections for the future do not show much change (Figures 53 and 57).

The map for current economic risk to extreme weather is also low to very low for the whole province and projections for the future follow the same trend (Figures 54 and 58).

The composite map for risk to extreme weather episodes shows that the province has a rather low to very low profile, and projections for the future do not show much change as can be seen in the table below and Figures 55 and 59.

Table 35. Distribution of extreme weather (cyclones) risk classes in Madang Province

	HAZARD : CYCLONE													
	RISK 1960-1990 %							RISK 2030-2050 %						
District	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**
Bogia District	18,2	49,1	0,0	0,0	0,0	32,7	0	18,2	49,1	0,0	0,0	0,0	32,7	0
Madang District	49,8	49,4	0,0	0,0	0,0	0,8	0	49,8	49,4	0,0	0,0	0,0	0,8	0
Middle Ramu District	38,3	21,7	0,0	0,0	0,0	40,0	0	38,3	21,7	0,0	0,0	0,0	40,0	0
Rai Coast District	27,4	25,0	0,0	0,0	0,0	47,6	0	27,4	25,0	0,0	0,0	0,0	47,6	0
Sumkar District	37,6	53,9	0,0	0,0	0,0	8,5	0	37,6	53,9	0,0	0,0	0,0	8,5	0
Usino Bundi District	41,8	14,3	0,0	0,0	0,0	43,8	0	41,8	14,3	0,0	0,0	0,0	43,8	0

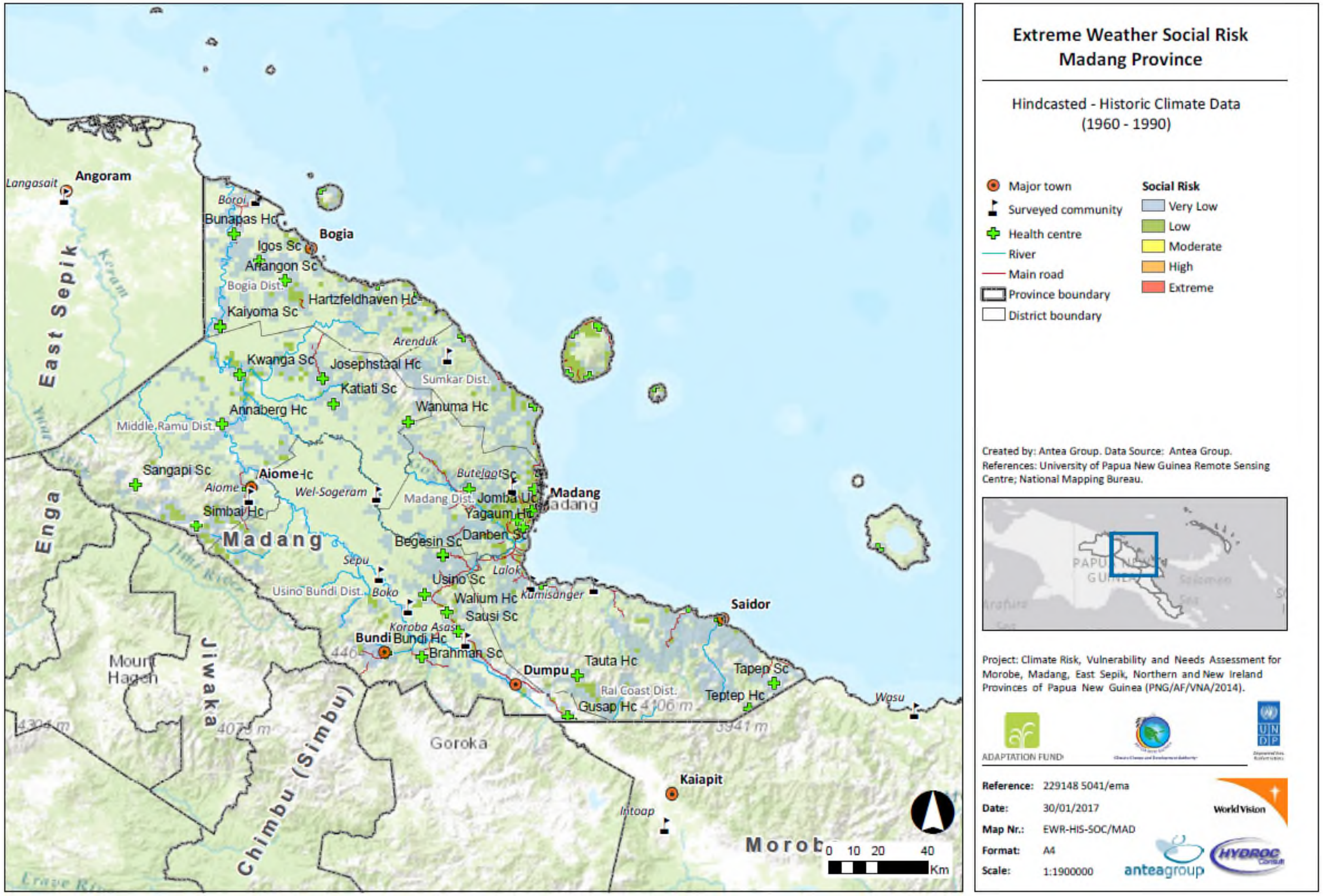

Figure 52. Tropical cyclones Social Risk (current climate) Very Low Low Moderate High Extreme

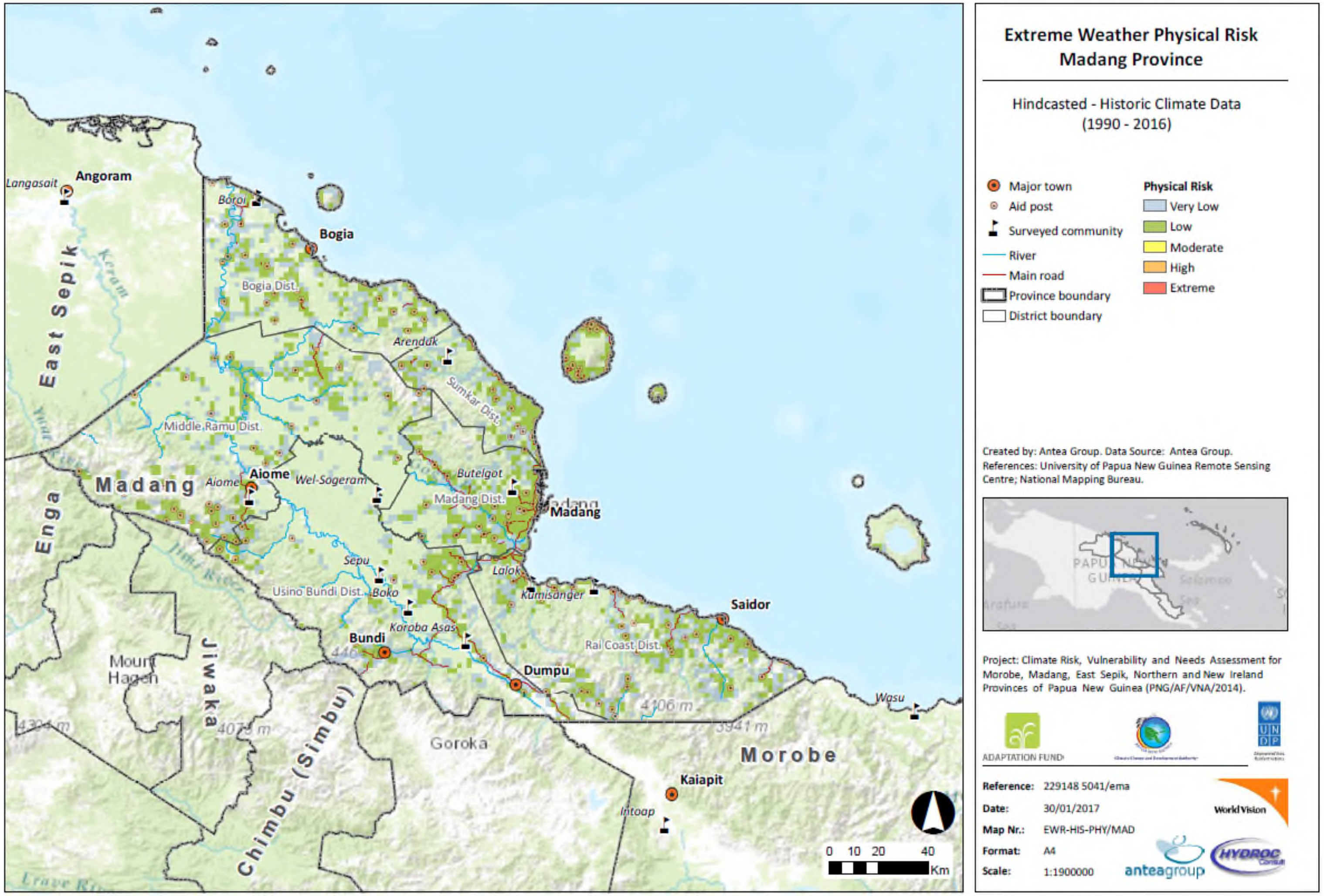

Figure 53. Tropical cyclones Physical Risk (current climate) Very Low Low Moderate High Extreme

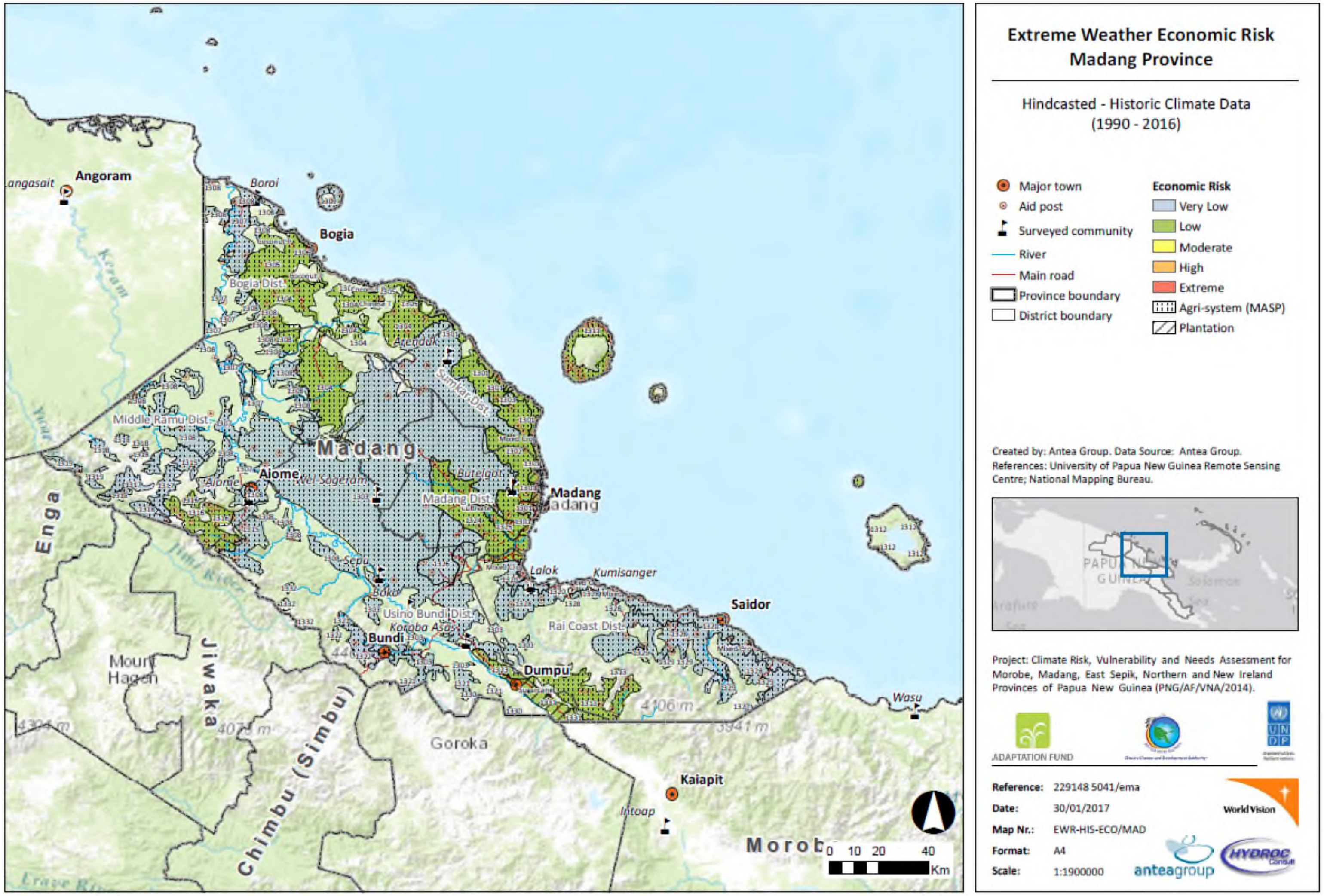

Figure 54. Tropical cyclones Economic Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

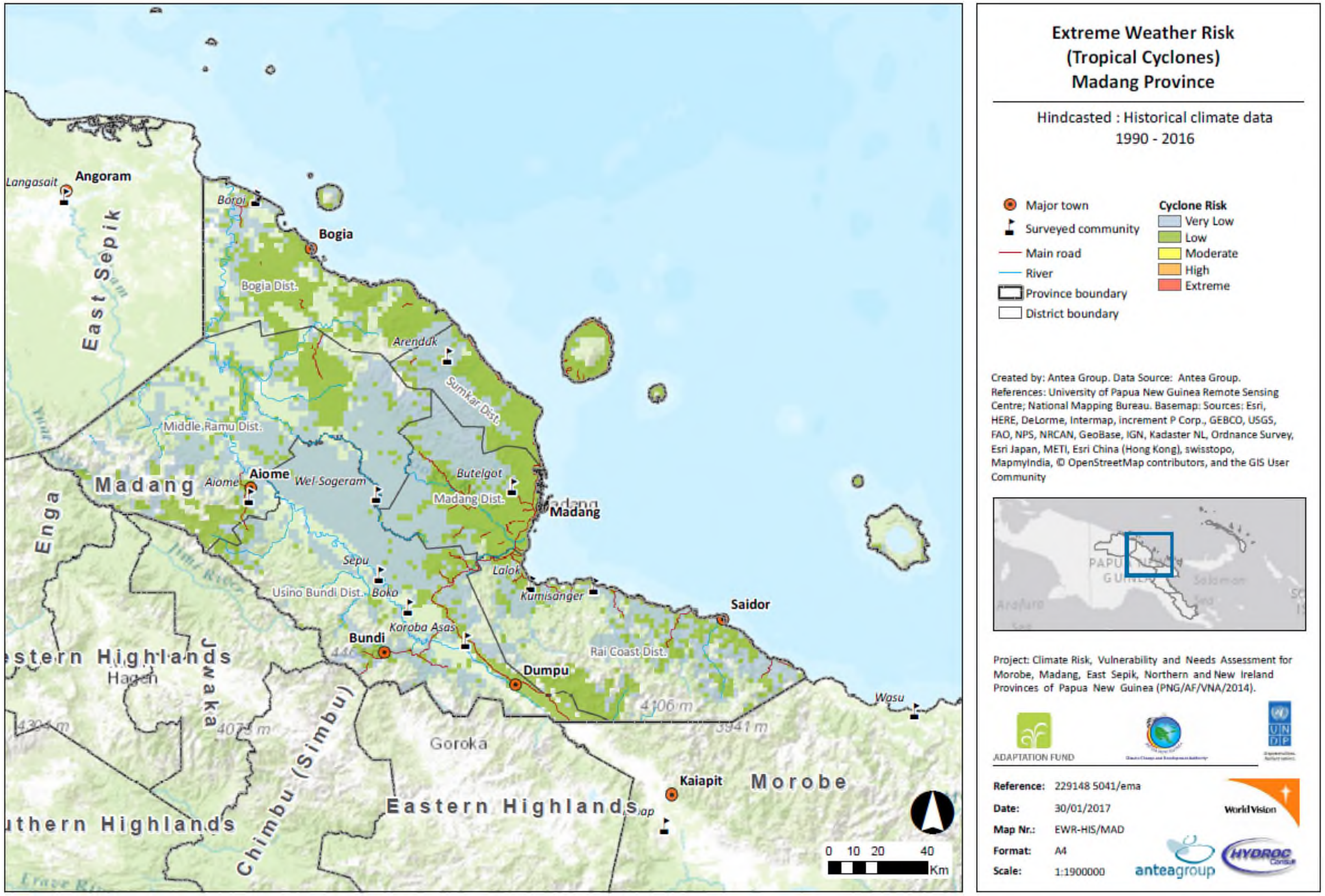

Figure 55. Tropical cyclones Composite Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

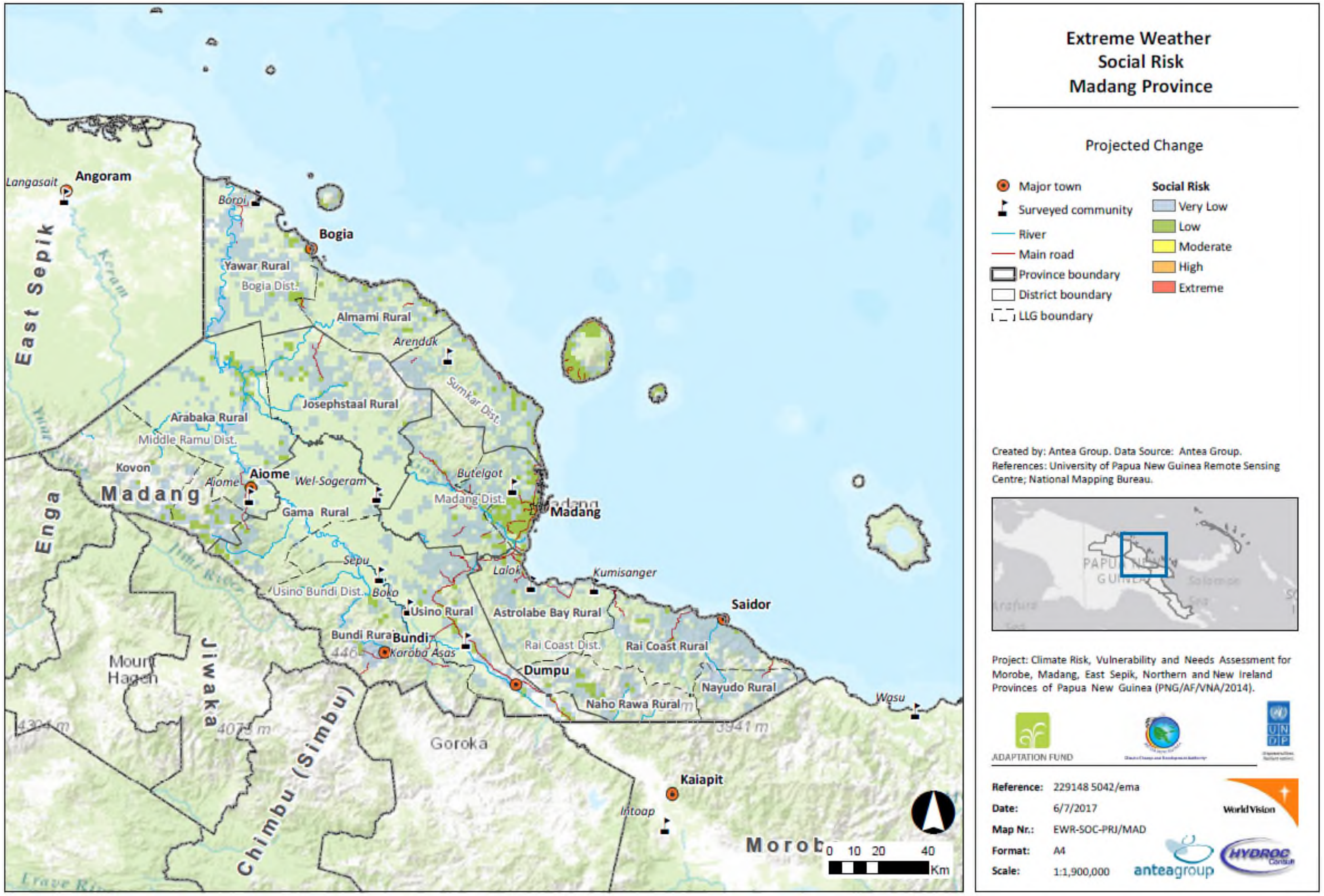

Figure 56. tropical cyclones Social Risk (projected climate) **Very Low** **Low** **Moderate** **High** **Extreme**

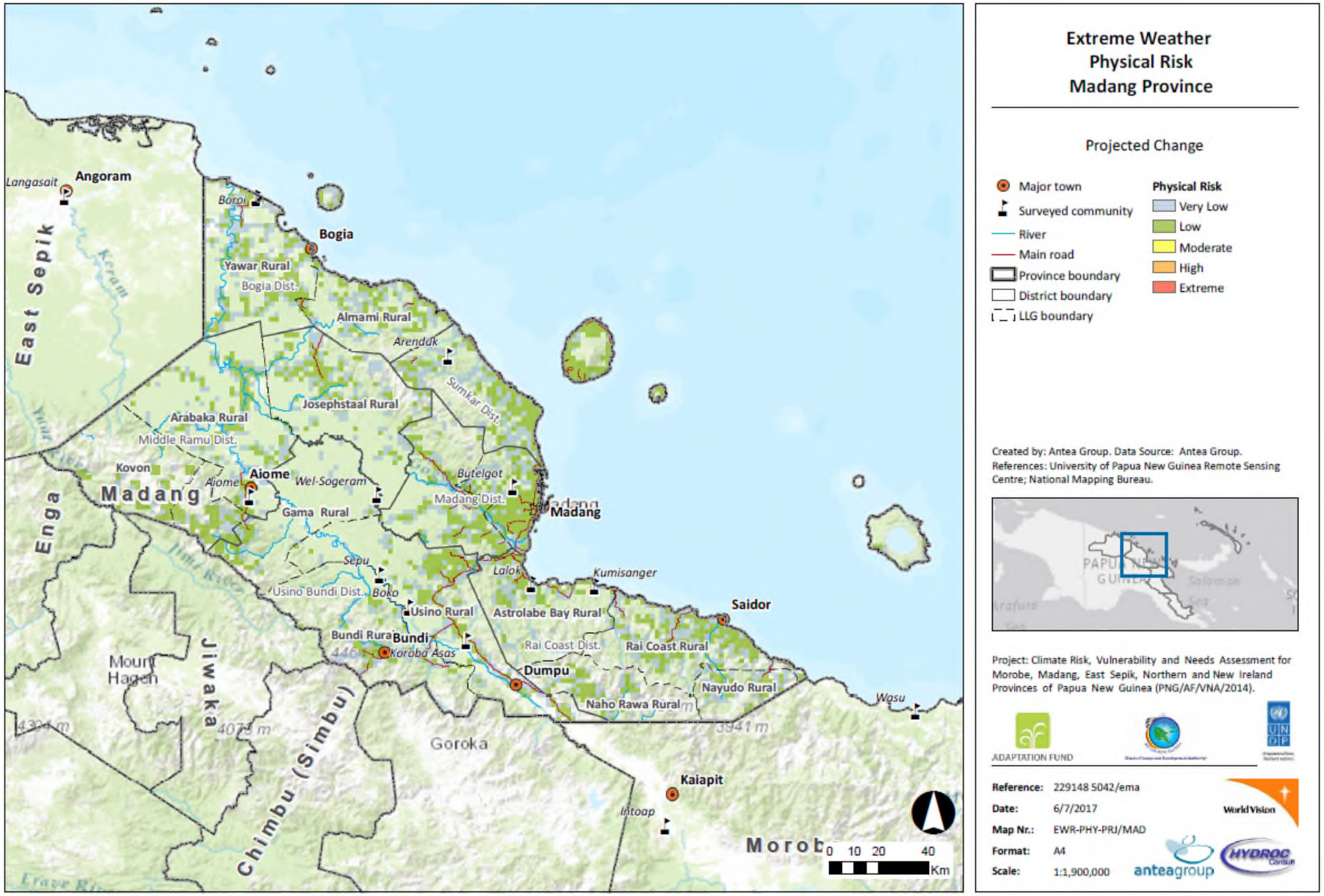

Figure 57. Tropical cyclones Physical Risk (projected climate) Very Low Low Moderate High Extreme

