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

COLOPHON

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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 Popondetta and the Kokoda Valley. 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 Northern 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 (Kokoda Valley), 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 like Popondetta, 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 Northern 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.

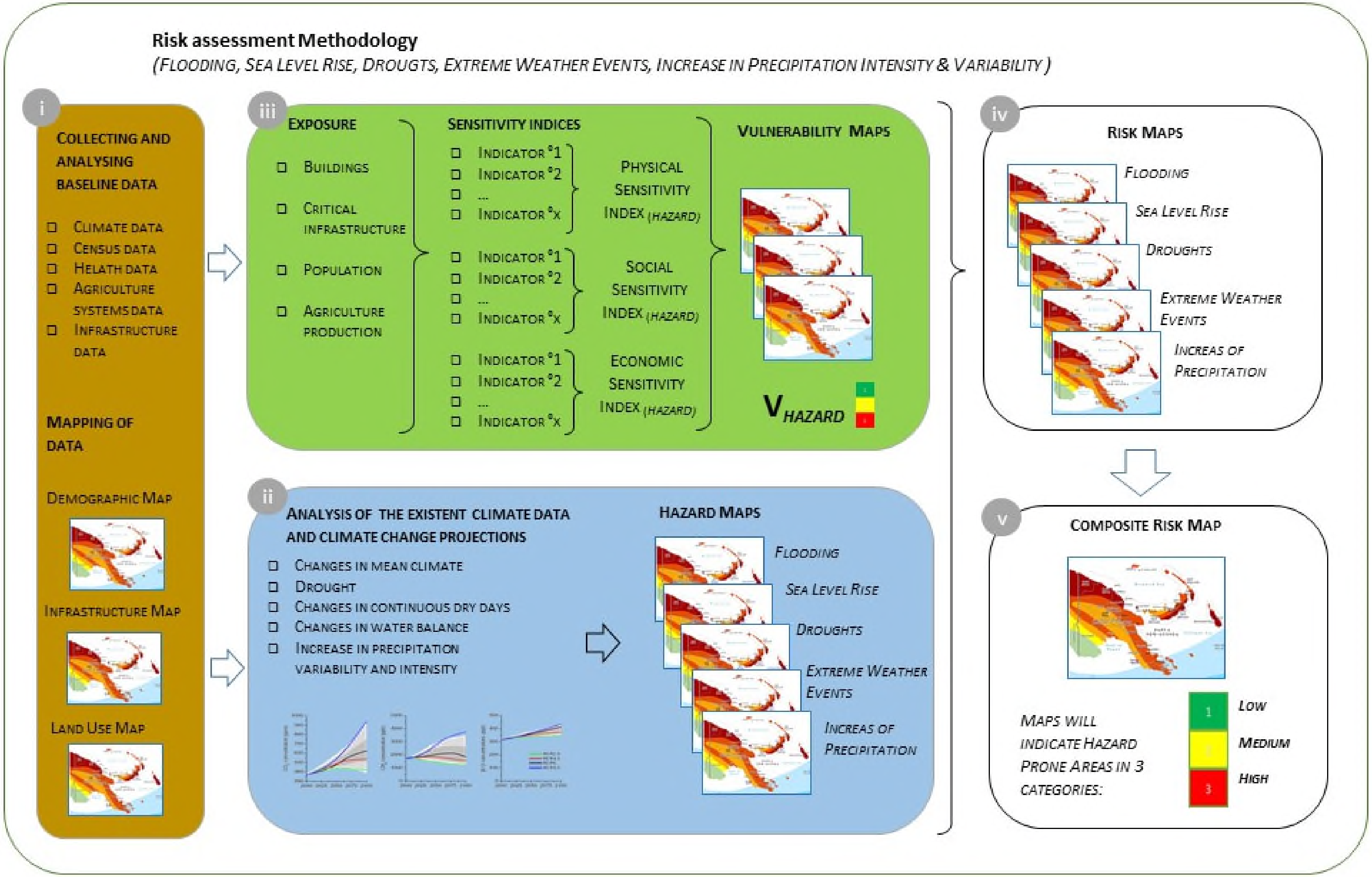

Figure 1. Risk mapping methodology

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			

N°	Indicator	Inland flooding	Coastal flooding	Cyclonic wind
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

Attribute name	Description	Value	Legend	Sensitivity Inland Flooding	Sensitivity Coastal Flooding	Sensitivity Cyclonic Wind
		10	masonry	0	0	0
		30	plywood sheet	2	2	2
		40	timber board	1	1	1
		50	fibre-cement sheet	2	2	2
		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)**	**CYCLO NIC 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.

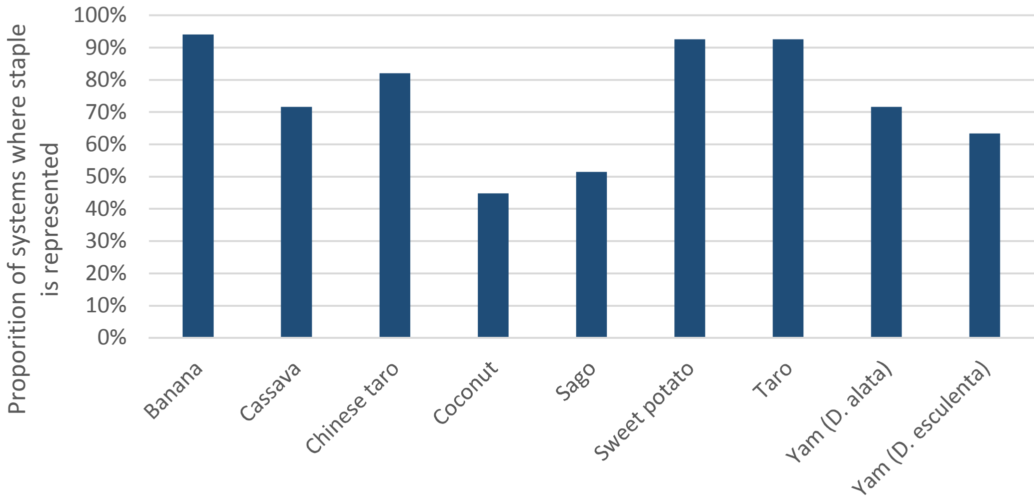

Figure 2. Representativeness of each staple crop across all systems

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

Indicator	Comment
	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 (mm.)	Average annual rainfall requirement is a very rough measure. Its distribution through the 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).

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

Equation 1 Expression of physical/economic vulnerability

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

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

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 (Table 14).

Table 14. Statistics for building physical vulnerability for inland flood hazard for Northern Province

	Number of buildings	Number of exposed buildings (H40)	Average exp. building value	Maximum exp. building value	Average exp. building vulnerability	Maximum exp. building vulnerability
Northern (Oro)	10,434	1,328	82,143	7,548,139	65,155	6,604,621

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 $/km (Table 15), whereas the replacement costs of punctual infrastructures are absolute values ($)(Table 16, Table 17 and Table 18).

Table 15. Replacement cost for roads

Surface	Replacement cost ($/km)
Dirt	100.000
Gravel	250.000
Sealed	500.000

Table 16. Replacement cost for bridges

Type	Replacement cost ($)
Concrete/Steel	10.000
Steel	10.000

Wooden	1.000
Causeway/Ford/Culvert (insensitive)	-

Table 17. Replacement cost for airstrips

Type	Replacement cost ($)
Airstrip	10.000

Table 18. 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 19. 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 19).

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 20).

Table 20. 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).

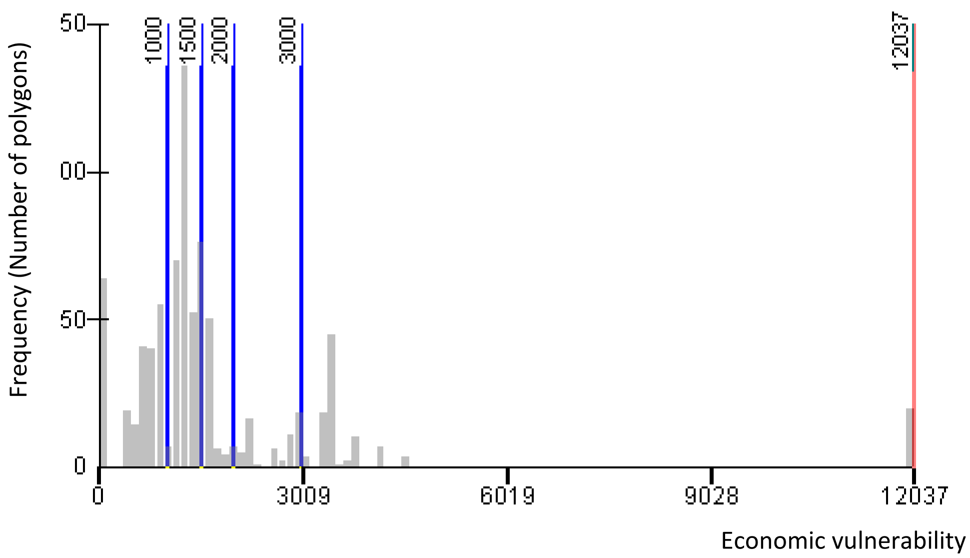

Figure 3. Frequency distribution of agricultural systems (MASP) and plantations vulnerability to extreme weather

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).

1	*Very Low*
2	*Low*
3	*Moderate*
4	*High*
5	*Extreme*

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.

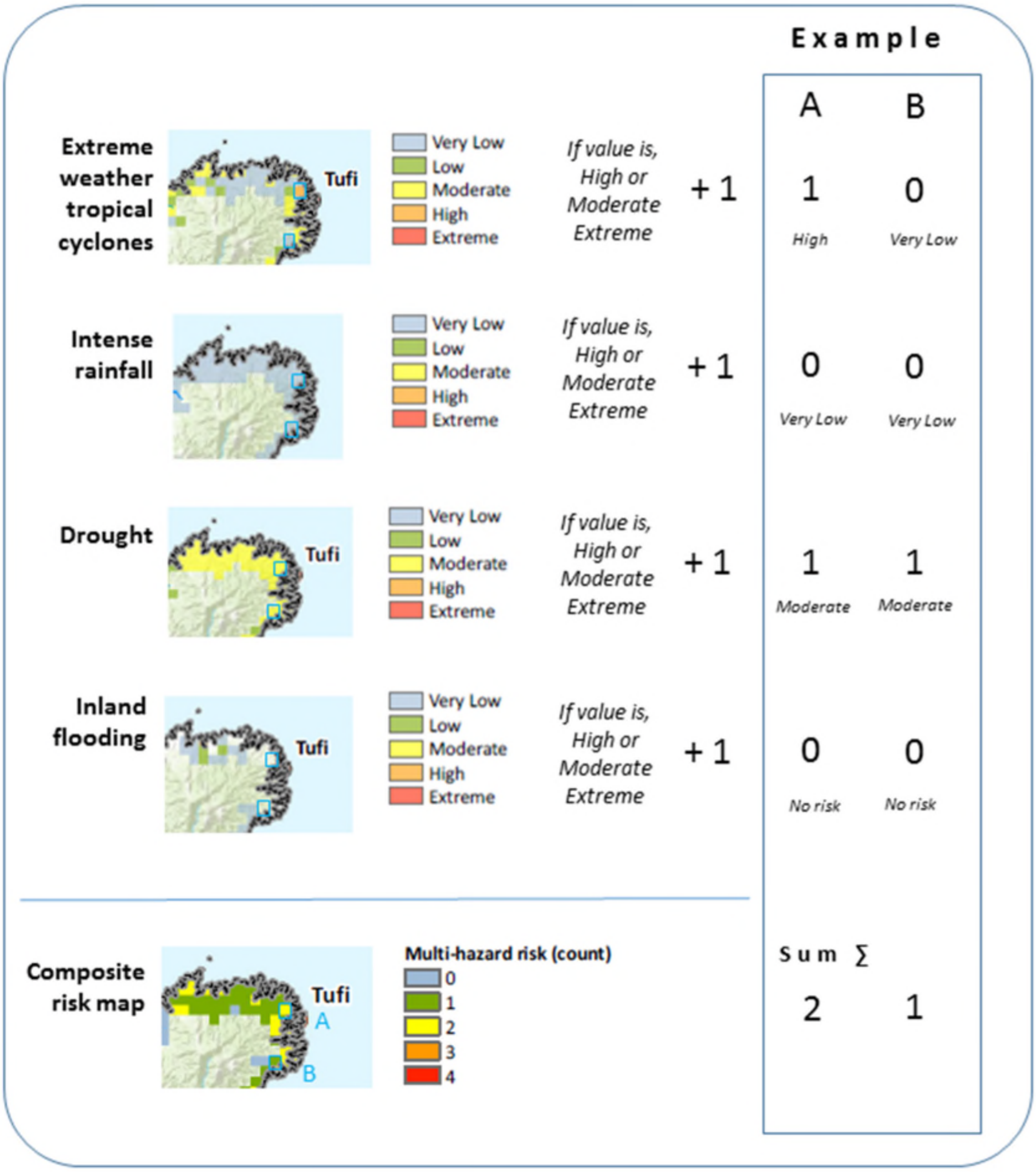

Figure 5. Example calculation of composite risk

1.3. Baseline information of Northern Province

1.3.1. Administrative

The Northern (Oro) Province is located in southeast Papua New Guinea along the northern coast, with the city of Popondetta as its provincial headquarters.

Northern Province – also known as Oro - belongs to the Southern Region and is divided into Ijivitaru District and Sohe District, shown in Figure 6. Each district is divided into Local-Level Government Areas (LLGs) which are further divided into wards. There are a total of 9 LLGs in the province as is shown in Table 21.

Table 21. Number of wards per LLG

District	LLG	Number of wards	Number of wards
Ijivitari District	Afore rural	18	84
	Safia Rural	13	
	Cape Nelson	20	
	Oro Bay Rural	26	
	Popondetta Urban	7	
Sohe District	Higaturu Rural	28	74
	Kira Rural	5	
	Kokoda Rural LLG	24	
	Tamata Rural	17	

Figure 6. Administrative map Northern province

1.3.2. *Topography*

Northern Province covers the northern side of Owen Stanley Ranges and a stretch of coastline from Cape Ward Hunt in the north to Collingwood Bay in the south. It includes the village of Kokoda near the eastern border with Central Province, as well as Cape Nelson and the coastal fjords near Tufi on the coast.

Figure 8 shows the main rivers flowing through Northern Province. The border between Northern Province and Central Province roughly follows the watershed boundary; this implies that most of the river systems originate in the mountains and flow (North-) Eastwards to reach the sea. The most important river systems are the Mambare, Kumusi, and Musa catchments. Seasonal rains can lead to local floods in areas like Mamba, Gira, Eia, Kokoda, and Oro Bay .

Figure 9 show the slope map for Northern Province. The slopes map is obtained by classifying the digital elevation model into three classes as presented in Table 22.

Table 22. Slope classes an occurrence in Norther Province

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

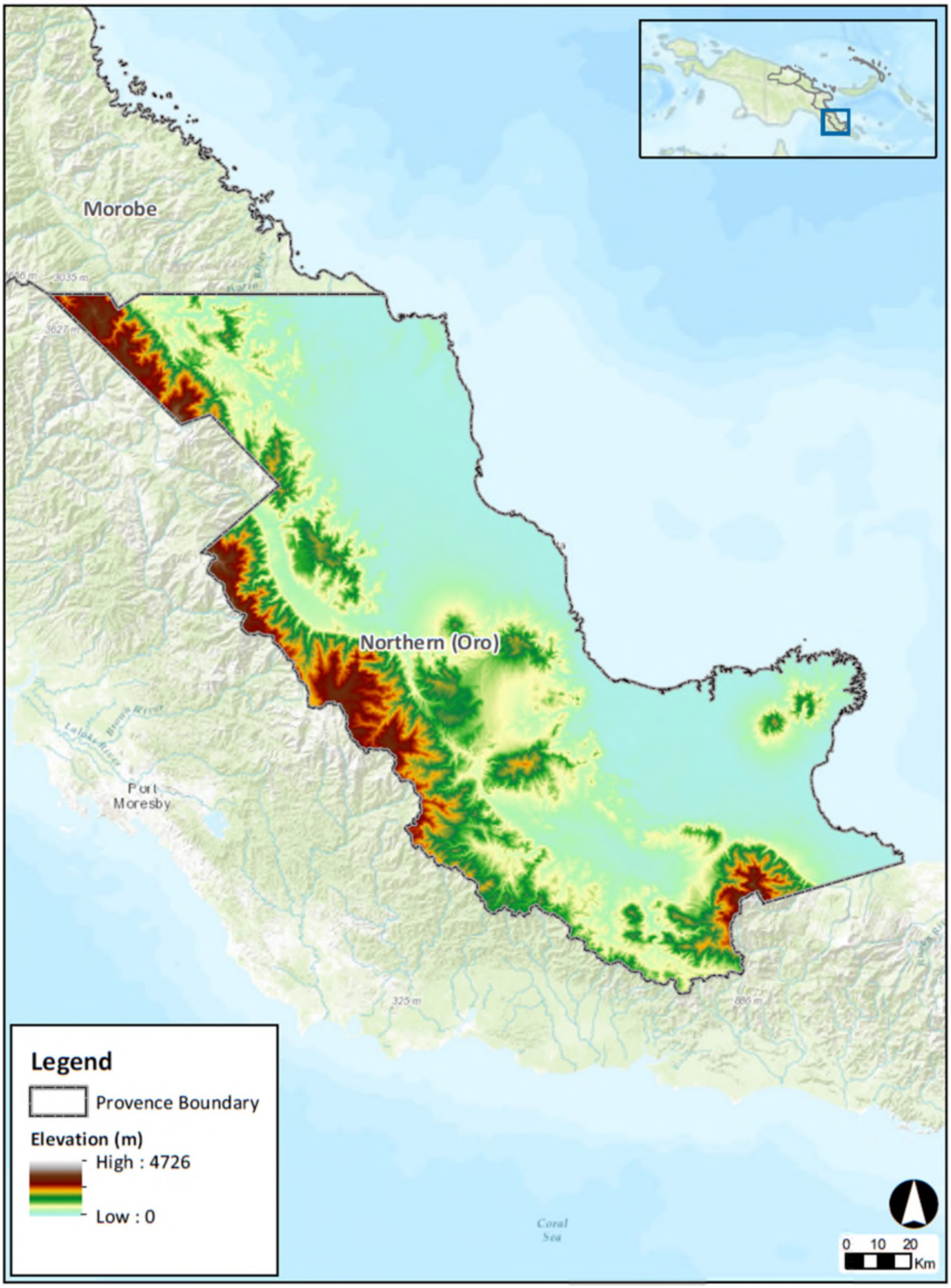

Figure 7. Elevation map of Northern Province

Figure 8. Main rivers found in Northern Province

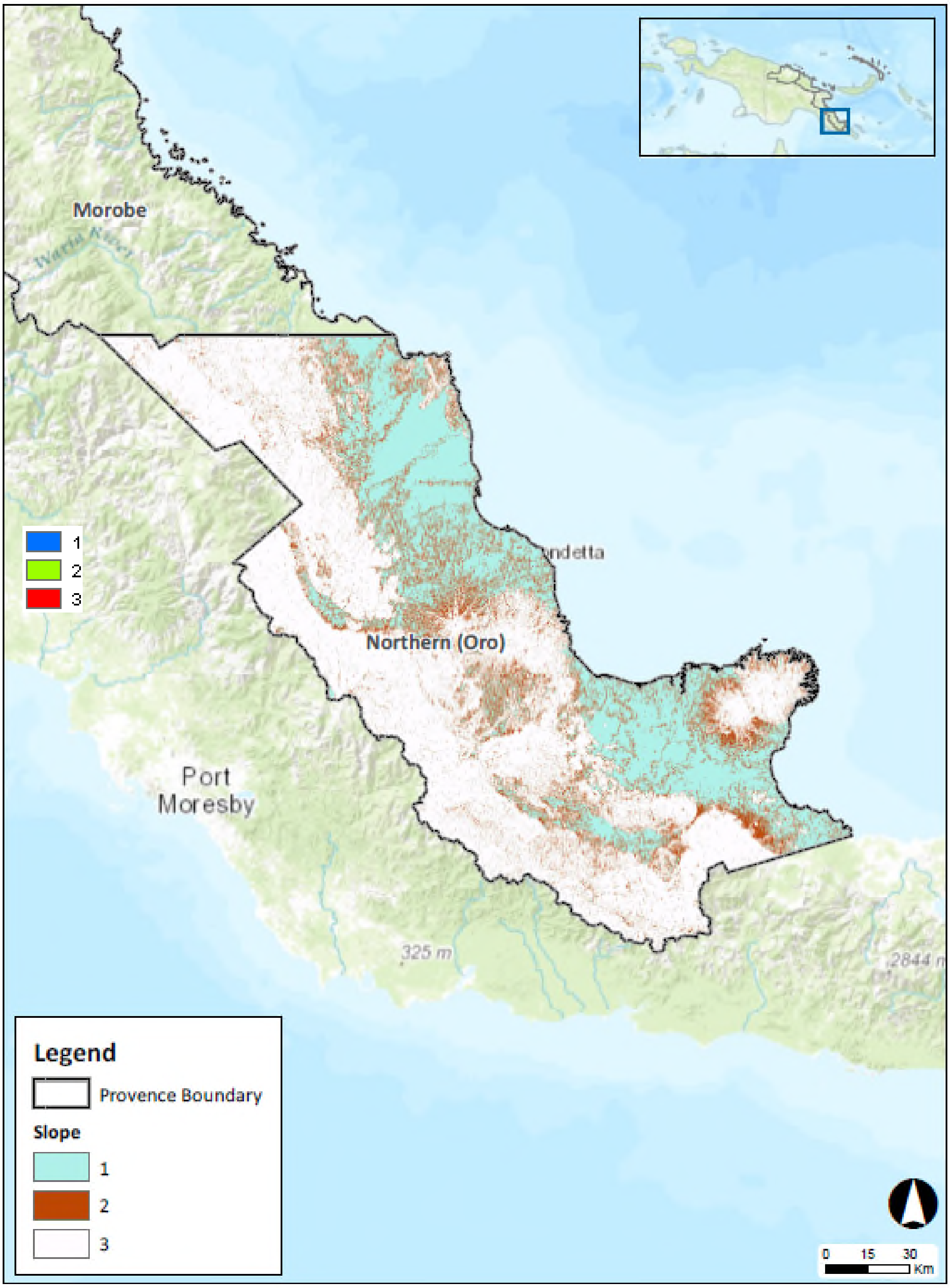

Figure 9. Slopes classification map for Northern province (from DTM, from SRTM-3, 90m).

1.3.3. *Land use / land cover*

Figure 10 show the soil cover map for Northern Province. The largest part of the province is classified as 'other' which is mostly forest or other uncultivated land. These parts of the province are very sparsely populated. About 20% of the province is marked as agriculture. There is a variety of mixed cropping systems, with some mono cropped plantations around Popondetta.

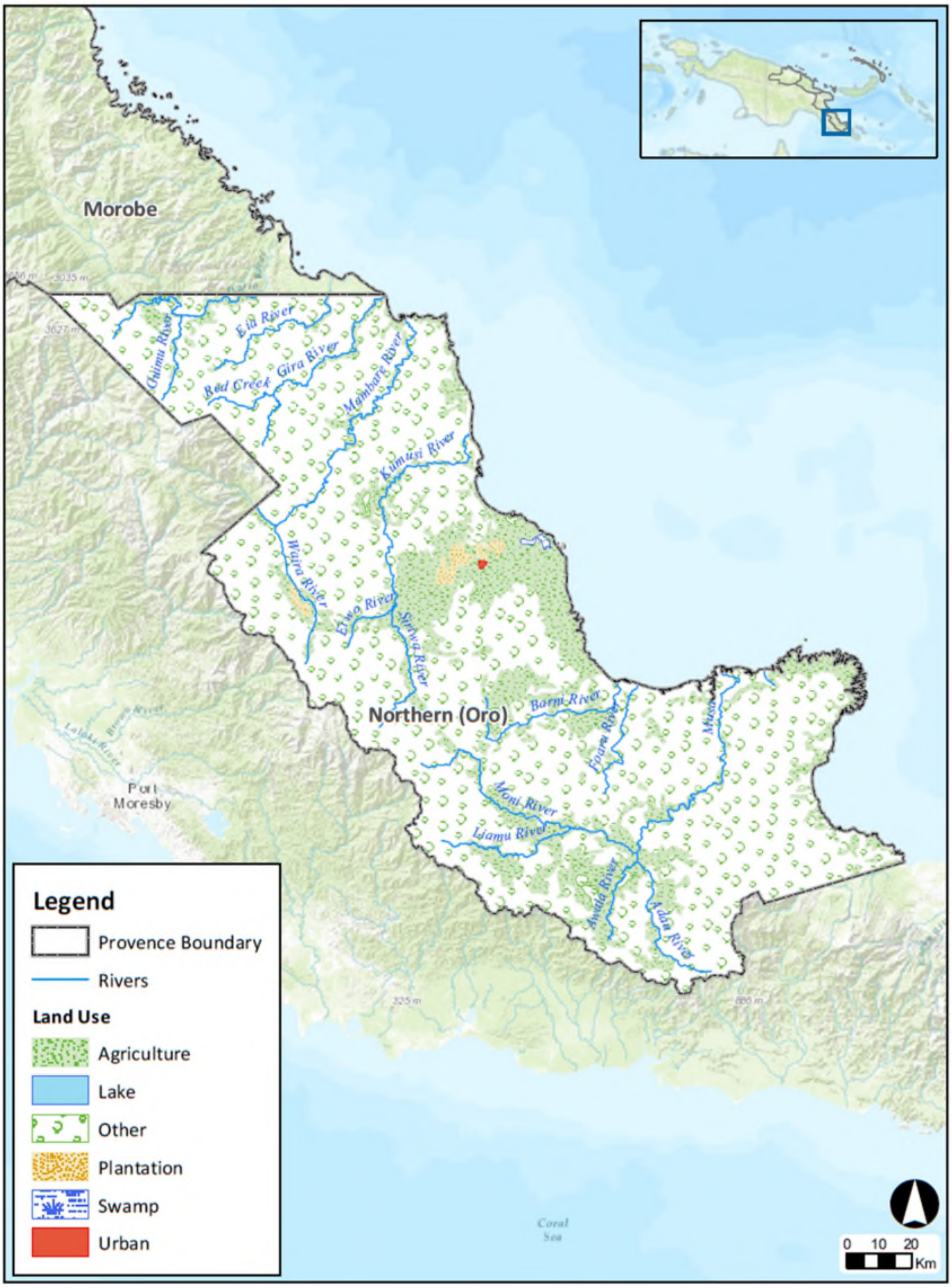

Figure 10. Land Use map Northern Province

1.3.4. *Population and health*

According to the latest census, the population of Oro Province was 186,309[4]. During the period from 2000 to 2011 the Province's average annual growth rate was 3.1%, which is the same as the national average for PNG.

The Province consists of two districts, Ijivitari, with a population of 99,762 and Sohe, with a population of 86,547. The main urban area is the provincial capital, Popondetta, with a population of 29,454, 15.8% of the province's population. The remaining population is predominately rural. The population density is 8.1 inhabitants per km^2, somewhat lower than the national average of 11. The average household size in the province is 5.5 persons. The age dependency ratio[5] is 75.8, which is significantly higher than the national average of 61.7.

Table 23. Population numbers per age group and per district.

District	Age Group				
	Age not stated	0 - 4 yr	< 15 Yrs	15-64 yrs	> 65 yrs
Ijivitari District	211	14,457	38,302	57,562	2,994
Sohe District	161	13,745	36,537	47,135	1,887

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

Villagers typically live on land they have inherited from their ancestors and which they use for both residential, agricultural, and other purposes. It is culturally diverse, with 24 recorded languages across the two districts[6].

The adult literacy rate for the province is 78.4%, which is relatively high and significantly higher than the national average of 67.6%. The poverty headcount rate for the Province is 0.39%, which is in the moderate range compared to the other provinces in this study.

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

[5] % of working-age population

[6] Languages of Papua New Guinea, An Ethnologue Country Report, 2012.

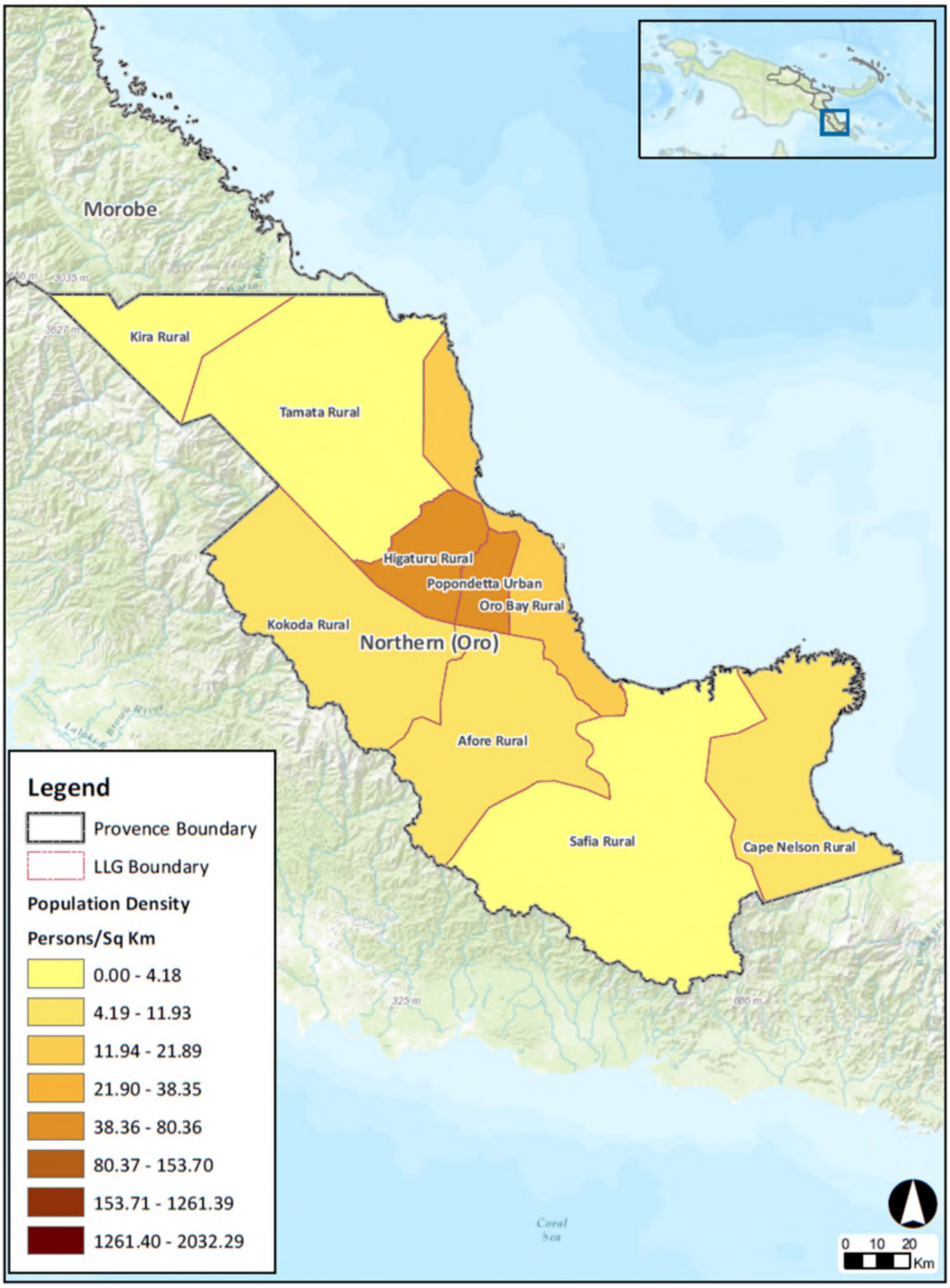

Figure 11. Population density map of Northern Province

Selected health indicators taken from the health performance report 2010-2014 for the province and its respective districts are shown in the Table 24, together with the national average.

Table 24. Selected Health Indicators for Northern Province (2014)

	Low Weight for Age < 5 years old (%)[7]	Low Birth Weight (%)[8]	Incidence of Malaria (1,000 population)[9]	Incidence of Diarrhoea (<5 years/1,000 pop.)[10]
Ijivitari District	25.3	15.8	191	283
Sohe District	22.9	4.6	43	255
Northern Province	24.3	14.6	122	270
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 60 aid posts, 31 located in Ijivitari District and 29 in Sohe District. And there is a total of 18 health centres in the province, of which 11 are located in Ijivitari District and 7 in Sohe District. The number of children born in health centres having a low brith weight is significantly higher in Norther Province compared to the national average. This is completely on the account of Ijivitari District which scores much worse than Sohe. Also the incidence of malaria is much higher in Ijivitari District.

Table 25. Number of Healthcare facilities per LLG

District	Number of aid posts	Number of health centres
Ijivitari District	31	11
Sohe District	29	7
Total	**60**	**18**

[7] 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

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

[9] 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

[10] 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.

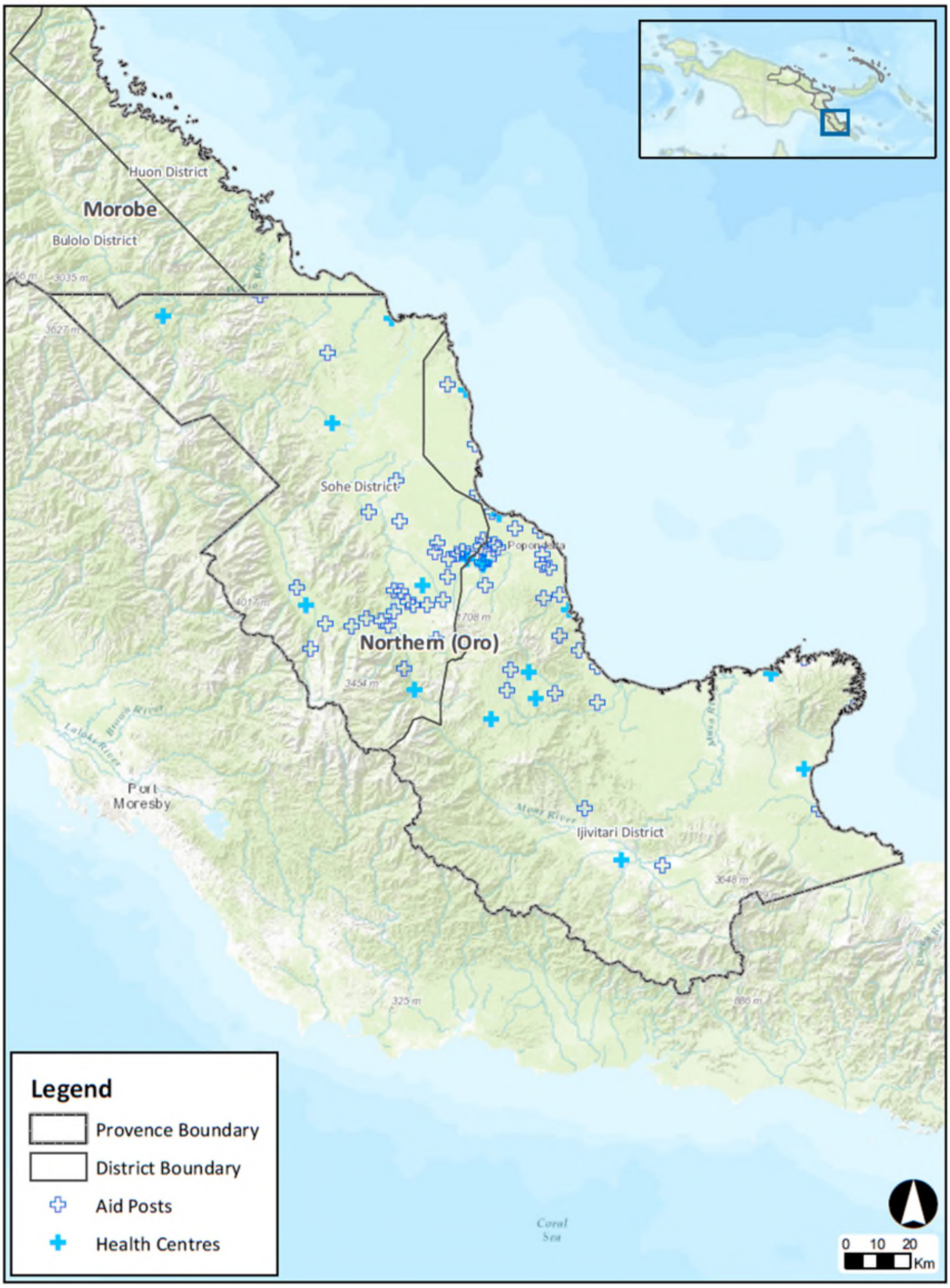

Figure 12. Location of health centers and aid posts in Norther Province

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 Popondetta with Kokoda to the west, and Orobay to the east / south east. A large part of the province is not easy accessible by road.

Table 26 Kilometers of roads in Madang

	Highway	National Road	Provincial road
Km of roads in Northern	166.08	317.07	846.93

Table 27 Number of bridges in Madang

District	LLG	Number of bridges	Number of bridges
Ijivitari District	Afore rural	0	21
	Safia Rural	0	
	Cape Nelson	0	
	Oro Bay Rural	12	
	Popondetta Urban	9	
Sohe District	Higaturu Rural	52	74
	Kira Rural	0	
	Kokoda Rural LLG	22	
	Tamata Rural	0	

Table 28 Total of public establishment

District	LLG	Aid posts	Health centres	Police stations	Airports	Schools	Religion	Government	Public facility
Ijivitari District	Afore rural	3	3	1	0	9	14	25	5
	Safia Rural	2	1	0	0	7	0	0	0
	Cape Nelson	3	3	1	1	17	19	27	8
	Oro Bay Rural	15	3	2	0	24	24	47	6
	Popondetta Urban	6	2	3	1	12	5	13	5
Sohe District	Higaturu Rural	14	2	4	0	23	56	59	16
	Kira Rural	1	1	0	0	2	2	8	1
	Kokoda Rural LLG	10	2	1	1	16	30	35	8
	Tamata Rural	4	2	1	0	16	22	25	7

Figure 13. Road infrastructure in Northern Province

1.3.6. Agriculture and livelihood

Northern Province has a considerable coastal plain before the land rises towards the southwest to the Owen Stanley Range. The economy is largely subsistence based, though palm oil plantations in Sohe district provides a cash income for some in the vicinity of Popondetta. Less formally, betelnut is traded across the Owen Stanley Range to Central Province.

Kaukau (sweet potatoes), coconut, and sago (starch from palm stems) are important subsistence crops for the province, but there are few opportunities for income from these activities. Sago is specific to lowland river margins, where the palm grows naturally, and coconut is a coastal plant, mainly grown in the Popondetta area and around Collingwood Bay. Palm oil is a high income earner on the coast, near Popondetta, though it is also present along the river valleys to the West, towards Kokoda. The inland areas of Ijivitari, in the south, have a high potential for agriculture but remain very isolated from services and, more importantly, from markets. The agricultural systems on the coastal plain and in the river valleys of Sohe make up the agricultural activity of 48% of the entire province and rely mainly on kaukau.

There are 13 identifiably different farming systems[11] (based on crops, physical ecology, land preparation, fallow systems, etc.), but all except one has sweet potato (kaukau) as its most important staple crop, representing 94% of the population. In some cases, cash crops have been overlaid onto these systems, principally coffee, but also cocoa and oil palm. Coconut and betel nut also provide income for a small percentage of the population (Table 29).

Table 29. Main agricultural activities of citizen households in Oro Province[12]

Main agricultural activities of citizen households [13]	% engaged	%* engaged for cash
Coconut	76.6	11.8
Food crops (sweet potato, banana, taro, cassava, et al.)	73.3	7
Betel nut	75.7	16.4
Cocoa	-	-
Coffee	29.5	28.3
Livestock	28	4.4
Fishing	-	-

**of total citizen households*

High incomes can be earned in the Kokoda Valley from oil palm, cocoa and selling fresh food. More moderate incomes from oil palm can be earned near the coast, but the number of households involved is small compared to other crops. Some wage employment is also available in Popondetta. Elsewhere in the province incomes are very low.

There is no paid off-farm work in the rural areas. Off-farm sources of income come from various forms of exploitation of the forests and fishing, but that is also small in scale.

