METEOR: Hazard footprints for Nepal and Tanzania

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Approved by: UKSA IPP Project Officer		
Name:	Signature:	Date:

Date	Version	Alterations	Editor

About this report

This report shows the hazard footprints generated for Nepal and Tanzania through the METEOR project. Detail on the methodology for these footprints will be detailed in subsequent METEOR deliverable documents. The footprints are all present on the METEOR data portal (https://maps.meteor-project.org/) together with abstracts on data generation.

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1. METEOR Project Introduction

1.1. Project Summary

Project Title	Modelling Exposure Through Earth Observation Routines (METEOR): EO-based Exposure, Nepal and Tanzania
Starting Date	08/02/2018
Duration	36 months
Partners	UK Partners: The British Geological Survey (BGS) (Lead), Oxford Policy Management Limited (OPM), SSBN Limited International Partners: The Disaster Management Department, Office of the Prime Minister – Tanzania (DMD), The Global Earthquake Model (GEM) Foundation, The Humanitarian OpenStreetMap Team (HOT), ImageCat, National Society for Earthquake Technology (NSET) – Nepal
Target Countries	Nepal and Tanzania for "level 2" results and all 47 Least Developed ODA countries for "level 1" data
IPP Project	IPPC2_07_BGS_METEOR

Table 1: METEOR Project Summary

1.2. Project Overview

At present, there is a poor understanding of population exposure in some Official Development Assistance (ODA) countries, which causes major challenges when making Disaster Risk Management decisions. Modelling Exposure Through Earth Observation Routines (METEOR) takes a step-change in the application of Earth Observation exposure data by developing and delivering more accurate levels of population exposure to natural hazards. METEOR is delivering calibrated exposure data for Nepal and Tanzania, plus 'Level-1' exposure for the remaining Least developed Countries (LDCs) ODA countries. Moreover, we are: (i) developing and delivering national hazard footprints for Nepal and Tanzania; (ii) producing new vulnerability data for the impacts of hazards on exposure; and (iii) characterising how multi-hazards interact and impact upon exposure. The provision of METEOR's consistent data to governments, town planners and insurance providers will promote welfare and economic development and better enable them to respond to the hazards when they do occur.

METEOR is co-funded through the second iteration of the UK Space Agency's (UKSA) International Partnership Programme (IPP), which uses space expertise to develop and deliver innovative solutions to real world problems across the globe. The funding helps to build sustainable development while building effective partnerships that can lead to growth opportunities for British companies.

1.3. Project Objectives

METEOR aims to formulate an innovative methodology of creating exposure data through the use of EO-based imagery to identify development patterns throughout a country. Stratified sampling techniques harnessing traditional land use interpretation methods, modified to characterise building patterns, can be combined with EO and in-field building characteristics to capture the distribution of building types. The associated protocols and standards will be developed for broad application to ODA countries and will be tested and validated for both Nepal and Tanzania to assure they are fit-for-purpose.

Detailed building data collected on the ground for the cities of Kathmandu (Nepal) and Dar es Salaam (Tanzania) were used to compare and validate the EO generated exposure datasets. Objectives of the project look to: deliver exposure data for 47 of the least developed ODA countries, including Nepal and Tanzania; create hazard footprints for the specific countries; create open protocol; to develop critical exposure information from EO data; and capacity-building of local decision makers to apply data and assess hazard exposure. The eight work packages (WP) that make up the METEOR project are outlined below in section 1.4.

1.4. Work Packages

Outlined below are the eight work packages that make up the METEOR project (Table 2). These are led by various partners, with a brief description of what each of the work packages cover provided in Table 2. BGS is leading WP.6: Multiple Hazard impact, which focuses on the multiple hazard impacts on exposure and how they may be addressed in disaster risk management by a range of stakeholders.

Work Package	Title	Lead	Overview
WP.1	Project Management	BGS	Project management, meetings with UKSA, quarterly reporting and the provision of feedback on project deliverables and direction across primary stakeholders.
WP.2	Monitoring and Evaluation	OPM	Monitoring and evaluation of the project and its impact, using a theory of change approach to assess whether the associated activities are leading to the desired outcome.
WP.3	EO Data for Exposure Development	ImageCat	EO-based data for exposure development, methods and protocols of segmenting/classifying building patterns for stratified sampling of building characteristics.
WP.4	Inputs and Validation	HOT	Collect exposure data in Kathmandu and Dar es Salaam to help validate and calibrate the data derived from the classification of building patterns from EO-based imagery.
WP.5	Vulnerability and Uncertainty	GEM	Investigate how assumptions, limitations, scale and accuracy of exposure data, as well as decisions in data development

			process lead to modelled uncertainty.
WP.6	Multiple Hazard Impact	BGS	Multiple hazard impacts on exposure and how they may be addressed in disaster risk management by a range of stakeholders.
WP.7	Knowledge Sharing	GEM	Disseminate to the wider space and development sectors through dedicated web-portals and use of the Challenge Fund open databases.
WP.8	Sustainability and Capacity-Building	ImageCat	Sustainability and capacity-building, with the launch of the databases for Nepal and Tanzania while working with in-country experts.

Table 2: Overview of METEOR Work Packages

1.5. Multiple Hazard Impact

The multiple hazard impact work package (WP6) led by BGS includes four deliverables, which are focused on developing footprints of the hazards that have been designated as of most importance to our partner countries of Nepal (flooding, earthquake and landslide) and Tanzania (flooding, earthquake and volcanic activity) and modelling their potential impacts on exposure (Table 3).

Deliverable	**Title**
M6.1	Deliver national hazard footprints for Nepal and Tanzania
M6.2	Develop models for analysing multi-hazards with exposure
M6.3	Draft protocols on hazard and exposure modelling
M6.4	Final report on multiple hazard impact

Table 3: Overview of BGS multi-hazard impact deliverables

2. Flooding:

2.1. Abstract

Nepal Flood maps: Fluvial Defended, Undefended and Pluvial for various return periods.

The data presented show the modelled water depth for flood events of different return periods. Both fluvial flooding (flooding from rivers) and pluvial flooding (local surface water flooding from extreme rainfall) have been simulated and can be displayed. Depths are shown in meters. Note that one would not expect all the displayed flooding to happen *at the same time*; rather, the data show the maximum water depth that would be expected if a flood event of the specified return period were occurring at that location. Another way of expressing this is to say that the data show the probability of experiencing a given water depth within a single year; i.e. depths shown by the '1-in-100 year' layer have a 1-in-100 (or 1%) chance of occurrence in any given year.

The data has been produced using the Fathom global flood hazard modelling framework (a development of Sampson et al., 2015 and Smith et al., 2015). The model uses the MERIT global DEM and hydrography for elevation and river network data sources respectively (Yamazaki et al., 2017; Yamazaki et al., 2019). The framework automatically constructs flood models across a specified region, using the two-dimensional shallow water equations to simulate the behaviour of floodwaters during the modelled flood events. The framework produces maps of flood depths at 3 arcsecond (~90m) spatial resolution for a specified range of return periods. For a detailed technical description of the methods, please see the open-access academic papers listed below.

Given that the modelling framework used to create this data is semi-autonomous and uses data available at the regional to global scale, its accuracy is limited by the quality of this input data and the simplified range of processes it can represent. While the data is suitable for providing guidance at the regional scale, it is not recommended to use the data for detailed local scale assessments or engineering purposes. More details around appropriate use can be found in the user training documentation.

2.1.1. References

Sampson et al 2015: **https://doi.org/10.1002/2015WR016954**

Smith et al 2015: **https://doi.org/10.1002/2014WR015814**

Yamazaki et al 2017: **https://doi.org/10.1002/2017GL072874**

Yamazaki et al 2019: **https://doi.org/10.1029/2019WR024873**

2.2. Pluvial: Nepal

METEOR Hazard footprints for Nepal and Tanzania

METEOR Hazard footprints for Nepal and Tanzania

METEOR Hazard footprints for Nepal and Tanzania


Pluvial
1 in 75 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Dharan
Biratnagar
Pithoragarh
Pilibhit
UTTAR PRADESH
SIKKIM
BIHAR
Lucknow
Kanpur
Gorakhpur
Patna
Allahabad
Darjiling
Gangtok
Sources: Esri, Garmin, USGS, NPS
1 in 75 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Pluvial
1 in 100 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangadhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Dharan
Biratnagar
Pithoragarh
Pilibhit
UTTAR PRADESH
Shahjahanpur
Sitapur
Hardoi
Mahmudabad
Bahraich
Balrampur
Gonda
Kannauj
Sandila
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Tanda
Deoria
Motihari
Sitamarhi
Rae Bareli
Sultanpur
Azamgarh
Siwan
Muzaffarpur
Darbhanga
Saharsa
BIHAR
Fatehpur
Mau
Ballia
Chhapra
Ara
Buxar
Patna
Jaunpur
Allahabad
Banda
Baruni
Munger
Purnia
Katihar
Kishanganj
Raiganj
SIKKIM
Gangtok
Darjiling
Sources: Esri, Garmin, USGS, NPS
1 in 100 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Pluvial
1 in 200 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Dharan
Biratnagar
UTTAR PRADESH
BIHAR
SIKKIM
Lucknow
Kanpur
Gorakhpur
Patna
Allahabad
Sources: Esri, Garmin, USGS, NPS
1 in 200 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

METEOR Hazard footprints for Nepal and Tanzania

1 in 250 years

- No Flooding
- 0 - 0.1
- 0.100000001 - 1
- 1.000000001 - 2
- 2.000000001 - 3
- 3.000000001 - 4
- 4.000000001 - 5
- Permanent Water


Pluvial
1 in 500 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangadhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Dharan
Biratnagar
UTTAR PRADESH
BIHAR
SIKKIM
Pithoragarh
Pilibhit
Shahjahanpur
Sitapur
Hardoi
Mahmudabad
Bahraich
Balrampur
Gonda
Kannauj
Sandila
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Motihari
Sitamarhi
Tanda
Deoria
Rae Bareli
Sultanpur
Azamgarh
Siwan
Muzaffarpur
Darbhanga
Saharsa
Fatehpur
Mau
Ballia
Chhapra
Ara
Patna
Jaunpur
Buxar
Banda
Allahabad
Baruni
Munger
Purnia
Katihar
Raiganj
Kishanganj
Gangtok
Darjiling
Sources: Esri, Garmin, USGS, NPS
1 in 500 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

METEOR Hazard footprints for Nepal and Tanzania

2.3. Fluvial Defended: Nepal


Fluvial - Defended
1 in 10 year event
0 50 100 200 km
NEPAL
UTTAR PRADESH
BIHAR
SIKKIM
Kathmandu
Pokhara
Dailekh
Dhangarhi
Pithoragarh
Pilibhit
Nepalganj
Shahjahanpur
Sitapur
Hardoi
Kannauj
Sandila
Lucknow
Kanpur
Rae Bareli
Fatehpur
Banda
Allahabad
Bahraich
Mahmudabad
Balrampur
Gonda
Faizabad
Basti
Tanda
Sultanpur
Azamgarh
Jaunpur
Butwal
Bharatpur
Gorakhpur
Deoria
Mau
Bagaha
Bettiah
Siwan
Ballia
Buxar
Chhapra
Ara
Patna
Birganj
Motihari
Muzaffarpur
Janakpur
Sitamarhi
Darbhanga
Saharsa
Baruni
Munger
Dharan
Biratnagar
Kishanganj
Purnia
Katihar
Gangtok
Darjiling
Xigaz
Sources: Esri, Garmin, USGS, NPS
1 in 10 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

Fluvial - Defended
1 in 20 year event
0
50
100
200 km
NEPAL
UTTAR PRADESH
BIHAR
SIKKIM
Kathmandu
Pokhara
Dailekh
Dhangarhi
Pithoragarh
Pilibhit
Nepalganj
Shahjahanpur
Bahraich
Butwal
Bharatpur
Balrampur
Sitapur
Hardoi
Mahmudabad
Gonda
Kannauj
Sandila
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Birganj
Motihari
Janakpur
Sitamarhi
Dharan
Biratnagar
Darjiling
Gangtok
Tanda
Deoria
Siwan
Azamgarh
Muzaffarpur
Darbhanga
Saharsa
Kishanganj
Rae Bareli
Sultanpur
Fatehpur
Mau
Ballia
Chhapra
Ara
Patna
Buxar
Jaunpur
Allahabad
Banda
Baruni
Munger
Purnia
Katihar
Raiganj
Sources: Esri, Garmin, USGS, NPS
1 in 20 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Fluvial - Defended
1 in 50 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Dharan
Pithoragarh
UTTAR PRADESH
BIHAR
SIKKIM
Pilibhit
Shahjahanpur
Sitapur
Hardoi
Lucknow
Kanpur
Bahraich
Balrampur
Gonda
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Motihari
Sitamarhi
Muzaffarpur
Darbhanga
Saharsa
Patna
Gangtok
Darjiling
Kishanganj
Purnia
Katihar
Sources: Esri, Garmin, USGS, NPS
1 in 50 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

METEOR Hazard footprints for Nepal and Tanzania

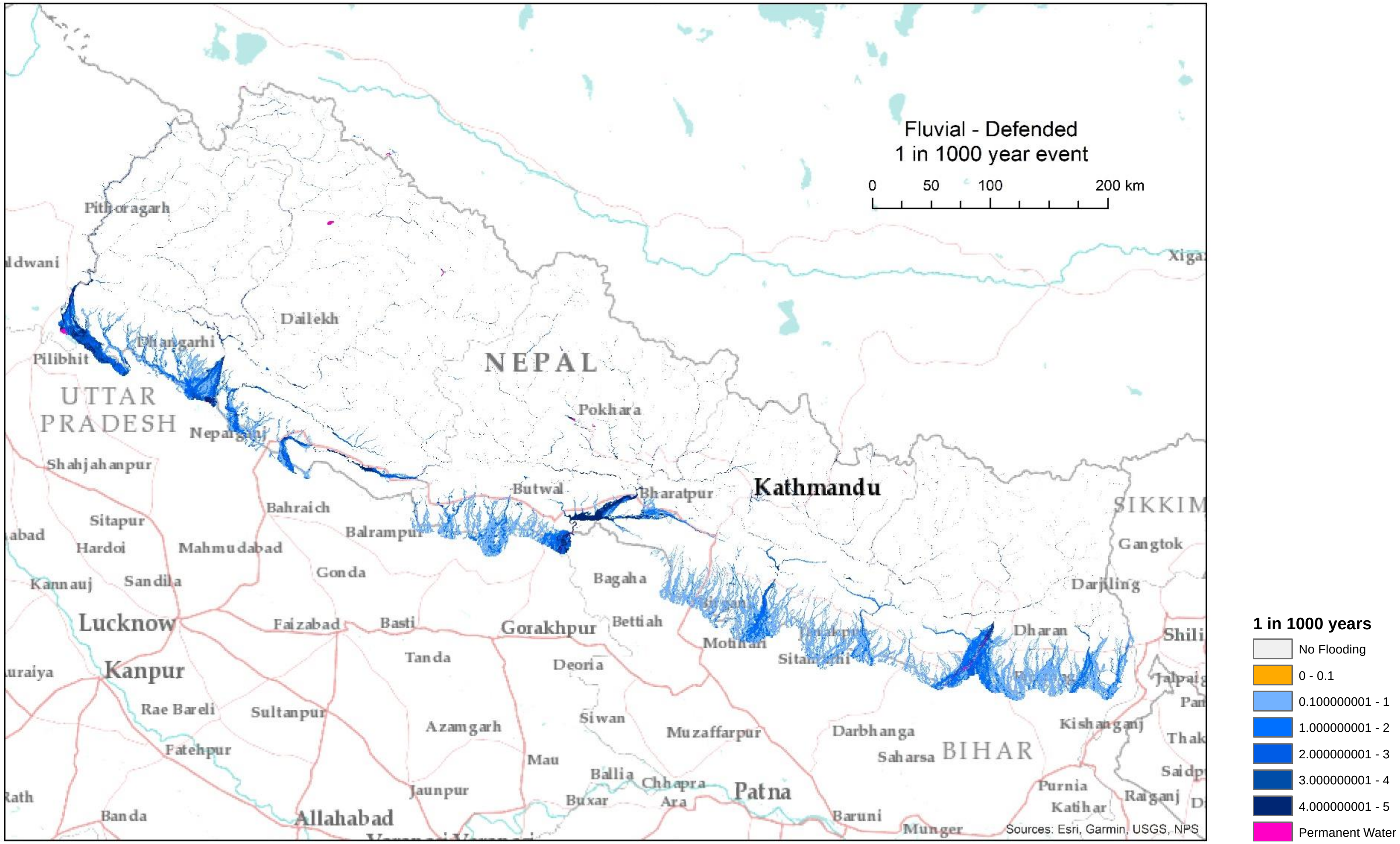

Fluvial - Defended
1 in 100 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Dharan
Biratnagar
UTTAR PRADESH
BIHAR
SIKKIM
Lucknow
Kanpur
Gorakhpur
Patna
Allahabad
1 in 100 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water
Sources: Esri, Garmin, USGS, NPS

1 in 200 years

- No Flooding
- 0 - 0.1
- 0.100000001 - 1
- 1.000000001 - 2
- 2.000000001 - 3
- 3.000000001 - 4
- 4.000000001 - 5
- Permanent Water


Fluvial - Defended
1 in 250 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Pithoragarh
Pilibhit
UTTAR PRADESH
Shahjahanpur
Bahraich
Balrampur
Sitapur
Hardoi
Mahmudabad
Gonda
Kannauj
Sandila
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Tanda
Deoria
Motihari
Sitamarhi
Dharan
Rae Bareli
Sultanpur
Azamgarh
Siwan
Muzaffarpur
Darbhanga
Saharsa
BIHAR
Kishanganj
Fatehpur
Mau
Ballia
Chhapra
Ara
Patna
Buxar
Jaunpur
Allahabad
Banda
Baruni
Munger
Purnia
Katihar
Raiganj
SIKKIM
Gangtok
Darjiling
Sources: Esri, Garmin, USGS, NPS
1 in 250 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Fluvial - Defended
1 in 500 year event
0 50 100 200 km
NEPAL
UTTAR PRADESH
BIHAR
SIKKIM
Kathmandu
Pokhara
Dailekh
Pithoragarh
Dhangarhi
Pilibhit
Nepalganj
Shahjahanpur
Butwal
Bharatpur
Bahraich
Balrampur
Sitapur
Hardoi
Mahmudabad
Gonda
Kannauj
Sandila
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Tanda
Deoria
Rae Bareli
Sultanpur
Azamgarh
Fatehpur
Siwan
Muzaffarpur
Darbhanga
Saharsa
Mau
Ballia
Chhapra
Ara
Patna
Jaunpur
Buxar
Allahabad
Banda
Baruni
Munger
Purnia
Katihar
Kishanganj
Dharan
Darjiling
Gangtok
Motihari
Sitamarhi
Xigaz
Sources: Esri, Garmin, USGS, NPS
1 in 500 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Fluvial - Defended
1 in 1000 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Pithoragarh
Pilibhit
UTTAR PRADESH
Shahjahanpur
Sitapur
Hardoi
Bahraich
Balrampur
Mahmudabad
Gonda
Sandila
Kannauj
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Tanda
Deoria
Motihari
Sitamarhi
Rae Bareli
Sultanpur
Azamgarh
Siwan
Muzaffarpur
Darbhanga
Saharsa
BIHAR
Fatehpur
Mau
Ballia
Chhapra
Ara
Patna
Jaunpur
Buxar
Banda
Allahabad
Baruni
Munger
Purnia
Katihar
Raiganj
Kishanganj
Dharan
Darjiling
Gangtok
SIKKIM
Sources: Esri, Garmin, USGS, NPS
1 in 1000 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

2.4. Fluvial Undefended: Nepal


Fluvial - Undefended
1 in 10 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Biratnagar
Dharan
Pithoragarh
Pilibhit
UTTAR PRADESH
Shahjahanpur
Sitapur
Hardoi
Sandila
Kannauj
Lucknow
Kanpur
Rae Bareli
Fatehpur
Banda
Allahabad
Bahraich
Balrampur
Mahmudabad
Gonda
Faizabad
Basti
Tanda
Sultanpur
Azamgarh
Jaunpur
Gorakhpur
Deoria
Bettiah
Bagaha
Motihari
Sitamarhi
Siwan
Mau
Ballia
Buxar
Chhapra
Ara
Muzaffarpur
Patna
Darbhanga
Saharsa
BIHAR
Baruni
Munger
Purnia
Katihar
Kishanganj
Raiganj
Darjiling
Gangtok
SIKKIM
Sources: Esri, Garmin, USGS, NPS
1 in 10 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Fluvial - Undefended
1 in 20 year event
0 50 100 200 km
1 in 20 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Biratnagar
Dharan
UTTAR PRADESH
BIHAR
SIKKIM
Sources: Esri, Garmin, USGS, NPS

Fluvial - Undefended
1 in 50 year event
0
50
100
200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Dharan
Biratnagar
Pithoragarh
Pilibhit
UTTAR PRADESH
Shahjahanpur
Sitapur
Hardoi
Mahmudabad
Bahraich
Balrampur
Gonda
Kannauj
Sandila
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Motihari
Sitamarhi
Tanda
Deoria
Rae Bareli
Sultanpur
Azamgarh
Siwan
Muzaffarpur
Darbhanga
Saharsa
BIHAR
Fatehpur
Mau
Ballia
Chhapra
Ara
Patna
Jaunpur
Buxar
Banda
Allahabad
Baruni
Munger
Purnia
Katihar
Kishanganj
Raiganj
SIKKIM
Gangtok
Darjiling
Xigaz
Sources: Esri, Garmin, USGS, NPS
1 in 50 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

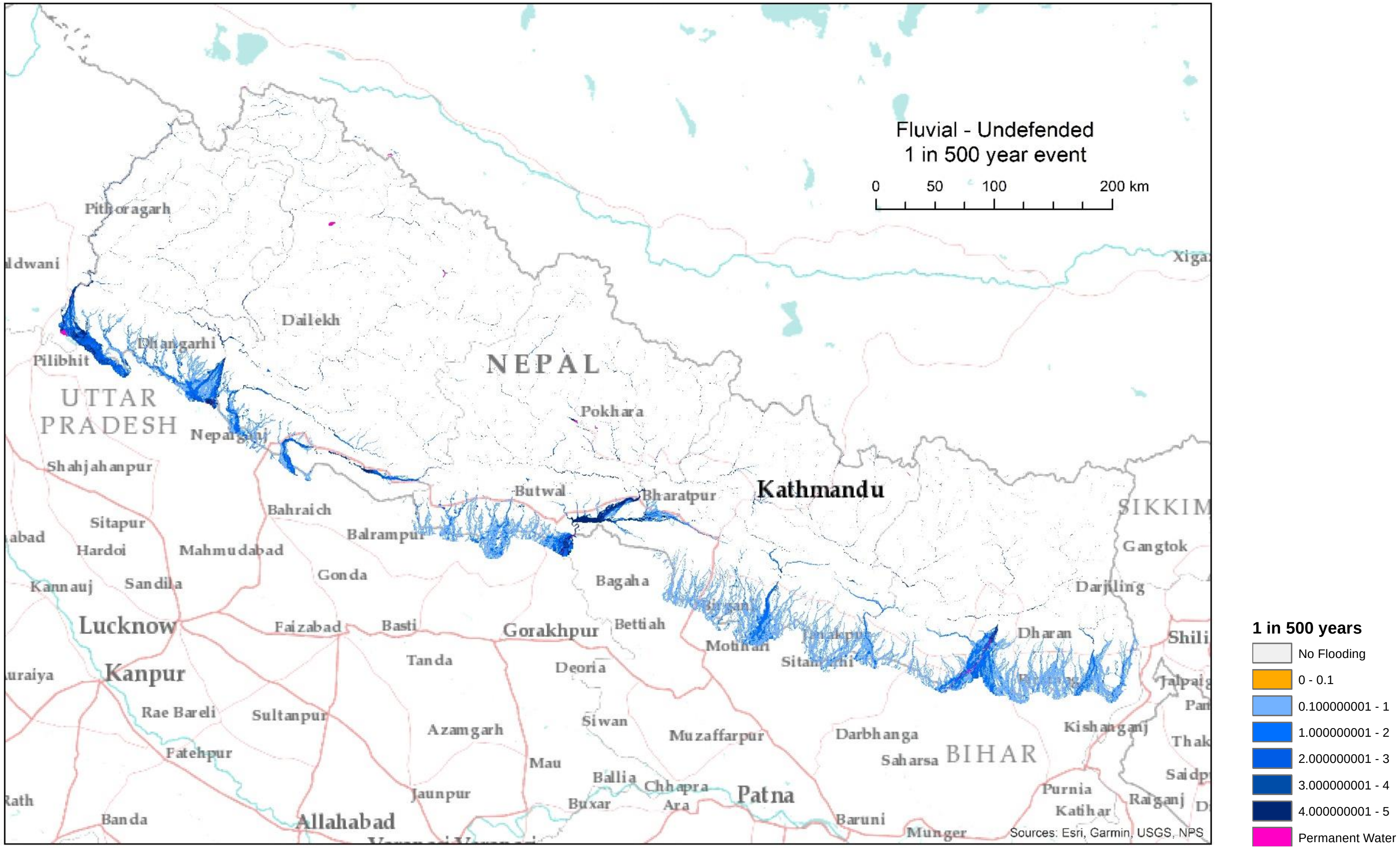
METEOR Hazard footprints for Nepal and Tanzania

Fluvial - Undefended
1 in 100 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Birganj
Janakpur
Dharan
Biratnagar
Pithoragarh
Pilibhit
UTTAR PRADESH
Shahjahanpur
Sitapur
Hardoi
Kannauj
Sandila
Mahmudabad
Bahraich
Balrampur
Gonda
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Motihari
Sitamarhi
Tanda
Deoria
Rae Bareli
Sultanpur
Azamgarh
Siwan
Muzaffarpur
Darbhanga
Saharsa
BIHAR
Fatehpur
Mau
Ballia
Chhapra
Ara
Patna
Buxar
Jaunpur
Allahabad
Banda
Baruni
Munger
Purnia
Katihar
Raiganj
Kishanganj
SIKKIM
Gangtok
Darjiling
Sources: Esri, Garmin, USGS, NPS

1 in 100 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

Fluvial - Undefended
1 in 200 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Pithoragarh
Pilibhit
UTTAR PRADESH
Shahjahanpur
Sitapur
Hardoi
Mahmudabad
Bahraich
Balrampur
Gonda
Kannauj
Sandila
Lucknow
Kanpur
Faizabad
Basti
Gorakhpur
Bettiah
Bagaha
Tanda
Deoria
Rae Bareli
Sultanpur
Azamgarh
Fatehpur
Siwan
Mau
Ballia
Chhapra
Ara
Patna
Buxar
Jaunpur
Allahabad
Banda
Muzaffarpur
Motihari
Sitamarhi
Darbhanga
Saharsa
BIHAR
Dharan
Darjiling
Gangtok
SIKKIM
Kishanganj
Purnia
Katihar
Baruni
Munger
Sources: Esri, Garmin, USGS, NPS
1 in 200 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

Fluvial - Undefended
1 in 250 year event
0 50 100 200 km
NEPAL
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Butwal
Bharatpur
Pithoragarh
Pilibhit
UTTAR PRADESH
Shahjahanpur
Sitapur
Hardoi
Bahraich
Balrampur
Mahmudabad
Gonda
Sandila
Kannauj
Lucknow
Kanpur
Faizabad
Basti
Tanda
Gorakhpur
Deoria
Bagaha
Bettiah
Motihari
Sitamarhi
Dharan
Darjiling
Gangtok
SIKKIM
Rae Bareli
Sultanpur
Azamgarh
Fatehpur
Mau
Siwan
Ballia
Chhapra
Ara
Buxar
Patna
Muzaffarpur
Darbhanga
Saharsa
BIHAR
Kishanganj
Purnia
Katihar
Raiganj
Jaunpur
Allahabad
Banda
Baruni
Munger
Xigaz
Sources: Esri, Garmin, USGS, NPS
1 in 250 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

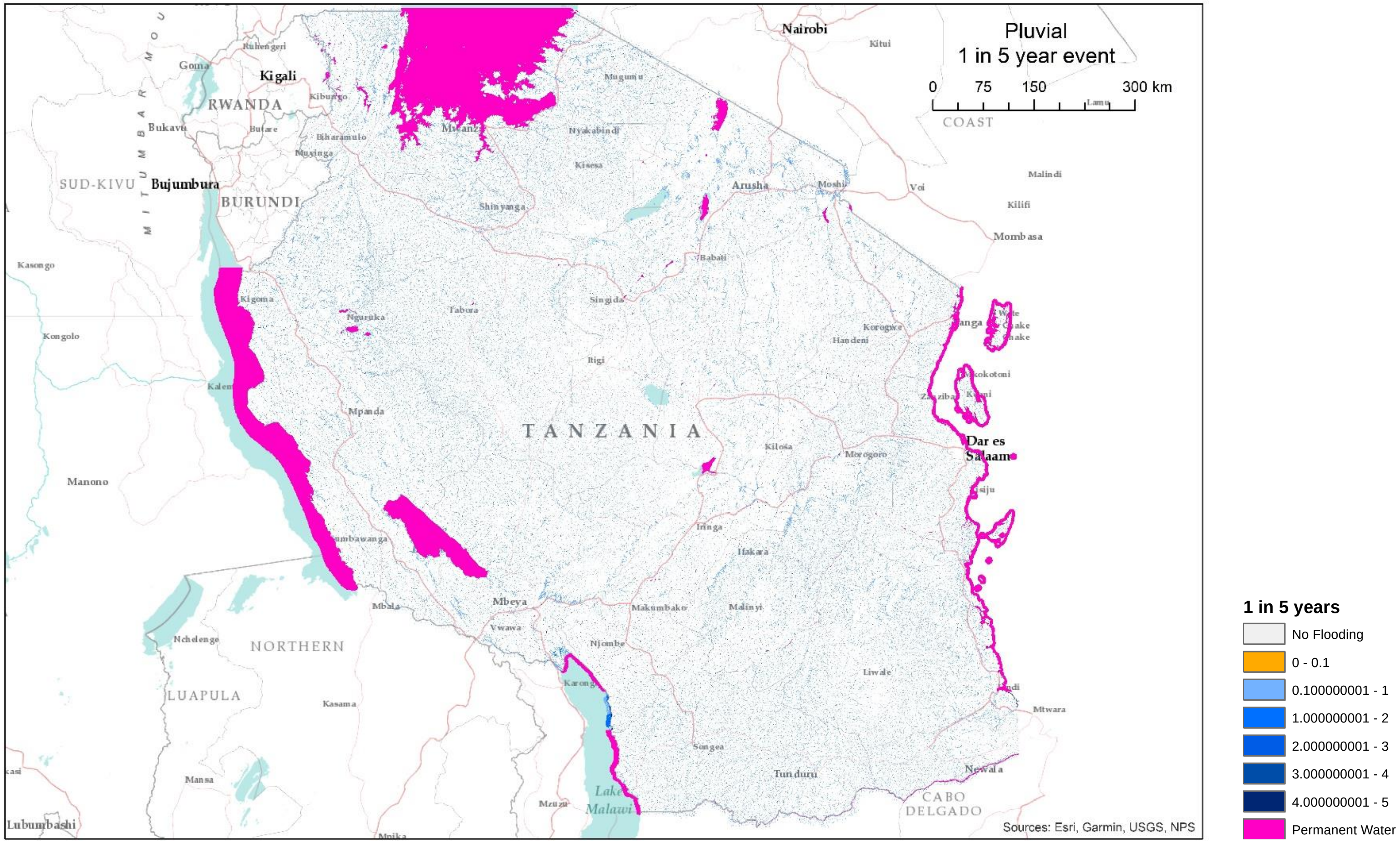

Fluvial - Undefended
1 in 500 year event
0
50
100
200 km
NEPAL
UTTAR PRADESH
BIHAR
SIKKIM
Kathmandu
Pokhara
Dailekh
Dhangarhi
Nepalganj
Pithoragarh
Pilibhit
Shahjahanpur
Sitapur
Hardoi
Kannauj
Sandila
Lucknow
Kanpur
Mahmudabad
Bahraich
Balrampur
Gonda
Faizabad
Basti
Tanda
Gorakhpur
Butwal
Bharatpur
Bagaha
Bettiah
Deoria
Motihari
Sitamarhi
Siwan
Muzaffarpur
Darbhanga
Saharsa
Dharan
Darjiling
Gangtok
Kishanganj
Purnia
Katihar
Raiganj
Rae Bareli
Sultanpur
Azamgarh
Fatehpur
Mau
Ballia
Chhapra
Ara
Buxar
Patna
Jaunpur
Allahabad
Banda
Baruni
Munger
Sources: Esri, Garmin, USGS, NPS
1 in 500 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

