Building Geospatial Tools and Applications in support of DRM

Workshop 2: Technical Issues Towards Effective Applications of Geospatial Technologies and Data in DRM

Date : Monday 6-8 September 2021

Presented by Dr. Jacob Opadeyi,
Disaster Risk Management Consultant

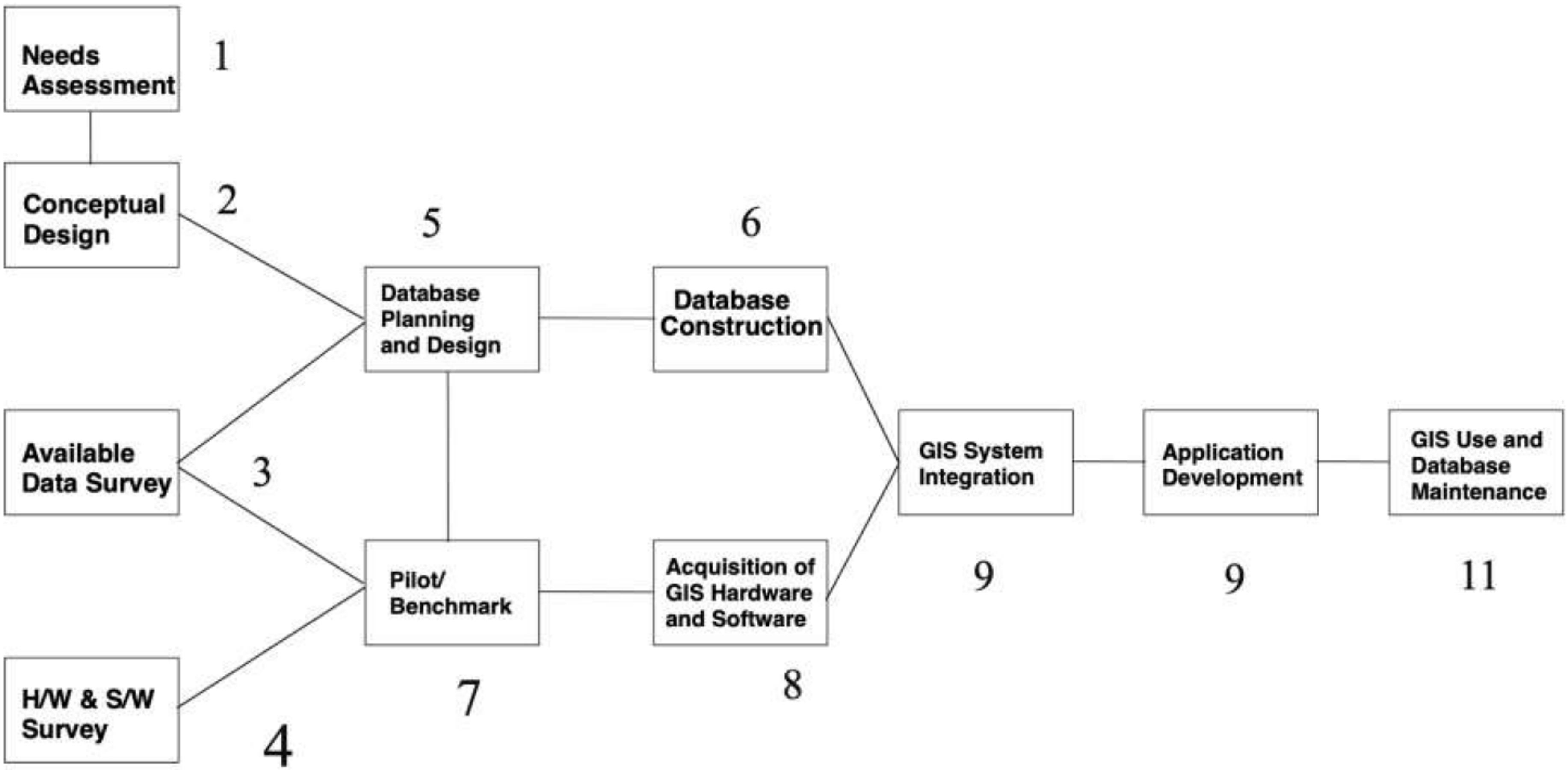
Objectives

- Introduce participants to the GIS applications development process and familiarize them with GIS Needs Assessment steps needed to develop GIS applications
- Introduce participants to GIS platforms and technologies used in application development

The major areas of DRM application

a. **Temporal analysis of natural hazard parameters.**
b. **Trend analysis of the occurrence of disasters.**
c. **Spatial analysis of the impact of disaster over a geographic region.**
d. **Three-dimensional analysis of the effect of natural hazards.**
e. **Multivariable disaster risk analysis.**
f. **Natural hazard prediction and modelling.**
g. **Simulation of response rate to vulnerable communities.**
h. **Cause-Effect analysis.**
i. **Analysis of impact zones or anticipated degree of severity.**
j. **Storm runoff prediction from urban watersheds.**
k. **Site suitability screening for hazardous waste facilities.**
l. **Public health and epidemiology**

GIS Applications Development Process



Needs assessment

- A needs assessment is the first step in implementing a successful GIS applications within any organization.
- A needs assessment is a systematic look at how departments function and the spatial data needed to perform these functions

Results of a needs assessment

At the conclusion of a needs assessment, an organization will have all the information needed to plan the development of GST/D applications:

- The Applications to be developed
- The GIS Functions required
- The Data needed in the GIS database
- The Data maintenance procedures

Possible DRM Applications

Function	Potential Applications	Examples
Assessment	Information source, data display	How many many people will be affected by storm surge?
	Index of information	Find all shelters in a 1-mile radius
	Status reporting	Assess coastal erosion over time
	Monitoring change	
Analysis	Research support	What is contributing to landslides in an area?
	Forecasting	What is the effect of a 5 ft storm surge?
	Policy development	Where should building restrictions be implemented?
	Project evaluation	

Adapted from United Nations Environmental Program (UNEP). GRID (1985)

TYPICAL TWO STEPS IN DEVELOPING GIS APPLICATIONS

Design Stage

1. **What are the *objectives* and the *decisions* required to be made using this application?**
2. **What are the *criteria* for making the decisions?**
3. **What *information* is needed in order to evaluate the criteria?**
4. **What *data* must be acquired to generate the information?**
5. **What GIS functions will turn the data into information?**

TYPICAL TWO STEPS IN DEVELOPING GIS APPLICATIONS

Development Stage

1. **Prepare the data for spatial operations**
2. **Perform spatial operations**
3. **Prepare derived data for tabular analysis**
4. **Perform tabular analysis**
5. **Evaluate and interpret results**
6. **Refine the analysis as necessary**
7. **Produce the final maps and tabular reports of the results**

Towards Landslide and Flood Hazard Mitigation Planning and Management in Trinidad and Tobago

A GIS-based Landslide and Flood Susceptibility Mapping and Risk Mapping for the Island of Trinidad Using Weight Factor Modeling



A 76-year old pensioner died when a landslide destroyed part of his Santa Cruz home.

Trinidad Express - Aug 6, 201

Two people are dead after a landslide struck the village of Delaford on Tobago's west end.

Caribbean Net News **Tuesday, November 16, 2004**

On May 27th 2010 at around 6.30 am the Caroni River, which runs to the back of El Socorro South burst its bank due to heavy rainfall. As a result hundreds of acres of crops were submerged in water.

Trinidad Guardian 28 May 2010

Project Objectives

1: To develop a model of areas that are susceptible to landslide and flood hazard in Trinidad .

The model will be based on the **spatial analysis of bio-geophysical factors** that contribute to the occurrence of landslides and flooding in Trinidad using GIS, satellite imagery & field observation to validate the model

2: To develop a risk model of buildings and populations at risk due to landslide and flood susceptibilities in Trinidad.

- The model was based on the spatial correlation of landslide and flooding susceptibility with population and buildings at risk.

- The model evaluates and ranks the exposure to landslides and floods of resident population and the physical assets in Trinidad.

Methodology for Susceptibility Mapping

Phases	Tasks to be performed
1: Selection of Model	Review of scientific literature that leads to the selection of a suitable susceptible mapping model.
2: Identification of data	Gathering of pertinent data layers to be used by the model.
3: Cartographic Model	Formulation and ordering of model design concepts, criteria, and techniques
4: Data Preparation	Review, editing, conversion and reclassification of collected data into the appropriate data structures required by the model
5: Model Builder	Building of a user-centred cartographic model using ESRI ArcGIS model builder.

Methodology for Susceptibility Mapping

Phases	Tasks to be performed
6: Sensitivity Analysis	Testing of alternative scenarios, with varying criteria to determine which variables or factors predominantly influence the susceptibility of landslides in Trinidad.
7: Verification	Conducting limited field validation to confirm the results of the landslide susceptibility map
8: Result Visualization	Creation of map products
9: Technical Report	Preparation of technical report that documents the process, results and recommendations on how to maintain the model

Landslide Susceptibility

Landslide Susceptibility

- The ability to express the likelihood that a landslide will occur in an area as a function of local terrain conditions (Soeters and Van Westen, 1996.)
- Susceptibility mapping of landslides determines the vulnerability of an area to landslides by correlating the major factors causing landslides in the area.
- In order to evaluate an area's susceptibility to landslides, the factors leading to this hazard must be identified and analyzed.

Instability Factors

- Most hazards are the result of complex interaction among several instability factors, primarily:
    - Geological,
    - Geomorphological,
    - Human and
    - Meteorological factors.
- The overall estimation of the landslide susceptibility for an area results from the combination of the susceptibility levels of the individual instability factors.
- Thus, instability factors are ranked and weighted according to their assumed or expected importance in causing disaster.

Instability Factors

- Tectonic Features
- Lithological Formation
- Slope Angle
- Road Network
- Drainage Network
- Land Use
- Rainfall

Landslide Factor Ranking

Instability Factors	Classifications	Susceptibility Level	Rank
Lithological Formation	**Formations**		
	Alluvium, Navet, Palmiste	Very High	5
	Moruga, Lengua, Brasso, Manzanilla, Maracas, Galera	High	4
	Toco, Maraval, Rio Seco, Springvale, Nariva, Chaudiere, Cipero, Morne L'Enfer,Mud Volcanoes Cones & Flows,Gros Morne, Karamat, Mayaro, San Fernando	Moderate	3
	Cedros, Diorite, Laventille, Guayamara, Tompire, Chancellor, Guayamara, Talparo, Lopinot, Cushe, Cunapo, Concord, Gautier, Naparima, Lizard Springs, Chaudiere	Low	2
	Sans Souci, Arima, Water, Pointe-a-Pierre, Cruse, Erin	Very Low	1

Landslide Factor Ranking

Instability Factors	Classifications	Susceptibility Level	Rank
Tectonic Features	**Proximity (m)**		
	0-100	Very High	5
	100-200	High	4
	200-400	Moderate	3
	400-600	Low	2
	> 600	Very Low	1
Slope Angle	**Angles (degrees)**		
	48 - 87	Very high	5
	27- 48	High	4
	15 - 27	Moderate	3
	5 - 15	Low	2
	0 - 5	Very Low	1

Landslide Factor Ranking

Instability Factors	Classification	Susceptibility Level	Rank
Road Network	**Proximity (m)**		
	0-100m	Very high	5
	101-200m	Very high	4
	201-400m	High	3
	401- 600m	Moderate	2
	>600m	Low	1

Landslide Factor Ranking

Instability Factors	Classifications	Susceptibility Level	Rank
Drainage Network	**Proximity (m)**		
	0-100m	Very high	5
	101-200m	Very high	4
	201-400m	High	3
	401-700m	Moderate	2
	>700m	Low	1

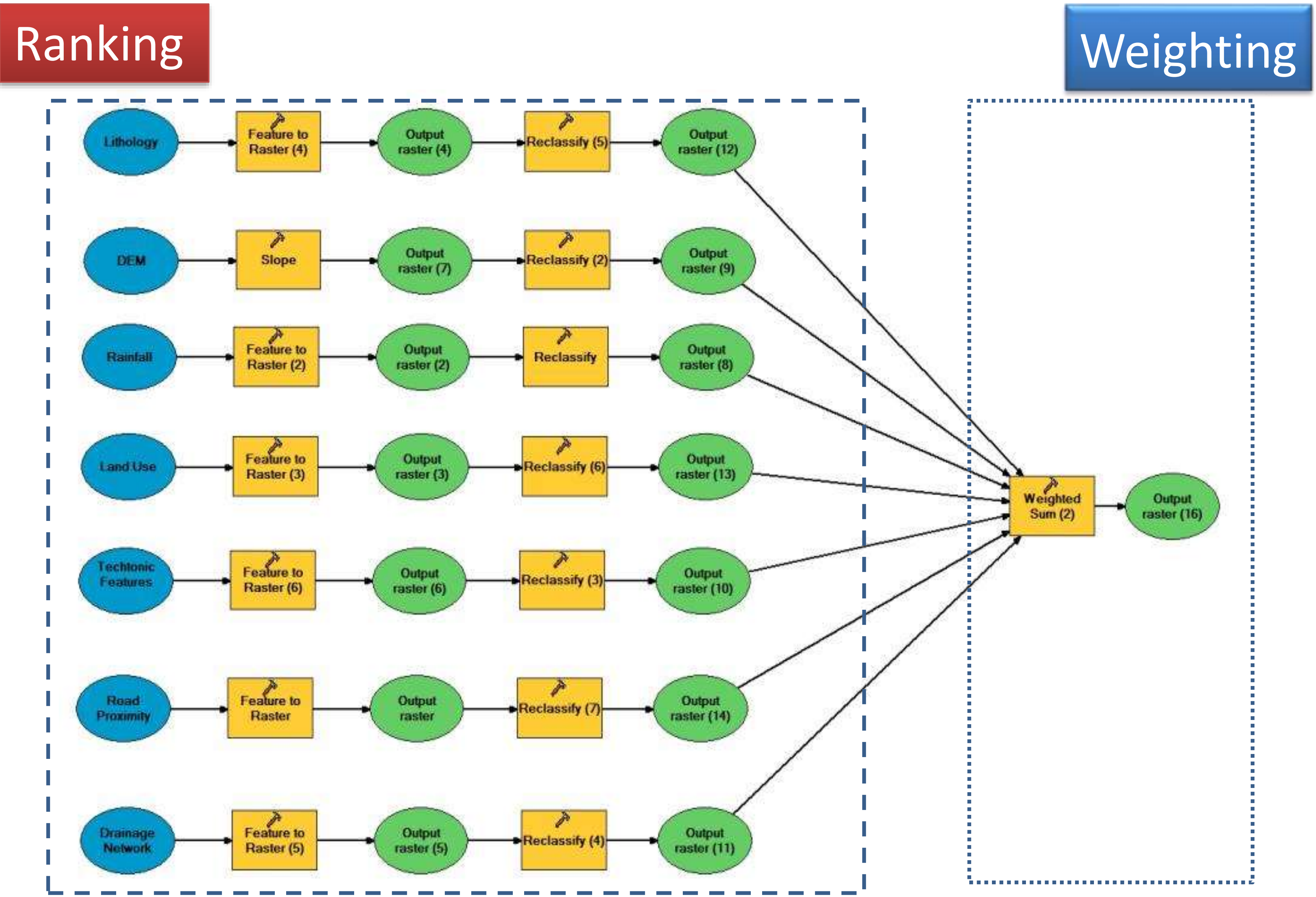
Landslide Factor Ranking

Instability Factors	Classifications	Susceptibility Level	Rank
Land Use	**Classes**		
	Barren land	Very High	5
	Urban or built-up land	High	4
	Rangeland	Moderate	3
	Agricultural land	Low	2
	Forest , Wetland, Water	Very Low	1

Landslide Factor Ranking

Factors	Classification Scheme	Rank	Rating
Rainfall (mm)	207 - 225	Very High	5
	193 -206	High	4
	181 - 192	Low	3
	167 - 180	Moderate	2
	143 -166	Low	1