Sweet Potato (Kaukau) is grown by 94% of the rural population. Its short growing season makes it very suitable to grow repeatedly on small areas. Because its growing season is so short, it is the crop of first recourse in the case of any local disaster (flooding, landslide, etc). It is susceptible to flood and particularly salinity (and thus to sea level rise and coastal storm surge). Prolonged drought affects it

[11] We have adapted the system divisions established by the Australian National University, which are the divisions and definitions used by the PNG Agricultural Research Institute. They are determined by ecological, topographical and cultural factors. The systems, as defined, are smaller in area than a district, and sometimes fragmented. For more details, please refer to Allen, B.J., Nen, T., Hide, R.L., Bourke, R.M., Fritsch, D., Grau, R., Hobsbawn, P., Lyon, S. and Sem, G. (2002). Northern Province: Text Summaries, Maps, Code Lists and Village Identification. Agricultural Systems of Papua New Guinea Working Paper No. 16. Land Management Group, Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra. Revised edition.

[12] NRI (2010), NRI (National Research Institute); Papua New Guinea District and Provincial Profiles, 2010

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

negatively but, lying close to the soil, it is resistant to high winds and it can withstand high temperatures.

Taro: Almost all households (87%) grow small plots of taro. It is a broad-leafed root crop that takes about a year to reach ripeness. Its advantage is that it can be harvested over many months; once grown to maturity, it remains as an easily accessible source of food. It is sensitive to flooding, sea level rise, high winds that strip its leaves, and low night temperatures. It will be an increasingly risky crop to grow in coastal regions, but its range will extend to altitudes above 1300 m, as average temperatures rise.

Cassava: About half of all households grow cassava – all for home consumption. Like taro, cassava is harvested continuously throughout a year or, at times, more. Because of this, production figures recorded are likely to underestimate significantly the reality. It is often considered to be a famine crop that is very resistant to drought and can survive on the poorest of soils. Conversely, it is sensitive to waterlogging and salinity, and its weak superstructure makes it sensitive to high winds.

Bananas are grown by only about 20% of Oro households. They are often intercropped as a kind of catch crop. Banana is nutritionally important as a continuously available snack food, especially for infants. It likes a lot of rain, but is comfortable only at temperatures between 20^o and 30^oC. It is strictly a lowland crop, with no tolerance of frost, but it is being bred for increased tolerance to salinity, which will give it greater importance in coastal areas.

Yam is not a popular crop in these systems: only about 20% of households grow it – almost exclusively (96%) for home consumption. Since yams grow on trained vines, they can be easily destroyed by high wind, but wild yams, which support themselves on trees, are a good emergency crop.

Pumpkin, pineapple, and sugar cane are very minor crops in the system. Reported production figures are not reliable.

There are few cash crops. **Betelnut** is a source of cash revenue mainly in the lowland areas. **Coffee**, where grown, is of the highland Arabica type and, if mean temperatures rise considerably in the future, it may no longer withstand temperatures at the altitudes where it is currently grown. **Palm oil** is grown by certain households, where out-grower schemes have been established in the District of Sohe. It is highly tolerant to waterlogging, even over several weeks, which makes it a potentially useful in low-lying river margins and coastal areas, although its sensitivity to winds over 90 km/hr makes coastal plantations more risky. **Cocoa** is a new crop to the area, promoted from outside as a cash crop. It is sensitive to salinity and prolonged high wind, but can withstand drought. In high rainfall areas (over 2,5 m/yr) it is prone to fungal attacks. **Coconut** is grown along the coastal margins but is virtually only a subsistence crop in this region.

Animal Production is essentially limited to pigs, where households might have 5 or 6, of varying ages, but only about 20% of households are involved. Approximately one third of rural households keep chickens, also in small numbers.

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 Norther 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)[14]. 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.

[14] 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 flood maps show that the Eia (Tavi) River, located at the most northern region of the province and crossing the border to the Morobe Province, does not show broad floodplains within Oro Province. Some communities located along the floodplains (Tave, Muinde, Boke Ina, Baba, Waude, etc.), however, can be subjected to floods depending on the local terrain features[15].

The Gira River, locater further to the east, includes wider floodplains such that communities downstream Warawagi until Batari can experience regular high waters.

The Mambare River, with its origins in Central Province, is among the two longest rivers within the province. It shows a well-defined flood course depicting some floodplains along Kapatutu, Ginemai, Darara, and Biaga. The tributary coming from the left bank downstream of Biaga comprises a relevant flood zone, but there is no evidence of communities affected within the flooded areas. The flood maps show no flooded areas downstream of Bubewa.

Further south is the Opi River following a northeast course, beginning at the Kokoda mountains and reaching the sea at Oure. The Opi and its tributaries produce wide floodplains along the entire path. Riparian communities like Aurita, Utukiari, Petikiari, Koninida, Kikinonda, and Tambarasis lie in flood prone areas. Further downstream until Todinsi the river depicts remarkable floodplains, but the zone does not seem to be heavily populated. The zone between the Mambare and the Opi, west of Begabari, is a vast plain that presumably experiences regular flooding.

Further south is the Kumusi River, one of the two longest rivers within the province. Its catchment begins high in the mountains at the border with Central Province. The Kumusi flows further north following the foot of Mount Lamington until Avata, where it turns eastward to flow into the sea at Auroau. The maps shows that most of the riparian communities can be affected by flooding of varying

[15] The available DEM data was too coarse to allow for a reliable statement if these communities may be flooded, or not.

intensity. Ajeka, visited during the community risk assessment, is not shown within a flood prone area. This is consistent with the risk map drawn during the Community Risk Assessment (CRA) which was conducted by the team as part of the risk assessment study. The community lies sufficiently higher than the river banks[16] and cannot be flooded.

Siai, also visited during the CRA[17], is located along the river bank of the Kumusi just at the mouth of one of its tributaries called Bariji (also at the right bank, not the one flowing to the ocean, southeast. Close to Afore). At that location the river section stretches significantly (also confirmed during CRA) leading to marginal flooding. More significant flooding is observed in the vicinity of the Siai village, particularly along the floodplains of the Kumusi which are used for cultivating gardens and palm trees.

The coastal zone between Auroau and Pongani (Oro Bay and Popondetta LLGs) comprises a wide system of rivers and creeks initiating at Mount Lamington and Hydrographers Range. Although the catchment of these water courses is not extensive, there are locations along the rivers depicting flooding in three different clusters: above Gona, between Gona and Emo, and south of Emo. Some of the communities located within these clusters include: Butawote, Fufuda, Kipore, Senani, Huhuru, Kendata, Embogo, Kovira, Boboda, Warigena and Peresa.

The zone around Iakori village, also visited during the CRA[18], is located close to a confluence on the Bariji river (flowing into the sea east from Songade). The maps show limited flood centred around Sariri, Gora, and Ungoda.

East from there, a wide flat area stretches between the Bariji and the Foaru Rivers, leading to a complex system of floodplains and small rivers. It is mostly uninhabited (Agaiambo swamps), but some communities located nearby can be affected by the regular floods including Koipade, Goworode, and Moiave.

In the south and further to the east lies the complex system of the Musu and Moni Rivers, reaching the sea in the vicinity of Sebaga. This system comprises a considerable catchment covering smooth reaches which allow the development of substantial floodplains. These plains are flooded with some frequency, affecting communities like (from upstream to downstream): Bibira (1 and 2), Safia, Domara, Bare, Ibinamo, Guruguru, Alegari, Erika , Savion and Monganai.

[16] CRA Ajeka village, Ward 15, Kokoda llg, Sohe district, Oro Province, Papua New Guinea
[17] CRA Siai Village, Ward 2,Tamata Llg, Sohe District, Oro Province, Papua New Guinea
[18] CRA Iakori Village, Ward 1, Oro Bay Llg, Ijivitari District, Oro Province, Papua New Guinea

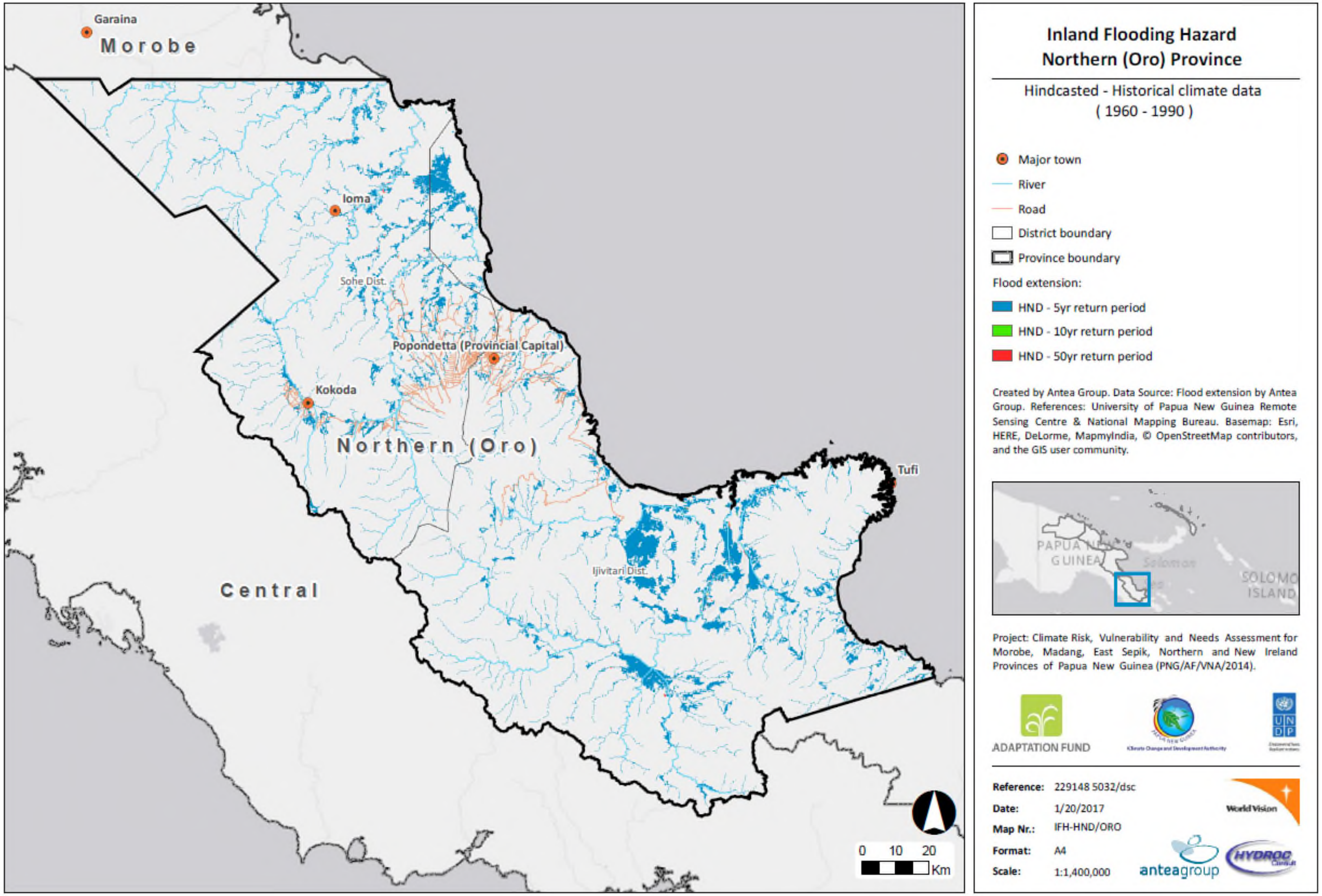

Figure 14. Inland flooding (current climate) ■ flooded

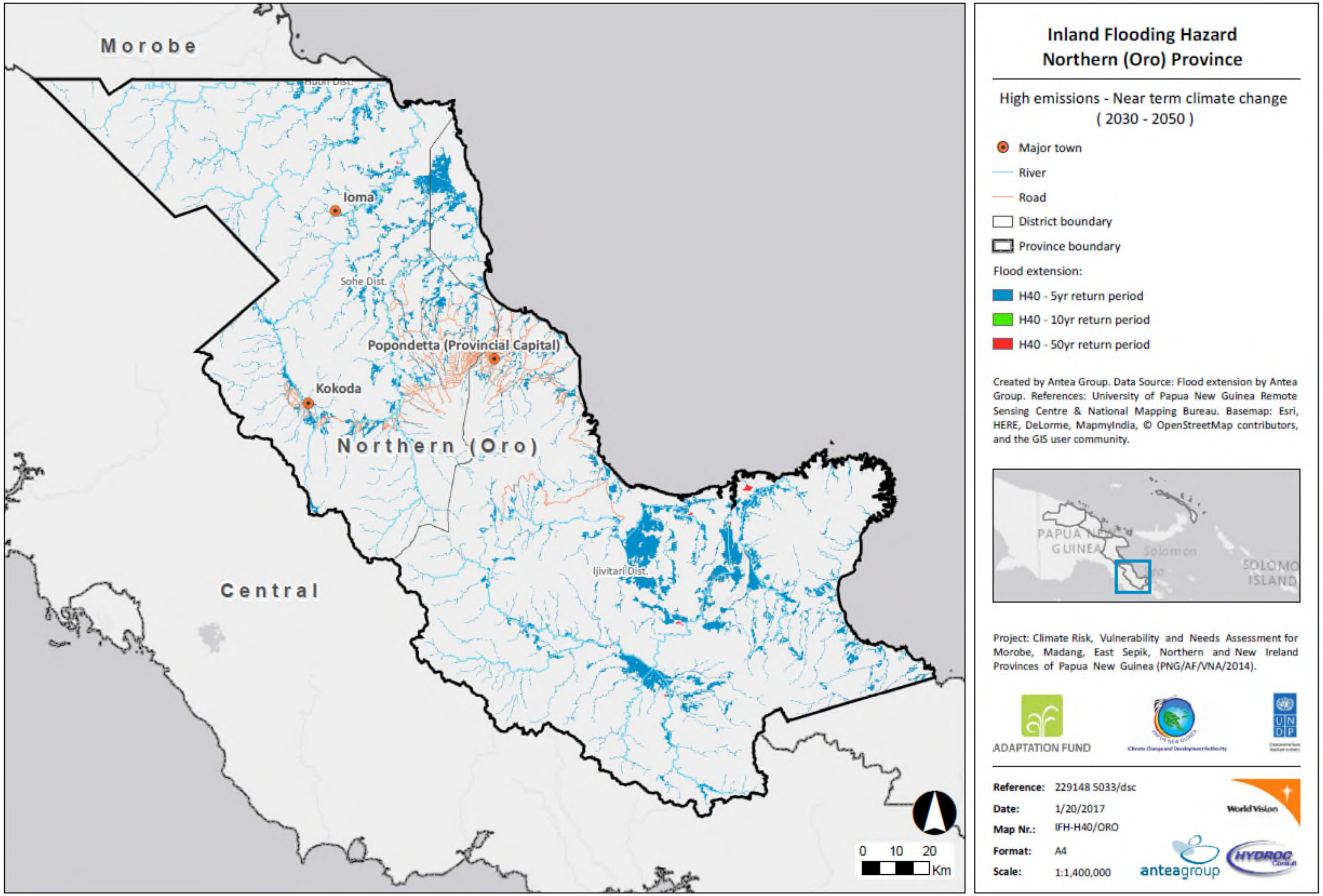

Figure 15 Inland flooding (projected climate) ■ flooded

The impact of climate change in flooding patterns cannot be perceived at the provincial (or even at district) scale. Although the increasing rainfall patterns lead to higher flood discharges and higher water levels, this effects are not clearly perceived due to the coarse terrain model that is available for this purpose. Detailed flooding effects could be investigated at a refined scale for priority zones (beyond the scope of this assignment) using more detailed survey data. The produced maps are a valuable instrument to assess critical/priority zones for subsequent analysis.

For the purposes of this study it can be concluded that the flood patterns are slightly exacerbated by climate change, but the exposed areas do not increase significantly.

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

Drought, defined as the number of continuous dry days within a one-year period, affects Oro Province in a homogeneous way. Based on the available information, the entire province is currently subject to a maximum drought period between 24 and 29 days. A small zone at the northeast end of Cape Nelson Rural is the exception; this area seems to be subjected to a slightly shorter period with no rain. So far there is no explicit evidence confirming that coastal communities within in this area (between Gobe and Kuna) effectively are less affected by drought.

Under the climate scenario there is a minor increase of the number of drought days per year. This can be observed along the Cape Nelson Rural area. However, the increase of drought is such that the maximum still remains below 29 days. There are other provinces in Papua New Guinea in which drought will have a greater impact in the future.

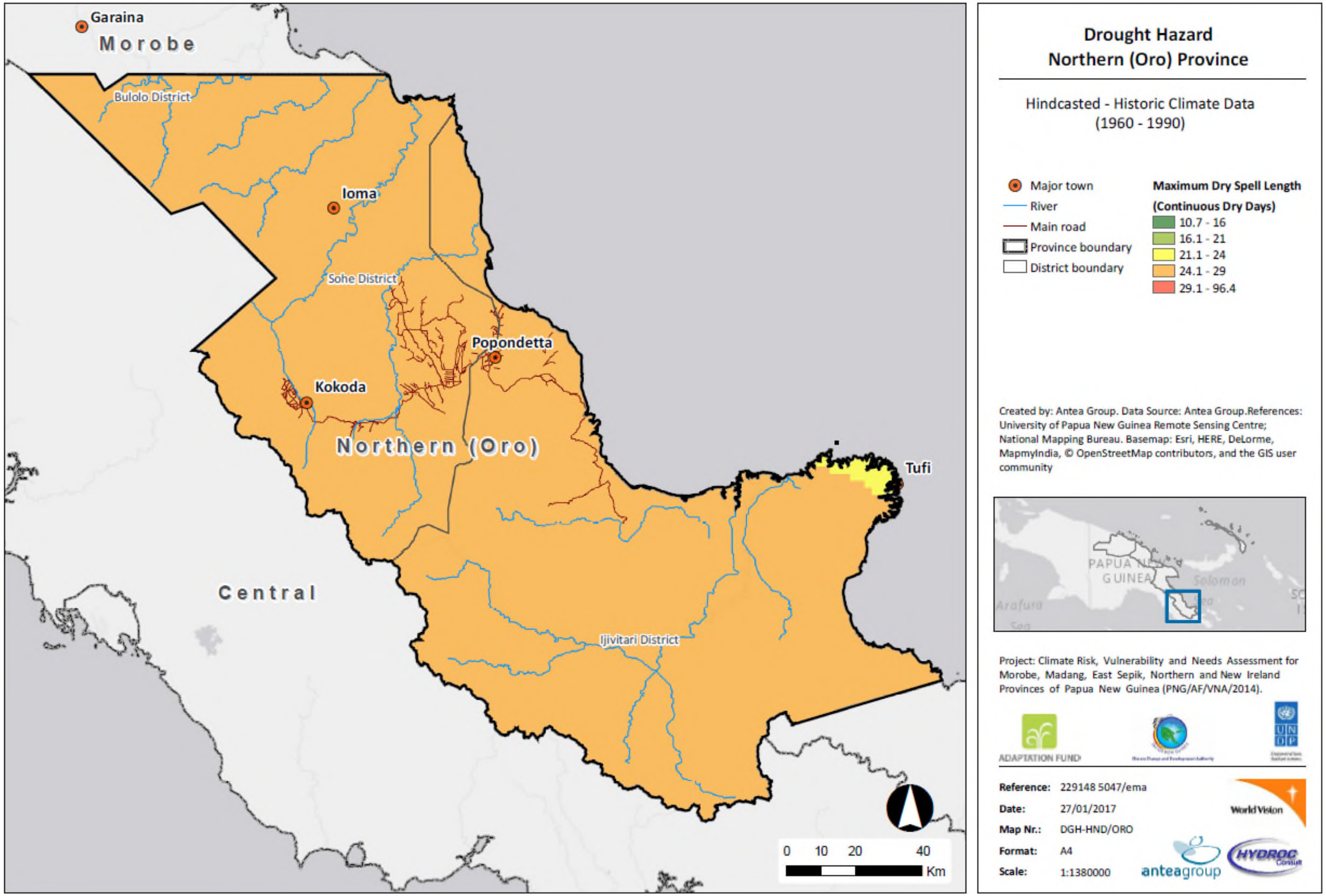

Figure 16. Drought (current climate) expressed as number of continuous dry days 10-16 16-21 21-24 24-29 >29

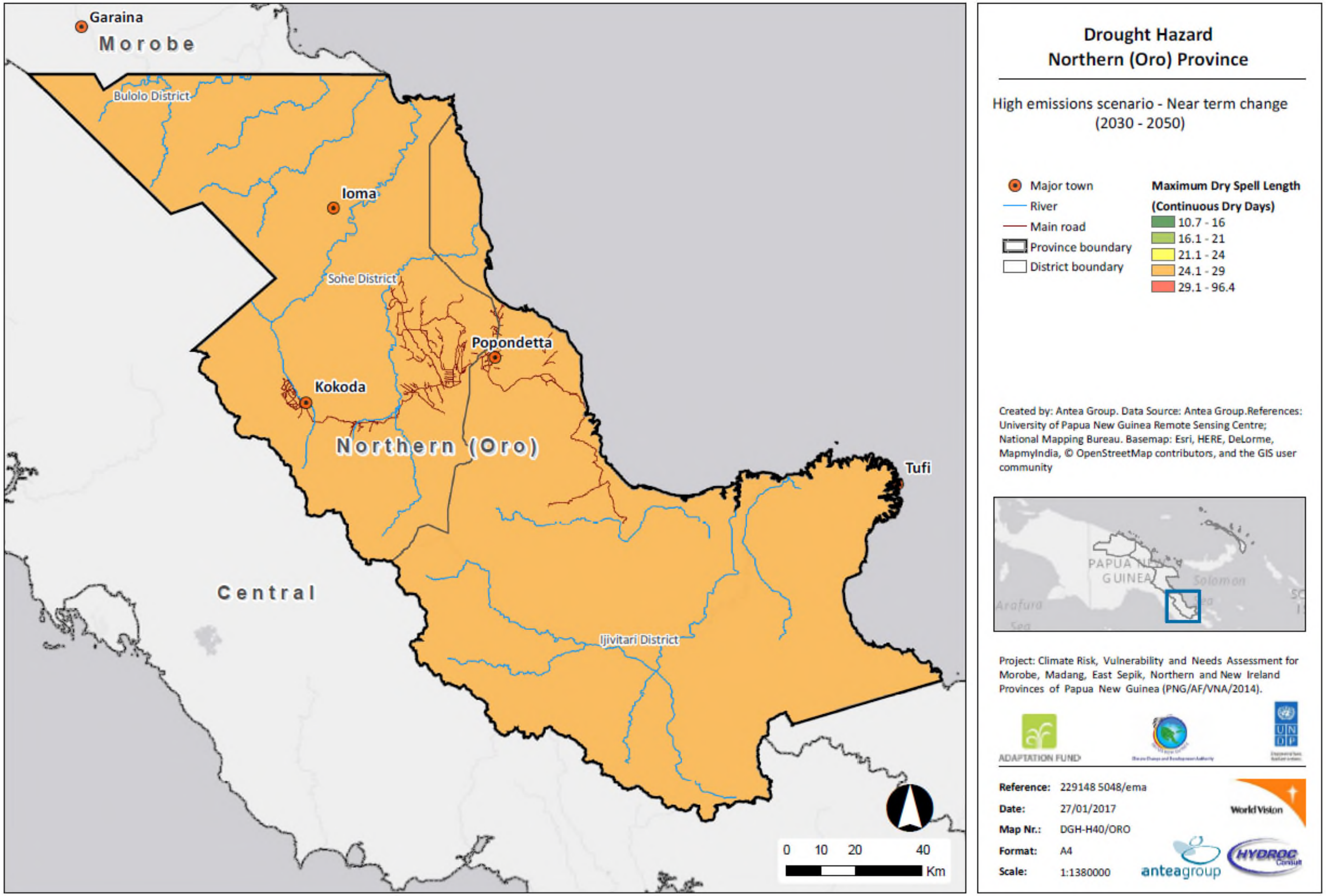

Figure 17. Drought (projected climate) expressed as number of continuous dry days 10-16 16-21 21-24 24-29 >29

2.1.5. *Extreme weather events (tropical cyclones)*

Oro Province is not prone to cyclones, although it has experienced some cyclones in the past. This is illustrated in maps on the next pages. Cyclone Guba in 2007 is a cyclone event in recent history.

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 diameter of cyclones with destructive wind speeds is assumed as 2 degrees).

Under existing climate conditions (Figure 18), Ijivitaru District and Sohe District show a low frequency of cyclones (less than 3) in recent history. Only the southern part of Ijivitaru District, close to Mount Clarence and Keveri Hills, showed a higher expectance (between 6 and 9).

The impact of climate change on the frequency of cyclones, is depicted in Figure 19. The effects are expected to diminish in the future; the small yellow region, located at the southern part of Ijivitaru District, comprising a slightly greater likelihood of being affected by cyclones (between 6 and 9), has changed to green (less than 4).

For the purposes of this study, it can be concluded that the cyclone likelihood patterns are slightly improved by climate change such that exposed areas will show less likelihood of cyclones in the future.

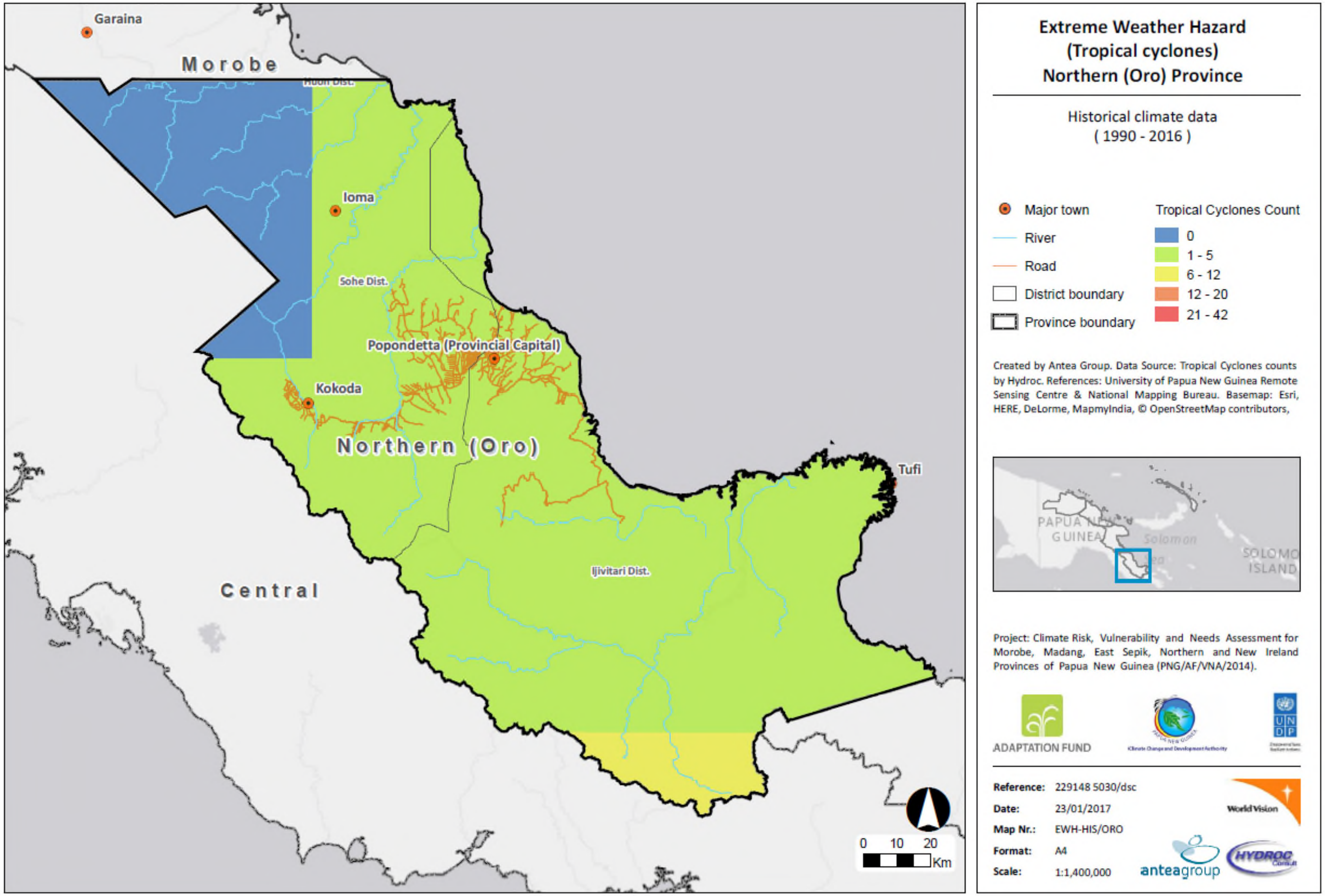

Figure 18. Tropical cyclones (current climate) as number of cyclones 0 1-5 6-12 12-20 >21

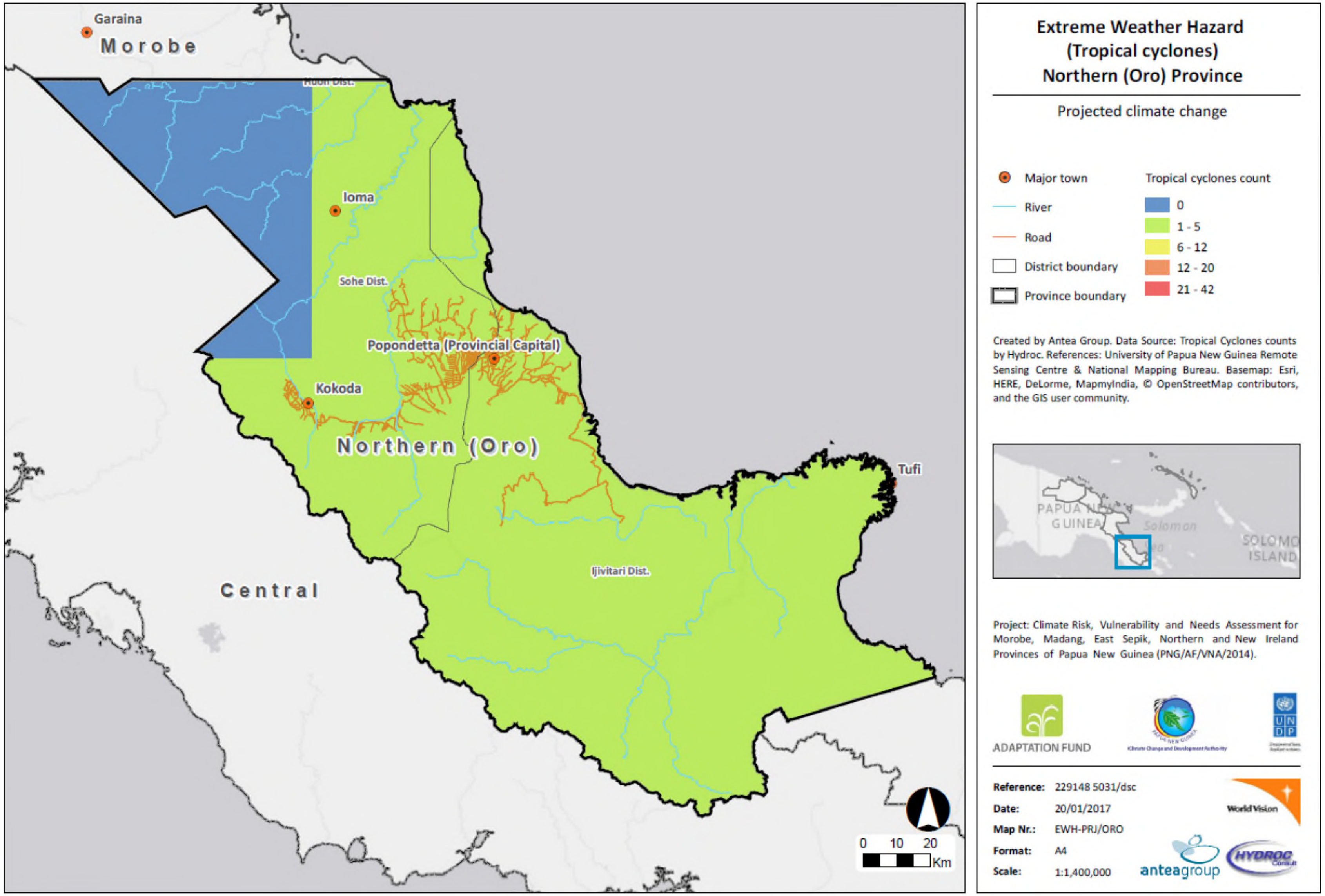

Figure 19. Tropical cyclones (projected climate) as number of cyclones 0 1-5 6-12 12-20 >21

2.1.6. *Increase of precipitation intensity and variability*

The variability in precipitation is described in terms of two parameters: a) the total annual rainfall and b) the rainfall on wet days depicting how much rainfall occurs during the most intense rainfall events.

The map in Figure 20 shows that the total annual rainfall is quite homogeneous across the province, varying between 2079 mm and 2710mm.

Figure 21 shows that, annually, about 250mm to 500mm of precipitation are produced on days with high precipitation intensity (when the daily rainfall exceeds the 95th percentile).

The effects of climate change in the future consist of a limited increase in yearly precipitation, visible for the northern zone of the province close to the coast; the downstream reaches of some of the rivers flowing through this area will experience a slight increase in total rainfall (Eia (Tavi) River downstream of Boke, the Gira Rivers downstream of Taire, the Mambare River downstream of Biaga, and the Kumusi River downstream of Batari). It is possible that the rest of the province experiences an increase also but, in any case will not reach 2711 mm per year.

Moreover, the intensity of the heaviest rainfall will increase due to climate change, with the change following a homogeneous pattern along the province. The most intense rainfall events would produce up to 600 mm of rainfall per year with the future climate being 100 mm more than now.

For the particular case of Oro the maps show that the climate projections lead to a homogeneous but moderate increase in total annual precipitation and precipitation intensities.

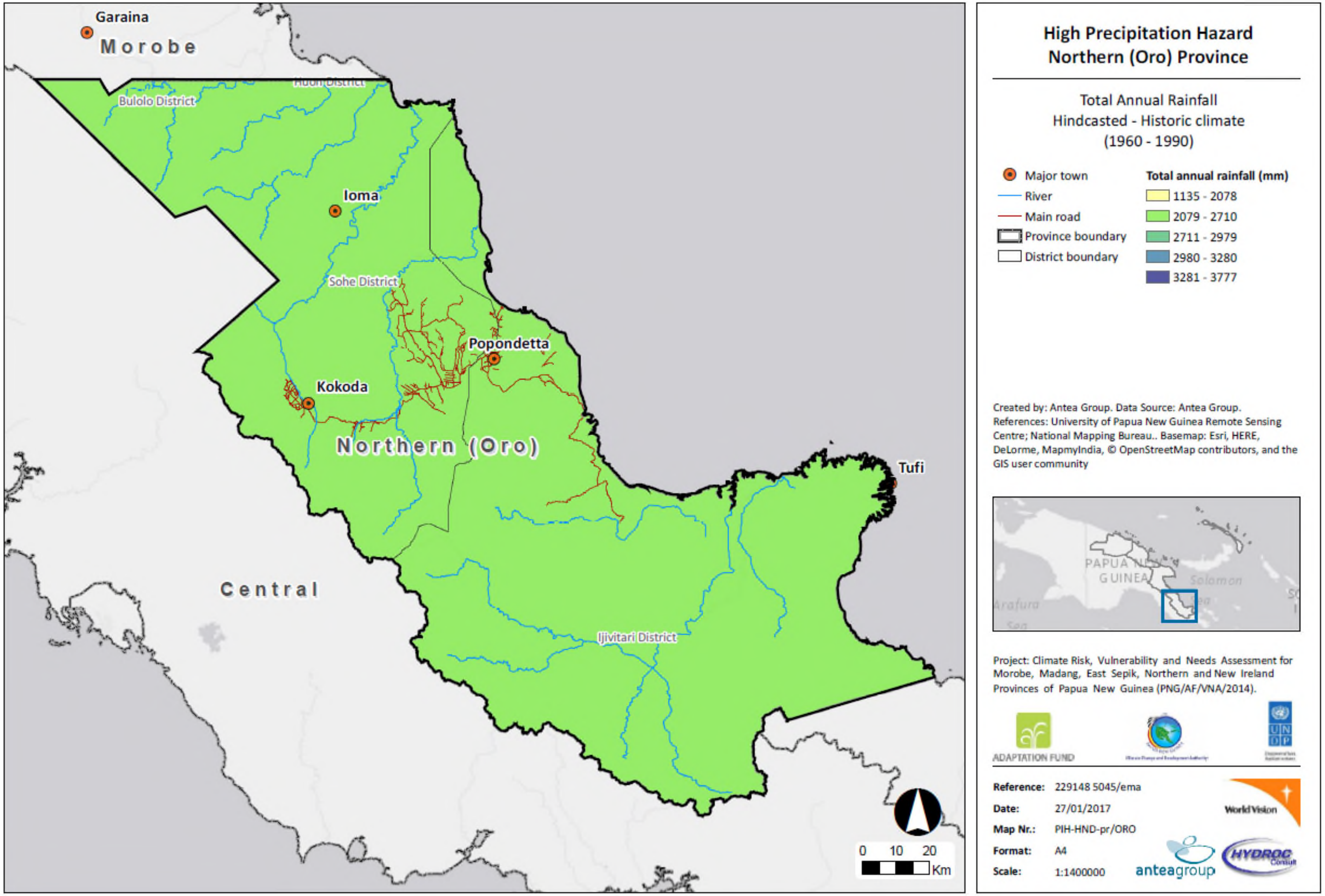

Figure 20. Total annual rainfall in mm (current climate) 1135-2078 2079-2710 2711-2979 2980-3280 3281-3777

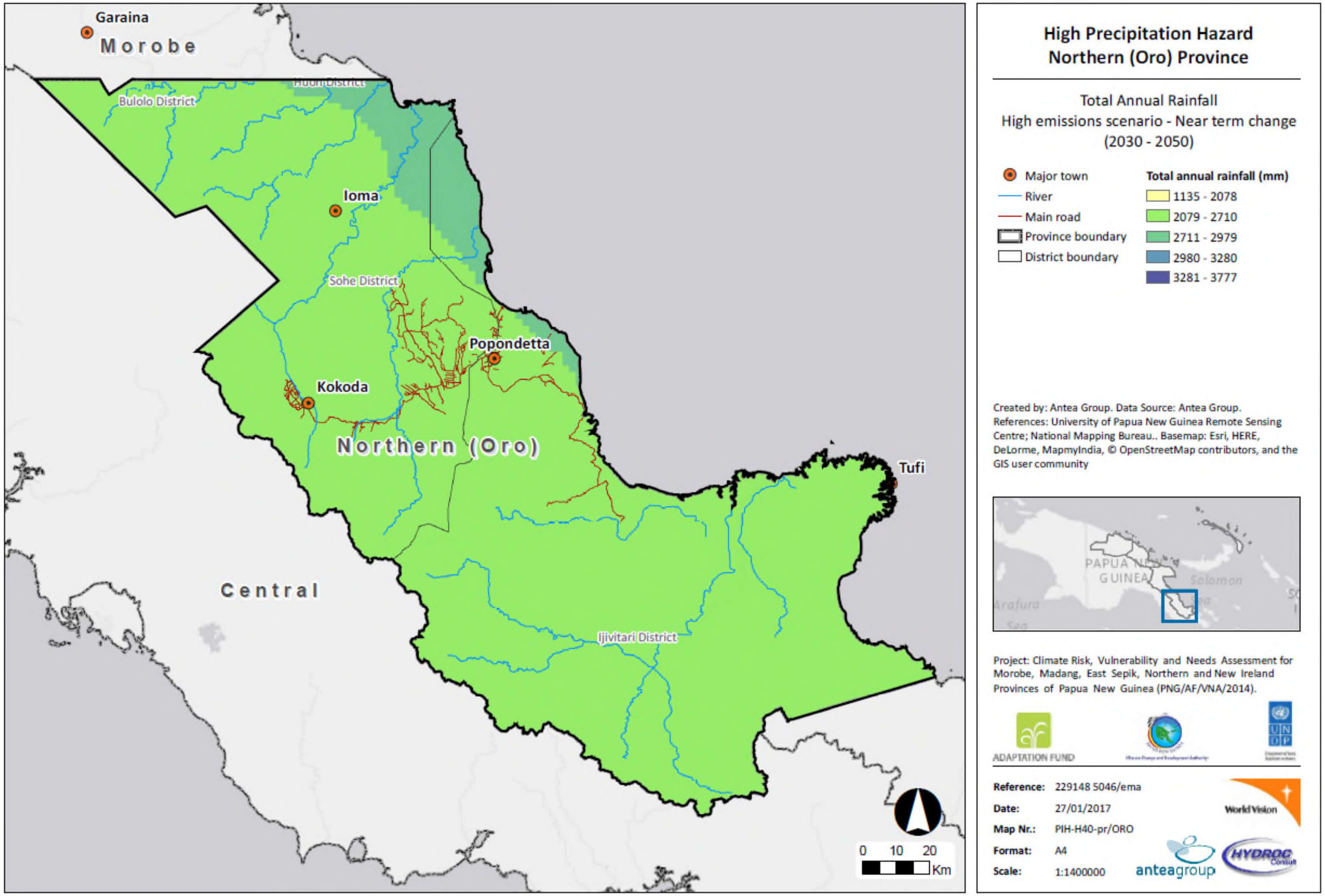

Figure 21. Total annual rainfall in mm (projected climate) 1135-2078 2079-2710 2711-2979 2980-3280 3281-3777

