Last-Mile - Numerical *Last-Mile* Tsunami Early Warning and Evacuation Information System

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1 Introduction

The joint research project funded by DFG/BMBF (Sponsorship code: 03G0666A-H) develops a numerical last-mile tsunami early warning and evacuation information system on the basis of detailed earth observation data and techniques as well as unsteady, hydraulic numerical modelling of small-scale flooding and inundation dynamics of the tsunami, including evacuation simulations in the coastal hinterland for the city of Padang, West Sumatra, Indonesia.

The joint research project is composed of five working packages, based on field expertise of each working partners namely socio-economic vulnerability assessment (WP 1000), inundation scenarios, flow analysis (WP 2000), geodatabase, information system and vulnerability assessment (WP 3000), evacuation analysis, and pedestrian traffic optimization (WP 4000) and highly-resolved 3D-model of Padang (WP 5000) based on aerial large-scale topographic mapping.

The following sections display the results of each working package for the third and last year of the project.

2 WP 1000: Socio-economic vulnerability assessment

Within this working package, the main parameters in the social dimension that create vulnerability of the people to tsunamis in the context of evacuation were identified and assessed, related with the following objectives:

- To identify how the urban spatial structure shapes the exposure of various population groups as a function of time, which will differ their evacuation capability spatially
- To identify spatial difference of access to various warning dissemination media as well as their dissemination effectiveness, which determine delay in starting an evacuation
- To identify need of socialization activities to enhance awareness and knowledge related with evacuation, which promote appropriate evacuation behaviour

Descriptive and multivariate analysis were carried out to identify the significant parameters for each theme and objective (Taubenböck et al., 2009a), primarily using data from our questionnaire-based household and critical infrastructures surveys as well as additional qualitative information from the local actors. Additionally, surveys from other organizations conducted in Padang city were used to complement our analysis. In the final phase of the project, the previously identified parameters were further developed into applicable tools in form of vulnerability indicators and maps to support evacuation planning and associated urban planning purpose, such as urban settlement and infrastructure development strategies.

Dynamic Exposure

Distribution of population as a function of time was found to vary by social groups due to the fact that different social groups have different daily activity pattern. The variation was analysed especially between the more vulnerable group in terms of physical ability to conduct evacuation: the women, children and elderly, and the less vulnerable group: the men in productive age. The parameters and analysis results were combined with the physical structure of the coastal city of Padang derived from remote sensing analysis and additional building survey, as an extension of the population distribution conducted by the Working Package 3000 (See Setiadi et al, 2010, Taubenböck et al. 2008). It was identified that especially the dense settlement areas, areas with a lot of mixed use houses with trading activities and schools are the places where the women, elderly and children are concentrated during the morning and afternoon time. These are also the places facing most difficulties if there is lack of access to evacuation places.

As the final product, a set of exposure maps for three different day times (morning, afternoon, night) showing the distribution of women, children and elderly, and male in productive age was generated (Figure 1). The maps shall be used as basis information to estimate the potentially affected population by social groups and to identify the places where evacuation shelters and assistance are mostly needed. The results were also delivered to the Working Package 4000 as input parameters for evacuation scenarios in the evacuation modelling.

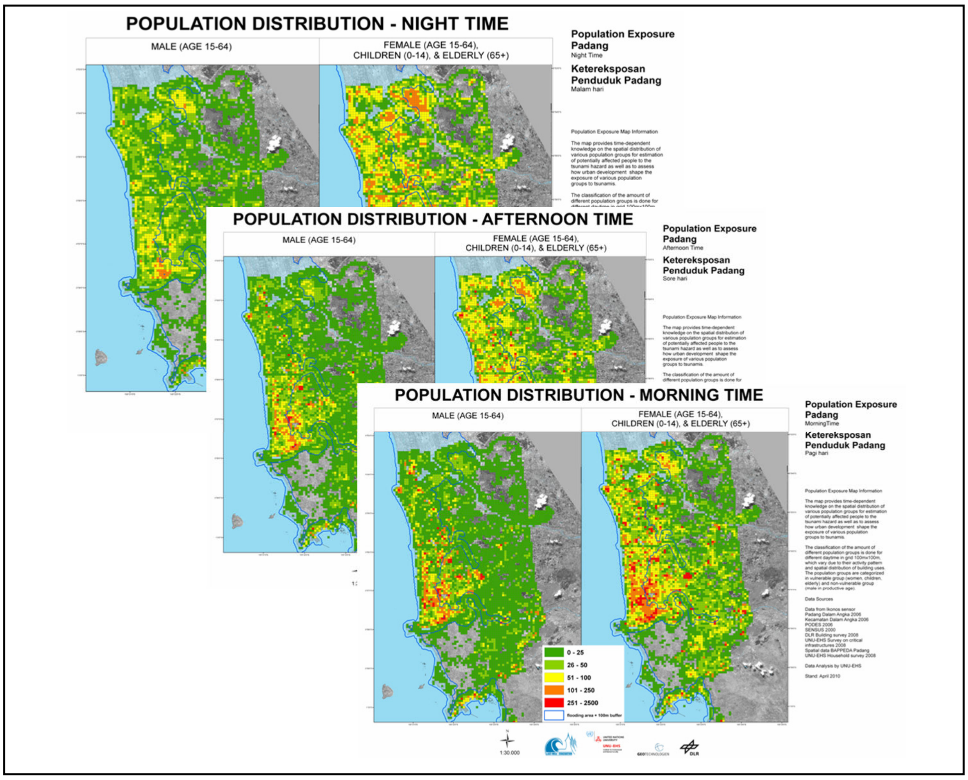

Figure 1. Maps of Distribution of Population Groups in the Night, Afternoon, and Morning Time

Effective Dissemination of Tsunami Early Warning and Evacuation Guidance

The tsunami early warning can be disseminated to the people either through public media or private media. The currently existing public media in Padang are the official siren towers, pilot mosques trained and equipped with radio to access the official warning, and community response teams in some villages trained and equipped with radio to access the official warning. The private media are radio and television which can directly receive and transmit the official warning, as well as mobile and landline phone to indirectly disseminate the warning to social network.