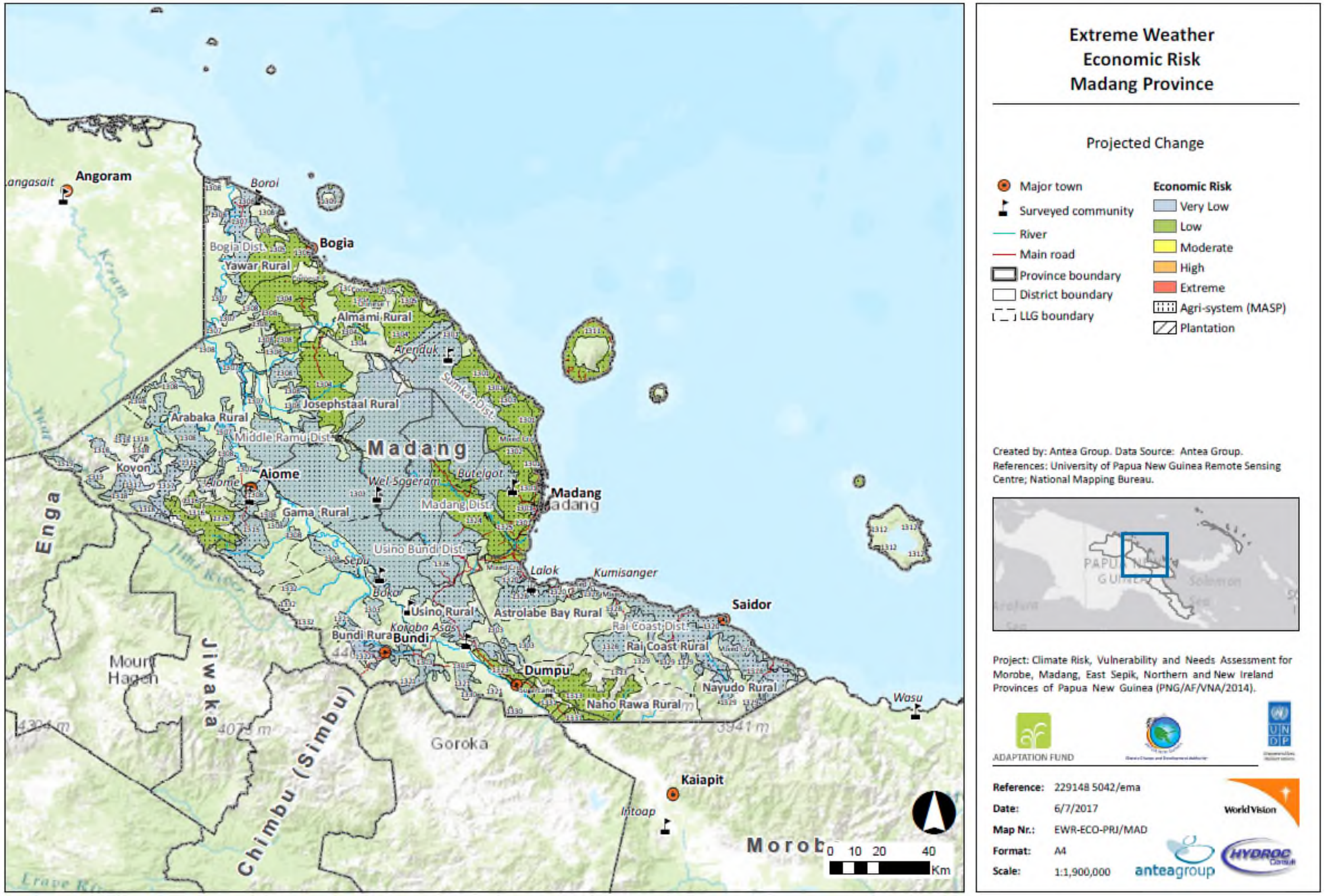

Figure 58. tropical cyclones Economic Risk (projected climate) **Very Low** **Low** **Moderate** **High** **Extreme**

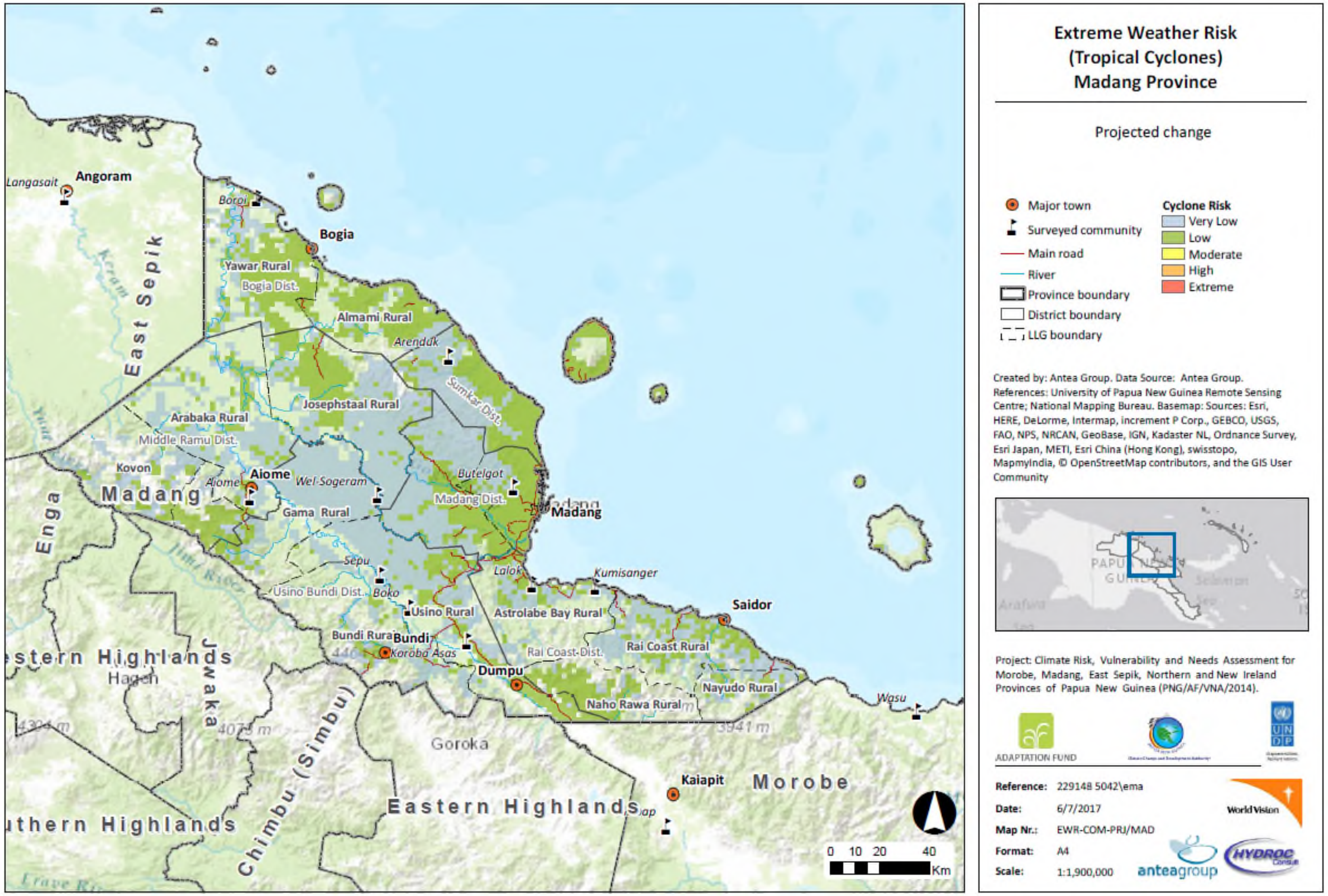

Figure 59. Tropical cyclones Composite Risk (projected climate) **Very Low** **Low** **Moderate** **High** **Extreme**

2.3.5. *Increase of precipitation intensities and variability*

The social risk from precipitation intensity and variability in the province varies from low to high, with the highest social risk found in and around Madang town, on the coast of Karkar Island, around Bogia Town on the northern coast of the province, southwest of Aiome town in Middle Ramu District, and along the Ramu River between Bokoi and Dumpu in Usino-Bundi District (see Figure 60).

Projections for the future show a generalized increase in all districts, as can be seen in Figure 63).

The map for historic climate economic risk of the province (Figure 61) shows some high hotspot in the area of Sambai Rural, in the area southeast of Dumpu and around Madang Town. Incipient moderate risk can be seen in the southwest of Rai Coast District, in Usino Bundi District and in a big part of Sumkar District (see Figure 61).

Projections for the future (Figure 64) do not show much change.

The composite map for intense rainfall risk of the Province of Madang (Figure 62) shows three main hotspots: around southern Middle Ramu District, around the upper stretch of River Ramu and in the northern part of the coast of Madang District.

Projections for the future show a general increase in the risk for intense rainfall throughout the province, especially along the coast of Madang District, around the coast of Karkar Island, north and southwest of Middle Ramu District and a long stretch in Usino Bundi District, amongst others. More details on the magnitude can be seen in the table below:

Table 36. Distribution of precipitation intensity and variability risk classes in Madang Province

	HAZARD : PRECIPITATION													
	RISK 1960-1990 %							RISK 2030-2050 %						
District	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**
Bogia District	6,5	54,7	3,2	0,2	0,6	34,7	4,0	0,0	41,5	16,2	5,4	2,2	34,7	23,8
Madang District	0,4	77,6	19,2	0,0	1,4	1,3	20,6	0,0	60,6	23,5	7,1	8,0	0,8	38,6
Middle Ramu District	3,4	48,4	4,6	3,6	0,0	40,0	8,2	0,0	34,2	1,5	16,4	3,7	44,1	21,6
Rai Coast District	27,7	16,3	7,4	0,1	0,0	48,5	7,5	0,0	14,8	15,8	2,7	0,1	66,7	18,6
Sumkar District	3,5	57,6	30,2	0,0	0,0	8,7	30,2	0,0	36,8	38,5	8,8	7,2	8,7	54,5
Usino Bundi District	1,8	44,8	5,9	2,5	0,0	45,1	8,4	0,0	16,2	3,8	11,6	2,5	65,9	17,9

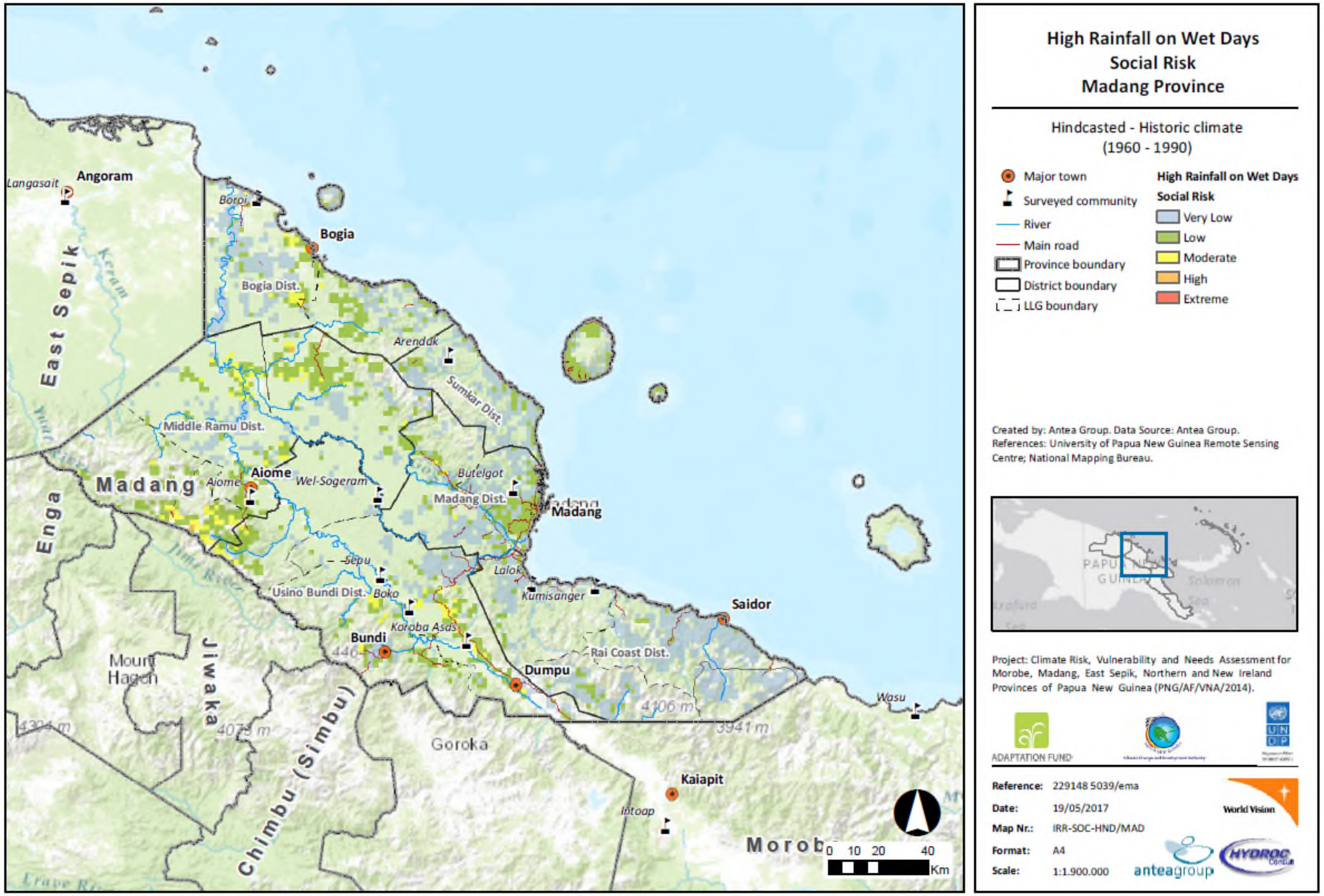

Figure 60. Precipitation intensities and variability social risk (current climate) Very Low Low Moderate High Extreme

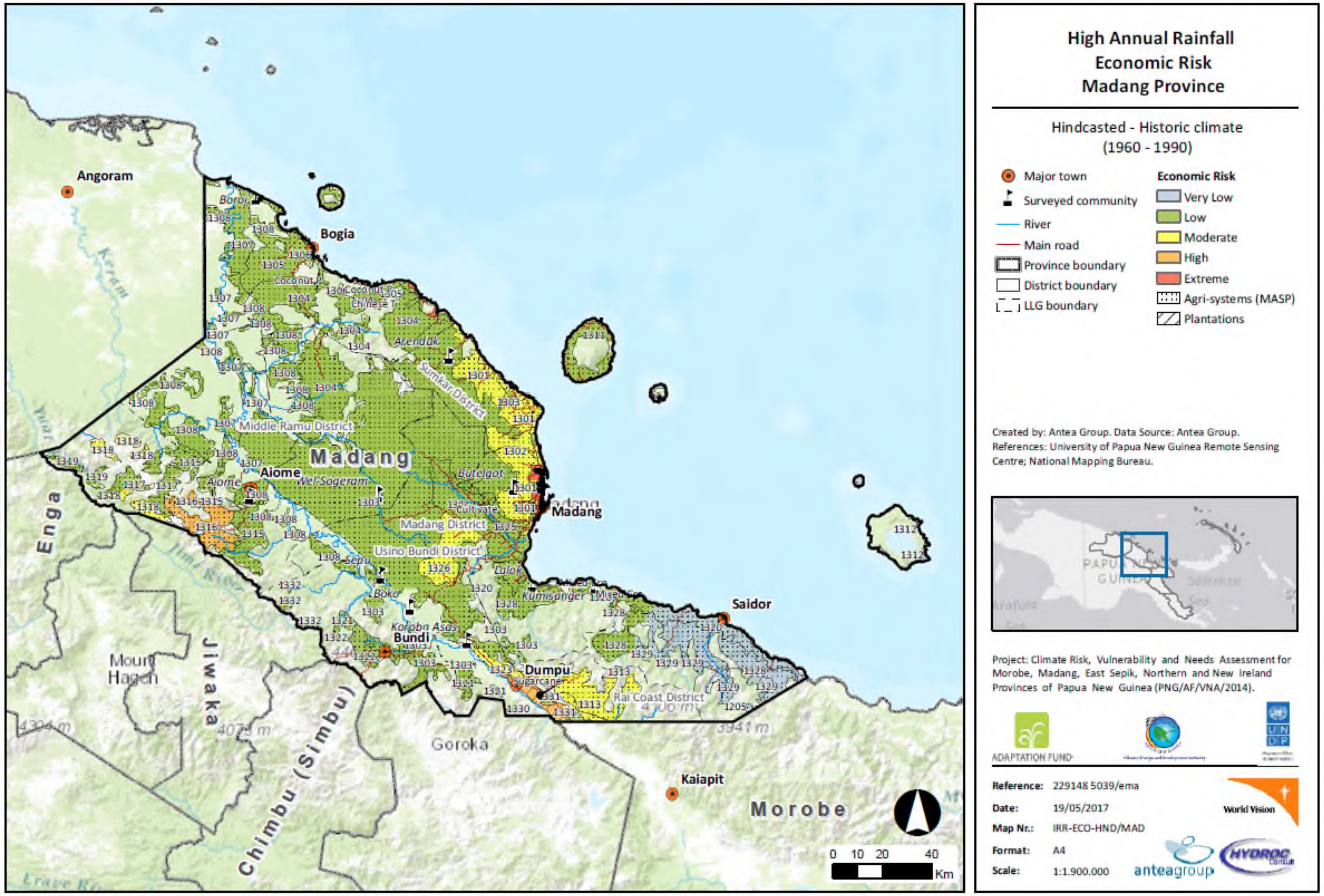

Figure 61. Precipitation intensities and variability Economic Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

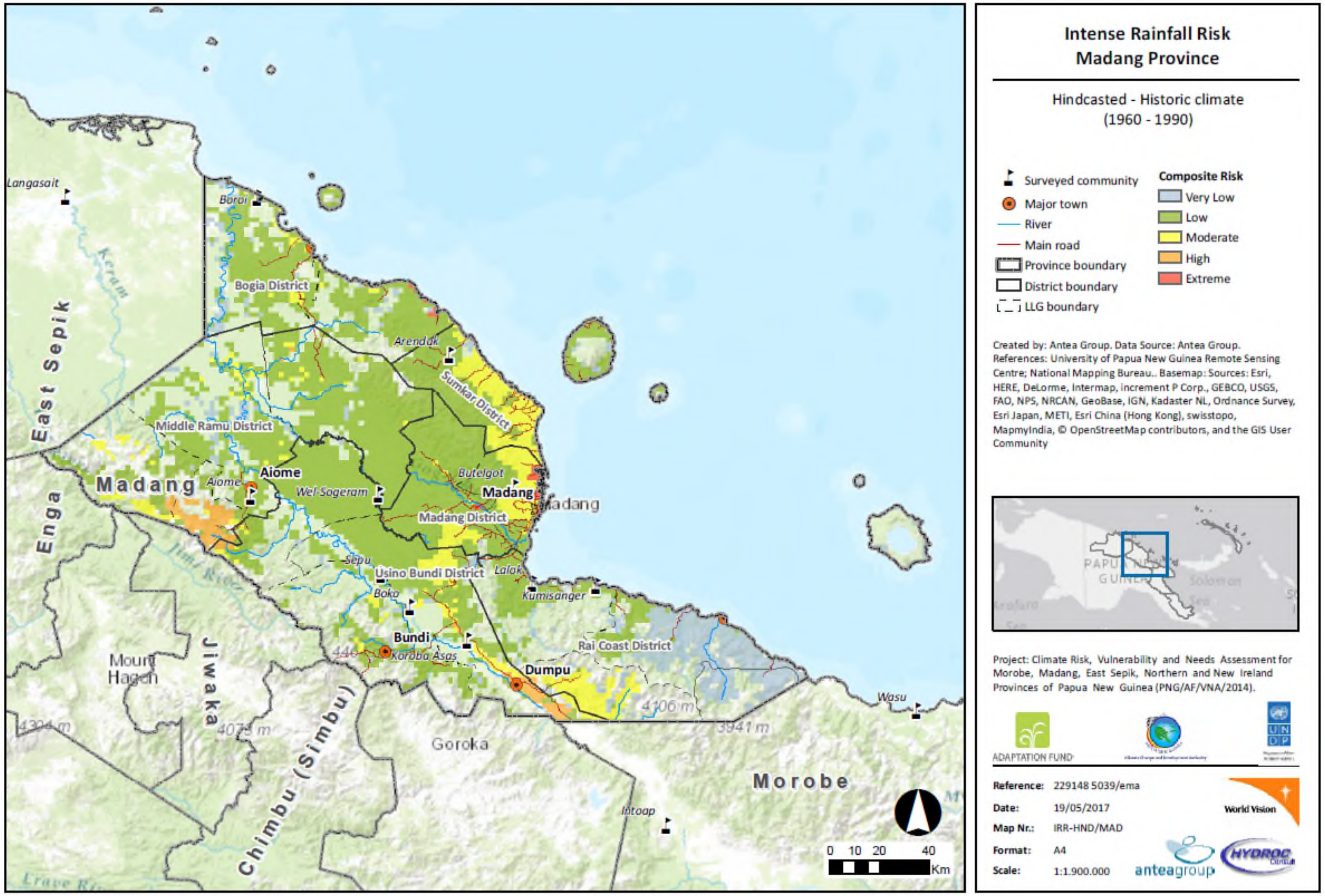

Figure 62. Precipitation intensities and variability composite Risk (current climate) ■**Very Low** ■**Low** ■**Moderate** ■**High** ■**Extreme**

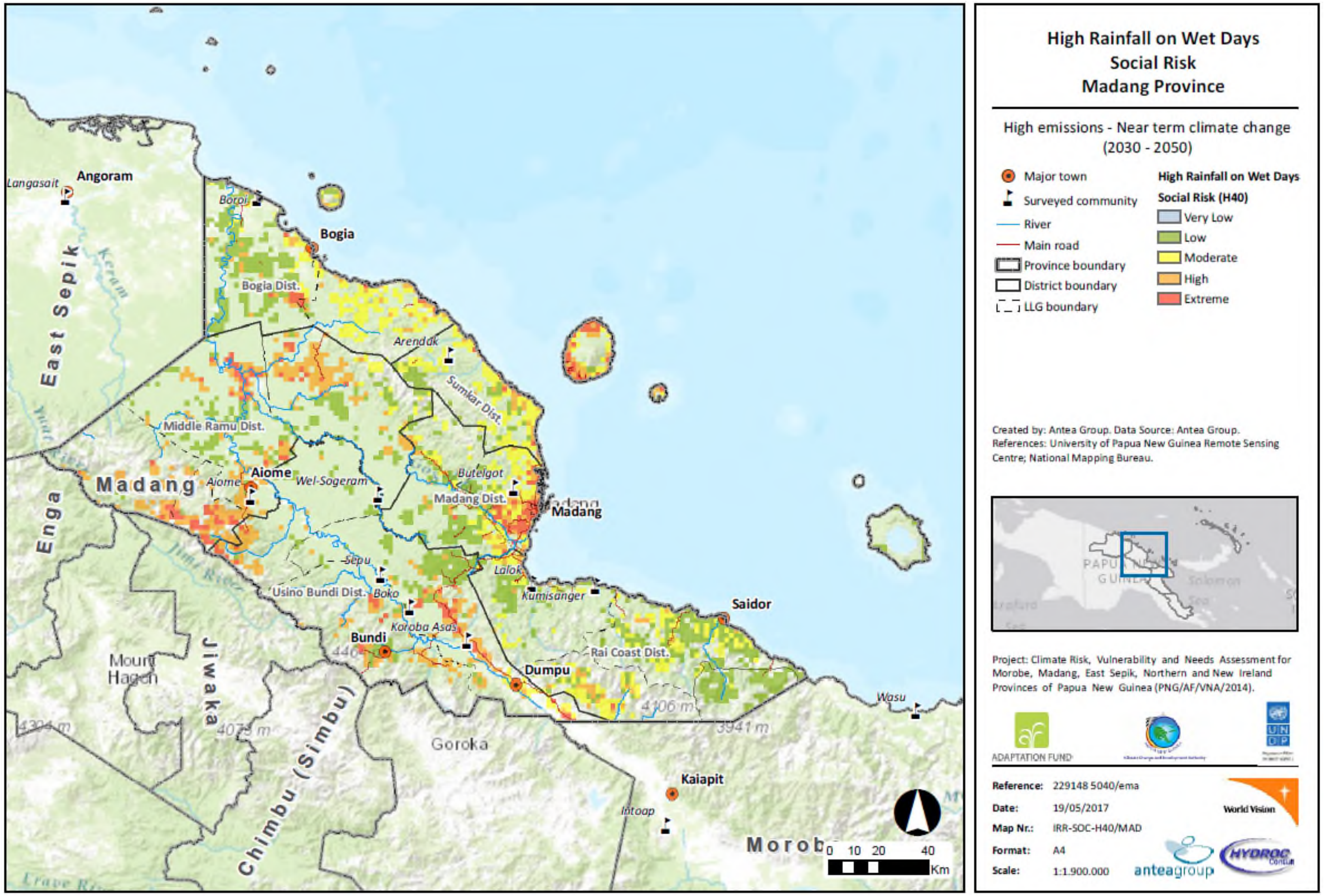

Figure 63. Precipitation intensities and variability Social Risk (projected climate) Very Low Low Moderate High Extreme

