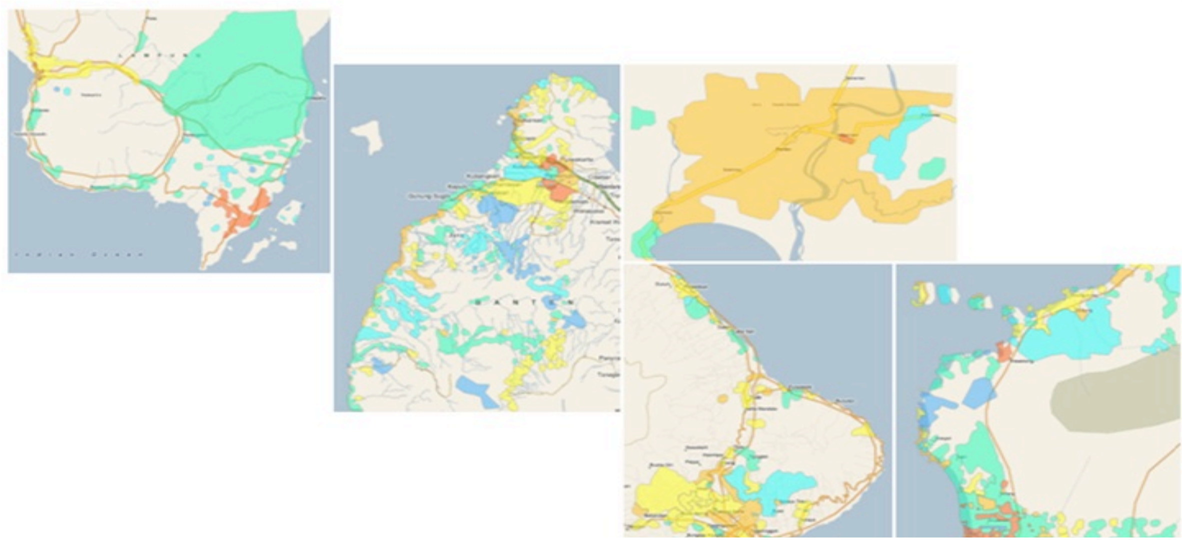
Indonesia Building Exposure Development

Report produced in the context of the
Inventory Data Capture Tools Risk Global Component



Version 1.0 – January 2012

J. Bevington[1], R. Eguchi[2], S. Ghosh[2], W. Graf[2], Z. Hu[2], P. Amyx[2], C. Huyck[2],

M. Huyck[2], G. Esquivias[2], M. Eguchi[2], A. Vicini[1]

[1] ImageCat, UK [2] ImageCat, USA

Indonesia Building Exposure Development

Inventory Data Capture Tools Risk Global Component

Deliverable: D13. Tool Development

Version: 1.0

Authors: J. Bevington, R. Eguchi, S. Ghosh, W. Graf, Z. Hu, P. Amyx, C. Huyck, M. Huyck, G. Esquivias, M. Eguchi, A. Vicini

Date: January 2012

Citation: J Bevington, R Eguchi, S Ghosh, W Graf, Z Hu, P Amyx, C Huyck, M Huyck, G Esquivias, M Eguchi, A Vicini. (2012) Indonesia Building Exposure Development. Inventory Data Capture Tools Risk Global Component. Available from www.nexus.globalquakemodel.org/IDCT/posts/

www.globalquakemodel.org

ABSTRACT

This report provides a full description of the GEM-AIFDR (Australia-Indonesia Facility for Disaster Reduction) data collection pilot in Indonesia. Key processes central to the development of the IDCT (Inventory Data Capture Tools) are described, including development of homogenous zones for land use characterization, sampling building data in the field, creating mapping schemes from sampled data, applying mapping schemes to building count data, and validating the results. These steps, tested through this pilot, form the basis of the Spatial Inventory Data Developer (SIDD) Product Requirements Document (PRD). The SIDD PRD describes in detail many of the lessons learned in preparing the attached document, such as the need for an iterative approach which focuses on validation and the requirement of a simple hierarchal taxonomy to represent structure type.

Keywords: remote sensing, mapping schemes, exposure data development, IDCT, Indonesia

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 OVERVIEW

This report summarizes the results of an accelerated study to develop a building exposure model for three regions of Indonesia. This study – conducted through the Global Earthquake Model (GEM) Project – for the Australian-Indonesia Facility for Disaster Reduction (AIFDR) and the Indonesian Government reflects the collaboration of local and regional disaster reduction experts, technology providers and earthquake risk modeling specialists. The project is unique in that preliminary methodologies to "streamline" building exposure model development that are part of the GEM initiative through its Inventory Data Capture Tools (IDCT) project are being used to test and validate a new set of technologies and sensors, tools that are essential for "upgrading" current earthquake loss estimation models. To a large extent, the lessons learned from this effort will intelligently inform data developers on the challenges that exist in creating building inventory data in areas where little cadastral information is publicly available.

The findings in this study are considered preliminary in that future efforts in the GEM IDCT project may uncover more efficient and accurate methods of developing inventories and that those methods may be applied in reanalyzing the data collected in this study. The GEM IDCT project will involve a series of *case studies* each addressing a different set of evaluation criteria, all designed to assess the efficacy of remote sensing technologies for particular data and methodological conditions. We expect that any improvements in the current Indonesian dataset from further analysis in the GEM IDCT project will be mainly in better mapping schemes to distribute number of buildings into different occupancy and/or structural categories. The techniques used in the current study to "count" the number of buildings and the amount of building area (i.e., footprint area and number of stories), however, are considered credible and reliable.

This report is presented in four parts. We first describe the scope-of-work for this project focusing on both data collection and data analysis. We present next a description of the study area. In total, close to 2,000 sq. km were analyzed by project engineers and scientists. We then lay out the methodology used by the study team to develop our Level 1 (urban area delineation) and Level 2 (building counts with attribute information) databases. Finally, we discuss the results of this study providing details on selected areas to demonstrate the nature of the final datasets.

Finally, the project team would like to acknowledge the participation and support of the following organizations: The Government of Indonesia who will be using these data in a study to make critical decisions regarding risk-reduction strategies for Indonesian territories; Australian Aid (AusAid) and National Disaster Management Agency (BNPB); AIFDR for facilitating the collaboration between project partners and providing the initial guidance to structure the details of this study; the Global Earthquake Model Foundation for allowing its research infrastructure to serve as the platform for performing this study; PT Maipark for partnering in this effort and who will be performing the risk-based study for the Government of Indonesia; and Waindo SpecTerra (an Indonesia-based GIS company) who worked tirelessly to collect the field data needed to refine the building mapping schemes used in this study. We gratefully acknowledge this help and support.

2 OBJECTIVES AND SCOPE

In consultation with AIFDR, the following objective and scope of work was established for this study.

Objective – To develop a set of building inventory exposure models for three areas within Indonesia for the purpose of performing loss estimation studies for the Government of Indonesia.

Scope – The scope for this project consisted of four (4) major tasks: 1) Urban Area Delineation; 2) Key Parameters for Loss Estimation Model; 3) Building Exposure Model for Urban Areas; and 4) Integration of Ground Survey Results.

2.1 Task 1 – Urban Area Delineation

a. This task will separate rural areas from cities and towns, using moderate-resolution imagery, city populations, delineations of contiguous areas, and night-time light imagery. A key product from this task will be the identification of urban areas which will be the exclusive focus of the project.
b. Recommendation on Earth Observation (EO) imagery to be purchased. ImageCat will purchase imagery for those urban areas identified in (a), and advise on potential aerial image collection.

2.2 Task 2 – Key Parameters for Loss Estimation Model

a. Coordinate the development of building exposure model with PT Maipark to ensure compatibility with loss estimation (risk) parameters.
b. Develop a short and long list of parameters (building inventory mapping schemes) required for vulnerability modeling. For the current study, the focus will be on the short list of parameters (i.e., breakdown by building use – residential, commercial, and industrial). The longer list will be for the GEM IDCT project where Padang or some other Indonesian city will be potentially included as part of the four case studies in the IDCT project.

2.3 Task 3 – Building Exposure Model for Urban Areas

a. Supervised classifications will be used to identify areas of homogenous building use types. Residential, commercial and industrial buildings will be identified.
   i. Residential areas will have proportion of large/medium/small buildings attributed to the homogenous areas, estimated number of buildings, and estimated proportion of structural type.
   ii. Commercial and industrial zones will have estimated number of buildings, with estimates of the percentage of buildings by height range, and structure type corresponding to the PT Maipark loss estimation model.

2.4 Task 4 – Integration of Ground Validation Results

a. Statistical inference of structural types discussed above can be substantially improved with ground surveys. Under this task, we would provide instructions on the ideal method of sampling key locations for field teams in order to reduce bias in the results. Specifically, key areas in all three regions will be identified where information and data on building use, building size and structural properties will be collected.
b. The results will be used to update inferences of structural type. These will be used to inform the type of earthquake vulnerability model used by PT Maipark.

2.5 Deliverables

All data deliverables will be GIS compatible, and consist of:

a. Major urban areas within the studied regions (Level I).

b. Estimated building counts for residential/commercial/industrial development within urban areas (Level II)

c. Estimates of number buildings by major building types (e.g., wood-frame, masonry) and neighborhood inventory estimates (e.g., no. of buildings, sq. footage, building heights) for each residential/commercial/industrial area. Structural type and height class information will be based on the best available information on Indonesian construction. This will translate into a building mapping scheme that PT Maipark can use to link the exposure data to its vulnerability models, as well as use within the GEM OpenQuake framework under development.

d. Validation of inventories utilizing a combination of sources, including geo-tagged photographs taken from ground surveys and the internet.

3 STUDY AREA

The study area for the exposure data development consists of five areas spread across three region- Java, Sumatra & Bali/Lombok (see Figure 1 and Table 1 below). These are a mix of residential (sparse residential type to dense residential in the city of Mataram in Lombok), commercial, and industrial facilities including ports. There are also a number of resorts located in the study areas.