Based on the qualitative information, the need of using public media in synergy with private media to disseminate the warning was emphasized. To assess the effectiveness of different private media, data analysis of the surveys on experiences particularly during the two recent strong earthquakes in Padang (UNU-EHS survey for the event in year 2007 and GTZ survey for the recent one in 2009) was conducted and weights for the media were derived (Table 1). Additionally, the public media were equally weighted due to the consideration that both official sirens and further guidance from the mosques or community response teams are necessary for an effective warning and evacuation guidance dissemination.

Table 1. Ranking and Weighting of Various Private Media for Warning Dissemination

Rank	Media	Average dissemination rate from the 2 EQ events	Derived weights (0-1)
1	Radio	53%	0.6
2	Television	24%	0.25
3	Landline phones	9%	0.1
4	Mobile phone	5%	0.05

As the final product, a set of maps showing a classification of access to warning as a composite index of the weighted media availability by village unit was generated based on the household survey and spatial coverage areas of the allocated public media in the city.

Awareness and Knowledge of Evacuation

Based on correlation analysis for single nominal variables with the intended evacuation behaviour variable (cross-tabulations analysis using Kendall tau-b coefficient), and multinomial logistic regression for testing the model for the household awareness index, the variables were filtered. The final "Awareness Index" consists of the parameters of basic knowledge of tsunami, acknowledgement of tsunami hazard, acknowledgement of vulnerability and need for preparedness, and perception of own evacuation capability. The final index using three awareness classes shows significant correlation with the intended evacuation behaviour with Kendall Tau-b coefficient 0.146 (significance level 0.001), where the households categorized as having high awareness showed almost 20% more households with intention to immediately evacuate compared to the ones with low awareness. Additionally, other variables which did not show significant correlation with the intended evacuation behaviour but considered as important for conducting a time-efficient evacuation were comprised in the "Additional Knowledge Index", namely knowledge of existing tsunami early warning system, knowledge of recommended evacuation routes, location and signs, and existing preparedness actions such as participation in socialization or simulation. In the process of developing the indicators, we acknowledged that there are other factors besides awareness and knowledge that play additional significant role in evacuation behaviour such as clearness of the evacuation guidance, current availability of evacuation infrastructures, etc.; nevertheless, these indices emphasize the importance of socialization activities and their continuous monitoring to support evacuation planning

3 WP 2000: Tsunami Inundation Scenarios

Latest results from the work package 2000 "Tsunami inundation modelling and flow analysis" are presented herein. Recent findings reported in Taubenböck et al (2009a) revealed the general meaningful methodology of a probabilistic approach (multi-scenario) in tsunami inundation modelling where calibration datasets are unavailable. Subsequently, more recent analysis focused on the special demands that were addressed by local stakeholders in the city of Padang in a first Padang consensus workshop held in August, 28th, 2008. The consensus members agreed the deployment of best available geo data in combination with the most plausible tsunami source modelling by D. H. Natawidjaja (LIPI) in order to produce credible tsunami inundation and hazard maps for official deployment. The methodology and the modelling strategy have been adopted from former approaches, i.e. published in Goseberg and Schlurmann (2009b) and Taubenböck et al. (2009c).

To fulfil the given requirements and demands stated by the Padang community, additional numerical simulations were accomplished. A consistent set of eight plausible scenarios was derived based on the variable parameters, namely: total amount of slip in the source region, tidal water level in the vicinity of Padang and the utilisation of either digital elevation (DEM) employing roughness values or digital surface models (DSM) incorporating houses and other infrastructure. Table 2 summarizes the various parameter combinations for the most plausible scenario development.

Table 2: Combination matrix for scenario development in the Padang consensus process

Scenario identifier (SID)	Source 1b	Source 2b	MSL[1]	MMHWL[2]	Digital elevation model (DEM)	Digital surface model (DSM)
SID – 01	X		X		X	
SID – 02	X			X	X	
SID – 03	X		X			X
SID – 04	X					X
SID – 05		X	X		X	
SID – 06		X		X	X	
SID – 07		X	X			X
SID – 08		X		X		X

The source model parameters (coupling amount, slip angle, dip angle, moment magnitude, etc.) were personally communicated by D. H. Natawidjaja, LIPI. The initial seafloor displacement for the single model runs was calculated according to Mansinha & Smylie's model (Mansinha & Smylie, 1971). In contrast to the original methodology in which only one fault patch was applied, here a set of 342 sub-patches are mimicking the rupture mechanism instead. The initial sea surface displacement has been gained by a superposition of every single result for each sub-patch. A sensitivity analysis varying the patch geometry and size revealed the applicability of the new approach using 20 by 20 km patches. The resulting initial seafloor displacement was transferred to the sea surface to impel the numerical hydrodynamic model at the initial time step. Aiming at an equivalent level of confidence compared to the probabilistic analysis, a safety factor of 0.50 was applied to the initial source model's displacement as a further conservative alteration approach. Hence, epistemic uncertainties associated with incomplete knowledge of the geophysical phenomena and in relation to the mathematical derivation of the source model by analysis of cGPS measurements and micro coral proxies are appropriately covered (cp. Sieh et al. (2008)). Additionally, two different initial water levels in the numerical model were tested. Mean sea level and the mean of the monthly highest water level were integrated for the scenario development. Since different types of geometries affect the results of the numerical models to first order (Goseberg et al (2009a)), digital elevation as well as digital surface models were applied to the numerical scheme.