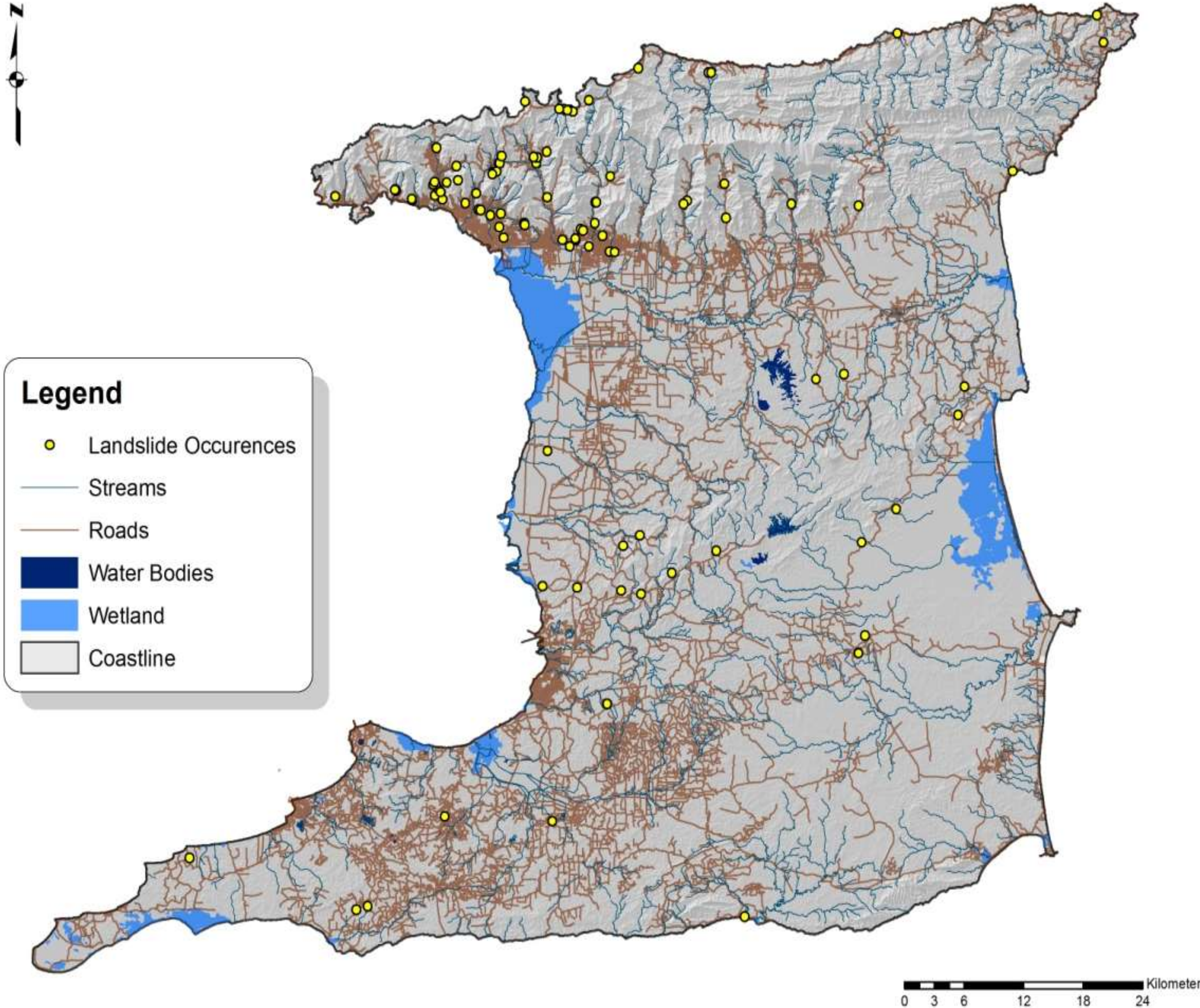
Cartographic Model - Landslide



Factor Weight Analysis

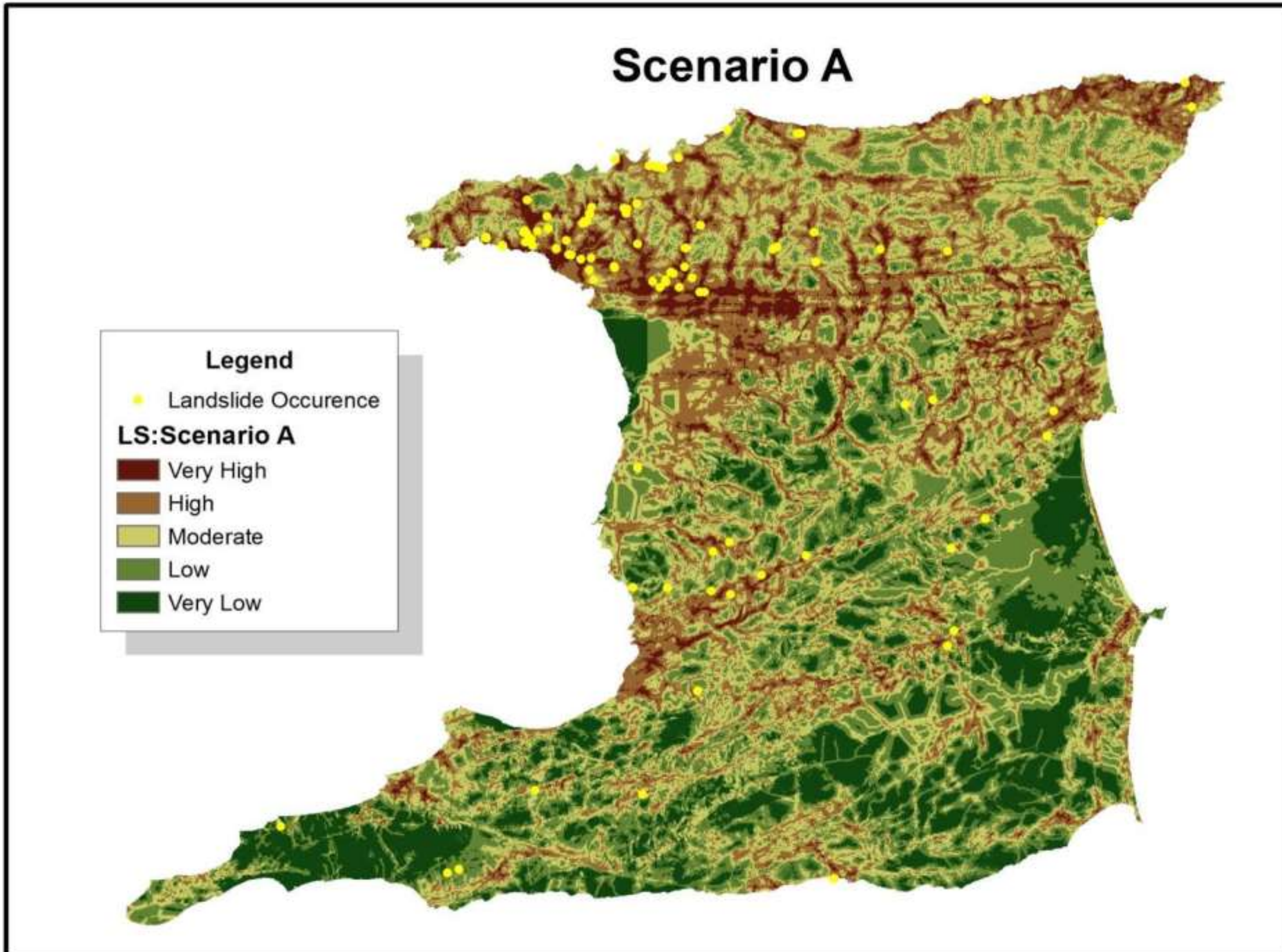
- Five (5) scenarios of the model were run using different weighting schemes
- The output of each scenario was overlaid on the landslide past occurrence map to provide a visual checking for coincidence of the occurrence in the five susceptibility classes.

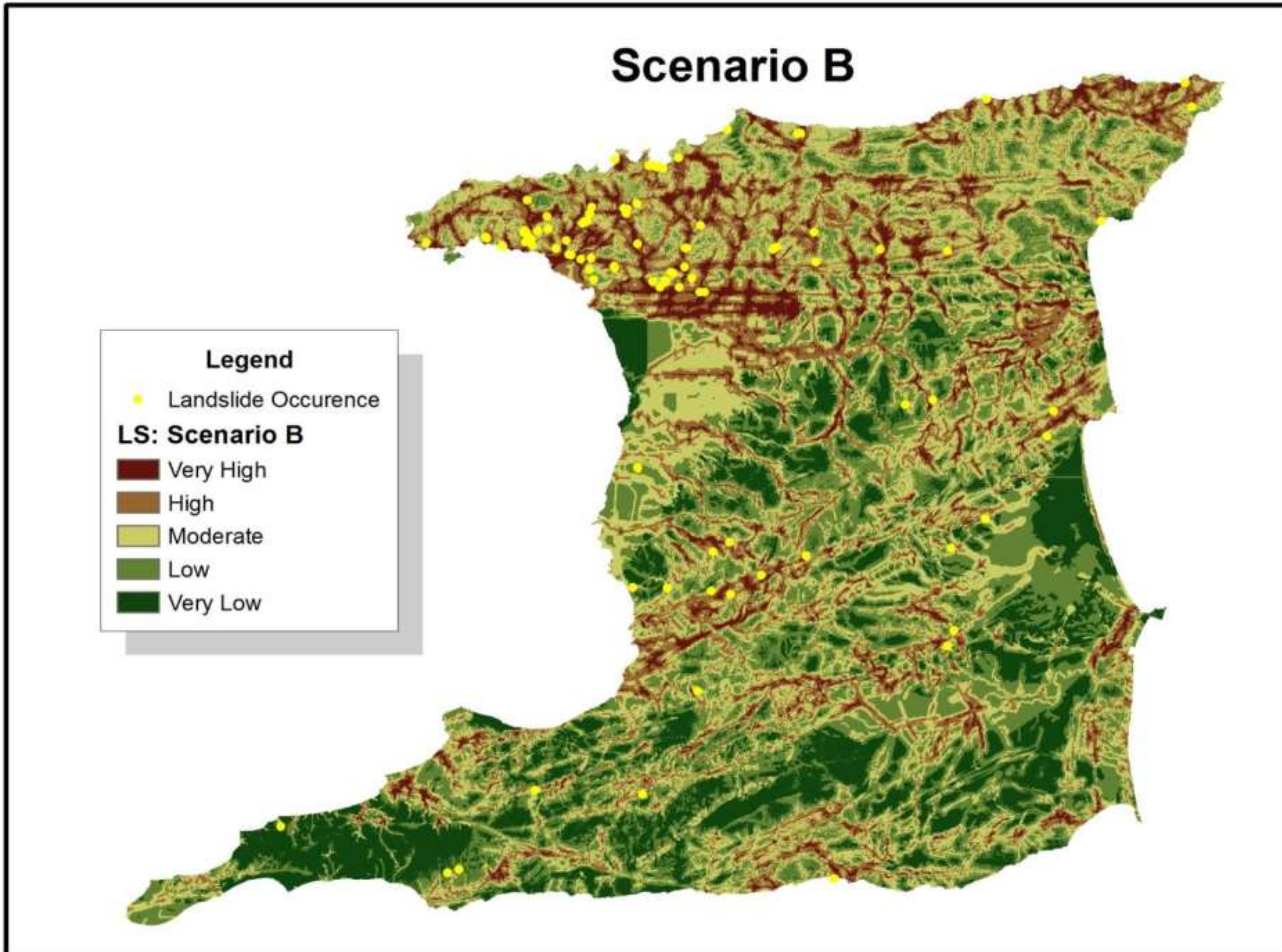
Landslide Occurences

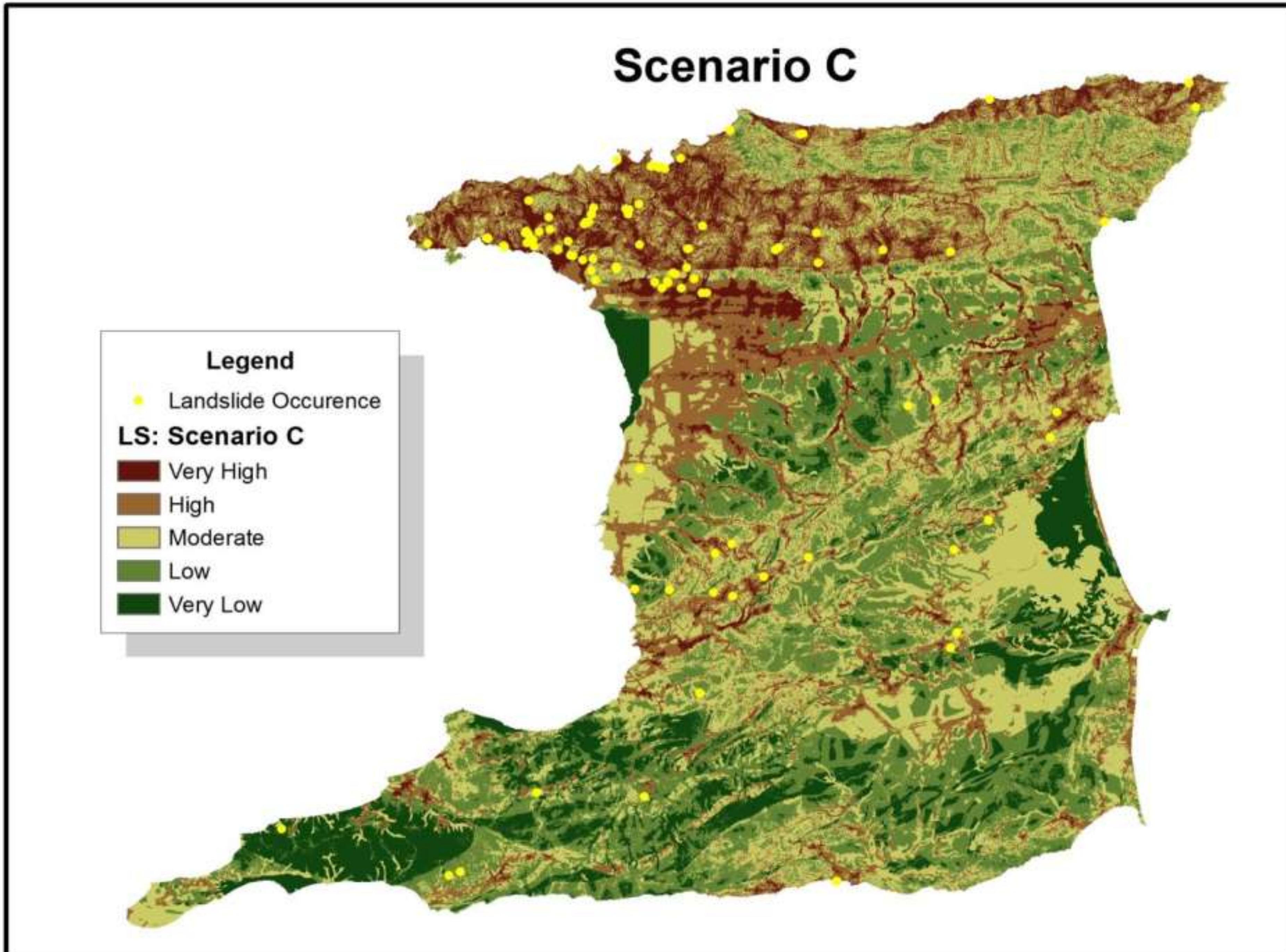


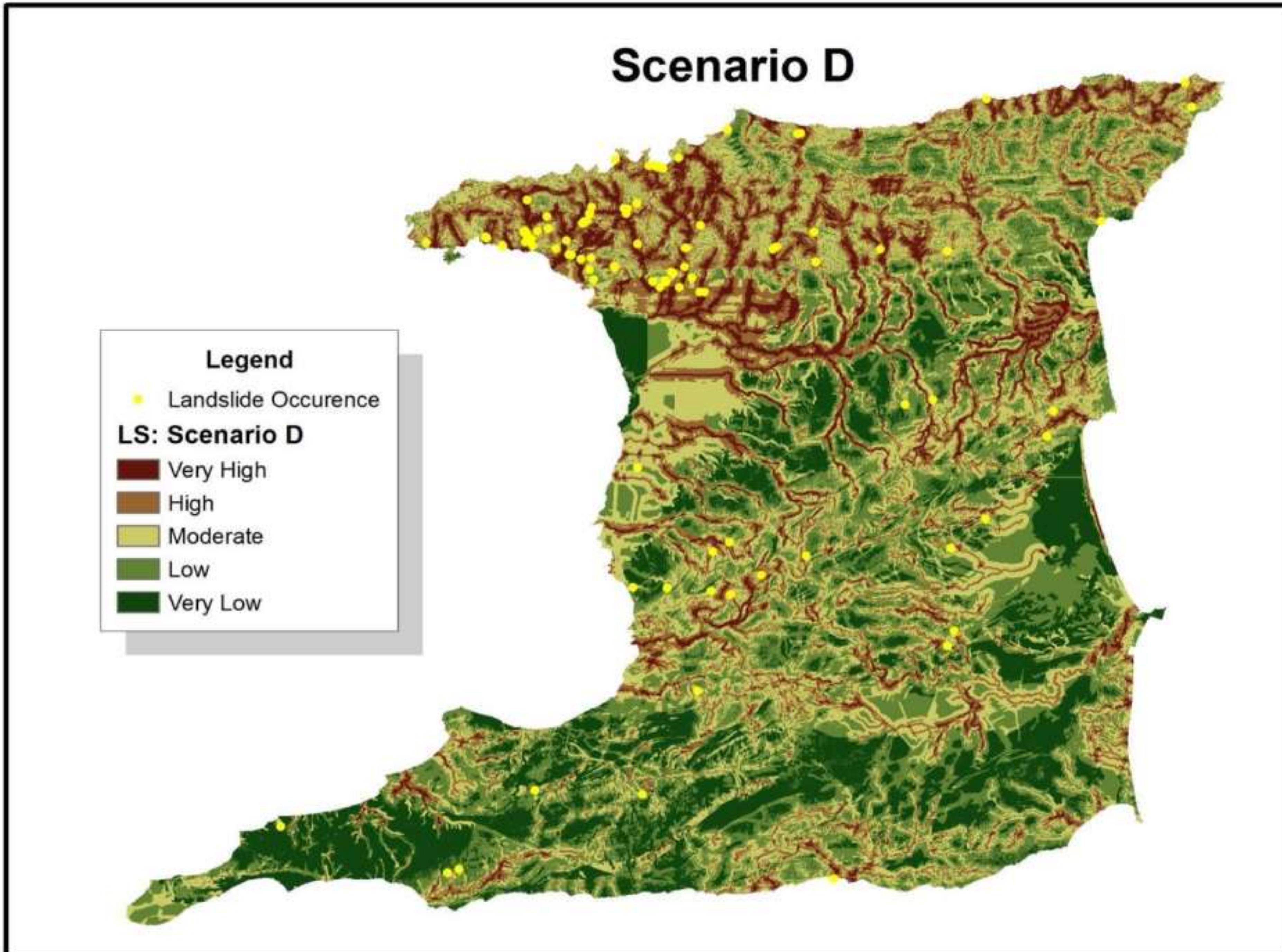
Weight Scenario Modeling

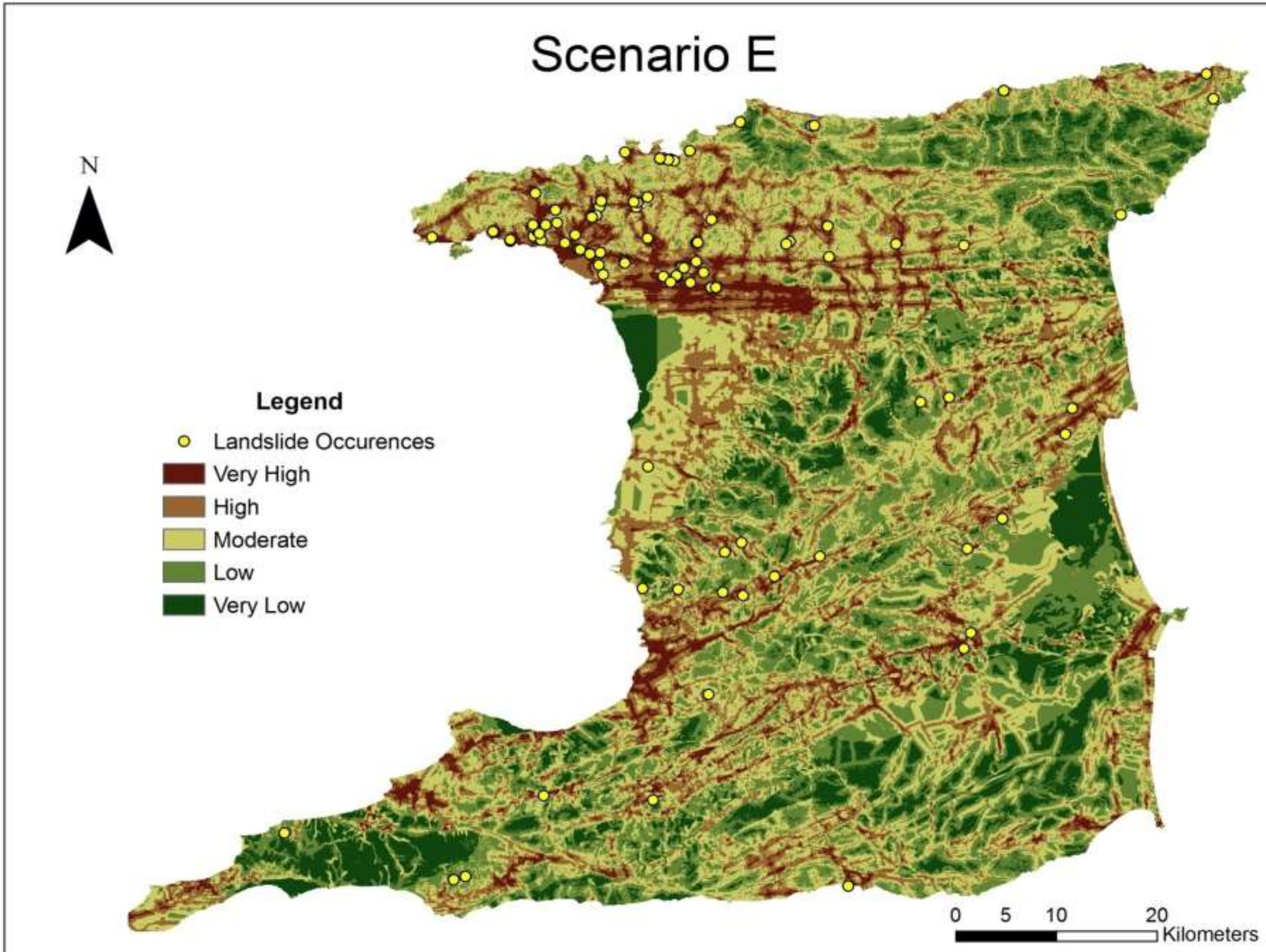
Instability Factors	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Tectonic Features	1	2	1	1	2
Lithological Formation	1	2	3	3	2
Slope Angle	1	2	3	3	2
Landcover	1	2	1	3	1
Drainage Network	1	1	1	1	1
Road Network	1	1	1	1	1
Rainfall	1	1	1	1	1
Total	7	11	11	13	10


Scenario A
Legend
Landslide Occurence
LS:Scenario A
Very High
High
Moderate
Low
Very Low


Scenario B
Legend
Landslide Occurence
LS: Scenario B
Very High
High
Moderate
Low
Very Low


Scenario C
Legend
Landslide Occurence
LS: Scenario C
Very High
High
Moderate
Low
Very Low


Scenario D
Legend
Landslide Occurence
LS: Scenario D
Very High
High
Moderate
Low
Very Low


Scenario E
N
Legend
Landslide Occurences
Very High
High
Moderate
Low
Very Low
0 5 10 20
Kilometers