Figure 1: The red regions highlight the spatial extent of each study site of the region.(Imagery Google 2011)

Table 1: Study Area Regions

Region	Approximate Area of Regions (sq. km.)
Sunda Strait West (Sumatra)	355.97
Sunda Strait East (Java)	610.03
Pacitan (Java)	39.85
Bali	302.87
Lombok	504.06
Total	**1,812.78**

4 APPROACH

Our approach for building inventory data development combines remote sensing analysis, GIS data, and in-field survey data. This approach involves a four- step process:

1. Delineating areas of urban development using remotely-sensed data
2. Categorizing land cover into homogenous areas of development
3. Characterizing development within each use category using the results of ground surveys and the best available information on Indonesian construction practices
4. Estimating number of buildings, square footage and distribution of building types for all delineated areas

4.1 Delineating Areas of Development

Data used for the delineation included high-resolution satellite and aerial imagery, moderate-resolution satellite imagery, world population datasets, nightlights, and GIS data of settlements. In general, areas of development would include small to large settlements where it is obvious that a neighborhood exists. Although somewhat arbitrary, these delineations would include over a dozen or so buildings within a reasonably closed polygon. The important objective in this delineation is to ensure that large, unoccupied areas are not included in the assessment process. Therefore, agricultural land would not be considered a developed area.

4.2 Categorizing Land Cover into Homogenous Areas of Development

Homogeneous zones (in terms of texture and density) were delineated using remote sensing data noting the distinct characteristics of building inventory in the region. For example, in the Mataram area of Lombok additional categories were used to characterize the urban density. Land cover was used to infer land use, which was verified in field deployments. The categories considered for the final exposure data in this study are:

- Residential
- Commercial
- Industrial
- Airport
- Port
- Resort
- Mataram Residential
- Mataram Commercial
-

4.3 Characterizing Development of each Category

Ground survey data and discussions with PT Maipark engineers on local construction practices were the primary sources of information used to characterize development within each use category. Such characterization schemes - also known as “Mapping Schemes” - were developed for the study areas to show the distribution of structural types, building heights and year built data. For example, for a typical residential neighborhood in Java, the mapping scheme tells us what percentage of all buildings are wood structures, what percentage is confined masonry etc; what is the building height profile for this neighborhood, and what is the typical age range for buildings in this area. The following paragraphs describe in a little more detail some of the key steps in this part of the analysis.

- ***Collecting ground survey data.*** The selection of key study sites for the ground surveys was critical in order to ensure that we adequately captured each development type and covered as many of the diverse geographic regions of Java, Sumatra and Lombok. Survey teams collected building specific information and geo-tagged photographs of over 800 buildings in the various study sites. All this information was collated and formatted for creating building mapping schemes for various study sites.
- ***Creating mapping schemes for Indonesia construction.*** Based on the survey data, building mapping schemes for Indonesia construction types were developed. These mapping schemes are based on statistics that establish the general relationship between the various building exposure data attributes (such as number of stories, structural type, year of construction, etc). These statistical models were used to distribute building counts into different structural type and building stories categories.
-

4.4 Estimating number of buildings, square footage and distribution of building types for all study areas

Typical building densities by use category were developed from remote sensing data using a sampling-based approach. These densities were then applied across the various study zones to estimate the final building counts. Building footprint areas for the complete field survey dataset were developed to come up with typical building square footages by detailed structure type (see Table 2). These along with number of stories were used to calculate total square footages. Applying the mapping schemes developed from the ground surveys, the number of buildings were distributed into major structural types and neighborhood inventory estimates (number of buildings, square footage, height etc) for each category (residential, commercial, industrial etc).

4.5 Validation

4.5.1 Validating datasets

Checking and validating the final datasets was done using a variety of techniques and data sources. Because this study has multiple objectives (producing data for risk-based loss modeling and pre-testing data collection and building inventory techniques), the accuracy of the data was evaluated at several levels. In general, the results (building counts and building mapping schemes) were compared to available imagery, geo-tagged photos, Google Earth data, and reports that were obtained either online or while in Indonesia during our site visit. Where possible, spot checks were performed for all areas for which ground survey data were available. In addition, statistical checks were made in order to evaluate the overall efficacy of the data.

However, even with these checks, there remains uncertainty in many of the mapping assignments and building counts. This is because the sample size established for the ground survey task was limited by an aggressive time schedule. So, the purpose of this section is to describe the process followed to quantify uncertainties and to explain the overall review process. This review process is described below beginning with a description of “confusion” matrices.

4.5.2 Confusion Matrices

A statistical test involving confusion matrices was used to compare and evaluate the distribution of buildings by mapping scheme in the various study areas. A confusion matrix is a statistical tool that helps to identify where the distribution is confusing two classes (mislabeling one as another). The test was used in this study to quantify the accuracy of assigning structural types to building categories based on occupancy. A "model" set was created with a random sample of 75% of the ground survey data, Table 2. The remaining 25% of the survey data were used as the "test" case. Using the distribution of structural types in the "model" dataset, the number of buildings in each structural class for each occupancy type was estimated for the "test" area, Table 3. The estimated numbers were then compared with the 25% sample of "known" data from the ground surveys. The overall accuracy of extrapolating structural types for all occupancy classes was found to be very high – see Table 4. The overall accuracy is estimated at 87%, i.e., in 87% of the cases, the model correctly identified the appropriate structural class based on occupancy information. The accuracy levels were highest for masonry and reinforced concrete assignments; for wood structures, the accuracy was significantly less.

We note that 39 out of the 40 masonry buildings, 10 out of 16 reinforced-concrete buildings, and 4 out of 4 of the wood structures were accounted for in the projected distribution. One (1) masonry, six reinforced concrete and one (1) steel structure were incorrectly designated as wood. Either the proportion of wood structures based on the 75% sample was too high, or the count in this particular 25% sample was too low. The producer's accuracy shows the percentage of structures that were correctly classified. In this case, wood structures were poorly identified (33%), whereas all other structures were 100% identified/accounted for. The User's accuracy shows the percentage of those structures designated to the wrong class. In the masonry field, only one (1) structure was incorrectly categorized, resulting in a high percentage. Nonetheless, the overall accuracy of the sample is 87% (sum of numbers along the diagonals, i.e. 1,1; 2,2; 3,3.. divided by the # of samples (39+10+0+4)/61).

Table 2: Model and Test Set Distributions of Building Structural Type by Occupancy

•

Model Set: 75% sample from survey data[1] - Actual Ground Survey Data						
Structure Type	*C*	*I*	*MC*	*MR*	*R*	*Total*
Masonry	*115*	*5*	*65*	*145*	*154*	*484*
Reinforced Concrete	*31*	*1*	*0*	*1*	*9*	*42*
Steel	*1*	*4*	*1*	*0*	*1*	*7*
Timber/Wood	*34*	*0*	*0*	*3*	*23*	*60*
Total	*181*	*10*	*66*	*149*	*187*	*593*

[1] C=commercial, I=Industrial, MC=Mataram Commercial, MR=Mataram Residential, and R=residential

Test Set Results: 25% sample from survey data – Actual Ground Survey Data						
Structure Type	*C*	*I*	*MC*	*MR*	*R*	*Total*
Masonry	*40*	*1*	*22*	*49*	*54*	*166*
Reinforced Concrete	*16*	*1*	*0*	*0*	*4*	*21*
Steel	*1*	*2*	*0*	*0*	*0*	*3*
Timber/Wood	*4*	*0*	*0*	*1*	*5*	*10*
Total	*61*	*4*	*22*	*50*	*63*	*200*

Table 3: Projected or Estimated Distribution of Building Structural Type by Occupancy for Test Set Area

Projected Values using Model Set Distributions						
Structure Type	C	I	MC	MR	R	Total
Masonry	39	2	22	49	52	163
Reinforced Concrete	10	0	0	0	3	14
Steel	0	2	0	0	0	3
Timber/Wood	12	0	0	1	8	21
Total	61	4	22	50	63	200

Table 4: Sample Confusion Matrix for Commercial Occupancy

Predicted

Actual

	Masonry	R.C.	Steel	Wood	Row Total	Producer's Accuracy
Masonry	39	0	0	0	39	100%
Reinforced Concrete	0	10	0	0	10	100%
Steel	0	0	0	0	0	N/A
Timber/Wood	1	6	1	4	12	33%
Column Total	40	16	1	4	61	
User's Accuracy	98%	63%	0%	100%		87%

4.5.3 Spot Checks

To ensure the most accurate building exposure database, a rigorous verification process was implemented. Since the timing was a key issue, a sampling of estimated buildings counts (falling within 100m x 100m grids selected randomly) drawn from different use or occupancy classes spread across the three geographic region (Java, Sumatra, and Bali/Lombok) were examined for errors by comparing against actual counts from high resolution imagery and other data sources. Estimated building counts and classifications were also validated against the ground survey data and updated when there were discrepancies.

A second level of review was performed with emphasis on counts and classification of high value facilities such as airports, ports, industrial and commercial buildings in highly urbanized areas such as in Mataram. Counts and classification was also checked for sparsely populated areas as well such as the primarily residential zones in the West Sunda Straits region of Sumatra. The spot checks resulted in scaling up or down of building counts for some of the delineated land use zones.

4.5.4 Remote Sensing based checks of building floor areas and count

Overall estimates of square footages and building counts were also cross-checked against data extracted from the high-resolution remote sensing imagery. Square footage of the built environment was extracted incorporating a variety of techniques including anomaly detection, automated classification based on reflectance values, textural analysis, and normalized difference vegetation index (NDVI). The resulting total building footprint areas were summarized for each zone and compared with density-based estimates. Discrepancies were examined individually. For these outliers the density for a given area was adjusted to reflect the results from imagery or the value from remote sensing was used directly, with the exception of areas where the results from imagery were incorrect due to cloud-cover or there was only partial coverage of imagery. Figure 2 illustrates the graph used for cross comparison with the imagery.

