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

COLOPHON

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CONTENTS

0. EXECUTIVE SUMMARY 11

1. INTRODUCTION 17

1.1. Objectives 17
1.2. Methodology 17
1.3. Baseline information of Morobe Province 41

2. PROVINCE RISK PROFILE 57

2.1. Hazard Assessment 57
2.2. Vulnerability Assessment 74
2.3. Risk Assessment 95
2.4. Composite Risk 128

3. DISTRICT RISK PROFILES 131

3.1. Bulolo Risk Profile 131
3.2. Finschafen Risk Profile 139
3.3. Huon Risk Profile 146
3.4. Kabwum Risk Profile 153
3.5. Lae Risk Profile 160
3.6. Markham Risk Profile 166
3.7. Menyamya Risk Profile 173
3.8. Nawae Risk Profile 180
3.9. Tawae/Siassi Risk Profile 187

4. RECOMMENDATIONS 194

4.1. Needs and priorities 194
4.2. Opportunities 194
4.3. Way forward 195

ANNEXES 197

ANNEX 1 DEFINITIONS 198

ANNEX 2 DATA SOURCES USED 199

ANNEX 3 CROP TOLERANCE SCORES 205

TABLES

Table 1. Overview of social sensitivity indicators and data 24
Table 2. Overview of infrastructure sensitivity indicators and data 25
Table 3. Indicators influencing building sensitivity 25
Table 4 Indicators influencing road and bridge vulnerability 26
Table 5 Building sensitivity indicators scores....26
Table 6 Bridge sensitivity indicators scores 27
Table 7 Road sensitivity indicators scores 28
Table 8. Overview of economic sensitivity indicators and data....29
Table 9. Indicators for crop tolerance assessment 29
Table 10. Selection of indicators for crop tolerance assessment 30
Table 11. Tolerance score for staple crops 30
Table 12. General comments of crop tolerance scores 31
Table 13. Relevant risk components per hazard 33
Table 14. Replacement cost for roads 34
Table 15. Replacement cost for bridges....34
Table 16. Replacement cost for airstrips 34
Table 17. Replacement cost for special infrastructure 35
Table 18. Weighting of crops in agricultural systems 37
Table 19. Economic vulnerability reclassification 37
Table 20. Number of wards per LLG 41
Table 21. Slope classes an occurrence in Morobe Province 43
Table 22. Population numbers per age group and per district 49
Table 23. Selected Health Indicators for Morobe Province (2014)....51
Table 24. Number of Healthcare facilities per LLG 52
Table 25 Kilometers of roads in Morobe 54
Table 26 Number of bridges in Morobe....54
Table 27 Total of public establishment....54
Table 28 Flood areas (km²) for current and future climate 58
Table 29. Distribution of vulnerability classes for inland flooding in Morobe Province (combined social, economic and physical)....75
Table 30. Distribution of vulnerability classes for drought in Morobe Province (combined social and economic) 81
Table 31. Distribution of vulnerability classes for extreme weather (cyclones) in Morobe Province (combined social, economic and physical) 86
Table 32. Distribution of vulnerability classes for precipitation intensity and variability in Morobe Province (combined social and economic) 91

Table 33. Distribution of inland flood risk classes....95
Table 34. Distribution of drought risk classes....105
Table 35. Distribution of cyclone risk classes....112
Table 36. Distribution of precipitation intensities and variability risk....121
Table 37. Distribution of composite risk classes....128
Table 38. Selected Health Indicators for Bulolo District (2014)....132
Table 39. Top agricultural activities of citizen households in Bulolo....134
Table 40. Selected Health Indicators for Finschafen District (2014)....140
Table 41. Top agricultural activities of citizen households in Finschafen....141
Table 42. Selected Health Indicators for Huon District (2014)....147
Table 43. Top agricultural activities of citizen households in Huon....148
Table 44. Selected Health Indicators for Kabwum District (2014)....154
Table 45. Top agricultural activities of citizen households in Kabwum....155
Table 46. Selected Health Indicators for Lae District (2014)....161
Table 47. Selected Health Indicators for Markham District (2014)....167
Table 48. Selected Health Indicators for Menyamya District (2014)....174
Table 49. Selected Health Indicators for Nawae District (2014)....181
Table 50. Selected Health Indicators for Tawae-Siassi District (2014)....188
Table 51. Unit replacement costs of infrastructure in PIC (Source: PCRAFI 2013)....201
Table 52 Replacement costs for key crops under different production systems in the PICs (PCRAFI 2013 p 28)....204

FIGURES

Figure 1. Risk mapping methodology 19
Figure 2. Representativeness of each staple crop across all systems 31
Figure 3. Frequency distribution of agricultural systems (MASP) and plantations vulnerability to extreme weather 38
Figure 4. Vulnerability and risk classes 38
Figure 5. Example calculation of composite risk 40
Figure 6. Administrative map Morobe province 42
Figure 7. Elevation map of Morobe Province 44
Figure 8. Main rivers found in Morobe Province 45
Figure 9. Slopes classification map for Morobe province (from DTM, from SRTM-3, 90m). 46
Figure 10. Land Use map Morobe Province 48
Figure 11. Population density map of Morobe Province 50
Figure 12. Location of health centers and aid posts in Morobe Province 53
Figure 13. Road infrastructure in Morobe Province 55
Figure 14. Inland flooding (current climate) ■ flooded 61
Figure 15 Inland flooding (projected climate) ■ flooded 62
Figure 16. Drought (current climate) expressed as number of continuous dry days ■10-16 ■16-21 ■21-24 ■24-29 ■>29 64
Figure 17. Drought (projected climate) expressed as number of continuous dry days ■10-16 ■16-21 ■21-24 ■24-29 ■>29 65
Figure 18. Tropical cyclones (current climate) as number of cyclones ■0 ■1-5 ■6-12 ■12-20 ■>21 67
Figure 19. Tropical cyclones (projected climate) as number of cyclones ■0 ■1-5 ■6-12 ■12-20 ■>21 68
Figure 20. Total annual rainfall in mm (current climate) ■1135-2078 ■2079-2710 ■2711-2979 ■2980-3280 ■3281-3777 70
Figure 21. Total annual rainfall in mm (projected climate) ■1135-2078 ■2079-2710 ■2711-2979 ■2980-3280 ■3281-3777 71
Figure 22. Rainfall on wet days in mm (current climate) ■250-500 ■501-600 ■601-700 ■701-800 ■801-900 72
Figure 23. Rainfall on wet days in mm (projected climate) ■250-500 ■501-600 ■601-700 ■701-800 ■801-900 73
Figure 24. Social vulnerability to inland flooding in Morobe Province 77
Figure 25. Physical vulnerability to inland flooding in Morobe Province 78
Figure 26. Economic vulnerability to inland flooding in Morobe Province 79
Figure 27. Combined inland flood vulnerability map for Morobe Province 80
Figure 28. Social vulnerability to drought in Morobe Province 83
Figure 29. Economic vulnerability to drought in Morobe Province 84

Figure 30. Combined drought vulnerability map for Morobe Province 85

Figure 31. Social vulnerability to cyclones in Morobe Province 87

Figure 32. Physical vulnerability to cyclones in Morobe Province 88

Figure 33. Economic vulnerability to cyclones in Morobe Province 89

Figure 34. Combined vulnerability to cyclones in Morobe Province 90

Figure 35. Social vulnerability to precipitation intensity and variability (intense rainfall) in Morobe Province 92

Figure 36. Economic vulnerability to precipitation intensity and variability (intense rainfall) in Morobe Province 93

Figure 37. Combined vulnerability to precipitation intensity and variability (intense rainfall) in Morobe Province 94

Figure 38. Inland Flooding Social Risk (current climate) Very Low Low Moderate High Extreme 96

Figure 39. Inland Flooding Infrastructure Risk (current climate) Very Low Low Moderate High Extreme 97

Figure 40. Inland Flooding Economic Risk (current climate) Very Low Low Moderate High Extreme 98

Figure 41. Inland Flooding Composite Risk (current climate) Very Low Low Moderate High Extreme 99

Figure 42. Inland Flooding Social Risk (projected climate) Very Low Low Moderate High Extreme 100

Figure 43. Inland Flooding Physical Risk (projected climate) Very Low Low Moderate High Extreme 101

Figure 44. Inland Flooding Economic Risk (projected climate) Very Low Low Moderate High Extreme 102

Figure 45. Inland Flooding Composite Risk (projected climate) Very Low Low Moderate High Extreme 103

Figure 46. Drought Social Risk (current climate) Very Low Low Moderate High Extreme ...106

Figure 47. Drought Economic Risk (current climate) Very Low Low Moderate High Extreme 107

Figure 48. Combined Drought Risk (current climate) Very Low Low Moderate High Extreme 108

Figure 49. Drought Social Risk (projected climate) Very Low Low Moderate High Extreme109

Figure 50. Drought Economic Risk (projected climate) Very Low Low Moderate High Extreme 110

Figure 51. Combined Drought Risk (projected climate) Very Low Low Moderate High Extreme 111

Figure 52. Tropical cyclones Social Risk (current climate) Very Low Low Moderate High Extreme 113

Figure 53. Tropical cyclones Physical Risk (current climate) Very Low Low Moderate High Extreme 114

Figure 54. Tropical cyclones Economic Risk (current climate) Very Low Low Moderate High Extreme 115

Figure 55. Tropical cyclones Composite Risk (current climate) Very Low Low Moderate High Extreme 116

Figure 56. Tropical cyclones Social Risk (projected climate) Very Low Low Moderate High Extreme 117

Figure 57. Tropical cyclones Physical Risk (projected climate) Very Low Low Moderate High Extreme 118

Figure 58. Tropical cyclones Economic Risk (projected climate) Very Low Low Moderate High Extreme 119

Figure 59. Tropical cyclones Composite Risk (projected climate) Very Low Low Moderate High Extreme 120

Figure 60. Precipitation intensities and variability social risk (current climate) Very Low Low Moderate High Extreme 122

Figure 61. Precipitation intensities and variability Economic Risk (current climate) Very Low Low Moderate High Extreme 123

Figure 62. Precipitation intensities and variability composite Risk (current climate) Very Low Low Moderate High Extreme 124

Figure 63. Precipitation intensities and variability Social Risk (projected climate) Very Low Low Moderate High Extreme 125

Figure 64. Precipitation intensities and variability Economic Risk (projected climate) Very Low Low Moderate High Extreme 126

Figure 65. Precipitation intensities and variability Composite Risk (projected climate) Very Low Low Moderate High Extreme 127

Figure 66. Composite Multi-Risk Map Morobe Province (current) 129

Figure 67. Composite Multi-Risk Map Morobe Province (future) 130

Figure 68. Bulolo District 131

Figure 69. Composite risk map for Bulolo District (current climate) 137

Figure 70. Composite risk map for Bulolo District (future climate) 138

Figure 71. Finschafen District 139

Figure 72. Composite risk map for Finschafen District (current climate) 144

Figure 73. Composite risk map for Finschafen District (future climate) 145

Figure 74. Huon District 146

Figure 75. Composite risk map for Huon District (current climate) 151

Figure 76. Composite risk map for Huon District (future climate) 152

Figure 77. Kabwum District 153

Figure 78. Composite risk map for Kabwum District (current climate) 158

Figure 79. Composite risk map for Kabwum District (future climate) 159

Figure 80. Lae District 160

Figure 81. Composite risk map for Lae District (current climate) 164

Figure 82. Composite risk map for Lae District (future climate) 165
Figure 83. Markham District 166
Figure 84. Composite risk map for Markham District (current climate) 171
Figure 85. Composite risk map for Markham District (future climate) 172
Figure 86. Menyamya District 173
Figure 87. Composite risk map for Menyamya District (current climate) 178
Figure 88. Composite risk map for Menyamya District (future climate) 179
Figure 89. Nawae District 180
Figure 90. Composite risk map for Nawae District (current climate) 185
Figure 91. Composite risk map for Nawae District (future climate) 186
Figure 92. Tawae-Siassi District 187
Figure 93. Composite risk map for Tawae/Siassi District (current climate) 192
Figure 94. Composite risk map for Tawae/Siassi District (future climate) 193
Figure 95. Location of Global Surface Summary of the Day (GSOD) weather stations across Papua New Guinea. 199
Figure 96. Location of buildings in PNG (Source: PCRAFI) 202

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.

(iii) Developing social, infrastructure and economic vulnerability indices & vulnerability maps

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 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.

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[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

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: adequately provisioned with boats to access difficult coastal areas, such as Tufi, 4x4 vehicles to reach inland, and standing arrangements with the air force and police, to reach populated areas not served by roads. This needs to be backed up with meteorological and early warning information, and a network that allows this information to reach areas likely to be affected. Emergency preparation, at the district and LLG level is essential, to know in advance how to cope with rescue and care of displaced people. In many places, local level organisation is the only way to ensure some buffer of security.

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

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

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

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

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

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

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

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

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

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

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

Organization of chapters

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

1. INTRODUCTION

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

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

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

This report describes the hazard, vulnerability and risk assessment for the Morobe 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.

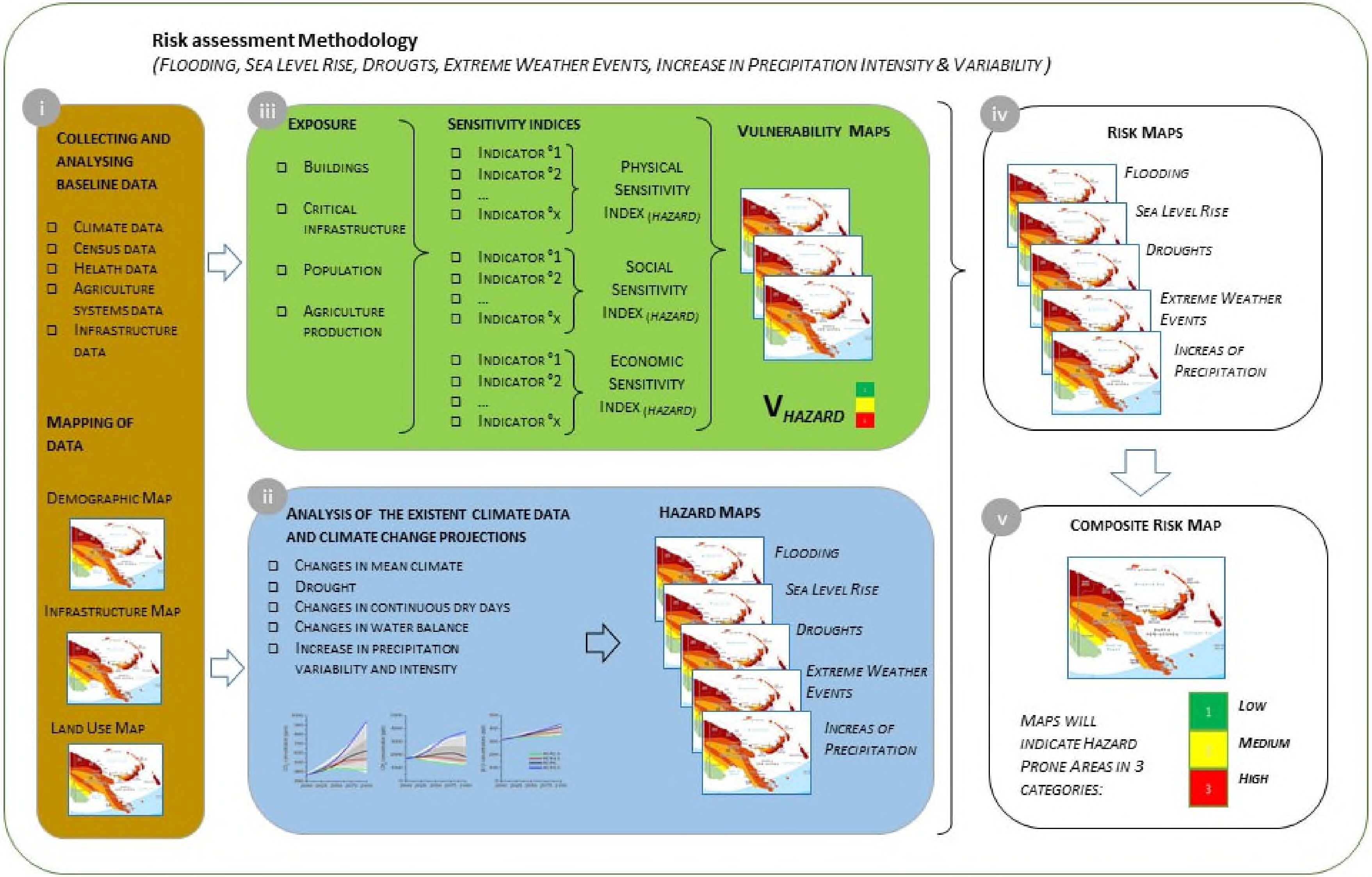

Figure 1. Risk mapping methodology

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 95^{th} percentile and the simple precipitation intensity index.

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

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

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

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

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

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

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

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

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

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

1.2.1.5. Coastal floods

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

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

1.2.2. Vulnerability assessment

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

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

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

1.2.2.1. Exposure

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

The 'elements' considered in this study are:

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

1.2.2.2. Sensitivity indices

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

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

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

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

Social sensitivity

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

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

Table 1. Overview of social sensitivity indicators and data

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

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

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

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

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

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

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

Physical sensitivity

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

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

Table 2. Overview of infrastructure sensitivity indicators and data

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

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

Table 3. Indicators influencing building sensitivity

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

N°	Indicator	Inland flooding	Coastal flooding	Cyclonic wind
6	Roof material			x
7	Shutter type			x
8	Wall opening type			x
9	Wall material	x	x	x
10	Minimum floor height	x	x	

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

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

Table 4 Indicators influencing road and bridge vulnerability

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

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

Table 5 Building sensitivity indicators scores

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

Attribute name	Description	Value	Legend	Sensitivity Inland Flooding	Sensitivity Coastal Flooding	Sensitivity Cyclonic Wind
		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)**	**CYCLONIC WINDS (km/hr)**
Critical range	*0.5–5*	*0.5–5*	*0–500*	*3500 – 5000*	*14–30*	*60–120*
Banana (Musa cvs)	1	2	2	1	2	2
Cassava (Manihot esculenta)	2	2	0	1	0	2
Chinese taro (Xanthosoma sagittifolium) also Cocoyam/Tannia	2	2	2	1	2	2
Coconut (Cocos nucifera)	2	0	2	1	1	2
Sago (Metroxylon sagu)	1	2	2	1	1	2
Sweet potato (Ipomoea batatas)	2	2	2	1	2	0
Taro (Colocasia esculenta)/	1	2	2	1	2	2

	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)
dasheen						
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.

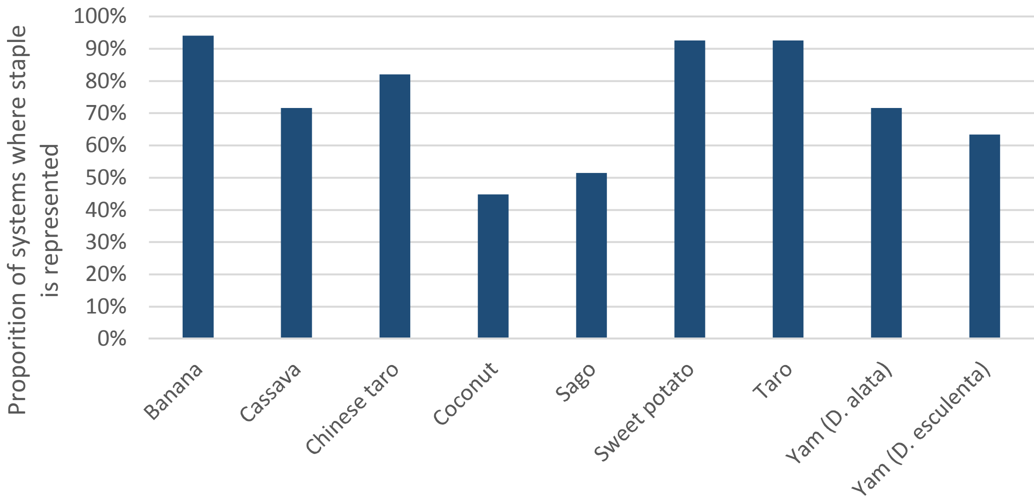

Figure 2. Representativeness of each staple crop across all systems

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

Indicator	Comment
	remove the soil. Since most inland flood is caused by rivers breaking their banks, the effect of velocity is the most critical, but also the least studied. Trees can withstand deeper floods, but still only for very short periods in most cases.
Sea level rise (m)	Most of the tolerance scores relates to a crop's tolerance to salinity in the soil. Tidal surges, due to storms, will have immediate effects similar to river floods (lodging of plants, erosion of soil). They will also leave behind salt residues in the soil, which may last for a considerable time before rain leaches it out. The longer term problem is the effect that mean sea-level rise has on subterranean water reserves. This excludes salt-intolerant crops from being grown on that land for the future. This is a growing problem on the coasts. Certain important crops (e.g. cocoa, papaya, banana) can be adversely affected even by salt born on the wind)
Annual rainfall (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).

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

Equation 1 Expression of physical/economic vulnerability

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

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

Equation 2 Expression of social vulnerability

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

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

Table 13. Relevant risk components per hazard

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

Social vulnerability

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

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

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

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

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

Physical vulnerability

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

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

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

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

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

For the computation, linear and punctual infrastructure need be distinguished because the replacement cost of linear infrastructure such as roads is expressed in $/km (Table 14), whereas the replacement costs of punctual infrastructures are absolute values ($)(Table 15, Table 16 and Table 17).

Table 14. Replacement cost for roads

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

Table 15. Replacement cost for bridges

Type	Replacement cost ($)
Concrete/Steel	10.000
Steel	10.000
Wooden	1.000
Causeway/Ford/Culvert (insensitive)	-

Table 16. Replacement cost for airstrips

Type	Replacement cost ($)
Airstrip	10.000

Table 17. Replacement cost for special infrastructure

	Maximum loss fraction	Replacement cost ($)	Equivalent PCRAFI
AIRPORT	0,5	100.000	Small airport
CHEMICAL	1	10.000	Storage tank
CROP	0	-	Counted in economic vulnerability
ELECTRICITY - Generator	1	1.000	
ELECTRICITY - Substation	1	500.000	
FUEL	1	20.000	
MINE	0,5	10.000	Small mine
OTHER TRANSPORT	1	30.000	Bus station
PORT	0,5	5.000	Small port
PRODUCE	1	10.000	Storage tank
TELECOMMUNICATION	1	5.000	communication
UNKNOWN	0	-	
WASTE WATER - Treatment ponds	1	2.000.000	Water Treatment
WASTE WATER - Others	1	10.000	Storage tank
WATER - Treatment plant	1	2.000.000	Water Treatment
WATER - Pump station	1	40.000	Water intake
WATER - Others	1	10.000	Storage tank

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

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

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

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

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

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

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

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

Economic vulnerability

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

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

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

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

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

- Weights for dominant crops should have a minimum of 0,33 (one third)
- Weights for subdominant crops should have a minimum of 0,1 and maximum of 0,33 (one third)
- Weights for other present crops should be below 0,1

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

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

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

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

Table 18. Weighting of crops in agricultural systems

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

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

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

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

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

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

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

Table 19. Economic vulnerability reclassification

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

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

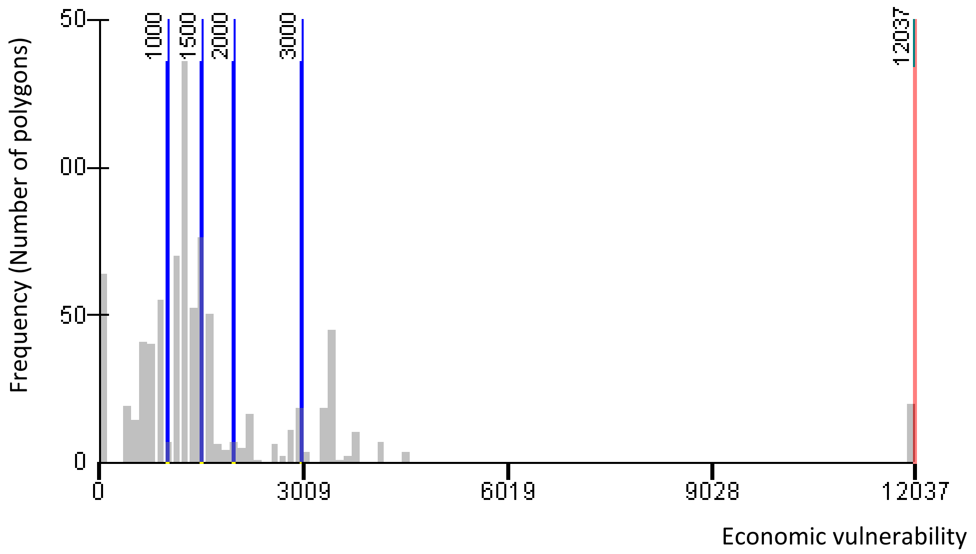

Figure 3. Frequency distribution of agricultural systems (MASP) and plantations vulnerability to extreme weather

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

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

Symbology

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

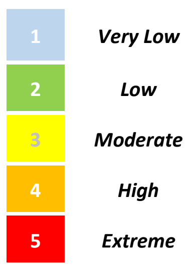

Figure 4. Vulnerability and risk classes

1.2.3. *Risk assessment*

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

Once the three vulnerability components (physical, economic and social) computed and mapped, risk is calculated as the product of the hazard index and the vulnerability index (Equation 1).

$$Risk = Hazard\ x\ Vulnerability$$

Equation 1. 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…

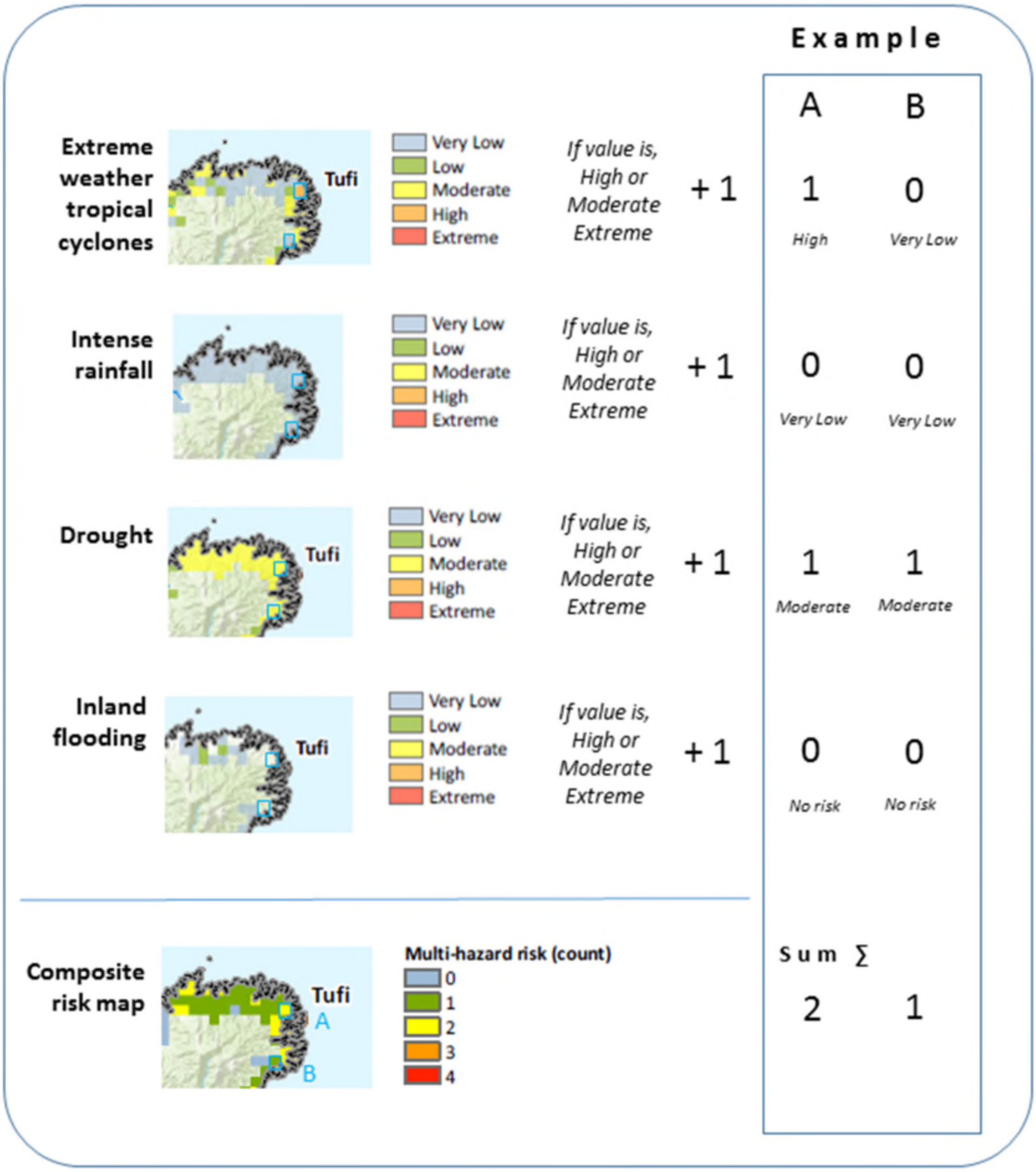

Figure 5. Example calculation of composite risk

1.3. Baseline information of Morobe Province

1.3.1. Administrative

The Morobe Province is located in central Papua New Guinea along its northern coast and has the city of Lae as its provincial headquarters. It belongs to the Momase Region and it is composed from a total of nine districts: Bulolo, Finschhafen, Houn, Kabwum, Lae, Markham, Menyamya, Nawae and Tewae-Siassi. Each district is in turn divided into Local-Level Government Areas (LLGs). There are a total of 33 LLGs in Morobe.

Table 20. Number of wards per LLG

District	LLG	Number of wards	
Bulolo District	Mumeng Rural	20	91
	Waria Rural	17	
	Watut Rural	12	
	Wau/Bulolo Urban	2	
	Wau Rural	20	
	Buang Rural	20	
Finschafen District	Hube Rural	16	71
	Kotte Rural	10	
	Yabim Mape Rural	20	
	Burum Kwat	24	
	Finschafen Urban	1	
Huon District	Morobe Rural	21	65
	Salamaua Rural	17	
	Wampar Rural	27	
Kabwum District	Deyamos Rural	16	66
	Yus Rural	13	
	Komba Rural	19	
	Selepet Rural	18	
Lae District	Ahi Rural	1	2
	Lae Urban	1	
Markham District	Onga/Waffa Rural	13	63
	Umi/Atzera Rural	30	
	Wantoat/Leron Rural	20	
Menyamya District	Kome Rural	16	60
	Wapi Rural	15	
	Kapao Rural	15	
	Nanima Kariba	14	
Nawae District	Labuta Rural	14	46
	Nabak Rural	14	
	Wain-Erap Rural	18	
Tawae/Siassi District	Sialum Rural	19	57
	Siassi Rural	20	
	Wasu Rural	18	

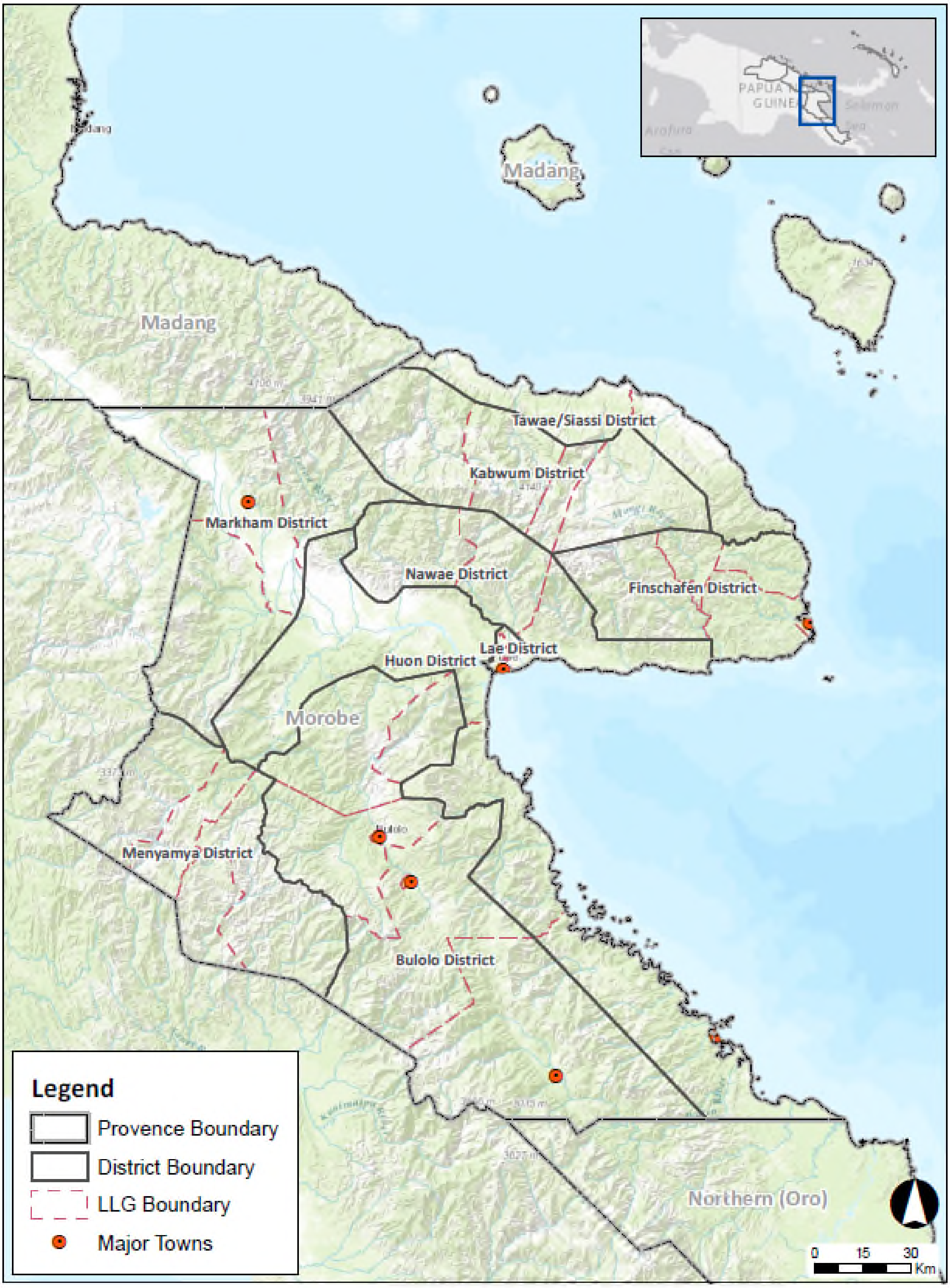

Figure 6. Administrative map Morobe province

1.3.2. *Topography*

Morobe Province is located in central Papua New Guinea along the northern coast. It includes the Huon peninsula, the Markham River and delta and all coastal territories along the Huon Gulf. Islands also make part of Morobe Province with Umboi (777 sq km) and Tami islands as most prominent. Neighbouring provinces include Madang to the north, Eastern Highlands to the west and Gulf, Central and Oro (Northern) to the south.

Figure 8 shows the main rivers flowing through Morobe Province. The most important river systems are Waria and Markham, which originates in the Finisterre Range.

Figure 9 show the slope map for Morobe Province. The slopes map is obtained by classifying the digital elevation model into three classes as presented in Table 21***Fout! Ongeldige bladwijzerverwijzing.***.

Table 21. Slope classes an occurrence in Morobe Province

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

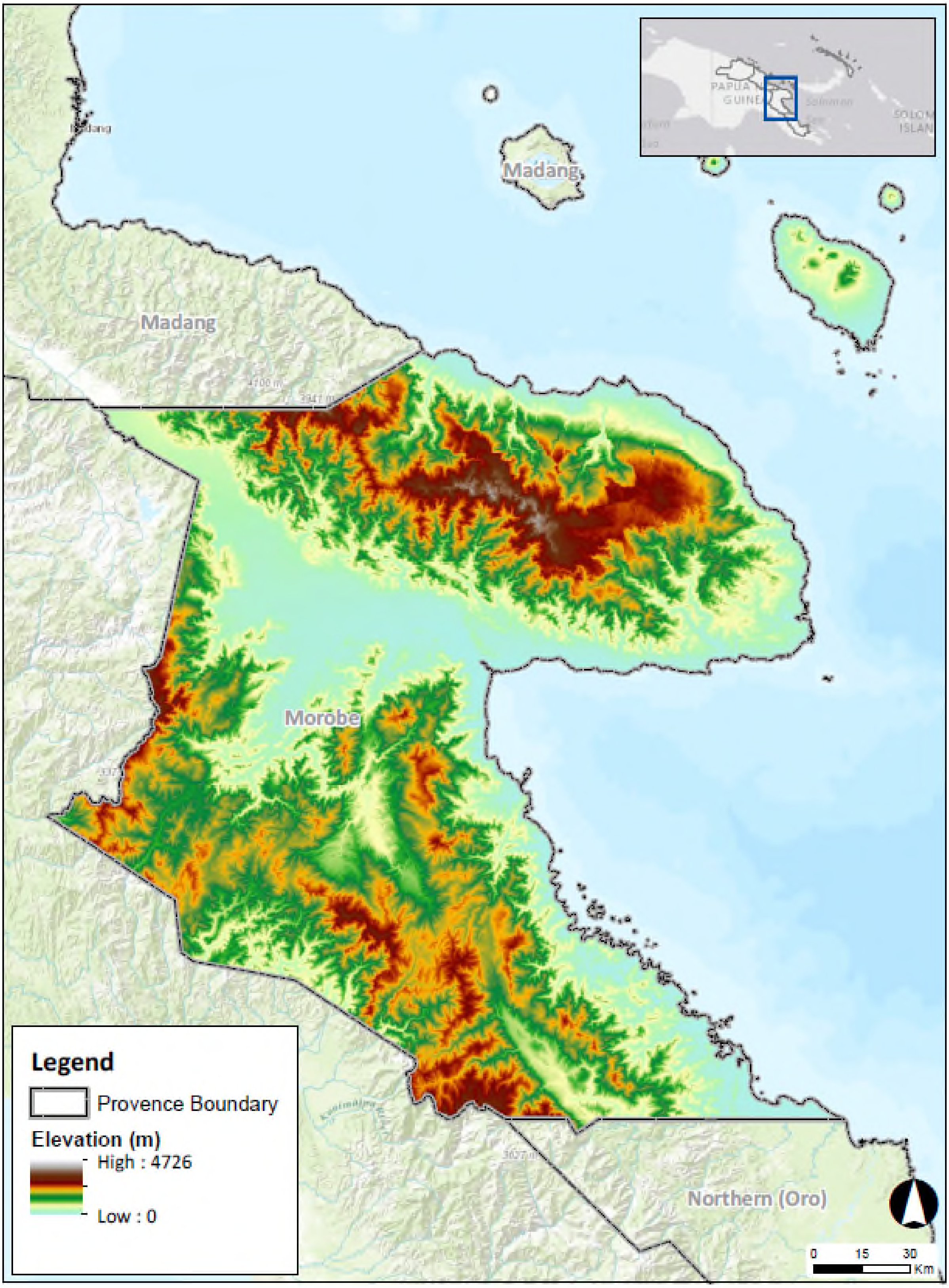

Figure 7. Elevation map of Morobe Province

Figure 8. Main rivers found in Morobe Province

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

1.3.3. *Land use / land cover*

Figure 10 show the soil cover map for Morobe 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 34% of the province is marked as agriculture and just 2% for plantations. The Markham Basin is the most used for agriculture and plantations in this province.

Figure 10. Land Use map Morobe Province

1.3.4. *Population and health*

The Morobe Province has a total of 674,810 inhabitants and 130,109 households according to the 2011 national census. It comprises the 9.3% of PNG's total population, making it the most populated province in PNG, and has an annual growth rate of 2.0% for the period 2000-2011.

The Province consists of nine districts, Finschafen District is found to have the highest population (1,176,603), which accounts for 26% of the total population of Morobe Province, whereas Huon District had the lowest population with approximately 9.2% (418,601).

The population density is 20 inhabitants per km^2, somewhat higher than the national average of 11. The average household size in the province is 5.2 persons. The age dependency ratio[4] is 80 which is significantly higher than the national average of 61.7.

Table 22. Population numbers per age group and per district

District	Age Group				
	Age not stated	0 - 4 yr	< 15 Yrs	15-64 yrs	> 65 yrs
Bulolo District	1815	138928	400308	598945	28480
Finschafen District	1783	140022	403583	602664	28551
Huon District	716	49774	142803	214734	10574
Kabwum District	1725	135180	390958	585801	27647
Lae District	1020	73034	212159	317443	14012
Markham District	458	31304	88347	142301	6967
Menyamya District	1213	98041	284180	428236	19484
Nawae District	809	61691	178384	272786	12995
Tawae/Siassi District	341	26800	75595	123824	5490

The more densely populated LLGs are Lae Urban and Wae Bulolo Urban, followed by Ahi Rural which is situated along the coast in the vicinity of Lae. 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 27 recorded languages across the nine districts[5].

The adult literacy rate for the province is 80%, which is relatively high and significantly higher than the national average of 67.6%.

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[4] % of working-age population

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

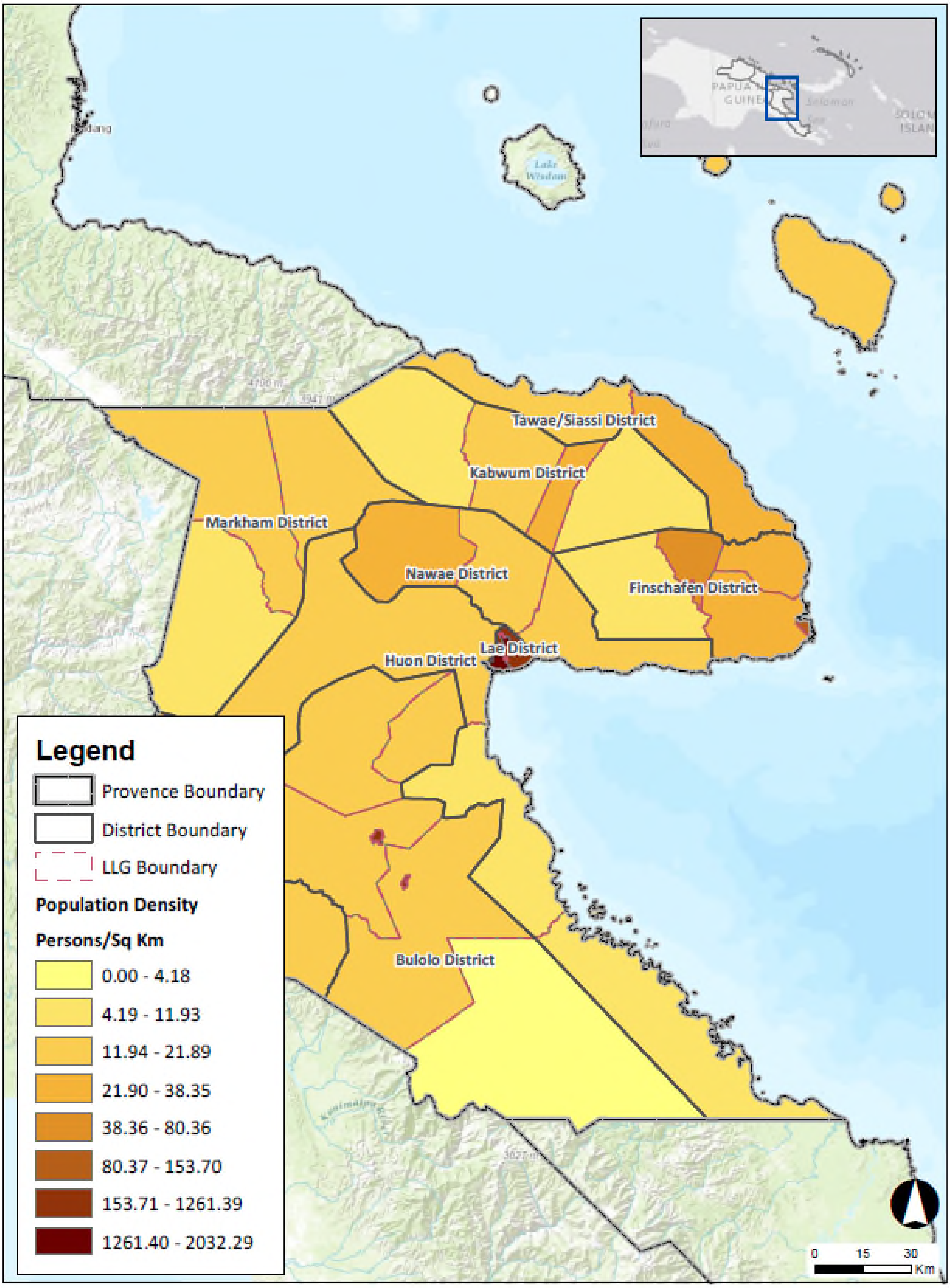

Figure 11. Population density map of Morobe Province

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

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

	Low Weight for Age < 5 years old (%)[6]	Low Birth Weight (%)[7]	Incidence of Malaria (1,000 population)[8]	Incidence of Diarrhoea (<5 years/1,000 pop.)[9]
Bulolo District	39	0.5	28	126
Finschafen District	23	11.9	78	53
Huon District	16	0.0	58	115
Kabwum District	46	0.0	20	80
Lae District	14	0.0	338	489
Markham District	17	8.4	40	155
Menyamya District	61	34.6	46	132
Nawae District	27	0.0	33	166
Tawae/Siassi District	14	10.7	36	56
Morobe Province	**25**	**11.0**	**106**	**194**
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 164 aid posts and 49 health centres in the province. The percentage of children weighed at clinics is less than 80% of the normal weight for their age in Morobe Province during the period from 2010-2014.

In 2014, Menyamya District had by far the highest percentage of low birth weight children in Morobe Province, 34.6%, compared with the provincial and national averages of 11% and 7.7% respectively. This district also had the highest percentage of children with low weight for age under 5 years old in the province (61%), compared to the provincial and national averages of 25% and 24.5% respectively.

Lae District had by far the highest reported incidence of diarrhoea in children under 5 years old and number of recorded cases of malaria. Menyamya District has the significantly highest cumulative score (i.e. the highest ranking) on key health indicators relating to social vulnerability, followed by Lae District[10].

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[6] 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

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

[8] 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

[9] 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.

[10] 2011 National Population and Housing Census of Papua New Guinea

Table 24. Number of Healthcare facilities per LLG

District	Aid posts	Health centres
Bulolo District	15	7
Finschafen District	18	7
Huon District	26	4
Kabwum District	22	4
Lae District	2	10
Markham District	24	3
Menyamya District	14	5
Nawae District	22	3
Tawae/Siassi District	21	6

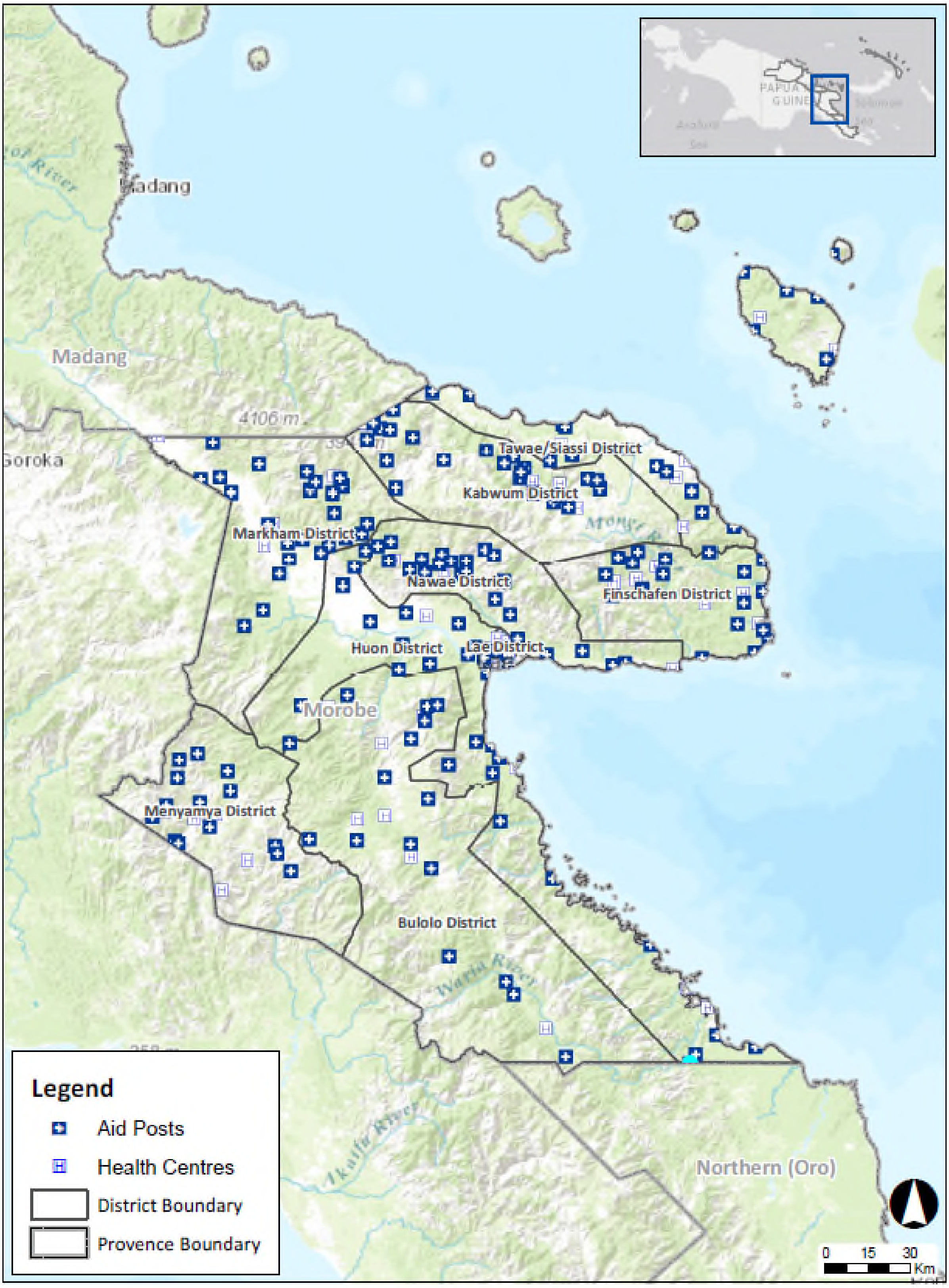

Figure 12. Location of health centers and aid posts in Morobe Province

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 Kalapit to Lae District to Bulolo to Wau, and Madang to Morobe Province. A large part of the province is not easy accessible by road.

Table 25 Kilometers of roads in Morobe

	Highway	National Road	Provincial road	Others
Km of roads	294.15	459.79	1489.98	60.12

Table 26 Number of bridges in Morobe

District	Number of bridges
Bulolo District	92
Finschafen District	39
Huon District	17
Kabwum District	8
Lae District	5
Markham District	54
Menyamya District	53
Nawae District	37
Tawae/Siassi District	50

Table 27 Total of public establishment

District	Aid posts	Health centres	Police stations	Airports	Schools	Religion	Government	Public facility
Bulolo District	15	7	4	2	49	135	161	31
Finschafen District	18	7	2	1	42	80	100	23
Huon District	26	4	4	1	48	88	119	25
Kabwum District	22	4	1	0	34	53	75	15
Lae District	2	10	8	0	26	107	503	136
Markham District	24	3	1	0	38	80	100	27
Menyamya District	14	5	2	0	28	108	122	35
Nawae District	22	3	1	0	33	76	63	16
Tawae/Siassi District	21	6	2	0	43	66	73	28

Figure 13. Road infrastructure in Morobe Province

1.3.6. *Agriculture and livelihoods*

Coffee and Cocoa are the main agricultural activities observed in Morobe Province. Coffee itself is the main source of income for an estimated 2.5 million people in PNG, with Morobe Province serving as one of the several key coffee-producing regions according to the Oxford Business Group. Morobe Province along with Western, Eastern Highlands and Simbu provinces account for more than 80% of coffee yield in PNG. Moreover, almost 85% of coffee produced in PNG is grown, harvested and partly processed by smallholder growers. Coffee is thus the main source of cash income for a large proportion of the population, surpassing even minerals and other agricultural products.

Coffee exports were worth PGK927m ($316.5m) in 2011, but production has declined since then, a victim of aging trees and an El Niño-induced drought and frost during the crucial production period of April to November, according to Charles Dambui, acting CEO, Coffee Industry Corporation (CIC). Between 2013 and 2015, exports declined by 24% compared with the 2010-12 period, according to CIC. In 2015, the total value of coffee exports was down to PGK393.6m ($134.4m), with a total production of 44,030 tonnes, which is 7% lower in volume than the 2014 production level (Oxford Business Group, 2016).

Regardless, recent rise in coffee prices provides an incentive for coffee growers to increase their yield and profit from favorable market circumstances. The province's growers need however to access funds in order to invest in new trees with stress-resistant bean varieties that can thrive in PNG's climate. The World Bank, the EU and the International Fund for Agricultural Development are currently financing a large-scale programme known as the Productive Partnerships in Agriculture Project (PPAP). With an investment of $46m, the initiative aims to develop links between producers and markets and key players in PNG's coffee industry.

International aid has provided similar incentives for cocoa production in Morobe province in recent years according to the Oxford Business Group. From an almost non-producer of cocoa, Morobe is now only behind the cocoa industry leaders in PNG, East New Britain and East Sepik provinces. The Productive Partners in Agriculture Project (PPAP) established the link between cocoa industry representatives and farming groups in Morobe Province. As a result, disease-free hybrid plantings have substantially contributed to local incomes. The awarding of the Cocoa of Excellence Award in 2015 to the Wals Cocoa Cooperative in the *Lower Watut* area of the provinces stands as proof of this success. The Wampar people earned 2m PNG Kinas ($682,742) from cocoa exports in 2015, according to Morobe Provincial Governor Kelly Naru.

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)[11]. 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.

[11] 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 northern and central parts of the province have higher potential to inland flooding along the banks of the Markham River and its tributary the Watut River (across the Markham and Huong Districts). Additionally, there are some hotspots in Kabwum District (Timbe river and upper Mongi River) and in the small coastal catchments in the Southern part of Morobe District (see Figure 14).

Future projections, as shown in Figure 15, do not show much variation. The table below gives the flood areas (km²) for current and future climate conditions in the Morobe province. Overall, an increase of 2 % is expected.

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

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

Morobe	HND	H40
T 0-5y	2485.0	2520.8
T 5-10y	21.0	25.4
T 10-50y	48.7	69.2
Total	2554.6	2615.4

During the community risk assessment (CRA[12]), 6 communities were visited in the Madang Province: Lokep Island, Wasu, Sialum, Tami Island, Buang, Labu-Lupo, Intoap, Karanas Settlement, Kumalu.

According to its CRA[13], Lokep Island, the most north Island in the Morobe Province, close to its boundary with Madang Province, is affected by flash floods along the banks of its rivers and creeks. However, these rivers and creeks are no part of the stream channel network derived from the flow accumulation map, this is likely caused by the filtering step applied to remove any small river or creeks where the contributing watershed area is less than 30 km^2. Beside the methodology does not focus in the estimation of flash flood.

The Wasu community usually experiences heavy rainfall from November to March (CRA[14]), most of the small streams and brooks suddenly become big rivers and inundate low-lying areas. Most houses, food gardens, cocoa plantation and livestock (pigs) are located in low-lying areas and along the sides of streams and brooks which suddenly become big rivers that rapidly inundate, submerge and wipe out this low-lying areas before the people can properly evacuate them. The people experienced a heightened intensity of the floods recently that is also worst due to unhealthy and destructive practices like cutting trees along the river bank and coastal areas, clearing of mangrove areas to get mangrove trunks and branches for housing and fuel, creasing density of houses near the shores. The inland flood mapping model estimated in this project, identifies 2 of the major rivers in this area and their corresponding flood plains within this community. Smaller rivers and brooks are filtered out if their contributing area is less than 30 km^2. Beside the methodology does not focus in the estimation of flash flood.

According to its CRA[15], Sialum village is highly vulnerable to inland flooding since it is located in between the Qangam (center) and Saboro (north) Rivers. Sialum is basically flatland and 4-5 miles from the shoreline the terrain slowly becomes elevated. At the backside of the community is a wide swath of savannah grassland which is an ideal area for pastureland. Past experiences showed that heavy rains from January to March always generate huge perennial flooding affecting food gardens, houses and road access outside of the village for days. The continuous cutting of trees of people in upstream areas and along the riverbanks will continue to impact the flooding situation in the village. Flood plains are identified in Figure 14 and Figure 15 along the coast, in south and in between both rivers, although only the lowest part of Qangam river is part of the stream channel network derived from the flow accumulation map, this is likely caused by the use of the 90m resolution SRTM and the filtering step applied to remove river or creeks where the contributing watershed area is less than 30 km^2.

According to its CRA[16], Tami Island is not vulnerable for inland flooding, only coastal flooding. Any river, creek, brook or a related flooding area is identified in this area due to its small area.

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

[13] Report Community Risk Assessment, Lokep Island, Siassi Rural LLG, Tewai-Siassi District, Morobe Province, Papua New Guinea.