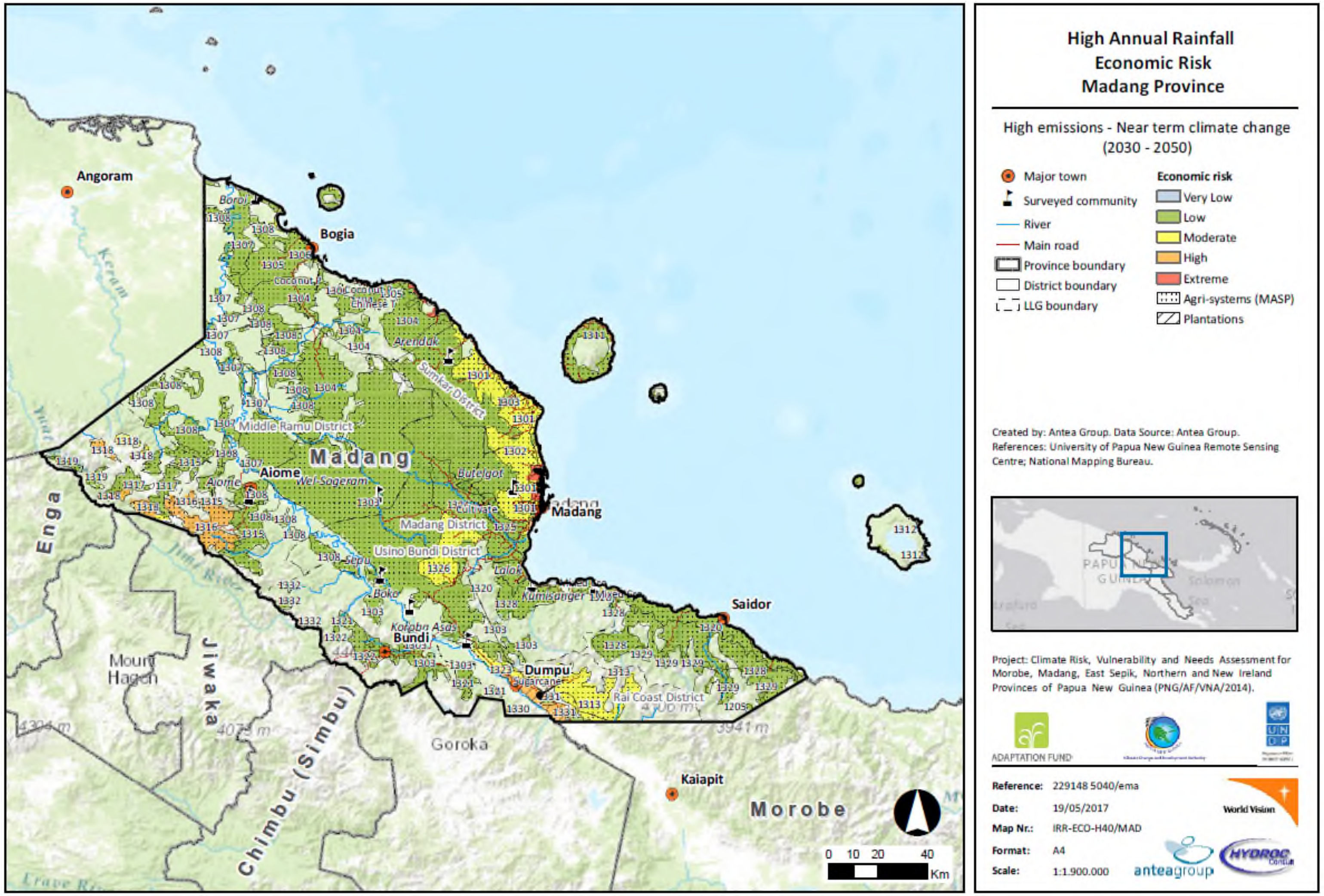

Figure 64. Precipitation intensities and variability Economic Risk (projected climate) **Very Low** **Low** **Moderate** **High** **Extreme**

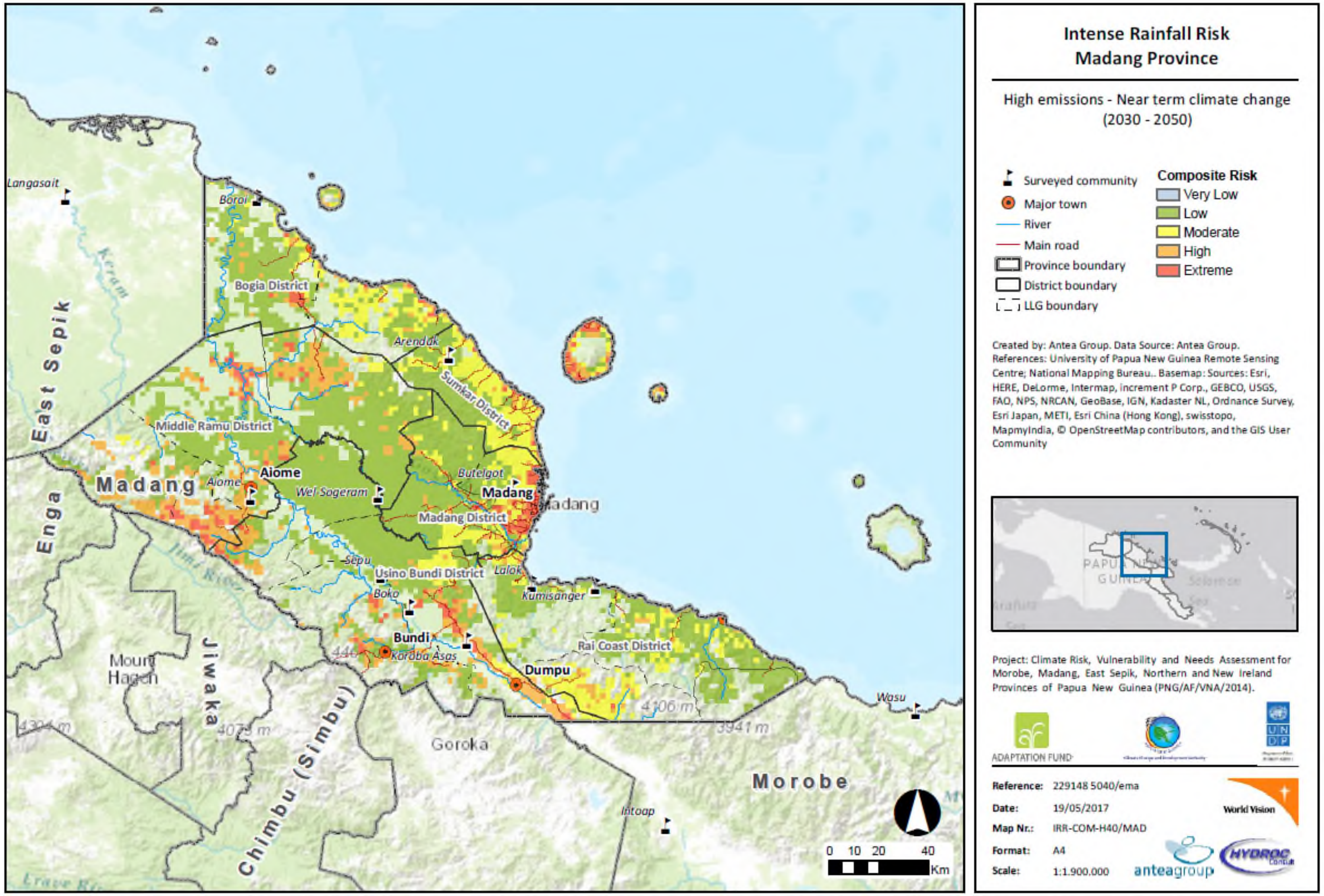

Figure 65. Precipitation intensities and variability Composite Risk (projected climate) Very Low Low Moderate High Extreme

2.4. *Composite Risk*

The overall composite risk map for the province has been derived from the risk maps for the respective hazards as presented in the previous chapter.

The map indicated areas that are exposed to multiple risks. To count the number of risks per pixel on the map, risks occurrence with values moderate, high or very high were counted. This results in the following categories. The area that are exposed to some very low of low risks for one or more hazards have received a value '0', areas that are not coloured on the map have not been characterised at risk for any of the considered hazards. All areas with a values 1 to 5 are have been identified as having a moderate (or higher) risk for 1 to 5 hazards.

map therefore is 4 and not 5.

Table 37 shows the percentage distribution of composite risk classes in the province for the current and projected climate. This tables how that xx % of the province is prone to some risks. ..

Note: the map needs to be updated to count coastal risk, for the moment this is not included and the maximum value on the map therefore is 4 and not 5.

Table 37. Distribution of composite risk classes

	HAZARDS													
	RISK 1960-1990 %						RISK 2030-2050 %							
District	**0**	**1**	**2**	**3**	**4**	**5**		**0**	**1**	**2**	**3**	**4**	**5**	
Bogia District	57,8	10,6	3,1	0,9	0,0		27,7	40,9	22,1	7,8	1,5	0,0		27,7
Madang District	67,2	21,4	7,8	3,1	0,0		0,5	28,2	36,0	27,2	8,1	0,0		0,5
Middle Ramu District	55,3	5,8	6,6	1,4	0,0		30,9	43,9	15,0	8,9	1,4	0,0		30,8
Rai Coast District	29,0	18,3	8,3	0,4	0,0		44,1	16,3	20,3	17,5	1,7	0,0		44,1
Sumkar District	44,2	36,2	10,1	1,4	0,0		8,1	10,3	30,0	46,5	5,1	0,0		8,1
Usino Bundi District	51,5	4,7	4,4	2,1	0,0		37,3	40,9	12,4	6,7	2,7	0,0		37,3

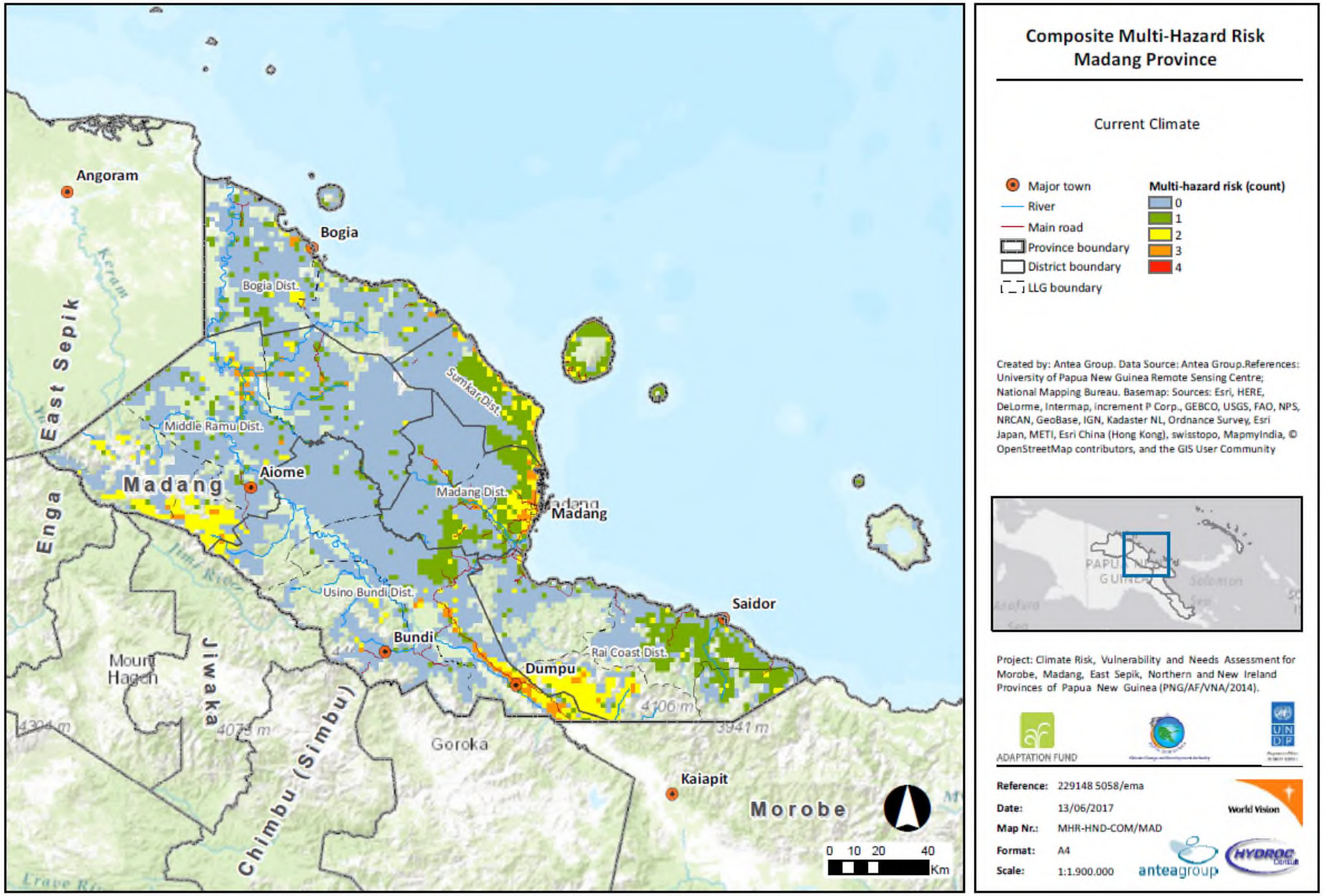

Figure 66. Composite Multi-Risk Map Madang Province (current)

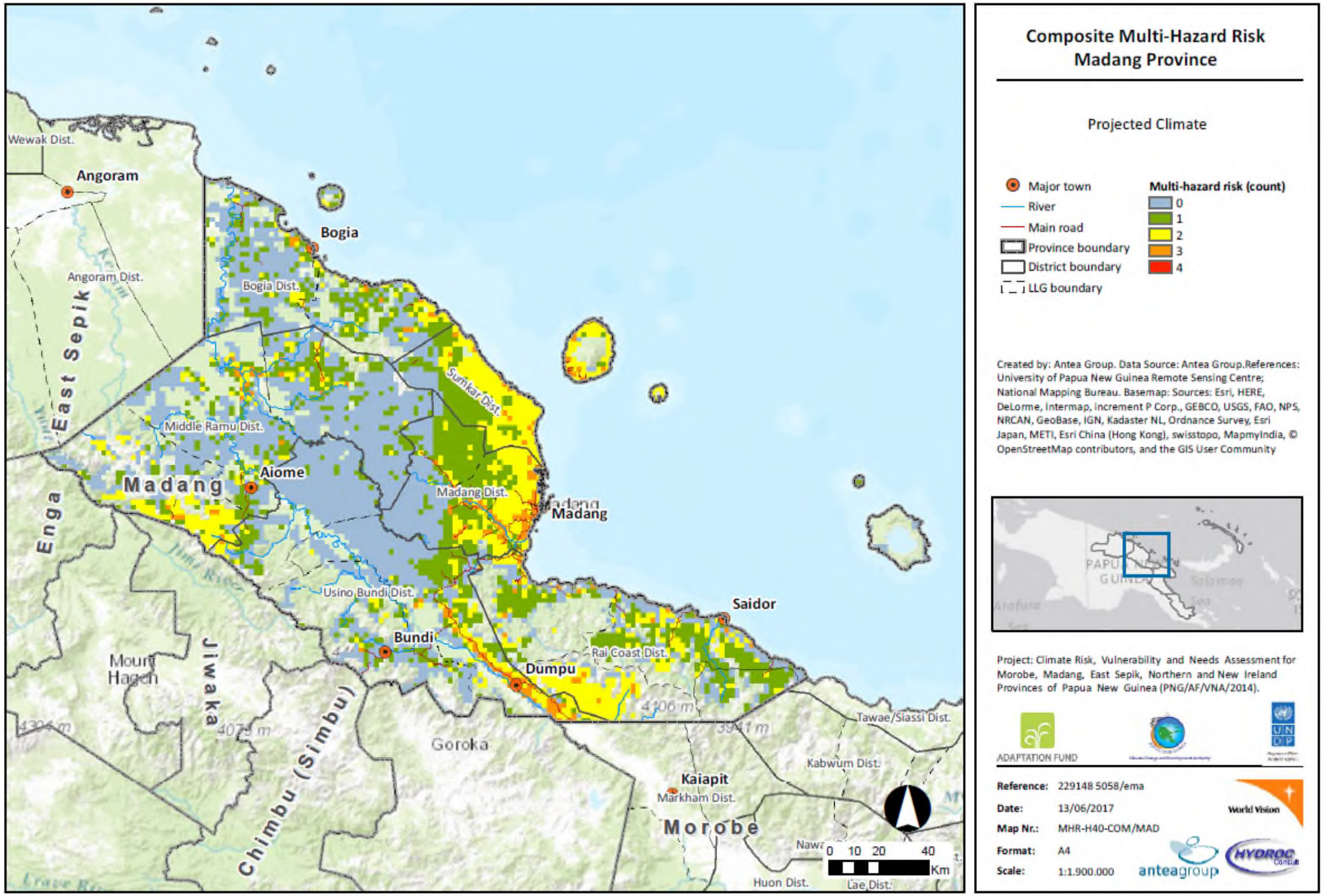

Figure 67. Composite Multi-Risk Map Madang Province (future)

3. DISTRICT RISK PROFILES

3.1. Bogia Risk Profile

3.1.1. General description

Bogia district encompasses the northern tip of Madang Province, with the Ramu River flowing to the sea in the north. The Ramu plains are surrounded by the Ruboni and Adelbert Ranges. This district also includes Manam Island, an active volcano that has recently seen most of the island's affected villages evacuated. The district headquarters is located in Bogia. There are 3 Local Level Governments in this district: Amami Rural, Iabu Rural and Yawar Rural. Number of wards assigned to this district is 91.

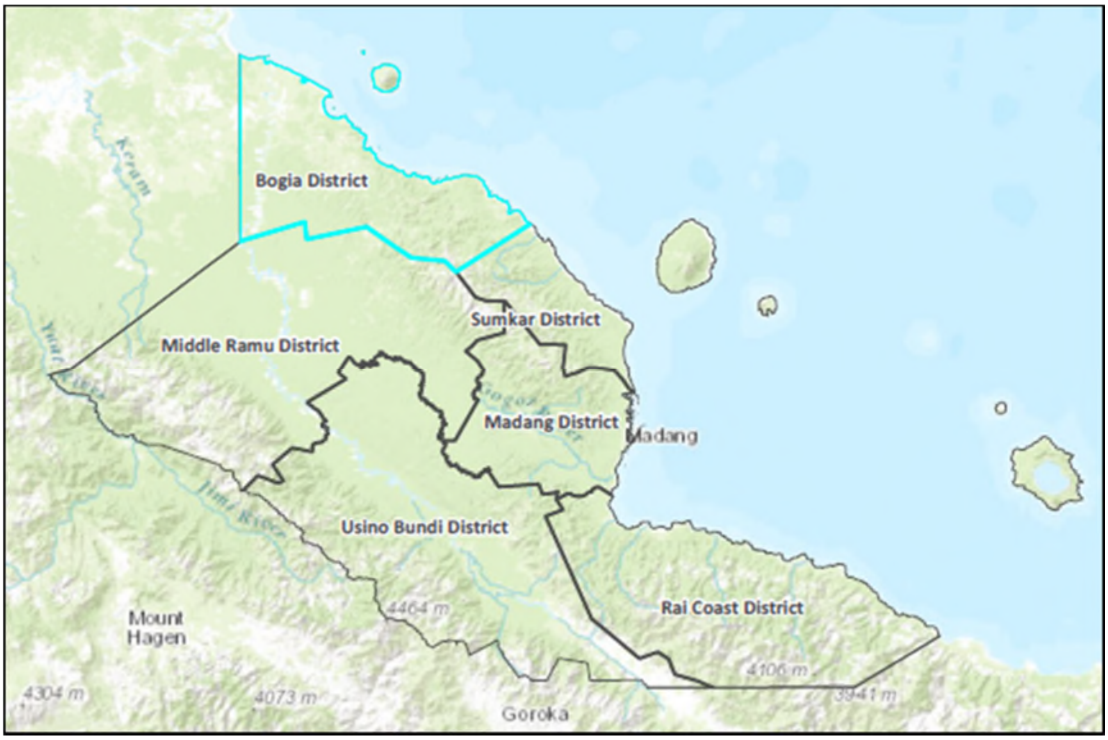

Figure 68. Bogia District

Bogia District has a population of 75,067[19]. The average population density is relatively low, 14.4 inhabitants per km^2. Boisa Island has the highest population density with over 230 persons/km^2. Manam Island also has a very high density of over 120 persons/km^2. The Ramu floodplain and Adelbert Range are largely unoccupied. The coastal plains east of Cape Gourdon have experienced significant in-migration. The population of the district has increased by over 4 per cent per year in recent decades.

The most disadvantaged people in the district are those on the Ramu floodplain who are affected by very low incomes and low potential environments. People in Bogia District are moderately disadvantaged relative to people in other districts in PNG. There is little agricultural pressure, land potential is moderate, access is moderate and cash incomes are low. Incomes are very low to low in the entire district and are derived mainly from sales of small amounts of fresh food, cocoa and copra.

[19] National Population and Housing Census, 2011, National Statistical Office, 2013.

Most people in the district are within 4-8 hours' travel of Madang town. A good road links Bogia to Madang, while another tarred road runs south from Bogia to Josephstaal.

Table 38. Selected Health Indicators for Bogia District (2014)

Low Weight for Age < 5 years old (%)[20]	Low Birth Weight (%)[21]	Incidence of Malaria (1,000 population)[22]	Incidence of Diarrhoea (<5 years/1,000 pop.)[23]
38	14.5	153	126

Bogia District has an adult literacy rate of 58.5%, with a significant disparity in literacy rates between males (65.0%) and females (51.7%).

3.1.2. *Hazards*

Hazard maps can be found in the province description (refer to Section 1) and the annex.

The District of Bogia is not prone to tropical cyclones and projections for the future do not show much change.

The map of inland flood hazard shows a couple of hotspots: along the border with East Sepik, along the north coast and to the east of Bogia. Projections for the future follow the same trend.

High precipitation hazard for the District of Bogia shows a rather high profile with values for total annual rainfall that range from 29810 to 3280mm. Projections for the future show an increase in this hazard with values up to 3281 to 3777 for most of the district, except in the easternmost corner.

Total rainfall on wet days shows a set of values that range from 501 to 600mm throughout the whole district. Projections for the future show an increase in these values (from 701 to 800) in most of the district except along the south eastern coast and the north eastern half of Iabu Rural.

On the contrary, drought risk is rather low with values that range the 16,1 to 21 continuous dry days, according to historic climate data from 1990 to 2016. Projections for the future show that the tendency remains the same except on the south eastern most corner of the district, where there will be a slight increase (21,1 to 24 continuous dry days).

3.1.3. *Risk*

Risk maps can be found in the province description (refer to Section 1) and the annex.

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[20] The indicator measures total number of children under 5 who have attended MCH clinic and weight less than 60% or 60% - 80% weight for age

[21] The indicator measures the proportion of those children that are born in health centres and hospitals and weigh less than 2500 gm.

[22] The indicator measures the total number of presentations to health centre/hospitals in the districts during the year, expressed as a ratio for every 1000 people in that district. The number is based upon clinical diagnosis, not RDT or microscopy

[23] The indicator measures the number of children under 5 yrs who seek care for diarrhoeal illness as a proportion of all children under five years. Diarrhoeal illness serves as an indicator of water quality, food hygiene and personal hygiene.

3.1.3.1. Social risk

Small, scattered areas of moderate to extreme social risk for inland flooding are found mainly in Yawar Rural LLG and to a lesser extent in Almani Rural LLG. Moderate to extreme risk from high rainfall is found mainly in Almani Rural LLG, but extending into the southern part of Yawar Rural LLG and around Bogia town, as well as the coastal areas of Labu Island in Labu Rural LLG. In the projected climate, there is a lot of risk evolution for high rainfall. Lot of areas are classified in moderate, high or extreme risk.

3.1.3.2. Economic risk

The economic risk is mostly low to very low. However, there are some agricultural lands exposed by inland flood. Projections for the future do not show much change.