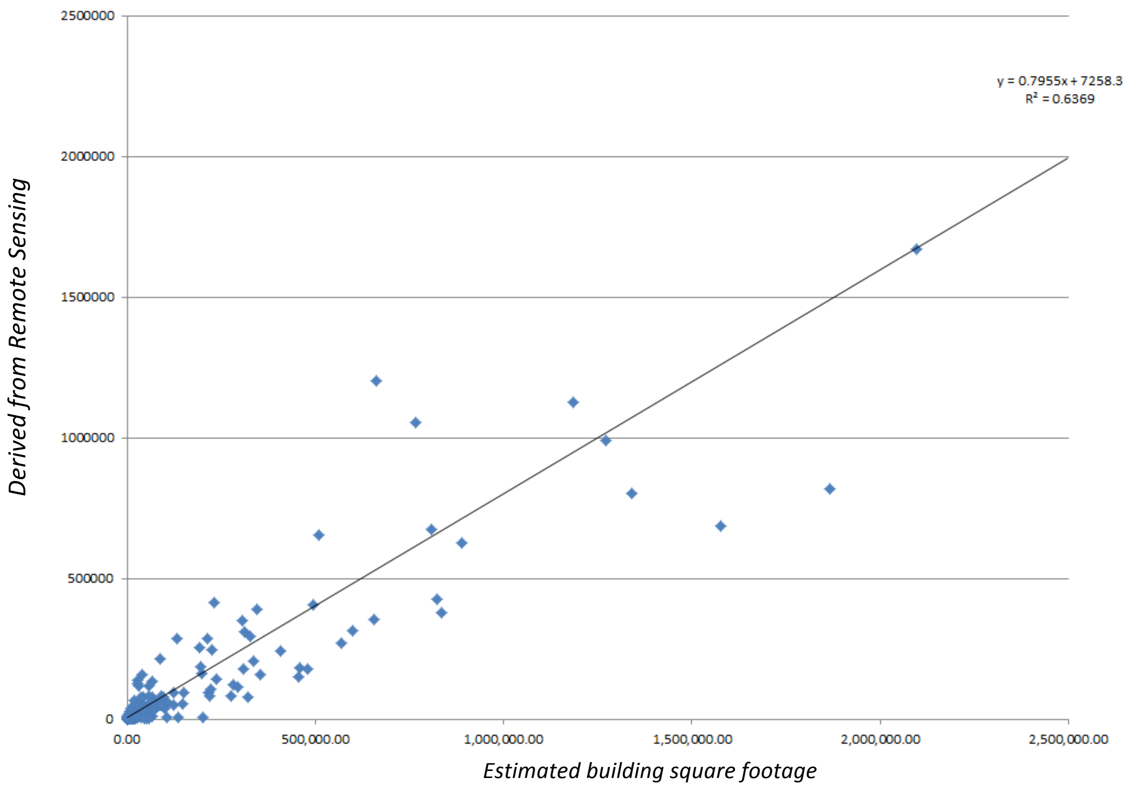


Figure 2: Cross comparison of estimated square footage (X-axis) with remote sensing based square footage (Y-axis)ross comparison of estimated square footage (X-axis) with remote sensing based square footage (Y-axis)

5 RESULTS

This section provides a high-level summary of the results of this study. Maps and tables are provided for five sub-regions: Bali, Lombok, Pacitan, Sunda East, and Sunda West.

Based on our analysis, we estimate the total building count for all five areas is about 300,000. Note that the focus of this study is on urbanized areas; therefore, some developments that may be associated with rural areas are not counted in this summary. Building counts by area are shown in Table 5. Lombok and Sunda East make up the largest totals and account for 43% and 29%, respectively, of the total. As expected, residential buildings comprise the vast majority of the building use types with about 90% of the total. Commercial buildings make up 5% of the buildings; industrial buildings make the remaining portion at 1.25%

The total building floor area (i.e., square footage) for all five areas is estimated at 71.5 million square meters, see Table 6. Lombok accounts for 47% of this total. The breakdown by occupancy is 90% residential, 8% commercial, and 3% industrial.

Table 5: Total Building Counts

Region	Number of Buildings	Percentage
Bali	31,585	11%
Lombok	125,106	43%
Pacitan	10,940	4%
Sunda East	86,162	29%
Sunda West	38,584	13%
Grand Total	**292,376**	**100%**

Table 6: Total Building Floor Area in Square Meters

Region	Total Floor Area (sq m)	Percentage
Bali	6,839,424	10%
Lombok	33,824,372	47%
Pacitan	2,407,782	3%
Sunda East	20,014,897	28%
Sunda West	8,495,828	12%
Grand Total	**71,582,303**	**100%**

With respect to structural categories- according to the field surveys- most of the buildings are either unreinforced clay bricks (42%) or confined masonry (35%), see Table 7. About 8% of the buildings are reinforced concrete with another 9% either wood or timber.

Most of the buildings in the region are either one or two stories, Table 8. There are very few structures over three stories; these are mainly resort facilities or industrial complexes. About 98% of the buildings are less than three stories.

The age of buildings - as estimated through field surveys - suggests that more than 80% of the buildings were built after 1983, Table 8. A very small percentage of the buildings (less than 3%) are older than 40 years.

Clay tile roofs are the most predominant roof type comprising about 66% of the roofs, Table 8. Corrugated metal roofs are also present accounting for roughly 24% of all roofs. Roof types vary with structural and occupancy type for buildings but there is no strong correlation between roof type and structural parameters of the building.

Finally, Table 9 provides a summary of building counts and floor area by land use, number of stories and structural type. These building counts are based on the statistical models that were derived from the ground survey results. While the ground surveys resulted in useful data samples for creating these statistics, a more comprehensive survey (that is, one which considers the number of parameters and a specific level of confidence) might result in different distributions. This specific issue will be addressed during the GEM IDCT study when the project team selects and analyzes data in its case studies. If appropriate, updates on the datasets in this study will be provided back to Indonesian government, AIFDR, and all project partners.

In order to display the results in a graphically manner, Appendix A includes maps for each study region focusing on land use delineations, total building counts and total floor area.

Appendix B contains the Meta Data for the project data files. Appendix C describes the exposure classification based on the requirements of the PT Maipark Loss Estimation Model. Appendix D includes field survey form and Appendix E presents summary tables of the building attributes by region.

Table 7: Structural Types Tables

Structural Type	**Percentage**
Masonry: Confined masonry	35%
Masonry: Reinforced masonry	2%
Masonry: Unreinforced clay brick	42%
Masonry: Unreinforced, with manufactured stone units	<1%
Masonry: Unreinforced, with reinforced concrete floors	2.2%
Reinforced Concrete: Frame	6%
Reinforced Concrete: Moment frame	<1%
Reinforced Concrete: Precast frame	<1%
Reinforced Concrete: Shear wall	1%
Steel: Braced frame	<1%
Steel: Light frame (transverse-frame; longitudinal-steel rod tension-only bracing)	<1%
Steel: Moment frame	<1%

Timber/Wood: Open frame at grade	8%
Timber/Wood: Shear Wall at Grade	<1%
Timber: Unknown	<1%
Total	**100%**

Table 8: Attribute Summary Tables

Roof Type	Percentage
Clay tile	66%
Concrete slab	8%
Corrugated Metal	24%
Plywood	1%
Thatched	1%
Unknown	1%
Total	**100%**

Stories	Percentage
1	80%
2	18%
3	1%
4	0.2%
7	0.1%
8	0.1%
Total	**100%**

Occupancy	Percentage
Commercial	26%
Education	3%
Government	5%
Industrial	2%
Religious	2%
Residential	60%
Resort	2%
Total	**100%**

YearBuilt	Percentage
Pre-1955	1%
1955-1971	2%
1971-1983	10%
1983-1991	20%
1991-2002	32%
2002-present	35%
Total	**100%**

Table 9: Building Counts and Floor Area (Sq M) by Land Use, Number of Stories and Structural Type

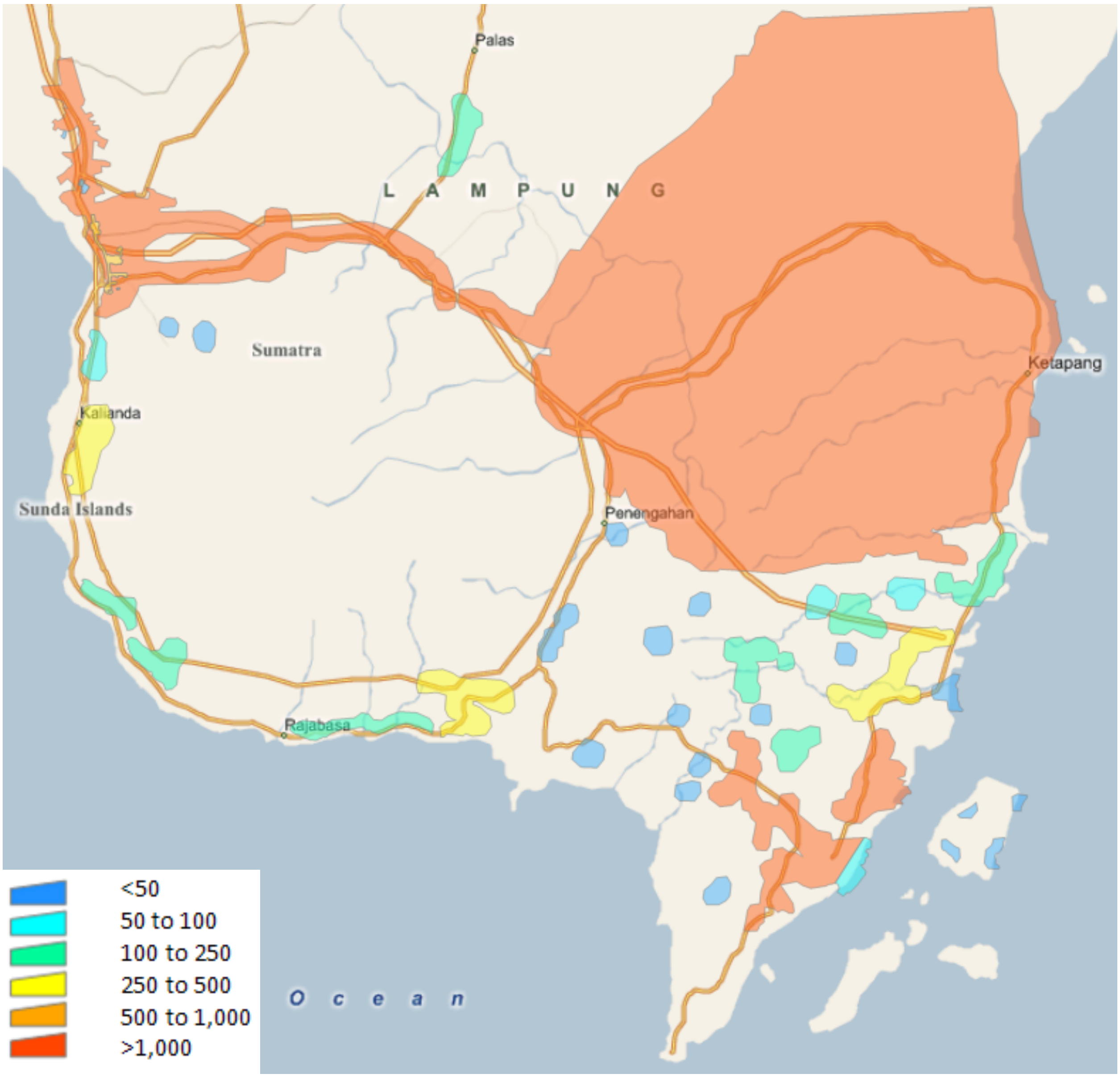
Zone Land Use	Basic Structural Type	Detailed Structural Type	Stories	# of Buildings	Total Sq Meters
Airport	Reinforced Concrete	Frame	1	20	15,000
Commercial	Masonry	Confined masonry	1	861	173,413
Commercial	Masonry	Confined masonry	2	270	173,616
Commercial	Masonry	Reinforced masonry	1	175	37,352
Commercial	Masonry	Unreinforced clay brick	1	2151	303,389
Commercial	Masonry	Unreinforced clay brick	2	97	35,452
Commercial	Masonry	Unreinforced, with reinforced concrete floors	2	97	41,191
Commercial	Reinforced Concrete	Frame	1	451	105,211
Commercial	Reinforced Concrete	Frame	2	296	387,201
Commercial	Reinforced Concrete	Shear wall	1	77	12,214
Commercial	Reinforced Concrete	Shear wall	2	146	57,050
Commercial	Timber/Wood	Open frame at grade	1	886	118,346
Commercial	Other	Other		171	173,692
Industrial	Masonry	Confined masonry	1	849	171,021
Industrial	Masonry	Reinforced masonry	1	849	181,263
Industrial	Reinforced Concrete	Frame	2	562	735,185
Industrial	Steel	Braced frame	1	280	134,875
Industrial	Steel	Braced frame	7	1	8,784
Industrial	Steel	Light frame (transverse-frame; longitudinal-steel rod tension-only bracing)	1	562	762,777
Industrial	Steel	Moment frame	1	280	58,204
Industrial	Steel	Moment frame	2	280	48,667
Mataram Commercial	Masonry	Confined masonry	1	4250	856,158
Mataram Commercial	Masonry	Confined masonry	2	3612	2,322,726
Mataram Commercial	Masonry	Confined masonry	3	195	461,887
Mataram Commercial	Masonry	Unreinforced clay brick	1	939	132,445
Mataram Commercial	Other	Other		273	56,991
Mataram Residential	Masonry	Confined masonry	1	25059	5,048,226
Mataram Residential	Masonry	Confined masonry	2	9889	6,359,222
Mataram Residential	Masonry	Confined masonry	3	1140	2,700,305
Mataram Residential	Masonry	Unreinforced clay brick	1	19807	2,793,956
Mataram Residential	Timber/Wood	Shear Wall at Grade	1	845	72,913
Mataram Residential	Other	Other		1087	490,425
Port	Masonry	Confined masonry	1	31	6,244
Port	Masonry	Reinforced masonry	1	35	7,472
Port	Reinforced Concrete	Frame	2	20	26,163
Port	Steel	Braced frame	1	10	4,817
Port	Steel	Light frame (transverse-frame; longitudinal-steel rod tension-only bracing)	1	20	27,144
Port	Steel	Moment frame	1	10	2,078
Port	Steel	Moment frame	2	10	1,738
Residential	Masonry	Confined masonry	1	21147	4,260,025
Residential	Masonry	Confined masonry	2	5819	3,741,892
Residential	Masonry	Reinforced masonry	1	3261	696,175
Residential	Masonry	Unreinforced clay brick	1	125997	17,773,065
Residential	Masonry	Unreinforced clay brick	2	8351	3,053,240
Residential	Masonry	Unreinforced, with reinforced concrete floors	2	6668	2,832,794
Residential	Reinforced Concrete	Frame	1	6668	1,555,777
Residential	Reinforced Concrete	Frame	2	2410	3,152,623
Residential	Timber/Wood	Open frame at grade	1	22004	2,939,742
Residential	Other	Other		8518	5,430,268
Resort	Masonry	Confined masonry	1	405	81,575
Resort	Masonry	Reinforced masonry	2	127	40,785
Resort	Masonry	Unreinforced clay brick	1	3054	430,783
Resort	Masonry	Unreinforced, with reinforced concrete floors	2	264	112,147
Resort	Reinforced Concrete	Frame	2	127	166,128
Resort	Reinforced Concrete	Frame	8	1	71,960
Resort	Timber/Wood	Open frame at grade	1	962	128,511
				292,376	71,572,303