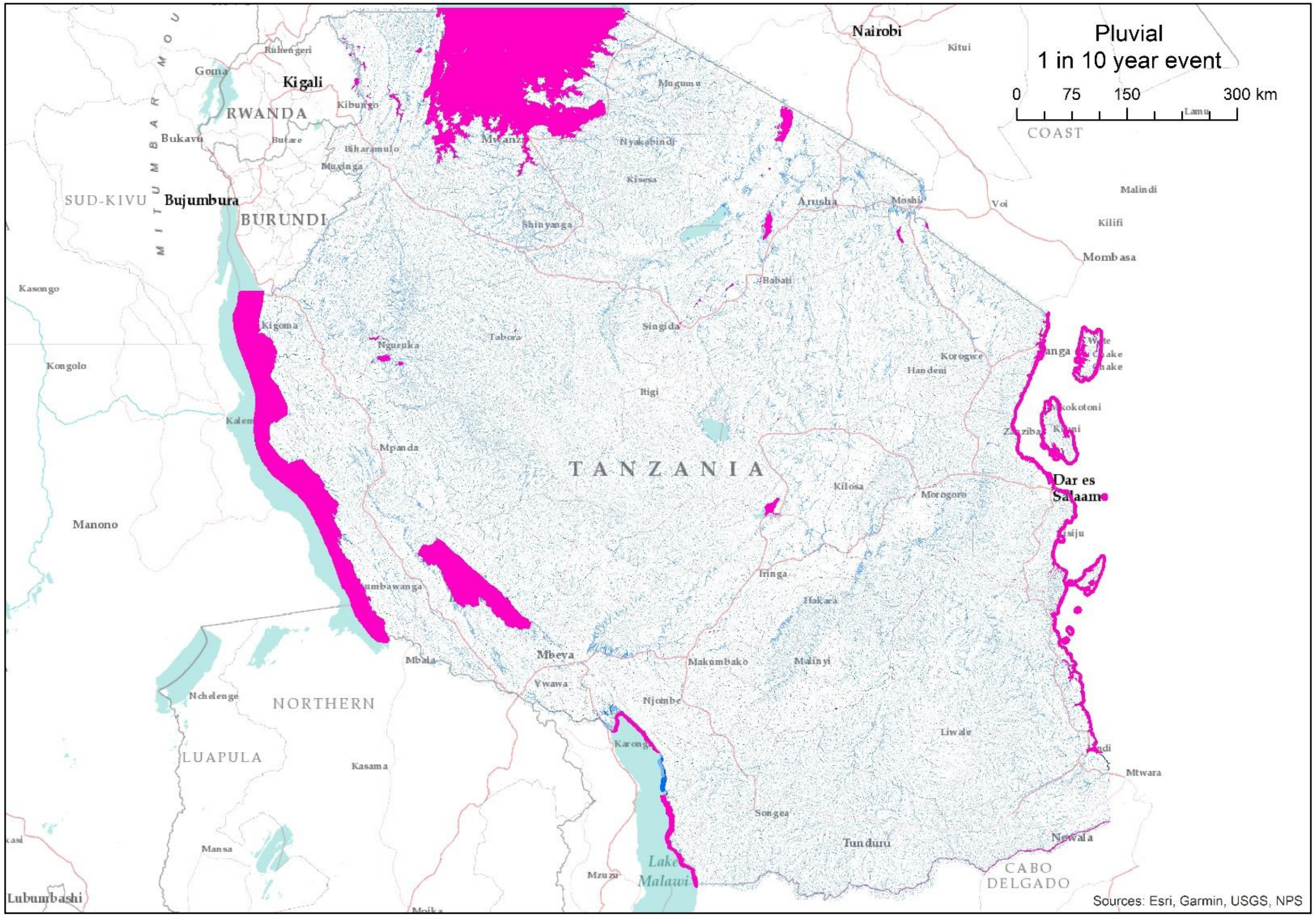
METEOR Hazard footprints for Nepal and Tanzania

2.5. Summary of Geospatial Detail of Flooding Hazard Products for Nepal

Layer	Return Period	Type	Format	Native Spatial Reference	Units	Cell Size	Data Type
Flooding: Pluvial	1 in 5 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 10 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 20 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 50 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 75 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 100 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 200 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 250 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 500 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 1000 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 5 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 10 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 20 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 50 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 75 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 100 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 200 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 250 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 500 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 1000 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 5 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 10 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 20 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 50 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 75 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 100 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 200 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 250 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 500 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 1000 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point

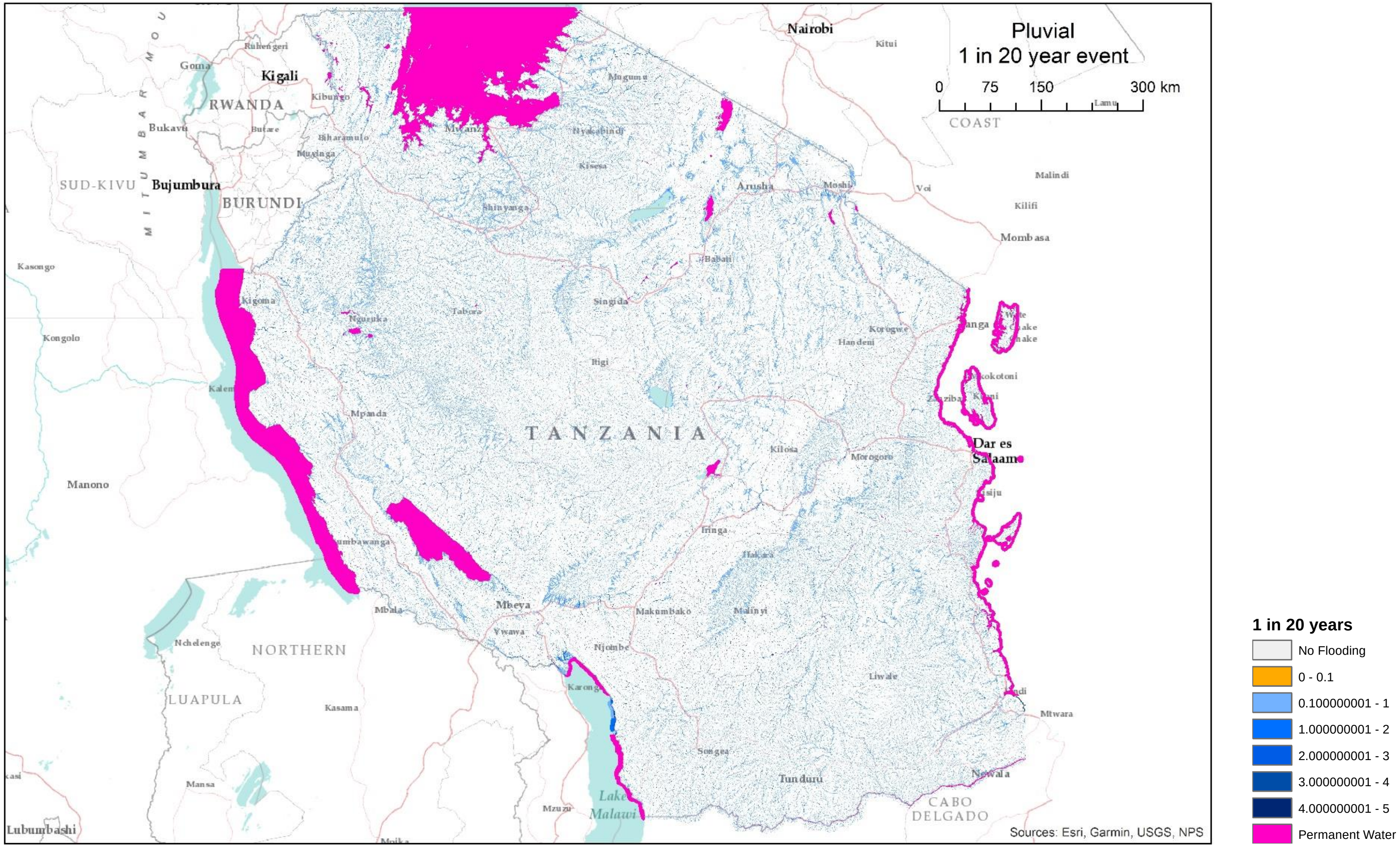
2.6. Pluvial: Tanzania

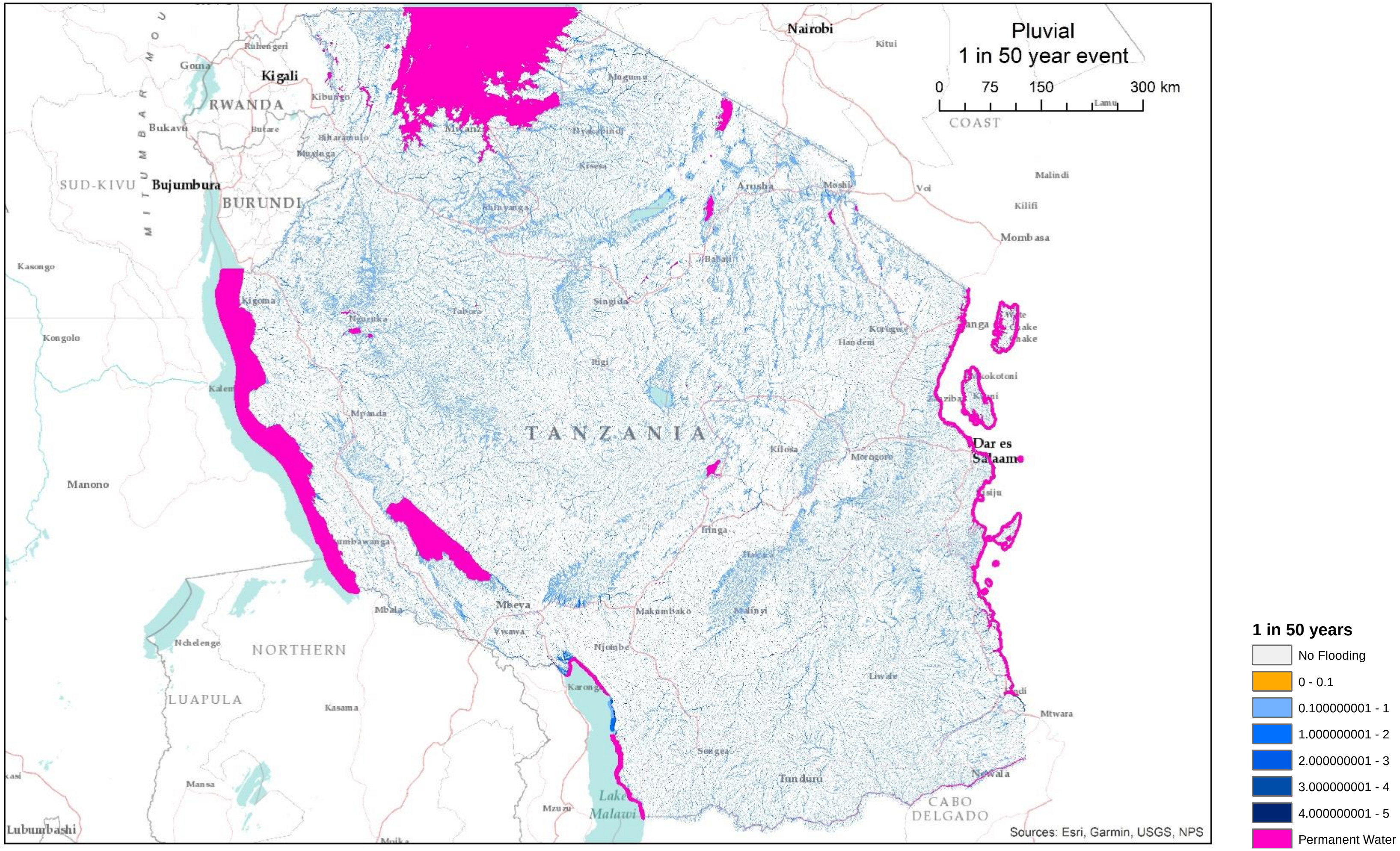




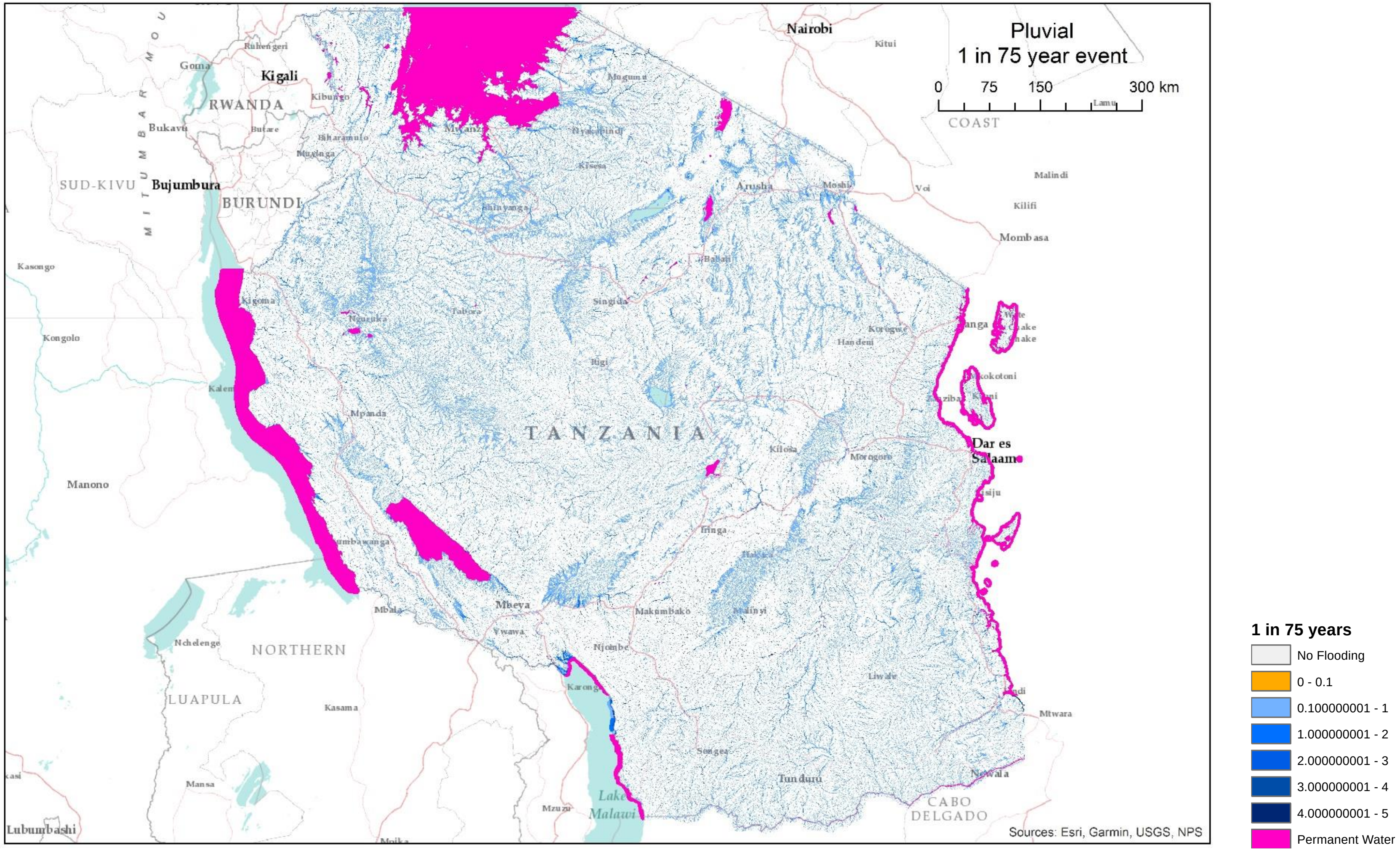
1 in 10 years

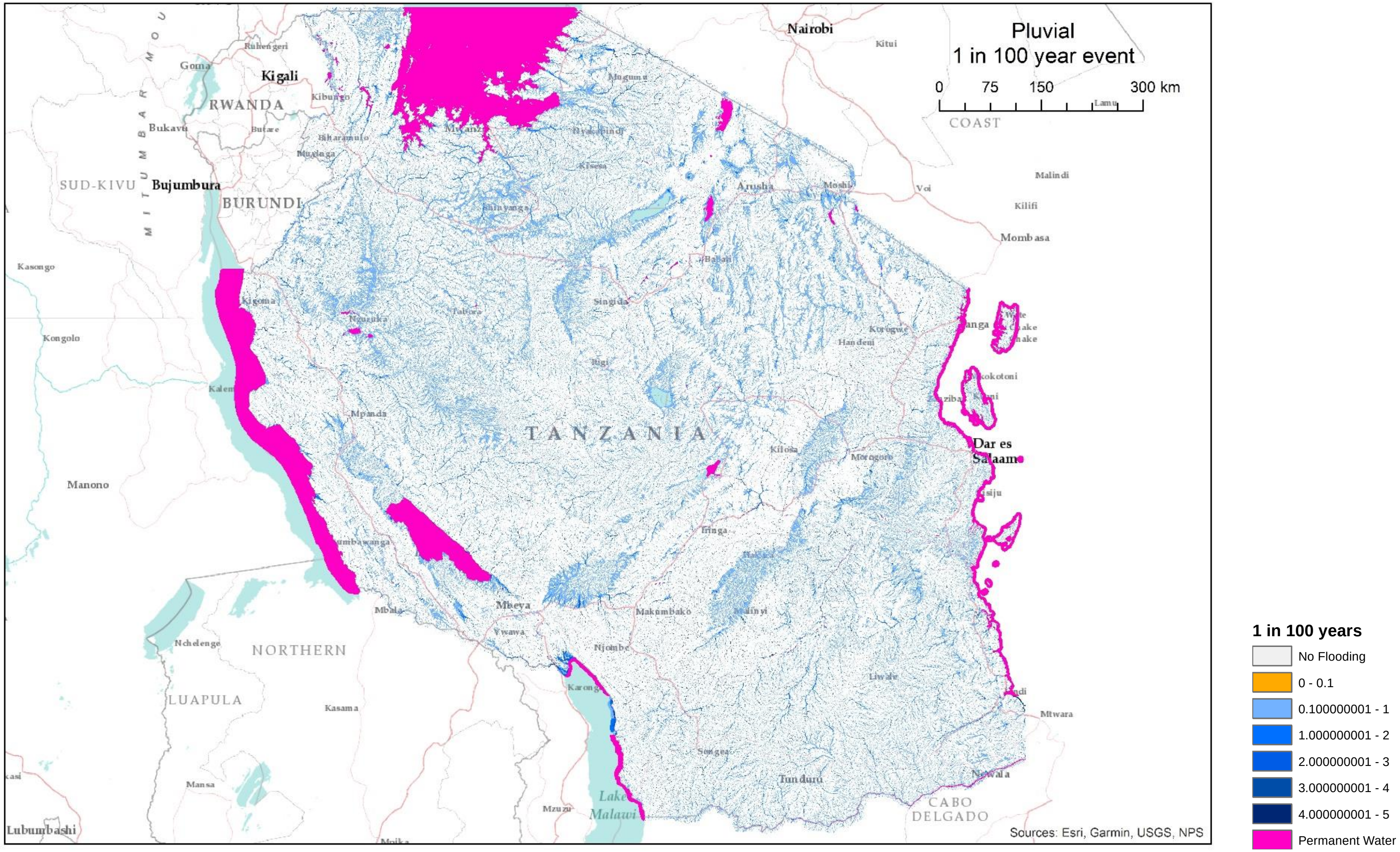
- No Flooding
- 0 - 0.1
- 0.100000001 - 1
- 1.000000001 - 2
- 2.000000001 - 3
- 3.000000001 - 4
- 4.000000001 - 5
- Permanent Water

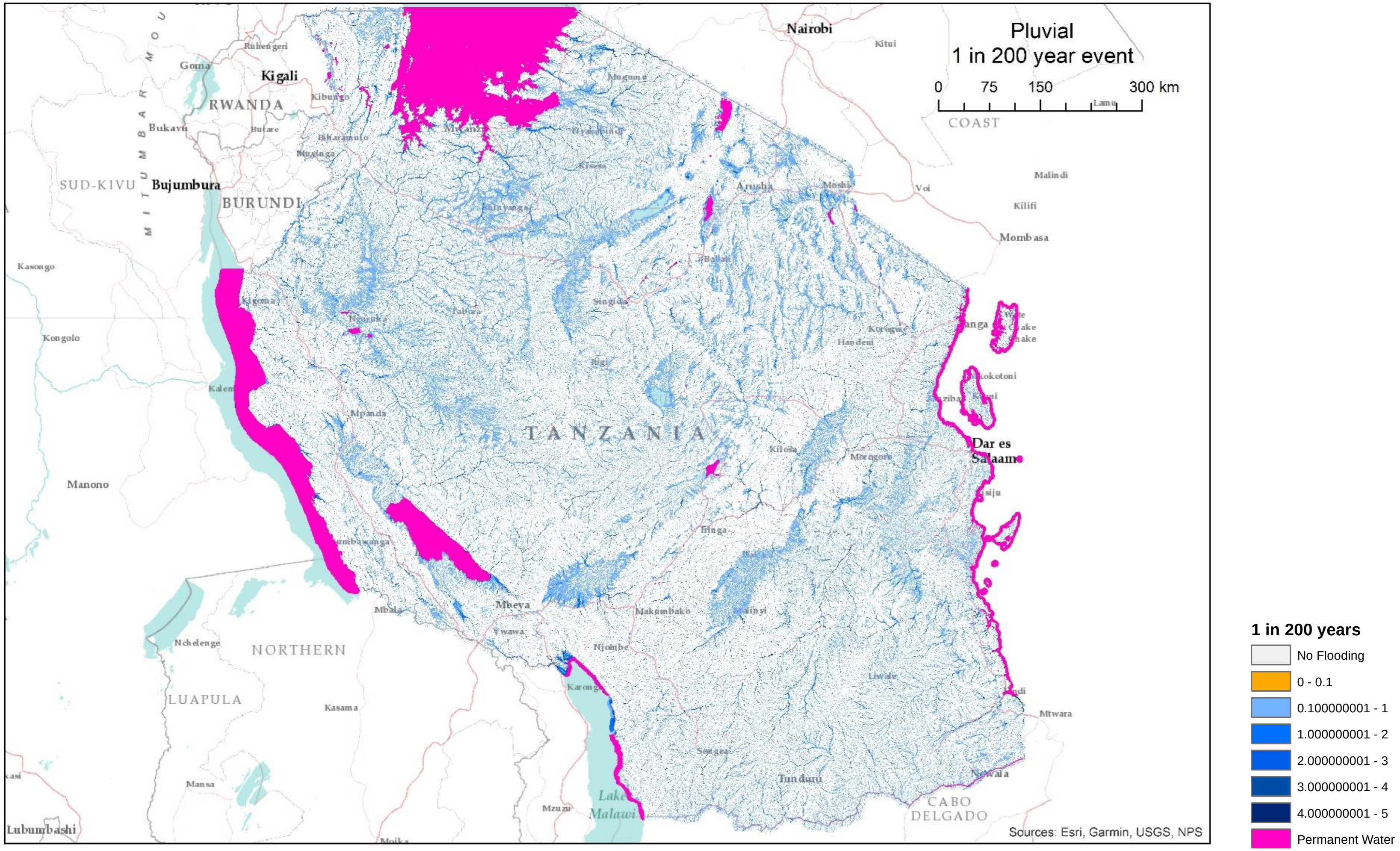

Pluvial
1 in 20 year event
0 75 150 300 km
Nairobi
Kigali
RWANDA
Bujumbura
BURUNDI
SUD-KIVU
TANZANIA
Dar es Salaam
Mbeya
NORTHERN
LUAPULA
Lubumbashi
Lake Malawi
CABO DELGADO
COAST
Sources: Esri, Garmin, USGS, NPS
1 in 20 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

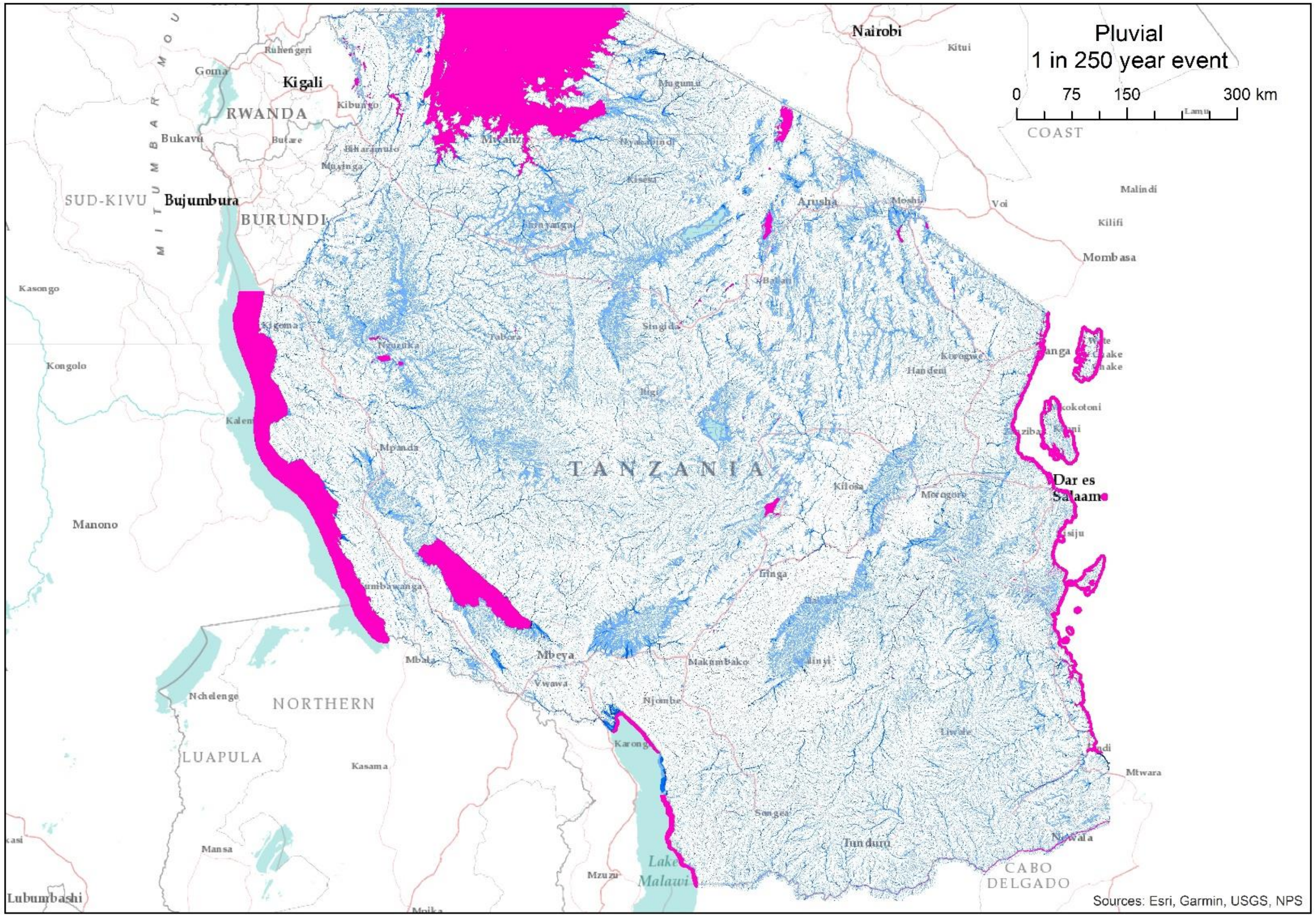

Pluvial
1 in 50 year event
0 75 150 300 km
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
SUD-KIVU
TANZANIA
Arusha
Moshi
Mombasa
Dar es Salaam
Kigoma
Mpanda
Mbeya
Iringa
Morogoro
Tunduru
Mtwara
NORTHERN
LUAPULA
Lake Malawi
CABO DELGADO
Lubumbashi
Manono
Sources: Esri, Garmin, USGS, NPS
1 in 50 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

METEOR Hazard footprints for Nepal and Tanzania




Pluvial
1 in 100 year event
0 75 150 300 km
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
SUD-KIVU
TANZANIA
Dar es Salaam
Mbeya
Lake Malawi
NORTHERN
LUAPULA
COAST
CABO DELGADO
Lubumbashi
Sources: Esri, Garmin, USGS, NPS
1 in 100 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

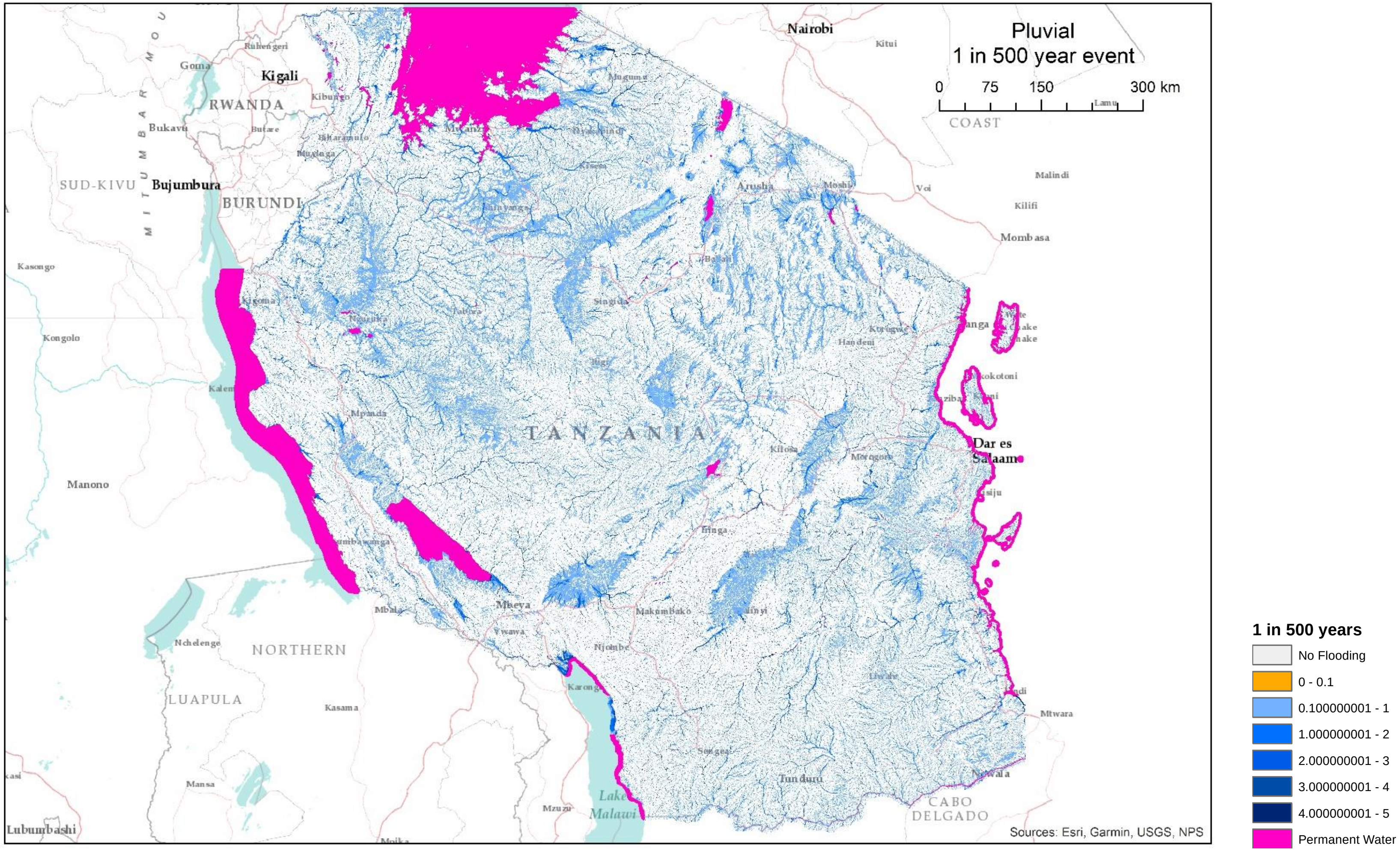

Pluvial
1 in 200 year event
0 75 150 300 km
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
SUD-KIVU
TANZANIA
Dar es Salaam
Arusha
Moshi
Mombasa
Malindi
Kilifi
Kitui
Voi
COAST
Goma
Bukavu
Kasongo
Kongolo
Manono
NORTHERN
LUAPULA
Kasama
Mansa
Lubumbashi
Mbeya
Iringa
Morogoro
Singida
Tabora
Kigoma
Mpanda
Songea
Tunduru
Mtwara
Lake Malawi
CABO DELGADO
Sources: Esri, Garmin, USGS, NPS
1 in 200 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