Table 39. Top agricultural activities of citizen households in Bogia[24]

Activities	% engaged	% engaged for cash
Coconut	84,7	42,3
Food crops	83,9	13,7
Betel nut	82,7	25,4
Cocoa	61,1	60,5
Fishing	41,3	7,9

3.1.3.3. Physical risk

The map for inland flooding physical risk shows a couple of scattered hotspots where either there are some buildings exposed, for example, around Bulivar or Ulatepun, or there are some roads that can be compromised, such as around the city of Bogia or the road that goes from Goinbang to the coast.

Projections for the future show a slight increase for this type of risk.

The map for extreme weather physical risk shows that the district presents a low to very low profile and projections for the future do not show much change.

3.1.3.4. Composite risk

The composite multi-hazard risk map for the District of Bogia shows a couple of minor hotspots, one of them, for example around the city of Bogia. Projections for the future show a slight increase. Figures 69 and 70.

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	**1**	**2**	**3**	**4**	**5**	
Almani Rural	1,1	11,4	3,1	45,2	7,1	32,0
Labu Rural	0,0	23,7	14,2	14,2	28,4	19,4
Yawar Rural	10,5	11,0	5,7	31,7	7,5	33,6

[24] National Research Institute (2010), ‘Papua New Guinea District and Provincial Profiles)

LLG	HAZARD : DROUGHT COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Almani Rural	0,0	58,0	5,7	0,3	2,8	33,2
Iabu Rural	14,2	37,9	28,4	0,0	0,0	19,4
Yawar Rural	26,9	34,4	2,1	0,4	0,4	35,9

LLG	HAZARD : INLAND FLOODING COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Almani Rural	17,1	10,2	2,6	0,9	8,0	61,3
Iabu Rural	0,0	0,0	0,0	0,0	0,0	100,0
Yawar Rural	21,0	12,3	5,2	0,9	10,9	49,8

LLG	HAZARD : PRECIPITATION COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Almani Rural	27,3	31,3	5,7	0,3	2,3	33,2
Iabu Rural	28,4	23,7	28,4	0,0	0,0	19,4
Yawar Rural	50,9	10,0	2,1	0,4	0,4	36,3

LLG	HAZARD : CYCLONE RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Almani Rural	12,5	55,5	0,0	0,0	0,0	32,0	12,5	55,5	0,0	0,0	0,0	32,0
Iabu Rural	23,7	56,9	0,0	0,0	0,0	19,4	23,7	56,9	0,0	0,0	0,0	19,4
Yawar Rural	21,5	44,9	0,0	0,0	0,0	33,6	21,5	44,9	0,0	0,0	0,0	33,6

LLG	HAZARD : DROUGHT RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Almani Rural	0,0	58,0	6,0	2,8	0,0	33,2	0,0	51,5	12,5	1,1	1,7	33,2
Iabu Rural	14,2	37,9	28,4	0,0	0,0	19,4	14,2	37,9	28,4	0,0	0,0	19,4
Yawar Rural	26,9	34,4	2,5	0,4	0,0	35,9	26,9	34,4	2,5	0,4	0,0	35,9

LLG	HAZARD : INLAND FLOODING RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Almani Rural	18,5	12,2	5,4	1,7	0,9	61,3	18,5	12,2	5,4	1,7	0,9	61,3
Iabu Rural	0,0	0,0	0,0	0,0	0,0	100,0	0,0	0,0	0,0	0,0	0,0	100,0

Yawar Rural	24,0	14,8	6,6	1,6	2,8	50,2	22,6	15,3	7,5	1,8	3,0	49,8

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Almani Rural	3,4	59,2	2,6	0,0	1,7	33,2	0,0	27,3	30,7	5,4	3,4	33,2
Iabu Rural	9,5	66,4	4,7	0,0	0,0	19,4	0,0	28,4	23,7	28,4	0,0	19,4
Yawar Rural	8,4	51,4	3,6	0,4	0,0	36,3	0,0	50,9	6,8	4,4	1,6	36,3

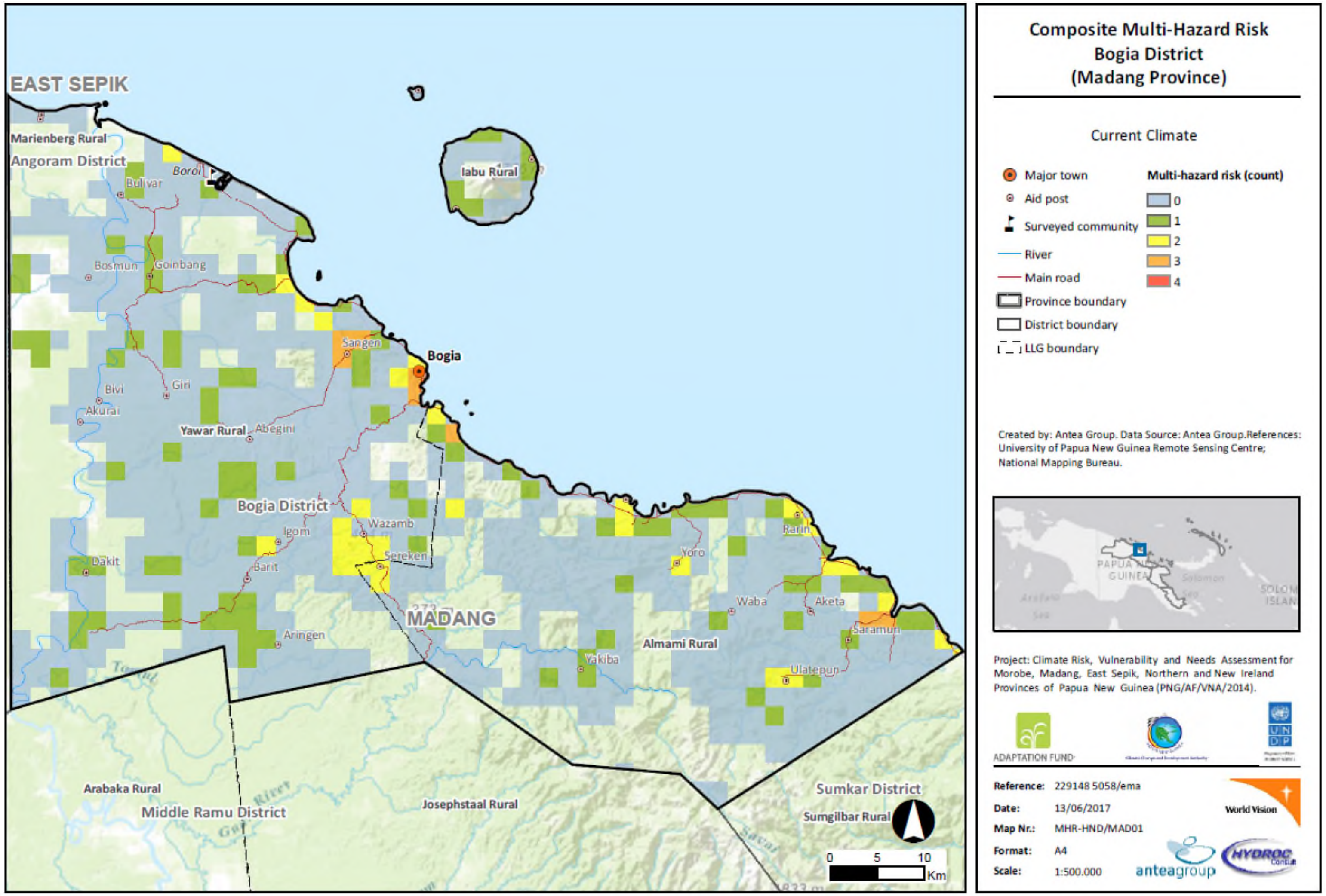

Figure 69. Composite risk map for Bogia District (current climate)

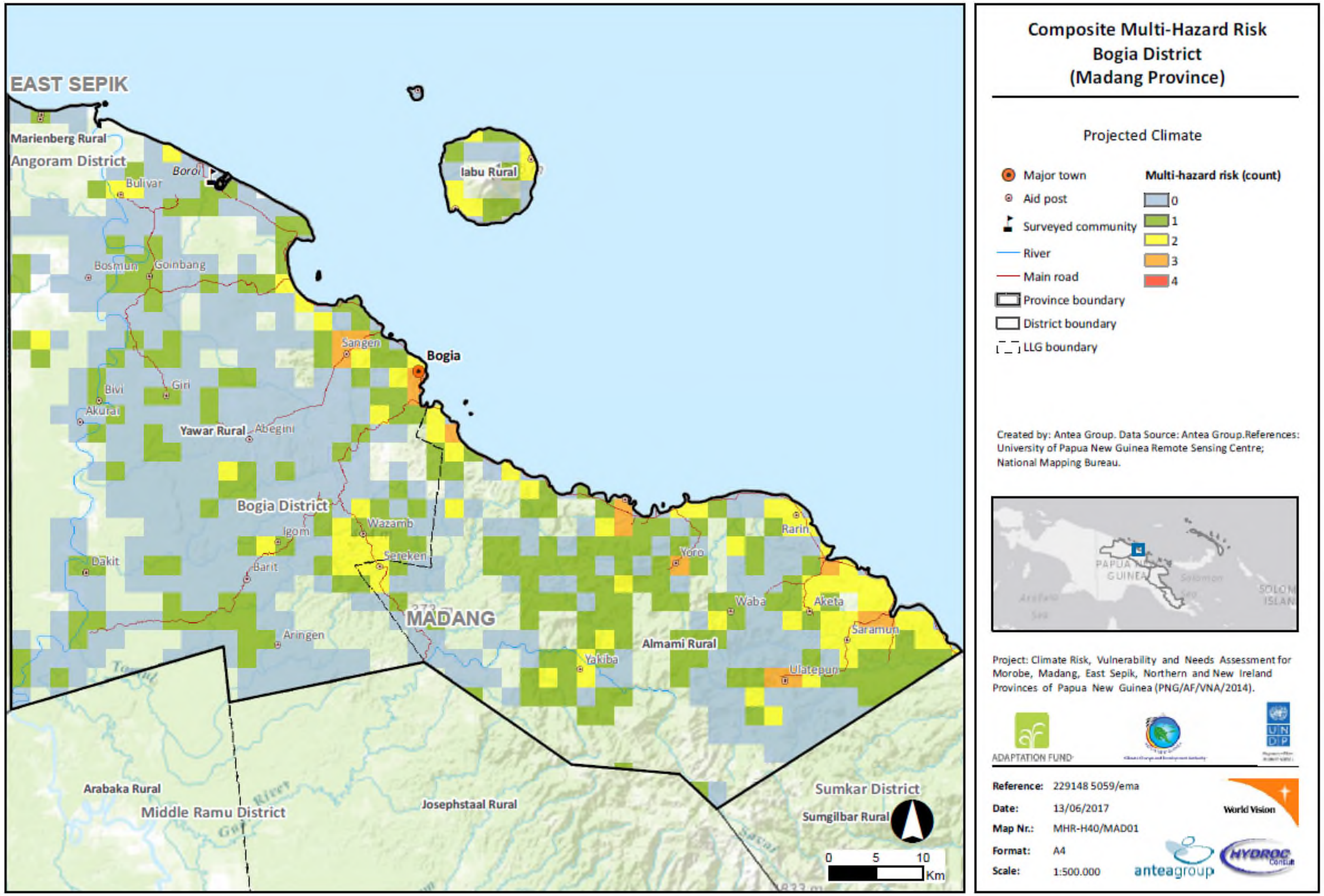

Figure 70. Composite risk map for Bogia District (future climate)

3.2. Madang Risk Profile

3.2.1. General description

Madang District centres on Madang town, and includes the Adelbert Range, Gogol Valley and Upper Sogeram valley. People near the coast can make higher incomes from the sale of cocoa, copra, betel nut and food, as well as access some wage employment in various industries in Madang town. However, those in the western, ranges and valleys have few income-earning opportunities. The district headquarters is located in Madang. There are 3 Local-Level Governments in Madang District: Ambenob Rural, Madang Urban and Transgogol Rural. Number of assigned wards to this district is 39.

Figure 71. Madang District

Madang District has a population of 110,978[25]. The average population density is 33.8 inhabitants per km^2. The coastal plains and Gogol Valley have high population densities of over 70 persons/km^2. The coastal hills have a moderate density of over 15 persons/km^2, while the Adelbert Range and Upper Sogeram Valley are sparsely populated with less than 10 persons/km^2. The coastal plains have experienced significant in-migration, particularly in the peri-urban areas around Madang. The population in the district has increased by over 4 per cent per year in recent decades.

The most disadvantaged people in the district are those living in the in the Adelbert Range who have very low incomes and live in low potential environments. People in the upper Sogeram Valley earn very low incomes, while those in the lower Gogol Valley are constrained by moderate agricultural pressure. Overall, people in Madang District are slightly disadvantaged relative to people in other districts in PNG. There is some agricultural pressure, land potential is moderate, access to services is good and cash incomes are moderate.

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[25] National Population and Housing Census, 2011, National Statistical Office, 2013.

Incomes are high on the coastal plains and are derived from the sale of cocoa, copra, betel nut and fresh food. In the Gogol Valley and on the coastal hills, people earn moderate incomes from sales of fresh food and cocoa. Those in the Adelbert Range and upper Sogeram Valley earn very low incomes from sales of small amounts of betel nut and fresh food.

People on the coastal plains require less than one hour's travel to reach Madang town, while those in the coastal hills and Gogol Valley are within four hours' travel. People in the Adelbert Range and upper Sogeram Valley require up to eight hours' travel to reach the nearest service centre. The north coast road runs from Madang to Bogia and connects to numerous branch roads which run into the coastal hills. The road to Lae passes through the low saddle between the Adelbert and Finisterre ranges into the Ramu Valley.

Table 40. Selected Health Indicators for Madang District (2014)

Low Weight for Age < 5 years old (%)[26]	Low Birth Weight (%)[27]	Incidence of Malaria (1,000 population)[28]	Incidence of Diarrhoea (<5 years/1,000 pop.)[29]
26	12.2	110	183

Madang District has an adult literacy rate of 75.2%, with a significant disparity in literacy rates between males (79.0%) and females (70.8%).

3.2.2. *Hazards*

Hazard maps can be found in the province description (refer to Section 1) and the annex.

The district of Madang is not prone to tropical cyclones, as can be seen in the map of extreme weather hazard for the district, built up from historic climate data from 1990 to 2016. Projections for the future show that the tendency will remain the same.

The map for inland flood hazard shows a couple of flooding zones, mostly along the Gogol River and in some spots along the coast. Projections for the future show the same tendency.

The map for total annual rainfall shows that the district presents a high profile, with values that range from 2980 to 3280mm. Projections for the near future show an increase of these values along the western part of the district, with ranges around the 3281 to 3777mm.

The map for total rainfall on wet days shows a range of values that go from 501 to 600mm for the whole province. Projections for the future show a big increase throughout the district, with values that range from 701 to 800mm, except in the northeast part, where these values remain in the 601 to 700mm.

[26] The indicator measures total number of children under 5 who have attended MCH clinic and weight less than 60% or 60% - 80% weight for age

[27] The indicator measures the proportion of those children that are born in health centres and hospitals and weigh less than 2500 gm.

[28] The indicator measures the total number of presentations to health centre/hospitals in the districts during the year, expressed as a ratio for every 1000 people in that district. The number is based upon clinical diagnosis, not RDT or microscopy

[29] The indicator measures the number of children under 5 yrs who seek care for diarrhoeal illness as a proportion of all children under five years. Diarrhoeal illness serves as an indicator of water quality, food hygiene and personal hygiene.

Finally, drought risk is rather low for the district, with values from 16,1 to 21 continuous dry days but projections show that 3/4ths of the eastern part of the district will be dryer in the near future, with values ranging from 21,1 to 24 continuous dry days.

3.2.3. *Risk*

Risk maps can be found in the province description (refer to Section 1) and the annex.

3.2.3.1. Social risk

Due to the high population and population density in and around Madang town in Madang Urban LLG and the presence of critical social infrastructure such as hospitals, government institutions dealing with disaster management, markets, transportation, communication and other key functions, Madang District, and Madang Urban and Ambenob LLGs in particular, have a high social risk for all hazards except cyclones. In the projected climate, there is a lot of risk evolution for high rainfall and drought. Lot of areas are classified in moderate, high or extreme risk.

3.2.3.2. Economic risk

The economic risk in Madang District is mostly low or very low but there is a hotspot around Madang city for inland flood, rainfall and drought. The economic risk is moderate to high in this area because there are plantations and cultures like food crops and betel nut (Table 41). Projections for the future do not show much change.

Table 41. Top agricultural activities of citizen households in Madang[30]

Activities	% engaged	% engaged for cash
Coconut	22,9	4,9
Food crops	61,7	32,0
Betel nut	57,7	18,9
Coffee	52,9	23,2
Livestock	26,8	26,3

3.2.3.3. Physical risk

The inland flooding physical risk map of the District of Madang shows some critical hotspots, especially around Madang Urban, where some buildings, roads, bridges and critical infrastructure are exposed. Other hotspots concentrate along the road that goes from Imam to the coast, which also shows sections of road, bridges and some buildings compromised, for example in Imam, Maritambu, Mawan or Bau. Projections for the future follow the same tendency with a slight increase in the extension of the risk.

The extreme weather physical risk map shows that the district has a rather low profile and projections for the future follow a similar tendency.

3.2.3.4. Composite risk

The composite map for multi-hazard risk of the Province of Madang shows some hotspots on the east coast and around the main river. The rest of Madang district is mostly low to very low risk. Projections for the future show a general slight increase in the risk to multi-hazards for the whole province (Figures 72 and 73).

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[30] National Research Institute (2010), 'Papua New Guinea District and Provincial Profiles)

LLG	HAZARD : CYCLONE COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Ambenob Rural	0,0	22,0	33,5	13,4	32,5	0,0
Madang Urban	0,0	0,0	0,0	0,0	100,0	0,0
Transgogol Rural	0,2	62,6	22,4	9,3	3,7	1,8

LLG	HAZARD : DROUGHT COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Ambenob Rural	0,0	65,5	13,9	4,8	17,2	0,0
Madang Urban	0,0	0,0	0,0	0,0	100,0	0,0
Transgogol Rural	0,4	94,3	2,8	0,6	0,0	1,8

LLG	HAZARD : INLAND FLOODING COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Ambenob Rural	28,2	11,5	2,4	4,8	12,9	40,3
Madang Urban	0,0	0,0	0,0	0,0	89,4	10,6
Transgogol Rural	35,0	13,0	2,8	2,8	8,9	37,6

LLG	HAZARD : PRECIPITATION COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Ambenob Rural	28,2	38,7	12,4	1,0	21,0	0,0
Madang Urban	0,0	0,0	0,0	0,0	100,0	0,0
Transgogol Rural	75,8	19,0	2,8	0,2	0,4	1,8

LLG	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Ambenob Rural	22,0	79,3	0,0	0,0	0,0	0,0	22,0	79,3	0,0	0,0	0,0	0,0
Madang Urban	0,0	100,0	0,0	0,0	0,0	0,0	0,0	100,0	0,0	0,0	0,0	0,0
Transgogol Rural	62,8	35,4	0,0	0,0	0,0	1,8	62,8	35,4	0,0	0,0	0,0	1,8

LLG	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Ambenob Rural	0,0	65,5	18,6	17,2	0,0	0,0	0,0	0,0	79,3	4,8	17,2	0,0
Madang Urban	0,0	0,0	0,0	100,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0	0,0

Transgogol Rural	0,4	94,3	3,5	0,0	0,0	1,8	0,0	50,3	47,3	0,6	0,0	1,8

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Ambenob Rural	30,1	12,9	6,2	5,7	4,8	40,3	30,1	12,9	6,2	5,7	4,8	40,3
Madang Urban	0,0	0,0	0,0	0,0	89,4	10,6	0,0	0,0	0,0	0,0	89,4	10,6
Transgogol Rural	36,7	17,9	4,1	2,2	1,5	37,6	36,7	17,7	4,3	2,2	1,5	37,6

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Ambenob Rural	0,5	53,1	42,5	0,0	5,3	0,0	0,0	28,2	38,7	12,4	22,0	0,0
Madang Urban	0,0	100,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0	0,0
Transgogol Rural	0,4	88,5	8,9	0,0	0,4	1,8	0,0	75,8	16,8	4,7	0,9	1,8

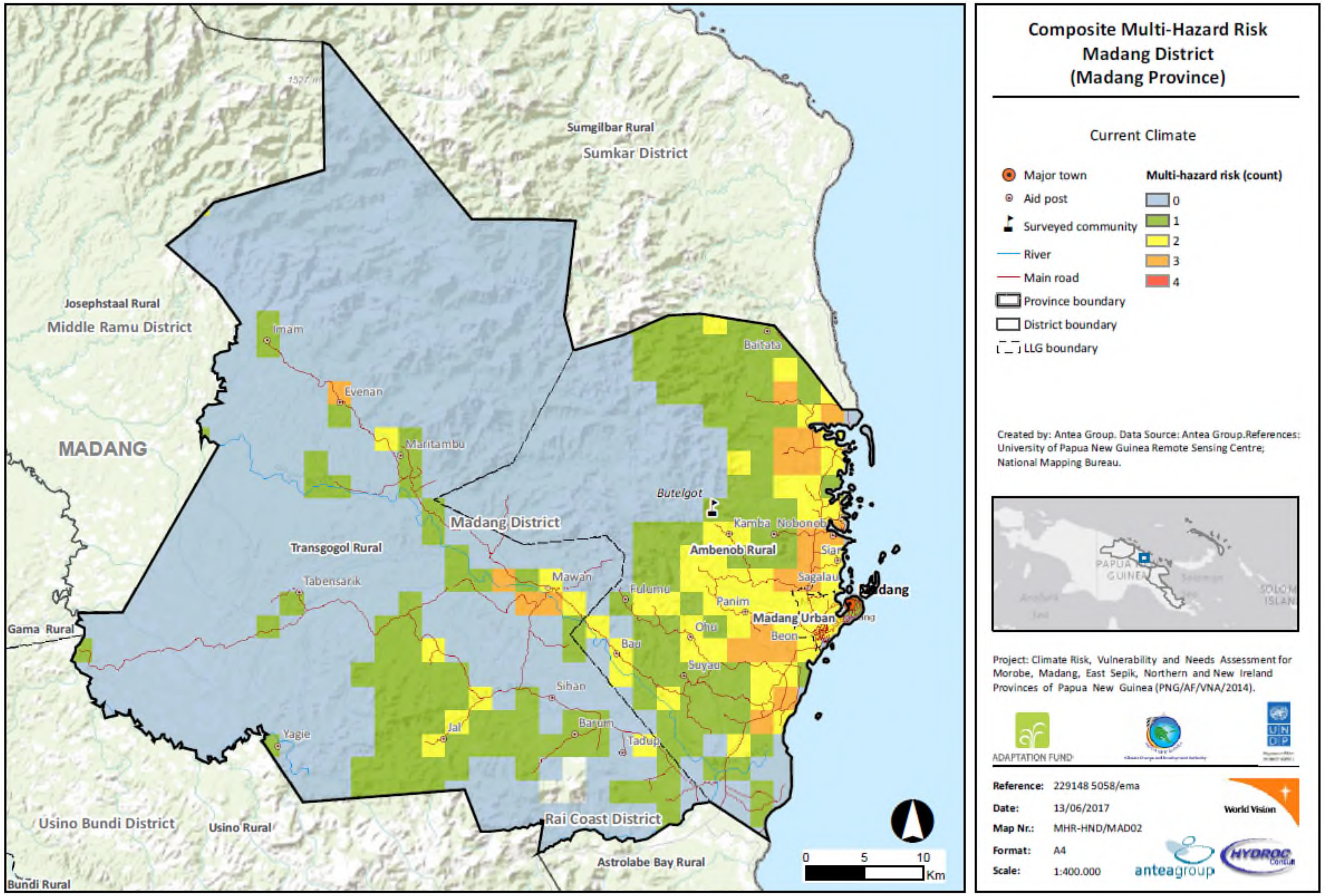

Figure 72. Composite risk map for Madang District (current climate)