APPENDIX A Study Area Maps

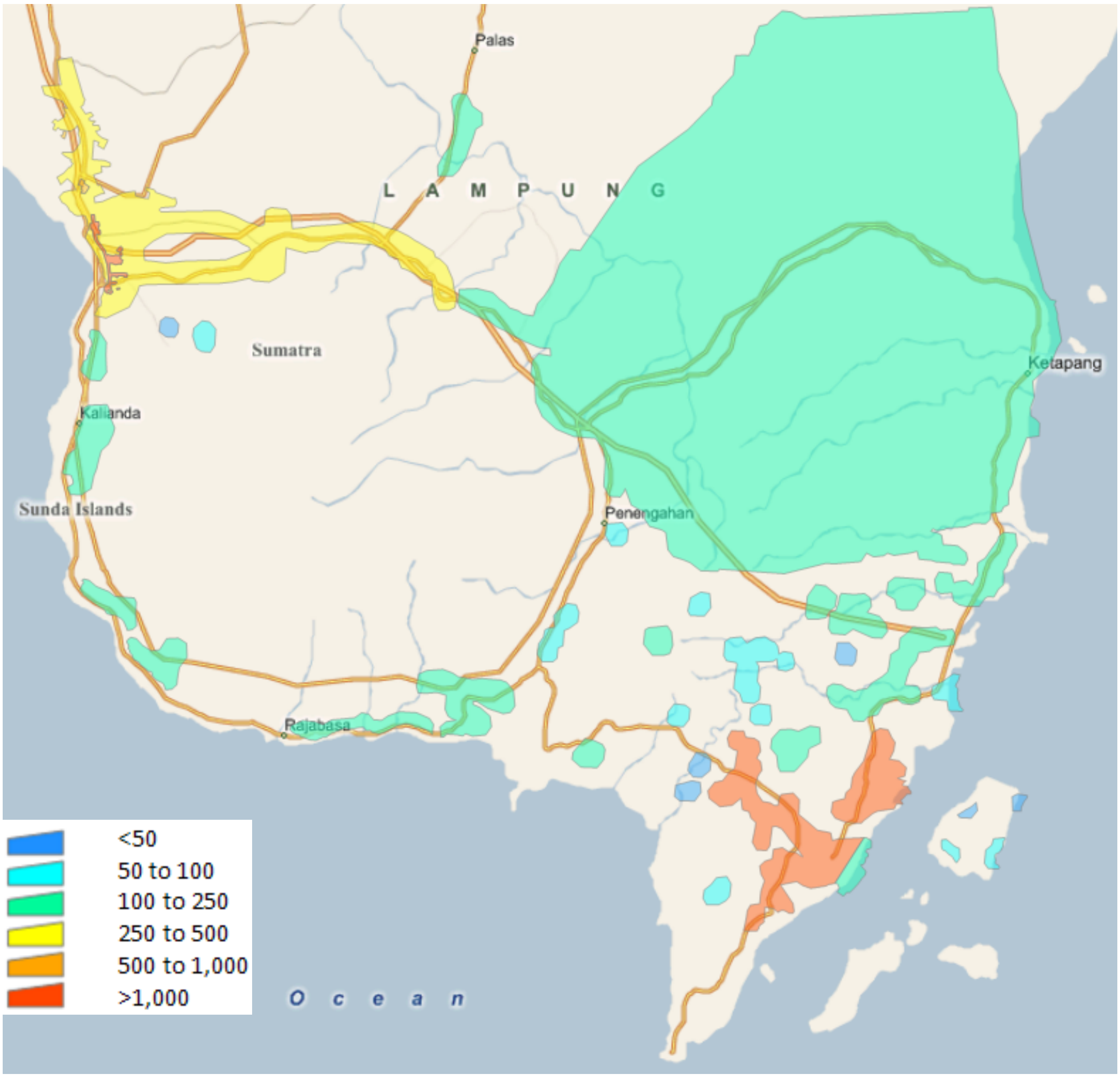
A.1 Sunda West

A.1.1 LAND USE CLASSIFICATION MAP

A.1.2 BUILDING COUNT MAP

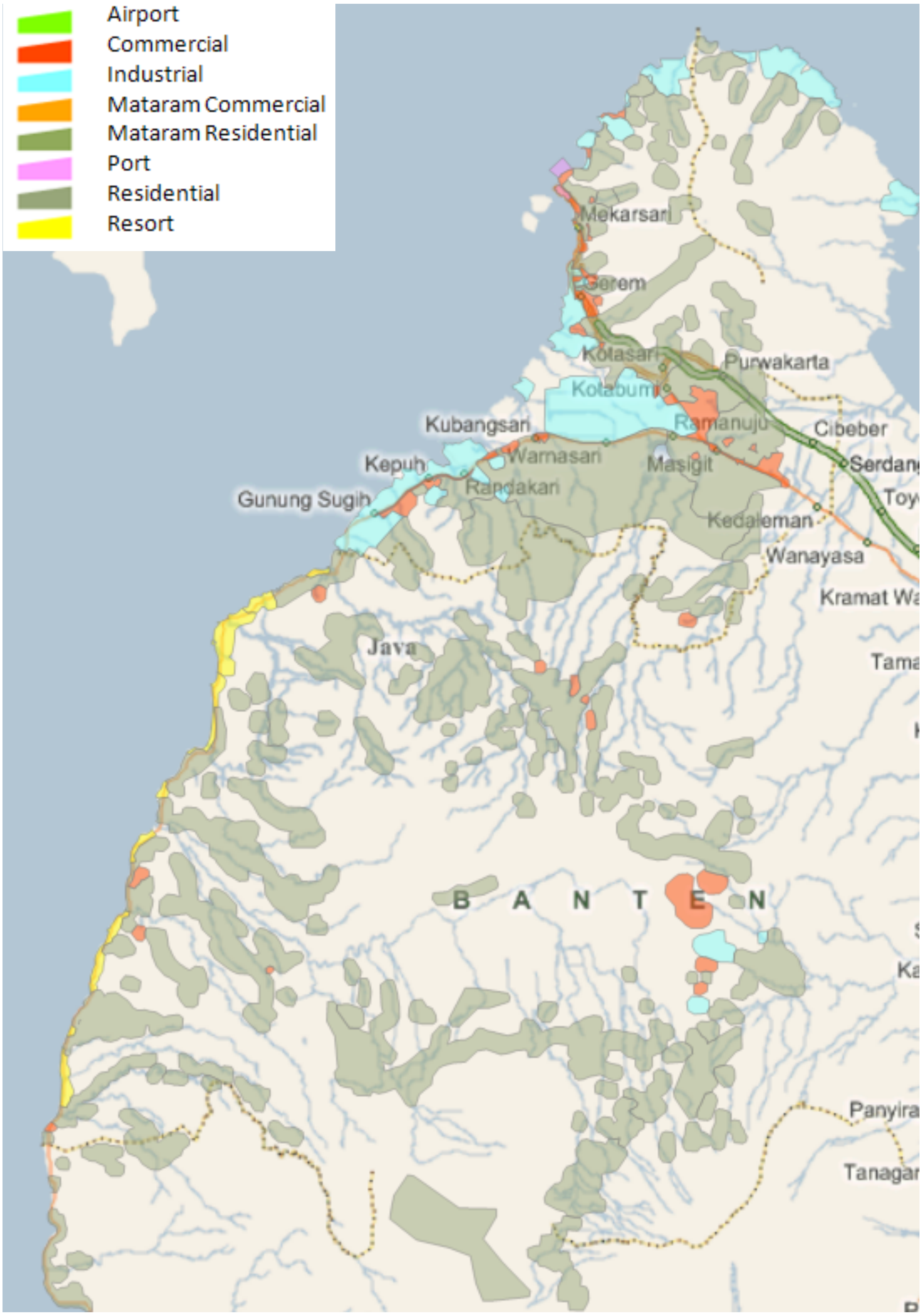


A.1.3 BUILDING DENSITY (BUILDINGS PER SQ KM) MAP

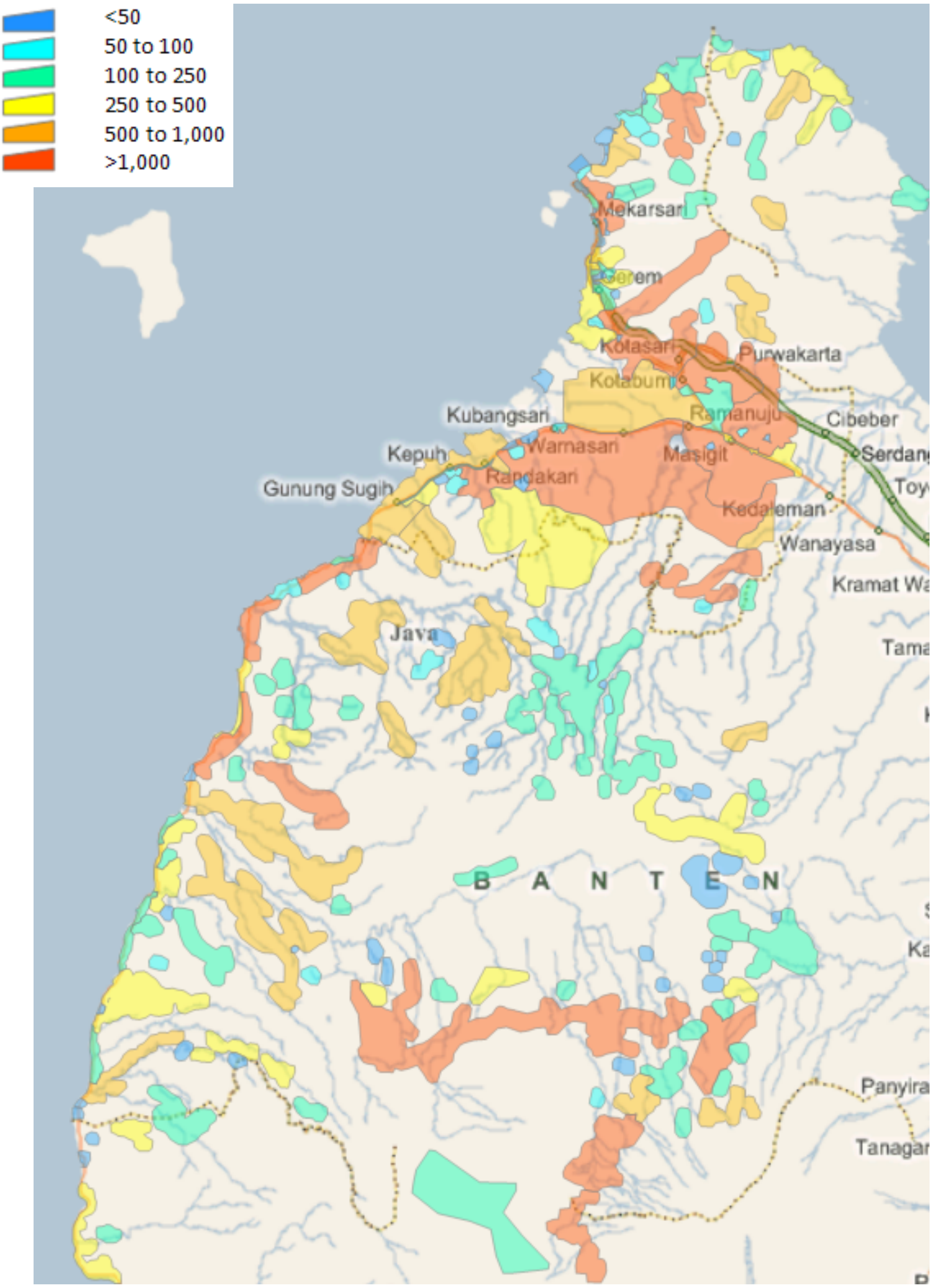


A.2 Sunda East

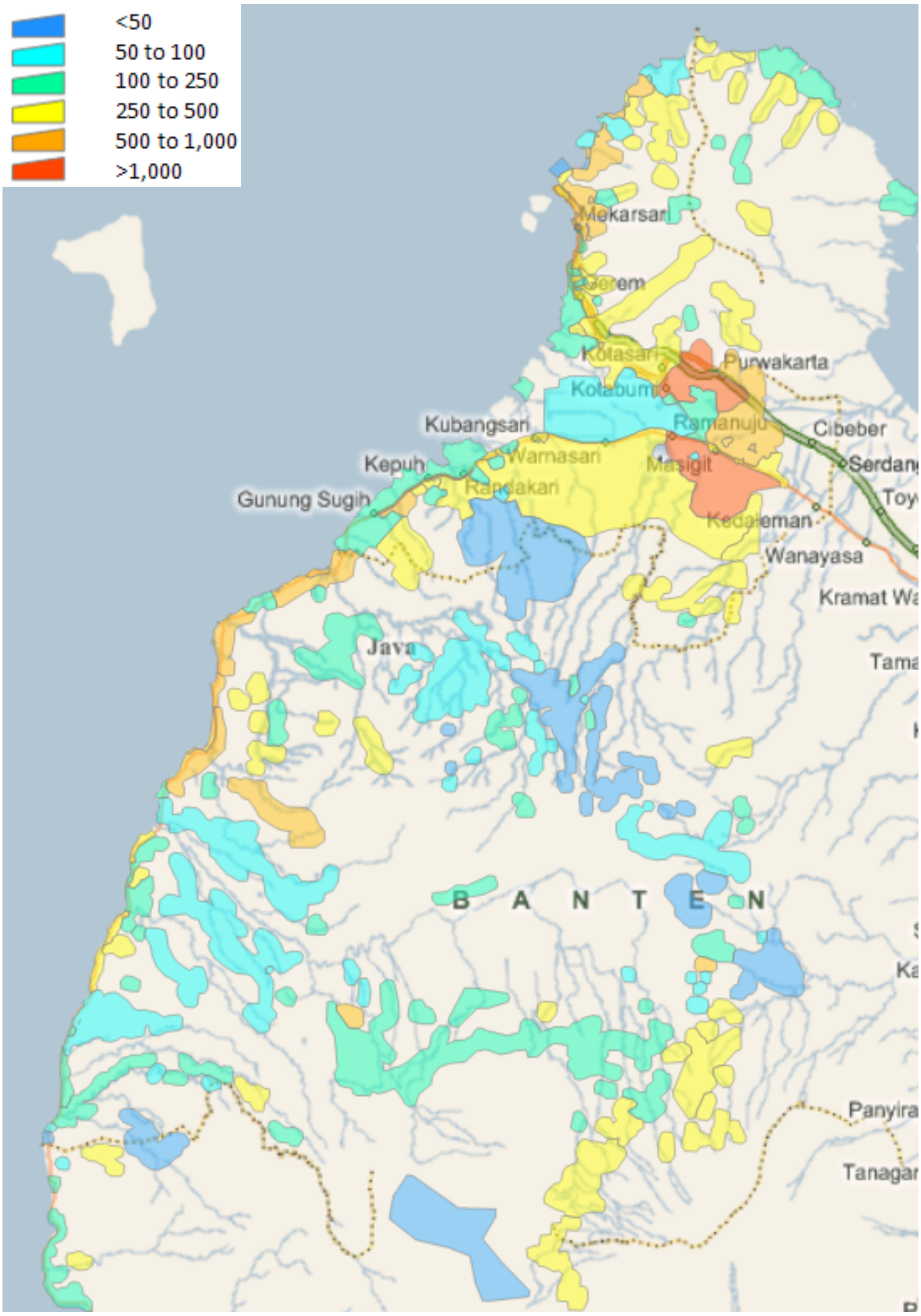
A.2.1 LAND USE CLASSIFICATION MAP



A.2.2 BUILDING COUNT MAP



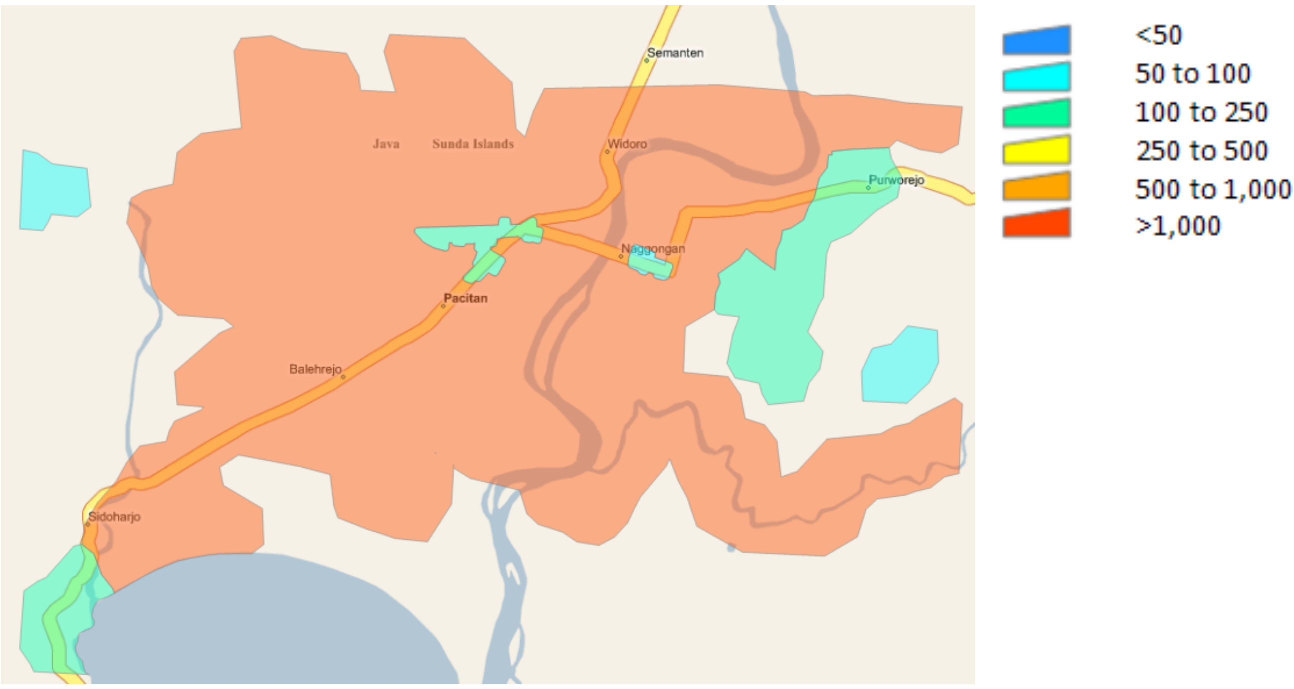
A.2.3 BUILDING DENSITY (BUILDINGS PER SQ KM) MAP



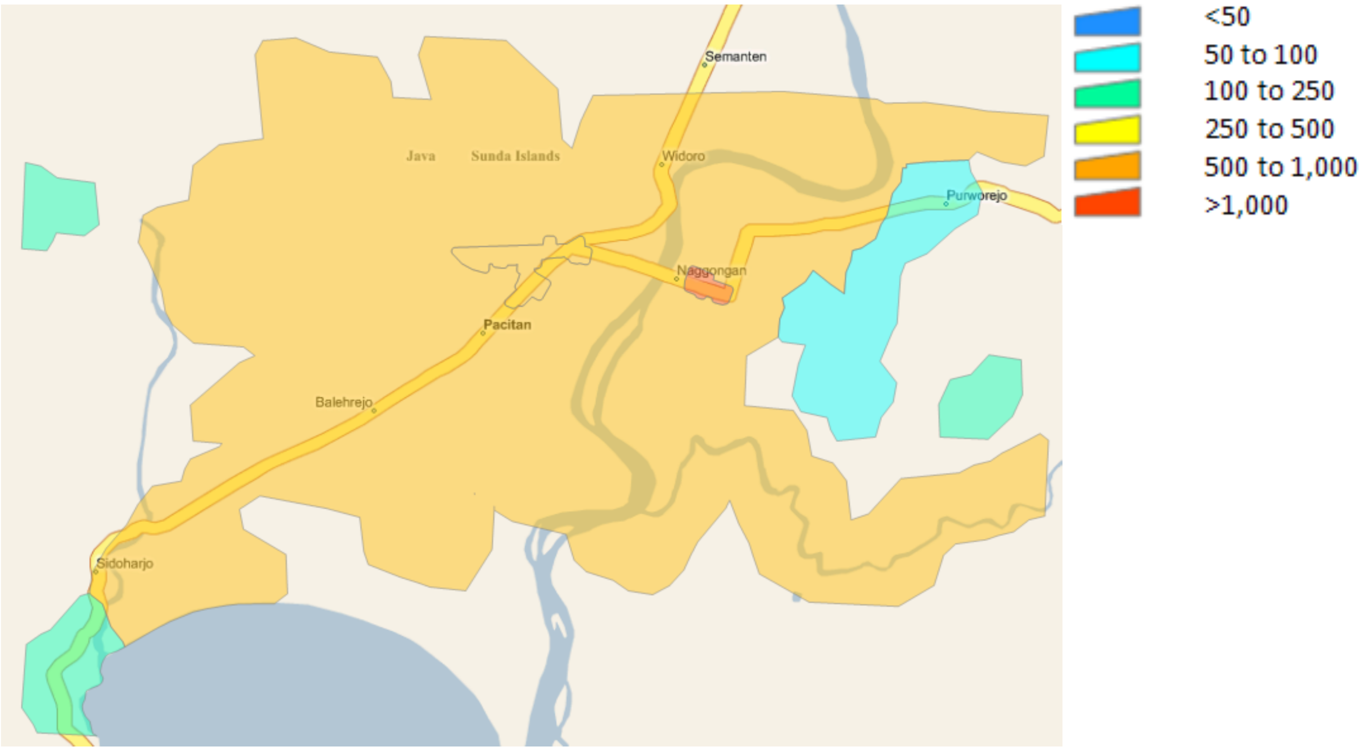
A.3 Pacitan

A.3.1 LAND USE CLASSIFICATION MAP

A.3.2 BUILDING COUNT MAP



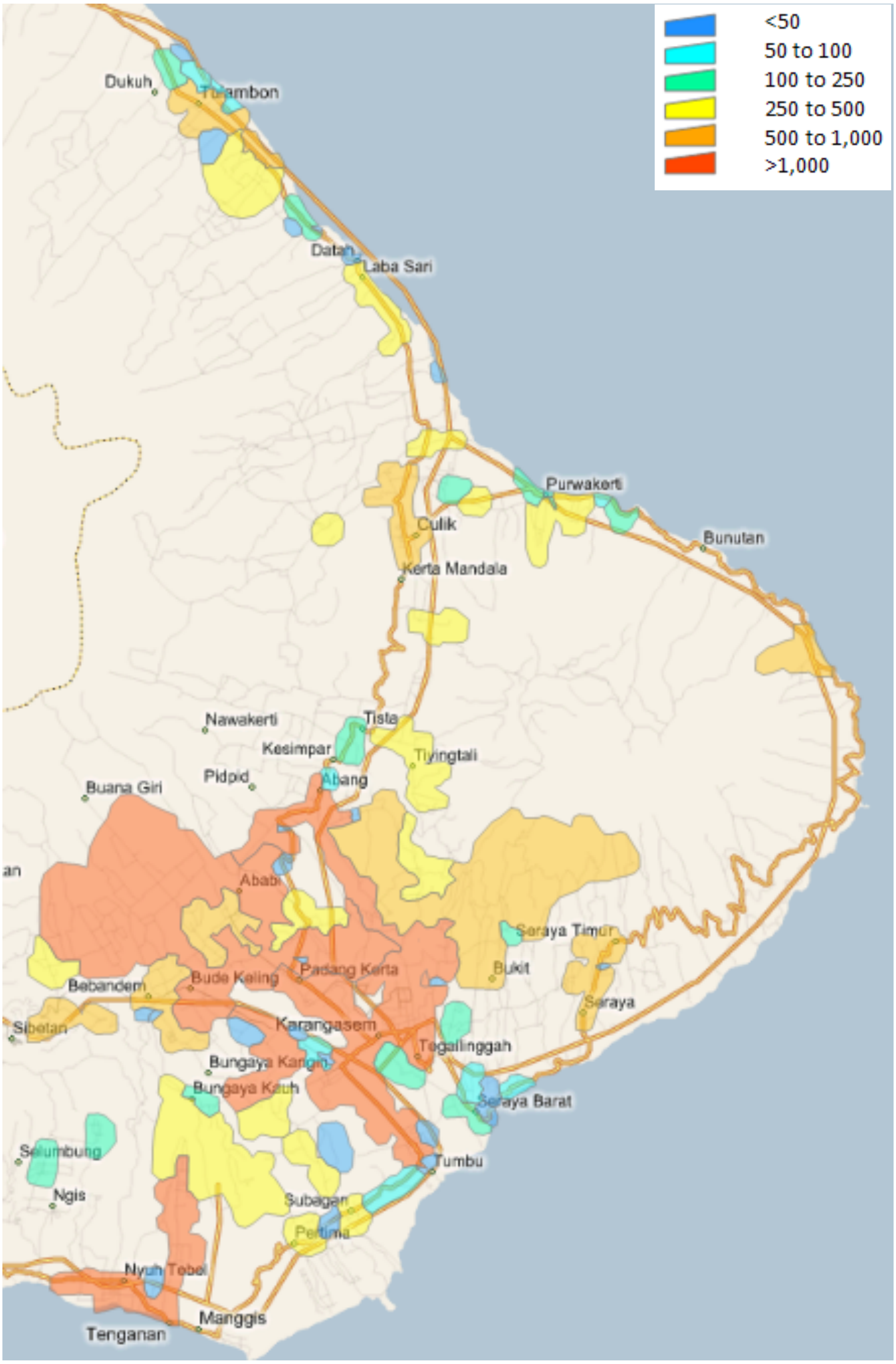
A.3.3 BUILDING DENSITY (BUILDINGS PER SQ KM) MAP



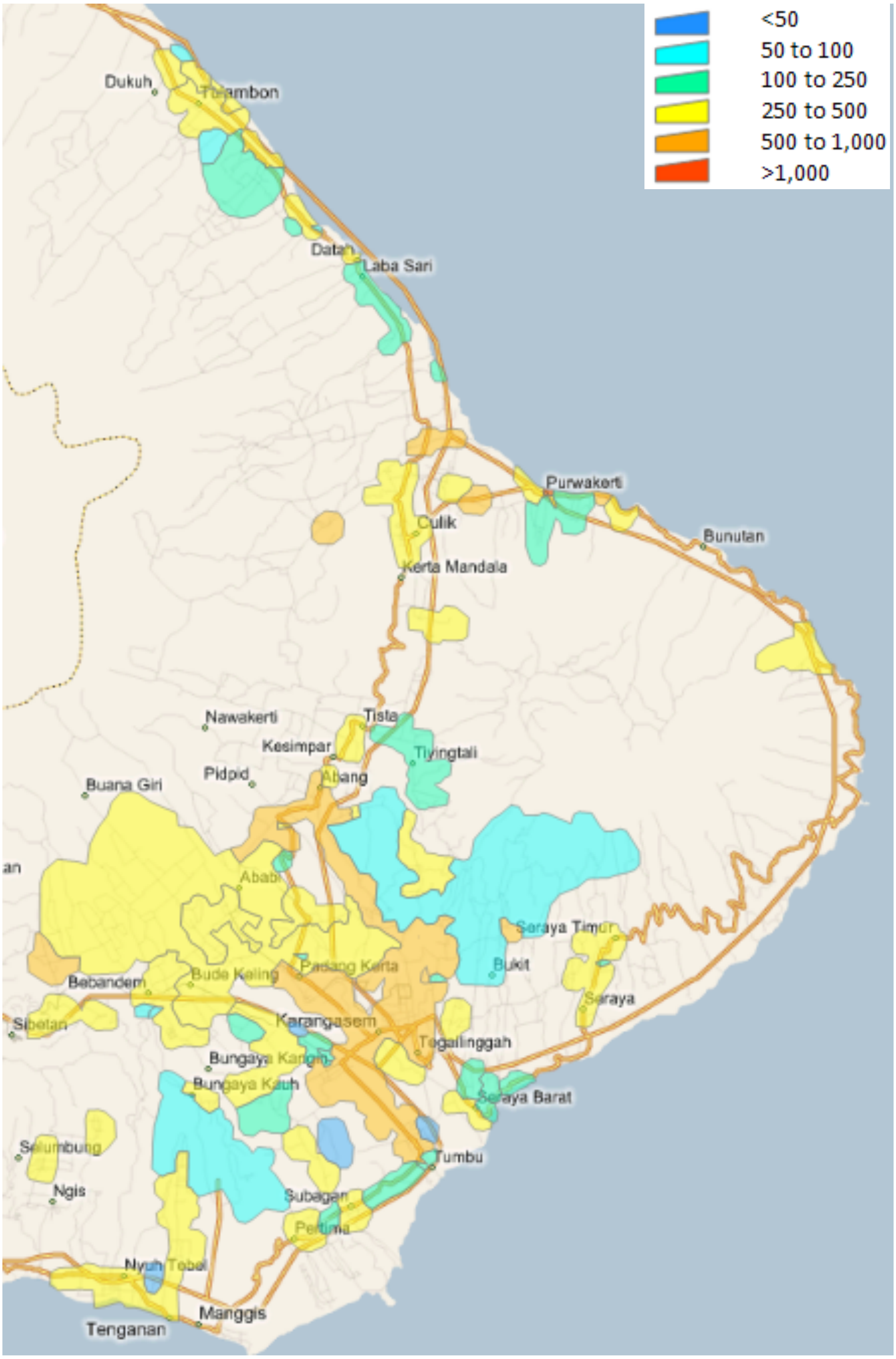
A.4 Bali

A.4.1 LAND USE CLASSIFICATION MAP

A.4.2 ***BUILDING COUNT MAP***

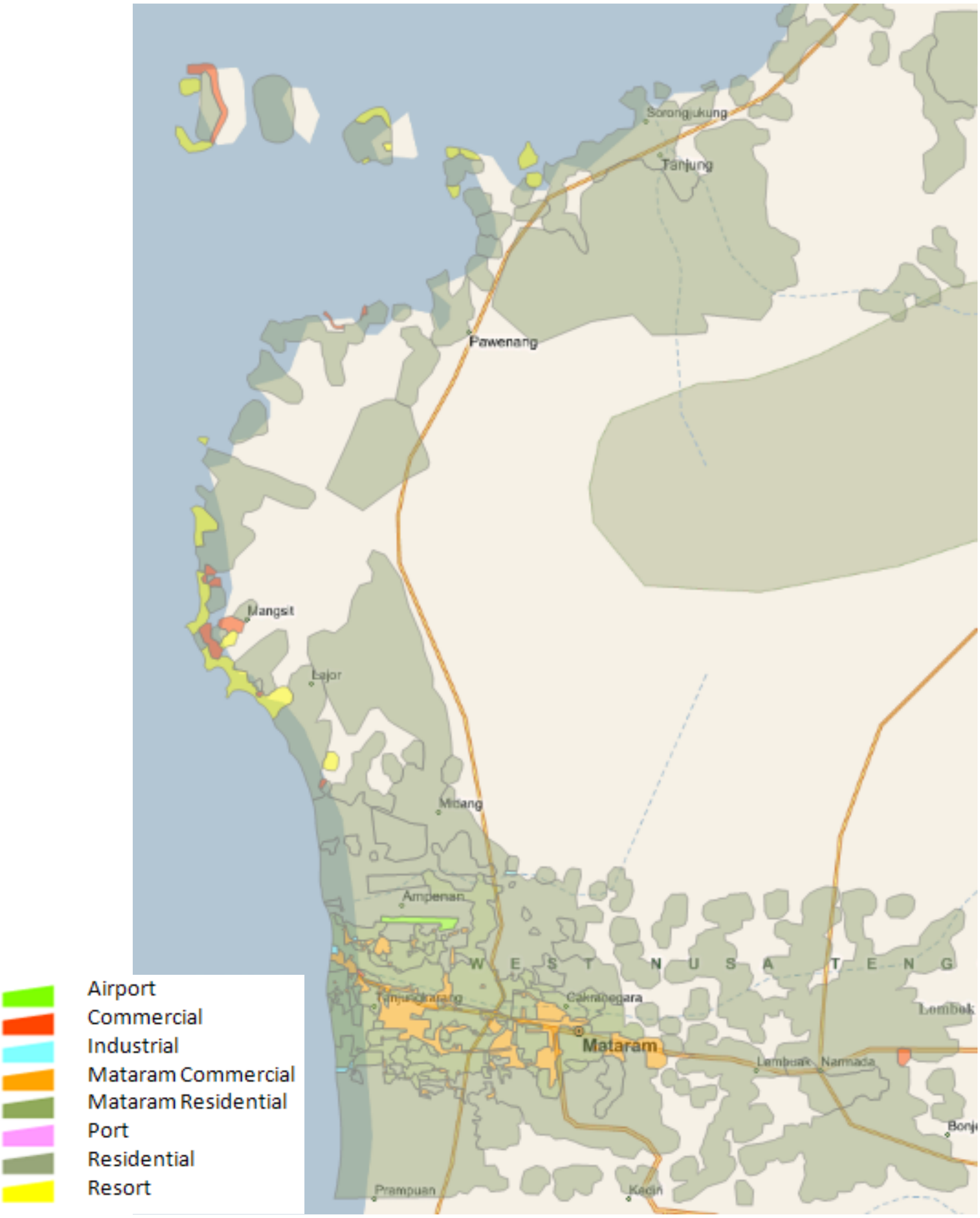


A.4.3 BUILDING DENSITY (BUILDINGS PER SQ KM) MAP

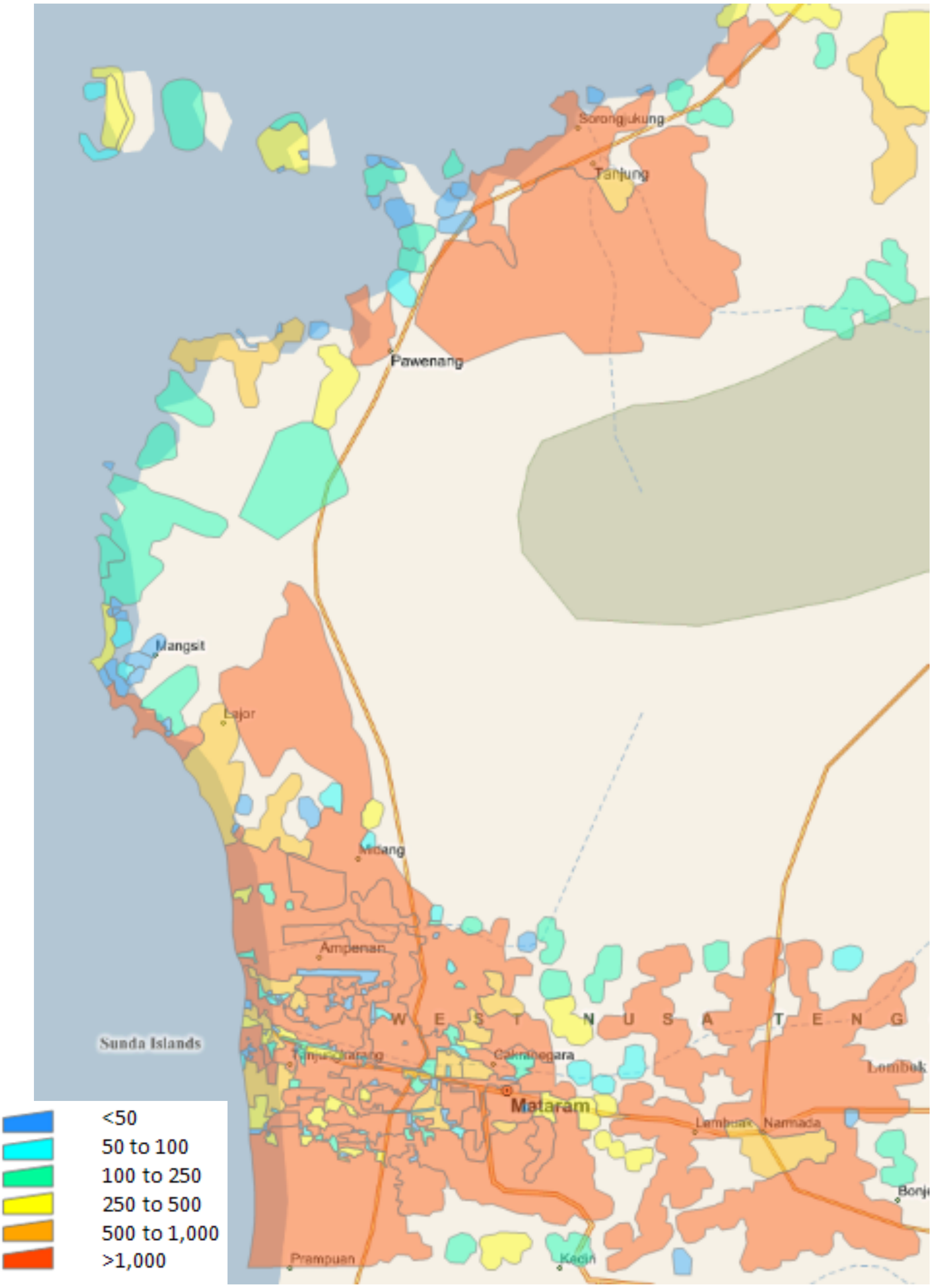


A.5 Lombok

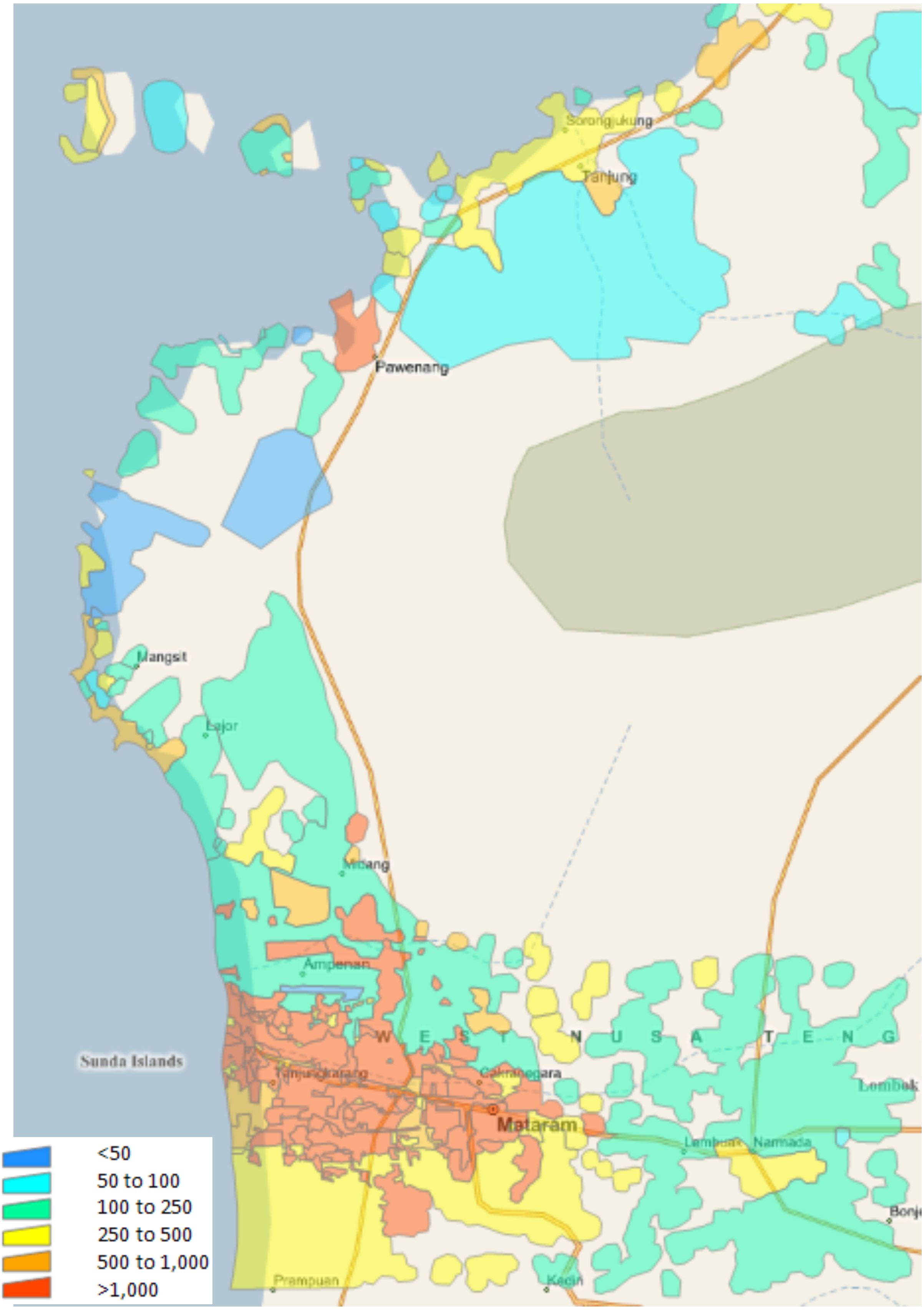
A.5.1 LAND USE CLASSIFICATION MAP



A.5.2 BUILDING COUNT MAP



A.5.3 BUILDING DENSITY (BUILDINGS PER SQ KM) MAP



APPENDIX B Metadata

B.1 Land Use

Format: ShapeFile

Projection: WGS84 Lat/Long

Fields:

- ZoneID: Unique ID of the land use zone
- Location: Location of the zone
- LandUse: Land use category
- LandUseKM: Area of the zone in square kilometers
- Num_bldgs: Number of buildings in the zone
- Bldg_Sq_Mt: Area of buildings in square meters

B.2 Building Counts

Format: Access Table