The recent 2nd workshop on the Padang Consensus Process (PCP) was held on 12th – 13th of April, 2010 in Padang. The attendees consisted of representatives from Padang city, province

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[1] Mean sea level

[2] Mean of monthly highest water level

West Sumatra, Andalas University as well as scientists from Indonesia, Germany and other countries. From the scenario matrix (cp. table 2), scenario SID – 08 and - based on this scenario - the Last-Mile – Evacuation inundation/hazard results were chosen for official purposes and for further spatial and evacuation planning efforts. The chosen combination of modelling parameters most suitably reflects the excellent quality of the underlying data sets and the demand for the most credible as well as secured tsunami hazard mapping in the city of Padang. Furthermore, this modelling approach is widely accepted in the scientific community as stated by internationally well known geophysicist and engineers consulted during decision-making process.

Based on the constraints in modelling described above, final tsunami inundation and hazard maps which have been chosen are presented here. Figure 2 depicts the discrepancies in the maximum inundation area between both approaches when either DEM or DSM datasets are applied in the hydro-numerical tsunami simulation onshore. Evaluating the content of employing these two geo-datasets, the most significant dissimilarity is related to the absence houses and, thus, the lack of infrastructure induced macro-roughness in the DEM. These urban features are clearly represented in the DSM by incorporating the real solid objects, which – in terms of hydrodynamics – clearly redirect, canalize and retard the onshore tsunami flow field by means of higher impacts (larger wave heights and flow velocities) on the beach front and evidently a lower inundation extent on land. The maximum affected area by the tsunami run-up amounts to 24.6 km² for the DSM and to 38.8 km² for the DEM. The increase in inundated costal hinterland is therefore 57.6 percent of the inundation due to the simulation run applying the DSM.

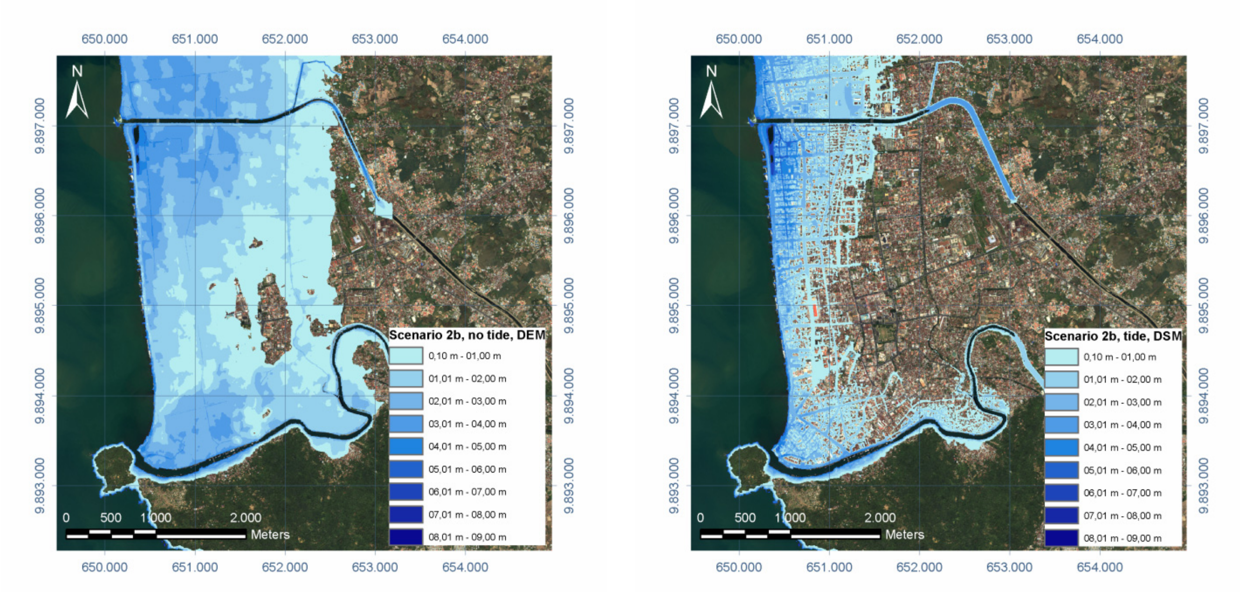


Figure 2. Comparison of maximum inundation areas, when either digital elevation models (left or digital surface models (right) are applied, classification of inundation depth in classes of 1.0m from dark blue (higher water level) to light blue

Since the physically meaningful terms inundation and flow impact are not directly equivalent to the commonly proposed tsunami hazard approach, an eligible measure for the final hazard mapping is required and subsequently determined for dealing with evacuation planning. Both inundation and flow depth quantifies the instantaneous potential energy pertained by the tsunami-induced flow onshore. In line with eye witness reports and various other media coverage, the flooding phase of the wave penetration inland is most often characterised by an accelerated, dynamic and violent flow carrying suspended sediments and debris taking entirely action in the streets normal to the shoreline. Therefore a second physically significant part is added to the commonly employed tsunami hazard measure in form of incorporating the inherent kinetic energy stemming from the canalized flow field in the urban street network. Thus, equation 1 accounts for either physically meaningful quantifies and resembles the specific energy of the flow field.

$$E_{spec} = h + \frac{v^2}{2g} \qquad \text{Eq. 1}$$

Figure 3a displays this particularly proposed tsunami hazard mapping approach in the city of Padang, where five hazard classes are utilised. The measure for the depicted hazard map is the specific energy governed in [m]. The medium class category has been selected according to recent, full scale physical model tests, which analysed the interaction between humans exposed to steady state flow conditions. Figure 3b illustrates the main result of the physical model test (Rescdam, 2000). It shows that a threshold of 1 m/s and 1 m flow depth is sufficient for humans to lose stability or manoeuvrability in the flow while trying to evacuate. Therefore the medium class category (red colour) in the hazard classification has been adjusted to these parameters and is proposed for further planning processes.