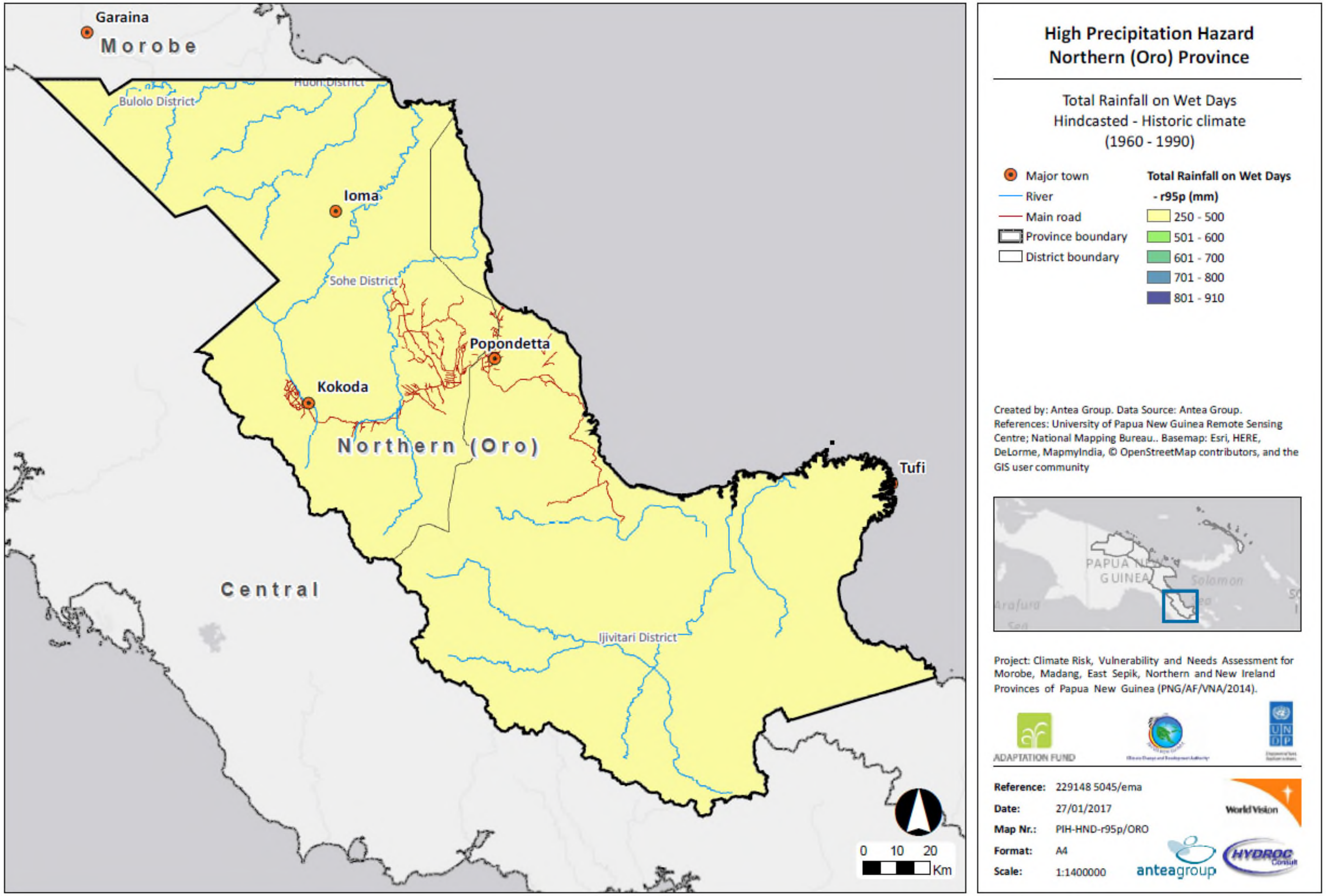

Figure 22. Rainfall on wet days in mm (current climate) 250-500 501-600 601-700 701-800 801-900

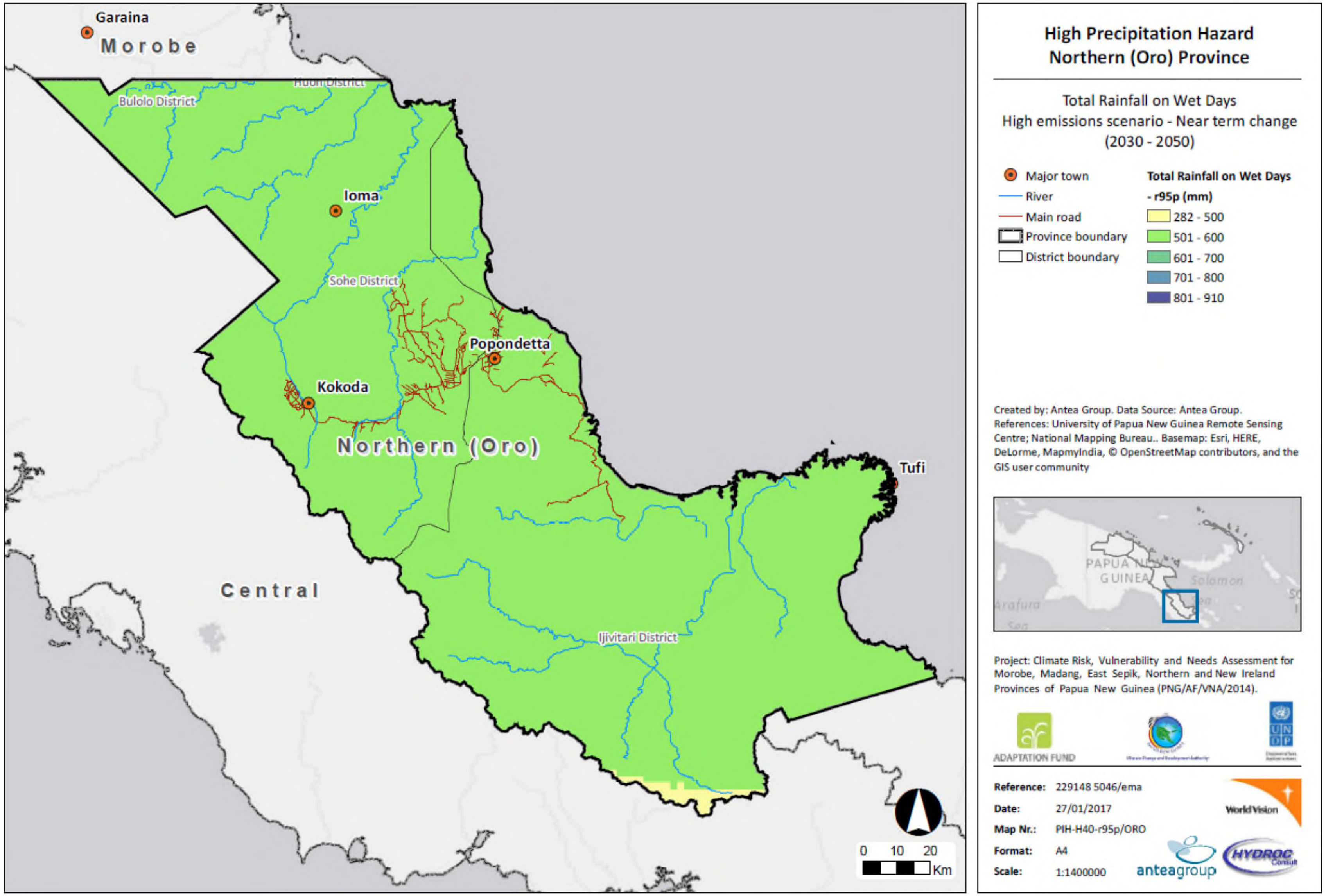

Figure 23. Rainfall on wet days in mm (projected climate) 250-500 501-600 601-700 701-800 801-900

2.2. Vulnerability Assessment

In this chapter we discuss the vulnerability maps for Northern 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

There are five main clusters with high social vulnerability to inland flooding in Oro Province, as follows:

1. Along the main road between Popondetta and Kokoda, including Popondetta and Kokoda towns and parts of Hingaturu Rural LLG and along the Waira River north of Kokoda town in Kokoda Rural LLG (Ijivitari and Sohe Districts)
2. Along the upper and middle reaches of the Kumusi River largely in Higaturu Rural LLG (Sohe District)
3. Along the middle reaches of the Mambare River and around Ioma Town in Tamata Rural LLG (Sohe District)
4. Along the middle and lower reaches of the Gira River in Tamata Rural LLG (Sohe District)
5. Along the middle and lower reaches of the Eia River in Tamata Rural LLG (Sohe District)

The factors used to determine social vulnerability include population size and density, health status, the presence of important social infrastructure such as health facilities, schools and markets, access points linking more remote areas to main roads. Access to social and kinship networks are also important as a coping mechanism.

Seen from the perspective of reducing social vulnerability to disasters in Oro province, emergency staging, supply and evacuation centers should be established in Popondetta, Kokoda and Ioma towns as well as a shelter in a suitable public building near the mouth of the Gira River in Tamata Rural LLG. In a serious flood event, this shelter/center can be accessed by boat.

Additional details can be obtained from the Community Risk Assessments carried out as part of this study. One such community was Ajeka Village.

Excerpt from the Community Risk Assessment – Ajeka Village, Kokoda LLG, Sohe District

Flooding is a seasonal hazard in the community. It normally occurs during wet period from November to April. Comes flood, people normally experience outbreak of malaria which is a common illness in the area. People in the area have understood the nature of normal floods that occur in their place, which can be seen by the increasing level of water in Kumusi River and the muddy colour of water. The flood normally destroys the river banks and washes away gardens that are located at the riverbeds.

However, a flood that occurred in 2007 brought about by Cyclone Guba was very destructive. It destroyed and swallowed a huge portion of the river banks of Kumusi River. Since the community is located on the hill about 16 metres high, on a steep cliff, the edge of the cliff was washed away and nearly causing a massive landslide which would have taken down almost a quarter of the village. In fact, the floods had actually washed away a huge portion of oil palm plantation located in low-lying areas of the village. The flooding incidents in the past have made people adjust and cope every time the village gets inundated by heavy rains. Most of them moved to higher ground away from the river. Since almost all of them live in this place for a long time, they helped each other during this time by *sharing food, clothing, and water particularly to distressed families. There were also situations in the past that some villagers have to be relocated to neighbouring villages due to the floods.*

Table 30. Distribution of vulnerability classes for inland flooding in Oro Province (combined social, economic and physical)

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
District	**1**	**2**	**3**	**4**	**5**	
Ijivitari District	17.6	5.7	1.6	1.6	1.9	71.7
Sohe District	10.8	3.2	1.5	1.5	6.0	76.9

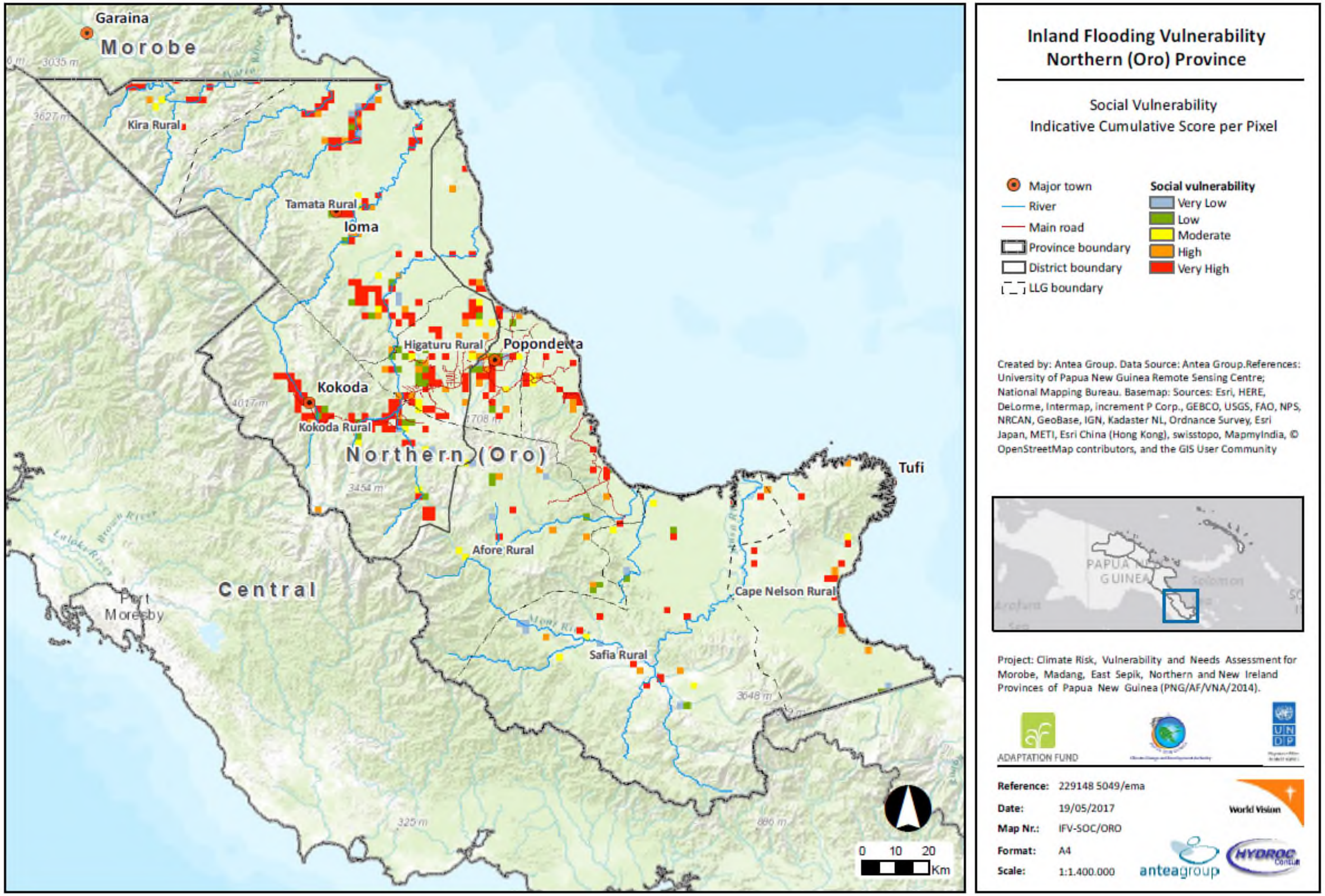

Figure 24. Social vulnerability to inland flooding in Northern Province

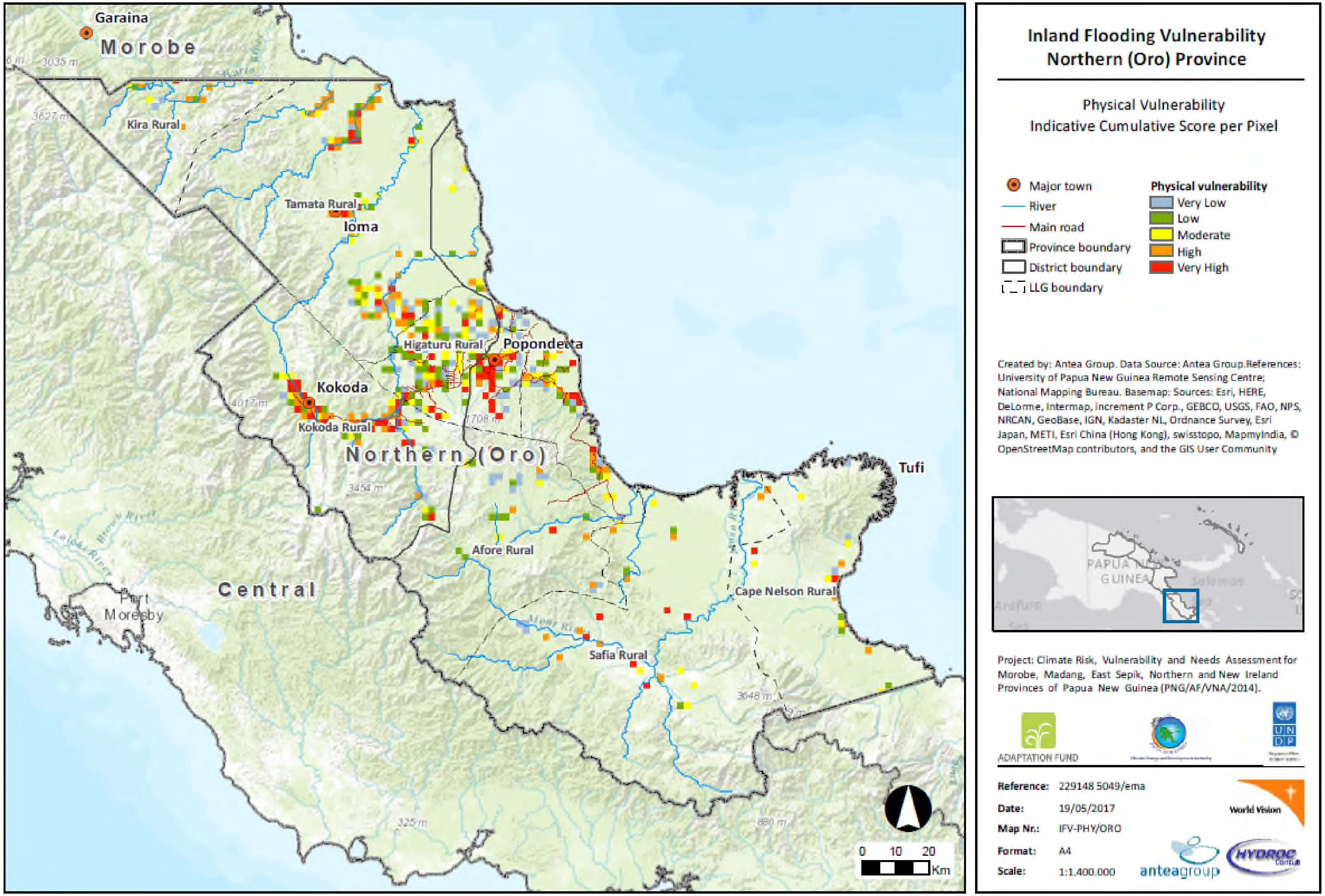

Figure 25. Physical vulnerability to inland flooding in Northern Province

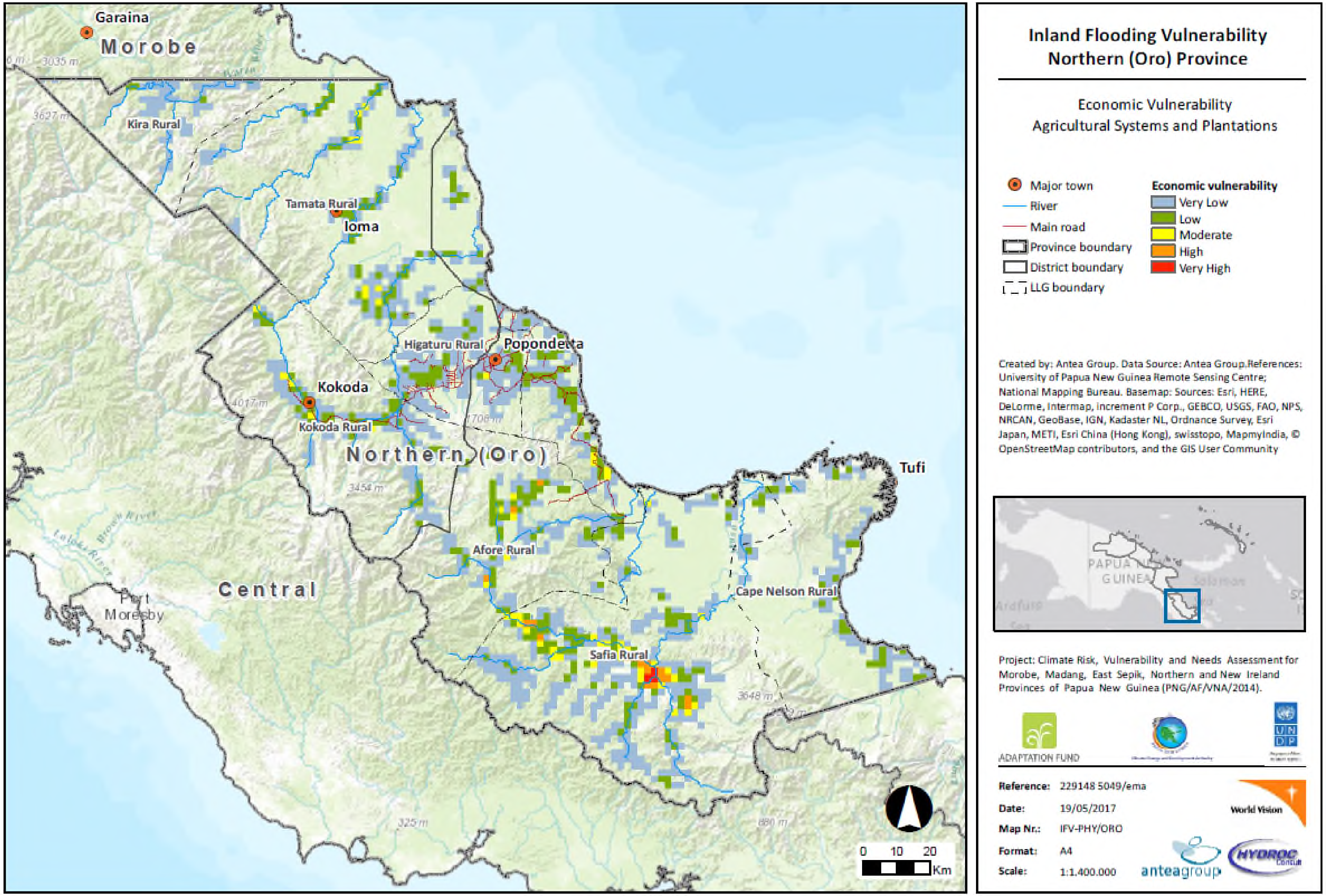

Figure 26. Economic vulnerability to inland flooding in Northern Province

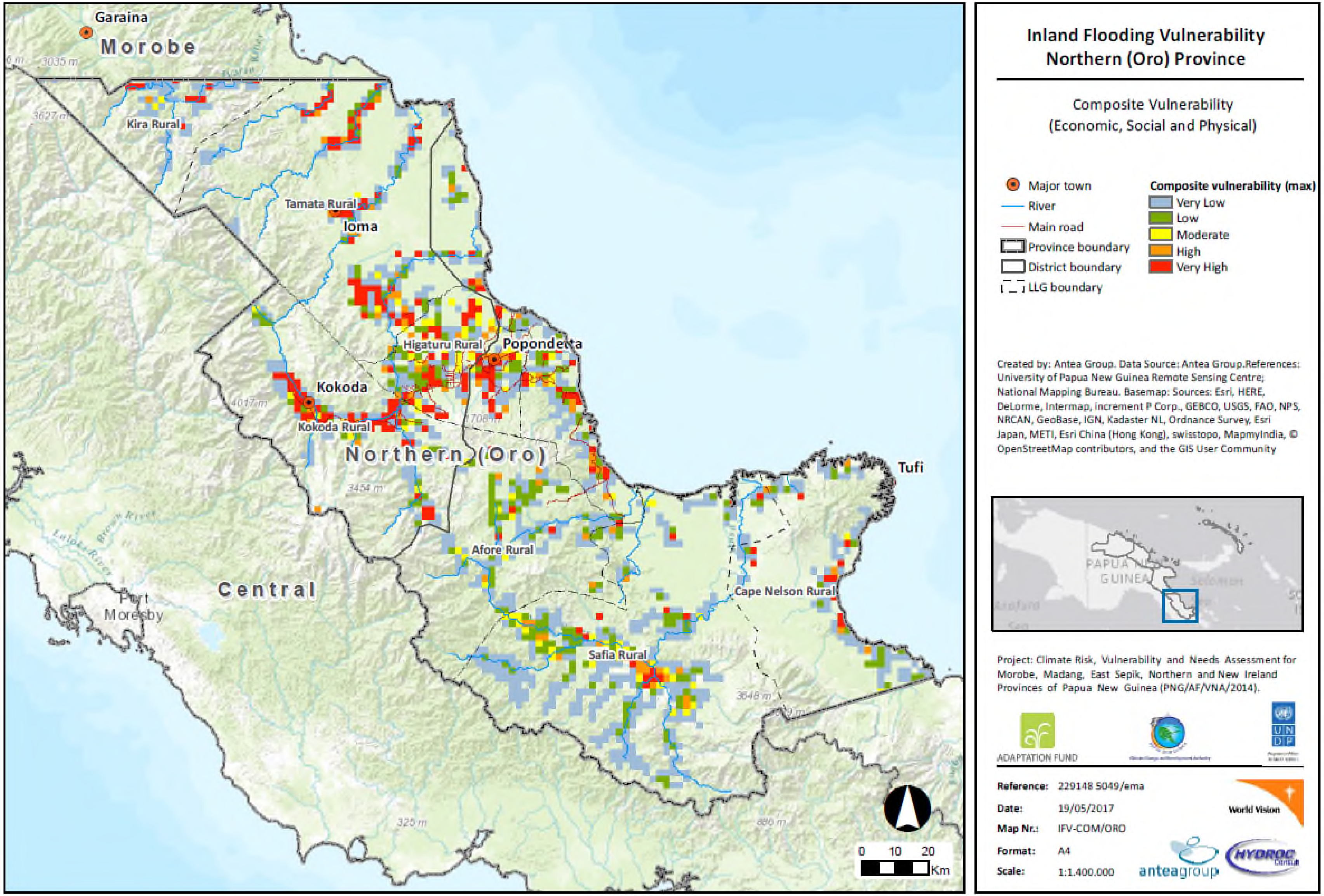

Figure 27. Combined inland flood vulnerability map for Northern Province

2.2.2. Vulnerability to coastal flooding

<maps not available>

2.2.3. Vulnerability to drought

The maps on the following pages respectively represent social and economic vulnerability to drought in the province. A physical vulnerability map has not been created for drought, as physical infrastructure is regarded as not being sensitive to drought.

Social vulnerability as explained in the first chapter of this report is based on a set of social sensitivity indicators and size and density of the population. Population size and density contribute significantly to the vulnerability calculation, as can be seen in Figure 28.

Social vulnerability to droughts can be seen as an effect of its negative impact on food and cash crops, which is discussed below. Therefore, the areas of highest social vulnerability to droughts arecorrelated with the areas with highest economic vulnerability. The lower availability of food and cash income can produce added stress on families and social networks. Reduced access to safe sources of drinking water can have negative health impacts, especially on infants and children.

Economic vulnerability is calculated using sensitivity of the dominant crops and the replacement values of crops. Plantations situated in the vicinity of Popondetta are the most vulnerable, followed by the cultivated systems stretching between Kokoda over Popondetta to Oro Bay. This can be seen in Figure 29.

In addition to the two vulnerability components depicted in the first two maps, a combined drought vulnerability map for the province was created. Figure 30 shows high drought vulnerability around Kokoda and Popondetta, moderate drought vulnerability in the populated areas stretching from Kokoda to Oro Bay and some less vulnerable patches in the mountain areas and coastal areas where the population density is lower and the sensitivity to drought of the agriculture systems, and crop values also is lower. Table 31 shows the percentage distribution of drought vulnerability classes in the province.

Table 31. Distribution of vulnerability classes for drought in Oro Province (combined social and economic)

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
District	1	2	3	4	5	
Ijivitari District	10.6	11.7	6.4	0.2	0.4	70.7
Sohe District	5.2	9.3	7.4	0.2	1.3	76.6

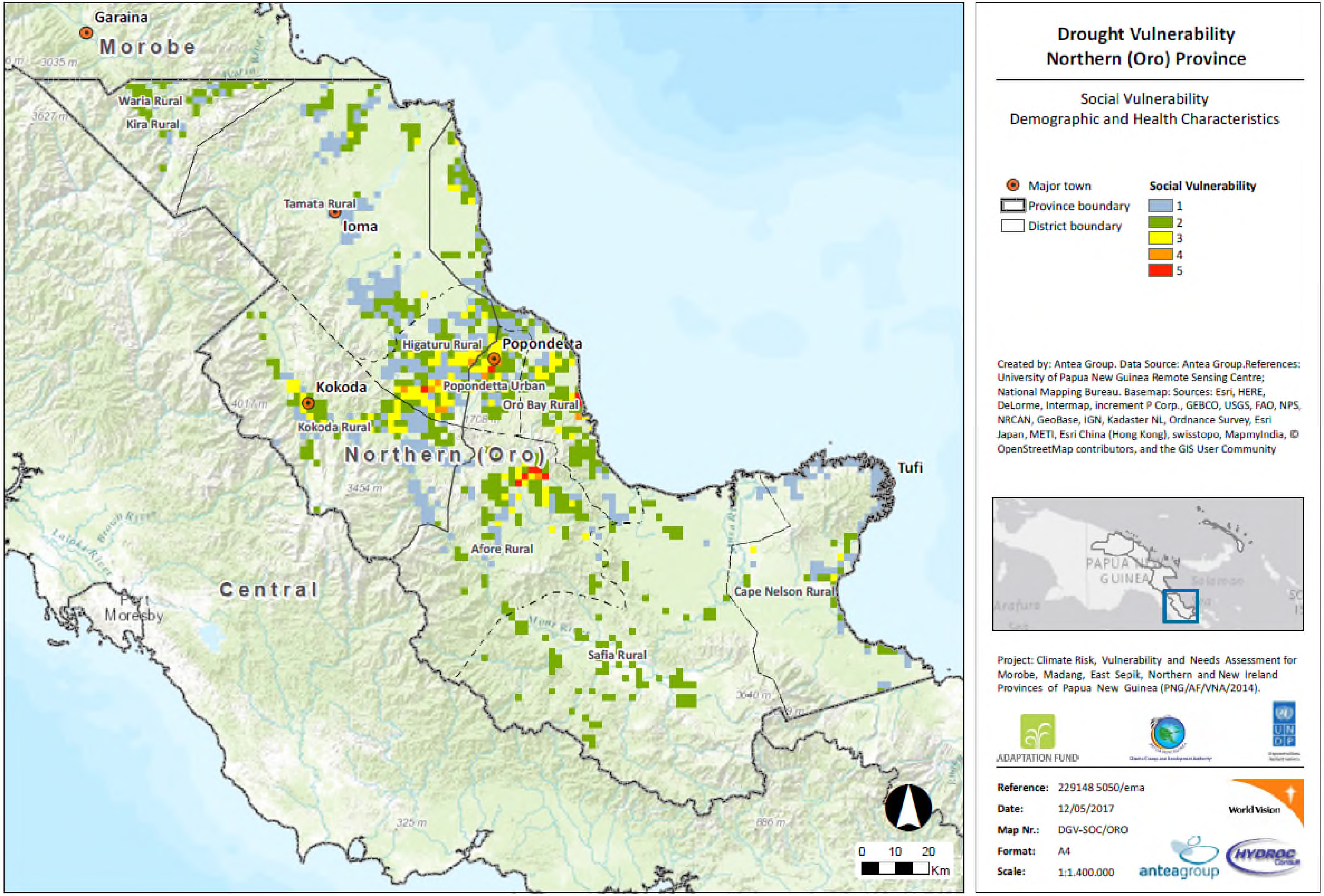

Figure 28. Social vulnerability to drought in Northern Province

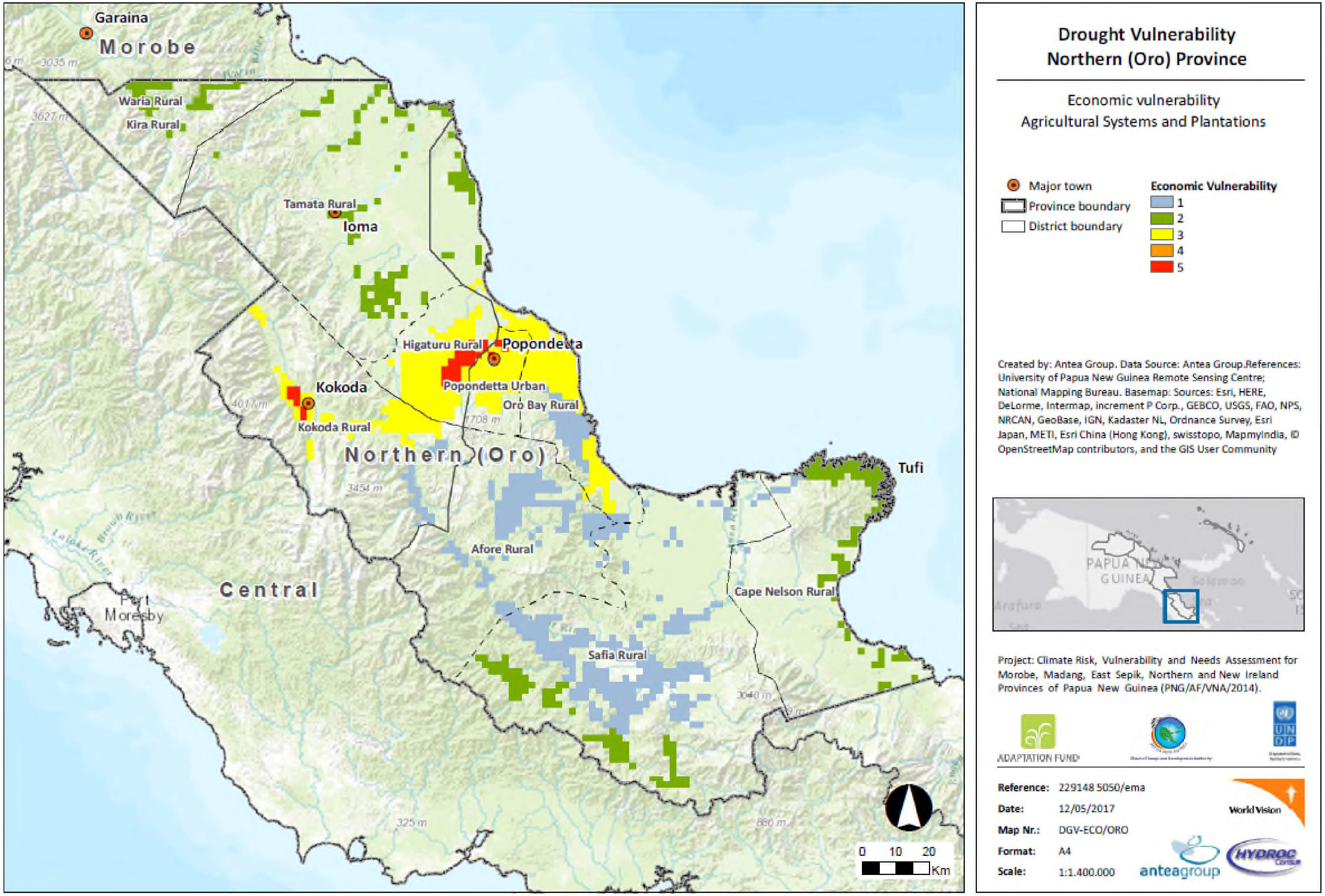

Figure 29. Economic vulnerability to drought in Northern Province

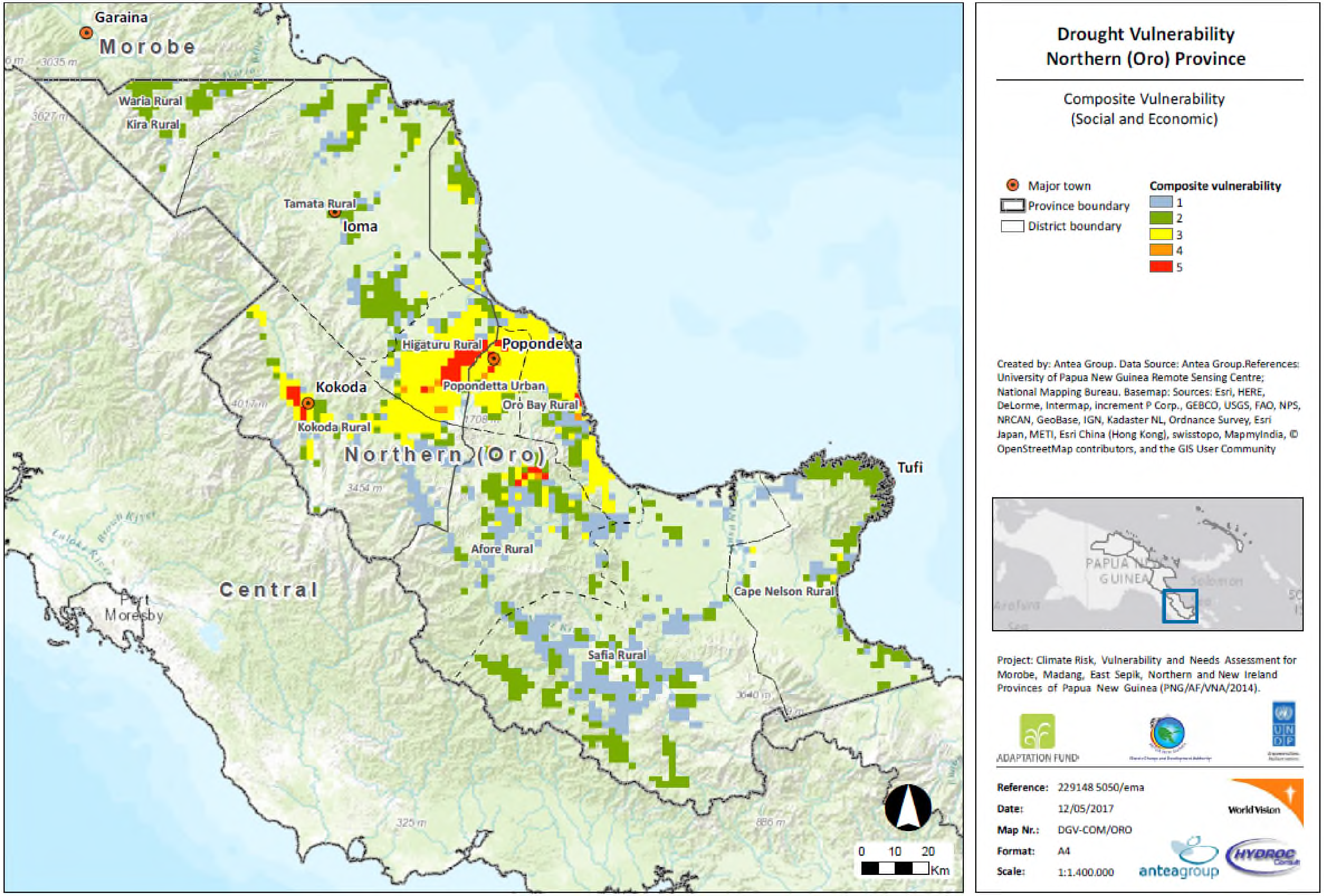

Figure 30. Combined drought vulnerability map for Northern Province

2.2.4. *Vulnerability to extreme weather (cyclones)*

The maps on the following pages respectively represent the social, physical and economic vulnerability to cyclones in the province.

Social vulnerability as explained in the first chapter of this report is based on a set of social sensitivity indicators and size and density of the population. Population density contributes significantly to the vulnerability calculation, as can be seen in Figure 31. Since the social sensitivity indicators are generic for all hazards, the resulting social vulnerability maps are similar to those presented in the previous sections of this report.

Physical vulnerability (Figure 32) is calculated using building characteristics representing the sensitivity of the structures to cyclones and the replacement costs of the structures. The physical vulnerability is highest in the more densely populated areas in the province, i.e. between Kokoda, Popondetta and Oro Bay.

Economic vulnerability is calculated using sensitivity of the dominant crops and the replacement values of crops. Plantations situated in the vicinity of Popondetta are the most vulnerable, followed by the cultivated systems stretching between Kokoda over Popondetta to Oro Bay. This can be seen in Figure 33.

