British Geological Survey

METEOR: Hazard footprints for Nepal and Tanzania. Report M6.1/P

UKSA IPP2 Grant Programme

Open File Report OR/19/066

BRITISH GEOLOGICAL SURVEY

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METEOR (Modelling Exposure Through Earth Observation Routines) Project logo

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Glossary

ASL	Above Sea Level
BGS	British Geological Survey: An organisation providing expert advice in all areas of geosciences to the UK government and internationally
CSV	Comma-Separated Values text file format
DEM	Digital Elevation Model
DfiD	Department for International Development
DMD	Disaster Management Department, Prime Minister's Office of Tanzania, focused on disaster risk
DRM	Disaster Risk Management; the application of disaster risk reduction policies and/or strategies
DRR	Disaster Risk Reduction; disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development
ECMWF	European Centre for Medium-Range Weather Forecasts
EO	Earth Observation; the gathering of information about Earth's physical, chemical and biological systems via remote sensing technologies, usually involving satellites carrying imaging devices
ERA	ECMWF ERA-Interim is a global atmospheric reanalysis dataset
Fluvial	Related to rivers, in this case flooding
GEM	Global Earthquake Model; a non-profit organisation focused on the pursuit of earthquake resilience worldwide
GFDRR	Global Facility for Disaster Risk Reduction and Recovery; a global partnership that helps developing countries better understand and reduce their vulnerability to natural hazards and climate change
HOT	Humanitarian OpenStreetMap Team; a global non-profit organisation that uses collaborative technology to create OSM maps for areas affected by disasters
ICIMOD	International Centre for Integrated Mountain Development
IPP	International Partnership Programme; the UK Space Agency's International Partnership Programme (IPP) is a £30M per year programme, which uses expertise in space-based solutions, applications and capability to provide a sustainable economic or societal benefit to emerging nations and developing economies
LDC	Least Developed Country on the Organisation for Economic Co-operation and Development's (OECD) Development Assistance Committee (DAC) list
M	Milestone, related to work package deliverable
M&E	Monitoring and Evaluation
MERIT	Multi-Error-Removed Improved-Terrain DEM
METEOR	Modelling Exposure Through Earth Observation Routines; a three-year project funded by the UK Space Agency to develop innovative application of Earth Observation (EO) technologies to improve understanding of exposure and multihazards impact with a specific focus on the countries of Nepal and Tanzania
MOFAGA	Ministry of Federal Affairs and General Administration, Nepal
NSET	National Society for Earthquake Technology, non-governmental organisation working on reducing earthquake risk in Nepal and abroad
ODA	Official Development Assistance; government aid that promotes and specifically targets the economic development and welfare of developing countries
OPM	Oxford Policy Management, organisation focused on sustainable project design and implementation for reducing social and economic disadvantage in low-income countries
PDC	Pyroclastic Density Current

PGA	Peak Ground Acceleration
Pluvial	Relating to or characterised by rainfall, in this case flooding
RP	Return Period
SDGs	Sustainable Development Goals; these goals were set up in 2015 by the United Nations General Assembly and are intended to be achieved by the year 2030
SSAHARA	USAID-supported project within which the Sub-Saharan Africa (SSA) Earthquake Model was developed by GEM in collaboration with AfricaArray
UKSA	United Kingdom Space Agency; an executive agency of the Government of the United Kingdom, responsible for the United Kingdom's civil space programme
VEI	Volcanic Explosivity Index; a numeric scale to measure the relative explosivity of historical volcanic eruptions.
WGS84	World Geodetic System 1984
WP	Work Package; discrete sets of activities within the METEOR Project, each work package is led by a different partner and has specific objectives

Foreword

This report is the published product of a study by the British Geological Survey (BGS), Global Earthquake Model Foundation (GEM) and Fathom (SSBN) as part of the Modelling Exposure Through Earth Observation Routines (METEOR) project led by British Geological Survey (BGS).

METEOR is grant-funded by the UK Space Agency's International Partnership Programme (IPP), a >£150 million programme which is committed to using the UK's space sector research and innovation strengths to deliver sustainable economic, societal, and environmental benefit to those living in emerging and developing economies. IPP is funded from the Department for Business, Energy and Industrial Strategy's (BEIS) Global Challenges Research Fund (GCRF). This £1.5 billion Official Development Assistance (ODA) fund supports cutting-edge research and innovation on global issues affecting developing countries. ODA-funded activity focuses on outcomes that promote long-term sustainable development and growth in countries on the OECD Development Assistance Committee (DAC) list. IPP is ODA compliant, being delivered in alignment with UK Aid Strategy and the United Nations' (UN) Sustainable Development Goals (SDGs).

This report shows the hazard footprints generated for Nepal and Tanzania through the METEOR project. Detail on the full methodology for footprint generation and their function 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, with data being more openly available through a number of open global platforms.

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Summary

This report describes a specific piece of work conducted by British Geological Survey (BGS), Global Earthquake Model Foundation (GEM) and Fathom (SSBN) as part of the METEOR (Modelling Exposure Through Earth Observation Routines) project, led by British Geological Survey (BGS) with collaborative partners Oxford Policy Management Limited (OPM), SSBN Limited, The Disaster Management Department, Office of the Prime Minister – Tanzania (DMD), The Global Earthquake Model Foundation (GEM), The Humanitarian OpenStreetMap Team (HOT), ImageCat and the National Society for Earthquake Technology (NSET) – Nepal.

The 3-year project was funded by UK Space Agency through their International Partnership Programme, details of which can be located in the Foreword, and was completed in 2021.

The project aimed to provide an innovative solution to disaster risk reduction, through development of an innovative methodology of creating exposure data from Earth Observation (EO) imagery to identify development patterns throughout a country and provide detailed information when combined with population information. Level 1 exposure was developed for all 47 least developed countries on the OECD DAC list, referred to as ODA least-developed countries in the METEOR documentation, with open access to data and protocols for their development. New national detailed exposure and hazard datasets were also generated for the focus countries of Nepal and Tanzania and the impact of multiple hazards assessed for the countries. Training on product development and potential use for Disaster Risk Reduction was performed within these countries with all data made openly available on data platforms for wider use both within country and worldwide.

This report (M6.1/P) is the first generated by BGS for the work package on Multiple hazard impact (WP6) led by BGS. The other 7 METEOR work packages included, Project Management (WP1 – led by BGS), Monitoring and Evaluation (WP2 – led by OPM), EO data for exposure development (WP3 – led by ImageCat), Inputs and Validation (WP4 – led by HOT), Vulnerability and Uncertainty (WP5 - led by GEM), Knowledge sharing (WP7 – led by GEM) and Sustainability and capacity building (WP8 – led by ImageCat).

1. METEOR Project

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, 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

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 technique 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. These 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) will be 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, which are led by various partners. Table 1 provides an overview of the work packages together with a brief description of what each of the work packages cover.

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 1: 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 2).

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 2: Overview of BGS multi-hazard impact deliverables

2. Flooding

2.1. FLOODING 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. Flooding 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

Figure 1: Nepal Pluvial Flooding Hazard Footprint for 1 in 5 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 2: Nepal Pluvial Flooding Hazard Footprint for 1 in 10 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 3: Nepal Pluvial Flooding Hazard Footprint for 1 in 20 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 4: Nepal Pluvial Flooding Hazard Footprint for 1 in 50 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 5: Nepal Pluvial Flooding Hazard Footprint for 1 in 75 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 6: Nepal Pluvial Flooding Hazard Footprint for 1 in 100 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 7: Nepal Pluvial Flooding Hazard Footprint for 1 in 200 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 8: Nepal Pluvial Flooding Hazard Footprint for 1 in 250 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 9: Nepal Pluvial Flooding Hazard Footprint for 1 in 500 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 10: Nepal Pluvial Flooding Hazard Footprint for 1 in 1000 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

2.3. FLUVIAL DEFENDED: NEPAL

Figure 11: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 5 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 12: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 10 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 13: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 20 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 14: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 50 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 15: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 75 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 16: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 100 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 17: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 200 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 18: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 250 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 19: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 500 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

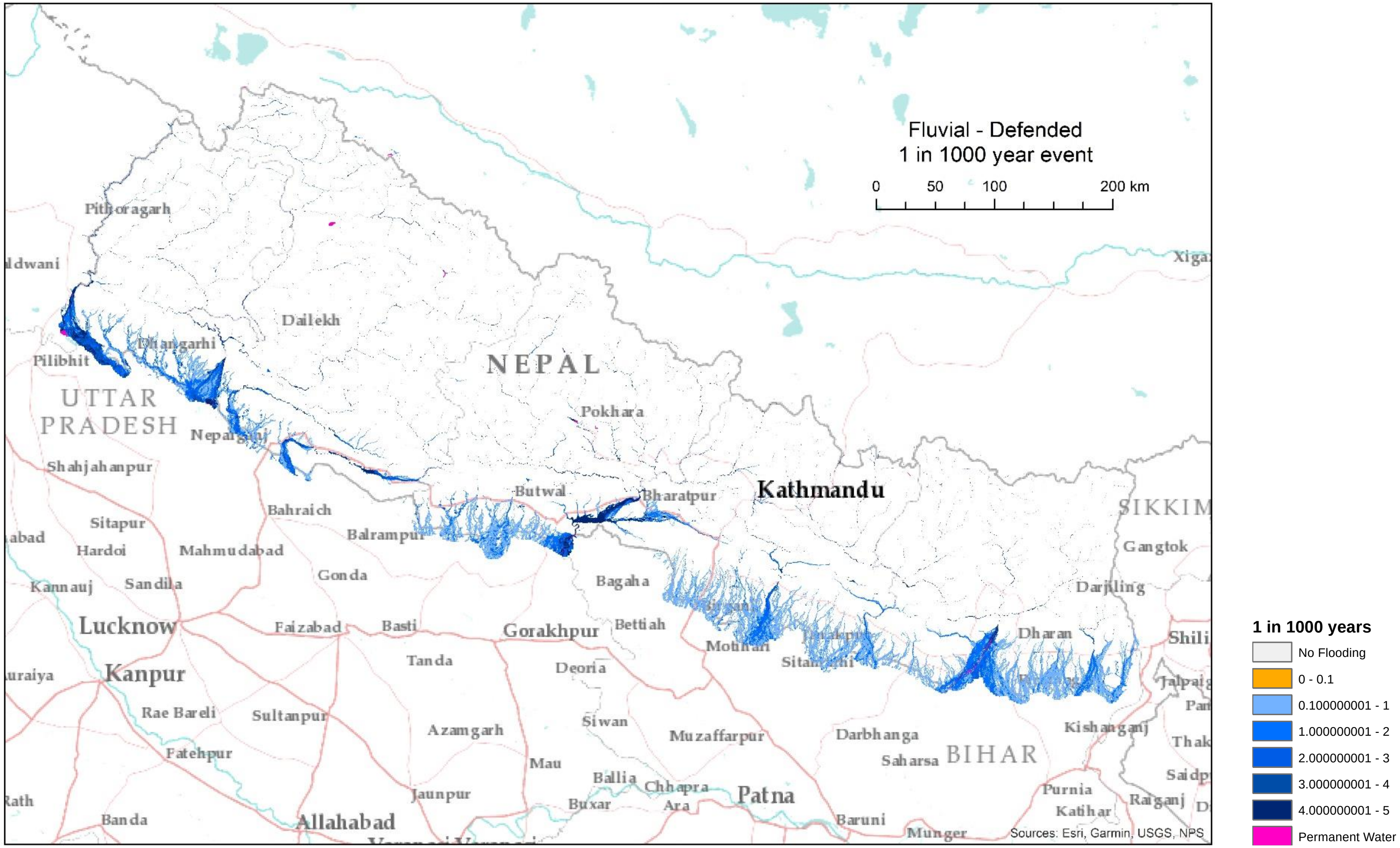

Figure 20: Nepal Fluvial Defended Flooding Hazard Footprint for 1 in 1000 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

2.4. FLUVIAL UNDEFENDED: NEPAL

Figure 21: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 5 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 22: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 10 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 23: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 20 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 24: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 50 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 25: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 75 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 26: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 100 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 27: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 200 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 28: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 250 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

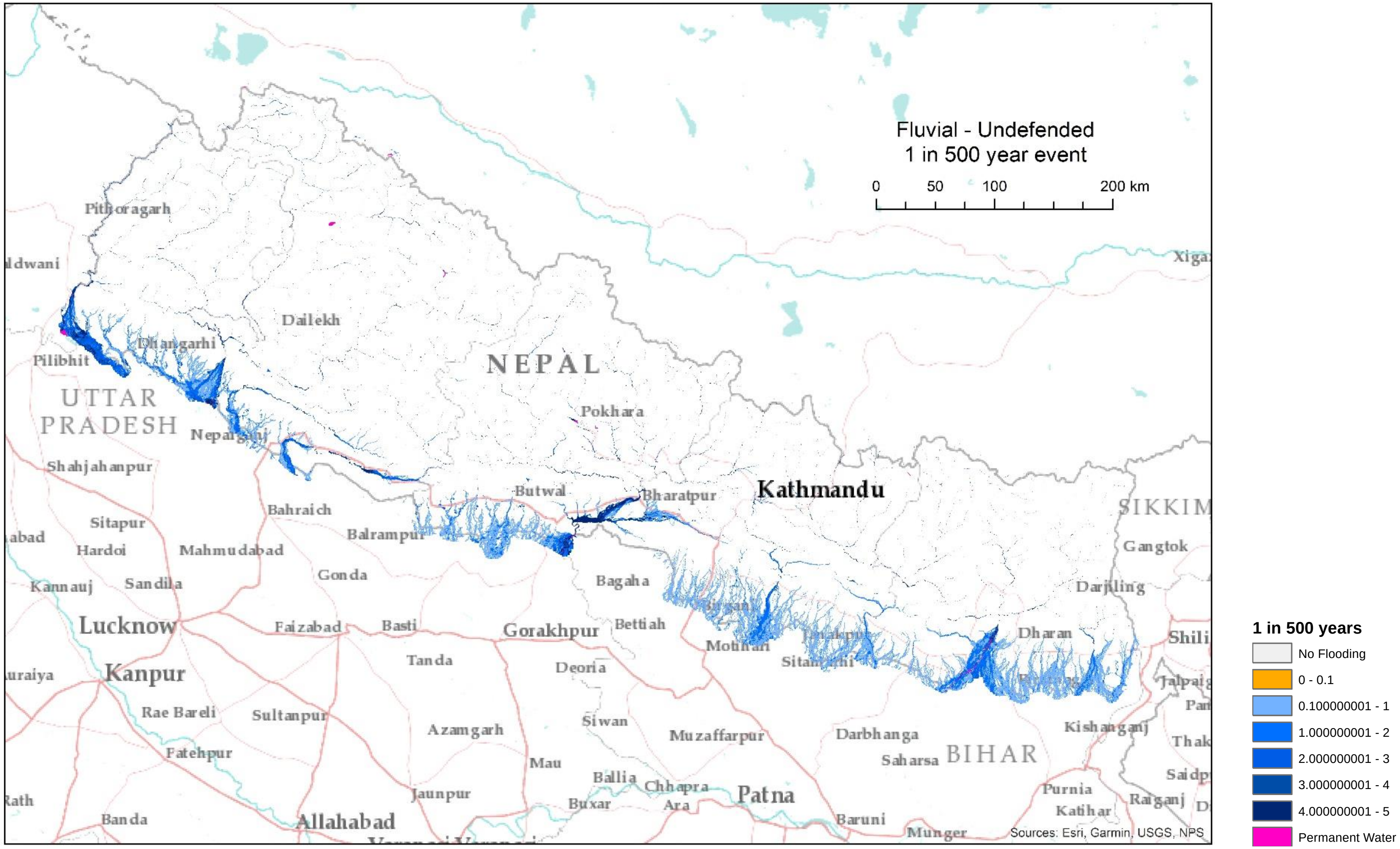

Figure 29: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 500 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

Figure 30: Nepal Fluvial Undefended Flooding Hazard Footprint for 1 in 1000 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

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

Table 3: Summary of geospatial detail for METEOR-derived flood hazard products for Nepal

2.6. PLUVIAL: TANZANIA

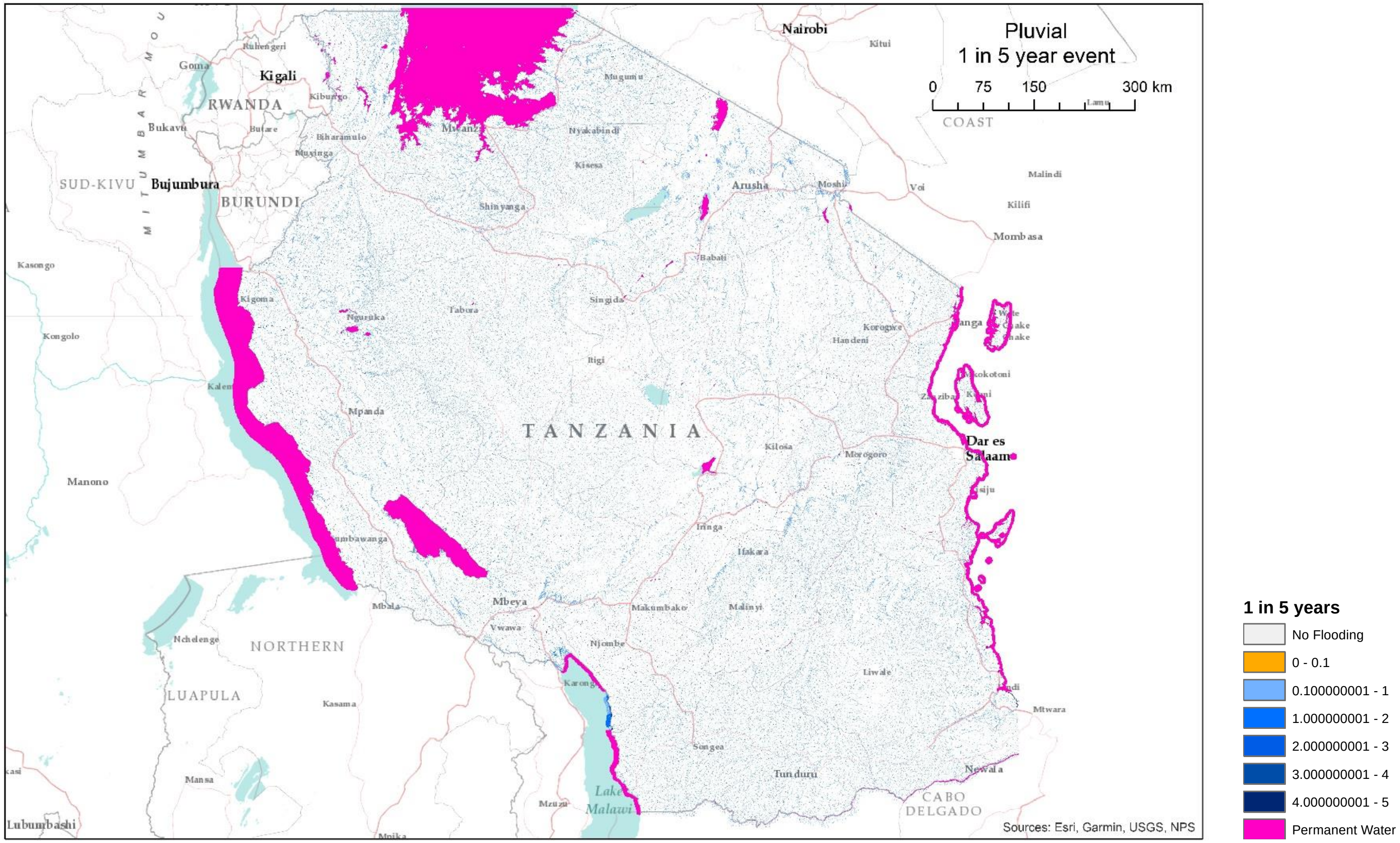

Figure 31: Tanzania Pluvial Flooding Hazard Footprint for 1 in 5 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

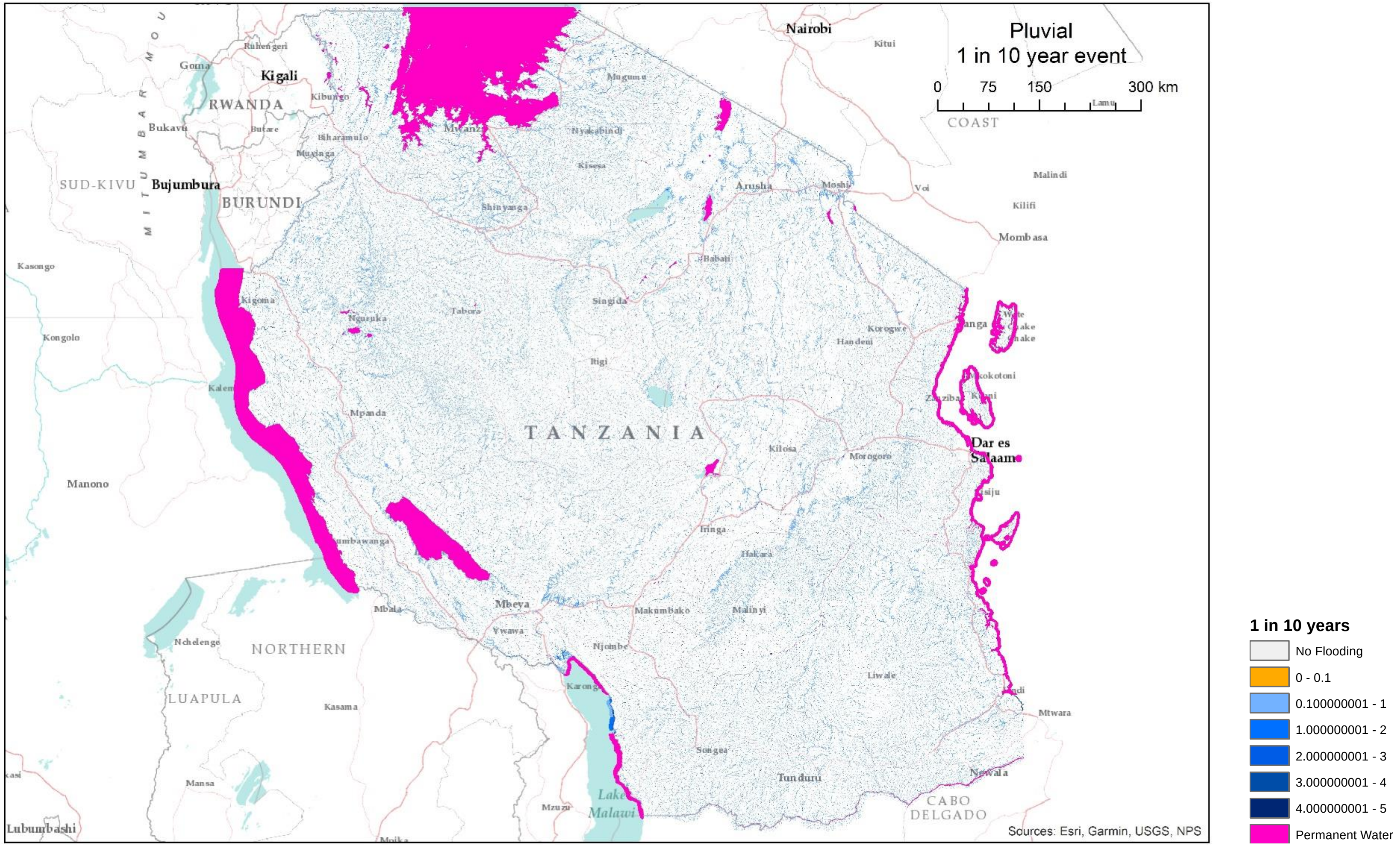

Figure 32: Tanzania Pluvial Flooding Hazard Footprint for 1 in 10 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

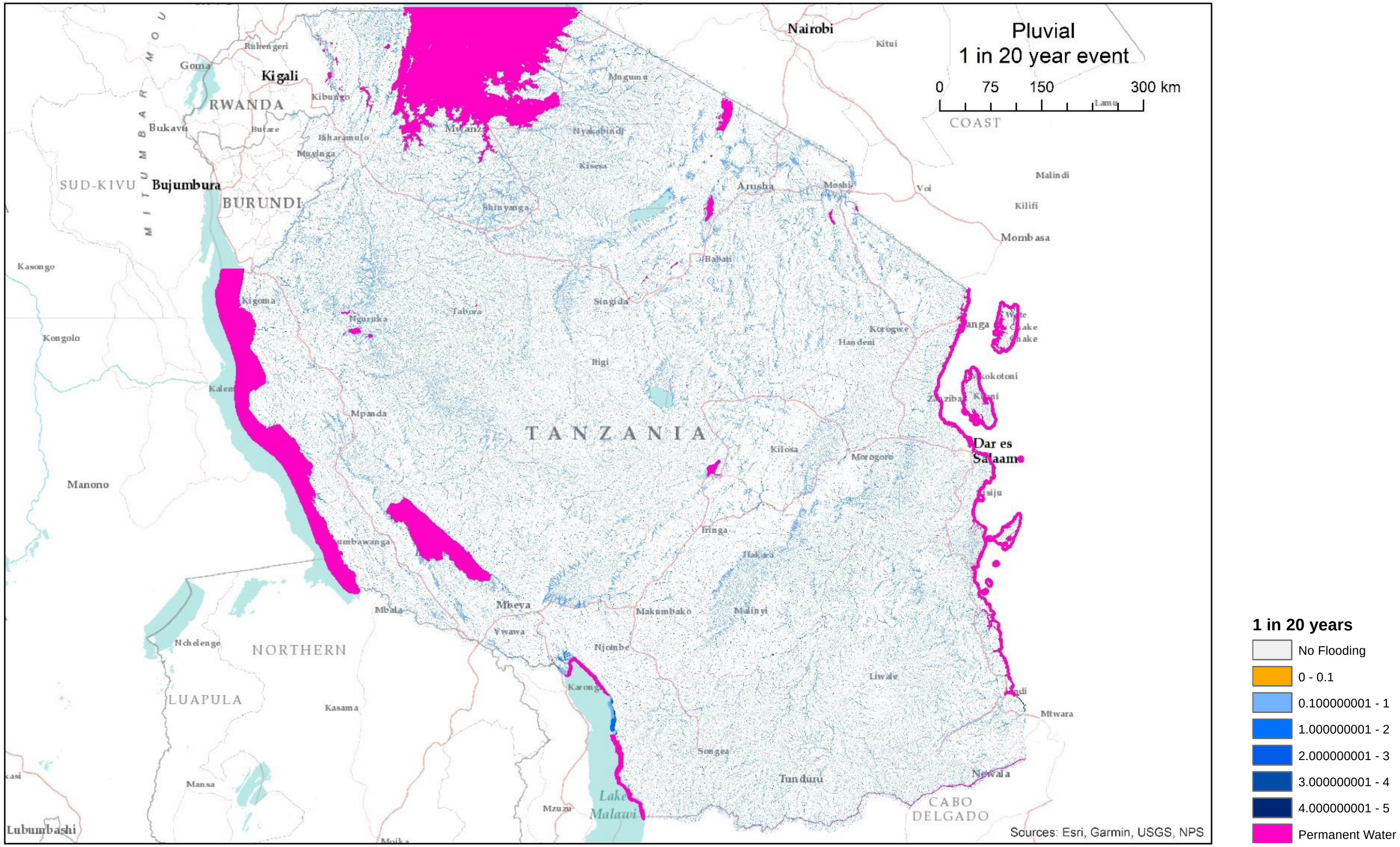

Figure 33: Tanzania Pluvial Flooding Hazard Footprint for 1 in 20 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