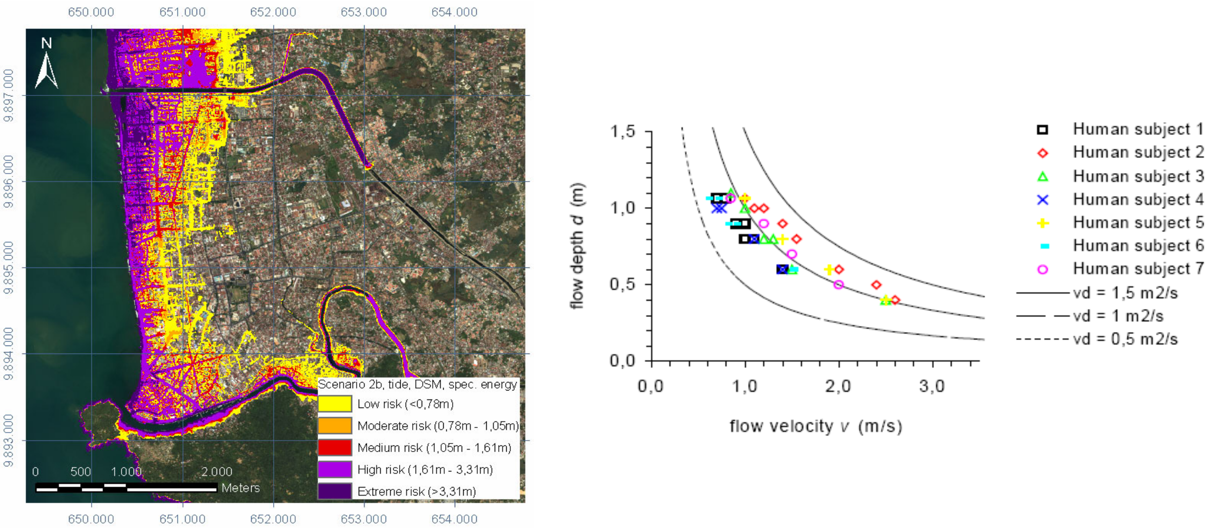


Figure 3. (a) Example of the proposed hazard mapping at Padang displaying specific energy in five classes. (b) Loss of stability or manoeuvrability due to different flow regimes (Rescdam, 2000)

The validation and calibration of the hydro-numerical models is of essential importance. However, for the Padang region meaningful data from historical tsunami occurrences are sparse and lack in terms of calibration of the regional, but detailed tsunami inundation model. Nonetheless calibration datasets are consequently unavailable. To foster advances in credibility in the present tsunami hazard mapping in order to reduce underlying uncertainties governed by the incompleteness and numerical diffusion from mathematical formulations, a comparison of two different numerical model packages based entirely on an identical set of geo-data has been accomplished. Numerical results originating from both software packages ANUGA (Nielsen et al. (2005)) and TUNAMI N2 (Goto (1997)) have been analysed and evaluated for the near-shore wave forms and onshore inundation area. This direct comparison yields an excellent correspondence of both applied models. The overall agreement of maximum inundation contour lines exceeds 95 percent in most areas in the modelled urban domain. Thus, this validation adds further confidence to the inundation and hazard modelling in Padang and stresses the argumentation, if available, for the utilisation of highly-resolved geo-data basis and subsequent products in the subsequent processes of optimized evacuation planning and furthermore in coastal spatial planning efforts to lead in the long run to an overall disaster risk reduction attempt