[14] Report Community Risk Assessment, Wasu village, Wasu Rural LLG, Tewai-Siassi District, Morobe Province, Papua New Guinea.

[15] Report Community Risk Assessment, Sialum village, Sialum Rural LLG, Tewai-Siassi District, Morobe Province, Papua New Guinea.

[16] Report Community Risk Assessment, Tami Island, Yabim-Mape Rural LLG, Finschaffen District, Morobe Province, Papua New Guinea.

According to its CRA[17], Buang village is highly vulnerable to inland flooding. Buang village is located North west of Finschhaffen city and is dominated by rolling hills surrounded by thick vegetation. At the middle of the village is the big Mape River which stretches from Burum Kuat and Hube LLGs to the Bismarck Sea. The Buming and Gebec creeks as well as Buang River are tributaries of the Mape river and they crisscross the northeast sections of the village where several cash crop plantations are located. Perennial flooding between April and October destroys food gardens and houses located near the Mape river banks. There is the perception that in the recent years the frequency and intensity of the regular floods is increasing, as well as the reached water level during floods. The expected flood plains identified in Buang CRA were also identified in the estimated inland flood maps.

According to its CRA[18], Labu-Lupu village is highly vulnerable to inland flooding. Labu-Lupu village is located North west of Lae city, along the banks of the big Markham River which reaches the sea south from Lae city. Perennial flooding occur between May and August. The flood plains identified in Labu-Lupu CRA were also identified in the estimated inland flood maps (some differences in extension), south and downstream from the Markham bridge.

According to its CRA[19], Intoap village is highly vulnerable to inland flooding. Labu-Lupu village is located South of Kaiapit town, along the upstream banks of the big Markham River which reaches the sea south from Lae city. Intoap is located in a flat land low-lying area that was part of the river bed in the past, its elevation is way below the bed of Markham River thus the place is prone to flooding during the wet season. Perennial floodings occur between September and April. Large inland flood plains are estimated around this community.

According to its CRA[20], Karanas village is highly vulnerable to inland flooding. Karanas village is located East of Bulolo town and the banks of the Bulolo River. Perennial flooding occur between December and March. Over the course of time, due to sedimentation and soil erosion the river changes its course. The flood plains identified in Karanas CRA are expected between the Bulolo River and the Wau-Bulolo highway, while the estimated inland flood areas are located mostly east from Bulolo River. This differences are most likely due to the SRTM, since it is remarked that this river changes its course constantly.

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[17] Report Community Risk Assessment, Buang village, Yabim-Mape Rural LLG, Finschaffen District, Morobe Province, Papua New Guinea.

[18] Report Community Risk Assessment, Labu-Lupu village, Wampar Rural LLG, Huon Gulf District, Morobe Province, Papua New Guinea.

[19] Report Community Risk Assessment, Intoap village, Markham Rural LLG, Umi/Atzera District, Morobe Province, Papua New Guinea.

[20] Report Community Risk Assessment, Karanas village, Bulolo Rural LLG, Wau/Bululo Urban District, Morobe Province, Papua New Guinea.

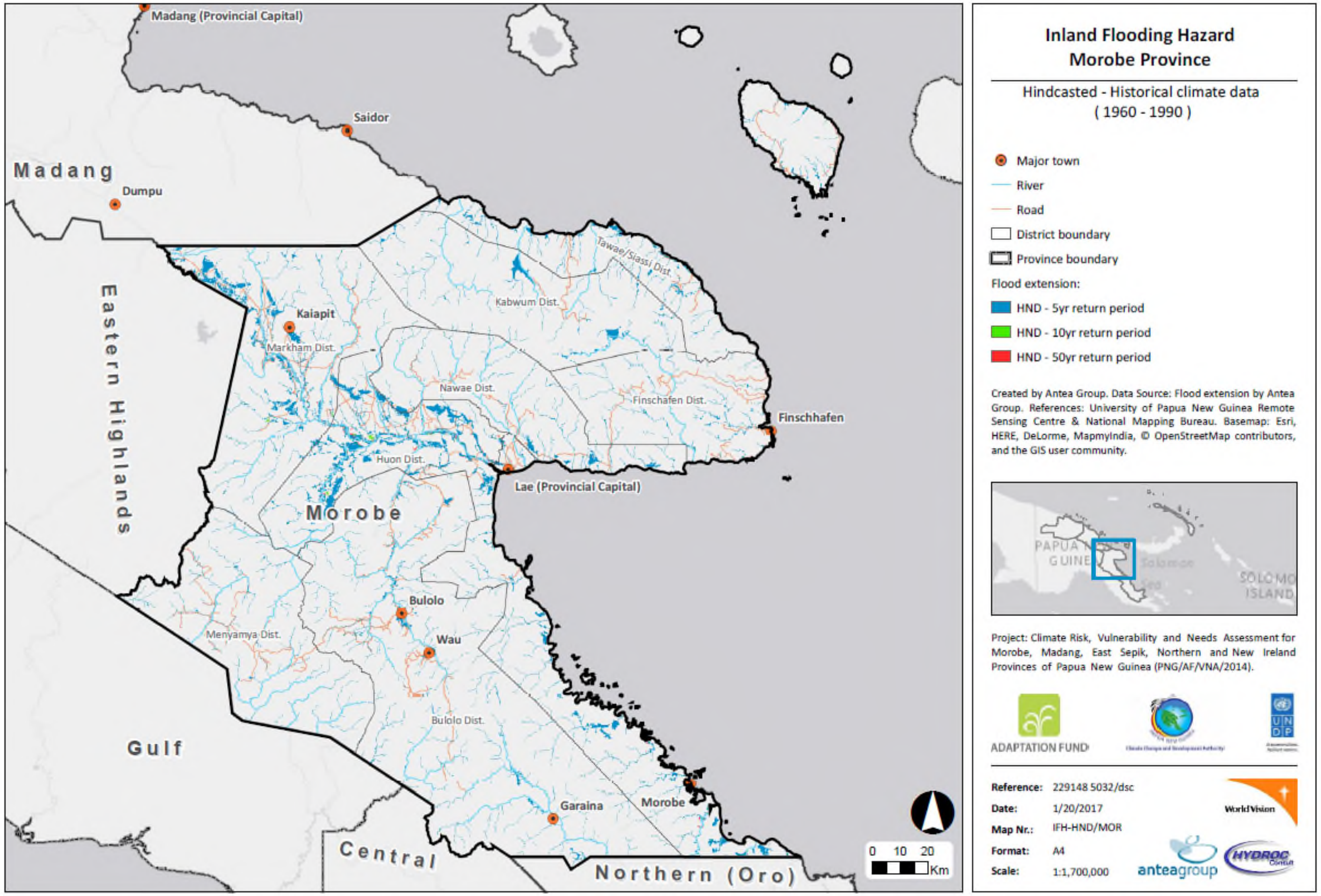

Figure 14. Inland flooding (current climate) ■ flooded

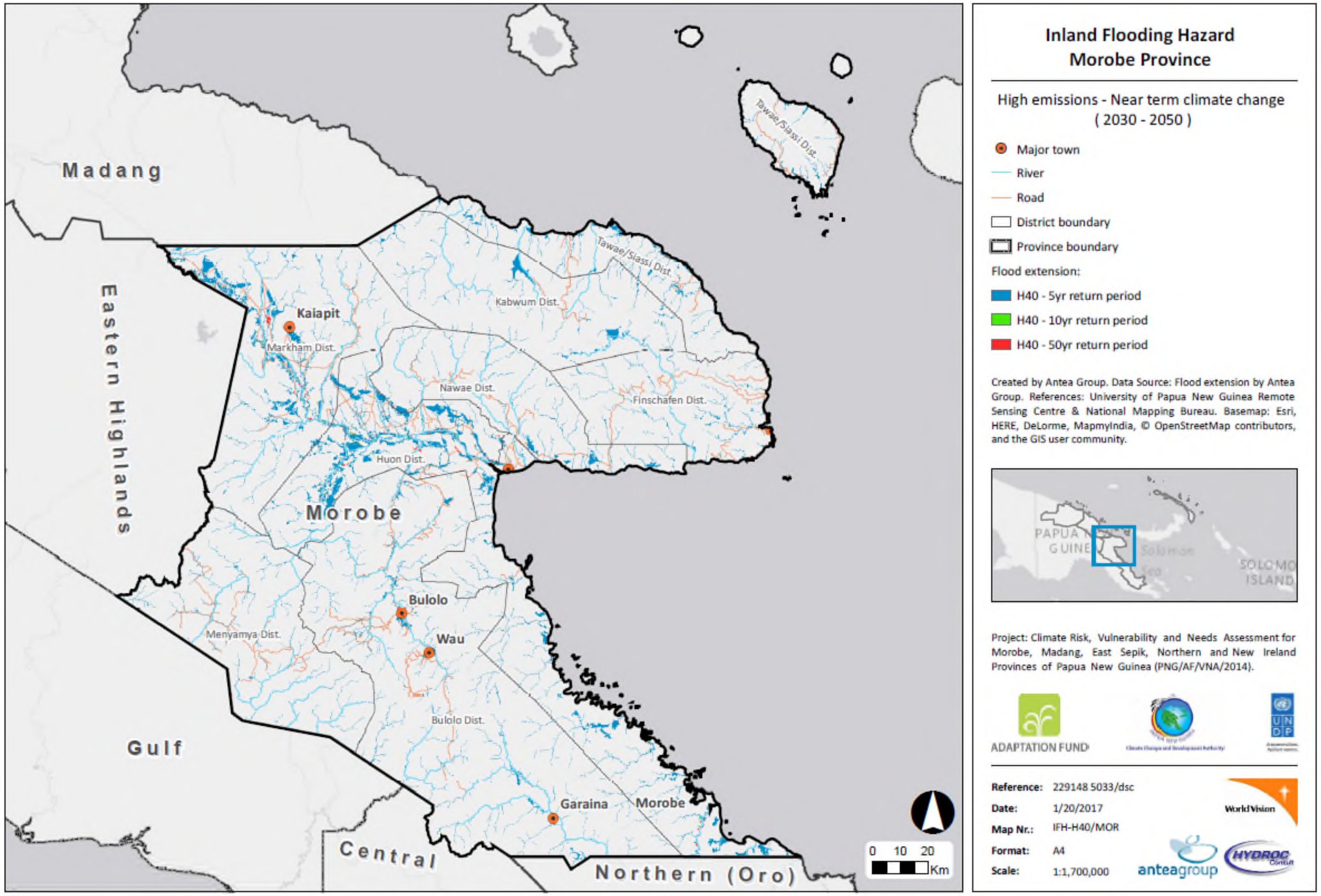

Figure 15 Inland flooding (projected climate) ■ flooded

2.1.3. *Coastal flooding*

The coastal flooding analysis estimated water levels for different return periods for the existing and projected sea level. The available coarse (30 x 30 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*

Historic data show that the southern part of the province is the most affected by drought, with longer continuous dry days (in the range of 25). Projected scenarios show a slight increase in the number of continuous dry days and a tendency of this dryness to spread to the north (see Figures 16 and 17).

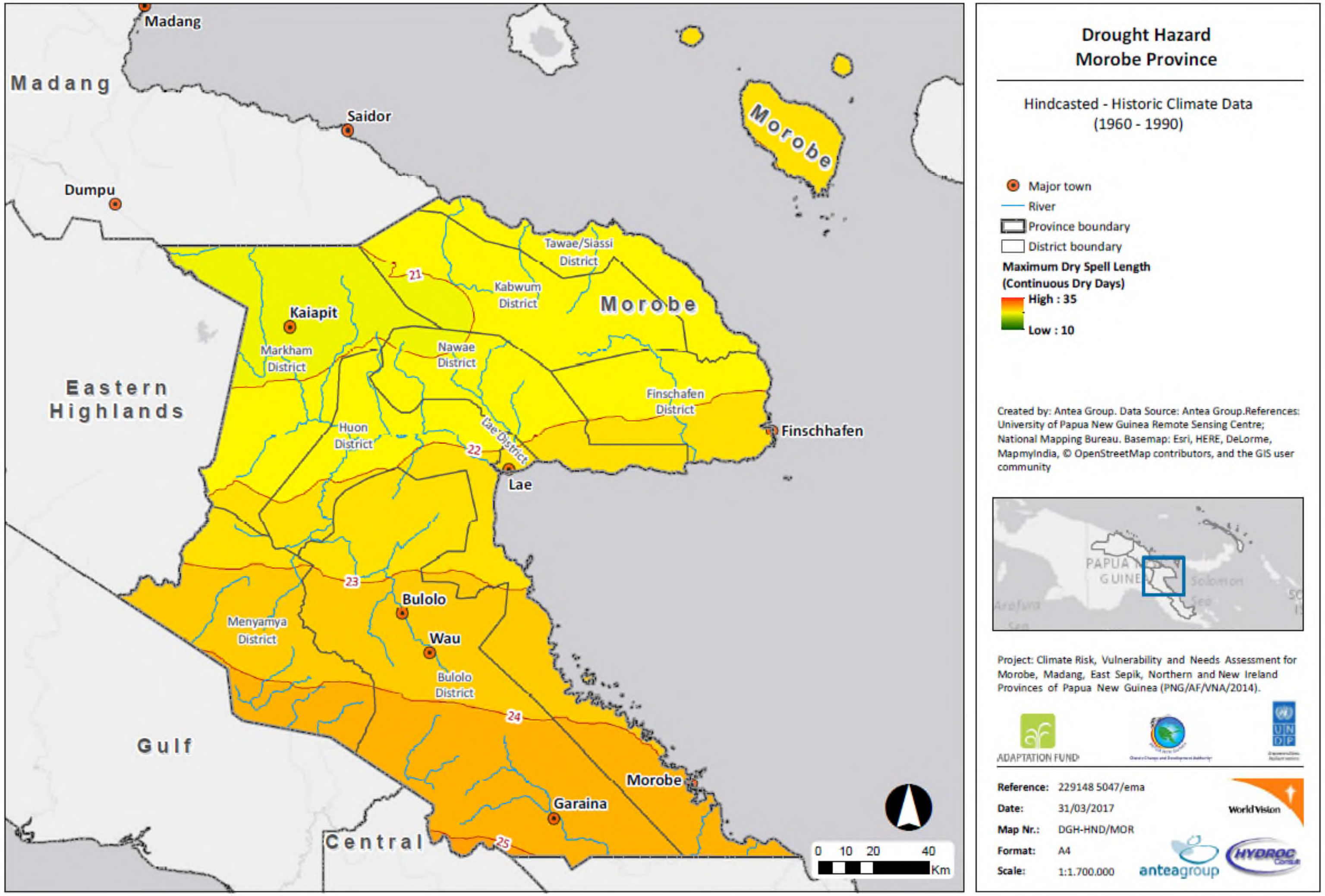

Figure 16. Drought (current climate) expressed as number of continuous dry days 10-16 16-21 21-24 24-29 >29

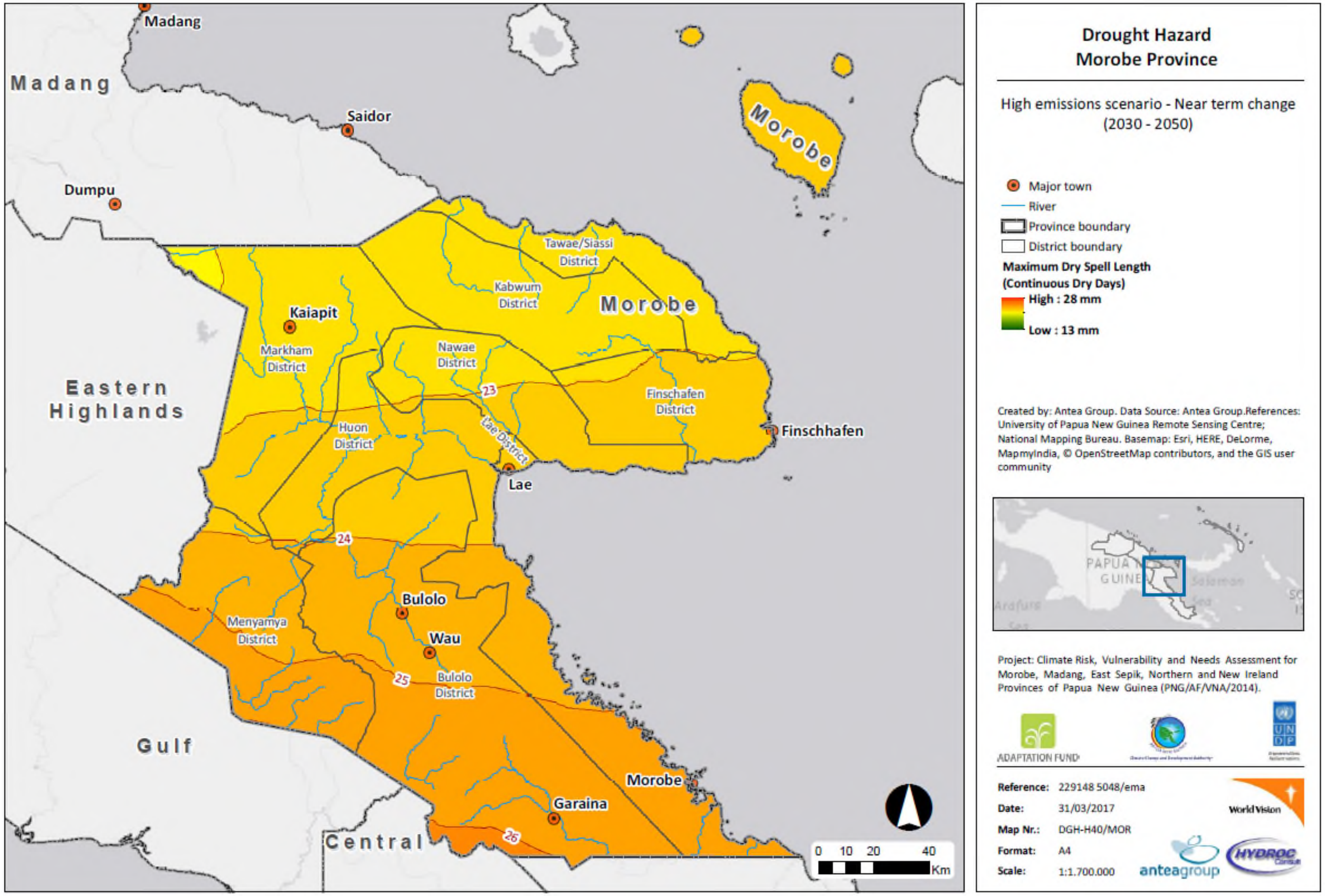

Figure 17. Drought (projected climate) expressed as number of continuous dry days ■10-16 ■16-21 ■21-24 ■24-29 ■>29

2.1.5. *Extreme weather events (tropical cyclones)*

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

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

Under existing climate conditions, only a little corner in the southern coast, in the limits of the Huon District registered one extreme weather event (green area in Figure 18, which also correspond to the border of the assumed destructive diameter of that cyclone). This event correspond to Cyclone Guba in 2007, the only cyclone event in recent history.

The impact of climate change on the frequency of cyclones, is depicted in Figure 19, where the cyclone likelihood remains the same as in the current scenario.

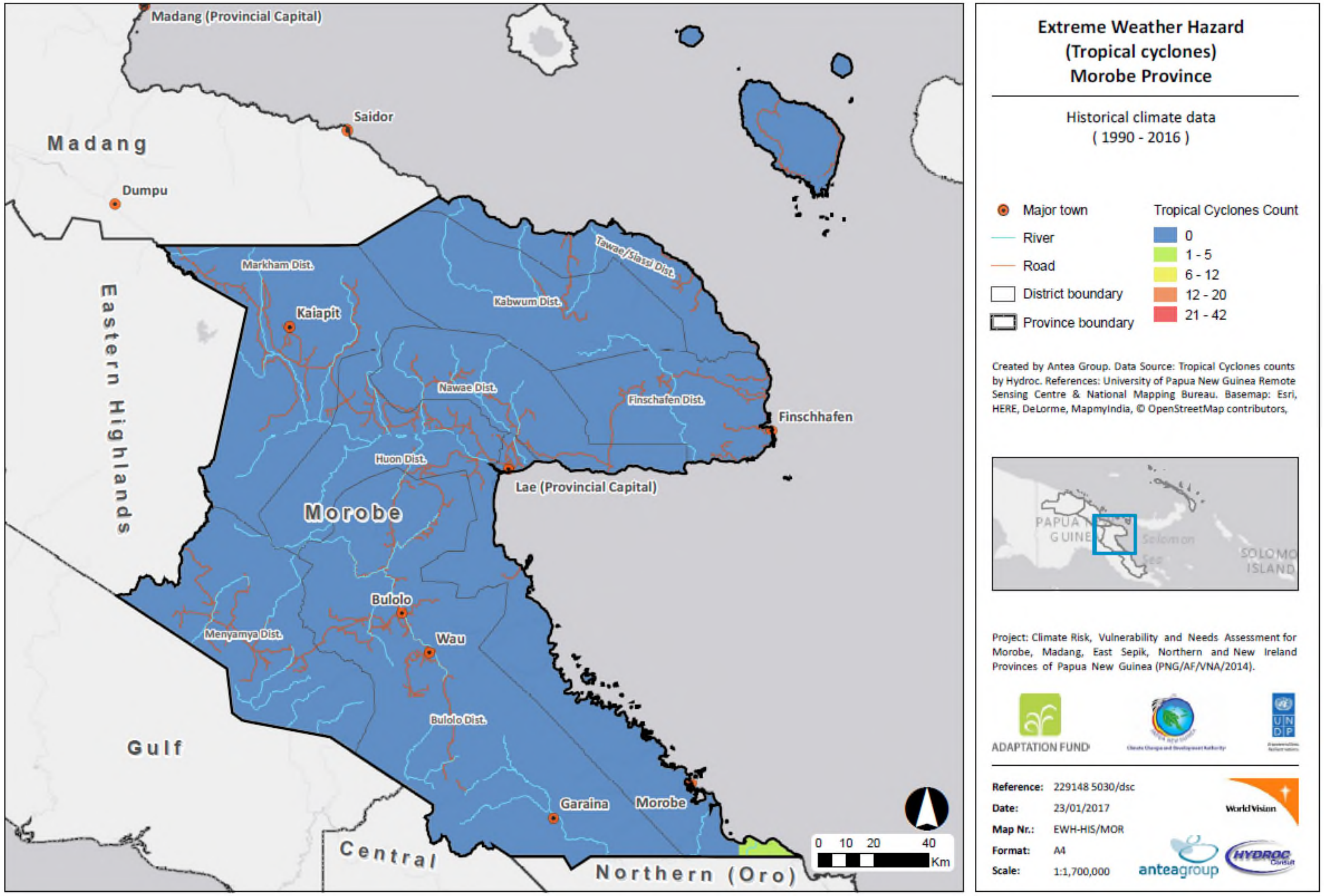

Figure 18. Tropical cyclones (current climate) as number of cyclones 0 1-5 6-12 12-20 >21

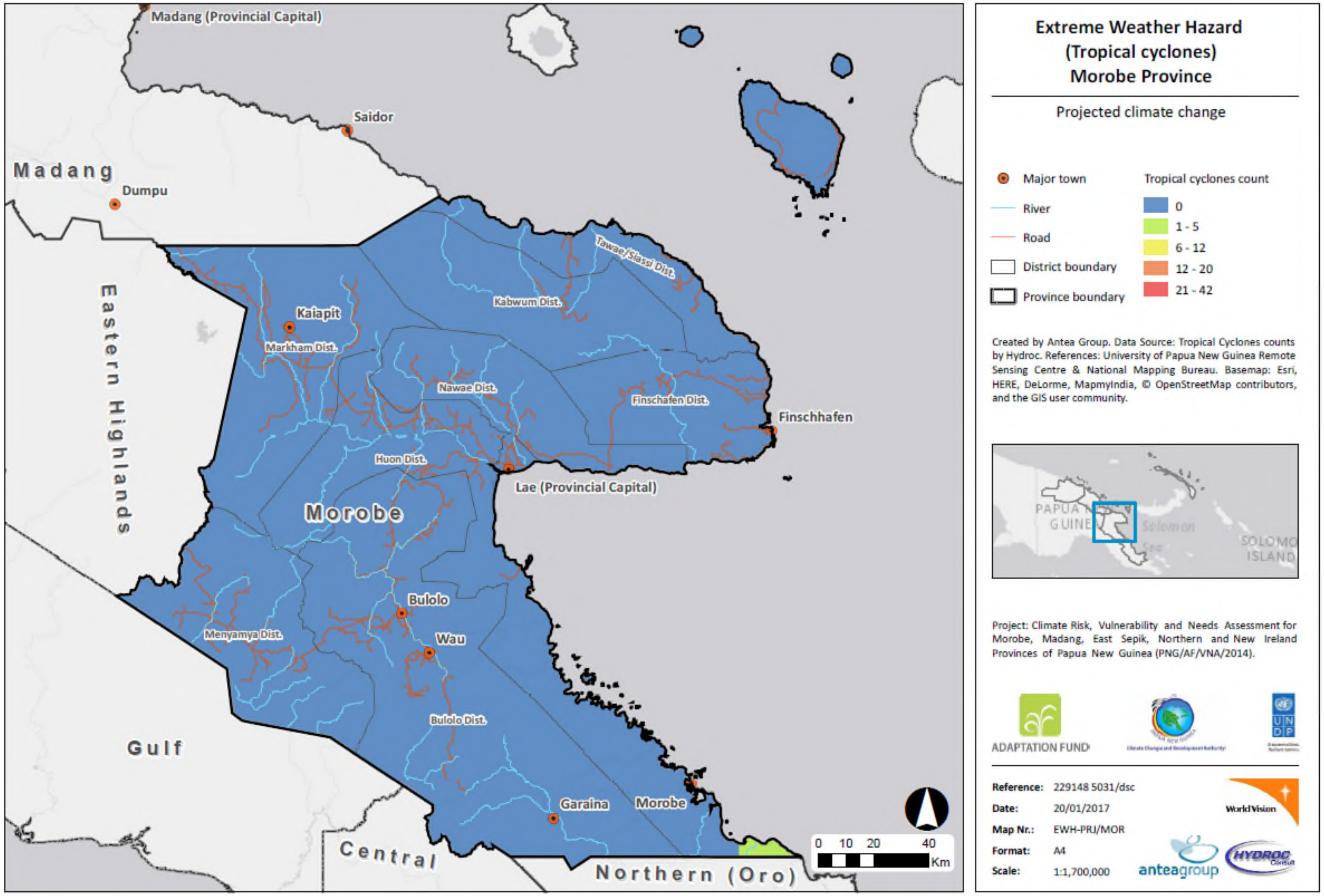

Figure 19. Tropical cyclones (projected climate) as number of cyclones ■0 ■1-5 ■6-12 ■12-20 ■>21

2.1.6. *Increase of precipitation intensity and variability*

Rainfall intensity is historically higher in the highlands in the north, source of the Markham River, and gradually decreases to the south, reaching the lower values in the southernmost points of the Province. The figures for average total annual rainfall in the northern most point reach 3000 mm, while in the south around 2600 mm. Likewise, the average total rainfall on wet days ranges from 560mm in the north to 500mm in the south (see Figures 20 and 22).Projections for the future show a slight increase in rainfall intensity throughout the province and a gradual shift of this intensity towards the south, as can be seen in Figures 21 and 23.

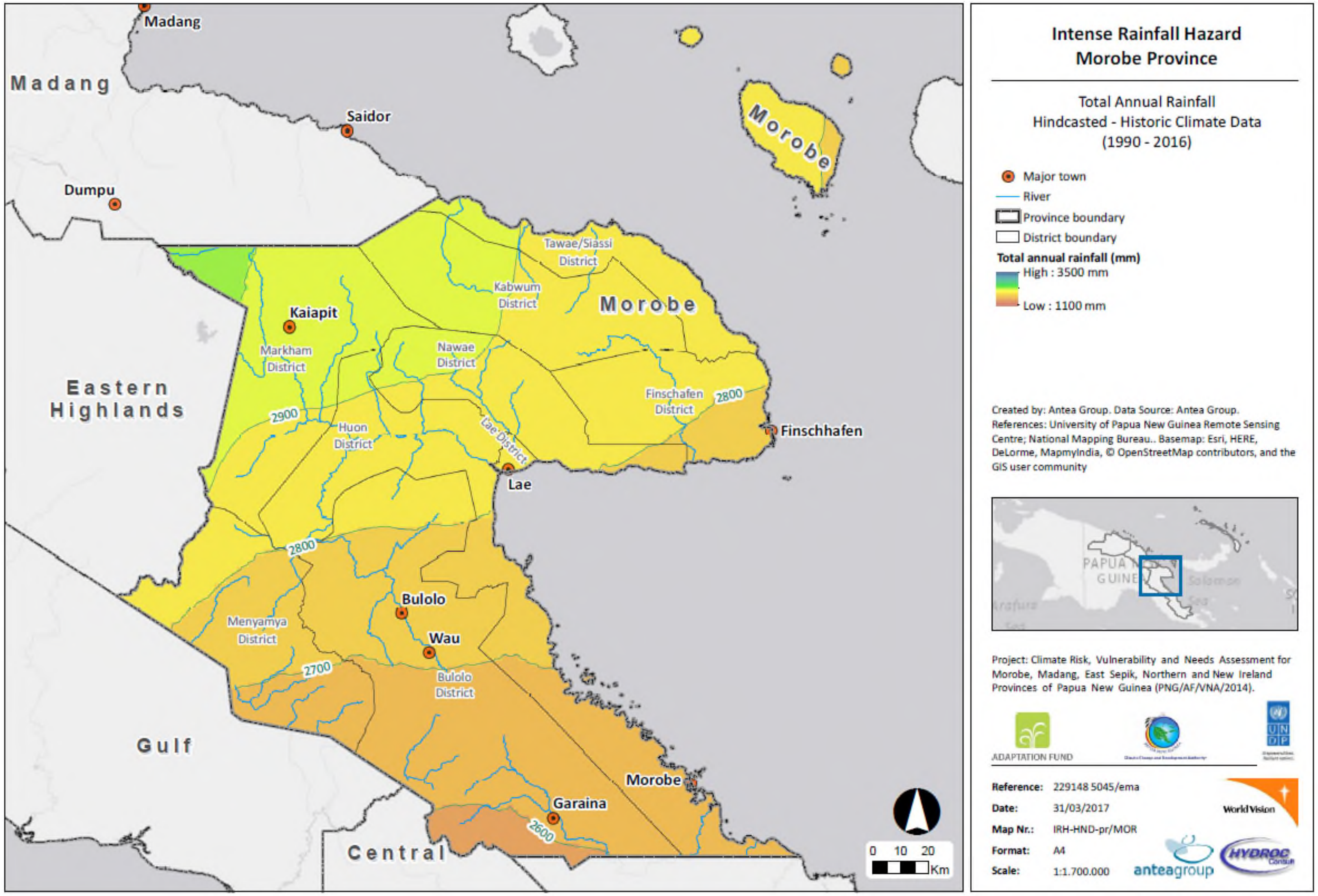

Figure 20. Total annual rainfall in mm (current climate) 1135-2078 2079-2710 2711-2979 2980-3280 3281-3777

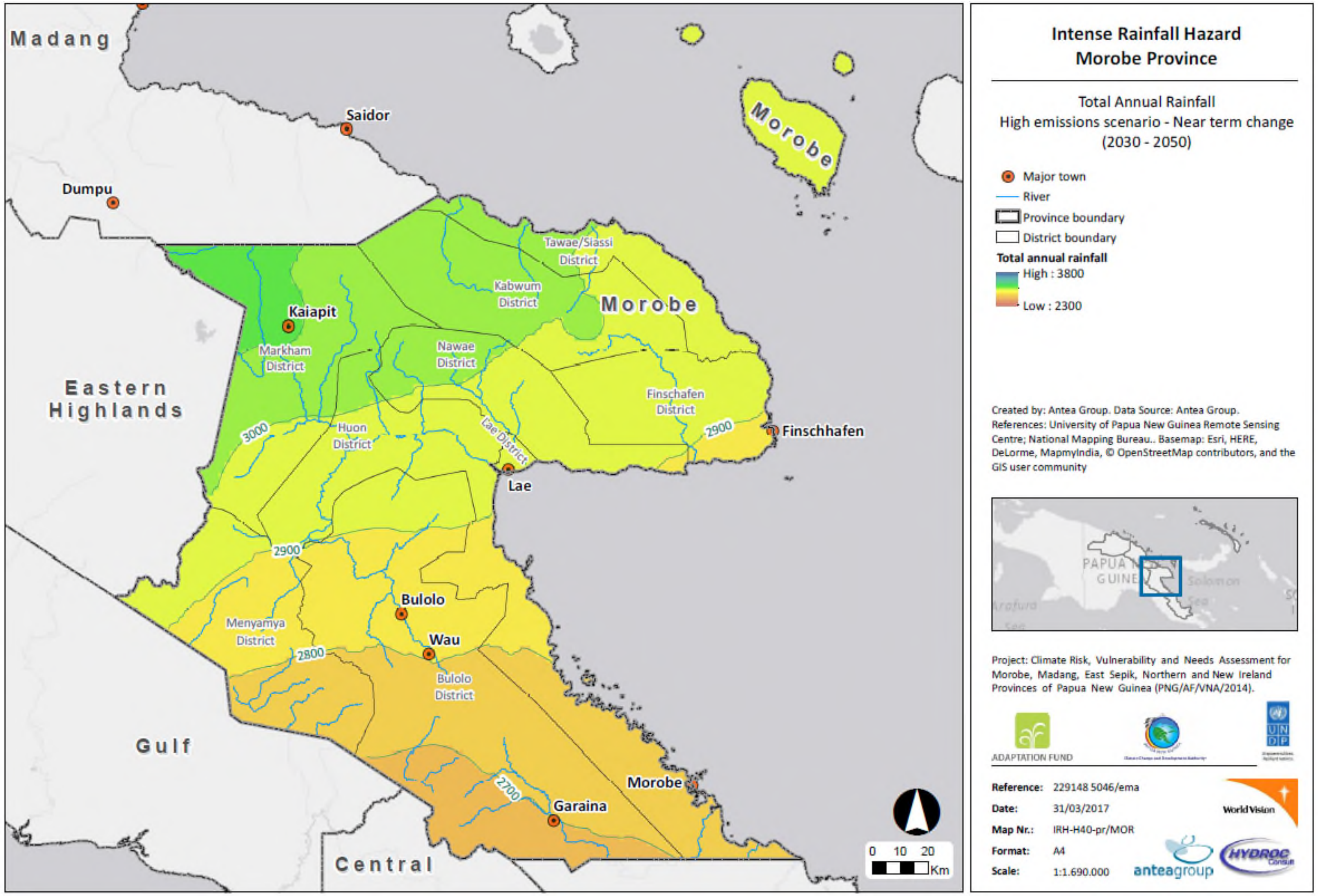

Figure 21. Total annual rainfall in mm (projected climate) 1135-2078 2079-2710 2711-2979 2980-3280 3281-3777

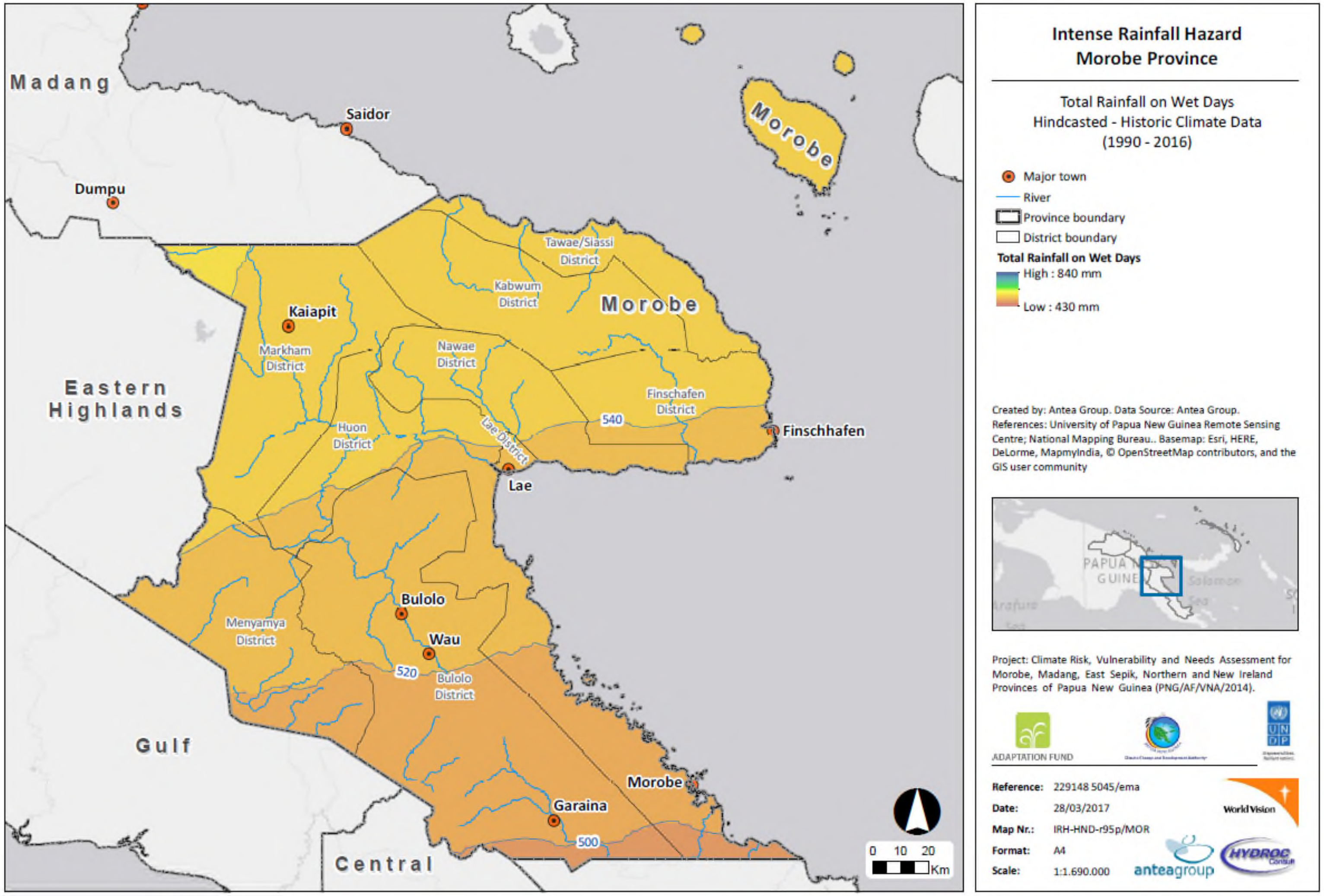

Figure 22. Rainfall on wet days in mm (current climate) 250-500 501-600 601-700 701-800 801-900

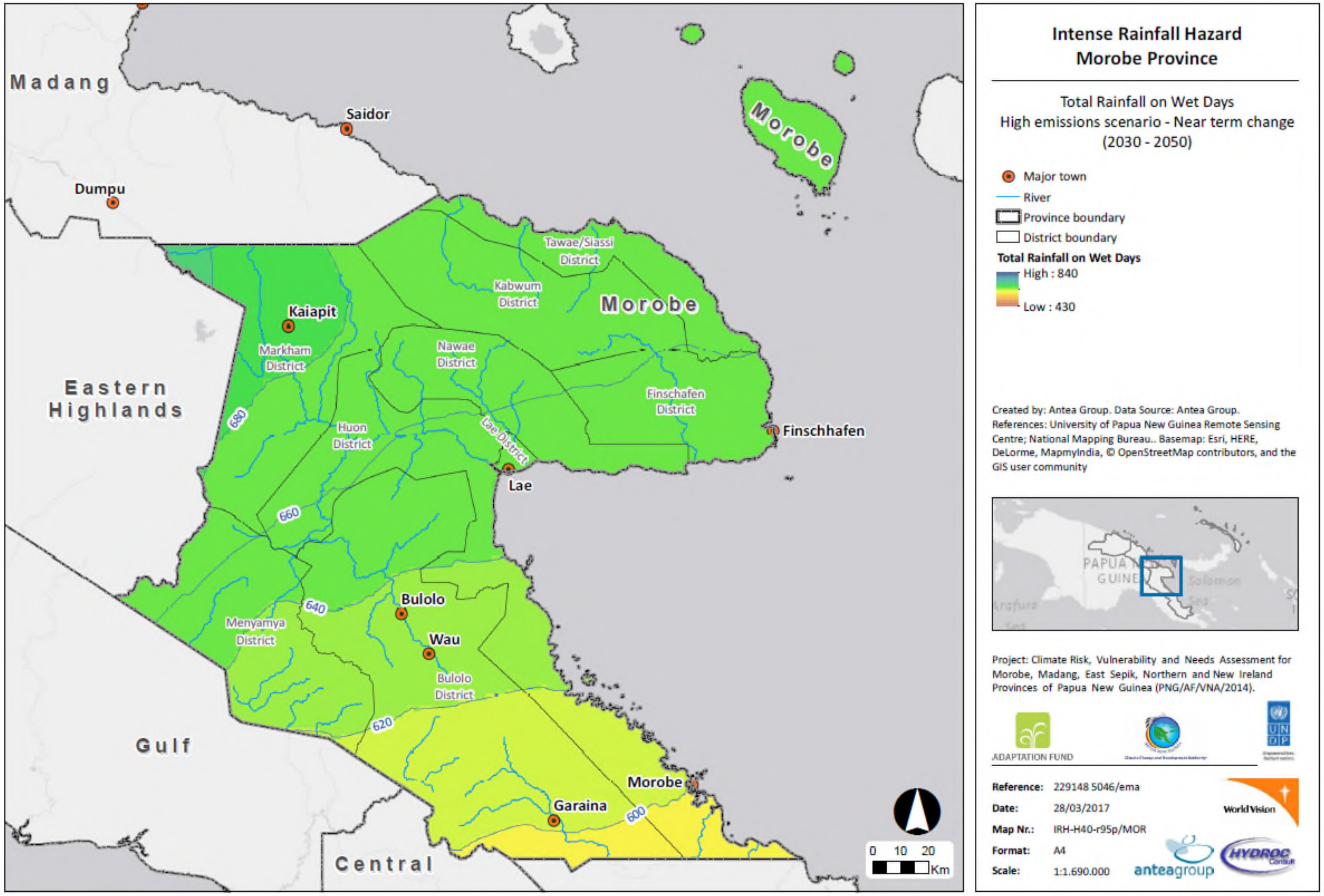

Figure 23. Rainfall on wet days in mm (projected climate) 250-500 501-600 601-700 701-800 801-900

2.2. Vulnerability Assessment

In this chapter we discuss the vulnerability maps for Morobe 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

Areas of very high social vulnerability to inland flooding are found along the Markham River in Lae, Nawae, Huon and Markham districts and along the Kumalu River in Bulolo District. Other area with very high social vulnerability to inland flooding are found in the southern part of the province around Garaina in Bulolo District and in smaller, scattered areas in Menyamya, Finschafen and Kadwum districts as well as the southern part of the offshore island in Siassi Rural LLG (see Figure 24).

An example of one community's experience with floods, that of Labu-Lupo Village, in Ward 5, Wampar LLG, in Huon District visited during the Community Risk Assessment provides additional information about the impacts of and responses to inland flooding in the province.

Flooding has been the biggest natural risks the families of Labu-Lupu face through the years. The first big flood according to older people in the village came sometime in 1950. According to the elders, the entire village comprised of few houses at that time was wiped out. The flood was so huge that people were displaced for a long time. Apart from this first recorded flooding, Labu-Lupu experienced heavy flooding in 1978, 1996, 2002 and 2004. Although there have been series of flooding events in the area recently, these recorded flooding events in the past were the biggest flooding disasters in the history of the village.

Flooding usually happens during May to August each year. It disrupts the normal lives of people particularly their livelihood activities, education of children and movements in and out of the village.

Floodwaters usually cover the only road to the village from the main highway cutting off access of people to the village and vice versa. The floods inundate food gardens and threatened some of the houses located near the banks of the Markham River. There were times that houses got swept away especially when the water is huge and floods come without warning. People also mourn the loss of their precious livestock in previous flooding incidents in the area where pigs were lost to the raging floodwaters.

Over the years people have coped with the impacts of flooding in their village. Most of households have acquired canoes which they use to move from one place to another during the floods. With their food gardens destroyed by flood waters, people turn to sago as their main source of food during the floods.

Small boats are kept for transportation during floods

Physical vulnerability

The physical vulnerability map for Inland flood vulnerability of the province of Morobe (Figure 25) concentrates hotspots mostly in the northern and central part of the Province. Two big hotspots can be seen around the populated areas of Kaiapit and Lae.

Economic vulnerability

Economic vulnerability to inland flooding is higher in the surroundings of Markham River, where there are the most plantations in the province and many agricultural land. Other incipient hotspots can be seen in the upper section of Timbe River, as can be seen in Figure 26.

Combined vulnerability to inland flooding

The combined inland flood vulnerability map of the Province of Morobe (Figure 27) shows a higher exposure to vulnerability in the norther part of the province. The source and the mouth regions of River Markham present the most combined vulnerabilities. Wau and Bulolo also concentrate some vulnerability hotspots although their extent is much less. Finally, some scattered high vulnerability hotspots can be pointed out mainly in the Komba Rural, Hube Rural and Kome Rural districts.

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

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

	HAZARD : INLAND FLOODING						
	COMPOSITE VULNERABILITY %						
District	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**
Bulolo District	17,3	2,8	1,2	0,8	4,6	73,3	6,6
Finschafen District	36,0	5,7	2,5	1,6	6,6	47,6	10,7
Huon District	18,0	6,6	3,7	2,5	4,5	64,7	10,7
Kabwum District	10,3	1,1	1,0	0,7	3,2	83,7	4,9
Lae District	21,8	5,0	1,8	1,6	5,0	64,8	8,4
Markham District	19,5	5,4	2,3	3,3	7,4	62,1	13

	HAZARD : INLAND FLOODING						
	COMPOSITE VULNERABILITY %						
District	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**
Menyamya District	21,9	2,8	1,8	1,1	3,3	69,1	6,2
Nawae District	29,6	5,3	3,0	4,0	5,7	52,4	12,7
Tawae/Siassi District	17,1	2,4	1,0	0,6	3,0	75,9	4,6

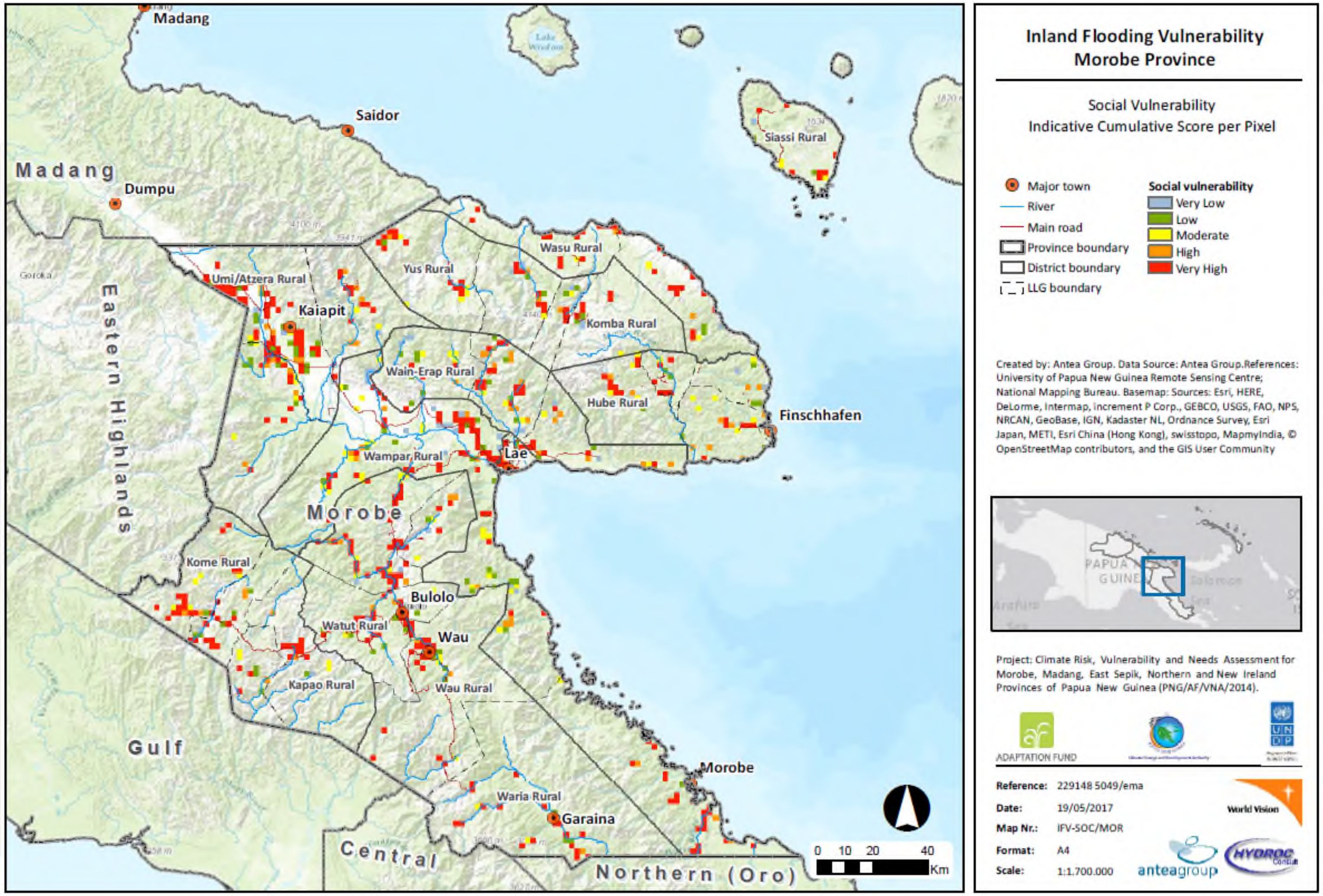

Figure 24. Social vulnerability to inland flooding in Morobe Province

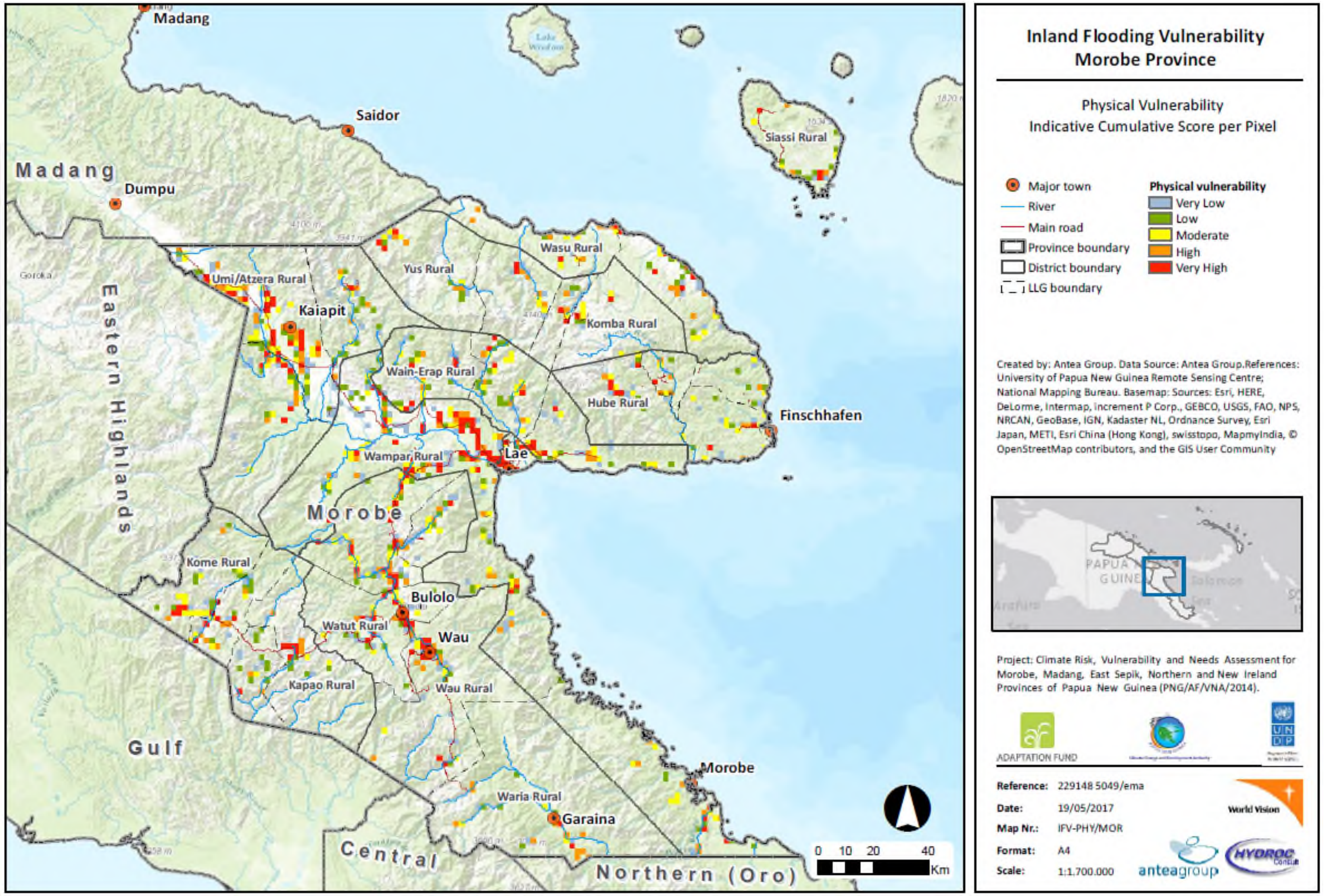

Figure 25. Physical vulnerability to inland flooding in Morobe Province

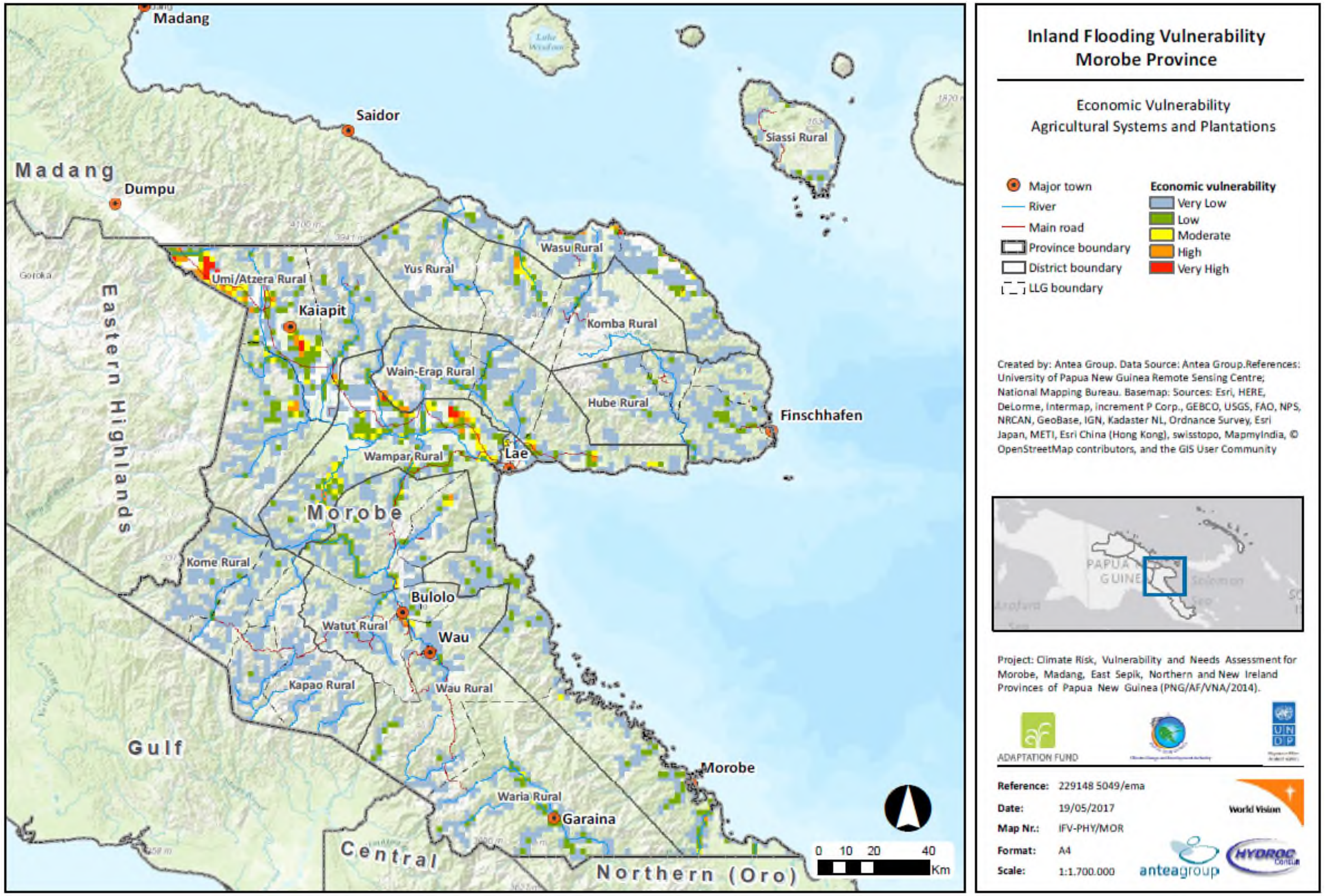

Figure 26. Economic vulnerability to inland flooding in Morobe Province

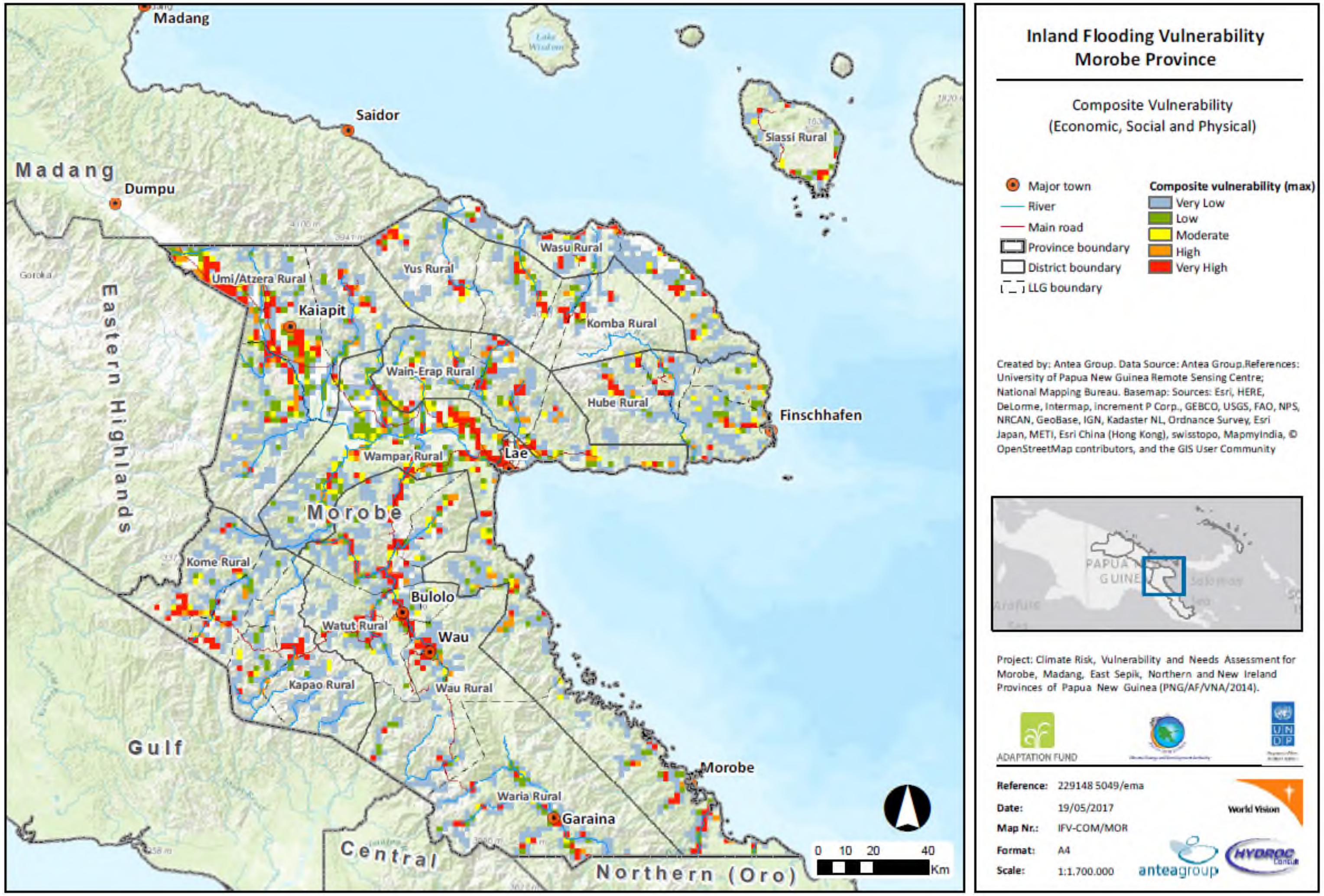

Figure 27. Combined inland flood vulnerability map for Morobe Province

2.2.2. Vulnerability to coastal flooding

<maps not yet available>

2.2.3. Vulnerability to drought

Social vulnerability

There are two areas with very high social vulnerability to droughts in the province; in the vicinity of and extending inland from Lae town into Lae District, and in the Kome Rural LLG in Menyamya District in the western part of the province bordering Gulf Province (Figure 28).