Fields:

- Zone ID: Unique ID of the land use zone
- Location: Location of the land use zone
- Land Use: Land use category
- Basic Structure Type: Structural categorization – Basic types
- Detailed Structure Type: Structural categorization – Detailed types
- Number of Stories: Number of Stories
- Number of Buildings: Number of buildings in this zone

Square Meters of Building Area: Total number of square meters for building area

B.3 Imagery and Field Photographs

Satellite Imagery:

- The satellite imagery is first separated by original vs. pan sharpened then by the area the imagery covers.
    - The original imagery is provided in two formats: multispectral (R,G,B,NIR) and panchromatic, all as geo-referenced TIFF files.
    - The pan-sharpened imagery is provided as combined band geo-referenced ECW and TIFF files.

Ground survey photos:

- The ground survey photos are named according to the team that collected the photos in JPEG format. Refer to the master survey data tables (fields Photo1 to Photo9) for building-to-photo association. Smaller thumbnails of the imagery are also included in the thumbs folder.

APPENDIX C Exposure Classification Based on Requirements from PT Maipark Loss Model

The basis for establishing these classifications were 1) what data was obtainable through aerial and satellite data, 2) what data was accessible through ground surveys, and 3) what general construction information was obtainable from local engineers in Indonesia.

1. **Occupancy** (assigned using satellite imagery; confirmed in field)