In addition to the vulnerability components depicted in the first three maps, a combined cyclone vulnerability map for the province was created. Figure 34 shows high vulnerability around Kokoda and Popondetta, moderate vulnerability in the populated areas stretching from Kokoda to Oro Bay and some less vulnerable patches in the mountain areas and coastal areas where the population density is lower and the sensitivity to drought of the agriculture systems, and crop values also is lower.

Table 32. Distribution of vulnerability classes for extreme weather (cyclones) in Oro Province (combined social, economic and physical)

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
District	**1**	**2**	**3**	**4**	**5**	
Ijivitari District	4.0	12.3	4.8	5.3	2.9	70.6
Sohe District	4.7	5.5	3.2	7.7	3.9	75.1

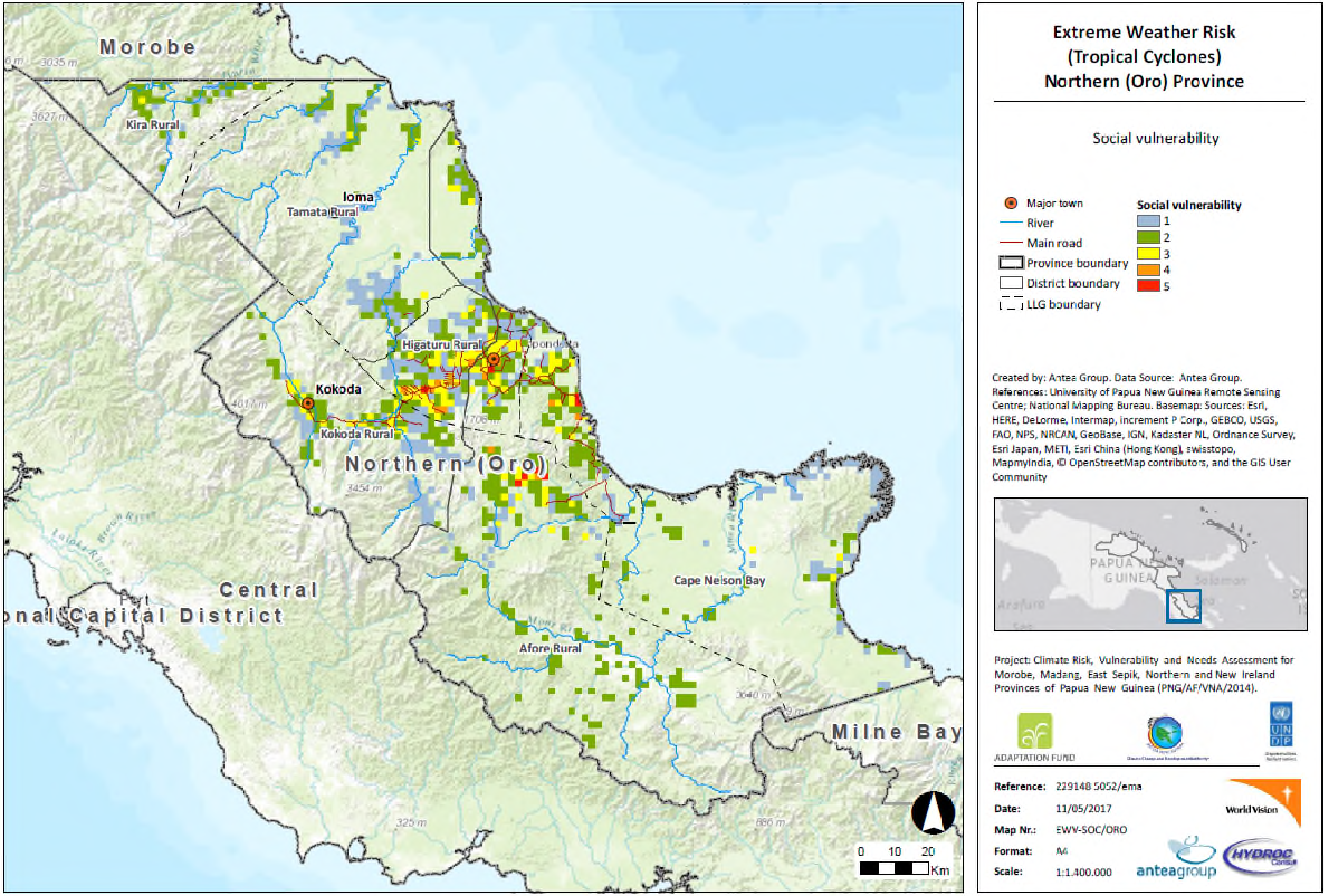

Figure 31. Social vulnerability to cyclones in Northern Province

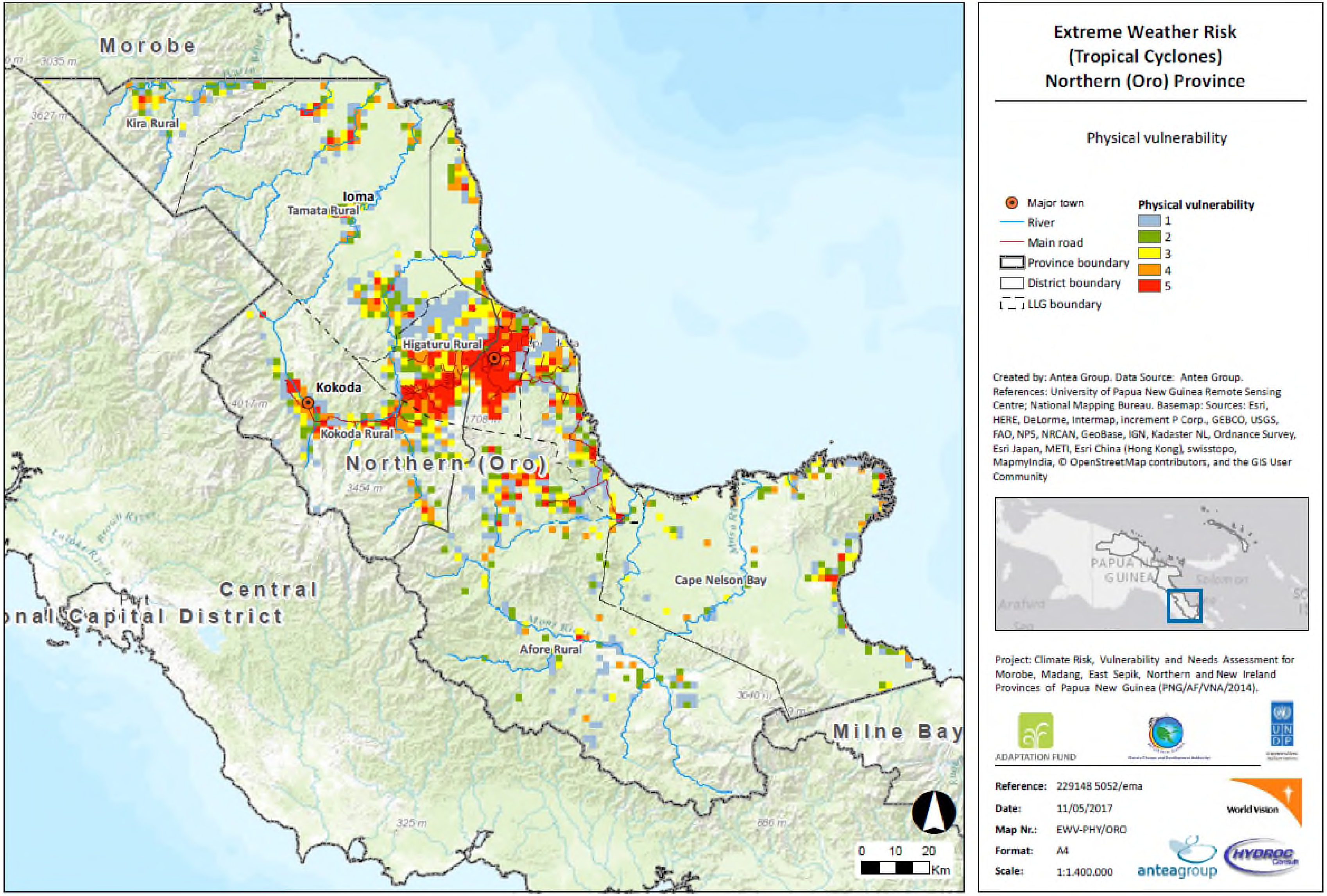

Figure 32. Physical vulnerability to cyclones in Northern Province

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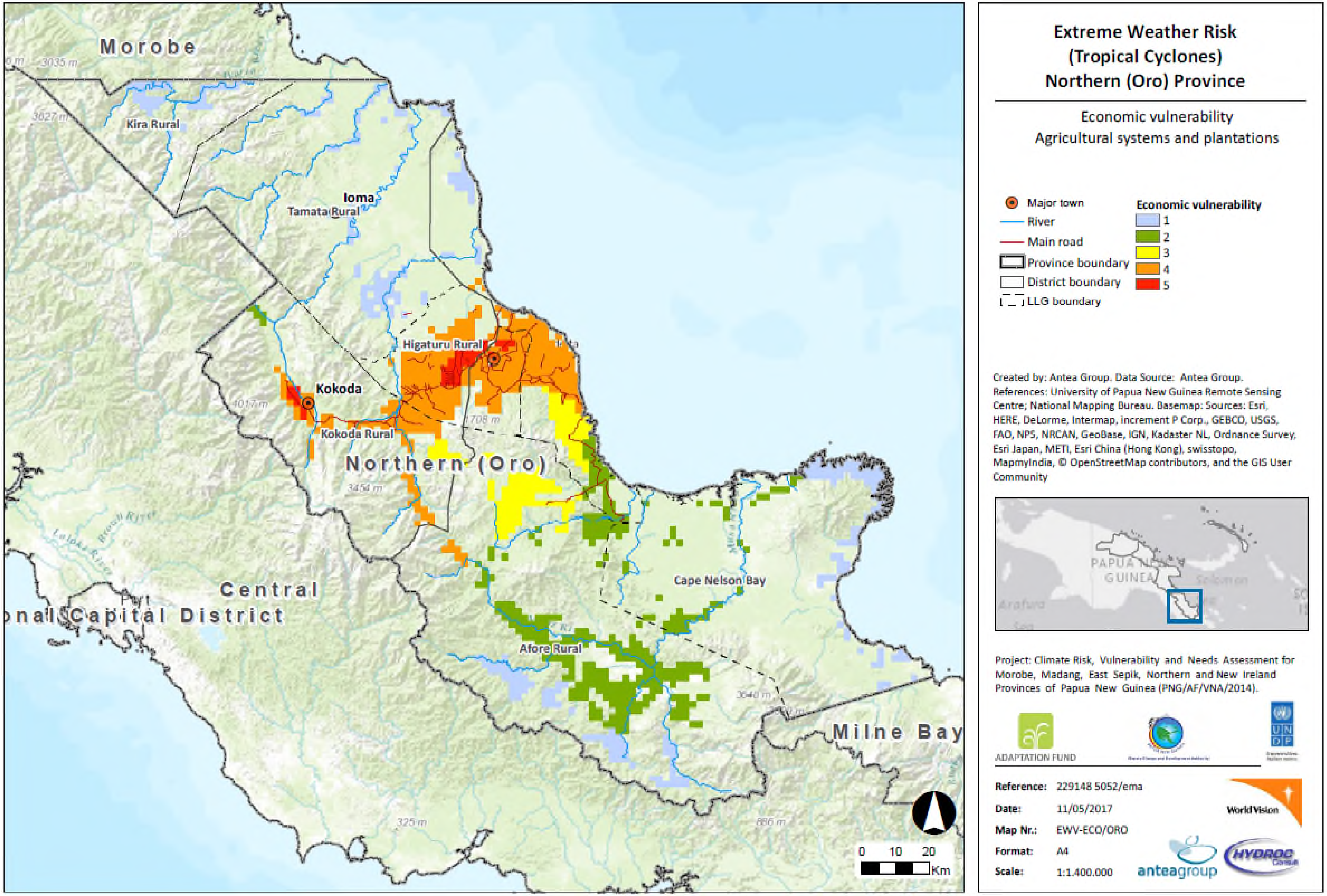

Figure 33. Economic vulnerability to cyclones in Northern Province

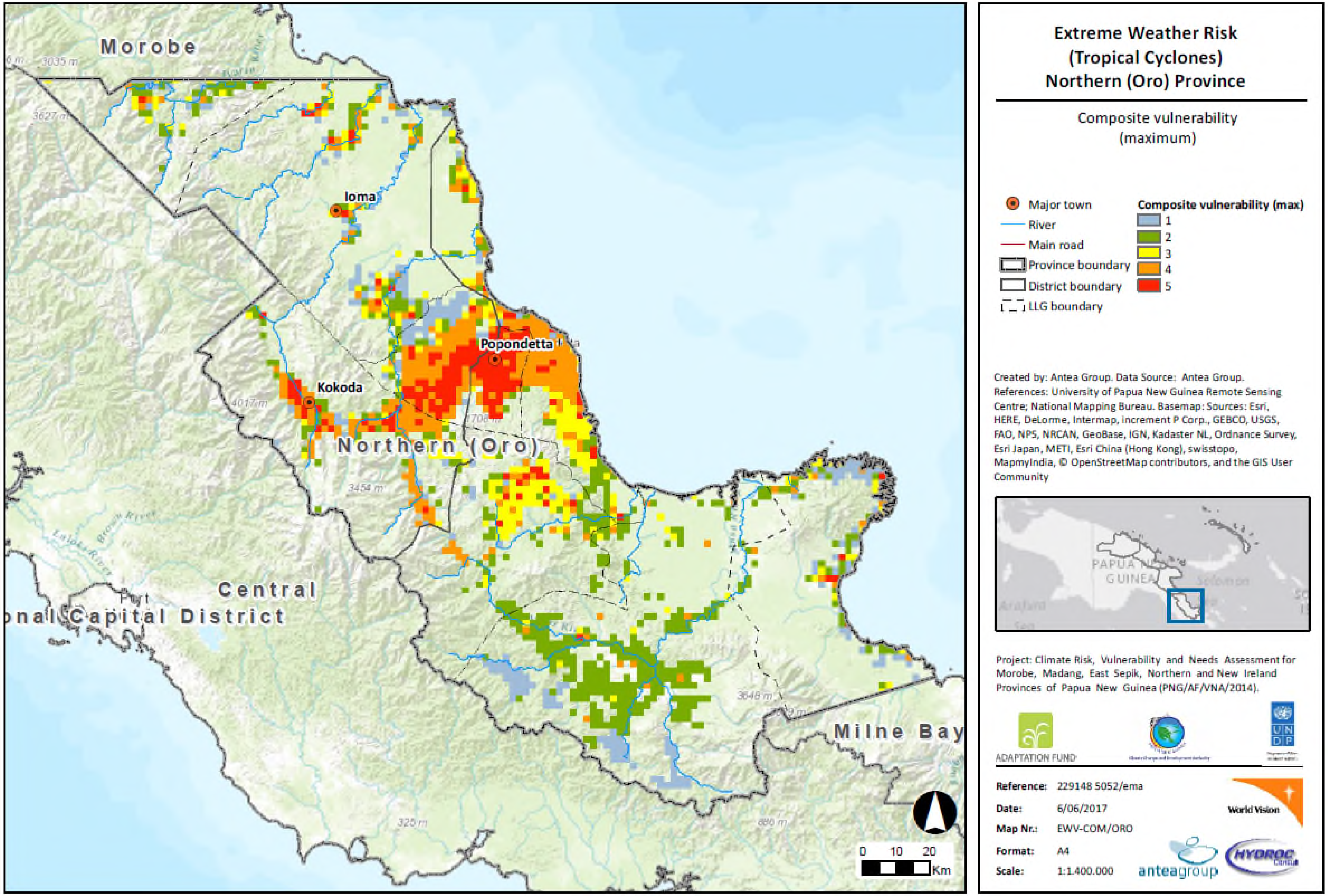

Figure 34. Combined vulnerability to cyclones in Northern Province

2.2.5. *Vulnerability to precipitation intensity and variability*

The degree and distribution of social vulnerability to precipitation intensity and variability in Northern Province is similar to that for inland flooding, drought, and extreme weather events as described above.

Table 33. Distribution of vulnerability classes for precipitation intensity and variability in Oro Province (combined social and economic)

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
District	1	2	3	4	5	
Ijivitari District	17.1	9.7	1.9	0.2	0.2	70.8
Sohe District	11.3	8.9	2.8	0.3	0.0	76.7

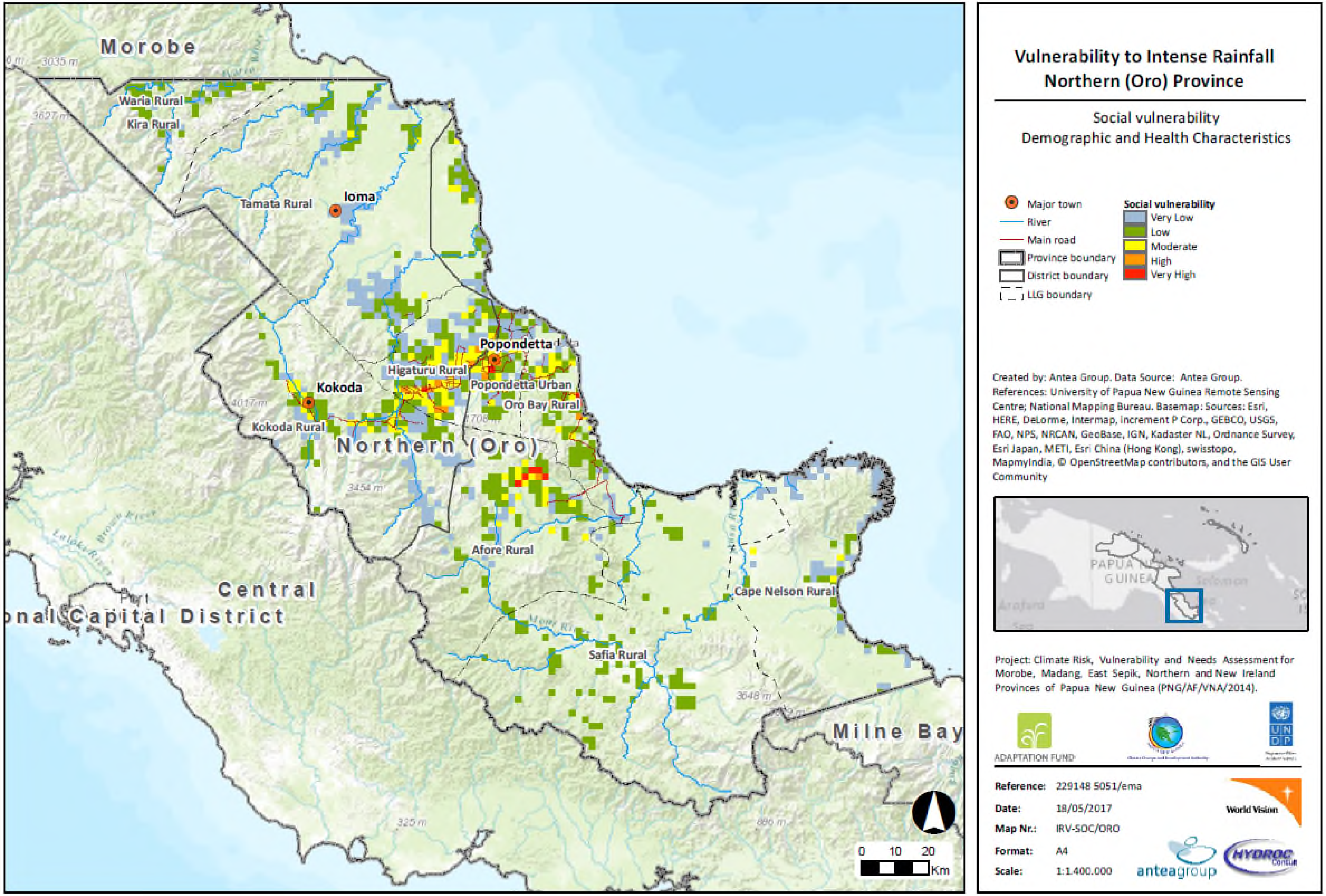

Figure 35. Social vulnerability to precipitation intensity and variability (intense rainfall) in Northern Province

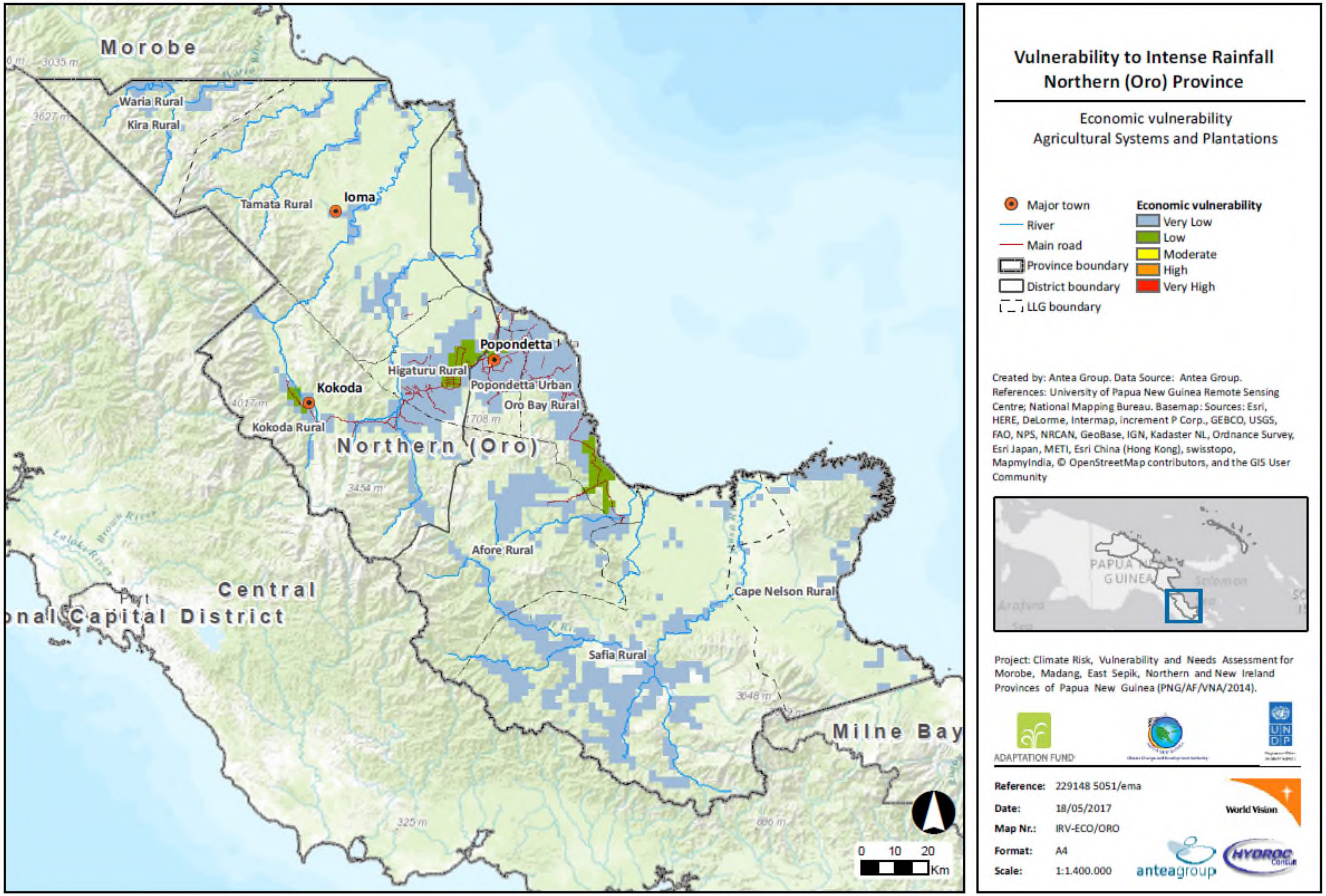

Figure 36. Economic vulnerability to precipitation intensity and variability (intense rainfall) in Northern Province

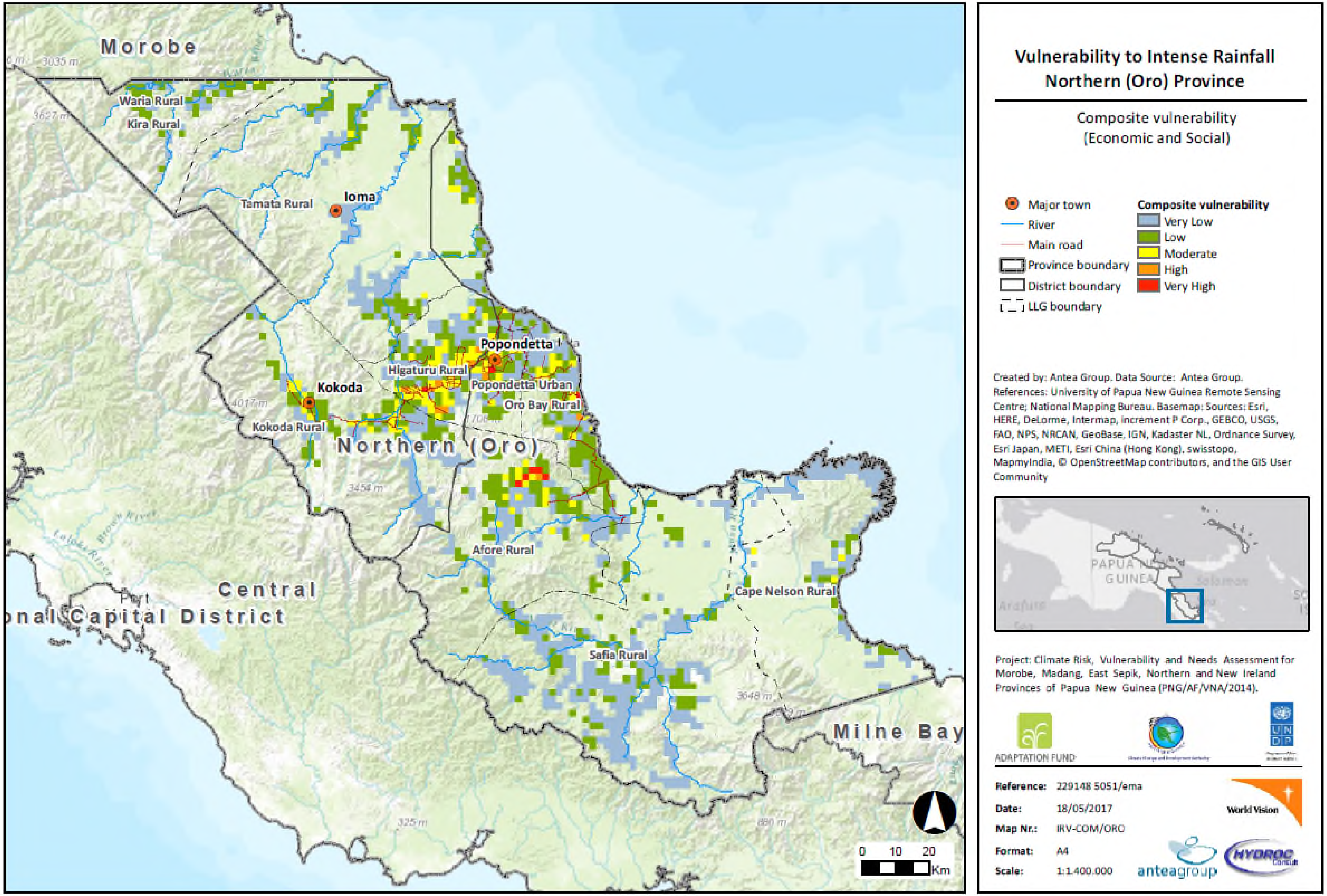

Figure 37. Combined vulnerability to precipitation intensity and variability (intense rainfall) in Northern Province

2.3. Risk Assessment

In this chapter we discuss the risk maps produced for Northern 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

The effects of inland flooding in the risk conditions of the province can be observed as concentrated in three geographic clusters as depicted on the next pages.

Firstly, the areas surrounding Popondetta and those along the road between Kokoda and Popondetta show a higher concentration of pixels at high or extreme risk than in the rest of the province. The main reason for this are the numerous roads and communities distributed along the northern face of Mount Lamington and in the floodplains of the Kumusi River (high exposure and value of assets). Communities at highest risk are the city of Poppondeta, Sangara, Ombisusu, around Komo village and Ebei Creek, Hurata and Orasusu, around Sewa on the footslope of Mount Lamington, Soputa, and, finally, Dombada and Embogo at the mouth of the Emboga River.

Secondly, in the northern part of the province, communities located along the downstream reaches of the Eia (Tavi) and Gira Rivers show low to moderate flood risk with a few exceptions (Manakatai/ Onombatutu, Waude and Tabara) where high risk is observed along the Gira.

A third cluster is located in the southern part of the province (Afoe rural) mainly due to the large floodplains of the Moni Valley, in the headwaters of the Musa River. There is a vast flood zone in the vicinity of Safia, where the Moni River and several tributaries flow into the Musa River. This confluence is largely agricultural and therefore sensitive to floods.

The highest social risk for inland flooding is near the main population centers in the province, i.e. the corridor extending along the main road from Kokoda in the west-central part of the province eastward through Ajeka to Saiho and around Ioma in the north. Smaller areas of high risk for inland flooding are in the north around Siai, and in the south along the middle reaches of the Musa River. The social risk from inland flooding is expected to be low in the remaining sparsely populated parts of the province.

The impact of climate change on flooding patterns cannot be depicted at the provincial (or even at district) scale as stated before (see Section 2.1.2). The risk maps for the projected climate change conditions show a slight deterioration of the risk but it is not a fundamental change in terms of intensity or location. For the Northern Province in particular, the level of aggregation prevents visualizing this change. For the purposes of this study it can be concluded that the flood risk will be slightly exacerbated due to climate change.

Table 34. Distribution of inland flood risk classes

	INLAND FLOOD RISK											
	RISK 1960-1990 %						RISK 2030-2050 %					
District	1	2	3	4	5		1	2	3	4	5	
Ijivitari District	18.6	6.5	1.8	1.1	0.6	71.4	18.5	6.6	1.8	1.1	0.6	71.4
Sohe District	14.0	4.9	2.4	1.4	0.3	77.0	14.0	4.9	2.4	1.4	0.3	76.9

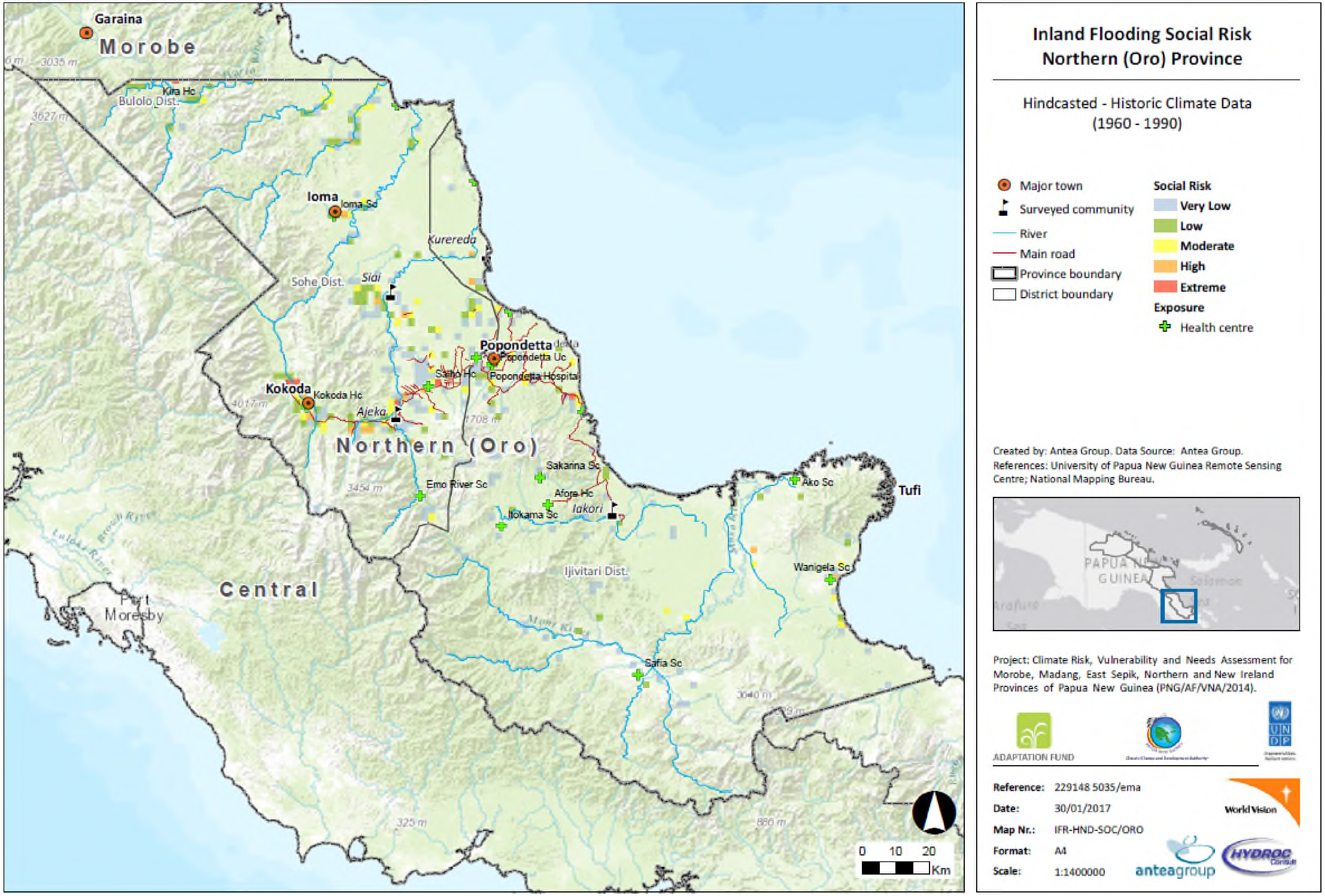

Figure 38. Inland Flooding Social Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

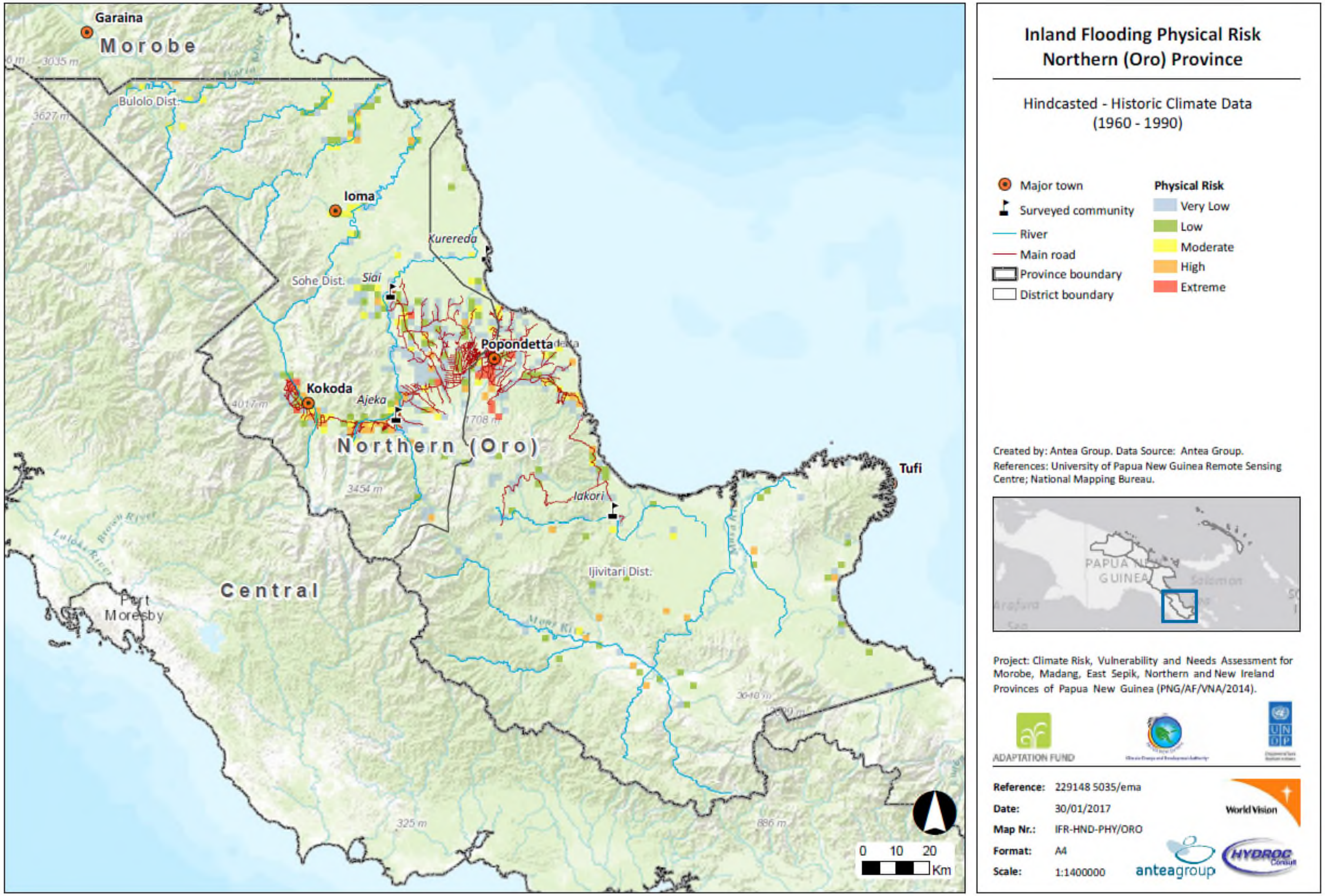

Figure 39. Inland Flooding Infrastructure Risk (current climate) ■**Very Low** ■**Low** ■**Moderate** ■**High** ■**Extreme**

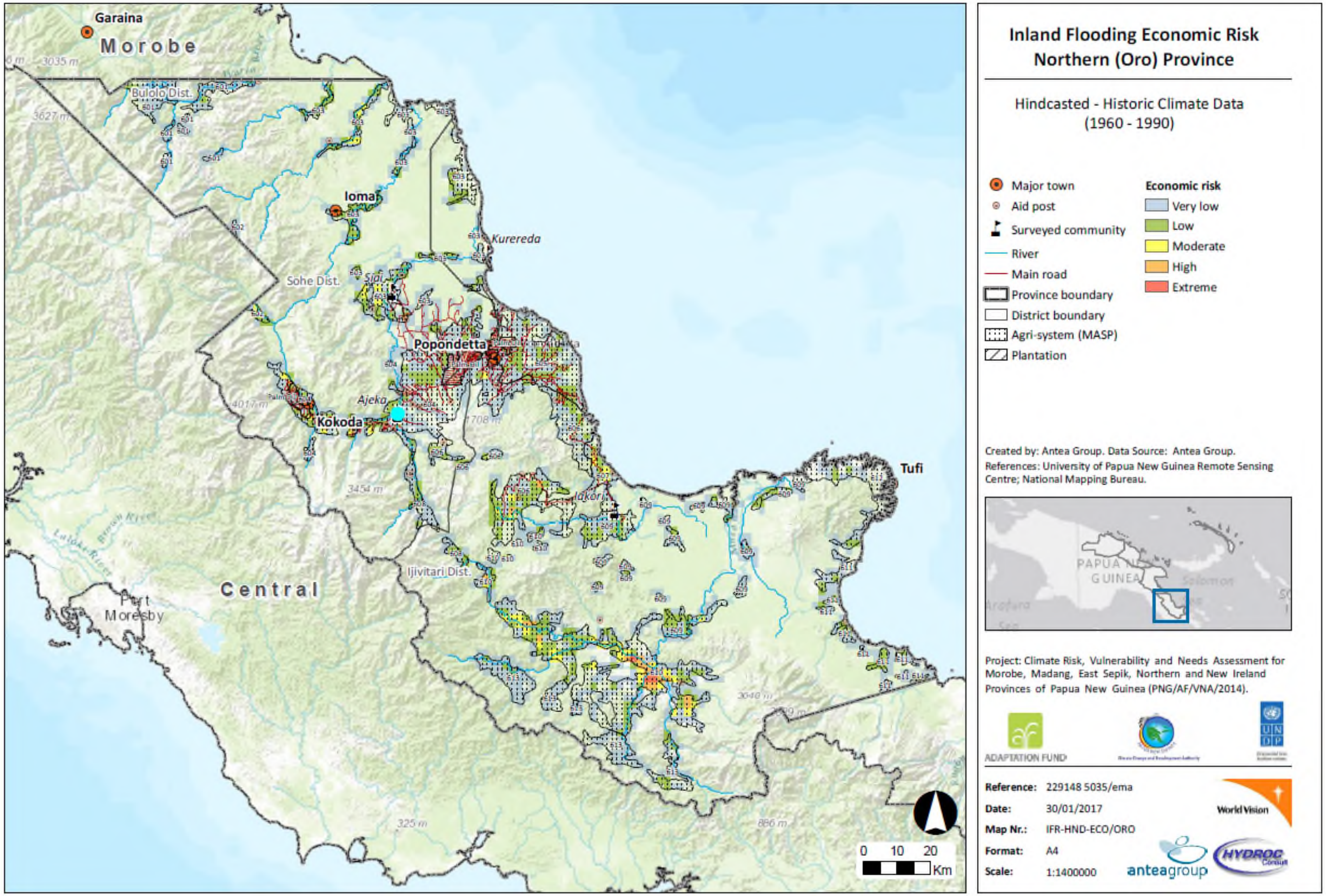

Figure 40. Inland Flooding Economic Risk (current climate) Very Low Low Moderate High Extreme