Following is information obtained during the Community Risk Assessment about the impact and experience of Kumalu Village in Ward 13 of Mumeng LLLG in Bulolo District to dtoughts.

Droughts hit the village in 1997, 2007 and 2015. Food and water shortages became a big problem for the villagers. With the extreme heat, most food crops (e.g. banana, kaukau, taro and cassava) perished. People were left with nothing to eat except for wild food from the forest. Most people had to walk for hours foraging food from the wild to survive. Women and girls in particular had to seek distant water sources to meet their drinking needs. Some womwn had to walk several hours up into the mountains to get water.

Kumalu's surroundings are almost barren, and the drought has impacted the water reserves in these areas. Rivers and creek quickly run dry because the porous soil allows water to infiltrate into ground. Domestic animals and livestock also suffer because of the lack of water. Many families sell their pigs at a lower price because it is difficult to keep them due to the lack of water. .

Economic vulnerability

The map for economic vulnerability to drought (Figure 29) shows the highest hotspots along the Markham River, specially upstream Umi /Atzera Rural and in Wampar Rural. Other hotspots can be seen in Bulolo District, both near the boundary with Huon District and in the region between Bulolo and Wau.

Combined drought vulnerability

The combined drought vulnerability map of the Province of Morobe (Figure 30) shows three major hotspots with a higher exposure to vulnerability: the mouth region of River Markham up to almost the boundary with Markham District; the agricultural areas of Umi/Atzera Rural and the agricultural areas of Wapi Rural. It is also worth pointing out an area with high vulnerability in the region of Mumeng rural, near the boundary with Huon District, due to its big extension.

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

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

	HAZARD : DROUGHT						
	COMPOSITE VULNERABILITY %						
District	1	2	3	4	5		(3+4+5)
Bulolo District	13,7	5,8	9,9	5,1	0,0	65,4	15
Finschafen District	5,2	49,7	2,7	0,3	0,0	42,0	3
Huon District	11,3	8,4	12,3	8,4	2,5	57,1	23,2

	HAZARD : DROUGHT						
	COMPOSITE VULNERABILITY %						
District	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**
Kabwum District	3,5	23,0	1,7	0,0	0,0	71,8	1,7
Lae District	0,0	6,1	0,0	3,0	73,1	17,8	76,1
Markham District	10,3	17,6	16,4	1,0	3,4	51,4	20,8
Menyamya District	21,8	33,6	6,5	0,5	3,9	33,6	10,9
Nawae District	8,6	35,2	7,3	2,5	1,0	45,4	10,8
Tawae/Siassi District	16,2	37,0	4,2	0,6	0,4	41,5	5,2

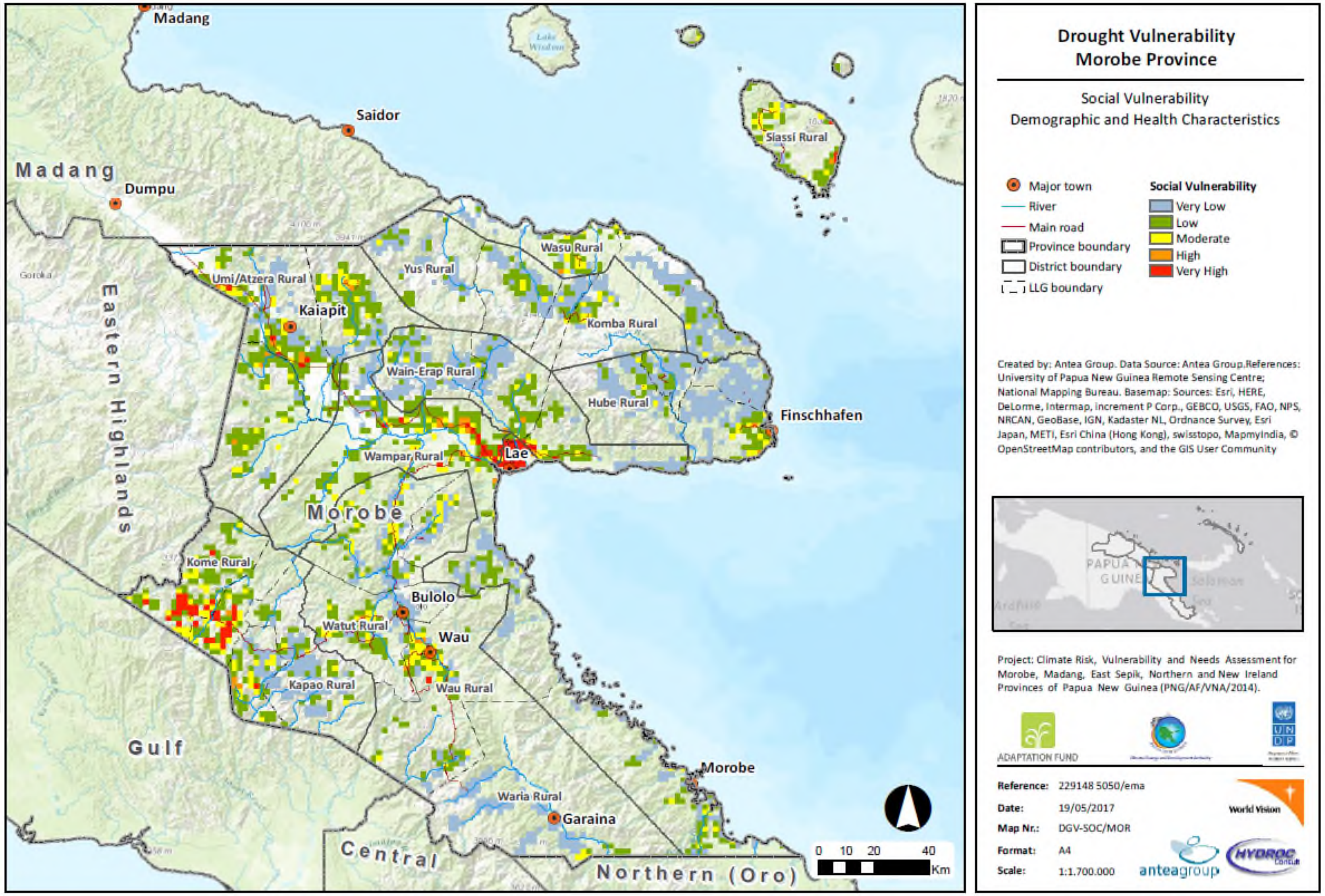

Figure 28. Social vulnerability to drought in Morobe Province

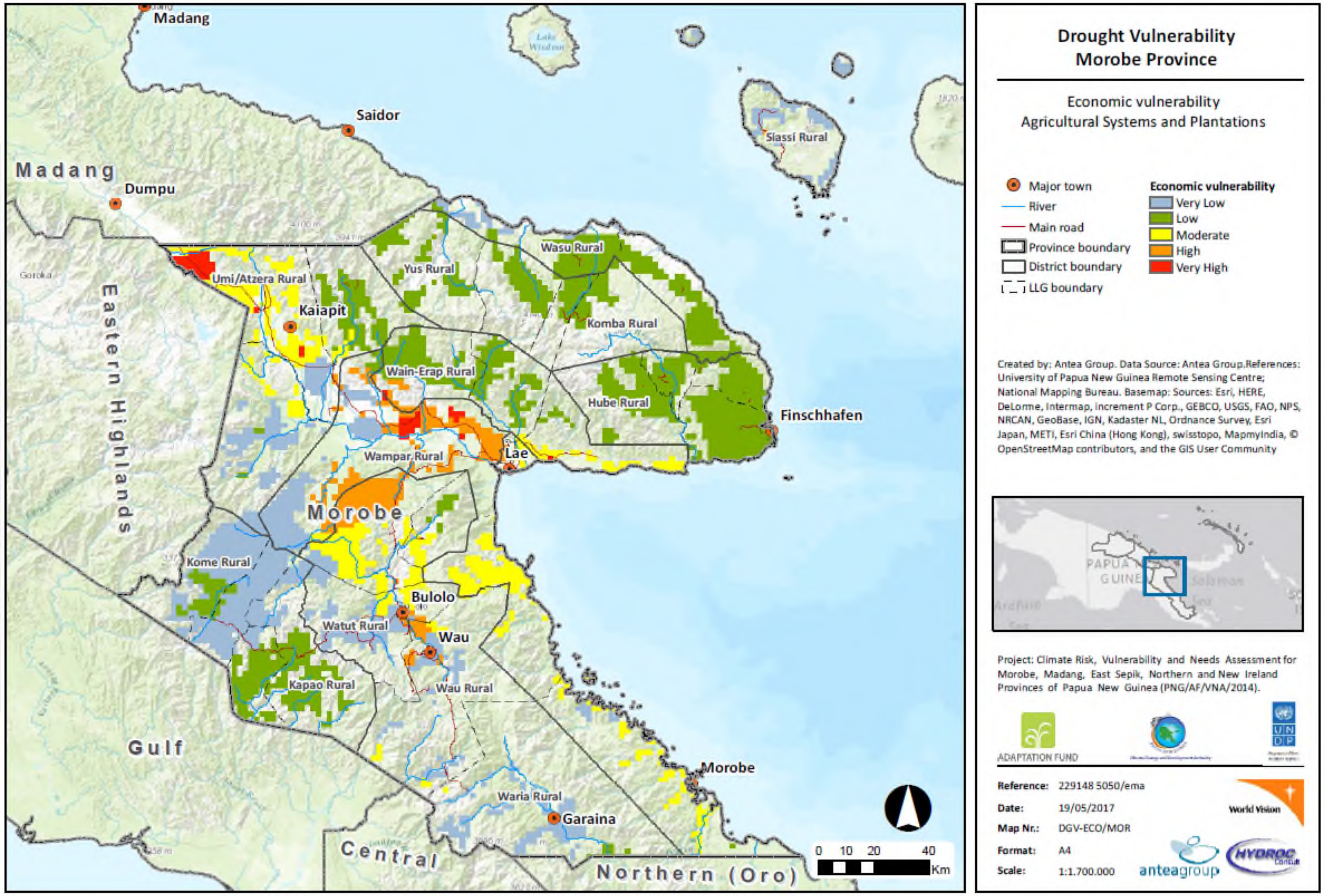

Figure 29. Economic vulnerability to drought in Morobe Province

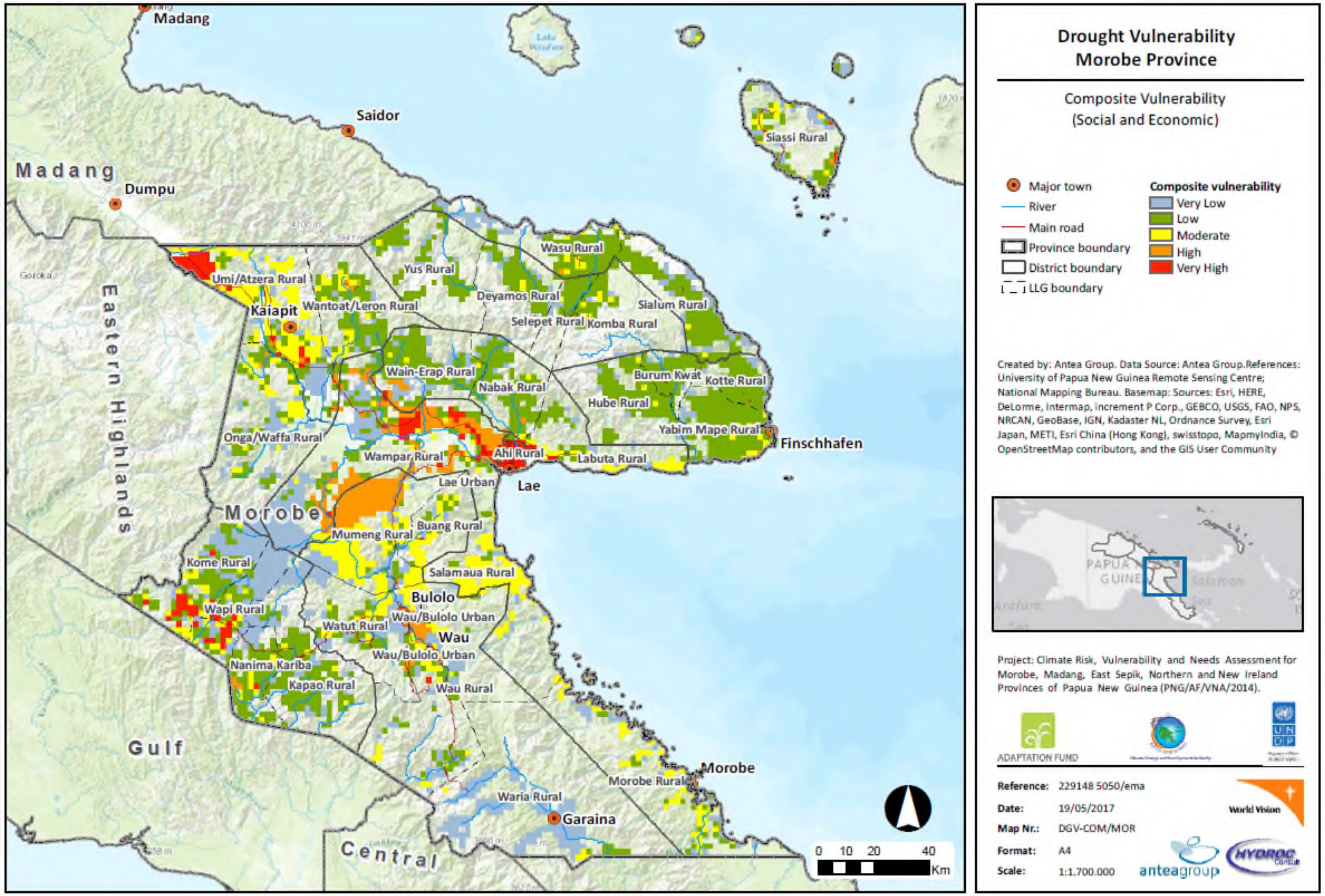

Figure 30. Combined drought vulnerability map for Morobe Province

2.2.4. *Vulnerability to extreme weather (cyclones)*

Social vulnerability

Very high social vulnerability to extreme weather conditions is found in the vicinity of and extending inland from Lae town into Lae District, and in the Kome Rural LLG in Menyamya District in the western part of the province bordering Gulf Province, as can be seen in Figure 31.

Physical vulnerability

The physical vulnerability map for extreme weather of the province of Morobe (Figure 32) shows rather scattered hotspots along the northern and central urban and agricultural axis of the province.

Economic vulnerability

Very high economic vulnerability can be seen along the left bank of the Markham River in its flow through Huon District. Other hotspots include thenorth of Mumeng Rural, and the region between Bulolo and Wau, as can be seen in Figure 33.

Combined vulnerability to extreme weather

The combined extreme weather vulnerability map of the Province of Morobe (Figure 34) presents scattered nucleus all along the northern and central parts of the province. The source and the mouth regions of River Markham present the most combined vulnerabilities. Wau and Bulolo also concentrate some vulnerability hotspots although their extent is much less. Finally, some scattered high vulnerability hotspots can be pointed out mainly in the northern districts along the coast (Tawae/Siassi, Kabwum and Finschafen) and Menyamya District.

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

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

	HAZARD : CYCLONE						
	COMPOSITE VULNERABILITY %						
District	**1**	**2**	**3**	**4**	**5**		**(3+4+5)**
Bulolo District	6,4	8,7	9,8	7,8	4,6	62,7	22,2
Finschafen District	7,5	23,7	9,0	12,6	7,3	39,9	28,9
Huon District	9,0	6,1	12,5	10,0	7,1	55,3	29,6
Kabwum District	4,2	8,3	3,8	5,3	6,6	71,8	15,7
Lae District	0,0	0,0	0,0	0,0	82,2	17,8	82,2
Markham District	7,2	10,9	18,1	7,8	5,9	50,1	31,8
Menyamya District	27,4	11,2	8,6	9,1	11,0	32,8	28,7
Nawae District	4,9	20,2	12,7	11,8	7,3	43,0	20,8
Tawae/Siassi District	10,9	22,3	8,5	8,5	10,9	38,7	27,9

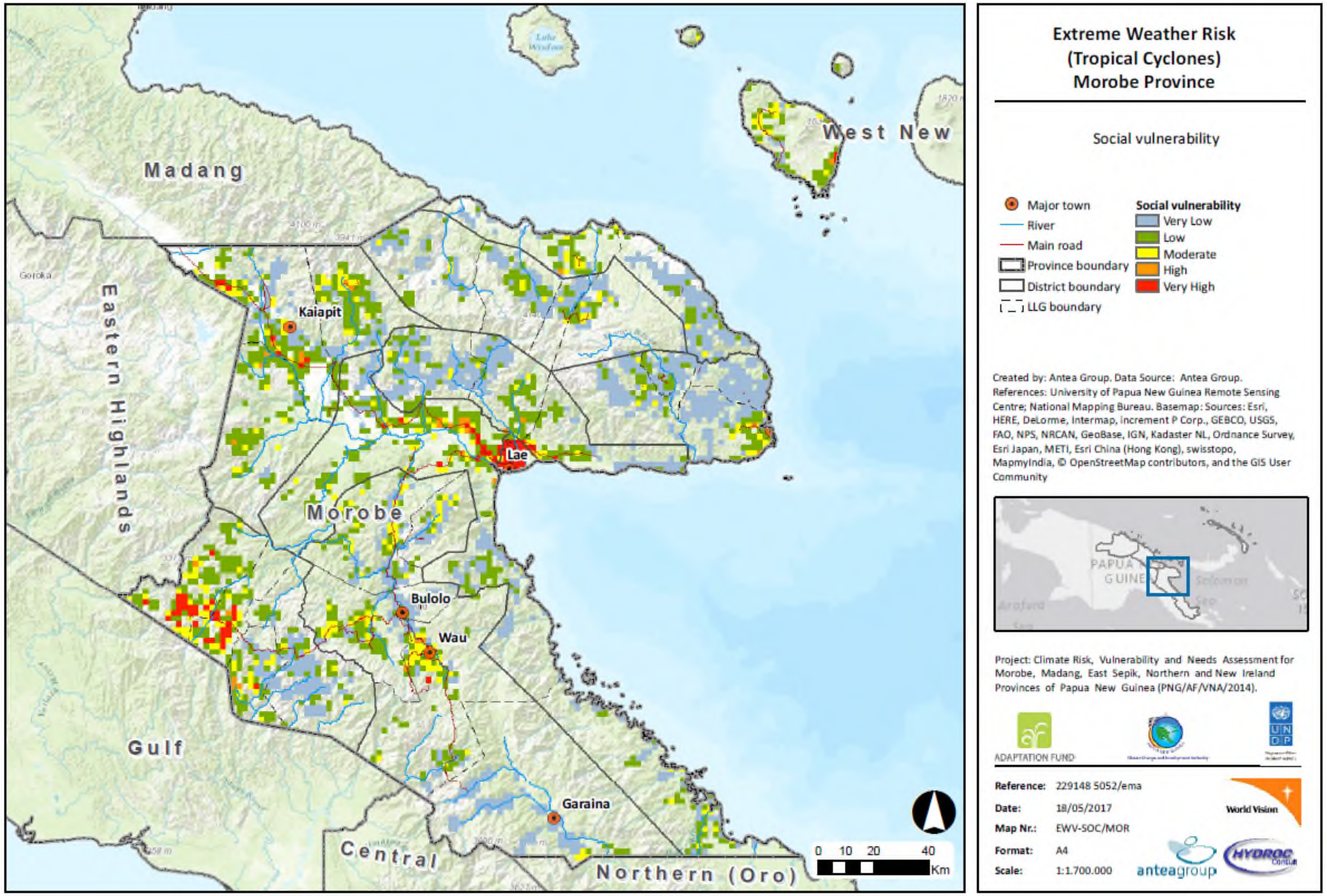

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Figure 31. Social vulnerability to cyclones in Morobe Province

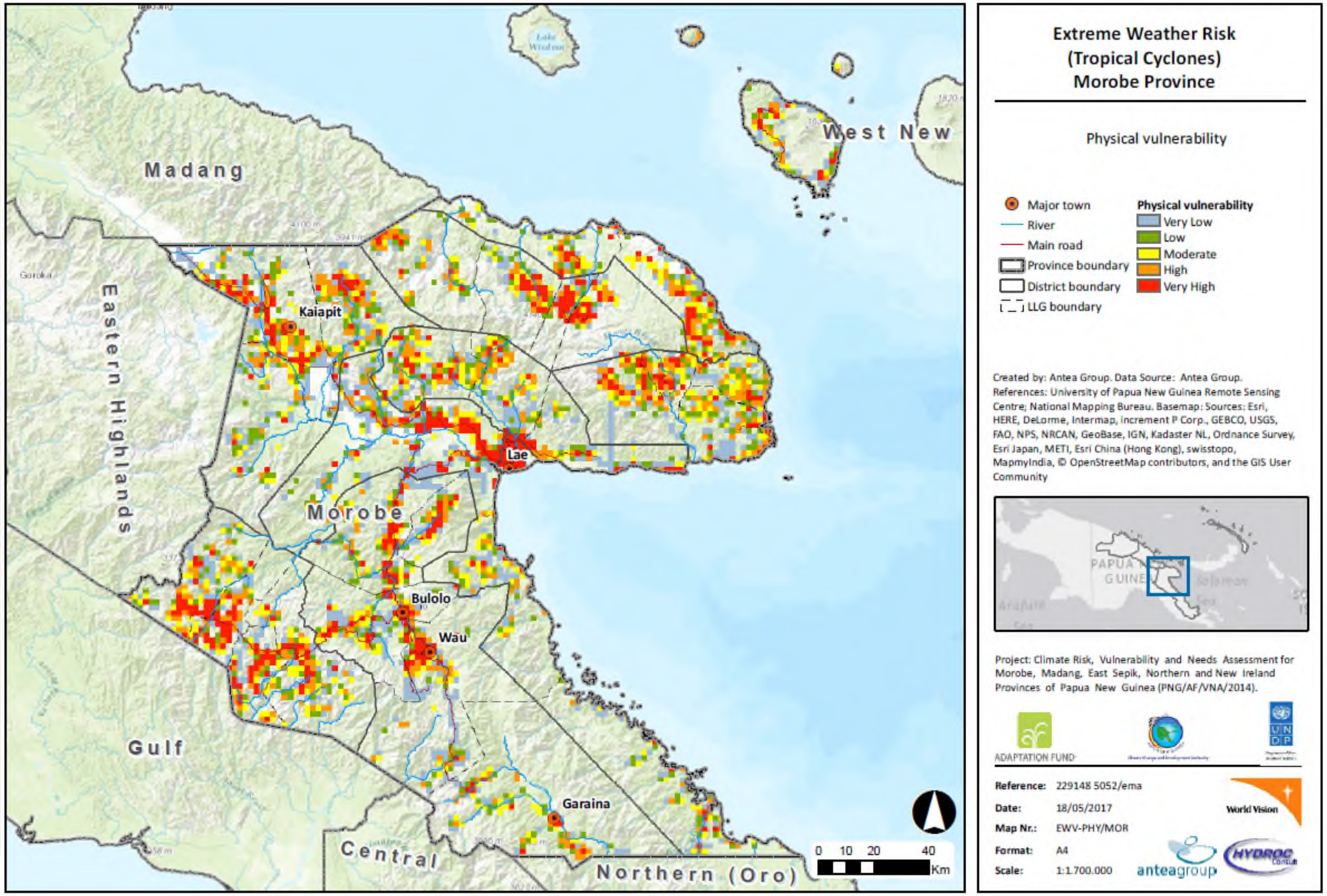

Figure 32. Physical vulnerability to cyclones in Morobe Province

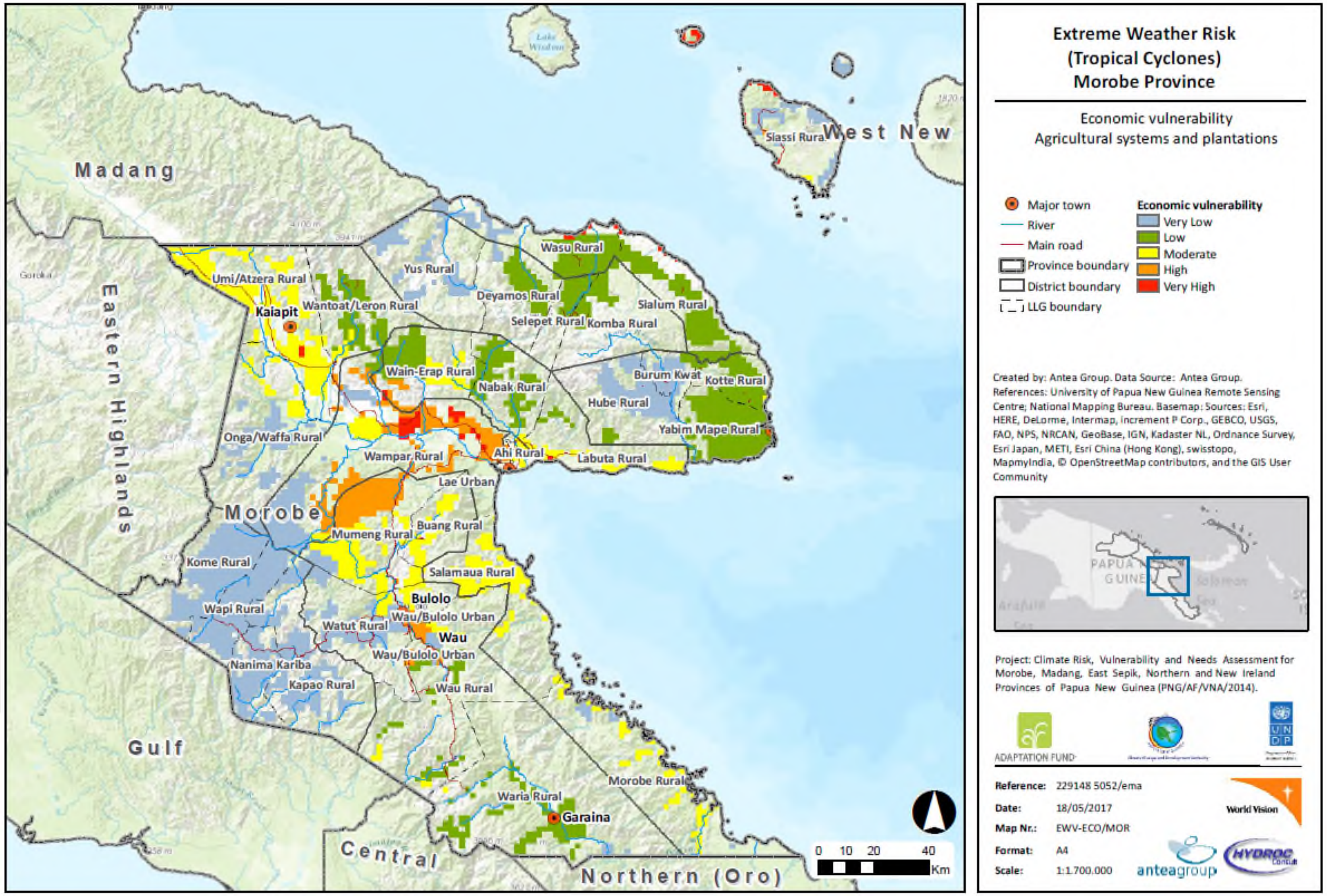

Figure 33. Economic vulnerability to cyclones in Morobe Province

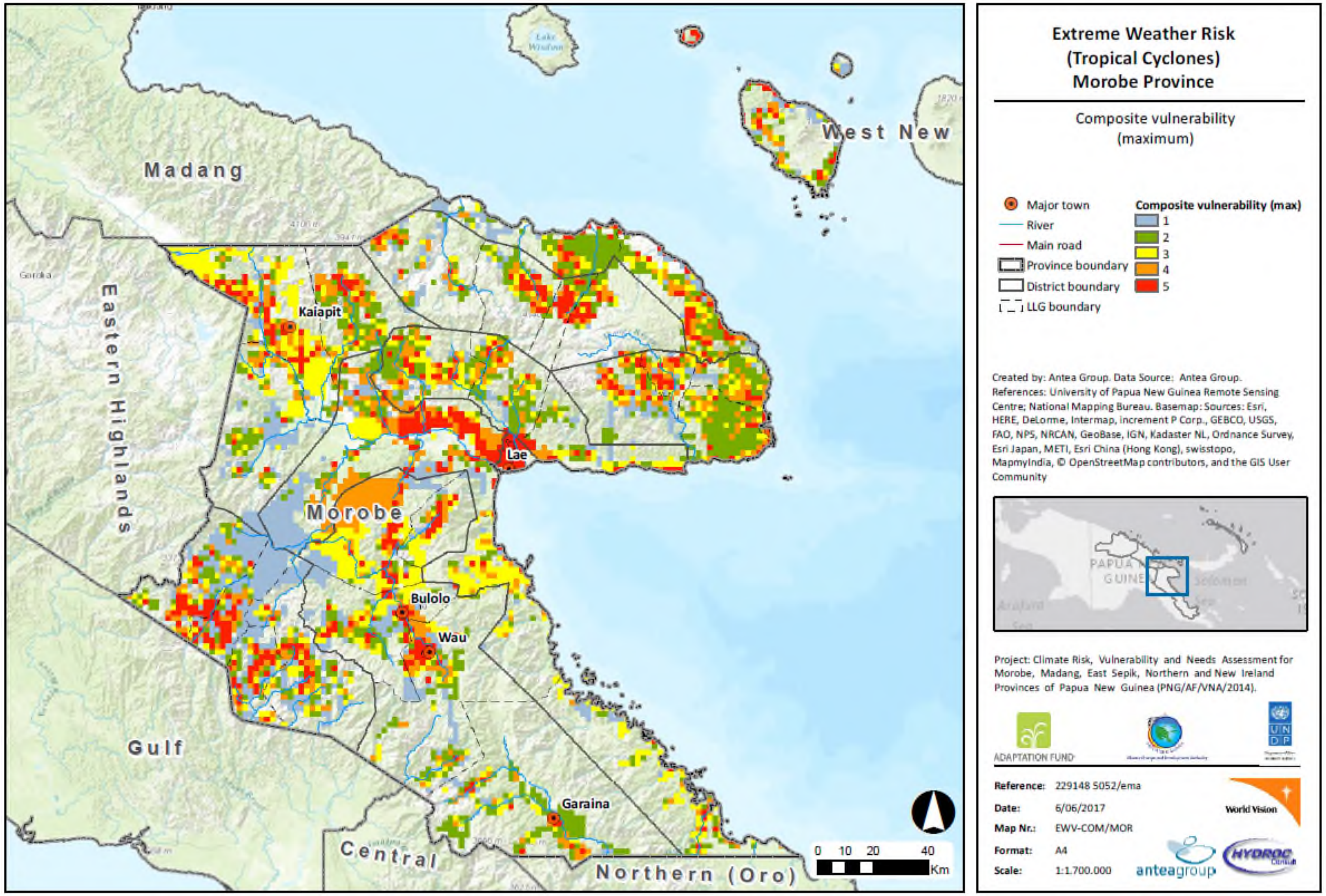

Figure 34. Combined vulnerability to cyclones in Morobe Province

2.2.5. *Vulnerability to precipitation intensity and variability*

Social vulnerability

There are two areas with very high social vulnerability to intense and variable precipitation in the province; in the vicinity of and extending inland from Lae town into Lae District, and in the Kome Rural LLG in Menyamya District in the western part of the province bordering Gulf Province (Figure 35).

Economic vulnerability

Figure 36 shows that the economic vulnerability to intense rainfall of the province has a rather low profile, except for some very high hotspots along the Markham River in its flow through Huon District and in the region near Kaiapit. Additionally, there is a high and moderate hotspot in the region of Umi/Atzera Rural. Other moderate spots are to be found also in the northern part of Bulolo District and to a lesser extent in Wain-Erap Rural.

Combined vulnerability to intense rainfall

The combined intense rainfall vulnerability map of the Province of Morobe (Figure 37) shows that the biggest hotspot is in the region of Lae and further upstream. Some scattered hotspots can also be found around the rural areas of Wapi Rural, and to a less extent, around the regions of Kaiapit and Umi/Atzera Rural.

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

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

	HAZARD : PRECIPITATION						
	COMPOSITE VULNERABILITY %						
District	1	2	3	4	5		(3+4+5)
Bulolo District	14,3	9,3	10,7	0,3	0,2	65,2	11,2
Finschafen District	46,3	9,0	2,7	0,3	0,0	41,7	3
Huon District	17,6	19,7	3,4	0,6	1,6	57,0	5,6
Kabwum District	15,9	10,5	1,7	0,0	0,0	71,8	1,7
Lae District	0,0	6,1	3,0	0,0	73,1	17,8	76,1
Markham District	16,0	20,6	8,2	3,1	0,9	51,3	12,2
Menyamya District	35,3	19,8	6,5	0,5	3,9	33,9	10,9
Nawae District	27,4	18,6	6,8	0,5	1,0	45,7	8,3
Tawae/Siassi District	37,8	15,6	4,2	0,3	0,7	41,4	5,2

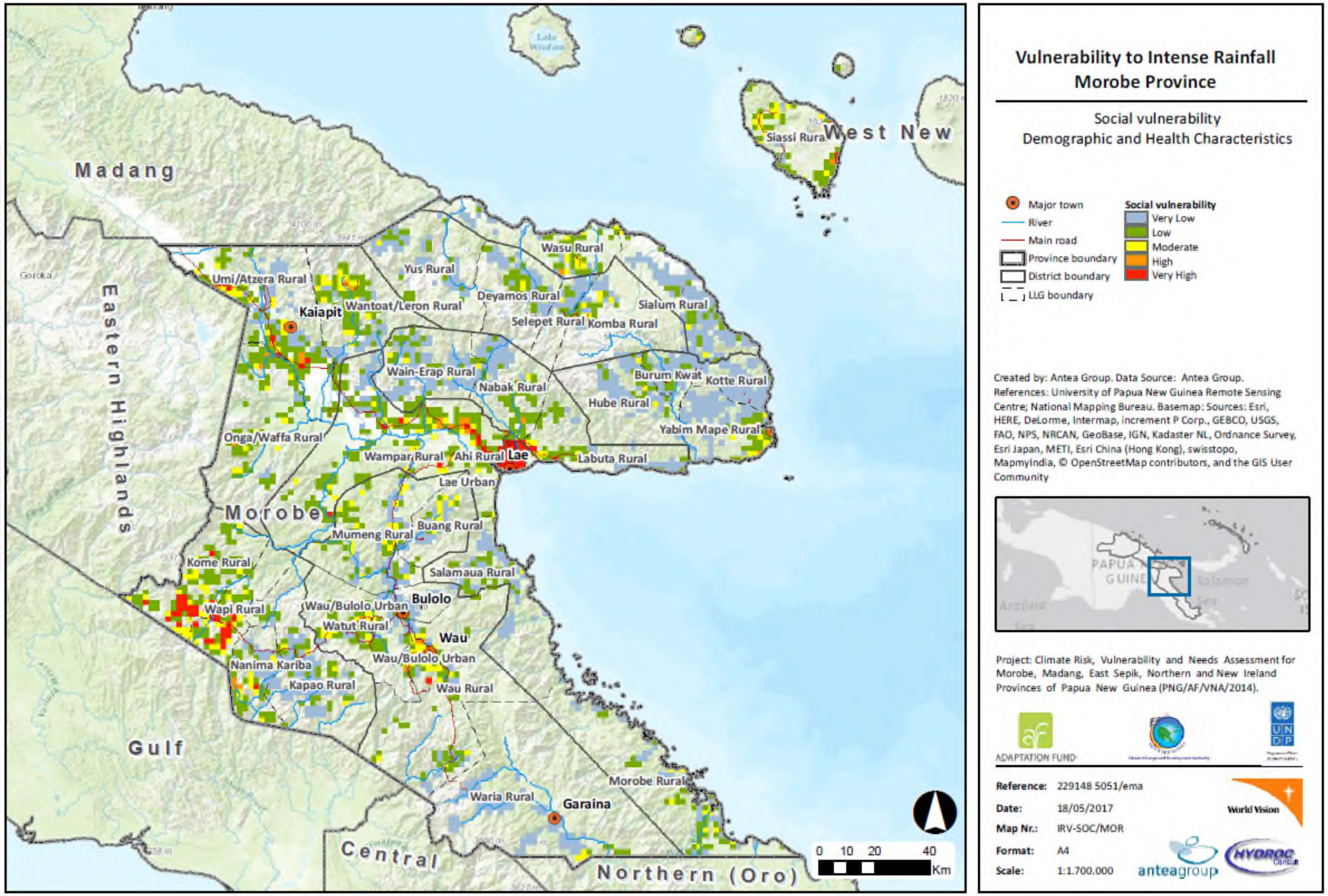

Figure 35. Social vulnerability to precipitation intensity and variability (intense rainfall) in Morobe Province

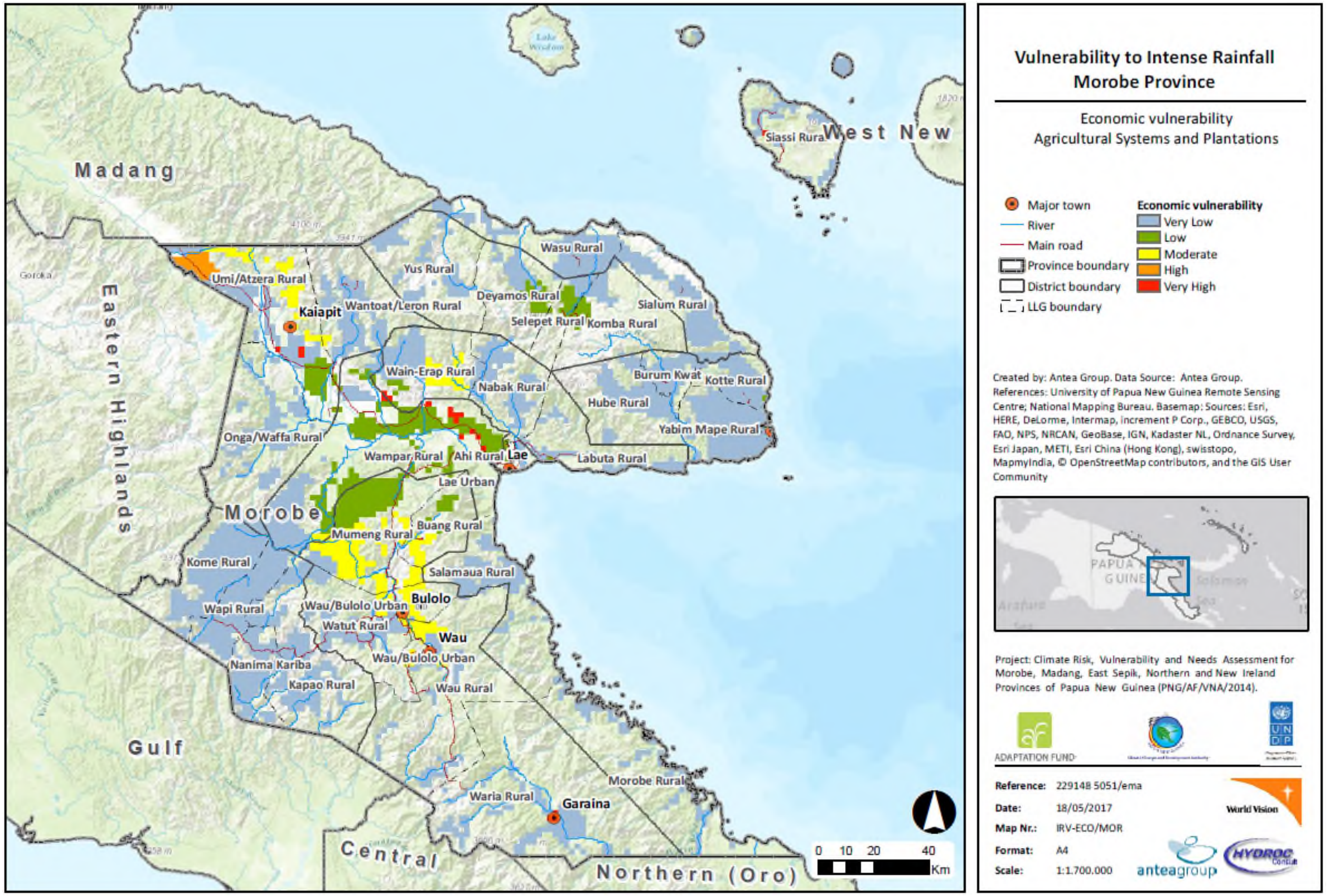

Figure 36. Economic vulnerability to precipitation intensity and variability (intense rainfall) in Morobe Province

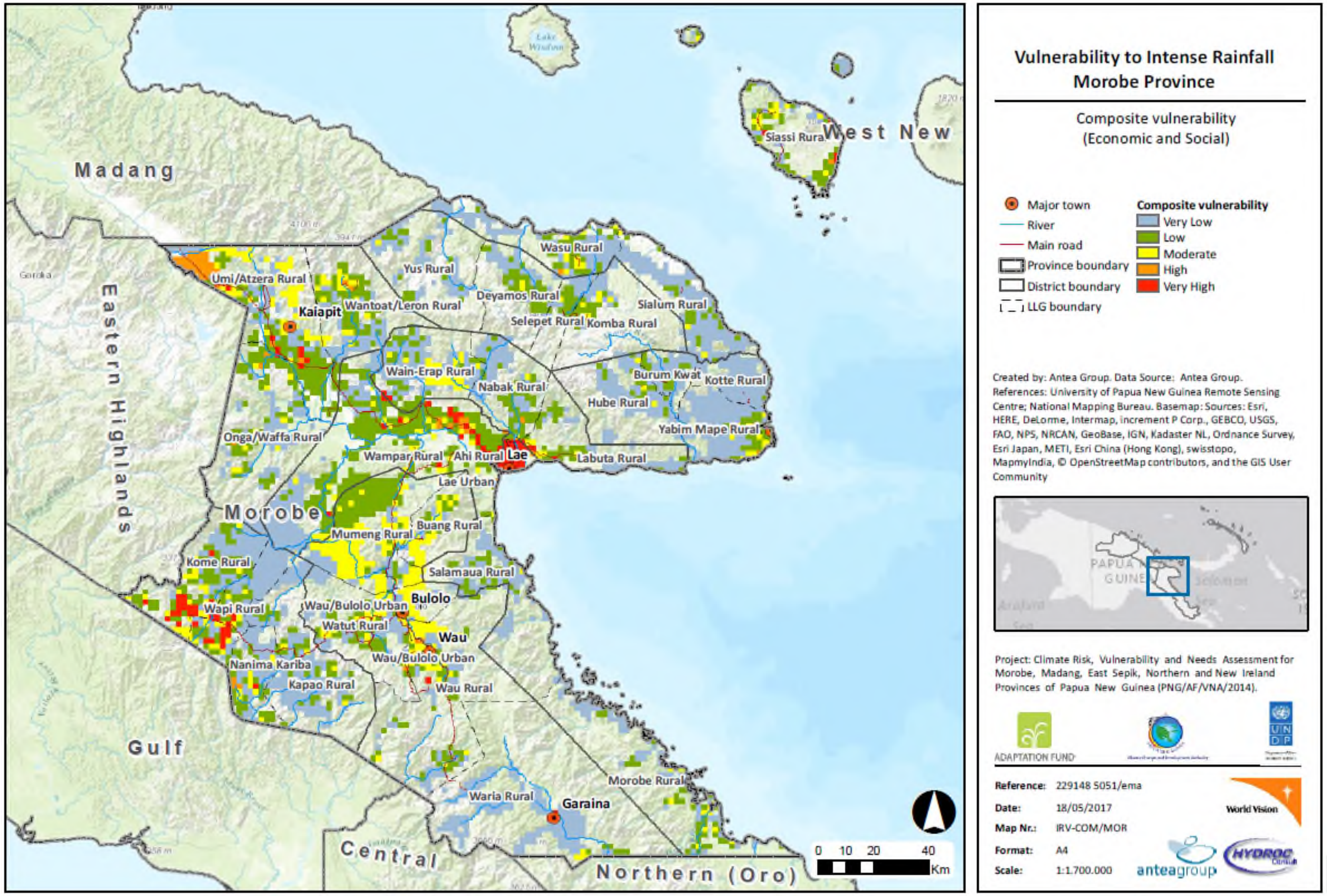

Figure 37. Combined vulnerability to precipitation intensity and variability (intense rainfall) in Morobe Province

2.3. *Risk Assessment*

In this chapter we discuss the risk maps produced for Morobe 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

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

2.3.1. *Inland Flood Risk*

According to Figure 38 the social risk from inland flooding is generally low to very low throughout the province. It can be expected that social risk will be highest in and around the major population centres like Lae, Bulolo, Wau, Kalapit and Garaina. Projections for the future follow the same tendency.

The inland flooding physical risk map for the province of Morobe (Figure 39) shows that the highest risk is around Lae and the main road that gets there from the north. This is due to the combination of the final stretch of River Markham with the high density of infrastructure in the area. Projections for the future follow the same tendency.

Economic risk for inland flooding is rather low for the district and the higher hotspots are in the sugar cane plantations in Umi/Atzera Rural. Projections for the future show an increase in the risk in the region of Umi/Atzera Rural.

The combined inland flooding risk map of the Province of Morobe shows two main hotspots: around Lae and the main road that gets to it from the north; and around Umi/Atzera Rural. In much less extent, risk can be found in Bulolo, Wau and Menyamya District.