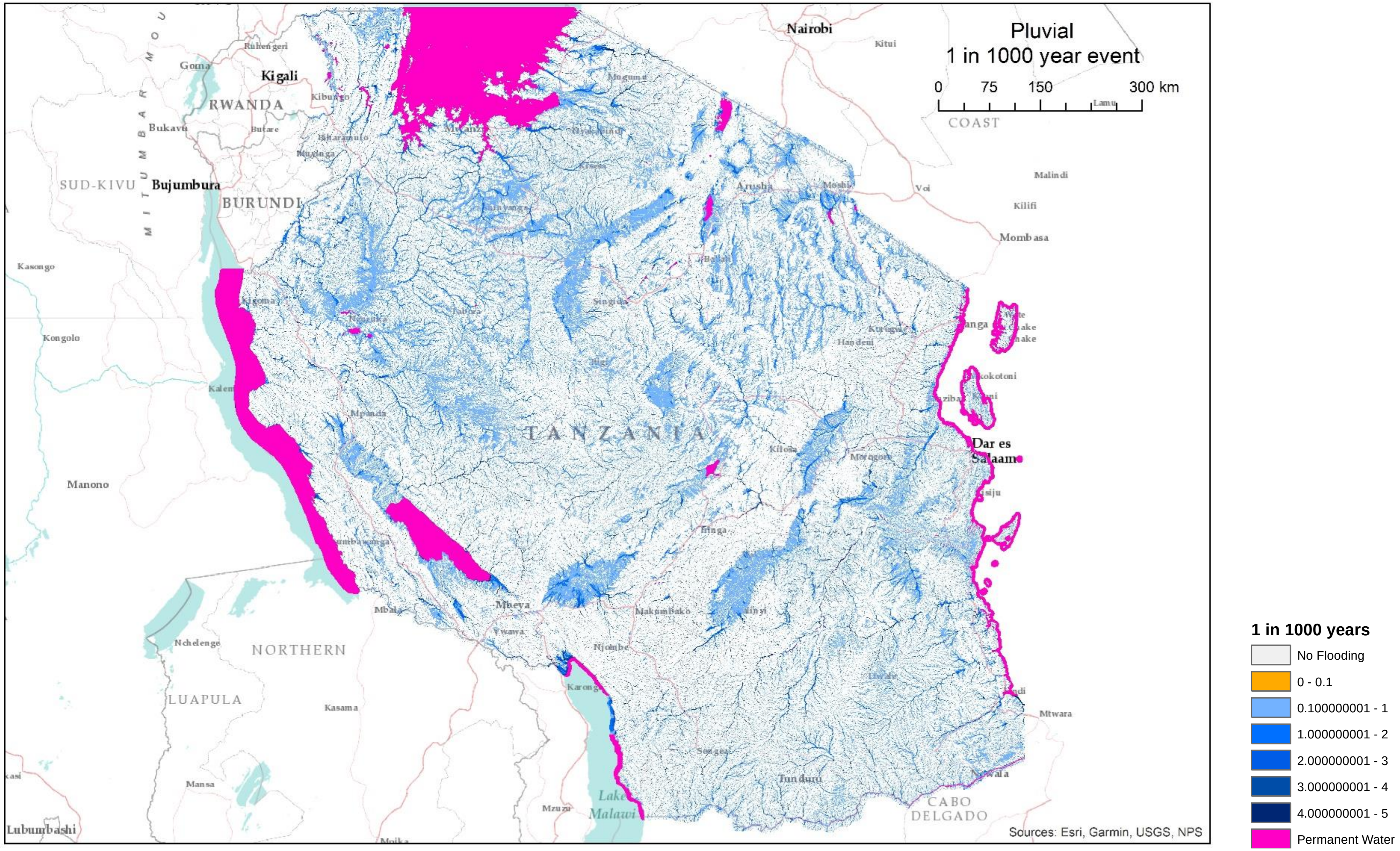


1 in 250 years

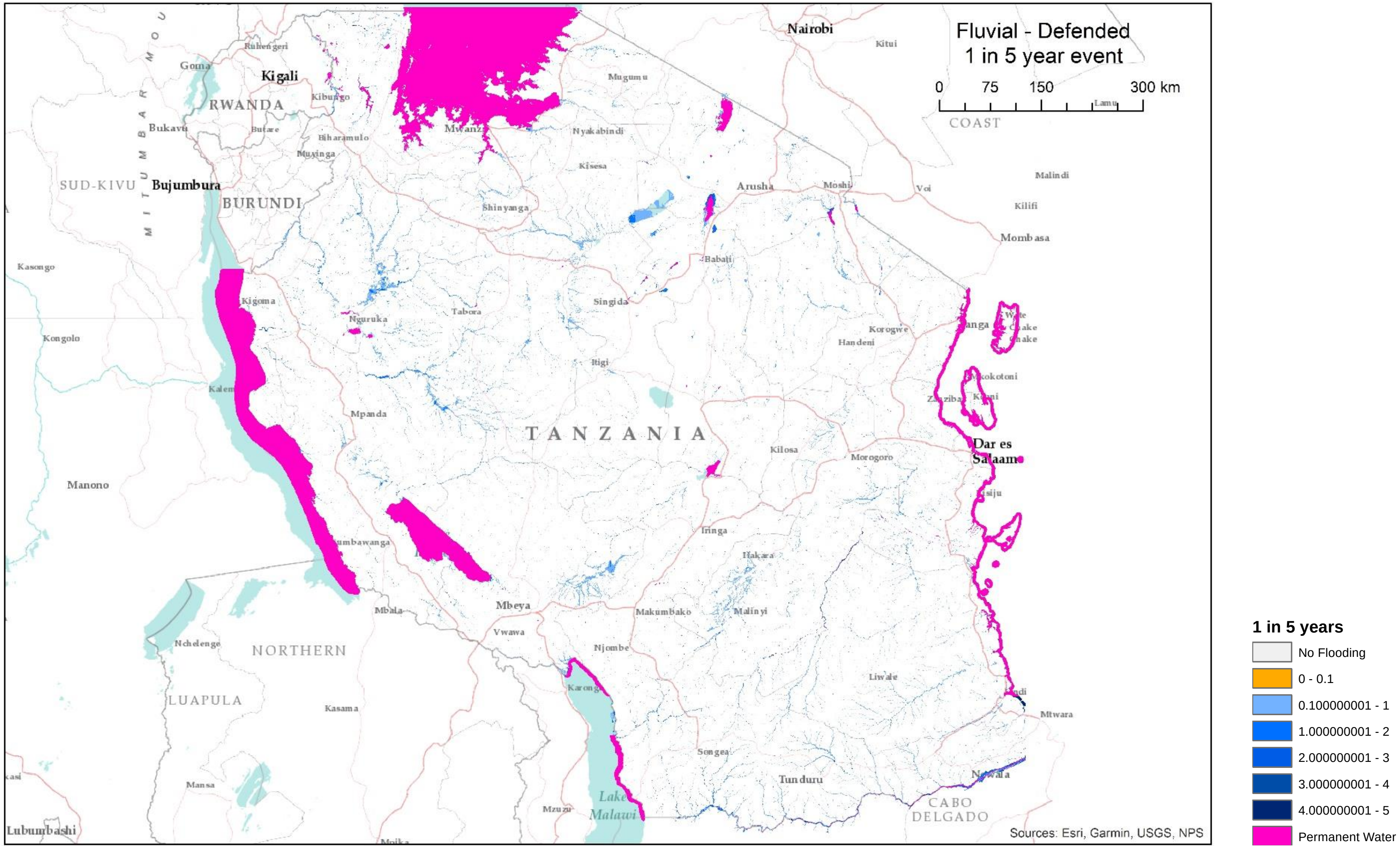
- No Flooding
- 0 - 0.1
- 0.100000001 - 1
- 1.000000001 - 2
- 2.000000001 - 3
- 3.000000001 - 4
- 4.000000001 - 5
- Permanent Water

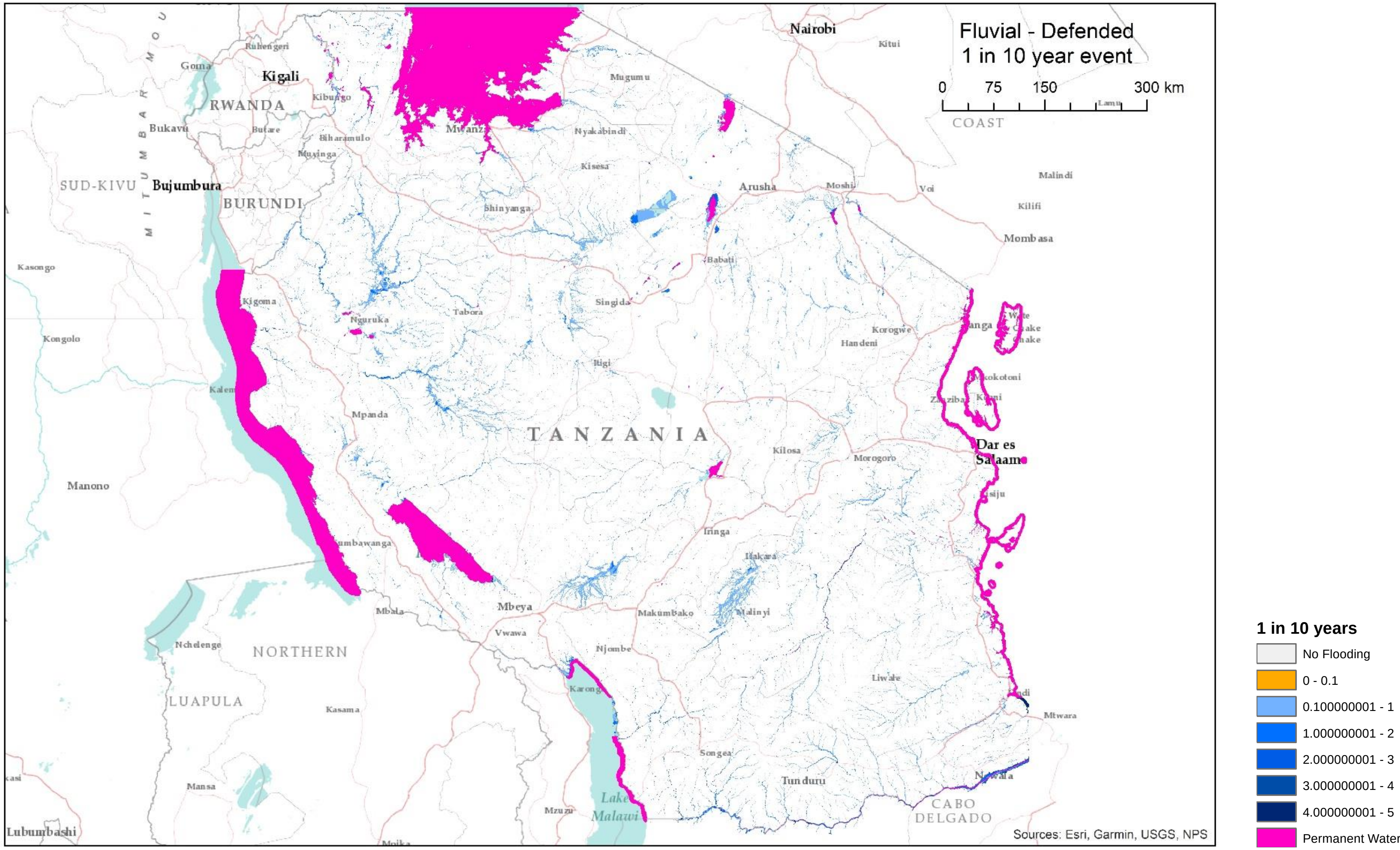
METEOR Hazard footprints for Nepal and Tanzania

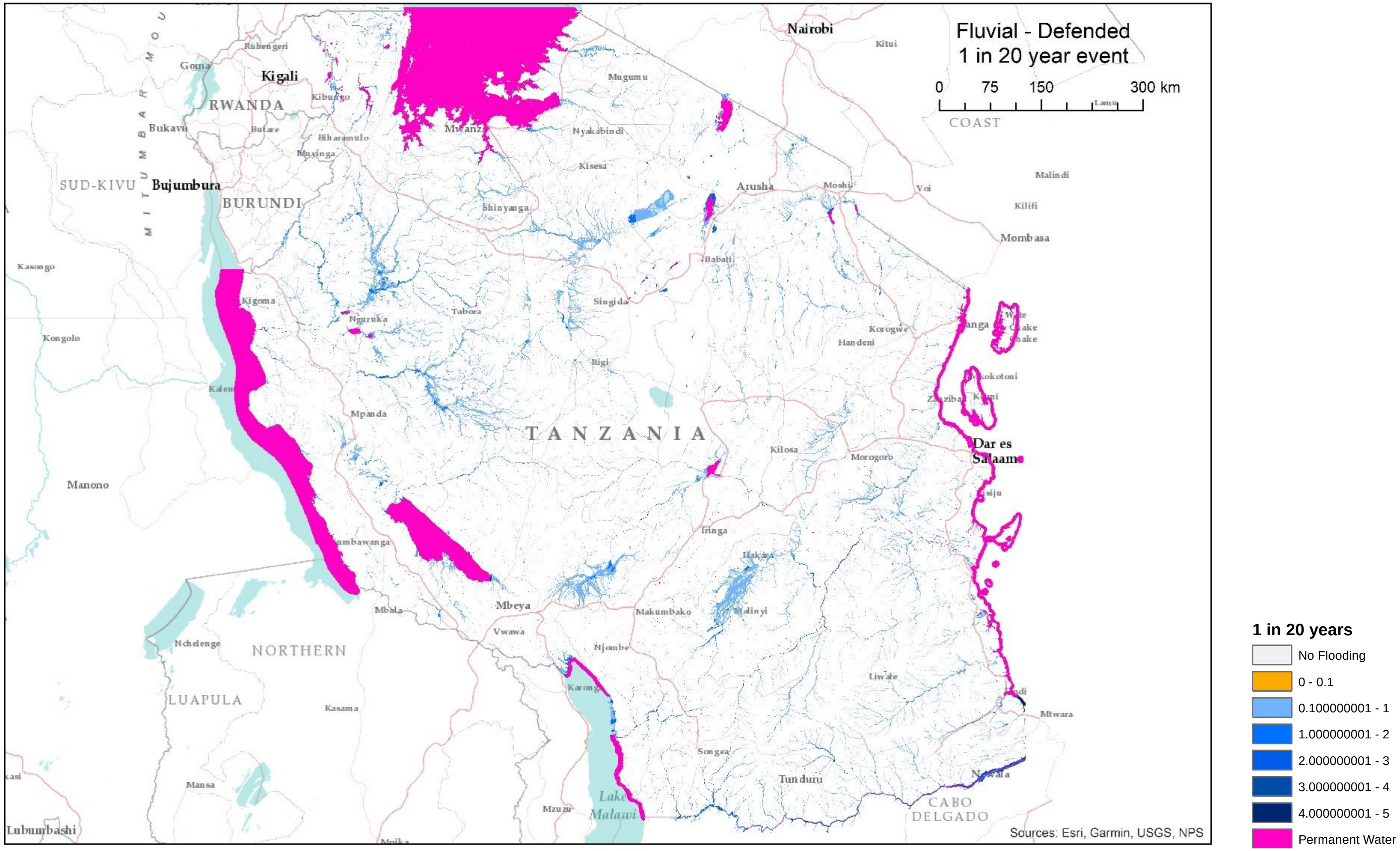


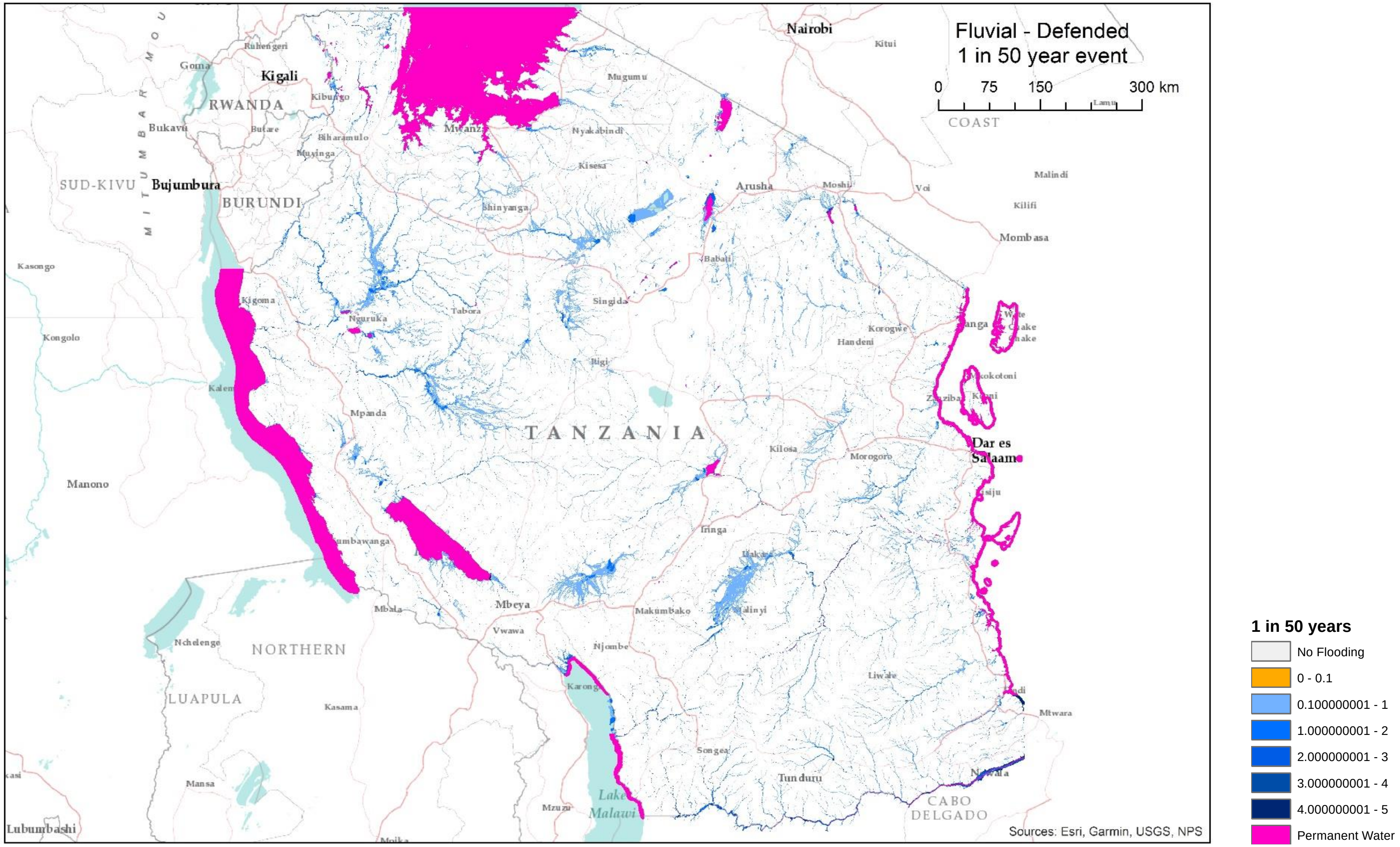

Pluvial
1 in 1000 year event
0 75 150 300 km
TANZANIA
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
Dar es Salaam
Mbeya
Arusha
Mombasa
Lake Malawi
NORTHERN
LUAPULA
SUD-KIVU
Lubumbashi
CABO DELGADO
COAST
Sources: Esri, Garmin, USGS, NPS
1 in 1000 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

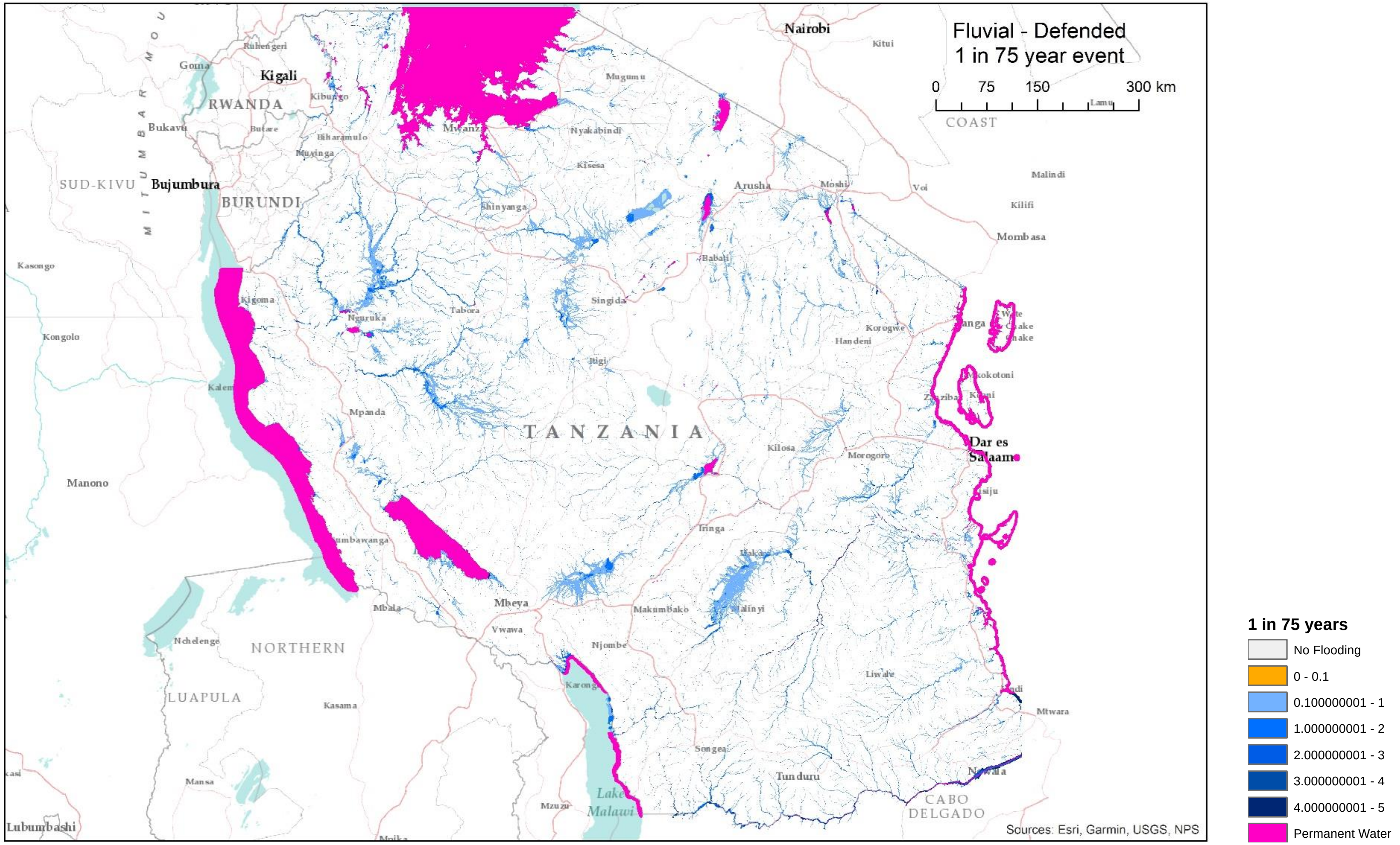
2.7. Fluvial Defended: Tanzania

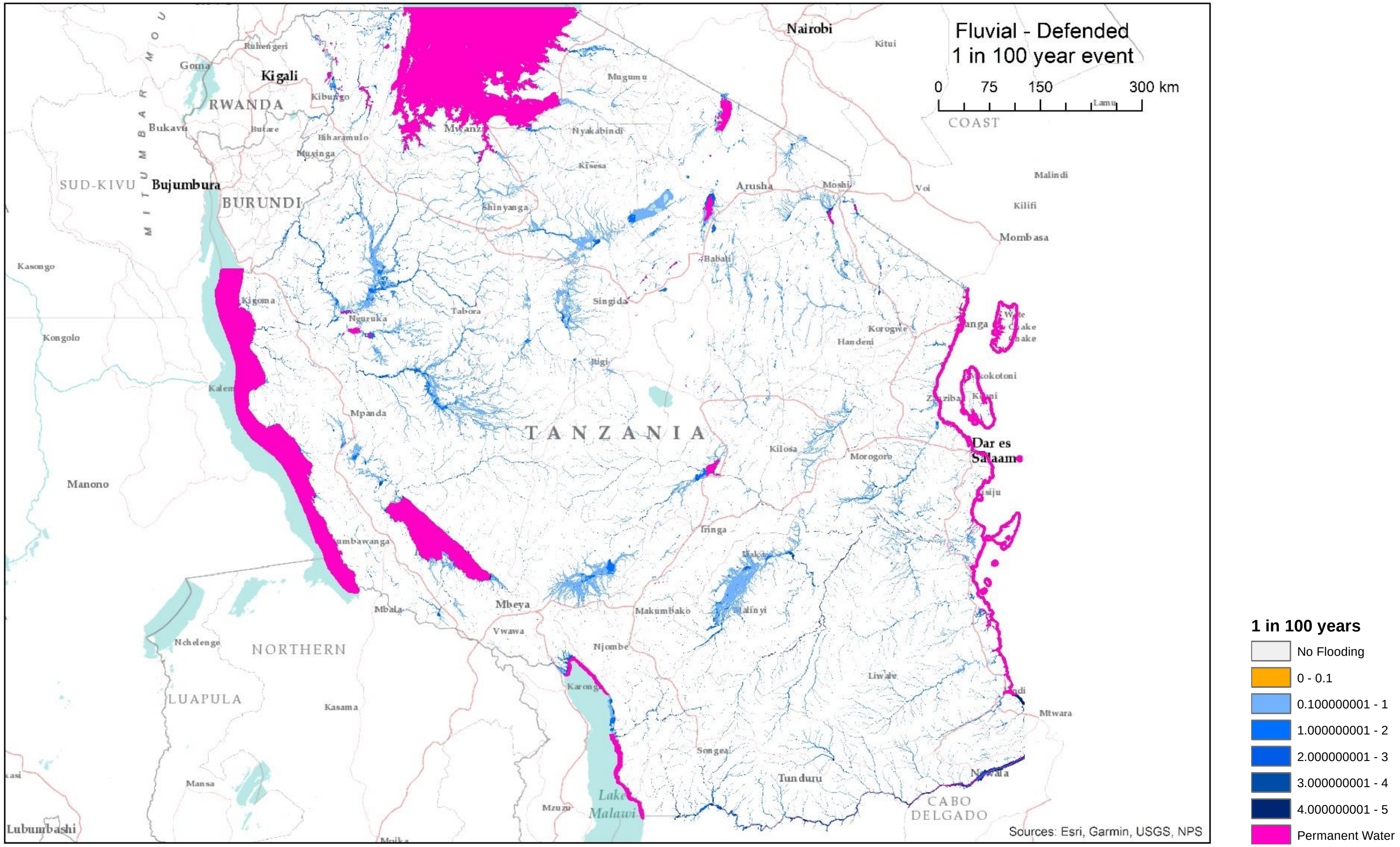


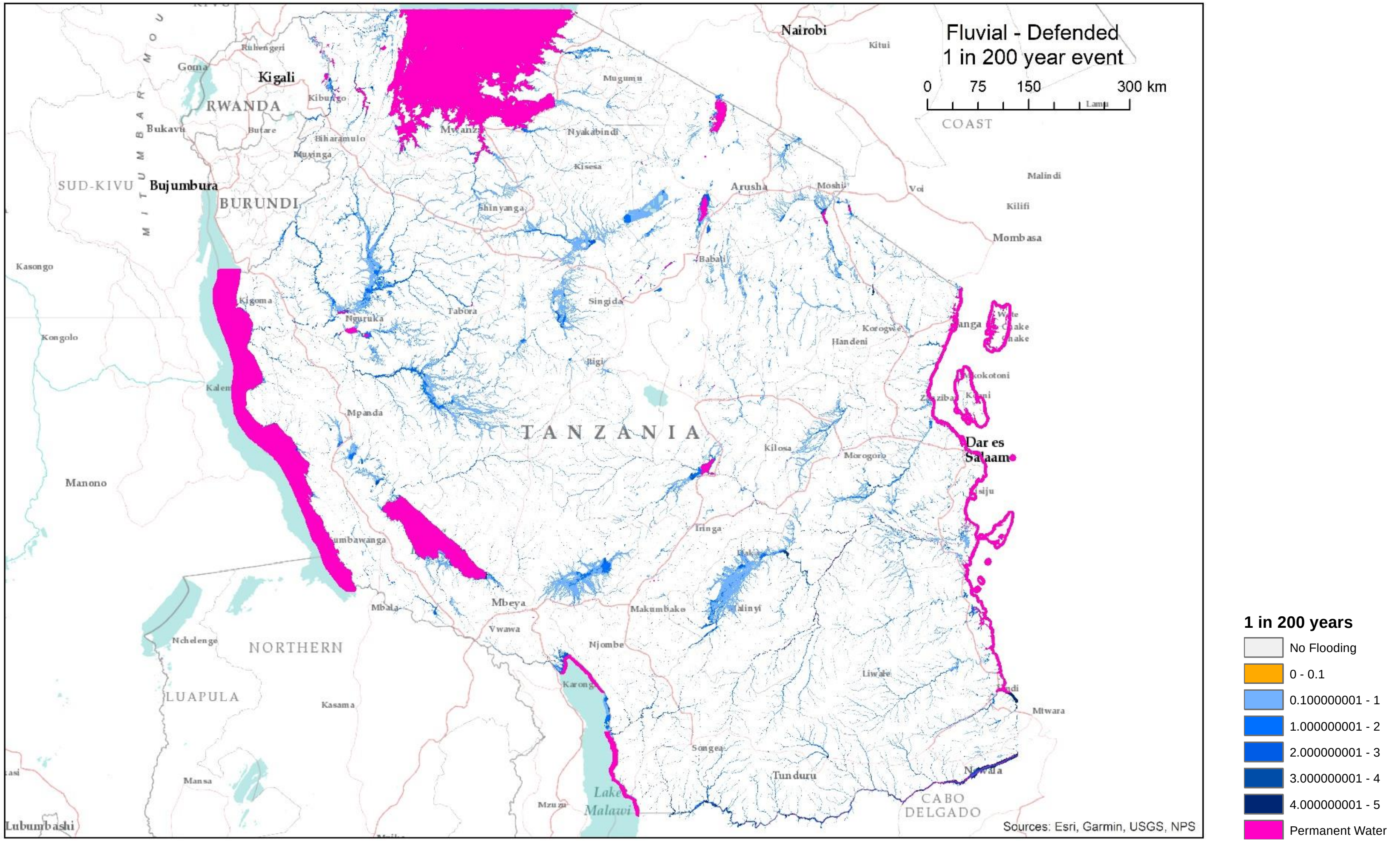

Fluvial - Defended
1 in 10 year event
0 75 150 300 km
T A N Z A N I A
RWANDA
BURUNDI
NORTHERN
LUAPULA
SUD-KIVU
COAST
CABO DELGADO
Nairobi
Kigali
Bujumbura
Mwanza
Shinyanga
Arusha
Moshi
Babati
Singida
Tabora
Kigoma
Mpanda
Sumbawanga
Mbeya
Iringa
Morogoro
Dar es Salaam
Tunduru
Songea
Njombe
Mombasa
Lake Malawi
Sources: Esri, Garmin, USGS, NPS
1 in 10 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

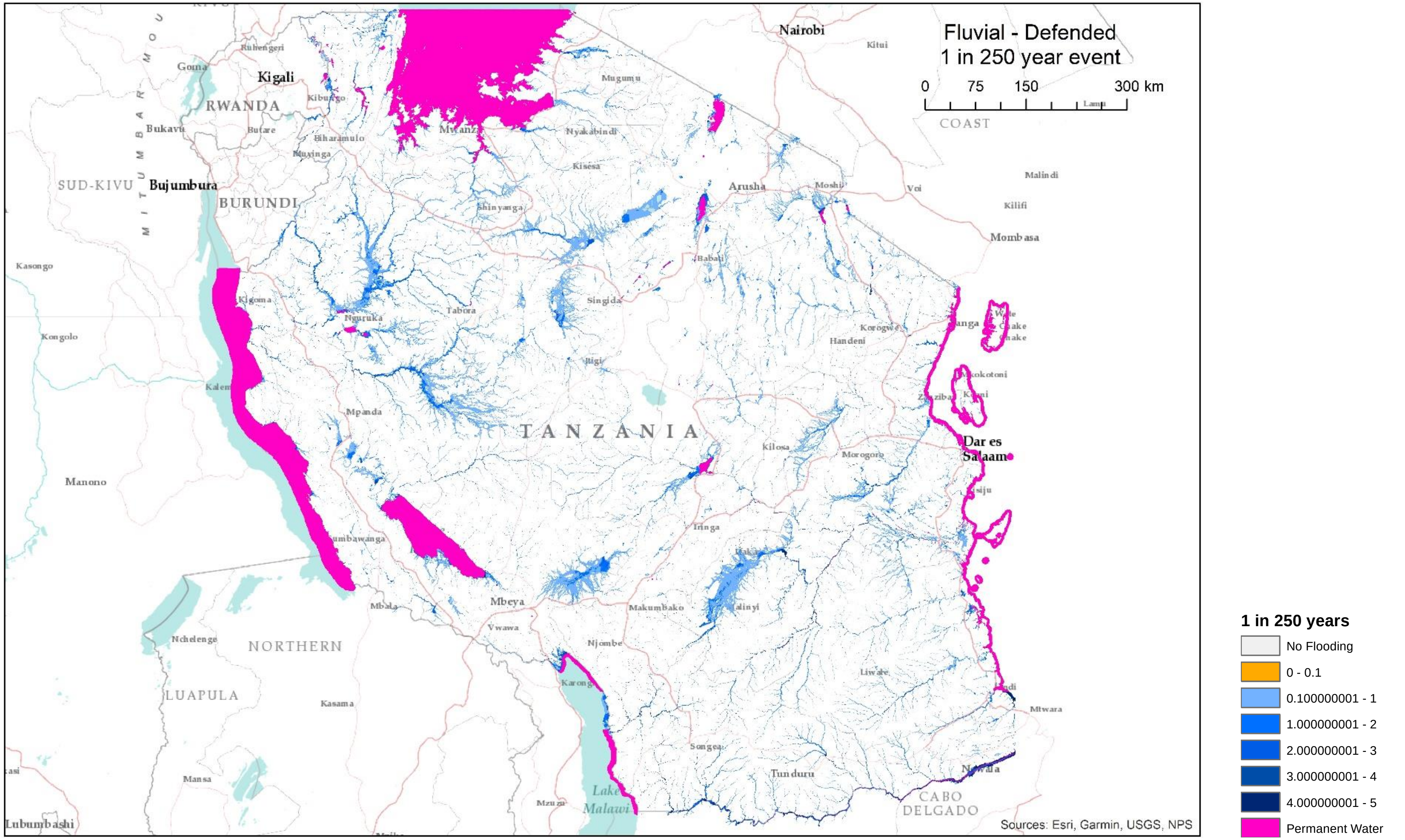

Fluvial - Defended
1 in 20 year event
0 75 150 300 km
TANZANIA
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
SUD-KIVU
NORTHERN
LUAPULA
Arusha
Dar es Salaam
Mbeya
Lake Malawi
CABO DELGADO
Sources: Esri, Garmin, USGS, NPS
1 in 20 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

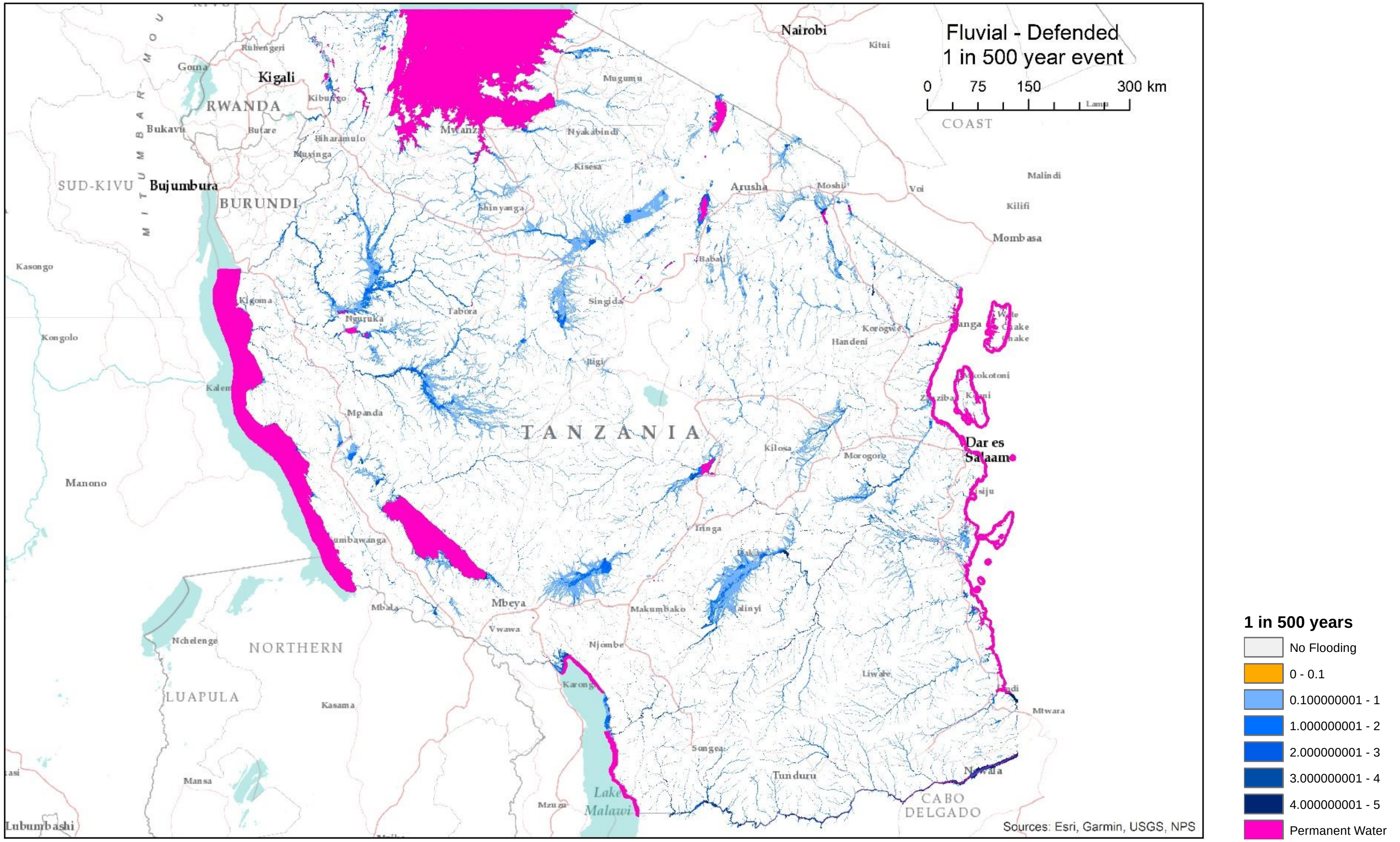

Fluvial - Defended
1 in 50 year event
0 75 150 300 km
TANZANIA
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
SUD-KIVU
NORTHERN
LUAPULA
Arusha
Mwanza
Shinyanga
Tabora
Kigoma
Mpanda
Mbeya
Iringa
Dar es Salaam
Mtwara
Mombasa
Lake Malawi
Lubumbashi
Manono
Sources: Esri, Garmin, USGS, NPS
1 in 50 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