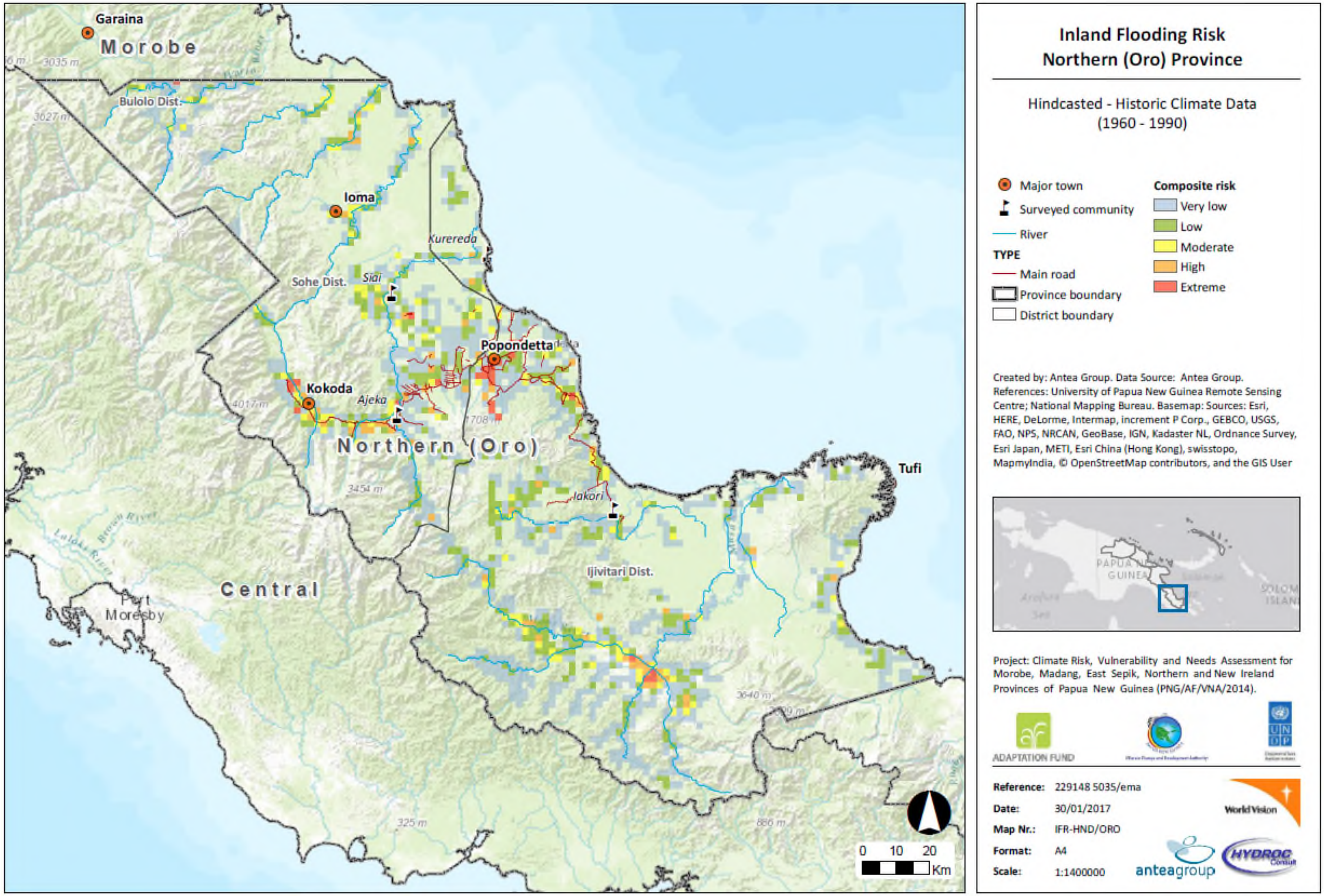

Figure 41. Inland Flooding Composite Risk (current climate) Very Low Low Moderate High Extreme

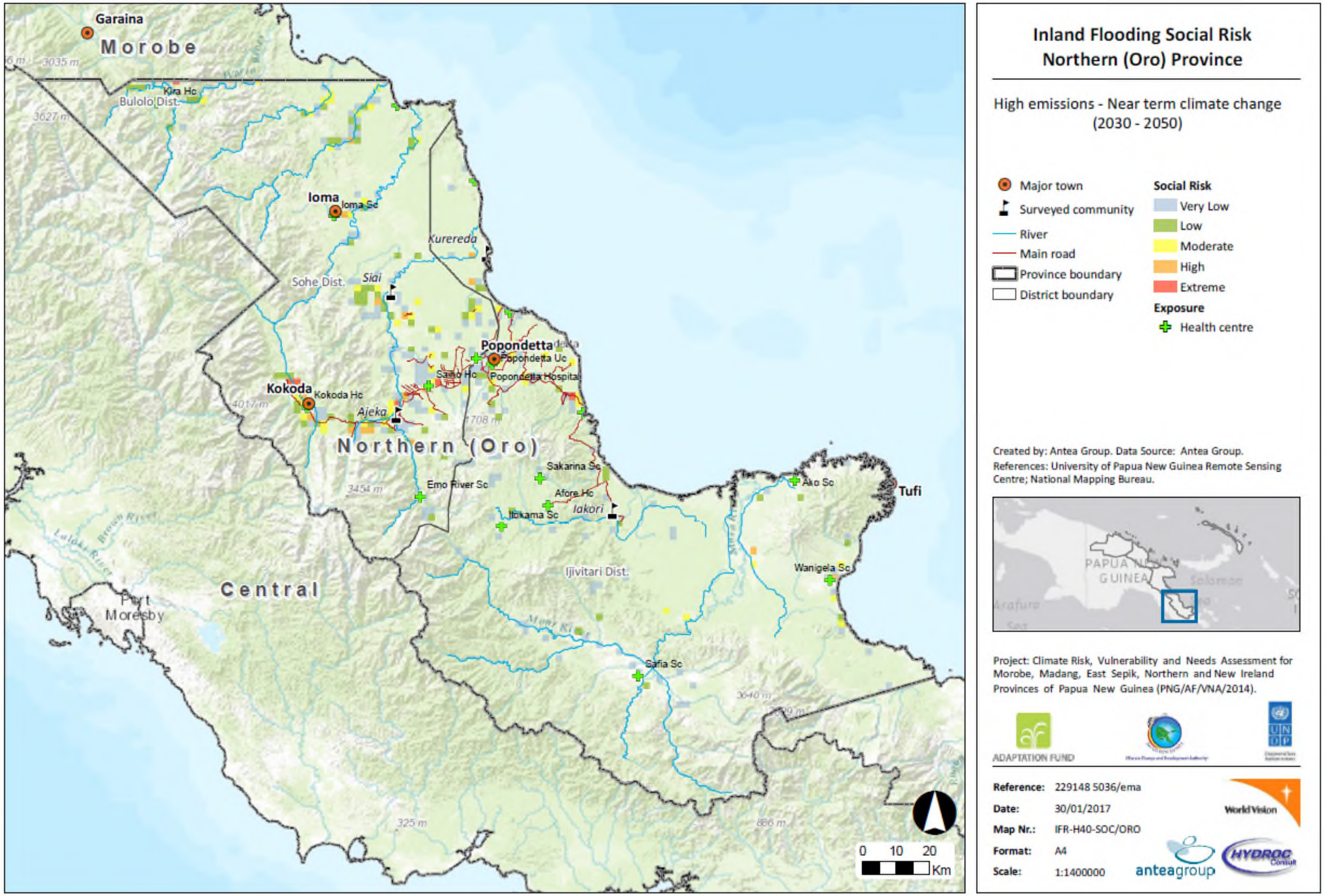

Figure 42. Inland Flooding Social Risk (projected climate) Very Low Low Moderate High Extreme

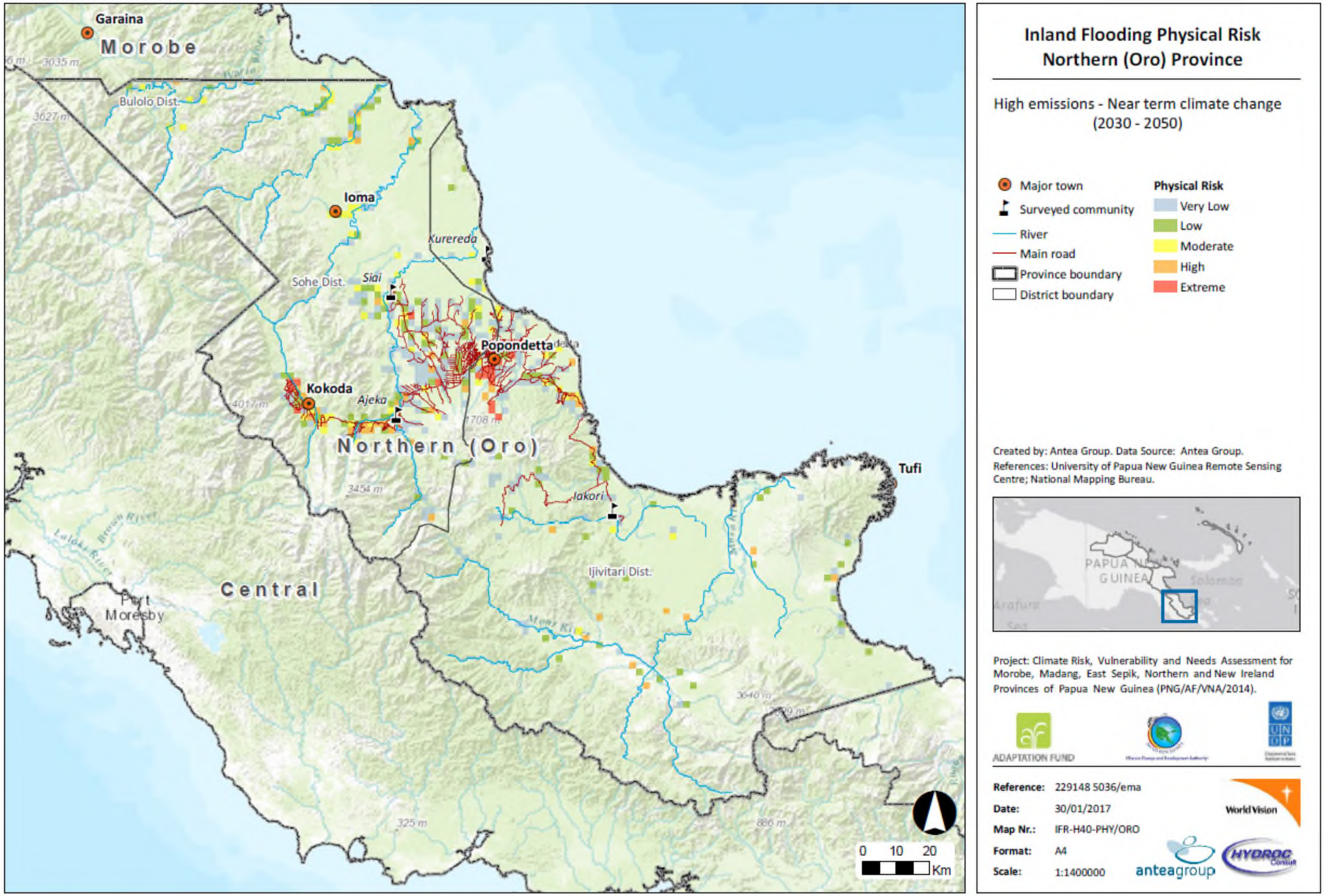

Figure 43. Inland Flooding Physical Risk (projected climate) Very Low Low Moderate High Extreme

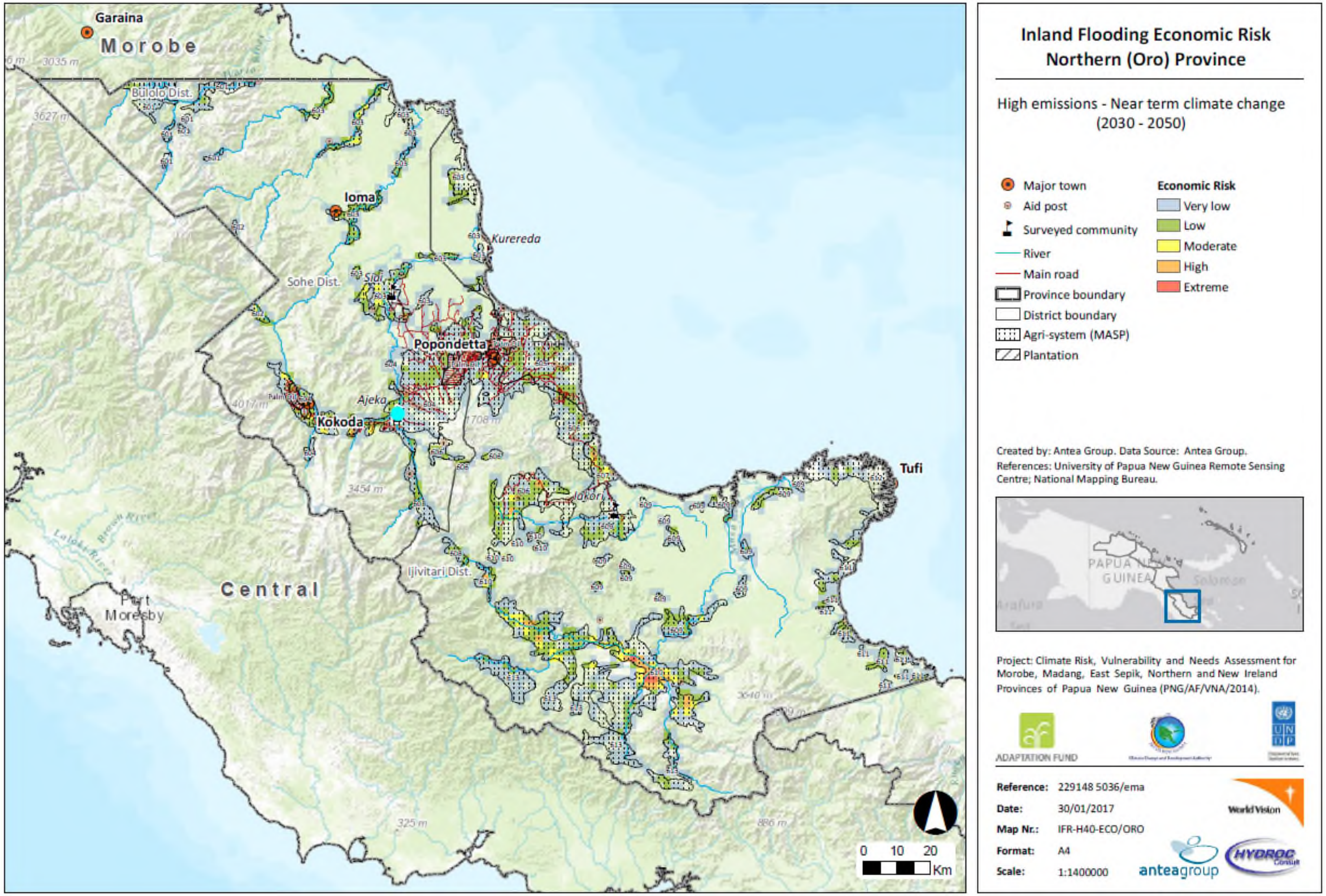

Figure 44. Inland Flooding Economic Risk (projected climate) Very Low Low Moderate High Extreme

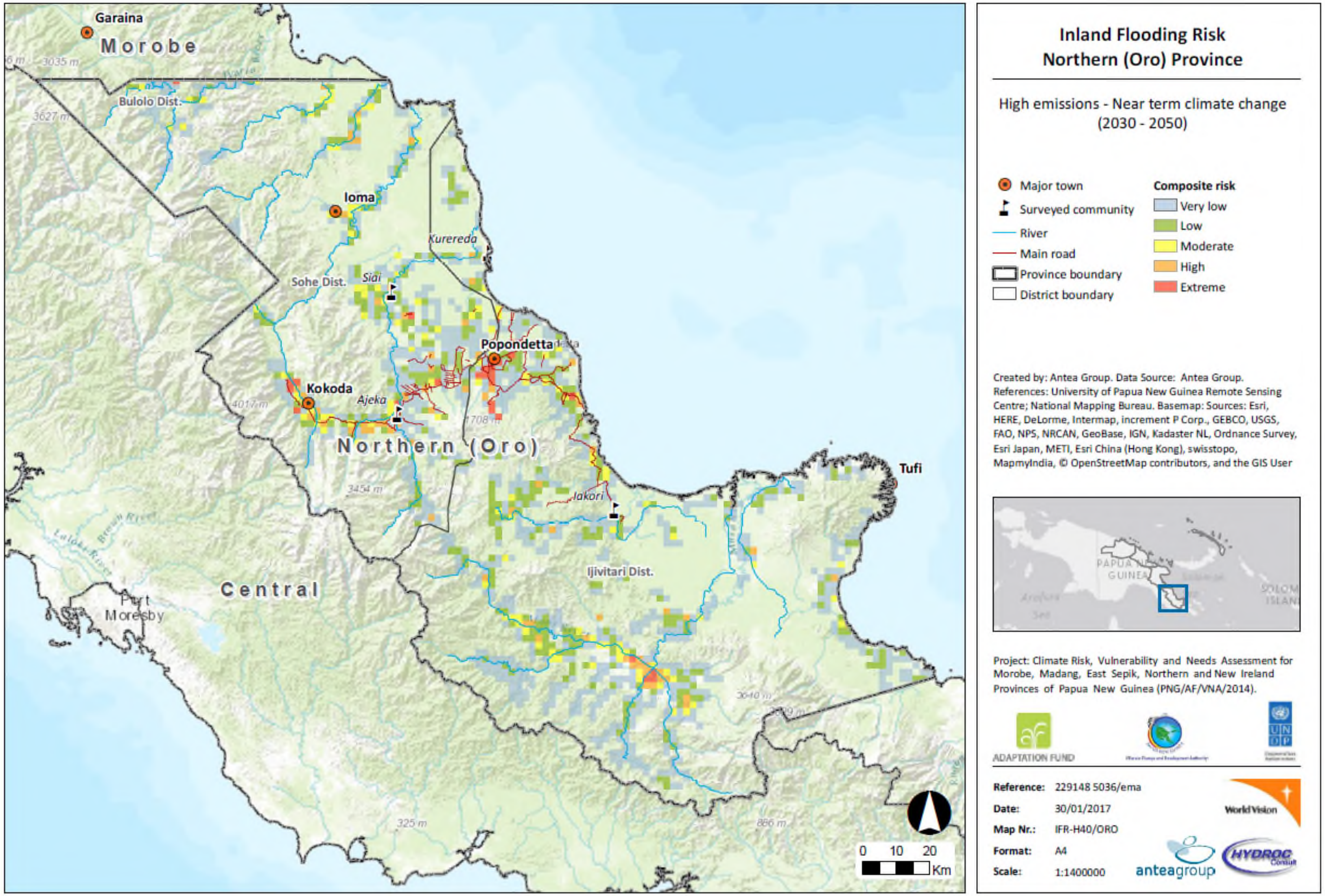

Figure 45. Inland Flooding Composite Risk (projected climate) Very Low Low Moderate High Extreme

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*

The most visible impact of drought in the province is observed at the northern face of Mount Lamington in the vicinity of Popondetta and the Kokoda Valley; the risk in these zones varies between 'High' and 'Extreme'. The whole province is subject to similar drought conditions but, as these specific regions contemplate important agricultural activity, they are more sensitive to extended periods without rain.

Zones where drought risk is expected to be the highest are the two palm oil plantation areas east of Kokoda and Popondetta, where drought risk is classified as extreme. The surrounding agricultural system is also characterized by the presence of palm oil blocks. The entire zone appears at high risk of drought because of the higher sensitivity to drought of these monoculture blocks, and the heavy reliance of the local communities on palm oil fruit to Popondetta, at the Higaturu oil palm factory and Kokoda . In addition, a smaller strip of land in the Pongani Valley on Dyke Ackland Bay, between Oro Bay and Tufi station, appears to have high drought risk due to the dominance of taro, sweet potato and banana cultures that are comparatively more sensitive than the surrounding systems.

Moderate drought risk, also due to agricultural activity, is expected at Cape Nelson in the vicinity of Gavida and Tufi, and more southerly on the lower slopes of the Topographers Range along Collingwood Bay and extending into Milne Bay area. Some farming clusters in the very flat alluvial flood plains of the Mambare, Opi, and Kumusi Rivers (and less significantly the Eia and Gira Rivers) are responsible for moderate drought risk depicted in the north of the province.

Finally, most of the upper catchments of the Musa and the Bariji rivers have a low drought risk, with the exception of the mountainous country in the Owen Stanley Range, which boasts gardens on very steep slopes at altitudes higher than 600 m. The data from the agricultural survey is however very uncertain for this last system.

The effect of climate change in drought patterns was shown to be limited for Oro Province (limited deterioration observed along Cape Nelson Rural). Consistently, the composite risk does not show a significant change in the future; a limited exacerbation of drought risk is expected.

Table 35. Distribution of drought risk classes

	DROUGHT RISK											
	RISK 1960-1990 %						RISK 2030-2050 %					
District	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Ijivitari District	0.0	10.6	11.7	6.4	0.6	70.7	0.0	10.6	11.7	6.4	0.6	70.7
Sohe District	0.0	5.2	9.3	7.4	1.5	76.6	0.0	5.2	9.3	7.4	1.5	76.6

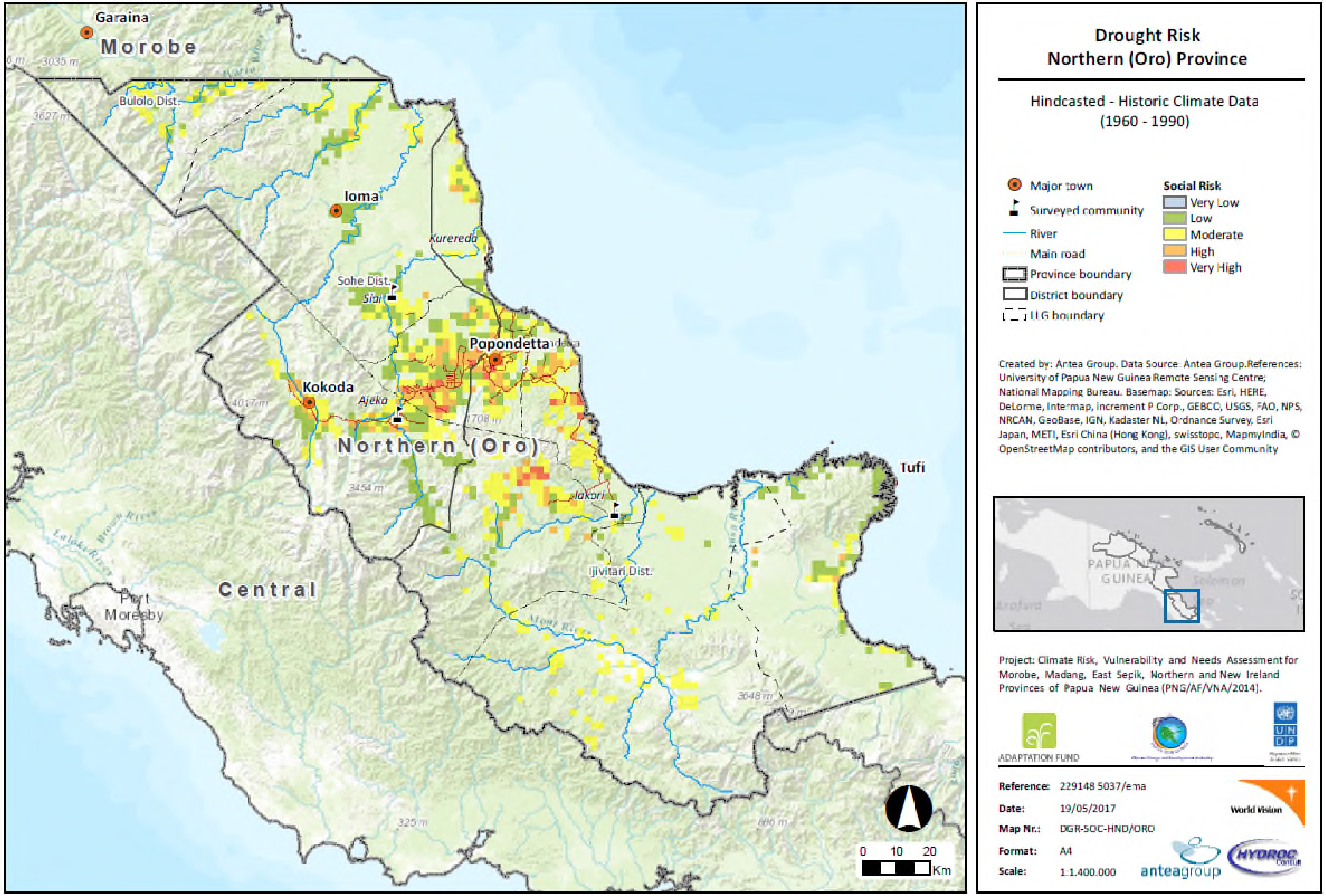

Figure 46. Drought Social Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

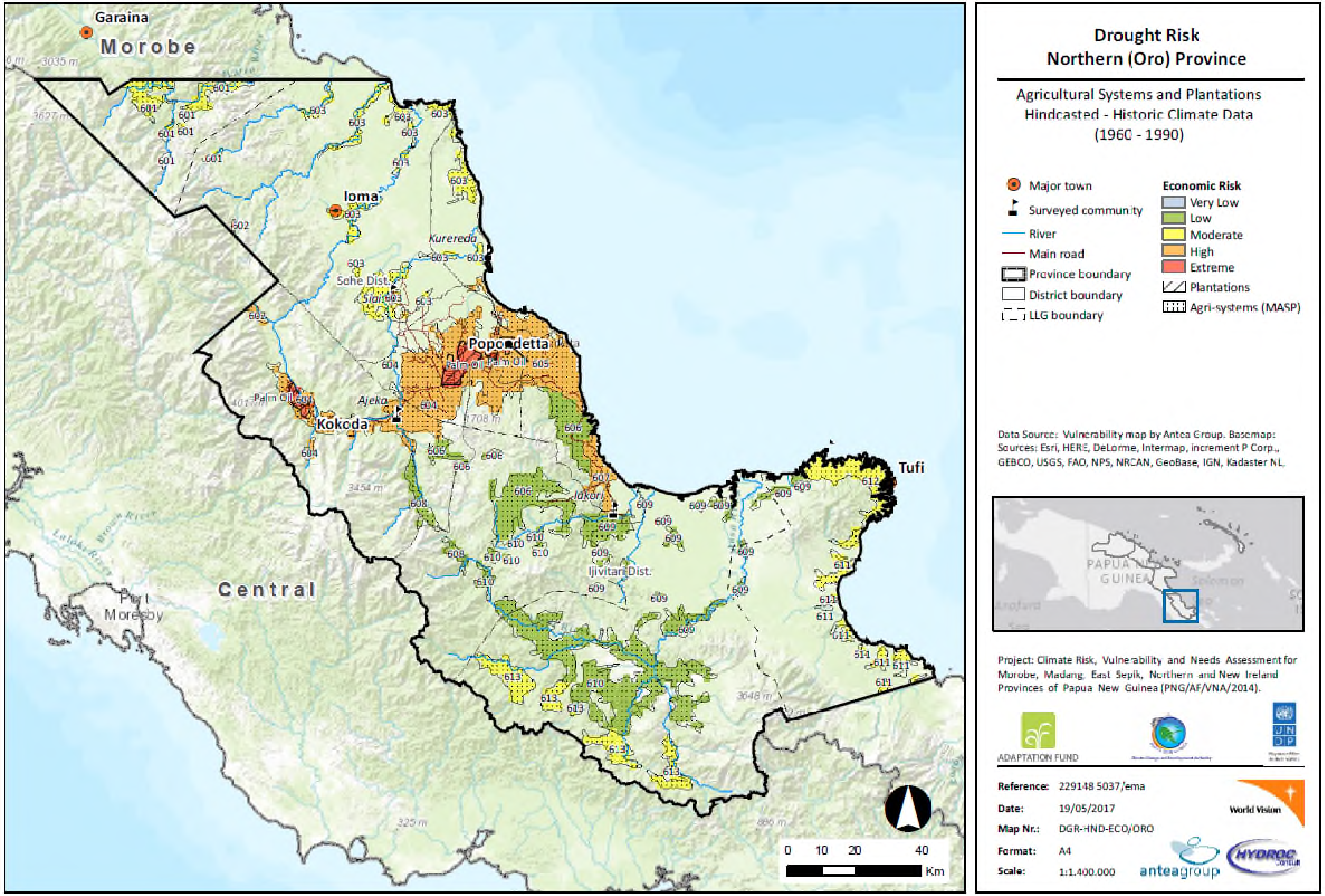

Figure 47. Drought Economic Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

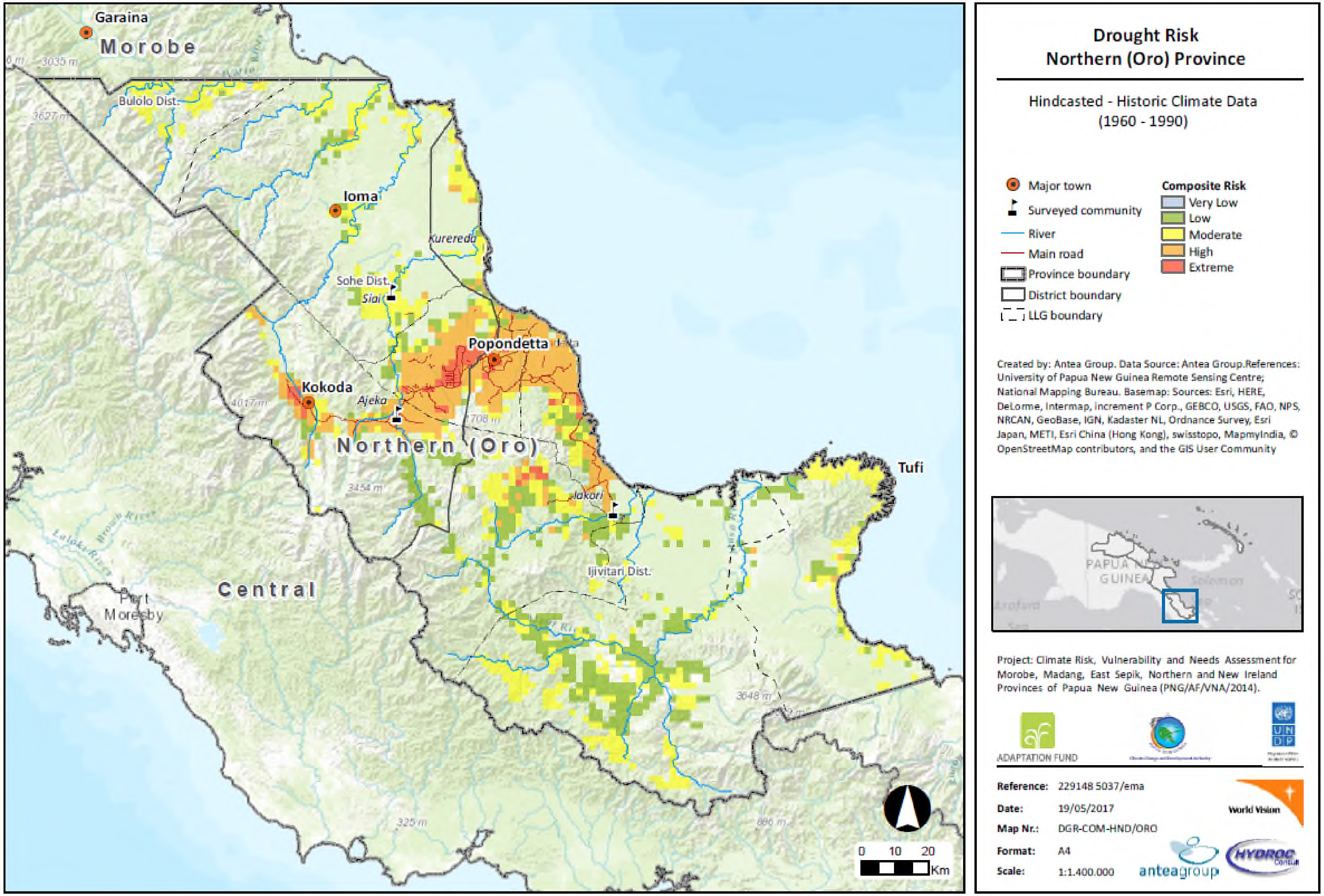

Figure 48. Combined Drought Risk (current climate) Very Low Low Moderate High Extreme

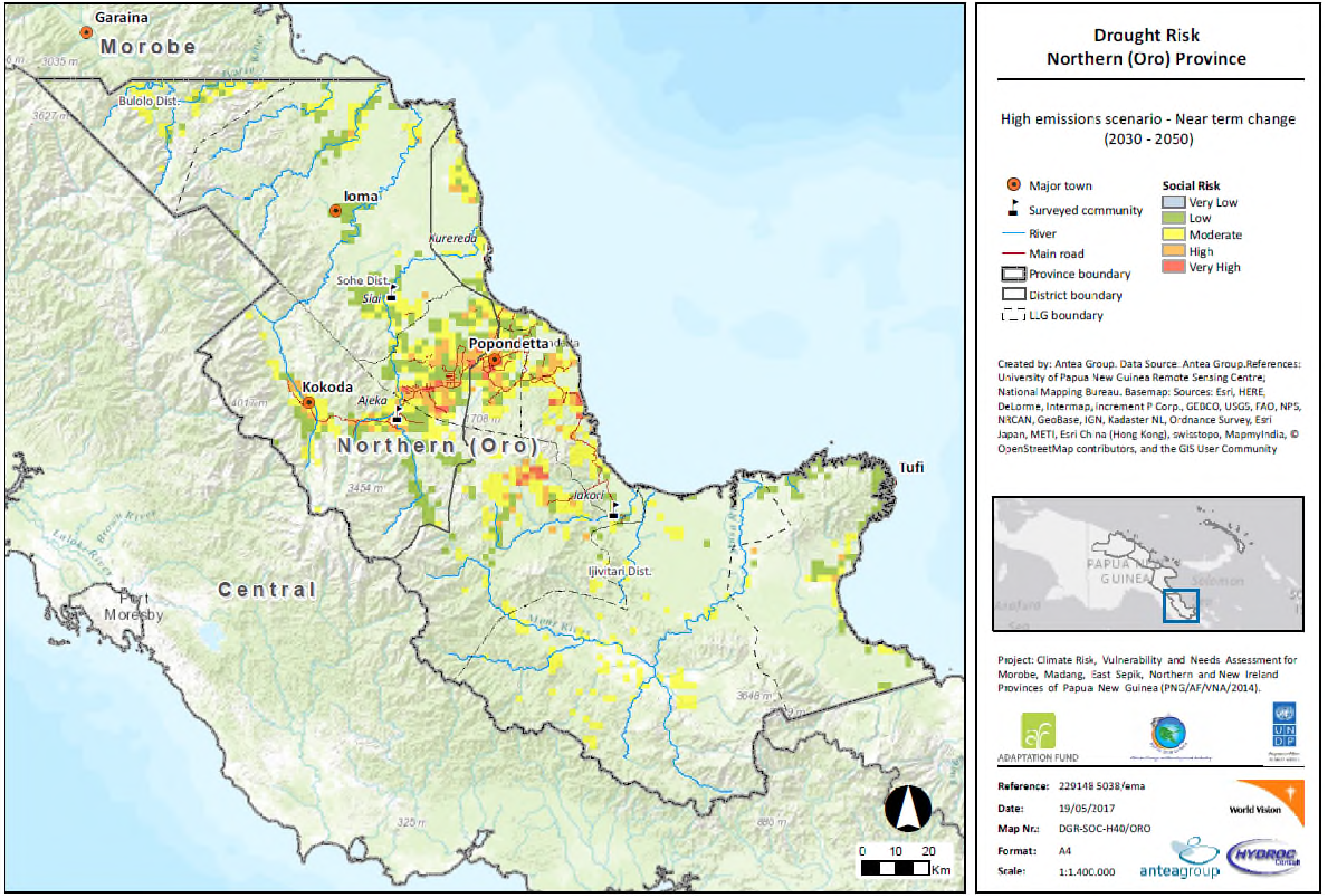

Figure 49. Drought Social Risk (projected climate) Very Low Low Moderate High Extreme

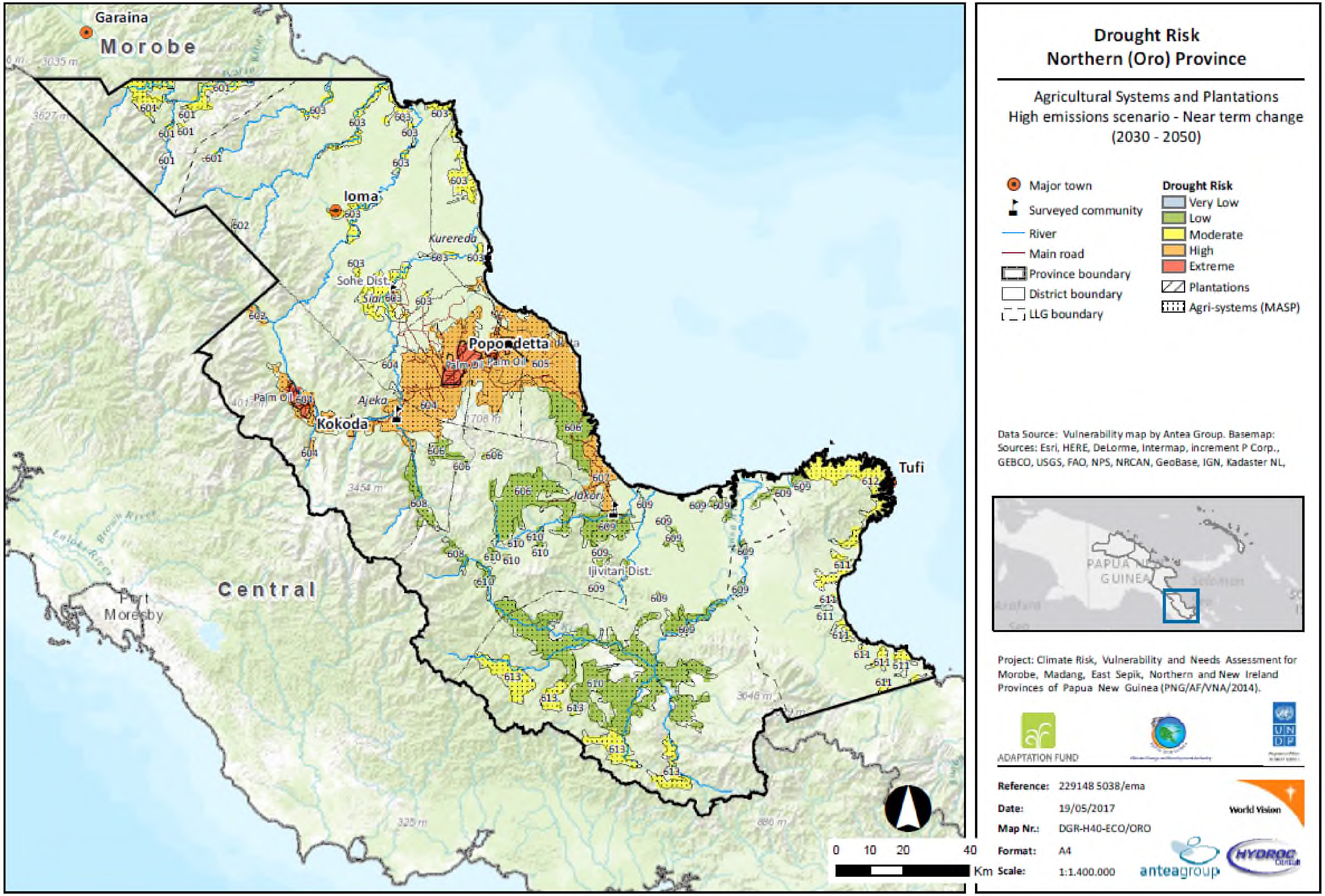

Figure 50. Drought Economic Risk (projected climate) Very Low Low Moderate High Extreme

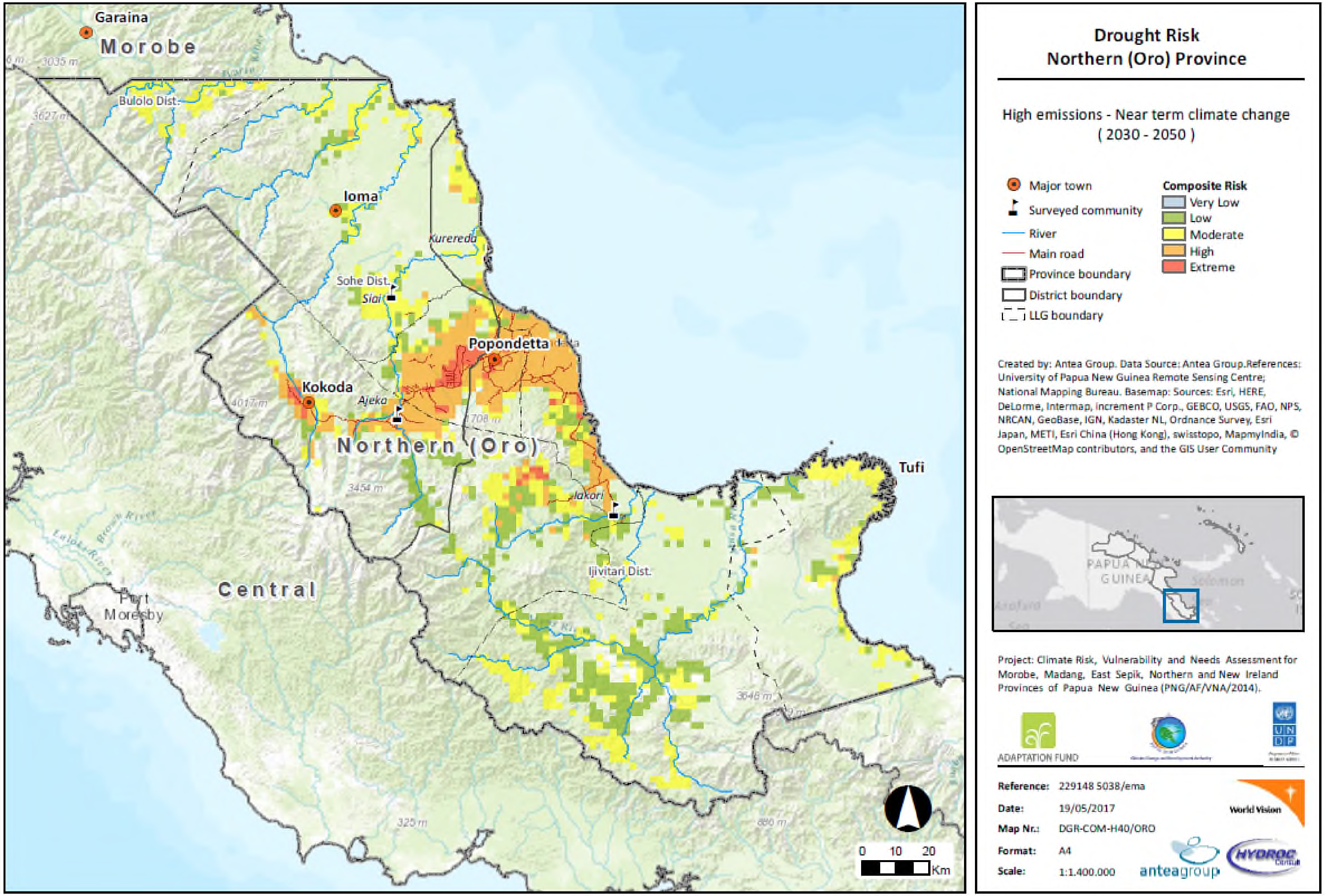

Figure 51. Combined Drought Risk (projected climate) Very Low Low Moderate High Extreme

2.3.4. *Extreme weather (tropical cyclone) Risk*

The extreme weather hazard is low in the Oro province, with historic cyclone occurrences between 1 and 5 for most of the territory. Vulnerability to cyclone is concentrated in the most developed areas and where agricultural activity is sensitive to extreme wind. Consequently, the associated extreme weather risk ranges from moderate to high in the more densely populated area of Popondetta and the Kokoda Valley.