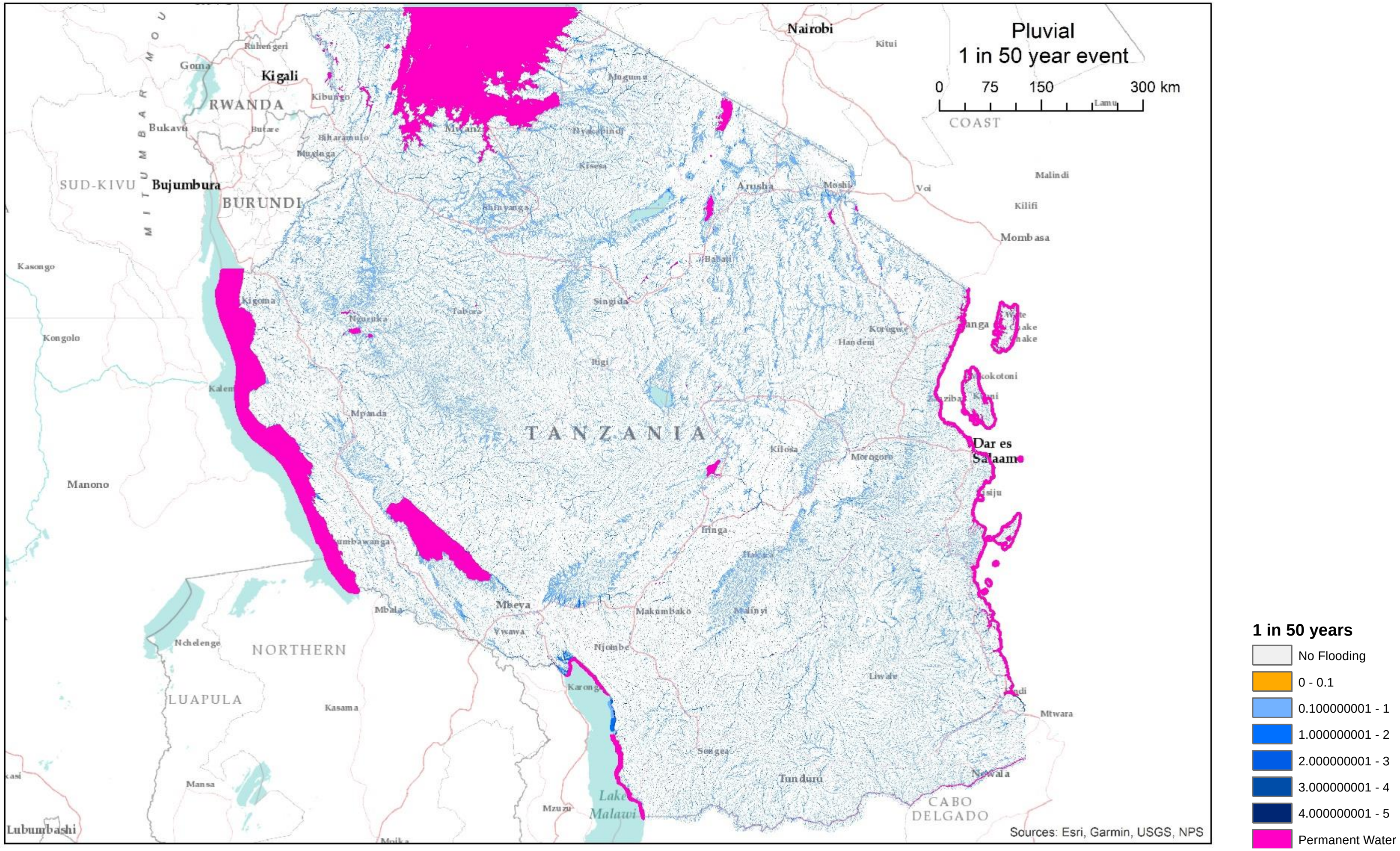

Figure 34: Tanzania Pluvial Flooding Hazard Footprint for 1 in 50 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

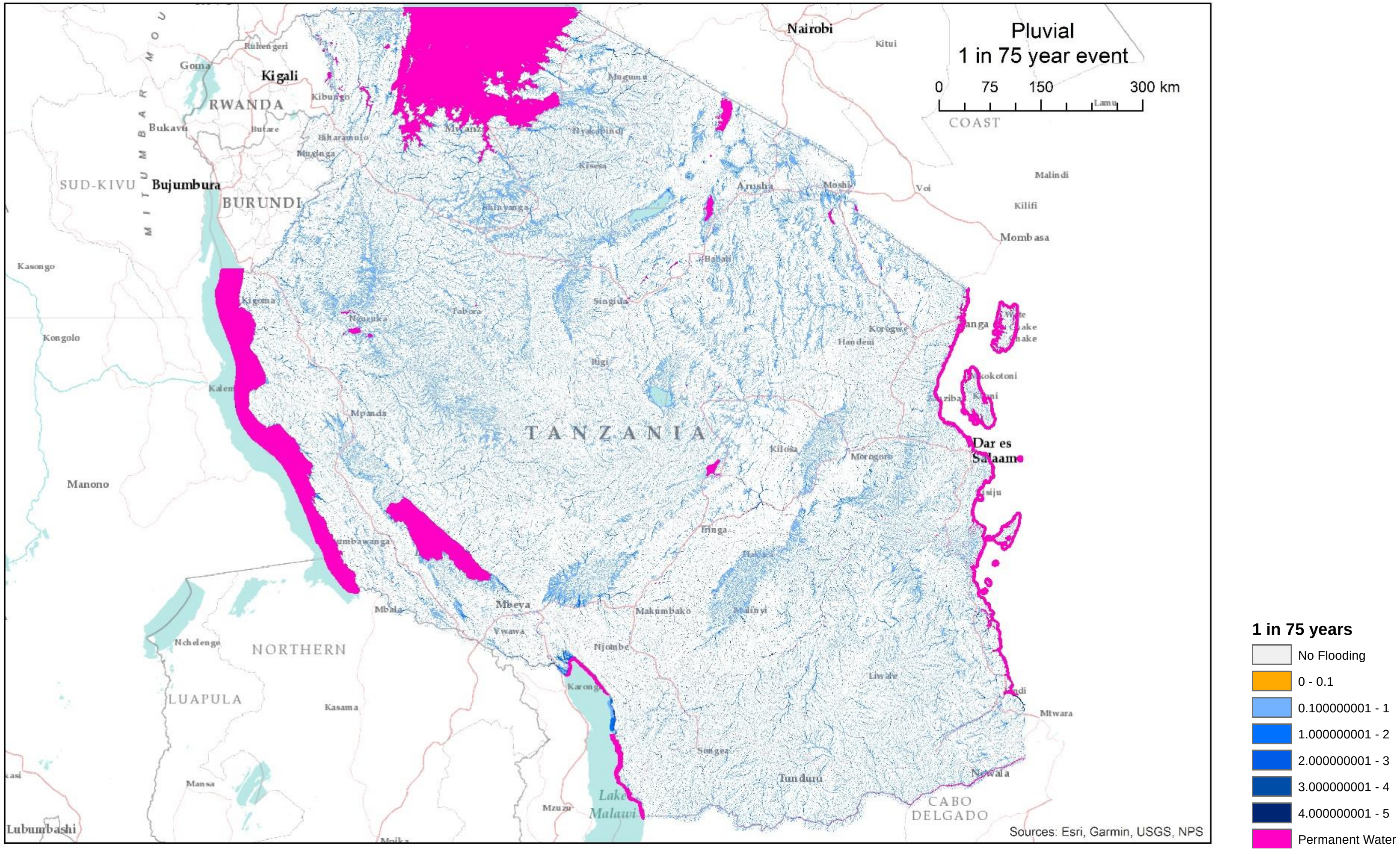

Figure 35: Tanzania Pluvial Flooding Hazard Footprint for 1 in 75 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

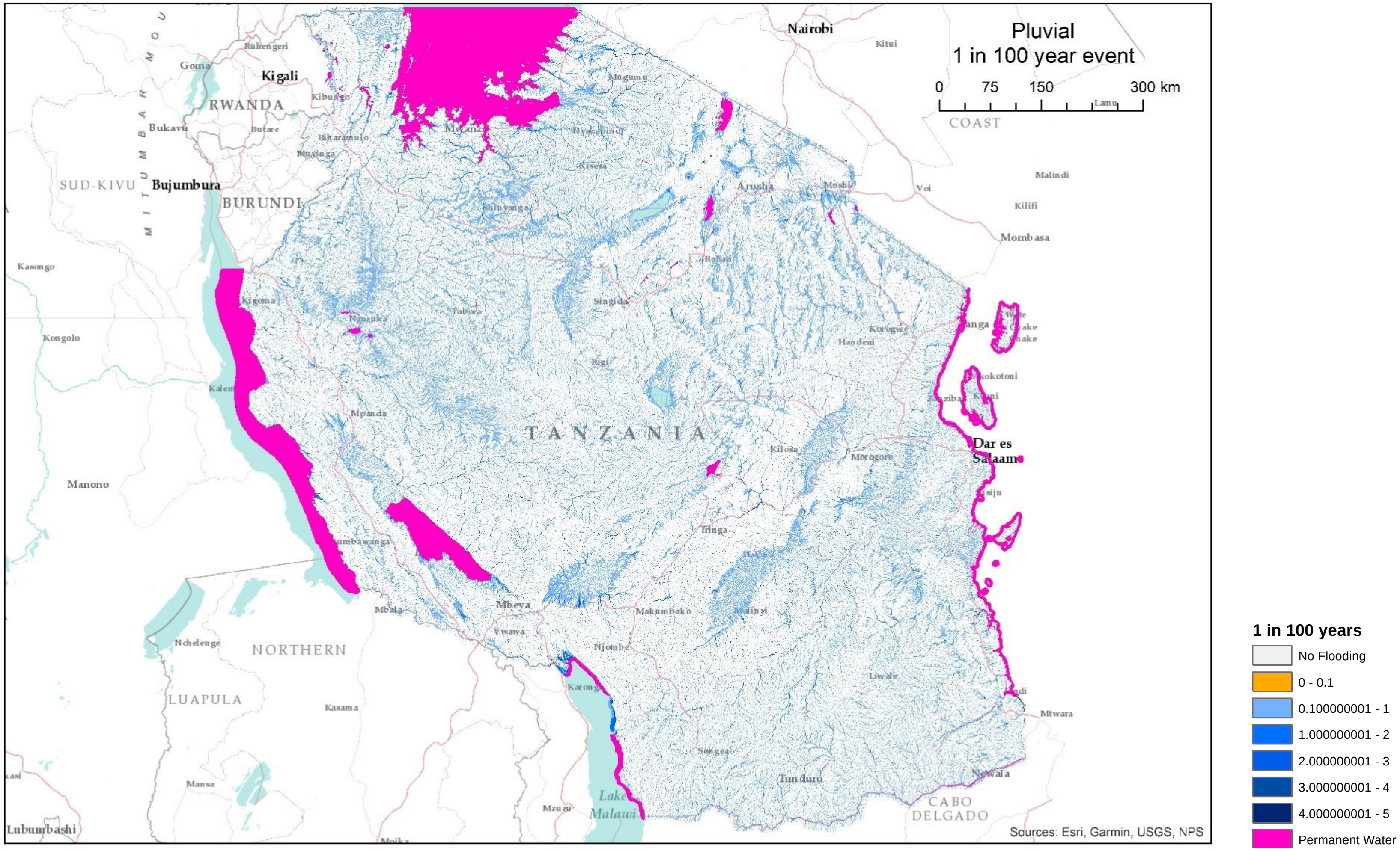

Figure 36: Tanzania Pluvial Flooding Hazard Footprint for 1 in 100 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

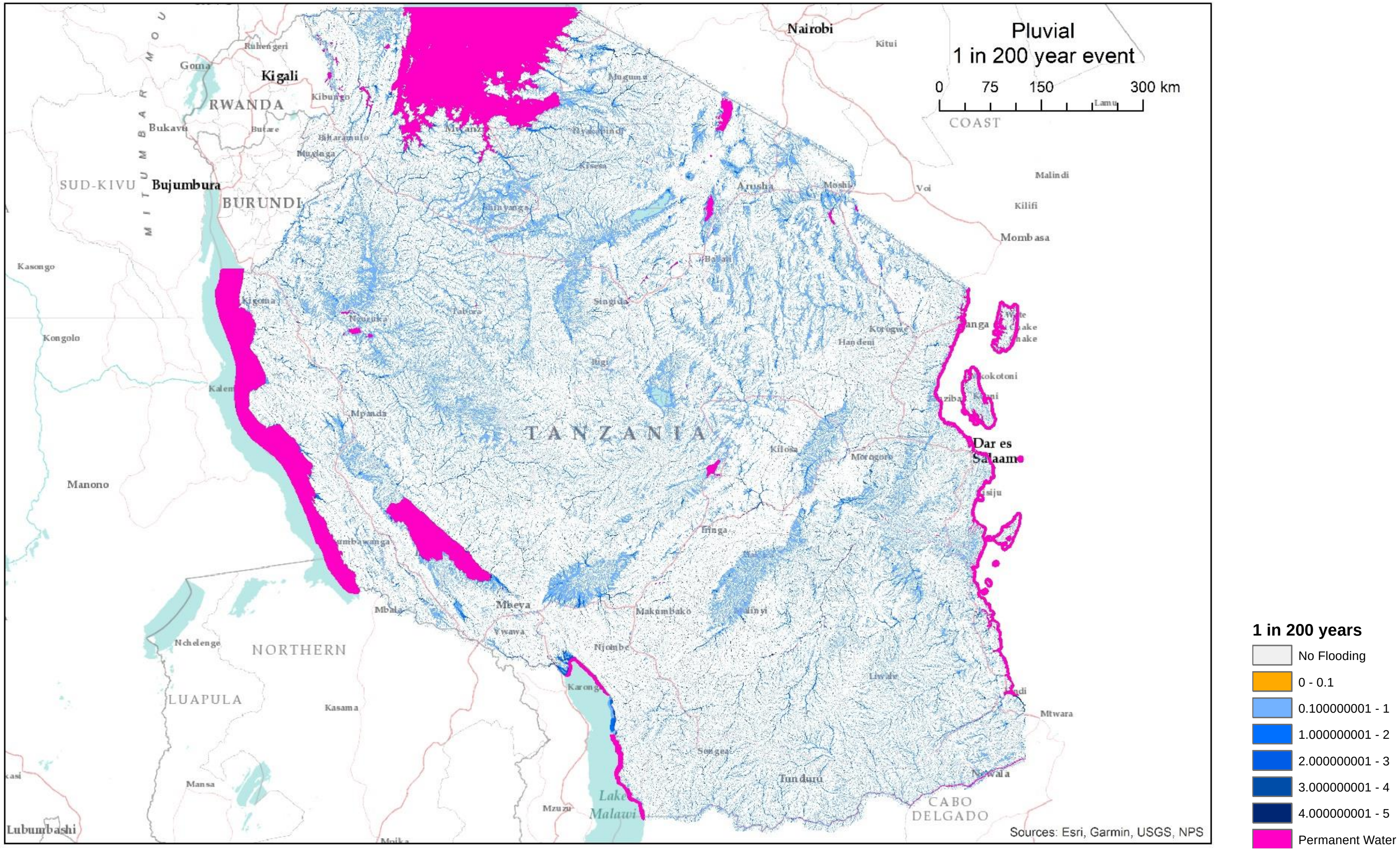

Figure 37: Tanzania Pluvial Flooding Hazard Footprint for 1 in 200 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

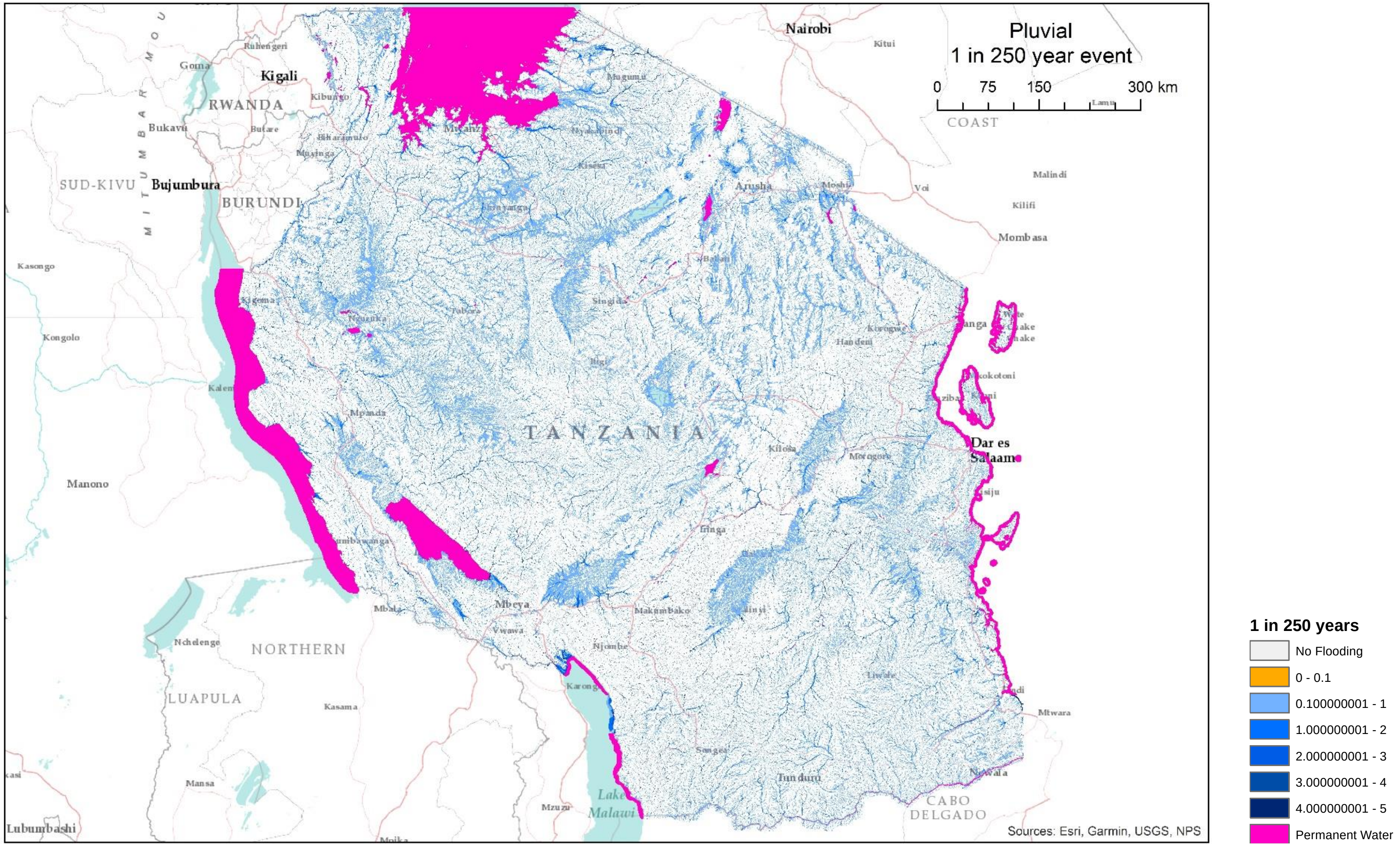

Figure 38: Tanzania Pluvial Flooding Hazard Footprint for 1 in 250 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

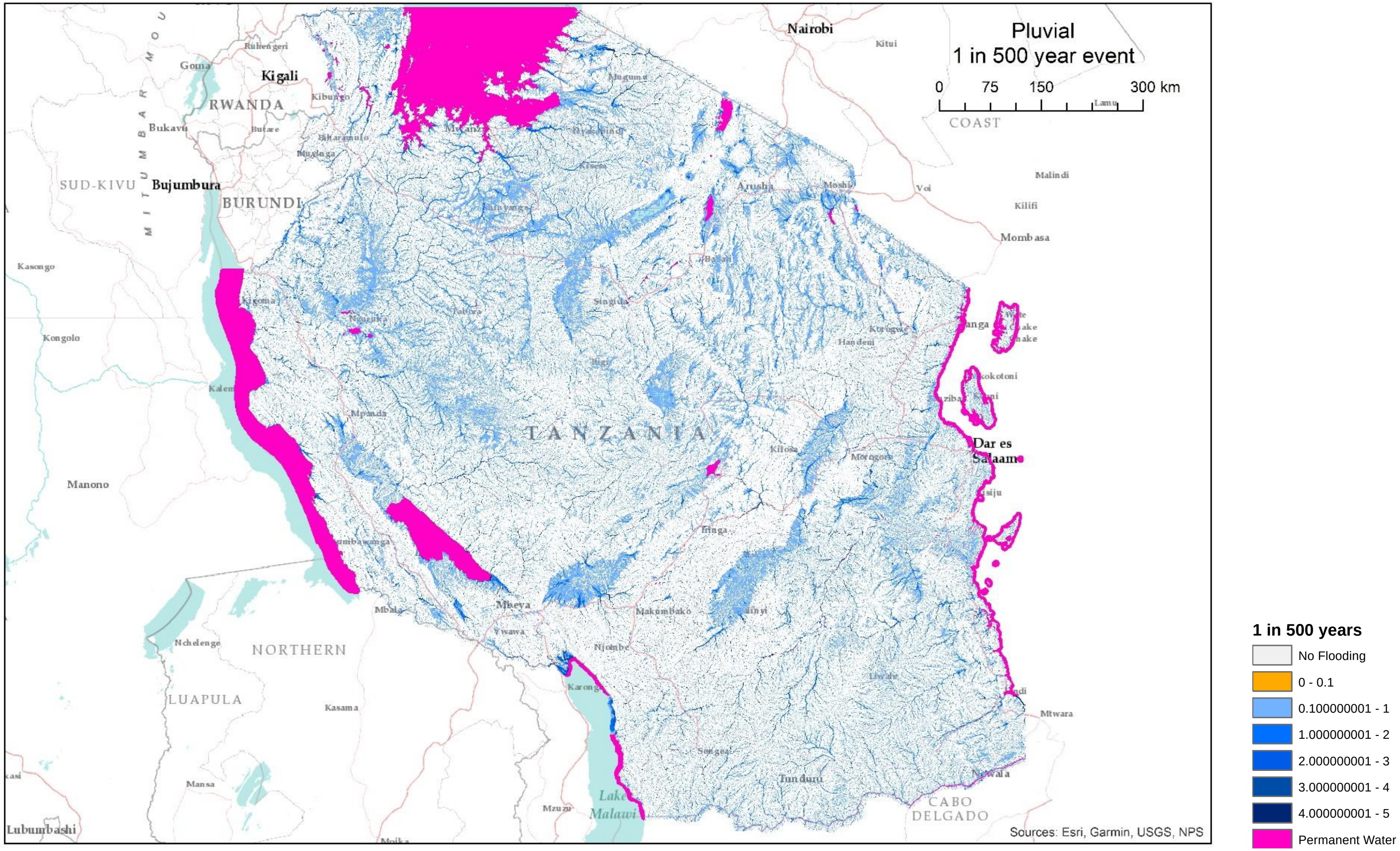

Figure 39: Tanzania Pluvial Flooding Hazard Footprint for 1 in 500 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

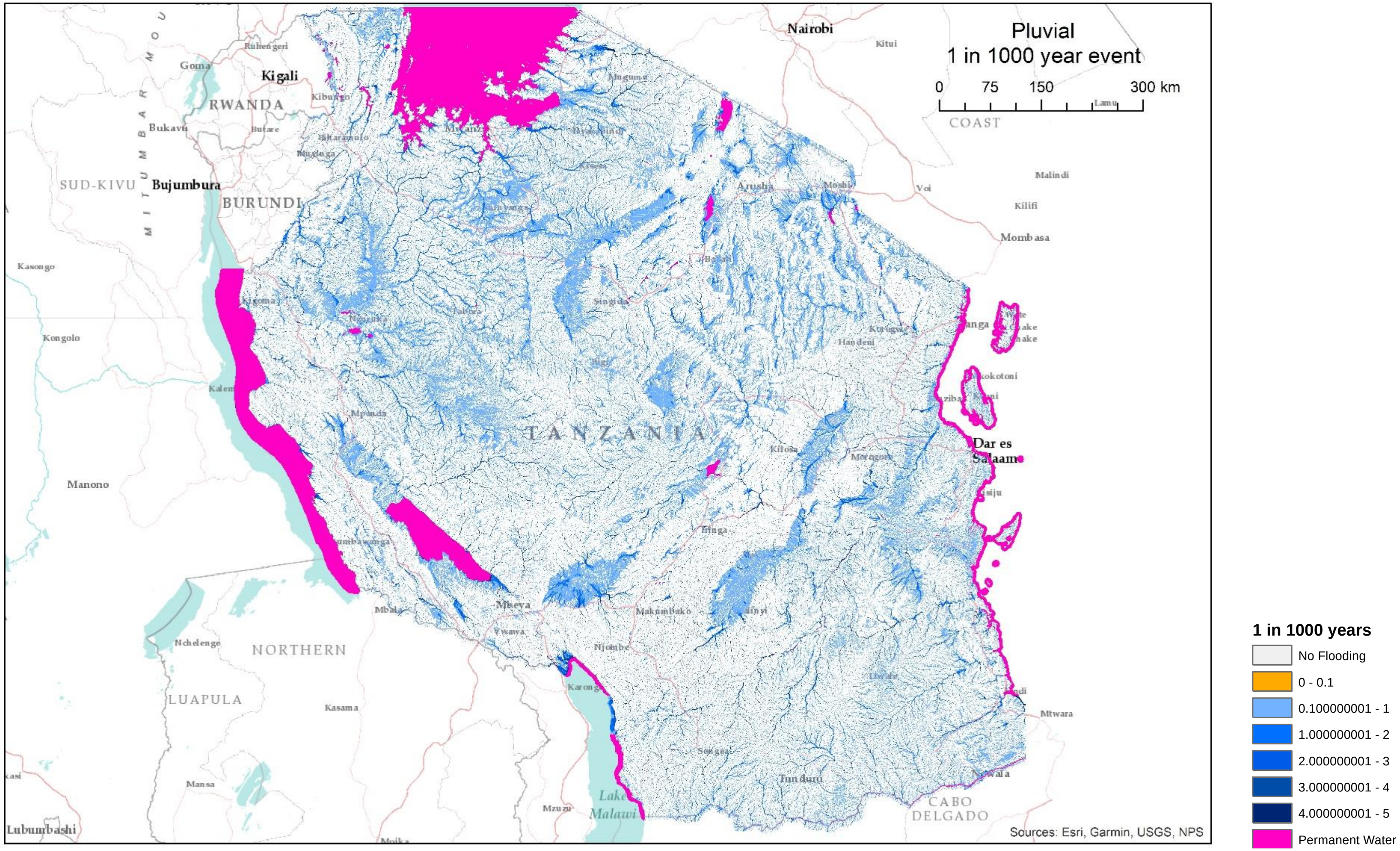

Figure 40: Tanzania Pluvial Flooding Hazard Footprint for 1 in 1000 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

2.7. FLUVIAL DEFENDED: TANZANIA

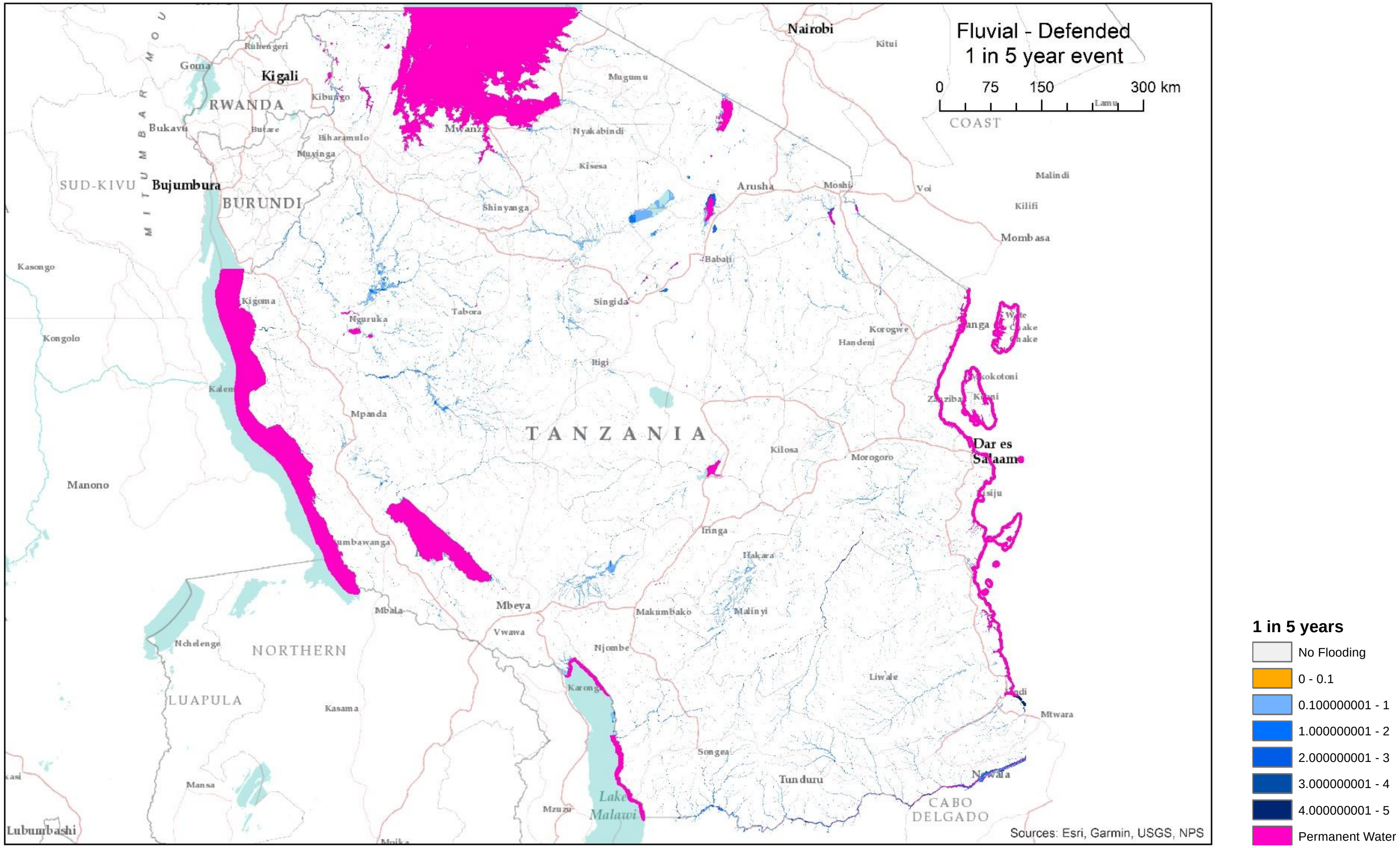

Figure 41: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 5 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