4 WP 3000: Contribution of Remote Sensing to a comprehensive early warning chain

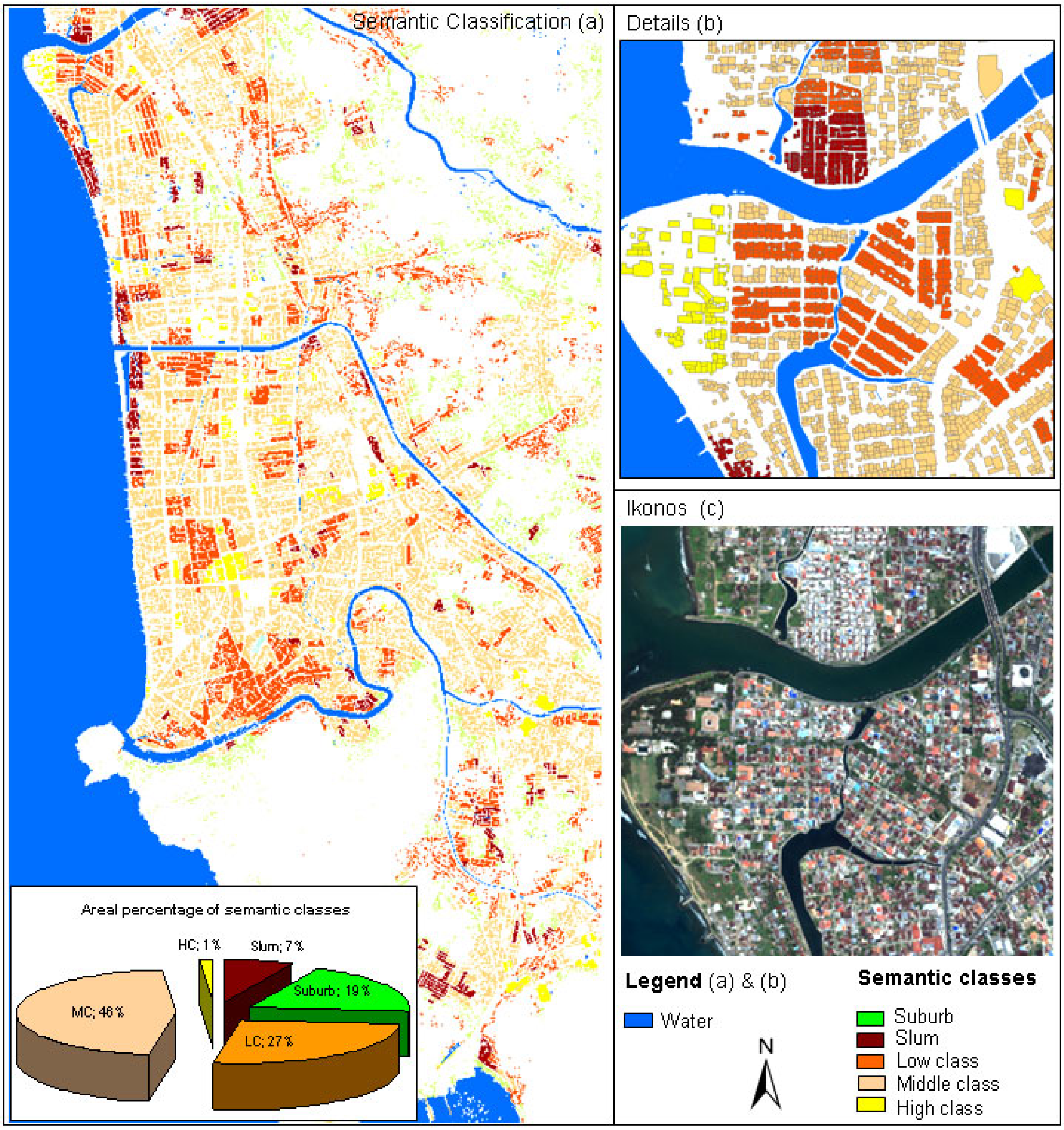
Multi-sensoral remotely sensed data from medium and high resolution optical as well as radar data enabled us to independently derive manifold land-cover information on the complex urban landscape of Padang: From a digital elevation model to a multi-temporal change detection on urban footprint level to an area-wide and up-to-date 3-D city model (Taubenböck et al., 2009a). Furthermore we now integrated additional external data sets for a more holistic data base. As examples, we surveyed the location of the planned and already installed sirens along the coastline in Padang; we also integrated detailed knowledge on the usage of the buildings from survey information in combination with structural information from remote sensing analysis.

We now used the knowledge on the physical environment of the urban landscape for interdisciplinary value-adding. Remote sensing generally enables direct measurements of the earth's surface and the spatial distribution of its physical objects. Social science is generally more concerned with why things happen than where they happen. "Socializing the pixel" is to take remote sensing imagery beyond this use in the applied sciences and toward its application in addressing the concerns of the social sciences. We stated the hypothesis that a city is the physical and architectonic reflection of the society that created it. We followed from it that the physical environment correlates with socio-economic parameters of the people residing there.

Using the physical urban morphology parameters from the manifold land-cover information a semantic classification has been performed. The idea of semantic classification aims at a first assumed interrelation between physically homogeneous sectors within the complex urban morphology and the socioeconomic characteristics of people residing there. The combination of the area-wide available statistical physical parameters describing the building stock of Padang per sector – built-up density, average house size, average building height, location – enables to identify physically homogeneous areas. This approach for semantic classification is generic, aiming at transferability on any urban area throughout the world with similar physical parameters available. Therefore, we used descriptive statistic values as Quartile (Q1, Q3), Median (Med) or Mean (M) to subdivide the different classes. The six resulting semantic classes are defined by the following statistical borders. An example, we classify 'slums' using built-up density values higher than the third quartile (Q3) of the complete spectrum of the built-up density values classified in Padang. Analogous, the buildings of slums are assumed to be smaller than Q3 and lower than Q1 of the particular spectrum of values classified for the city of Padang. Utilizing these statistical parameters the classification is not affected by cultural or regional characters of urban morphology occurring worldwide. With respect to this methodology, only the semantic nomenclature has to be adjusted on the particular structures and locations Taubenböck et al, 2009b).

Terminology of the semantic classes is based on housing quality and location. The housing quality is assumed to be higher with rising building size or height and lower built-up density.

We classify six different semantic classes – ‘informal settlements (slums)’, ‘suburbs’, ‘low class areas’ (LC), ‘middle class areas’ (MC) and ‘high class areas’ (HC). For every semantic class we assume typical physical conditions. As an example, slum areas are defined by the highest built-up density measured within the urban environment with mostly one storey buildings, with the smallest buildings sizes. With the nomenclature ‘slum’ the classification by solely physical parameters sets a first hint in the direction of assumed socioeconomic r3elevance.



The analysis if the socioeconomic parameter derived from the survey (WP1000) correlate with the semantic classification result from remote sensing data is two fold: First of all we test if the complete 1000 surveyed buildings show a basic interrelation with the classification based on the physical parameters and its subsequent semantic assumptions. Therefore we use the average values for the particular socioeconomic parameter for every semantic class as well as the standard deviation as a measure of homogeneity within one semantic class. In a second step we analyse if certain semantic classes, like slums or low class areas, although located at different areas of the urban environment (e. g. at the coast close to the city centre or at a suburban area), show homogeneous socioeconomic parameters. Therefore we use location-based analysis of the same semantic classes for testing homogeneity.