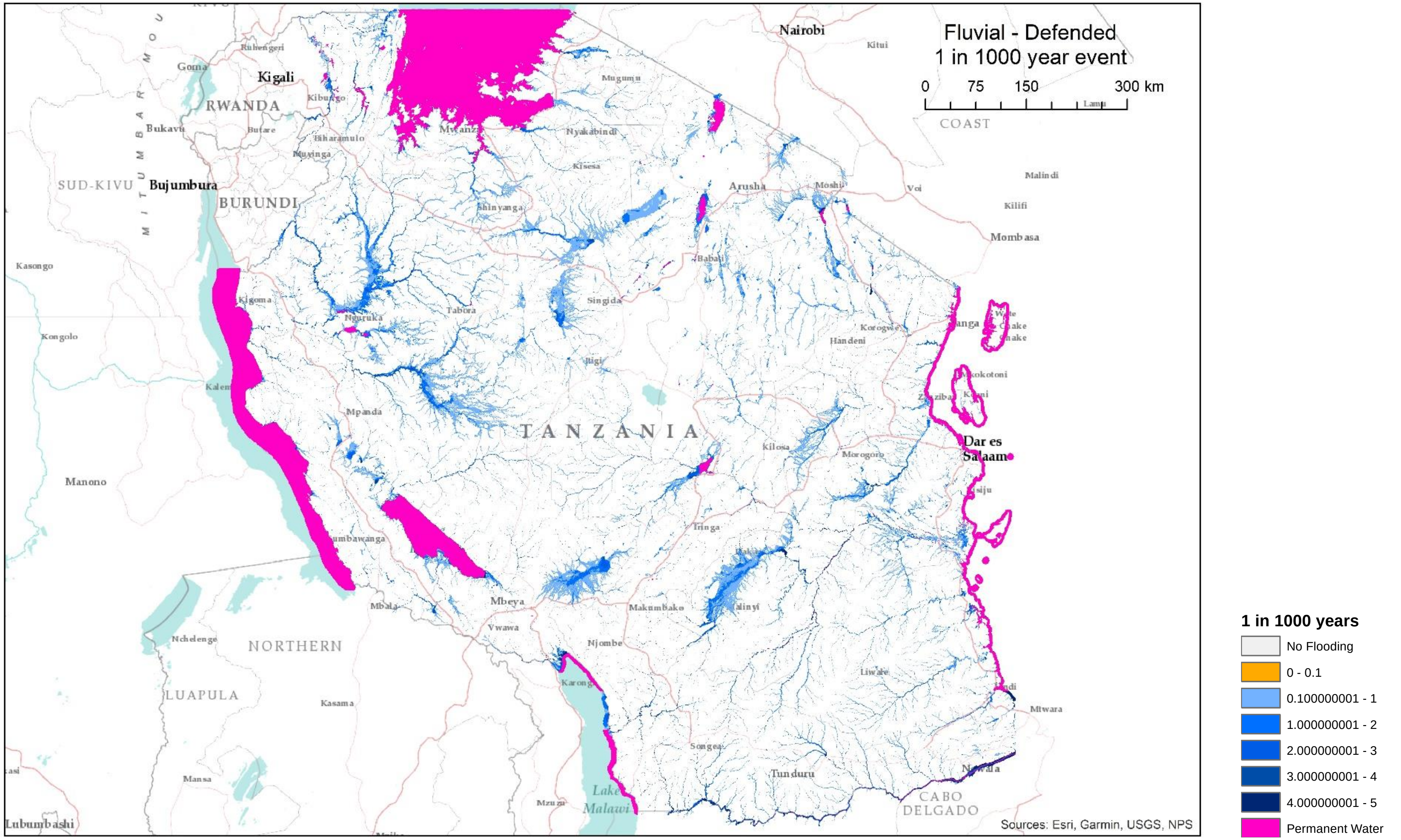

Fluvial - Defended
1 in 75 year event
0 75 150 300 km
TANZANIA
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
SUD-KIVU
Goma
Bukavu
Kigoma
Mwanza
Arusha
Moshi
Tabora
Singida
Mpanda
Mbeya
Iringa
Dar es Salaam
Morogoro
Tanga
Mombasa
Malindi
Kilifi
Voi
Kitui
Lake Malawi
NORTHERN
LUAPULA
CABO DELGADO
Mtwara
Tunduru
Songea
Njombe
Lubumbashi
Manono
Kongolo
Kasongo
Mansa
Kasama
Sources: Esri, Garmin, USGS, NPS
1 in 75 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Fluvial - Defended
1 in 100 year event
0 75 150 300 km
Sources: Esri, Garmin, USGS, NPS
1 in 100 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

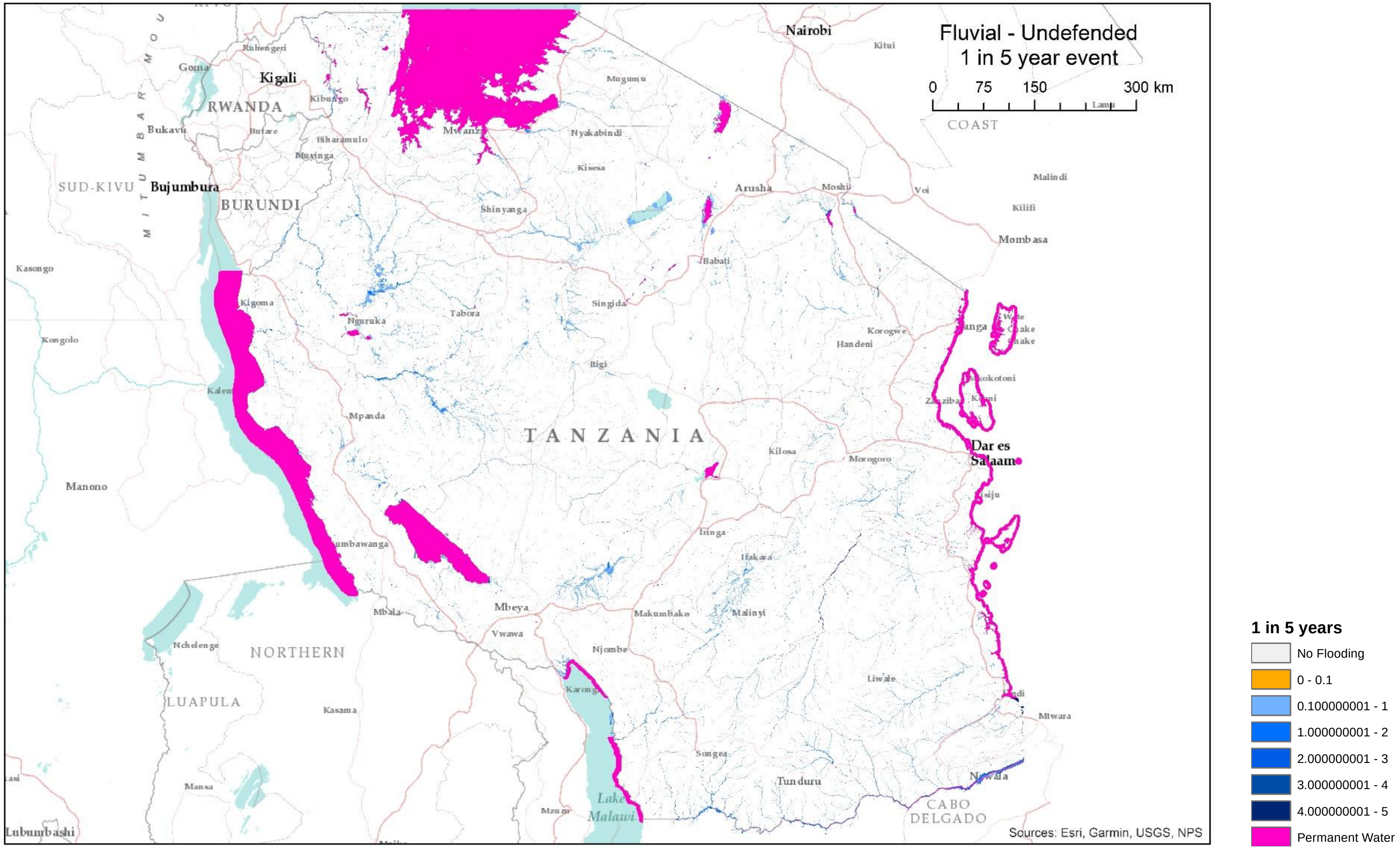

Fluvial - Defended
1 in 200 year event
0 75 150 300 km
1 in 200 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water
Sources: Esri, Garmin, USGS, NPS
TANZANIA
Dar es Salaam
Nairobi
Kigali
Bujumbura
RWANDA
BURUNDI

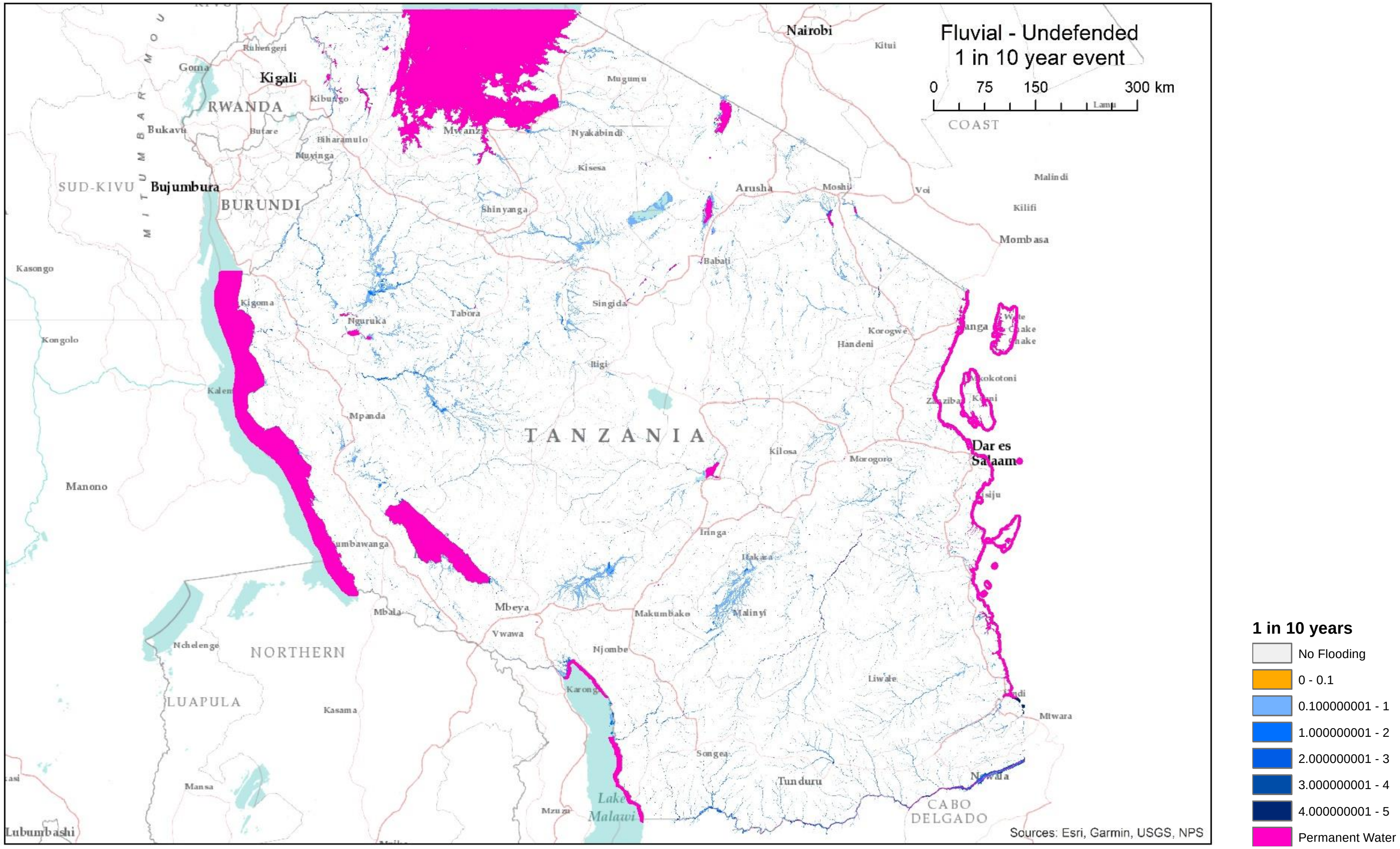

Fluvial - Defended
1 in 250 year event
0 75 150 300 km
TANZANIA
1 in 250 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water
Sources: Esri, Garmin, USGS, NPS

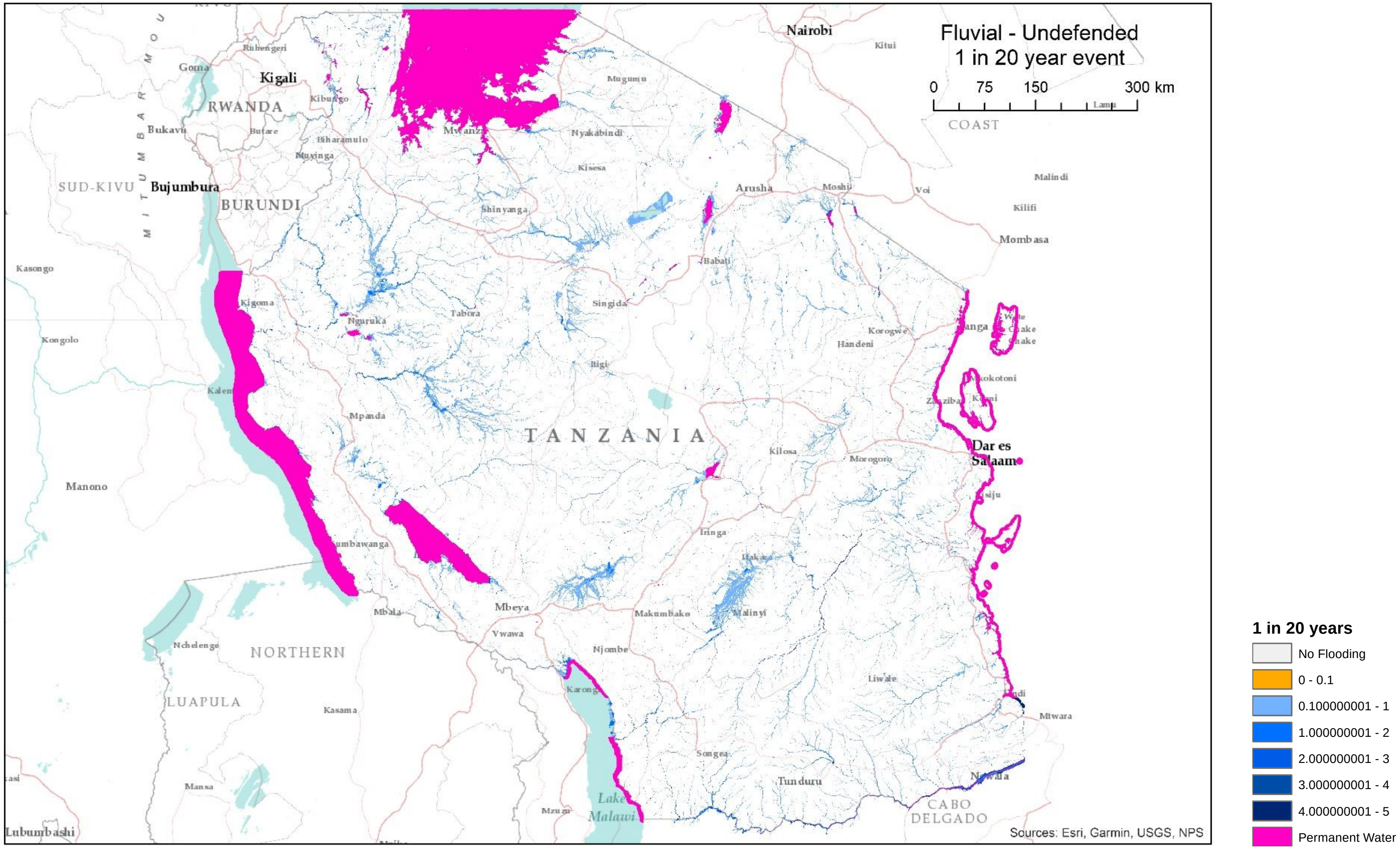

Fluvial - Defended
1 in 500 year event
0 75 150 300 km
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
TANZANIA
Arusha
Moshi
Mombasa
Dar es Salaam
Mbeya
Mwanza
Kigoma
Tabora
Singida
Morogoro
Iringa
Songea
Tunduru
Mtwara
Lake Malawi
NORTHERN
LUAPULA
SUD-KIVU
Lubumbashi
Sources: Esri, Garmin, USGS, NPS
1 in 500 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

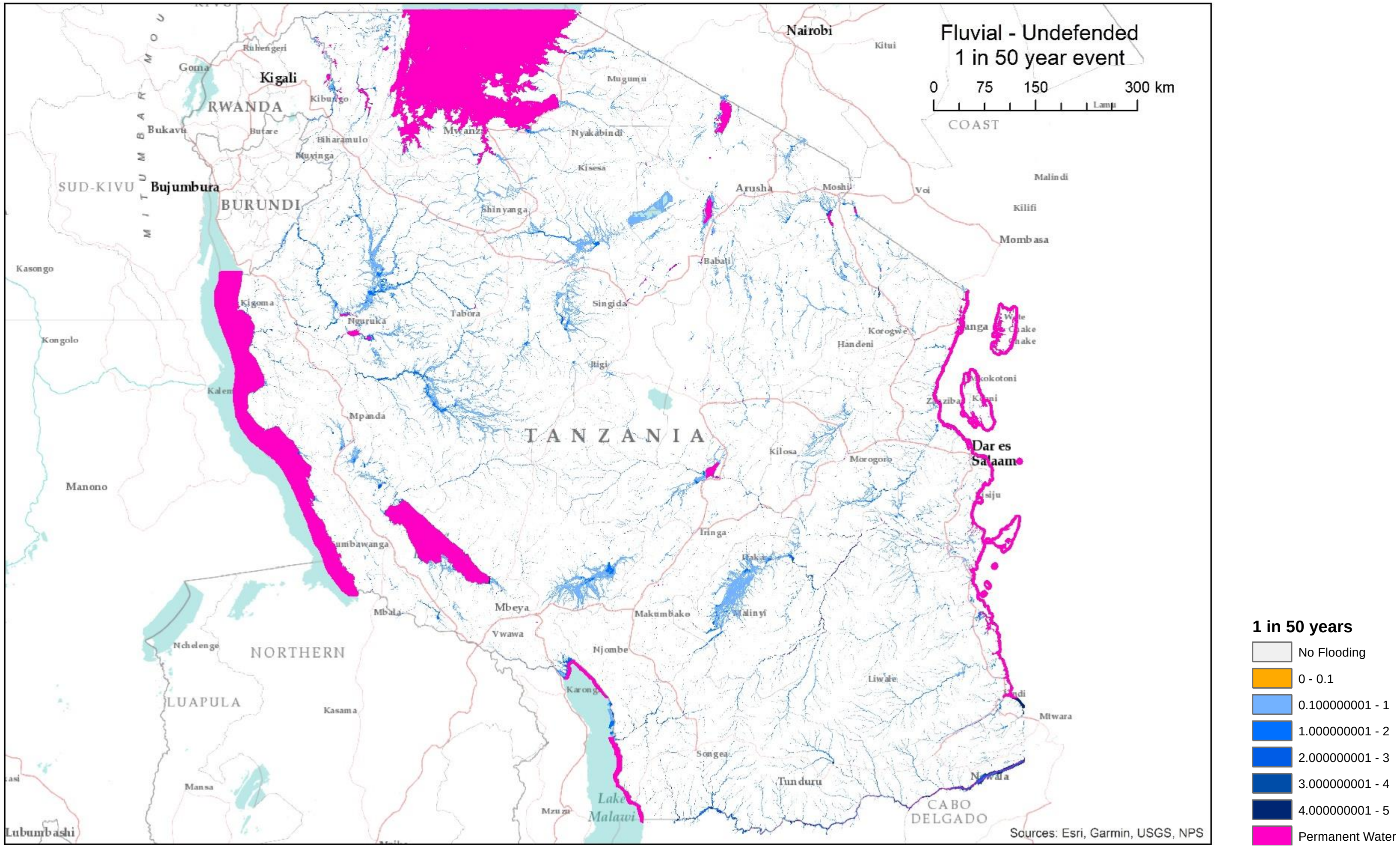

Fluvial - Defended
1 in 1000 year event
0 75 150 300 km
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
SUD-KIVU
TANZANIA
Dar es Salaam
Arusha
Moshi
Mwanza
Shinyanga
Tabora
Kigoma
Mpanda
Singida
Dodoma
Morogoro
Iringa
Mbeya
Njombe
Songea
Tunduru
Mtwara
Lake Malawi
NORTHERN
LUAPULA
CABO DELGADO
COAST
Mombasa
Malindi
Kilifi
Manono
Kasongo
Kongolo
Lubumbashi
Sources: Esri, Garmin, USGS, NPS
1 in 1000 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

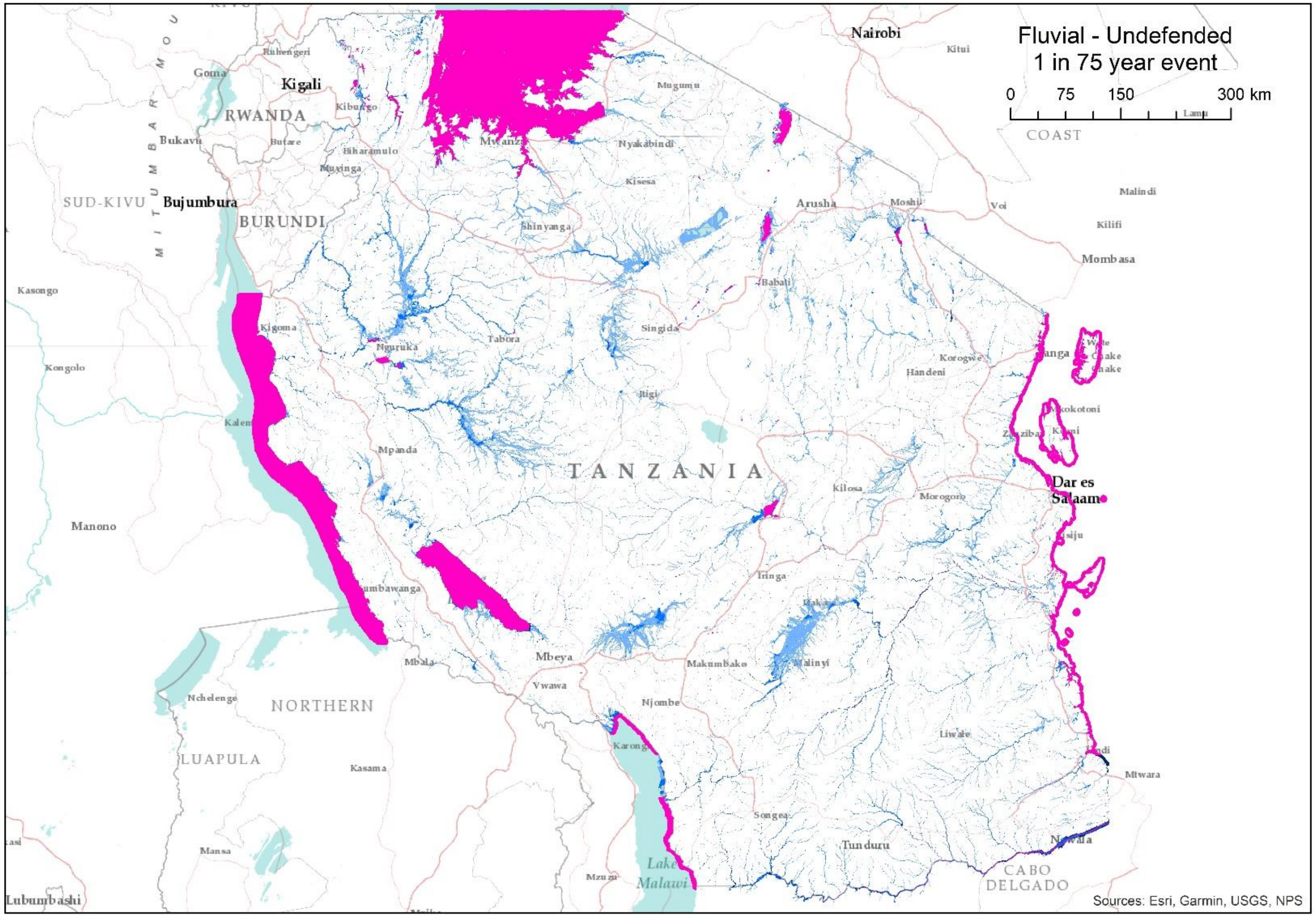
2.8. Fluvial Undefended: Tanzania




Fluvial - Undefended
1 in 10 year event
0 75 150 300 km
TANZANIA
RWANDA
BURUNDI
Nairobi
Kigali
Bujumbura
Mwanza
Arusha
Moshi
Shinyanga
Singida
Tabora
Kigoma
Mpanda
Kilosa
Morogoro
Dar es Salaam
Mbeya
Iringa
Songea
Tunduru
Mtwara
Mombasa
Lake Malawi
CABO DELGADO
NORTHERN
LUAPULA
SUD-KIVU
Lubumbashi
Sources: Esri, Garmin, USGS, NPS
1 in 10 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

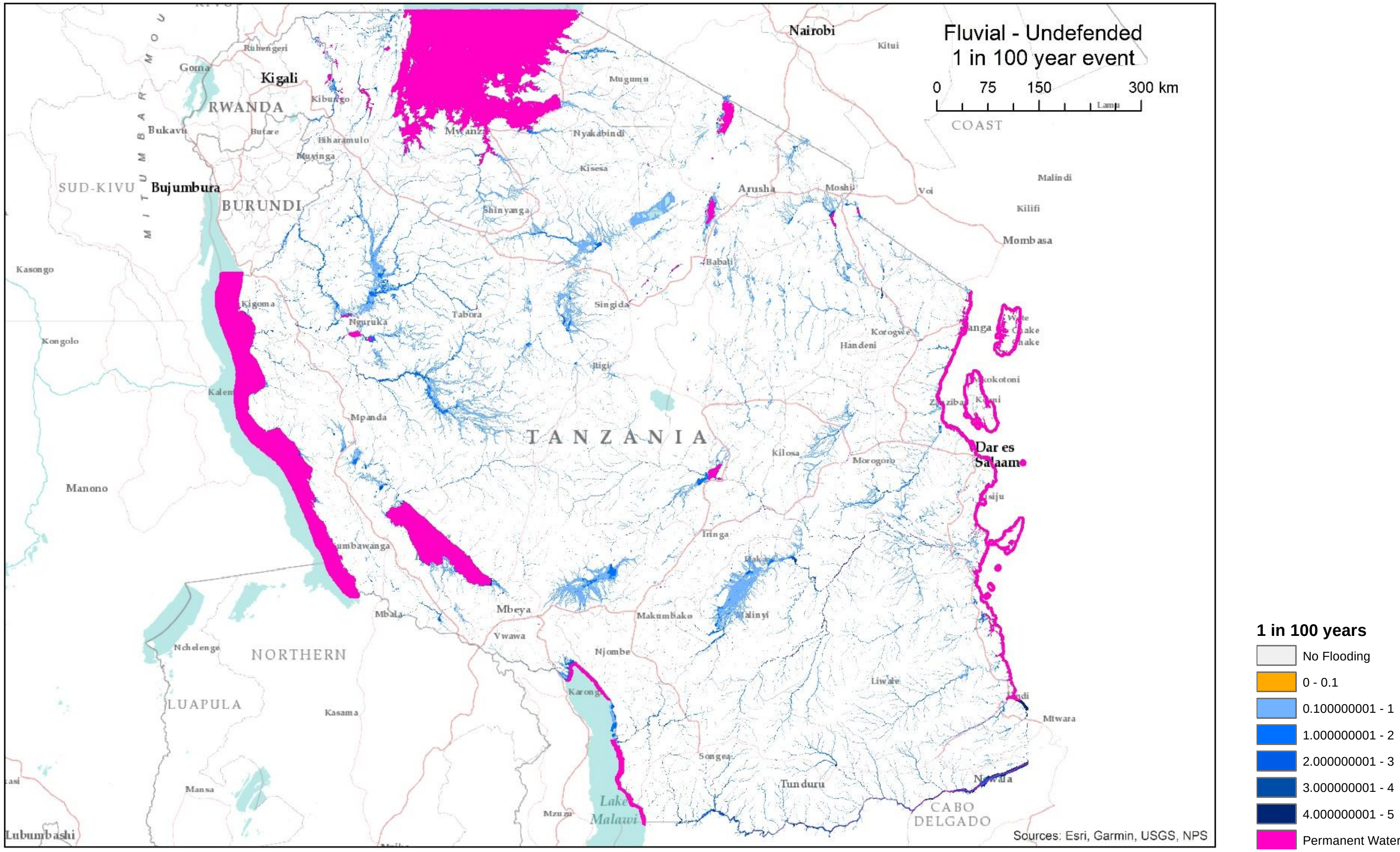

Fluvial - Undefended
1 in 20 year event
0 75 150 300 km
Nairobi
Kigali
RWANDA
Bujumbura
BURUNDI
SUD-KIVU
T A N Z A N I A
Arusha
Moshi
Mombasa
Dar es Salaam
Mwanza
Shinyanga
Kigoma
Tabora
Singida
Mpanda
Morogoro
Iringa
Mbeya
Njombe
Songea
Tunduru
Mtwara
NORTHERN
LUAPULA
Lubumbashi
Manono
Lake Malawi
CABO DELGADO
Sources: Esri, Garmin, USGS, NPS
1 in 20 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

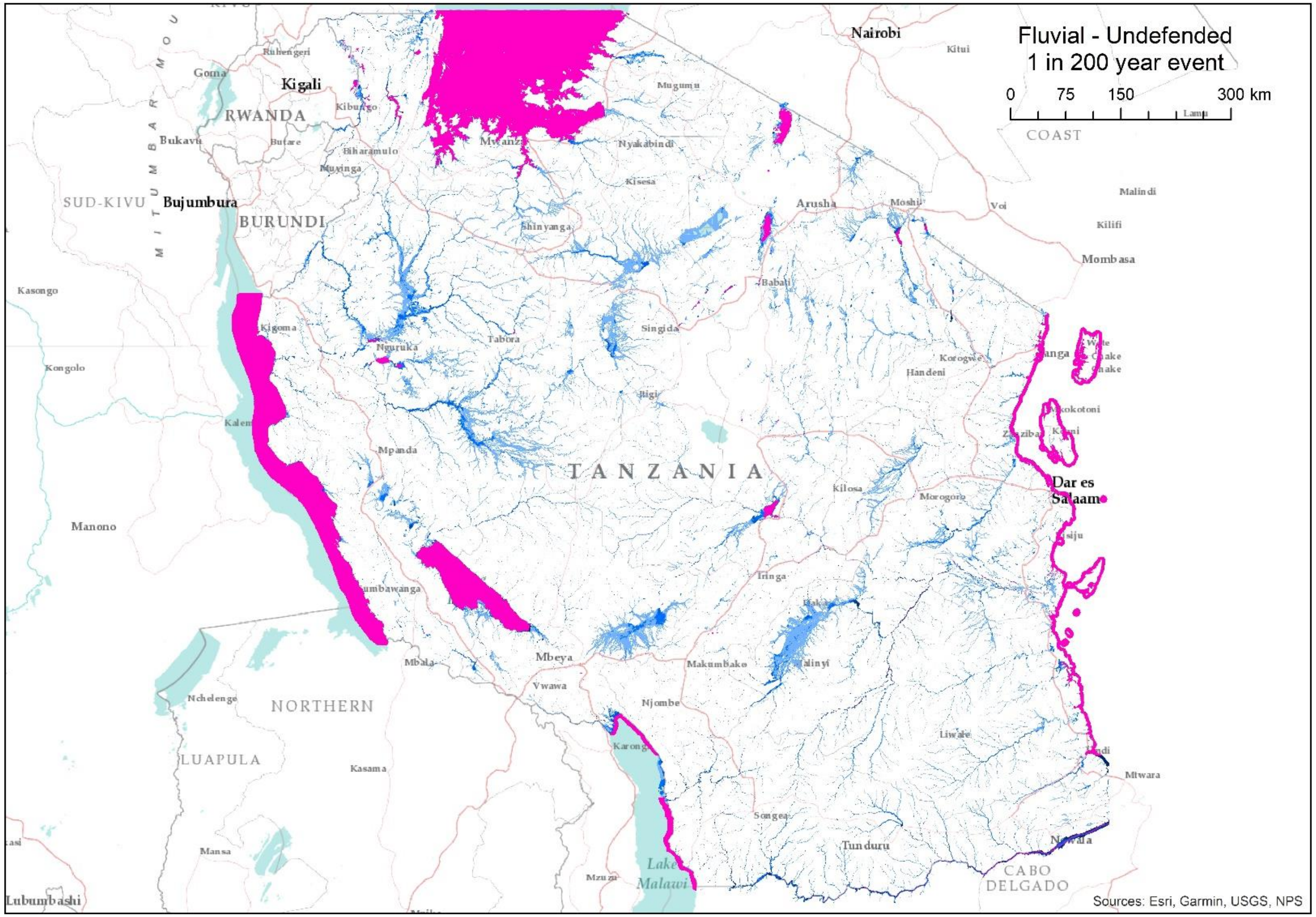

Fluvial - Undefended
1 in 50 year event
0 75 150 300 km
TANZANIA
1 in 50 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water
Sources: Esri, Garmin, USGS, NPS