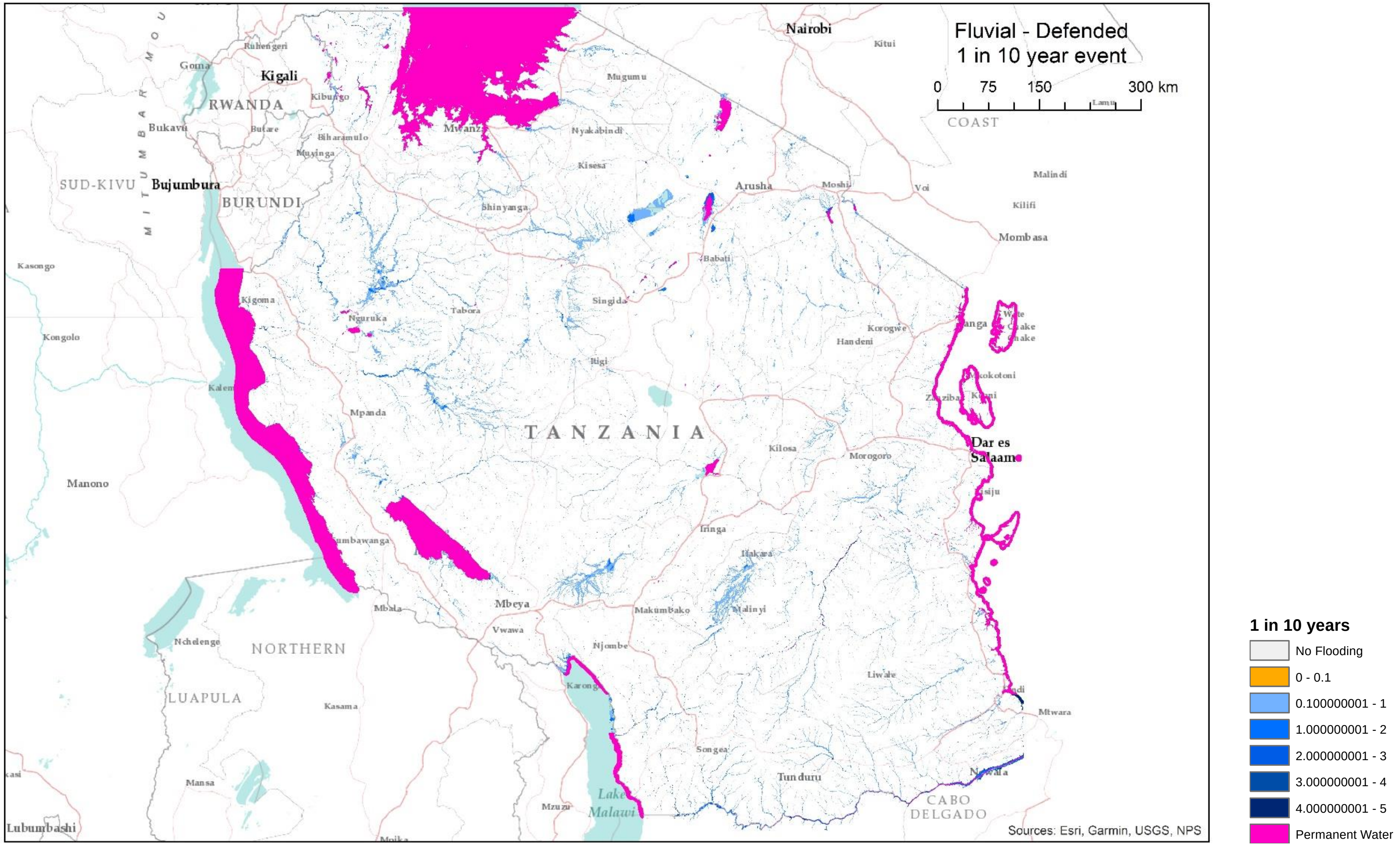

Figure 42: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 10 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

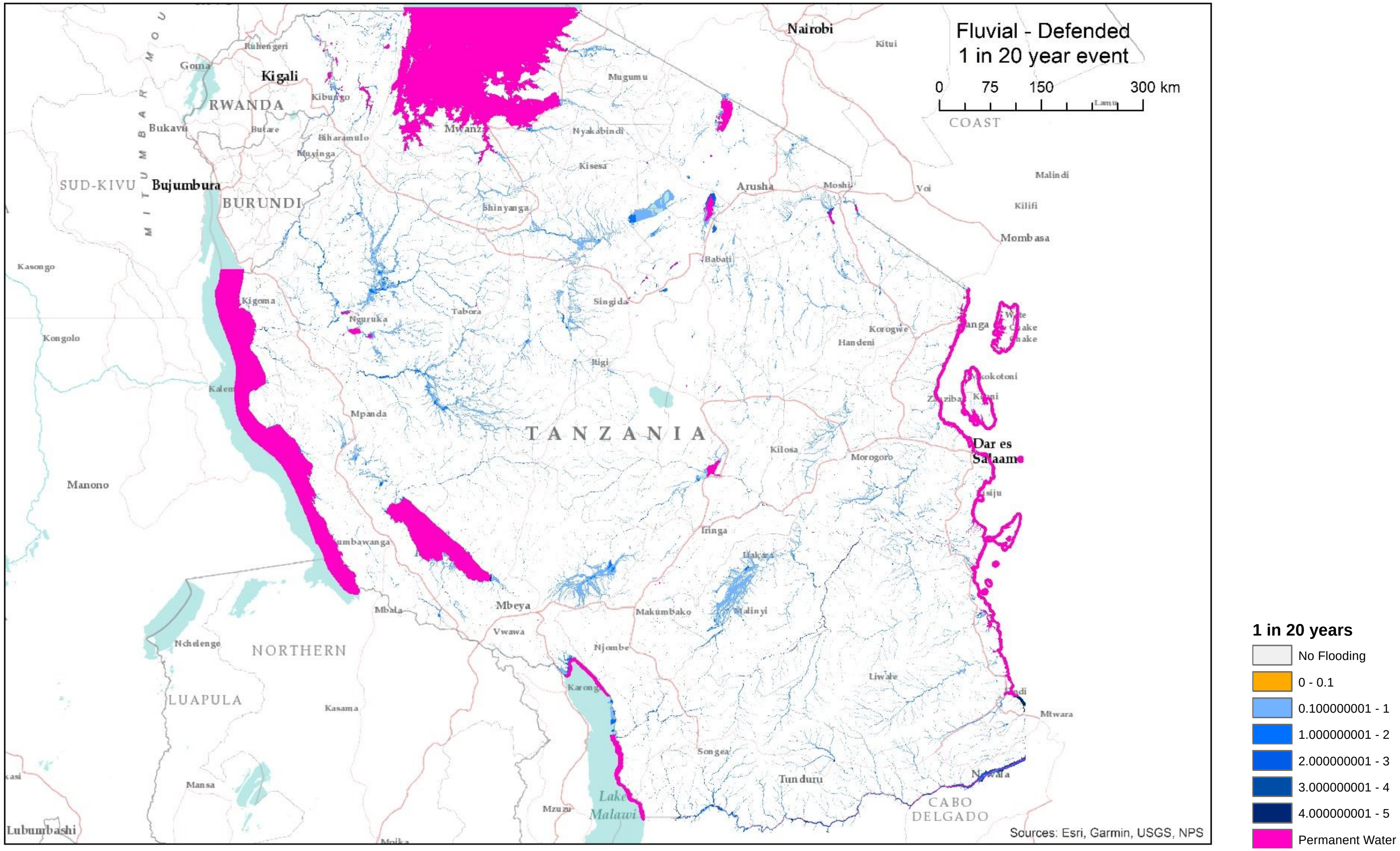

Figure 43: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 20 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

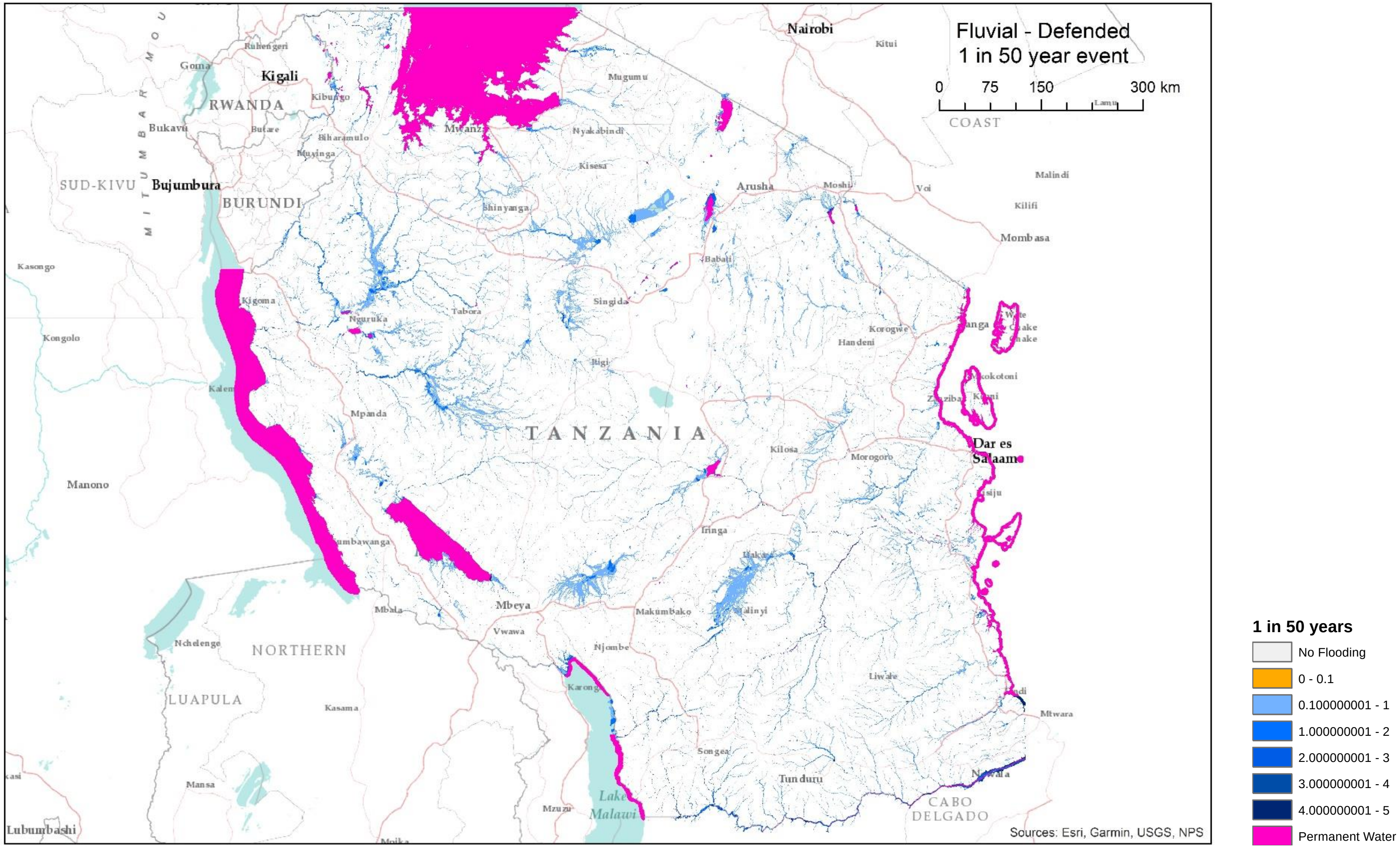

Figure 44: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 50 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

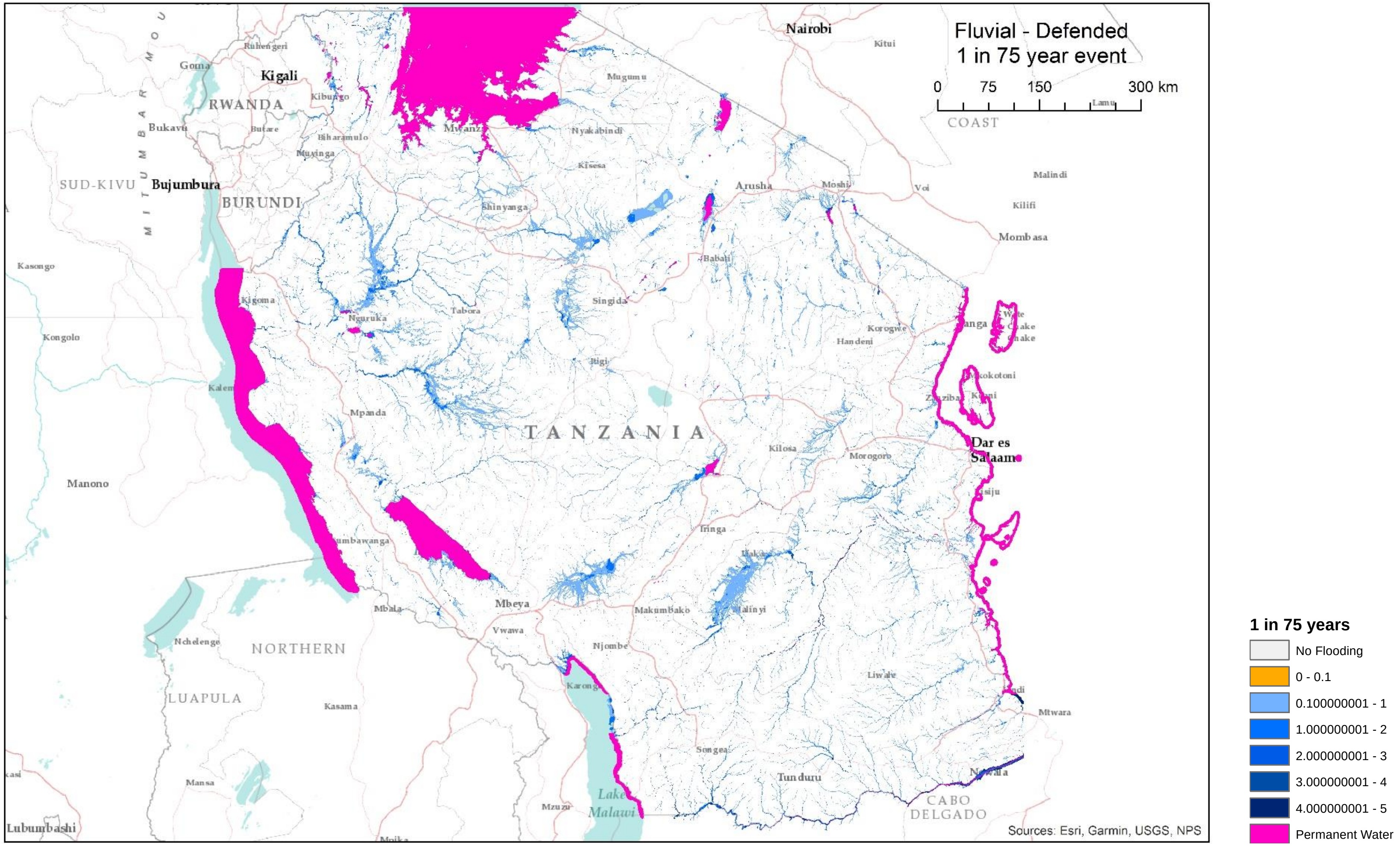

Figure 45: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 75 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

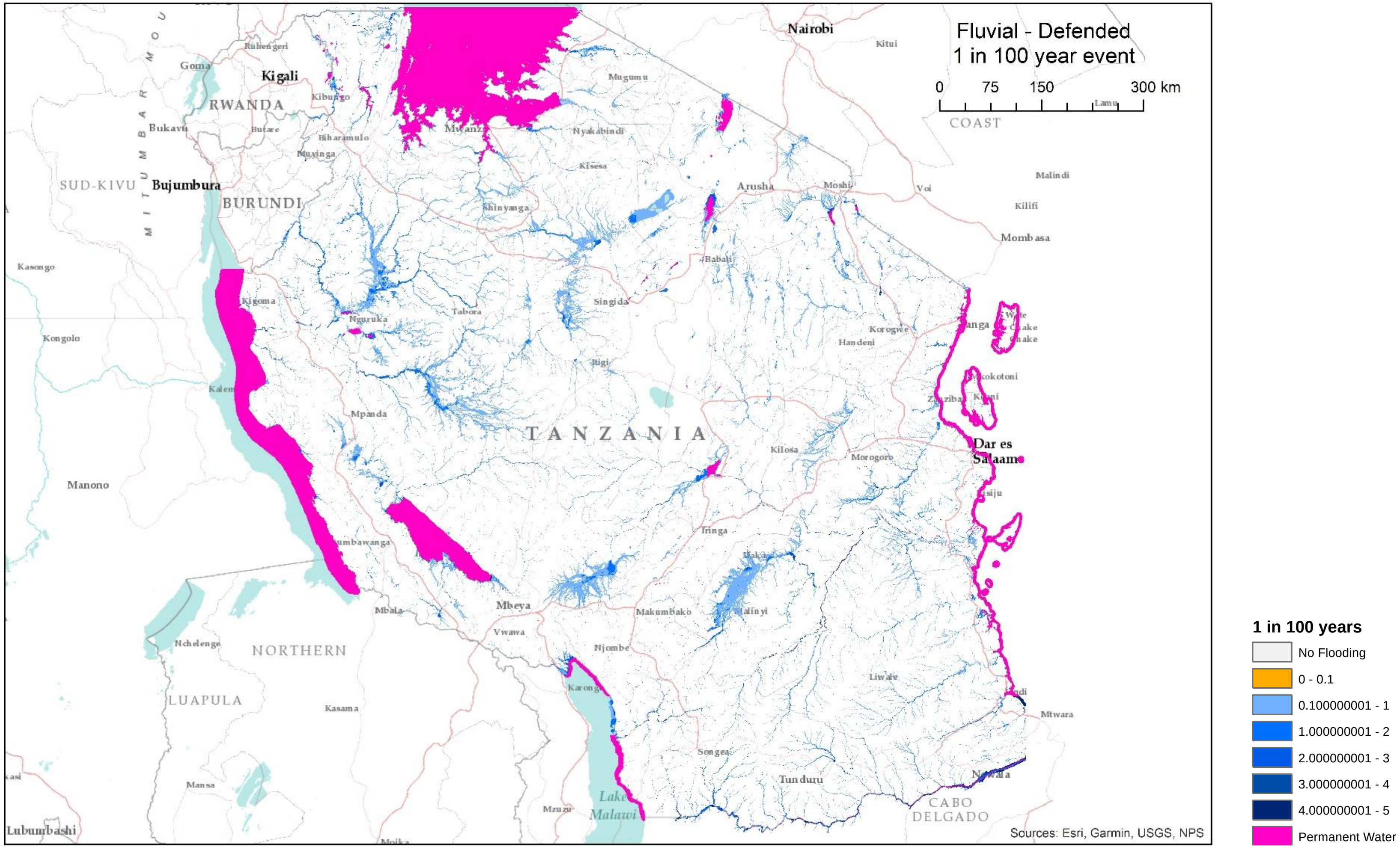

Figure 46: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 100 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

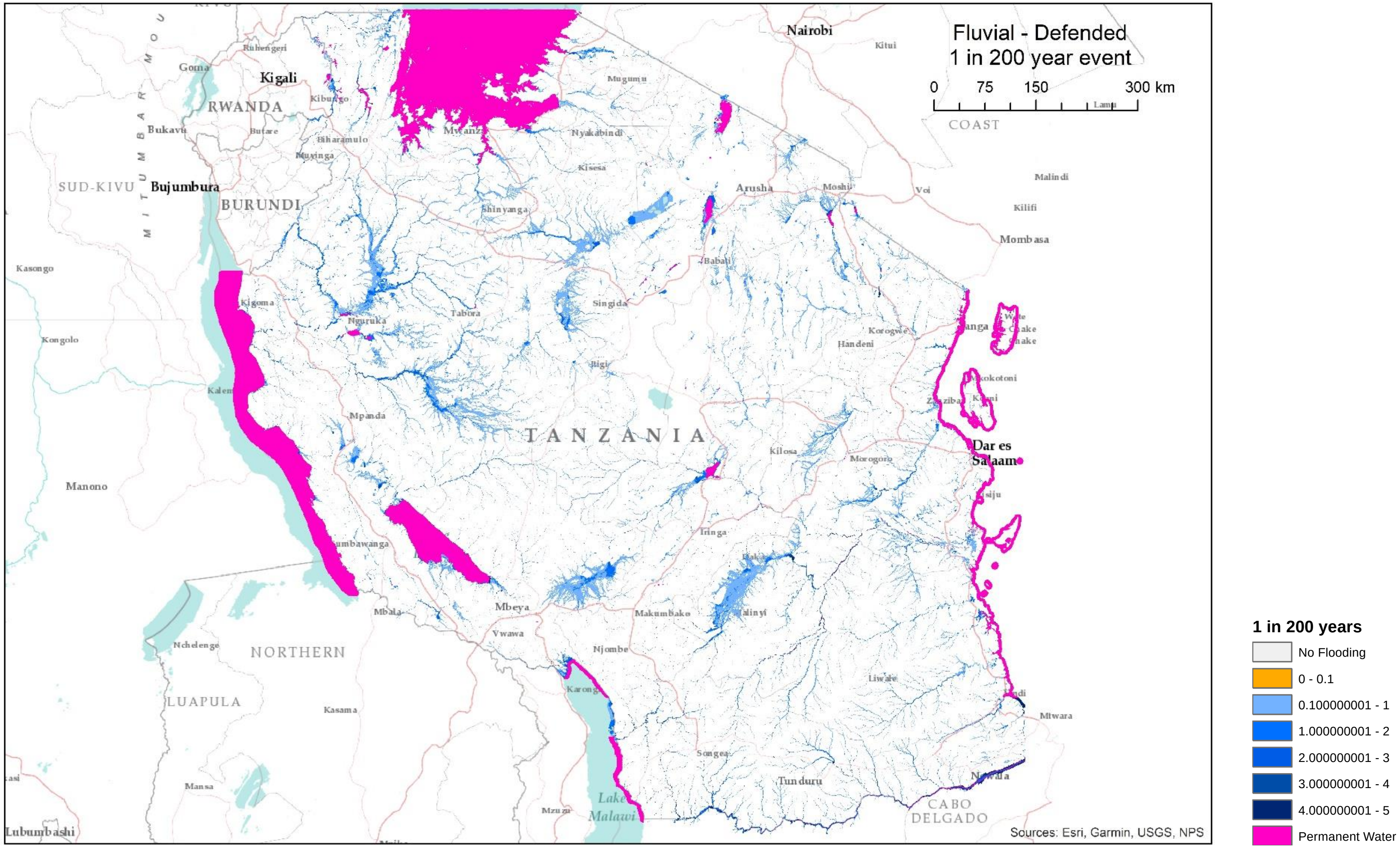

Figure 47: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 200 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

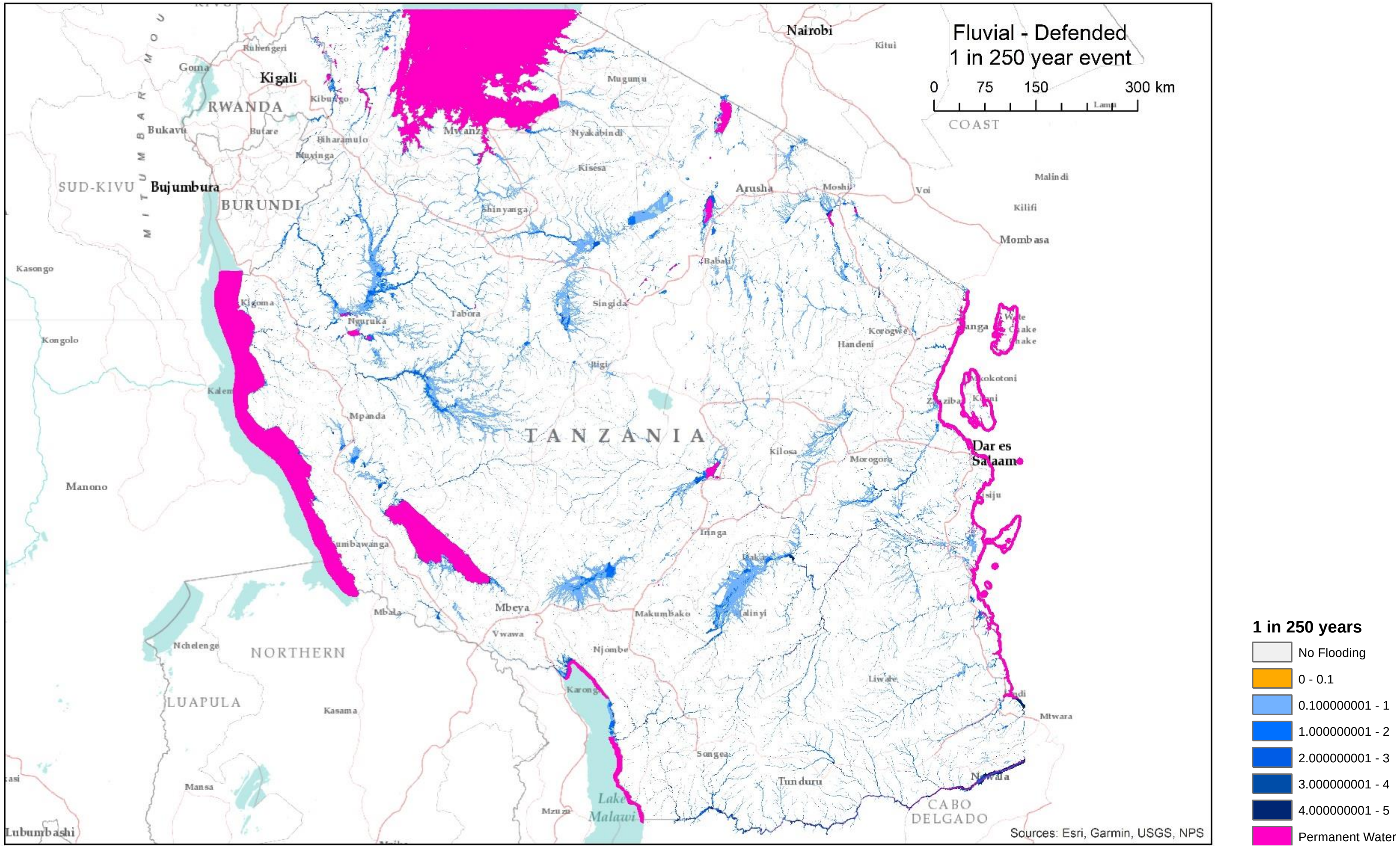

Figure 48: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 250 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

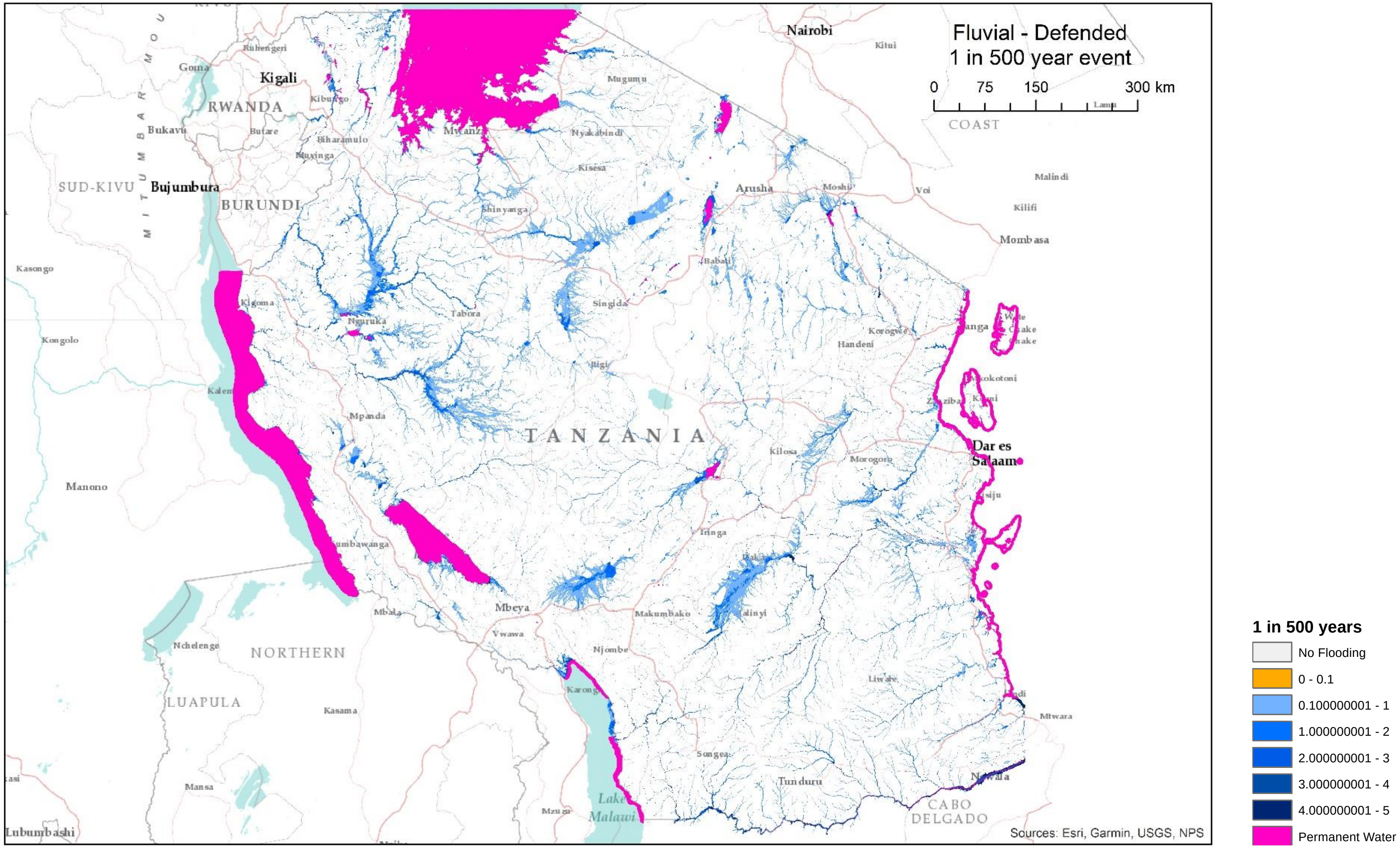

Figure 49: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 500 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