The results between the semantic classification results and the survey data basically show a correlation. Although the Pearson's correlation coefficient, which is a common measure to indicate the strength and direction of a linear relationship between two variables – shows for the socioeconomic parameter 'income' only a low correlation of 0.32, the location-based analysis shows a clear correlation. The analysis shows that the classified slum areas as well as the classified suburb areas reveal lowest income values independent from their location within the urban landscape. We also found consistent rising income levels to the semantic classes 'low class' and subsequently to 'middle class' areas. But, contradicting our hypothesis we measure lower income for the 'high class' in the northern area, while for the central area we have no high class buildings (Figure 5). In the southern area we observe what was stated in the initial hypothesis – a rising income. The analysis of the 'high' semantic class generally had a high uncertainty, due to very small number of sample buildings with complete information and also the fact that some of these buildings were found to have other functions as merely dwelled houses (e.g. storage, school, etc.). Thus we state that this consistent homogeneity of socioeconomic parameters within semantic classes is not applicable for the high class areas and that the location has higher impact on the income level at this semantic class. Despite this constraint the interdisciplinary approach enables to extrapolate punctual field work data onto the complete area of the urban landscape using remote sensing. Thus, remote sensing may provide a cost-effective method to reduce, but not replace, expensive ground data collection.

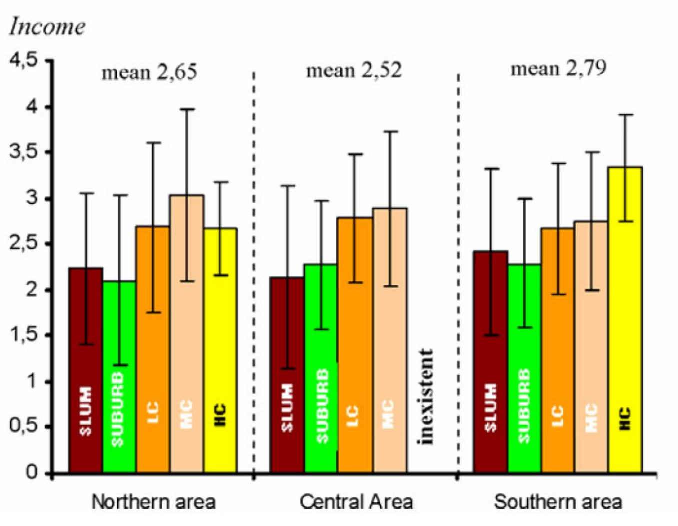


Figure 5: Location-based mean value correlation of semantic classes and the socioeconomic parameter income and its standard deviation

A further example of interdisciplinary value-adding is shown by WP 1000; with an assessment of population distribution at 3 times per day based on the correlation of survey and remotely sensed results. Basically all derived land-cover information was used by the project partners for inundation modelling (WP2000), evacuation modelling (WP4000) and visualization (WP5000).

The Earthquake in Padang on September 30, 2009

On September 30, 2009, a severe earthquake took place in the Indian Ocean with a magnitude of 7.9 and several aftershocks. The epicentre was registered about 50 km north-eastern of Padang in a depth of 85 km. Heavy shocks caused the collapse of many buildings and bridges, fires broke out and major parts of the technical infrastructure failed. More than 770 people died, more than 2100 are injured (information of October 2, 2009). A second earthquake with a magnitude of 6.6 occurred hours later on October 1 near the town of Sungai Penuh. Here as well, hundreds of houses were damaged, two people died and a large number became injured or homeless. Strong rain make rescue work difficult and caused landslides in some areas of the affected region. The International Charter on Space and Major Disasters was triggered to provide post-disaster satellite imagery for damage mapping and to support the aid response (www.zki.dlr.de).

The Last-Mile Project consortium was able to support the rapid mapping activities substantially with the manifold available data sets in the pre-disaster phase. While usually damages are mapped using post-disaster data on a raster basis of 250 meters, the preparation within the Last-Mile consortium to now deliver fast and reliable information on individual building level. The combination of the 3-D city model, the population distribution, the street network, the knowledge on safe areas, etc. with post-disaster remote sensing data, allowed within a few hours and days to provide a fast and more detailed spatial and quantitative information for rescue teams than ever before in the history of remote sensing. Figure 6 shows an overview on potential damage mapped after the earthquake on 30th of September 2009 using post-disaster satellite data. Figure 7 displays one example of an highly resolved map of the urban center in Padang indicating completely destroyed, damaged or not damaged buildings in addition with the calculated number of people in these buildings at the particular time of the earthquake.

Figure 6. City-wide overview of potential damage mapped after the earthquake on 30th of September 2009 using post-disaster satellite data

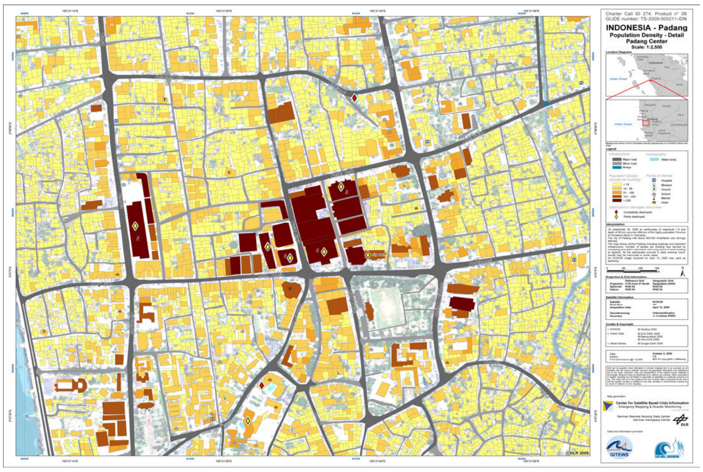


Figure 7. Rapid mapping result showing collapsed, damaged and non-damaged buildings at Padang center

5 WP 4000: General evacuation recommendations

In the last three years a comprehensive evacuation simulation framework has been developed for the city of Padang. The framework relies on results from the other working packages. The data integration and the framework itself have been discussed extensively (see e.g. Lämmel et al (2009, 2010a, 2010b). This section discusses the final results of the evacuation simulation and gives, based on these results, some general recommendations.