According to expected temperature increases in the Pacific region, cyclones are expected to become less frequent in the Oro Province. Therefore, the composite risk does not show a significant change in the future. Only in the extreme south of the province at the headwaters of the Musa River in the Owen Stanley Range, does the risk level decrease from low to very low.

Overall, the composite risk does not show a significant change in the future; a slight reduction in cyclone risk is expected.

Table 36. Distribution of cyclone risk classes

	CYCLONE RISK											
	RISK 1960-1990 %						RISK 2030-2050 %					
District	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Ijivitari District	3.0	13.2	10.3	2.9	0	70.6	4.0	12.3	10.1	2.9	0	70.6
Sohe District	6.4	4.8	10.0	3.7	0	75.1	6.4	4.8	10.0	3.7	0	75.1

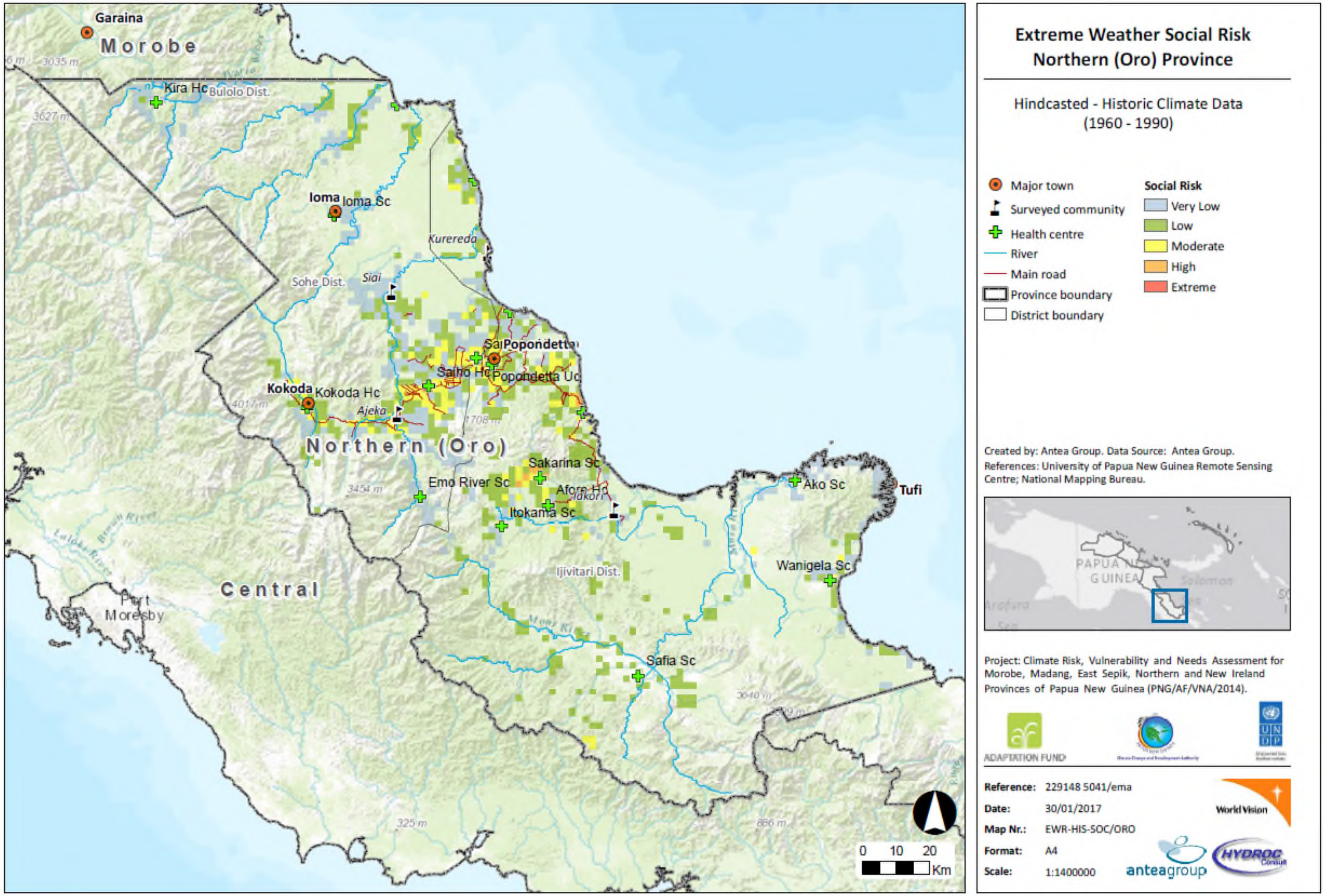

Figure 52. Tropical cyclones Social Risk (current climate) Very Low Low Moderate High Extreme

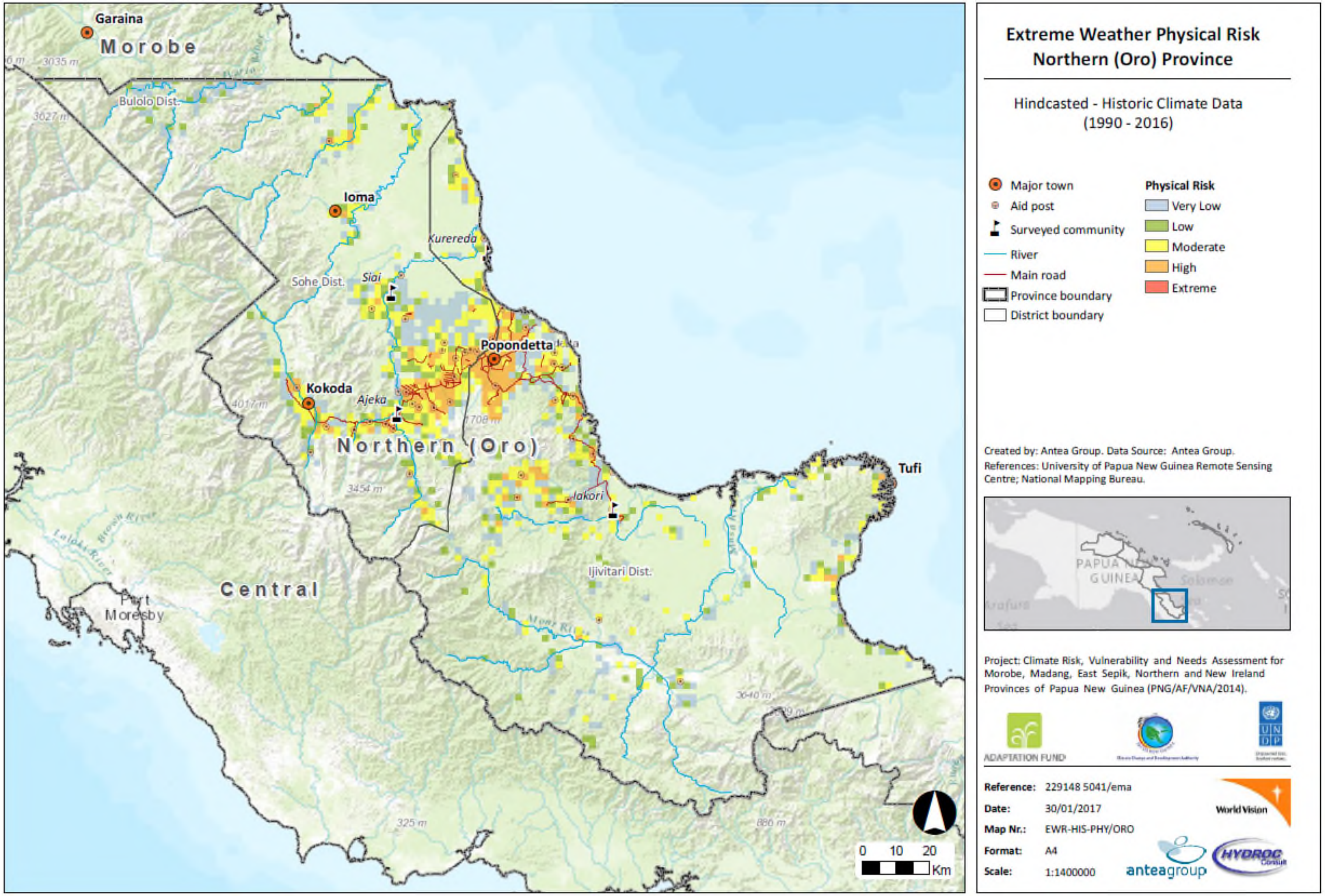

Figure 53. Tropical cyclones Physical Risk (current climate) Very Low Low Moderate High Extreme

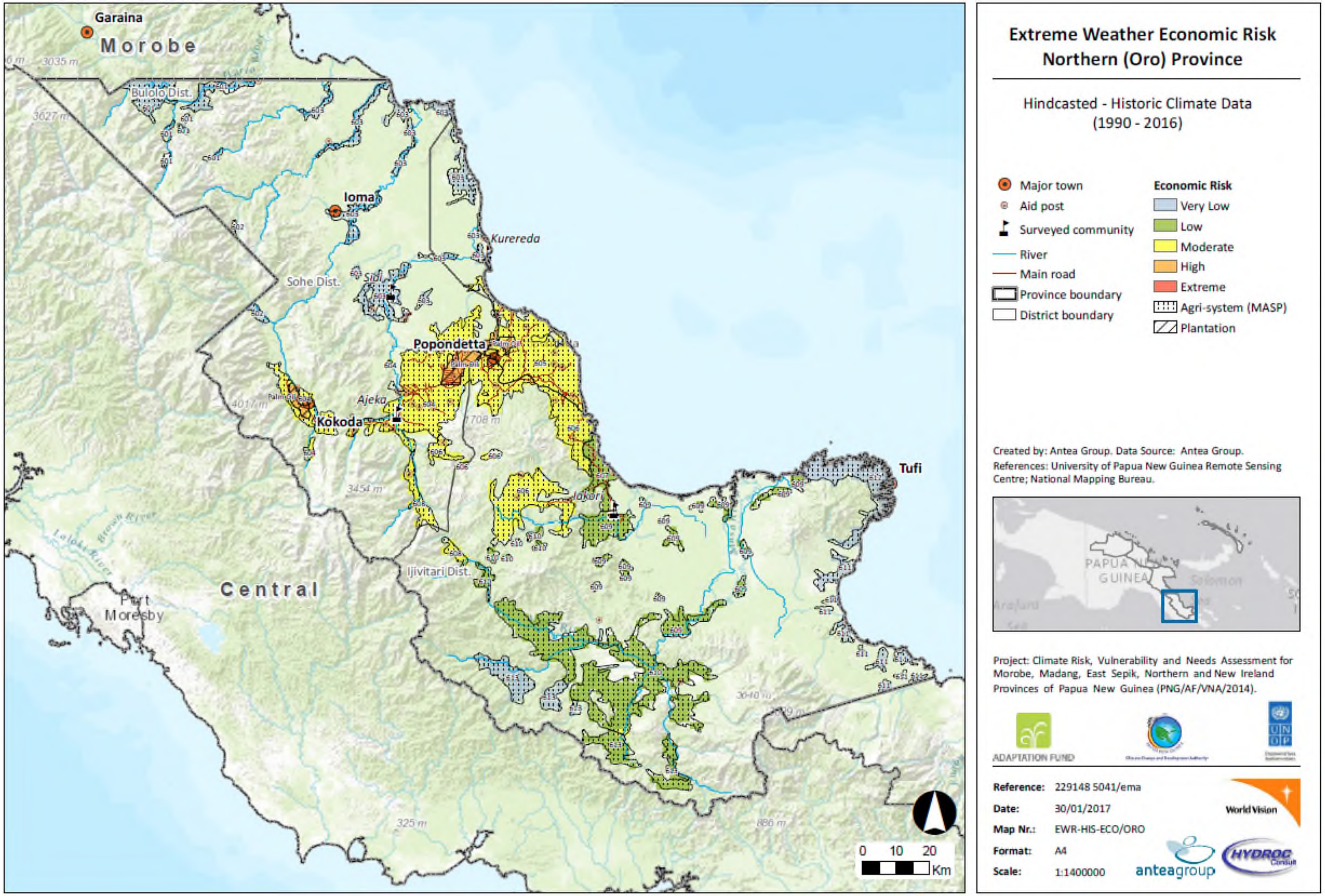

Figure 54. Tropical cyclones Economic Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

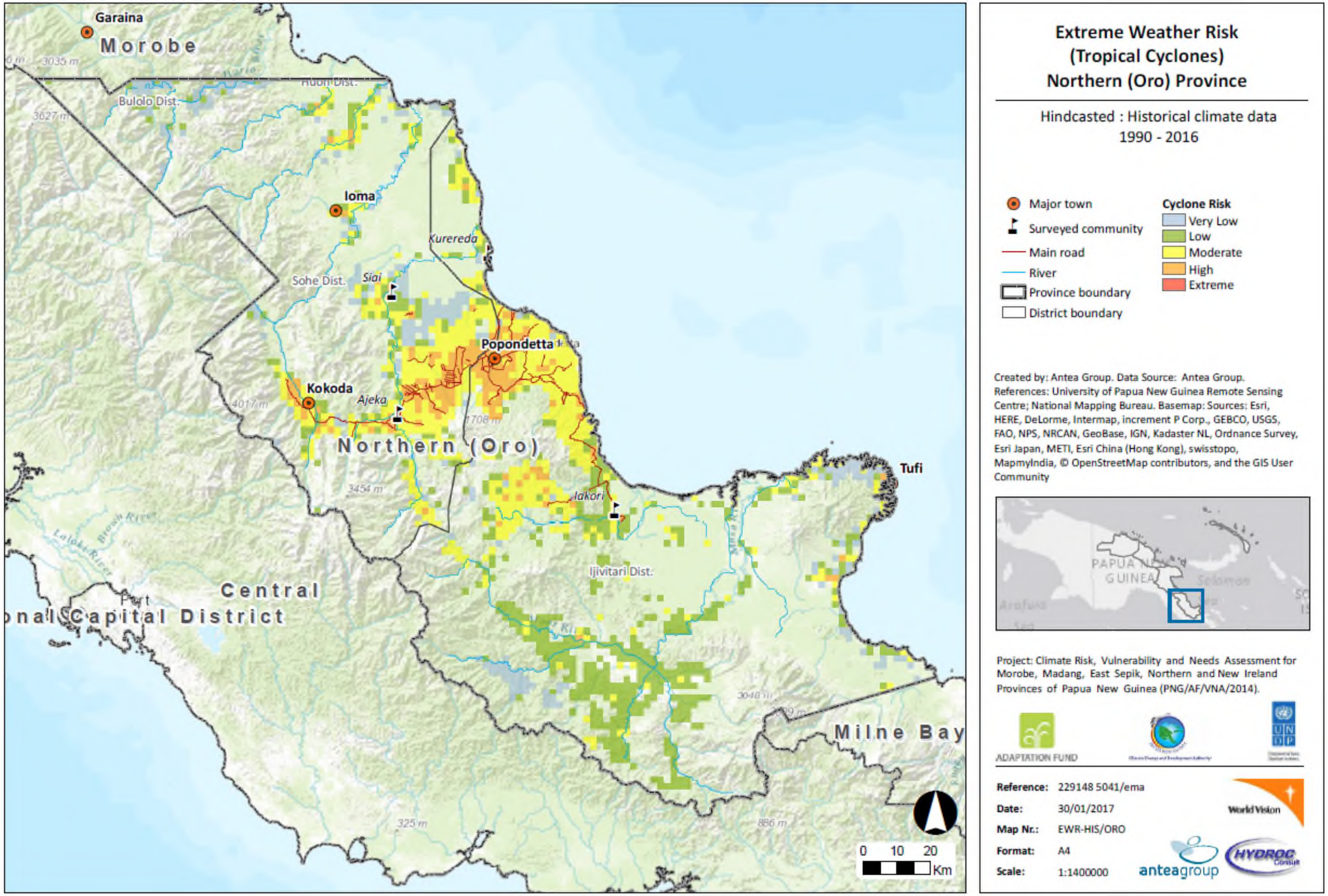

Figure 55. Tropical cyclones Composite Risk (current climate) Very Low Low Moderate High Extreme

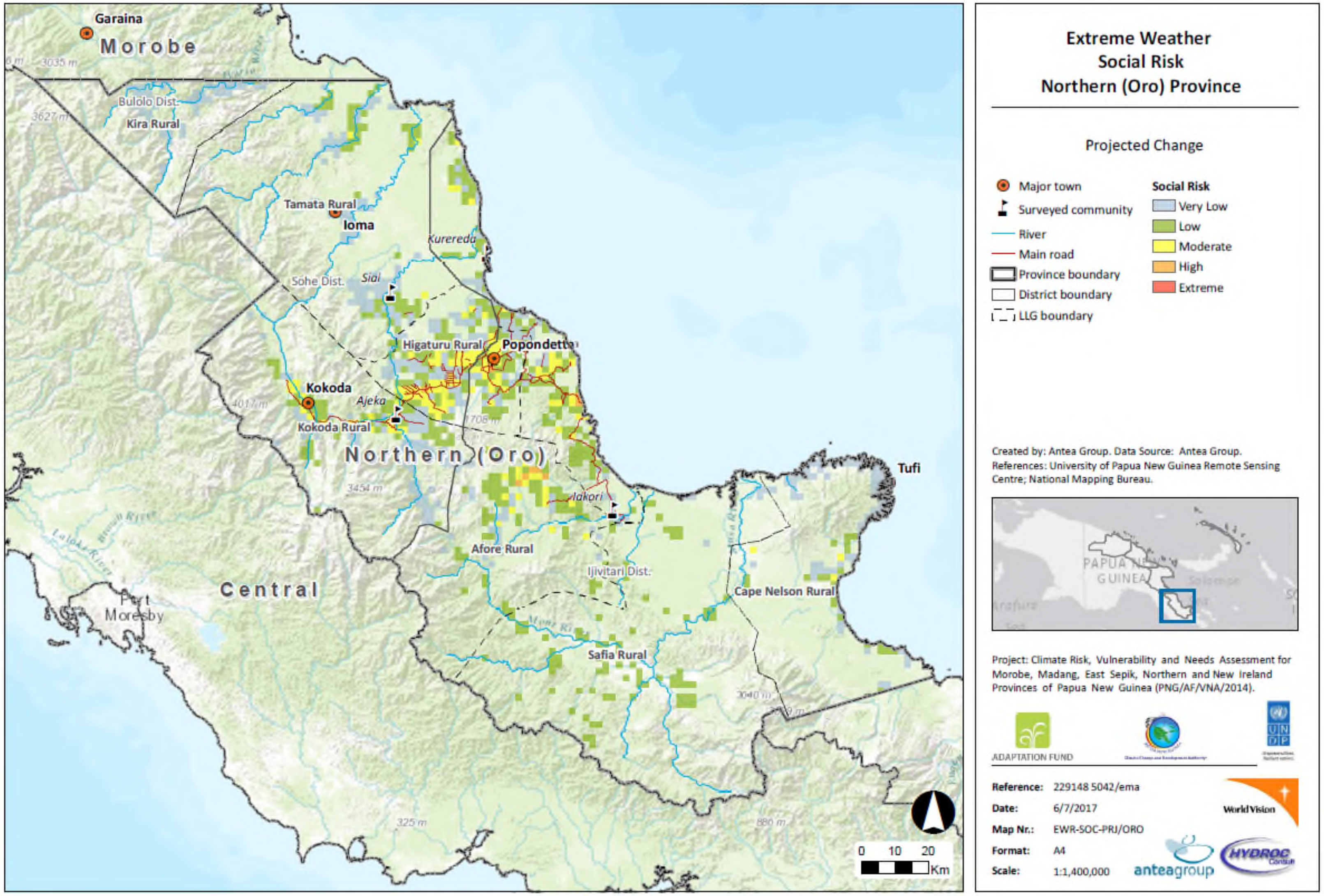

Figure 56. tropical cyclones Social Risk (projected climate) Very Low Low Moderate High Extreme

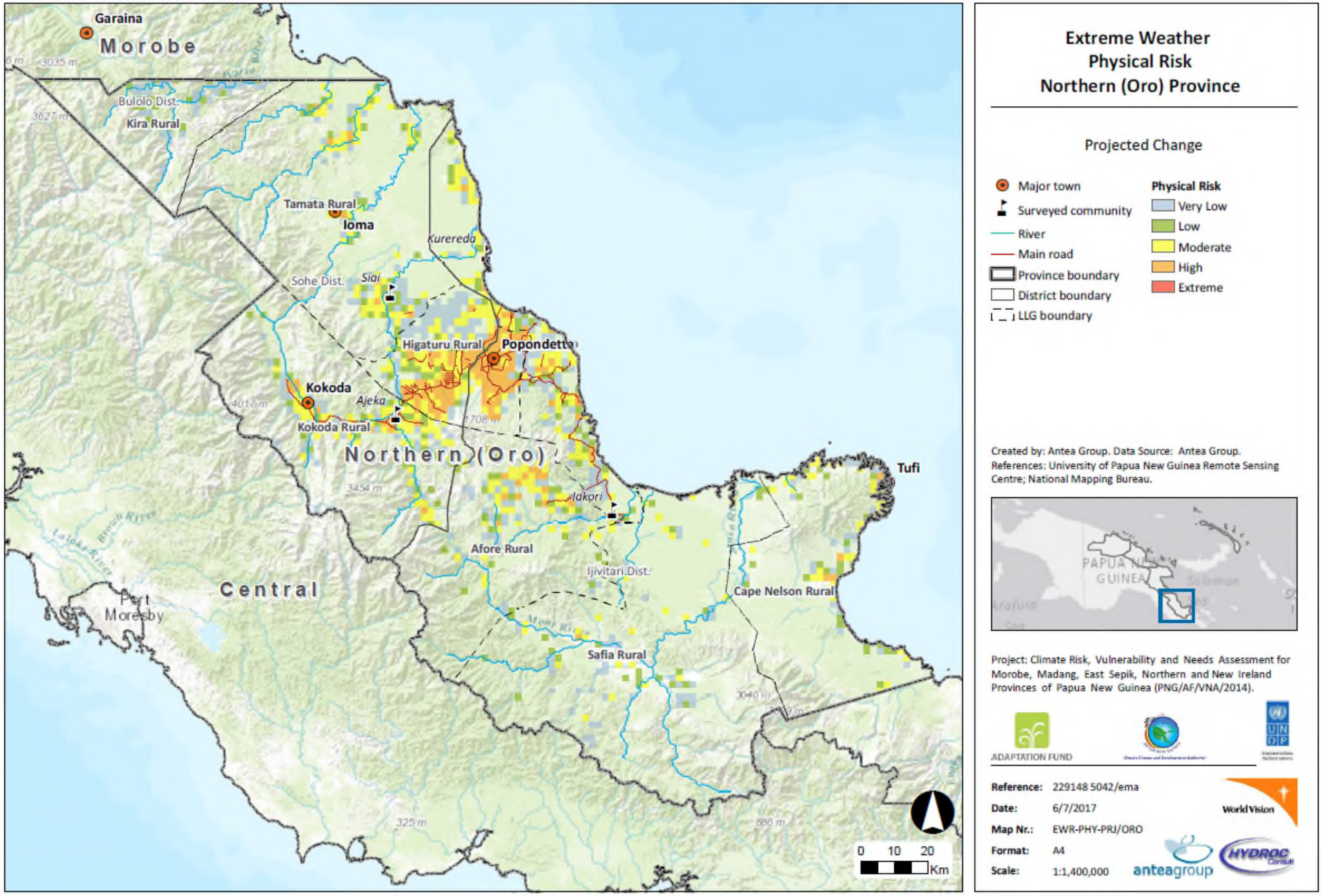

Figure 57. Tropical cyclones Physical Risk (projected climate) Very Low Low Moderate High Extreme

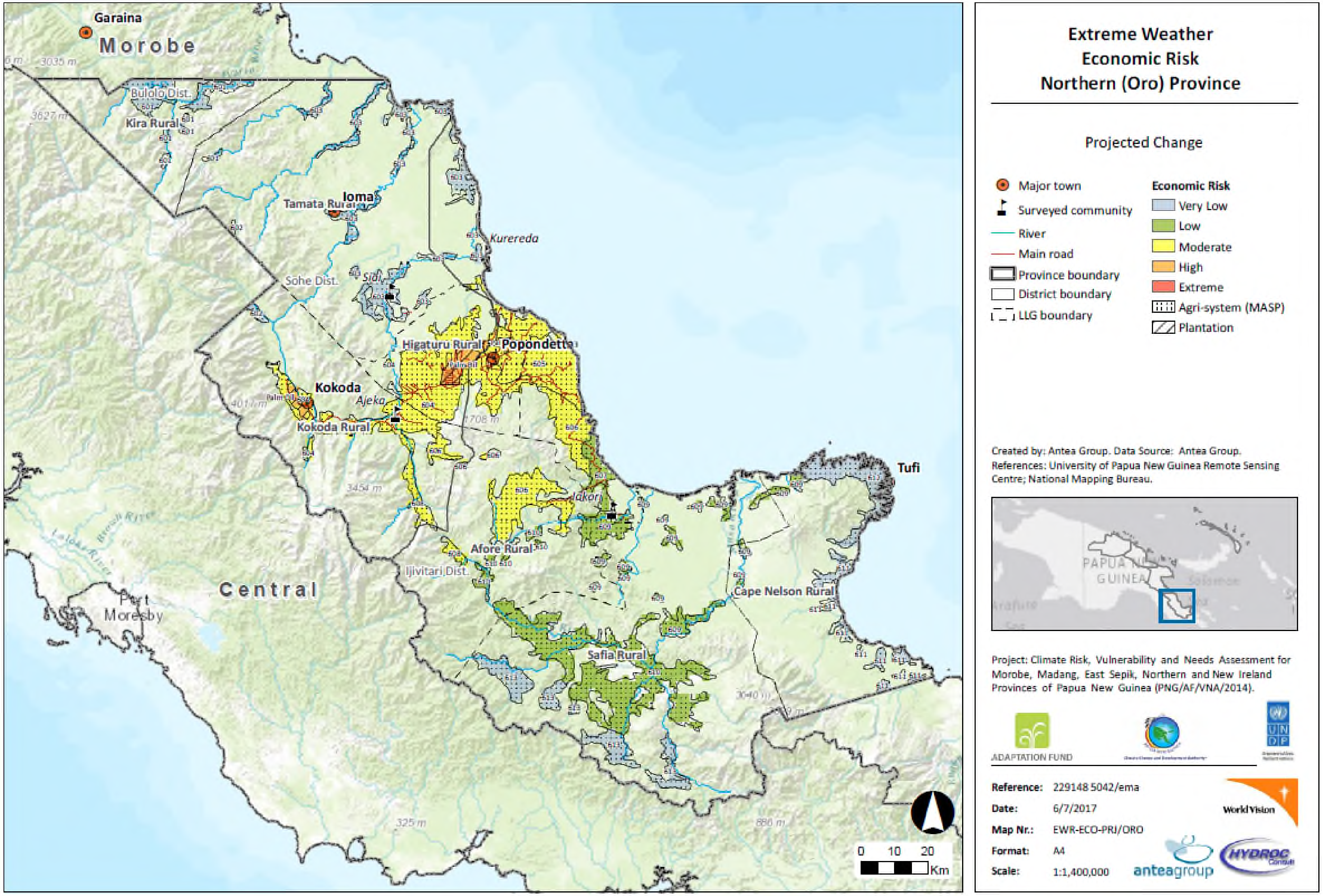

Figure 58. tropical cyclones Economic Risk (projected climate) Very Low Low Moderate High Extreme

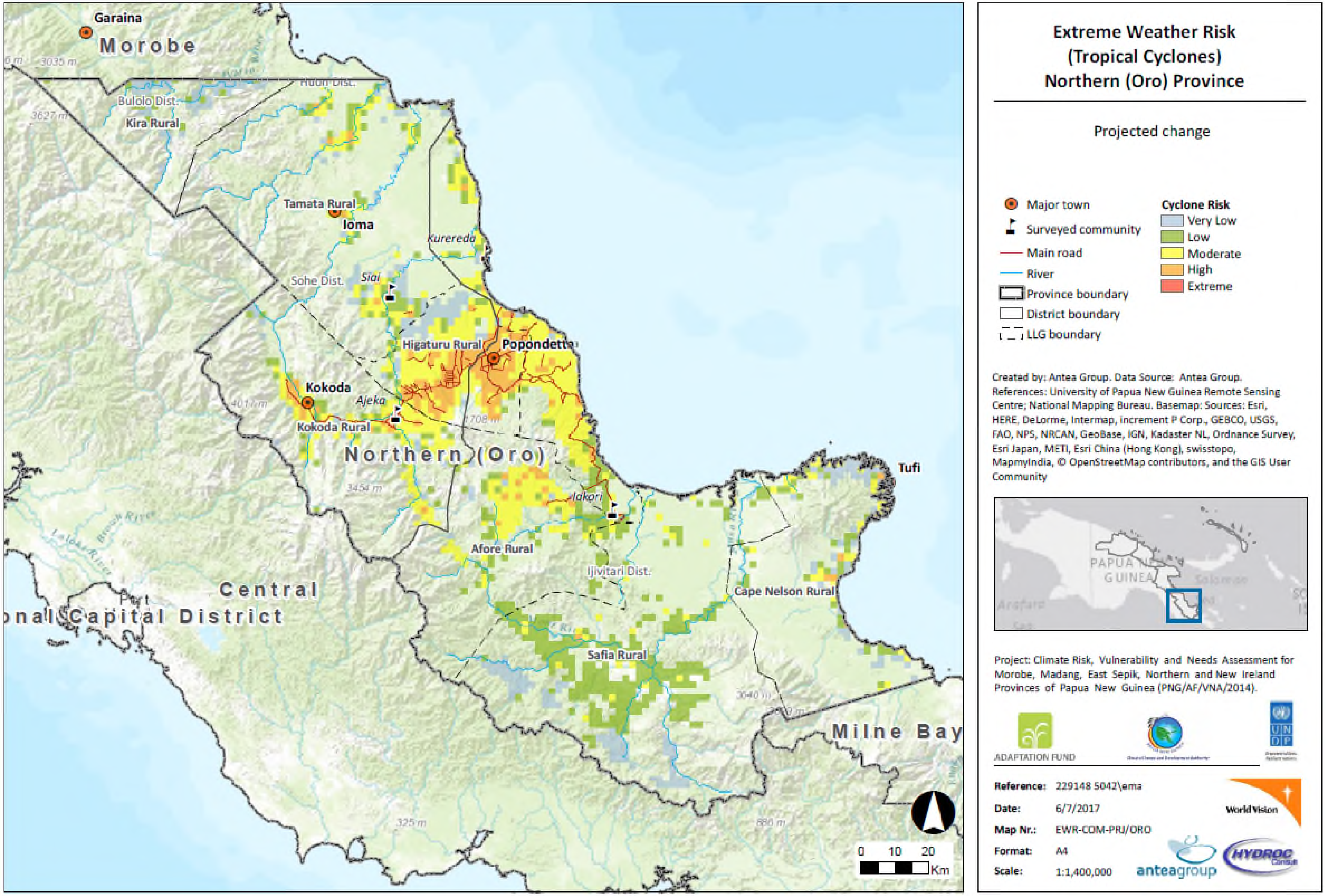

Figure 59. Tropical cyclones Composite Risk (projected climate) Very Low Low Moderate High Extreme

2.3.5. *Increase of precipitation intensities and variability*

Because the Northern Province has a drier climate than the other studied provinces, this hazard is relatively low over the whole territory. Subsequently, respective risk levels also remain relatively low. On the one hand, vulnerability to intense rainfall is highest in the urbanised areas where more runoff is generated. On the other hand, vulnerability to high annual rainfall influences the composite risk more strongly where valuable sensitive crops are being cultivated.

Under current climate conditions, the composite risk is mostly driven by the urban component and appears at higher levels in Popondetta and the neighbouring agglomerations of Soputa, Irigi, Siroga,, Kiorota, along the road between Sangara and Waseta and between Sivepe and Kendata. Except for a small area of moderate risk near Ioma in the north, the social risk from high rainfall is low.

Both annual rainfall and rainfall intensity are expected to increase in the future. Heavier rainfall should occur primarily on the north-western coast of the Oro Province, and the associated risk should increase accordingly in the agricultural alluvial plains of the Opi River delta and in the gardens and plantations around Kendata, between Sanananda and Dombada. Risk also increases slightly in Ioma and the villages of the Eia and Gira Rivers north of the province.