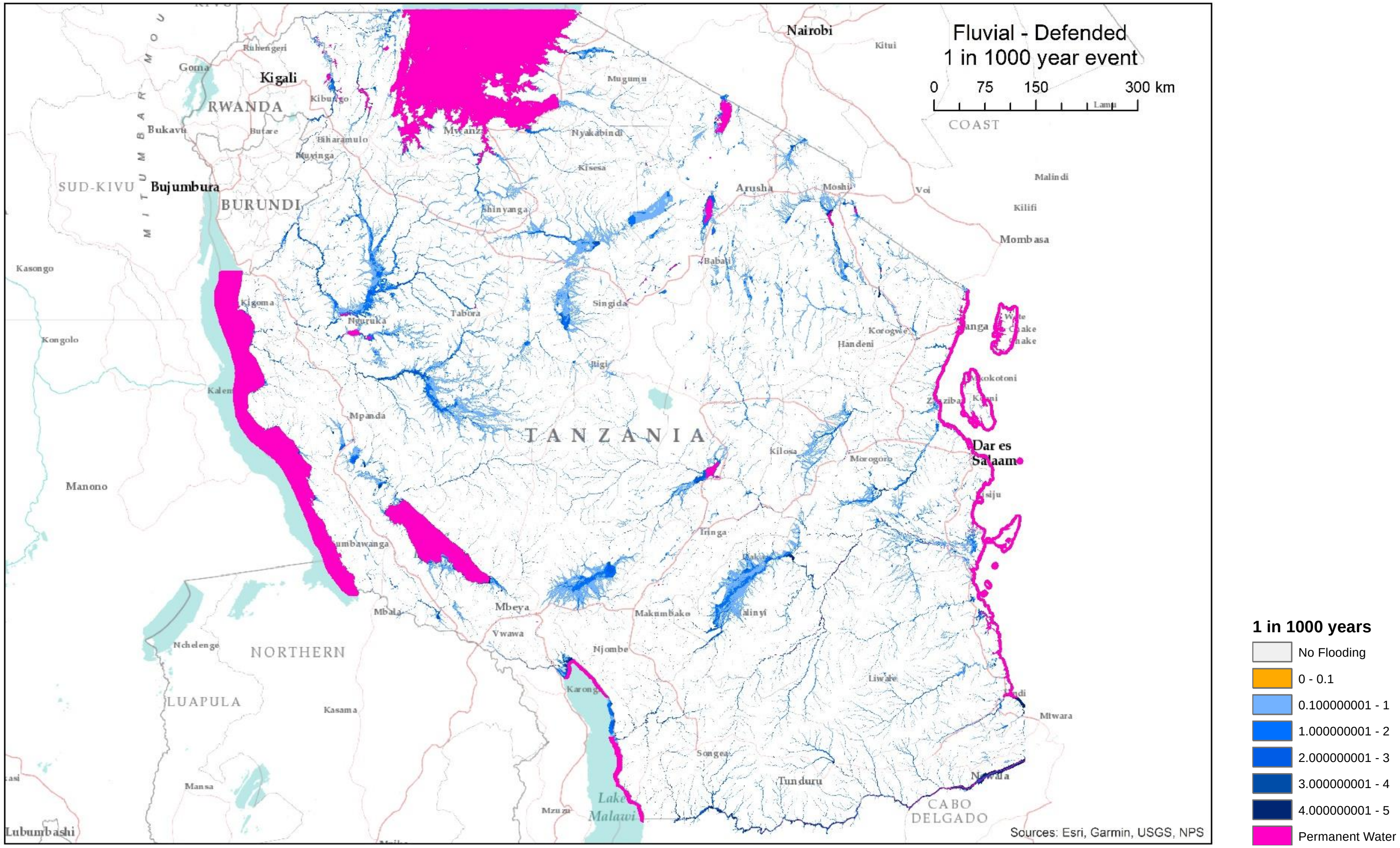

Figure 50: Tanzania Fluvial Defended Flooding Hazard Footprint for 1 in 1000 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

2.8. FLUVIAL UNDEFENDED: TANZANIA

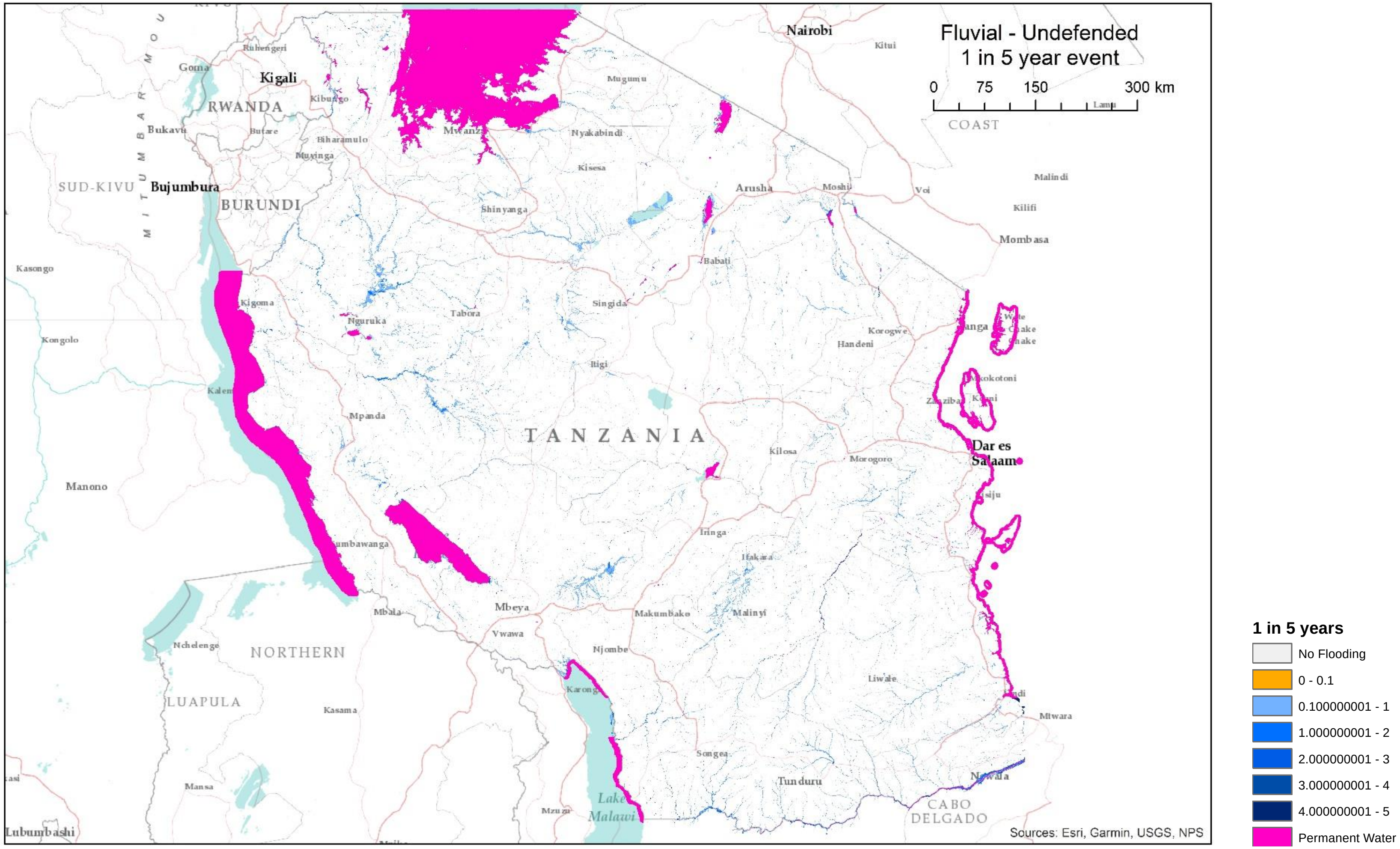

Figure 51: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 5 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

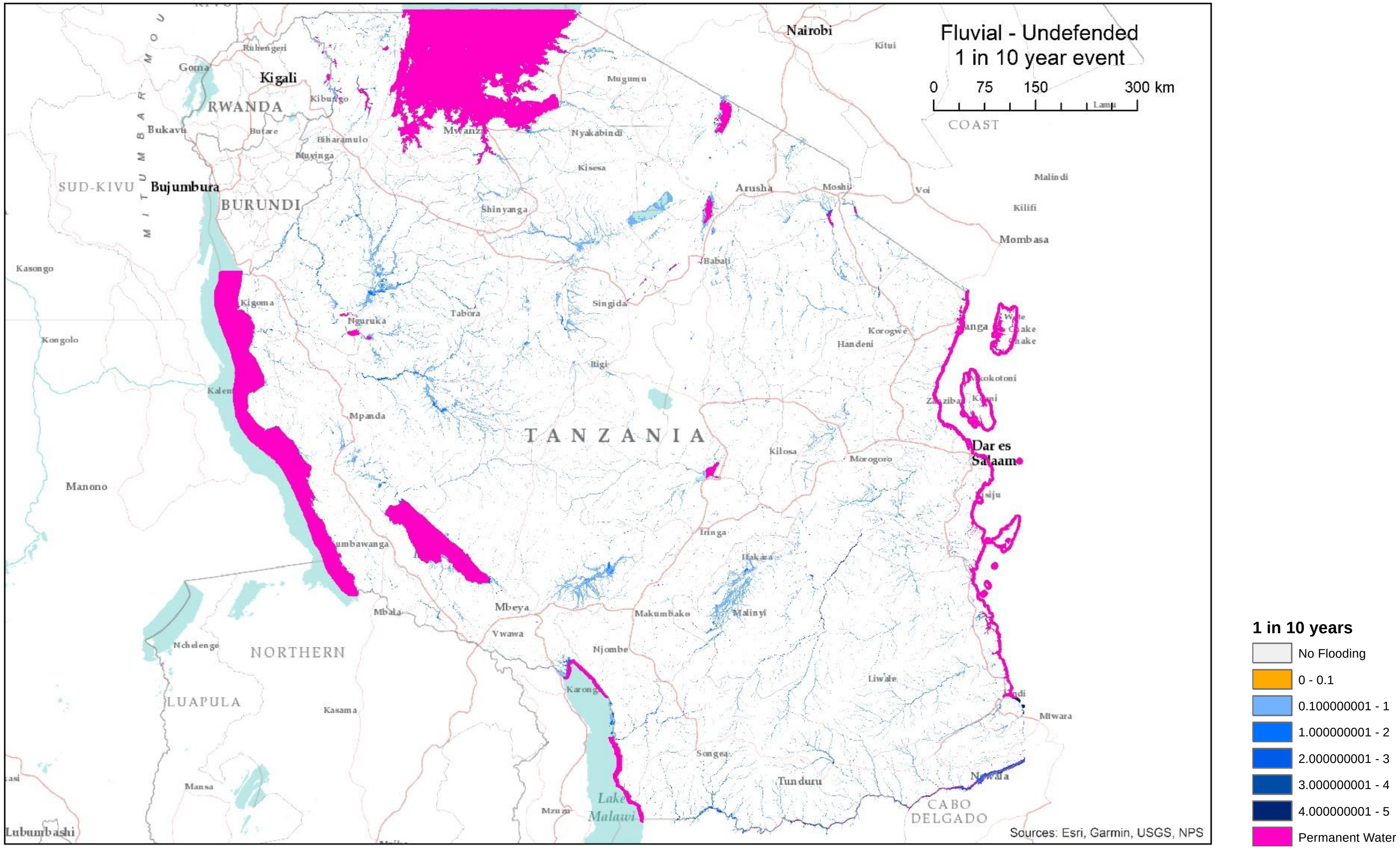

Figure 52: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 10 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

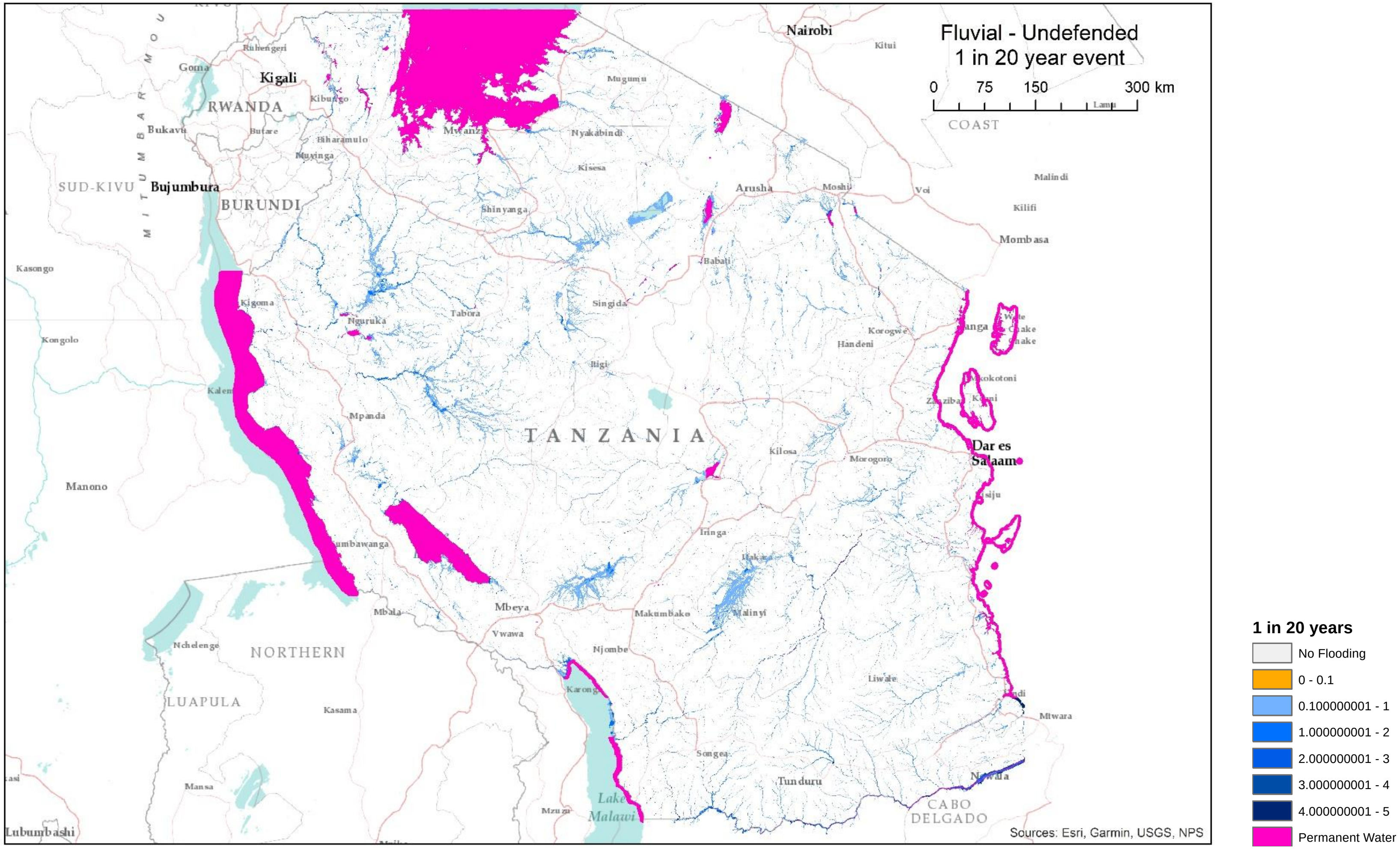

Figure 53: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 20 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

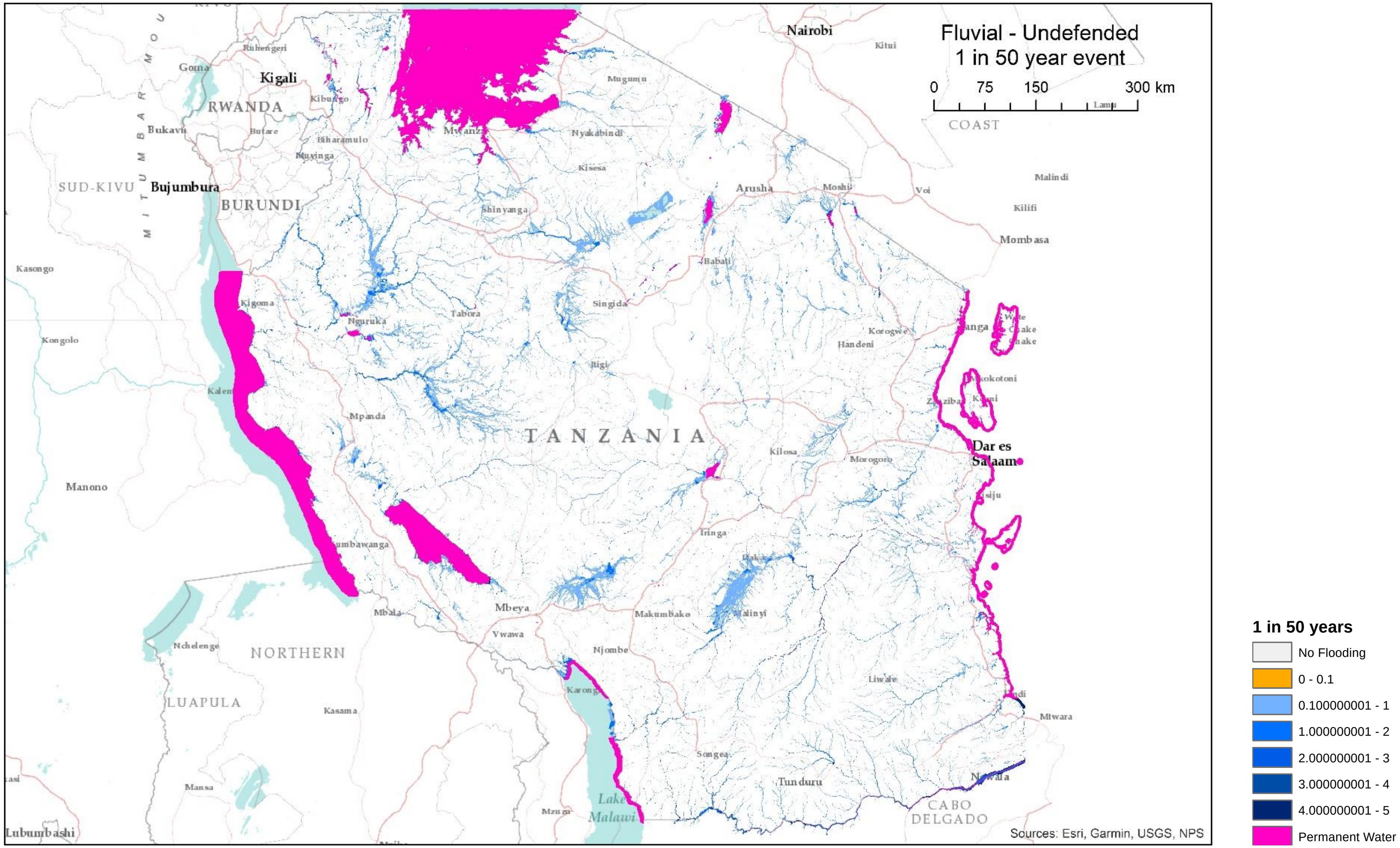

Figure 54: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 50 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

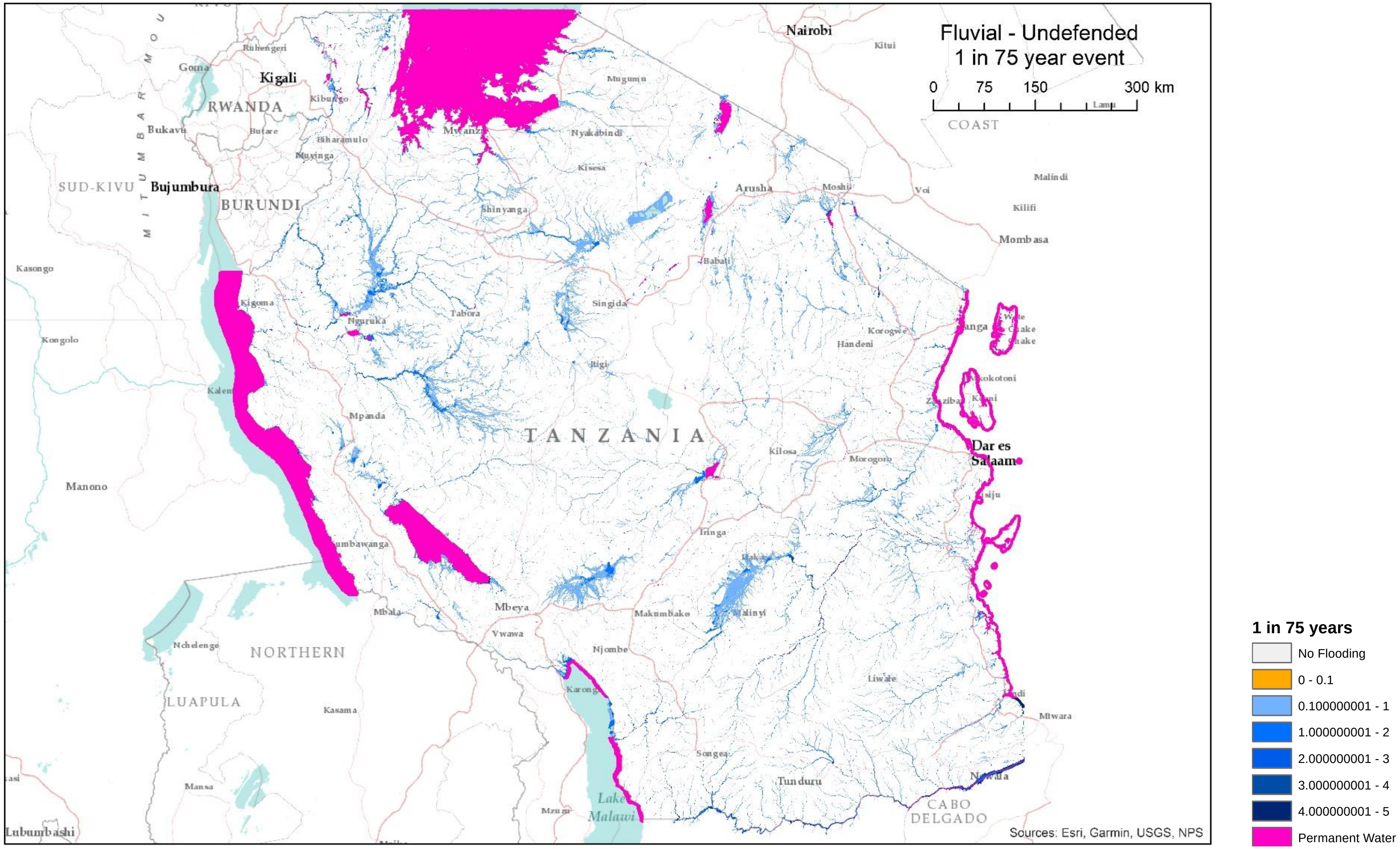

Figure 55: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 75 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

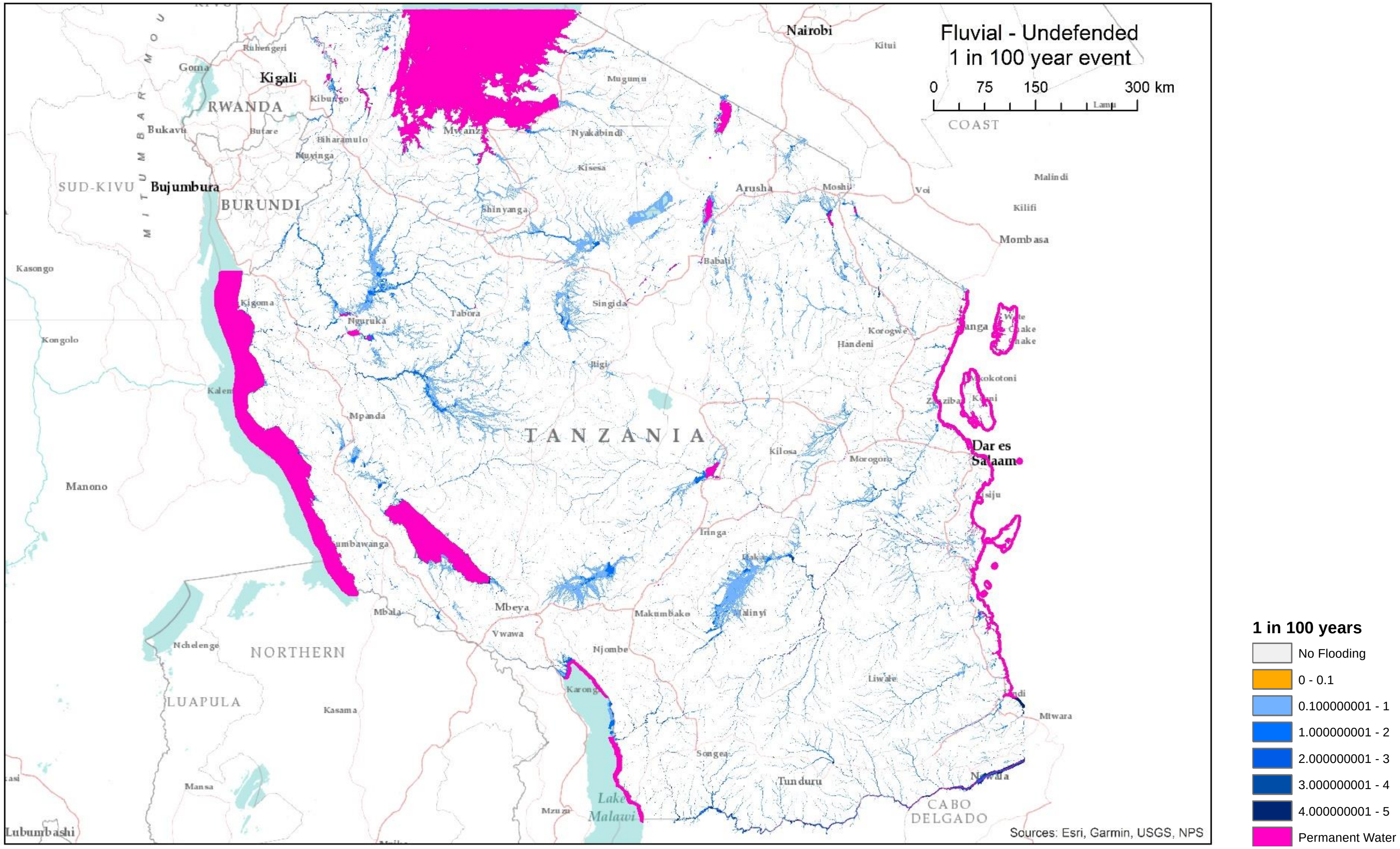

Figure 56: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 100 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