Estimated Area of Land Under Each Class of for the Selected Weight Model (E)

Susceptibility Level	Class Value	Area (ha)	% of total land mass of Trinidad
Very Low	10 - 18	62,766.5	13.1
Low	19 - 22	143,494.6	29.9
Moderate	23 -27	161,343.7	33.6
High	28 – 31	84,187.6	17.5
Very High	32 - 49	28,060.9	5.8

Communities that are susceptible to landslide hazard in Trinidad

Very Highly Susceptible	Highly Susceptible	
Los Bajos	San Francique	St. Helena
Point Fortin	Moruga	Guanapo
Plaisance	Toco	Maracus, St. Joseph
San Fernando	Las Cuevas	Oropouche
Rio Claro	Debe	Santa Rosa
Morichal	Santa Cruz	Tunapuna
Brasso	St. Margaret	Mount Lambert

Flood Susceptibility

Flood Factors

- Rainfall (mm)
- Slope (%)
- Land Cover
- Drainage density
- Road Density
- Elevation (m)

Flood Factor Ranking

Factors	Classification Scheme	Rank	Rating
Rainfall (mm)	143 -166	Very low	1
	167 – 180	Low	2
	181 – 192	Moderate	3
	193 -206	High	4
	207 - 225	Very High	5
Elevation (m)	477.0 – 931.4	Very low	1
	286.4 – 477.0	Low	2
	147.1 – 286.4	Moderate	3
	55.5 – 147.1	High	4
	0 – 55.5	Very High	5

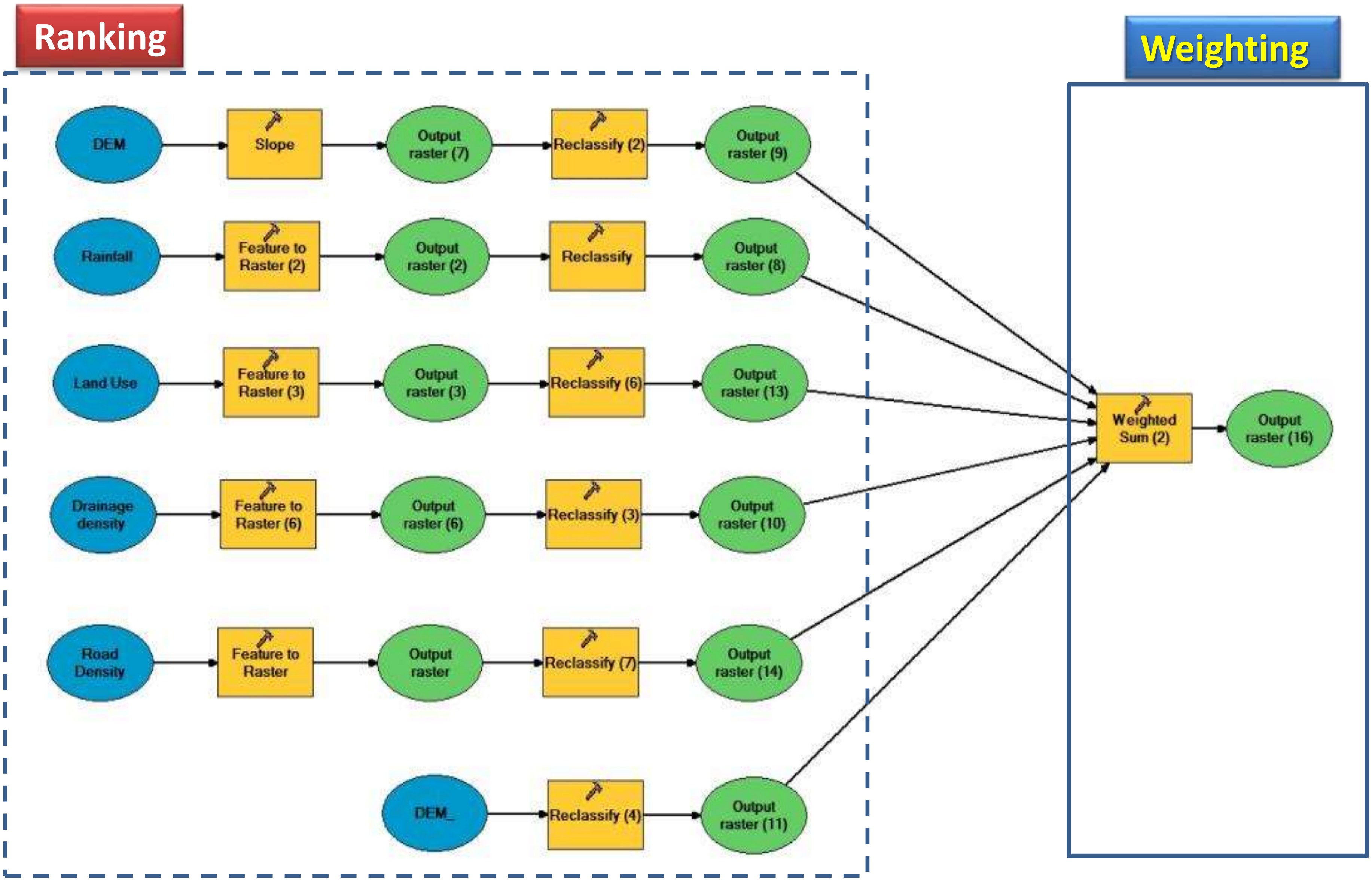
Flood Factor Ranking

Factors	Classification Scheme	Rank	Rating
Slope (%)	569.1– 2748.7	Very low	1
	257.7– 569.1	Low	2
	85.9 – 257.7	Moderate	3
	21.5 – 85.9	High	4
	0 - 21.5	Very High	5
Drainage density (% each watershed)	0 – 0.004674	Very low	1
	0.004674 – 0.006769	Low	2
	0.006769 – 0.0083	Moderate	3
	0.0083 – 0.009508	High	4
	0.009508 – 0.020628	Very High	5

Flood Factor Ranking

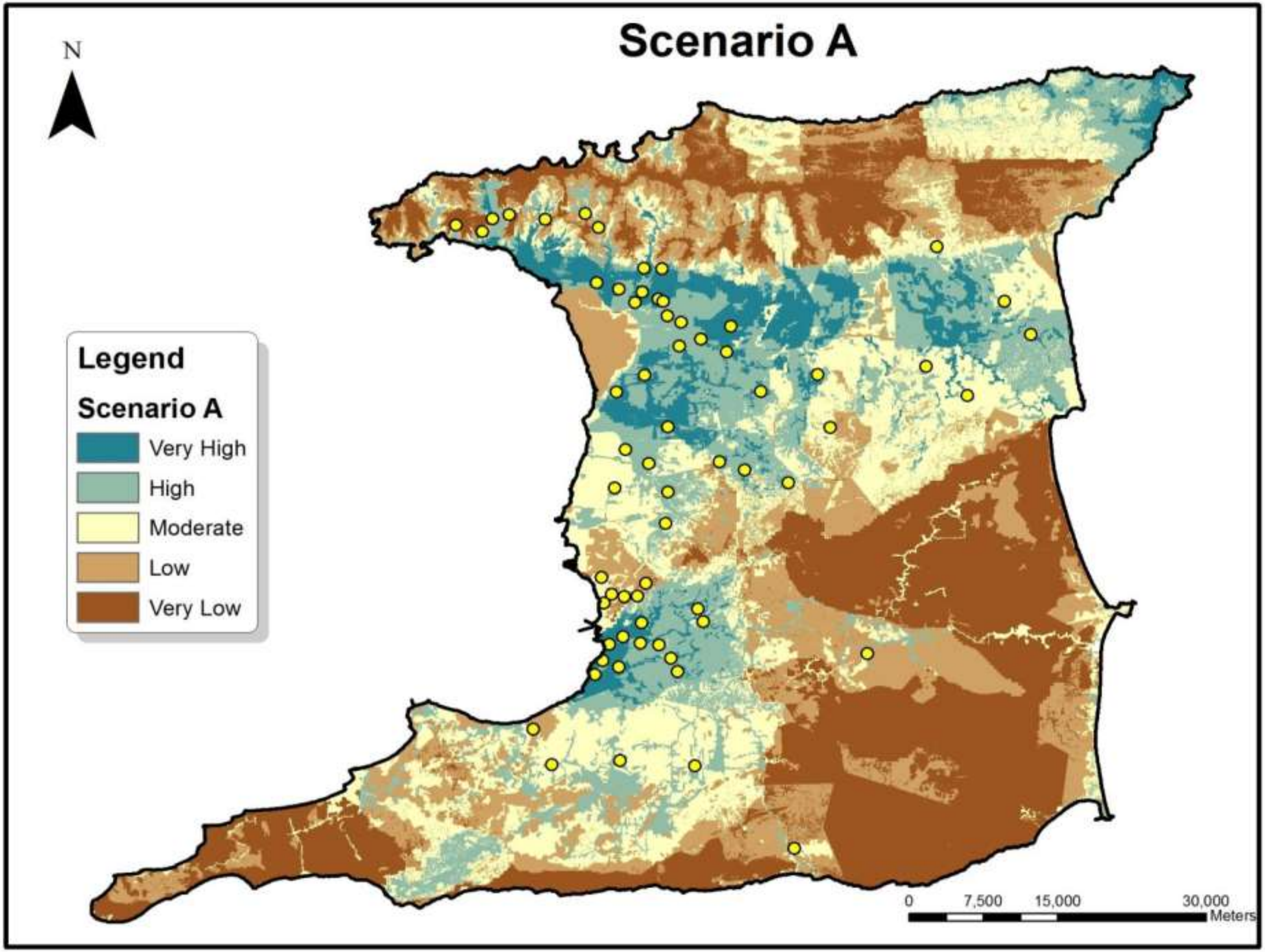
Factors	Classification Scheme	Rank	Rating
Road Density (% each watershed)	0.000194 – 0.004626	Very low	1
	0.004626 – 0.009335	Low	2
	0.009335 – 0.018198	Moderate	3
	0.018198 – 0.039249	High	4
	0.039249 – 0.071101	Very High	5
Land Use (related to water absorption and drainage capacities)	Forest, Water	Very Low	1
	Rangeland (Non-wetland)	Low	2
	Agricultural land	Moderate	3
	Barren land	High	4
	Urban or built-up land, Wetland,	Very High	5

Cartographic Model - Flood

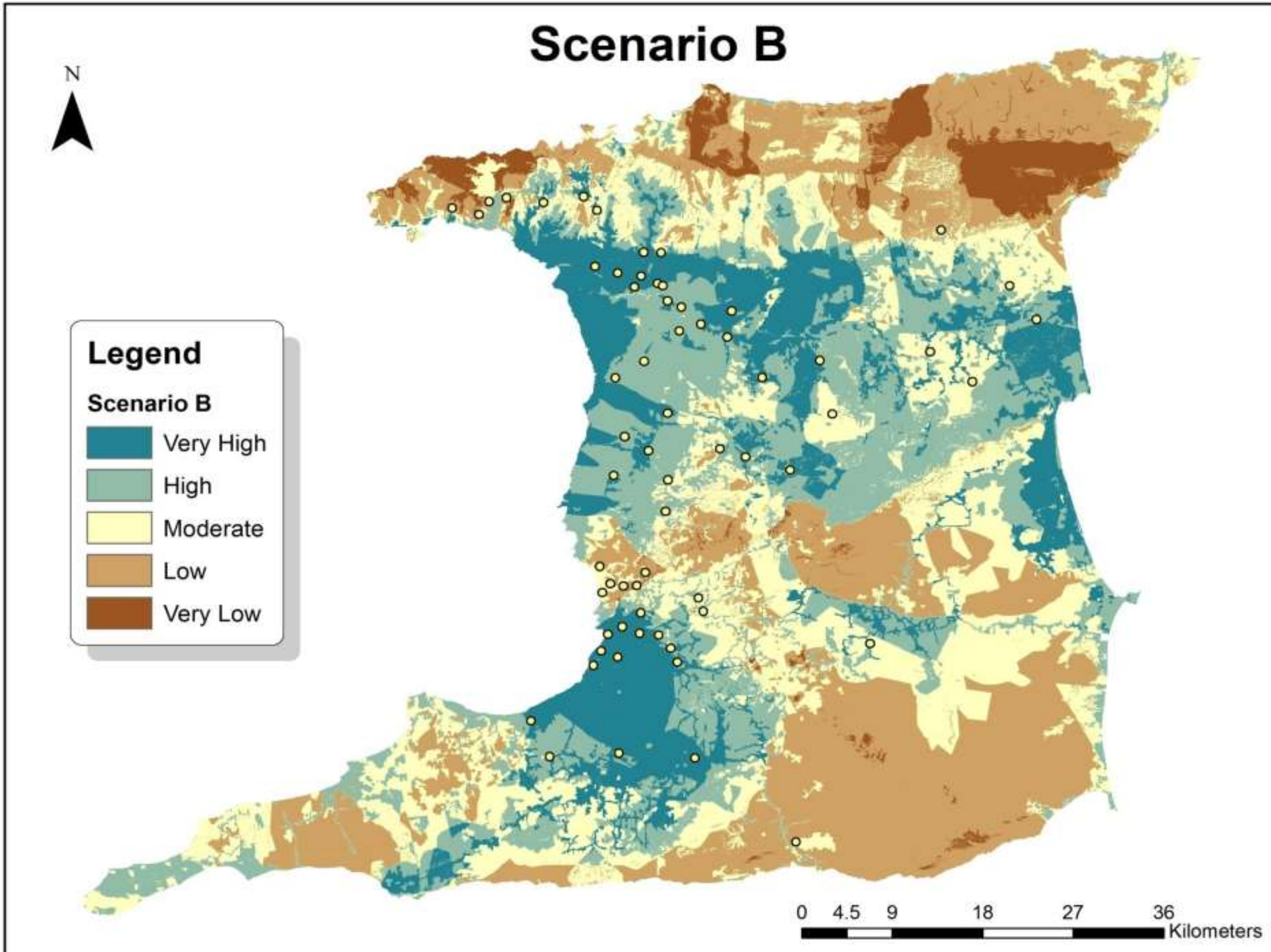


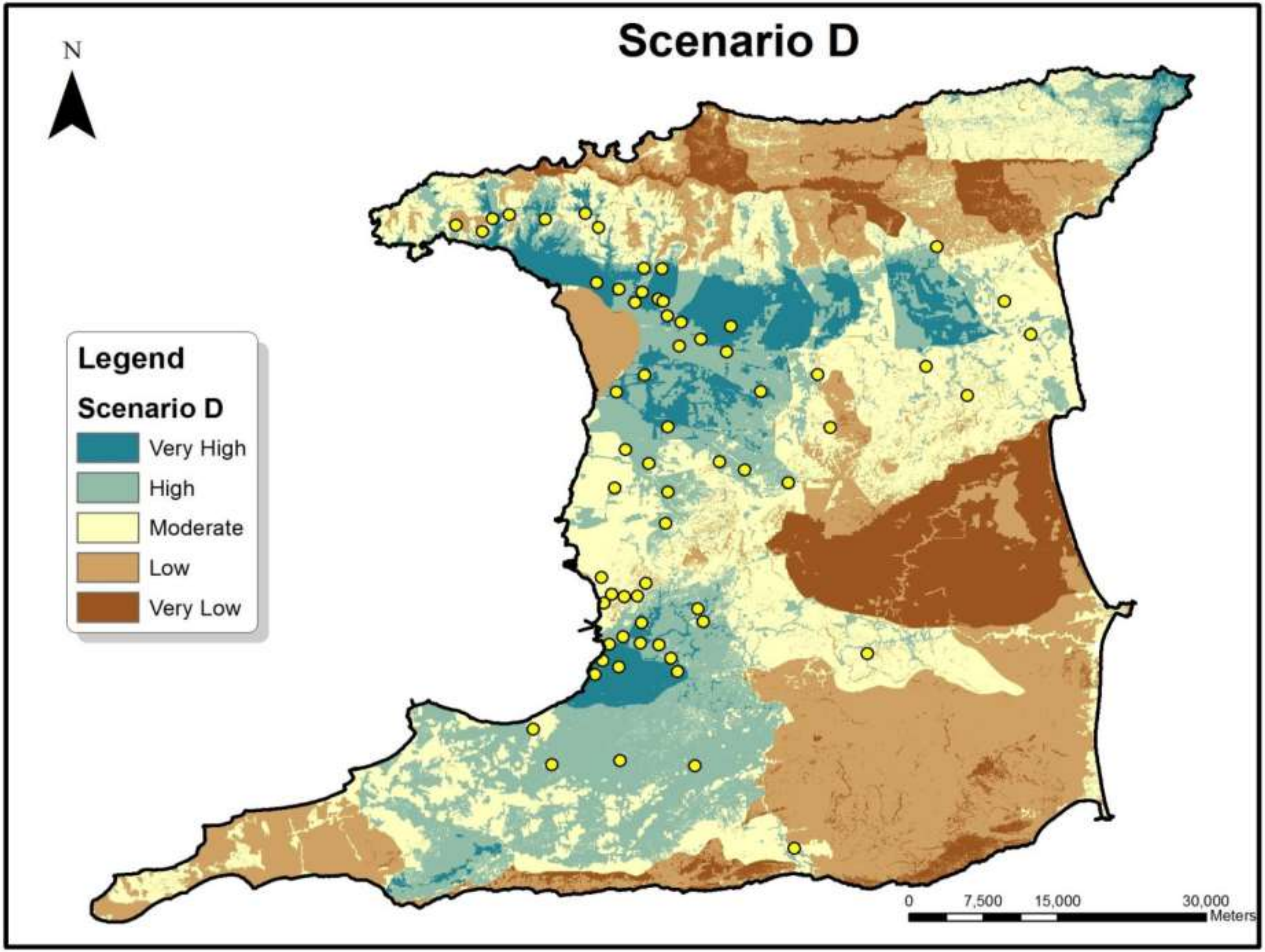
Flood Factor Weighting

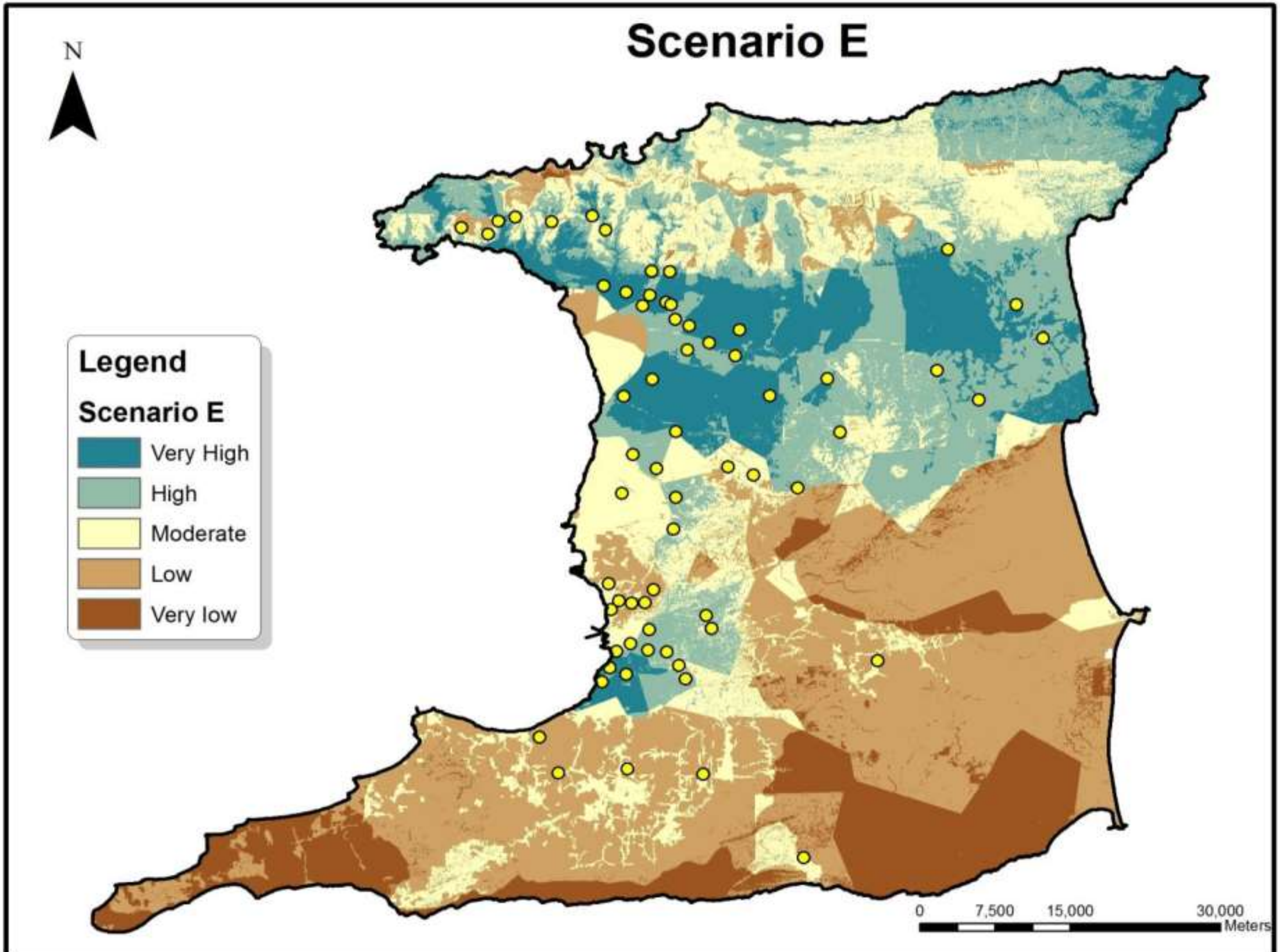
Instability Factors	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Rainfall	1	3	3	2	2
Slope %	1	2	2	3	2
Landcover	1	2	2	1	3
Drainage Density	1	2	0.5	1	0.5
Road Density	1	1	0.5	1	0.5
Elevation	1	1	1	1	1
Total	**6**	**11**	**9**	**9**	9