Table 37. Distribution of precipitation intensities and variability risk

	PRECIPITATION INTENSITY AND VARIABILITY RISK											
	RISK 1960-1990 %						RISK 2030-2050 %					
District	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Ijivitari District	26.9	2.3	0.0	0.0	0.0	70.8	26.4	2.7	0.1	0.0	0.0	70.8
Sohe District	20.2	3.1	0.0	0.0	0.0	76.7	17.0	6.1	0.2	0.0	0.0	76.7

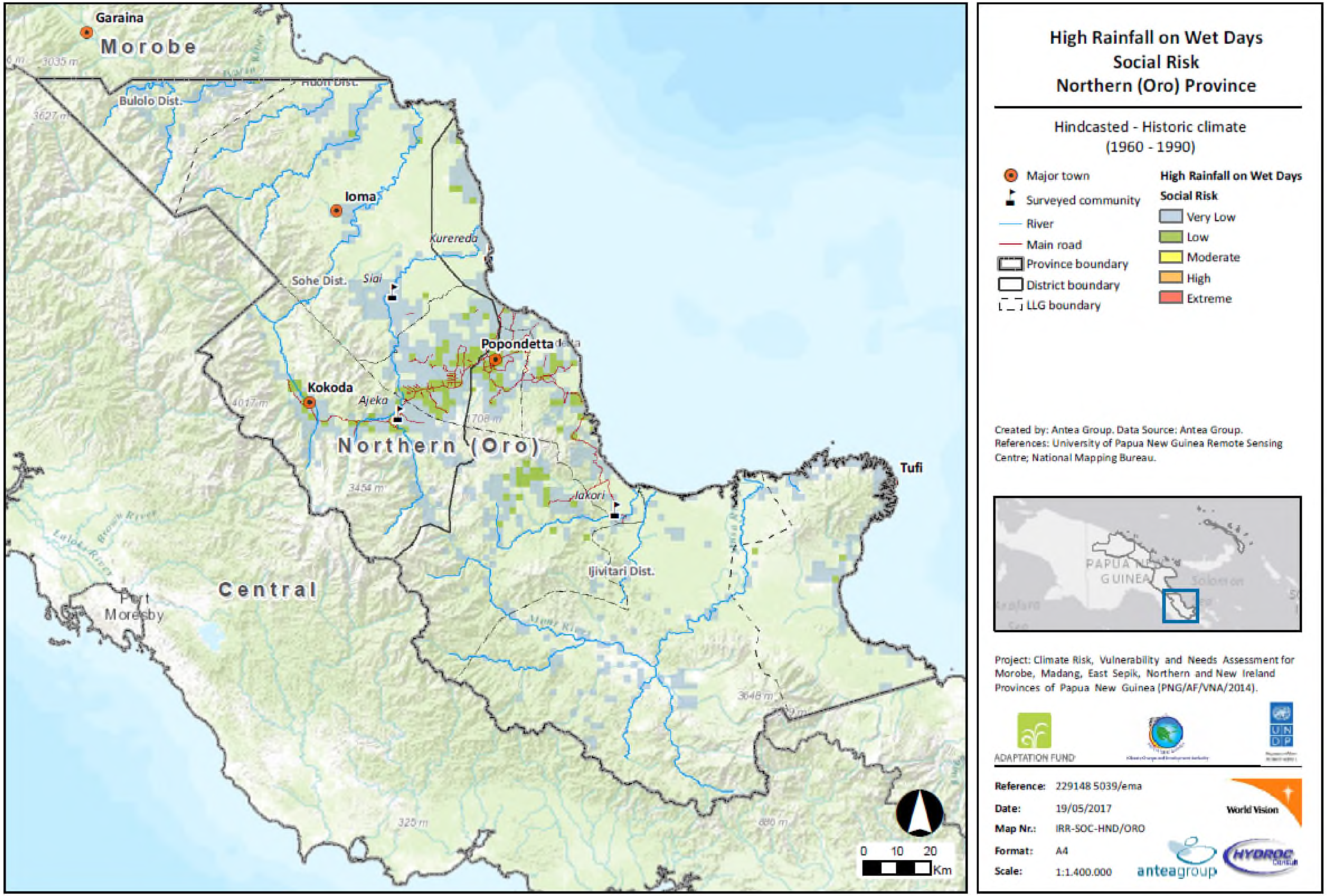

Figure 60. Precipitation intensities and variability social risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

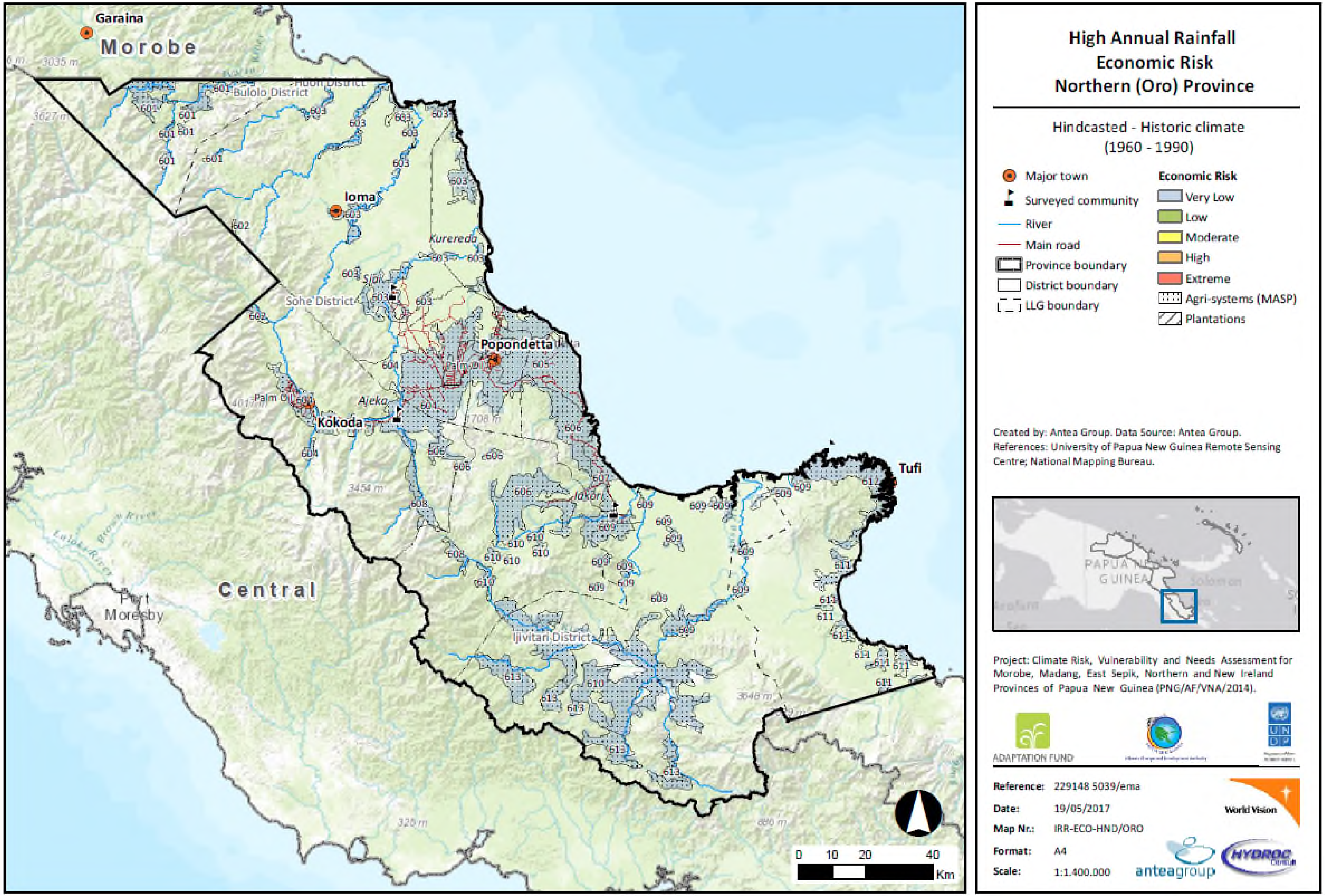

Figure 61. Precipitation intensities and variability Economic Risk (projected climate) Very Low Low Moderate High Extreme

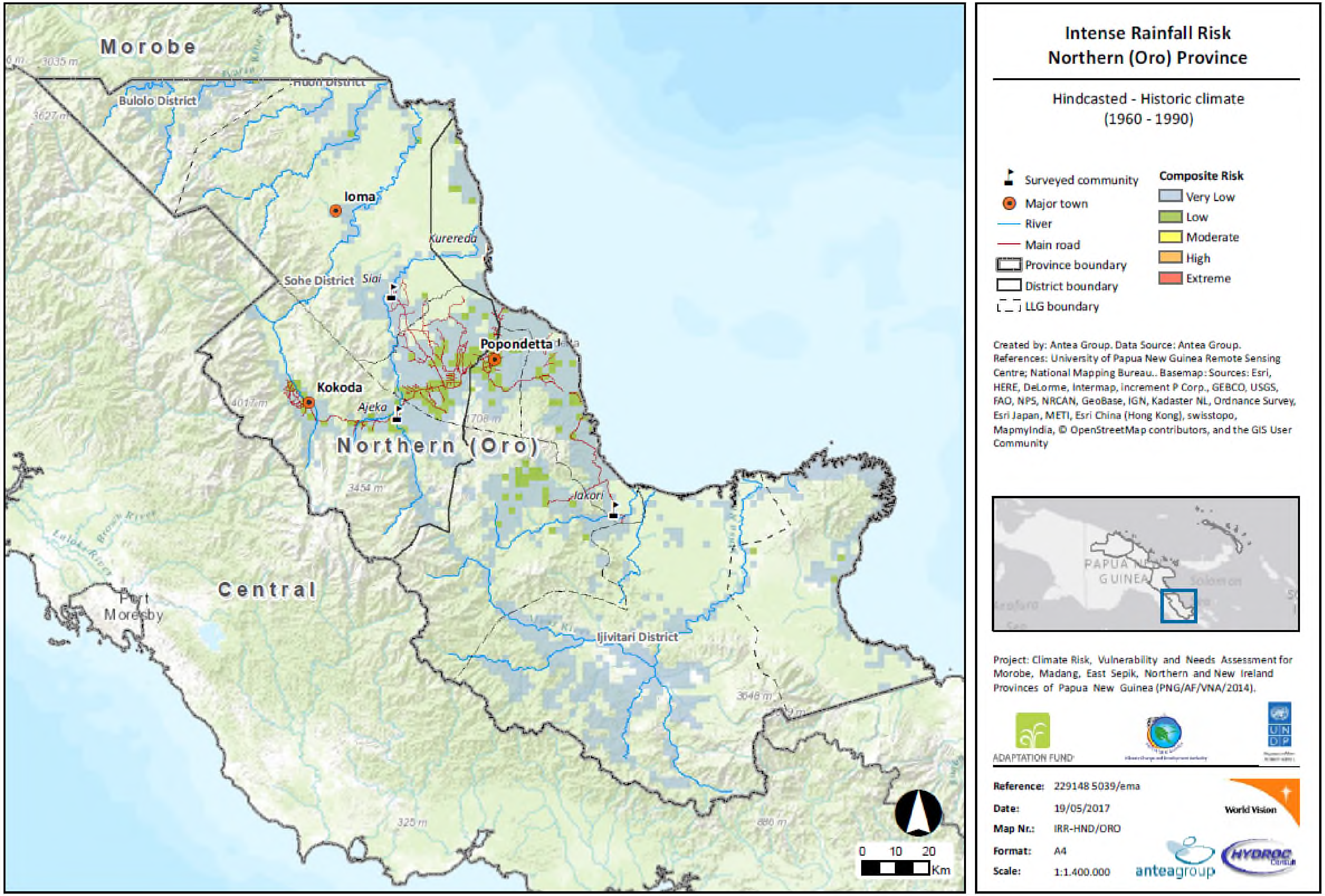

Figure 62. Precipitation intensities and variability Risk (projected climate) Very Low Low Moderate High Extreme

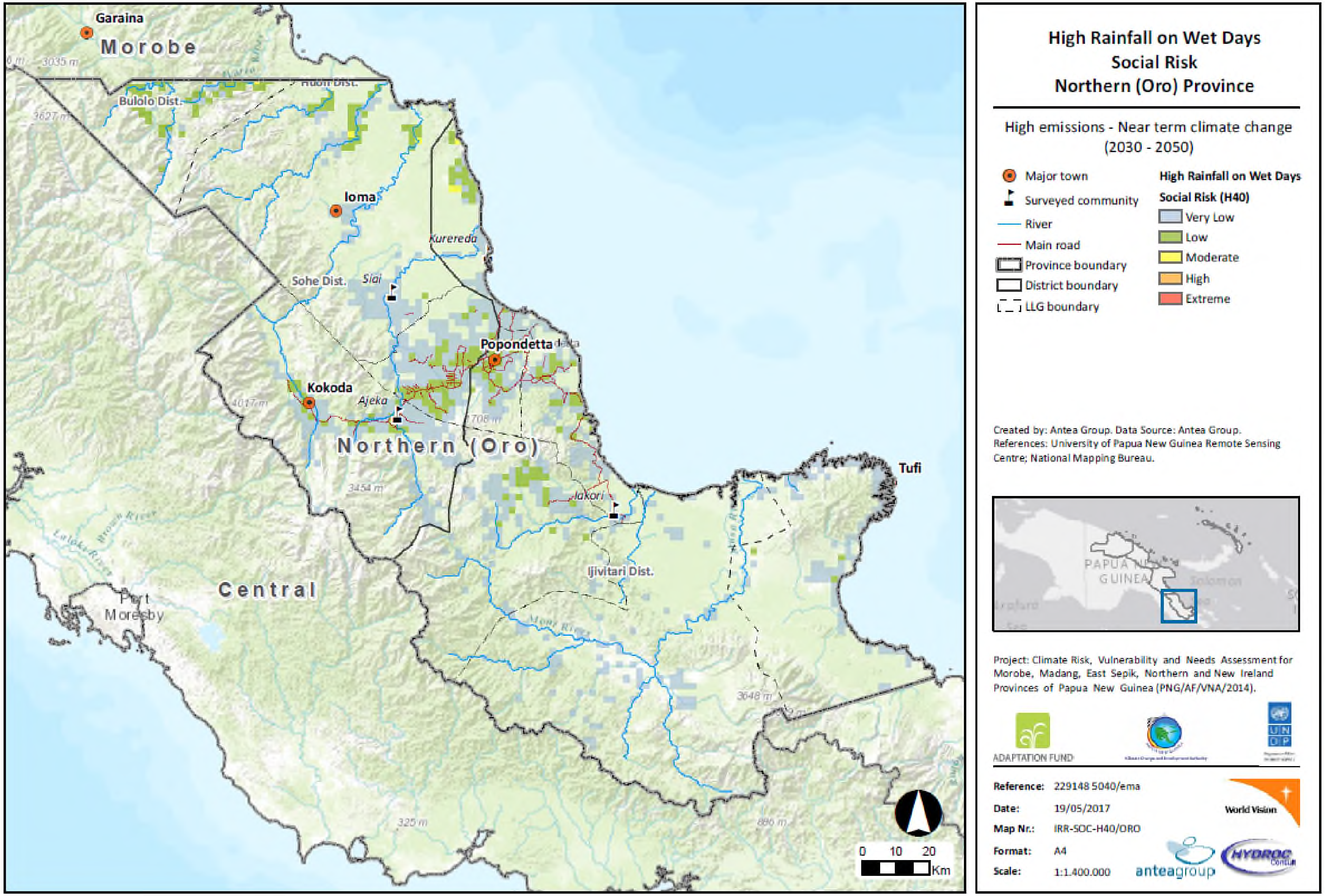

Figure 63. Precipitation intensities and variability Social Risk (projected climate) Very Low Low Moderate High Extreme

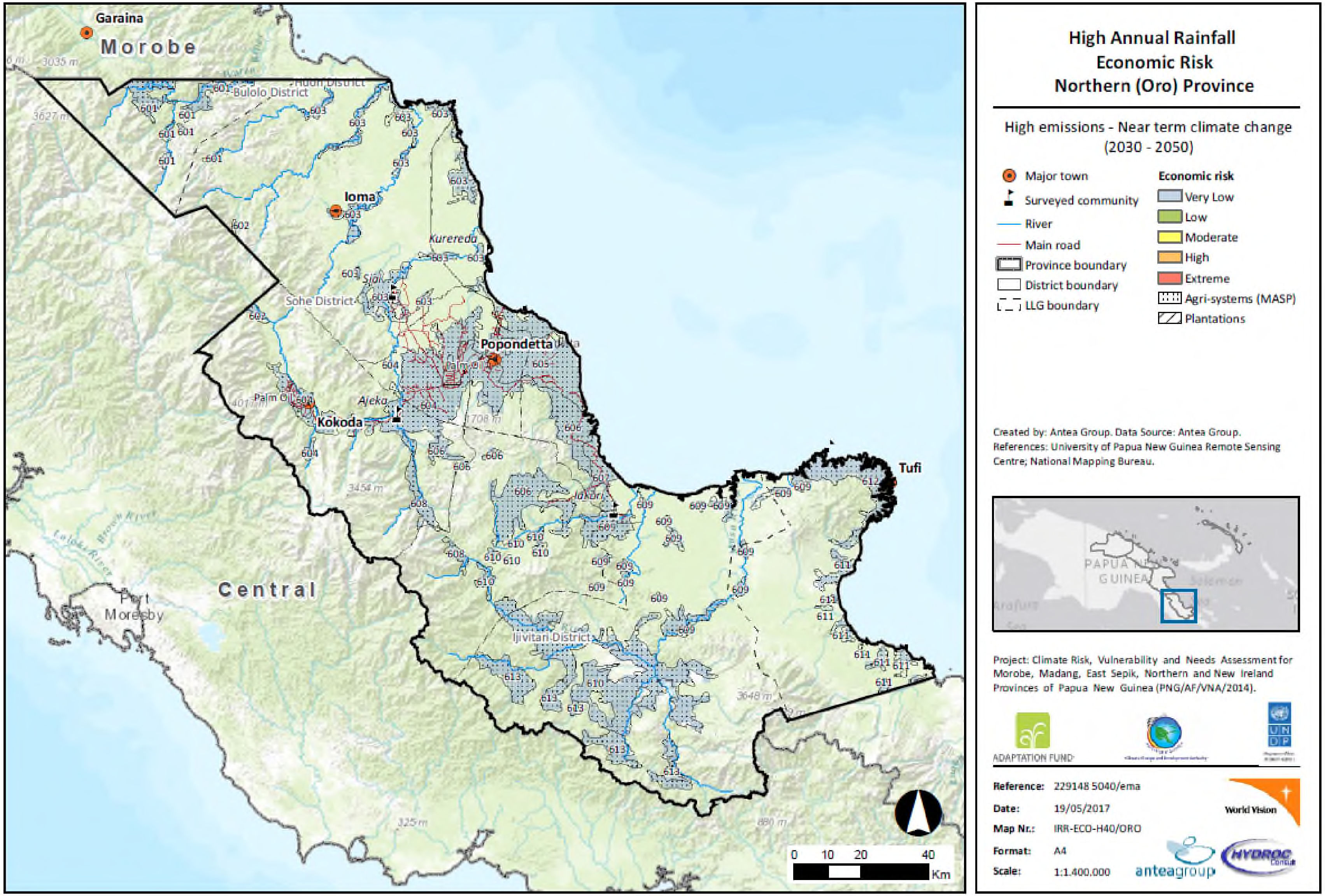

Figure 64. Precipitation intensities and variability Economic Risk (projected climate) Very Low Low Moderate High Extreme

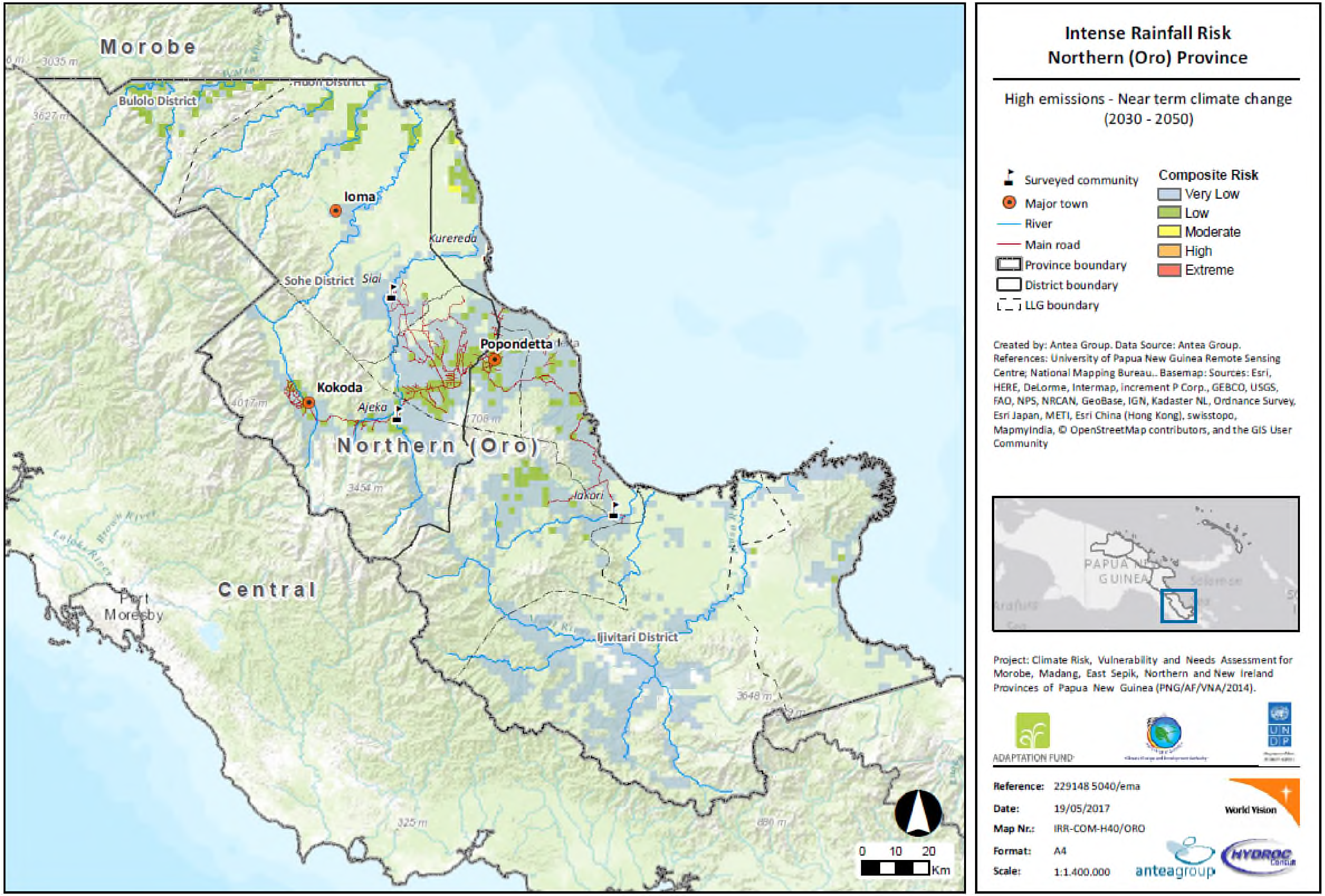

Figure 65. Precipitation intensities and variability Composite Risk (projected climate) Very Low Low Moderate High Extreme

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.

Table 38 shows the percentage distribution of composite risk classes in the province for the current and projected climate.

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 38. Distribution of composite risk classes

	COMPOSITE RISK											
	RISK 1960-1990 %						RISK 2030-2050 %					
District	**0**	**1**	**2**	**3**	**4**		**0**	**1**	**2**	**3**	**4**	
Ijivitari District	15.3	11.2	9.4	1.8	0.0	62.3	15.3	11.2	9.2	1.9	0.0	62.3
Sohe District	8.7	8.8	9.0	3.1	0.0	70.5	8.7	8.7	9.0	3.0	0.1	70.5

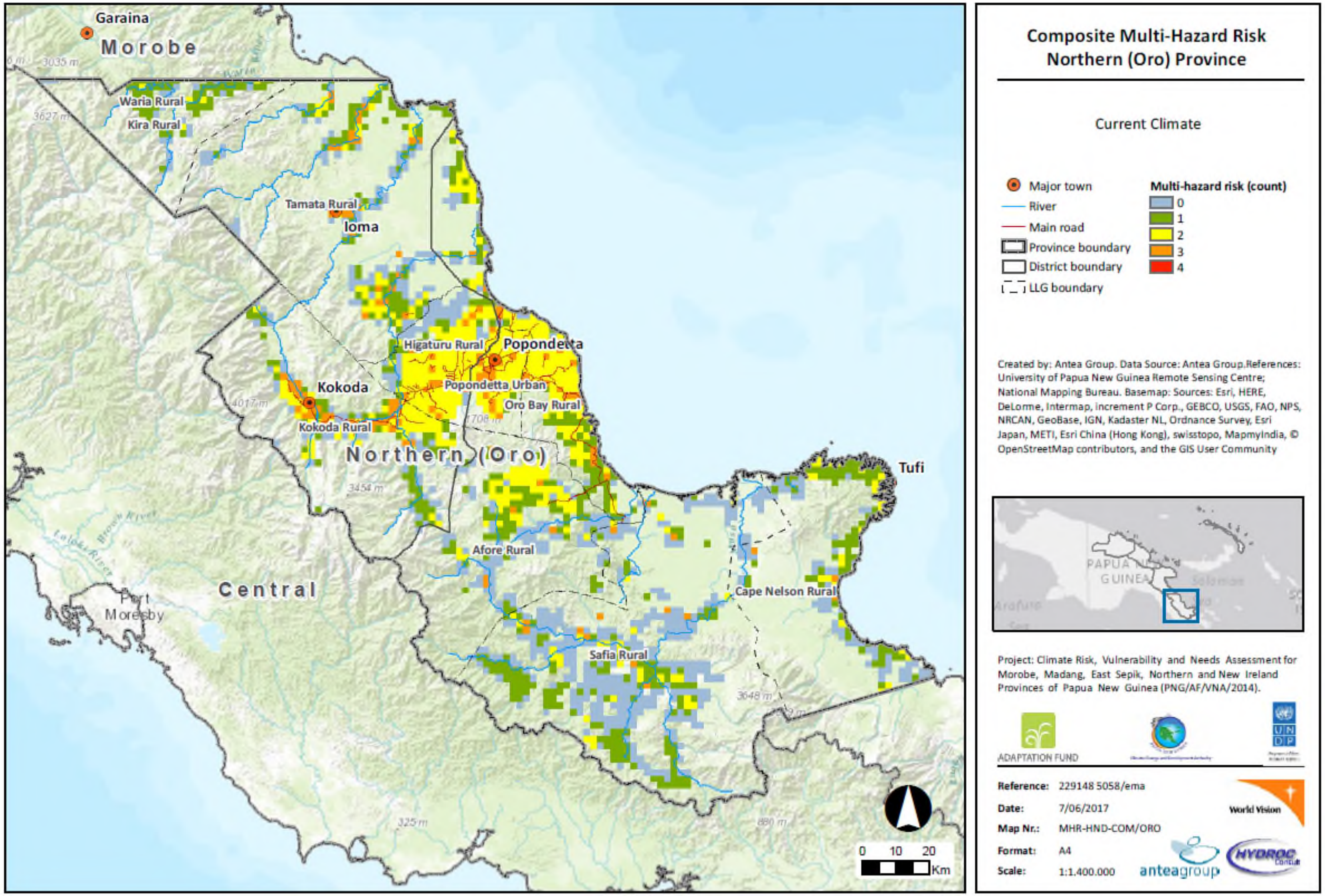

Figure 66. Composite Multi-Risk Map Northern Province (current).

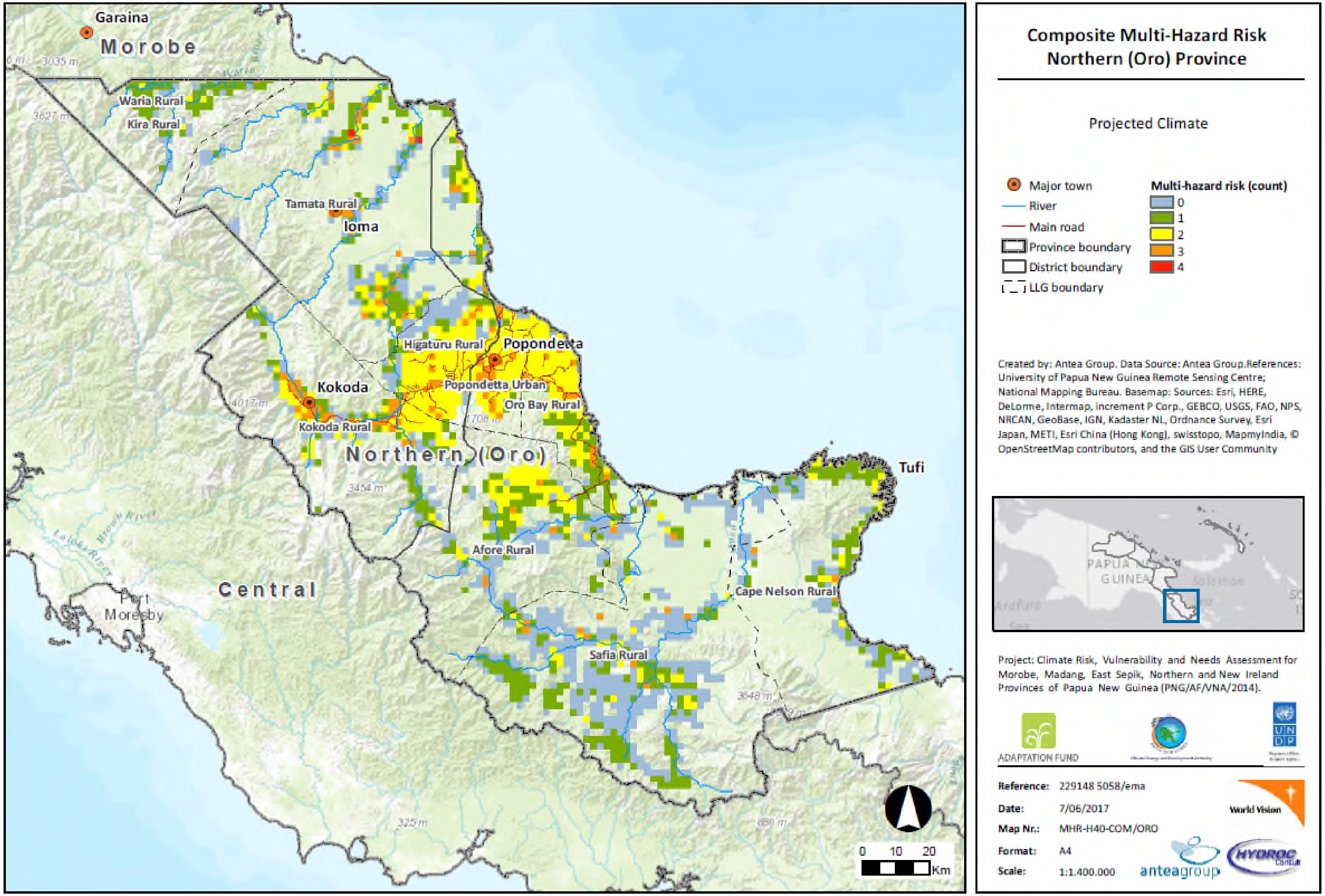

Figure 67. Composite Multi-Risk Map Northern Province (future).

3. DISTRICT RISK PROFILES

3.1. *Ijivitari Risk Profile*

3.1.1. *General description*

Ijivitari District stretches south east of Popondetta and from the Owen Stanley Ranges in the west across the Managalas Plateau and Mt. Lamington to the Nelson Range in the east. The district continues down to the coastal fjords of Tufi and then further south to Collingwood Bay. Much of ijivitari is mountainous, and only 24% of the land area is occupied, mostly on the coast and the lowland river margins.

Kaukau, coconut and sago are important subsistence crops for the district but there are few opportunities for income from these activities. Oil Palm is a high income earner on the coast. The inland areas of Ijivitari have a high potential for agriculture but remain very isolated from services.

Figure 68. Ijivitari District

The district headquarters is located in Ijivitari. There are 5 Local Level Governments in this district: Oro Bay Rural, Safia Rural, Afore Rural, Popondetta Urban and Tufi Rural. The number of wards assigned to this district is 84.

Ijivitari District has a population of 99,762[19]. The average population density is relatively low, 22.4 inhabitants per km^2, with the highest population densities occurring on the northern coastal floodplains, on the Managalas Plateau and in the coastal areas of Collingwood Bay. The Moni Valley and floodplains of the Musa River have lower densities of 10 persons/km^2 or less. Over half of the district consists of unoccupied swamps and mountains. The age dependency ratio for the district is 83.5.

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

The most vulnerable and disadvantaged people in the district are those living in and around Tufi and in the coastal areas of Collingwood Bay who are constrained by moderate agricultural pressure and very low incomes. People in the Moni Valley around Safia, Obea, Oroubi, Awala and Namudi generally earn very low incomes and have poor access to basic services.

People on the floodplains of the Musa River and in the lower Pongani and Bariji valleys earn low incomes. People in Ijivitari District are moderately disadvantaged relative to people in other districts in PNG. There is some agricultural pressure, land potential is moderate, access to services is moderate and cash incomes are generally low.

People engaged in oil palm cultivation earn the highest and most reliable incomes. In the coastal areas around Oro Bay incomes are low to moderate and are mostly derived from the sale of cocoa, betel nut and fresh produce and food items. On the Managalas Plateau, people earn generally low incomes from the sale of coffee, betel nut and fresh food. People in the Moni Valley and along the coast of Collingwood Bay also have relatively low incomes. There is some small-scale industry on the Managalas Plateau and a former cattle ranch at Safia.

People in the coastal areas around Oro Bay have access by good roads that are mostly sealed. People in the coastal floodplains, the Managalas Plateau and on the coast of Collingwood Bay are within 4-8 hours' travel of Popondetta. Elsewhere there are few roads, and it is more than one day's travel to the nearest service centre.

The adult literacy rate for the district is 76.4, which is relatively high compared to other districts in this Study. Selected health indicators for the district are shown in the following table:

Table 39. Selected Health Indicators for Ijivitari District (2014)

Low Weight for Age < 5 years old (%)	Low Birth Weight (%)	Incidence of Malaria (1,000 population)	Incidence of Diarrhoea (<5 years/1,000 pop.)
25.3	15.8	191	283

3.1.2. *Hazards*

Hazard maps can be found in the province description (refer to Section 1, § **Fout! Verwijzingsbron niet gevonden.**) and the annex.

Inland flooding

In the southern part of the district, the system of the Musu and Moni rivers stretching first East from Adiabo to Gobera, then North to Sebaga. This system comprises a considerable catchment covering flat reaches which allow the development of substantial flood plains

A large flood plain appears on the flood hazard map in the lower parts of the Bariji river and the Foaru river but is largely unpopulated (Agaiambo swamps).

The river mouth of the Kamasi river threatens communities such as Batari, Daria and Auroau of occasional floods. Between Auroau and Gona, the Kakita river flows into the see with Butawote, Fufuda located in the flood plain. The zone between Gona and Pongani comprises a wide system of rivers and creeks initiating at Mount Lamington and Hydrographers Range. Floods affect some communities mostly along the coast between Emo and Pongani, but also around Sariri.

The area around Popondetta experiences limited flooding along the small rivers flowing from Mount Lamington.

Drought

The entire district is currently subjected to a maximum drought period between 24 and 29 days with a slight increase trend for future projections, in particular at Cape Nelson.

Extreme weather

The Ijivitari district does not lay within a zone with frequent passage of cyclones but this part of Papua New Guinea belongs to the band that has recorded between 1 and 5 events since 1990. An increasing gradient goes from North to South of the district.

High rainfall

Total yearly rainfall as well as the intense rainfall indicator (rainfall on 95 % wettest days) are quite homogeneous over the territory of the district. Intense rainfall is expected to increase in future conditions.

3.1.3. Risk

The effect of floods is mostly felt along populated areas. The zone around Popondetta comprises a dense system of communities located at the northern face of Mount Lamington; the same area shows high risk against extreme weather. This outcome is due to the concentration of population and infrastructure such as roads and bridges. Risk towards drought is also higher in that area of high economic importance due to the presence of gardens and plantations that are vulnerable to long periods of continuous dry days.

In addition, the vicinity of the catchment of the Moni river depicts a low risk to drought, turning into moderate risk towards extreme weather events. More south of the top of the mountain, close to the border with the Central Province, risk is inverse; it is Moderate to drought and low to extreme weather.

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

3.1.3.1. Social risk

Social exposure is very often overlapping with physical exposure as the most buildings and infrastructure can be found where most people live. Therefore, the physical and social components of the risk are often redundant as it is in the Popondetta-Kokoda junction area for flood and cyclone risk.

Inland Flood

High and moderate social risks from inland flooding in the district are found in the Kurereda area north of Popondetta and in the Popondetta urban and Oro Bay LLGs east and southeast of Popondetta. The coast of the Collongwood Bay appears at moderate to high risk, mostly because of high concentration of both buildings and inhabitants.

In Hombariri, South-East of Popondetta, social risk is again the main contributor to composite risk because of high population density, and despite low building replacement cost (leading to low physical risk). Small areas with high risk of inland flooding are to be found in the Kurereda area in the northern part of the district and along the middle reaches of the Musa River in the Cape Nelson Bay LLG in the southern part of the district.

High Precipitation and Extreme Weather

High and moderate social risks from both high precipitation and extreme weather events are found in the Begabari area in the far northern part of the district, in Popondetta Urban and Oro Bay Rural LLGs and around Dea and Koruwo in the northern part of the Afore LLG. The social risk from high rainfall in the district is expected to be low or very low

3.1.3.2. Economic risk

Kaukau, coconut and sago are important subsistence crops for the district but there are few opportunities for income from these activities. Sago is specific to lowland river margins, where the sago palm grows naturally (agricultural system 609[20]), and coconut is mainly a coastal plant, grown in the Popondetta area and around Collingwood Bay. Oil palm is a high income earner on the coast.

The inland areas of Ijivitari have a high potential for agriculture but remain very isolated from services and, more especially, from markets.

Table 40. Top agricultural activities of citizen households in Ijivitari[21]

Activity	*% engaged*	*%* engaged for cash*
Coconut	74.8	18.4
Betel nut	72.9	17.4
Food crops (sweet potato, banana, taro, cassava, et al.)	71.9	9.0
Fishing	34.5	7.9
Coffee	24.9	24.2

Cocoa plantations were tried in parts of Ijivitari by the government, but have since been abandoned. Betelnut, on the other hand is a lively informal export to traders from Central Province, who come to buy the crop.

The main area of economic risk is within the area around Popondetta and, to a lesser extent, the coastline by Tufi. Tufi is a promontory, more exposed to maritime weather and on the northern edge of the cyclone belt. The Popondetta area is heavily populated up, westward into the Mambare valley, and includes several commercial oil-palm blocks, whose commercial value, coupled with a sensitivity to both drought and wind, raise the risk factor.

Inland Flood

A zone at higher agricultural risk is located in the southern part of the province (Afoe Rural) mainly due to the large floodplains of the Moni valley, in the headwaters of the Musa River. There is a vast flooding zone in the vicinity of Safia where the Moni river and several tributaries flow into the Musa river. This confluence zone is largely agricultural, although much of the cultivation is on steeply sloping land[20]. The danger would therefore be from flash floods, washing gardens away. Susceptible crops would be sweet potato, principally, and cassava.

Drought

Oil palm, the region's principal export cash crop, is relatively sensitive to drought lasting longer than about three months. The monoculture plantation system increases the risk. This accounts for the greater risk factor shown around Popondetta.

A moderate risk from drought is shown in the southern slopes pf the Owen Stanley Range, on the border with Central Province. This is shown on the maps as the 613 agricultural system. This is an inaccessible area, dependent primarily on Sweet potato, Chinese taro, banana and, as insurance

[20] Allen, B.J., Nen, T., Hide, R.L., Bourke, R.M., Fritsch, D., Grau, R., Hobsbawn, P., Lyon, S. and Sem, G. (2002). Northern Province: Text Summaries, Maps, Code Lists and Village Identification. Agricultural Systems of Papua New Guinea Working Paper No. 16. Land Management Group, Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra. Revised edition.

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

against drought, cassava. Many in this areas also have blocks of rubber on the Cape Rodney Agricultural Project in Central Province.

Sweet potato, which dominates most gardens, is moderately sensitive to drought (or, correspondingly, moderately resistant), as is banana, which is also important in the region. Cassava has a strong resistance to drought, and most systems in the district include cassava, as one of the staple alternatives, to cover this eventuality.

Extreme weather events

Oil palm plantations and coconut dominated agricultural systems and plantation are the most vulnerable to cyclones which lead the large Oil Palm zone around Popondetta to be high risk areas.

Note that agricultural systems along the coast of Nelson Cape also contain subdominant coconut culture and are located in zone of non-negligible cyclone-hazard.

Elsewhere in the district the risks from extreme weather, albeit present, are small.

High Precipitation

This has always been a region of relatively high and constant rainfall, and agricultural systems have developed in response to that environment. Projections seem to indicate that the rainfall patterns will not change sufficiently in the next 50 years to cause stress either from waterlogging or from extended droughts. Crops in this area are grown to cope with and profit from the high rainfall. Drought is a more serious danger.

3.1.3.3. Physical risk

A good network of all-weather roads insure connections between Kokoda and Popondetta, and ramifies to give access the oil palm blocks in that area. Moderate physical risk is also associated to the road between Popondetta and Oro Bay. In Popondetta LLG, clusters of extreme risk around Sewa, the Popondetta agglomeration, Sorovi and Soputa are all dominated by physical risk because the number and the value of buildings and infrastructures located in the flood zone are high. Both social and physical components contribute the high composite risk level of the villages of Embogo and Dombada in Oro Bay LLG.

The same zones as the ones mentioned for flood risk are generally vulnerable to cyclones when they concentrate valuable (and damageable) buildings. Additionally, some relevant villages appear at high cyclone risk in Nelson Cape and have mostly potential physical damage to account for risk level: the surroundings of Tufi, Managa, Iagirua, Orede and Berebona. More South along the coast, the surroundings of Maffar show both high flood- and cyclone-related physical risk; Ajoa however only shows cyclone risk as it is not located in a flood zone.

3.1.3.4. Composite Risk

The composite risk maps for Ijivitari district are shown in Figure 69 (current climate) and Figure 70 (projected climate). Tables below show the % distribution of vulnerability and risk classes for the district, for each hazard, in each LLG.