The evacuation simulation has been performed for several scenarios. Because of the limited space in this publication only two different scenarios will be discussed. The synthetic population corresponds to Padang's population distribution as it is in the morning for both scenarios. This data has been provided by WP 1000 and WP 3000 and comprises the spatial location of 321029 evacuees. The flooding data has been provided by WP 2000. The first scenario discussed in this section reflects the evacuation of the city without shelters for vertical evacuation and the second scenario corresponds to an evacuation with shelters.

In the simulation every evacuee chooses the fastest evacuation route under the given circumstances. The simulation result is an approximate Nash equilibrium. The advantage over the shortest path solution, where every one is on the shortest evacuation route, is that the Nash equilibrium takes congestion effects into consideration. This leads to substantial shorter evacuation times. A detailed discussion on this issue can be found in Lämmel et al, 2009.

Figure 6 (left) depicts the resulting evacuation times for the first scenario on a 250 m grid. Red colored areas are areas with an evacuation time of more than 40 minutes. Those areas are to be considered as highly endangered, where the situation could be improved by shelters for vertical evacuation.

Another important aspect is the street utilization during an evacuation. The red colored streets in Figure 8 (left) are highly utilized. Those streets can be seen as part of major evacuation routes. It is important that those streets are clear of obstacles during an evacuation. It seems natural to broaden those streets to get less congestion. However, this would not be robust since streets can become blocked (e.g. by collapsed buildings or abandoned cars) during an evacuation. Instead one could build evacuation routes in parallel to existing ones to get a more robust situation.

As discussed above the evacuation time in some areas of the city are more than 40 minutes, which is too high if the advance warning time is less than 40 minutes. Shelters for vertical evacuation could reduce the evacuation time. However, an arbitrary shelter constellation does not necessarily improve the situation for everyone. This phenomenon is shown in Figure 9. This figure shows the gains and losses on street level if shelters are integrated in the simulation (second scenario). Evacuees starting their evacuation on light green and green

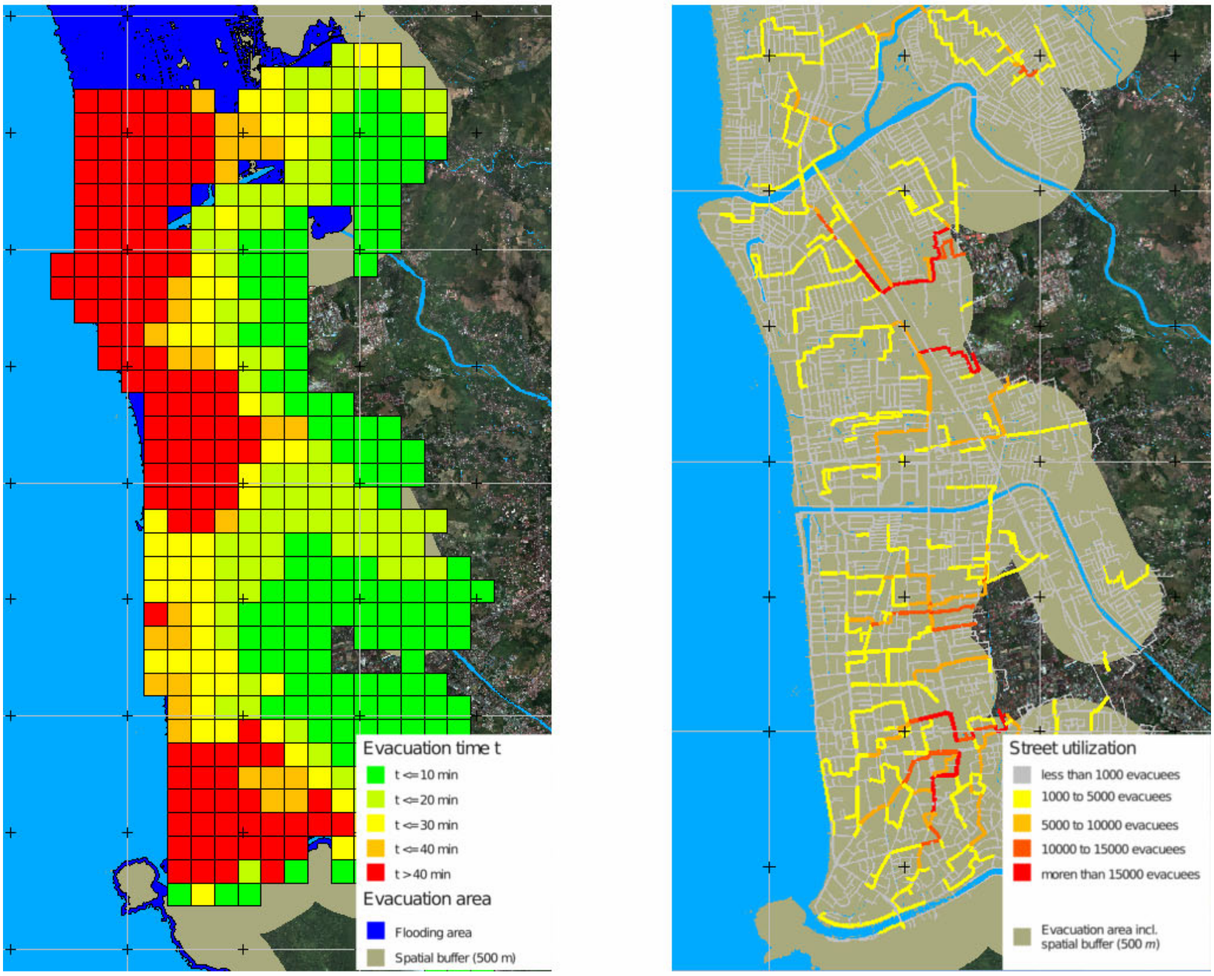


Figure 8. The left image shows evacuation times. Evacuation time increases from green (t <= 10 min) to red (t > 40 min). The right image shows the street utilization. Of particular interest are the red colored streets, those streets haven been taken by more than 15000 evacuees.