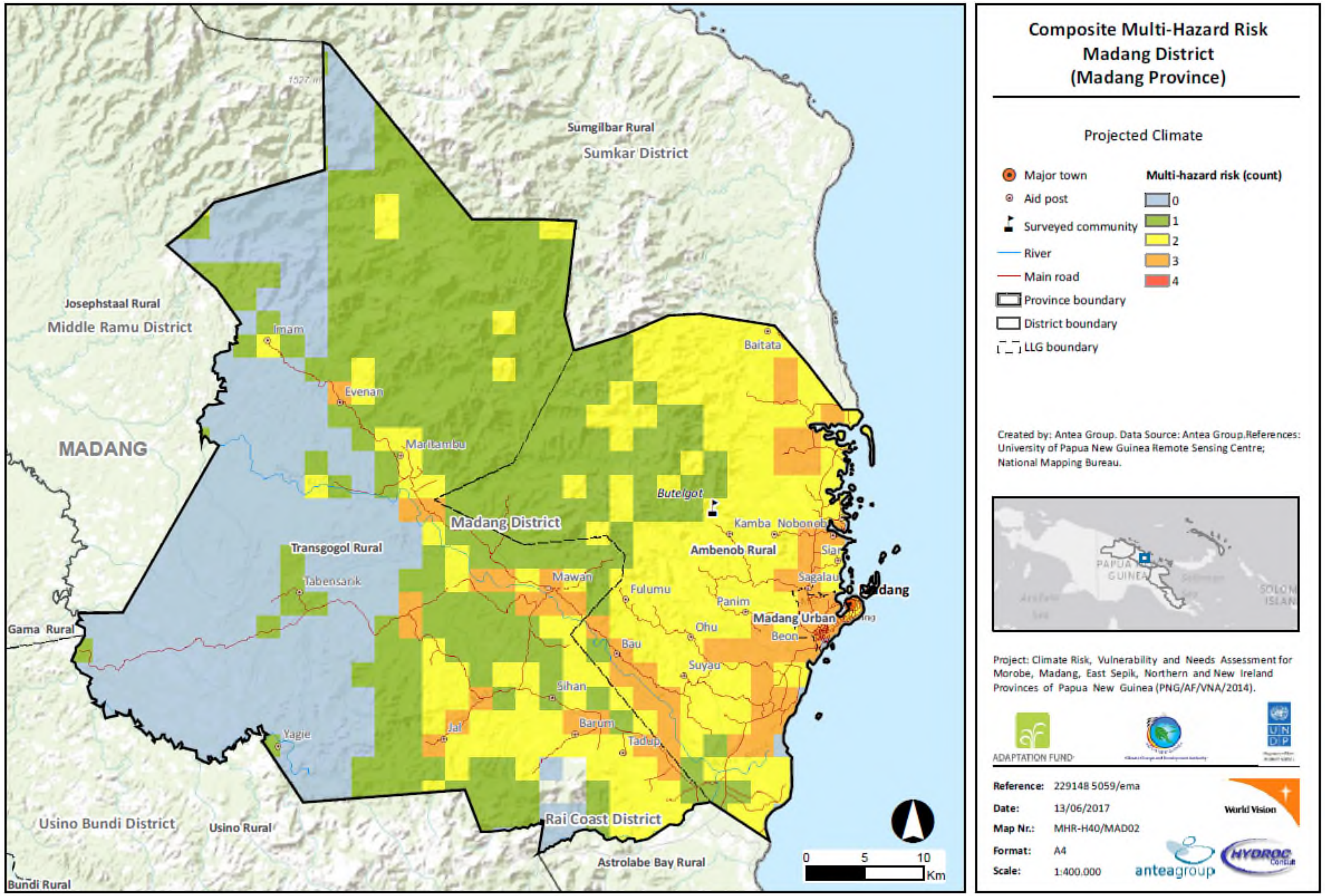

Figure 73. Composite risk map for Madang District (future climate)

3.3. Middle Ramu Risk Profile

3.3.1. General description

The plains of the Ramu Valley run through the centre of this district. It also includes parts of the Schrader Range in the west and the Adelbert Range and Sogeram Valley in the east. Incomes across the district are very low with small sales of food, coconut and betel nut. Logging and mining developments offer some income and royalties. The district headquarters is located in Simbai. There are 4 Local-Level Governments in Middle Ramu District: Arabaka Rural, Josephstaal Rural, Simbai Rural and Gama Rural. Number of assigned wards to this district is 93.

Figure 74. Middle Ramu District

Middle Ramu District has a population of 78,892[31]. The average population density is relatively low, 8 inhabitants per km^2. Areas around Dusin on the southern side of the Schrader Range have moderate population densities of over 40 persons/km^2. The northern side of the Schrader Range and lower Sogeram Valley have scattered populations with average densities of over 15 persons/km^2. The middle Ramu and Sogeram valleys are very sparsely populated with less than 10 persons/km^2.

The most disadvantaged people in the district are those in the Schrader Range where small numbers of people occupy low potential environments, earn very low incomes and have poor access to services. Large numbers of people in the Ramu Valley and Adelbert Range live in low potential environments and earn very low incomes. People in the Sogeram Valley earn very low incomes, while those around Josephstaal live in low potential environments.

[31] National Population and Housing Census, 2011, National Statistical Office, 2013.

People in Middle Ramu District are extremely disadvantaged relative to people in other districts of PNG. There is no agricultural pressure, land potential is low, access to services is poor and cash incomes are very low.

Incomes are derived from sales of small quantities of fresh food, betel nut and cocoa around Josephstaal, and coffee at higher altitudes around Dusin. Some people receive moderate incomes from wages and royalties associated with the Ramu Nickel mine and logging operations in the Sogeram Valley.

People on the southern side of the Schrader Range are very remote and require over one day's travel to reach the nearest service centre, while those in the remainder of the district require up to eight hours' travel. Outboard motor powered canoes are used to travel along the Ramu River. There is a road from Bogia to Josephstaal and a link to this road back towards Madang through the Sogeram Valley, where there have been logging roads. There is also a road to the Ramu nickel mine near Aiome.

Table 42. Selected Health Indicators for Middle Ramu District (2014)

Low Weight for Age < 5 years old (%)[32]	Low Birth Weight (%)[33]	Incidence of Malaria (1,000 population)[34]	Incidence of Diarrhoea (<5 years/1,000 pop.)[35]
49	6.3	112	88

Middle Ramu District has an adult literacy rate of 23.7%, with a significant disparity in literacy rates between males (30.7%) and females (16.6%).

3.3.2. *Hazards*

Hazard maps can be found in the province description (refer to Section 1) and the annex.

The district of Middle Ramu is not prone to extreme weather events, and projections for the future show that the tendency will remain the same, as shown in the maps for extreme weather hazard for the district.

The map for inland flood hazard shows many flooding zones along the Ramu River and its tributaries, mostly 5 year return periods, but also some with 10 and some with 50 year return periods.

Projections show the same trend in the near future.

The map for high precipitation hazard shows that 2/3rds of the district presents values of total annual rainfall around the 2980 to 3280mm, while the remaining 1/3rd presents a higher range with values

[32] The indicator measures total number of children under 5 who have attended MCH clinic and weight less than 60% or 60% - 80% weight for age

[33] The indicator measures the proportion of those children that are born in health centres and hospitals and weigh less than 2500 gm.

[34] The indicator measures the total number of presentations to health centre/hospitals in the districts during the year, expressed as a ratio for every 1000 people in that district. The number is based upon clinical diagnosis, not RDT or microscopy

[35] The indicator measures the number of children under 5 yrs who seek care for diarrhoeal illness as a proportion of all children under five years. Diarrhoeal illness serves as an indicator of water quality, food hygiene and personal hygiene.

around 3281 to 3777mm. Projections for the future show that precipitation values will increase throughout the district in the near future to 3281 to 3777mm for the whole district.

Values for total rainfall on wet days show that Josephstaal Rural and Arabaka Rural present values between 501 to 600mm, while Simbai rural presents a bit higher (from 601 to 700mm). projections for the future show that these figures will also increase to 701 to 800mm throughout the district in the near future, except in the south east of Simbai Rural, where they will be even higher (around 801 to 910mm).

The map for drought hazard shows that the district has a low profile for dry spells, with values that range the 16,1 to 21 continuous dry days in average. Projections for the futures remain in the same range.

3.3.3. Risk

Risk maps can be found in the province description (refer to Section 1) and the annex.

3.3.3.1. Social risk

There are small scattered areas of high to extreme social risk from inland flooding in Arabaka Rural LLG. Areas of high and extreme risk from high rainfall events are located in Simbai Rural, Arabaka Rural and Josephstal Rural LLGs. In the projected climate, there is a lot of risk evolution for high rainfall. Lot of areas are classified in moderate, high or extreme risk.

3.3.3.2. Economic risk

The economic risk is mostly low to very low, but there is a hotspot for high rainfall and drought. The economic risk is moderate to high in this area where there are agricultural systems : food crops (Table 43). Projections for the future do not show much change.

Table 43. Top agricultural activities of citizen households in Middle Ramu[36]

Activities	% engaged	% engaged for cash
Poultry	54,0	3,6
Food crops	84,4	6,7
Betel nut	58,7	23,6
Coffee	47,0	44,4
Livestock	54,0	3,8

3.3.3.3. Physical risk

The map for physical risk for inland flooding for the district shows some hotspots, mostly around Chungribu, Bumbera and Aiome. The infrastructure exposed is mostly buildings.

Projections for the future do not show much change.

The map for extreme weather physical risk shows that the district has a low profile and projections for the future remain the same.

3.3.3.4. Composite risk

The map for composite multi-hazard risk shows a concentration of high hotspots in the area between Romaken and Chungribu, mostly due to the presence of River Ramu and its tributaries, and a

[36] National Research Institute (2010), 'Papua New Guinea District and Provincial Profiles)

concentration of moderate hotspots in the southern part of Simbai Rural. Projections for the future show a slight increase in the extension of moderate risk (Figures 75 and 76).

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Arabaka Rural	7,4	31,1	6,5	6,1	2,5	46,4
Kovon	1,4	49,4	3,6	24,1	2,1	19,4
Josephstaal Rural	7,5	5,5	27,3	9,5	14,3	36,0
Simbai Rural	17,0	10,2	2,8	3,8	3,3	62,9

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Arabaka Rural	25,3	24,0	3,7	0,4	0,0	46,5
Kovon	6,8	70,8	1,7	0,2	0,3	20,3
Josephstaal Rural	0,0	15,0	42,2	3,4	1,4	38,0
Simbai Rural	0,2	25,7	11,1	0,0	0,0	62,9

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Arabaka Rural	30,3	6,9	1,1	0,7	14,3	46,7
Kovon	35,7	14,6	4,7	1,5	7,1	36,4
Josephstaal Rural	25,2	3,4	2,0	1,4	4,8	63,2
Simbai Rural	29,3	0,2	0,7	0,2	1,2	68,4

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Arabaka Rural	37,3	12,9	3,7	0,4	0,0	45,6
Kovon	60,3	17,9	1,7	0,2	0,3	19,7
Josephstaal Rural	5,5	9,5	42,2	3,4	1,4	38,0
Simbai Rural	17,0	17,7	2,1	0,0	0,0	63,2

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Arabaka Rural	38,5	15,1	0,0	0,0	0,0	46,4	38,5	15,1	0,0	0,0	0,0	46,4
Kovon	50,8	29,8	0,0	0,0	0,0	19,4	50,8	29,8	0,0	0,0	0,0	19,4
Josephstaal Rural	12,9	51,1	0,0	0,0	0,0	36,0	12,9	51,1	0,0	0,0	0,0	36,0

Simbai Rural	27,2	9,9	0,0	0,0	0,0	62,9	27,2	9,9	0,0	0,0	0,0	62,9

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Arabaka Rural	25,3	24,0	4,2	0,0	0,0	46,5	25,3	24,0	4,2	0,0	0,0	46,5
Kovon	6,8	70,8	1,8	0,3	0,0	20,3	6,8	70,8	1,8	0,3	0,0	20,3
Josephstaal Rural	0,0	15,0	45,6	1,4	0,0	38,0	0,0	15,0	45,6	1,4	0,0	38,0
Simbai Rural	0,2	24,6	11,1	0,0	0,0	64,1	0,2	25,7	11,1	0,0	0,0	62,9

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Arabaka Rural	31,2	11,0	3,6	2,8	3,9	47,5	31,2	10,8	3,3	3,5	4,4	46,7
Kovon	37,7	17,3	6,2	1,7	0,3	36,8	37,4	18,1	6,2	1,7	0,3	36,4
Josephstaal Rural	29,3	4,1	2,7	0,7	0,0	63,2	29,3	4,1	2,7	0,7	0,0	63,2
Simbai Rural	29,8	1,4	0,0	0,5	0,0	68,4	29,8	1,4	0,0	0,5	0,0	68,4

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Arabaka Rural	8,1	42,2	4,2	0,0	0,0	45,6	0,0	37,3	0,0	12,9	4,2	45,6
Kovon	1,2	77,0	1,8	0,3	0,0	19,7	0,0	60,3	3,2	15,1	1,8	19,7
Josephstaal Rural	0,0	15,0	2,7	44,3	0,0	38,0	0,0	5,5	0,0	39,5	17,0	38,0
Simbai Rural	0,2	25,5	10,2	0,9	0,0	63,2	0,0	17,0	1,9	16,5	1,4	63,2

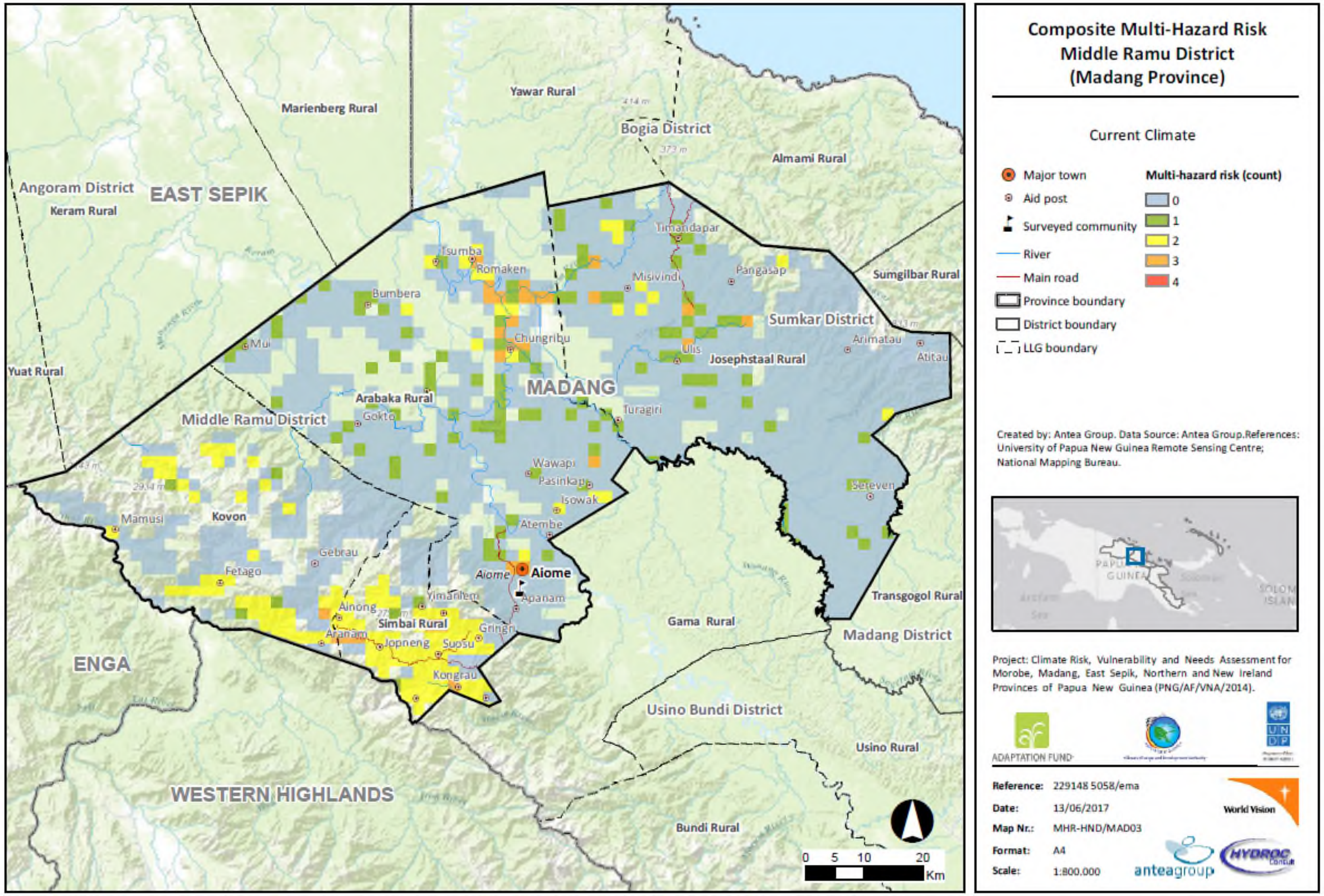

Figure 75. Composite risk map for Middle Ramu District (current climate)

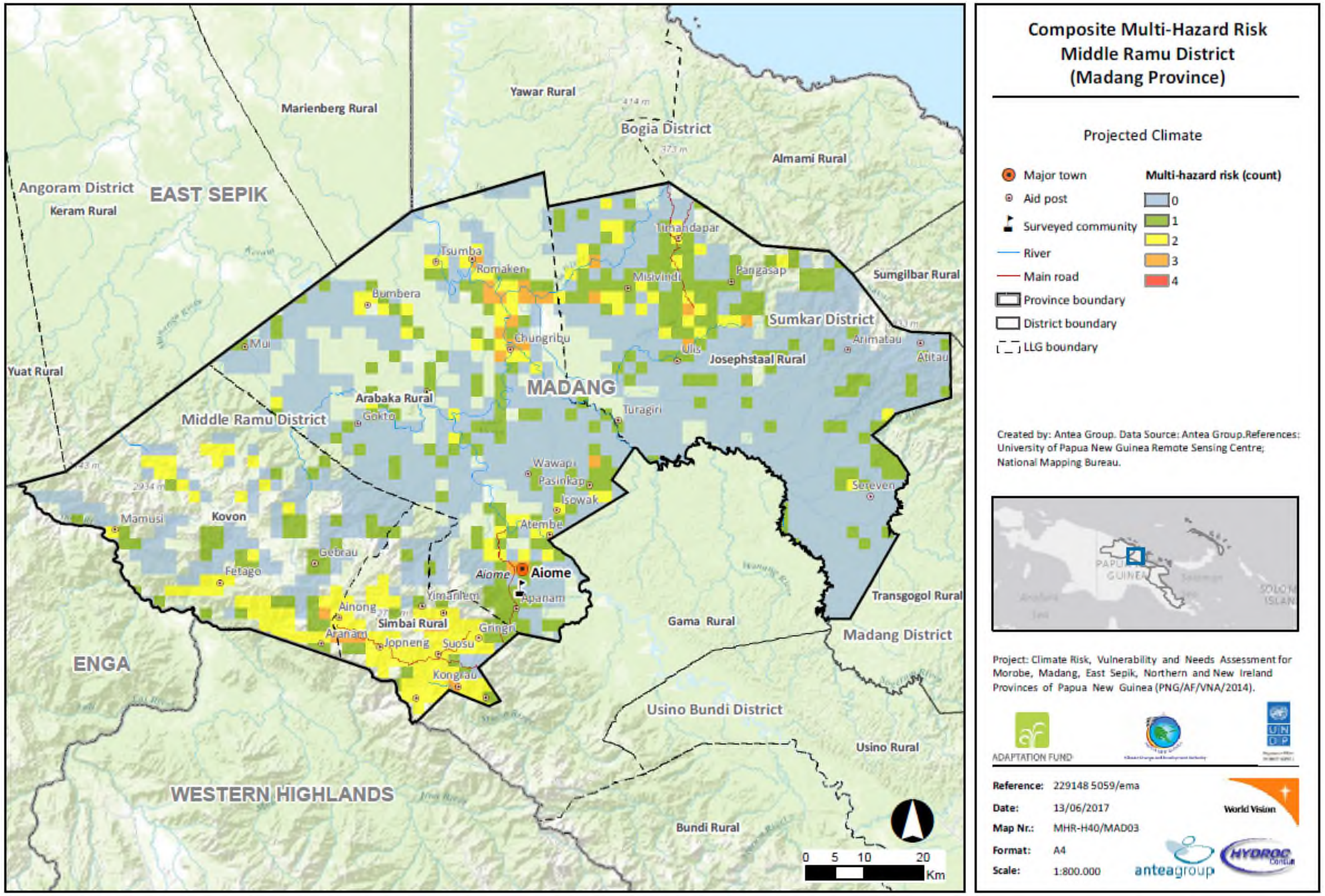

Figure 76. Composite risk map for Middle Ramu District (future climate)

3.4. Rai Coast Risk Profile

3.4.1. General description

Rai Coast District cover the length of coast south of Madang, which rises up to the Finisterre Range. It also includes the volcanic Long Island. Incomes are low to very low in the district. The coast and ranges have low potential for cultivation, further challenged by high population pressure in the ranges. Good land on Long Island is constrained by distance and the presence of a volcano. The district headquarters is located in Rai Coast. There are 4 Local-Level Governments in Rai Coast District: Astrolabe Bay Rural, Naho Rawa Rural, Rai Coast Rural and Nayudo Rural. Number of assigned wards to this district is 89.

Figure 77. Rai Coast District

Rai Coast District has a population of 83,218[37]. The average population density is relatively low, 10.4 inhabitants per km^2. The high valleys on the northern side of the Finisterre Range around Teptep, Gwarawon and Tariknam have the highest population densities that average over 50 persons/km^2. The Rai Coast and Long Island have average densities of over 25 persons/km^2, while the valleys on the southern side of the Finisterre Range have less than 20 persons/km^2.

The most disadvantaged groups in the district are those around Teptep where small numbers of people experience strong agricultural pressure and earn very low incomes. People are vulnerable to the effects of land degradation, declining crop yields, frost and food shortages, and have limited cash to purchase supplementary food.

Large numbers of people in the northern valleys of the Finisterre Range are constrained by low potential environments and very low incomes. People in the southern valleys of the Finisterre Range occupy very low potential environments. Overall, people in Rai Coast District are extremely

[37] National Population and Housing Census, 2011, National Statistical Office, 2013.

disadvantaged relative to people in other districts of PNG. There is some agricultural pressure, land potential is low, access to services is moderate and cash incomes are very low. Incomes are derived from sales of betel nut, cocoa and copra. Incomes are low on Long Island. Some coffee and tobacco is grown and sold in the Teptep and Gwarawon areas. The highest cash incomes are in villages associated with the Ramu Sugar estates and palm oil cultivation and milling derived from wage employment on the estates and in the mills.

People on the Rai Coast require around four hours' travel to reach Madang town, while those

in the Finisterre Range require up to eight hours' travel. During the wet season, travel times from the Rai Coast to Madang rise significantly because of flooded unbridged rivers. Long Island is 70 km from Saidor and 130 km from Madang. It is the most remote part of the district as small boat travel is expensive and dangerous from December to March. People in the Finisterre Range are very remote and must walk to roads on the Rai Coast and in the Ramu Valley.

Table 44. Selected Health Indicators for Rai Coast District (2014)

Low Weight for Age < 5 years old (%)[38]	Low Birth Weight (%)[39]	Incidence of Malaria (1,000 population)[40]	Incidence of Diarrhoea (<5 years/1,000 pop.)[41]
32	8.1	79	75

Rai Coast District has an adult literacy rate of 44.8%, with a significant disparity in literacy rates between males (52.9%) and females (36.4%).

3.4.2. *Hazards*

Hazard maps can be found in the province description (refer to Section 1) and the annex.

Hazard maps can be found in the province description (refer to Section 1) and the annex.

The map for extreme weather hazard of Rai Coast District shows that it is not prone to tropical cyclones, and projections for the future remain the same.

The map for inland flood hazard shows some minor floodplains (the biggest in the crater in Long Island) and projections for the future remain in the same magnitude.

Total annual rainfall is moderate to high, distinguishing the highest values to the west of Saidor (2980 to 3280mm) and the moderate to the east (2711 to 2979mm, including Long Island). Projections for the future show that the whole district will experience an increase in precipitation (2980 to 3280mm).

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[38] The indicator measures total number of children under 5 who have attended MCH clinic and weight less than 60% or 60% - 80% weight for age

[39] The indicator measures the proportion of those children that are born in health centres and hospitals and weigh less than 2500 gm.

[40] The indicator measures the total number of presentations to health centre/hospitals in the districts during the year, expressed as a ratio for every 1000 people in that district. The number is based upon clinical diagnosis, not RDT or microscopy

[41] The indicator measures the number of children under 5 yrs who seek care for diarrhoeal illness as a proportion of all children under five years. Diarrhoeal illness serves as an indicator of water quality, food hygiene and personal hygiene.