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Oro Bay Rural	22.1	8.5	1.7	2.7	5.7	59.2
Cape Nelson	13.7	3.2	0.5	0.6	0.2	81.9
Afore rural	13.2	6.2	1.0	1.2	0.6	77.9
Popondetta Urban	24	6.3	6.3	5.4	15.3	42.6

Safia Rural	19.6	5.8	1.9	1.5	1.2	70.0

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Oro Bay Rural	9.4	14.4	30.3	0.5	0.5	44.8
Cape Nelson	5.1	14.6	0.5	0.0	0.0	79.8
Afore rural	10.7	10.4	2.5	0.3	0.7	75.4
Popondetta Urban	0	6.3	57.4	1.8	5.4	29.1
Safia Rural	14.1	10.8	0.0	0.0	0.0	75.1

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Oro Bay Rural	1.7	10.9	14.2	24.6	4.0	44.6
Cape Nelson	7.5	6.2	3.2	2.4	1.0	79.8
Afore rural	1.2	8.8	9.4	3.4	2.1	75.2
Popondetta Urban	0	1.8	0.9	17.1	51.2	29.1
Safia Rural	4.8	18.0	0.9	1.0	0.1	75.1

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Oro Bay Rural	22.1	26.6	5.0	0.5	0.5	45.3
Cape Nelson	15.7	3.5	0.5	0.0	0.0	80.3
Afore rural	10.9	10.4	2.3	0.3	0.7	75.4
Popondetta Urban	20	26.9	19.7	1.8	0.9	30.9
Safia Rural	19.1	6.0	0.0	0.0	0.0	74.9

	HAZARD : INLAND FLOODING											
	RISK (Current) %						RISK (projected) %					
LLG	1	2	3	4	5		1	2	3	4	5	
Oro Bay Rural	25.1	10.4	3.7	1.2	0.2	59.2	25.1	10.4	3.7	1.2	0.2	59.2
Cape Nelson	14.6	4.0	0.6	0.3	0.0	80.5	14.6	4.0	0.6	0.3	0.0	80.5
Afore rural	14.2	6.5	0.9	0.6	0.0	77.9	14.2	6.5	0.9	0.6	0.0	77.9
Popondetta Urban	31	9.0	2.7	1.8	12.6	42.6	31	9.0	2.7	1.8	12.6	42.6
Safia Rural	19.6	6.4	2.2	1.5	0.3	70.0	19.4	6.6	2.2	1.5	0.3	70.0

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Oro Bay Rural	0.0	9.4	14.4	30.3	1.0	44.8	0.0	9.4	14.4	30.3	1.0	44.8
Cape Nelson	0.0	5.1	14.6	0.5	0.0	79.8	0.0	5.1	14.6	0.5	0.0	79.8
Afore rural	0.0	10.7	10.4	2.5	1.0	75.4	0.0	10.7	10.4	2.5	1.0	75.4
Popondetta Urban	0	0.0	6.3	57.4	7.2	29.1	0	0.0	6.3	57.4	7.2	29.1
Safia Rural	0.0	14.1	10.8	0.0	0.0	75.1	0.0	14.1	10.8	0.0	0.0	75.1

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Oro Bay Rural	1.7	10.9	38.8	4.0	0	44.6	1.7	10.9	38.8	4.0	0	44.6
Cape Nelson	7.5	6.2	5.6	1.0	0	79.8	7.5	6.2	5.6	1.0	0	79.8
Afore rural	1.2	8.8	12.8	2.1	0	75.2	1.2	8.8	12.8	2.1	0	75.2
Popondetta Urban	0	1.8	17.9	51.2	0	29.1	0	1.8	17.9	51.2	0	29.1
Safia Rural	2.4	20.1	2.3	0.1	0	75.1	4.8	18.0	1.9	0.1	0	75.1

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Oro Bay Rural	48.7	6.0	0.0	0.0	0.0	45.3	45.0	9.0	0.7	0.0	0.0	45.3
Cape Nelson	19.2	0.5	0.0	0.0	0.0	80.3	19.2	0.5	0.0	0.0	0.0	80.3
Afore rural	21.3	3.4	0.0	0.0	0.0	75.4	21.3	3.4	0.0	0.0	0.0	75.4
Popondetta Urban	47	22.4	0.0	0.0	0.0	30.9	47	22.4	0.0	0.0	0.0	30.9
Safia Rural	25.1	0.0	0.0	0.0	0.0	74.9	25.1	0.0	0.0	0.0	0.0	74.9

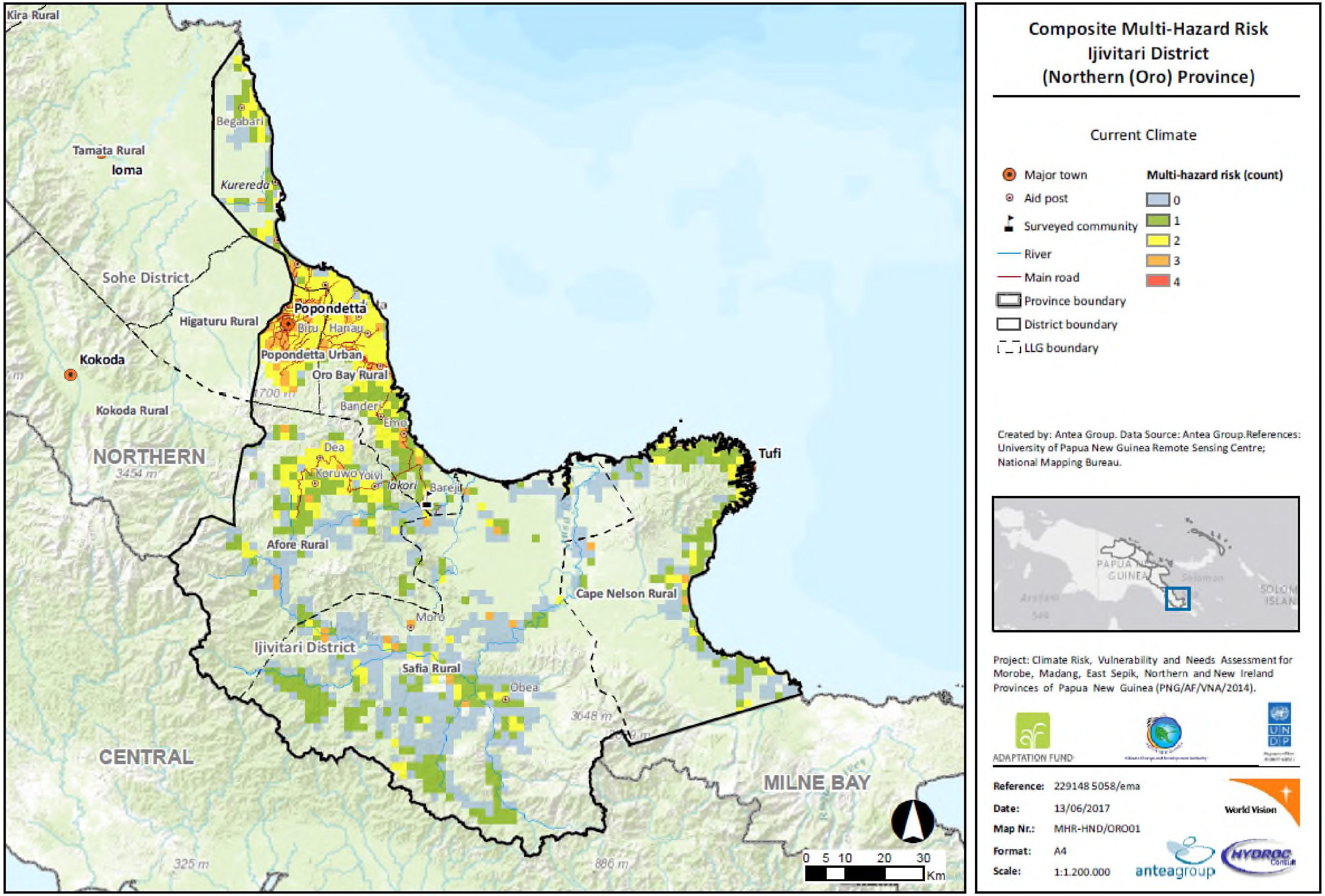

Figure 69. Composite risk map for Ijivitari District (current climate)

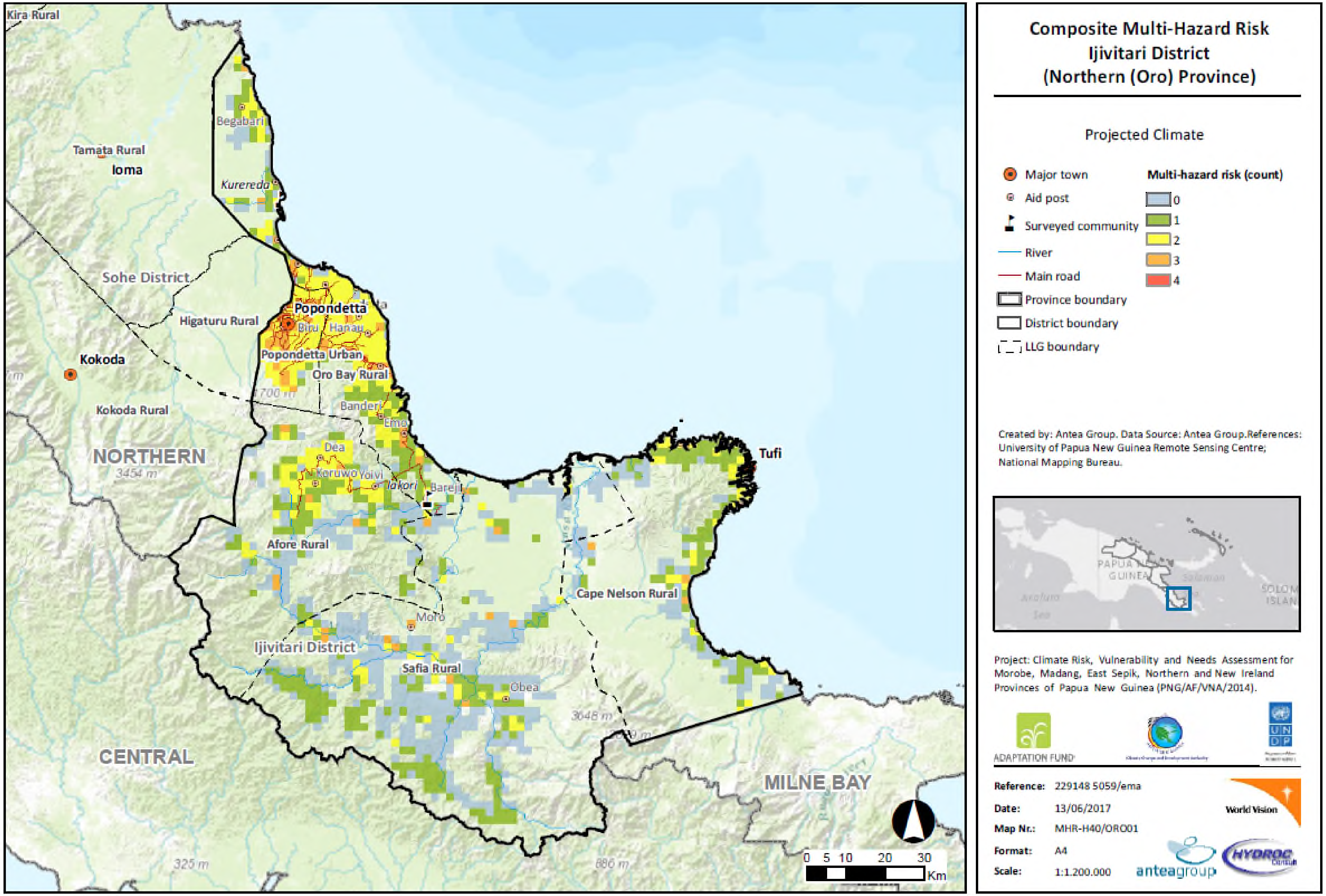

Figure 70. Composite risk map for Ijivitari District (future climate)

3.2. Sohe Risk Profile

3.2.1. General description

The Owen Stanley Ranges run along the south western border of Sohe District. The district includes the village of Kokoda and the Mambera, Pio and Kamusi Rivers. The district headquarters is located in Sohe. There are 4 LLGs in Sohe District: Kokoda Rural, Higaturu Rural, Tamata Rural and Kira Rural. The number of assigned wards to this district is 74.

Oil palm delivers comparatively high incomes for those in the Mambare Valley and there are low incomes available for sales of fresh food and fish. Some wage-earning opportunities also exist in the businesses of Popondetta.

Figure 71. Sohe District

In Sohe District the population at the latest census was 86,547[22]. The age dependency ratio is 46.1. The population density is relatively high, 43.7 inhabitants per km^2. The highest population densities are found on the volcanic plains and fans inland of Popondetta and in the upper Mambare Valley around Kokoda. The northern coastal floodplains and Kumusi Valley have moderate population densities. The Waria Valley and isolated valleys in the Owen Stanley Range have the lowest population densities in the district. Areas around Popondetta have the highest population densities and experience significant in-migration with new settlers moving in to work on oil palm blocks. The population of the district has experienced a rapid increase in recent years.

The most disadvantaged and vulnerable groups in the district are those living in the isolated Waria Valley who earn very low incomes and also have poor access to basic services. People in the Kumusi Valley also earn low incomes and are affected by moderate pressure on arable land, while those on the northern floodplains live in a low potential environment. Overall, people in Sohe District are not disadvantaged relative to people in other districts of PNG. There is some agricultural pressure, land potential is very high, access to services is good and cash incomes are relatively high.

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

People living around Popondetta and in the upper Mambare Valley around Kokoda earn relatively high cash incomes from the sale of oil palm. Those who do not grow oil palm sell cocoa, betel nut and fresh food. People in the northern floodplains earn lower cash incomes from sales of fish, fresh food and betel nut, while those in the Waria Valley have low cash incomes derived mainly from sales of fresh food. There are many sources of non-agricultural income around Popondetta including small businesses such as PMVs and trade stores, and wage employment provided by businesses and the oil palm industry. There is small-scale alluvial gold mining in the Waria and upper Mambare valleys.

The area between Popondetta and the Kokoda Valley has generally good roads and is within four hours' travel of Popondetta. Oil palm development around Popondetta has spurred the development of a network of sealed all-weather roads. Outside of this area there are few roads, and access is generally poor. On the coastal floodplains and along the Mambare and Kumusi rivers, people must travel by canoe or motor boat along the coast, and then by road to Popondetta. The Waria Valley in the mountains is the most isolated, and people require more than one day's travel to reach the nearest service centre.

The adult literacy rate for the district is 62.7, which is relatively high compared to the other districts in this Study. Selected health indicators for the district are shown in the following table:

Table 41. Selected Health Indicators for Sohe District (2014)

Low Weight for Age < 5 years old (%)	Low Birth Weight (%)	Incidence of Malaria (1,000 population)	Incidence of Diarrhoea (<5 years/1,000 pop.)
25.3	15.8	191	283

3.2.2. *Hazards*

Inland Flooding

In the northern part of the district, in the Kira rural LLG, the Waria river and its tributaries in the Tamata Rural LLG, the Eia (Tavi) river show very low flooding frequency while the Gira river, located further to the East, includes wider floodplains such that communities downstream Warawagi until Batari can undergo regular high waters.

The Mambare river, with its origins in the Central province, is among the two longest rivers within the province; the tributary coming from the left bank downstream Biaga comprises a important flood zone but there is no evidence of communities affected within the flooded areas.

The Opi and its tributaries depict wide floodplains along the entire path.

Further south is the Kumusi River, one of the two longest rivers within the province; its catchment begins high in the mountains at the border with Central Province. The Kumusi flows further north following the foot of the Mount Lamington until Avata where it turns Eastwards to flow into the sea at Auroau. The maps shows that most of the riparian communities can be affected by flood with different intensities. Ajeka, visited during the community risk assessment, is not shown within a flood prone area. This is consistent with the risk map drawn during the CRA; the community as such lays sufficiently higher than the river banks[23] and cannot be flooded.

Drought

The entire district is currently subjected to a maximum drought period between 24 and 29 days with a slight increase trend for future projections.

[23] CRA Ajeka village, Ward 15, Kokoda llg, Sohe district, Oro Province, Papua New Guinea

Extreme weather

The Ijivitari district does not lay within a zone with frequent pass of cyclones but this part of Papua New Guinea, between 0 and 5 have been recorded since 1990. An increasing gradient goes from North to South of the district.

High rainfall

Total yearly rainfall as well as the intense rainfall indicator (rainfall on 95 % wettest days) are quite homogeneous over the territory of the district. Intense rainfall is expected to increase in future conditions.

3.2.3. Risk

The risk of inland flooding is most present along the upper catchment of the Mambare river in the vicinity of Kokoda; Communities like Ebea, Ebel-Ebel, and Komo are subjected to the highest risk levels. The projected climate has a limited impact in the inland risk distribution. The same regions depict a clear susceptibility of drought risks; in particular Komo, Kovelo, Kolasi and Botu along the Mambare while Agora, Trail.311 Sumbiripa an Opra located west of Popondetta. The projected drought depicts a slight modification in the future but it does not lead to relevant changes in the maps.

Tropical cyclones have a moderate to low impacts in the district while the increase on precipitation intensities remains moderate for current and projected conditions

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

3.2.3.1. Social risk

Social exposure is very often overlapping with physical exposure as the most buildings and infrastructure can be found where most people live. Therefore, the physical and social components of the risk are often redundant as it is in the Popondetta area for flood and cyclone risk.

High and moderate social risk for inland flooding are to be found in a corridor extending along the main road from Kokoda eastward through Ajeka to Saiho in the Kokoda Rural LLG, and around Ioma town and around Siai and Hurata in Tamata Rural LLG.

Inland Flood

In Tamata Rural, high and moderate social risk can be found along the Eia, Gira an Mambare rivers in relation to flooding. Further, north and north-east of Ioma, in the Siai and Hurata areas in Tamata Rural LLG, in the Harange, Sangara and Lejo areas and along the rivers north of Ondahare in the Higaturu Rual LLG and in the Kokoda, Hanjiri, Ilimo and Ajeka areas in the Kokoda Rural LLG similar risk levels are present. Except in Tiwa, Pewa and close to the border with the Morobe province, the Kira rural LLG shows very low to moderate social flood risk, both because of the very low population density in the Waria valley and the limited flood zone extent in those catchments.

Secondary high risk zones such as the cluster of Embogo, Busega, Kopure and Dombada in Oro Bay (at the mouth of the Emboga river) are dominated by the high social sensitivity of the population located in the flood plains.

High Precipitation and Extreme Weather

Moderate social risks from high precipitation and extreme weather events in the district are found in isolated settlements along rivers in the far northern part of the district and in the Siai and Hurata areas in the Tamata Rural LLG, and in the Harange, Sivepe and Jajau areas and north of Ondahare in the Higatura Rural LLG, and in the vicinity of Kokoda town and in the Hanjiri, Ilimo, Eiwe and Ajeka areas in the Kokoda Rural LLG in the southern part of the district.

The social risk from high rainfall in the district is expected to be low or very low, except for a small area of moderate risk around Ioma town in Tamata Rural LLG.

3.2.3.2. Economic risk

Oil palm delivers comparatively high incomes for those in the Mambare Valley and there are low incomes available for sales of fresh food and fish. Some wage-earning opportunities also exist in the businesses of Popondetta

Table 42. Top agricultural activities of citizen households in Sohe (Source: NRI 2010)

	% engaged	*%* engaged for cash*
Betel nut	78.5	15.3
Coconut	78.4	5.1
Food Crops (sweet potato, banana, taro, cassava, et al.)	74.8	5.1
Coffee	34.2	32.5
Livestock	33.7	4.0

Sohe topographically is divided between a broad coastal plane and the rising foothills of the Owen Stanley Range. Economically subsistence agriculture based on sweet potato, dominates, but there are also two oil palm estates, at Kokoda and Higatura, The area westward of Popondetta is heavily populated up into the Mambare valley, and includes several commercial oil-palm blocks, whose commercial value, coupled with a sensitivity to both drought and wind, raise the risk factor.

The agricultural systems 603 (on the coastal plain) and 604 (in the river valleys) describe the agricultural activity of 48% of the entire province. Both rely on sweet potato (kaukau) as the main staple. It has been favoured, no doubt, because of its intrinsic resilience but also, given its short growing season, as a crop that allows a rapid come-back from any disaster-induced loss.

The climatic risks affect mainly the food crops, amongst which, in this province, coconut is included. The nature of those risks for each crop can be seen above in the general provincial profile. Coffee, grown on the slopes of the Owen Stanley Range, will be affected mostly by rising temperatures, which will cause it to rise to higher altitudes – or farmers will be obliged to grow the lower value Robusta varieties.

Inland Flood

The economic aspect is not the main factor for the composite risk calculation over the whole district, with the exception of Siai and close-by Sevape, Poho and Ehenade villages that show moderate economic risk related to relatively large agricultural areas being flooded. The risk is relatively small because these agricultural systems are already adapted to annual flood, and flood-prone land is generally avoided for agricultural activity.

Drought

The two areas marked as having extreme susceptibility to drought are notably oil palm plantations. Oil palm starts to experience a decline in yield after about 2 moths of drought. Extensive monoculture tends to exacerbate the effects, because there is no other vegetation acting to conserve groundwater. The risk is to the cash incomes of the relatively few farmers engaged in the scheme, and to the export income of the province and the country.

The main subsistence crops (sweet potato, taro and yam) depend on relatively high rainfall and are consequently susceptible to long periods of drought. There are plants in the system, notably cassava, that are drought resistant and exist in the system to help to withstand dry periods.

Extreme weather events

Oil palm plantations (Higatura and Kokoda) are sensitive to high wind over 90 km/hr, which can strip them of their leaves, or even uproot them. Palm trees, which are important for subsistence and for cash incomes on the coast, suffer in the same way.

The rest of the agricultural systems in Tamata and Kira Rural LLGs show very low agricultural risk, where lower-lying crops offer less resistance to wind.

High Precipitation and Extreme Weather

High rainfall, for the reasons explained above, does not generally present a risk, and the expected change over the next several decades will remain within the tolerance of the majority of crops in the agricultural systems.

In general, in Papua New Guinea, the agricultural sector is much more concerned about the dangers from increasing periods of drought than higher rainfall patterns (interview with ARI-PNG)

3.2.3.3. Physical risk

While road access between Wau, Bulolo and Lae is reasonably well developped, there close to no roads at all in the south of the district. Those in the Watut (Wutou) and Waria Valleys and surrounding mountains must travel up to eight hours to a service centre. Risk in the Northern part of the district is therefore mostly driven by the social component and not the potential physical damage.

The physical component is however dominant wherever composite risk is high or extreme in the Mamabare valley around Kokoda , and in the Kamasi valley. In Higaturu Rural LLG also, the roads and buildings associated with oil palm and other economic activities cause physical risk to be higher e.g. in Sui, Awala, Koipa and Susiilo. In southern Tamata Rural LLG in the Kumusi valley, the visited community of Siai shows high physical (and composite) risk. Close-by villages of Korisata and Toute (Hurata) also appear as affected in relation with the physical infrastructure. At that location the river section stretches significantly (also confirmed during CRA) leading to marginal flooding. A more significant flooding is observed in the vicinity of the village particularly along the floodplains of the Kumusi which are used for cultivating gardens and Palm trees.

3.2.3.4. Composite Risk

The composite risk maps for Sohe district are shown in Figure 72 (current climate) and Figure 73 (projected climate). Tables below show the % distribution of vulnerability and risk classes for the district, for each hazard, in each LLG.

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Kokoda Rural LLG	9.2	2.8	1.2	0.7	6.2	79.8
Higaturu Rural	20.4	13.0	9.5	5.2	13.0	38.9
Tamata Rural	8.4	2.4	0.4	1.6	5.2	82.1
Kira Rural	16.2	0.0	0.6	0.6	3.3	79.3

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Kokoda Rural LLG	6.9	3.7	9.8	0.0	0.9	78.7
Higaturu Rural	10.4	7.8	42.4	2.6	10.4	26.4
Tamata Rural	4.1	10.7	0.4	0.0	0.0	84.8
Kira Rural	1.2	19.2	0.6	0.0	0.0	79.0

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Kokoda Rural LLG	1.7	4.5	2.5	10.4	2.8	78.1
Higaturu Rural	15.6	6.1	6.1	31.2	25.6	15.5
Tamata Rural	4.8	4.5	2.8	2.6	1.1	84.3
Kira Rural	3.9	11.1	3.9	1.5	0.6	79.0

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Kokoda Rural LLG	10.9	7.4	2.7	0.0	0.0	79.0
Higaturu Rural	26.4	26.0	17.8	3.0	0.4	26.4
Tamata Rural	9.8	4.8	0.4	0.0	0.0	85.0
Kira Rural	6.9	13.8	0.6	0.0	0.0	78.7

	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Kokoda Rural LLG	11.4	4.0	2.1	2.1	0.6	79.8	11.4	4.0	2.1	2.1	0.6	79.8
Higaturu Rural	39.8	13.9	3.5	3.5	0.4	38.9	39.8	13.9	3.5	3.5	0.4	38.9
Tamata Rural	9.7	4.8	2.5	0.8	0.1	82.2	9.6	4.8	2.6	0.9	0.1	82.1
Kira Rural	16.8	1.8	2	0	0.3	79.3	16.8	1.8	2	0	0.3	79.3

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Kokoda Rural LLG	0.0	6.9	3.7	9.8	0.9	78.7	0.0	6.9	3.7	9.8	0.9	78.7
Higaturu Rural	0.0	10.4	7.8	42.4	13.0	26.4	0.0	10.4	7.8	42.4	13.0	26.4
Tamata Rural	0.0	4.1	10.7	0.4	0.0	84.8	0.0	4.1	10.7	0.4	0.0	84.8
Kira Rural	0.0	1.2	19	1	0.0	79.0	0.0	1.2	19	1	0.0	79.0

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Kokoda Rural LLG	2.4	4.1	12.7	2.7	0	78.1	2.4	4.1	12.7	2.7	0	78.1
Higaturu Rural	15.6	6.1	37.2	25.6	0	15.5	15.6	6.1	37.2	25.6	0	15.5
Tamata Rural	4.8	4.8	5.3	0.9	0	84.3	4.8	4.8	5.3	0.9	0	84.3
Kira Rural	15.0	6.0	0	0	0	79.0	15.0	6.0	0	0	0	79.0

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Kokoda Rural LLG	18.3	2.7	0.0	0.0	0.0	79.0	18.3	2.7	0.0	0.0	0.0	79.0
Higaturu Rural	52.4	21.2	0.0	0.0	0.0	26.4	52.4	21.2	0.0	0.0	0.0	26.4
Tamata Rural	14.6	0.4	0.0	0.0	0.0	85.0	11.7	3.0	0.3	0.0	0.0	85.0
Kira Rural	20.7	0.6	0	0	0.0	78.7	6.9	13.8	1	0	0.0	78.7

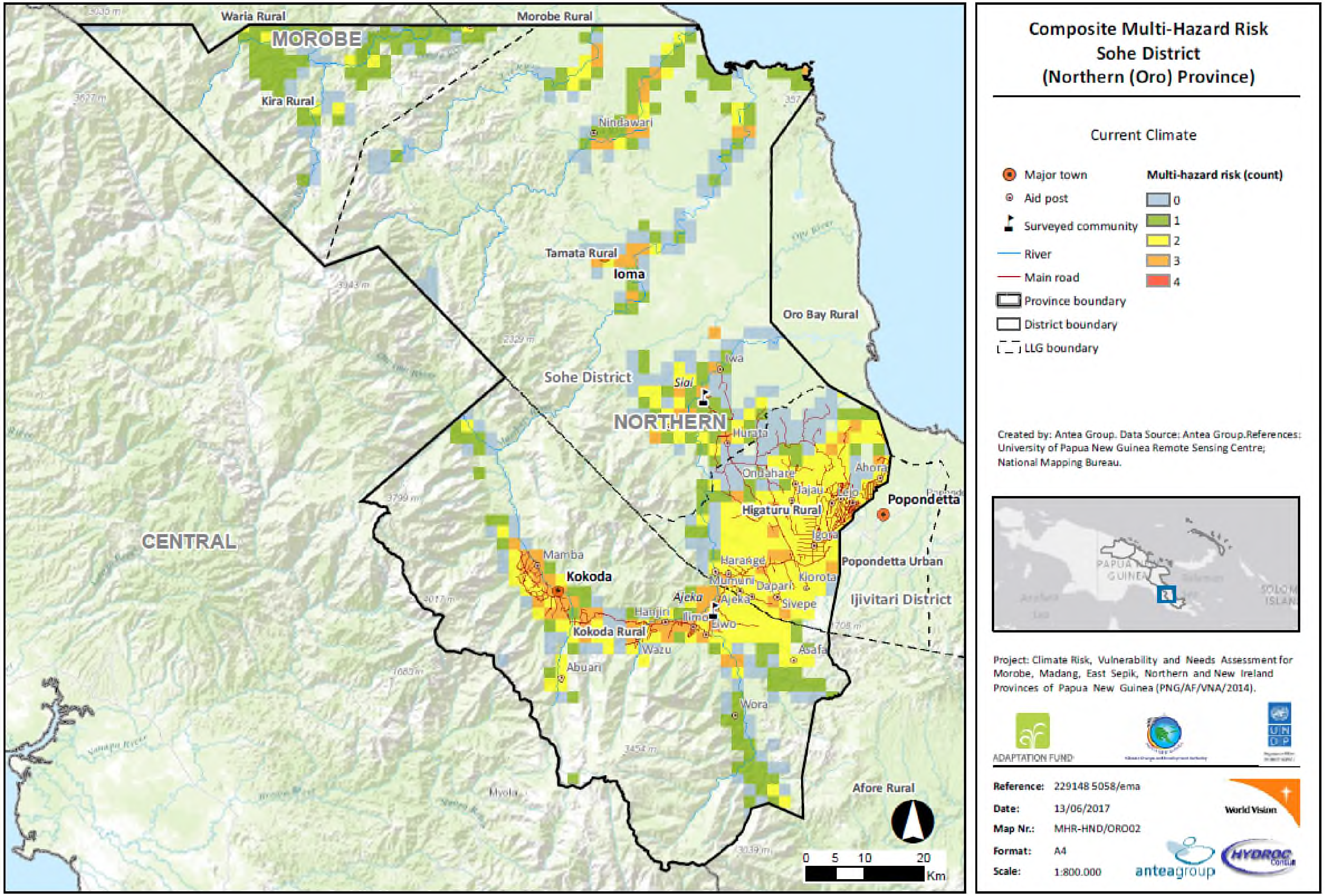

Figure 72. Composite risk map for Sohe District (current climate)

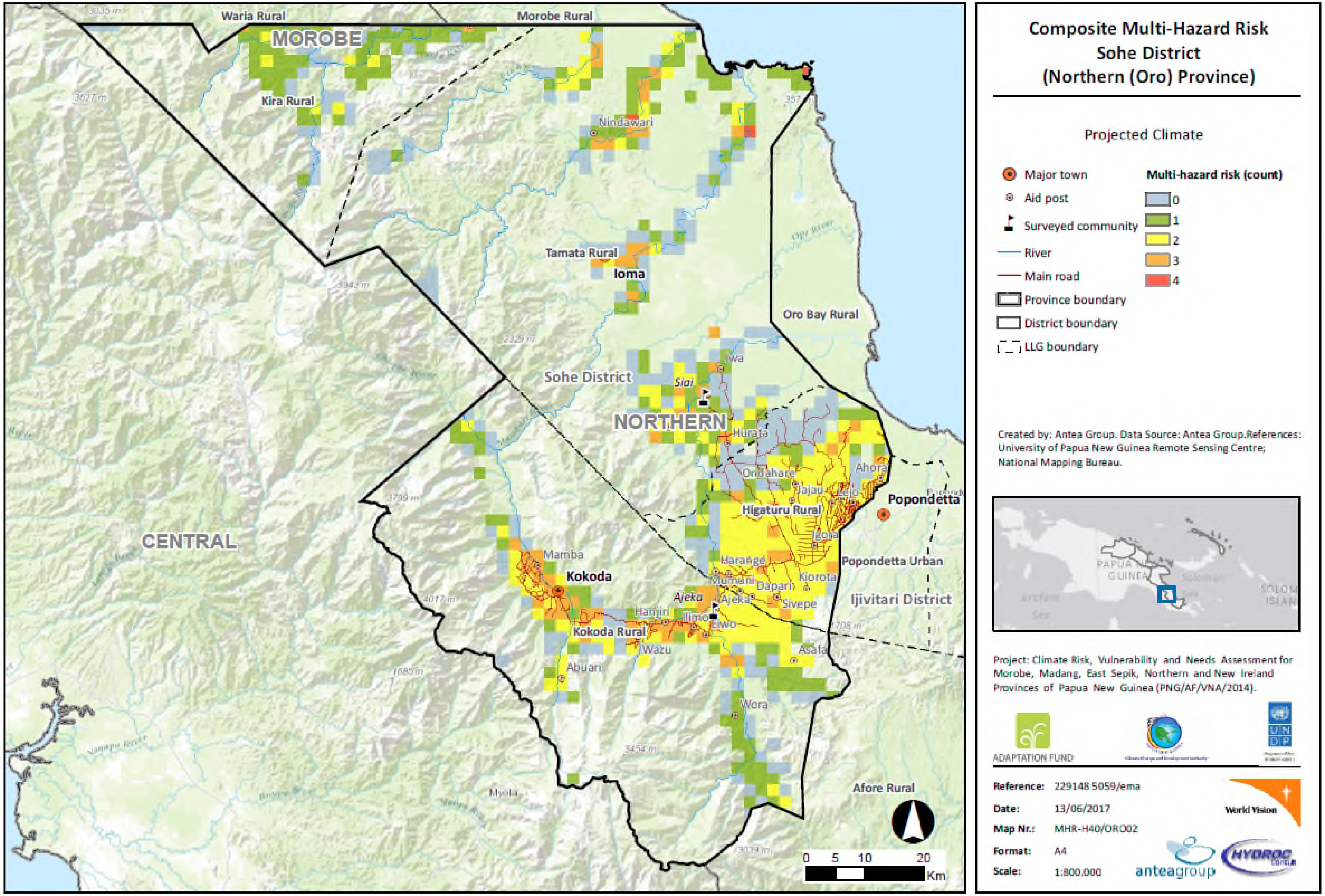

Figure 73. Composite risk map for Sohe District (future climate)

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, although it has experienced some cyclones in the past. The existing situation will be exacerbated slightly in the future (except for cyclones). 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 (except for cyclones).

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

From the geographical point of view, the analysis revealed that two areas within the province require more attention. The Kokoda Valley and the Popondetta region are at greatest risk, mostly due to inland flooding and drought intersecting agriculture and/or urban settlements, where social vulnerability becomes important.

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 such as Popondetta. In certain areas, namely Popondetta and Kokoda, 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.).

Except for coffee in the Owen Stanley foothills of the southwest, 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.

A provincial disaster plan was in preparation in 2015 . 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 2007 tropical cyclone showed that communities were not prepared. The situation can improve as the PDC has funding for additional staff, which they intend to place closer to the communities across the province.

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.

The Province has an Integrated Provincial Development Plan (IPDP), which outlines the priorities in the province, taking into account initiatives at the district and local level. Climate Change and Disaster Risk Management are included in the IPDP. As in other provinces, Northern 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 Northern (Oro) 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, and could be the model for other provinces such as Oro: 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 Popondetta and the Kokoda Valley. 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 Northern 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 (Kokoda Valley), 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 like Popondetta, 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

ANNEX 2 DATA SOURCES USED

ANNEX 3 CROP TOLERANCE SCORES

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.

Climate metrics

National Weather Service (NWS) is responsible for monitoring and forecasting weather in Papua New Guinea[24]. 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 74) including 3 automatic and 10 manual stations.[25] The following variables are recorded daily at the manual stations and hourly at the automatic stations: Rainfall, Air temperature, Wind, Pressure, and Humidity.

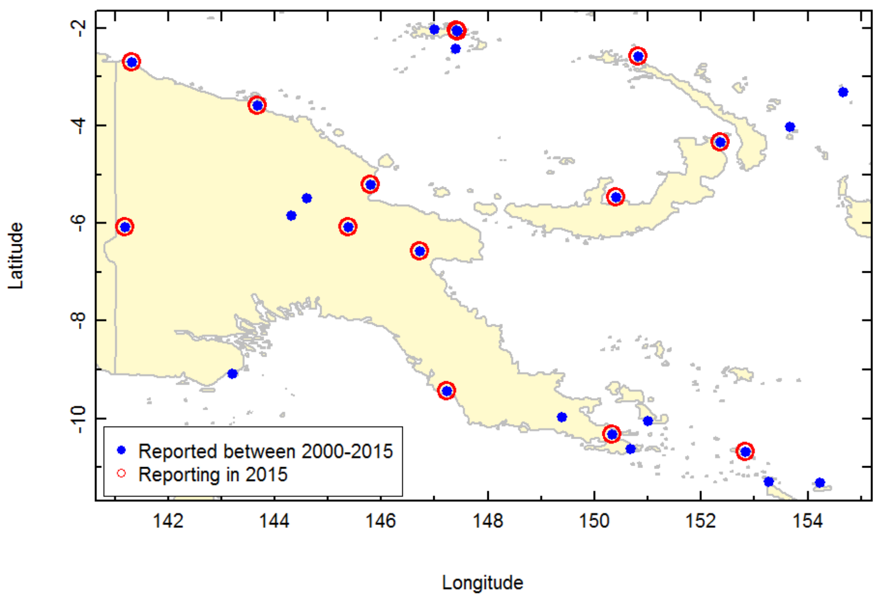

Figure 74. Location of Global Surface Summary of the Day (GSOD) weather stations across Papua New Guinea.

[24] 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.
[25] This information was obtained during interviews. Other sources report 14 manned National Weather Service stations, 7 automatic stations.

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 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[26] 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[27][28]. The Pacific Climate Change Portal[29] 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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[26] CliDE – Climate Data for the Environment; http://www.bom.gov.au/climate/pacific/about-clide.shtml

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

[28] 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.

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

Infrastructure 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 75) 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.

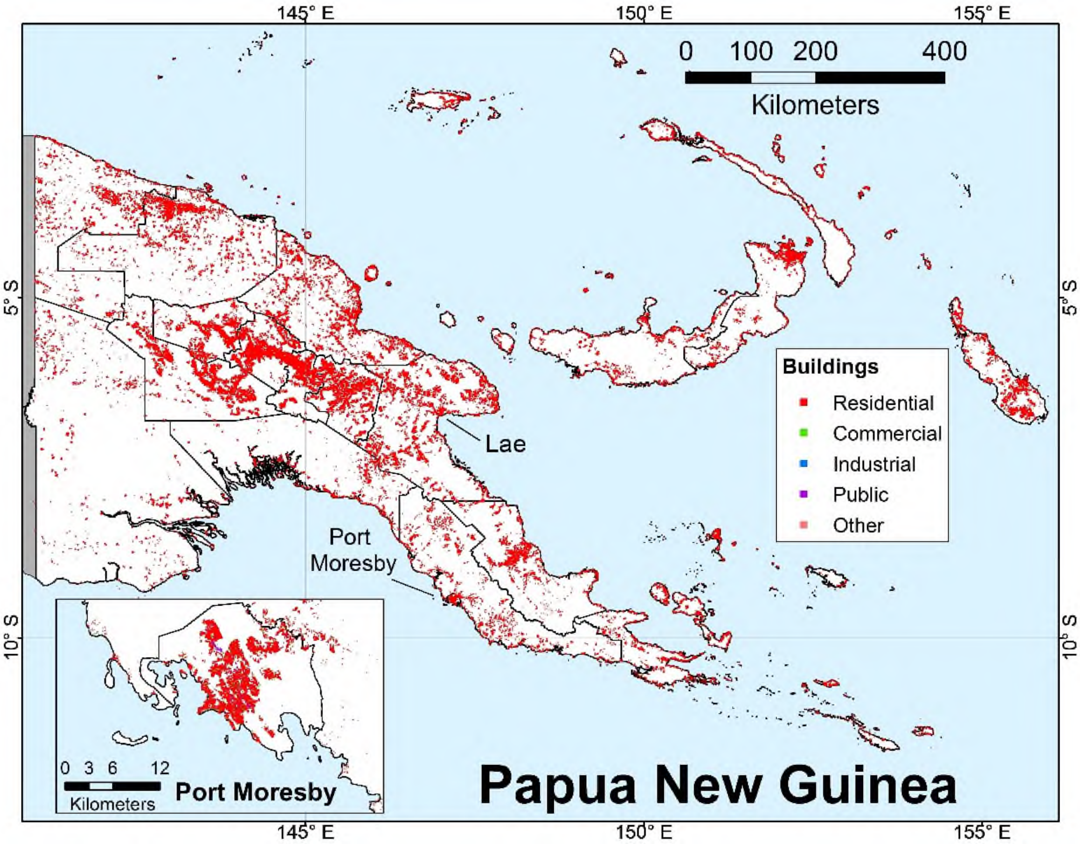

Figure 75. Location of buildings in PNG (Source: PCRAFI)

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.

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 43).

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

Table 43. 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

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 44 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 44. 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

		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)**
			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