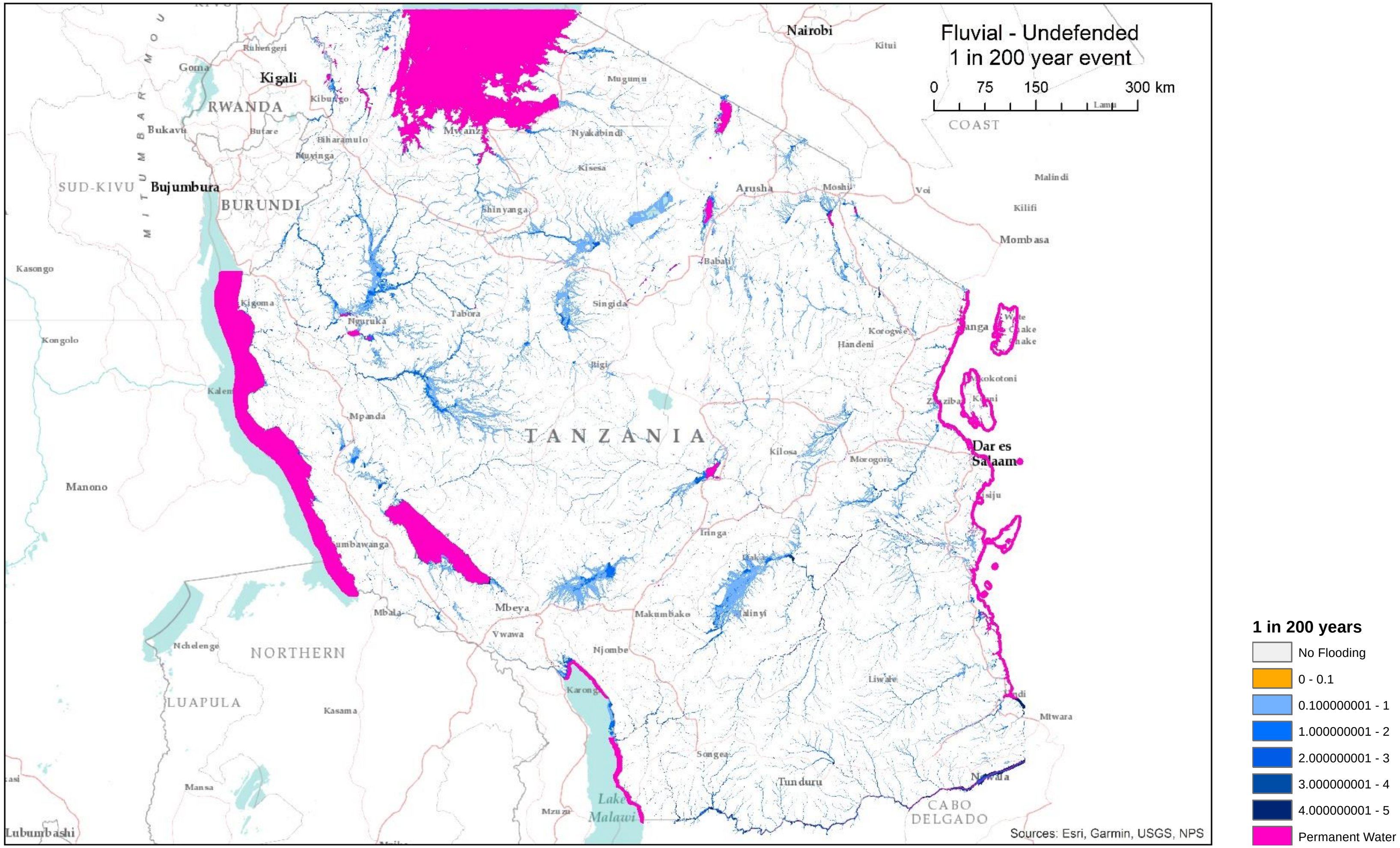

Figure 57: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 200 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

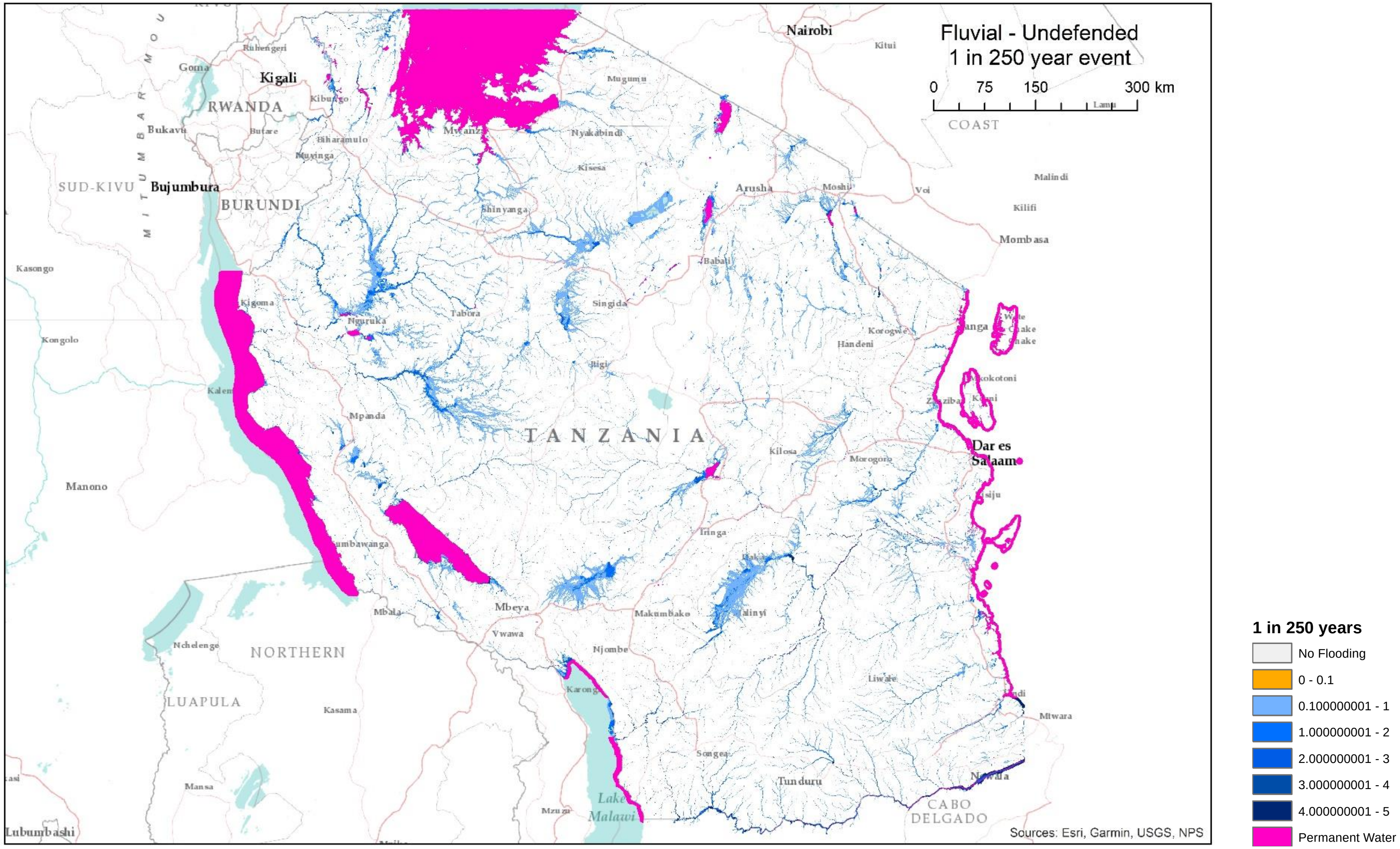

Figure 58: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 250 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

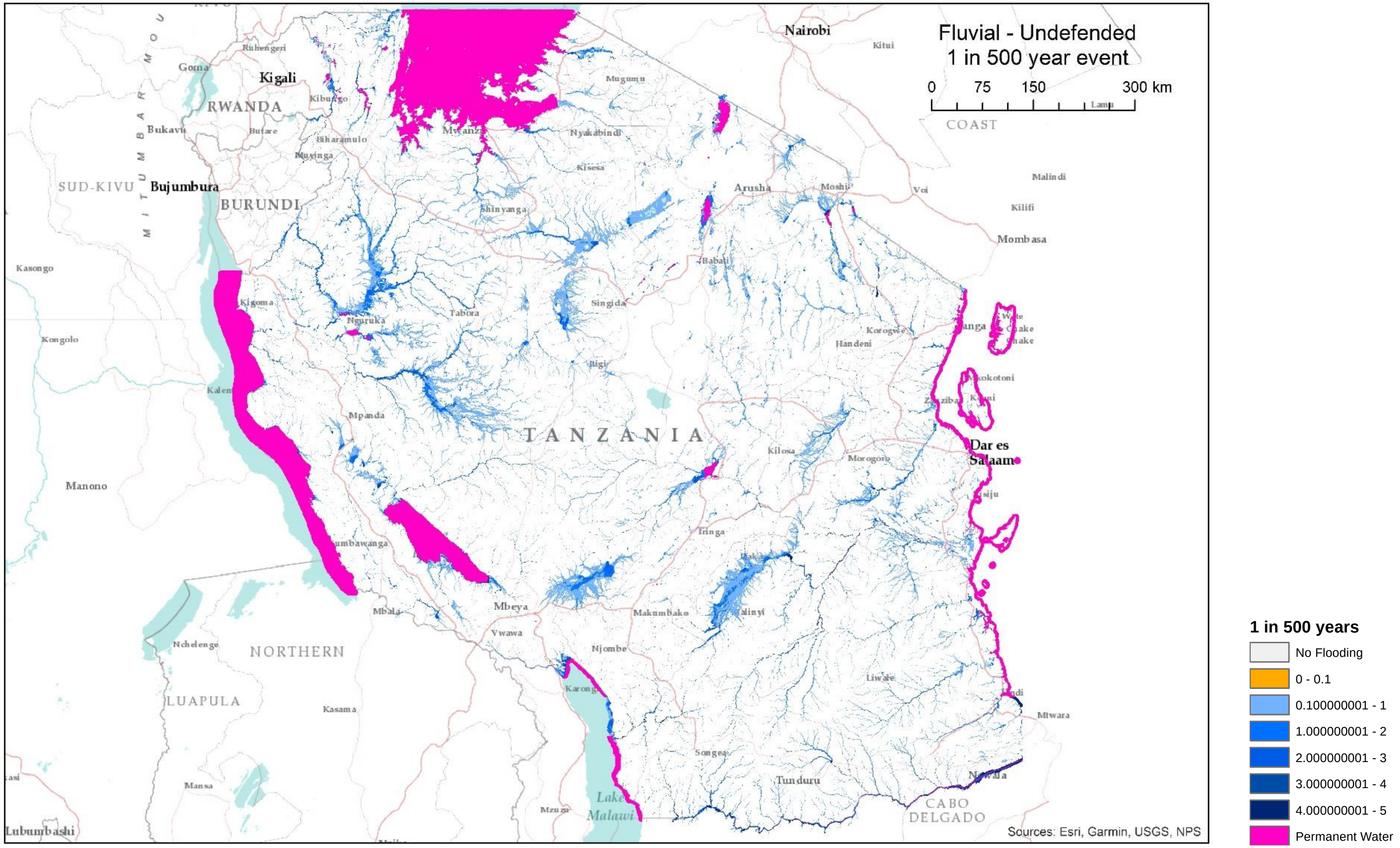

Figure 59: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 500 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

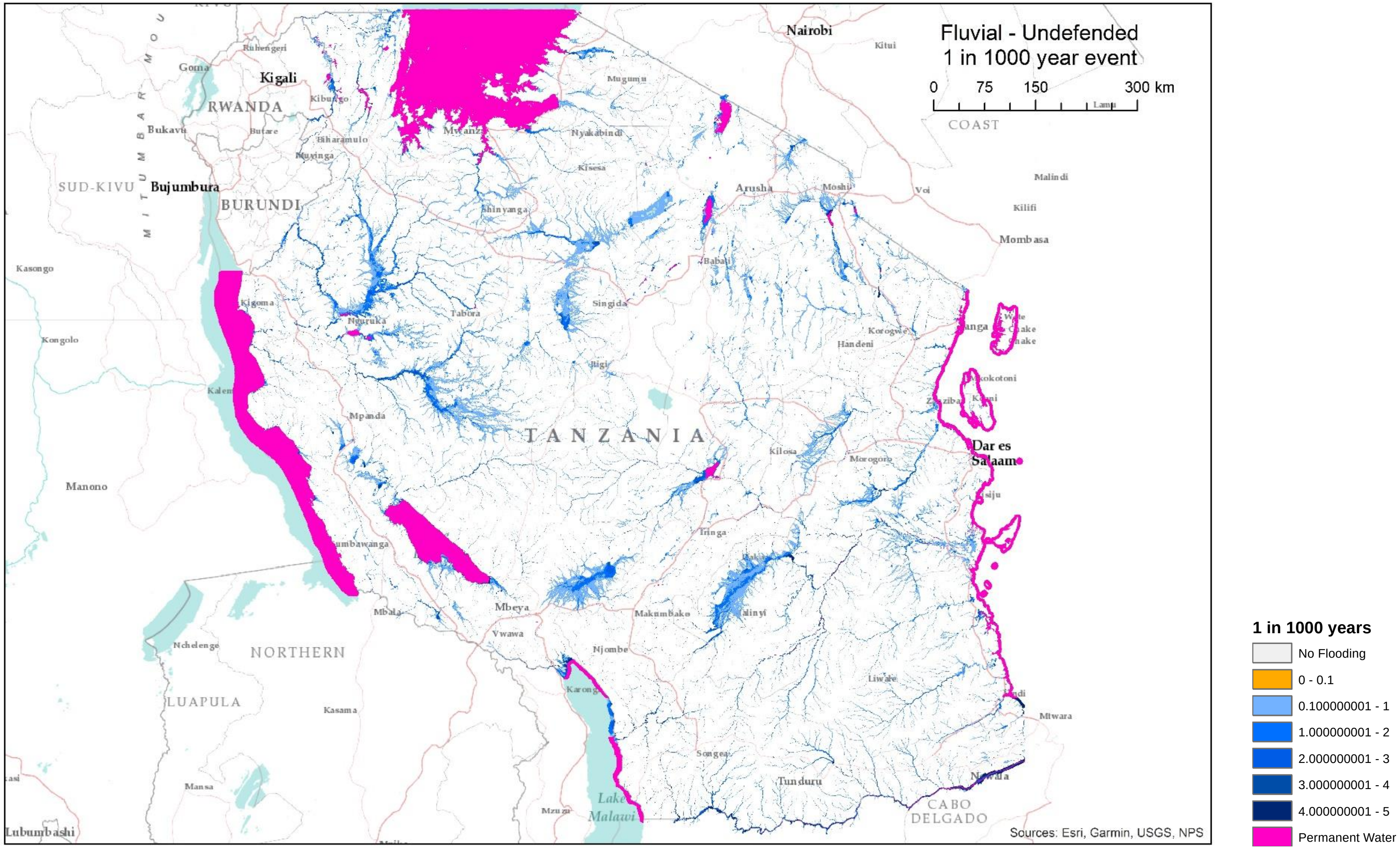

Figure 60: Tanzania Fluvial Undefended Flooding Hazard Footprint for 1 in 1000 year event, Fathom © SSBN LTD (Fathom) 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Flood data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

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

Table 4: Summary of geospatial detail for METEOR-derived flood hazard products for Tanzania

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 NEPAL

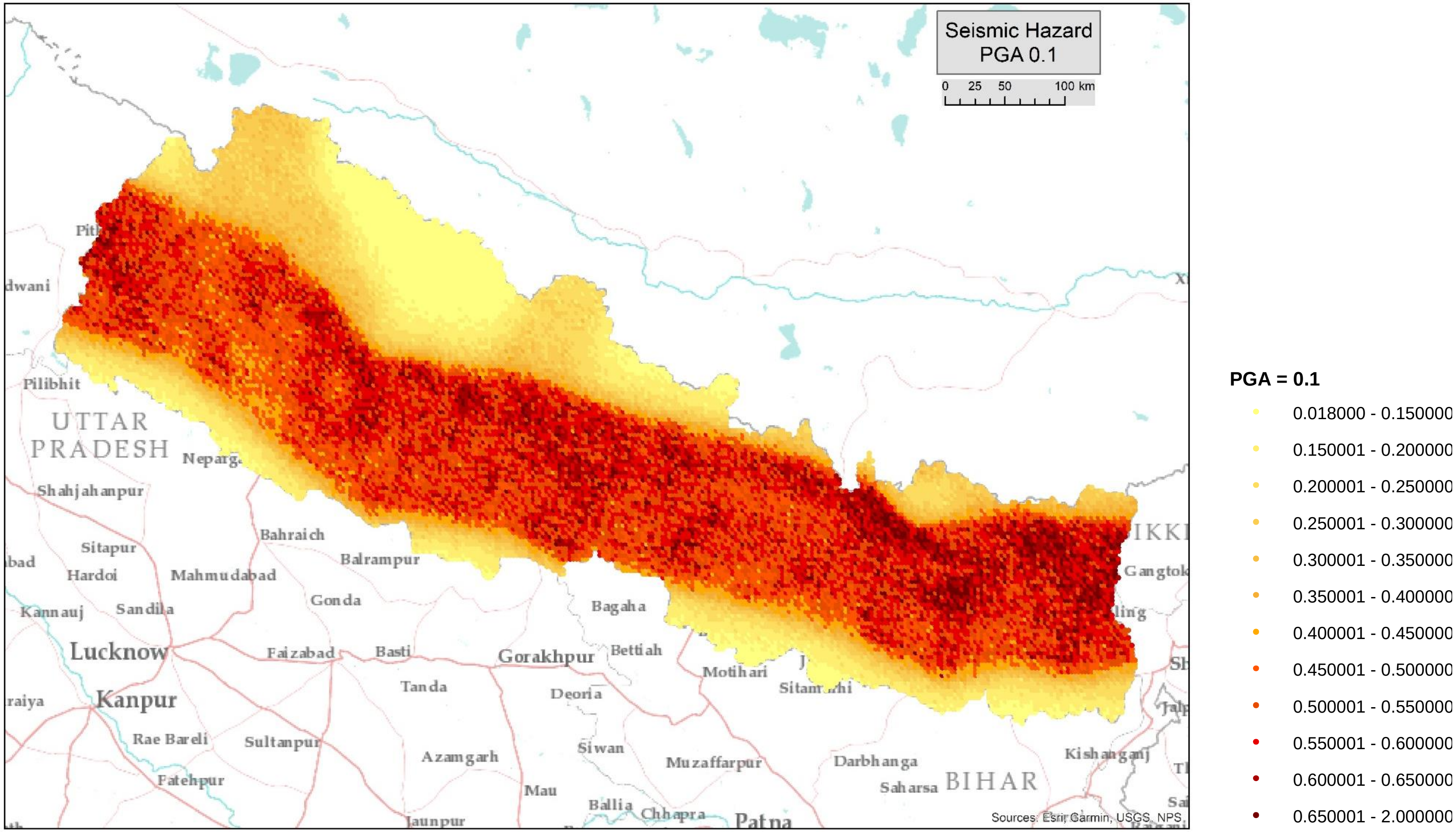

Figure 61: Nepal Seismic Hazard Footprint for Peak Ground Acceleration of 0.1 (10%)., GEM © 2019 GEM Foundation. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Seismic data is available under the Creative Commons BY-NC-SA 4.0 License (CC BY-NC-SA 4.0) on https://maps.meteor-portal.org

3.3. SEISMIC HAZARD: PGA 0.02 NEPAL

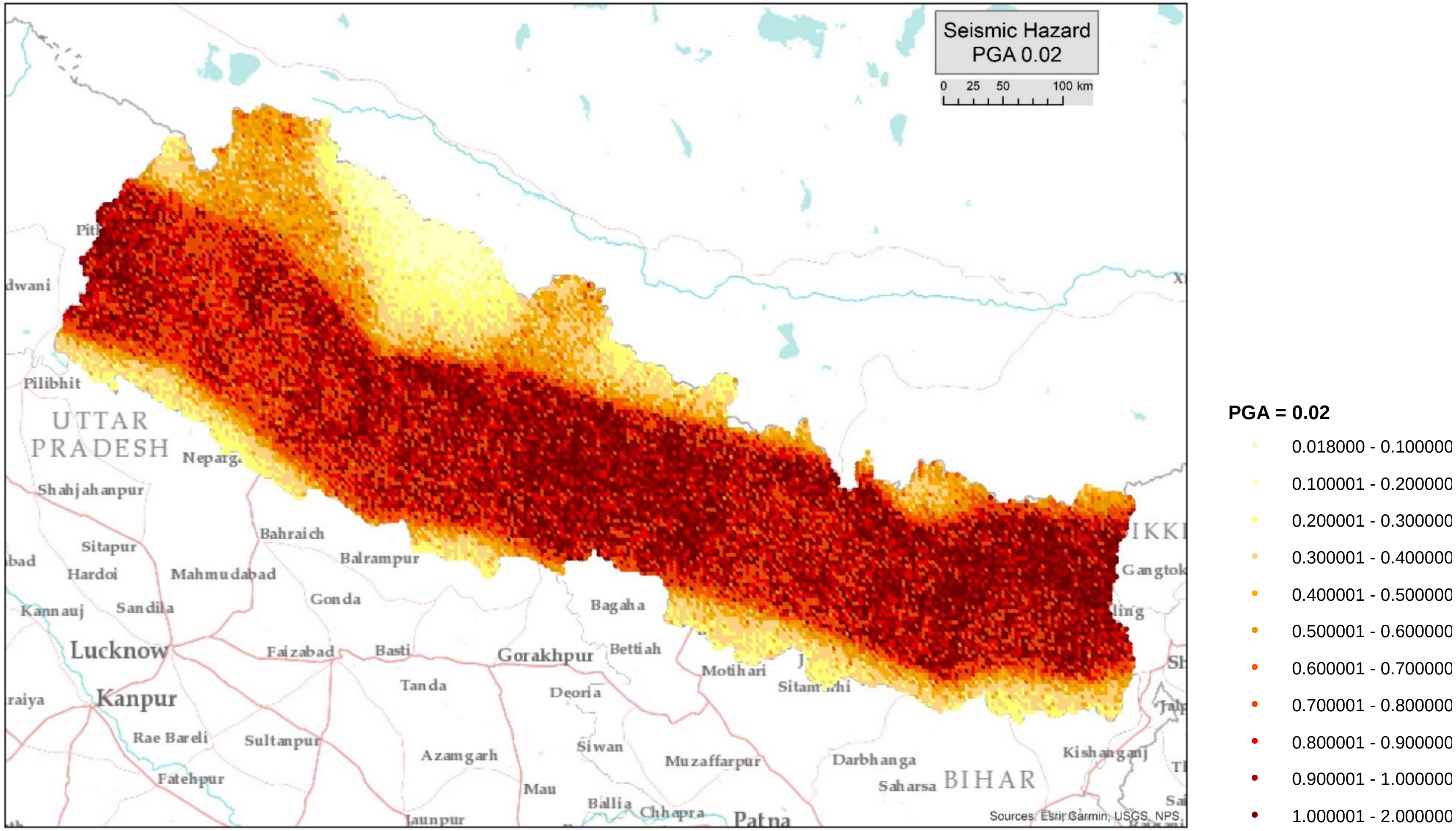

Figure 62: Nepal Seismic Hazard Footprint for Peak Ground Acceleration of 0.02 (2%), GEM © 2019 GEM Foundation. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Seismic data is available under the Creative Commons BY-NC-SA 4.0 License (CC BY-NC-SA 4.0) on https://maps.meteor-portal.org

3.4. 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

Table 5: Summary of geospatial detail for METEOR-derived seismic hazard products for Nepal

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 TANZANIA

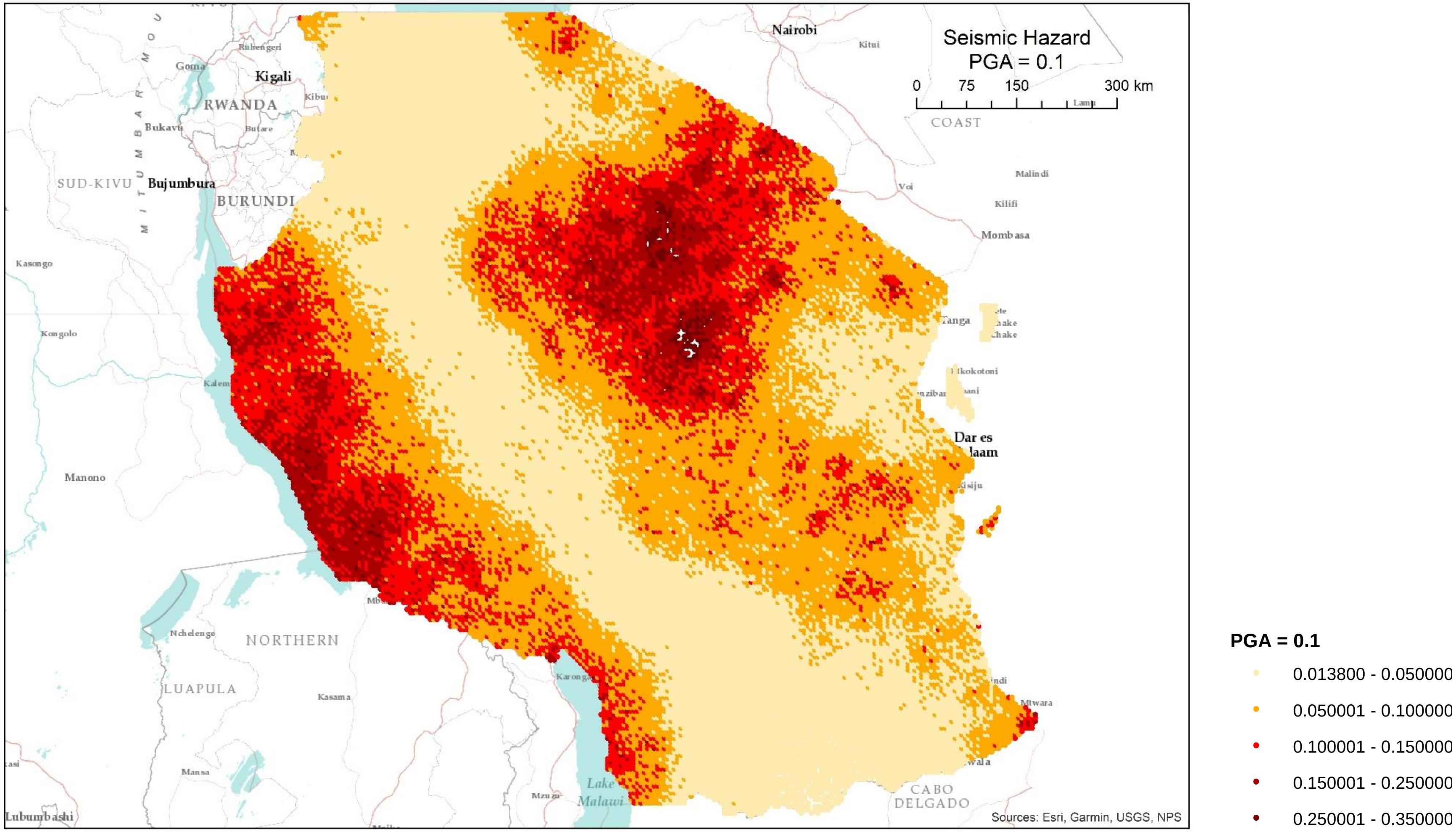

Figure 63: Tanzania Seismic Hazard Footprint for Peak Ground Acceleration of 0.1 (10%), GEM © 2019 GEM Foundation. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Seismic data is available under the Creative Commons BY-NC-SA 4.0 License (CC BY-NC-SA 4.0) on https://maps.meteor-portal.org

4.3. SEISMIC HAZARD: PGA 0.02 TANZANIA

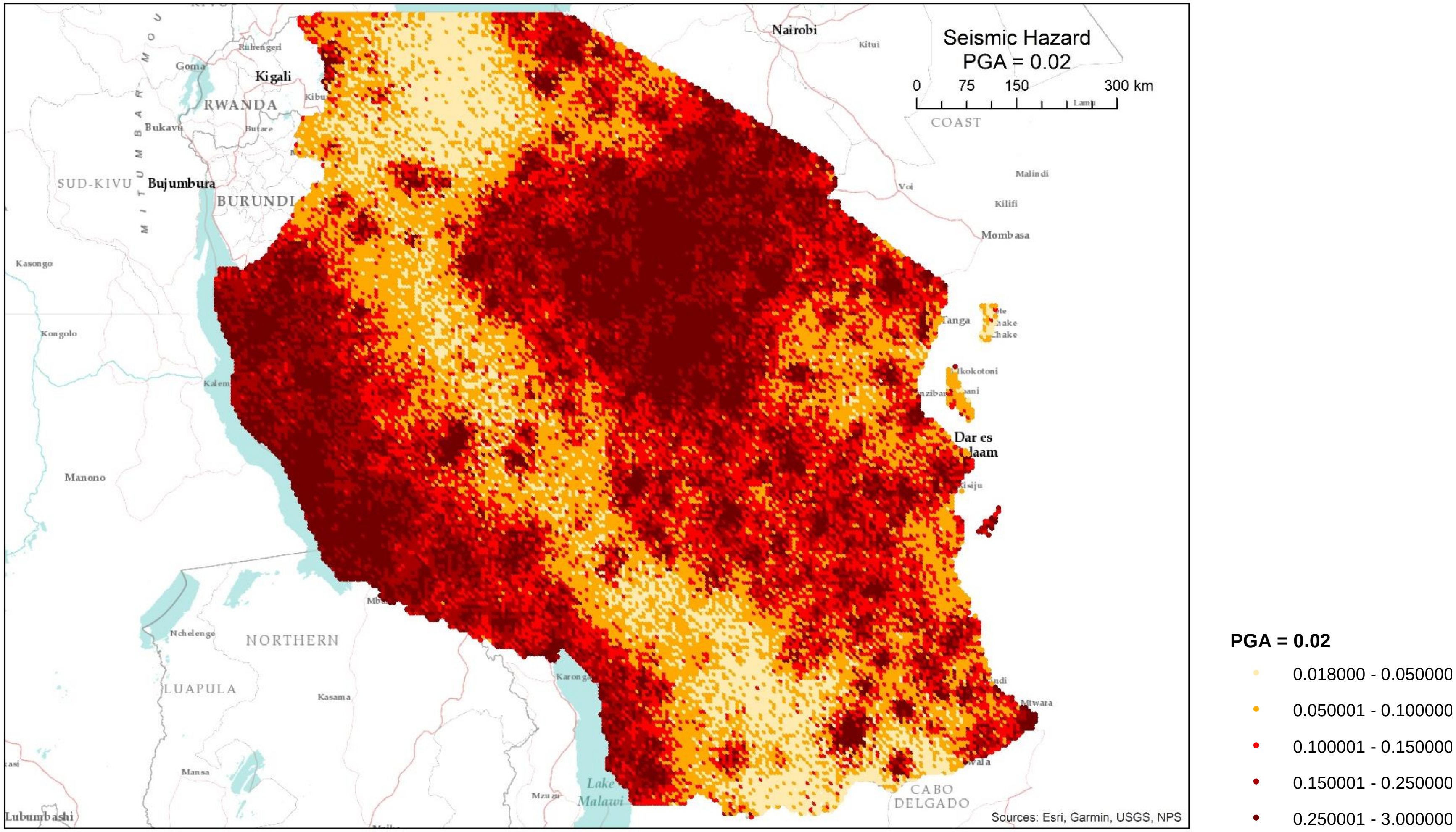

Figure 64: Tanzania Seismic Hazard Footprint for Peak Ground Acceleration of 0.02 (2%), GEM © 2019 GEM Foundation. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Seismic data is available under the Creative Commons BY-NC-SA 4.0 License (CC BY-NC-SA 4.0) on https://maps.meteor-portal.org

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

Table 6: Summary of geospatial detail for METEOR-derived seismic hazard products for Tanzania

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 & Connor, 2006). Eruption parameters are assumed to represent average conditions over the duration of the complete eruption (Connor & 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 & 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 65); 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).