The drought risk map of the province shows that Astrolabe Bay Rural and Naho Rawa Rural present a low profile for drought risk, with values that range from 16,1 to 24 continuous dry days, while most of Rai Coastal including Long Island, have a moderate profile, with values from 21,1 to 24 continuous dry days. Projections for the future show that dryness will extend to the whole district (21,1 to 24 continuous dry days).

3.4.3. *Risk*

Risk maps can be found in the province description (refer to Section 1) and the annex.

3.4.3.1. Social risk

There is an area of moderate to high social risk from both high rainfall and drought in the southwestern part of the district in Naho Rawa LLG, inland from Saidor town in Rai Coast Rural LLG and along the coast north of Lolok in Astrolabe Bay LLG in the northern part of the district near the border to Madang District. In the projected climate, there is a lot of risk evolution for high rainfall and drought. Lot of areas are classified in moderate, high or extreme risk.

3.4.3.2. Economic risk

The economic risk is mostly low to very low. However, there are some agricultural lands exposed by drought. Projections for the future show an evolution. Indeed, the economic risk from drought is moderate in a large part of the district.

Table 45. Top agricultural activities of citizen households in Rai Coast[42]

Activities	% engaged	% engaged for cash
Coconut	45,7	31,7
Food crops	79,6	16,9
Betel nut	70,9	23,6
Coffee	42,3	41,1
Livestock	41,6	8,4

3.4.3.3. Physical risk

The map for inland flooding physical risk shows only three minor hotspots (buildings exposed around the central part of the coast), and projections for the future do not show much change.

The map for extreme weather physical risk shows that the province presents a low to very low profile, and projections for the future show the same tendency.

3.4.3.4. Composite risk

The composite map for multi-hazard risk shows a concentration of moderate risk in the western part of Naho Rawa Rural. Projections for the future show a general increase of moderate risks (Figures 78 and 79).

[42] National Research Institute (2010), 'Papua New Guinea District and Provincial Profiles)

LLG	HAZARD : CYCLONE COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Astrolabe Bay Rural	15,6	9,7	8,2	4,7	3,8	58,1
Naho Rawa Rural	0,0	6,5	28,2	6,5	4,4	54,4
Rai Coast Rural	23,8	14,3	12,4	9,1	3,3	37,1
Nayudo Rural	20,0	15,1	6,7	10,9	3,6	43,7

LLG	HAZARD : DROUGHT COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Astrolabe Bay Rural	13,2	25,9	1,9	0,0	0,0	59,0
Naho Rawa Rural	1,0	7,5	35,4	0,7	1,0	54,4
Rai Coast Rural	19,9	40,4	1,6	0,0	0,0	38,0
Nayudo Rural	14,5	41,8	0,0	0,0	0,0	43,7

LLG	HAZARD : INLAND FLOODING COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Astrolabe Bay Rural	18,9	2,8	2,1	2,8	6,4	67,0
Naho Rawa Rural	24,5	4,4	0,0	0,0	4,4	66,6
Rai Coast Rural	30,9	1,5	0,5	1,5	5,5	60,1
Nayudo Rural	26,6	1,2	0,6	2,4	5,5	63,7

LLG	HAZARD : PRECIPITATION COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Astrolabe Bay Rural	30,2	8,2	1,9	0,0	0,0	59,7
Naho Rawa Rural	1,0	7,8	35,7	0,7	0,3	54,4
Rai Coast Rural	45,9	14,4	1,6	0,0	0,0	38,0
Nayudo Rural	54,5	1,8	0,0	0,0	0,0	43,7

LLG	HAZARD : CYCLONE RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Astrolabe Bay Rural	25,2	16,7	0,0	0,0	0,0	58,1	25,2	16,7	0,0	0,0	0,0	58,1
Naho Rawa Rural	6,5	39,1	0,0	0,0	0,0	54,4	6,5	39,1	0,0	0,0	0,0	54,4
Rai Coast Rural	38,0	24,9	0,0	0,0	0,0	37,1	38,0	24,9	0,0	0,0	0,0	37,1
Nayudo Rural	35,1	21,2	0,0	0,0	0,0	43,7	35,1	21,2	0,0	0,0	0,0	43,7

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Astrolabe Bay Rural	13,2	25,9	1,9	0,0	0,0	59,0	0,0	13,2	27,8	0,0	0,0	59,0
Naho Rawa Rural	1,0	7,5	36,1	1,0	0,0	54,4	0,0	1,0	42,9	0,7	1,0	54,4
Rai Coast Rural	2,7	28,3	30,9	0,0	0,0	38,0	0,0	19,9	42,1	0,0	0,0	38,0
Nayudo Rural	1,2	13,9	41,2	0,0	0,0	43,7	0,0	14,5	41,8	0,0	0,0	43,7

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Astrolabe Bay Rural	24,5	3,8	2,6	1,4	0,7	67,0	24,5	3,8	2,6	1,4	0,7	67,0
Naho Rawa Rural	25,2	5,8	1,7	0,7	0,0	66,6	25,2	5,8	1,7	0,7	0,0	66,6
Rai Coast Rural	32,6	3,8	1,5	1,1	0,9	60,1	32,6	3,8	1,5	1,1	0,9	60,1
Nayudo Rural	28,5	3,6	3,0	1,2	0,0	63,7	28,5	3,6	3,0	1,2	0,0	63,7

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Astrolabe Bay Rural	4,7	35,6	0,0	0,0	0,0	59,7	0,0	30,2	8,0	2,1	0,0	59,7
Naho Rawa Rural	7,5	1,4	36,1	0,7	0,0	54,4	0,0	1,0	37,4	6,8	0,3	54,4
Rai Coast Rural	47,7	14,3	0,0	0,0	0,0	38,0	0,0	45,9	14,4	1,6	0,0	38,0
Nayudo Rural	56,3	0,0	0,0	0,0	0,0	43,7	0,0	54,5	1,8	0,0	0,0	43,7

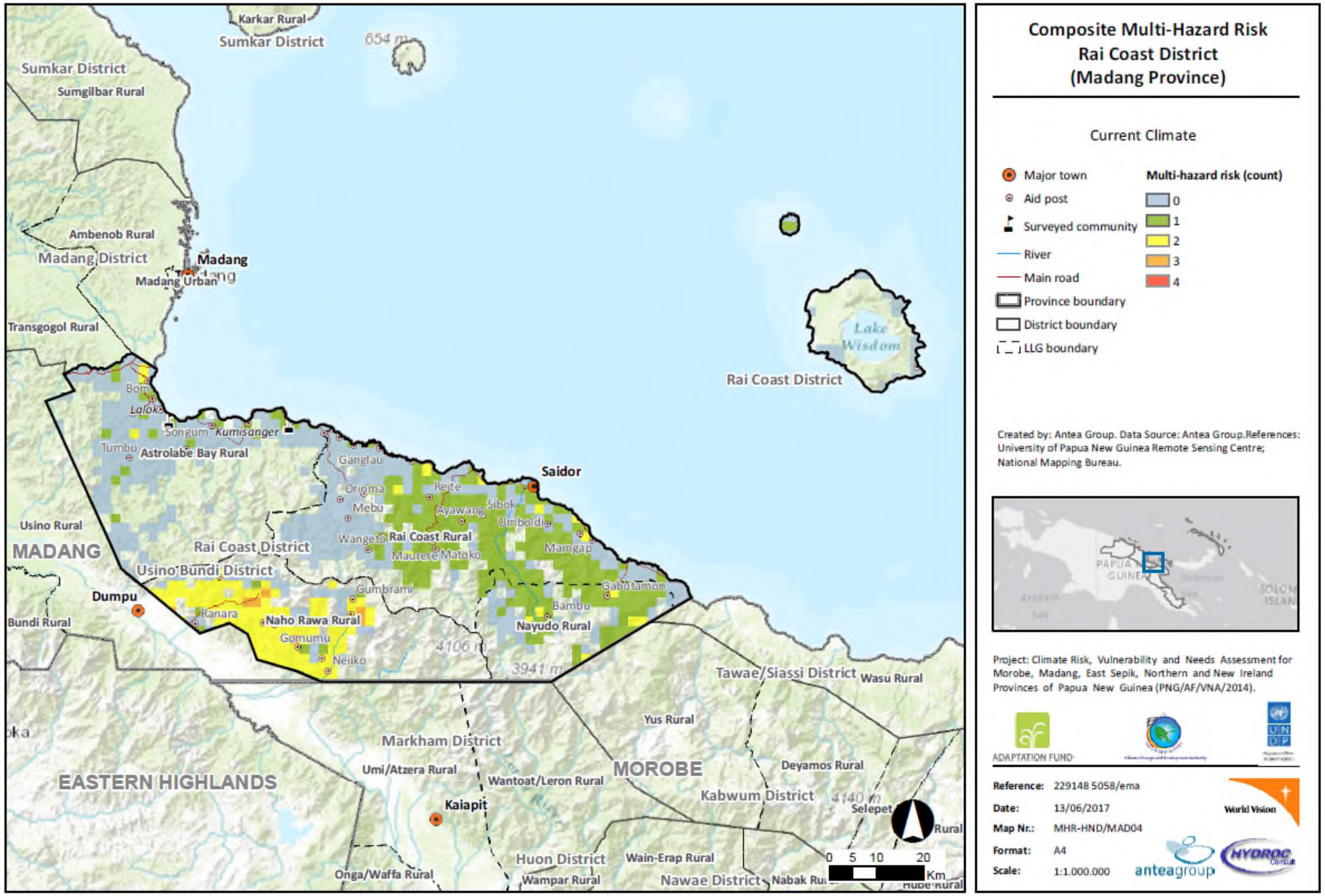

Figure 78. Composite risk map for Rai Coast District (current climate)

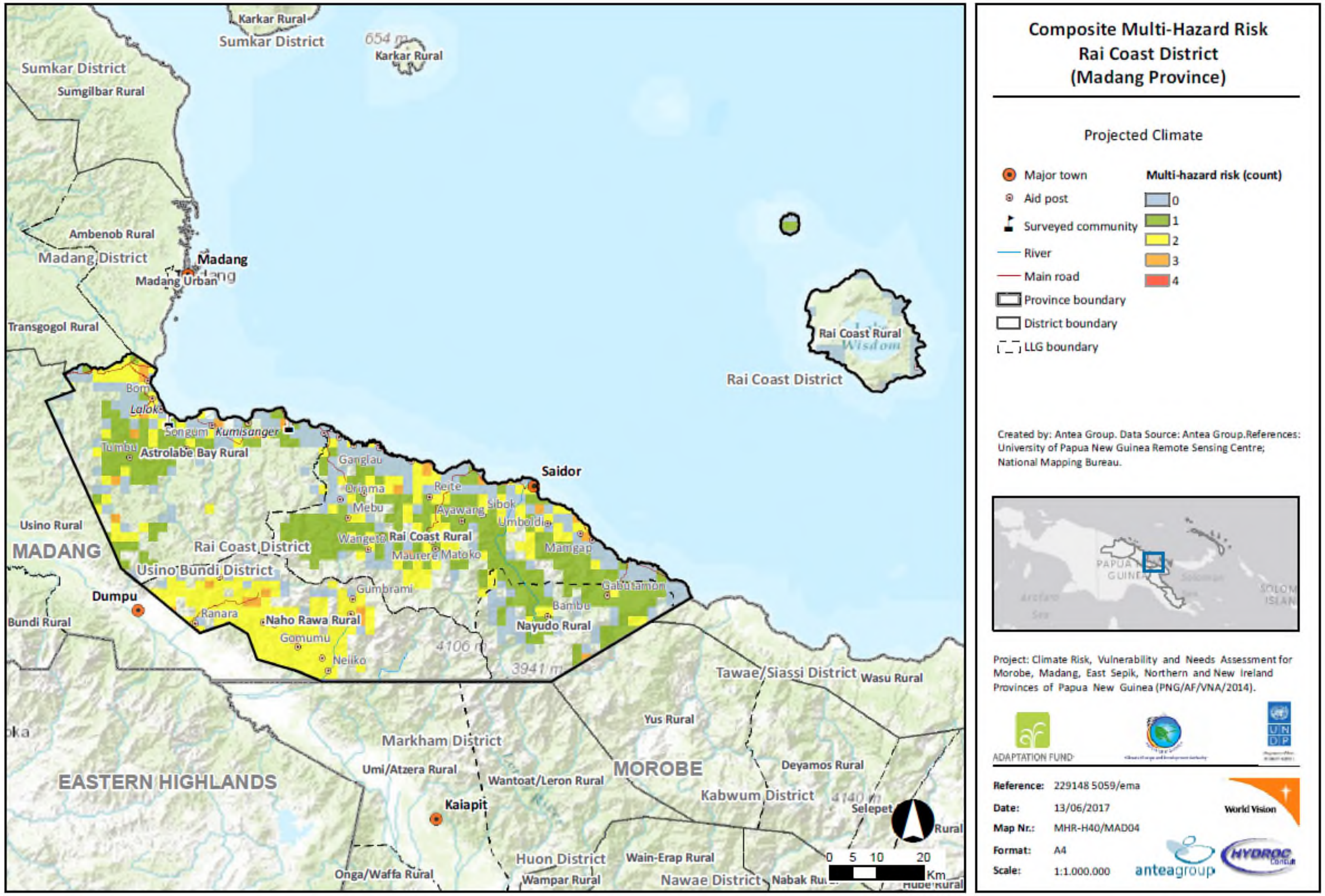

Figure 79. Composite risk map for Rai Coast District (future climate)

3.5. Sumkar Risk Profile

3.5.1. General description

Sumkar District stretches across the Adelbert Range, the plains of the Malas, Gilagil and Surumarang Rivers along the coast and also includes Karkar and Bagabag Islands. High incomes can be earned along the coast as well as on Karkar Island, from the sale of cocoa, copra, betel nut and fresh food, while incomes are more moderate in the Adelbert Range. The district headquarters is located in Karkar. There are 2 Local-Level Governments in Sumkar District: Karkar Rural and Sumgilbar Rural. Number of assigned wards to this district is 64.

Figure 80. Sumkar District

Sumkar District has a population of 75,067[43]. The average population density is relatively low, 14.4 inhabitants per km^2. Most people live on Karkar Island where the population density is over 120 persons/km^2. The coastal plains also have high densities of over 70 persons/km^2. The coastal hills have an average density of more than 15 persons/km^2, while the higher mountains are sparsely populated with less than 10 persons/km^2. The coastal plains have exerienced significant in-migration in recent years. The population in the district has increased by over 5 per cent per year in recent decades.

The most disadvantaged people in the district are those in the Adelbert Range where small groups of people are constrained by very low incomes and low potential environments. People on the coastal plains are affected by moderate agricultural pressure, while those in the coastal hills earn very low incomes.

Overall, people in Sumkar District are slightly disadvantaged relative to people in other districts of PNG. There is some agricultural pressure, land potential is very high, access to services is oderate and

[43] National Population and Housing Census, 2011, National Statistical Office, 2013.

cash incomes are high. Incomes are highest on Karkar Island and the coastal plains, and are derived from the sale of cocoa, copra, betel nut and fresh food. Incomes are moderate in the coastal hills and lowest in the Adelbert Range.

People on the coastal plains require less than one hour's travel to Madang, while those in the coastal hills are within four hours' travel. People on Karkar Island require around half a day's travel to reach Madang by boat, while those in the Adelbert Range require up to eight hours' travel. The north coast road runs through the district and connects with numerous branch roads which run into the coastal hills. Karkar Island has a good internal road network and is linked to the mainland by regular passenger boats.

Table 46. Selected Health Indicators for Sumkar District (2014)

Low Weight for Age < 5 years old (%)[44]	Low Birth Weight (%)[45]	Incidence of Malaria (1,000 population)[46]	Incidence of Diarrhoea (<5 years/1,000 pop.)[47]
40	1.9	94	92

Sumkar District has an adult literacy rate of 70.9%, with a significant disparity in literacy rates between males (74.1%) and females (67.4%).

3.5.2. *Hazards*

Hazard maps can be found in the province description (refer to Section 1) and the annex.

Sumkar District is not prone to tropical cyclones and projections for the future do not show much change.

Regarding inland flood hazard, there are some minor events in the continental part and some bigger in coastal areas around Kar Kar Island. Projections for the future keep the same tendency.

Total annual rainfall is very high for the whole district, with figures around the 2980 to 3280 mm, and projections for the future show a slight increase, especially in the easternmost corner of the district, where figures will reach the 3281 to 3777mm.

Ranges for total rain on wet days vary between 501 to 600mm, but projections for the future show an increase, bigger as we go to the west of the district (where it will reach values of 701 to 800mm).

Current drought risk is divided into low for the continental part of the district (16,1 continuous dry days) and moderate for the islands (21,1 to 24 continuous dry days). Projections for the future show

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[44] The indicator measures total number of children under 5 who have attended MCH clinic and weight less than 60% or 60% - 80% weight for age

[45] The indicator measures the proportion of those children that are born in health centres and hospitals and weigh less than 2500 gm.

[46] The indicator measures the total number of presentations to health centre/hospitals in the districts during the year, expressed as a ratio for every 1000 people in that district. The number is based upon clinical diagnosis, not RDT or microscopy

[47] The indicator measures the number of children under 5 yrs who seek care for diarrhoeal illness as a proportion of all children under five years. Diarrhoeal illness serves as an indicator of water quality, food hygiene and personal hygiene.

that this dryness to the continent, where only the westernmost corner will remain in the lower values between 16,1 to 21 continuous dry days.

3.5.3. Risk

Risk maps can be found in the province description (refer to Section 1) and the annex.

3.5.3.1. Social risk

There is an area with moderate to high social risk on the north and west coast of Karkar Island in Karkar Rural LLG. In the projected climate, there is a lot of risk evolution for high rainfall. Lot of areas are classified in moderate, high or extreme risk. In the projected climate, there is a lot of risk evolution for high rainfall. Lot of areas are classified in moderate, high or extreme risk.

3.5.3.2. Economic risk

The economic risk is mostly low to very low. However, there are some agricultural lands exposed in the coastal area. Projections for the future show an evolution. Indeed, the economic risk from drought is moderate in a large part of the district.

Table 47. Top agricultural activities of citizen households in Sumkar[48]

Activities	% engaged	% engaged for cash
Coconut	77,5	72,3
Food crops	83,2	9,6
Betel nut	86,2	23,2
Cocoa	67,3	66,7
Livestock	53,5	4,3

3.5.3.3. Physical risk

The inland flooding physical risk map for the district of Sumkar shows only one high hotspot in the continental part of the district, in the area around Dimer, where some buildings are exposed. The situation is a bit worse in Karkar Island, where some buildings and roads along the coast are compromised. Projections for the future do not show much change.

The map for extreme weather physical risk shows that Sumkar District has a low to very low profile, and projections for the future follow the same trend.

3.5.3.4. Composite risk

The map for composite multi-hazard risk for Sumkar District shows some moderate risks along the coastal areas of both the continental part as well as Karkar Island. Projections for the future show an increase in the extension and number of these risks (Figures 81 and 82).

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Karkar Rural	0,9	0,9	18,3	10,1	41,2	28,6
Sumgilbar Rural	0,3	47,7	30,8	7,4	11,1	2,7

[48] National Research Institute (2010), 'Papua New Guinea District and Provincial Profiles)

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Karkar Rural	1,8	22,0	22,0	21,1	3,7	29,5
Sumgilbar Rural	0,3	84,9	9,8	0,8	1,3	2,9

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Karkar Rural	7,3	2,7	3,7	1,8	11,0	73,4
Sumgilbar Rural	35,8	10,3	2,9	2,4	3,2	45,4

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Karkar Rural	6,4	17,4	22,0	21,1	3,7	29,5
Sumgilbar Rural	45,6	44,6	5,0	0,8	1,3	2,7

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Karkar Rural	1,8	69,6	0,0	0,0	0,0	28,6	1,8	69,6	0,0	0,0	0,0	28,6
Sumgilbar Rural	48,0	49,3	0,0	0,0	0,0	2,7	48,0	49,3	0,0	0,0	0,0	2,7

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Karkar Rural	0,0	1,8	44,0	21,1	0,0	33,2	0,0	1,8	44,0	21,1	3,7	29,5
Sumgilbar Rural	0,3	84,9	10,6	1,3	0,0	2,9	0,3	15,9	78,8	0,8	1,3	2,9

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Karkar Rural	10,1	4,6	4,6	6,4	0,9	73,4	10,1	4,6	4,6	6,4	0,9	73,4
Sumgilbar Rural	39,3	11,4	3,2	0,8	0,0	45,4	39,3	11,4	3,2	0,8	0,0	45,4

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Karkar Rural	10,1	60,4	0,0	0,0	0,0	29,5	0,0	6,4	17,4	22,0	24,7	29,5
Sumgilbar Rural	1,6	56,8	39,0	0,0	0,0	2,7	0,0	45,6	44,6	5,0	2,1	2,7

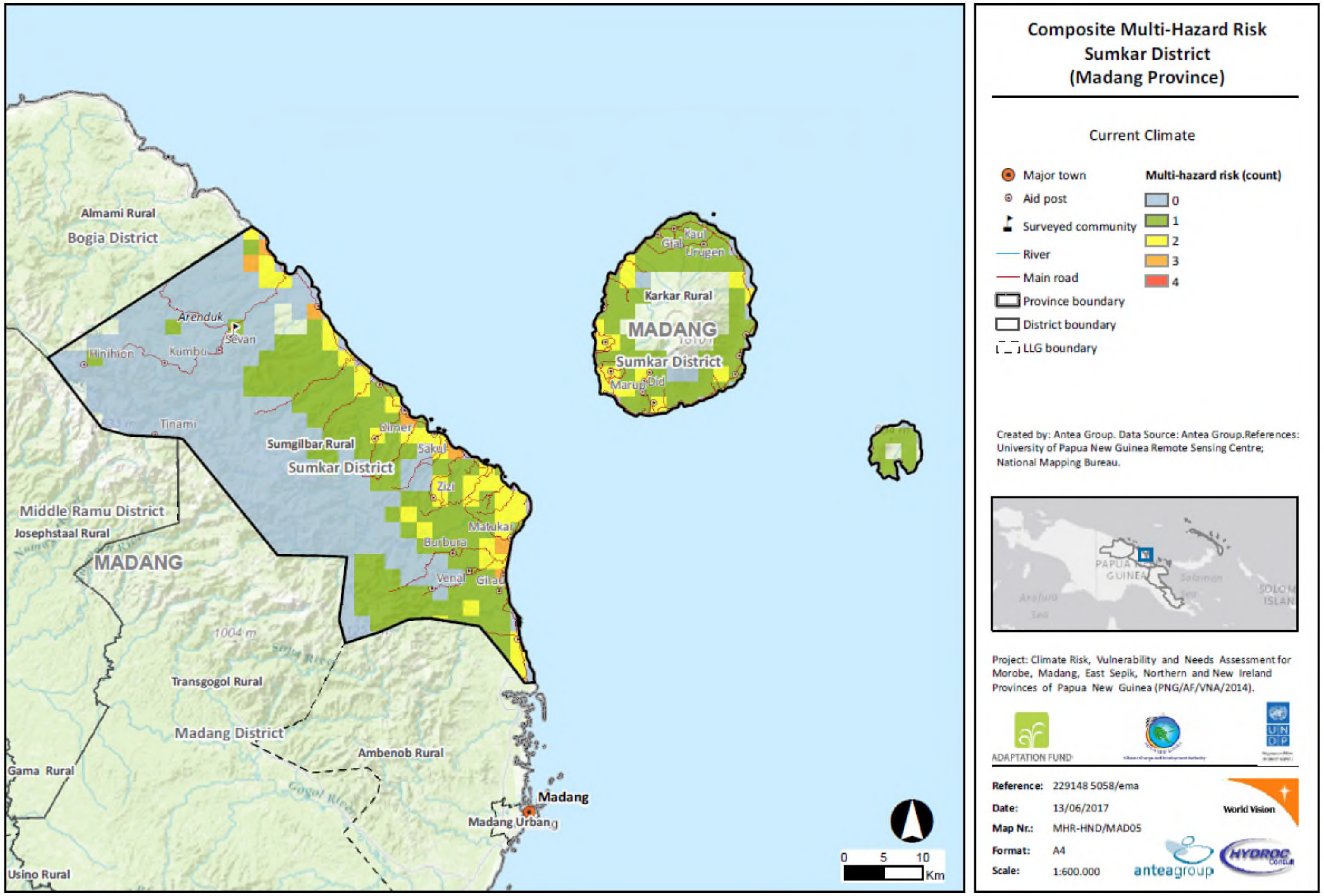

Figure 81. Composite risk map for Sumkar District (current climate)