Residential	Commercial
Government	Education
Industrial	Manufacturing
Emergency services	Agricultural
Petrochemical	Resort
Power generation	

2. **Height** (low-rise, medium-rise, high-rise) defined using field observation notes on number of stories.

3. **Year of construction** (determined using field observations: profile area by era, based on best information and local knowledge). Eras are: pre-1955, 1955-1971, 1971-1983, 1983-1991, 1991-2002, 2002-present

Code Timeline for Indonesia:

- 1955 – The Indonesian Reinforced Concrete Code.
- 1970 – The Indonesian Loading Code.
- 1971 – The Indonesian Reinforced Concrete Code.
- 1983 – The Indonesian Seismic Code for Building Design
- 1991 – The Indonesian Concrete Code.
- 2002 – The Indonesian Seismic Resistant Design Standard for Building Structures
- 2002 – The Indonesian Concrete Code
- 2006 – Technical guidelines for Seismic Resistant Home and Building
- 2010 – Earthquake Hazard Map as reference to The Indonesian Seismic Resistant
- Design Standard for Building Structures

4. **Structural Types** (determined from field observations – profile materials as a minimum, and framing systems where possible).

Masonry

Rubble stone, field stone, Adobe (earth brick), Simple stone or Massive stone
Unreinforced, with manufactured block units
Unreinforced, with reinforced concrete floors
Reinforced masonry
Confined masonry (within a reinforced concrete frame)

Reinforced Concrete

Frame
Shear wall
Precast frames

Steel Structures