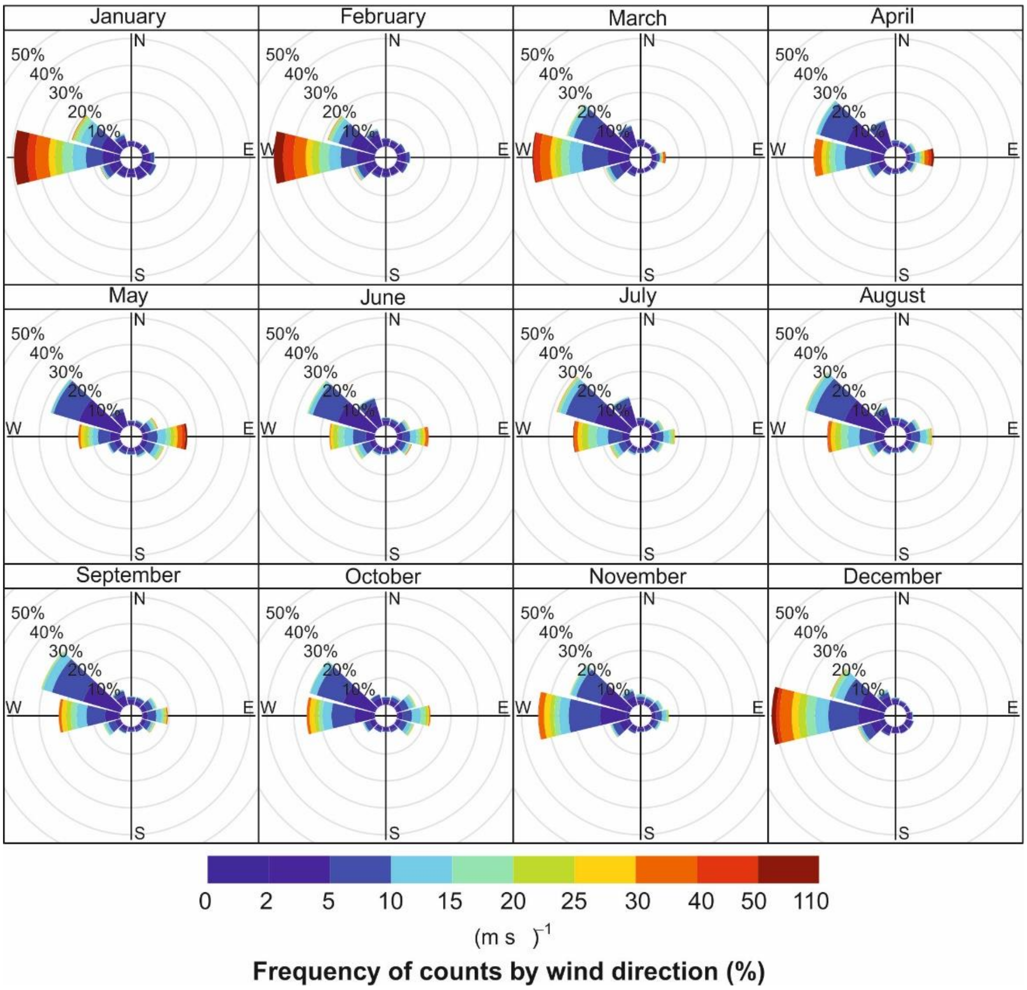

Figure 65: Ten-year ECMWF ERA-interim global reanalysis dataset for Rungwe from 1st January 2005 to 31st December 2014, separated by month to show seasonal variation in wind direction. Coloured bars show the direction the wind is blowing, colours represent the wind speed, and the length of the bar represents the frequency of counts by wind direction (%). Data: ECMWF ERA-Interim © 2020 European Centre for Medium-Range Weather Forecasts (ECMWF, www.ecmwf.int), this data is published under a CC BY 4.0 license (https://creativecommons.org/licenses/by/4.0)

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 & 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.

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5.2. TEPHRA HAZARD: RUNGWE, TANZANIA

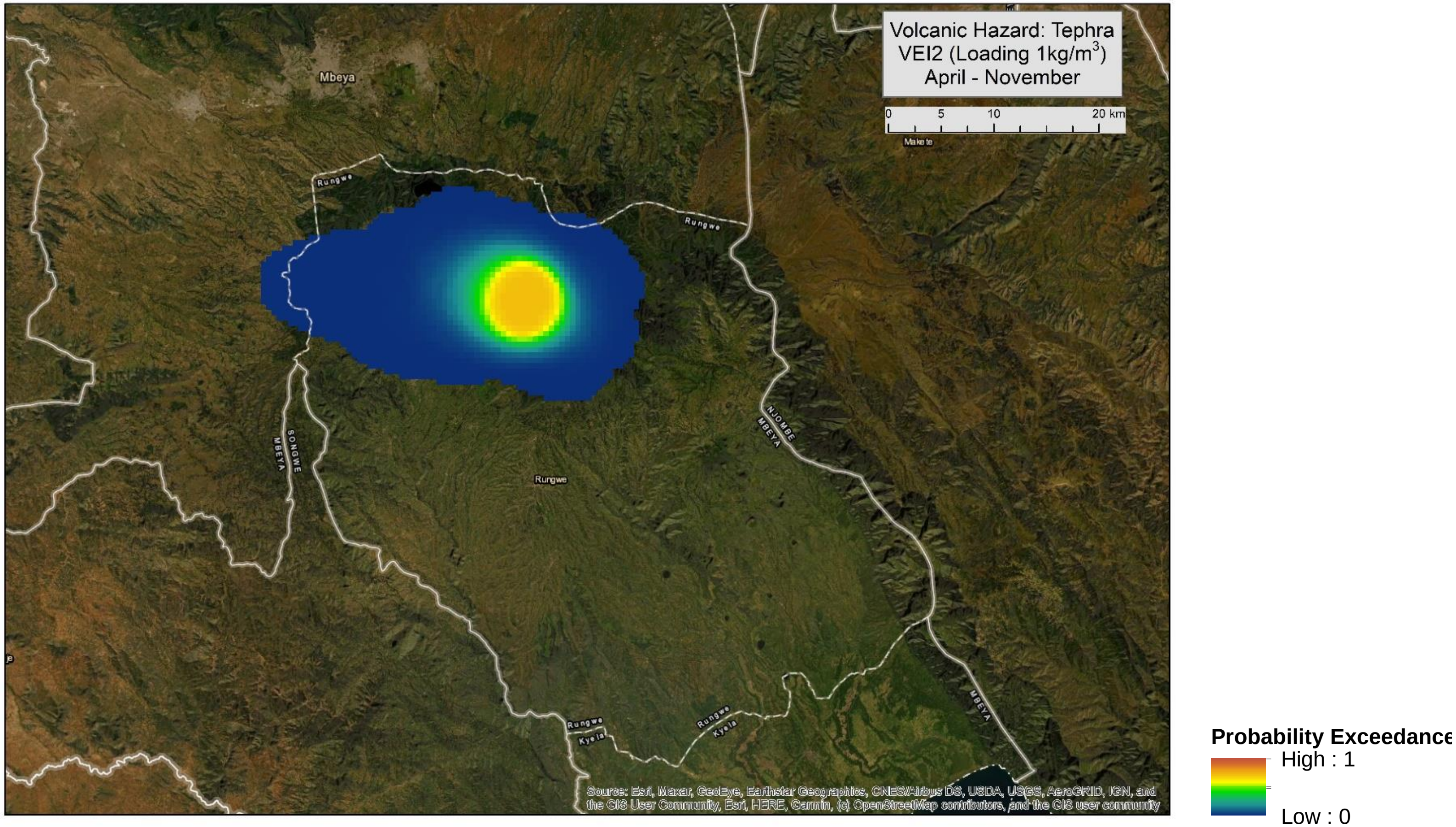

Figure 66: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 2 with loading of 1kg/m^3 for April-November, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

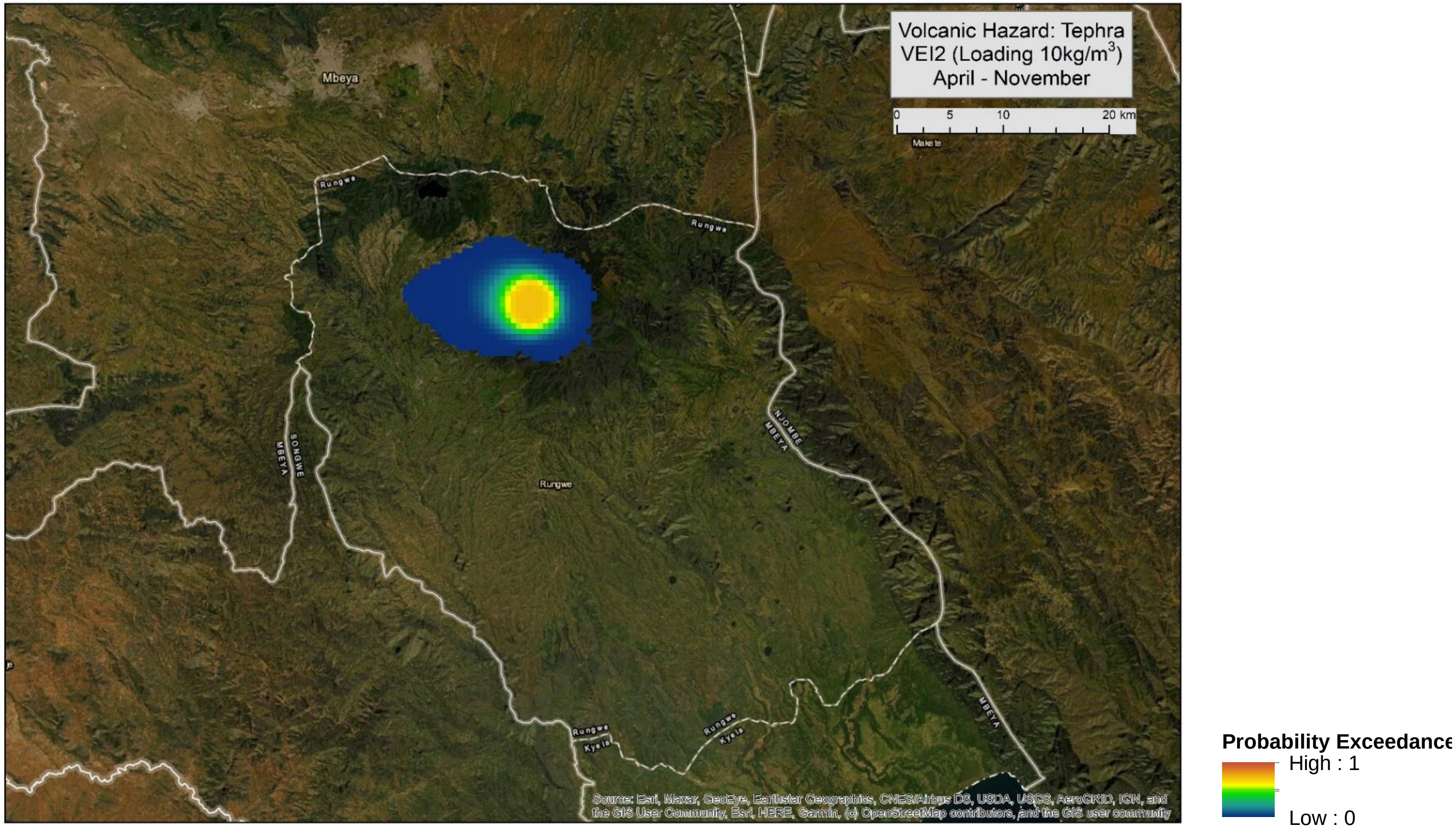

Figure 67: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 2 with loading of 10kg/m^3 for April-November, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

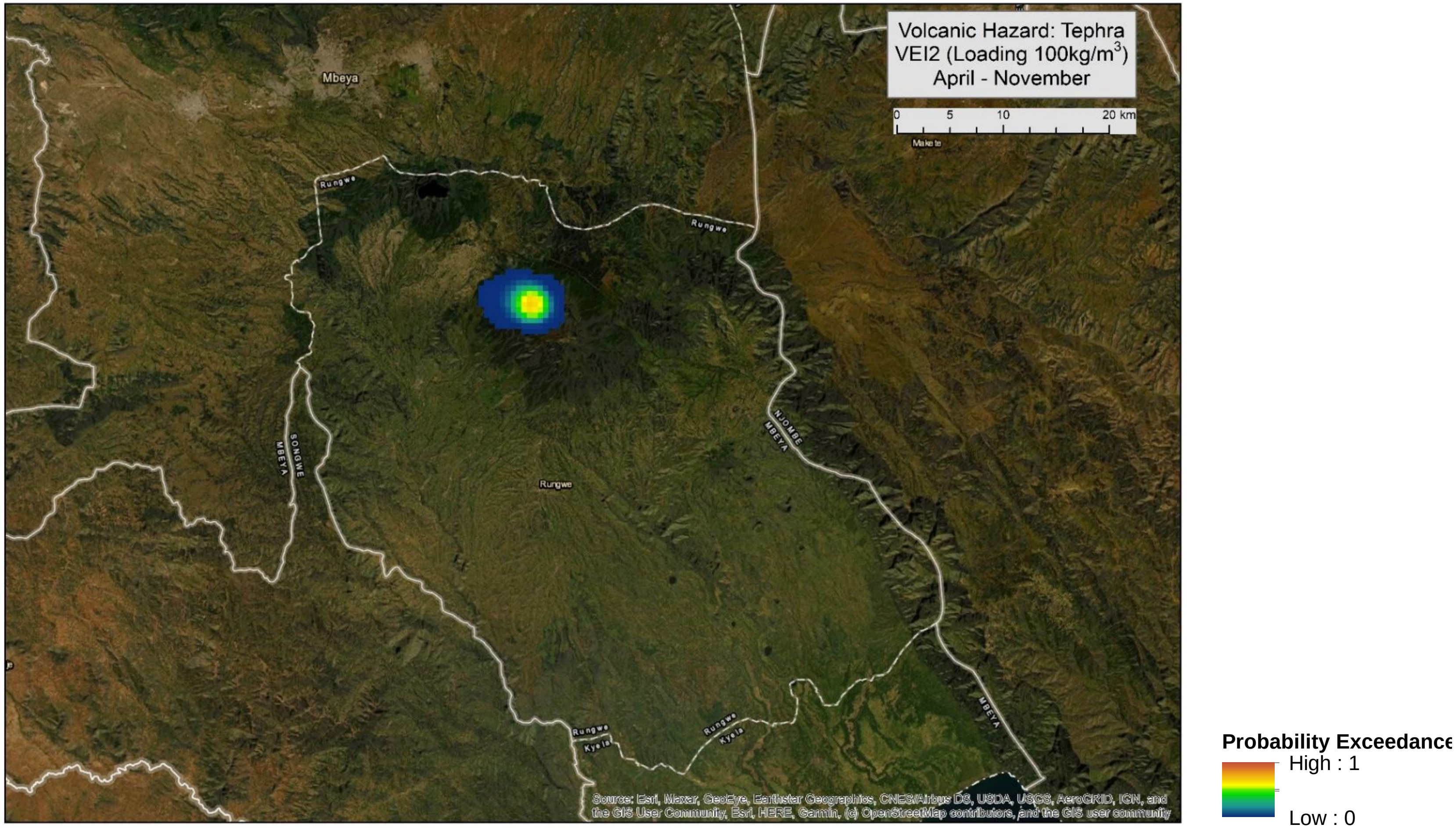

Figure 68: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 2 with loading of 100kg/m^3 for April-November, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

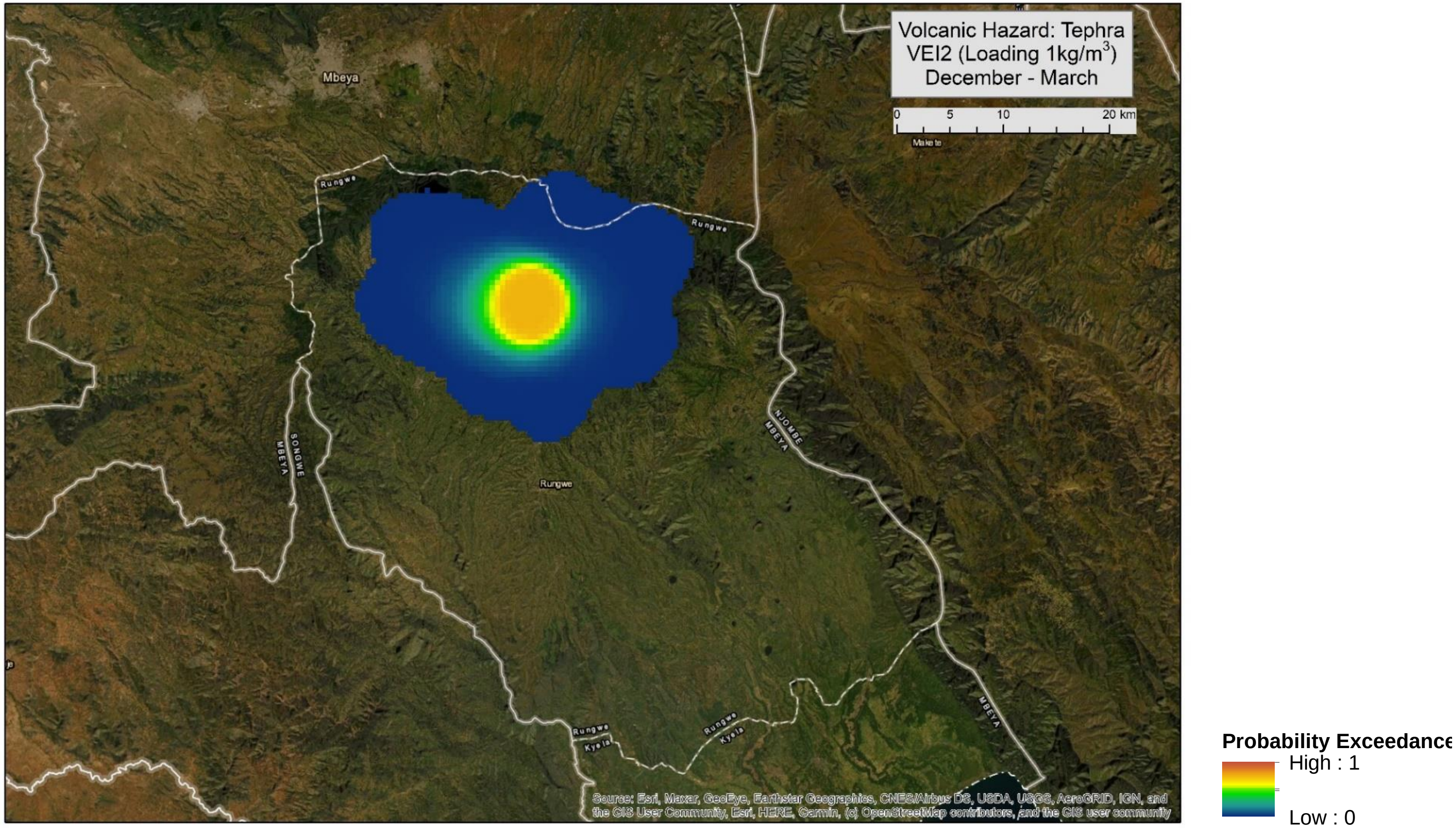

Figure 69: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 2 with loading of 1kg/m^3 for December-March, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

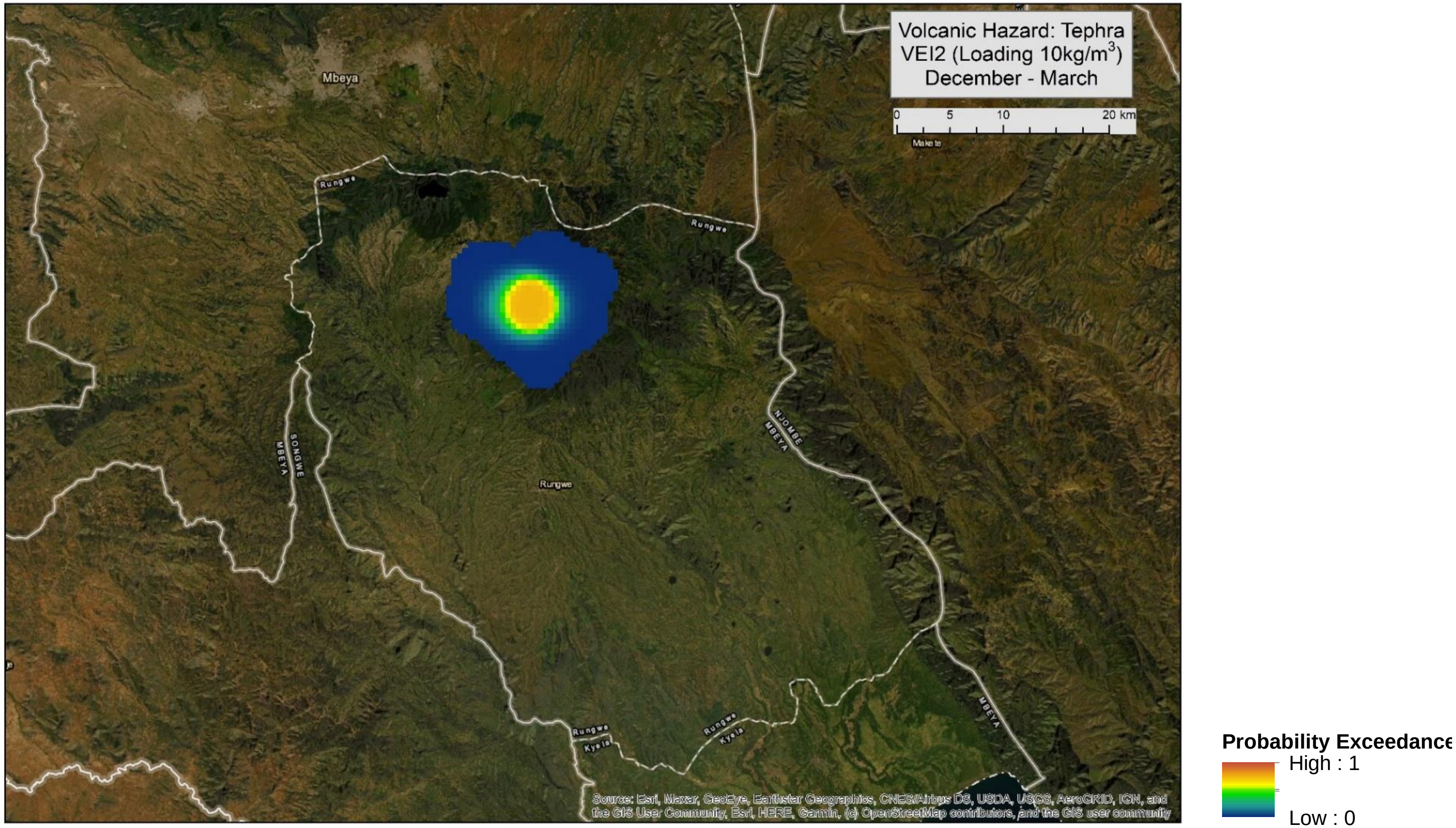

Figure 70: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 2 with loading of 10kg/m^3 for December-March, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

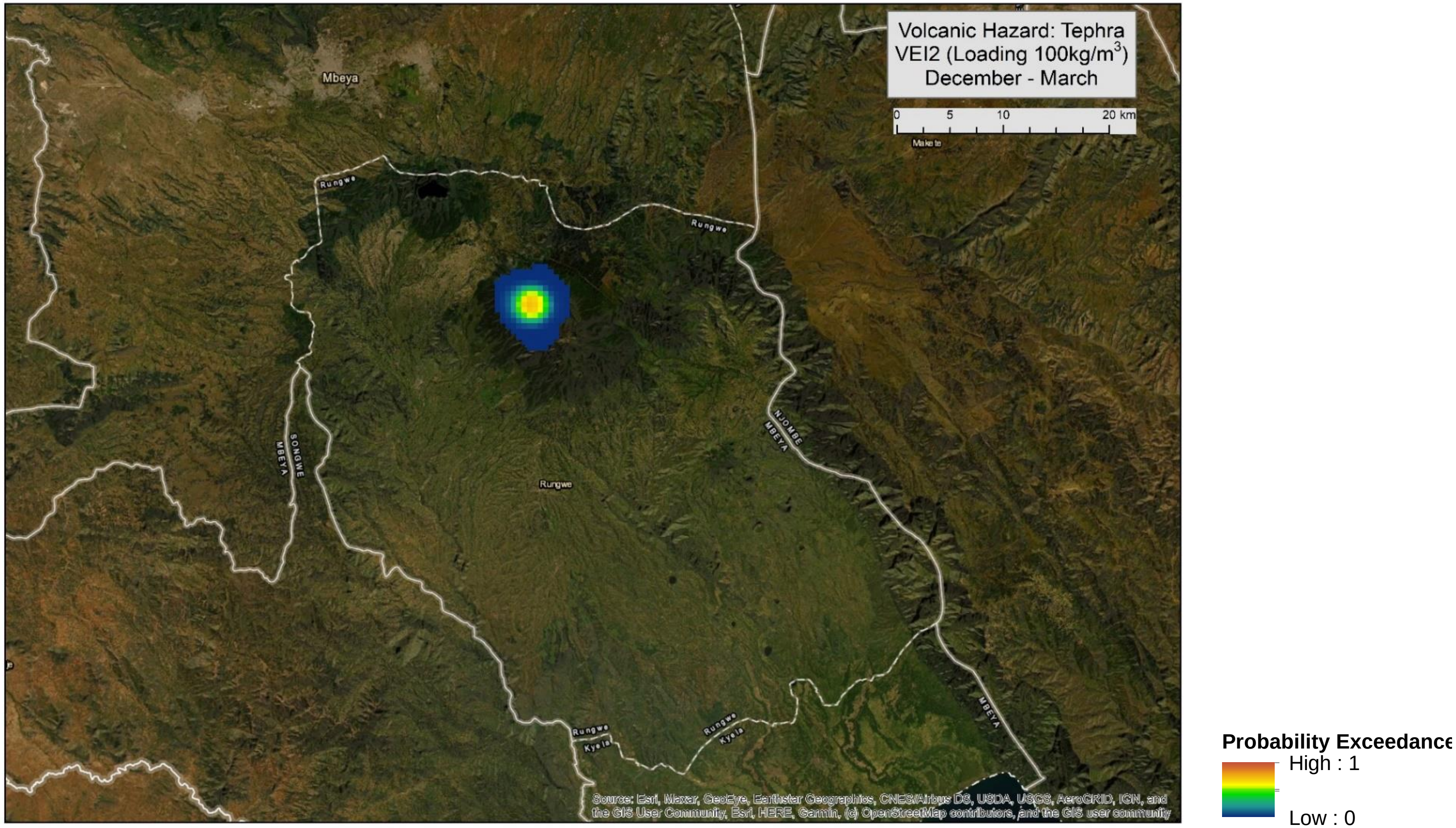

Figure 71: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 2 with loading of 100kg/m^3 for December-March, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