1 in 75 years

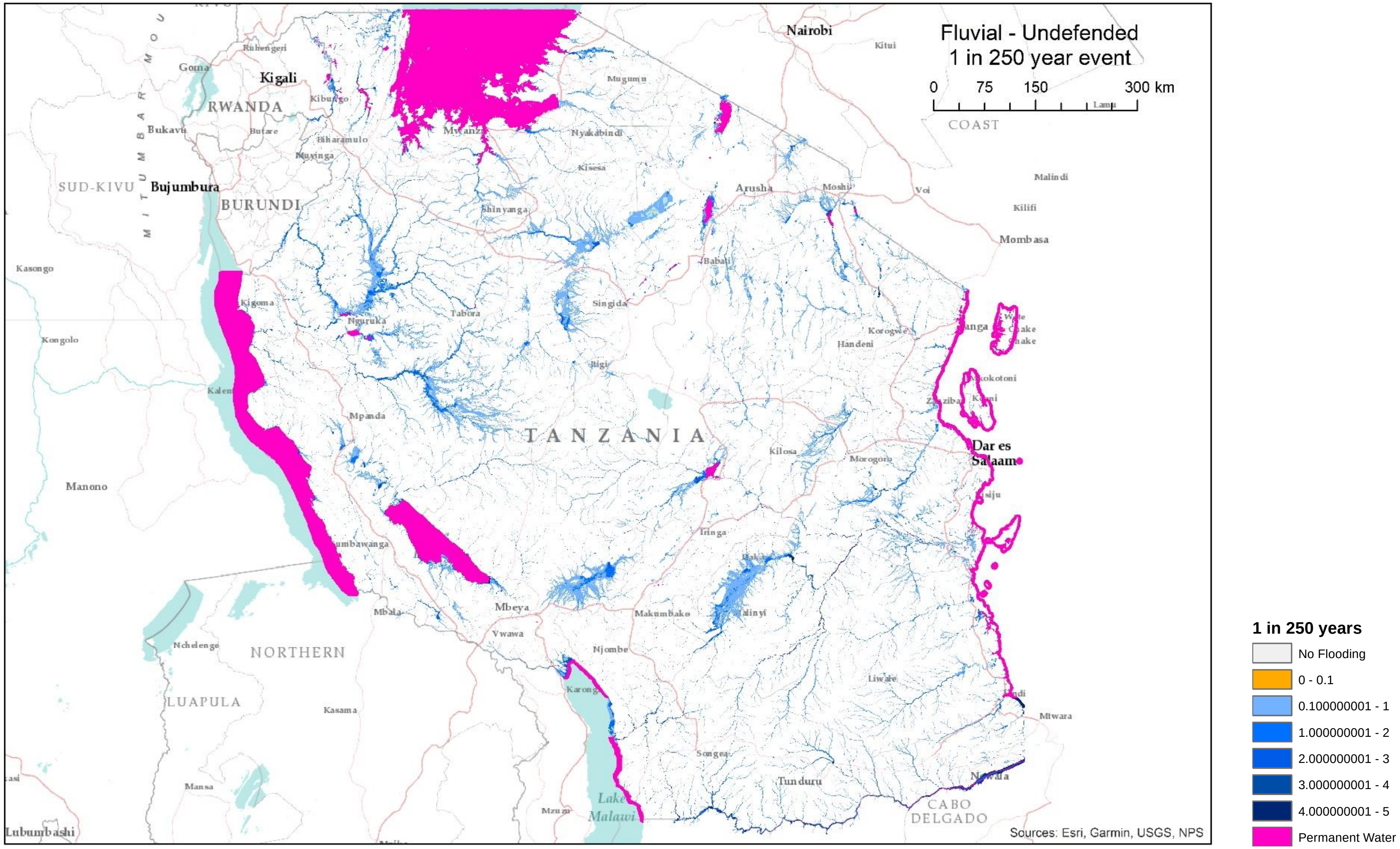
- No Flooding
- 0 - 0.1
- 0.100000001 - 1
- 1.000000001 - 2
- 2.000000001 - 3
- 3.000000001 - 4
- 4.000000001 - 5
- Permanent Water

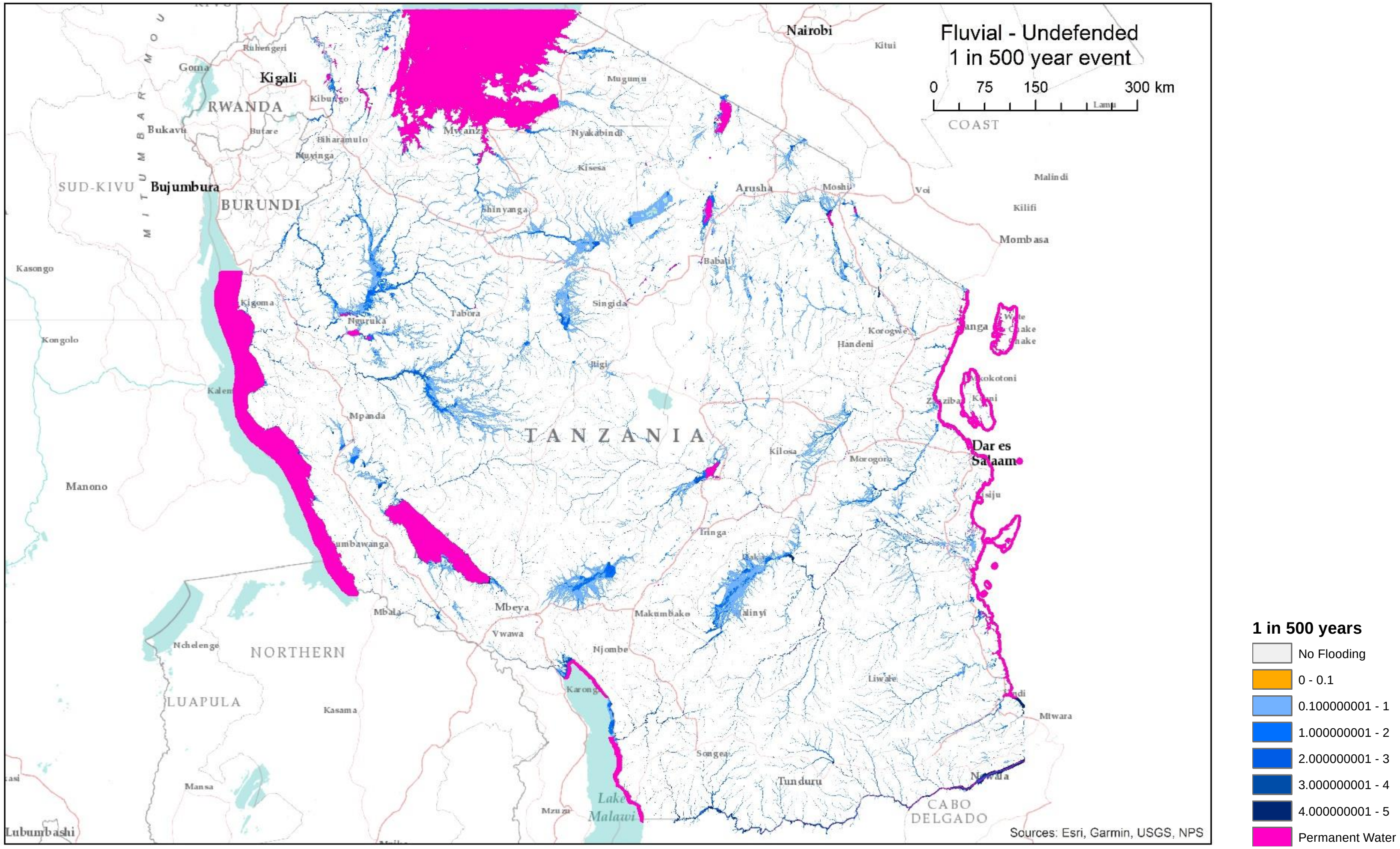

Fluvial - Undefended
1 in 100 year event
0
75
150
300 km
Sources: Esri, Garmin, USGS, NPS
1 in 100 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water
TANZANIA
RWANDA
BURUNDI
SUD-KIVU
NORTHERN
LUAPULA
COAST
CABO DELGADO
Nairobi
Kigali
Bujumbura
Goma
Bukavu
Arusha
Moshi
Mombasa
Malindi
Kilifi
Voi
Kitui
Mwanza
Shinyanga
Tabora
Kigoma
Mpanda
Singida
Dar es Salaam
Morogoro
Kilosa
Iringa
Mbeya
Vwawa
Mbala
Njombe
Makumbako
Songea
Tunduru
Mtwara
Kasama
Mansa
Manono
Kasongo
Kongolo
Lubumbashi
Lake Malawi
Nchelenge
Korogwe
Handeni
Babati
Mugumu
Kisesa
Liwale
Biharamulo
Muyinga
Butare
Ruhengeri
Mzuzu

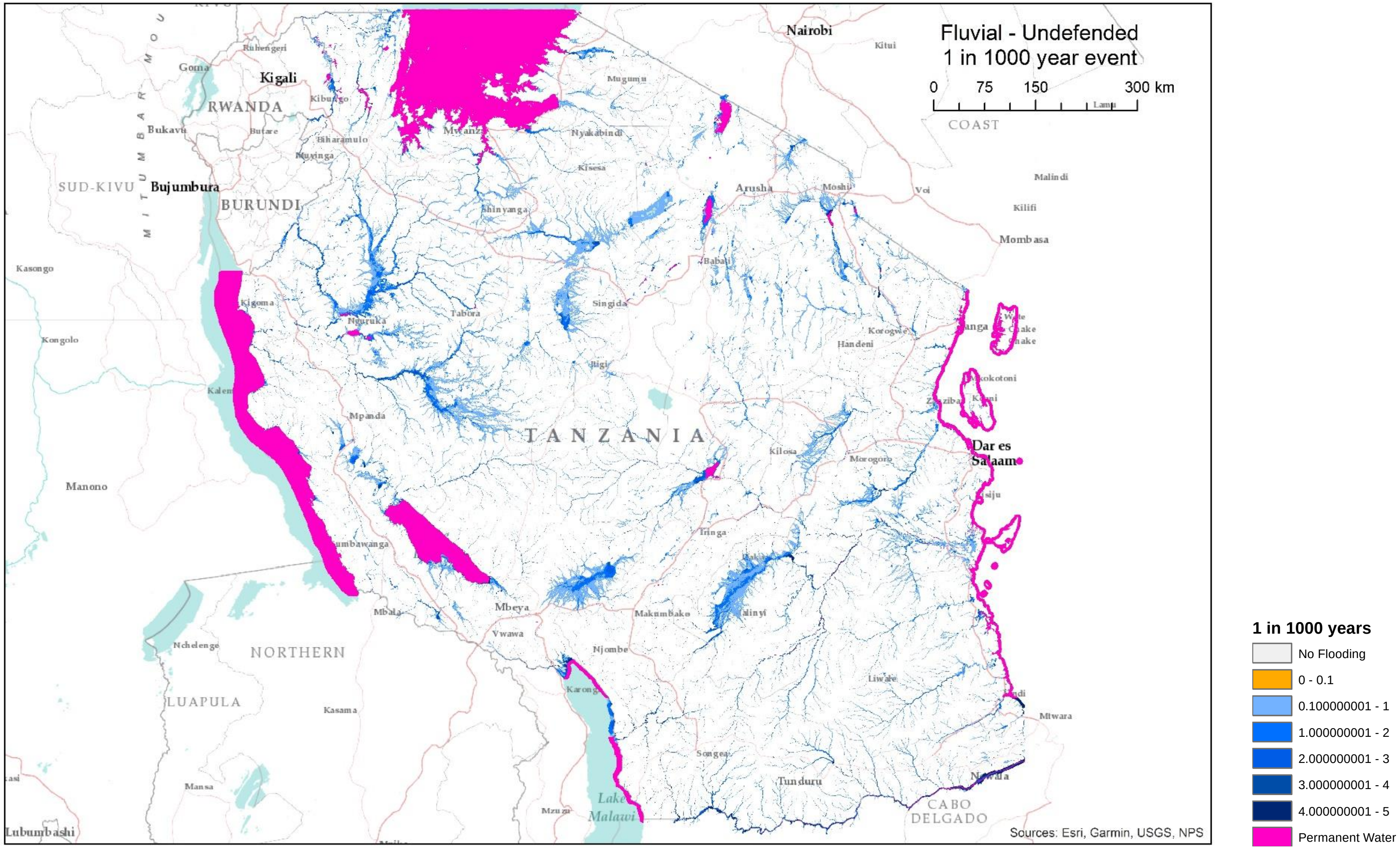


1 in 200 years

- No Flooding
- 0 - 0.1
- 0.100000001 - 1
- 1.000000001 - 2
- 2.000000001 - 3
- 3.000000001 - 4
- 4.000000001 - 5
- Permanent Water


Fluvial - Undefended
1 in 250 year event
0 75 150 300 km
TANZANIA
RWANDA
BURUNDI
Nairobi
Kigali
Bujumbura
Arusha
Moshi
Mwanza
Shinyanga
Tabora
Kigoma
Singida
Mpanda
Mbeya
Iringa
Morogoro
Dar es Salaam
Songea
Tunduru
Mtwara
Mombasa
Lake Malawi
NORTHERN
LUAPULA
Lubumbashi
CABO DELGADO
Sources: Esri, Garmin, USGS, NPS
1 in 250 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Fluvial - Undefended
1 in 500 year event
0
75
150
300 km
TANZANIA
RWANDA
BURUNDI
Kigali
Bujumbura
Nairobi
Dar es Salaam
Arusha
Moshi
Mwanza
Shinyanga
Tabora
Kigoma
Singida
Mpanda
Mbeya
Iringa
Morogoro
Njombe
Songea
Tunduru
Mtwara
Mombasa
Malindi
Kilifi
Voi
Kitui
SUD-KIVU
NORTHERN
LUAPULA
COAST
CABO DELGADO
Lake Malawi
Lubumbashi
Manono
Kasongo
Kongolo
Kasama
Mansa
Goma
Bukavu
Sources: Esri, Garmin, USGS, NPS
1 in 500 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water


Fluvial - Undefended
1 in 1000 year event
0 75 150 300 km
TANZANIA
Nairobi
Kigali
RWANDA
BURUNDI
Bujumbura
Dar es Salaam
Mombasa
Arusha
Mbeya
Sources: Esri, Garmin, USGS, NPS
1 in 1000 years
No Flooding
0 - 0.1
0.100000001 - 1
1.000000001 - 2
2.000000001 - 3
3.000000001 - 4
4.000000001 - 5
Permanent Water

2.9. Summary of Geospatial Detail of Flooding Hazard Products for Tanzania

Layer	Return Period	Type	Format	Native Spatial Reference	Units	Cell Size	Data Type
Flooding: Pluvial	1 in 5 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 10 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 20 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 50 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 75 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 100 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 200 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 250 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 500 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Pluvial	1 in 1000 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 5 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 10 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 20 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 50 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 75 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 100 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 200 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 250 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 500 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Defended	1 in 1000 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 5 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 10 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 20 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 50 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 75 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 100 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 200 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 250 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 500 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point
Flooding: Fluvial Undefended	1 in 1000 years	Raster	GeoTIFF	Geographic: WGS84	Decimal Degree	0.00083333333, 0.00083333333	32 Bit Floating Point

3. Seismic: Nepal

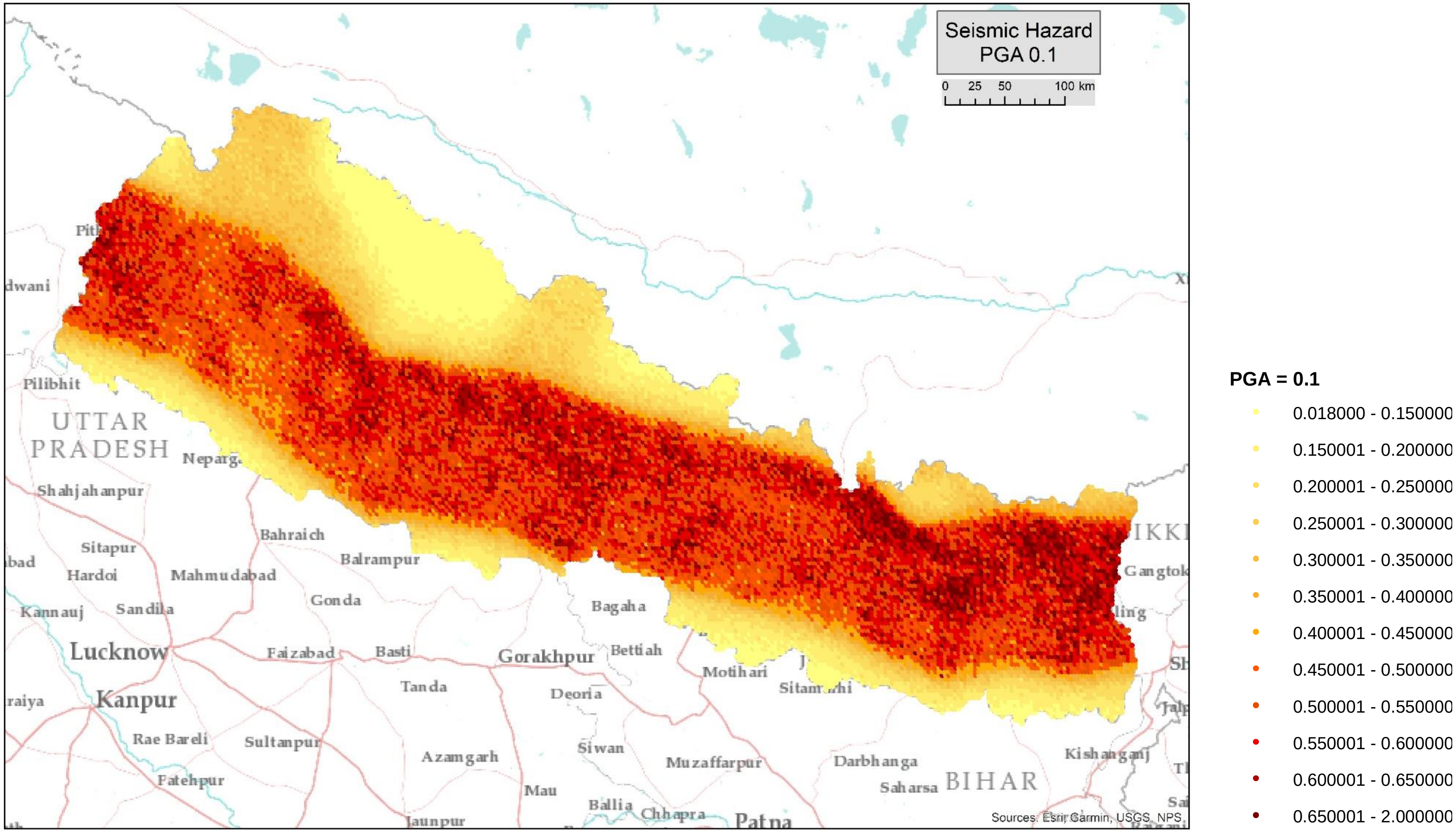
3.1. Abstract

Seismic hazard map for Nepal. Mean Peak Ground Acceleration (g) 10%/2% probability of exceedance in 50 years.

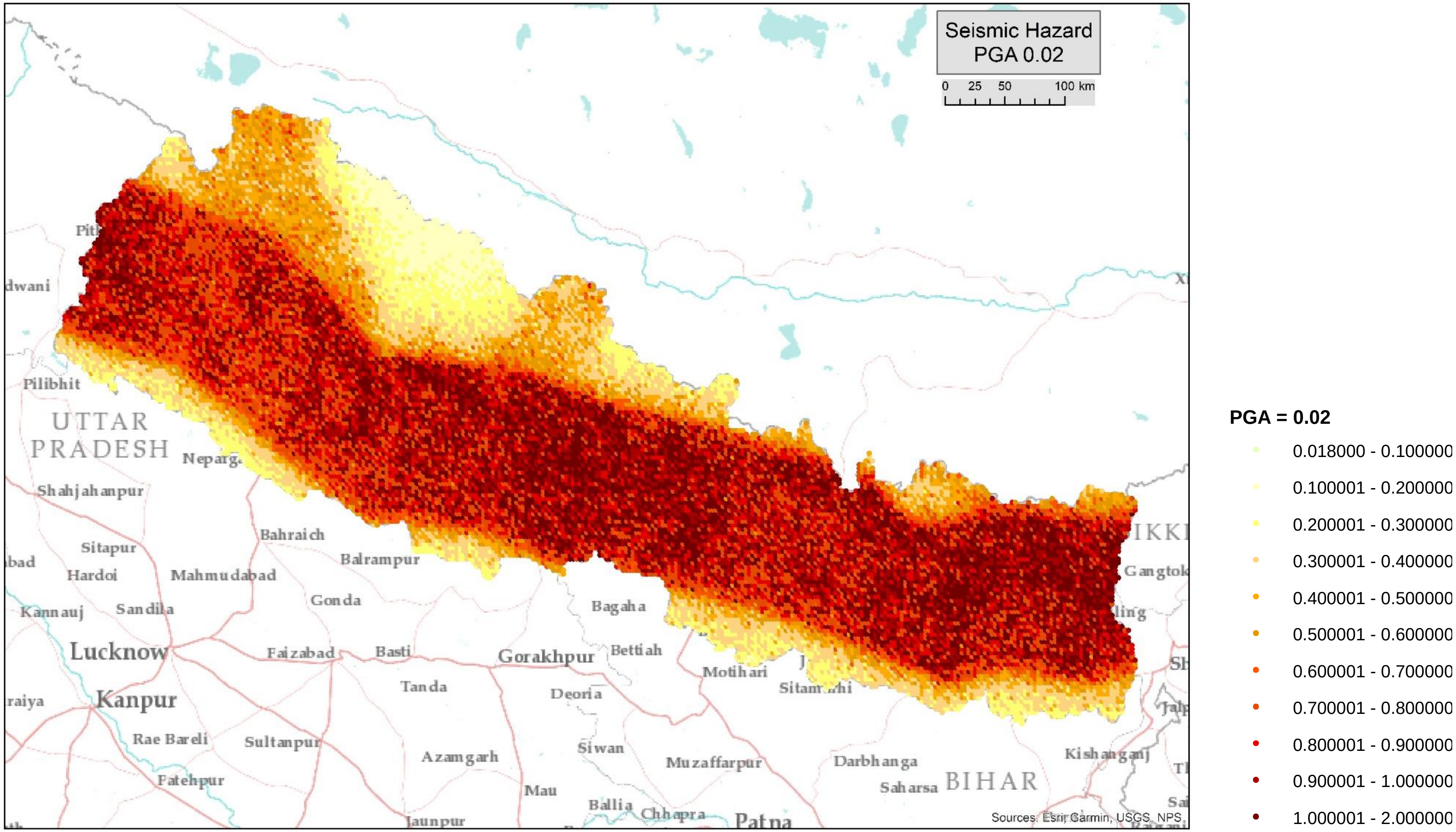
3.1.1. Citation

V. L. Stevens, S. N. Shrestha, D. K. Maharjan (2018) Probabilistic Seismic Hazard Assessment of Nepal. *Bulletin of the Seismological Society of America*; 108 (6): 3488–3510. doi:https://doi.org/10.1785/0120180022

3.2. Seismic Hazard: PGA 0.1



3.1. Seismic Hazard: PGA 0.02



3.2. Summary of Geospatial Detail of Seismic Hazard Products for Nepal

Layer	Type	Format	Native Spatial Reference	Units	Cell Size	Data Type
Seismic: PGA 0.02	ASCII	CSV	Geographic: WGS84	Decimal Degree	n/a	n/a
Seismic: PGA 0.1	ASCII	CSV	Geographic: WGS84	Decimal Degree	n/a	n/a

4. Seismic: Tanzania

4.1. Abstract

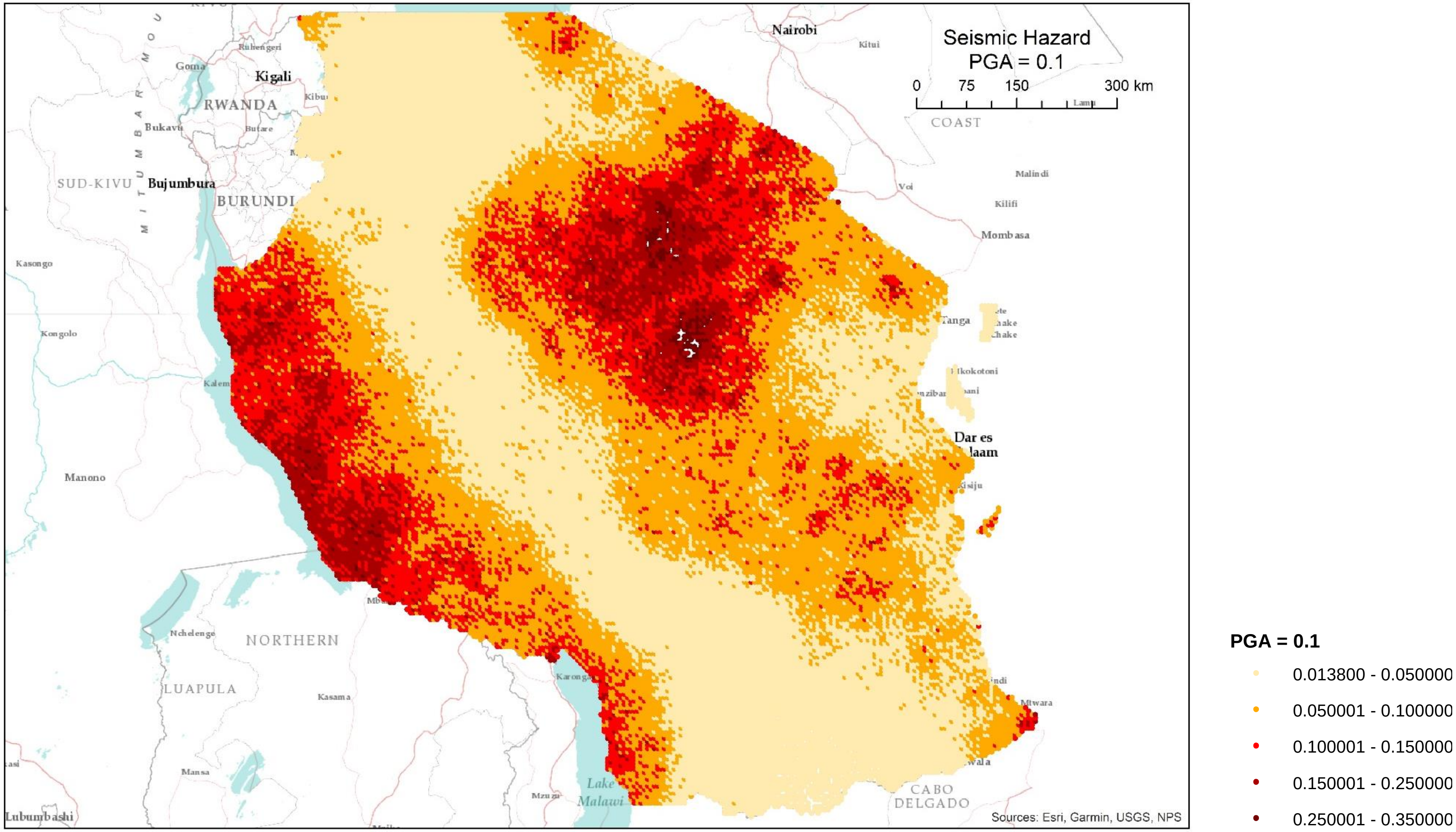
Seismic Hazard Map showing mean Peak Ground Acceleration (PGA) in ‘g’ for a 10%/2% probability of exceedance in 50 years for the country of Tanzania.

This map was produced using the GEM OpenQuake engine using the SSAHARA model produced, please see https://hazard.openquake.org/gem/models/SSA/ for further details.

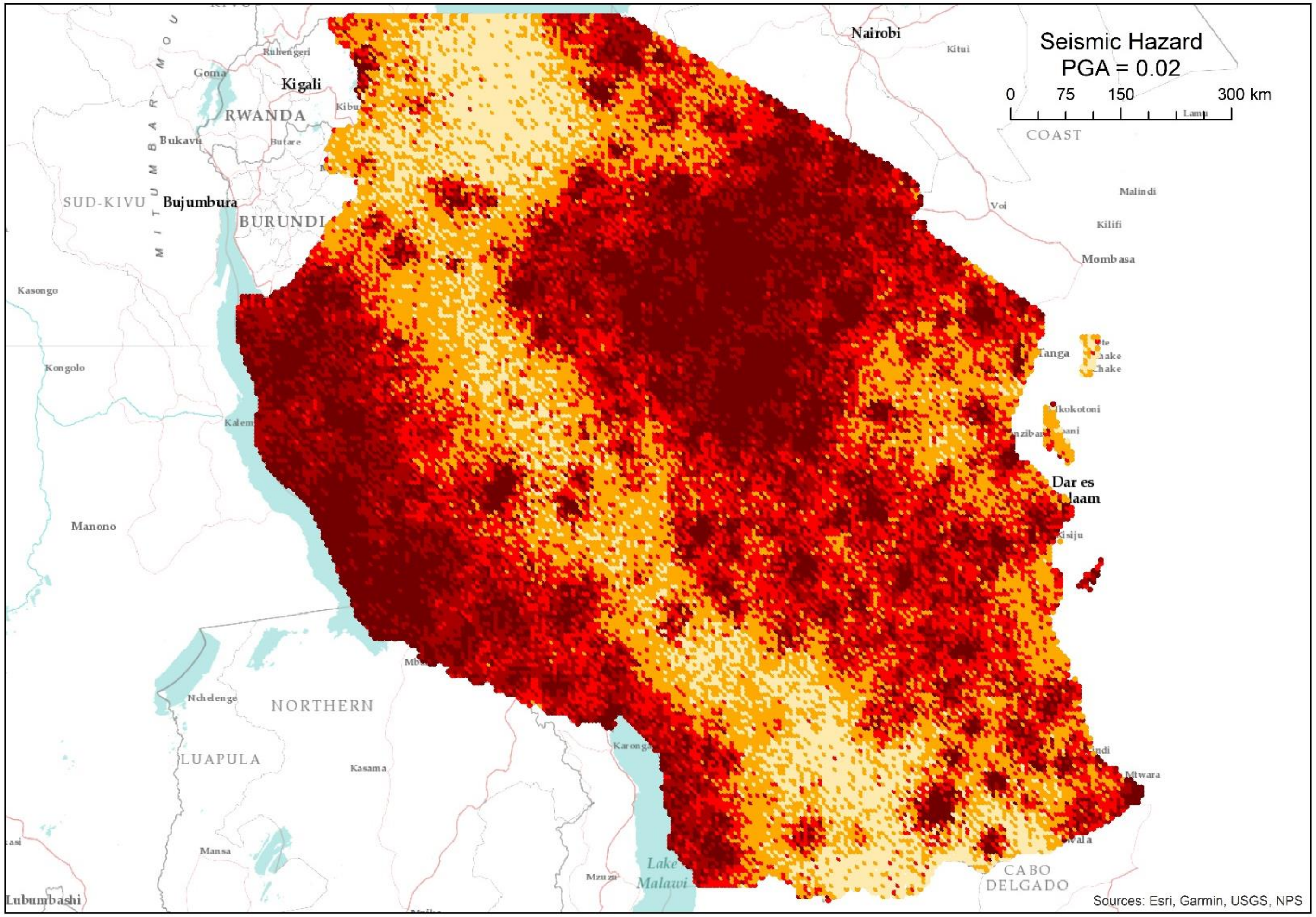
4.1.1. Citation

Poggi, V., Durrheim, R., Mavonga Tuluka, G., Weatherill, G., Gee, R., Pagani, M., Nyblade, A., Delvaux, D. (2017) Assessing Seismic Hazard of the East African Rift: a pilot study from GEM and AfricaArray. Bulletin of Earthquake Engineering. Volume 15, Issue 11, 4499–4529, DOI: 10.1007/s10518-017-0152-4

4.2. Seismic Hazard: PGA 0.1



4.3. Seismic Hazard: PGA 0.02



PGA = 0.02

- 0.018000 - 0.050000
- 0.050001 - 0.100000
- 0.100001 - 0.150000
- 0.150001 - 0.250000
- 0.250001 - 3.000000

4.4. Summary of Geospatial Detail of Seismic Hazard Products for Tanzania

Layer	Type	Format	Native Spatial Reference	Units	Cell Size (x, y)	Data Type
Seismic: PGA 0.01	Vector	Shapefile: point	Geographic: WGS84	Decimal Degree	n/a	n/a
Seismic: PGA 0.01	ASCII	CSV	Geographic: WGS84	Decimal Degree	n/a	n/a
Seismic: PGA 0.2	Vector	Shapefile: point	Geographic: WGS84	Decimal Degree	n/a	n/a
Seismic: PGA 0.2	ASCII	CSV	Geographic: WGS84	Decimal Degree	n/a	n/a

5. Volcanic Hazard: Tanzania

5.1. Abstract: ash fall hazard for Rungwe Volcano, Tanzania

Probabilistic ash fall (tephra) hazard footprints have been produced for a Volcanic Explosivity Index (VEI) (Newhall and Self, 1982) 2 and VEI 4 explosive eruption scenario at Rungwe Volcano for the METEOR project. Rungwe volcano in Southern Tanzania was chosen as it is one of the better-studied volcanoes in Tanzania, with a record of at least seven explosive eruptions within the last approximately 4000 years, including VEI 4 and 5 eruptions at approximately 2000 and 4000 year before present (yrs BP), respectively (Fontijn et al., 2010; Fontijn et al., 2011).