Moment frame
Braced frame

Light frame (transverse-frame; longitudinal-steel rod tension-only bracing)

Timber Structures

Open frame at grade

Shear wall at grade

Dwelling anchored at grade

Dwelling elevated on piers or stilts

Other Common Types (define in field)

____

For each structural type, also note:

Roof Type – thatched, plywood, corrugated metal, concrete slab, clay tile.

APPENDIX D Field Survey Form

Building Survey Form

Location

Latitude: Longitude:

Occupancy

Residential
Commercial
Industrial
Agricultural
Education
Emergency Services

Government
Manufacturing
Petrochemical
Resort
Port
Power generation

Number of stories: (1,2,3 etc):

Year of construction

pre-1955
1955-1971
1971-1983

1983-1991
1991-2002
2002-present

Structure Type

Reinforced Concrete
- Frame
- Shear wall
- Precast frames
- Unknown

Timber /Wood
- Open frame at grade
- Shear wall at grade
- Dwelling anchored at grade
- Dwelling elevated on piers or stilts
- Unknown

Steel
- Moment frame
- Braced frame
- Light frame (transverse-frame; longitudinal-steel rod tension-only bracing)
- Unknown

Masonry
- Rubble stone, field stone
- Adobe (earth brick)
- Simple stone
- Massive stone
- Unreinforced, with manufactured stone units
- Unreinforced, with reinforced concrete floors
- Reinforced masonry
- Confined masonry (within a reinforced concrete frame)
- Unknown

Roof Type
- Thatched
- Plywood
- Corrugated metal
- Concrete slab
- Clay tile
- Unknown

APPENDIX E Attribute Summary Tables by Region