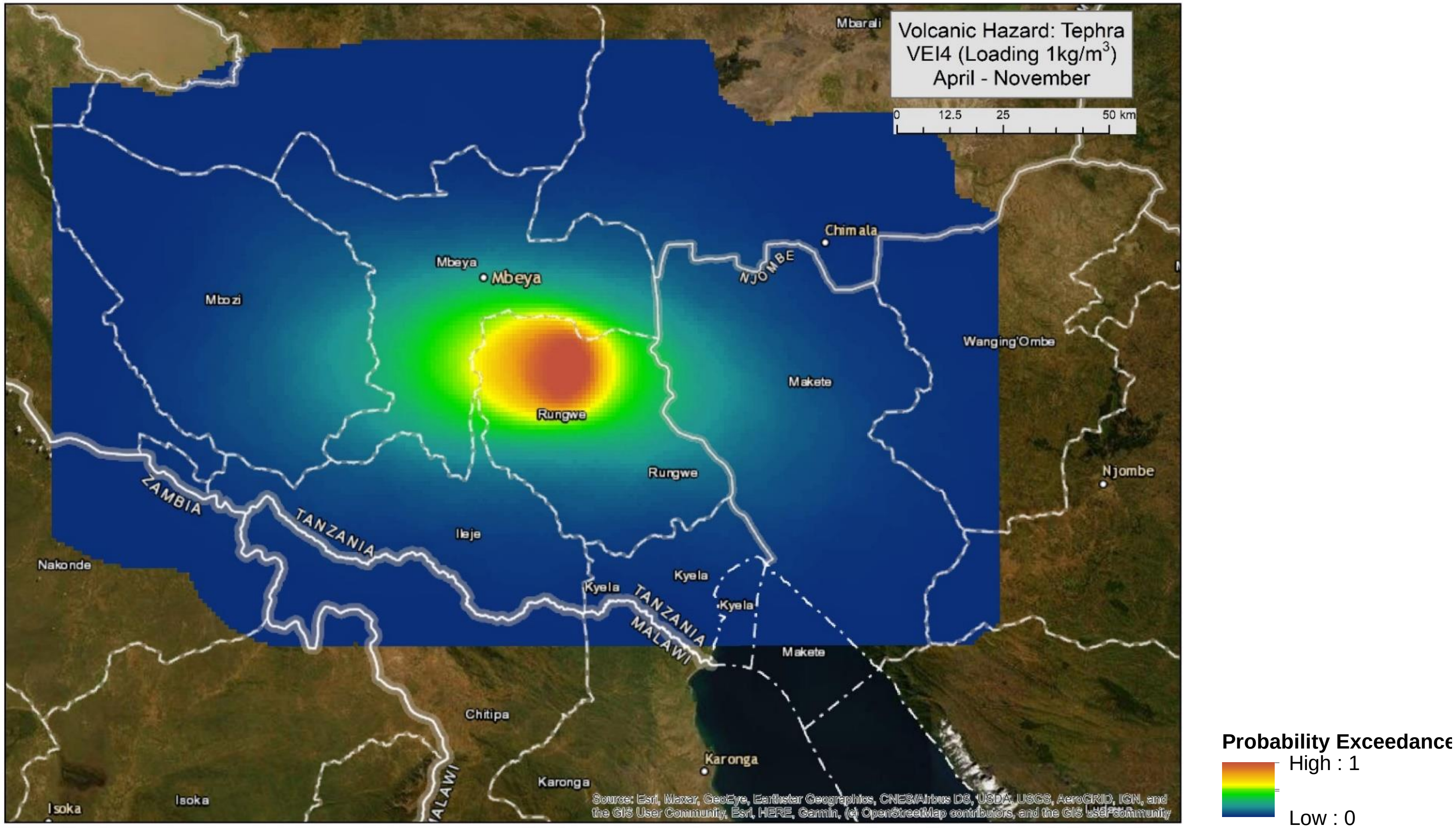

Figure 72: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 4 with loading of 1kg/m³ for April-November, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

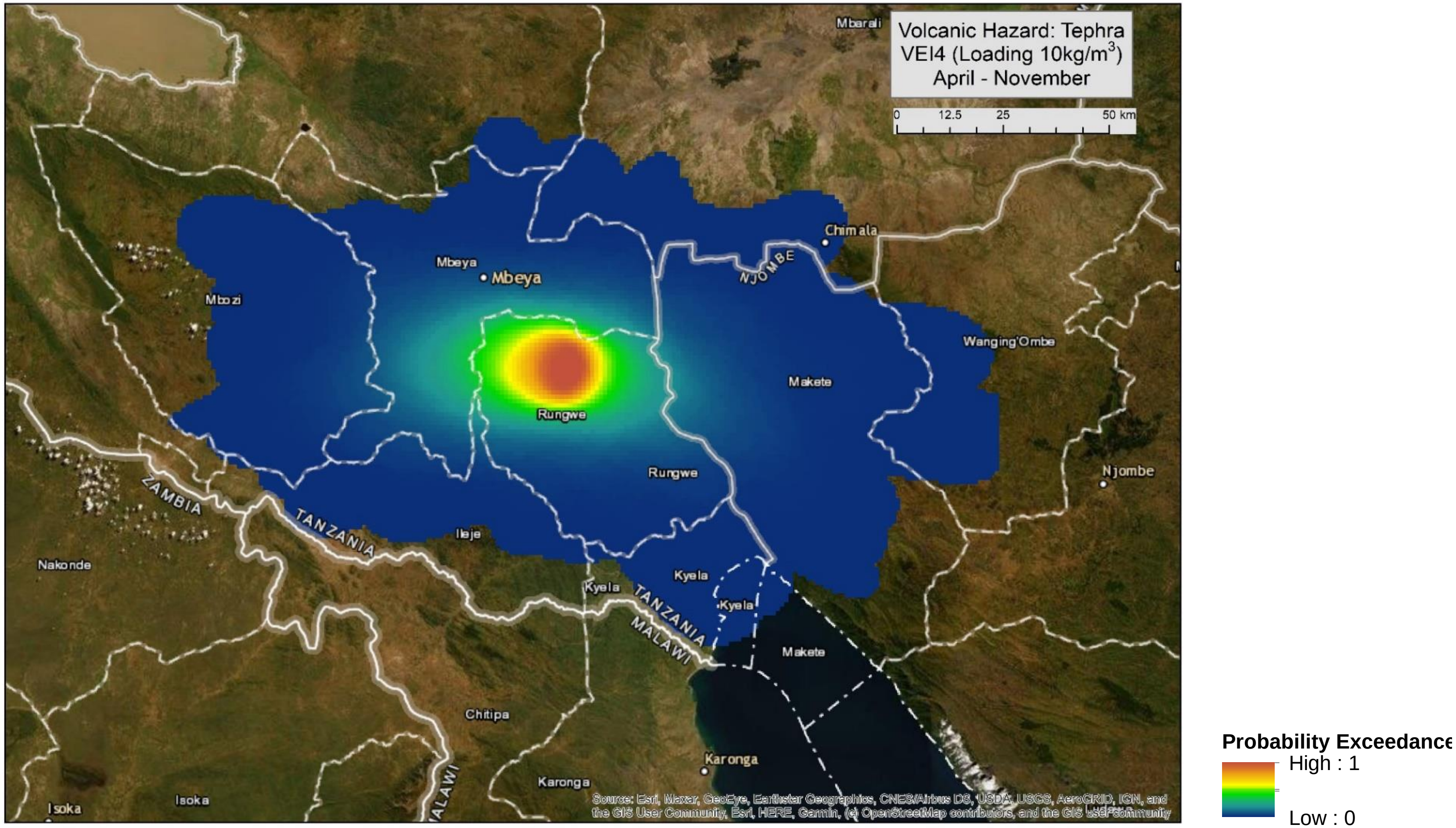

Figure 73: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 4 with loading of 10kg/m^3 for April-November, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

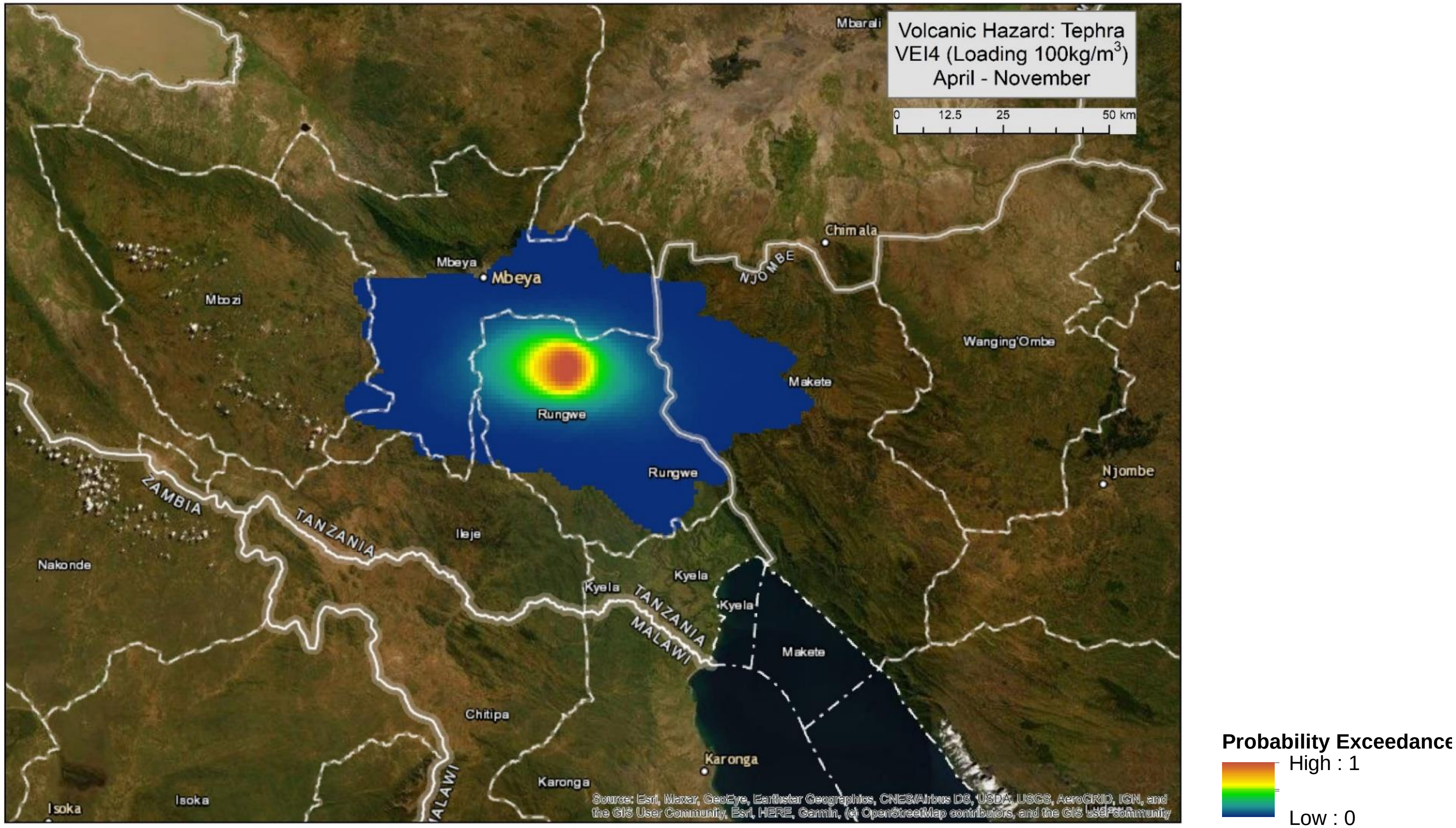

Figure 74: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 4 with loading of 100kg/m^3 for April-November, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

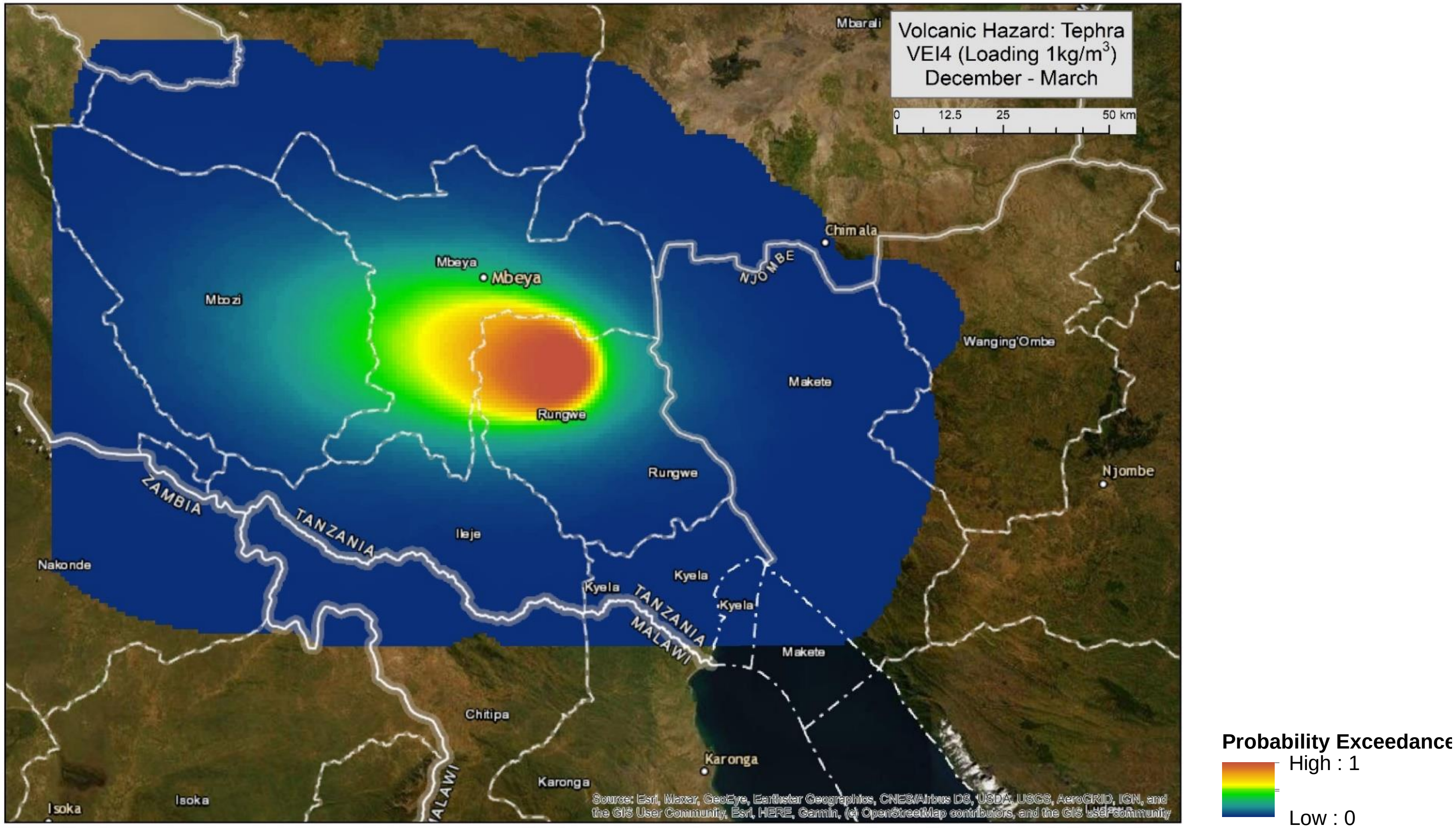

Figure 75: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 4 with loading of 1kg/m^3 for December-March, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

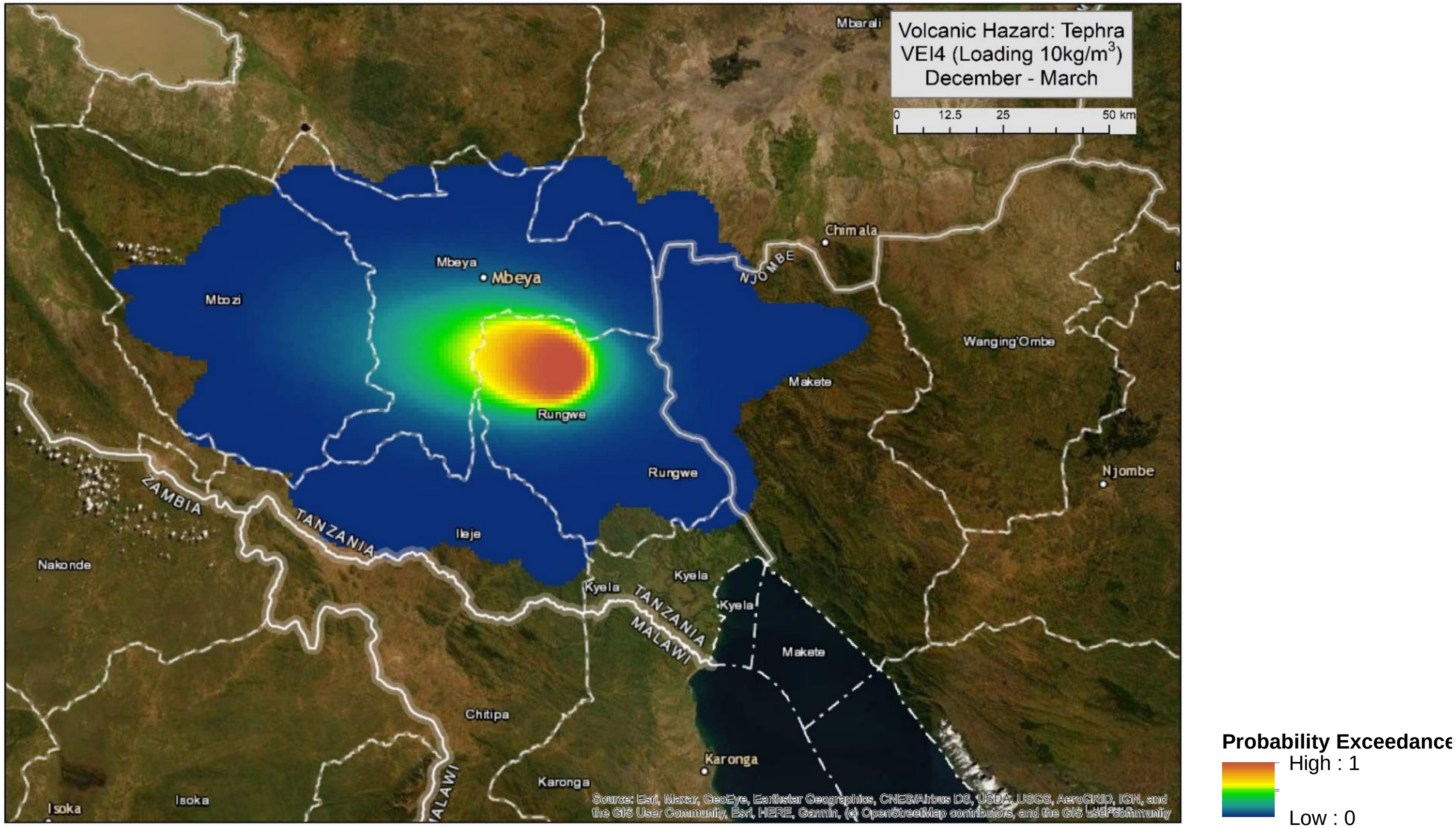

Figure 76: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 4 with loading of 10kg/m^3 for December-March, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

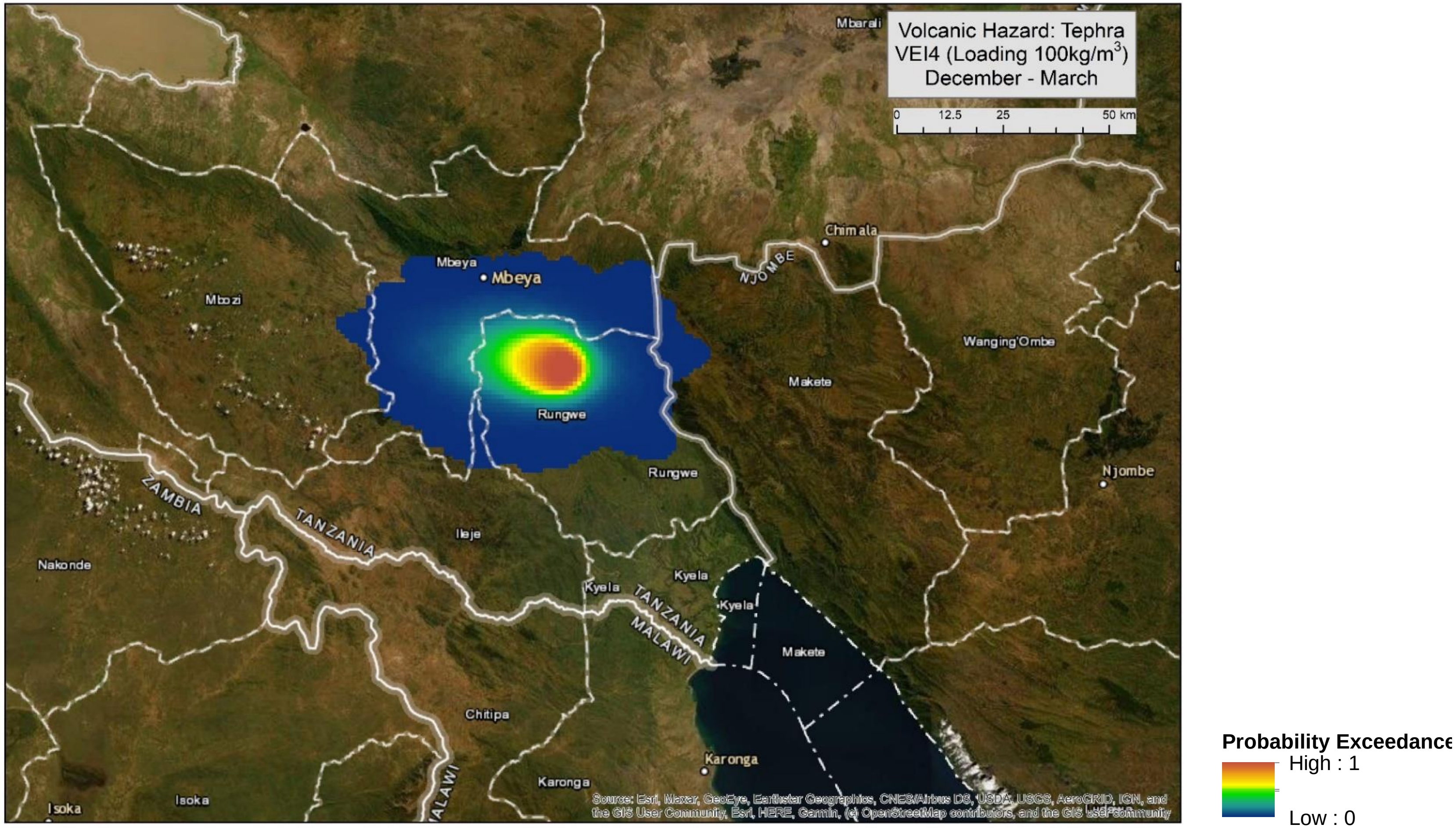

Figure 77: Rungwe Volcano, Tanzania, Volcanic Hazard Tephra Footprint for Volcanic Explosivity Index (VEI) of 4 with loading of 100kg/m^3 for December-March, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

5.3. VOLCANIC BASINS: TANZANIA

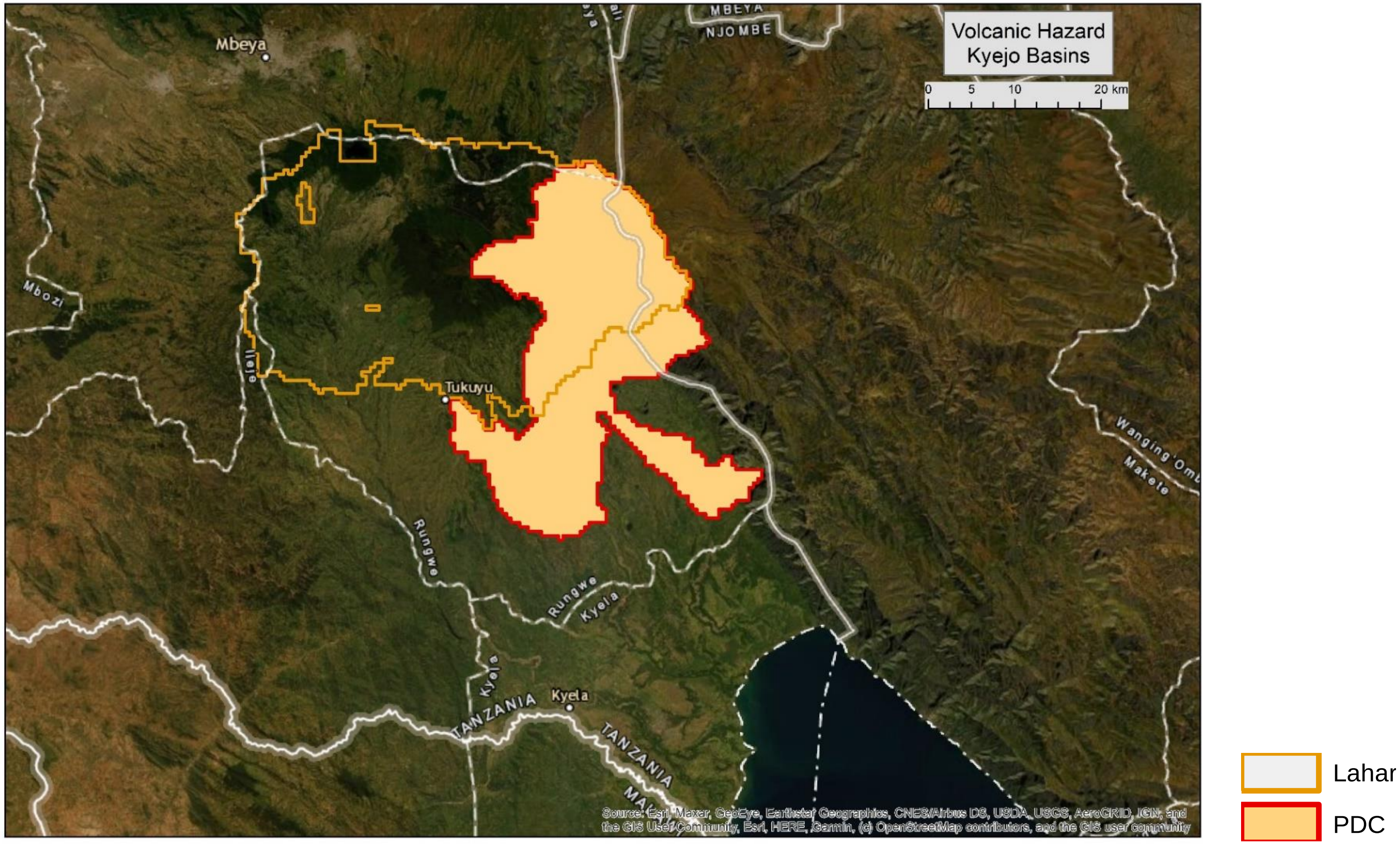

Figure 78: Volcanic Lahar and Pyroclastic Density Current Hazard Footprints for Kyejo Volcano, Tanzania, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

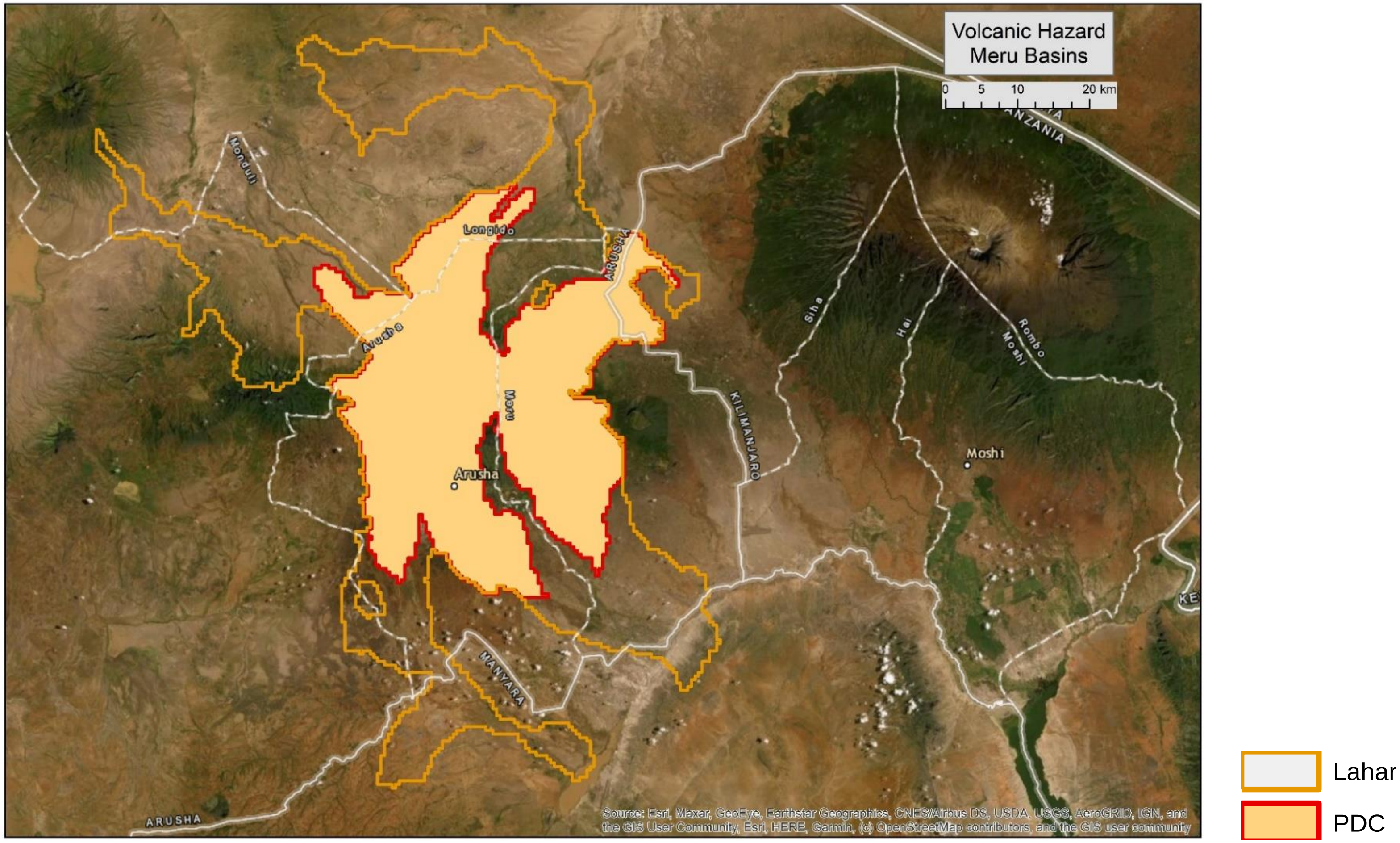

Figure 79: Volcanic Lahar and Pyroclastic Density Current Hazard Footprints for Meru Volcano, Tanzania, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