Projections under a high emission scenario show a slight risk increase in the provinces of Huon and Markham and a slight decrease in the district of Kabwum, as shown in the table below:

Table 33. Distribution of inland flood risk classes

	HAZARD : INLAND FLOODING													
	RISK 1960-1990 %							RISK 2030-2050 %						
District	1	2	3	4	5		(3+4+5)	1	2	3	4	5		(3+4+5)
Bulolo District	19,2	4,1	1,6	1,1	0,7	73,3	3,4	19,2	4,1	1,5	1,1	0,7	73,3	3,3
Finschafen District	29,1	9,7	1,5	1,0	0,0	58,7	2,5	29,1	5,5	1,5	0,7	0,0	63,2	2,2
Huon District	13,7	2,6	0,7	0,4	0,0	82,6	1,1	21,9	9,9	3,5	1,9	2,0	60,8	7,4
Kabwum District	35,9	16,2	5,3	3,3	3,2	36,2	11,8	15,2	2,5	2,0	0,7	0,2	79,4	2,9
Lae District	24,5	5,5	1,6	2,5	1,1	64,8	5,2	24,5	5,9	1,6	2,5	1,1	64,3	5,2
Markham District	4,5	0,3	0,4	0,2	0,4	94,1	1	24,5	7,9	4,3	3,3	1,5	58,6	9,1
Menyamya District	30,0	2,6	1,3	1,2	1,0	63,9	3,3	30,0	2,6	1,2	1,0	1,0	64,2	3,2
Nawae District	27,5	7,8	2,4	1,9	0,3	60,0	4,6	27,5	8,0	2,4	1,8	0,3	60,0	4,5
Tawae/Siassi District	30,9	3,3	2,4	0,4	0,7	62,2	3,5	30,9	4,9	2,4	1,0	0,7	60,0	4,1

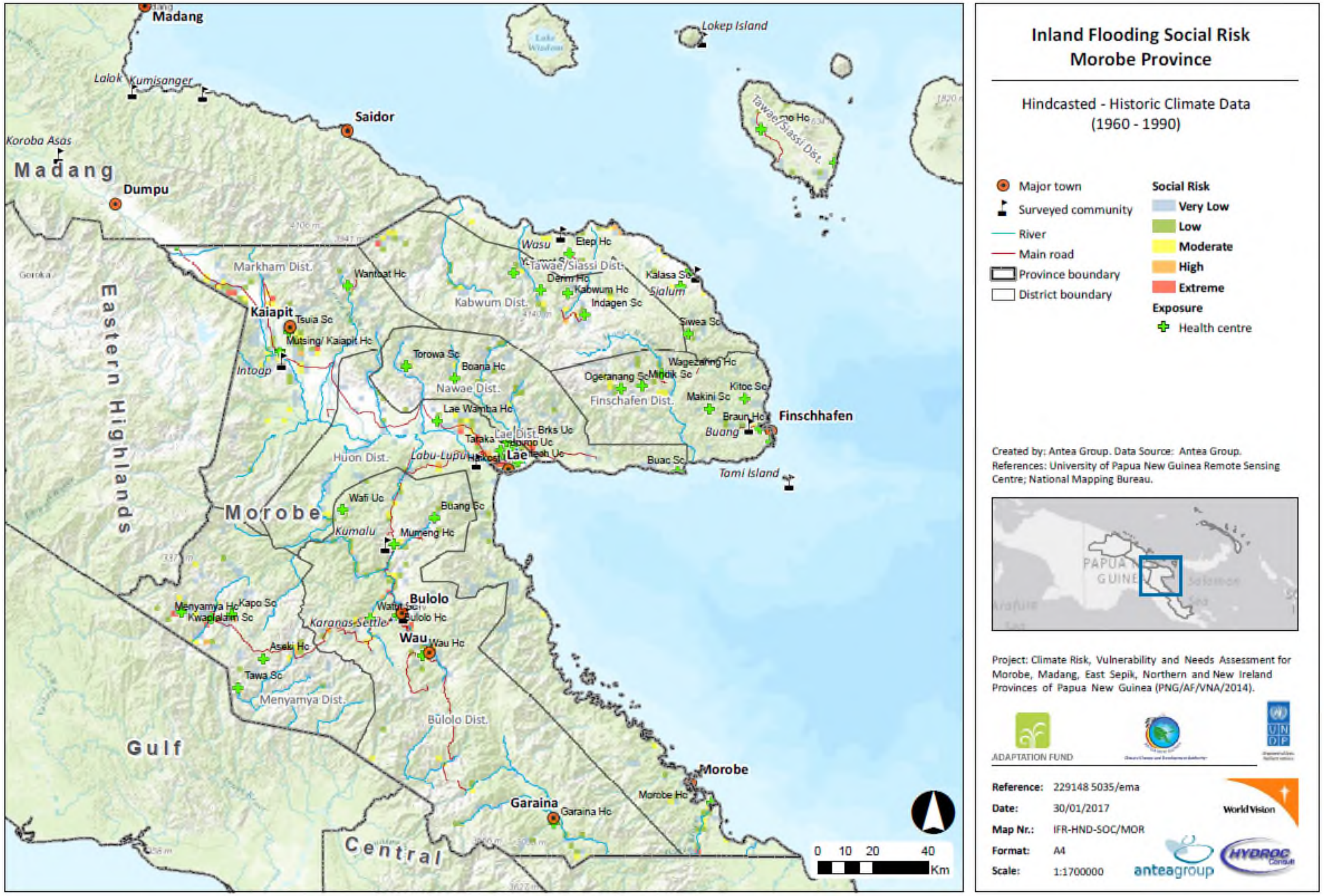

Figure 38. Inland Flooding Social Risk (current climate) ■ **Very Low** ■ **Low** ■ **Moderate** ■ **High** ■ **Extreme**

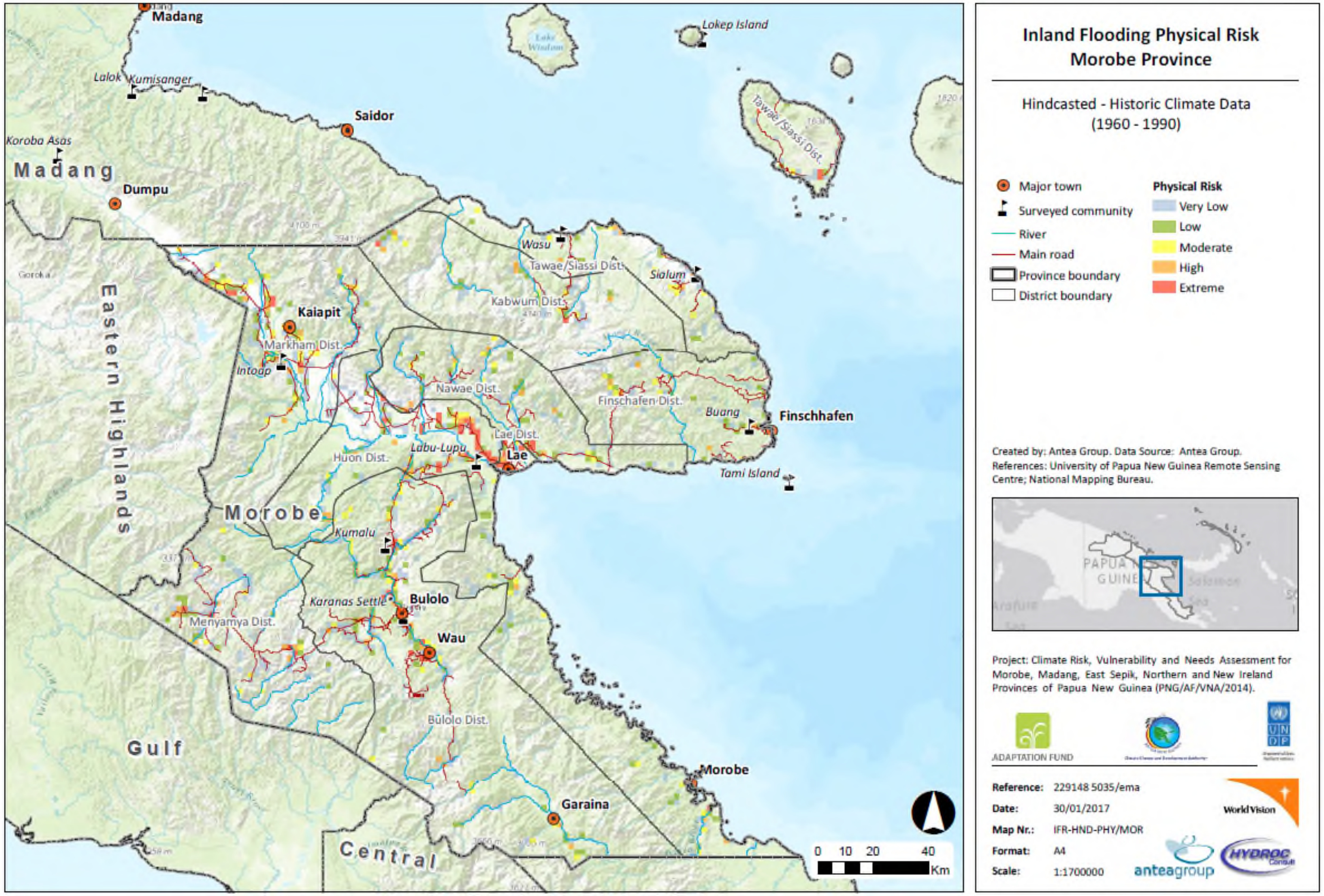

Figure 39. Inland Flooding Infrastructure Risk (current climate) ■ **Very Low** ■ **Low** ■ **Moderate** ■ **High** ■ **Extreme**

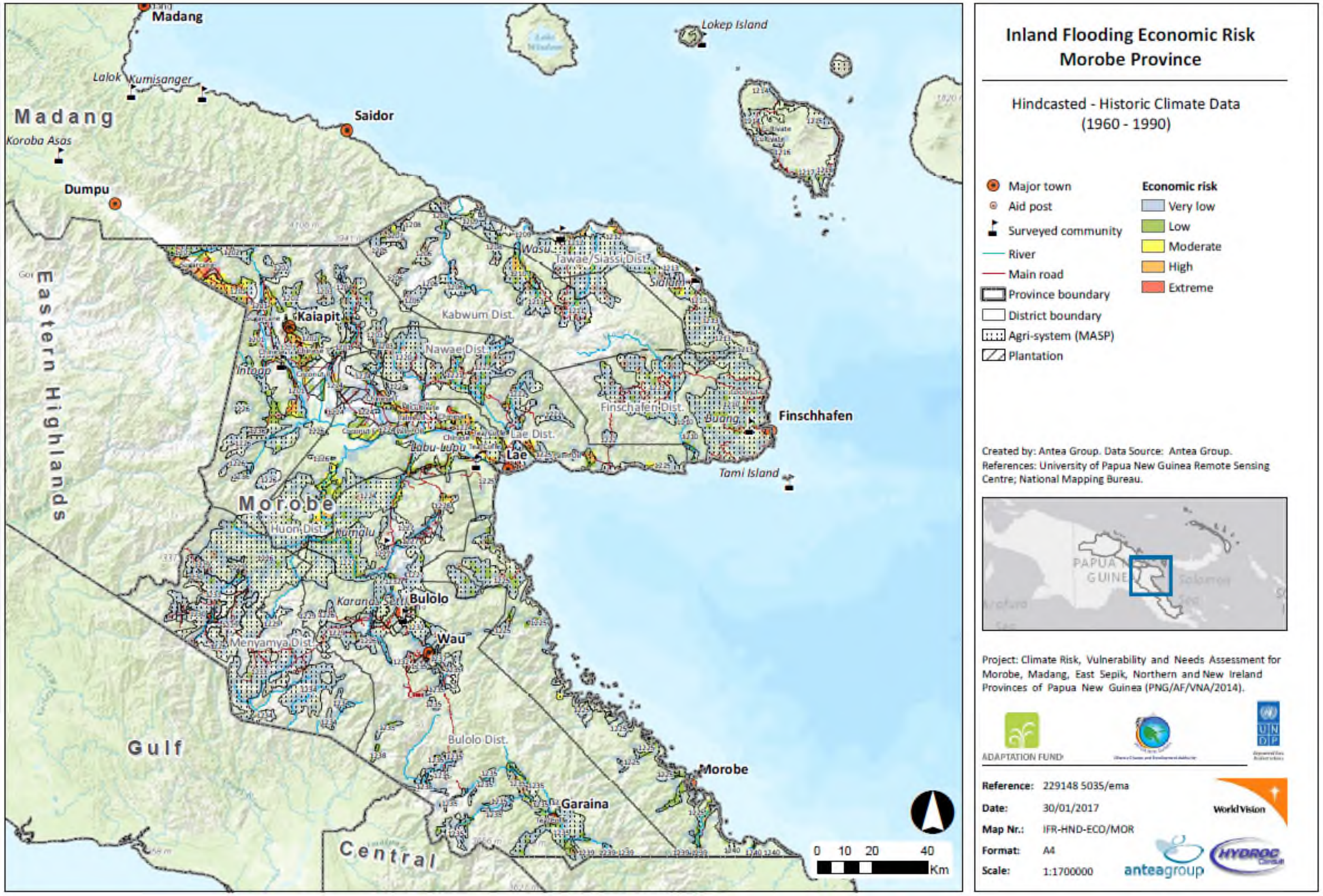

Figure 40. Inland Flooding Economic Risk (current climate) ■**Very Low** ■**Low** ■**Moderate** ■**High** ■**Extreme**

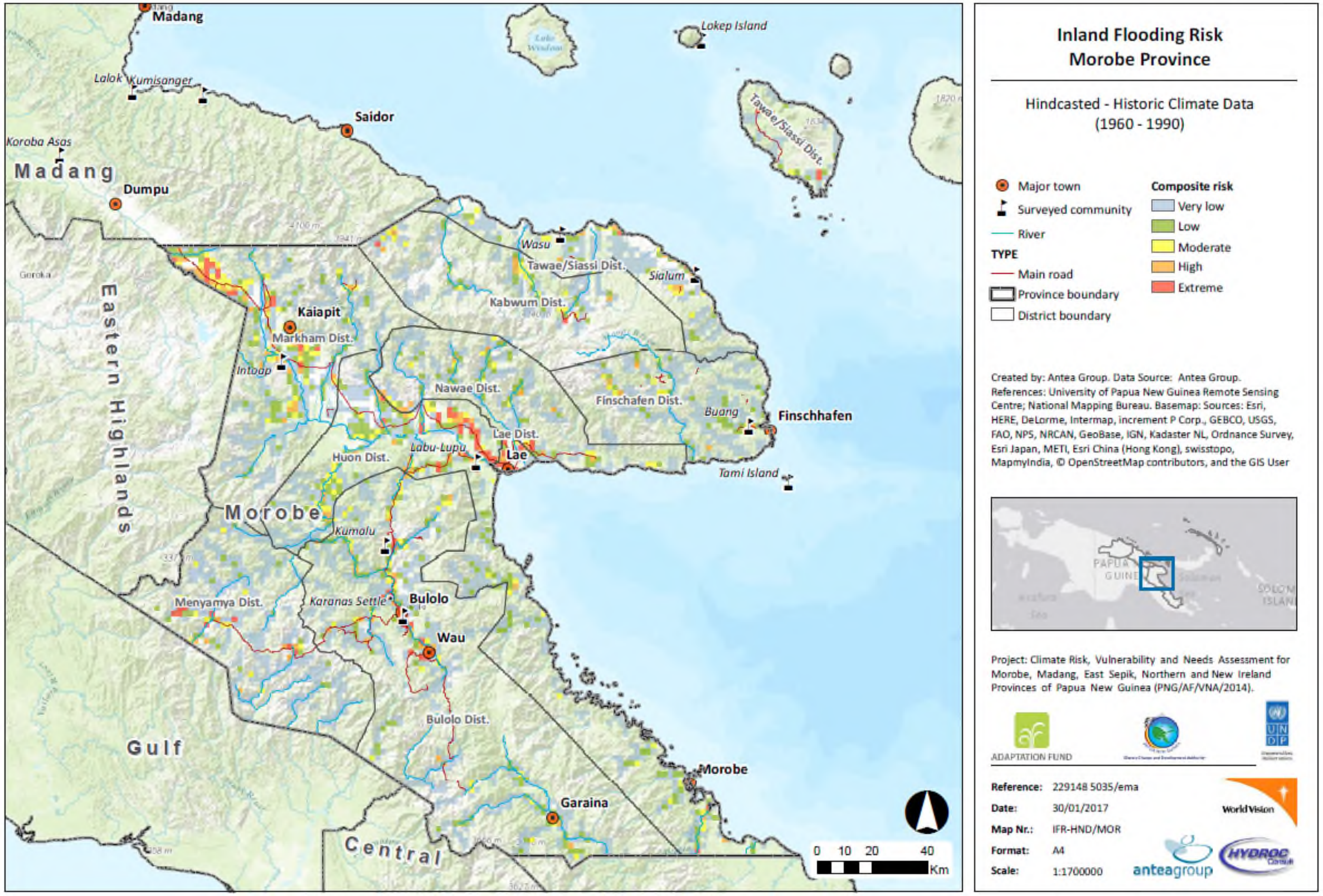

Figure 41. Inland Flooding Composite Risk (current climate) ■Very Low ■Low ■Moderate ■High ■Extreme

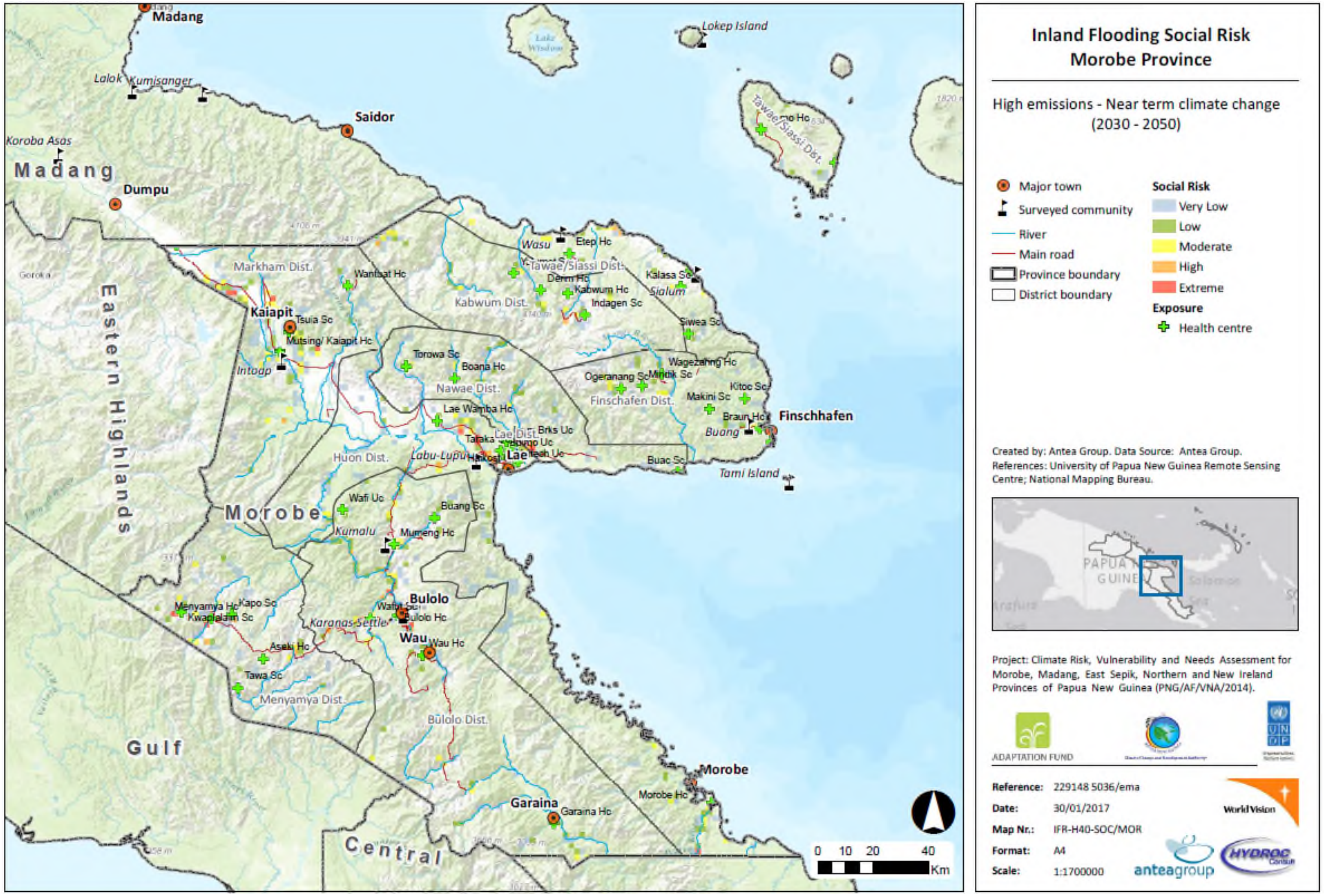

Figure 42. Inland Flooding Social Risk (projected climate) ■Very Low ■Low ■Moderate ■High ■Extreme

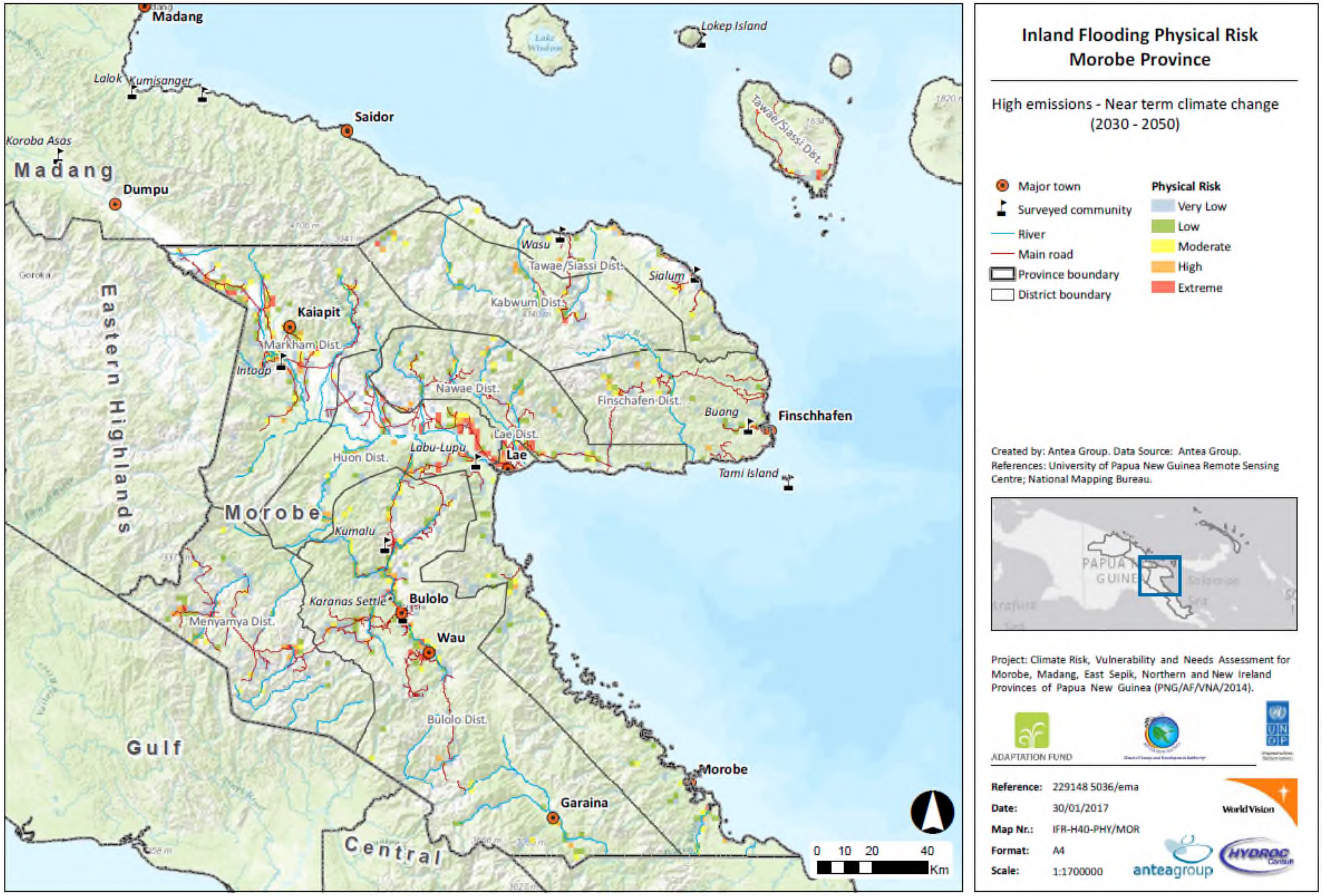

Figure 43. Inland Flooding Physical Risk (projected climate) Very Low Low Moderate High Extreme

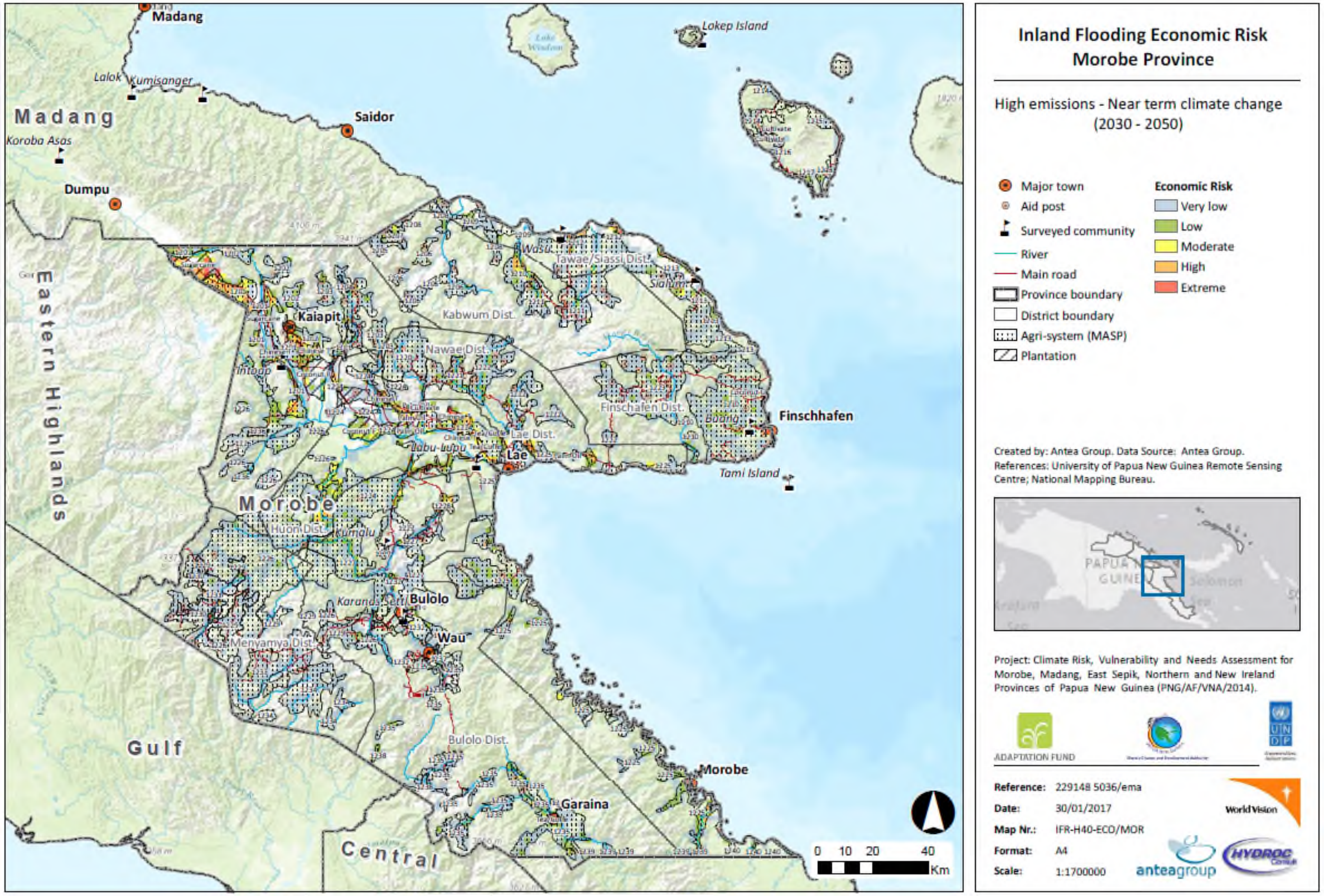

Figure 44. Inland Flooding Economic Risk (projected climate) ■Very Low ■Low ■Moderate ■High ■Extreme

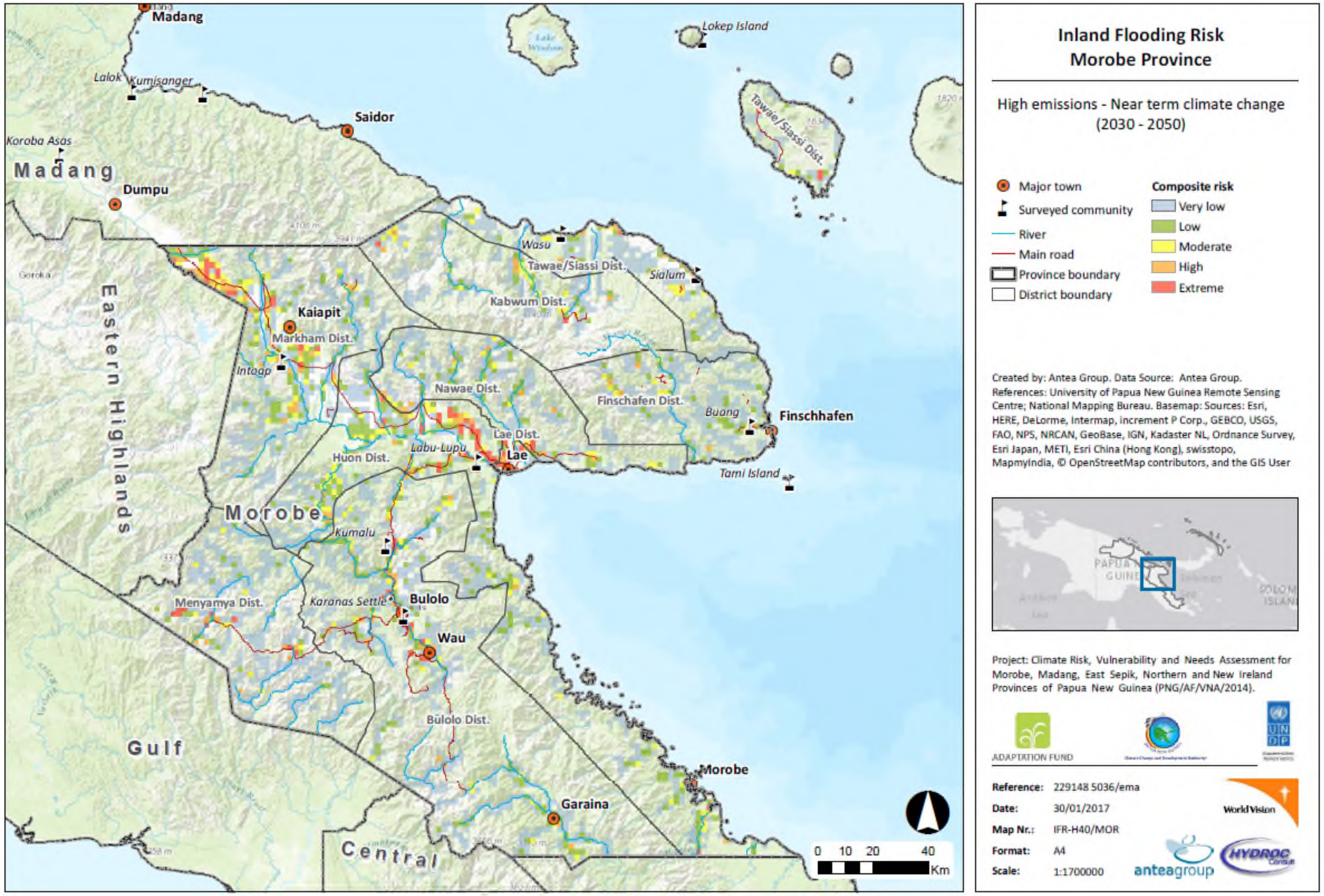

Figure 45. Inland Flooding Composite Risk (projected climate) ■ **Very Low** ■ **Low** ■ **Moderate** ■ **High** ■ **Extreme**

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

There are several areas with moderate to high social risk from droughts in the province, as can be seen in Figure 46. The largest areas are found along the Markham River extending from Lae town inland covering parts of Lae, Huon and Nawae districts and in Memyamya District in the western part of the province near the border to Gulf and Eastern Highlands provinces.

Smaller areas of moderate social risk to droughts are found in and around Finschafen town, around the town of Wau in Bulolo District and inland from Wasu in Tawae/Siassi District in the northern part of the province.

Projections for the future show a slight increase throughout the province, especially on the northern and central part (Figure 49).

Additional details on how droughts affect communities and how comunities respond are provided by the Comunity Risk Assessment in villages like Wasu Village in Ward 6, Wasu Rural LLLG, in Tewai-Siassi District:

Droughts have occurred in Wasu Village at least 3 times for the past 50 years. The most severe droughts took place in 1997 and 2015. In these cases, the drought dried up water sources and food gardens which tremendously affected people's lives. Food crops were wiped out and people suffered from the lack of food and the availability of suckers and seedlings to replant.

The drought also triggered bushfires in the area which threatened the forest in the upstream portion of the village. The fire destroyed remaining crops as well as threatened houses in the village including community facilities.

The destruction of crops, particularly the cocoa plantations, affected the livelihoods of the people in the area which resulted in lower or no income at all. In addition, villagers had to rely on wild foods in the forest to survive. They had to forage in distant areas for wild taro, wild yam and breadfruit. People also had to rely on the sea for food.

As water sources became contaminated, there was a high incident of water-borne diseases. Many people particularly children suffered from diarrhoea and cholera. Due to the extreme impact of drought in the village particularly on agriculture and livelihoods, many villagers left and went to Lae to find work. They left behind their families to earn income from which they sent money back to their families in the village.

The map for economic risk to drought in the province of Morobe (Figure 47) shows three main high hotspots: the sugar cane plantations around Umi/Atzera, the agricultural land in the north west of Bulolo District, and in the lower stretch of Markham River that goes from Huon District up to Lae. Moderat risk is more extended, showing large regions in the northern coast, Nawae District, the agricultural land north to Bulolo and the southern part of Menyamya District.

Projections for the future show a general increase in the extension of the risk, especially in the plantations in Umi/Atzara and in the region north of Bulolo and Wau.

The combined drought risk map of the Province of Morobe shows two main hotspots: around Lae and the main road that gets to it from the north and around the west of Menyamya District .

Projections under a high emission scenario show an increase in the northwest corner of Markham district. Other variations include a slight increase in Huon District and a slight decrease in Kabwum District, as shown in the table below:

Table 34. Distribution of drought risk classes

	HAZARD : DROUGHT													
	RISK 1960-1990 %							RISK 2030-2050 %						
District	1	2	3	4	5		(3+4+5)	1	2	3	4	5		(3+4+5)
Bulolo District	0,0	13,7	15,1	5,6	0,1	65,4	20,8	0,0	13,7	8,0	11,4	1,4	65,4	20,8
Finschafen District	0,0	5,2	52,4	0,3	0,0	42,0	52,7	0,0	5,2	52,4	0,3	0,0	42,0	52,7
Huon District	0,0	2,5	24,5	0,1	0,0	72,9	24,6	0,0	11,3	10,2	18,9	2,5	57,1	31,6
Kabwum District	0,0	18,1	28,2	18,9	4,0	30,9	51,1	0,0	3,5	24,7	0,0	0,0	71,8	24,7
Lae District	0,0	0,0	6,1	3,0	73,1	17,8	82,2	0,0	0,0	6,1	3,0	73,1	17,8	82,2
Markham District	0,0	1,2	6,7	0,0	1,2	90,9	7,9	0,0	10,3	34,0	1,0	3,4	51,4	38,4
Menyamya District	0,0	21,8	39,3	1,2	4,2	33,5	44,7	0,0	21,8	33,7	6,4	4,4	33,6	44,5
Nawae District	0,8	11,5	38,8	2,4	1,0	45,6	42,2	0,0	8,6	42,5	2,5	1,0	45,4	46
Tawae/Siassi District	0,0	16,2	41,2	0,6	0,4	41,5	42,2	0,0	16,2	41,2	0,6	0,4	41,5	42,2

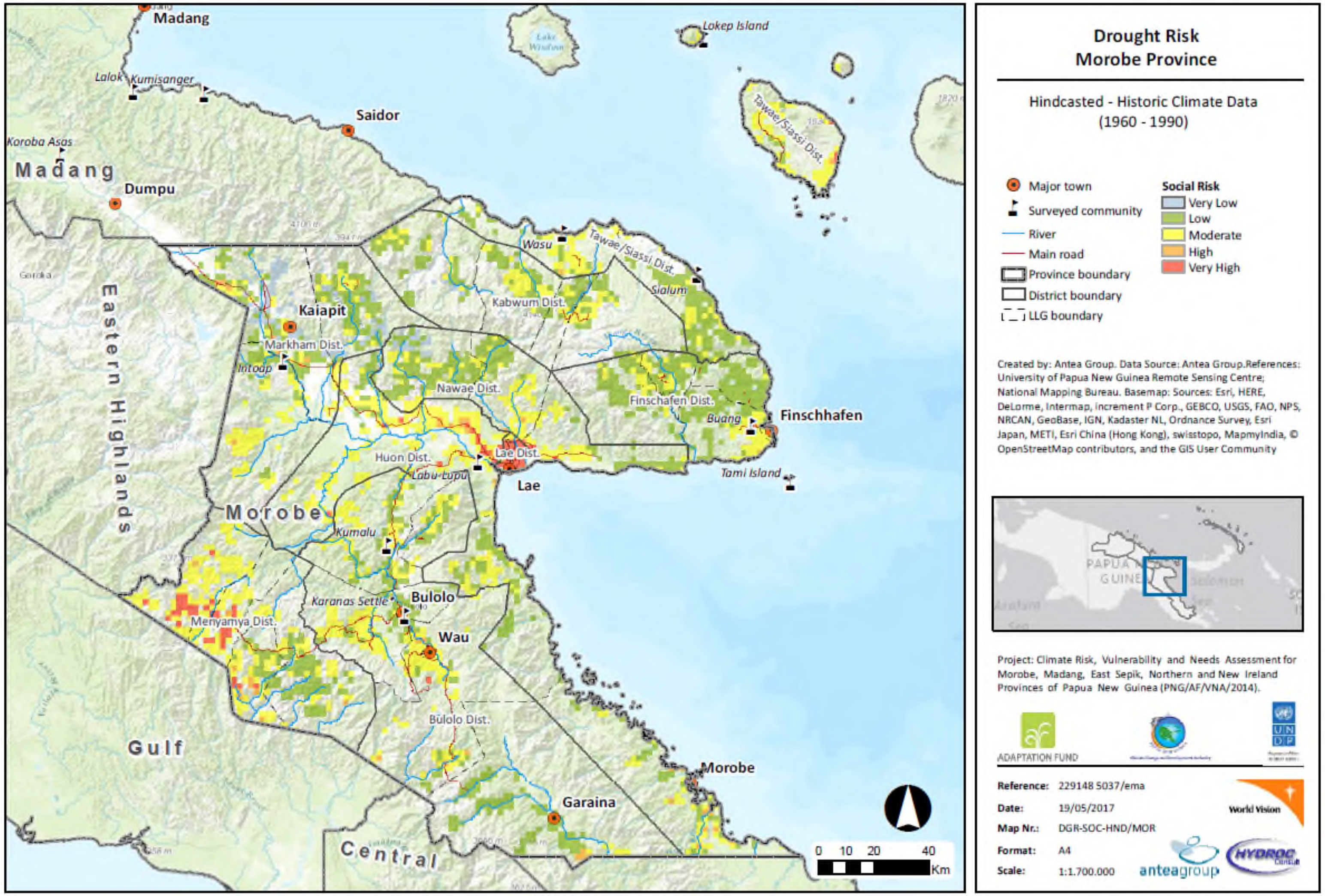

Figure 46. Drought Social Risk (current climate) ■**Very Low** ■**Low** ■**Moderate** ■**High** ■**Extreme**

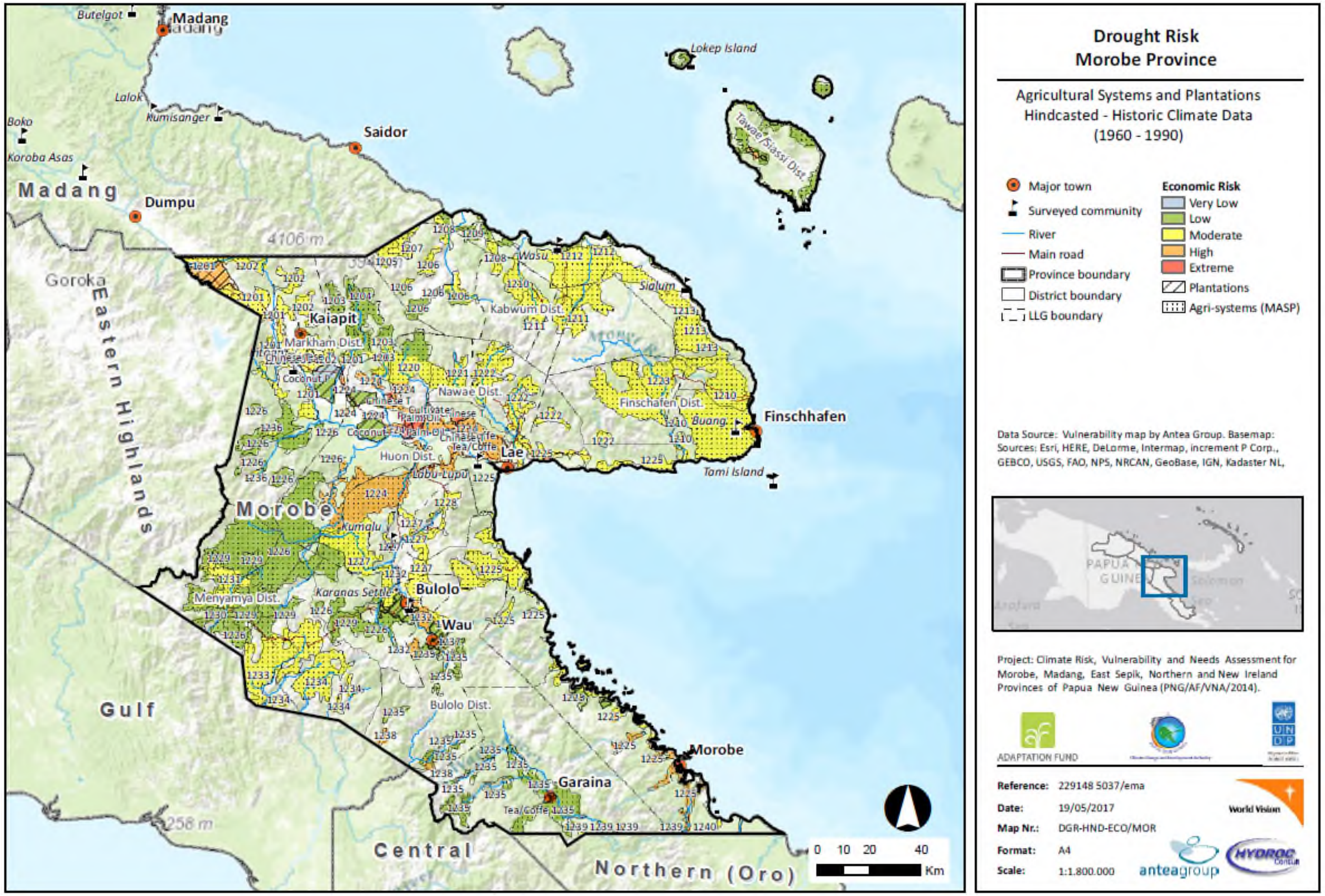

Figure 47. Drought Economic Risk (current climate) Very Low Low Moderate High Extreme

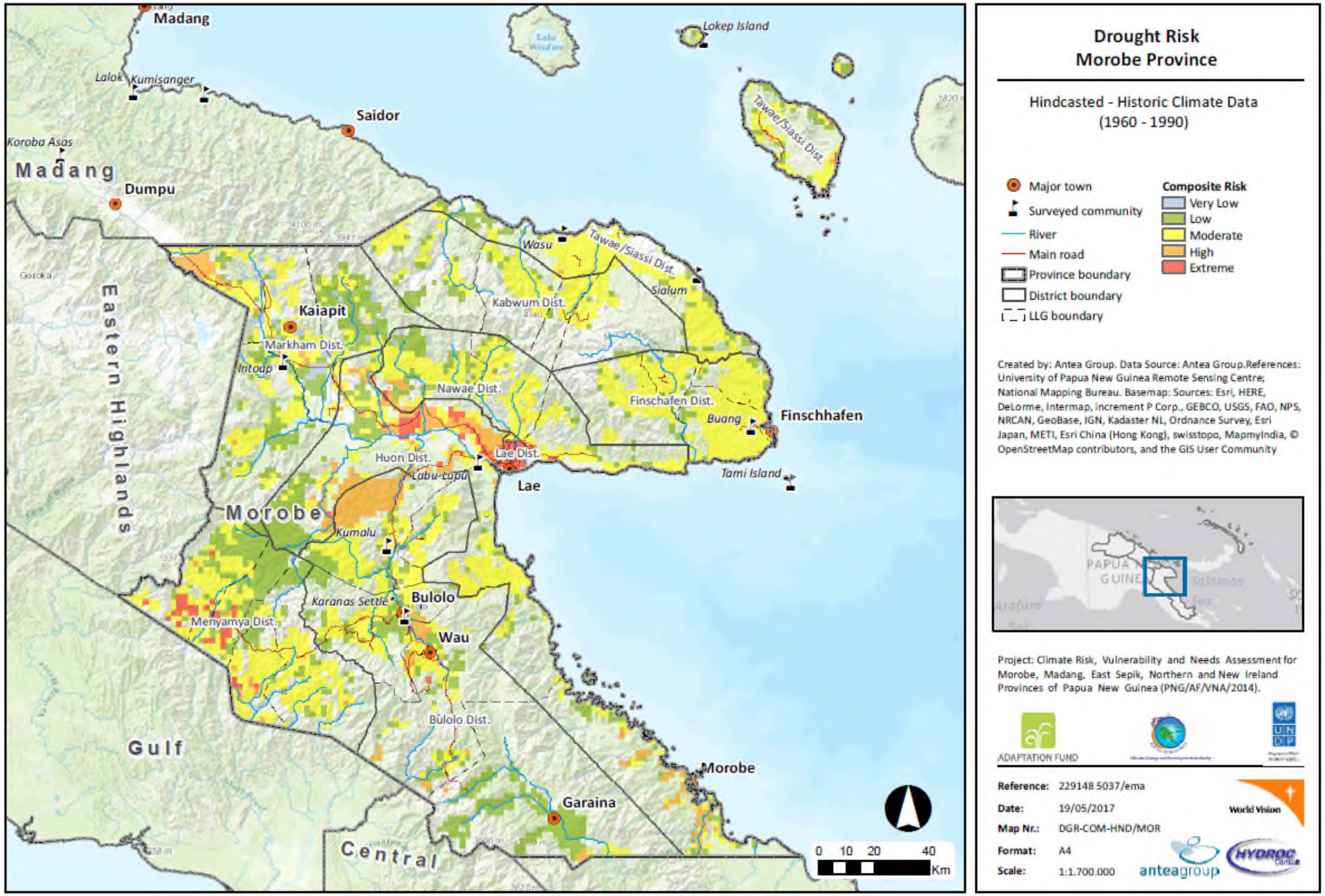

Figure 48. Combined Drought Risk (current climate) **Very Low** **Low** **Moderate** **High** **Extreme**

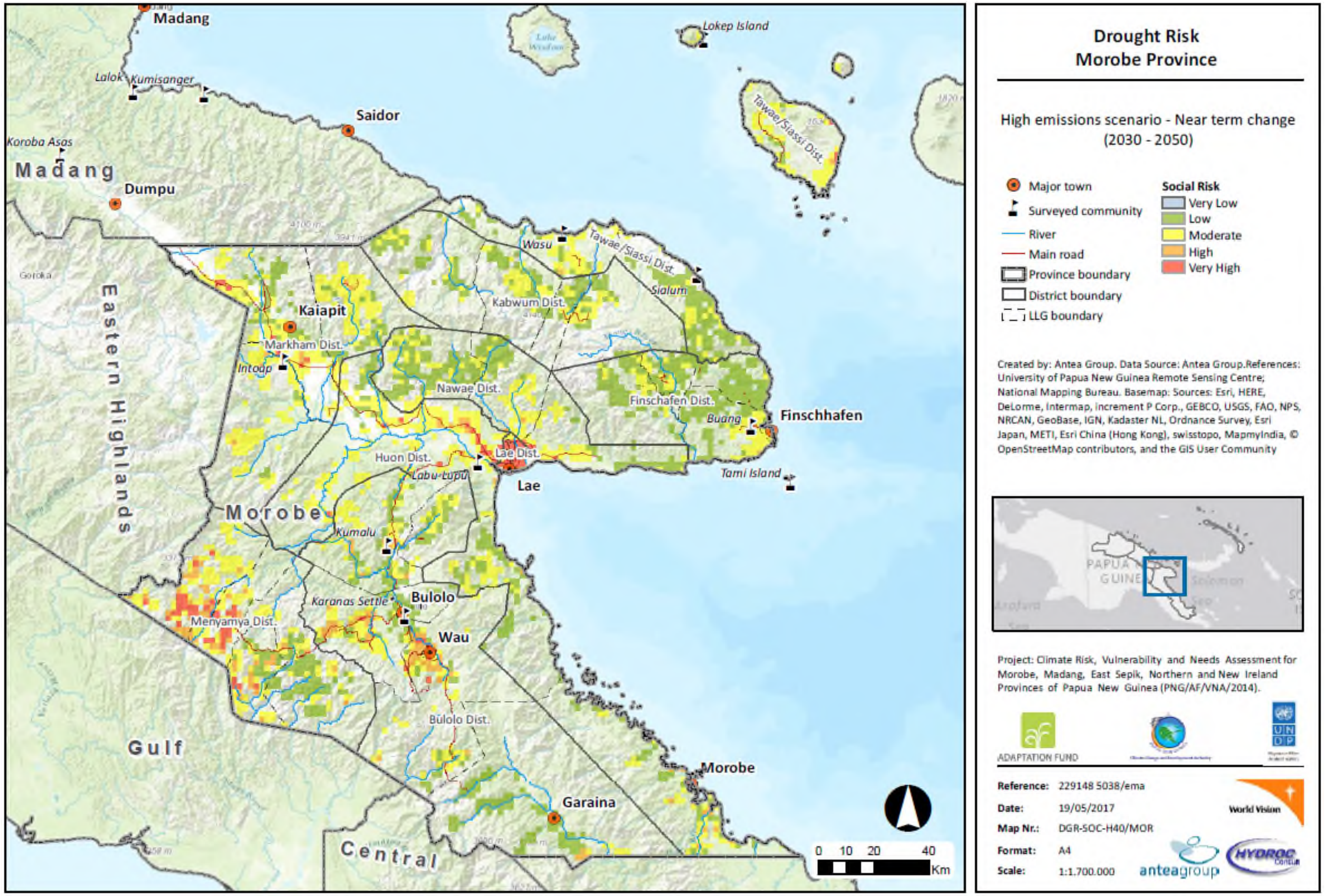

Figure 49. Drought Social Risk (projected climate) Very Low Low Moderate High Extreme

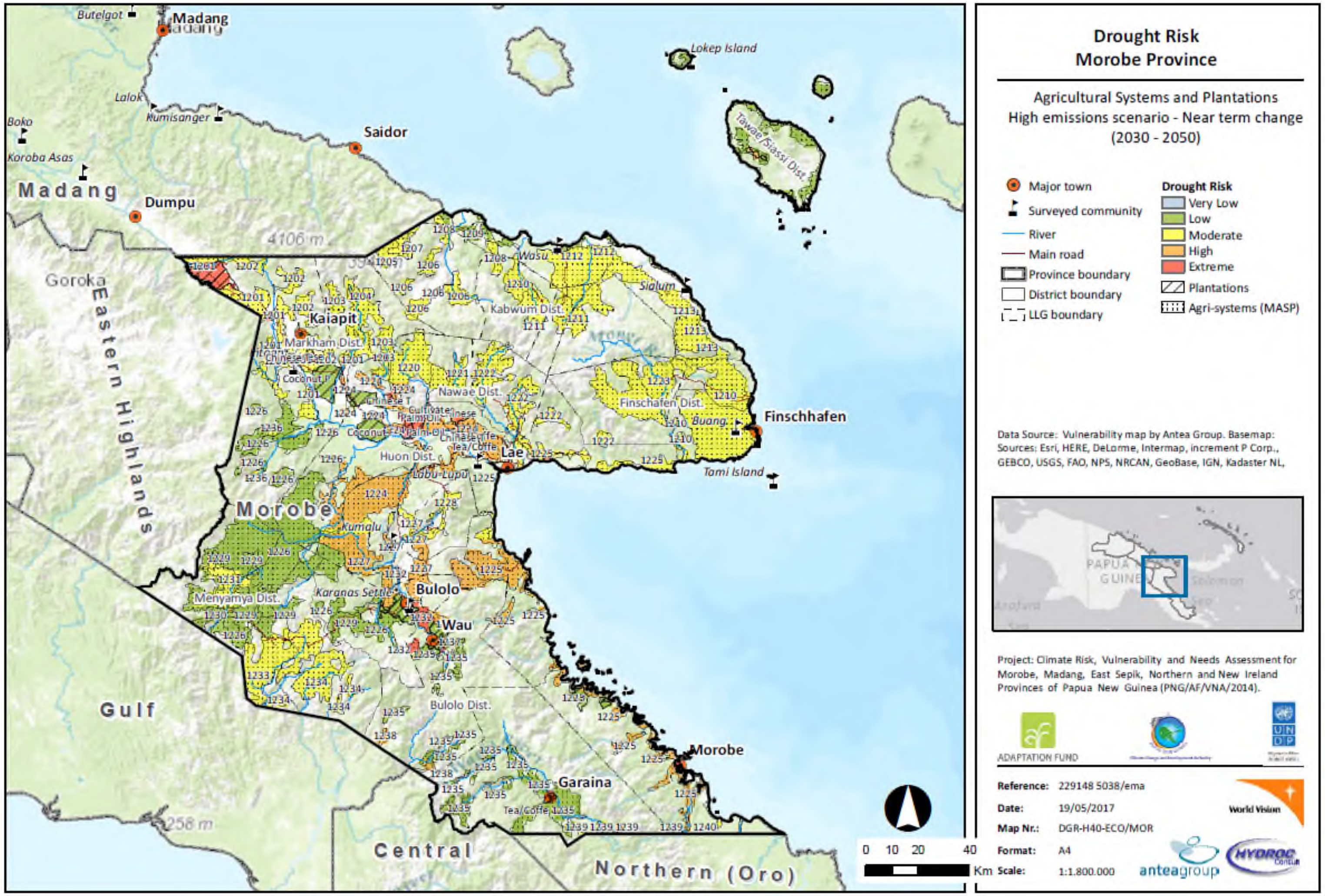

Figure 50. Drought Economic Risk (projected climate) **Very Low** **Low** **Moderate** **High** **Extreme**

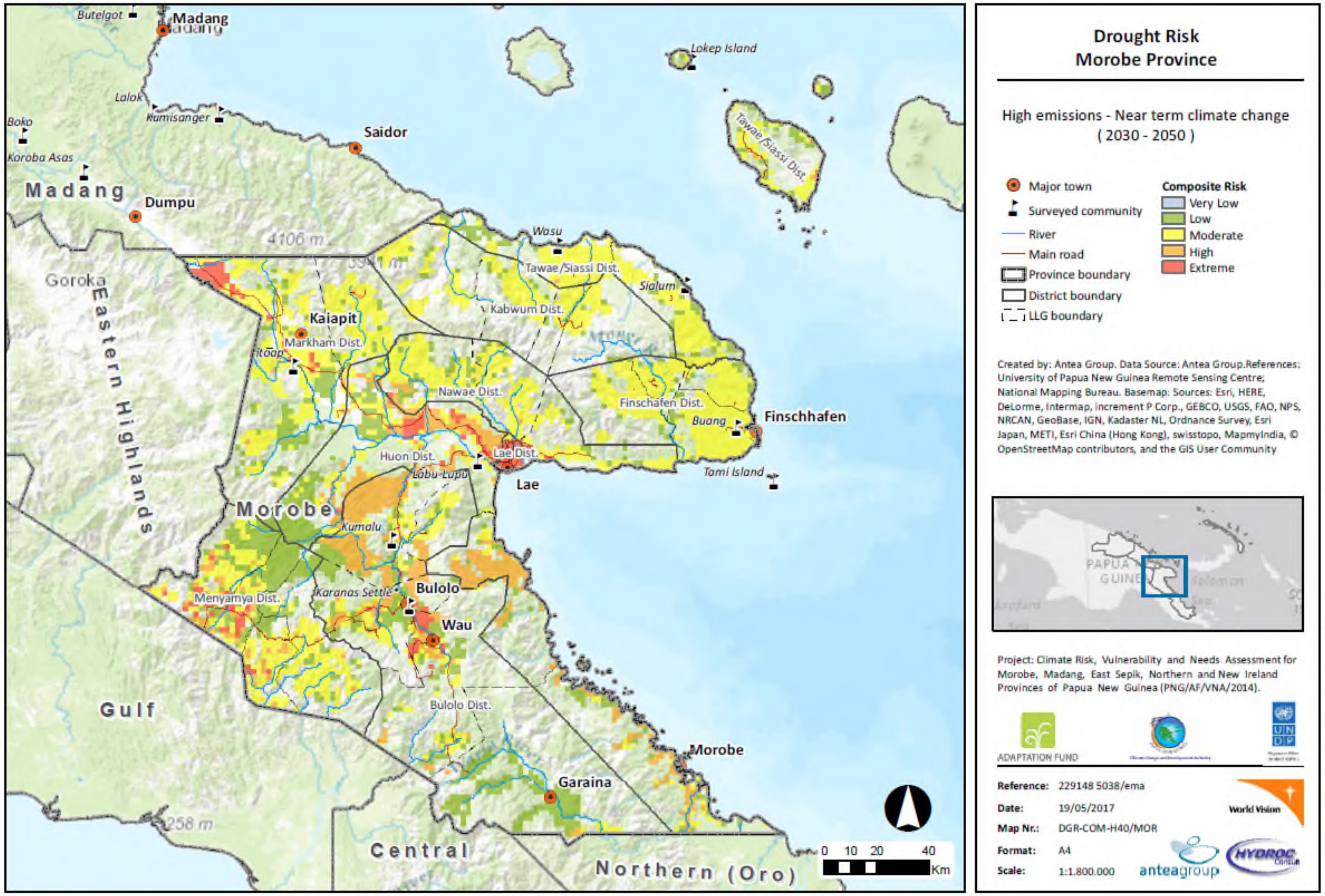

Figure 51. Combined Drought Risk (projected climate) ■Very Low ■Low ■Moderate ■High ■Extreme

2.3.4. *Extreme weather (tropical cyclone) Risk*

According to Figure 52, the social risk from extreme weather is generally low to very low throughout the province. It can be expected that social risk from extreme weather will be highest in and around population centers like Lae, Bulolo, Wau, Kalapit and Garaina. Projections for the future follow the same tendency.

Current extreme weather physical risk is low throughout the province (Figure 53), and projections for the future do not show much change.

Economic risk to extreme weather is low to very low for the province and projections for the future do not show much change.