The model

Ash fall hazard footprints were generated using *TephraProb*[1], a freely available *Matlab* package developed to produce probabilistic hazard assessments for tephra fallout (Biass et al., 2016). *TephraProb* uses the *Tephra2*[2] tephra dispersion model. *Tephra2* is an open source advection-diffusion model based on the work of Suzuki (1983) that describes diffusion, transport and sedimentation of tephra (ash) particles released from an eruption column (Connor et al., 2001; Bonadonna et al., 2005). It calculates the total mass per unit area (kg m-2) of tephra accumulation at individual grid locations by solving a simplified mass conservation equation. The mass conservation equation takes into account the distribution of tephra mass in the eruption column and particle settling velocity, as well as horizontal diffusion within the eruption column and atmosphere after the particle has been ejected from the plume (Connor et al., 2001; Bonadonna et al., 2005; Connor and Connor, 2006). Eruption parameters are assumed to represent average conditions over the duration of the complete eruption (Connor and Connor, 2006).

Scenarios

We have chosen to model two eruption scenarios for Rungwe volcano based on past eruption history:

- A VEI 2 scenario represents a relatively small eruption. Numerous small cones on the caldera and northwest flanks of Rungwe are indicative of such relatively small tephra-producing eruptions (Fontijn et al., 2010)
- A VEI 4 explosive eruption scenario based on the Isongole Pumice eruption, which occurred approximately 2000 yrs BP. The Isongole Pumice eruption produced an eruption column of 17.5 km (above the vent) and a volume of 0.25 km3 of tephra fallout (Fontijn et al., 2010). Based on this, the eruption was classified as a VEI 4, sub-Plinian event.

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[1] *TephraProb* can be downloaded from here: https://github.com/e5k/TephraProb

[2] The *Tephra2* source code can be downloaded from here: https://github.com/geoscience-community-codes/tephra2

Input Parameters

The model requires a number of inputs representing the vent location, eruption column, wind, grain size and model parameters.

The model was run with input parameter ranges for a number of eruption source parameters. The model was run probabilistically, 1000 times for each season (3000 in total), randomly selecting a wind file from a ten-year database for each run. We used different grid extents for the VEI 2 and 4 scenarios, with a larger grid for the VEI 4 scenario.

Total erupted mass

We assumed a total erupted volume of 0.001 – 0.009 for a VEI 2 and 0.1 - 0.99 km3 for a VEI 4 explosive event following the VEI classification of Newhall and Self (1982).

The bulk density of the deposits is estimated to be 820 kg/m3 assuming 20:80 lithic to pumice clast ratio, using a clast density of 2300 kg/m3 and pumice density of 450 kg/m3 (Fontijn et al., 2011). The ranges of total erupted mass, calculated from the deposit density and volumes, for VEI 4 is 8.2×1010 to 8.1×1011 kg, and for VEI 2 is 8.2×108 to 7.38×109 kg.

Eruption Column Height

The minimum and maximum eruption column heights for a VEI 4 eruption was calculated from the erupted volume based on the empirical relationship derived by Jenkins et al. (2007) for explosive eruptive events:

Height (km asl) = 8.67.log10(Volume in km3) + 20.2

The relationship assumes a sustained plume with no effect from wind on the plume height, therefore only works for larger magnitude eruptions. For a VEI 4 eruption, this gives an eruption column range of 11.5 to 20.16 km asl. Fontijn et al. (2010) calculated an eruption column height of 17.5 km above the event, equivalent to 20.5 km asl given a vent height of 2953 m asl, for the Isongole Pumice eruption. For a VEI 2 event, we assumed a column height of between 1 and 5 km asl, following the classification of Newhall and Self (1982).

Eruption Duration

Tephra2 assumes that the input parameters are representative for the average conditions over the peak eruption duration, and that most tephra is ejected in a short duration (few hours) explosive event (Connor and Connor, 2006).

Wind

TephraProb uses the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim global reanalysis dataset (Dee et al., 2011). We used a ten-year dataset from 1st January 2005 to 31st December 2014, sampled four-times daily (16068 wind files) to account for variations in wind conditions that could impact the ash fall footprint.

TephraProb has the option to run the model to reflect seasonal variation. When this option is enabled, the model will perform three runs: 1. All wind profiles; 2. Wind profiles for the rainy season; and 3. Wind profiles for the dry season. Winds in Southern Tanzania are predominantly easterlies and south-easterlies. From December to March, there is a stronger dominance of easterly winds with higher wind speeds (Figure 1); therefore the model was run to take into account this seasonal variation. We modelled 1000 simulations each for 1. all wind profiles (year-round), 2. wind profiles for December to March (dry), and 3. wind profiles for April to November (rainy).

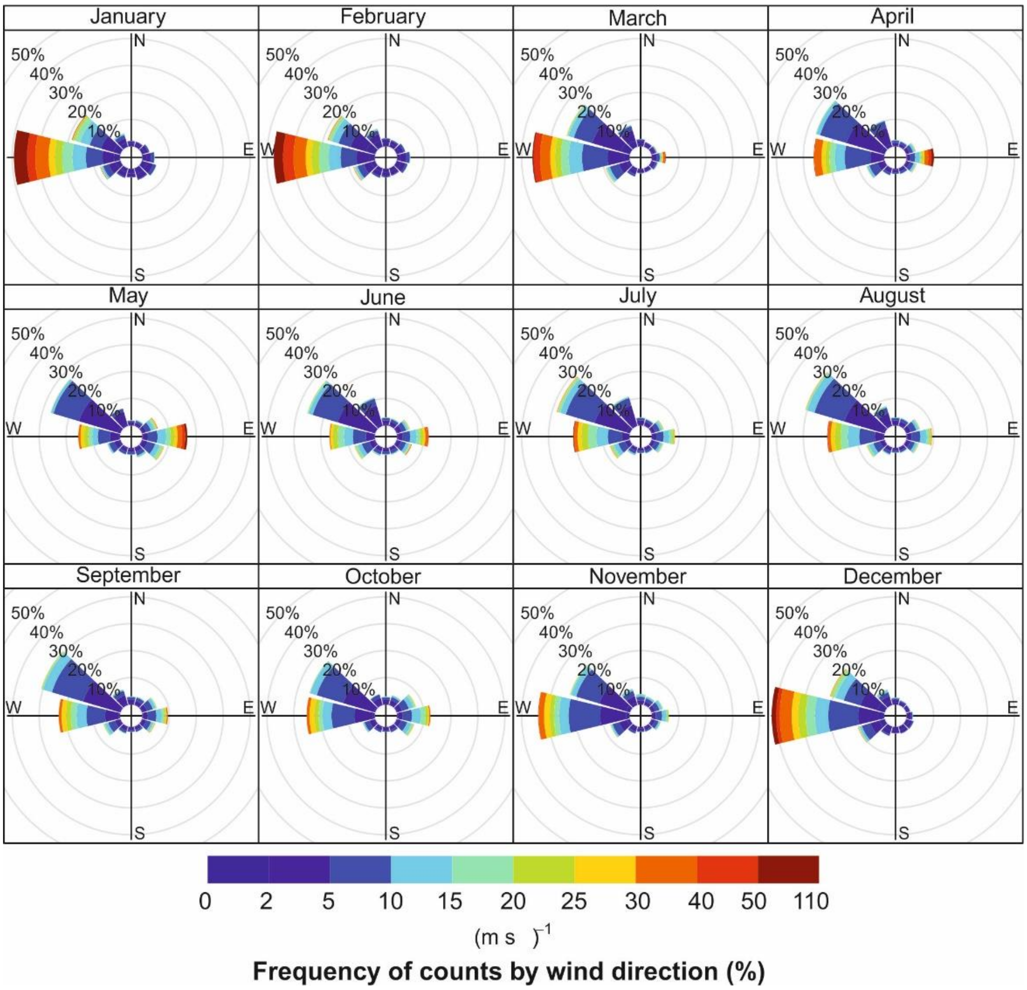

Figure 1: Ten-year ECMWF ERA-interim global reanalysis dataset for Rungwe from 1st January 2005 to 31st December 2014, separated by month to show seasonal variation in wind direction. Coloured bars show the direction the wind is blowing, colours represent the wind speed, and the length of the bar represents the frequency of counts by wind direction (%)

Grain Size Distribution

A normal distribution was used with minimum and maximum bounds of 4 phi (63 microns) and -5 phi (32 mm), respectively, with a median between -1 and -3 phi and standard deviation of 1.5 to 2.5 phi, following the total grain size distribution determined by Fontijn et al. (2011) for the Rungwe Pumice. It was assumed that finer material would either fall as aggregates (input aggregation factor) captured within these grain size bounds, or be dispersed much further than the ash fall footprints being simulated. Based on the similarity between the Isongole Pumice and the Rungwe Pumice deposit characteristics (Fontijn et al., 2010), and given the lack of grain size data for the Isongole Pumice deposit, it was deemed appropriate to use the Rungwe Pumice derived grain size distribution.

Eddy Constant

The eddy diffusivity term for small particles, which is 0.04 m2/s.

Diffusion Coefficient

The horizontal diffusion coefficient for large particles. A value of 3000 was used, consistent with the GFDRR/DfID Challenge Fund Project (Loughlin et al., 2018).

Fall Time Threshold

Threshold to allow fine particles to fall out. A value of 10000 was used, consistent with the GFDRR/DfID Challenge Fund Project (Loughlin et al., 2018).

Particle Density

Lithic density of 2300 kg/m3 and pumice density of 450 kg/m3 (Fontijn et al., 2011).

Integration Steps

Tephra2 models the fall of particles as they are transported away from the plume and deposited on the ground. In order to take into account variations in wind, flow regime, diffusion etc., the eruption column and atmosphere are discretised into integration steps. Previous studies have shown that more than 100 steps has no impact on the tephra fallout estimates at the grid locations (Connor and Connor, 2006).

Plume model (alpha & beta parameters)

The alpha and beta parameters describe the mass distribution of tephra within the plume:

If $\alpha=\beta=1$, then particles are dispersed uniformly within the plume;

If $\alpha>\beta$, then particles are concentrated in the top of the plume;

If $\alpha<\beta$, then particles are dispersed in the bottom of the plume.

For a less powerful, smaller magnitude VEI 2 eruption, we assume deposition from the majority of the whole plume, therefore assume only 30% of particles are concentrated in the top of the plume: $\alpha=1$, $\beta=0.7$. For a VEI 4, sub-Plinian type eruption, we assume 60% of particles are concentrated in the top of the plume: $\alpha=1$, $\beta=0.4$.

Outputs

TephraProb generates three types of output text files for each tephra accumulation threshold (from 0.01 to 1000 kg/m2) for plotting probability maps in different programs: GMT, Matlab and GIS.

Outputs of 1, 10 and 100 kg/m2 tephra accumulation thresholds were selected, which equate to thicknesses of approximately 0.1, 12 and 120 cm given the bulk deposit density of 820 kg/m3. Thicknesses of as little as 1 mm ash fall can cause transport problems, damage to electrical and mechanical components, blockages and clogging of water intake structures and infiltration systems (Jenkins et al., 2015).

Each threshold has two datasets for the two seasons modelled: December to March (dry) and April to November (rainy). *Note that TephraProb automatically names the two seasons dry and rainy. In Tanzania, these months were chosen to reflect the variability in wind conditions and do not necessarily reflect the dry and rainy seasons.*

Sources of Uncertainty

Although Rungwe is one of the best studied of the Tanzanian Holocene volcanoes, knowledge of its eruption history is still limited; therefore, any modelling of potential future volcanic ash fall hazard is subject to high degrees of uncertainty.

We have modelled a VEI 2 and VEI 4 explosive eruption scenario. This is not a forecast and should not be considered a most likely scenario. A future eruption is unlikely to have exactly the source parameters and wind conditions modelled here. There are a number of factors, which can have a strong influence on the area impacted by ash fall, for example, a finer particle size distribution will lead to a larger area being impacted. Particle size can be strongly influenced by magma composition or the presence of water; therefore, the explosive event does not necessarily need to be larger magnitude than modelled here to have a greater ash fall footprint. The resultant ash fall footprints are for communication purposes only and should not be considered hazard maps for use in practise for planning or preparedness.

The volcanic ash hazard to aviation and from wind remobilisation of ash fall deposits is not accounted for within our modelling. The hazard from airborne ash is likely to affect much larger areas, and hazard from ash remobilisation can continue for months, years or even decades after the event (e.g. Wilson et al., 2011).

Volcanic eruptions can last from a few hours to days, weeks, months and years. Based on global analysis, the median duration of an eruption is 7 weeks (Simkin and Siebert, 2000). Typically, an eruption comprises volcanic unrest prior to the onset of explosive activity and unrest that can continue after the explosive phase. Many explosive eruptions have multiple explosive events or phases, each lasting minutes to hours. *Tephra2* assumes that the input parameters are representative for the average conditions over the peak eruption duration, and that most tephra is ejected in a short duration explosive event (Connor and Connor, 2006).

The bulk density of the deposits was estimated to be 820 kg/m3 assuming 20:80 lithic to pumice clast ratio, using a clast density of 2300 kg/m3 and pumice density of 450 kg/m3 (Fontijn et al., 2011). Fontijn et al. (2010) report up to 30% lithics in the Isongole Pumice in samples collected within 10 km of the vent. As the data are from proximal deposits, it is likely that this lithic proportion is overestimated for the entire deposit; therefore, a 20:80 lithic to pumice ratio was used for the model. It should be noted, that this may still overestimate the proportion of lithics.

As well as uncertainties related to the input parameters, there are uncertainties related to the model itself. Due to the complexities involved in modelling atmospheric conditions, *Tephra2* does not take into account horizontal changes in wind conditions away from the vent. A number of assumptions have to be made on diffusion and particle fallout, which will be different for each explosive event depending on atmospheric conditions, mass eruption rate, particle size and particle density.

5.1.1. References

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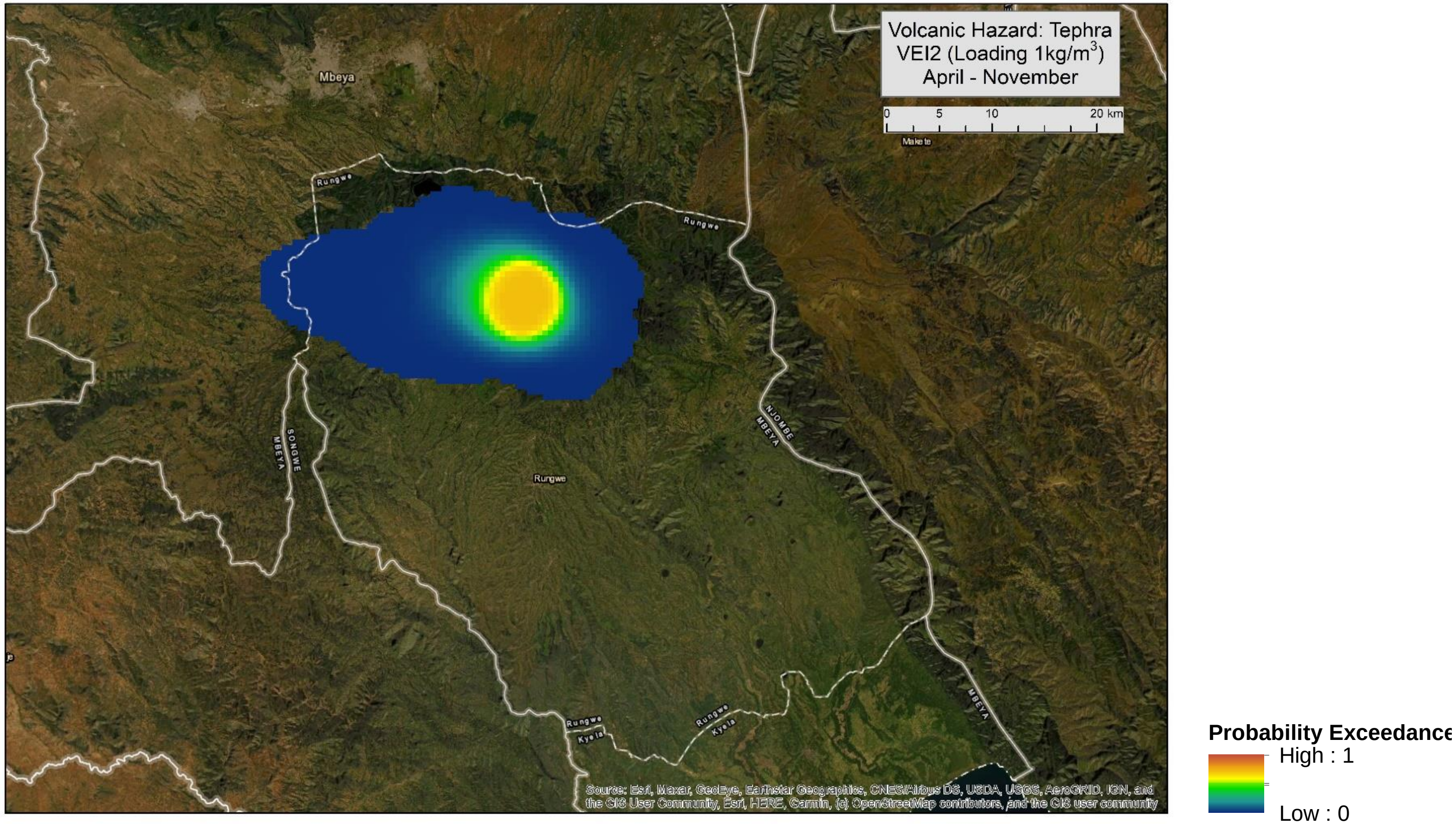
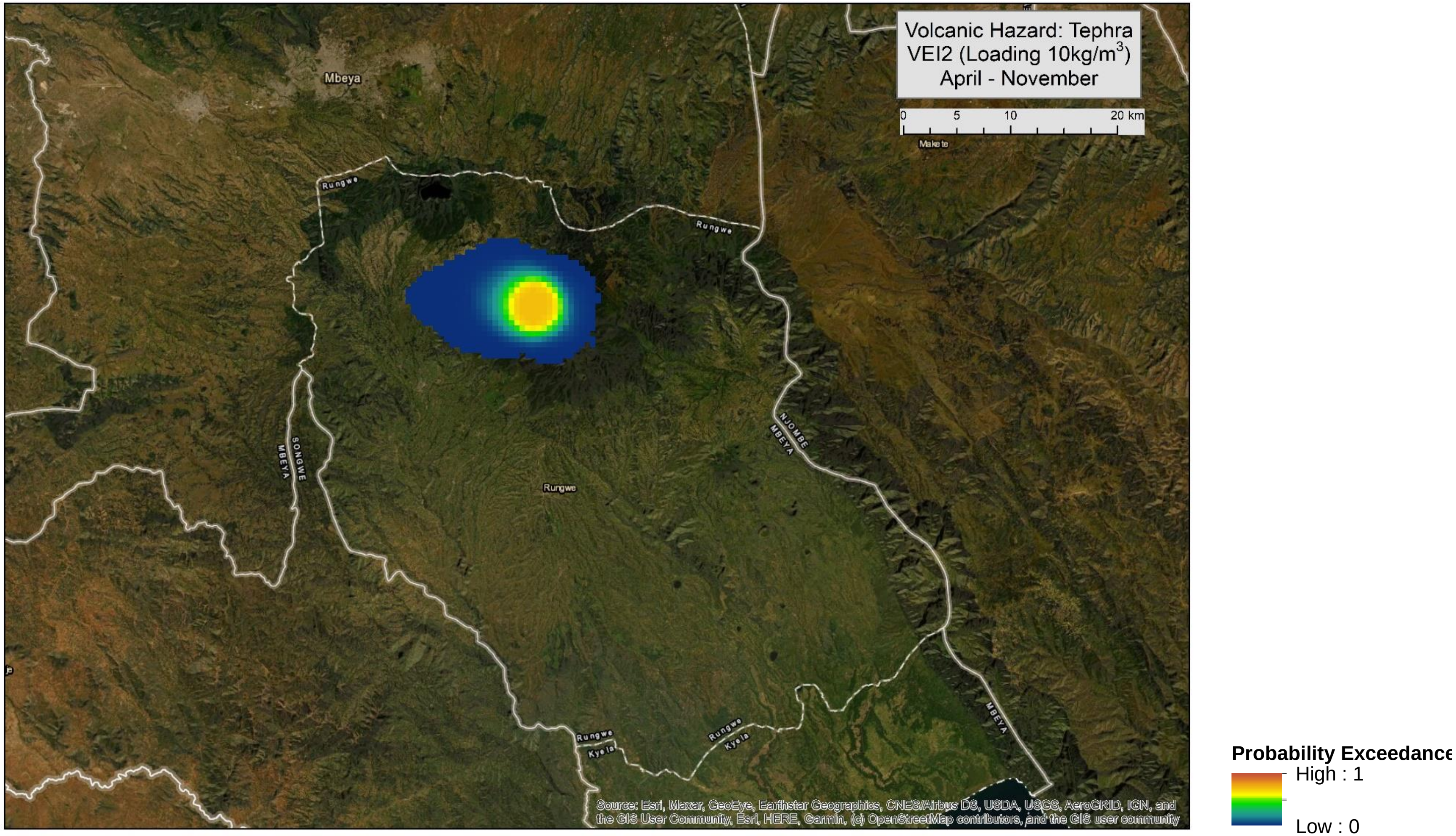
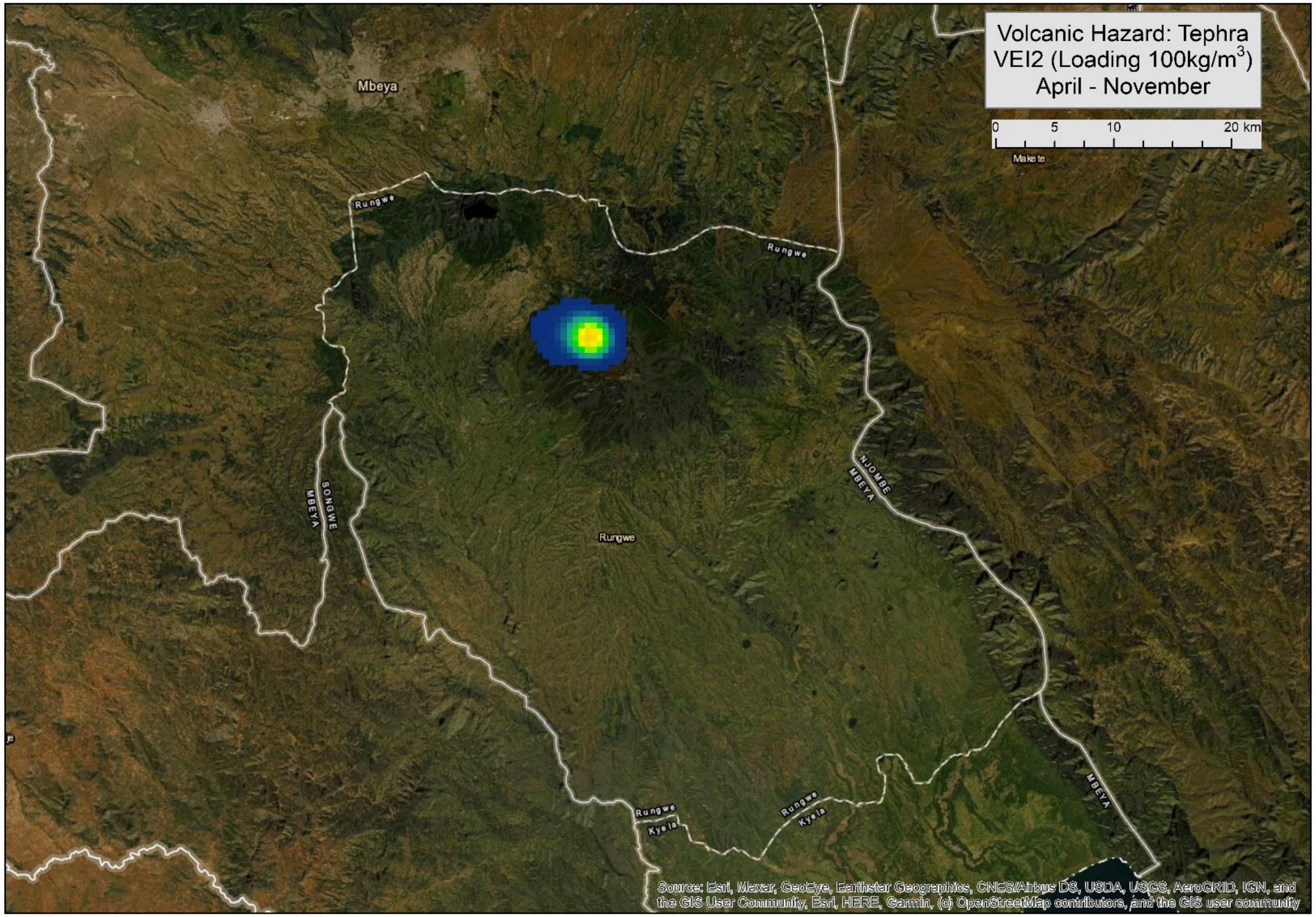
5.2. Tephra (Rungwe)

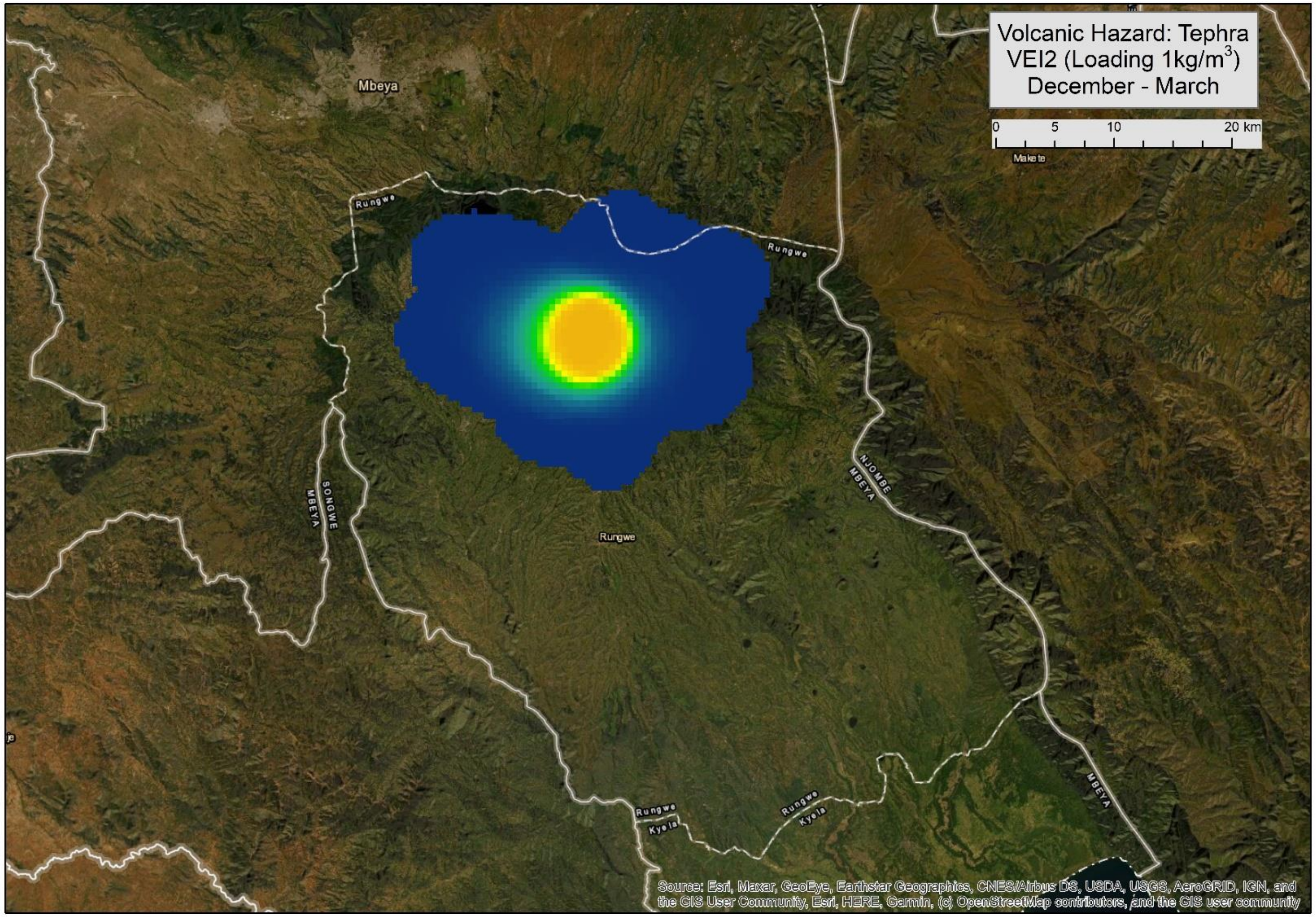


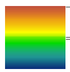

Volcanic Hazard: Tephra
VEI2 (Loading 10kg/m³)
April - November
0 5 10 20 km
Mbeya
Rungwe
NJOMBE
MBEYA
SONGWE
Kyela
Makete
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Probability Exceedance
High : 1
Low : 0

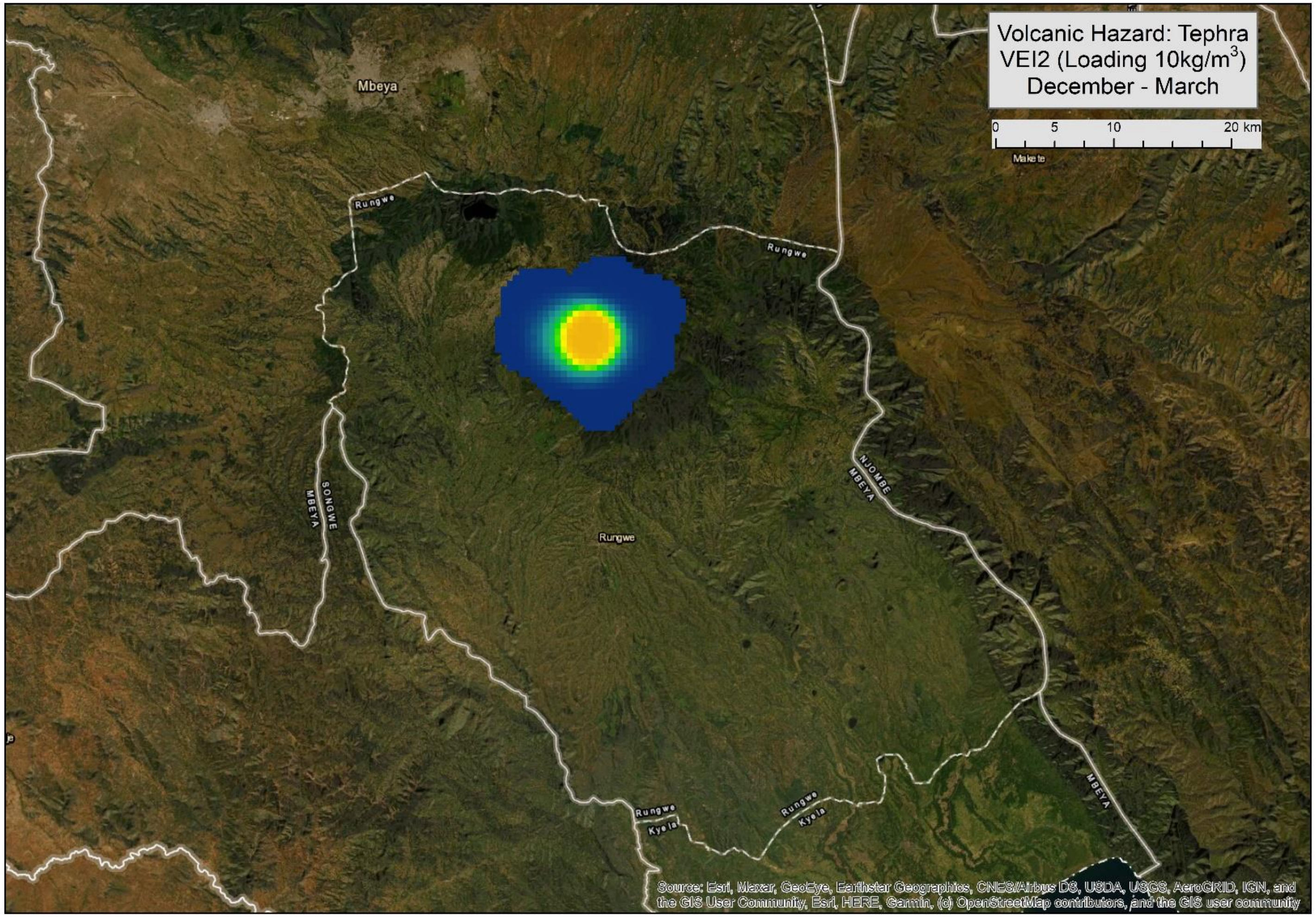


Probability Exceedance
High : 1
Low : 0

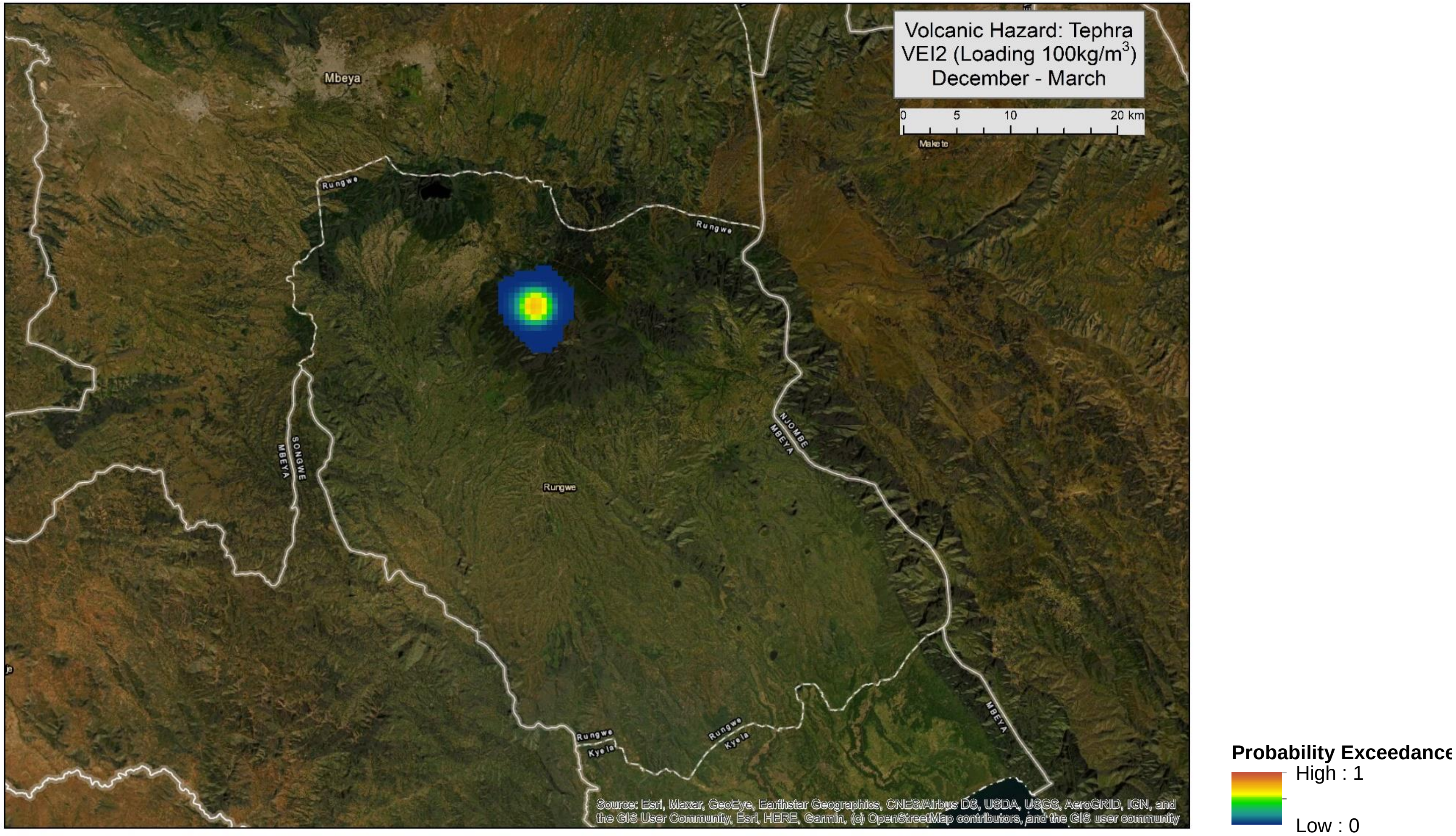
METEOR Hazard footprints for Nepal and Tanzania