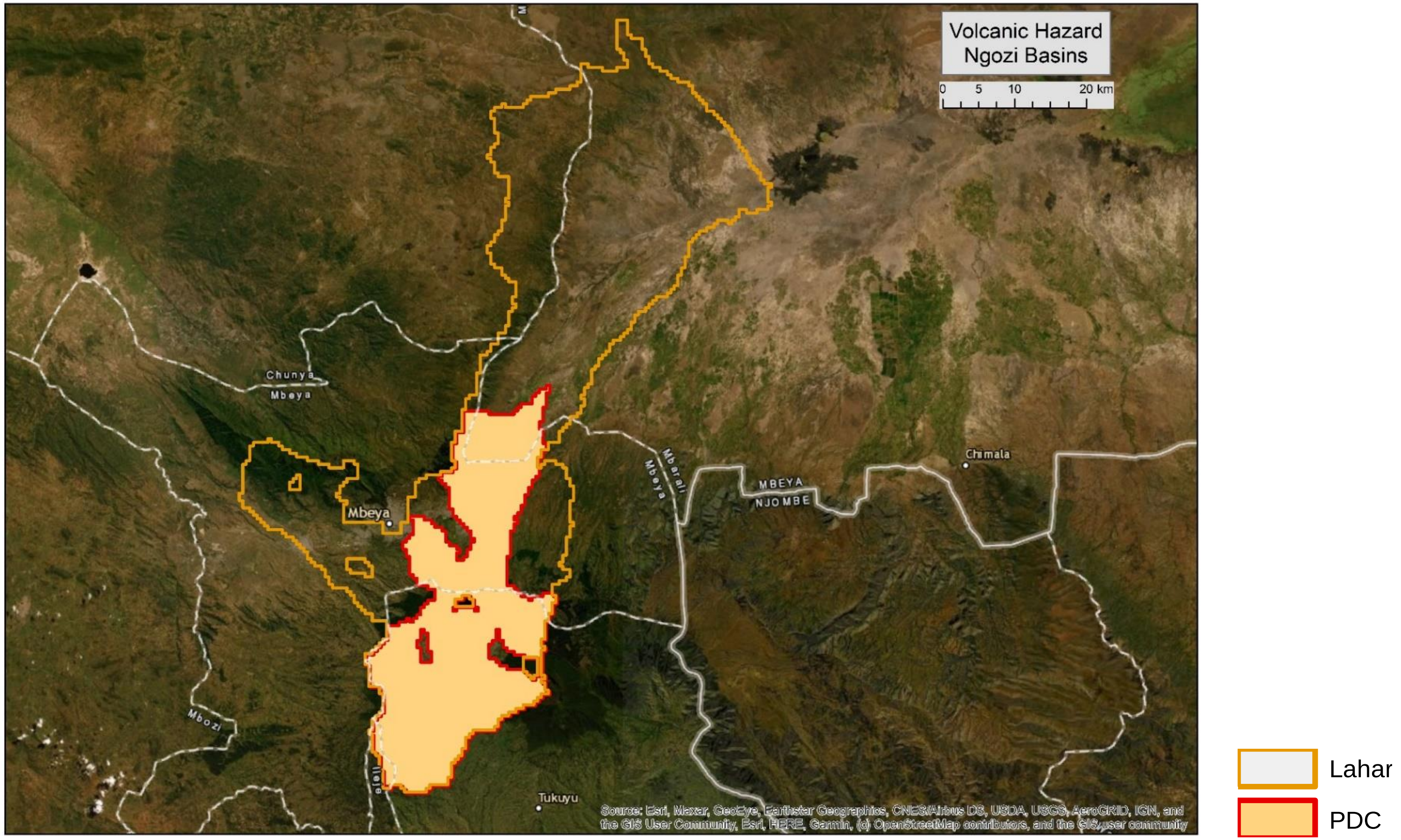

Figure 80: Volcanic Lahar and Pyroclastic Density Current Hazard Footprints for Ngozi Volcano, Tanzania, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

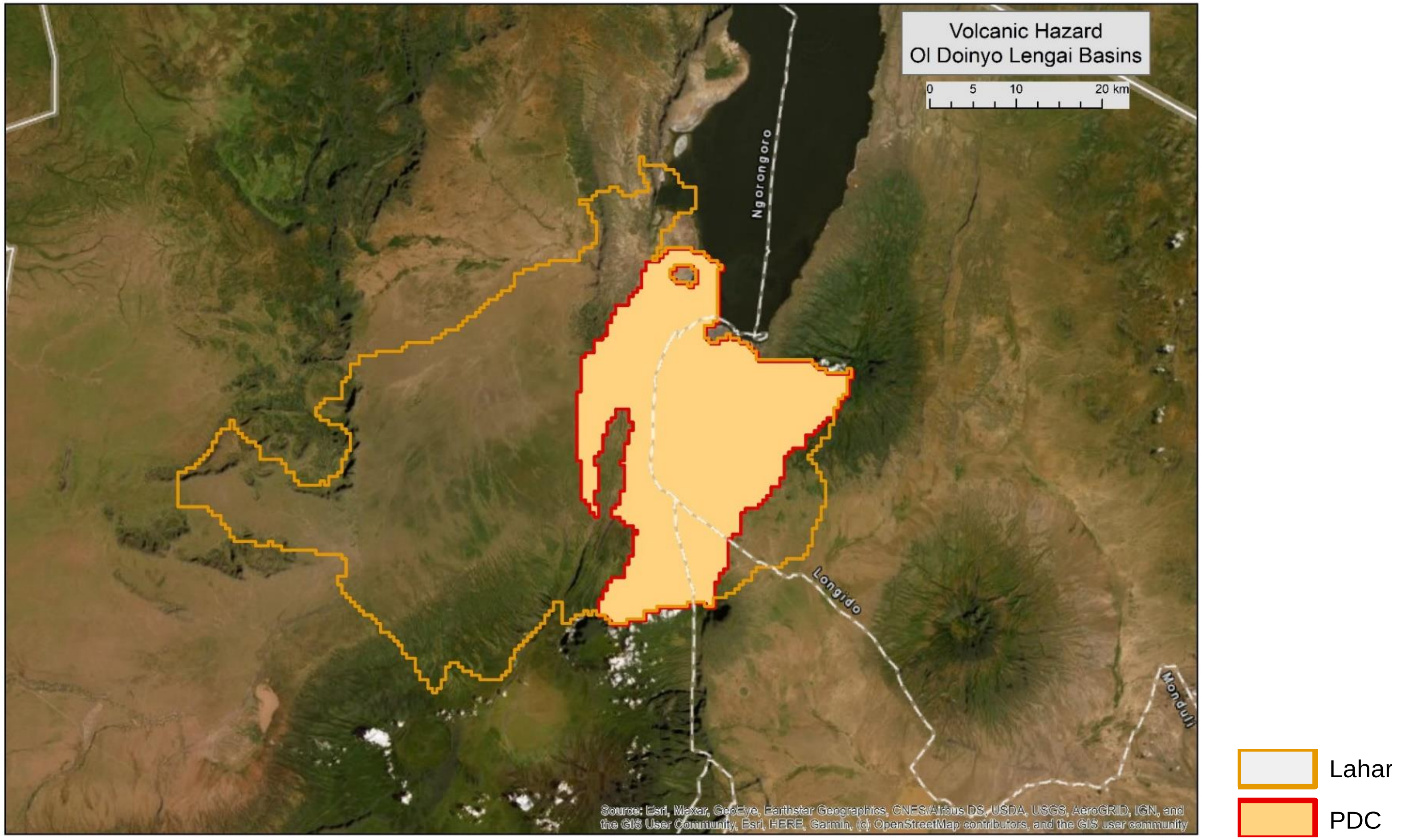

Figure 81: Volcanic Lahar and Pyroclastic Density Current Hazard Footprints for Ol Doinyo Lengai Volcano, Tanzania, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

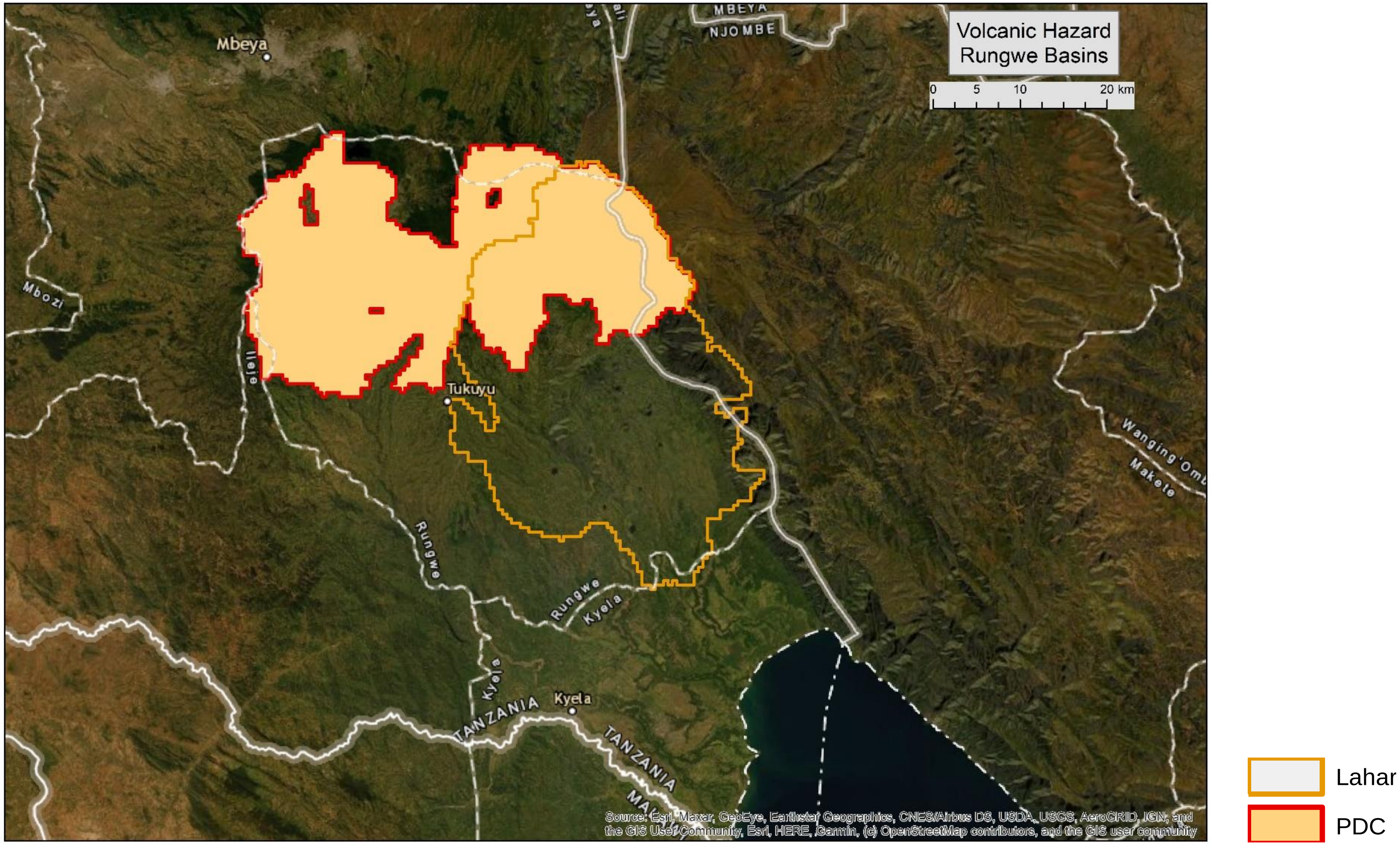

Figure 82: Volcanic Lahar and Pyroclastic Density Current Hazard Footprints for Rungwe Volcano, Tanzania, BGS © UKRI 2019. Data is displayed on Esri World Imagery with Reference Basemap layer. (Image Sources: Esri, Maxar, GoeEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community; Reference Sources: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community). Volcanic data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

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
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

Table 7: Summary of geospatial detail for METEOR-derived volcanic hazard products for Tanzania

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

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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

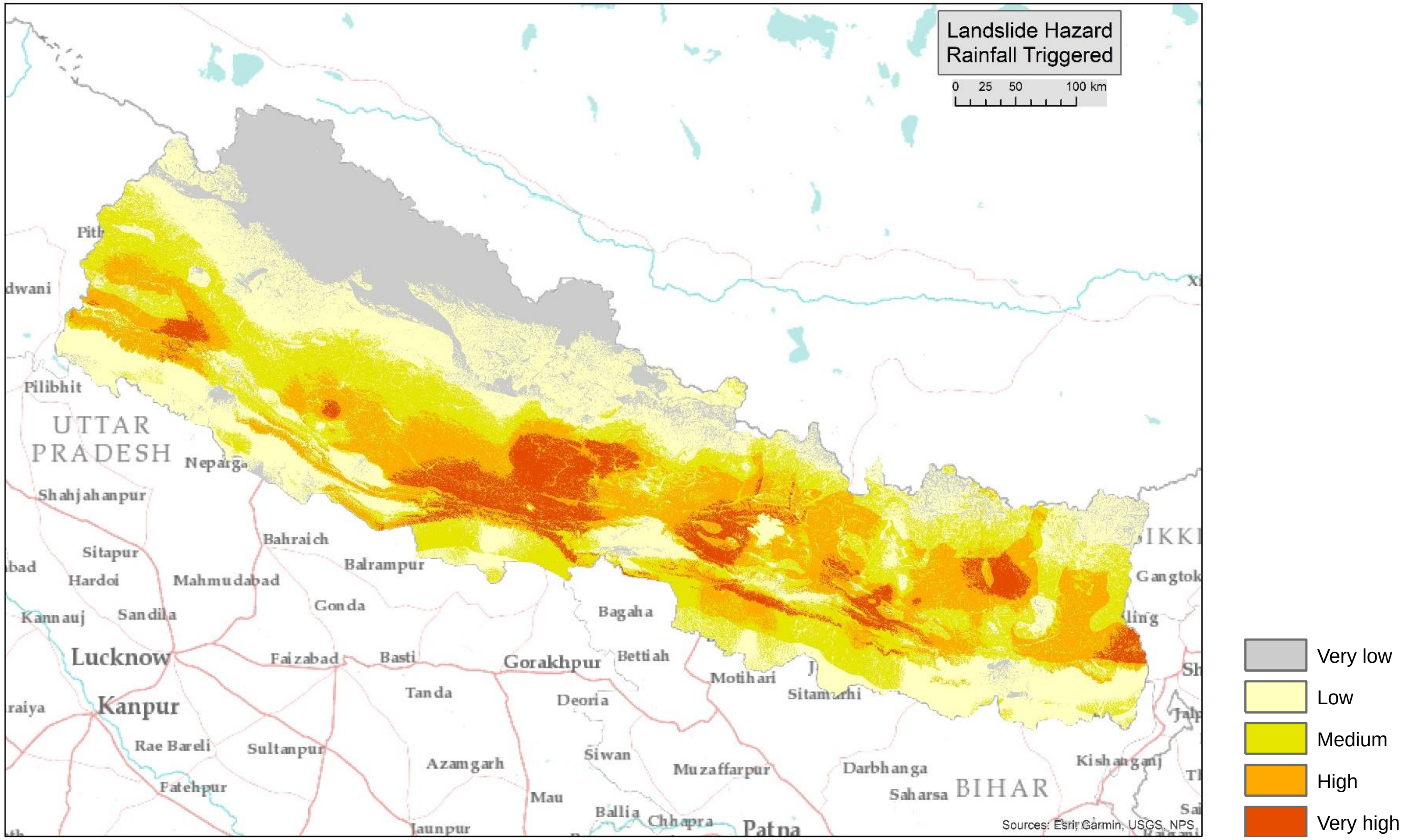

Figure 83: Nepal Landslide Hazard Footprint for rainfall-triggered landslides, BGS © UKRI 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Landslide data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

6.3. RAINFALL-TRIGGERED LANDSLIDE SUSCEPTIBILITY: NEPAL

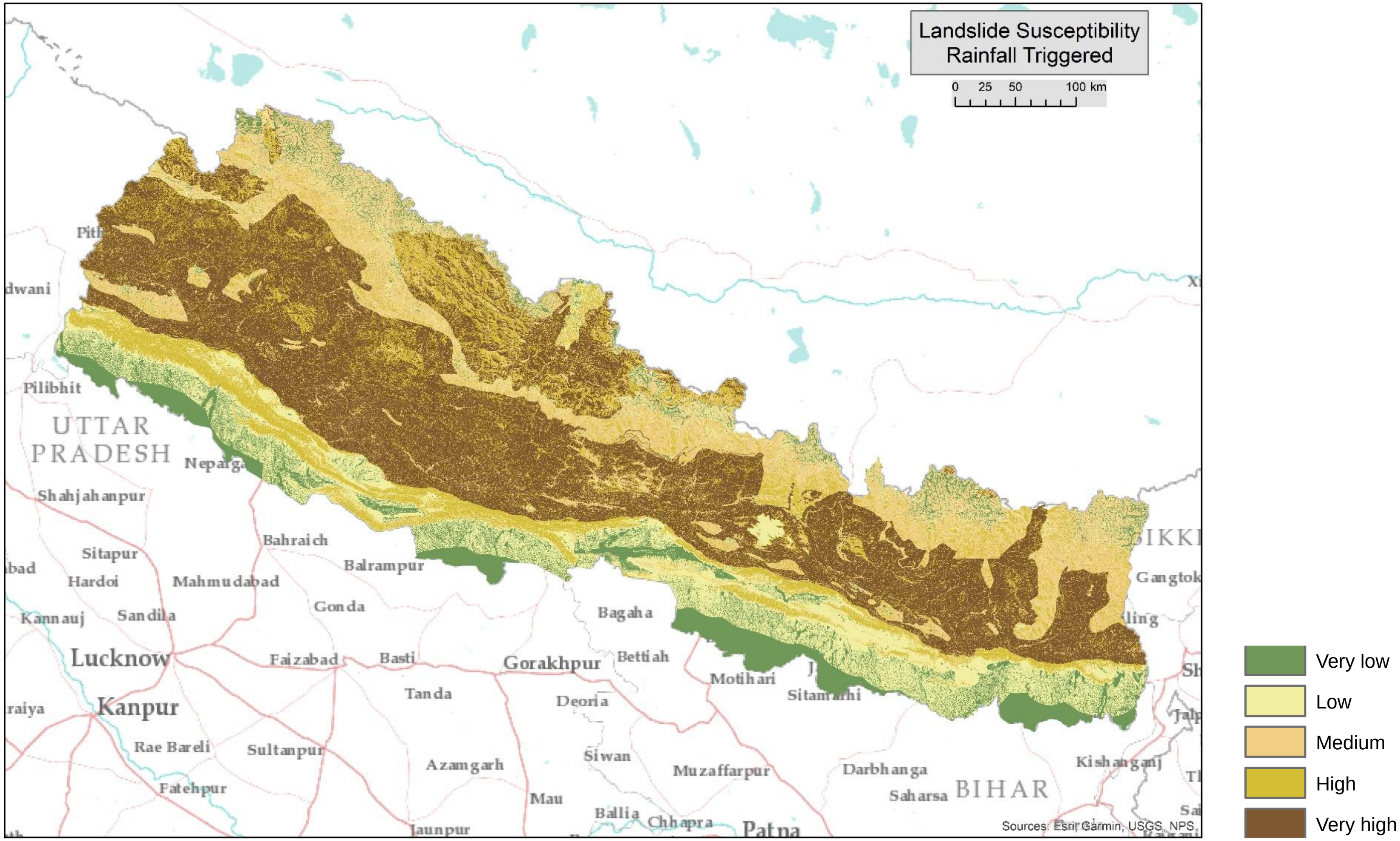

Figure 84: Nepal Landslide Susceptibility Footprint for rainfall-triggered landslides, BGS © UKRI 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Landslide data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

6.4. SEISMIC-TRIGGERED LANDSLIDE HAZARD: NEPAL

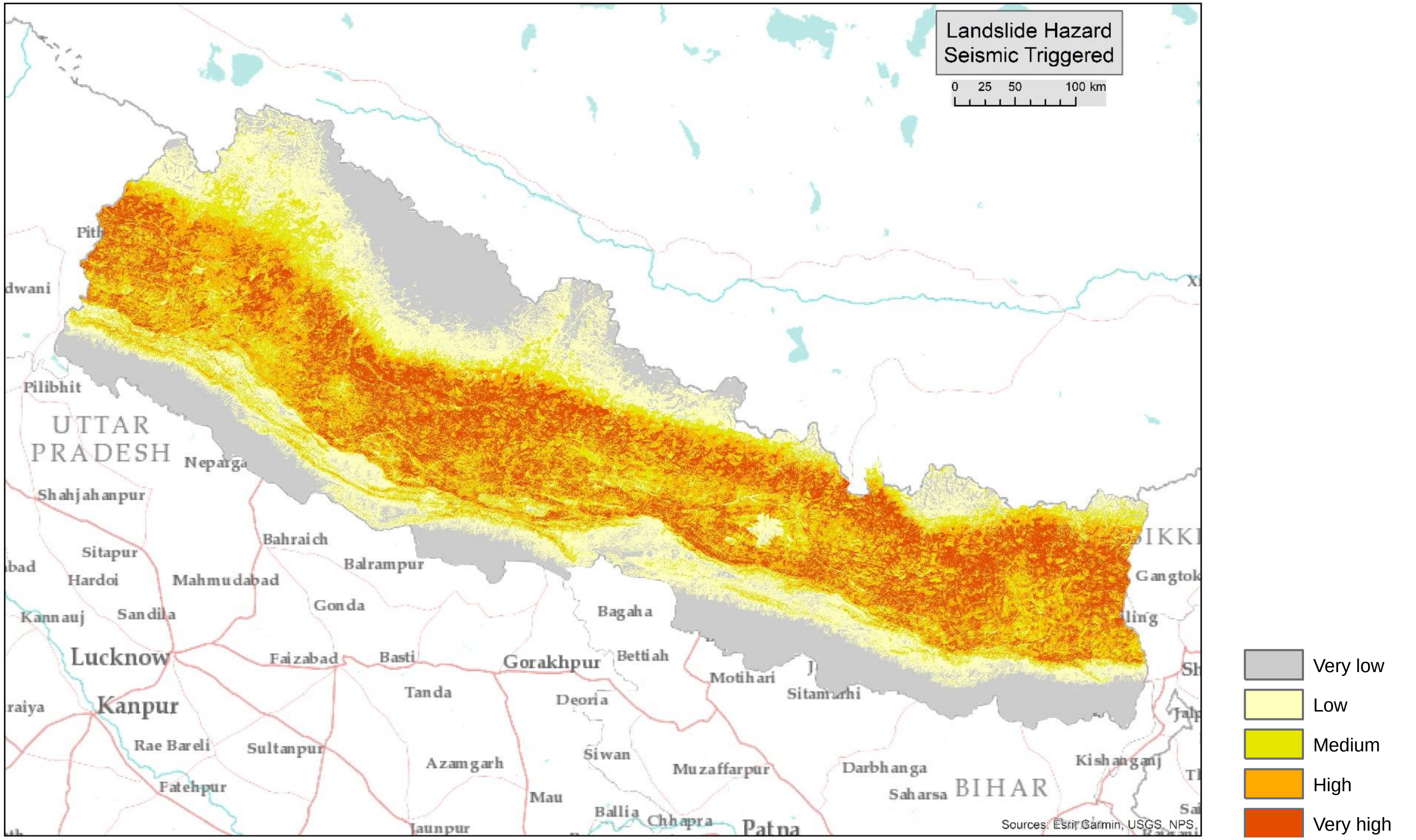

Figure 85: Nepal Landslide Hazard Footprint for seismic-triggered landslides, BGS © UKRI 2019. Data is displayed Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Landslide data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

6.5. SEISMIC-TRIGGERED LANDSLIDE SUSCEPTIBILITY: NEPAL

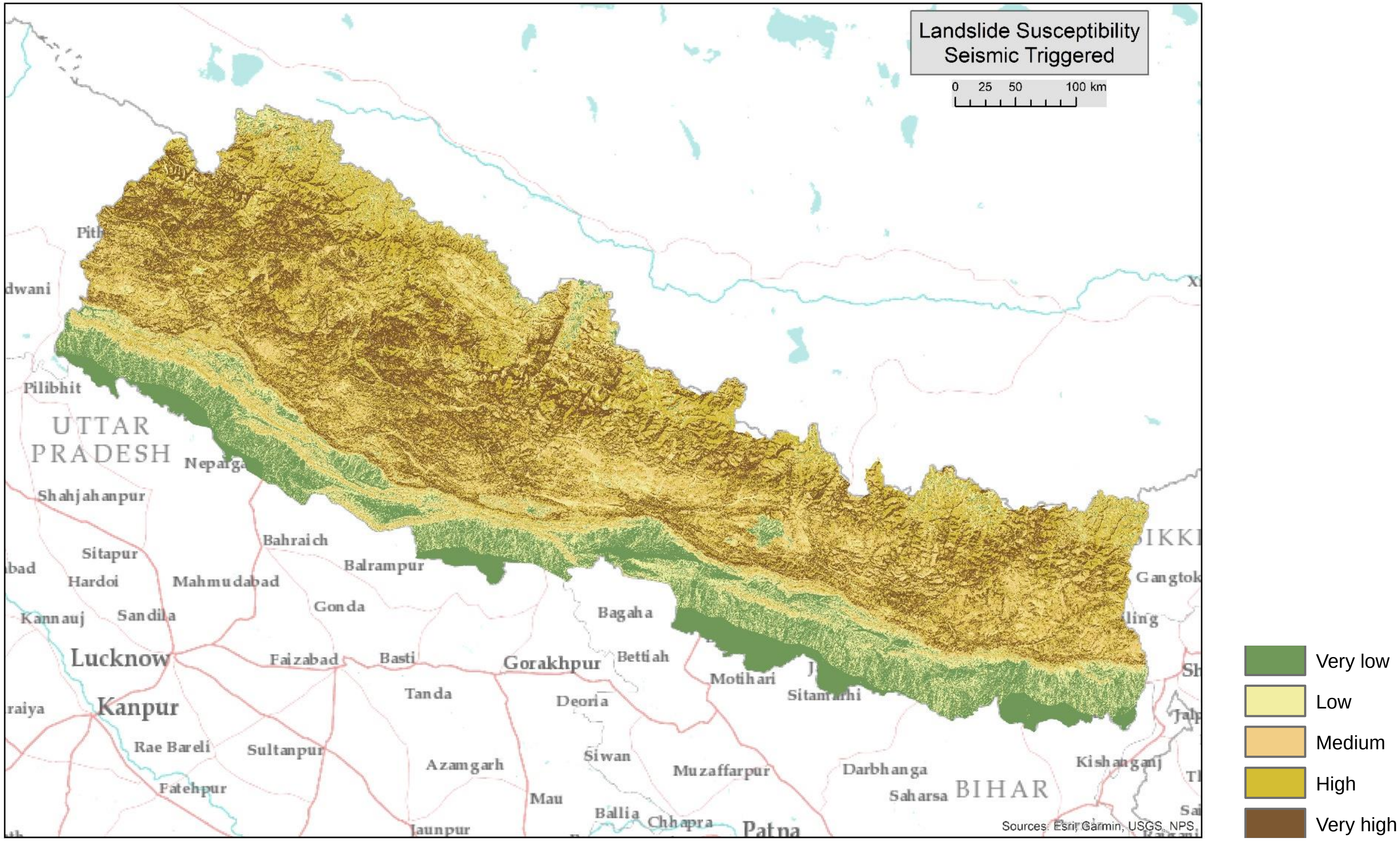

Figure 86: Nepal Landslide Susceptibility Footprint for seismic-triggered landslides, BGS © UKRI 2019. Data is displayed on Esri Topographic Basemap layer (Sources: Esri, Garmin, USGS, NPS). Landslide data is available under the Open Data Commons Open Database License (ODbL) on https://maps.meteor-portal.org

6.6. SUMMARY OF GEOSPATIAL DETAIL OF LANDSLIDE HAZARD AND SUSCEPTIBILITY 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

Table 8: Summary of geospatial detail for METEOR-derived landslide hazard and susceptibility products for Nepal

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