Extreme weather risks are not significant in the province according to hind cast data (Figure 55) , and projections for the future do not show much variation, as can also be seen in the table below:

Table 35. Distribution of cyclone risk classes

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
District	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Bulolo District	15,1	22,2	0,0	0,0	0,0	62,7	15,1	22,2	0,0	0,0	0,0	62,7
Finschafen District	31,2	28,9	0,0	0,0	0,0	39,9	31,2	28,9	0,0	0,0	0,0	39,9
Huon District	14,7	13,4	0,0	0,0	0,0	71,9	15,1	29,5	0,1	0,0	0,0	55,3
Kabwum District	24,1	47,7	0,2	0,0	0,0	28,0	12,4	15,7	0,0	0,0	0,0	71,8
Lae District	0,0	82,2	0,0	0,0	0,0	17,8	0,0	82,2	0,0	0,0	0,0	17,8
Markham District	2,8	6,4	0,0	0,0	0,0	90,9	18,1	31,8	0,0	0,0	0,0	50,1
Menyamya District	38,6	28,6	0,0	0,0	0,0	32,8	38,6	28,6	0,0	0,0	0,0	32,8
Nawae District	25,3	31,8	0,0	0,0	0,0	42,8	25,3	31,8	0,0	0,0	0,0	42,8
Tawae/Siassi District	33,3	28,0	0,0	0,0	0,0	38,7	33,3	28,0	0,0	0,0	0,0	38,7

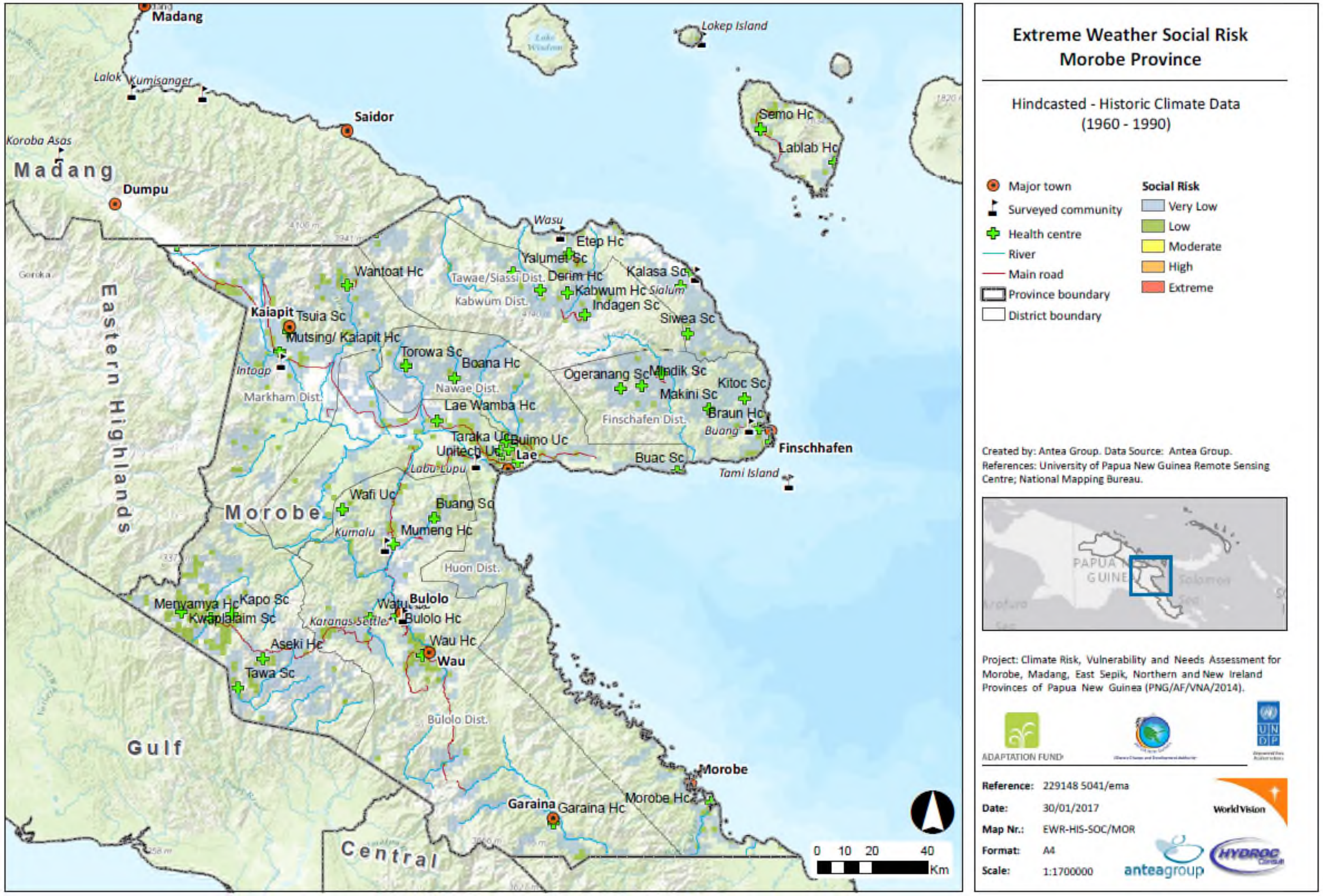

Figure 52. Tropical cyclones Social Risk (current climate) ■ **Very Low** ■ **Low** ■ **Moderate** ■ **High** ■ **Extreme**

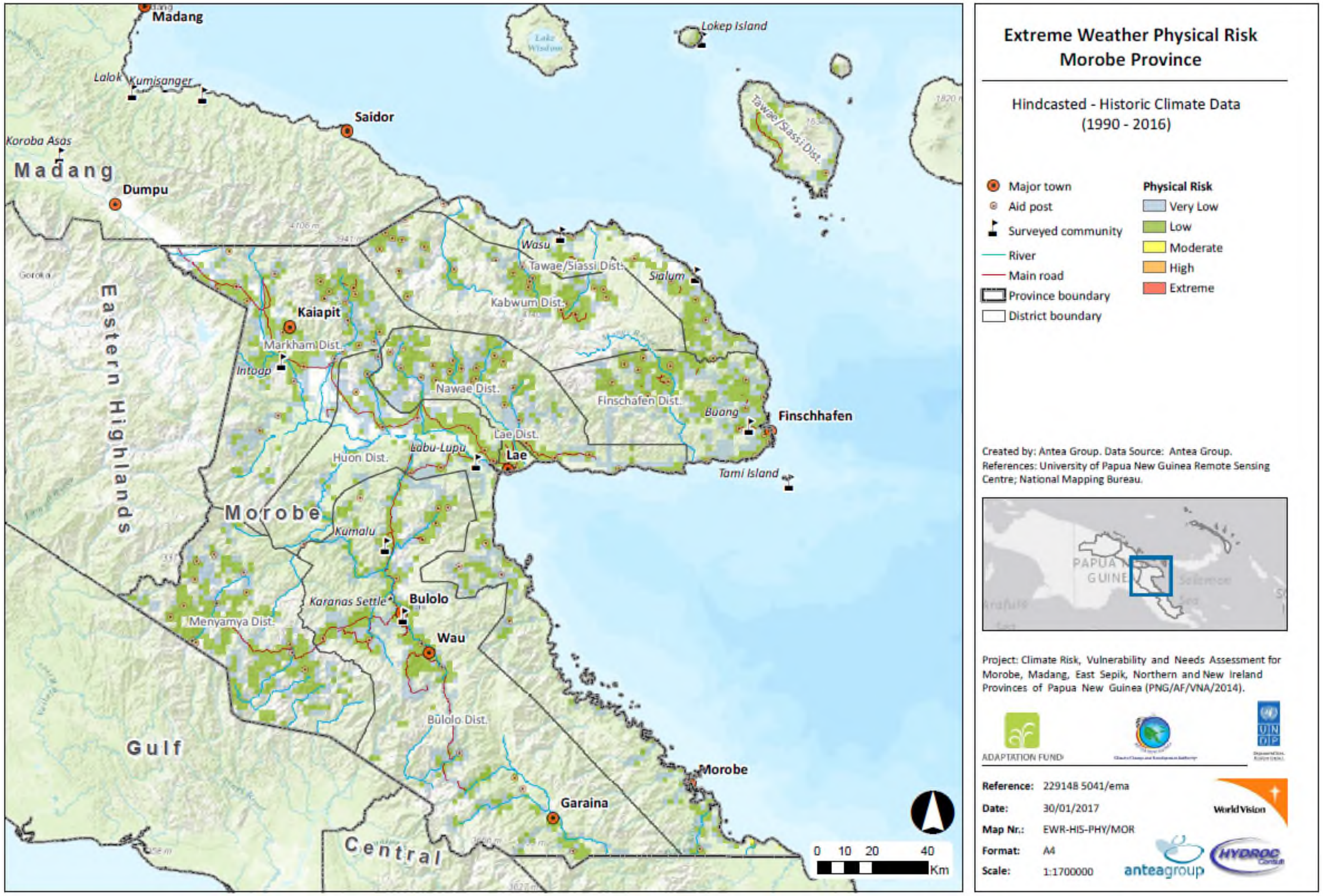

Figure 53. Tropical cyclones Physical Risk (current climate) Very Low Low Moderate High Extreme

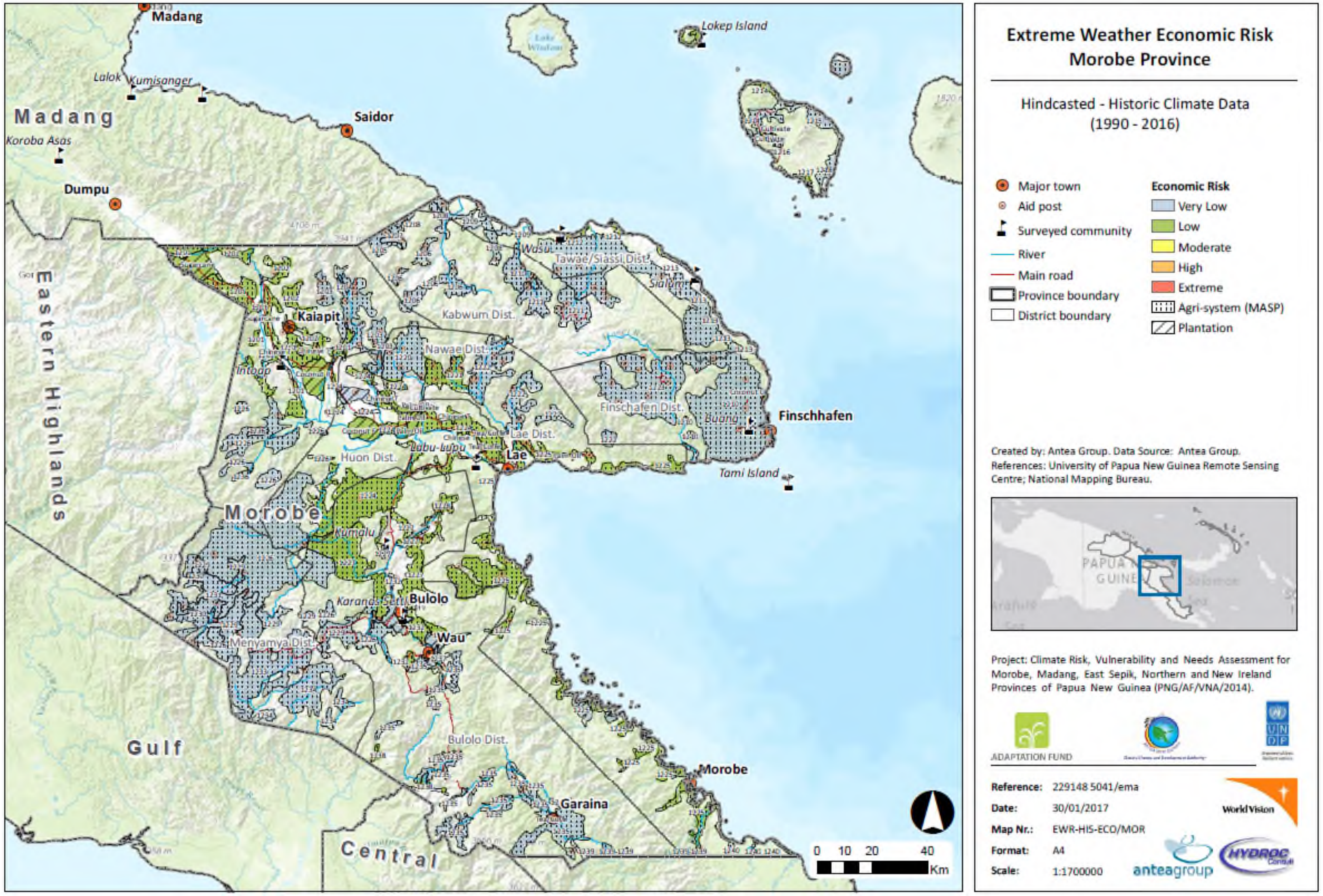

Figure 54. Tropical cyclones Economic Risk (current climate) ■Very Low ■Low ■Moderate ■High ■Extreme

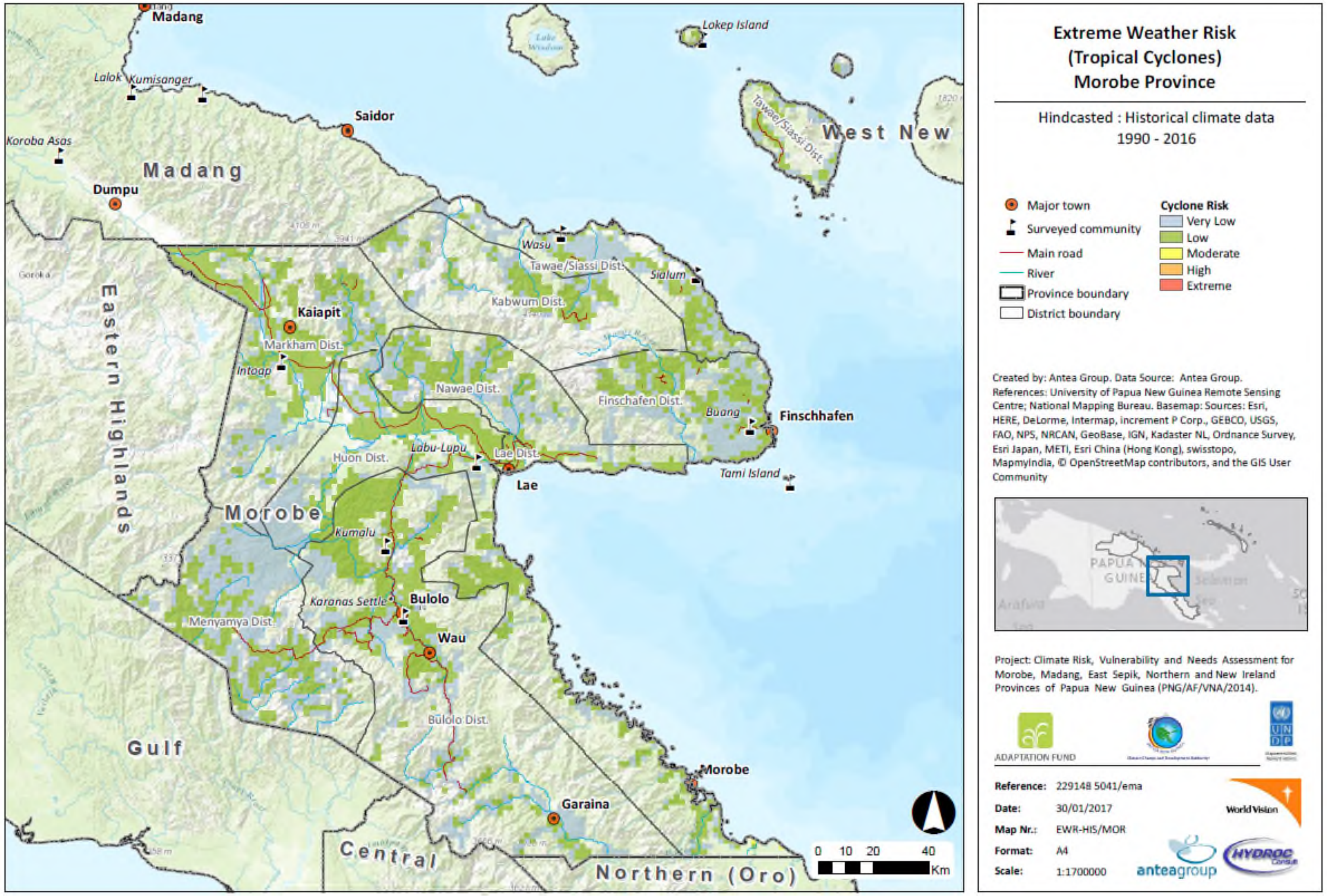

Figure 55. Tropical cyclones Composite Risk (current climate) Very Low Low Moderate High Extreme

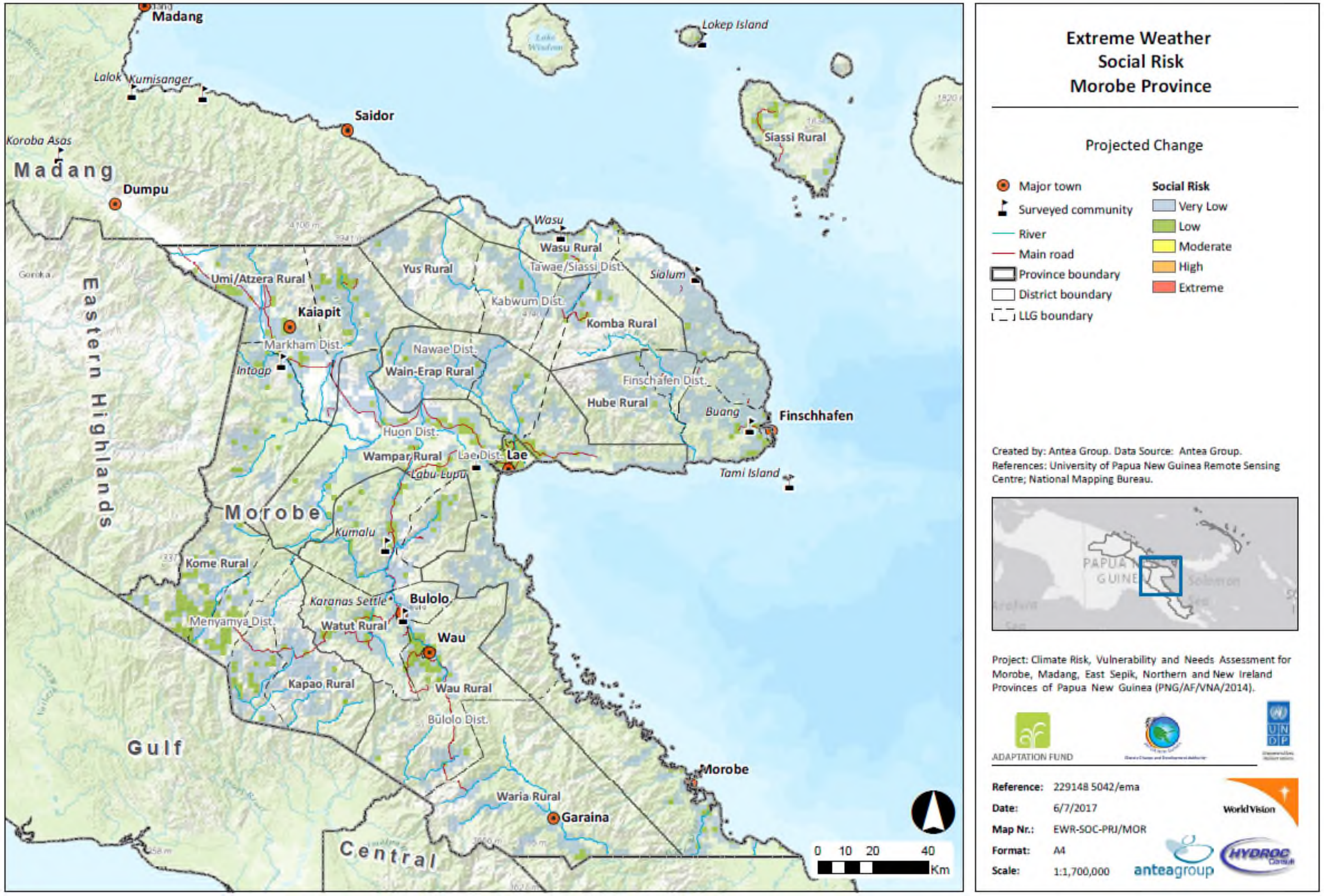

Figure 56. Tropical cyclones Social Risk (projected climate) ■Very Low ■Low ■Moderate ■High ■Extreme

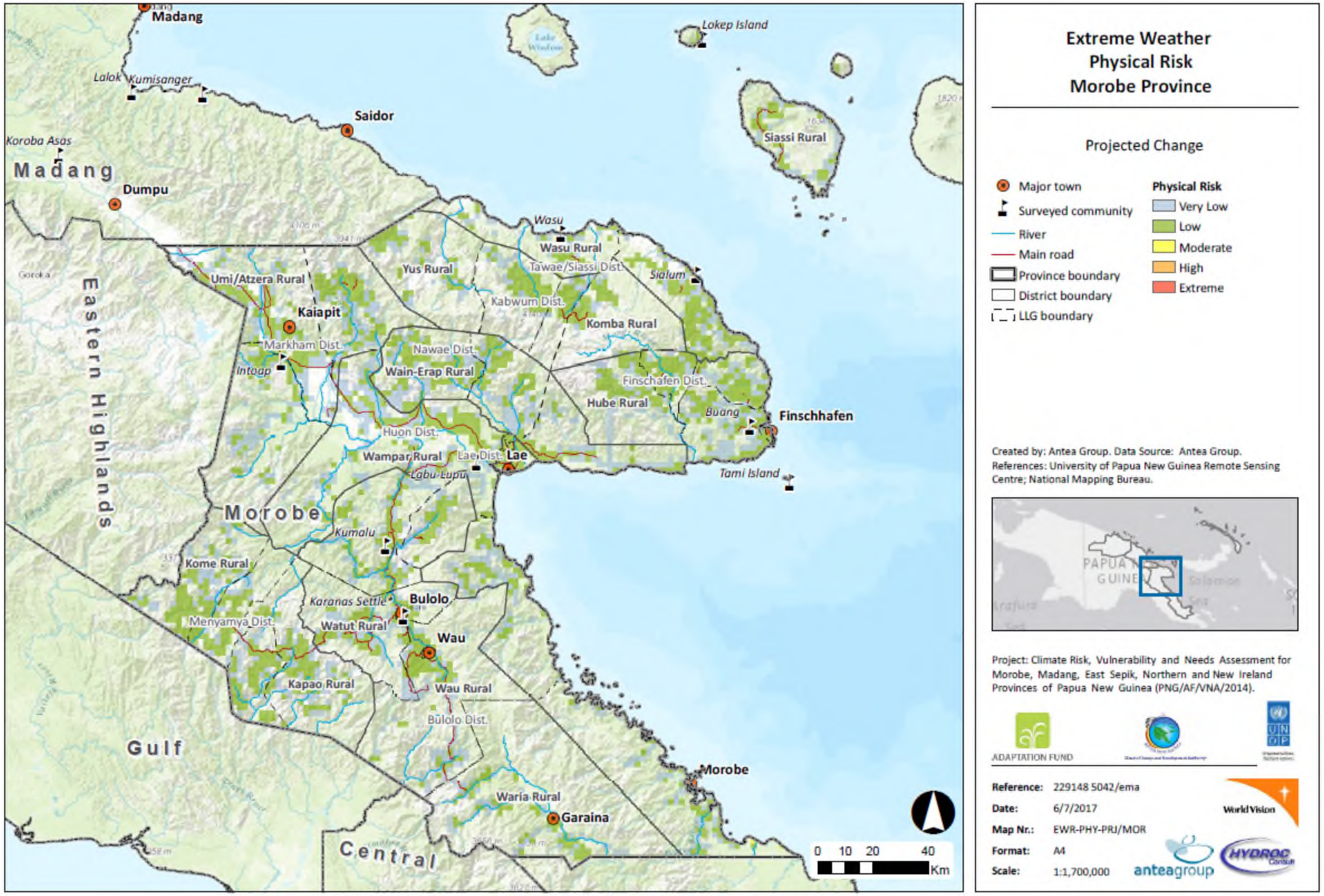

Figure 57. Tropical cyclones Physical Risk (projected climate) Very Low Low Moderate High Extreme

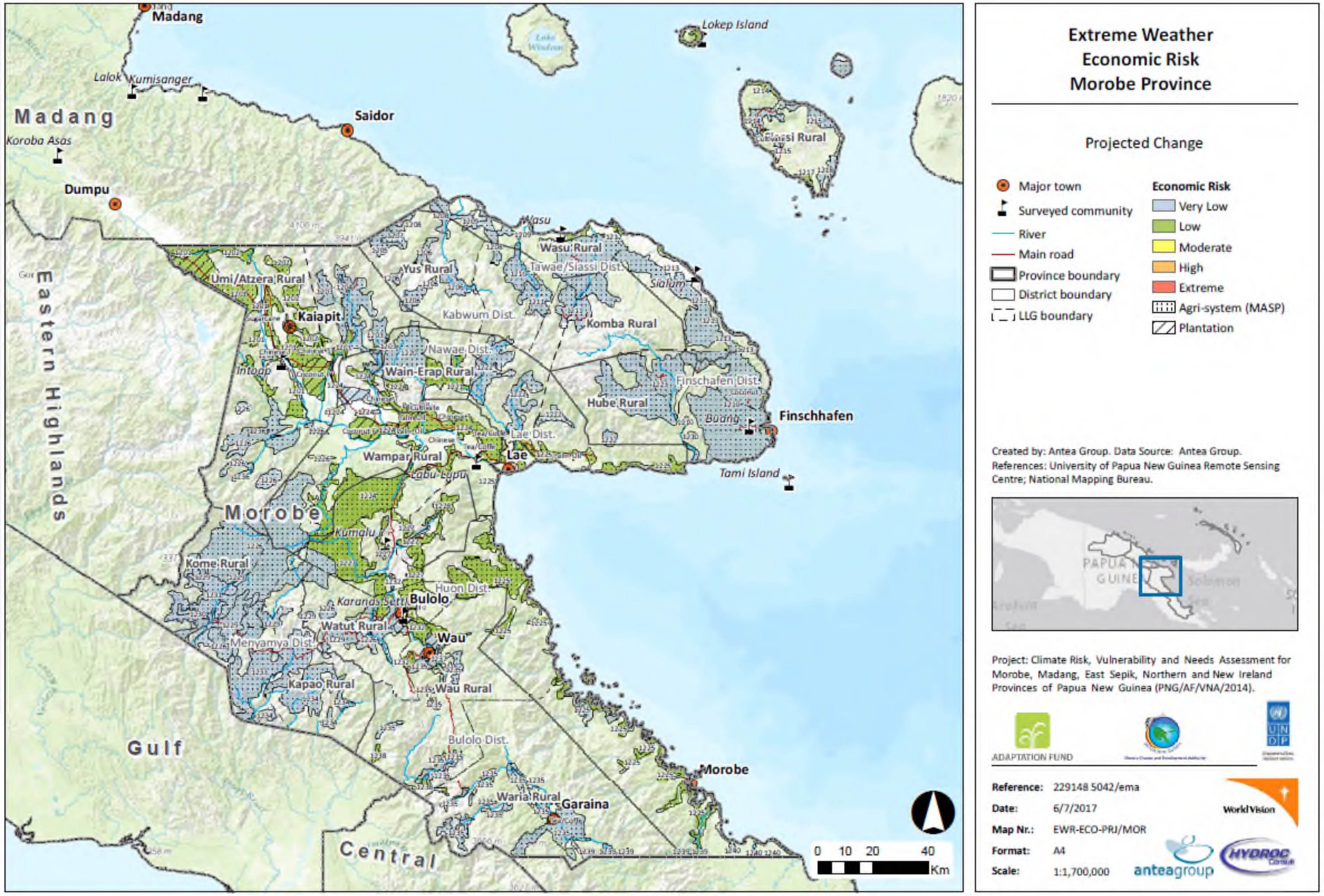

Figure 58. Tropical cyclones Economic Risk (projected climate) Very Low Low Moderate High Extreme

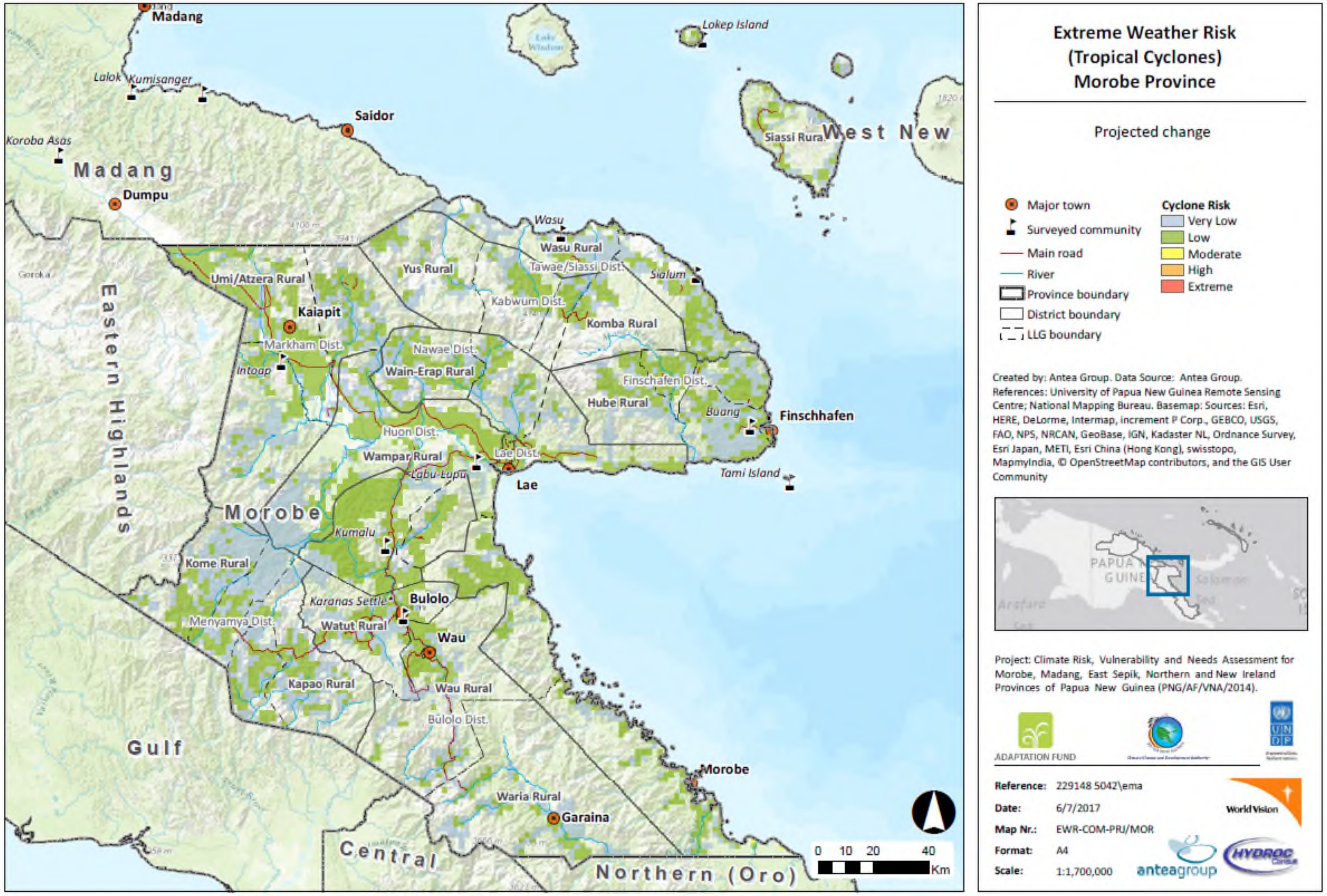

Figure 59. Tropical cyclones Composite Risk (projected climate) Very Low Low Moderate High Extreme

2.3.5. *Increase of precipitation intensities and variability*

According to the map below (Figure 60) the social risk from increased precipitation and variability is generally low to very low throughout the province. It can be expected that social risk will be highest in and around the major population centres in the province like Lae, Bulolo, Wau, Kalapit and Garaina.

Projections for the future show a considerable increase, especially in Lae, Huon, Markham and Menyamya Districts (Figure 63).

Current economic risk from intense rainfall is high in the sugar cane plantations in Umi/Atzera Rural and moderate in the centre of Nawae District and the north west of Bulolo District.

Projections for the future (Figure 64) show a slight increase, especially in Bulolo, Markham and Kabwum Districts.

The composite hind cast map for intense rainfall risk in the province of Morobe shows and incipient risk in the northwest part of Markham District and along the main road to Lae District.

Composite projections for the future show a very big increase in Lae District, considerable increase in Menyamya and slight increase in Huon, Nawae and Tawae/Siassi Districts, as can be seen in the table below:

Table 36. Distribution of precipitation intensities and variability risk

	HAZARD : PRECIPITATION													
	RISK 1960-1990 %							RISK 2030-2050 %						
District	1	2	3	4	5		(3+4+5)	1	2	3	4	5		(3+4+5)
Bulolo District	19,9	10,3	4,5	0,0	0,0	65,2	4,5	10,9	7,9	15,6	0,3	0,0	65,2	15,9
Finschafen District	55,1	3,1	0,0	0,0	0,0	41,7	0	12,9	33,6	11,4	0,4	0,0	41,7	11,8
Huon District	25,9	1,3	0,0	0,0	0,0	72,8	0	11,7	11,5	14,9	1,8	1,5	58,6	18,2
Kabwum District	45,2	22,1	0,7	1,2	0,0	30,8	1,9	1,1	14,8	10,5	1,7	0,0	71,8	12,2
Lae District	6,1	76,1	0,0	0,0	0,0	17,8	0	0,0	0,0	9,1	0,0	73,1	17,8	82,2
Markham District	4,7	4,3	0,0	0,0	0,0	90,9	0	3,7	12,2	24,8	6,3	1,6	51,3	10,7
Menyamya District	55,2	11,0	0,0	0,0	0,0	33,9	0	25,5	10,0	24,7	2,0	4,0	33,9	30,7
Nawae District	43,9	5,1	4,9	0,3	0,0	45,7	5,2	4,1	23,6	24,0	1,6	1,0	45,7	26,6
Tawae/Siassi District	53,4	4,9	0,0	0,3	0,0	41,4	0,3	13,5	24,3	18,0	2,2	0,6	41,4	20,8

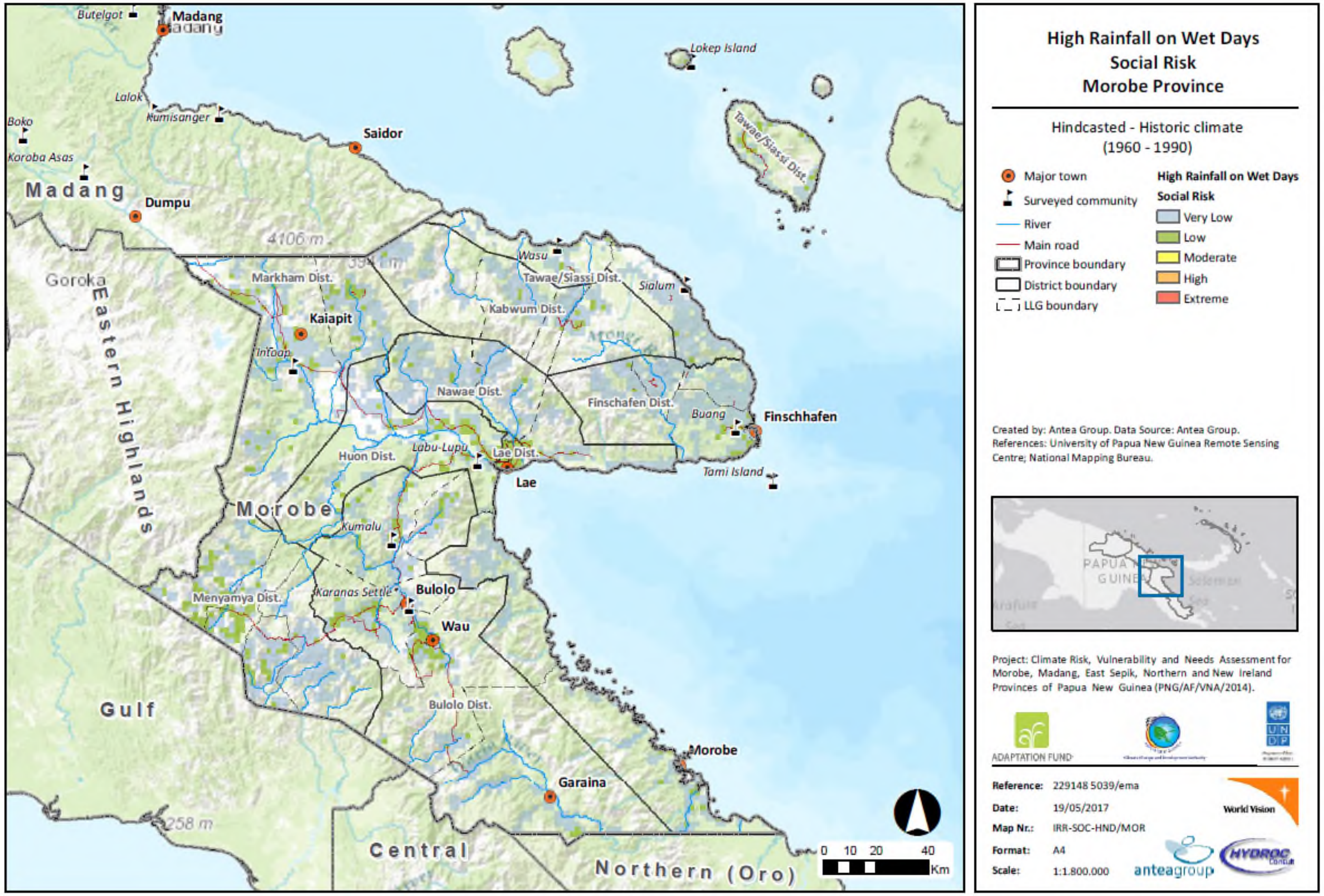

Figure 60. Precipitation intensities and variability social risk (current climate) Very Low Low Moderate High Extreme

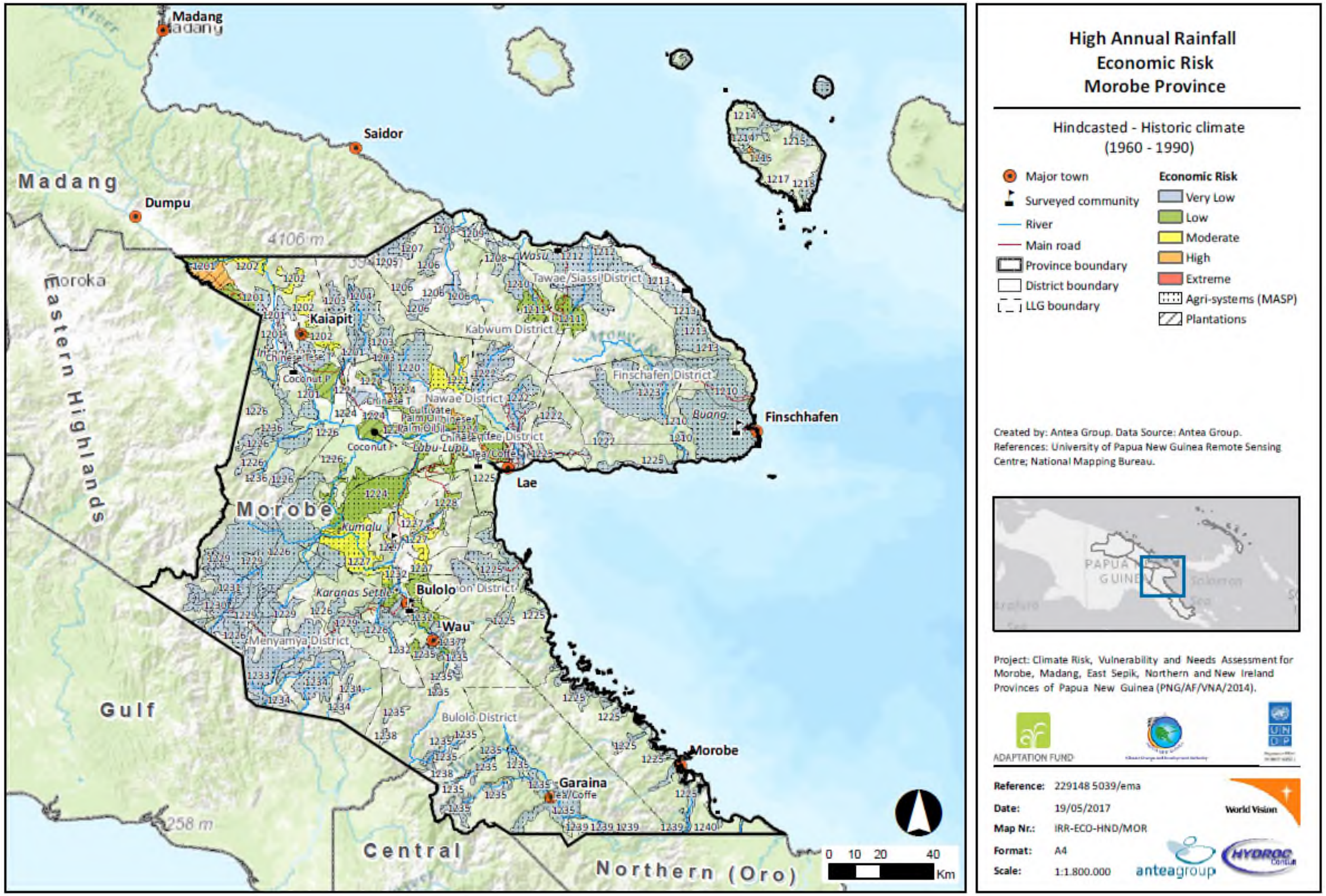

Figure 61. Precipitation intensities and variability Economic Risk (current climate) Very Low Low Moderate High Extreme

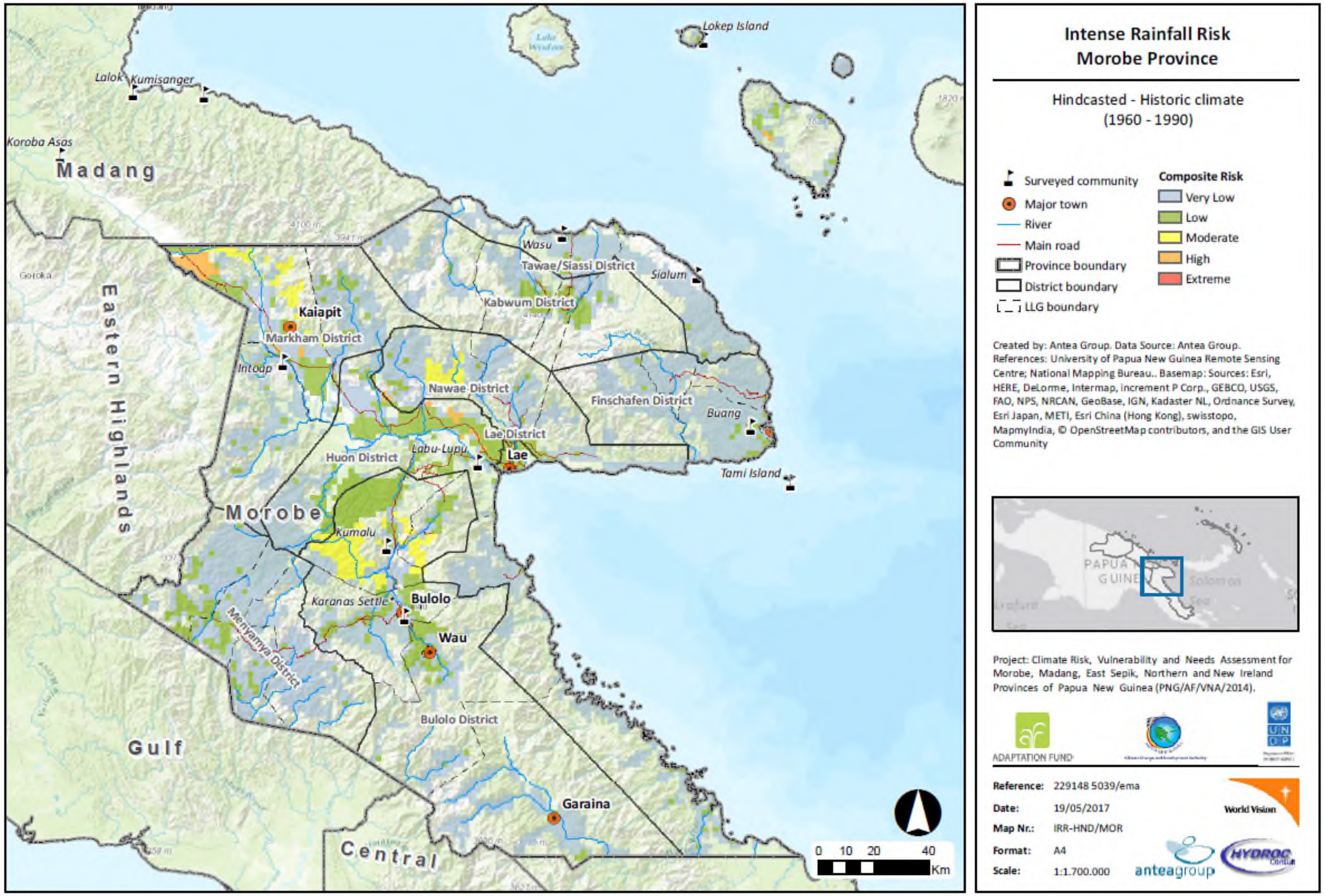

Figure 62. Precipitation intensities and variability composite Risk (current climate) Very Low Low Moderate High Extreme

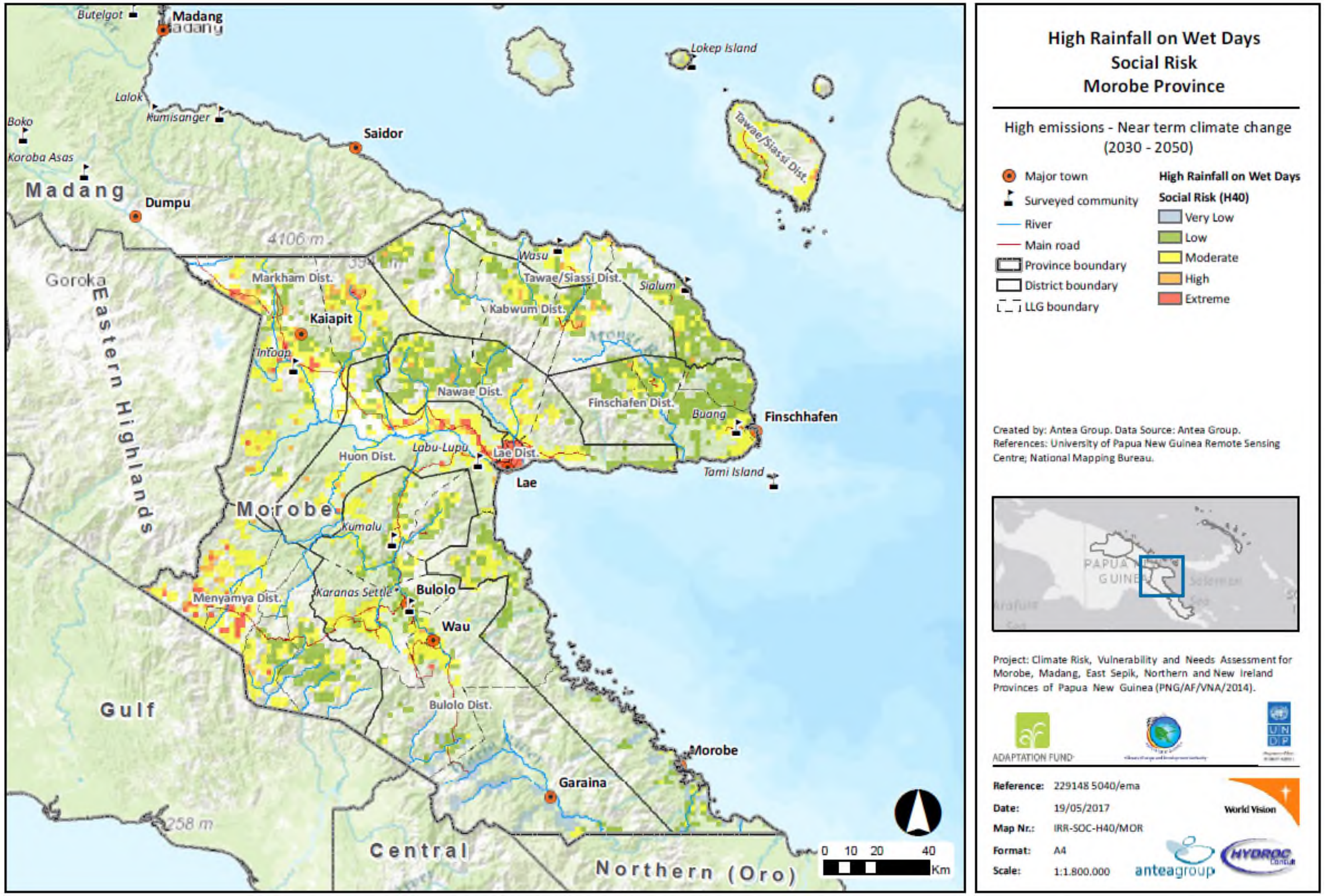

Figure 63. Precipitation intensities and variability Social Risk (projected climate) Very Low Low Moderate High Extreme

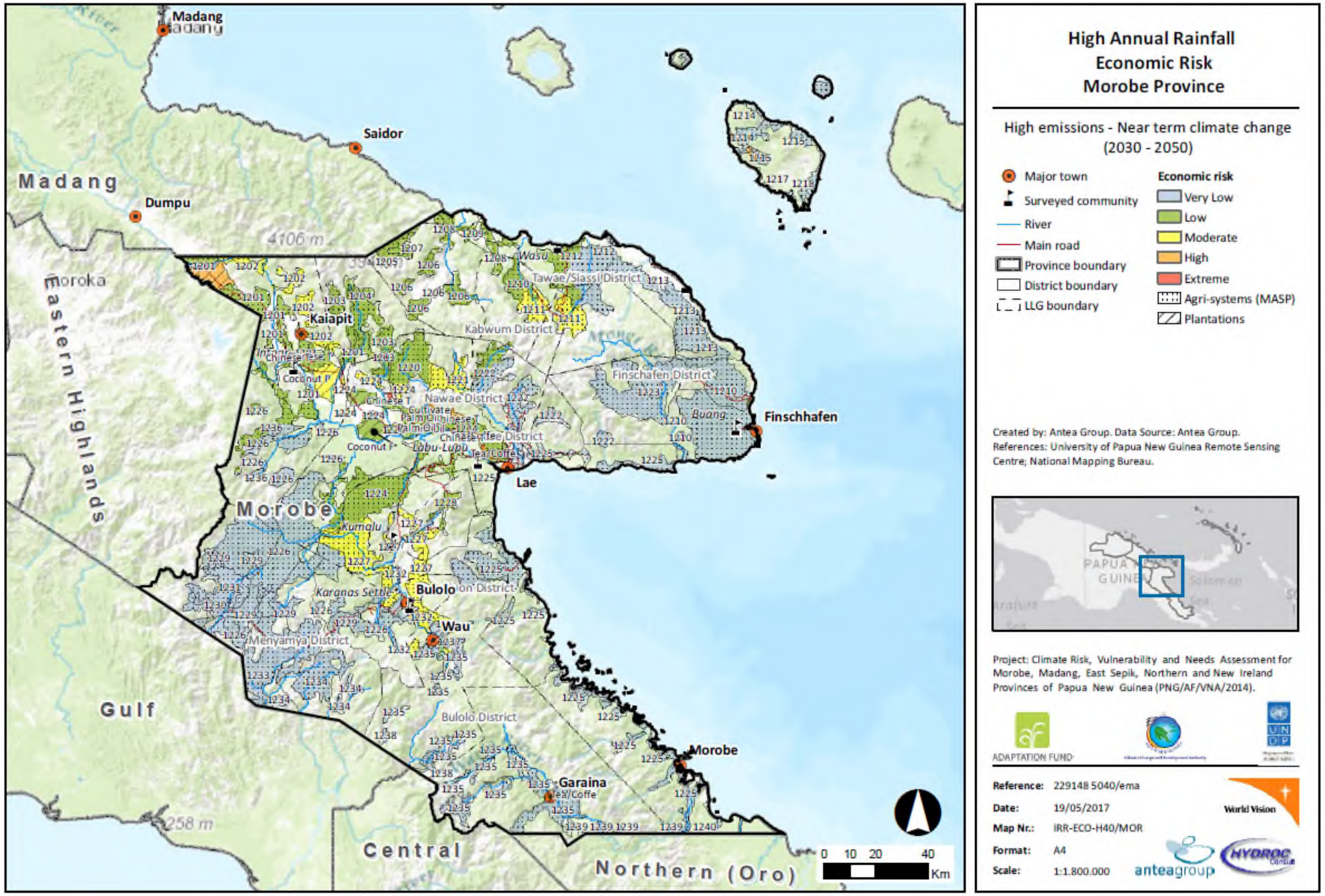

Figure 64. Precipitation intensities and variability Economic Risk (projected climate) Very Low Low Moderate High Extreme

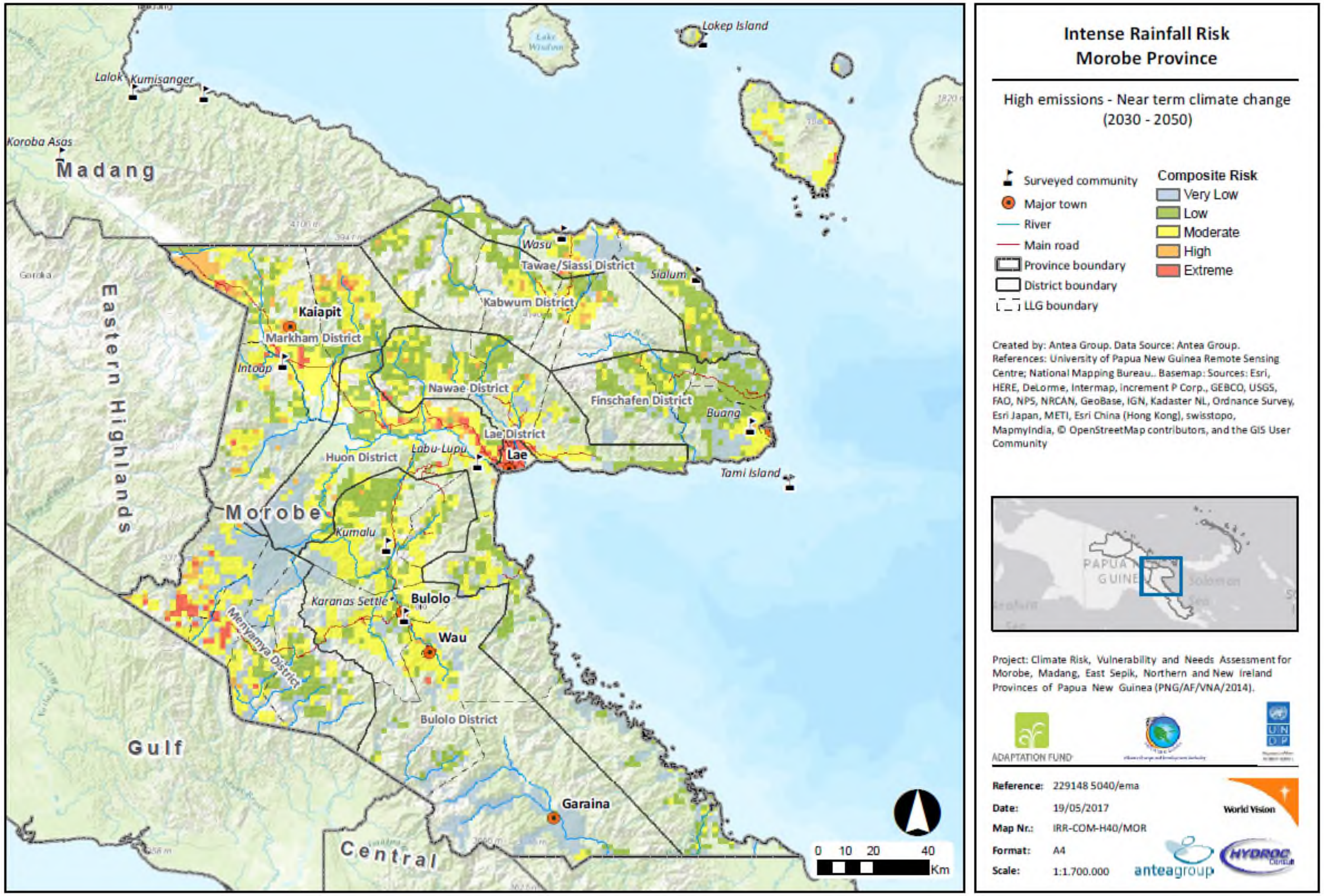

Figure 65. Precipitation intensities and variability Composite Risk (projected climate) Very Low Low Moderate High Extreme

2.4. *Composite Risk*

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

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

Table 37 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 37. Distribution of composite risk classes

	HAZARDS													
	RISK 1960-1990 %							RISK 2030-2050 %						
District	**0**	**1**	**2**	**3**	**4**	**5**		**0**	**1**	**2**	**3**	**4**	**5**	
Bulolo District	20,1	15,0	6,6	0,2	0,0		58,2	20,0	6,0	13,6	2,3	0,0		58,2
Finschafen District	9,9	50,8	2,1	0,0	0,0		37,2	9,9	39,7	12,4	0,7	0,0		37,2
Huon District	20,4	25,8	6,1	0,7	0,0		47,1	20,4	12,9	14,6	5,0	0,0		47,0
Kabwum District	9,6	19,1	2,9	0,0	0,0		68,3	6,9	11,6	11,2	1,9	0,0		68,3
Lae District	9,1	45,7	36,5	0,0	0,0		8,7	9,1	0,0	45,7	36,5	0,0		8,7
Markham District	28,8	15,8	10,6	1,6	0,0		43,2	15,8	8,6	25,6	6,7	0,0		43,2
Menyamya District	26,0	41,4	3,1	0,0	0,0		29,4	26,0	13,7	28,0	2,9	0,0		29,4
Nawae District	19,6	33,9	8,1	0,6	0,0		37,7	15,8	18,8	24,8	2,9	0,0		37,7
Tawae/Siassi District	24,3	40,0	3,4	0,0	0,0		32,3	24,3	21,9	19,3	2,2	0,0		32,3

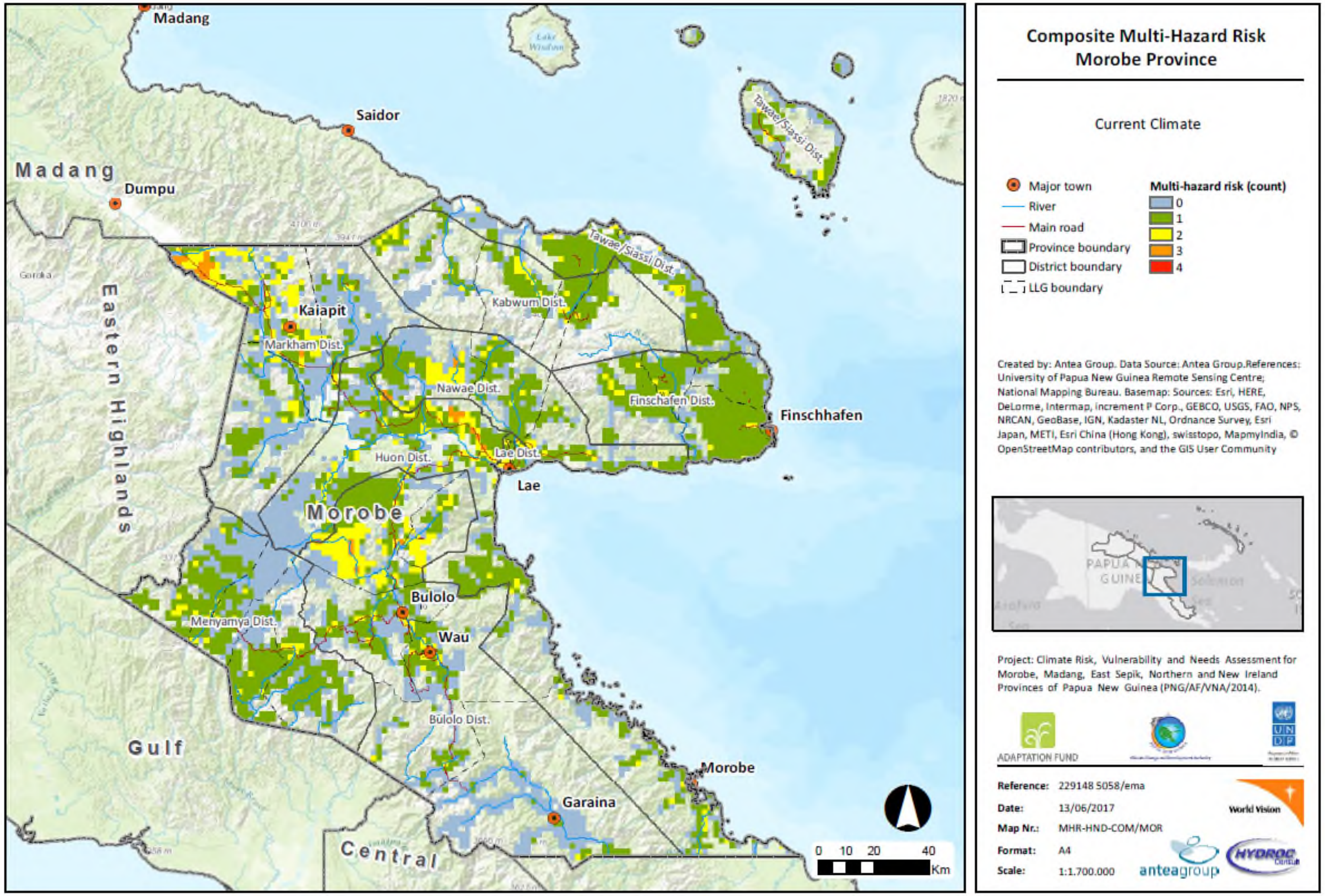

Figure 66. Composite Multi-Risk Map Morobe Province (current)

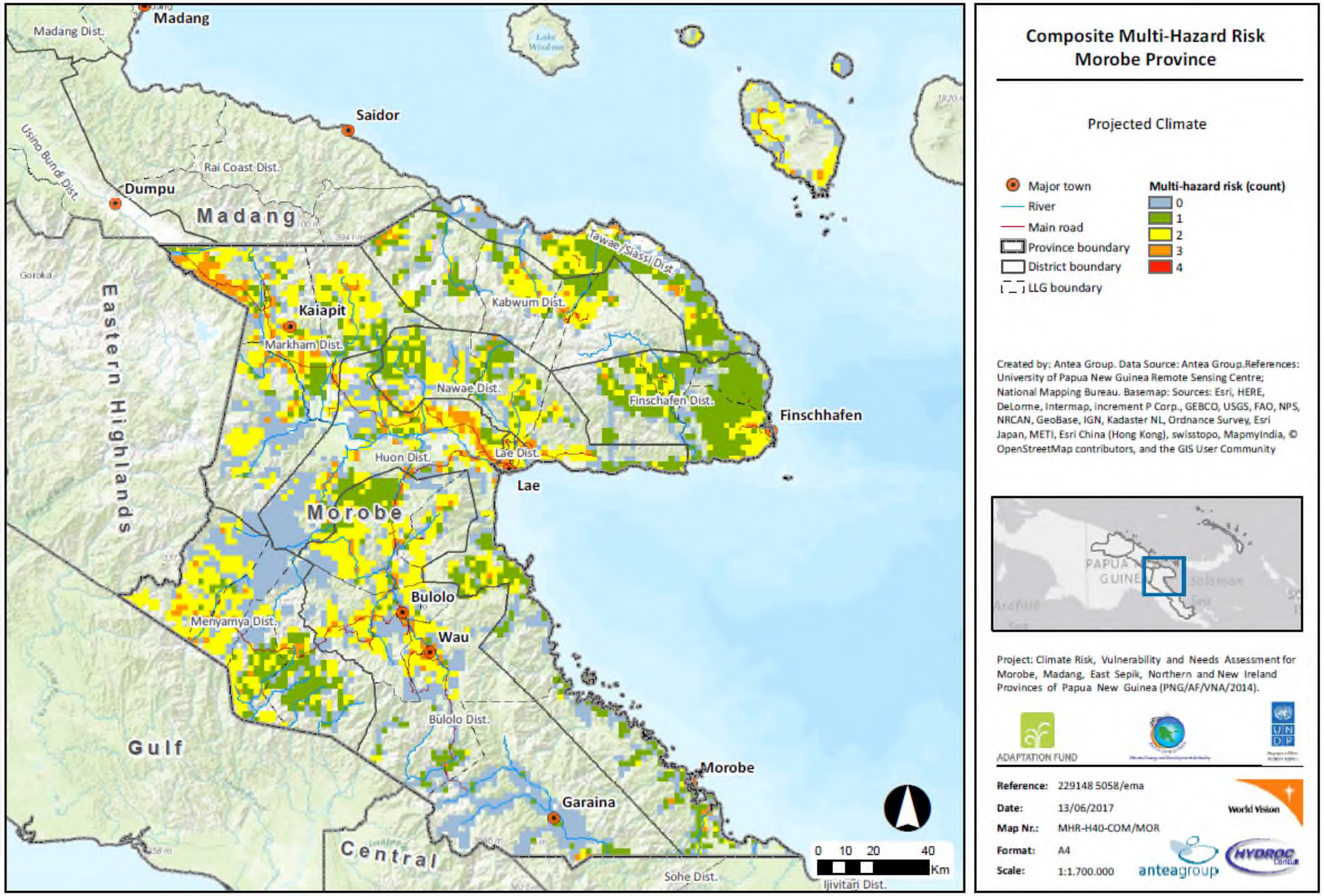

Figure 67. Composite Multi-Risk Map Morobe Province (future)

3. DISTRICT RISK PROFILES

3.1. Bulolo Risk Profile

3.1.1. General description

Bulolo District encompasses the Watut, Snake and Bulolo Valleys in the north and the Waria Valley, Kuper Range and Kodama Range in the south. The district headquarters is located in Bulolo. There are six Local Level Governments (LLGs) in this district: Mumeng Rural, Waria Rural, Watut Rural, Wau/Bulolo Urban, Wau Rural and Buang Rural. The number of wards in this district is 108.