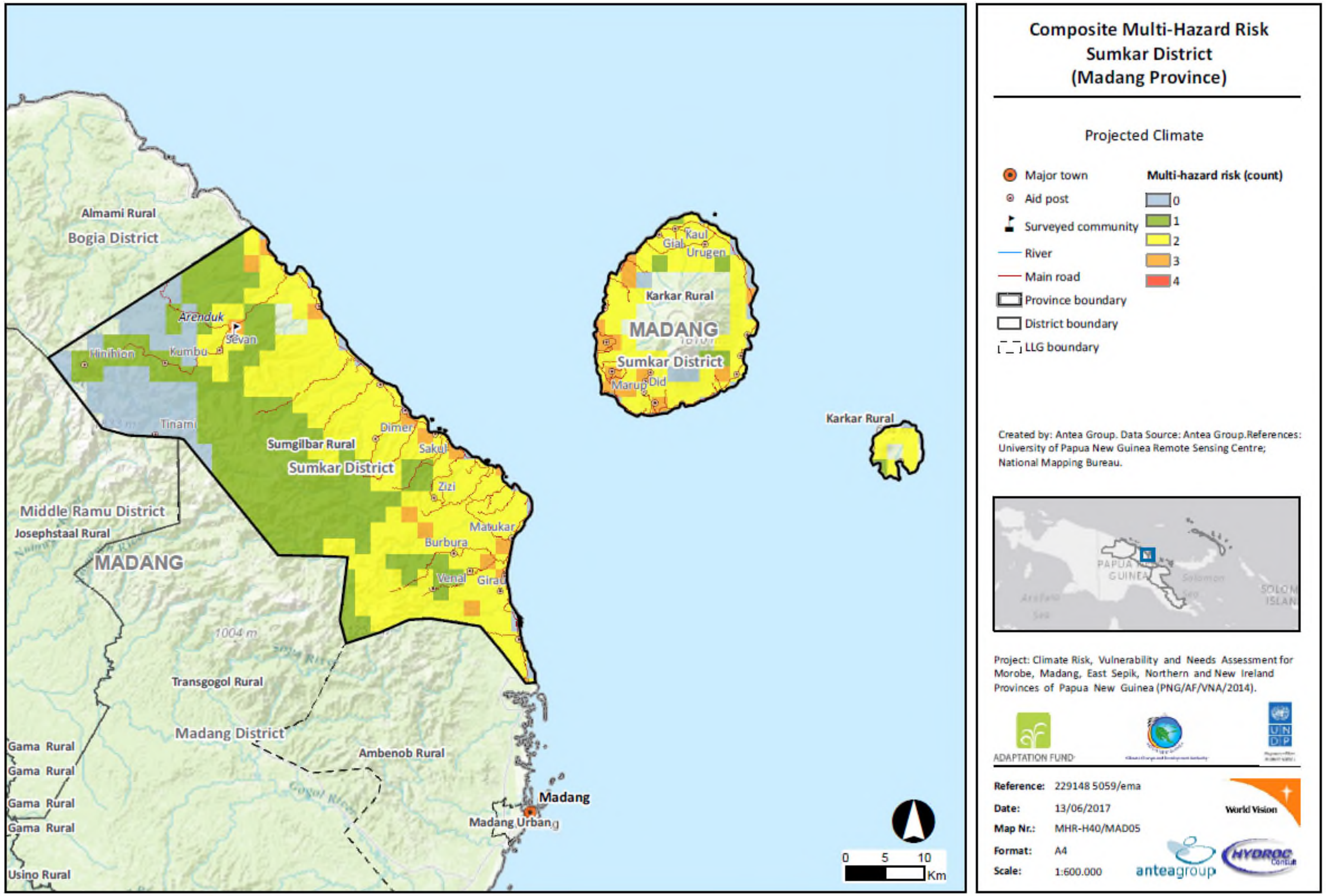

Figure 82. Composite risk map for Sumkar District (future climate)

3.6. Usino Bundi Risk Profile

3.6.1. General description

Usino Bundi District includes the mountains of the Bismarck Fall, the Simbai Valley and the plains of the Ramu and Sogerum Valleys. The people near the Ramu Highway have opportunities to earn moderate incomes from sales of food and other goods. A small population earns high incomes from wages at Ramu Sugar while some wages and royalties are available from mining and forestry operations. However most people in the district earn very low incomes. The district headquarters is located in Usino. There are 3 Local-Level Governments in Usino Bundi District: Bundi Rural, Usino Rural and Kovon Rural. Number of assigned wards to this district is 60.

Figure 83. Usino Bundi District

Usino District has a population of 60,807[49]. The average population density is relatively low, 5.2 inhabitants per km^2. Areas around Simbai and Bundi have moderate population densities of over 40 persons/km^2. Much of the Bismarck Falls area is unoccupied apart from isolated villages, with densities of below 10 persons/km^2. The Ramu and Sogeram valleys are also sparsely populated with under 15 persons/km^2. The upper Simbai Valley and upper Ramu Valley around Bundi, Brahman and Walium have significant out-migration. Populations in the Mareng, Bundi and Uringa-Kesawai areas decreased by an average of 5 per cent per year in recent decades.

The most disadvantaged people in the district are those to the east of Simbai and around Bundi who are affected by low incomes and low potential environments. There are similar constraints in the middle Ramu Valley, but fewer people are affected. People in the Sogeram Valley also earn low

[49] National Population and Housing Census, 2011, National Statistical Office, 2013.

incomes. People in Usino-Bundi District are extremely disadvantaged relative to people in other districts of PNG. There is low agricultural pressure, land potential is low, and access is generally poor.

People in villages associated with the Ramu Sugar estates and palm oil cultivation and milling have very high incomes derived from wage employment on the estates. Those living near the Ramu Highway earn moderate incomes from sales of betel nut, fresh food and other products. People in the remainder of the district earn very low incomes from minor sales of betel nut and fresh food. The Sogeram forestry operations and the Ramu nickel mine provide wage employment and royalties to a small number of people.

Most people in the Bismarck Fall, the middle Ramu Valley and the Sogeram Valley area require up to eight hours' travel to reach the nearest service centre. Outboard motor powered canoes are used to travel along the Ramu River to the Brahmin Bridge. This bridge links the Ramu Highway to Bundi. Areas in the southeast around Usino and Dumpu are up to four hours' travel from Madang town along the Ramu Highway. Road developments to the Ramu Nickel mine near Aiome and the Sogeram forestry operations have improved access to areas on the northern side of the Ramu River.

Table 48. Selected Health Indicators for Usino Bundi District (2014)

Low Weight for Age < 5 years old (%)[50]	Low Birth Weight (%)[51]	Incidence of Malaria (1,000 population)[52]	Incidence of Diarrhoea (<5 years/1,000 pop.)[53]
37	4.5	284	246

Usino Bundi District has an adult literacy rate of 39.2%, with a significant disparity in literacy rates between males (46.6%) and females (30.8%).

3.6.2. *Hazards*

Hazard maps can be found in the province description (refer to Section 1) and the annex.

The map of extreme weather hazard of Usino Bundi shows that the district is not prone to tropical cyclones and projections for the future follow the same trend.

The inland flood hazard map shows some floodplains along Ramu River and its tributaries, and projections for the future follow the same trend.

The map for total annual rainfall shows a high average of 2980 to 3280mm. Projections for the future show that precipitation will increase in most of the district (to the west of Naru), to a range between 3281 to 3777 mm.

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[50] The indicator measures total number of children under 5 who have attended MCH clinic and weight less than 60% or 60% - 80% weight for age

[51] The indicator measures the proportion of those children that are born in health centres and hospitals and weigh less than 2500 gm.

[52] The indicator measures the total number of presentations to health centre/hospitals in the districts during the year, expressed as a ratio for every 1000 people in that district. The number is based upon clinical diagnosis, not RDT or microscopy

[53] The indicator measures the number of children under 5 yrs who seek care for diarrhoeal illness as a proportion of all children under five years. Diarrhoeal illness serves as an indicator of water quality, food hygiene and personal hygiene.

Total rainfall on wet days currently ranges the 501 to 600mm according to historic climate data from 1990 to 2016. Projections for the future show a big increase in the near future, with values that could range from 701 to 800mm.

Drought hazard currently ranges values from 16,1 to 21 continuous dry days for the whole district, and projections for the future show an increase of this dryness, especially in the south eastern part of the district (around Dumpu), where values will reach the 21,1 to 24 continuous dry days.

3.6.3. Risk

Risk maps can be found in the province description (refer to Section 1) and the annex.

3.6.3.1. Social risk

There is an area of moderate to high social risk from hazards except for cyclones extending from the border with Morobe Province I the southern part of the district along the Ramu River northwesterly through the town of Dumpu to the area of Boko in Usino Rural LLG. In the projected climate, there is a lot of risk evolution for high rainfall. Lot of areas are classified in moderate, high or extreme risk.

3.6.3.2. Economic risk

The economic risk is moderate to high from inland flood, high rainfall and drought, around Dumpu where there are agricultural systems : food crops (Table 43). Projections for the future show an evolution. Indeed, the economic risk from drought is high to very high in around Dumpu.

Table 49. Top agricultural activities of citizen households in Rai Coast[54]

Activities	% engaged	% engaged for cash
Coconut	39,7	3,3
Food crops	75,6	11,8
Betel nut	62,5	20,2
Coffee	34,6	31,1
Livestock	50,4	5,7

3.6.3.3. Physical risk

The map of inland flooding for Usino Bundi District shows a couple of hotspots, mainly buildings and road, along the Ramu River, for example around Kesawai or Dumpu. Projections for the future do not show much change.

The map for extreme weather physical risk shows that the district has a very low profile to these episodes, and projections for the future do not show much change.

3.6.3.4. Composite risk

The composite multi-hazard risk map for the district of Usino Bundi shows some moderate to high risks along the axis of the road that goes parallel to Ramu River, passing through Dumpu and up to the boundary with Morobe. Another moderate hotspot is found in the westernmost corner of the district. Projections for the future follow the same trend (Figures 84 and 85).

[54] National Research Institute (2010), 'Papua New Guinea District and Provincial Profiles)

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Bundi Rural	10,9	14,3	3,6	3,2	1,2	66,9
Gama Rural	2,4	40,4	13,1	7,7	3,8	32,6
Usino Rural	5,1	55,6	3,1	1,9	2,1	32,3

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Bundi Rural	13,8	15,6	1,5	0,2	0,0	68,9
ama Rural	5,2	47,6	5,2	2,8	5,8	33,5
Usino Rural	2,1	62,6	2,9	0,0	0,0	32,5

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Bundi Rural	22,1	1,7	2,0	2,4	1,9	69,9
Gama Rural	25,7	6,8	2,0	4,8	6,9	53,9
Usino Rural	26,6	10,3	1,9	0,4	2,1	58,8

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Bundi Rural	18,9	10,4	1,5	0,2	0,0	69,1
Gama Rural	38,0	17,9	4,2	5,2	0,8	33,9
Usino Rural	57,6	7,0	2,9	0,0	0,0	32,5

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Bundi Rural	25,2	8,0	0,0	0,0	0,0	66,9	25,2	8,0	0,0	0,0	0,0	66,9
Gama Rural	42,8	24,6	0,0	0,0	0,0	32,6	42,8	24,6	0,0	0,0	0,0	32,6
Usino Rural	60,7	7,0	0,0	0,0	0,0	32,3	60,7	7,0	0,0	0,0	0,0	32,3

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Bundi Rural	13,8	15,6	1,7	0,0	0,0	68,9	12,2	17,2	1,7	0,0	0,0	68,9
Gama Rural	5,2	47,6	8,0	5,8	0,0	33,5	3,5	38,3	16,5	2,8	5,5	33,5
Usino Rural	2,1	62,6	2,9	0,0	0,0	32,5	2,1	62,6	2,9	0,0	0,0	32,5

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Bundi Rural	25,3	3,2	1,2	0,2	0,2	69,9	25,2	3,4	1,2	0,2	0,2	69,9
Gama Rural	28,0	9,3	3,7	3,0	2,1	54,0	27,7	9,6	3,8	3,0	2,1	53,9
Usino Rural	27,2	11,3	2,5	0,0	0,0	59,0	27,0	11,5	2,7	0,0	0,0	58,8

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Bundi Rural	1,2	28,0	1,7	0,0	0,0	69,1	0,0	18,9	0,0	10,4	1,7	69,1
Gama Rural	3,2	45,3	12,4	5,2	0,0	33,9	0,0	38,0	9,6	14,9	3,7	33,9
Usino Rural	0,4	64,2	1,4	1,4	0,0	32,5	0,0	57,6	0,0	8,2	1,6	32,5

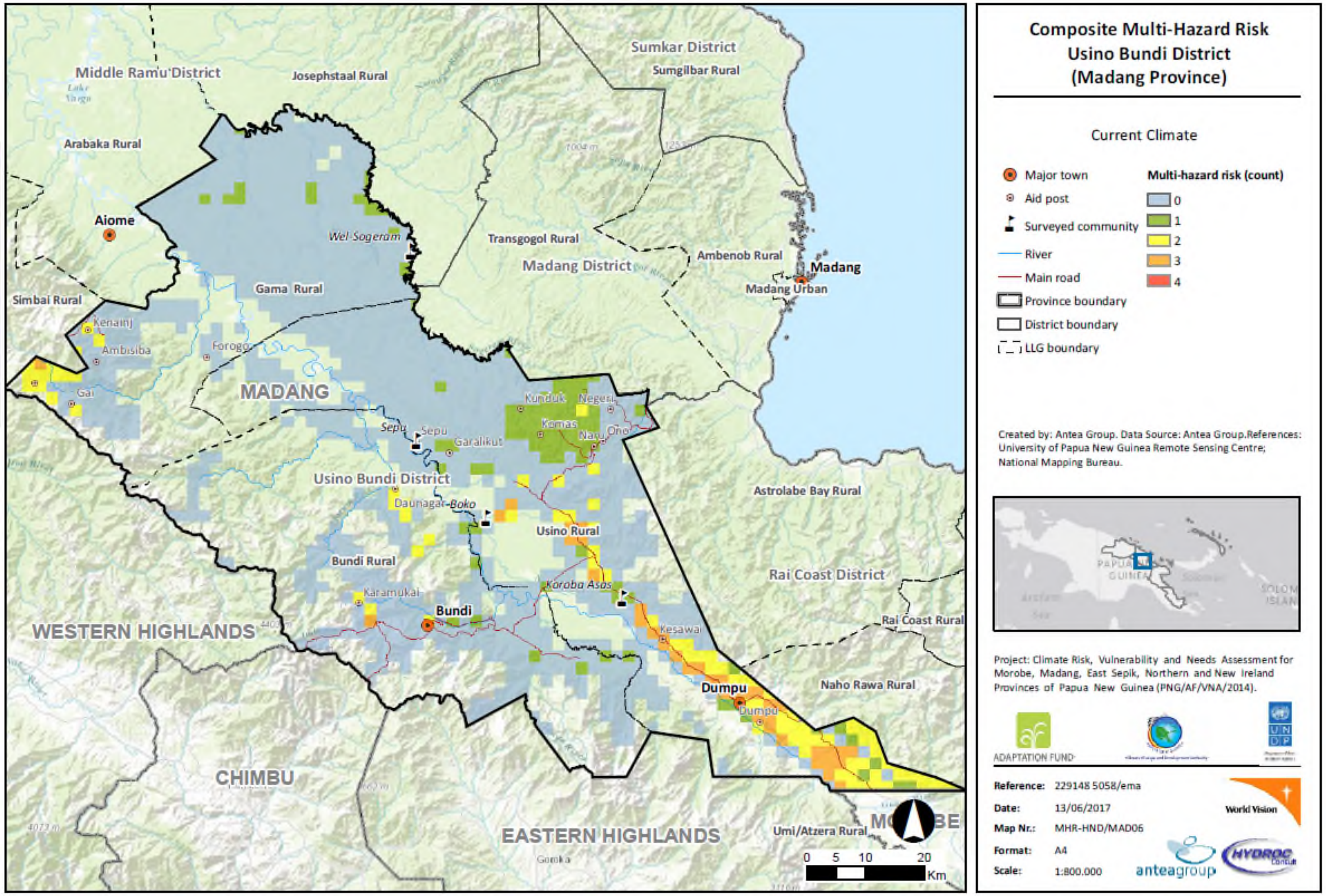

Figure 84. Composite risk map for Usino Bundi District (current climate)

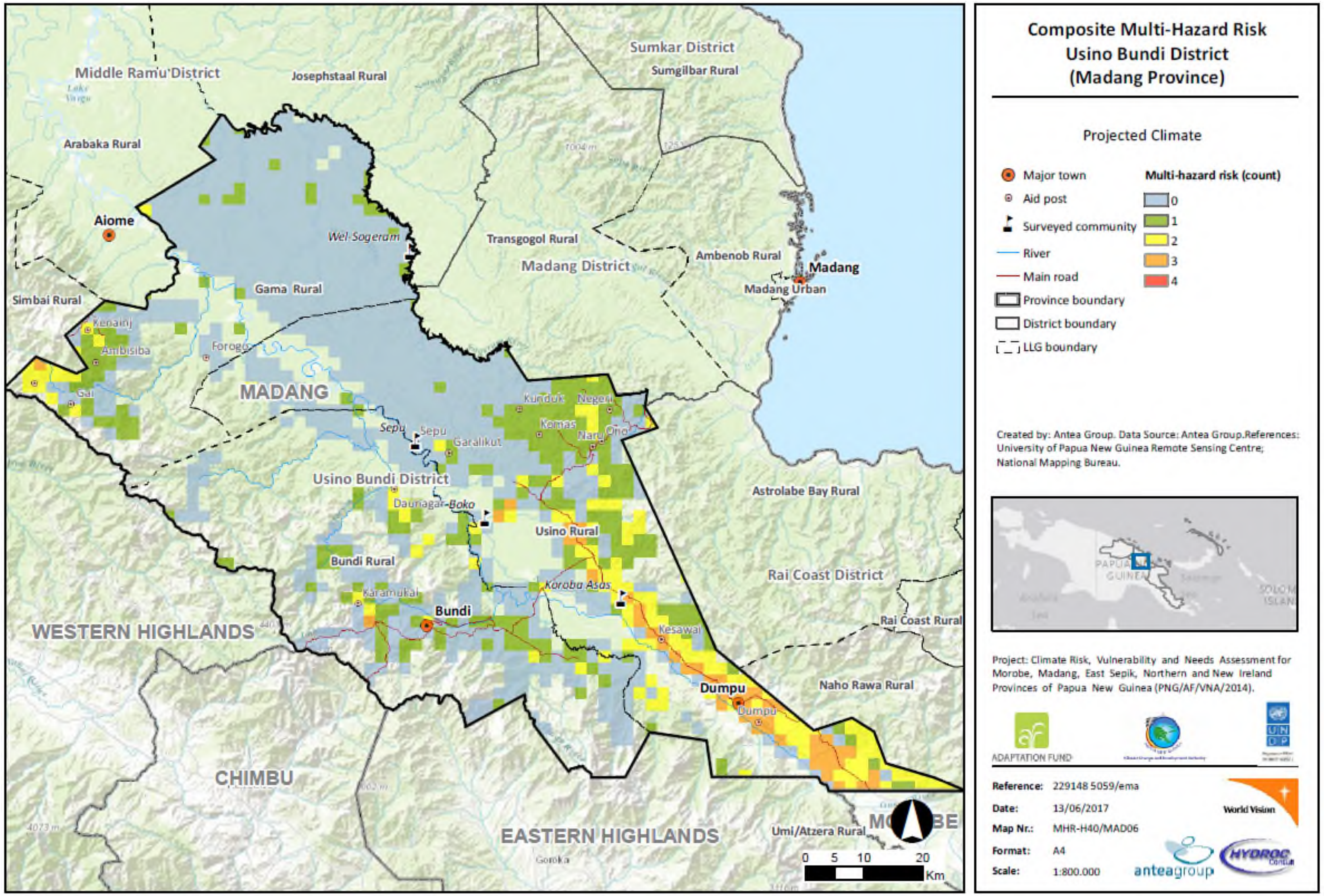

Figure 85. Composite risk map for Usino Bundi District (future climate)

4. RECOMMENDATIONS

This section focuses on the needs, priorities, and opportunities for reducing the impact of the major climate change hazards within the province. These recommendations are derived from the risk mapping and profiling carried out in the previous sections.

Based on these outcomes, ‘a way forward for reducing the impacts and vulnerabilities to climate change hazards’ is sketched at a high level, focusing on achievable solutions for the major issues identified during the hazards, vulnerability, and risk assessments.

4.1. Needs and priorities

The hydro meteorological hazard mapping carried out for the province shows that inland flooding, increase on precipitation intensities and drought are hazards affecting the province up to some extent. There is no evidence of the province being within a cyclone prone region. The existing situation will be exacerbated slightly in the future. Although the hazard patterns will remain as the ones produced by the current climate; it is expected that the intensity of their impacts would slightly increase.

Services like water supply, urban drainage and irrigation will be increasingly important in the future as problems like flash floods, bank erosion, landslides, drought, wild fires increase.

Projected hazards over the next 50 years are not remarkably more severe than over the past 50 years. Rather, increasing human activities and development may result in greater risk. In more remote areas, pressure grows to extend gardens further up steeper hillsides, increasing the risk of erosion and landslides. At the same time, populations density has increased, due to the introduction of the oil palm blocks, and due to the increasing attraction of urban areas. In certain areas, rural livelihood systems are becoming increasingly concentrated and dependent on cash incomes from a single source. Oil palm in smallholder blocks spreads wealth, but still creates large areas of monoculture which increases risk (from weather, disease, etc.).

The crop assortment is likely to remain similar. Subsistence crops will remain the same, but their relative importance may change in response to changes in climate.

4.2. Opportunities

Development opportunities were identified based on a previous study on the feasibility of EWS23 and missions for the present study.

The Provincial Disaster Committee is aware that more collaboration with private partners for disaster response would be recommended; private instances are often better equipped and Public Private Partnerships could be effective. Disaster plans, which are not currently based on vulnerability or risk maps, should be updated based on the results of this assessment.

The provincial government has several organisations and networks representing women, youth, or ethnic groups. These groups can be further involved in disaster preparedness. Although the PDC has some training materials, more would be needed to support a broader education campaign.

As in other provinces, this province intends to continue decentralisation towards districts and the LLG to improve service delivery. District Development Authorities are being established for this purpose. Districts are funded by the province but also by national government (See District Development Authority Act 2014). This opportunity would allow districts focusing on implementation plans customized for their regions.

The International Organisation for Migration (IOM) runs a community-based programme to develop disaster management plans at the community level. This work on awareness is certainly needed and can be further developed in synergy with the outcomes of the present study.

NGOs like World Vision, ADRA, and others are active in the province implementing projects on DRR; the risk assessment from this study can enrich the work of these NGOs.

4.3. Way forward

The way forward for Madang Province should comprise updating current provincial plans including following key elements:

The risks are predictable. Disasters occur through lack of preparedness for likely occurrences. The immediate steps should be to set in place an adequate mechanism to respond to the kinds of emergencies that are likely to occur: principally flooding, landslide, some storm effects, and occasional drought. The disaster response team in Morobe is one of the best we have seen in the studied area, and could be the model for other provinces like this one: adequately provisioned with boats to access difficult coastal areas, such as Tufi, 4x4 vehicles to reach inland, and standing arrangements with the air force and police, to reach populated areas not served by roads. This needs to be backed up with meteorological and early warning information, and a network that allows this information to reach areas likely to be affected. Emergency preparation, at the district and LLG level is essential, to know in advance how to cope with rescue and care of displaced people. In many places, local level organisation is the only way to ensure some buffer of security.

Invest in risk knowledge. Stakeholders can become more resilient by understanding the current and projected hydro climatological risks. Current initiatives in community-based disaster risk reduction could be enhanced to incorporate customized information related to the present risk mapping.

Incorporate adaptation strategies at various levels (community, district, province and national) to cope with changing climate. This should include institutional, physical, and structural measures. Integrating disaster management into school curriculum would be helpful.

Focus on urban flooding and the damage to infrastructure around major cities. This could imply the maintenance of drainage systems and clean-up of drainage infrastructure, bridges, and culverts before the rainy season begins. These measures should allow that the road network remains operational during the rainy season and that the urban damages are reduced.

Lowland flooding is a recognised feature of the rural ecology in this province that people have experienced for generations. Flooding in upland areas is likely to be exacerbated with greater intensities of rainfall. The practice of terracing could be introduced in the hilly regions of the province to reduce soil deterioration, erosion and flash floods.

The traditional crop mix is well established to distribute risk, and to cover for most eventualities. As the frequencies of hazards change, the relative importance of one crop may change with respect to others. For example, longer dry spells is likely to increase the importance of cassava.

In rural zones, the focus should be on revising cropping practices and strategies for controlling and managing flash floods and bank erosion within an integrated approach.