Scenario A
N
Legend
Scenario A
Very High
High
Moderate
Low
Very Low
0 7,500 15,000 30,000
Meters


Scenario B
N
Legend
Scenario B
Very High
High
Moderate
Low
Very Low
0 4.5 9 18 27 36
Kilometers


Scenario D
N
Legend
Scenario D
Very High
High
Moderate
Low
Very Low
0
7,500
15,000
30,000
Meters


Scenario E
N
Legend
Scenario E
Very High
High
Moderate
Low
Very low
0
7,500
15,000
30,000
Meters

Flood Susceptibility Map

Estimated Area of Land Under Each Class of Flood Susceptibility			
Susceptibility Level	**Class Value**	**Area (Ha)**	**% of land mass in Trinidad**
Very Low	14 - 25	21894.6	4.6
Low	26 -30	143756.9	30.1
Moderate	31 – 34	125057.2	26.2
High	35 - 39	113331.5	23.7
Very High	40 - 49	73171.2	15.3

Landslide Risk Mapping

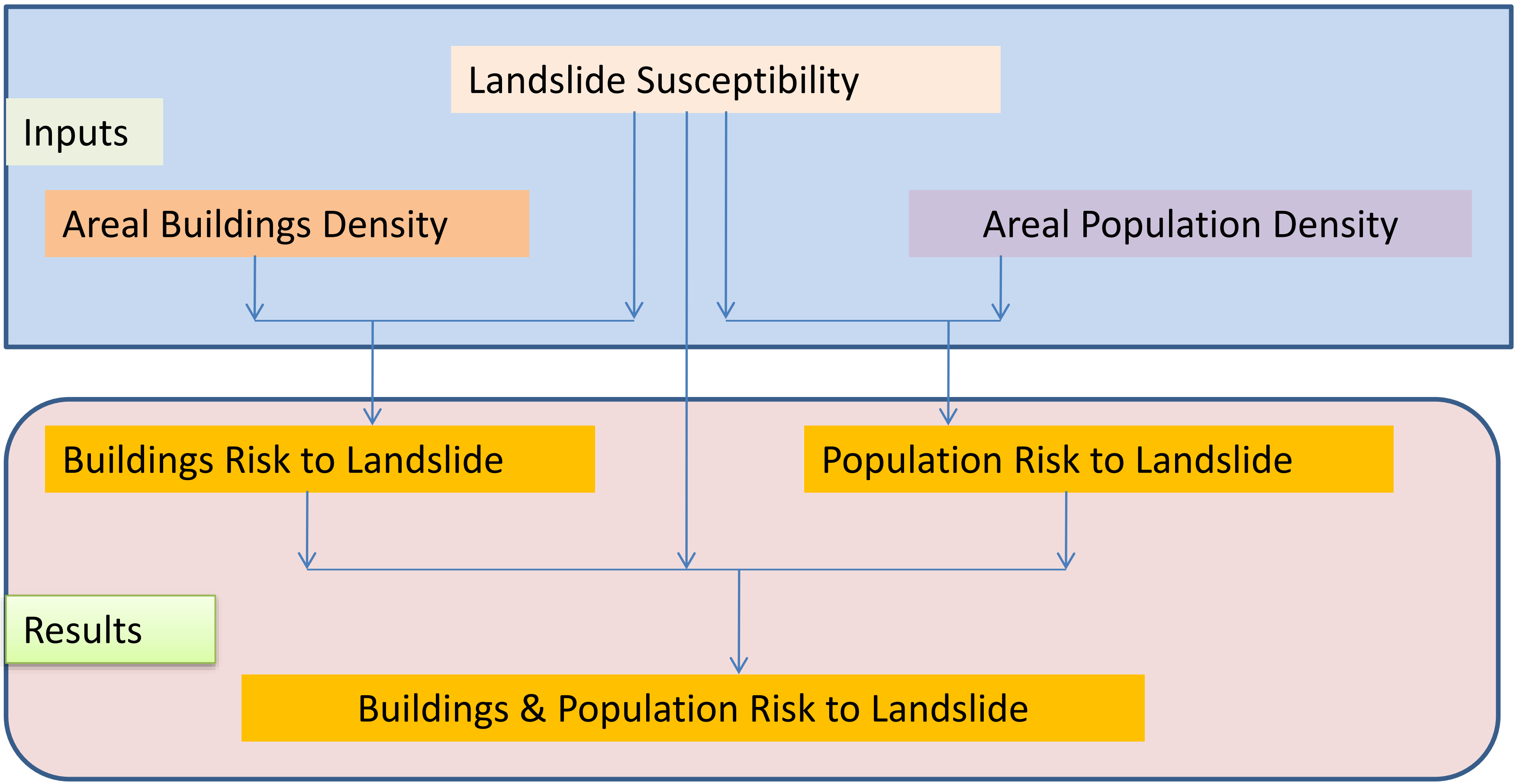
Risk Mapping

- For the purpose of this project two vulnerable elements were considered:
  - population density & building density.

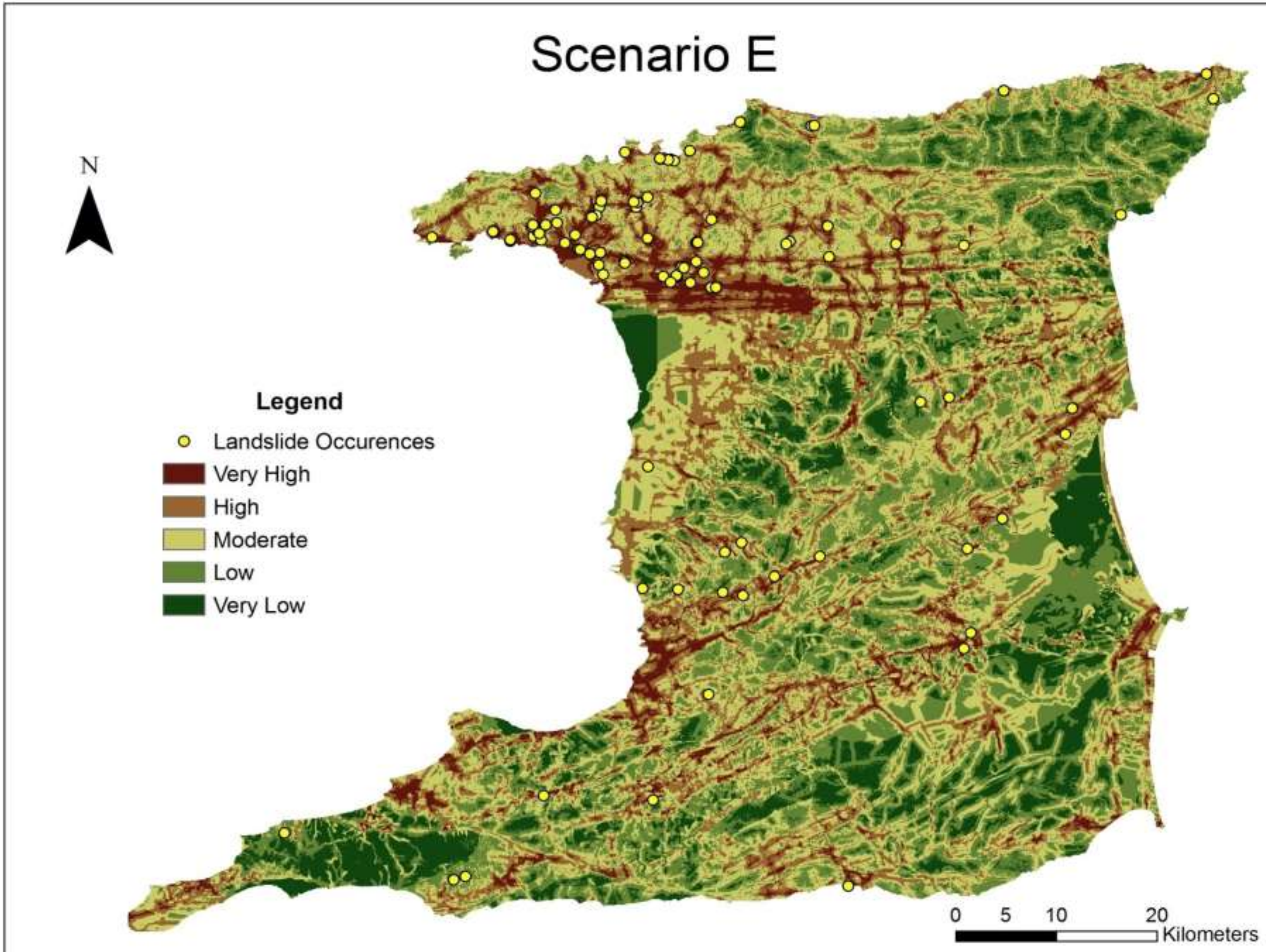
- The denser the population or buildings in a community, the higher the risk factors of that community.

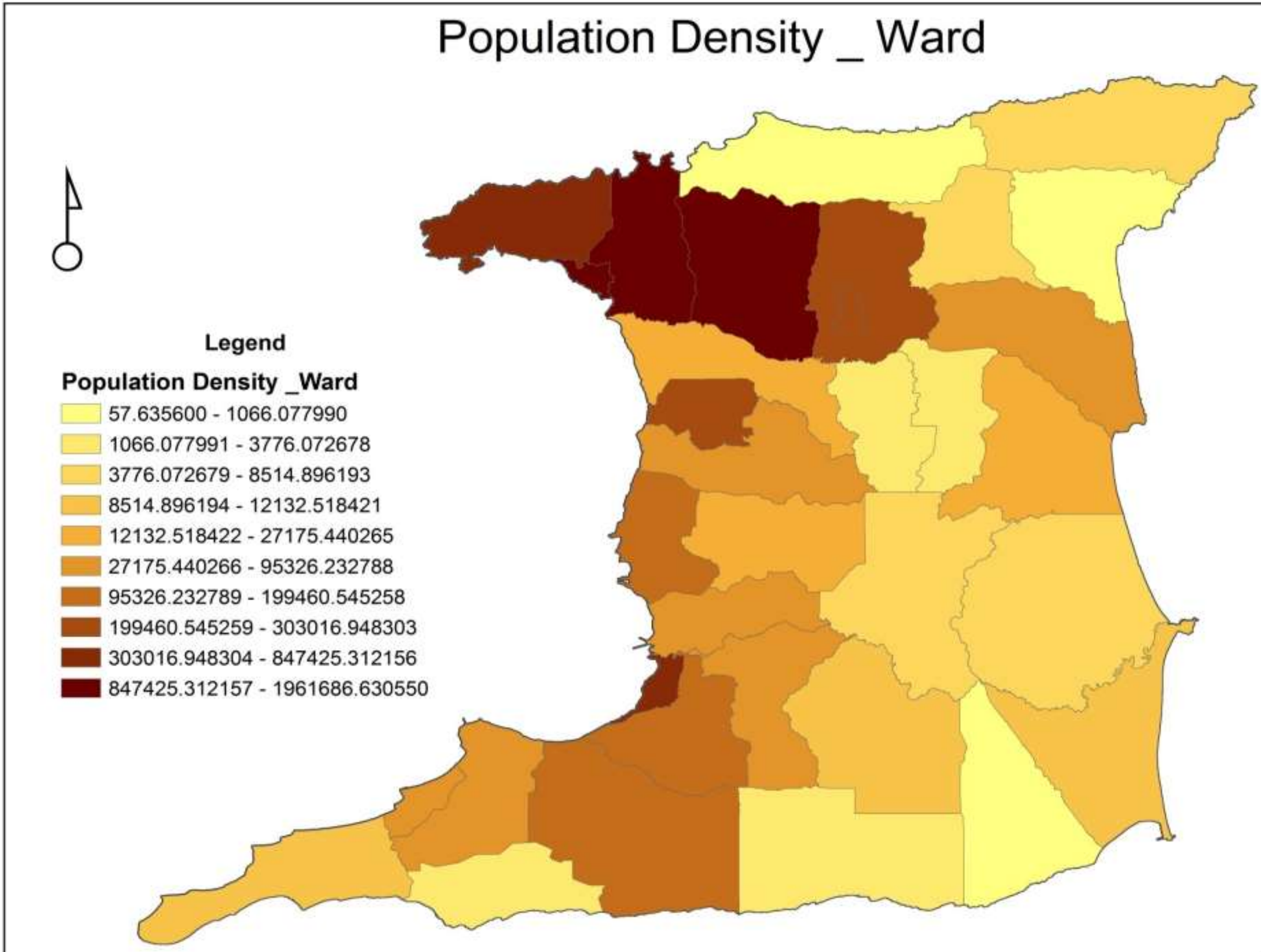
Conceptual Design

Risk = Susceptibility + Vulnerability (Population, Buildings)



Three Input Layers


Scenario E
N
Legend
Landslide Occurences
Very High
High
Moderate
Low
Very Low
0
5
10
20
Kilometers


Population Density _ Ward
Legend
Population Density _Ward
57.635600 - 1066.077990
1066.077991 - 3776.072678
3776.072679 - 8514.896193
8514.896194 - 12132.518421
12132.518422 - 27175.440265
27175.440266 - 95326.232788
95326.232789 - 199460.545258
199460.545259 - 303016.948303
303016.948304 - 847425.312156
847425.312157 - 1961686.630550

Areal Population Density

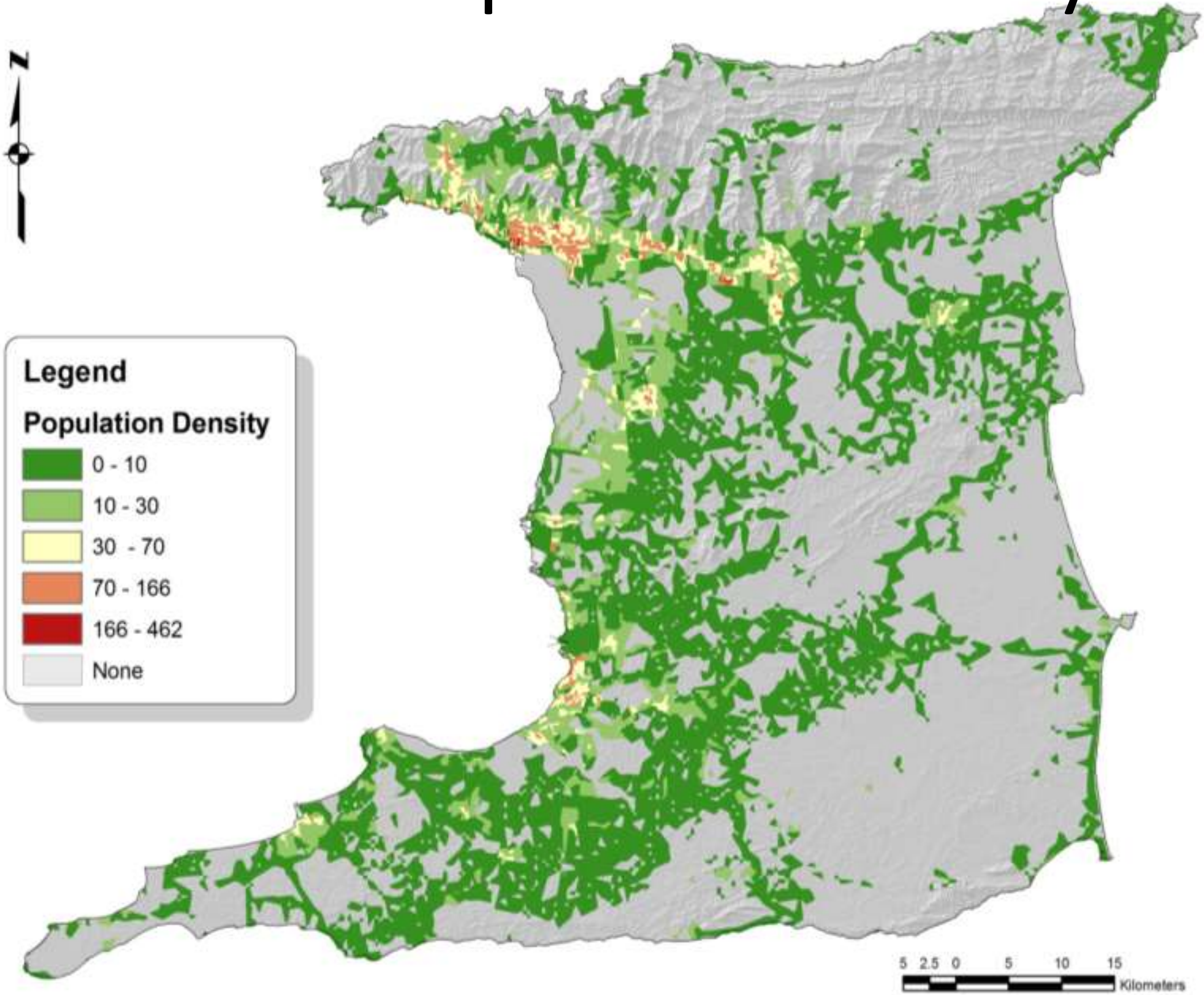
$$\textbf{Areal Population Density} = \frac{\text{(Population)}}{\text{(Areal Area of the ED)}}$$

Areal Area of the ED = (ED Area) – (Area of Built-Up in the ED)