High incomes from the sale of food and coffee are available in the Snake Valley, medium incomes and some wage-earning opportunities in mining and forestry are available near Wau and Bulolo, while incomes in the south of the district are very low.

Figure 68. Bulolo District

Bulolo District has a population of 101,568[21]. The average population density is relatively low, 14.15 inhabitants per km^2, with the highest population densities occurring on the Snake Valley with over 80

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

persons/km^2. The Mainyanda area in the upper Watut Valley has a density of over 50 persons/km^2, while the Wau area has over 30 persons/km^2. All other areas in the district have low densities with an average of around 20 persons/km^2.

The most disadvantaged people in the district are the small populations of the upper Bulolo Valley, Kuper Range and Kodama Range, where incomes are very low and the environment is poor. These people have few opportunities to improve their livelihoods. The very small number of people living in the Waria Valley have very low incomes.

However, the environment offers some potential for development. Overall, people in Bulolo District are slightly disadvantaged relative to people in other districts of PNG. There is little agricultural pressure, land potential is moderate, access to services is good and cash incomes are moderate.

Incomes are highest in the Snake Valley from the sale of fresh food, particularly green vegetables, and from coffee. In the Watut and Bulolo valleys, people earn low to moderate incomes from the sale of betel nut, fresh food and coffee. In the upper and lower Watut Valley, upper Bulolo Valley, Kuper Range, Kodama Range and Waria Valley, incomes are generally ery low. Wage employment and royalties are provided by mining and forestry operations near Wau and Bulolo respectively.

There are clear contrasts in access to services between the northern and southern parts of the district. The road from Wau and Bulolo to Lae is sealed. A surfaced road runs west from Bulolo to Menyamya and another road goes northeast from Mumeng to Wagau in the upper Snake Valley. A road in the Waria Valley north and south of Garaina has no external connections. People in the Watut, Snake and Bulolo valleys are within four hours of a service centre, and have good access to Lae and the Highlands Highway. In contrast, people in the upper Watut Valley, Waria Valley and the mountains to the north and south, require up to eight hours' travel to reach the nearest service centre.

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

Low Weight for Age < 5 years old (%)[22]	Low Birth Weight (%)[23]	Incidence of Malaria (1,000 population)[24]	Incidence of Diarrhoea (<5 years/1,000 pop.)[25]
39	0.5	28	126

Bulolo District has an adult literacy rate of 52.3%, with a significant disparity in literacy rates between males (58.2%) and females (45.3%). Bulolo District ranks sixth among the nine districts in Morobe Province in adult literacy.

[22] 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

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

[24] 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

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

3.1.2. Hazards

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

Bulolo District presents no hazard to extreme events and projections for the future do not show much variation.

When it comes to hazard for inland flooding, hotspots can be seen around Mapos, Baiyun, Bulolo, Wau Bapi and Garasa. Projections for the future do not show much variation.

Current total rain intensity hazard is low for the district, with total annual rainfall in ranges between 2979mm in the north and 2079mm in the south and total rainfall on wet days (p95) ranging between 600mm in the north and 250mm in the south. Future projections show a slight increase of rain intensity which additionally spreads towards the south.

Finally, drought risk in Bulolo District is currently moderate in the northern half of the district (ranging 22 to 24 continuous dry days) and high in the southern half (with ranges of 24 to 29 continuous dry days). Projections for the future, show a slight increase in drought hazard for the district, especially in the southern part.

3.1.3. Risk

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

3.1.3.1. Social risk

The highest social risk to hazards in Bulolo District is found in the area extending from the vicinity of Wau town northward to Bulolo town in Bulolo and Wau Urban LLGs. The most serious hazard in this area is inland flooding.

Additional details in how flooding affects communities and how they respond to this hazard can be obtained from the Community Risk Assessment carried out in villages like Kumalu in Ward 13, Mumeng Rural LLG in Bulolo District:

Flooding has been the most destructive and common hazard that impacts the community. The seasonal floods disrupt the lives and livelihoods of people in Kumalu Village. Food gardens located in lowlying areas and near the banks of the river are wiped out leaving many families without food for days. Water sources are also affected as springs and wells get covered by silt and mud.

Road access to the village is also cut off as floodwater from upstream causes the Kumalu River to swell, inundating the main roads in the village. There are cases where the floods have destroyed parts of the road and triggered landslides that blocked sections of the road.

Flooding occurs during the wet season, usually from November to March each year. However, heavy rains that come outside of this period still cause large floods. People in the village have noticed that recently rains have become increasingly unpredictable. People have also noticed that the bed of the Kumalu River near the community center was getting deeper and deeper every year after the floods. It is believed that the river is already at least 20 ft. deep. In addition, sections of the river bank are continuously eroding, thus further increasing the size of the river. Because of the sandy and porous soil in the area, soil erosion is rapidly affecting parts of the community center. Continued flooding in the future is likely to displace the entire village due to the erosion of the river banks.

Since the 1980s perennial flooding has caused the permanent displacement of people in the area. A number of times the village has been relocated as people attempted to cope with the situation. Community facilities like schools, health posts, teachers' and health workers' houses have also been moved to a safer location, only to be relocated again after several years due to landslides and erosion.

3.1.3.2. Economic risk

The economic risk in Bulolo District is mostly low or very low. Whoever, Current economic risk to drought is moderate to extreme. The various agricultural systems like food crops represent areas of moderate to high risk (**Fout! Verwijzingsbron niet gevonden.**). The projections for the future show a significate evolution for economic risk from drought.

Table 39. Top agricultural activities of citizen households in Bulolo[26]

Activity	*% engaged*	*%* engaged for cash*
Coconut	27.9	5.0
Betel nut	42.7	16.7
Food crops (sweet potato, banana, taro, cassava, et al.)	70.2	13.3
Livestock	19.7	5.8
Coffee	50.8	47.9

3.1.4. Physical risk

When it comes to talking about inland flooding physical risk, Bulolo district presents three hotspots: around Wau, around Bulolo and around Kumalu. Projections for the future remain more or less the same.

Extreme weather physical risk is low for the district and projections for the future remain the same.

3.1.5. Composite risk

The composite multi-hazard risk for Bulolo shows mostly low to very low risk in the southern part of the district but presents some moderate hotspots towards the northern half of the district, mostly around Wau, Bulolo and most of Mumeng Rural and Buang Rural (Figure 69).

Projections for the future show a general increase in the risk profile of the district, mostly in the northern half (Figure 70).

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	**1**	**2**	**3**	**4**	**5**	
Mumeng Rural	9,4	2,1	27,6	27,0	8,5	25,3
Waria Rural	1,6	11,6	3,0	2,5	1,5	79,8
Watut Rural	17,0	10,9	12,9	5,3	7,3	46,6
Wau/Bulolo Urban	0,0	0,0	0,0	0,0	100,0	0,0
Wau Rural	5,1	8,5	5,8	6,1	3,4	71,1
Buang Rural	5,7	4,3	15,7	5,7	8,6	60,0

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

LLG	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Mumeng Rural	11,8	3,6	30,7	24,9	0,0	28,9
Waria Rural	43,1	1,0	0,6	0,3	0,0	55,0
Watut Rural	20,3	13,5	12,6	2,3	0,0	51,2
Wau/Bulolo Urban	0,0	78,2	11,2	11,2	0,0	0,0
Wau Rural	13,7	7,5	7,1	3,2	0,2	68,3
Buang Rural	2,7	10,0	19,3	0,0	0,0	68,0

LLG	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Mumeng Rural	28,2	3,6	2,4	2,1	10,3	53,2
Waria Rural	12,4	2,6	0,6	0,1	2,4	81,8
Watut Rural	22,3	4,1	1,8	0,9	5,9	65,1
Wau/Bulolo Urban	22,3	0,0	0,0	0,0	78,2	0,0
Wau Rural	15,3	1,7	0,5	0,7	3,2	78,6
Buang Rural	15,0	3,6	3,6	2,1	3,6	72,1

LLG	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Mumeng Rural	12,5	26,4	32,5	0,0	0,0	28,6
Waria Rural	18,1	0,8	0,5	0,0	0,4	80,3
Watut Rural	19,6	13,5	14,4	0,6	0,0	51,9
Wau/Bulolo Urban	0,0	78,2	11,2	11,2	0,0	0,0
Wau Rural	9,2	8,3	8,0	0,5	0,2	73,9
Buang Rural	6,4	10,0	19,3	0,0	0,0	64,3

LLG	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Mumeng Rural	11,5	63,2	0,0	0,0	0,0	25,3	11,5	63,2	0,0	0,0	0,0	25,3
Waria Rural	13,2	7,0	0,0	0,0	0,0	79,8	13,2	7,0	0,0	0,0	0,0	79,8
Watut Rural	27,9	25,5	0,0	0,0	0,0	46,6	27,9	25,5	0,0	0,0	0,0	46,6
Wau/Bulolo Urban	0,0	100,0	0,0	0,0	0,0	0,0	0,0	100,0	0,0	0,0	0,0	0,0
Wau Rural	13,6	15,3	0,0	0,0	0,0	71,1	13,6	15,3	0,0	0,0	0,0	71,1
Buang Rural	10,0	30,0	0,0	0,0	0,0	60,0	10,0	30,0	0,0	0,0	0,0	60,0

LLG	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Mumeng Rural	0,0	11,8	34,3	24,9	0,0	28,9	0,0	11,8	12,8	46,2	0,3	28,9
Waria Rural	0,0	17,8	1,0	0,6	0,3	80,3	0,0	17,8	1,0	0,6	0,3	80,3
Watut Rural	0,0	19,6	26,1	2,3	0,0	51,9	0,0	19,6	13,5	12,6	2,3	51,9
Wau/Bulolo Urban	0,0	0,0	78,2	22,3	0,0	0,0	0,0	0,0	78,2	11,2	11,2	0,0
Wau Rural	0,0	7,6	13,1	4,8	0,2	74,4	0,0	7,6	7,5	7,1	3,4	74,4
Buang Rural	0,0	6,4	29,3	0,0	0,0	64,3	0,0	6,4	22,9	6,4	0,0	64,3

LLG	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Mumeng Rural	31,6	7,9	4,6	2,1	0,6	53,2	31,9	7,6	4,3	2,4	0,6	53,2
Waria Rural	13,3	3,6	1,0	0,3	0,0	81,8	13,3	3,6	1,0	0,3	0,0	81,8
Watut Rural	26,1	4,4	0,9	2,1	1,5	65,1	25,8	4,7	0,9	2,1	1,5	65,1
Wau/Bulolo Urban	22,3	0,0	0,0	22,3	55,9	0,0	22,3	0,0	0,0	22,3	55,9	0,0
Wau Rural	16,5	2,0	0,8	1,0	1,0	78,6	16,5	2,0	0,8	1,0	1,0	78,6
Buang Rural	18,6	5,7	2,9	0,7	0,0	72,1	18,6	5,7	2,9	0,7	0,0	72,1

LLG	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Mumeng Rural	16,1	30,4	24,9	0,0	0,0	28,6	4,6	25,8	40,7	0,3	0,0	28,6
Waria Rural	18,8	0,9	0,0	0,0	0,0	80,3	18,1	1,1	0,5	0,0	0,0	80,3
Watut Rural	33,1	15,0	0,0	0,0	0,0	51,9	10,3	9,4	27,9	0,6	0,0	51,9
Wau/Bulolo Urban	78,2	22,3	0,0	0,0	0,0	0,0	0,0	0,0	78,2	22,3	0,0	0,0
Wau Rural	17,5	8,7	0,0	0,0	0,0	73,9	7,8	5,4	12,2	0,5	0,2	73,9
Buang Rural	11,4	11,4	12,9	0,0	0,0	64,3	0,0	11,4	24,3	0,0	0,0	64,3

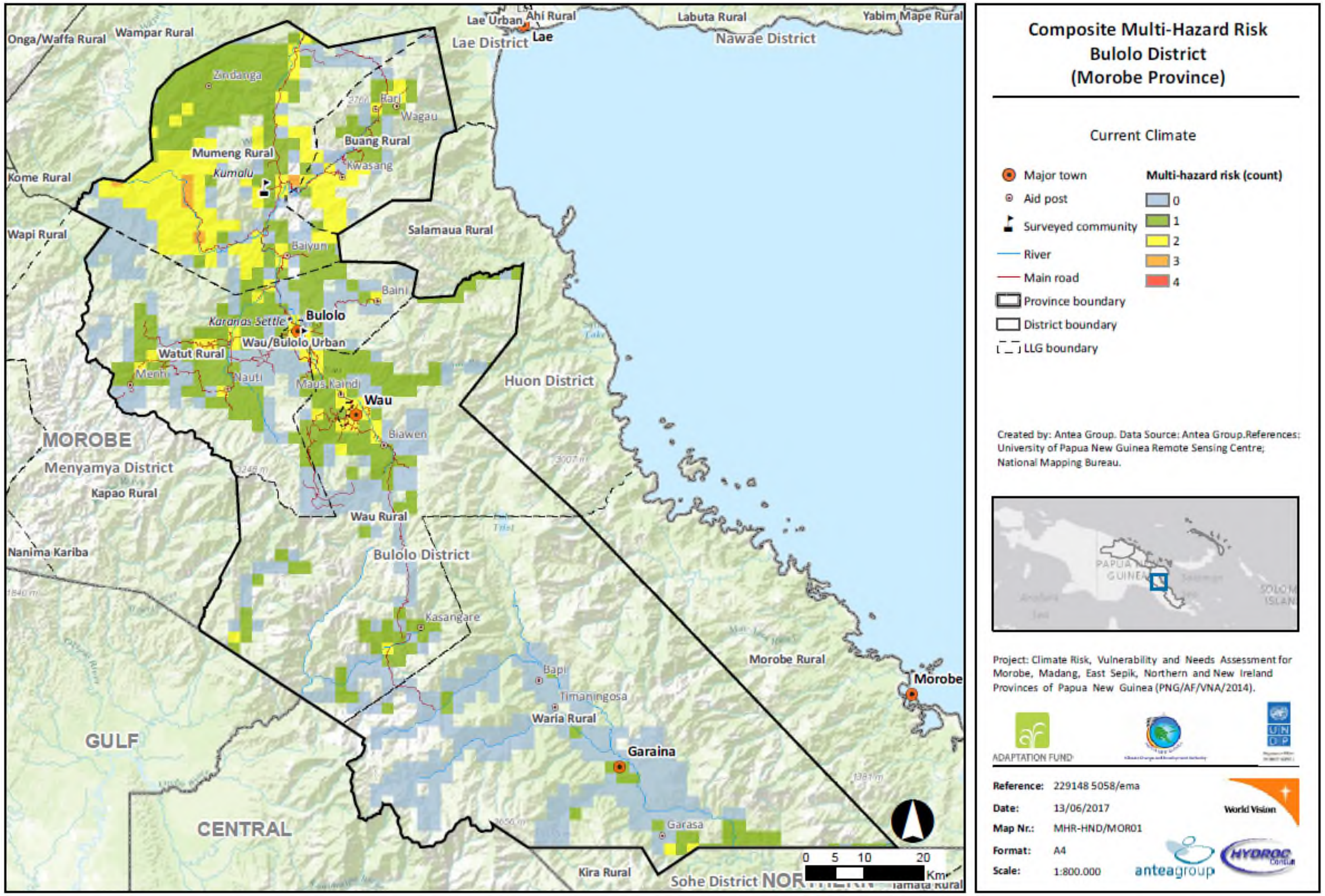

Figure 69. Composite risk map for Bulolo District (current climate)

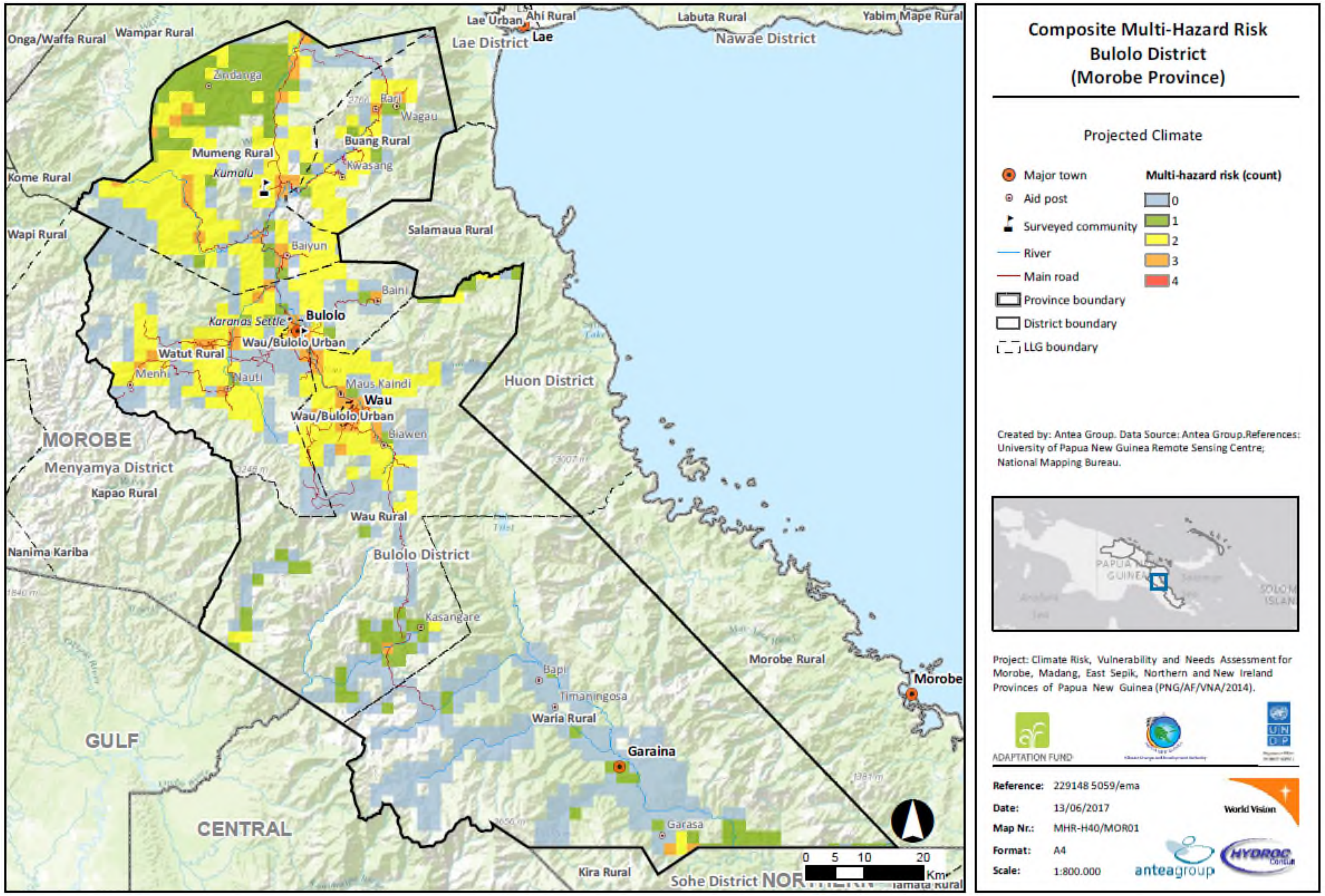

Figure 70. Composite risk map for Bulolo District (future climate)

3.2. Finschafen Risk Profile

3.2.1. General description

Finschhafen District occupies the end of the Huon Peninsula. It includes the Cromwell Mountains and the valleys of the Song, Mape, Mongi, Kua and Bulum Rivers. The district headquarters is located in Gagidu. There are five Local-Level Governments (LLGs) in Finschhafen District: Hube Rural, Kote Rural, Yabim Mape Rural, Finschhafen Urban and Burum Kuat Rural. The number of wards in this district is 57.

Incomes are very low in the entire district. Land potential is moderate to low and combined with poor transport access offers few potential livelihoods.

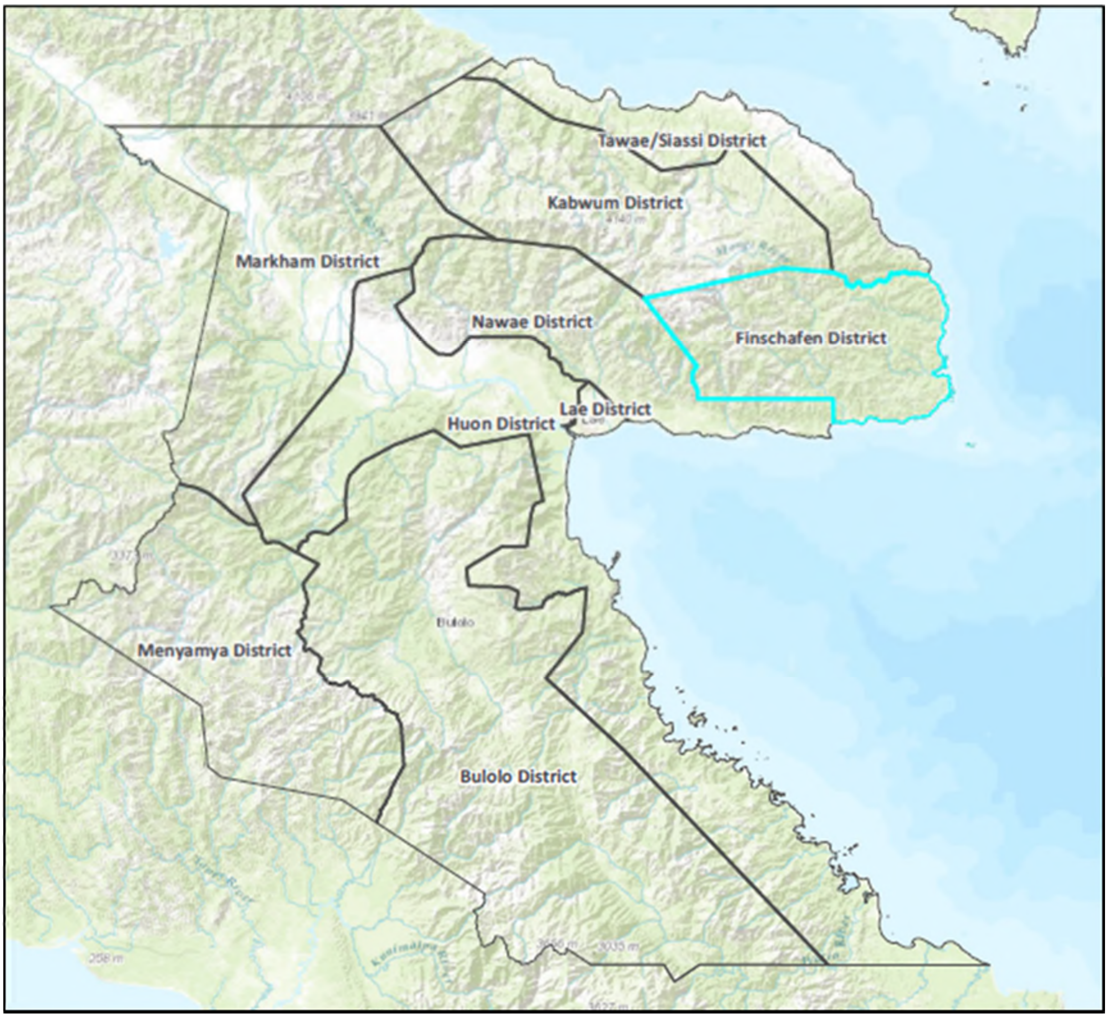

Figure 71. Finschafen District

Finschafen District has a population of 54,672[27]. The average population density is relatively low, 17.1 inhabitants per km^2, with the highest population densities occurring on the mountain valleys of the Mongi, Kua and Bulum rivers. The coastal plains and valleys around Finschhafen have population densities of over 25 persons/km^2.

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

The most disadvantaged people in the district are those in the Bulum Valley around Lengbati, Ogeranang and Mindik, where environments are unproductive and incomes are very low. Small numbers of people on the coastal plains around Finschhafen are constrained by moderate agricultural pressure and very low incomes. All other people in the district have very low incomes. Overall, people in Finschhafen District are extremely disadvantaged relative to people in other districts of PNG. There is some agricultural pressure, land potential is low, access to services is moderate, and cash incomes are very low. Cash is earned from minor sales of fresh food and betel nut in coastal areas, and some coffee in the mountains.

Accessibility is moderate over the whole district, with most people living within eight hours travel of Finschhafen. A road runs along the coast from Finschhafen to Sialum. Another road runs inland from Finschhafen to Pindiu, but there is no road connection to Lae. Small boat travel is common along the coast, but is dangerous between December and March. There is a daily passenger shipping service from Finschhafen to Lae.

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

Low Weight for Age < 5 years old (%)[28]	Low Birth Weight (%)[29]	Incidence of Malaria (1,000 population)[30]	Incidence of Diarrhoea (<5 years/1,000 pop.)[31]
23	11.9	78	53

The total adult literacy rate in Finschafen District is 75.4%, showing a moderate difference between males (80.3%) and females (70.6%). Finschafen District ranks second among the nine districts in Morobe Province in adult literacy.

3.2.2. Hazards

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

Finschafen District does not present tropical cyclone hazard and projections for the future do bring any change.

When it comes to talk about inland flood hazard, there are no major flood zones and according to the projections for the future, these will stay more or less the same.

Regarding rainfall intensity, the district presents a moderate profile. The current total annual rainfall ranges from 2711 to 2979 mm, and projections for the future show a slight increase in the northwest part of the district (2980 to 3280 mm average annual rainfall). Additionally, the current total rainfall on wet days ranges the 601 to 700 mm for the whole district, and projections for the future do not show significant change.

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[28] 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

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

[30] 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

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

Finally, Finschafen presents a moderate drought risk, with values which range from 21 to 24 continuous dry days average per year and it is not foreseen to change significantly in the near future.

3.2.3. Risk

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

3.2.3.1. Social risk

There are small, scattered areas of moderate social risk from inland flooding and droughts in the central part of Hube Rural LLG and the eastern part of Yabim Mape Rural LLG. Social risk from high rainfall and extreme weather events are low to very low throughout the district.

3.2.3.2. Economic risk

The economic risk in Finschafen District is mostly low or very low. Current economic risk to drought is moderate. The various agricultural systems like food crops and plantations represent areas of moderate risk (**Fout! Verwijzingsbron niet gevonden.**). Projections for the future do not show much change.

Table 41. Top agricultural activities of citizen households in Finschafen[32]

Activity	*% engaged*	*%* engaged for cash*
Coconut	36.1	17.9
Betel nut	70.0	44.8
Food crops (sweet potato, banana, taro, cassava, et al.)	84.3	16.6
Livestock	47.9	14.6
Coffee	67.5	66.1

3.2.3.3. Physical risk

Finschafen presents a moderate inland flooding risk profile, with some hotspots in Hube Rural (the middle upper reach of the Bulum Rivera and the surroundings of Tobou), and the surroundings of the mouth of the Mape river. Projections for the future remain the same.

Additionally, the district presents a low profile to extreme weather physical risk, and the general tendency in the near future remains the same.

3.2.3.4. Composite risk

The current composite multi hazard risk profile for the district is low, only presenting a higher risk in areas related to inland flooding risk. Nonetheless, projections for the future show an increased risk for the district, especially in two areas: the upper reaches of Mongi River and the south eastern coast (Figures 72 and 73).

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

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Hube Rural	10,6	7,5	4,7	6,6	5,0	65,6
Kotte Rural	7,2	34,7	12,3	23,5	5,1	17,3
Yabim Mape Rural	0,6	53,8	12,0	12,6	6,3	14,7
Burum Kwat	11,3	8,5	16,9	22,6	21,2	19,5
Finschafen Urban	0,0	0,0	0,0	42,3	42,3	15,3

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Hube Rural	3,0	27,9	1,3	0,0	0,0	67,8
Kotte Rural	3,3	66,4	0,0	0,0	0,0	30,3
Yabim Mape Rural	2,7	72,1	6,9	1,1	0,0	17,1
Burum Kwat	1,5	70,6	0,0	0,0	0,0	27,9
Finschafen Urban	0,0	42,3	42,3	0,0	0,0	15,3

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Hube Rural	16,3	1,6	1,3	0,6	2,8	77,5
Kotte Rural	27,6	6,1	3,1	2,0	0,0	61,2
Yabim Mape Rural	41,2	5,2	4,6	2,9	4,0	42,2
Burum Kwat	35,3	2,8	0,0	2,8	8,5	50,6
Finschafen Urban	0,0	0,0	0,0	0,0	0,0	100,0

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Hube Rural	25,4	5,6	1,3	0,0	0,0	67,8
Kotte Rural	75,6	2,0	0,0	0,0	0,0	22,4
Yabim Mape Rural	64,1	13,7	6,9	1,1	0,0	14,2
Burum Kwat	59,3	19,8	0,0	0,0	0,0	20,9
Finschafen Urban	0,0	42,3	42,3	0,0	0,0	15,3

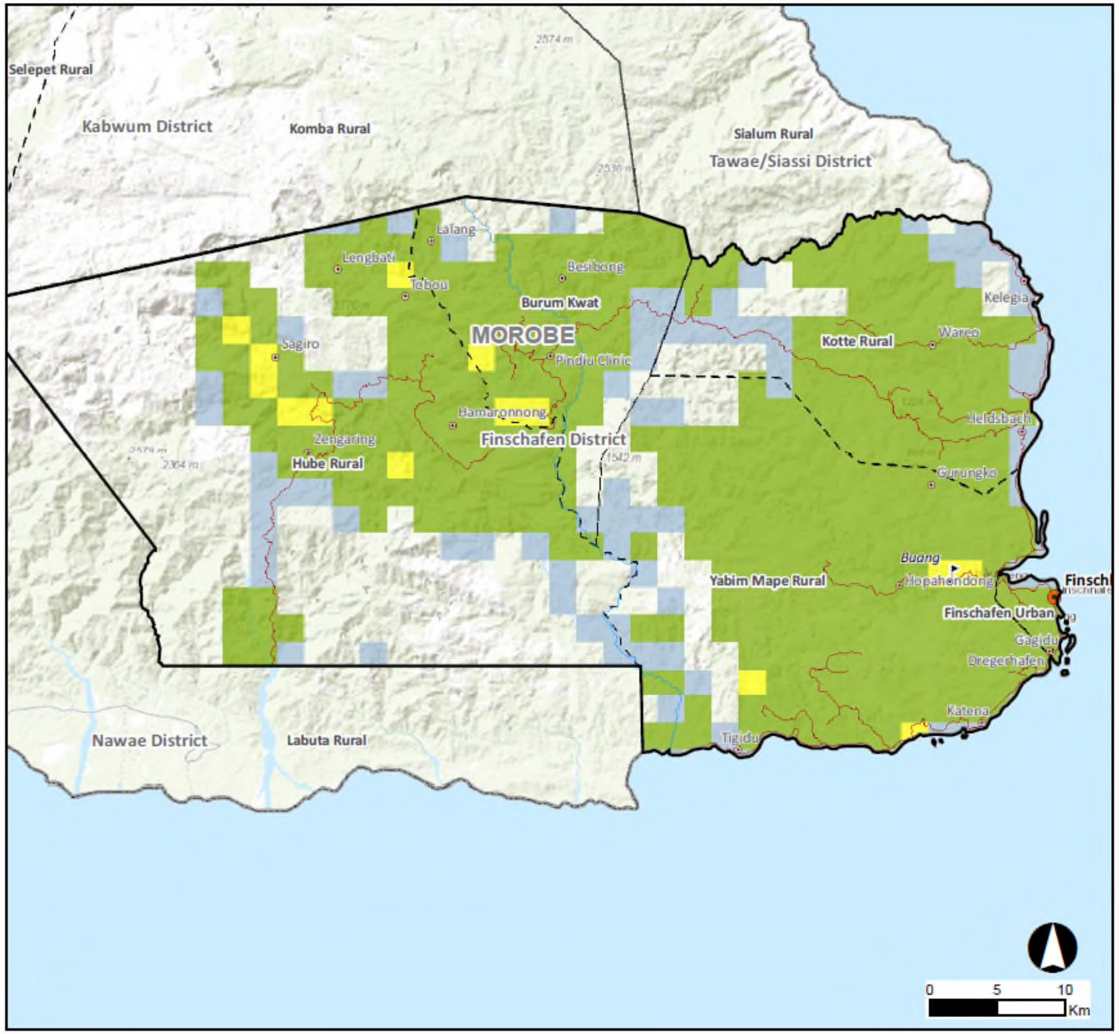
	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Hube Rural	18,2	16,3	0,0	0,0	0,0	65,6	18,2	16,3	0,0	0,0	0,0	65,6
Kotte Rural	41,9	40,9	0,0	0,0	0,0	17,3	41,9	40,9	0,0	0,0	0,0	17,3

Yabim Mape Rural	54,4	30,9	0,0	0,0	0,0	14,7	54,4	30,9	0,0	0,0	0,0	14,7
Burum Kwat	19,8	60,7	0,0	0,0	0,0	19,5	19,8	60,7	0,0	0,0	0,0	19,5
Finschafen Urban	0,0	84,7	0,0	0,0	0,0	15,3	0,0	84,7	0,0	0,0	0,0	15,3

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Hube Rural	0,0	3,1	29,1	0,0	0,0	67,8	0,0	3,1	29,1	0,0	0,0	67,8
Kotte Rural	0,0	11,2	66,4	0,0	0,0	22,4	0,0	11,2	66,4	0,0	0,0	22,4
Yabim Mape Rural	0,0	5,2	79,0	1,1	0,0	14,7	0,0	5,2	79,0	1,1	0,0	14,7
Burum Kwat	0,0	7,1	70,6	0,0	0,0	22,3	0,0	7,1	70,6	0,0	0,0	22,3
Finschafen Urban	0,0	0,0	84,7	0,0	0,0	15,3	0,0	0,0	84,7	0,0	0,0	15,3

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Hube Rural	17,8	2,5	1,3	0,9	0,0	77,5	17,8	2,5	1,3	0,9	0,0	77,5
Kotte Rural	34,7	4,1	0,0	0,0	0,0	61,2	34,7	4,1	0,0	0,0	0,0	61,2
Yabim Mape Rural	44,1	11,4	1,1	1,1	0,0	42,2	44,1	11,4	1,1	1,1	0,0	42,2
Burum Kwat	36,7	7,1	5,6	0,0	0,0	50,6	36,7	7,1	5,6	0,0	0,0	50,6
Finschafen Urban	0,0	0,0	0,0	0,0	0,0	100,0	0,0	0,0	0,0	0,0	0,0	100,0

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Hube Rural	31,0	1,3	0,0	0,0	0,0	67,8	7,2	18,2	6,6	0,3	0,0	67,8
Kotte Rural	76,6	1,0	0,0	0,0	0,0	22,4	13,3	63,3	1,0	0,0	0,0	22,4
Yabim Mape Rural	77,8	8,0	0,0	0,0	0,0	14,2	26,3	37,8	20,6	1,1	0,0	14,2
Burum Kwat	79,1	0,0	0,0	0,0	0,0	20,9	5,6	53,7	19,8	0,0	0,0	20,9
Finschafen Urban	42,3	42,3	0,0	0,0	0,0	15,3	0,0	0,0	84,7	0,0	0,0	15,3



Composite Multi-Hazard Risk Finschafen District (Morobe Province)

Current Climate

Major town
Aid post
Surveyed community
River
Main road
Province boundary
District boundary
LLG boundary

Multi-hazard risk (count)
0
1
2
3
4

Created by: Antea Group. Data Source: Antea Group.References: University of Papua New Guinea Remote Sensing Centre; National Mapping Bureau.

Project: Climate Risk, Vulnerability and Needs Assessment for Morobe, Madang, East Sepik, Northern and New Ireland Provinces of Papua New Guinea (PNG/AF/VNA/2014).

ADAPTATION FUND

Reference: 229148 5058/ema
Date: 13/06/2017
Map Nr.: MHR-HND/MOR02
Format: A4
Scale: 1:400.000

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

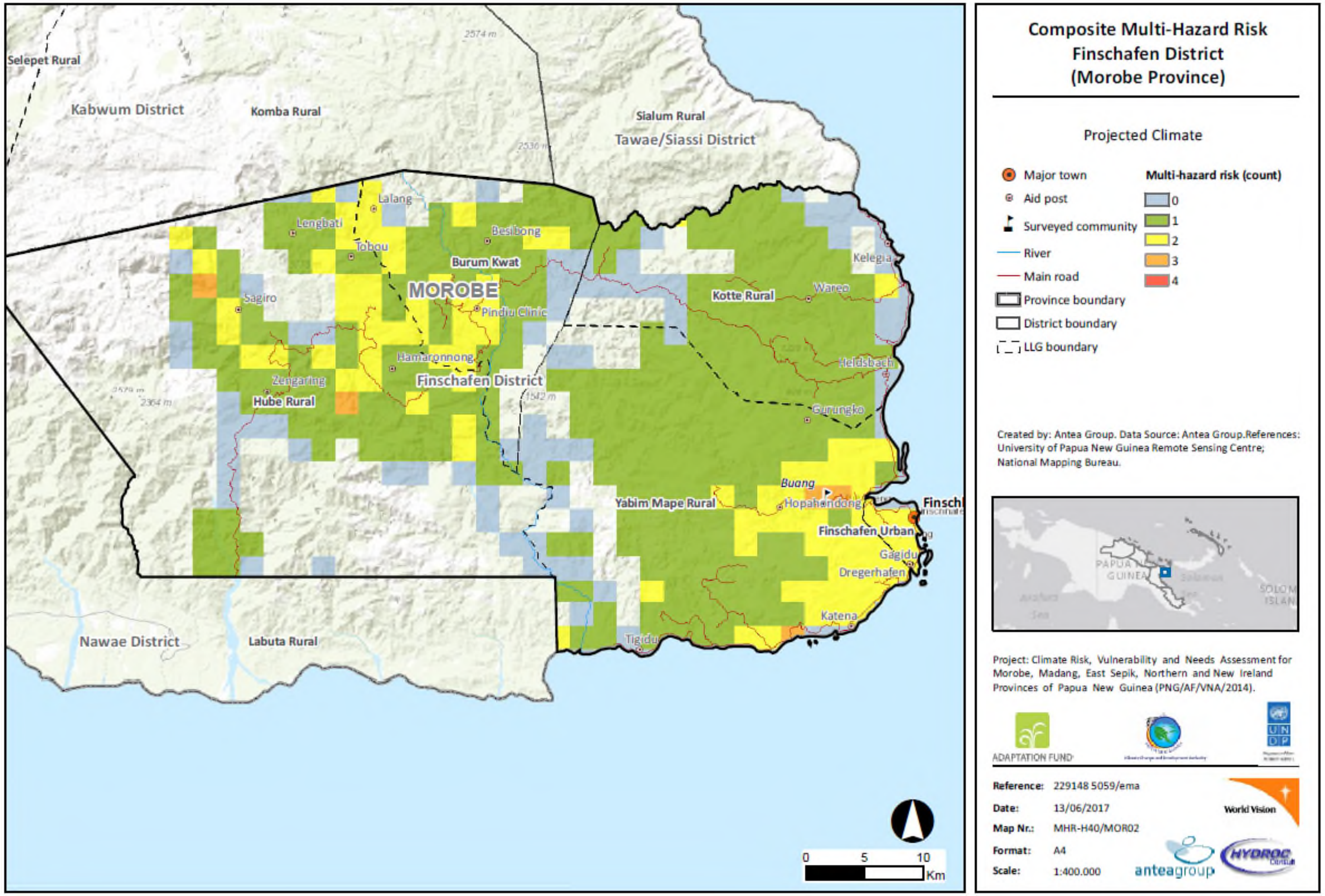


Figure 73. Composite risk map for Finschafen District (future climate)

3.3. Huon Risk Profile

3.3.1. General description

Huon Gulf District runs from the inland areas in the centre of Morobe Province, down the south coast to the border of Oro (Northern) Province. It covers the lower Markham, Watut and Ramu Valleys in the north and the coastal plains in the south. There are three Local-Level Governments (LLGs) in Huon Gulf District: Morobe Rural, Salamaua Rural and Wampar Rural. The number of wards in this district is 64.

High incomes from the sale of food and betel nut can be earned in the north, while moderate incomes can be earned on the coast selling food, coconut and fish in markets in Lae The district headquarters is located in Salamaua.

Figure 74. Huon District

Huon District has a population of 77,564[33]. The average population density is relatively low, 8.0 inhabitants per km^2, with the highest population densities occurring on the northwest of the Chivasing area with over 40 persons/km^2. The Morobe Coast has a density of over 30 persons/km^2, while the

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

Markham and Watut valleys have over 15 persons/km^2. The Engati area, west of the Watut Valley, has a very low population density of under 10 persons/km^2.

The most disadvantaged people in the district are the very small number of people living in the Engati area, where incomes are very low and the environment is poor. There is moderate agricultural pressure in parts of the Markham Valley and with steady in-migration to these areas, people may become vulnerable to the effects of land degradation and declining crop yields. People in Huon Gulf District are moderately disadvantaged relative to people in other districts of PNG. There is agricultural pressure, land potential is low, and access to services is moderate.

People in the northern part of the district, in the Markham and Watut Valleys, earn relatively high incomes from the sale of fresh food and betel nut. Along the Morobe Coast, incomes are moderate to low from the sale of betel nut, coconut, fish and fresh food, much of which is transported by boat to markets in Lae. People in the Engati area and north of Chivasing have very low incomes derived from the sale of coffee and betel nut.

The Highlands Highway runs through the lower Markam Valley in the north of the district, but there is a lack of all-weather roads serving the Watut Valley and the Morobe Coast. Nevertheless, most people in the district are within a day's travel of a service centre. Small boat travel is common along the Morobe Coast, but is dangerous between December and March. People in the Watut Valley use rafts to transport produce to markets which are located on the highway north of the Markham River.

Table 42. Selected Health Indicators for Huon District (2014)

Low Weight for Age < 5 years old (%)[34]	Low Birth Weight (%)[35]	Incidence of Malaria (1,000 population)[36]	Incidence of Diarrhoea (<5 years/1,000 pop.)[37]
16	0.0	58	115

Huon Gulf District ranks eighth among the nine districts in Morobe Province in adult literacy, with 48.8%. There is a large difference in literacy rates between males (55.6%) and females (42.3%) in the district.

3.3.2. Hazards

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

Huon District presents a very low hazard profile to extreme weather events, with just some counts (1 to 5) in the southernmost part of the district in the last 25 years. And projections for the future remain in the same magnitude.

---

[34] 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

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

[36] 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

[37] 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.

Current Inland flood hazard map shows some compromised areas, mostly around the lower stretch of Markham River, but also in the smaller river of Wana in the southern coast of the district. Projections for the future remain similar.

Regarding intense rainfall risk, the district is currently divided into two major zones , the northern half, which presents higher values for total annual rainfall (2711 to 2979 mm) and the southern half, which presents slightly lower values (2079 to 2710mm). Projections for the future present a gradual increase from north to south, with the higher values to the north (in the ranges of 3281-3777mm) than the south (2079 to 2710mm). Total rainfall on wet days ranges from 501 to 600 in most of the province, except on the southernmost corner, where it is from 250 to 500mm. Projections for the future show an increase in these values, reaching the range of 601 to 700mm in the highest points.

Drought risk in the province is higher in the southernmost half, with values of 21 to 24 continuous dry days, and projections show that this dryness tends to extend towards the north.

3.3.3. Risk

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

3.3.3.1. Social risk

There are areas of high to extreme social risk from inland flooding in the district along the Markham River in Wampar Rural LLG. The social risk from drought is found throughout the district, with areas of high risk found along the Markham River in Wampar Rural LLG. Areas of moderate social risk from drought are concentrated in the central and western parts of Wampar LLG, in inland parts of Salamaua LLG and the southern part of Morobe Rural LLG. The district has generally low risk from high rainfall and extreme weather events.

3.3.3.2. Economic risk

The economic risk in Huon District is mostly low or very low. Current economic risk from drought is moderate to high in the north. The various agricultural systems and plantations like coconut represent areas of moderate to high risk (**Fout! Verwijzingsbron niet gevonden.**). The projections for the future show a significate evolution for economic risk from drought.

Table 43. Top agricultural activities of citizen households in Huon[38]

Activity	***% engaged***	***%* engaged for cash***
Coconut	70.9	16.3
Betel nut	76.7	47.3
Food crops (sweet potato, banana, taro, cassava, et al.)	68.6	16.1
Livestock	22.8	4.8
Fishing	28.1	8.1

3.3.3.3. Physical risk

The map for current inland flooding physical risk shows a clear hotspot in the mouth of the Markham river. Projections for the future present a slightly extended surface of this risk.

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

The extreme weather physical risk profile for the district is low and projections show that the tendency remains the same in the near future, although the risk increases in extent.

3.3.3.4. Composite risk

The composite multi hazard map of Huon District shows some moderate hotspots (low to moderate) around the Markham River; a little bit more to the south, around Hote; and finally, around the mouth of Wana River (Figure 75).

The projected scenario shows an increased risk around these same hotspots (moderate to high) (Figure 76).

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Morobe Rural	2,8	5,2	14,1	3,8	2,4	71,8
Salamaua Rural	2,5	3,2	23,2	5,1	1,6	64,4
Wampar Rural	16,0	8,0	6,5	16,3	12,6	40,5

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Morobe Rural	9,4	5,6	15,3	0,0	0,0	69,7
Salamaua Rural	4,9	1,9	28,3	0,0	0,0	65,0
Wampar Rural	34,3	13,2	3,0	17,7	5,2	26,7

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Morobe Rural	15,0	3,8	0,5	1,2	5,2	74,4
Salamaua Rural	21,0	3,8	2,2	2,9	1,6	68,6
Wampar Rural	23,1	11,0	6,4	3,1	7,7	48,7

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Morobe Rural	15,7	9,2	2,8	0,0	0,0	72,3
Salamaua Rural	24,8	9,8	0,6	0,0	0,0	64,8
Wampar Rural	15,4	31,0	5,0	1,3	3,4	43,8

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Morobe Rural	7,8	20,0	0,5	0,0	0,0	71,8	7,8	20,0	0,5	0,0	0,0	71,8
Salamaua Rural	5,7	29,8	0,0	0,0	0,0	64,4	5,7	29,8	0,0	0,0	0,0	64,4
Wampar Rural	24,0	35,4	0,0	0,0	0,0	40,5	24,0	35,4	0,0	0,0	0,0	40,5

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Morobe Rural	0,0	7,3	9,6	11,3	0,0	71,8	0,0	7,3	5,6	15,3	0,0	71,8
Salamaua Rural	0,0	5,1	30,2	0,0	0,0	64,8	0,0	5,1	3,8	26,4	0,0	64,8
Wampar Rural	0,0	16,8	16,2	17,7	5,2	44,2	0,0	16,8	16,0	17,8	5,2	44,2

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Morobe Rural	16,2	6,6	1,9	0,5	0,5	74,4	15,3	7,3	2,1	0,5	0,5	74,4
Salamaua Rural	22,9	7,0	1,3	0,3	0,0	68,6	22,9	7,0	1,3	0,3	0,0	68,6
Wampar Rural	26,1	12,5	5,2	3,4	3,9	49,0	25,7	12,9	5,3	3,6	3,9	48,7

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Morobe Rural	24,9	2,8	0,0	0,0	0,0	72,3	15,5	9,4	2,8	0,0	0,0	72,3
Salamaua Rural	34,6	0,3	0,3	0,0	0,0	64,8	7,9	9,6	10,5	0,0	0,0	72,0
Wampar Rural	27,1	26,7	0,7	1,6	0,0	43,8	11,0	13,8	24,6	3,7	3,1	43,8

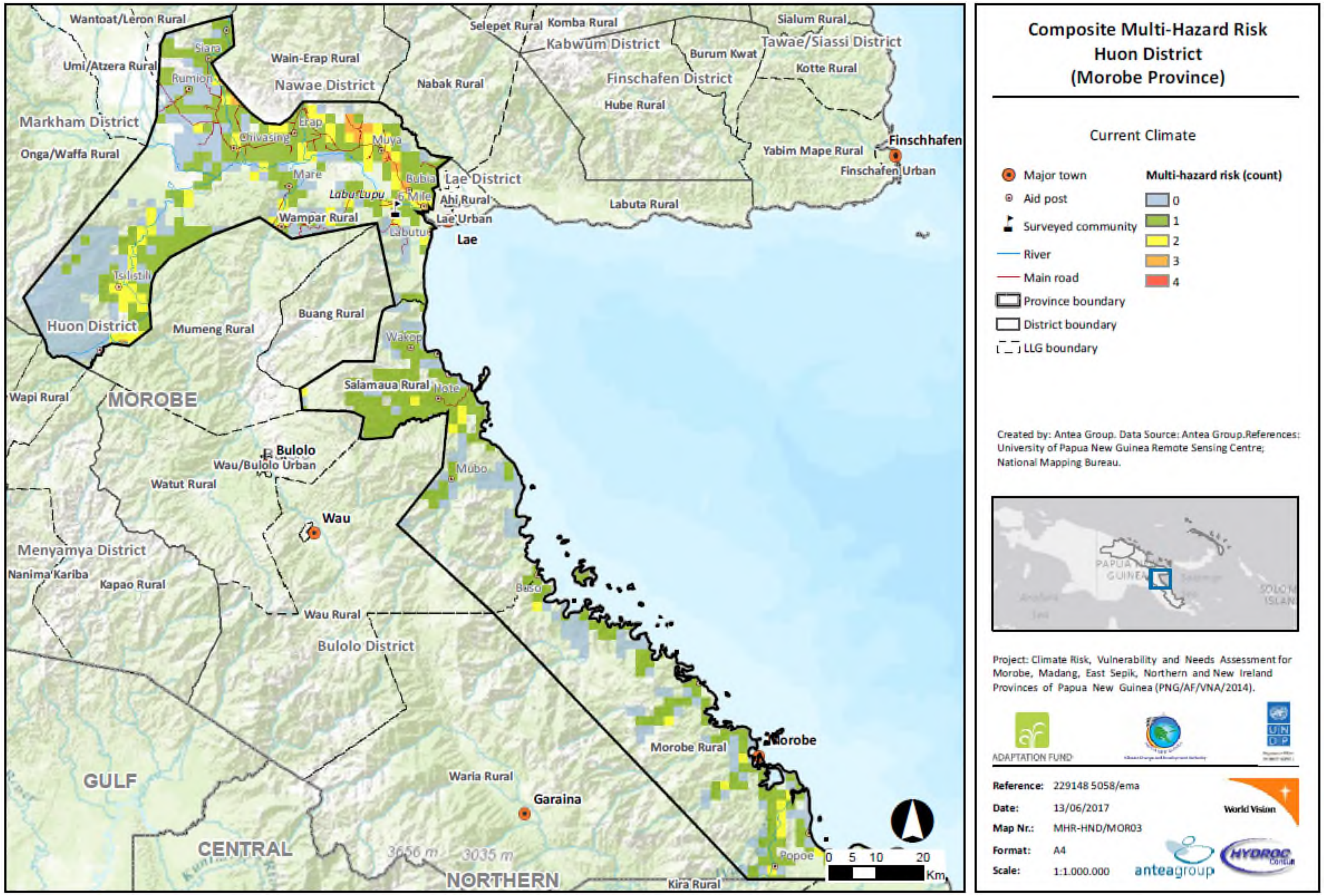


Figure 75. Composite risk map for Huon District (current climate)

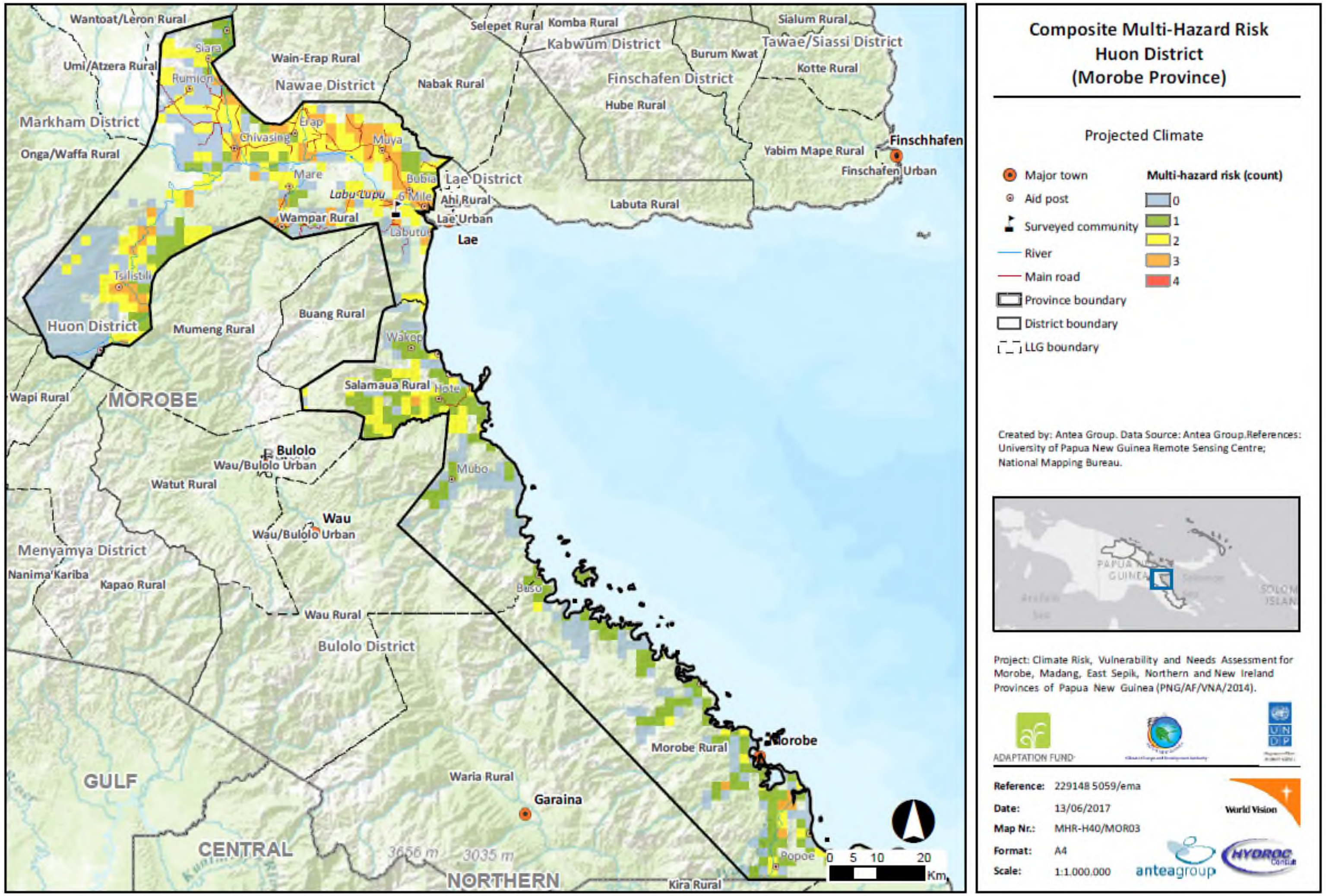


Figure 76. Composite risk map for Huon District (future climate)

3.4. Kabwum Risk Profile

3.4.1. General description

Kabwum District covers the north side of the Sarawaget Range. This includes the Yapna, Urawa, Som, Timbe and Kwama Rivers. Income is low throughout the district because of isolation from service centres. The district headquarters is located in Kabwum. There are four Local-Level Governments (LLGs) in Kabwum District: Deyamos Rural, Selepet Rural, Yus Rural and Komba Rural. The number of wards in this district is 67.