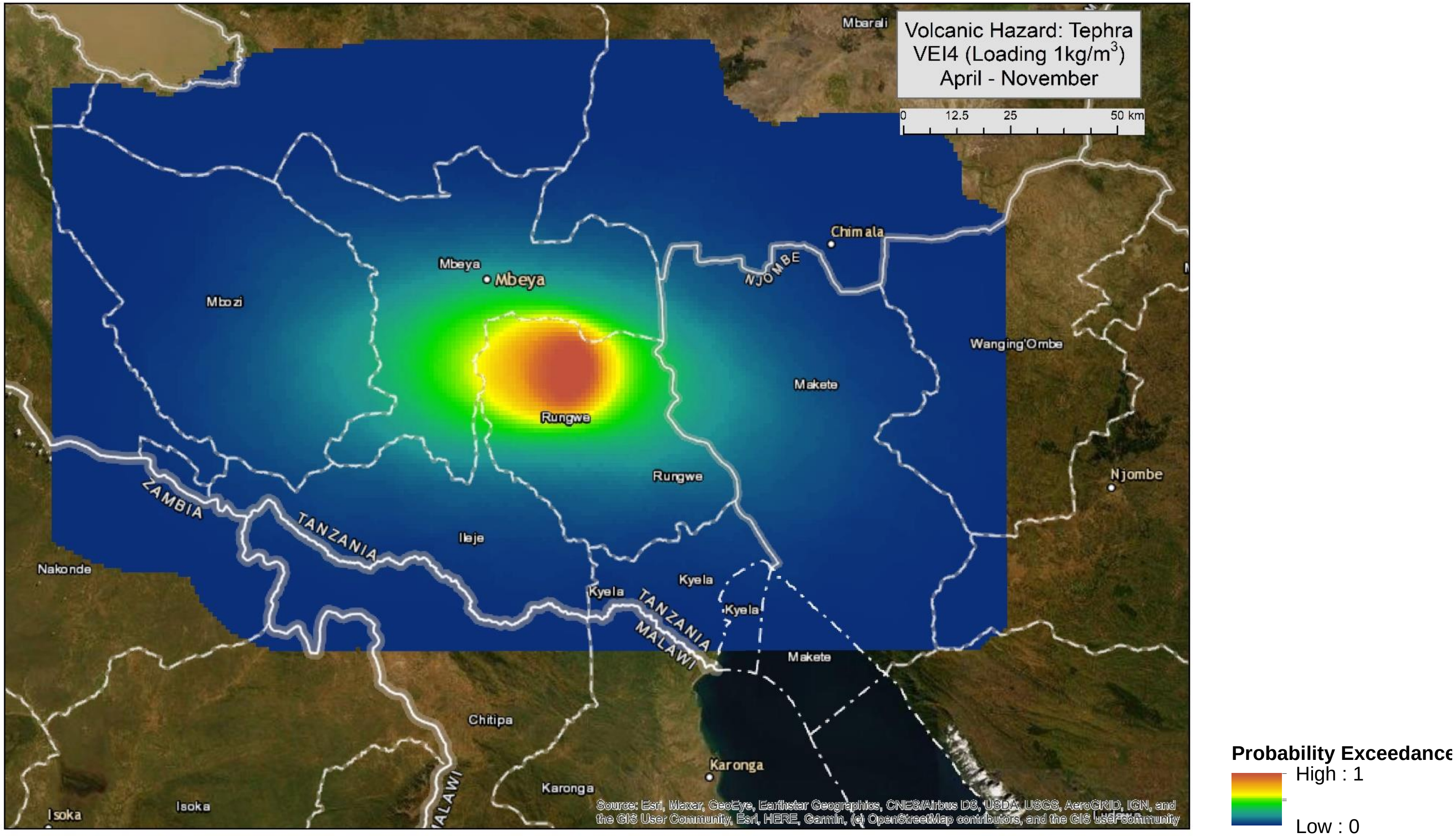




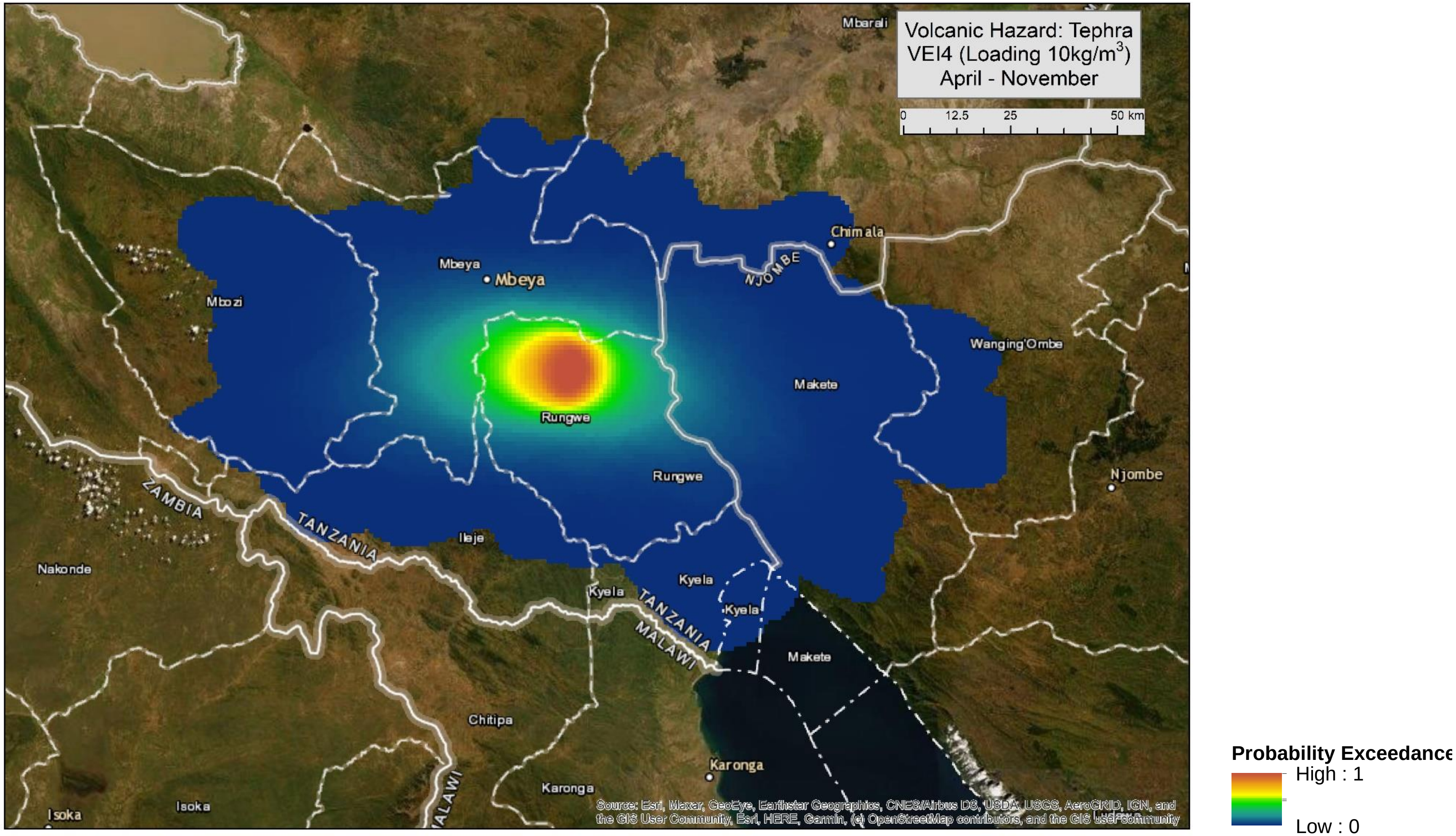
Probability Exceedance
High : 1
Low : 0



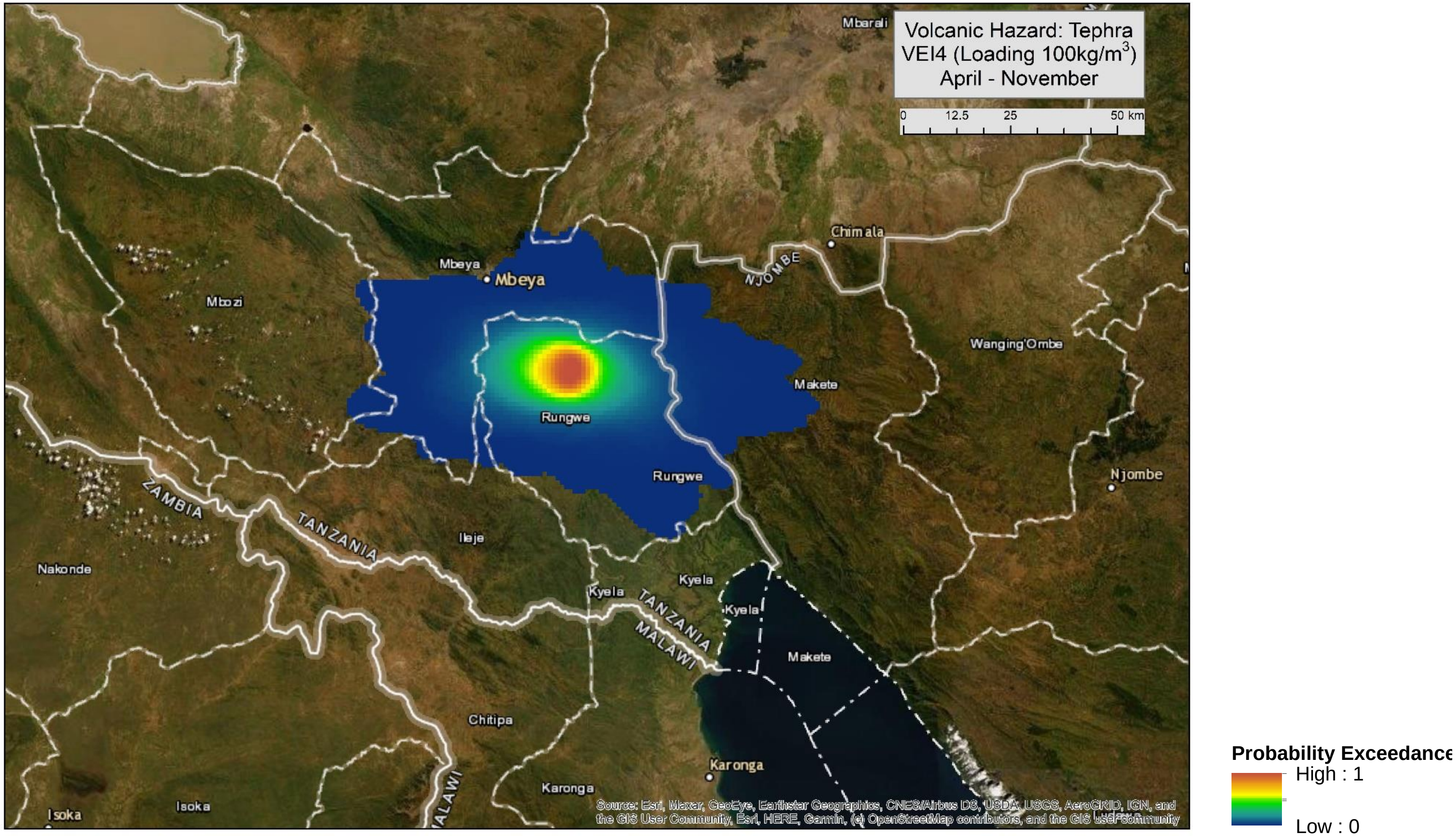
Volcanic Hazard: Tephra
VEI2 (Loading 100kg/m^3)
December - March
0 5 10 20 km
Makete
Mbeya
Rungwe
Rungwe
Rungwe
NJOMBE
MBEYA
SONGWE
MBEYA
Rungwe
Rungwe
Kyela
Rungwe
Kyela
MBEYA
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Probability Exceedance
High : 1
Low : 0

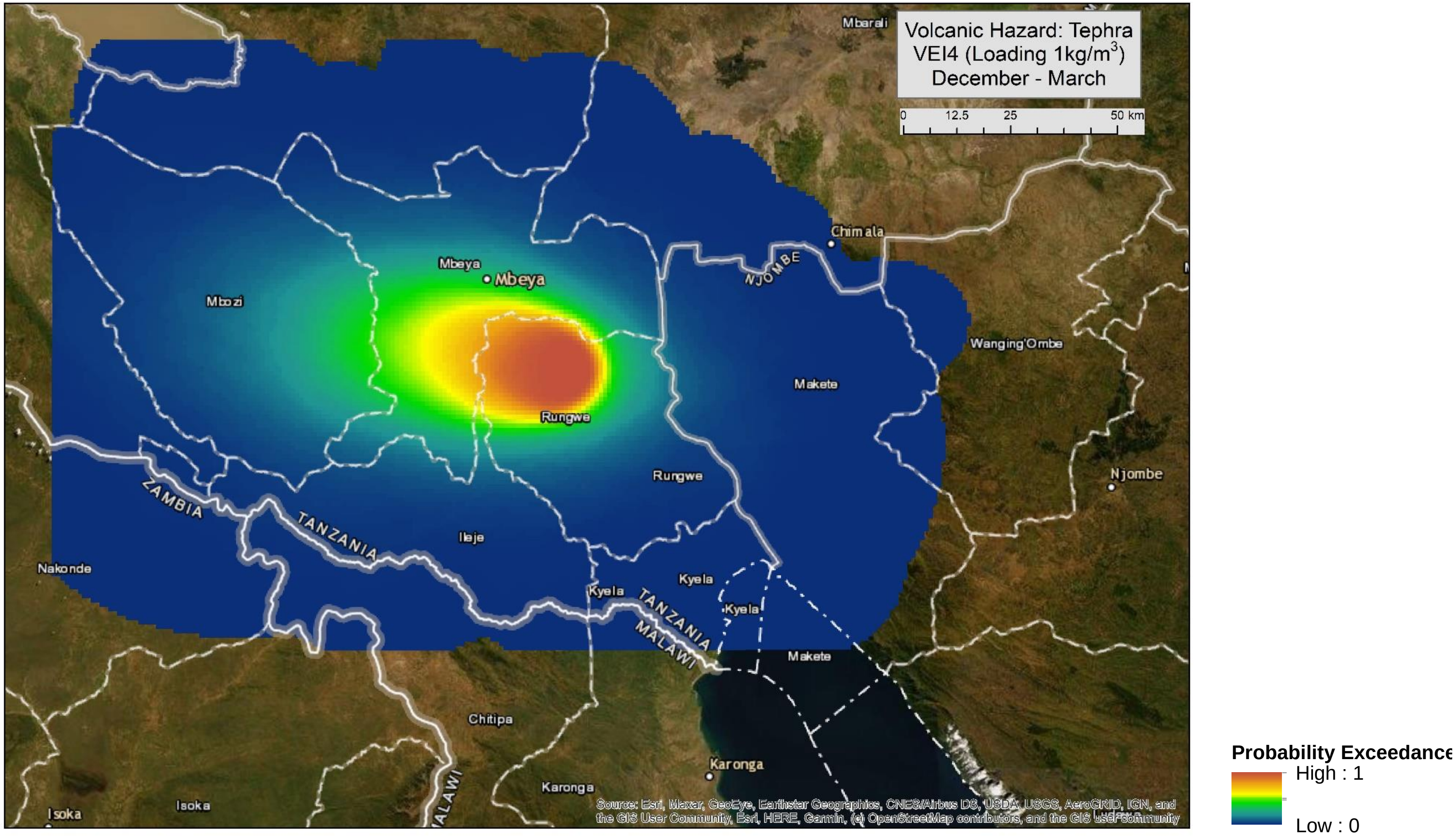


Volcanic Hazard: Tephra
VEI4 (Loading 1kg/m3)
April - November
0 12.5 25 50 km
Mbarali
Chimala
NJOMBE
Mbeya
Mbeya
Mbozi
Wanging'Ombe
Makete
Rungwe
Rungwe
Njombe
ZAMBIA
TANZANIA
Ileje
Nakonde
Kyela
Kyela
Kyela
TANZANIA
MALAWI
Makete
Chitipa
Karonga
Karonga
Isoka
Isoka
MALAWI
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Probability Exceedance
High : 1
Low : 0

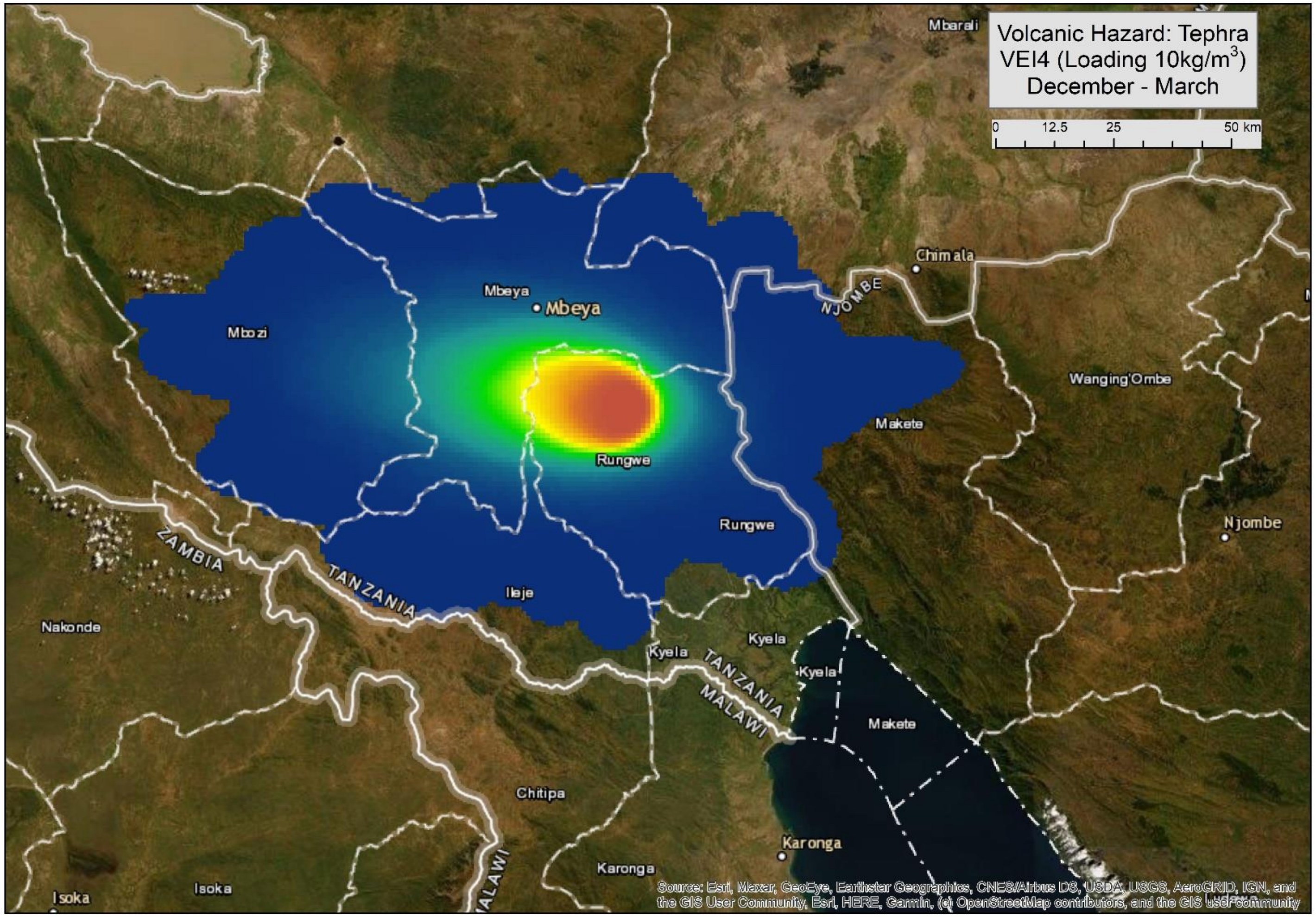


Volcanic Hazard: Tephra
VEI4 (Loading 10kg/m³)
April - November
0 12.5 25 50 km
Mbarali
Chimala
Mbeya
Mbeya
Mbozi
NJOMBE
Wanging'Ombe
Makete
Rungwe
Rungwe
Njombe
ZAMBIA
TANZANIA
Ileje
Nakonde
Kyela
Kyela
Kyela
TANZANIA
MALAWI
Makete
Chitipa
Karonga
Karonga
Isoka
Isoka
MALAWI
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Probability Exceedance
High : 1
Low : 0


Volcanic Hazard: Tephra
VEI4 (Loading 100kg/m^3)
April - November
0 12.5 25 50 km
Mbarali
Mbeya
Mbeya
Mbozi
Chimala
NJOMBE
Wanging'Ombe
Makete
Rungwe
Rungwe
Njombe
ZAMBIA
TANZANIA
Ileje
Nakonde
Kyela
Kyela
Kyela
TANZANIA
MALAWI
Makete
Chitipa
Karonga
Karonga
Isoka
Isoka
MALAWI
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Probability Exceedance
High : 1
Low : 0



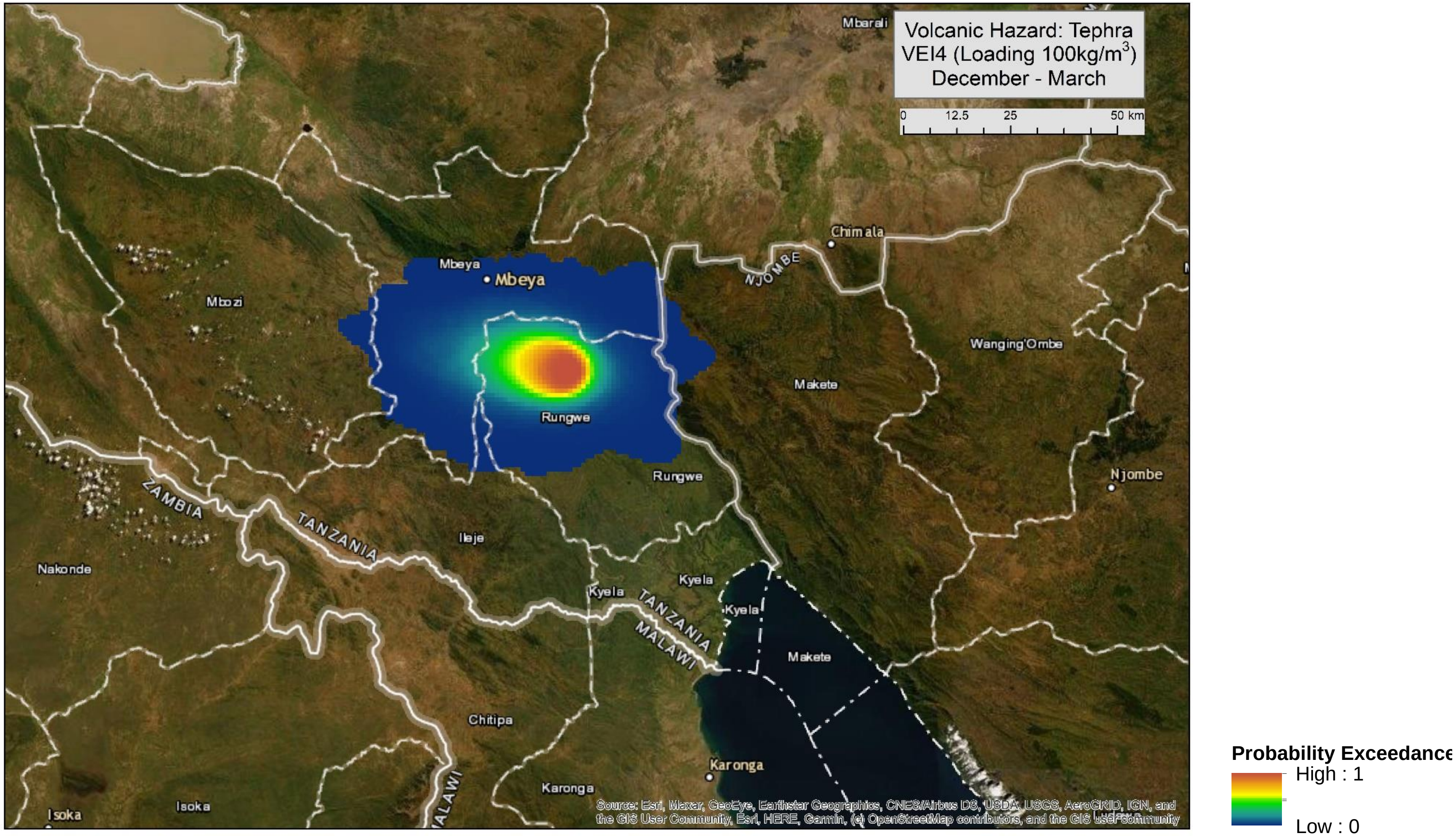
Volcanic Hazard: Tephra
VEI4 (Loading 1kg/m^3)
December - March
0 12.5 25 50 km
Mbarali
Chimala
NJOMBE
Mbeya
Mbeya
Mbozi
Wanging'Ombe
Makete
Rungwe
Rungwe
Njombe
ZAMBIA
TANZANIA
Ileje
Nakonde
Kyela
Kyela
Kyela
TANZANIA
MALAWI
Makete
Chitipa
Karonga
Karonga
Isoka
Isoka
MALAWI
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Probability Exceedance
High : 1
Low : 0