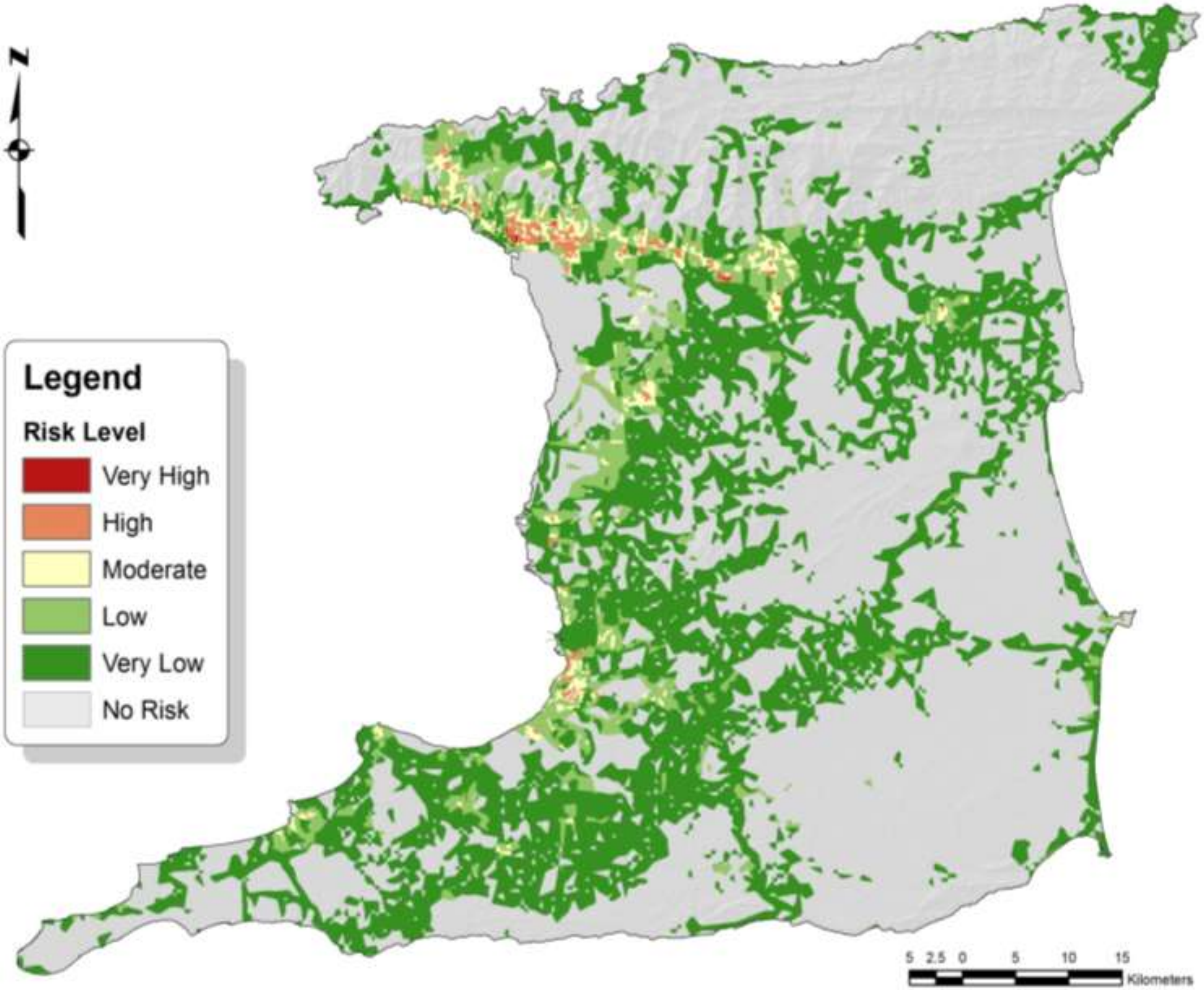
Areal Population Density by ED per hectare

Areal Population Density by ED per hectare	Vulnerability Level
0 - 10	Very Low
11 - 30	Low
31 - 70	Moderate
71 – 166	High
167 - 462	Very High

Areal Population Density



Areal Population Vulnerability



Areal Building Density

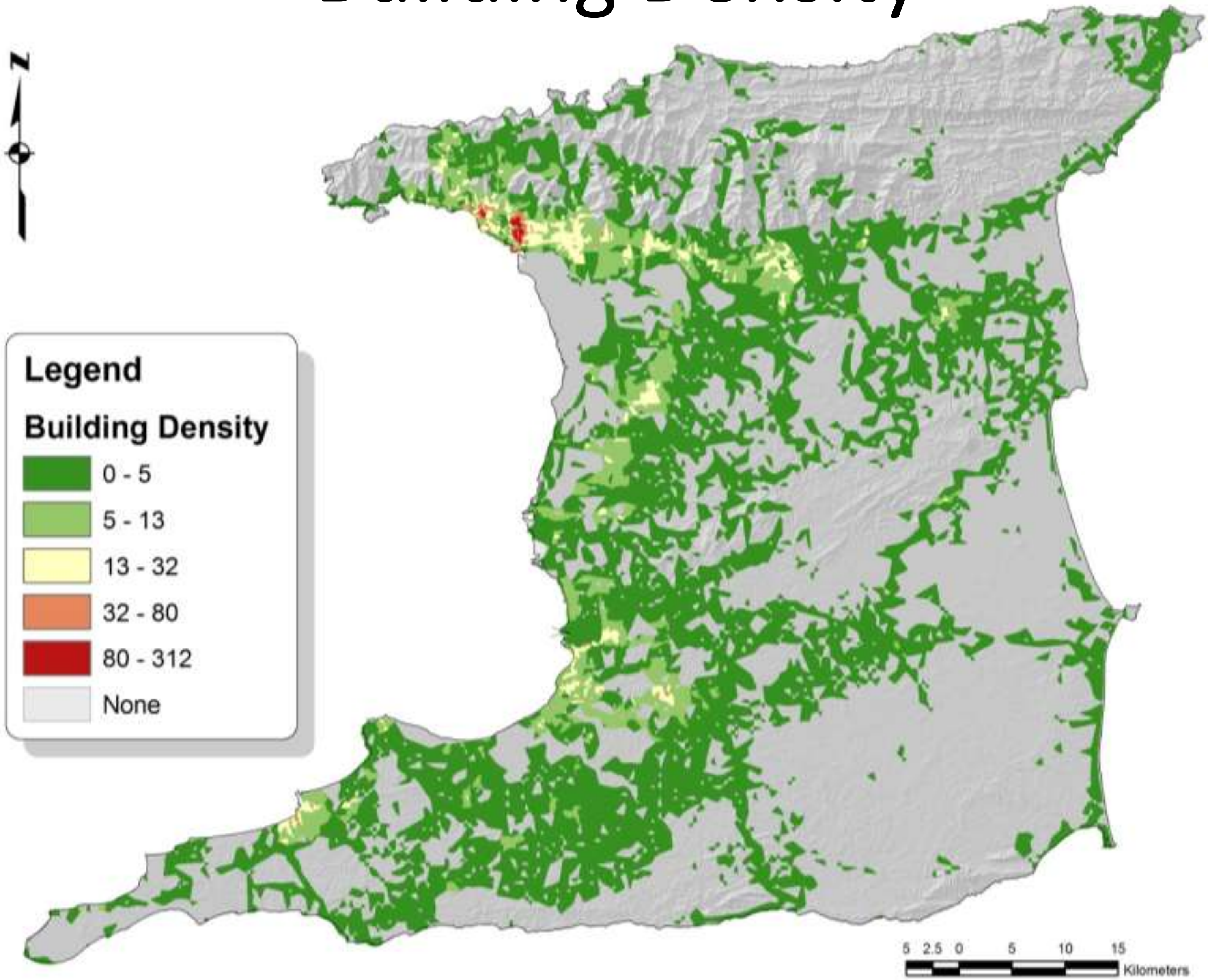
$$\textbf{Areal Building Density} = \frac{\text{(Number of Buildings in an ED)}}{\text{(Areal Area of the ED)}}$$

Areal Area of the ED = (ED Area) – (Area of Built-Up in the ED)

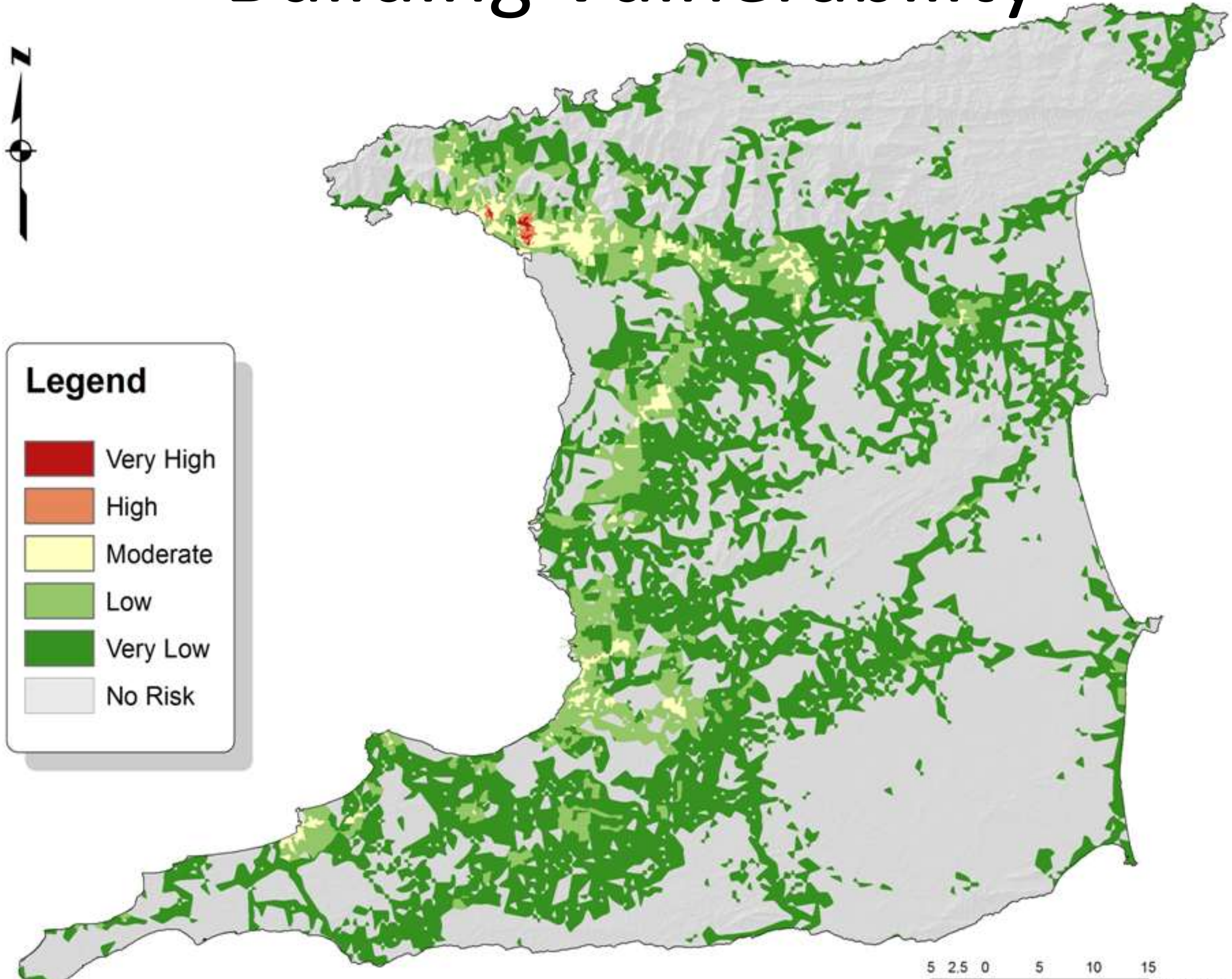
Building Vulnerability Classification Scheme

Building Density By ED per hectare	Vulnerability Level
0 - 5	Very Low
6 – 13	Low
14 – 33	Moderate
34 - 81	High
82 - 313	Very High

Building Density



Building Vulnerability

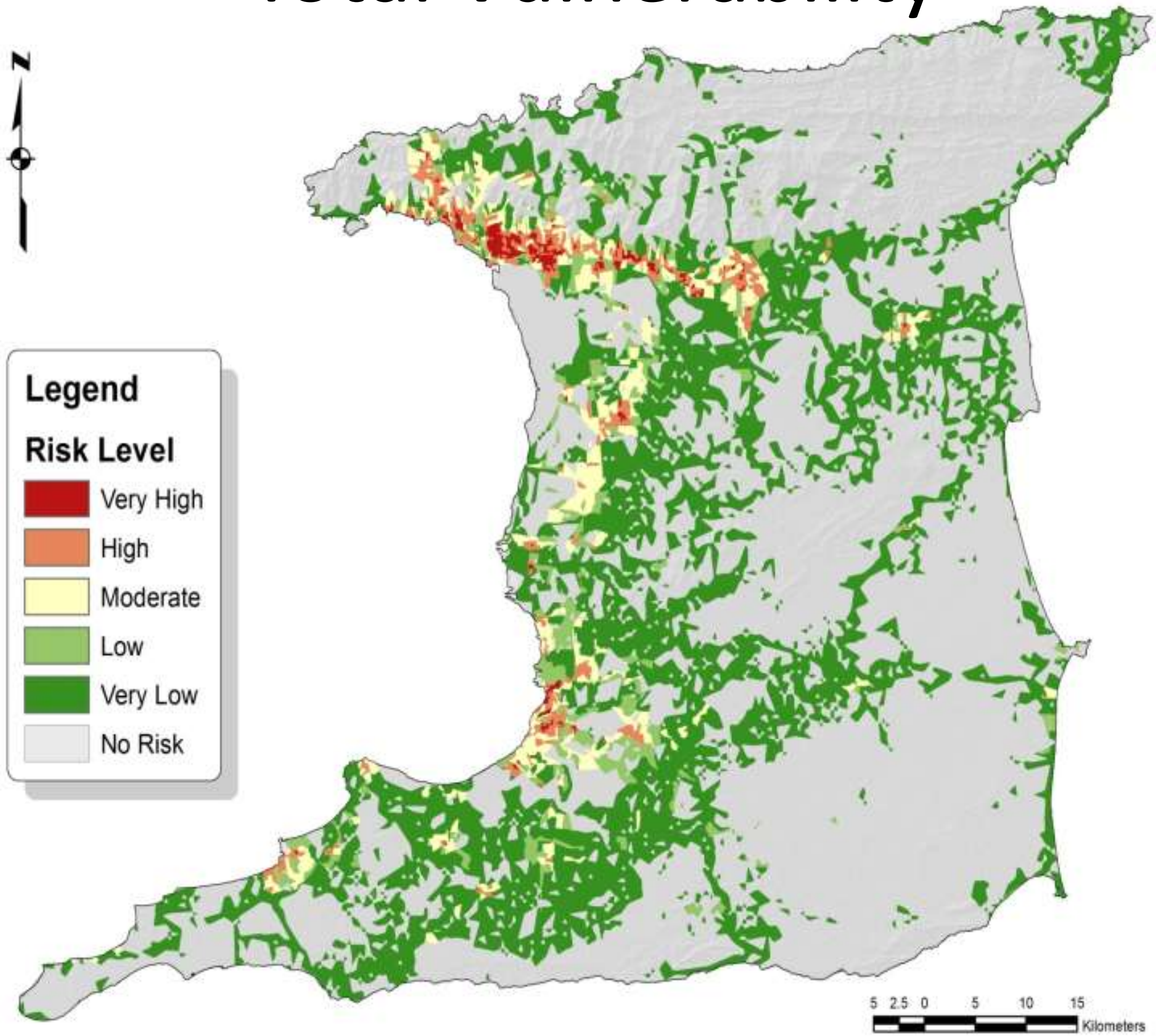


Single Risk Classification Scheme

Population Vulnerability Class		Building Vulnerability Class				
		Very Low	Low	Moderate	High	Very High
		1	2	3	4	5
Very low	1	2	3	4	5	6
Low	2	3	4	5	6	7
Moderate	3	4	5	6	7	8
High	4	5	6	7	8	9
Very High	5	6	7	8	9	10