There is no land in the district with a particularly high potential for cultivation. Food security is thus a concern and people have limited cash to purchase supplementary food.

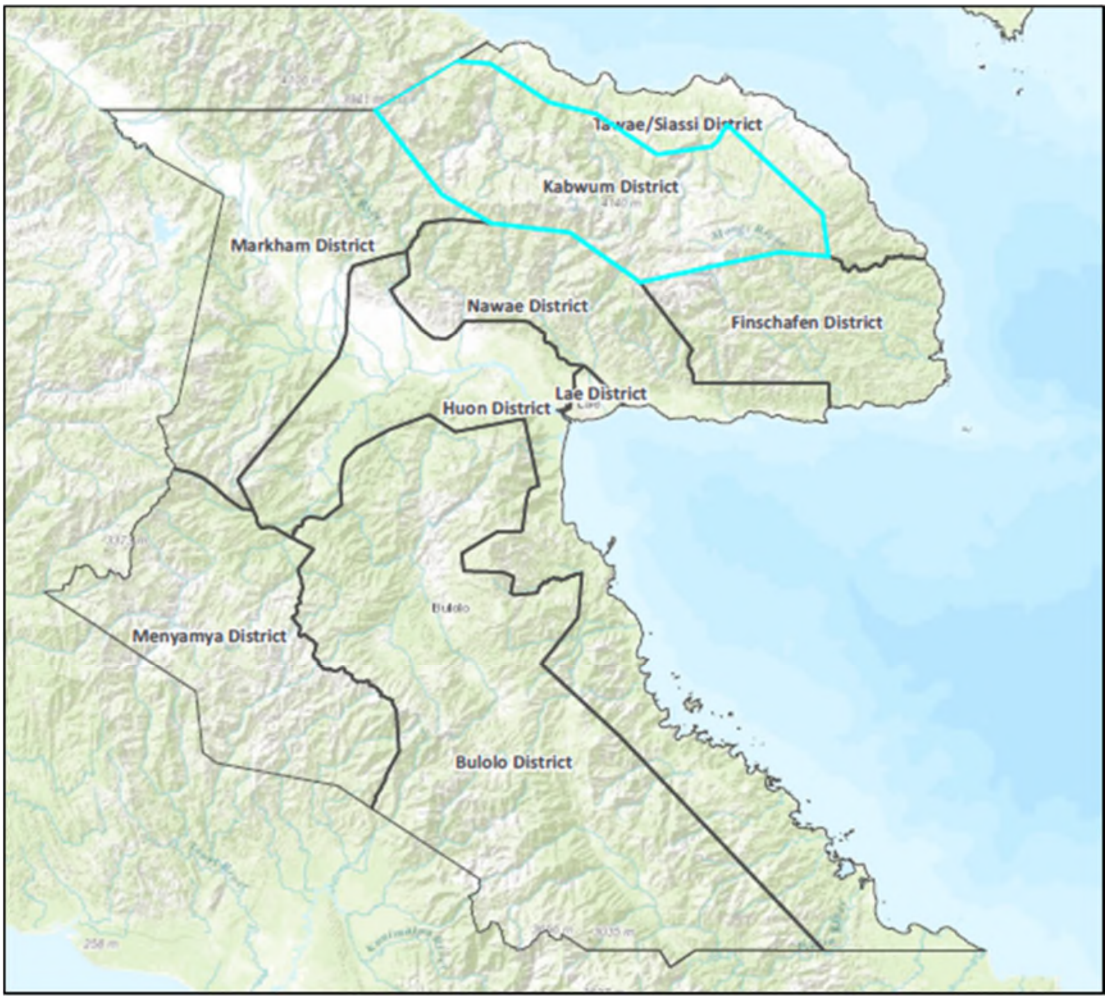


Figure 77. Kabwum District

Kabwum District has a population of 43,472[39]. The average population density is relatively low, 15.1 inhabitants per km^2, with the highest population densities occurring on the Kabwum, Konge, Derim and Yalumet with over 100 persons/km^2. The upper Yupna Valley, near Teptep, has a density of over 70 persons/km^2, while the lower Kwama and Kari valleys have over 25 persons/km^2. The upper Urawa

39 National Population and Housing Census, 2011, National Statistical Office, 2013.

and Som valleys, around Denanget, Yawan and Sapmanga, have lower population densities of around 20 persons/km^2.

The most disadvantaged people in the district are found southeast of Teptep who are constrained by strong agricultural pressure and very low incomes. People here are vulnerable to the effects of declining crop yields, frost and food shortages, and have limited cash to purchase supplementary food. Small numbers of people in the Denanget, Yawan and Sapmanga areas are constrained by poor access to services, low cash incomes and low potential environments. People in the upper Yupna Valley and lower Urawa, Som, Timbe and Kwama valleys have low potential environments and low incomes. Most people in the district have few opportunities to improve their livelihoods.

Overall, people in Kabwum District are seriously disadvantaged relative to people in other districts of PNG. There is some agricultural pressure, land potential is low and access to services is moderate. Isolation from main centres means incomes are very low to moderate throughout the district. Incomes are mainly derived from the sale of fresh food and coffee in the upper valleys around Kabwum, and cocoa, coconut and fresh food on the coast around Wasu.

A road from the coast at Wasu (in Tawae-Siassi District) to Kabwum means that the majority of people in the district have access to a service centre within eight hours' travel. However, people around Denanget, Yawan and Sapmanga require more than one day's travel to a service centre. Small boats are used to travel from the district to Sialum, Finschhafen and Lae, but sea travel is dangerous, especially during the wet season from around December to March.

Table 44. Selected Health Indicators for Kabwum District (2014)

Low Weight for Age < 5 years old (%)[40]	Low Birth Weight (%)[41]	Incidence of Malaria (1,000 population)[42]	Incidence of Diarrhoea (<5 years/1,000 pop.)[43]
46	0.0	20	80

The adult literacy rate in Kabwum District in 2000 is 51.0%, with a significant difference between males (59.2%) and females (43.8%). Kabwum District ranks seventh among the nine districts in Morobe Province in adult literacy.

3.4.2. *Hazards*

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

The extreme weather hazard profile for the District of Kabwum is very low and projections for the future state the same.

[40] 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

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

[42] 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

[43] 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.

When it comes to talk about inland flood hazard, there are two main hotspots: one around Yalumet, in the Timbe River, and the other in an upper stretch of the Mongi River. Projections for the future remain in the same line.

Rainfall intensity is moderate in the district, with total annual rainfall values around the 2711 to 2979mm. Projections for the future show a major increase throughout the district to values nearer the 2980 to 3280 mm excepting the easternmost corner of the district, which remains the same. The total rainfall on wet days, which ranges from 501 to 600mm will increase to the range of 601 to 700mm in the future.

Drought hazard in Kawbum District is mostly moderate, with values that range from 21.1 to 24 days of continuous dryness, except in the southwest part of the province, where the values remain a bit lower (16.1 to 21 days). Projections for the future show a completely moderate district (values from 21.1 to 24 days).

3.4.3. Risk

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

3.4.3.1. Social risk

Social risks from hazards are generally low in Kabwum Province, with the exception of several small areas with high to extreme risk from inland floods in the vicinity of Keweng village in Yus Rural LLG, around Yalumet Village in Deyamos Rural LLG and in the vicinity of Tipsit Village in Seko Rural LLG. Areas with moderate risk from droughts are extending from the vicinity of Tipsit village to Zegan village in Seko Rural LLG, in central Deyamos Rural LLG, and in the western part of Yus Rural LLG near the border with Madang Province.

3.4.3.2. Economic risk

The economic risk in Kabwum District is mostly low or very low. Current economic risk to drought is moderate. The various agricultural systems like food crops and plantations represent areas of moderate risk (**Fout! Verwijzingsbron niet gevonden.**). Projections for the future do not show much change.

Table 45. Top agricultural activities of citizen households in Kabwum[44]

Activity	*% engaged*	*%* engaged for cash*
Poultry	30.9	3.1
Betel nut	35.7	8.9
Food crops (sweet potato, banana, taro, cassava, et al.)	89.8	3.8
Livestock	74.5	7.0
Coffee	93.9	92.1

3.4.3.3. Physical risk

The map of inland flood risk shows only two hotspots for the district of Kabwum: one in the proximity of Keweng and the other in the proximity of Tipsit (Mongi River). Projections for the near future show the same hotspots.

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

The extreme weather risk map shows that Kabwum has a low to very low profile. Projections for the future do not show relevant change.

3.4.3.4. Composite risk

The current composite multi hazard risk map for Kabwum shows that the district has a rather low risk profile. Moderate hotspots can be seen both in the central area and the north westernmost part of the district. Nonetheless, projections show a general increase towards a moderate profile (Figures 78 and 79).

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Deyamos Rural	2,9	11,5	5,8	5,8	8,2	65,8
Yus Rural	8,6	6,4	3,7	6,4	2,8	72,1
Komba Rural	0,7	6,6	2,9	2,9	5,8	81,0
Selepet Rural	1,3	13,0	2,6	7,8	20,8	54,5

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Deyamos Rural	2,7	28,4	1,4	0,0	0,0	67,4
Yus Rural	2,7	24,3	0,9	0,0	0,0	72,1
Komba Rural	2,4	13,5	2,6	0,0	0,0	81,5
Selepet Rural	1,5	36,4	2,6	0,0	0,0	59,5

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Deyamos Rural	15,9	3,4	1,4	1,9	3,4	74,0
Yus Rural	15,0	0,9	1,8	0,3	4,3	77,6
Komba Rural	8,4	1,5	0,7	0,0	1,8	87,6
Selepet Rural	15,6	3,9	1,3	1,3	5,2	72,7

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Deyamos Rural	14,9	18,3	1,4	0,0	0,0	65,4
Yus Rural	20,3	6,8	0,9	0,0	0,0	72,1
Komba Rural	9,9	6,6	2,6	0,0	0,0	81,0
Selepet Rural	22,1	19,5	2,6	0,0	0,0	55,8

LLG	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Deyamos Rural	14,4	19,7	0,0	0,0	0,0	65,8	14,4	19,8	0,0	0,0	0,0	65,7
Yus Rural	15,0	12,9	0,0	0,0	0,0	72,1	15,0	12,9	0,0	0,0	0,0	72,1
Komba Rural	7,3	11,7	0,0	0,0	0,0	81,0	7,3	11,7	0,0	0,0	0,0	81,0
Selepet Rural	14,3	31,2	0,0	0,0	0,0	54,5	14,3	31,2	0,0	0,0	0,0	54,5

LLG	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Deyamos Rural	0,0	4,3	29,8	0,0	0,0	65,8	0,0	4,3	29,8	0,0	0,0	65,8
Yus Rural	0,0	9,8	18,1	0,0	0,0	72,1	0,0	2,8	25,2	0,0	0,0	72,1
Komba Rural	0,0	2,9	16,1	0,0	0,0	81,0	0,0	2,9	16,1	0,0	0,0	81,0
Selepet Rural	0,0	6,5	39,0	0,0	0,0	54,5	0,0	6,5	39,0	0,0	0,0	54,5

LLG	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Deyamos Rural	16,8	4,3	3,4	1,4	0,0	74,0	16,8	4,3	3,4	1,4	0,0	74,0
Yus Rural	17,2	2,1	2,1	0,6	0,3	77,6	17,2	2,1	2,1	0,6	0,3	77,6
Komba Rural	10,2	1,5	0,4	0,4	0,0	87,6	10,2	1,5	0,4	0,4	0,0	87,6
Selepet Rural	19,5	2,6	3,9	0,0	1,3	72,7	19,5	2,6	3,9	0,0	1,3	72,7

LLG	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Deyamos Rural	23,1	11,5	0,0	0,0	0,0	65,4	0,0	14,9	18,3	1,4	0,0	65,4
Yus Rural	27,0	0,9	0,0	0,0	0,0	72,1	0,0	20,3	6,8	0,9	0,0	72,1
Komba Rural	12,4	6,6	0,0	0,0	0,0	81,0	3,3	6,6	6,6	2,6	0,0	81,0
Selepet Rural	22,1	22,1	0,0	0,0	0,0	55,8	1,3	20,8	19,5	2,6	0,0	55,8

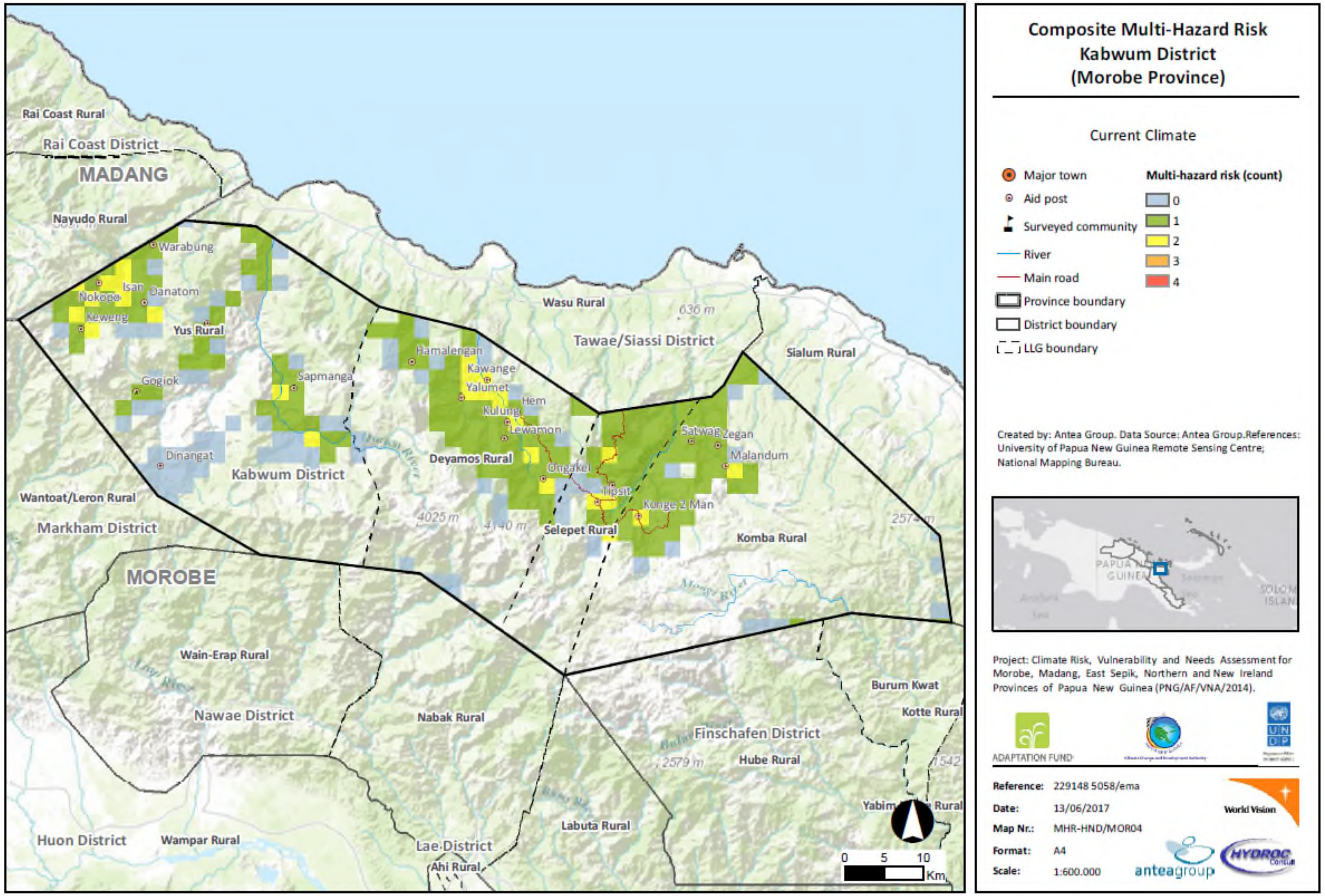


Figure 78. Composite risk map for Kabwum District (current climate)

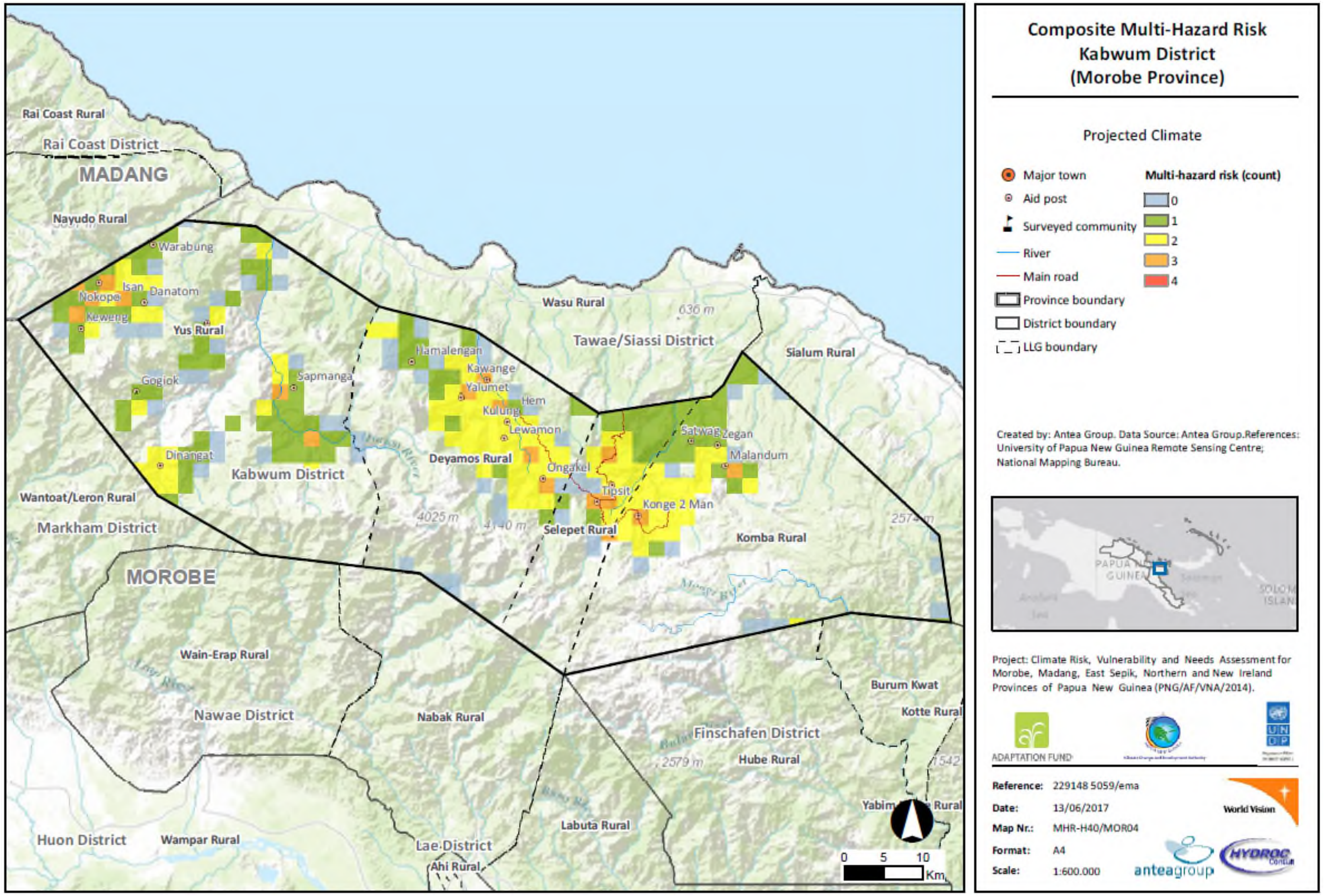


Figure 79. Composite risk map for Kabwum District (future climate)

3.5. Lae Risk Profile

3.5.1. General description

Lae District covers the largest urban centre of Papua New Guinea outside of Port Moresby and is a major commercial and industrial hub. The district headquarters is located in Lae. There are 2 Local-Level Governments in Lae District: Ahi Rural and Lae Urban. Number of ~~assigned~~ wards ~~to~~ in this district is 25.

Incomes are high from the sale of a range of goods in markets as well as many non-agricultural opportunities in Mae's commercial sector. There is very little rural, agricultural activity in this small, urban district.

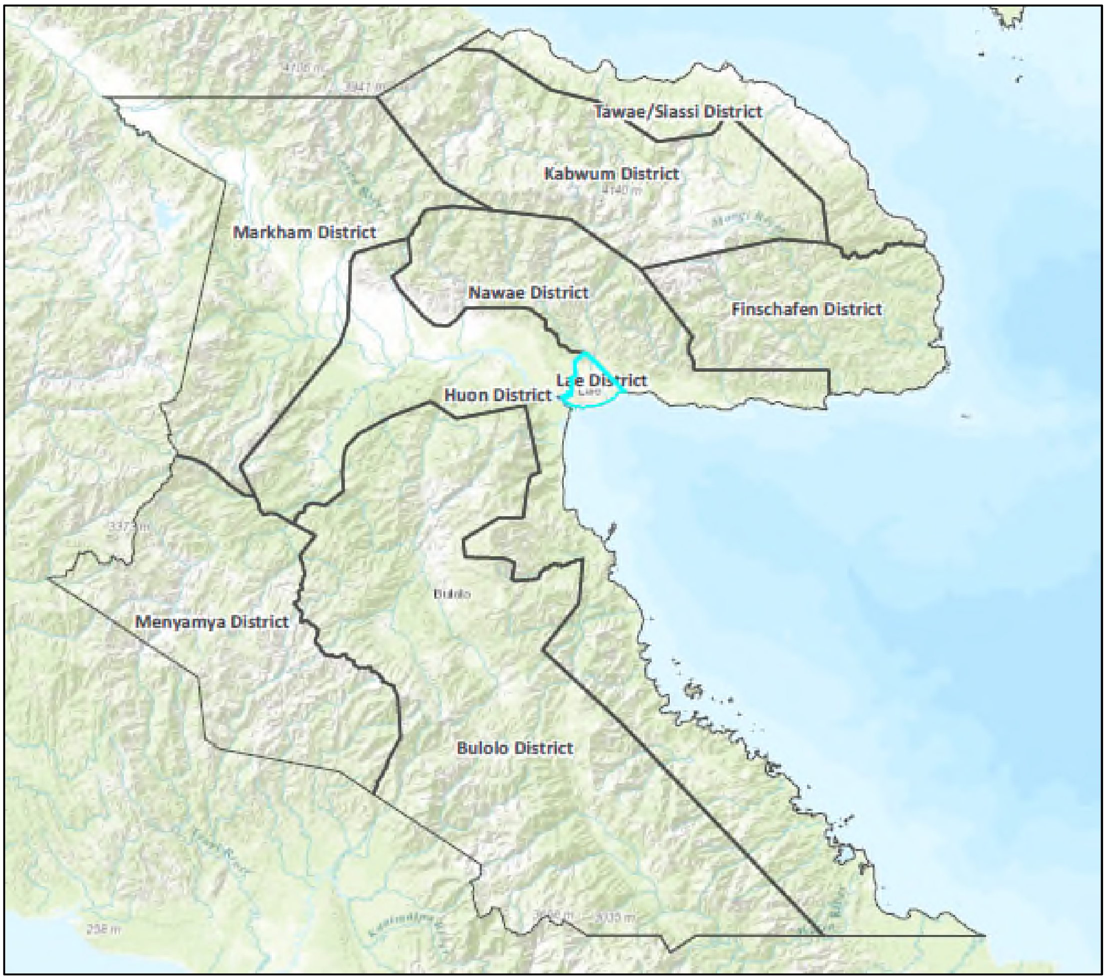


Figure 80. Lae District

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

Low Weight for Age < 5 years old (%)[45]	Low Birth Weight (%)[46]	Incidence of Malaria (1,000 population)[47]	Incidence of Diarrhoea (<5 years/1,000 pop.)[48]
14	0.0	338	489

Lae District has an adult literacy rate of 85.1%, without a significant disparity in literacy rates between males (88.1%) and females (81.5%).

3.5.2. Hazards

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

Lae District presents no extreme weather hazard counts and projections for the near future predict the same.

Instead, the Inland Flood hazard map shows that all the rivers that cross it are flooding the district on their way to the sea. Projections for the near future seem to worsen.

Rainfall intensity is moderate in the district with values that range from 2711 to 2979mm of total annual rainfall and 501 to 600 mm of total rainfall on wet days. Projections for the future follow the same tendency.

Drought hazard is moderate in the province with values ranging the 21.1 to 24 continuous dry days. Projections for the future remain in the same range.

3.5.3. Risk

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

3.5.3.1. Social risk

As expected Lae District, which includes the city of Lae, and has the highest population density in the province, has high to extreme levels of social risk for some hazards. The area along the Markham River west of Lae city has an extreme risk for inland flooding, while almost the entire district has an extreme risk for drought.

3.5.3.2. Physical risk

The map for physical risk of inland flooding shows many hotspots along the last stretch of the Markham River, up to the capital city. The high concentration of buildings and infrastructure (bridges,

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[45] 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

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

[47] 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

[48] 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.

infrastructure of public interest, roads) along the bank of the river makes the area very exposed. The situation is similar for the Bumbu River and Busu River areas. Projections for the near future show the same tendency.

Extreme weather physical risk is low and seems to remain the same in the near future according to projected scenarios for 40 years.

3.5.3.3. Composite risk

The composite multi hazard risk map for Lae shows a district with a low to moderate risk profile, mostly at Lae Urban (Figure 81). This is due to the agricultural lands and the people who live from it as well as the high concentration of population and infrastructure.

Projections in the near future show a tendency of these risks to increase, both in level and extent (Figure 82).

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Ahi Rural	0,0	0,0	0,0	0,0	72,9	27,1
Lae Urban	0,0	0,0	0,0	0,0	100,9	0,0

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Ahi Rural	0,0	9,1	0,0	0,0	63,8	27,1
Lae Urban	0,0	0,0	0,0	9,2	91,7	0,0

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Ahi Rural	31,9	0,0	0,0	9,1	22,8	36,2
Lae Urban	0,0	0,0	0,0	0,0	64,2	35,8

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Ahi Rural	0,0	9,1	0,0	0,0	63,8	27,1
Lae Urban	0,0	0,0	9,2	0,0	91,7	0,0

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Ahi Rural	0,0	72,9	0,0	0,0	0,0	27,1	0,0	72,9	0,0	0,0	0,0	27,1
Lae Urban	0,0	100,9	0,0	0,0	0,0	0,0	0,0	100,9	0,0	0,0	0,0	0,0

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Ahi Rural	0,0	0,0	9,1	0,0	63,8	27,1	0,0	0,0	9,1	0,0	63,8	27,1
Lae Urban	0,0	0,0	0,0	9,2	91,7	0,0	0,0	0,0	0,0	9,2	91,7	0,0

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Ahi Rural	36,4	4,6	4,6	0,0	18,2	36,2	36,4	4,6	4,6	0,0	18,2	36,2
Lae Urban	0,0	0,0	0,0	18,3	45,9	35,8	0,0	0,0	0,0	18,3	45,9	35,8

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Ahi Rural	9,1	63,8	0,0	0,0	0,0	27,1	0,0	0,0	9,1	0,0	63,8	27,1
Lae Urban	0,0	100,9	0,0	0,0	0,0	0,0	0,0	0,0	9,2	0,0	91,7	0,0

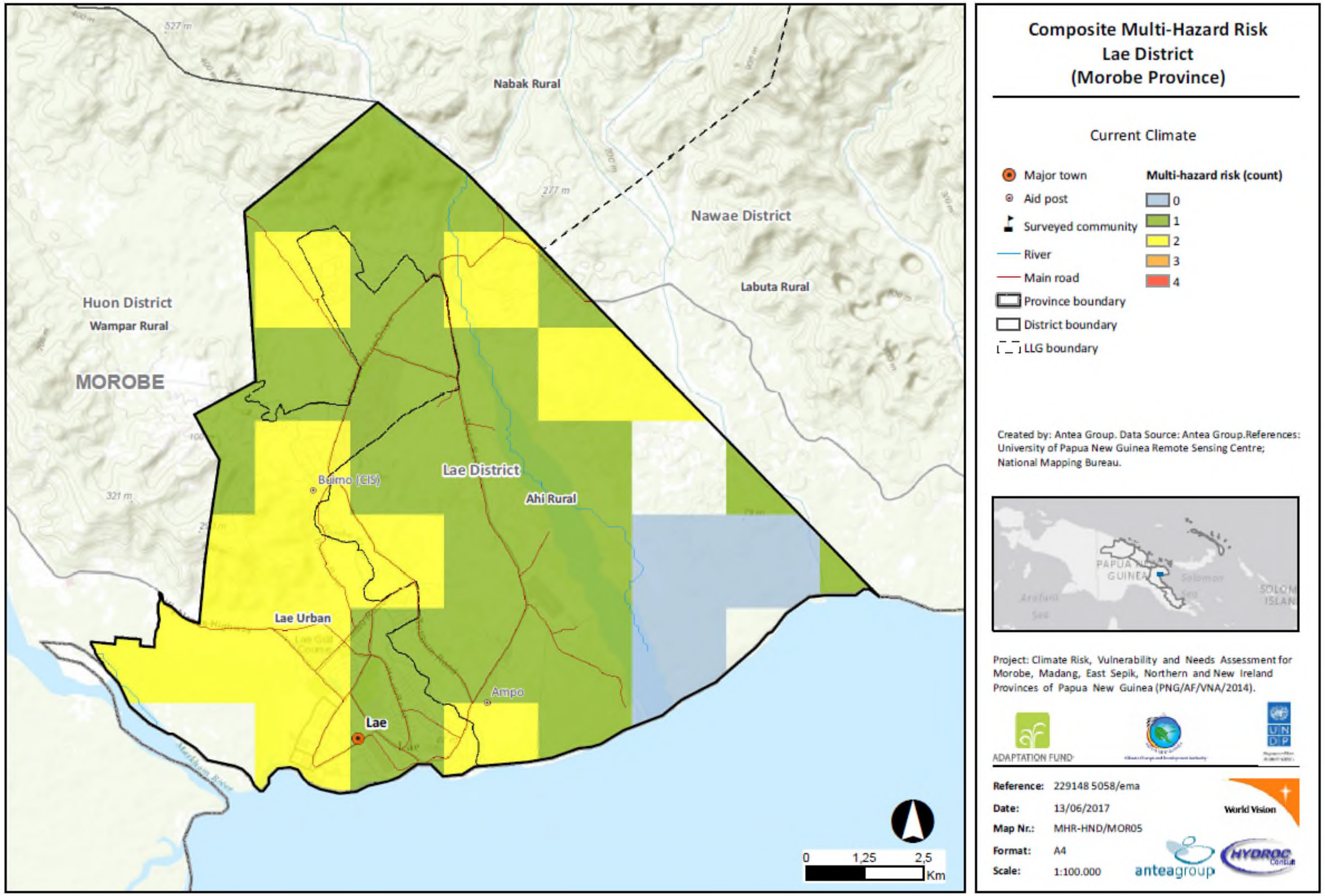

Figure 81. Composite risk map for Lae District (current climate)

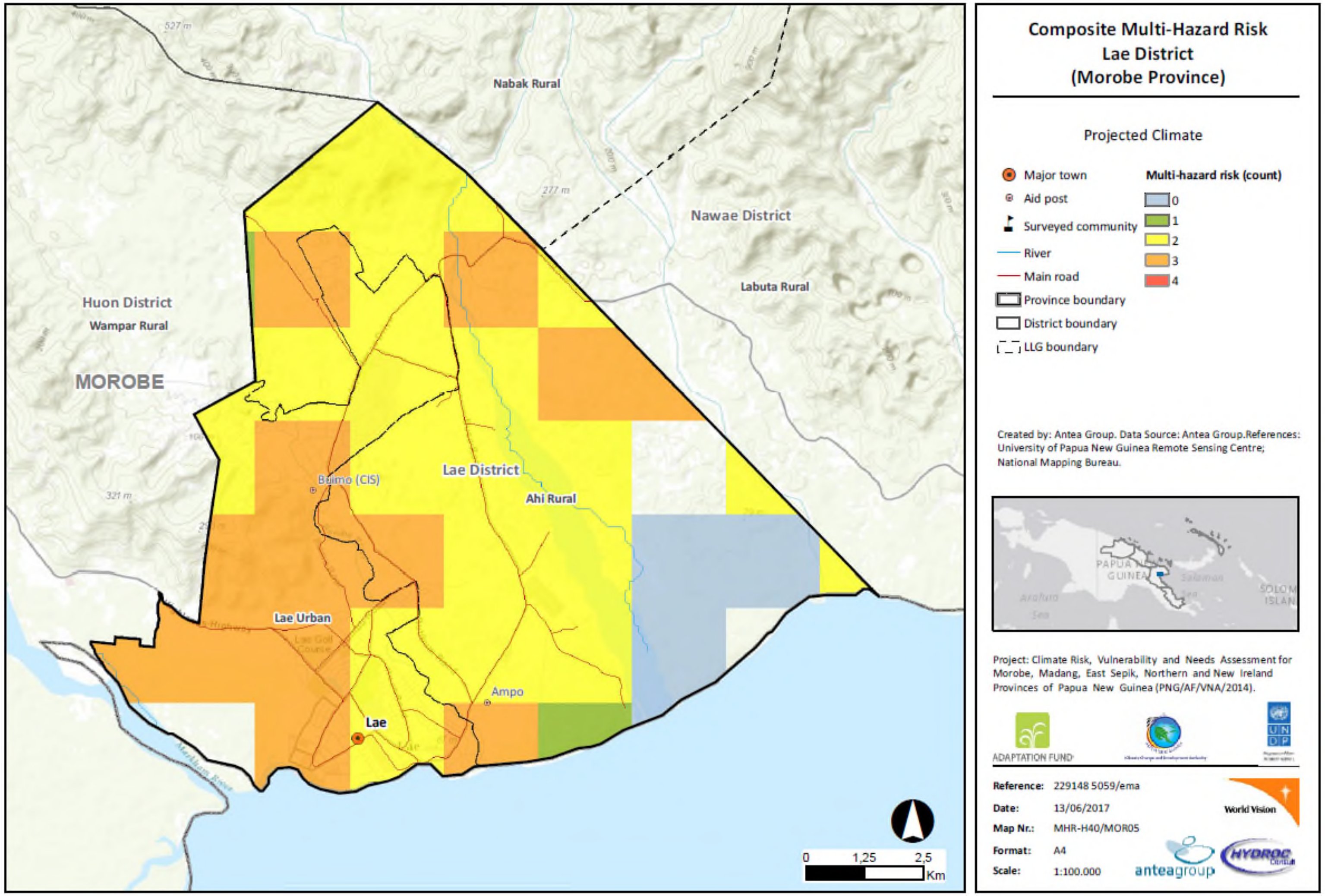

Figure 82. Composite risk map for Lae District (future climate)

3.6. Markham Risk Profile

3.6.1. General description

Markham District covers the Upper Ramu and Markham Valleys, including the Leron, Mami, Ufim, Ikwap and Wontaop Rivers. The Sarawaget Range is in the north, as are the Wanton and Wafu Valleys. Both the Markham and Ramu Valleys offer moderate to high land potential and good access to markets, with some small-holder activities. Incomes are therefore high from the sale of food and betel nut. However, incomes are low in the rest of the district, particularly in more mountainous areas. The district headquarters is located in Kalapit. There are 3 Local-Level Governments in Markham District: Onga Waffa Rural, Umi Atzera Rural and Wantoat Leron Rural. Number of assigned wards to this district is 63

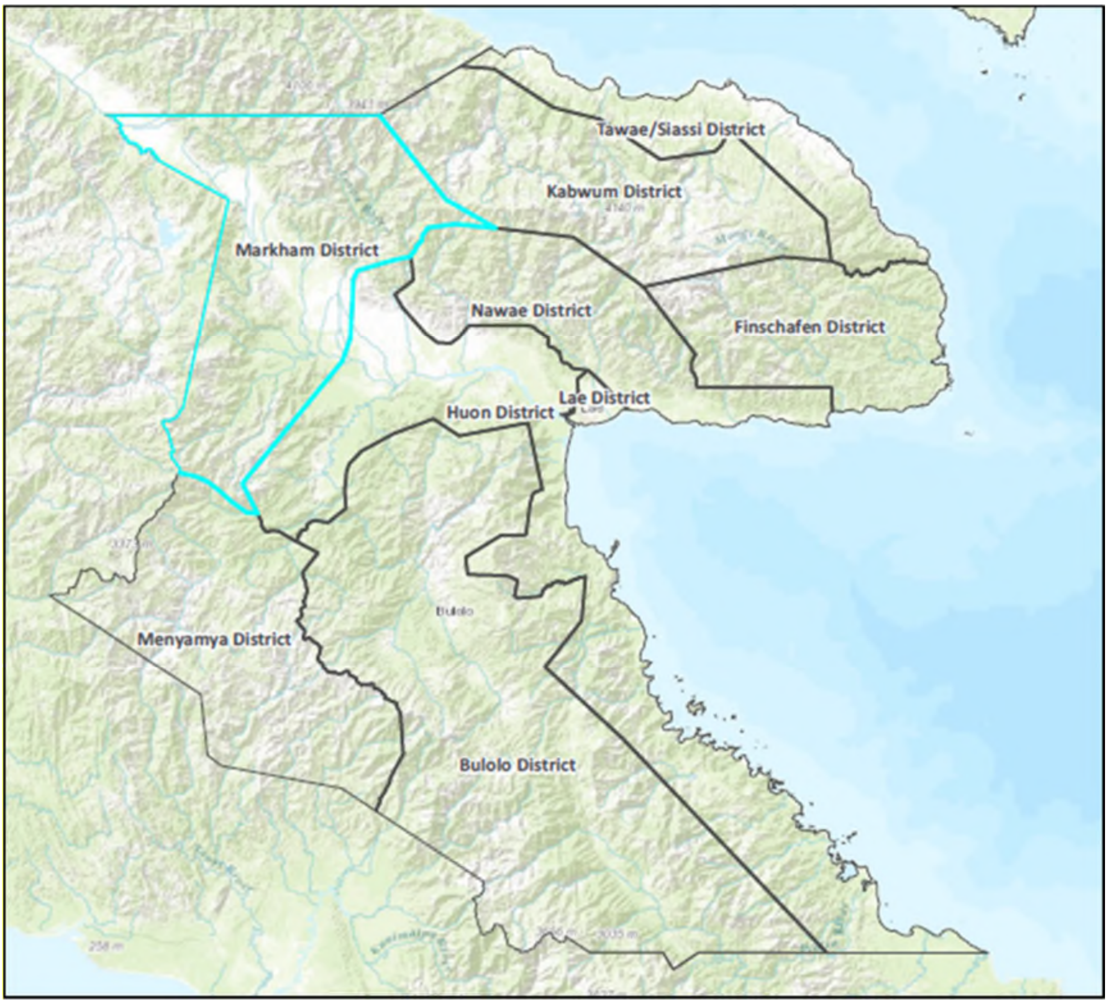

Figure 83. Markham District

Markham District has a population of 62,495[49]. The average population density is relatively low, 11.5 inhabitants per km^2, with the highest population densities occurring on the Wantoat, Yasuru and Imane with an average of over 80 persons/km^2. The Markham and Ramu valleys have densities of over 50 persons/km^2, while the Leron, Wontoap and Ikwap valleys have over 40 persons/km^2.The Ufim and

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

Mami valleys have lower densities of under20 persons/km^2, while the Mafu Valley has less than 10 persons/km^2. Over half of the district is sparsely populated or unoccupied.

The most disadvantaged people in the district are those north of the highway in the mountain valleys of the Sarawaget Range. People living in these areas are affected by very low incomes and low potential environments. The very small number of people who live around Yasuru and Imane are constrained by very low incomes and moderate agricultural pressure. People living in parts of the Markham Valley are constrained by moderate agricultural pressure. There is some agricultural pressure, land potential is moderate, access to services is good and cash incomes are relatively high.

People in the Markham and Ramu valleys have good access to markets in Lae and the highlands,

and consequently earn relatively high incomes from the sale of betel nut and fresh food. People in the remainder of the district have lower incomes derived from minor sales of betel nut, fresh food and, at higher altitudes, coffee.

The Highlands Highway runs through the centre of the district. As a result, people in the Markham, Ramu and lower Leron valleys are within four hours' travel of Lae. People in the mountain valleys to the north are within eight hours' travel of Lae. There is a good, but steep and narrow road through the Leron Valley to Wantoat. Accessibility is worst in the south of the district, around Imane and Yasuru.

Table 47. Selected Health Indicators for Markham District (2014)

Low Weight for Age < 5 years old (%)[50]	Low Birth Weight (%)[51]	Incidence of Malaria (1,000 population)[52]	Incidence of Diarrhoea (<5 years/1,000 pop.)[53]
17	8.4	40	155

Markham District has an adult literacy rate of 54.1%, with a significant disparity in literacy rates between males (62.8%) and females (45.2%).

3.6.2. *Hazards*

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

Markham district is currently not prone to tropical cyclones and projections show that it will also not be an issue in the near future.

The map for inland flooding hazard shows considerable flooded areas along the main and secondary stretches of Markham River. Projections for the future show that the situation will worsen.

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

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

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

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

Regarding rainfall intensity hazard, the district presents a moderate profile of total annual rainfall in most of its extension (with values that range from 2711 to 2979mm), except the north western most corner, where values are a bit higher(from 2980 to 3280mm). Projections for the future show a clear tendency for these values to increase. A deeper analysis on the total rainfall on wet days shows that current values range from 501 to 600 mm throughout the district, whereas these will be higher according to future projections (in the range of 601 to 700mm).

Drought hazard is moderate in the southern half of the province (values from 21.1 to 24 continuous dry days) and low in the northern half (values from 16.1 to 21 continuous dry days). Projections show that drought hazard trends to increase and extend to the north, putting the whole district to values from 21.1 to 24 continuous dry days.

3.6.3. Risk

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

3.6.3.1. Social risk

A small area of extreme social risk from inland flooding is found in the vicinity of Marawasa village in and north of Kalapit town in Umi/Atzera Rural LLG. There are large areas of moderate social risk and smaller areas of high social risk from drought in Wantoat/Leron Rural and Umi/Atzera Rural LLGs.

3.6.3.2. Physical risk

Current inland flooding physical risk for Markham District shows a couple of hotspots: the ones in the region of Marawasa implies a road, a bridge and some buildings being compromised. The hotspot in the region of Umi/Atzera Rural implies a road and a conglomeration of buildings. The situation is similar in the hotspot in the area of Garam. Projections forecast the same situation in the near future.

Markham District presents a low profile for extreme weather physical risk, and the tendency remains the same in the future.

3.6.3.3. Composite risk

The composite multi hazard risk map of Markham District shows some hotspots in the northwest corner of the district, related with the agricultural land and plantations in that area and the people who live from it. The hotspot in the region of Garam is related to exposure of infrastructure to flooding (Figure 84).

Projections for the future show a slight increase in the extension of these risks (Figure 85).

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Onga/Waffa Rural	14,2	9,6	8,4	4,4	1,6	61,8
Umi/Atzera Rural	4,3	6,5	34,0	8,4	9,8	37,1
Wantoat/Leron Rural	0,7	19,7	9,3	12,2	6,4	51,7

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Onga/Waffa Rural	18,2	14,9	7,5	0,7	0,0	58,7
Umi/Atzera Rural	14,0	9,8	29,9	1,0	9,1	36,3
Wantoat/Leron Rural	3,0	33,3	10,0	1,4	0,0	52,3

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Onga/Waffa Rural	22,4	5,1	1,9	1,6	3,5	65,5
Umi/Atzera Rural	21,1	10,3	4,1	6,0	12,9	45,7
Wantoat/Leron Rural	22,2	3,6	1,1	1,8	3,6	67,8

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Onga/Waffa Rural	16,5	17,5	2,1	0,7	0,0	63,2
Umi/Atzera Rural	15,1	21,8	14,8	7,2	2,4	38,8
Wantoat/Leron Rural	16,5	23,6	7,5	0,7	0,0	51,7

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Onga/Waffa Rural	23,8	14,4	0,0	0,0	0,0	61,8	23,8	14,4	0,0	0,0	0,0	61,8
Umi/Atzera Rural	10,8	52,1	0,0	0,0	0,0	37,1	10,8	52,1	0,0	0,0	0,0	37,1
Wantoat/Leron Rural	20,4	27,9	0,0	0,0	0,0	51,7	20,4	27,9	0,0	0,0	0,0	51,7

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Onga/Waffa Rural	0,0	18,9	17,9	0,2	0,0	63,0	0,0	14,0	22,4	0,7	0,0	63,0
Umi/Atzera Rural	7,7	11,5	32,3	9,3	0,0	39,2	0,0	11,0	39,7	1,0	9,1	39,2
Wantoat/Leron Rural	2,5	31,1	13,9	0,7	0,0	51,7	0,0	3,6	43,3	1,4	0,0	51,7

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Onga/Waffa Rural	25,2	5,6	1,6	2,1	0,0	65,5	25,2	6,1	1,6	2,1	0,0	65,0
Umi/Atzera Rural	23,9	12,2	8,4	5,5	4,1	45,9	23,4	12,0	8,6	6,2	4,1	45,7
Wantoat/Leron Rural	25,0	4,6	1,8	0,7	0,0	67,8	25,0	4,6	1,8	0,7	0,0	67,8

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Onga/Waffa Rural	34,0	2,8	0,0	0,0	0,0	63,2	9,8	6,8	17,5	2,1	0,7	63,2
Umi/Atzera Rural	26,3	16,7	11,0	7,2	0,0	38,8	0,0	15,1	32,5	10,5	3,1	38,8
Wantoat/Leron Rural	39,3	7,9	1,1	0,0	0,0	51,7	0,0	16,5	24,7	6,4	0,7	51,7

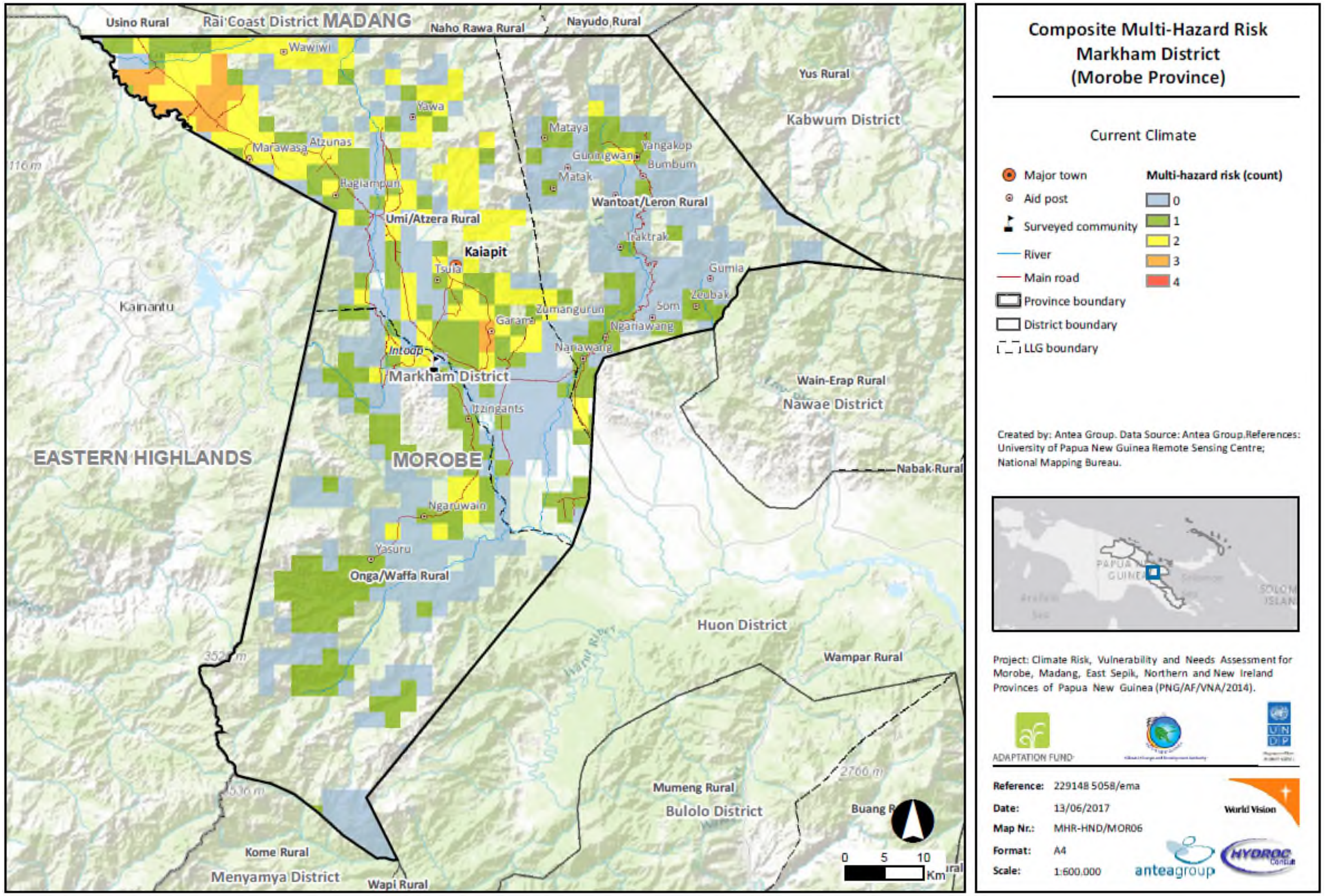

Figure 84. Composite risk map for Markham District (current climate)

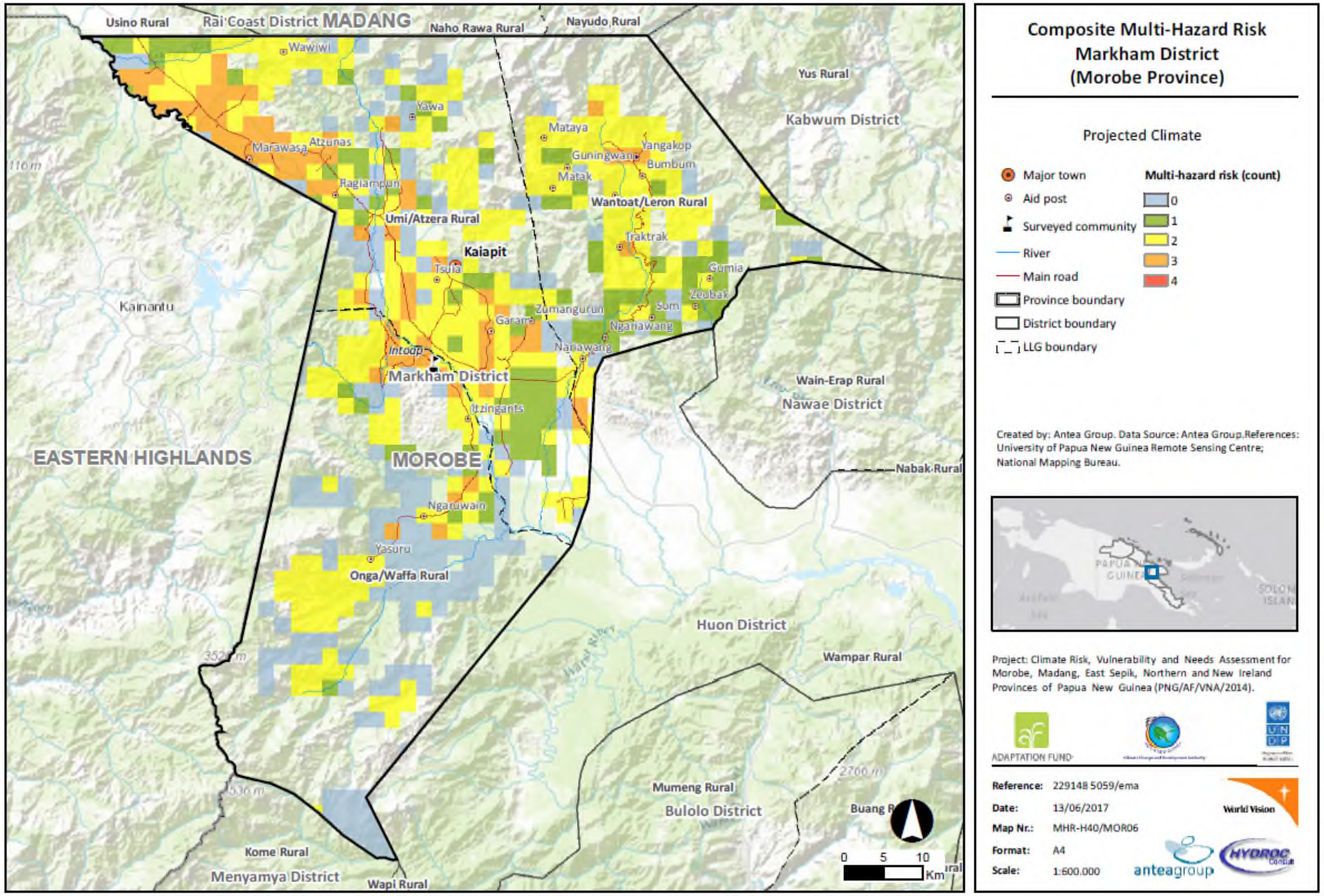

Figure 85. Composite risk map for Markham District (future climate)

3.7. Menyamya Risk Profile

3.7.1. General description

Menyamya District, on the south western border of Morobe Province, shares a border with Eastern Highlands and Gulf Provinces. It lies over the main mountain divide of PNG, with the Tauri River flowing south to the gulf and the Watut River flowing north. The district headquarters is located in Menyamya. There are 4 Local-Level Governments in Menyamya District: Kapao Rural, Koma Rural, Wapi Rural and Nanima. Number of assigned wards to this district is 60.

Average incomes across the whole district are low. Land potential is poor in most of the district and remoteness from matkets is a major handicap.