Location	Roof types	Percentage
Anyer	Clay tile	57%
Anyer	Concrete slab	9%
Anyer	Corrugated Metal	28%
Anyer	Plywood	2%
Anyer	Thatched	3%
Anyer	Unknown	1%
Total		**100%**
Kalianda	Clay tile	68%
Kalianda	Concrete slab	11%
Kalianda	Corrugated Metal	20%
Kalianda	Unknown	<1%
Total		**100%**
Lombok	Clay tile	70%
Lombok	Concrete slab	4%
Lombok	Corrugated Metal	25%
Lombok	Plywood	<1%
Lombok	Unknown	<1%
Total		**100%**

Location	Stories	Percentage
Anyer	1	87%
Anyer	2	12%
Anyer	3	<1%
Anyer	7	<1%
Anyer	8	<1%
Total		**100%**
Kalianda	1	82%
Kalianda	2	17%
Kalianda	3	1%
Total		**100%**
Lombok	1	72%
Lombok	2	25%
Lombok	3	2%
Lombok	4	1%
Total		**100%**

Location	Occupancy	Percentage
Anyer	Commercial	35%
nyer	Education	4%
Anyer	Government	2%
Anyer	Industrial	7%
Anyer	Religious	2%
Anyer	Residential	46%
Anyer	Resort	5%
Total		**100%**
Kalianda	Commercial	34%
Kalianda	Education	3%
Kalianda	Government	3%
Kalianda	Industrial	<1%
Kalianda	Religious	1%
Kalianda	Residential	58%
Total		**100%**
Lombok	Commercial	12%
Lombok	Education	3%
Lombok	Government	9%
Lombok	Industrial	<1%
Lombok	Religious	2%
Lombok	Residential	74%
Total		**100%**

Location	Year built	Percentage
Anyer	1955-1971	2%
Anyer	1971-1983	4%
Anyer	1983-1991	17%
Anyer	1991-2002	29%
Anyer	2002-present	48%
Total		**100%**
Kalianda	1971-1983	2%
Kalianda	1983-1991	17%
Kalianda	1991-2002	38%
Kalianda	2002-present	43%
Total		**100%**
Lombok	1955-1971	3%
Lombok	1971-1983	23%
Lombok	1983-1991	26%
Lombok	1991-2002	28%
Lombok	2002-present	17%
Lombok	Pre-1955	2%
Total		**100%**