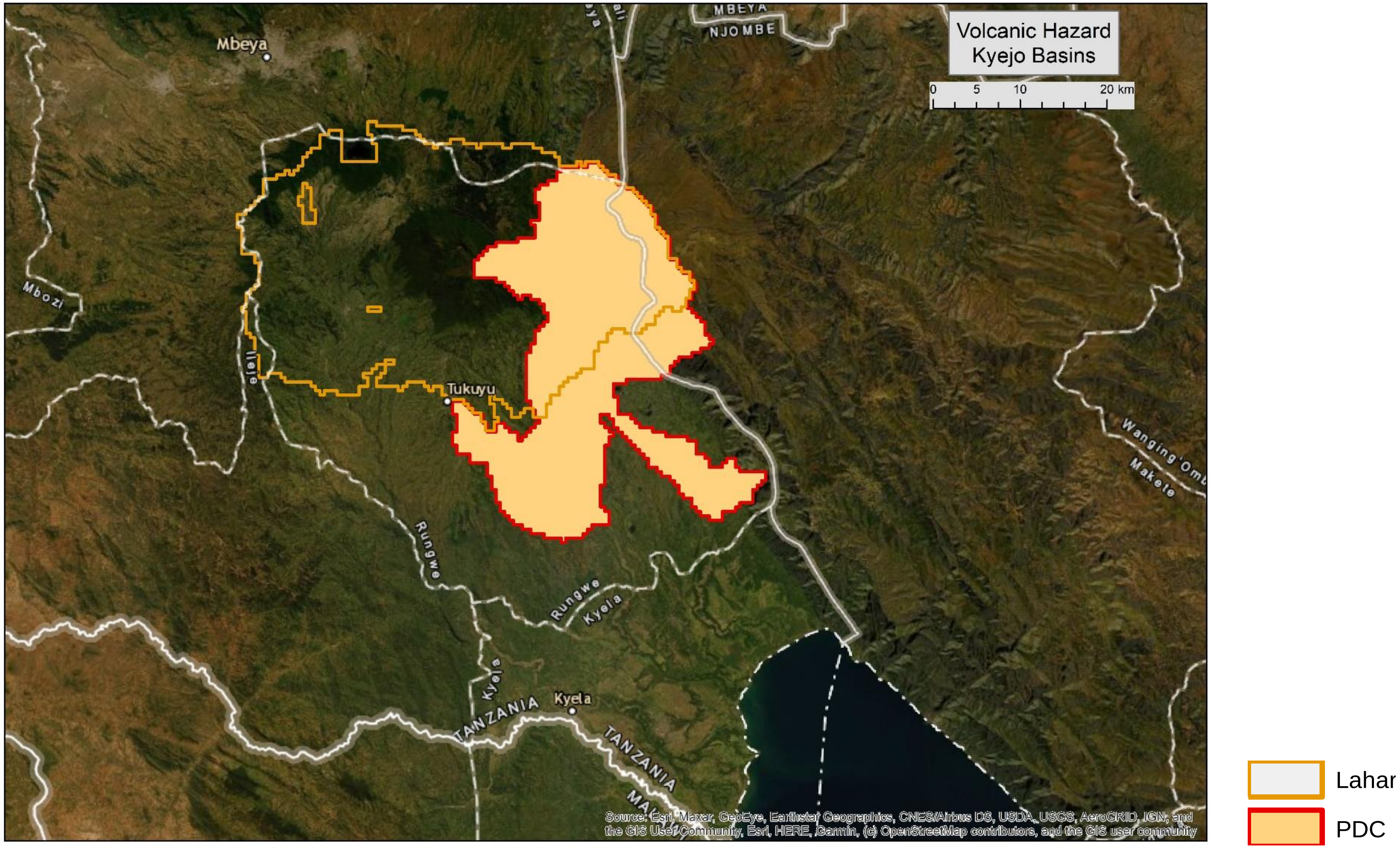
Probability Exceedance

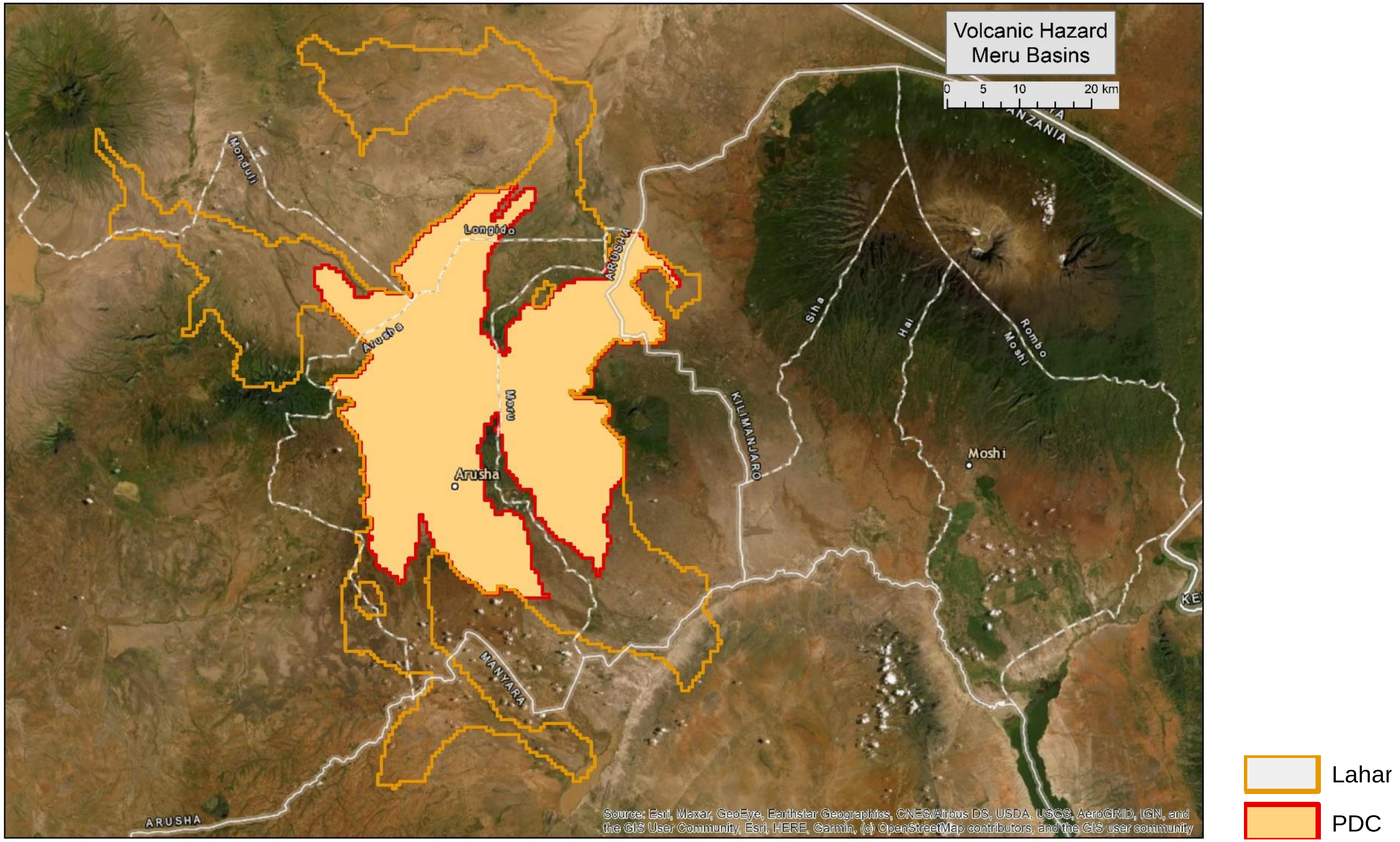
High : 1

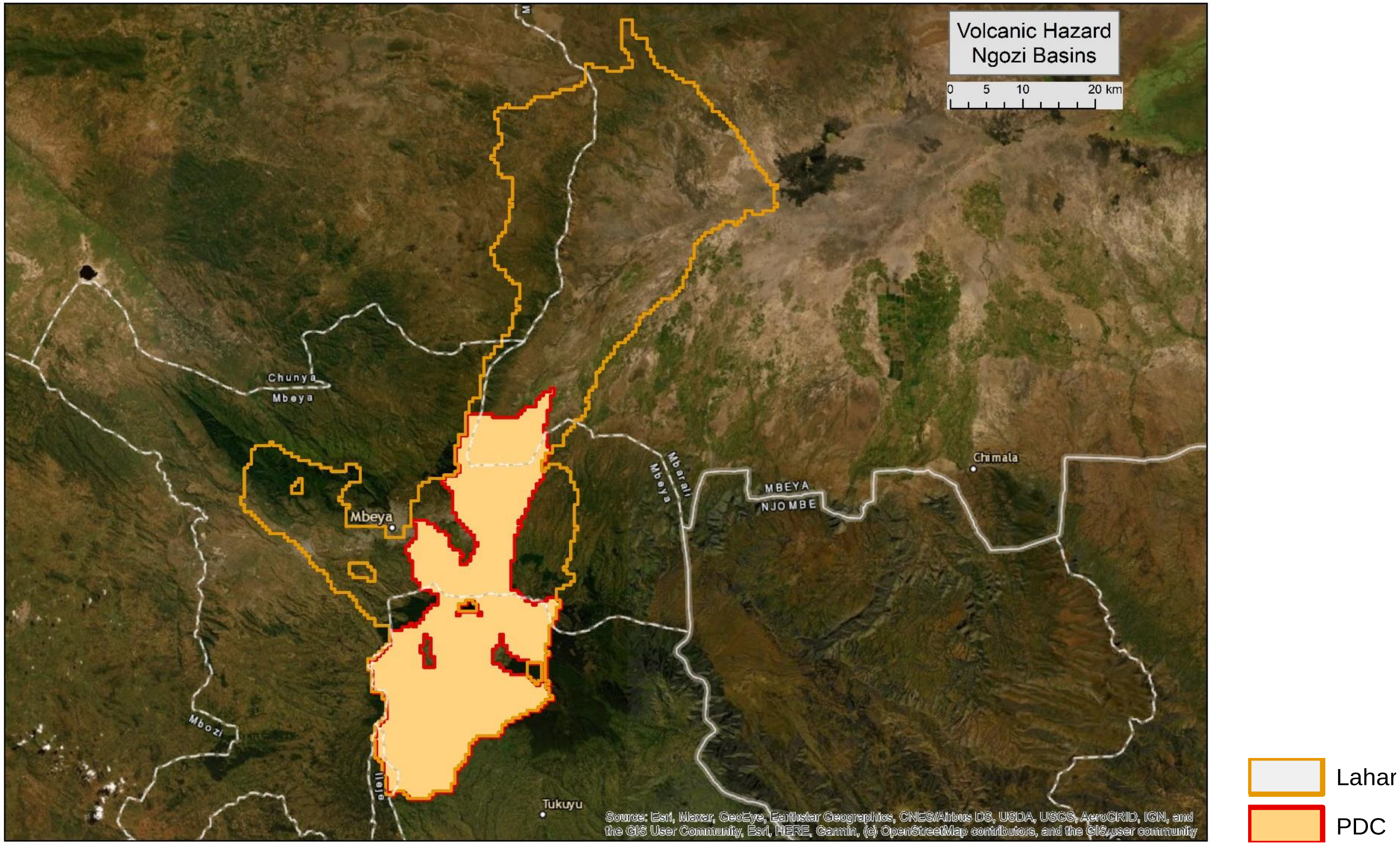
Low : 0

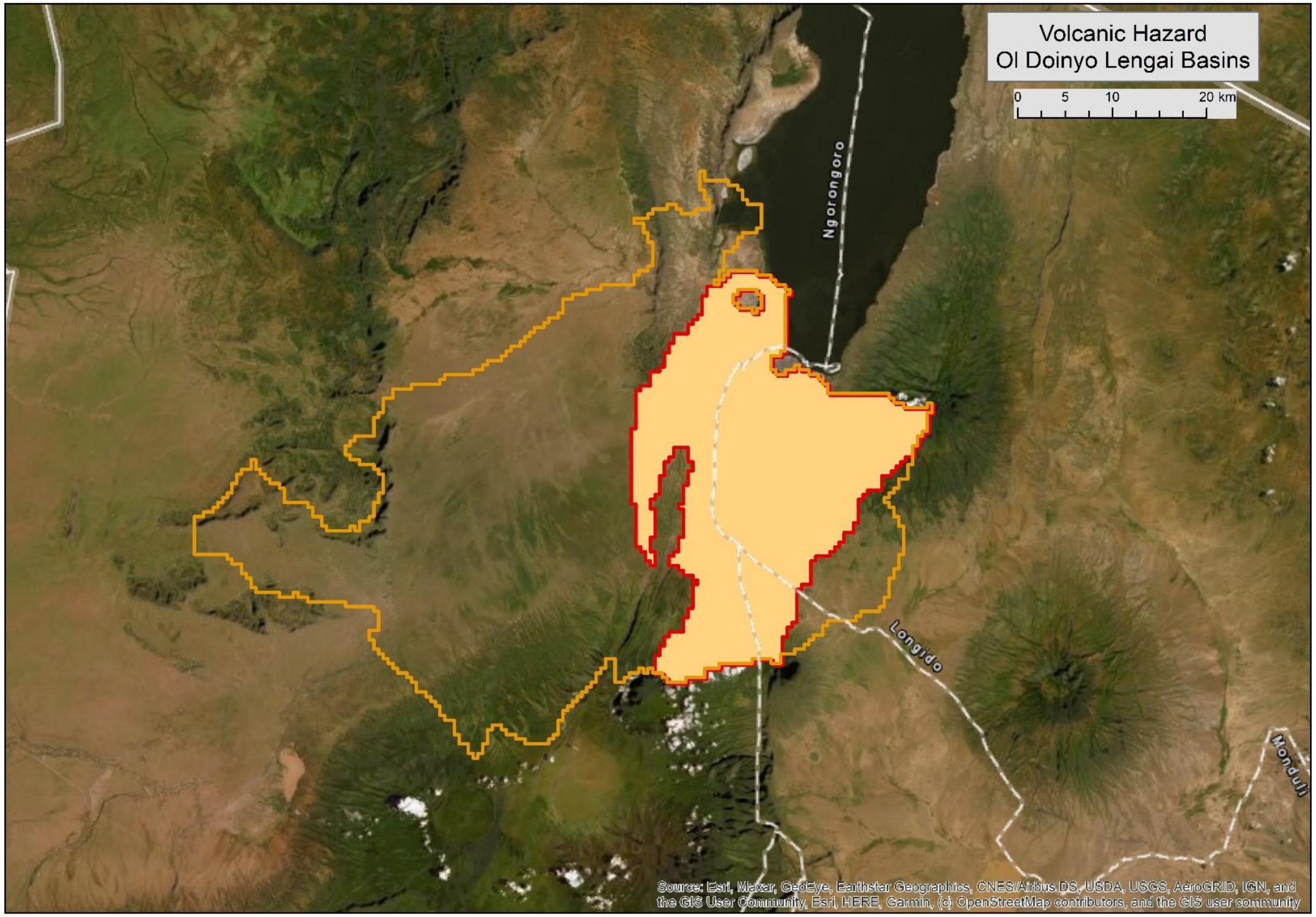

Volcanic Hazard: Tephra
VEI4 (Loading 100kg/m³)
December - March
0 12.5 25 50 km
Mbarali
Mbeya
Mbeya
Mbozi
Chimala
NJOMBE
Wanging'Ombe
Makete
Rungwe
Rungwe
Njombe
ZAMBIA
TANZANIA
Ileje
Nakonde
Kyela
Kyela
Kyela
TANZANIA
MALAWI
Makete
Chitipa
Karonga
Karonga
Isoka
Isoka
MALAWI
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Probability Exceedance
High : 1
Low : 0

5.3. Volcanic Basins



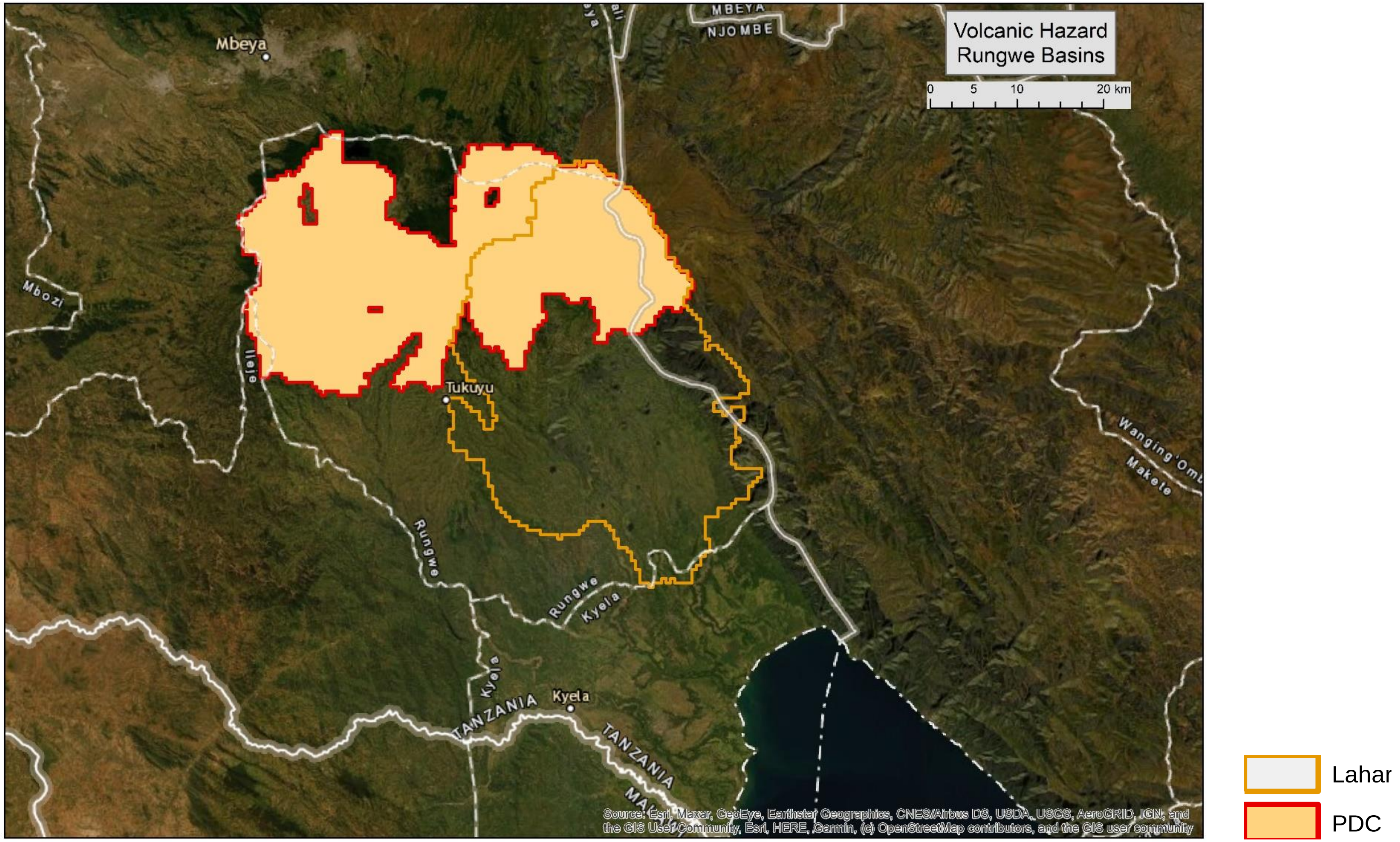

Volcanic Hazard
Meru Basins
0 5 10 20 km
Longido
Arusha
Meru
Arusha
Moshi
Monduli
ARUSHA
KILIMANJARO
MANYARA
Siha
Hai
Rombo
Moshi
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Lahar
PDC


Volcanic Hazard
Ngozi Basins
0 5 10 20 km
Chunya
Mbeya
Mbeya
Mbarali
Mbeya
MBEYA
NJOMBE
Chimala
Mbozi
Ileje
Tukuyu
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Lahar
PDC


Volcanic Hazard
Ol Doinyo Lengai Basins
0
5
10
20 km
Ngorongoro
Longido
Monduli
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Lahar

PDC


Volcanic Hazard
Rungwe Basins
0 5 10 20 km
Mbeya
MBEYA
NJOMBE
Mbozi
Ileje
Tukuyu
Rungwe
Kyela
TANZANIA
Wanging'Ombe
Makete
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Lahar
PDC

5.4. Summary of Geospatial Detail of Volcanic Hazard Products for Tanzania

Layer	Type	Format	Native Spatial Reference	Units	Cell Size (x, y)	Data Type
Volcanic: Ash fall VEI2 Apr-Nov @ 1km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI2 Dec-Mar @ 1km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI2 Apr-Nov @ 10km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI2 Dec-Mar @ 10km²	Vector	Shapefile: point	Projected WGS84: UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI2 Apr-Nov @ 100km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI2 Dec-Mar @ 100km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI4 Apr-Nov @ 1km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI4 Dec-Mar @ 1km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI4 Apr-Nov @ 10km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI4 Dec-Mar @ 10km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI4 Apr-Nov @ 100km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI4 Dec-Mar @ 100km²	Vector	Shapefile: point	Projected: WGS84 UTM Zone 36S	Metres	n/a	n/a
Volcanic: Ash fall VEI2 Apr-Nov @ 1km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI2 Dec-Mar @ 1km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI2 Apr-Nov @ 10km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI2 Dec-Mar @ 10km²	Raster	ESRI GRID	Projected WGS84: UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI2 Apr-Nov @ 100km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI2 Dec-Mar @ 100km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI4 Apr-Nov @ 1km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI4 Dec-Mar @ 1km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI4 Apr-Nov @ 10km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI4 Dec-Mar @ 10km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI4 Apr-Nov @ 100km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Ash fall VEI4 Dec-Mar @ 100km²	Raster	ESRI GRID	Projected: WGS84 UTM Zone 36S	Metres	500, 500	32-bit Floating point
Volcanic: Lahar Basins Keyjo	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a
Volcanic: Lahar Basins Meru	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a
Volcanic: Lahar Basins Ngozi	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a
Volcanic: Lahar Basins Ol Doinyo Lengai	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a
Volcanic: Lahar Basins Rungwe	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a
Volcanic: PDC Basins Keyjo	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a
Volcanic: PDC Basins Meru	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a
Volcanic: PDC Basins Ngozi	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a

Layer	Type	Format	Native Spatial Reference	Units	Cell Size (x, y)	Data Type
Volcanic: PDC Basins Ol Doinyo Lengai	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a
Volcanic: PDC Basins Rungwe	Vector	Shapefile: polygon	Geographic: WGS84	Decimal Degree	n/a	n/a

6. Landslide Hazard: Nepal

For the Landslide methodology adopted for the METEOR project please see Dashwood (2020) report.

6.1. Abstract

Earthquake-triggered landslide hazard

Landslide hazard map derived using PGA values with 10% probability of exceedance in 50 years (provided by the Global Earthquake Model- GEM)

Description
The map shows the spatial distribution of seismically induced landslide hazard across Nepal. The approach adopted to create the hazard assessment follows Nadim et al (2006) which defines the landslide hazard level as being a combination of the trigger, in this case ground shaking related to earthquakes, and the susceptibility. Derived using PGA values with 10% probability of exceedance in 50 years (provided by the Global Earthquake Model -GEM).

Earthquake-triggered landslide susceptibility

Susceptibility map for co-seismic landslides developed using a fuzzy logic approach and expert input.

Description
The map shows the spatial distribution of the susceptibility of an area to landslides. Susceptibility measures the degree to which a terrain may potentially be affected by landsliding; it is an estimate of where landslides are likely to occur in the future. The susceptible areas were determined by correlating a set of geo-environmental factors that contribute to slope instability with the past distribution of landslides triggered by seismicity.

Rainfall-triggered landslide hazard

Landslide hazard map derived using the METEOR rainfall-triggered susceptibility model and a 50 year return period (RP) rainfall model (Marahatta et al., 2009).

Description
The map shows the spatial distribution of landslide hazard across Nepal. Landslide hazard is the probability of occurrence within a specific period of time and within a given area of a potentially damaging landslide. The approach adopted here to create the hazard assessment defines the landslide hazard as being a combination of the trigger, in this case a 50 year return period (RP) rainfall mode land the landslide susceptibility (see the METEOR Rainfall-triggered landslide susceptibility model of Nepal).

Rainfall-triggered landslide susceptibility

Susceptibility map for landslides triggered by rainfall using a fuzzy logic approach and expert input.

Description
The map shows the spatial distribution of the susceptibility of an area to landslides. Susceptibility measures the degree to which a terrain may potentially be affected by landsliding; it is an estimate

of where landslides are likely to occur in the future. The susceptible areas were determined by correlating a set of geo-environmental factors that contribute to slope instability with the past distribution of landslides triggered by rainfall.

6.1.1. Credits

The maps were co-developed by the British Geological Survey in association with NSET, ICIMOD, Tribhuvan University and DoLIDAR/MOFAGA, within the framework of the UK Space Agency METEOR Project (https://meteor-project.org/).

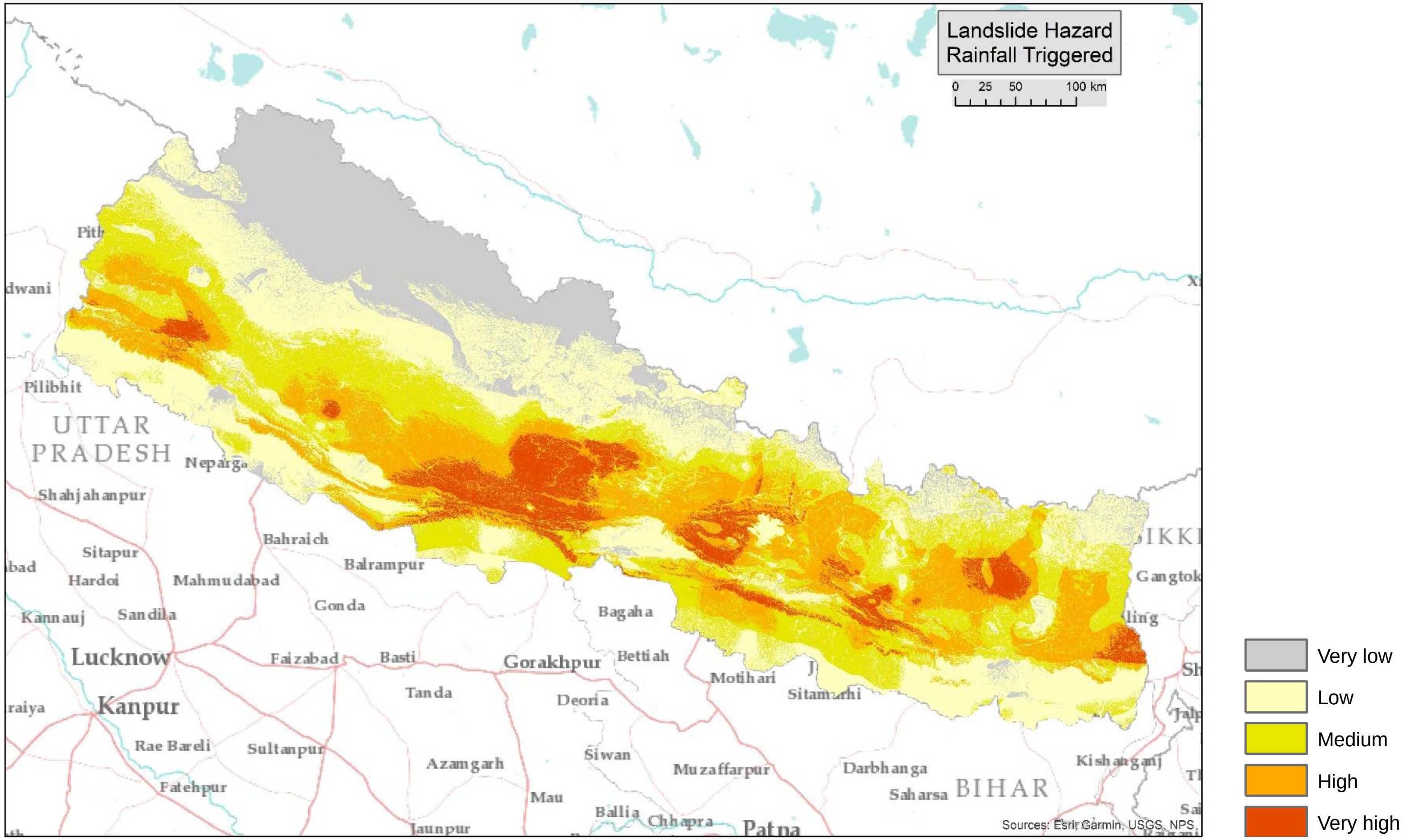
6.1.2. References

Dashwood, C. (2020) METEOR Landslide Hazard Report. Report M6.2b/P

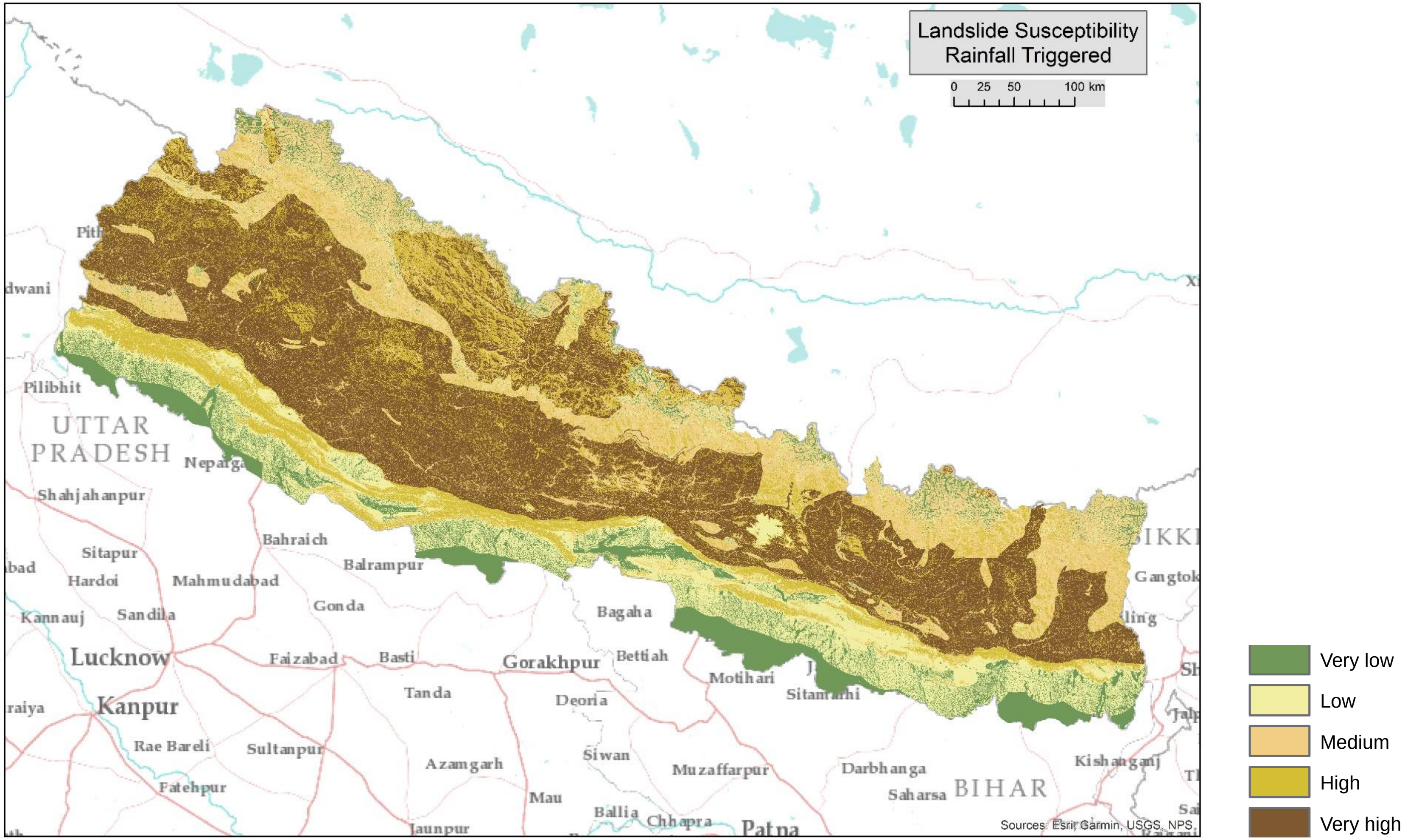
Marahatta, S., Dongol, B. and Gurung, G. (2009) Temporal and Spatial Variability of Climate Change over Nepal (1976-2005). Practical Action, Kathmandu

Nadim, F., Kjekstad, O., Peduzzi, P., Herold, C. & Jaedicke, C. (2006) Global landslide and avalanche hotspots. *Landslides* **3,** 159–173. https://doi.org/10.1007/s10346-006-0036-1

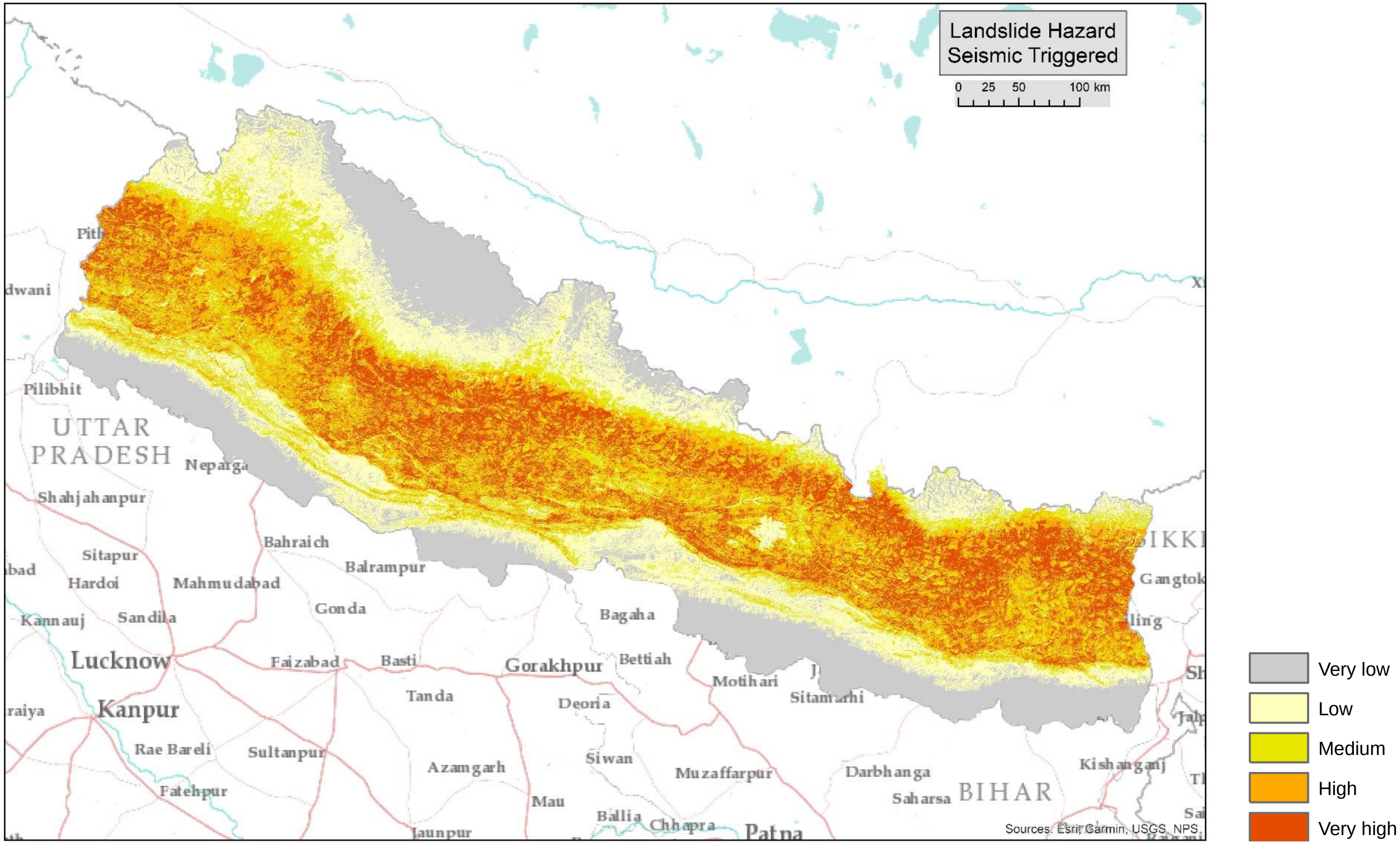
6.2. Rainfall-Triggered Landslide Hazard: Nepal



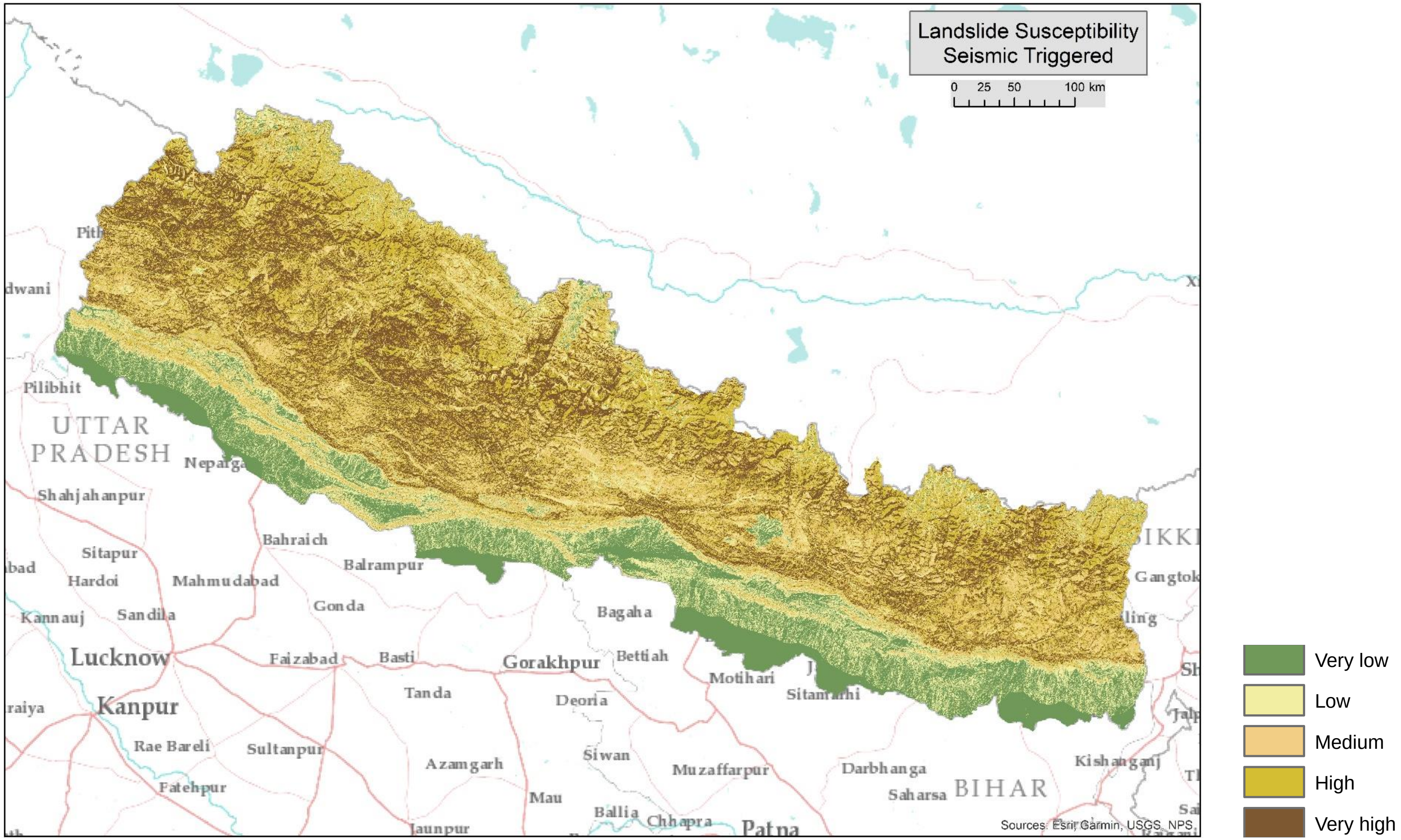
6.3. Rainfall-Triggered Landslide Susceptibility: Nepal



6.4. Seismic-Triggered Landslide Hazard: Nepal



6.5. Seismic-Triggered Landslide Susceptibility: Nepal



6.6. Summary of Geospatial Detail of Landslide Hazard Products for Nepal

Layer	Type	Format	Native Spatial Reference	Units	Cell Size	Data Type
Landslide: Rainfall Triggered Hazard	Raster	FGDBR	Projected: WGS84 UTM Zone 45N	Meters	90 x 90	64-bit Double
Landslide: Rainfall Triggered Susceptibility	Raster	FGDBR	Projected: WGS84 UTM Zone 45N	Meters	90 x 90	64-bit Double
Landslide: Seismic Triggered Hazard	Raster	FGDBR	Projected: WGS84 UTM Zone 45N	Meters	90 x 90	64-bit Double
Landslide: Seismic Triggered Susceptibility	Raster	FGDBR	Projected: WGS84 UTM Zone 45N	Meters	90 x 90	64-bit Double