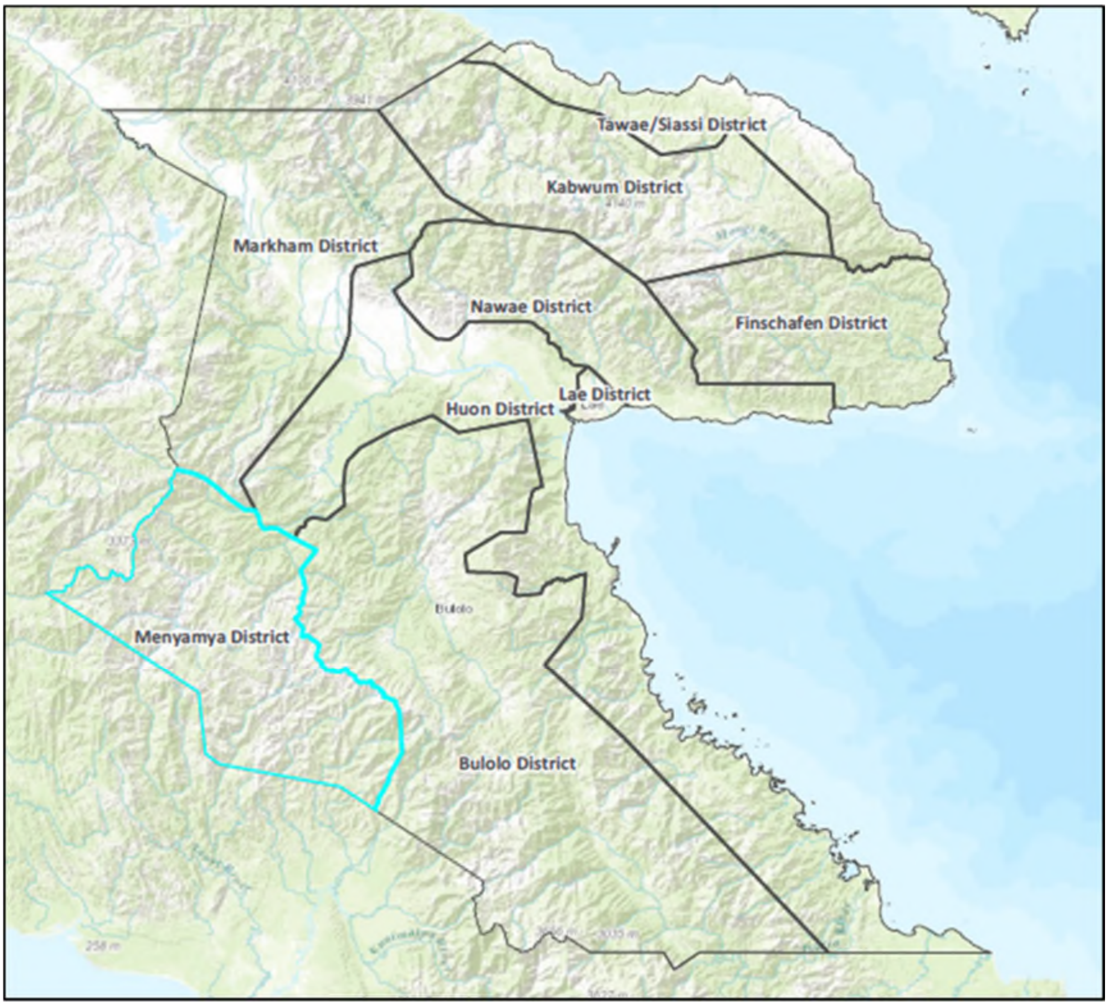

Figure 86. Menyamya District

Menyamya District has a population of 87,209[54]. The average population density is relatively low, 18.4 inhabitants per km^2, with the highest population densities occurring on the Tauri, Yakwoi and Langimar valleys with over 50 persons/km^2. The Kabu and Kapua valleys have a density of over 40 persons/km^2, while the Kariba Valley has 24 persons/km^2. The area north of Menyamya, towards Engati, has a very

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

low density of under 10 persons/km^2. The upper Tauri Valley and the area to the north of Menyamya has experienced significant outmigration.

The majority of the people in Menyamya District are constrained by very low incomes and low potential environments. There is some agricultural pressure, land potential is low and access to services is moderate. Cash incomes are uniformly very low across the district, and are mainly earned from the sale of coffee and fresh food. Poor access and low potential environments are major constraints to improving incomes in the district.

Most people in the district have to travel for up to eight hours to reach the nearest service centre. The Wau Road is surfaced, as is the road over the high watershed from Menyamya and Aseki to Bulolo. There is a road from Menyamya west to Marawaka in Eastern Highlands Province.

Table 48. Selected Health Indicators for Menyamya District (2014)

Low Weight for Age < 5 years old (%)[55]	Low Birth Weight (%)[56]	Incidence of Malaria (1,000 population)[57]	Incidence of Diarrhoea (<5 years/1,000 pop.)[58]
61	34.6	46	132

Menyamya District has an adult literacy rate of 26.1%, with a significant disparity in literacy rates between males (34.2%) and females (17.7%).

3.7.2. *Hazards*

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

Menyamya District is not prone to extreme weather hazard and projections show that it will remain the same in the future.

The inland flood hazard map shows that there are only minor flood zones and projections for the future do not show much change.

The total annual rainfall values range from 2079 to 2710mm in the south to 2711 to 2979 in the north, keeping it at moderated to low profile. Projections for the future show that annual rainfall will increase and extend to the south of the district. Values for total rainfall on wet days show a district with moderate values (in the range of 501 to 600mm) but projections for the future show that these will increase throughout the whole district (to ranges between 601 to 700mm).

Drought risk is higher in the lower quarter of the district, with values that range from 24.1 to 29 continuous dry days, in comparison to the 21.1 to 24 of the other three quarters more to the north of

[55] 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

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

[57] 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

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

the district. Projections for the future show that this dryness will increase and extend to the north in the near future.

3.7.3. *Risk*

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

3.7.3.1. Social risk

Areas of high to extreme social risk from inland flooding, high rainfall and drought are found in an area extending from the vicinity of Hekwange village in Kome Rural LLG and to Pinake village in Wapi Rural LLG.

3.7.3.2. Physical risk

The map for Inland flooding physical risk of the District of Menyamya shows only a couple of minor hotspots where mostly buildings or short sections of road are compromised. Projections for the future do not show much change.

The map for extreme weather physical risk shows a low profile for this district and projections for the future show the same tendency.

3.7.3.3. Composite risk

The composite multi-hazard risk map of the district shows minor moderate risks but projections for the future show that the impact of these hazards will increase in the near future (Figures 87 and 88). Potential future hotspots include the southern part of Wapi Rural, the southern part of Nanima Kariba and the area around Watabung.

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Kome Rural	27,5	14,5	9,3	8,9	11,1	28,7
Wapi Rural	51,0	9,4	5,4	10,7	18,8	4,7
Kapao Rural	19,2	8,9	8,7	7,6	5,1	50,5
Nanima Kariba	23,8	12,6	10,4	11,9	17,8	23,5

	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Kome Rural	18,8	29,7	9,7	0,4	7,1	34,4
Wapi Rural	22,2	23,5	11,4	0,7	10,7	31,5
Kapao Rural	16,4	33,6	1,1	0,0	0,0	49,0
Nanima Kariba	3,6	52,7	9,7	2,2	0,7	31,0

	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Kome Rural	26,0	3,0	2,2	0,7	7,1	61,0
Wapi Rural	32,2	4,7	1,3	2,7	6,7	52,4

Kapao Rural	23,0	0,8	0,8	0,5	2,7	72,1
Nanima Kariba	26,0	5,9	2,2	1,5	2,2	62,1

	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
LLG	**1**	**2**	**3**	**4**	**5**	
Kome Rural	25,3	26,8	9,7	0,4	7,1	30,9
Wapi Rural	50,3	21,5	11,4	0,7	10,7	5,4
Kapao Rural	36,3	11,6	1,1	0,0	0,0	51,0
Nanima Kariba	36,4	26,7	9,7	2,2	0,7	24,2

	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Kome Rural	42,0	29,4	0,0	0,0	0,0	28,7	42,0	29,4	0,0	0,0	0,0	28,7
Wapi Rural	60,4	34,9	0,0	0,0	0,0	4,7	60,4	34,9	0,0	0,0	0,0	4,7
Kapao Rural	28,1	21,4	0,0	0,0	0,0	50,5	28,1	21,4	0,0	0,0	0,0	50,5
Nanima Kariba	36,4	40,1	0,0	0,0	0,0	23,5	36,4	40,1	0,0	0,0	0,0	23,5

	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Kome Rural	0,0	23,0	39,4	0,4	7,1	30,2	0,0	23,0	30,1	9,3	7,4	30,2
Wapi Rural	0,0	49,0	34,9	0,7	10,7	4,7	0,0	49,0	23,5	11,4	11,4	4,7
Kapao Rural	0,0	14,6	34,4	0,3	0,0	50,7	0,0	14,6	33,6	1,1	0,0	50,7
Nanima Kariba	0,0	8,9	57,2	5,2	3,0	25,7	0,0	8,9	52,7	9,7	3,0	25,7

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Kome Rural	31,2	4,1	1,5	0,4	1,9	61,0	31,2	4,1	1,5	0,4	1,9	61,0
Wapi Rural	36,9	4,0	3,4	2,0	1,3	52,4	36,9	4,0	2,7	2,7	1,3	52,4
Kapao Rural	24,6	1,6	0,3	0,8	0,5	72,1	24,6	1,6	0,3	0,8	0,5	72,1
Nanima Kariba	34,9	0,7	1,5	0,7	0,0	62,1	34,9	0,7	1,5	0,7	0,0	62,1

LLG	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Kome Rural	52,0	17,1	0,0	0,0	0,0	30,9	25,3	0,0	31,2	5,2	7,4	30,9
Wapi Rural	71,8	22,8	0,0	0,0	0,0	5,4	50,3	0,0	32,9	0,7	10,7	5,4
Kapao Rural	47,9	1,1	0,0	0,0	0,0	51,0	17,3	19,2	12,4	0,0	0,0	51,0
Nanima Kariba	63,2	12,6	0,0	0,0	0,0	24,2	20,8	15,6	36,4	2,2	0,7	24,2

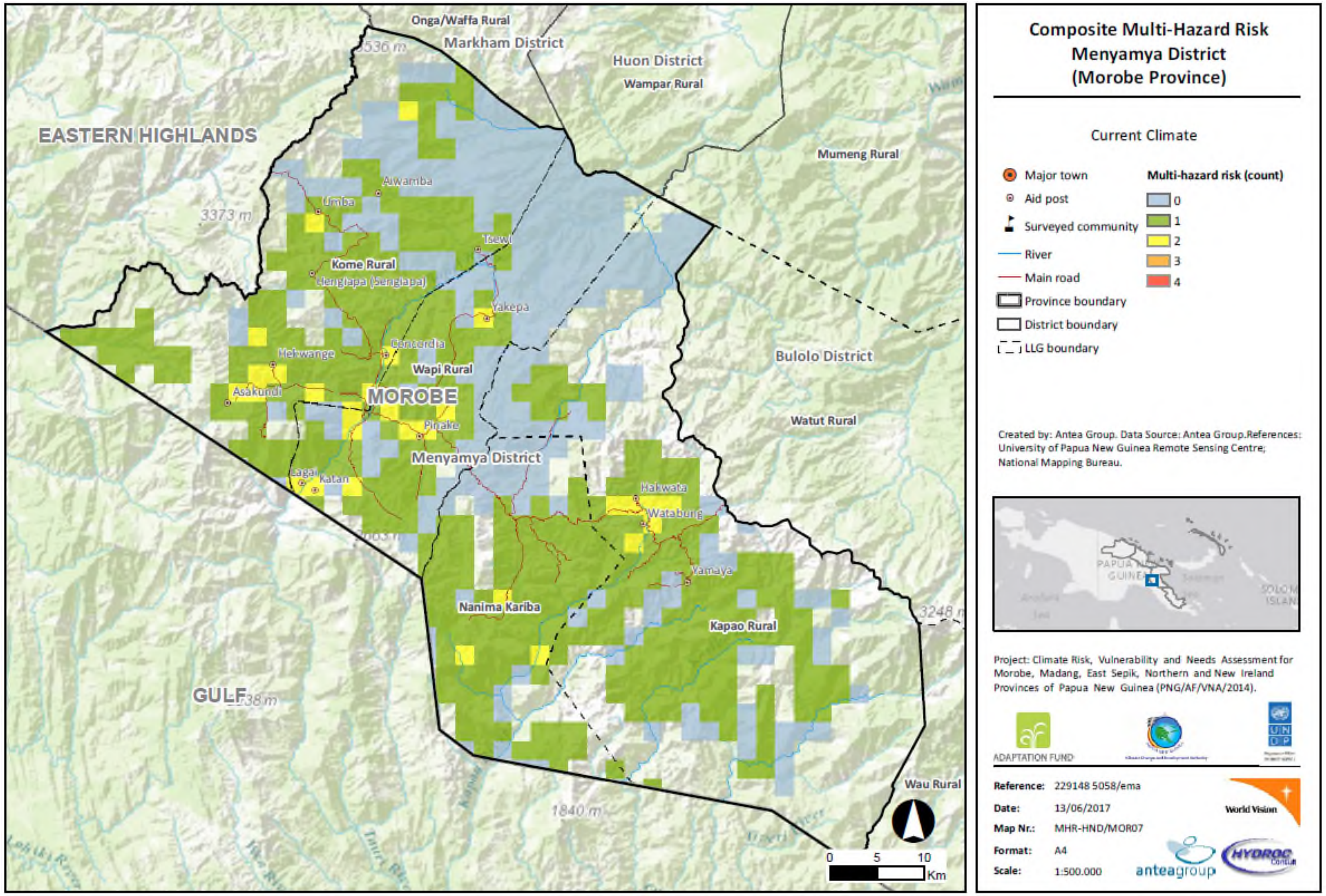

Figure 87. Composite risk map for Menyamya District (current climate)

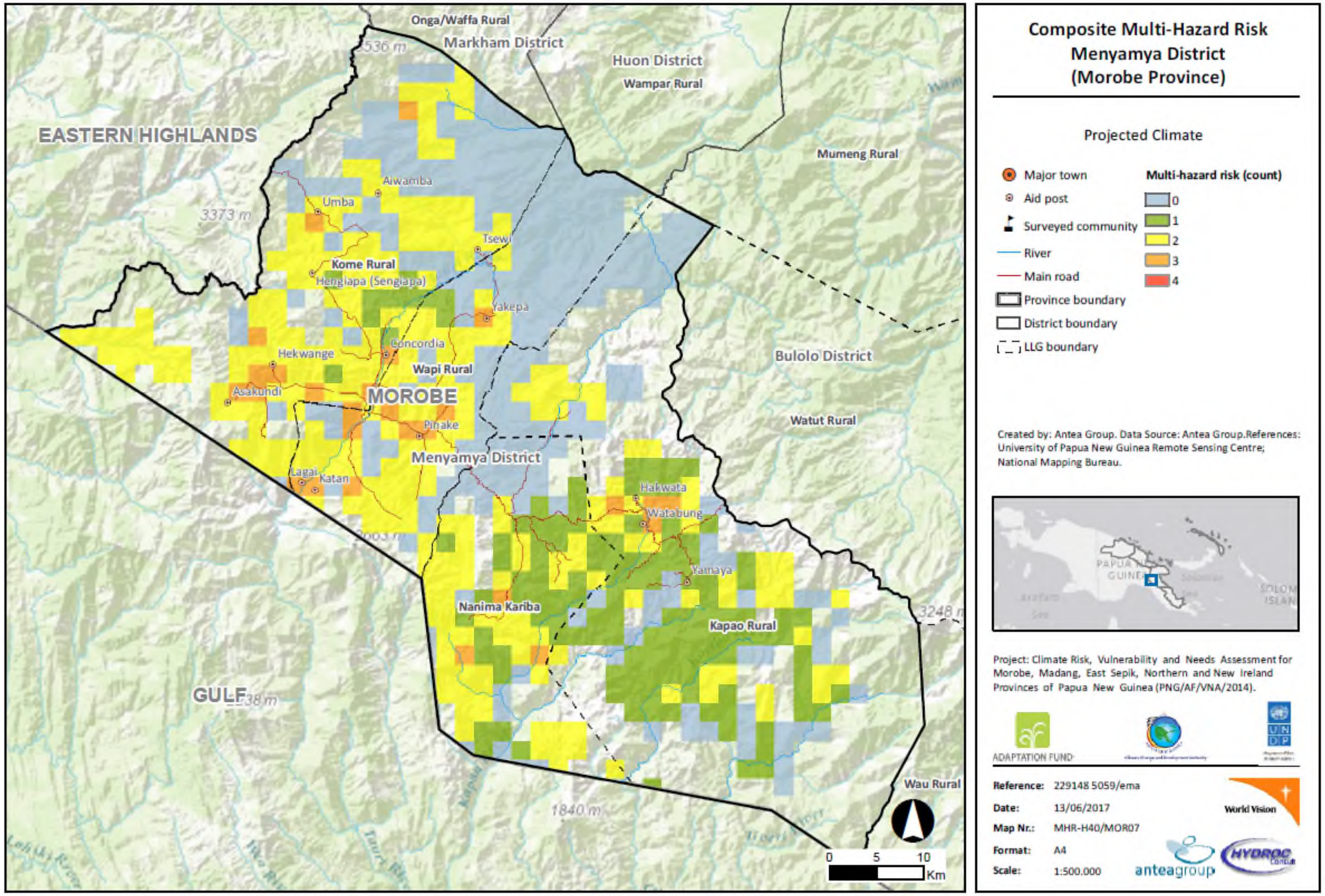

Figure 88. Composite risk map for Menyamya District (future climate)

3.8. Nawae Risk Profile

3.8.1. General description

Nawae District stretches north and east from Lae. In the east, it includes the coast of Bukaua. In the north, it covers parts of the Rawlinson and Sarawaget Ranges and numerous river valleys. While moderate incomes from betel nut, cocoa, coconut and fish can be earned on the coast, low incomes are earned in the majority of the district from sales of food and coffee, and very low incomes are earned in the most remote inmand areas. The district headquarters is located in Boana. There are 3 Local-Level Governments in Nawae District: Labuta Rural, Nabak Rural and Wain-Erap Rural. Number of assigned wards to this district is 46.

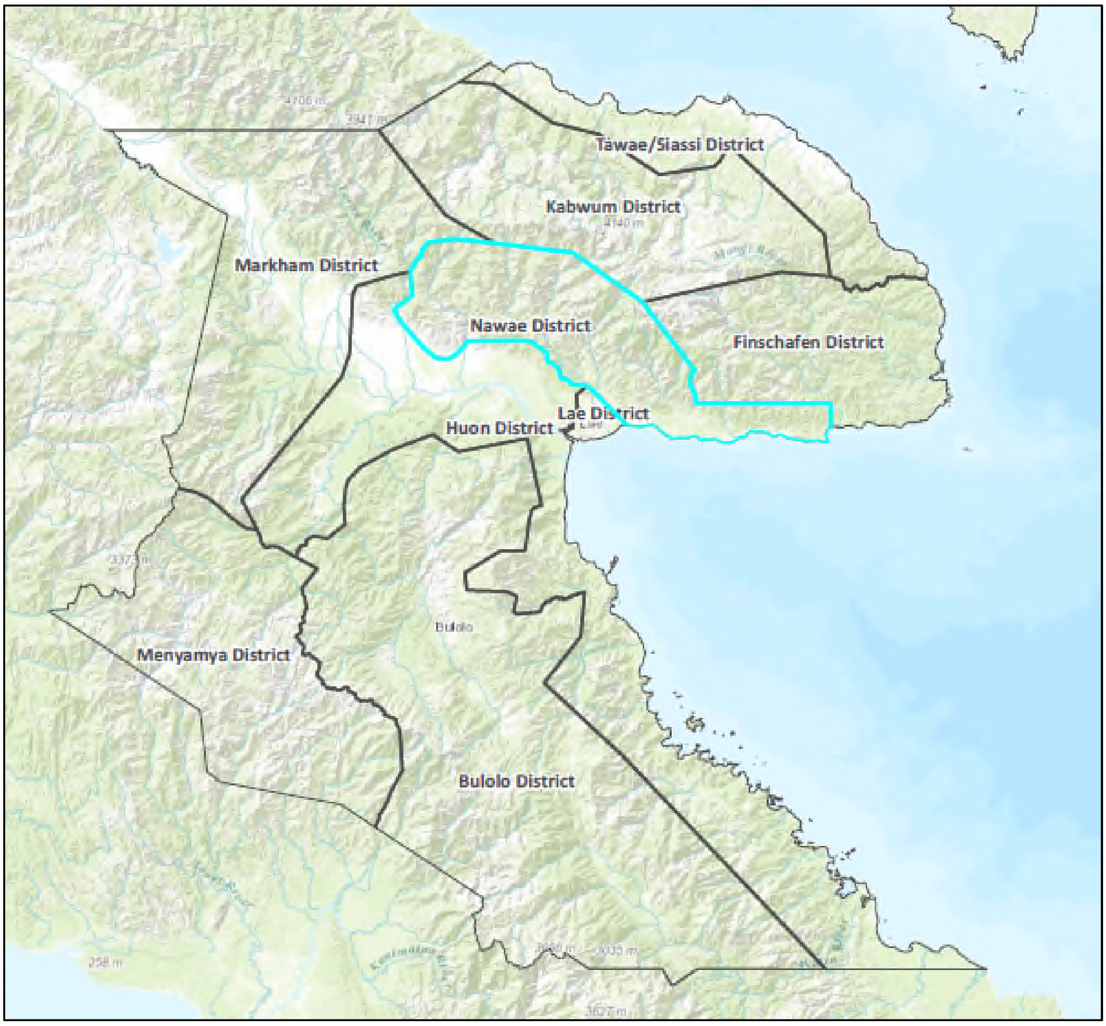

Figure 89. Nawae District

Nawae District has a population of 44,556[59]. The average population density is relatively low, 11.2 inhabitants per km^2, with the highest population densities occurring on the Bunbok and Gusap valleys with over 45 persons/km^2, while in the Erap and Nambuk valleys densities are over 35 persons/km^2. The Bukaua Coast and Busu, Sankwep, Nimba, Tuembi and Yanem valleys have population densities of over 25 persons/km^2. Significant outmigration has occurred from the upper Busu Valley.

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

The most disadvantaged people in the district live in the upper valleys of the Busu River, where

Land is unproductive and incomes are very low. These people have few opportunities to improve their livelihoods. People in the upper Erap Valley are constrained by moderate agricultural pressure, while those on the Bukaua coastal plains live in low potential environments. There is some agricultural pressure, land potential is low, access to services is moderate and cash incomes are generally low.

Incomes along the Bukaua Coast are moderate and are derived from sales of betel nut, cocoa, coconut, fish and fresh food. In the Boana area and the Erap, Nambuk and Gusap valleys, people earn low incomes from sales of fresh food, coffee, betel nut and tobacco. In the distant inland valleys, very low incomes are derived from sales of coffee, fresh food and potato.

Access to services in the district is good, and all areas are within eight hours' travel of Lae. There is a road from Lae running along the Bukaua Coast, but it is frequently closed due to flooded river crossings. Another road runs from Lae to Kwapsenek Village and Hobu School in the Busu Valley. The Boana area is linked to a road from the Highlands Highway in the Markham Valley. Small boat travel is common along the coast.

Table 49. Selected Health Indicators for Nawae District (2014)

Low Weight for Age < 5 years old (%)[60]	Low Birth Weight (%)[61]	Incidence of Malaria (1,000 population)[62]	Incidence of Diarrhoea (<5 years/1,000 pop.)[63]
27	0.0	33	166

Nawae District has an adult literacy rate of 71.5%, without a significant disparity in literacy rates between males (74.8%) and females (68.1%).

3.8.2. Hazards

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

The extreme weather hazard map for Nawae shows that the District is not prone to tropical cyclones. Projections for the future show the same tendency.

The inland flood hazard map shows a couple of hotspot areas along the coast and another on the eastern part of the district (in one of the tributaries of Markham River). Projections for the future keep the same tendency.

The District has a moderate profile regarding total annual rainfall, with values that range from 2711 to 2979mm and an even distribution of total rainfall on wet days in the range of 501 to 600mm.

[60] 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

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

[62] 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

[63] 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.

Projections for the future show an increase in the total annual rainfall, especially on the northern half of the district and well as in its intensity (601 to 700mm).

Counter wise, drought risk is currently moderate (21.1 to 24 continuous dry days) but projections for the future show a decrease, especially in the northern most corner of the district (16.1 to 21 continuous dry days).

3.8.3. Risk

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

3.8.3.1. Social risk

An area of extreme and high social risk from inland flooding is found in the vicinity of Situm town in Labuta Rural LLG near the border to Lae District. Moderate social risk from both drought and high rainfall is found in a large area extending from the southwestern part of Labuta Rural LLG to the northern part of Nabak Rural LLG from Situm town through Hobu and Musom villages along the river in the vicinity of Sambuen village. Other areas of the district have generally low social risk from hazards.

3.8.3.2. Physical risk

The inland flooding physical risk of Nawae District shows two main hotspots: one in the surroundings of Situm, where a stretch of road and a conglomeration of buildings are in big exposure, and the other in the south west part of Wain-Earp Rural, where some buildings in the boundary with Wampar Rural are exposed to potential flooding of Rumu River. Projections for the future show the same tendency.

The District shows a low profile regarding physical risk to extreme weather events. Projections for the near future do not show much change.

3.8.3.3. Composite risk

The current composite multi-hazard risk map of Nawae District shows two main hotspots, one around Bandong and the other in the south west part of Wain-Earp Rural.

Projections for the future show a general increase of risk throughout the district (Figure 91).

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Labuta Rural	4,3	11,4	11,4	5,7	7,6	59,6
Nabak Rural	4,8	28,2	10,1	11,2	5,3	40,4
Wain-Erap Rural	5,7	21,8	16,1	17,9	8,7	29,9

LLG	HAZARD : DROUGHT					
	COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Labuta Rural	3,6	12,4	17,6	0,5	2,4	63,6
Nabak Rural	2,4	48,4	2,1	1,1	0,0	46,0
Wain-Erap Rural	10,3	45,3	2,2	5,7	0,4	36,1

LLG	HAZARD : INLAND FLOODING					
	COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Labuta Rural	16,2	3,8	4,3	3,8	3,3	68,6
Nabak Rural	27,1	4,8	2,1	5,3	8,5	52,1
Wain-Erap Rural	25,3	6,5	3,9	3,0	2,6	58,6

LLG	HAZARD : PRECIPITATION					
	COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Labuta Rural	16,6	16,2	2,9	0,5	1,9	62,0
Nabak Rural	30,3	22,3	1,6	1,1	0,0	44,7
Wain-Erap Rural	34,8	17,9	14,8	0,0	0,9	31,6

LLG	HAZARD : CYCLONE											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Labuta Rural	16,2	24,7	0,0	0,0	0,0	59,1	16,2	24,7	0,0	0,0	0,0	59,1
Nabak Rural	33,0	26,6	0,0	0,0	0,0	40,4	33,0	26,6	0,0	0,0	0,0	40,4
Wain-Erap Rural	27,4	42,7	0,0	0,0	0,0	29,9	27,4	42,7	0,0	0,0	0,0	29,9

LLG	HAZARD : DROUGHT											
	RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Labuta Rural	0,0	5,7	29,9	0,5	2,4	61,5	0,0	5,7	29,9	0,5	2,4	61,5
Nabak Rural	0,0	4,3	50,5	1,1	0,0	44,1	0,0	4,3	50,5	1,1	0,0	44,1
Wain-Erap Rural	2,2	22,6	37,4	5,7	0,4	31,6	0,0	14,8	47,5	5,7	0,4	31,6

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Labuta Rural	20,4	5,2	2,9	1,9	1,0	68,6	20,4	5,2	2,9	1,9	1,0	68,6
Nabak Rural	32,4	11,7	2,7	1,1	0,0	52,1	32,4	11,7	2,7	1,1	0,0	52,1
Wain-Erap Rural	30,0	7,4	1,7	2,2	0,0	58,6	30,0	7,4	1,7	2,2	0,0	58,6

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Labuta Rural	32,3	5,7	0,0	0,0	0,0	62,0	3,8	12,8	19,0	0,5	1,9	62,0
Nabak Rural	52,7	2,7	0,0	0,0	0,0	44,7	9,6	20,7	22,9	2,1	0,0	44,7
Wain-Erap Rural	47,5	6,5	13,5	0,9	0,0	31,6	0,0	35,7	29,6	2,2	0,9	31,6

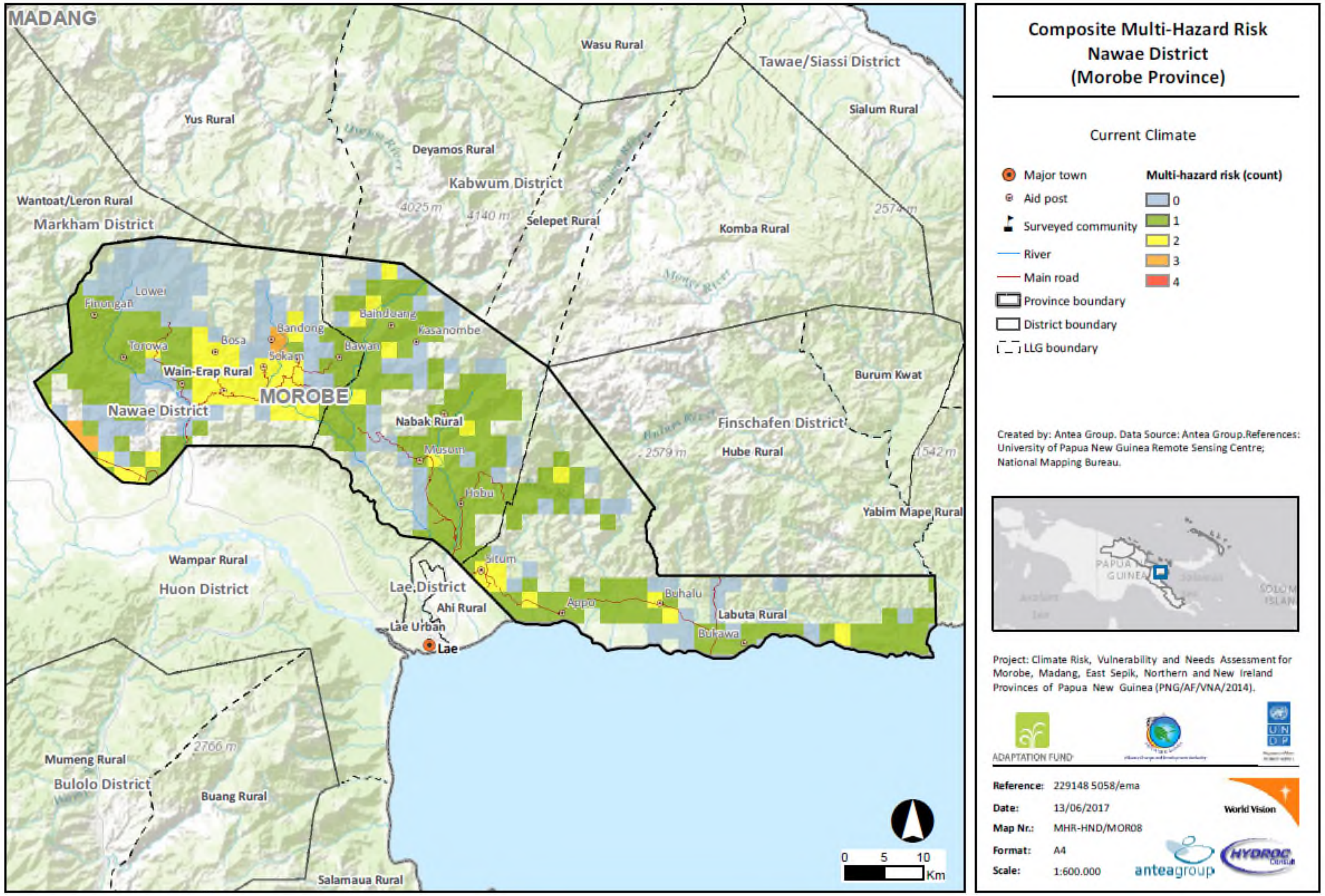

Figure 90. Composite risk map for Nawae District (current climate)

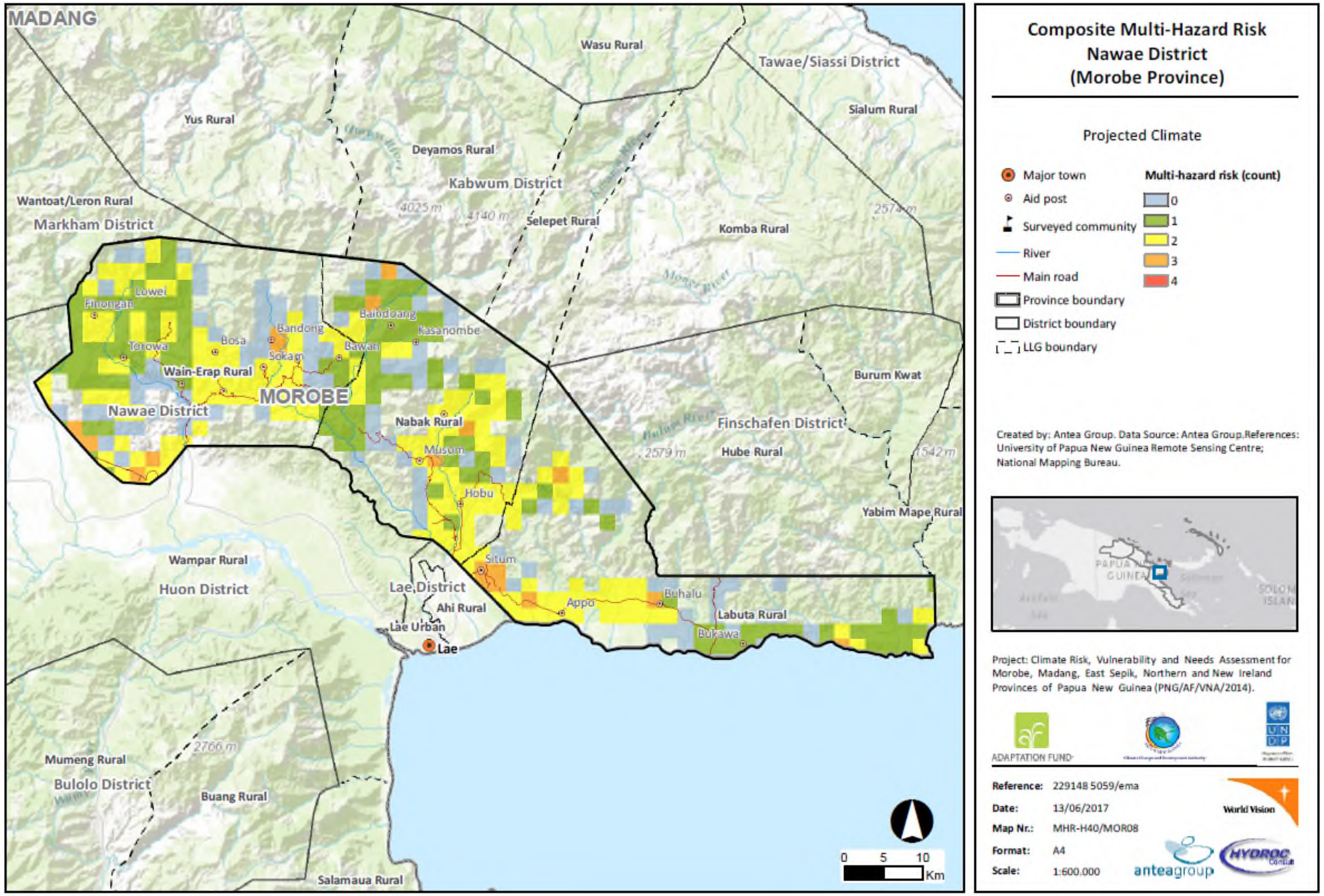

Figure 91. Composite risk map for Nawae District (future climate)

3.9. *Tawae/Siassi Risk Profile*

3.9.1. *General description*

Tawae-Siassi District is a long, narrrow strip of land along the north coast of the Huon Peninsula. It also includes the islands of Sakar, Umboi, Tolokiwa, Malai and Tuam. Low incomes are the norm across the district from the sale of food, fish, betel nut and coconut. There are some incomes and royalties from forestry on Umboi Island. The district headquarters is located in Sialum. There are 3 Local-Level Governments in Tawae-Siassi District: Sialum Rural, Siassi Rural and Wasu Rural. Number of assigned wards to this district is 57.

Figure 92. Tawae-Siassi District

Tawae District has a population of 54,340[64]. The average population density is relatively low, 17.1 inhabitants per km^2, with the highest population densities occurring on the Malai and Tuam islands with over 400 persons/km^2. These are some of the highest population densities in PNG. The south coast of Umboi Island also has very high densities of over 120 persons/km^2. On the mainland, along a narrow strip of land on the Sialum coastal plains, densities are over 110 persons/km^2. The area around Wasu has a density of over 70 persons/km2. The inland valleys of the Huon Peninsula, the west coast of Umboi Island and Sakar Island have lower densities of around 30 persons/km^2, while Tolokiwa Island and the plains around Singorokai have an average density of around 20 persons/km^2.

The most disadvantaged people in the district are the small number on Malai and Tuam islands, where very high population densities occur together with strong agricultural pressure and very low incomes. Development in the inland valleys of the Huon Peninsula and on Sakar Island is constrained by poor environments, low incomes and, in some places, moderate agricultural pressure. All other people in the district have very low incomes. Overall, people in Tawae-Siassi District are seriously disadvantaged relative to people in other districts of PNG. There is agricultural pressure, land potential is moderate, and access to services is moderate. Cash incomes are very low throughout the district and are mainly derived from sales of fresh food, fish, betel nut, cocoa and coconut. Forestry operations on Umboi Island provide wage employment and royalties to some people.

All parts of the district are within eight hours' travel of a service centre. There is a road from Finschhafen to Sialum and Kelanoa, but it is sometimes blocked by flooded rivers during the wet season. Small boat travel is used along the coast, but the Vitiaz Strait is subject to rough seas that make small boat travel between the islands and mainland dangerous, especially during the wet season. There is a regular passenger shipping service between Umboi Island and Finschhafen.

Table 50. Selected Health Indicators for Tawae-Siassi District (2014)

Low Weight for Age < 5 years old (%)[65]	Low Birth Weight (%)[66]	Incidence of Malaria (1,000 population)[67]	Incidence of Diarrhoea (<5 years/1,000 pop.)[68]
14	10.7	36	56

Tawae-Siassi District has an adult literacy rate of 68%, without a significant disparity in literacy rates between males (74.0%) and females (62.0%).

64 National Population and Housing Census, 2011, National Statistical Office, 2013.

65 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

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

67 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

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

3.9.2. Hazards

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

Tawae-Siassi District is not prone to tropical cyclones and projections for the near future remain the same.

The inland flood hazard map shows some flooded areas scattered throughout the district. Projections for the near future do not show much change.

The total annual rainfall for the region ranges the 2711 to 2979 mm, while the total rainfall on wet days ranges the 501 to 600 mm. Projections for the future show an increase in precipitation throughout the year, especially in the northwest of the district (2980 to 3280mm) and a general increase in the total rainfall on wet days (601 to 700 mm).

Drought risk is moderate in the district with values that range the 21.1 to 24 continuous dry days, and projections for the future do not show much change.

3.9.3. Risk

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

3.9.3.1. Social risk

According to the risk maps, there are no or only minimal areas with high or extreme social risk from hazards in this province.

3.9.3.2. Physical risk

The inland flooding physical risk map of Tawae-Siassi District only presents two minor hotspots in the island of Siassi Rural: one in the north (road flooding) and one in the south (bridge and buildings compromised). Projections for the future do not show much change.

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

3.9.3.3. Composite risk

The composite multi hazard map of the district has only some moderate hotspots but projections for the future show an increase in the extent of level of risks.

	HAZARD : CYCLONE					
	COMPOSITE VULNERABILITY %					
LLG	1	2	3	4	5	
Sialum Rural	6,8	23,2	13,2	13,6	14,5	28,7
Siassi Rural	13,2	11,1	6,2	6,6	11,1	51,7
Wasu Rural	12,7	34,7	6,3	5,4	6,8	34,1

LLG	HAZARD : DROUGHT COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Sialum Rural	10,9	49,5	1,4	0,0	0,0	38,2
Siassi Rural	11,2	19,8	6,6	1,2	1,2	59,9
Wasu Rural	10,6	44,0	4,4	0,5	0,0	40,5

LLG	HAZARD : INLAND FLOODING COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Sialum Rural	35,0	4,1	2,7	0,9	6,4	50,9
Siassi Rural	14,8	3,7	1,6	0,0	2,9	76,9
Wasu Rural	38,1	3,4	1,5	1,0	6,3	49,7

LLG	HAZARD : PRECIPITATION COMPOSITE VULNERABILITY %					
	1	2	3	4	5	
Sialum Rural	55,9	10,5	1,4	0,0	0,0	32,3
Siassi Rural	15,3	19,8	6,6	0,4	2,1	55,9
Wasu Rural	44,9	16,1	4,4	0,5	0,0	34,1

LLG	HAZARD : CYCLONE RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Sialum Rural	30,0	41,4	0,0	0,0	0,0	28,7	30,0	41,4	0,0	0,0	0,0	28,7
Siassi Rural	24,3	23,9	0,0	0,0	0,0	51,7	24,3	23,9	0,0	0,0	0,0	51,7
Wasu Rural	47,4	18,6	0,0	0,0	0,0	34,1	47,4	18,6	0,0	0,0	0,0	34,1

LLG	HAZARD : DROUGHT RISK 1960-1990 %						RISK 2030-2050 %					
	1	2	3	4	5		1	2	3	4	5	
Sialum Rural	0,0	16,4	50,9	0,0	0,0	32,7	0,0	16,4	50,9	0,0	0,0	32,7
Siassi Rural	0,0	15,3	26,4	1,2	1,2	55,9	0,0	15,3	26,4	1,2	1,2	55,9
Wasu Rural	0,0	17,1	48,4	0,5	0,0	34,1	0,0	17,1	48,4	0,5	0,0	34,1

	HAZARD : INLAND FLOODING											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Sialum Rural	37,7	4,5	3,6	2,3	0,9	50,9	37,7	5,0	3,6	1,8	0,9	50,9
Siassi Rural	18,1	3,3	0,4	0,0	1,2	76,9	18,1	3,3	0,4	0,0	1,2	76,9
Wasu Rural	38,6	6,8	3,4	1,5	0,0	49,7	38,6	6,8	3,4	1,5	0,0	49,7

	HAZARD : PRECIPITATION											
	RISK 1960-1990 %						RISK 2030-2050 %					
LLG	1	2	3	4	5		1	2	3	4	5	
Sialum Rural	66,3	1,4	0,0	0,0	0,0	32,3	10,9	45,0	10,5	1,4	0,0	32,3
Siassi Rural	35,1	8,2	0,0	0,8	0,0	55,9	13,2	2,1	26,4	1,2	1,2	55,9
Wasu Rural	61,1	4,9	0,0	0,0	0,0	34,1	16,6	28,3	16,1	4,4	0,5	34,1

anteagroup HYDROC Consult World Vision

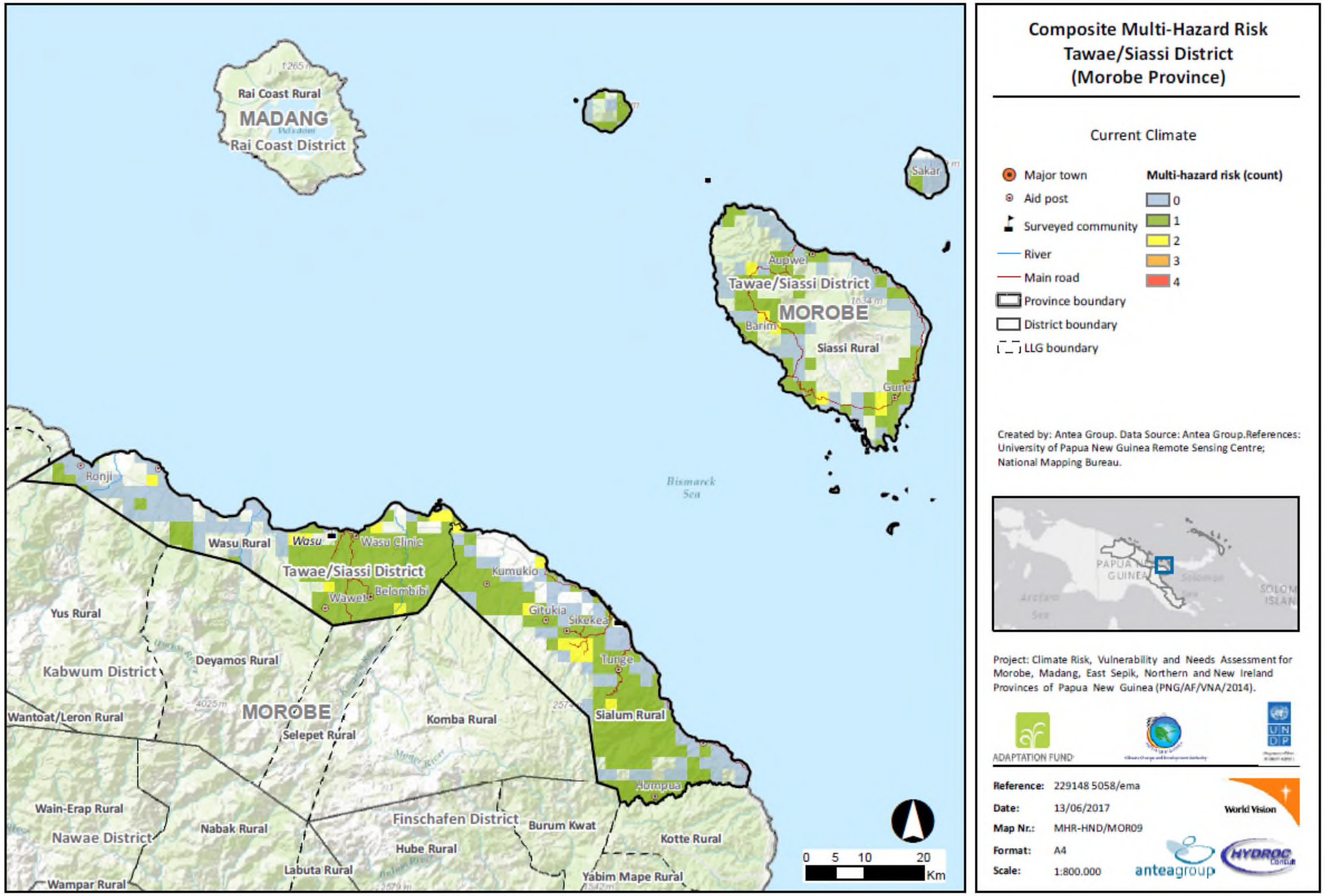

Figure 93. Composite risk map for Tawae/Siassi District (current climate)

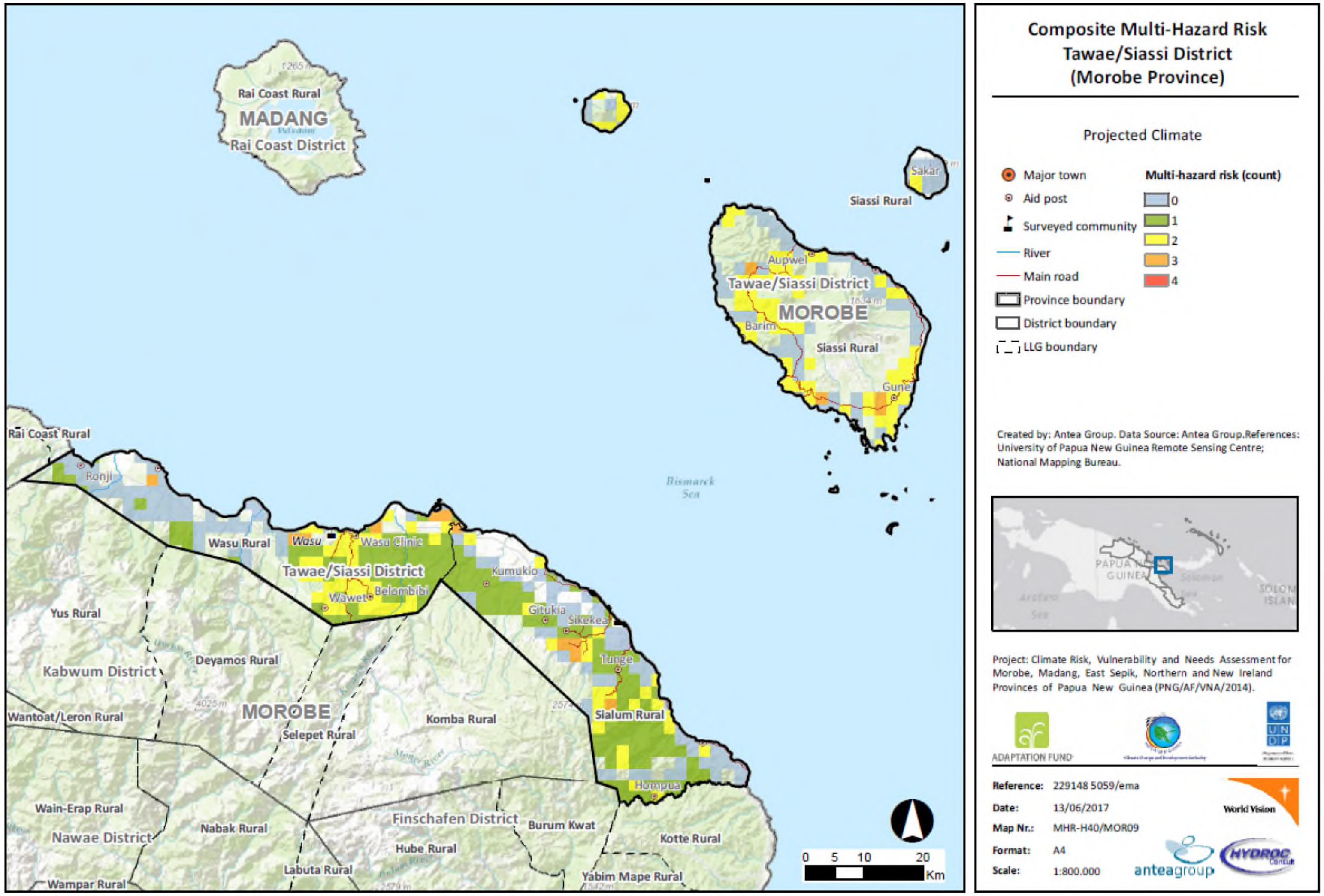

Figure 94. Composite risk map for Tawae/Siassi District (future climate)

4. RECOMMENDATIONS

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

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

4.1. Needs and priorities

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

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

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

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

4.2. Opportunities

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

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

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

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

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

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

4.3. *Way forward*

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

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

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

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

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

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

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

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

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

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

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

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

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

ANNEXES

ANNEX 1 DEFINITIONS

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 2 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[69]. 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 95) including 3 automatic and 10 manual stations.[70] The following variables are recorded daily at the manual stations and hourly at the automatic stations: Rainfall, Air temperature, Wind, Pressure, and Humidity.

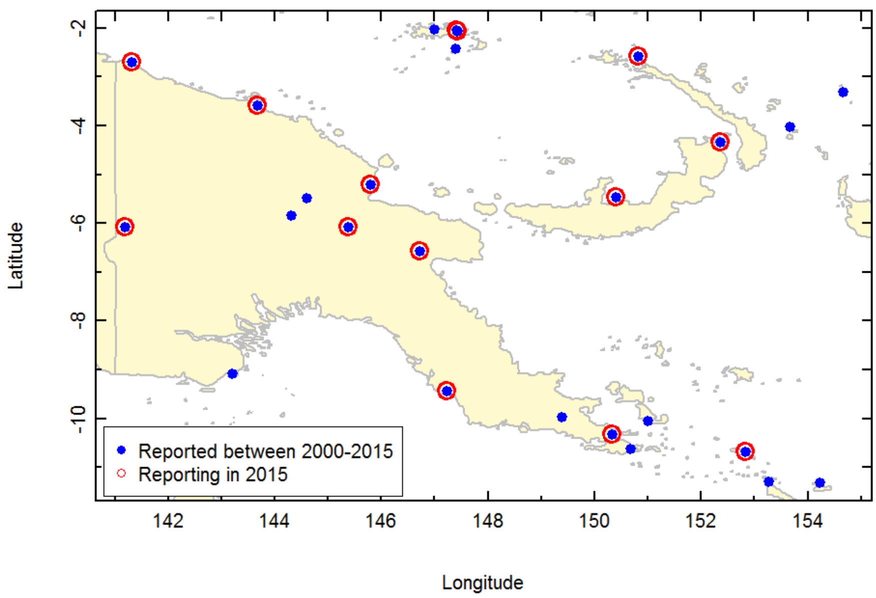

Figure 95. Location of Global Surface Summary of the Day (GSOD) weather stations across Papua New Guinea.

[69] 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.
[70] 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[71] 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[72][73]. The Pacific Climate Change Portal[74] 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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[71] CliDE – Climate Data for the Environment; http://www.bom.gov.au/climate/pacific/about-clide.shtml

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

[73] 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.

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

Infrastructure vulnerability

Infrastructure database

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

Replacement costs for buildings and infrastructure

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

The geodatabase with roads and other infrastructure does not c ontain location-specific replacement cost values, but the replacement cost of each piece of infrastructure can be estimated based on their characteristics (Table 51).

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

Table 51. Unit replacement costs of infrastructure in PIC (Source: PCRAFI 2013)

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

Economic vulnerability

Buildings database

The exposure database established by PCRAFI (Pacific Catastrophe Risk Financing and Insurance Initiative) includes a comprehensive inventory of residential, commercial, public and industrial buildings. It consists of their location, replacement cost and structural characteristics which affect their vulnerability to the effects of natural disasters. The locations of the buildings (Figure 96) 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.

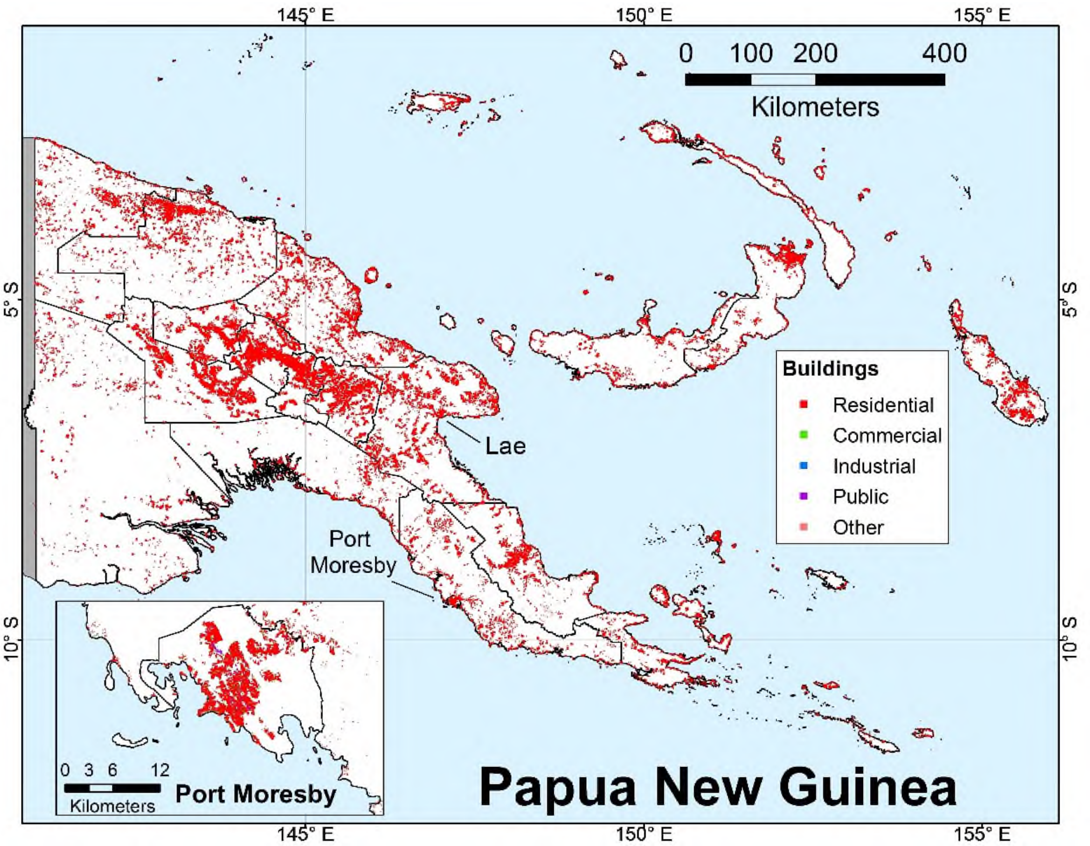

Figure 96. Location of buildings in PNG (Source: PCRAFI)

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

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

Land use/Land cover database

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

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

Agricultural systems survey

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

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

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

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

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

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

Replacement costs for key crops

Unit replacement costs of different cash crops in the PICs were derived by PCRAFI (2013) from crop production budgets issued by local governments. **Fout! Verwijzingsbron niet gevonden.** 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 52 Replacement costs for key crops under different production systems in the PICs (PCRAFI 2013 p 28)

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

Annex 3 Crop tolerance scores

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

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

		Representa tivity	Number of systems	**INLAND FLOOD DEPTH (m.)** ***(without flow)***	**SEA LEVEL RISE (m)** ***(assumes salinisation of groundwater)***	**LOW ANNUAL RAINFALL (mm.)** ***(assumes relatively even distribution)***	**HIGH ANNUAL RAINFALL (mm.)** ***(assumes relatively even distribution)***	**MAX. 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