Risk Level	Risk Value
Very low	<3
Low	4-5
Moderate	5-6
High	6-7
Very High	> 7

Total Vulnerability



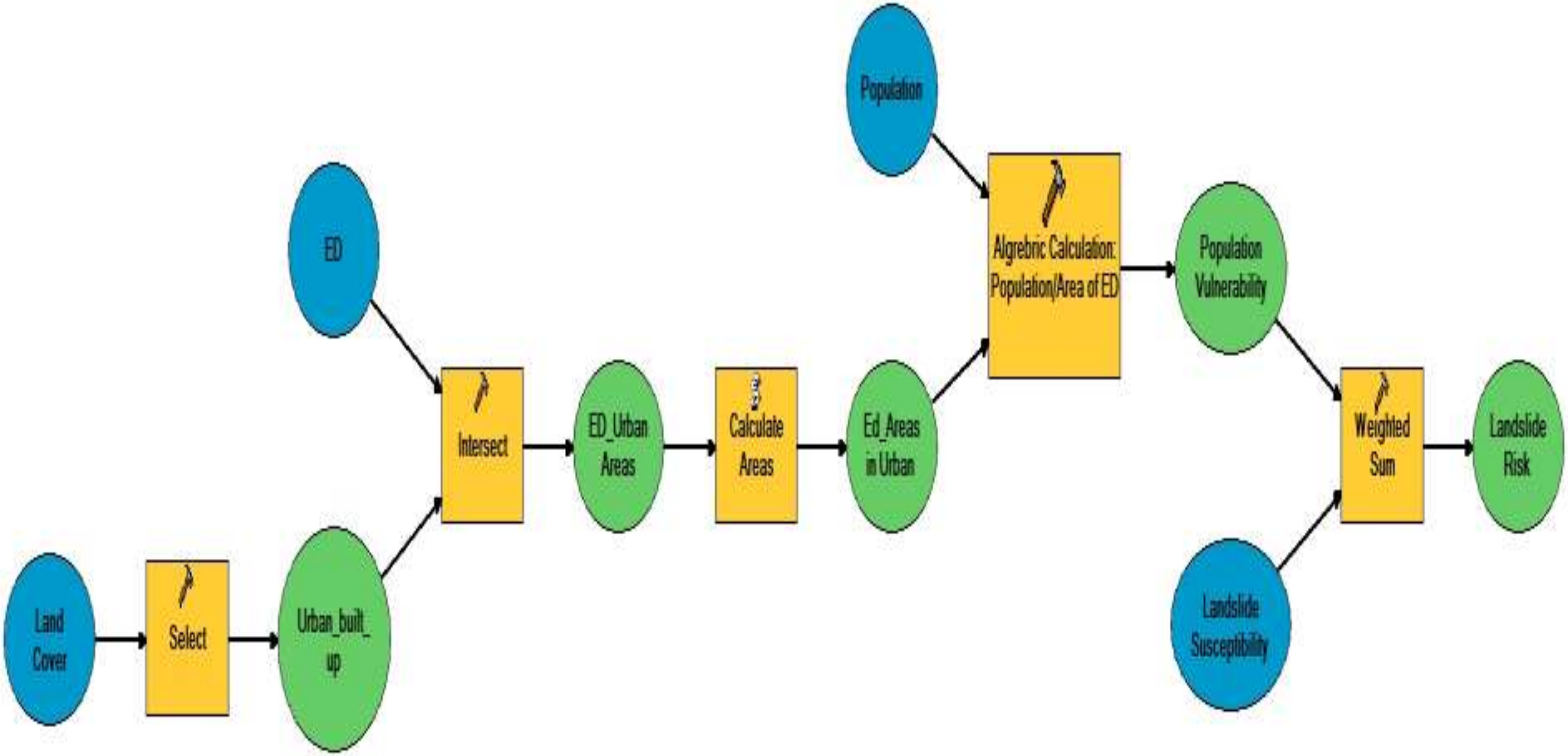
Results: Landslide Risk Maps

Single-Risk (Population) Map

Single-Risk (Buildings) Map

Multi-Risk (Buildings and population) Map

Landslide Population Risk Assessment

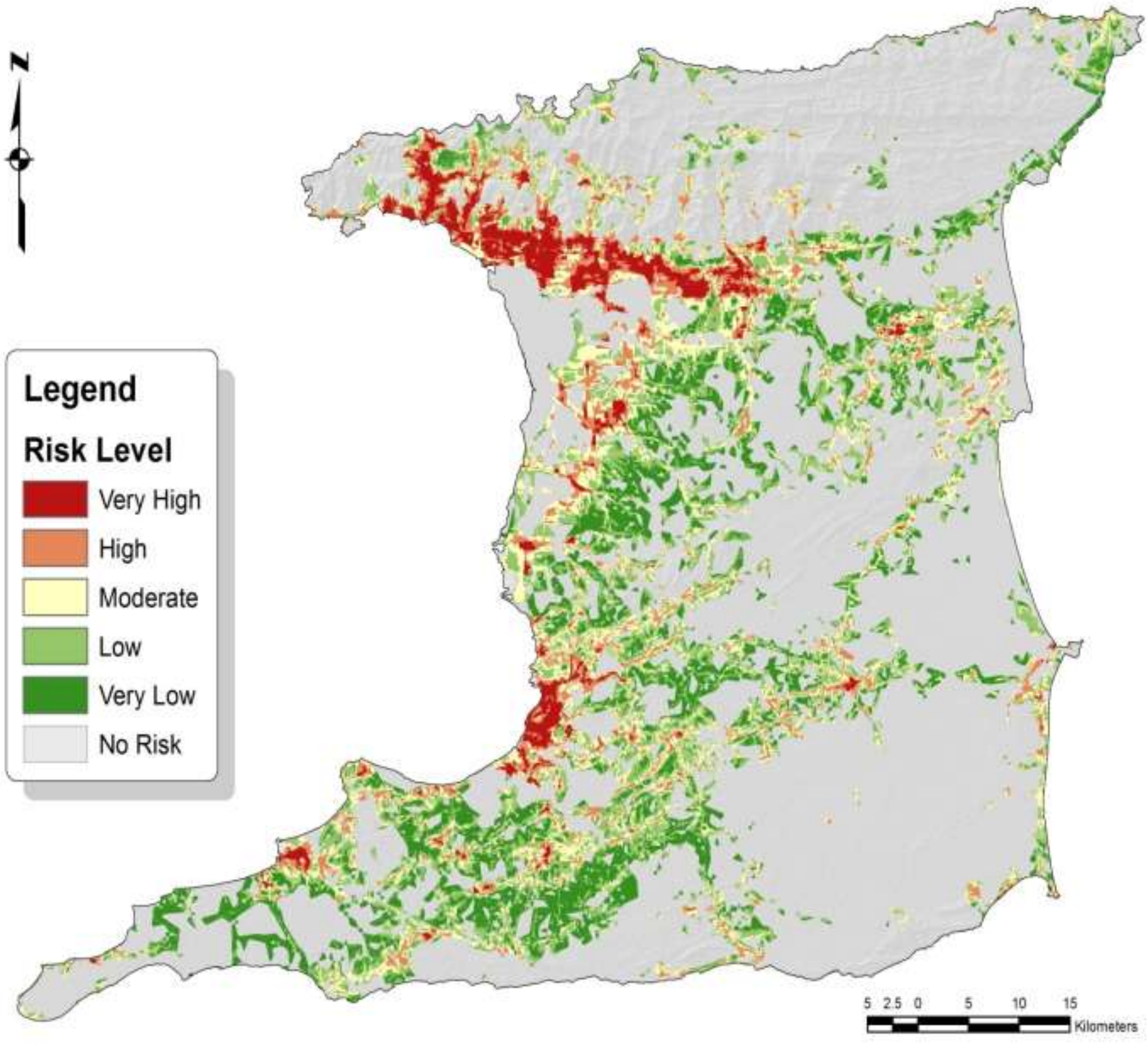


Single Risk Classification Scheme

Vulnerability Class		Susceptibility Class				
		Very Low	Low	Moderate	High	Very High
		1	2	3	4	5
Very low	1	2	3	4	5	6
Low	2	3	4	5	6	7
Moderate	3	4	5	6	7	8
High	4	5	6	7	8	9
Very High	5	6	7	8	9	10

Risk Level	Risk Value
Very low	< 3
Low	3-5
Moderate	5-6
High	6-7
Very High	> 7

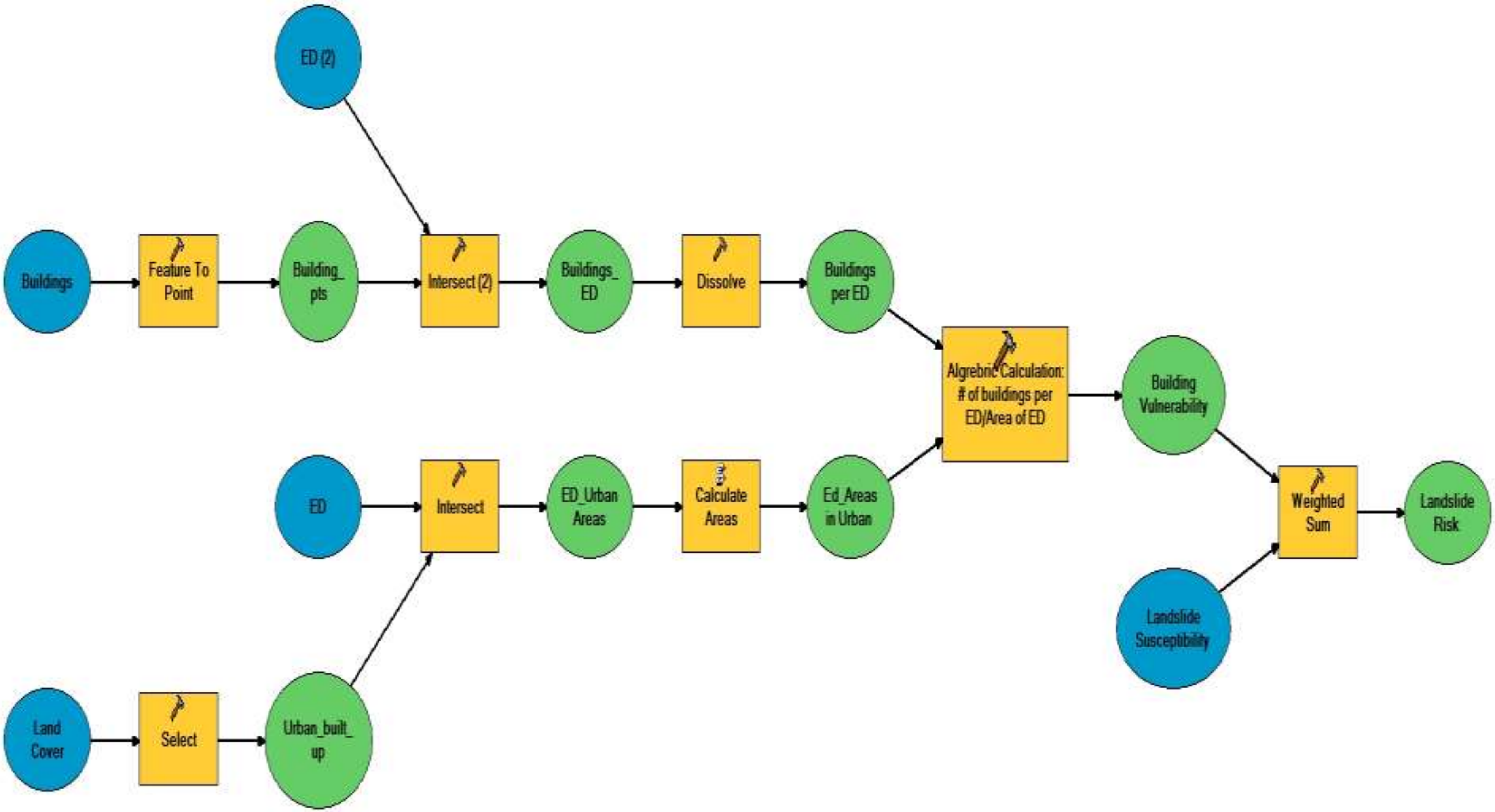
Landslide Population Risk



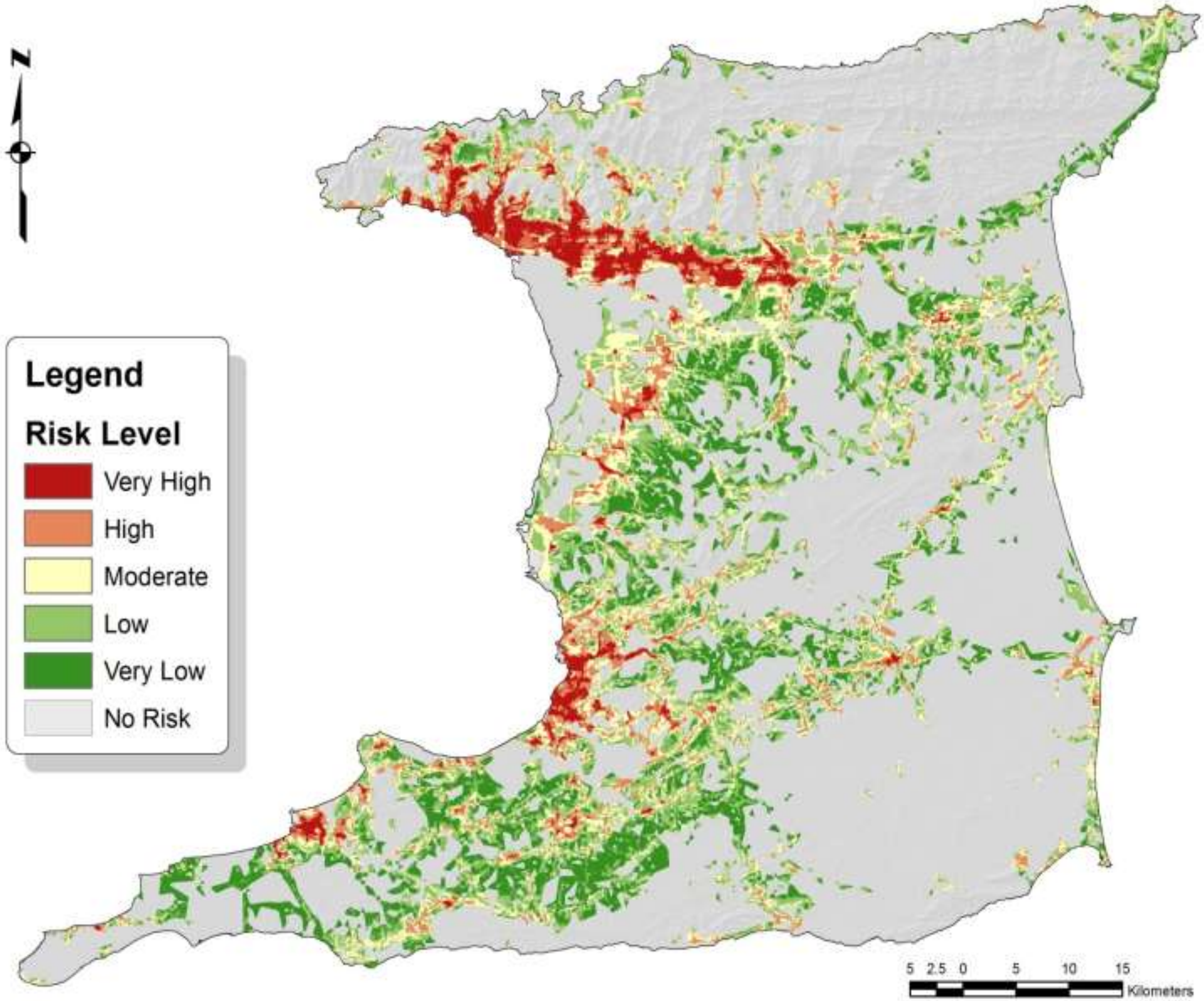
Landslide Population Risk

Landslide Population Risk (Sum of Land Area Under Each Risk Level)			
Risk Level	Number of Cells	Area (ha)	% of Trinidad Urban Land Mass
Very Low	4348906	43489.06	24.5
Low	5359844	53598.44	30.2
Moderate	4447166	44471.66	25.1
High	2372213	23722.13	13.4
Very High	1221068	12210.68	6.9

Landslide Building Risk Assessment



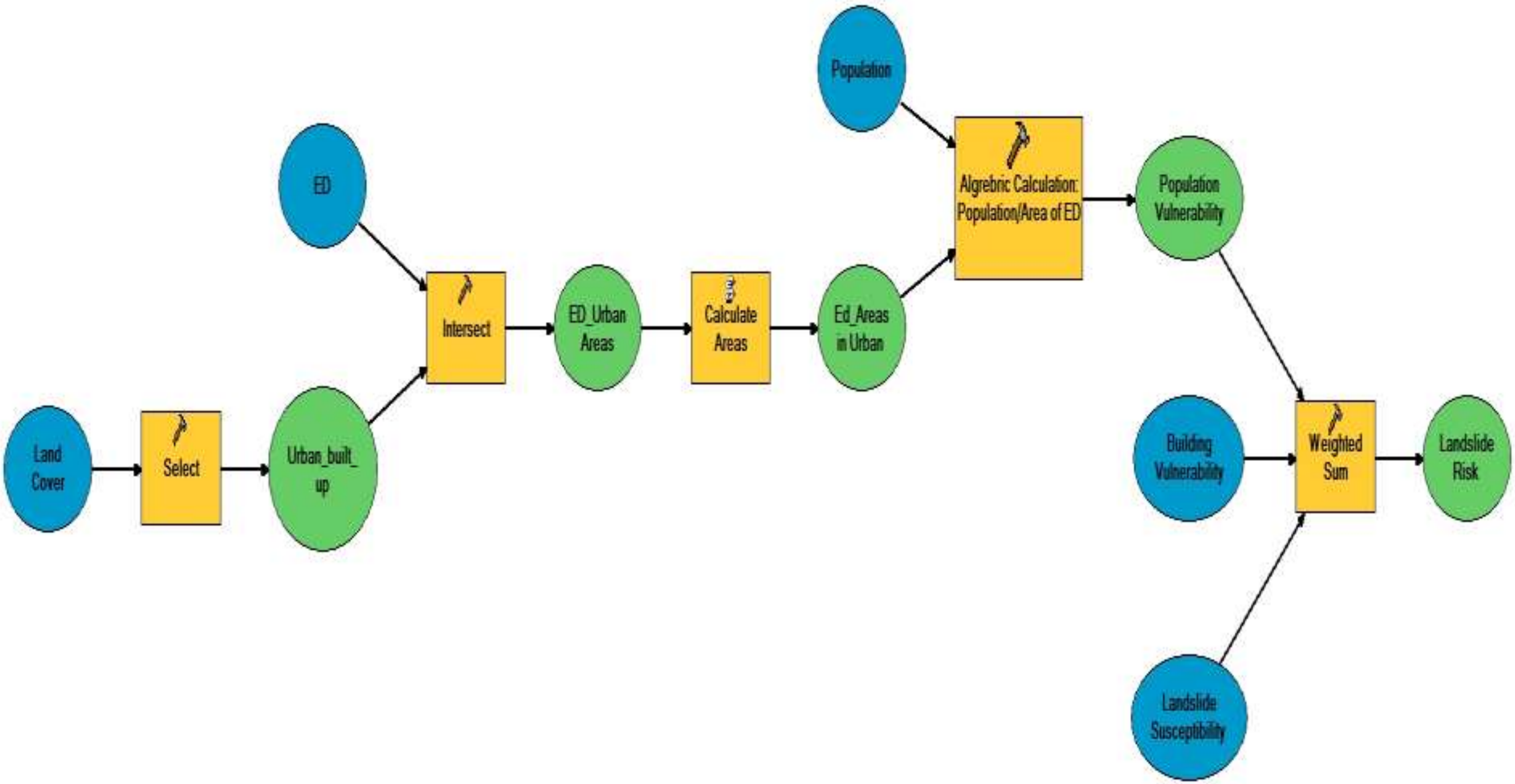
Landslide Building Risk Assessment



Landslide Building Risk

Landslide Building Risk Assessment (Sum of Built-up Area Under Each Risk Level)			
Risk Level	**No. of Cells**	**Area (ha)**	**% of Trinidad Urban Land Mass**
Very Low	4311324	43113.24	24.3
Low	5417247	54172.47	30.5
Moderate	4445792	44457.92	25.0
High	2453206	24532.06	13.8
Very High	1133082	11330.82	6.4