Adequate measures for coping with drought risk should be defined. These could include reforestation plans for upper catchments to increase infiltration (positive for ground water recharge and effective reducing surface runoff). Additionally, communities should be trained on digging and maintaining superficial wells to improve their resilience to drought. For urban areas, a master plan on water supply, taking in account population increase and climate change, should be developed.

Papua New Guinea's Agricultural Research Institute considers drought to be the major climatic threat to agriculture in the country and is breeding crops for drought resistance. This research should be tested as quickly as possible at the local level, to give local people the chance to adapt local practices.

Protecting against drought requires the same measures as protecting against flash floods, using land and water management to restrain water and allow it to permeate the soil.

Community based DRR actions should be furtherly developed, especially in the most critical communities. Actions should include shelters and evacuation plans in place and communicated to residents. Early warning systems should be put in place focussing on alerting the population by alerts broadcast on TV and radio and sent by text to cell phones in advance.

Local government officials, hospital staff, the Red Cross, NGOs, and community, school and religious leaders should be further trained in emergency response to disasters. Emergency supplies, clothes, food, medical items, etc. should be procured and stored in strategic locations, ready for rapid distribution by emergency management personnel.

ANNEXES

Annex 1 Definitions

Sensitivity

Sensitivity refers to "the physical predisposition of human beings, infrastructure , and environment to be affected by a dangerous phenomenon due to lack of resistance and […] intrinsic and context conditions making it plausible that such systems once impacted will collapse or experience major harm and damage" (IPCC 2012).

Capacity

Capacity is "the combination of all the strengths, attributes and resources available within a community, society or organisation that can be used to achieve agreed goals, in this context : to cope with disasters (UNISDR 2009).

Vulnerability

Vulnerability is defined by the UNISDR as a "set of conditions and processes resulting from physical, social and economic factors, which increase the susceptibility of a community to the impact of the hazard". This includes intrinsic characteristics that predispose the asset or the community to suffer from a hazard, but also the potential loss that can result from it (UNISDR 2009).

Vulnerability is interpreted in this methodology as the potential damage (potential negative effects) of the hazard, divided by a factor accounting for the coping capacity of the community at large:

$$Vulnerability = \frac{Potential\ damage}{Capacity}$$

Equation 4 Definition of vulnerability

Furthermore, vulnerability can be broken down in several components of the system, such as:

- Physical vulnerability
- Social vulnerability
- Economic vulnerability
- Environmental vulnerability (not considered in the present study)

Hazard

Hydrometeorological hazards are processes or phenomena of atmospheric, hydrological or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Hazards studied in this project are inland flooding, coastal flooding, extreme weather events i.e. cyclones, increase in rainfall intensity and variability, and drought.

Risk

Risk is defined by the United Nations International Strategy for Disaster Reduction as the combination of the probability of a hazardous event and its negative consequences which result from interactions(s) between natural or man-made hazard(s), vulnerability, exposure and capacity (UNISDR 2009).

Conventionally, risk is expressed by the notation **Risk = Hazard x Vulnerability**. Some disciplines also include the concept of exposure to refer particularly to the physical aspects of vulnerability.

Annex 2 Data sources used

Climate metrics

National Weather Service (NWS) is responsible for monitoring and forecasting weather in Papua New Guinea[55]. Secretariat of the Pacific Community (SPC, formerly SOPAC) observed that, in general, National Meteorological Services and National Geological Surveys in the Pacific are professionally staffed, well-supported, and well-trained in comparison to National Hydrological Services. This is also observed in Papua New Guinea, where hydrological services are part of the Conservation & Environment Protection Authority (CEPA, formerly the Department of Environment and Conservation).

Until the 80s and early 90s, at least 95 stream gauging stations were operational. An assessment by HYCOS of the PNG hydrological archive indicated a total of 357 sites (water level and/or gauging stations) that operated for varying periods, some of which were at mining sites. This data amounts to perhaps hundreds of station years of data. Between 2000 and 2010, the river monitoring was reduced from 130 stations to less than 10. The database compiled from historic records is available at CEPA, but were not made available to the consultant. It has been reported that PNG currently has no functional hydrological monitoring network.

The National Weather Service maintains a network of 13 weather stations (Figure 86) including 3 automatic and 10 manual stations.[56] The following variables are recorded daily at the manual stations and hourly at the automatic stations: Rainfall, Air temperature, Wind, Pressure, and Humidity.

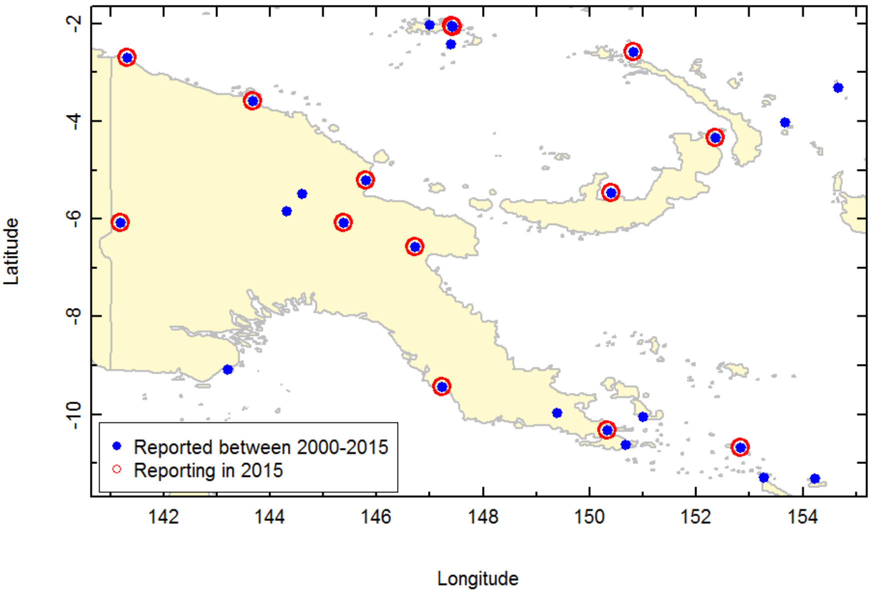

Figure 86. Location of Global Surface Summary of the Day (GSOD) weather stations across Papua New Guinea.

The applicability of the observed measurements for model calibration and disaster risk assessments is limited. Further, there are many gaps at the manual stations. This is primarily due to failure of the

[55] UNDP (2016) 'Assessment of early warning systems (ews) for inland and coastal flooding in papua new guinea - Final report - review, analysis, and recommendations', carried out by Antea Group.
[56] This information was obtained during interviews. Other sources report 14 manned National Weather Service stations, 7 automatic stations.

observers to report measurements. In addition, there is a significant delay in reporting (up to serval days).

The observational data, as described above, is managed within the NWS using the Australian Bureau of Meteorology's CliDE[57] system. CliDE incorporates a quality control (QC) module and has the ability to store both metadata and sub-daily observations. Data that fails the QC checks are flagged, but not discarded.

Additional data sources seem to be available country wide but they were not accessible to the consultant. For instance, following national regulations, mine companies are expected to monitor the environmental performance of each mine. They produce annual summary reports including tables of gauged data. However; the data is not stored in a central repository and is therefore only available as a hard copy.

Due to the limited availability and quality of historic hydro-meteorological datasets, time series data was downscaled for the area of interest from all applicable sources; 5th Coupled Model Intercomparison Project (CMIP5) and General Circulation Models (GCMs). The scale of the GCM data is too coarse for the analysis under this project, hence the data was downscaled to a common 0.5° grid and spatio-temporal data stored in netCDF files. A simple spatial correction, based on the ERA-Interim reanalysis was used for the downscaling (http://www.ecmwf.int/en/research/climate-reanalysis/era-interim).

There are several studies related to estimation of climate change projections in the pacific region and Papua New Guinea[58][59]. The Pacific Climate Change Portal[60] provides a helpful entrance to documentation, data and projects related to climate (projections) for the country.

Social vulnerability

Census units data

A shapefile with georeferenced census unit points was provided by the National Statistical Office. Geographic coordinates of each census unit was given with variable reliability. Additionally to census unit location, the attribute table contains information on the province, the district, the LLG, the Ward, the reliability of the GPS coordinates, the number of households, the number of people (male and female) and the average household size (in number of people per household).

From the National Statistical Office database, we can also retrieve information at census unit level such as literacy statistics and age distribution.

Health performance data

From the PCRAFI shapefiles provided by UNDP, we dispose of the geographic coordinates for most health centres on the territory.

The Health Information System / Department of Health provided Health Sector Performance data per health centre. Indicators are available regarding maternal health, child health and number of patients with some major diseases. Performance indicators are available per Health centre (2015), but also aggregated at district level in the annual sector review per district (2011 to 2014).

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[57] CliDE – Climate Data for the Environment; http://www.bom.gov.au/climate/pacific/about-clide.shtml

[58] Asian Development Bank (2013), 'The economics of climate change in the Pacific Mandaluyong City, Philippines'

[59] Australian Bureau of Meteorology and CSIRO (2011), ' Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1; Regional Overview. Volume 2: Country Reports. 288 pp.

[60] https://www.pacificclimatechange.net/

Infrastructure vulnerability

Infrastructure database

The infrastructure database was assembled using similar techniques to those used for buildings (see 1.1.1). It comprises a detailed and extensive inventory of major assets such as airstrips, major roads, and bridges. Other types of infrastructure are (non-exhaustively) geolocated: bus stations, communications, dams, docks, generators, helipads, mines, oil and gas infrastructure, ports, power plants, water intakes, storage tanks, water treatments etc.

Replacement costs for buildings and infrastructure

The economic losses from damage to buildings are directly related to the replacement cost (or value) of each building. The PCRAFI building database includes a replacement cost for each building/building cluster. The total value of a building is calculated as the product of the replacement cost for the building occupancy type (residential, commercial, industrial etc), floor area and number of stories. Replacement cost values for different types of buildings and occupancy types were collected from a variety of sources (PCRAFI 2012). On average in PNG, residential buildings a have replacement cost of $ 76,943 in urban and $ 5,510 in rural areas. Non-residential building have a replacement cost of $ 278,459 and $ 75,689 in urban and rural areas respectively.

The geodatabase with roads and other infrastructure does not c ontain location-specific replacement cost values, but the replacement cost of each piece of infrastructure can be estimated based on their characteristics (Table 50).

Replacement costs will be used for asset quantification in vulnerability computations.

Table 50. Unit replacement costs of infrastructure in PIC (Source: PCRAFI 2013)

Type	Cost (US$)	Metric
Large Airport	518	per linear foot of runway
Medium Airport	366	per linear foot of runway
Helipad	88,000	per unit (40 12.5'-by-20' slabs)
Airstrip	10,000	per unit
Small Airport	100,000	per unit
Dam	100,000,000	per unit
Large Scale Mine	500,000,000	per unit
Medium Scale Mine	100,000,000	per unit
Small Scale Mine	10,000,000	per unit
Steel/Concrete Bridge	10,000	per linear meter of span
Non-Steel/Concrete Bridge	1,000	per linear meter of span
Roads	500,000	per linear kilometer
Railroads	100,000	per linear kilometer
Dock	100,000	per unit
Water Treatment	2,000,000	per unit
Storage Tanks	10,000	per unit
Water Intake	40,000	per unit
Bus Station	30,000	per unit
Communications	5,000	per unit
Oil & Gas Facility	20,000,000	per unit
Power Plant - Very Large	40,000,000	per unit
Power Plant - Large	10,000,000	per unit
Power Plant - Medium	5,000,000	per unit
Power Plant - Small	1,000,000	per unit
Power Plant - Very Small	500,000	per unit
Generator	1,000	per unit
Substation	500,000	per unit
Port - Very Large	100,000,000	per unit
Port - Large	50,000,000	per unit
Port - Medium	10,000,000	per unit
Port - Small	5,000,000	per unit
Port - Very Small	1,000,000	per unit

Economic vulnerability

Buildings database

The exposure database established by PCRAFI (Pacific Catastrophe Risk Financing and Insurance Initiative) includes a comprehensive inventory of residential, commercial, public and industrial buildings. It consists of their location, replacement cost and structural characteristics which affect their vulnerability to the effects of natural disasters. The locations of the buildings (Figure 87) were determined using four different levels of building extraction methodologies: (i) manually digitized from high-resolution satellite imagery and surveyed in the field; (ii) manually digitized from high-resolution satellite imagery but not field verified; (iii) extraction of building clusters and manually counted from moderate to high-resolution satellite imagery; (iv) buildings that are mostly located in rural areas were inferred using image processing techniques from low to moderate resolution satellite imagery and/or census data.

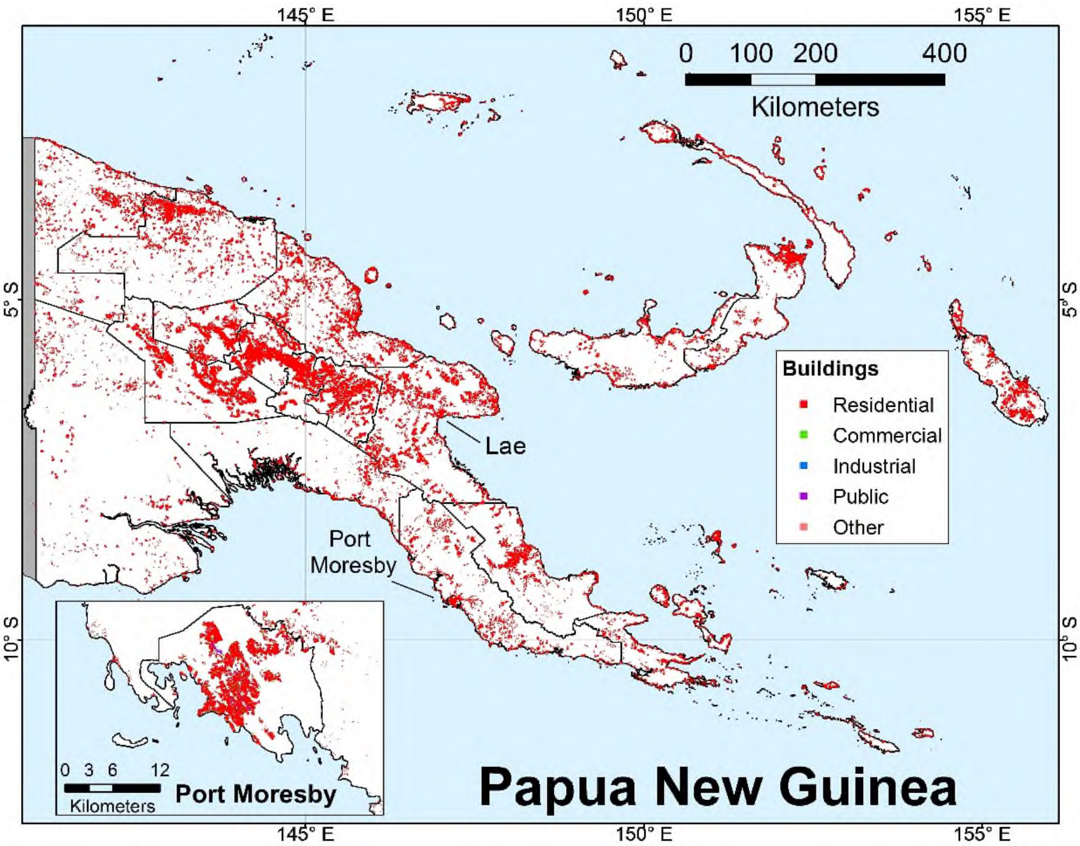

Figure 87. Location of buildings in PNG (Source: PCRAFI)

The building database provides information about occupancy (residential, commercial or other) and secondary characteristics that are relevant to sensitivity to hazard: specific structural details, such as wall type, roof type, foundation type, and presence of defects. There are also global characteristics such as number of stories and floor area.

These secondary modifiers refer to characteristics of the building which tend to increase or decrease the sensitivity with respect to that of the typical building in its respective construction class (residential/non-residential). For example, the presence of window shutters is likely to reduce the vulnerability of wind damage as compared to the vulnerability of a similar building with no shutters. Likewise, a building with a tall, unbraced, stilt-like foundation would be more vulnerable to ground shaking than a similar building with a slab foundation. The effects on the expected losses for buildings that have characteristics related to more than one modifier are cumulative.

Land use/Land cover database

The Land Use / Land Cover (LULC) geo-database in the PNG Resource Information System (PNGRIS) is a comprehensive inventory of major crops and other land use categories (e.g., forests, lakes and rivers, sand, settlements, barren land, and grass land). The LULC maps were generated primarily using remote sensing and were supplemented with various sources (PCRAFI 2013 p26-27). The main systems included in the LULC layer are (agricultural systems are in bold):

1. Open Land Grass Land
2. Forest
3. **Palm Oil** (subclass: Coffee, Coconut)
4. **Coconut Forest**
5. **Coconut Crops**
6. **Coconut Plantation**
7. **Banana** (subclass: Papaya, Taro, Yam, Cassava)
8. **Cultivated Land** (subclass**:** Rice, Vegetables & Fruits, Taro, Corn, Nuts, Peanu)
9. Settlement
10. Water
11. Wet Land

Agricultural systems survey

Reports of the agricultural survey carried out in by the ANU (Autralian University of Australia) were provided by the PNG National Agricultural Research Institute. The following reports on provincial level were analysed during this study: Allen et al. 2002a, Allen et al. 2002b, Allen et al. 2002c, Hide et al 2002 and Bourke et al. 2002. This survey provides detailed description of all the agricultural systems in each province and a shapefile with these agricultural systems and their descriptive attributes.

Subsistence crops, designated as staple crops, tend to divide between sweet potato systems, taro systems and, in places, cassava systems. In addition, some cash crops also influence the sensitivity of agricultural systems. For example, coffee has long been an important export earner, and dominates many highland systems. Rubber is also important in certain areas, as is sugar in the Ramu area.

The ANU agricultural survey describes staple crops in each system as dominant, subdominant or present. According to the methodology, the following definitions apply:

- Dominant staple crop: more than one third of staple garden area, and therefore no more than 3 dominant staples may be identified for a system.
  Exception: sago (palms are not cultivated in gardens)
- Subdominant staple crops: cover more than 10 per cent of the staple garden area; up to six crops may be listed.
  Exception: sago
- All staple crops: up to 10 staple crops including crops classed as dominant and subdominant, as well as other staple crops which occur commonly. (= other crops)

Presence of other products such as fruit, vegetables, nuts and narcotic is indicated as well in the survey data. There is also succinct information on the presence of cash crops such as rubber, tobacco, oil palms, sugar etc. Qualitative descriptors are:

0- None
1- Minor or insignificant
2- Significant
3- Very significant

Replacement costs for key crops

Unit replacement costs of different cash crops in the PICs were derived by PCRAFI (2013) from crop production budgets issued by local governments. **Table 51** shows the replacement costs per hectare computed for the key crops under production in the PICs. “The average replacement cost estimates are representative of production systems with average production and management practices. These average costs are not representative of subsistence farmers that use fewer inputs and therefore have less production costs, or commercial farmers that use inputs intensively and obtain higher prices when selling their products in the export markets" (PCRAFI 2013).

Replacement costs are note part of the sensitivity index but will be used for asset quantification in vulnerability computations.

Table 51. Replacement costs for key crops under different production systems in the PICs (PCRAFI 2013 p 28)

Crop type	Average replacement cost (US$ per hecatre)	Replacement cost subsistence (US$ per hecatre)	Replacement cost commercial farmer (US$ per hecatre)
Banana	4,065	1,016	6,098
Breadfruit	386	97	579
Cassava	2,468	617	3,702
Cocoa	1,766	442	2,649
Coconut (Copra)	294	74	441
Coconut (Fresh Nut)	504	126	756
Coconut (Mature Nut)	504	126	756
Coffee	1,512	378	2,268
Ginger	7,697	1,924	11,546
Gourd/Squash	1,213	303	1,820
Kava/Yaqona	3,532	883	5,298
Lemon	966	242	1,449
Mango	375	94	563
Nut Tree	1,750	438	2,625
Oil Palm	5,300	1,325	7,950
Papaya	3,039	760	4,559
Pineapple	2,009	502	3,014
Pumpkin	2,999	750	4,499
Rubber Tree	504	126	756
Sago Palm	1,488	372	2,232
Sugarcane	1,234	309	1,851
Sweet Corn/Maize	1,822	456	2,733
Sweet Potato	1,474	369	2,211
Giant Taro/Ta'amu	1,365	341	2,048
Taro	2,993	748	4,490
Tobacco	9,080	2,270	13,620
Vanilla	1,243	311	1,865
Yam	9,843	2,461	14,765

Annex 3 Crop tolerance scores

Scores in red are not directly supported by literature and have a higher degree of uncertainty.

TOLERANCES: 0 = Tolerant; 1 = Moderately tolerant; 2 = Intolerant

		Representa tivity	Number of systems	**INLAND FLOOD DEPTH (m.)** ***(without flow)***	**SEA LEVEL RISE (m)** ***(assumes salinisation of groundwater)***	**LOW ANNUAL RAINFALL (mm.)** ***(assumes relatively even distribution)***	**HIGH ANNUAL RAINFALL (mm.)** ***(assumes relatively even distribution)***	**MAX. CONSECUTI VE DROUGHT (days)**	**CYCLONIC WINDS (km/hr)**
			134	*0.5–5*	*0.5–5*	*0–500*	*3500 – 5000*	*14–30*	*60–120*
STAP	02 Banana (Musa cvs)	94.03%	126	1	2	2	1	2	2
STAP	04 Cassava (Manihot esculenta)	71.64%	96	2	2	0	1	0	2
STAP	05 Chinese taro (Xanthosoma sagittifolium) also Cocoyam/Tannia	82.09%	110	2	2	2	1	2	2
STAP	06 Coconut (Cocos nucifera)	44.78%	60	2	0	2	1	1	2
STAP	08 Potato (Solanum tuberosum)								
STAP	09 Sago (Metroxylon sagu)	51.49%	69	1	2	2	1	1	2
STAP	11 Sweet potato (Ipomoea batatas)	92.54%	124	2	2	2	1	2	0
STAP	13 Taro (Colocasia esculenta)/ dasheen	92.54%	124	1	2	2	1	2	2
STAP	14 Yam (Dioscorea alata)	71.64%	96	2	2	2	0	0	2
STAP	15 Yam (Dioscorea esculenta)	63.43%	85	2	2	2	0	0	2
CASH	Cocoa			2	2	2	1	1	2
CASH	Coffee Arabica			2	2	2	2	1	2
CASH	Coffee Robusta			2	2	2	2	1	2
CASH	Oil Palm			0	2	2	0	1	2
CASH	Rubber			2	2				

		Representativity	Number of systems	**INLAND FLOOD DEPTH (m.) *(without flow)***	**SEA LEVEL RISE (m) *(assumes salinisation of groundwater)***	**LOW ANNUAL RAINFALL (mm.) *(assumes relatively even distribution)***	**HIGH ANNUAL RAINFALL (mm.) *(assumes relatively even distribution)***	**MAX. CONSECUTIVE DROUGHT (days)**	**CYCLONIC WINDS (km/hr)**
CASH	Sugar			2	2	2	1	2	1
CASH	Chillies			2	2	2	1	1	1
CASH	Orchids – Vanilla			2	2	2	1	0	2
CASH	Cattle			2	2	2	1	2	2
CASH	Coconut			2	0	2	1	1	2
CASH	Betel			2	2	2	0	2	2
FRUIT	07 Mango (Mangifera indica)	70.15%	94	2	2	1	0	0	0
FRUIT	09 Orange (Citrus sinensis)	27.61%	37	2	2	1	1	0	0
FRUIT	12 Pawpaw (Carica papaya)	75.37%	101	2	2	2	1	2	2
FRUIT	13 Pineapple (Ananas comosus)	69.40%	93	2	2	2	2	0	0
FRUIT	15 Sugar (Saccharum officinarum)	97.76%	131	2	2	2	1	2	1
NARC	2 Betel nut, lowland (Areca catechu)	82.84%	111	2	2	2	0	2	2
NARC	4 Betel pepper, lowland (Piper betle)	81.34%	109	2	2	2	0	2	2
NARC	5 Tobacco (Nicotiana tabacum)	97.76%	131	2	0	2	1	2	2
NUT	01 Breadfruit (Artocarpus altilis)	83.58%	112	2	2	2	1	0	0
VEG	01 Aibika (Abelmoschus manihot)	86.57%	116	2	2	2	1	2	1
VEG	09 Corn (Zea mays)	93.28%	125	2	2	2	2	0	2
VEG	21 Pumpkin tips (Cucurbita moschata)	80.60%	108	2	2	2	1	1	0