Landslide Multi-Risk Assessment: Building and Population

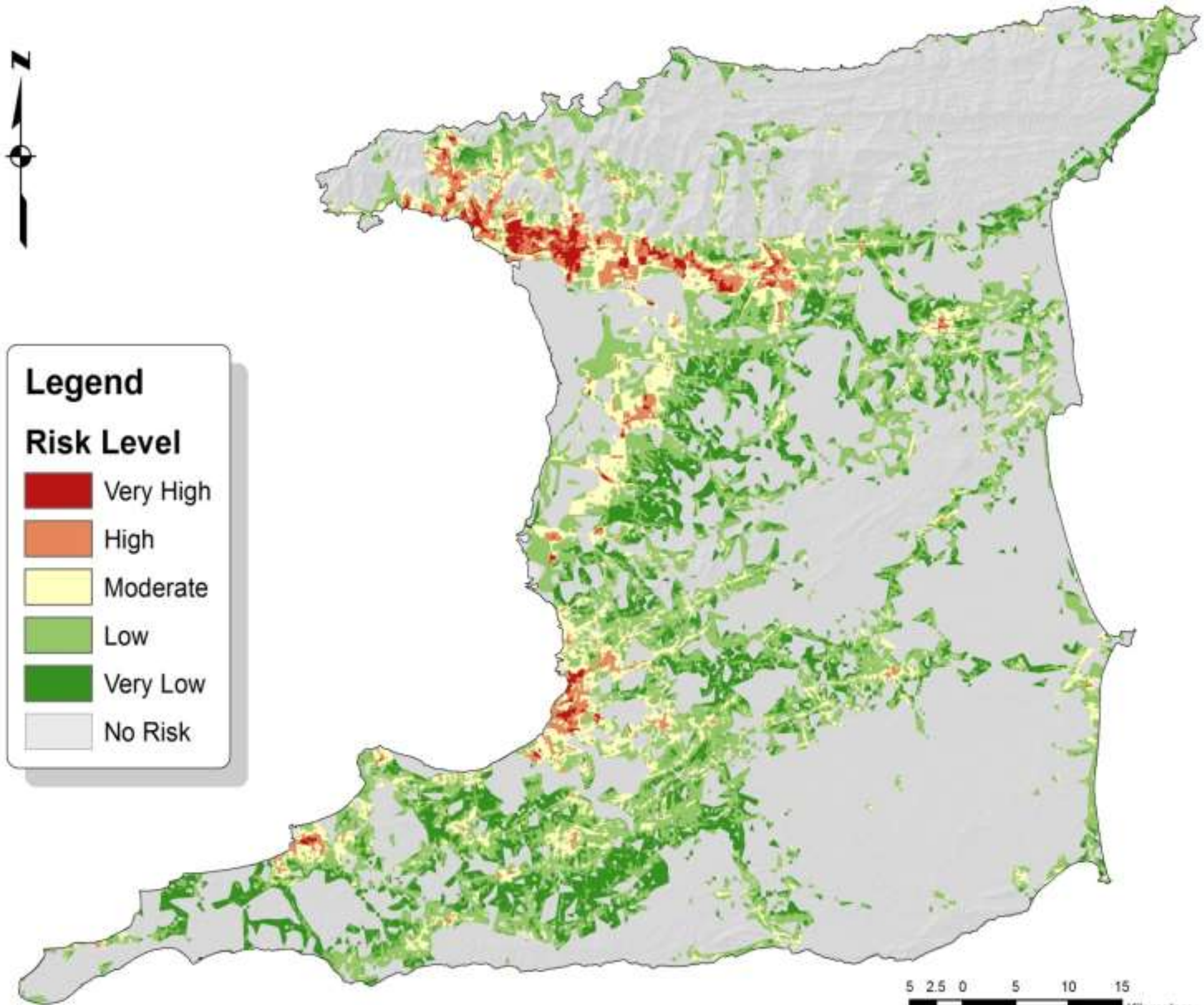


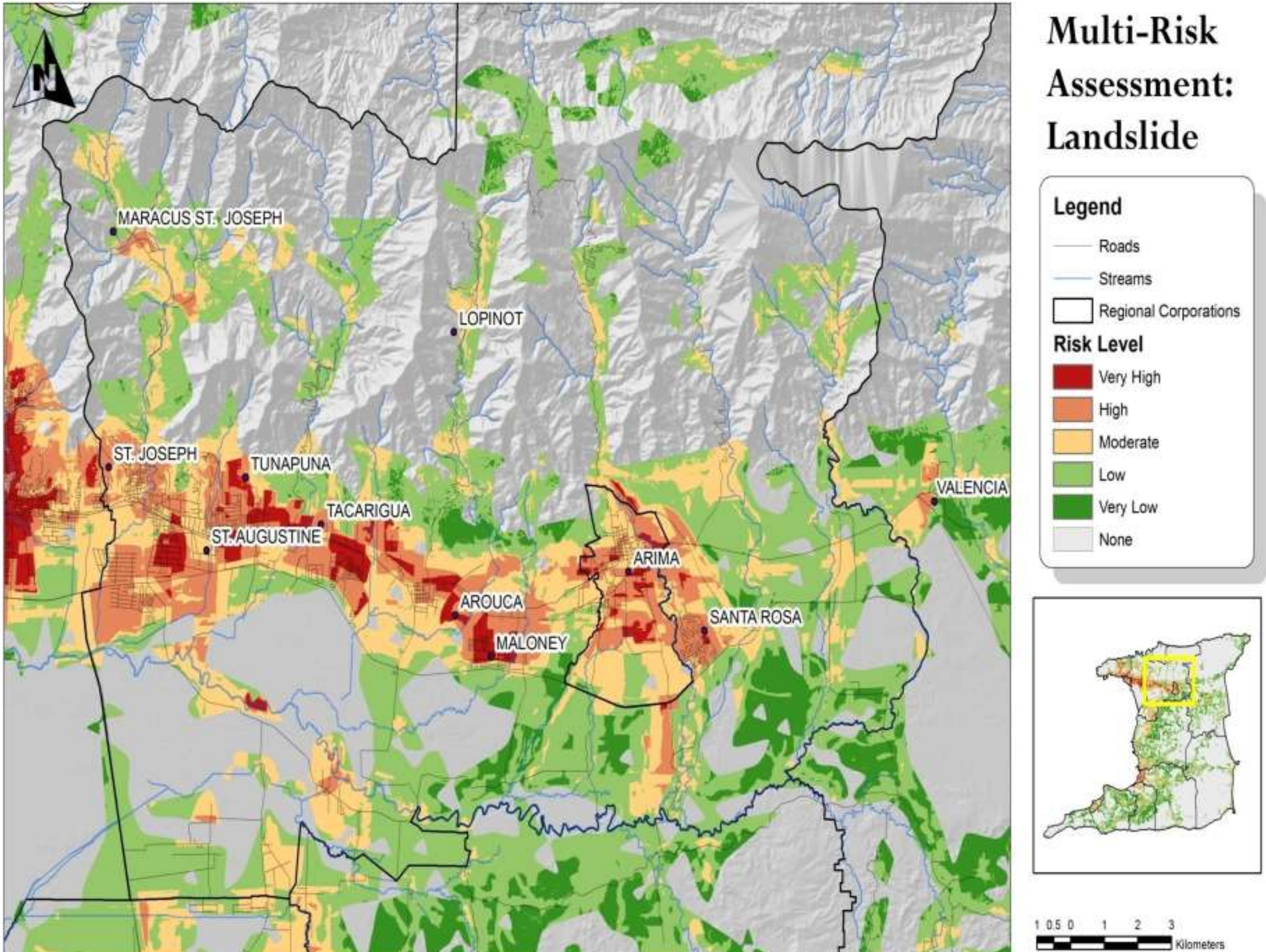
Multi-Risk Classification Scheme

Vulnerability Class		Susceptibility Class					
		Very Low	Low	Moderate	High	Very High	
		1	2	3	4	5	
Very low	1	3	4	5	6	7	1
Low	2	5	6	7	8	9	2
Moderate	3	7	8	9	10	11	3
High	4	9	10	11	12	13	4
Very High	5	11	12	13	14	15	5

Multi-Risk Level	Risk Value
Very low	< 6
Low	6-7
Moderate	8-9
High	10-11
Very High	> 12

Landslide Multi-Risk Assessment




MARACUS ST. JOSEPH
LOPINOT
ST. JOSEPH
TUNAPUNA
TACARIGUA
ST. AUGUSTINE
ARIMA
VALENCIA
AROUCA
SANTA ROSA
MALONEY
Multi-Risk Assessment: Landslide
Legend
Roads
Streams
Regional Corporations
Risk Level
Very High
High
Moderate
Low
Very Low
None
1 0.5 0 1 2 3
Kilometers

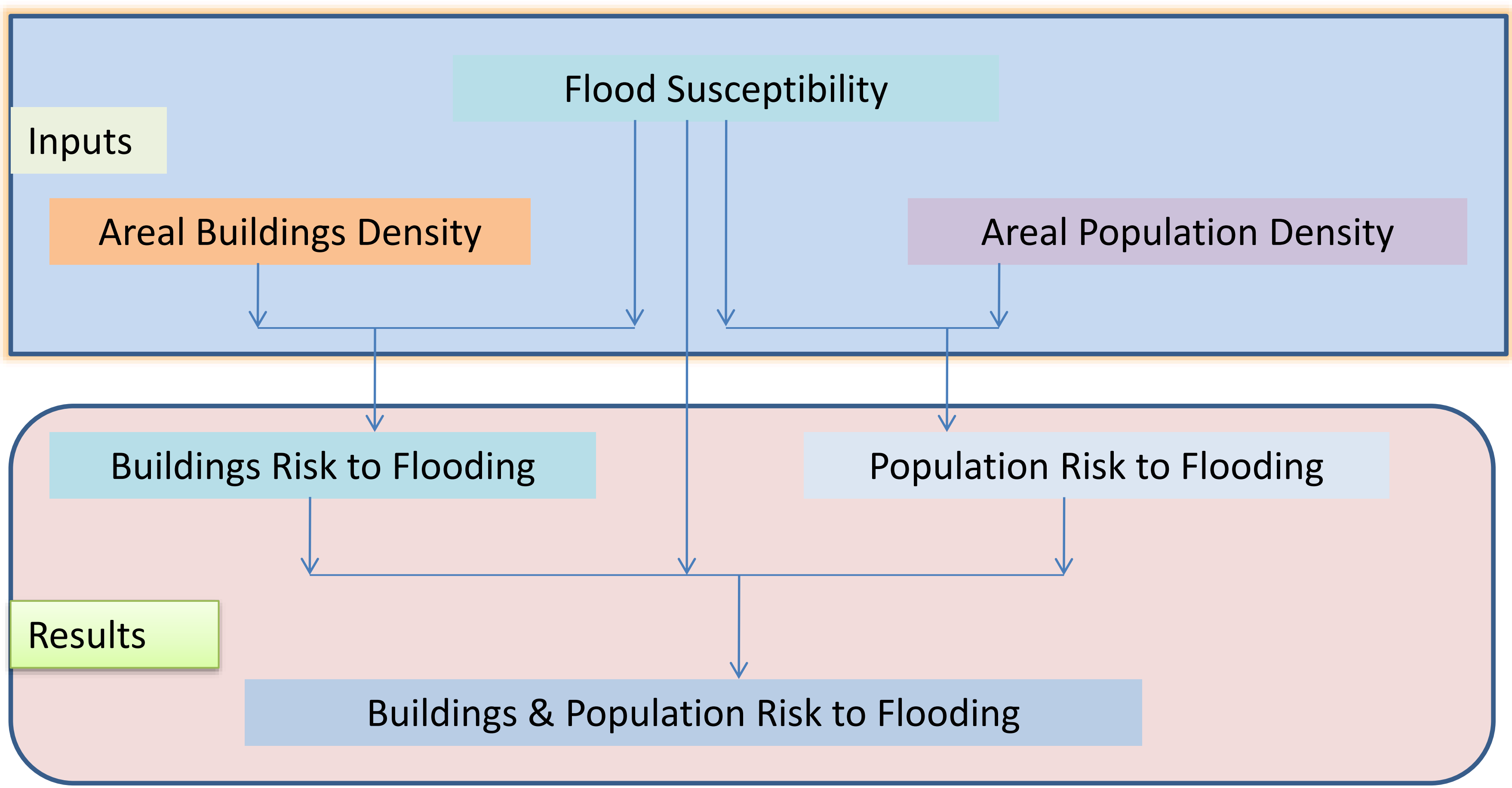
Landslide Multi-Risk Assessment

Landslide Multi (Building & Population) Risk Assessment (Sum of Land Area Under Each Risk Level)			
Risk Level	Number of Cells	Area (ha)	% of Trinidad Urban Land Mass
Very Low	802115	8021.15	4.6
Low	12114786	121147.86	69.9
Moderate	2241024	22410.24	12.9
High	1560213	15602.13	9.0
Very High	620939	6209.39	3.6

Flood Risk Mapping

Conceptual Design

Risk = Susceptibility + Vulnerability (Population, Buildings)



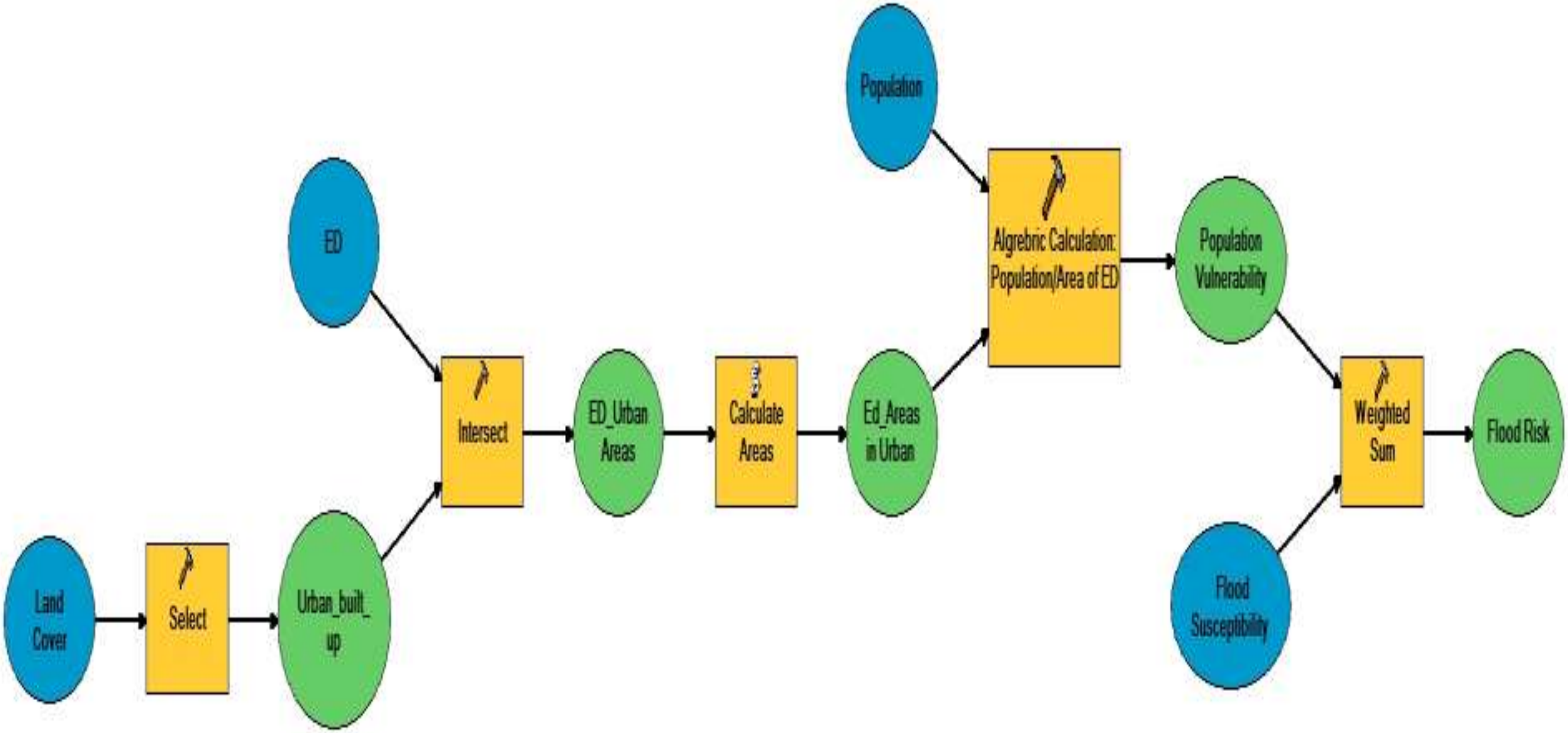
Results: Flood Risk Maps

Single-Risk (Population) Map

Single-Risk (Buildings) Map

Multi-Risk (Buildings and population) Map

Flood Population Risk Assessment

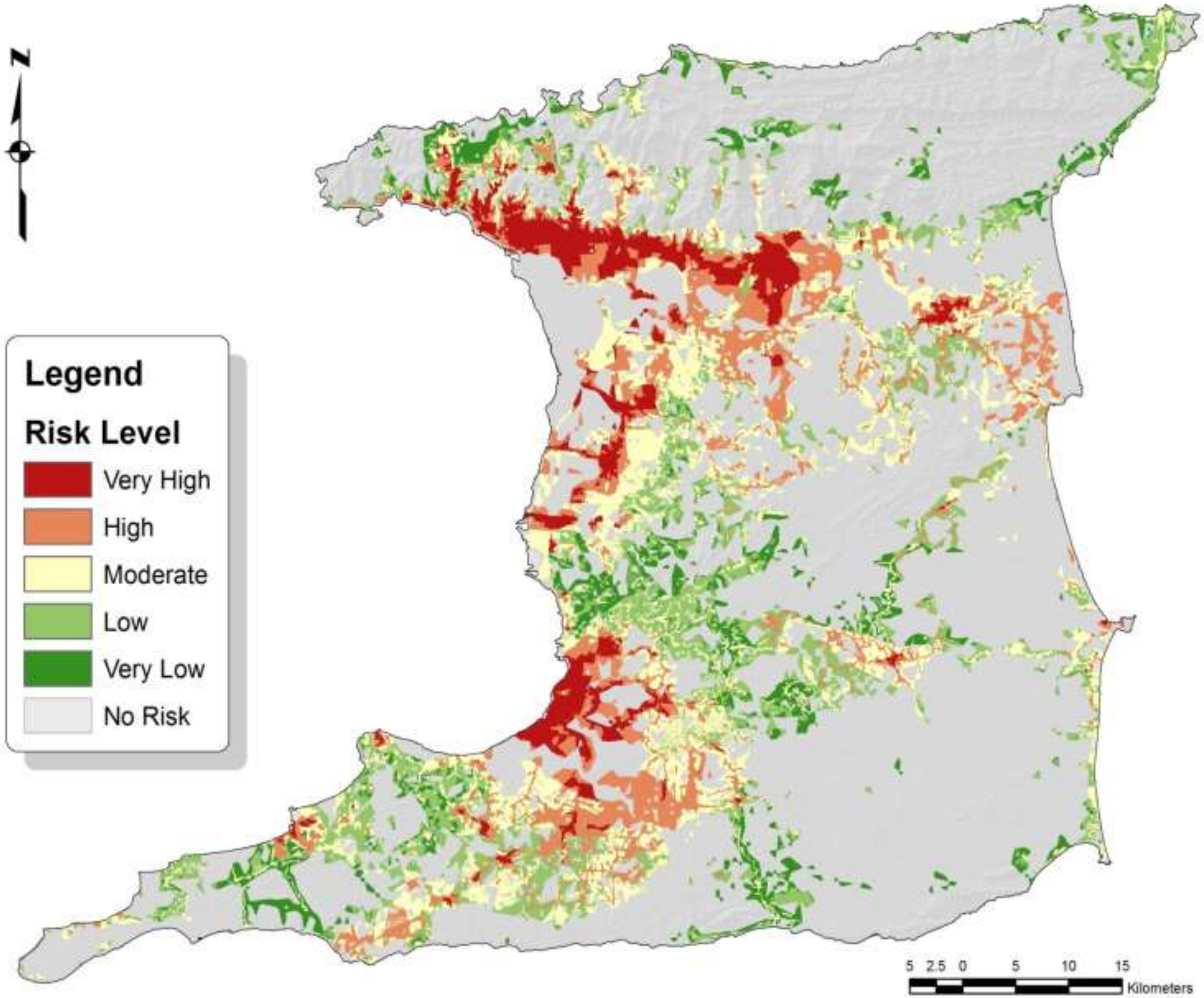


Single Risk Classification Scheme

Vulnerability Class (Population)		Susceptibility Class				
		Very Low	Low	Moderate	High	Very High
		1	2	3	4	5
Very low	1	2	3	4	5	6
Low	2	3	4	5	6	7
Moderate	3	4	5	6	7	8
High	4	5	6	7	8	9
Very High	5	6	7	8	9	10

Risk Level	Risk Class
Very low	< 4
Low	4-5
Moderate	6
High	7
Very High	> 7

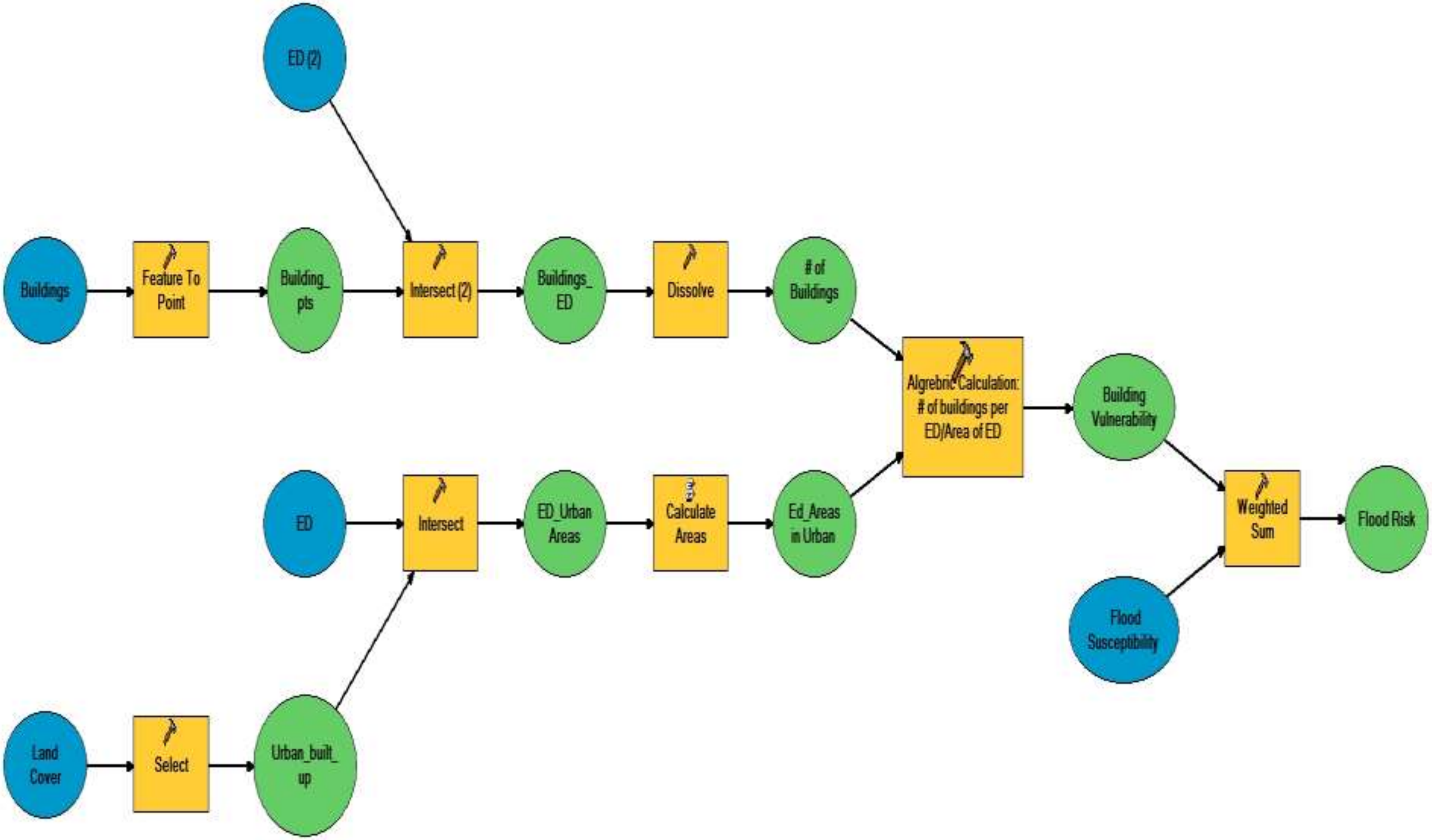
Flood Population Risk Assessment



Flood Population Risk

Flood Population Risk (Sum of Land Area Under Each Risk Level)			
Risk Level	**No. of Cells**	**Area (ha)**	**% of Trinidad Urban Land Mass**
Very Low	1994105	19941.05	11.3
Low	4397108	43971.08	24.9
Moderate	5371545	53715.45	30.4
High	4018501	40185.01	22.7
Very High	1896687	18966.87	10.7

Flood Building Risk Assessment

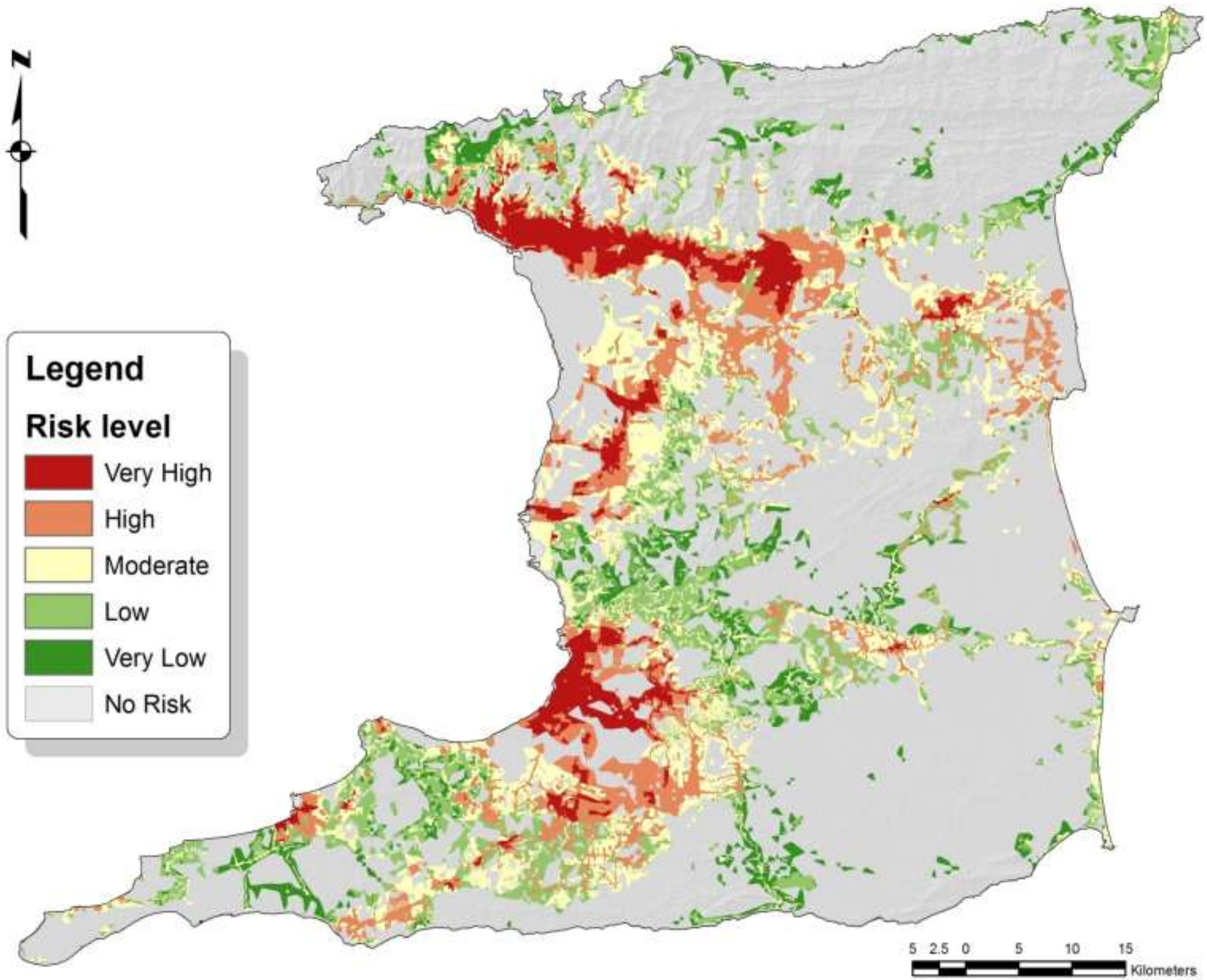


Single Risk Classification Scheme

Vulnerability Class (Building)		Susceptibility Class				
		Very Low	Low	Moderate	High	Very High
		1	2	3	4	5
Very low	1	2	3	4	5	6
Low	2	3	4	5	6	7
Moderate	3	4	5	6	7	8
High	4	5	6	7	8	9
Very High	5	6	7	8	9	10

Risk Level	Risk Value
Very low	< 3
Low	3-5
Moderate	6
High	7
Very High	> 7

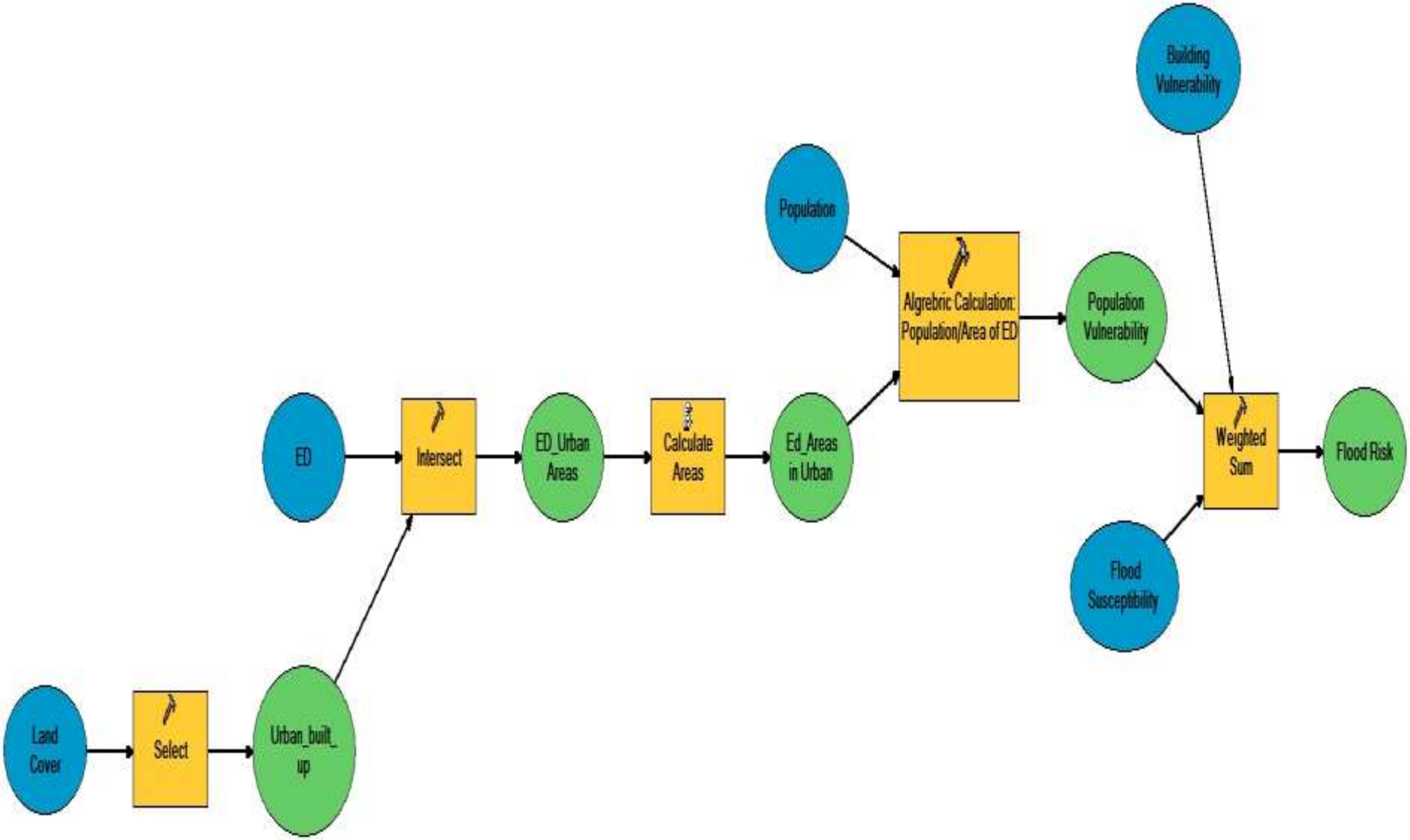
Flood Building Risk



Flood Building Risk Assessment

Flood Building Risk (Sum of Land Area Under Each Risk Level)			
Risk Level	**No. of Cells**	**Area (ha)**	**% of Trinidad Urban Land Mass**
Very Low	1999245	19992.45	11.3
Low	4395847	43958.47	24.9
Moderate	5313690	53136.9	30.1
High	4079469	40794.69	23.1
Very High	1886920	18869.2	10.7

Flood Multi-Risk Assessment: Building and Population

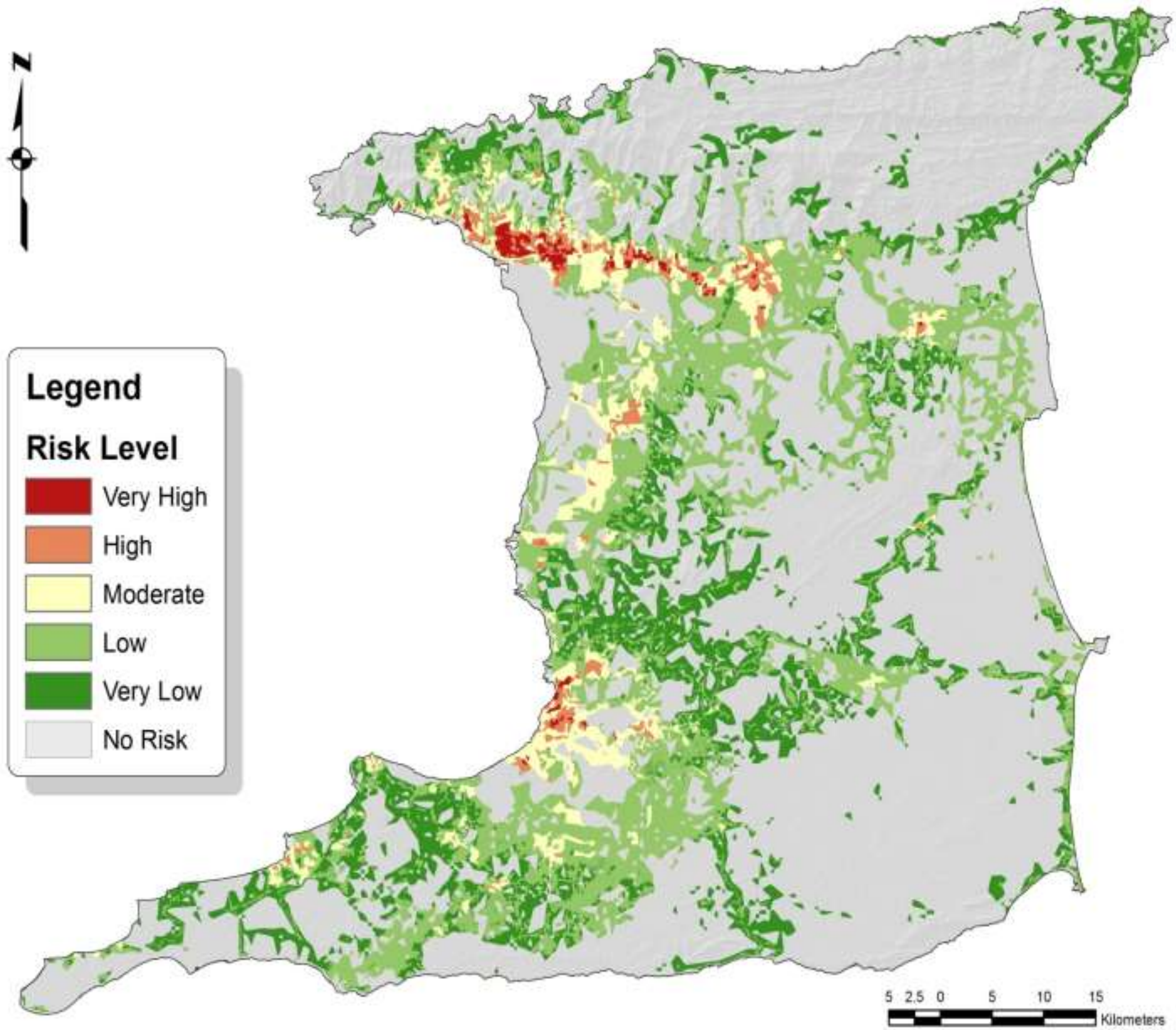


Multi-Risk Classification Scheme

Vulnerability Class		Susceptibility Class					
		Very Low	Low	Moderate	High	Very High	
		1	2	3	4	5	
Very low	1	3	4	5	6	7	1
Low	2	5	6	7	8	9	2
Moderate	3	7	8	9	10	11	3
High	4	9	10	11	12	13	4
Very High	5	11	12	13	14	15	5

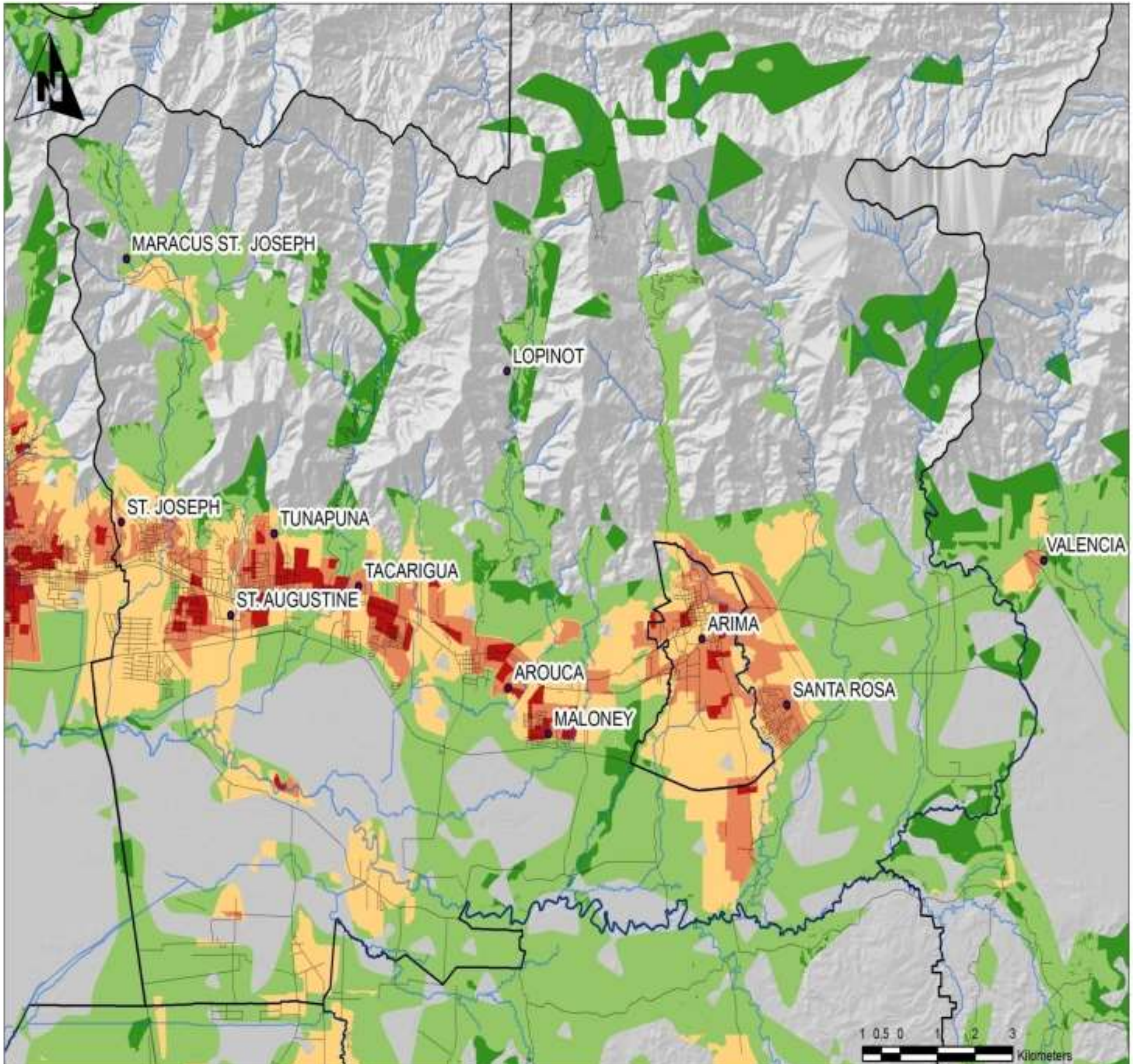
Multi-Risk Level	Risk Value
Very low	< 6
Low	6-7
Moderate	8-9
High	10-11
Very High	> 12

Flood Multi-Risk Assessment



Flood Multi-Risk Assessment

Flooding Multi (Building & Population) Risk Assessment (Sum of Land Area under each risk level)			
Risk Level	**No. of Cells**	**Area (ha)**	**% of Trinidad Urban Land Mass**
Very Low	1828829	18288.29	10.5
Low	9092542	90925.42	52.4
Moderate	5637018	56370.18	32.5
High	368174	3681.74	2.1
Very High	424685	4246.85	2.4



Multi-Risk Assessment: Flood

Legend

Roads

Streams

Regional Corporations

Risk Level

Very High

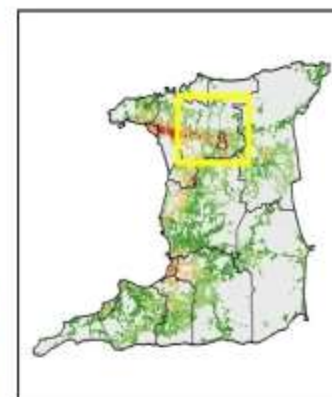
High

Moderate

Low

Very Low

None



Users

- Physical Planning Offices
- Non-Governmental Organizations
- Environmental Agencies
- Works Departments
- Utility Companies
- Insurance Agencies
- National Disaster Offices
- Security and Protective Services
- Lending Agencies
- Meteorology and Hydrology Departments
- Educational Institutions
- Land Developers
- General Public
- Foreign Investors

Uses

- Development control and planning
- Disaster mitigation planning
- Disaster management
- Policy formulation
- Law reforms
- Site analysis
- Review of insurance premium

Limitations of Methodology and Data

- The MFM is sound and logical. it does not consider some other important factors such as the size of the drains or whether they have been cleared of debris.
- The result could also be improved through:
  - A more improved records of past occurrences
  - Use of current landuse data
  - the utilization of rainfall intensity rather than mean rainfall.
- Use of a less biased weighting if the incidence data is more detailed and locational accurate

Thank you!

- ---------------END------------------

UNITED NATIONS
ECLAC

CCRIF SPC
The Caribbean Catastrophe Risk Insurance Facility