colored streets gain compared to an evacuation and those starting on orange and red colored streets loose. In particular evacuees starting from red colored streets lose more than 10 minutes compared to an evacuation without shelters. A reason for this phenomenon is that shelters can lead to additional queues on the streets, and thus to congestion which increases the evacuation time also for evacuees for whom there is not enough space in the shelters. To avoid this problem shelters should not be clustered but allocated corresponding to the demand and they should not be located too far away from the shore, so that evacuees from the coastal area have enough time to reach them.

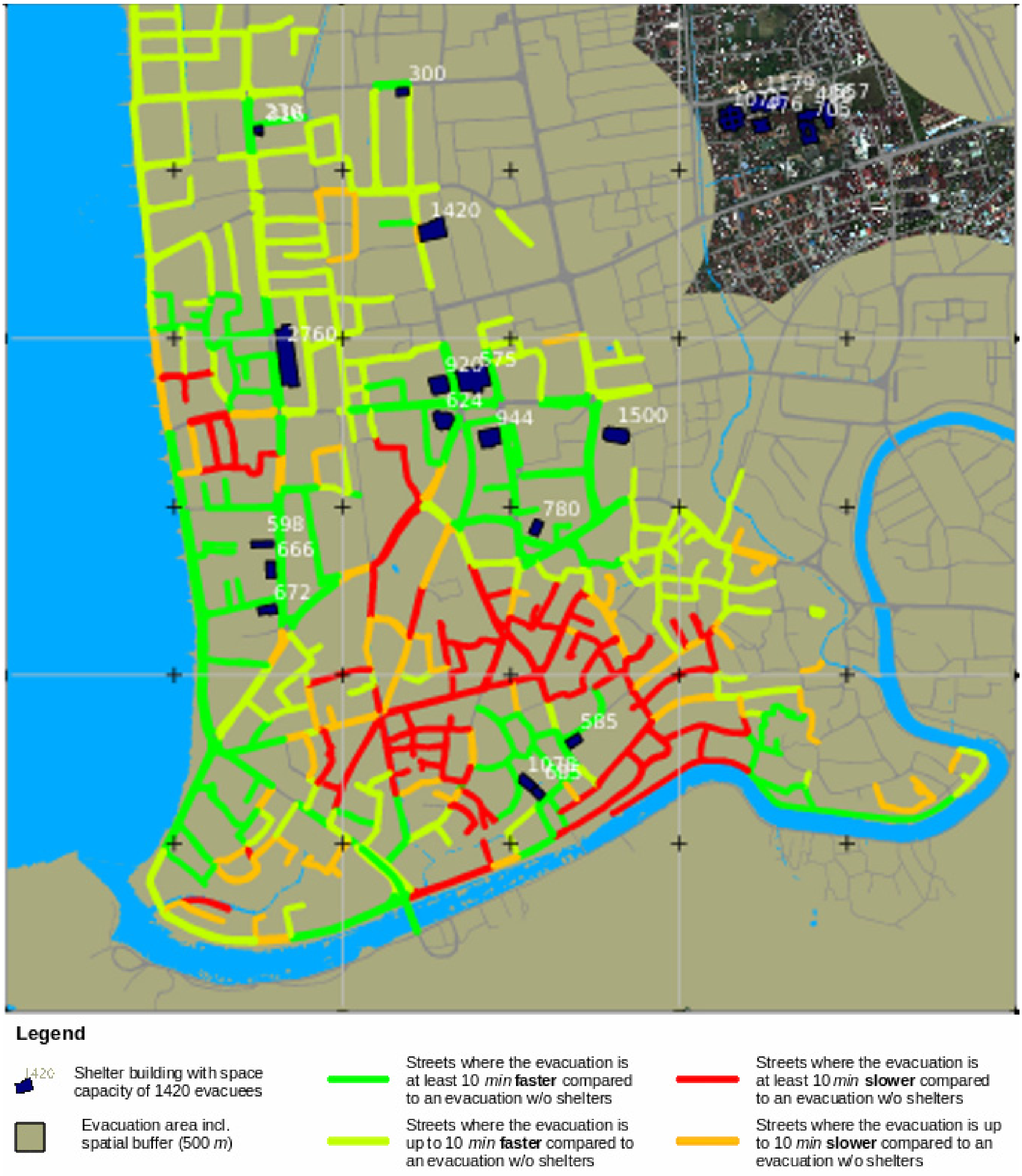


Figure 9. Gains and losses for an evacuation with shelters compared to an evacuation with out shelters.

6 WP 5000: Very high resolution topographic mapping of densely populated coasts in support of risk assessment of tsunami hazards in Indonesia

In 2007 an extensive data acquisition campaign was conducted in Padang using the Multi Functional Camera (MFC-3). This special camera, developed by the German Space Agency DLR (Deutsches Zentrum für Luft- und Raumfahrt), is one of the most advanced digital aerial photographic systems worldwide in the context of spaceborne, airborne and terrestrial data acquisition. The camera has a very high ground-resolution of 25 cm and a height estimation accuracy of +/- 40cm. High resolution Digital Surface Models (DEMs) were derived from the acquired stereo and multispectral images. They formed the essential basis of several working packages, i.e. the inundation modelling, and were the main source for the 3D Viewer applied for capacity building purposes.

Coping capacity, meaning the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters, encompasses management and physical planning, social and economic capacity. For the efficient management and in order to derive recommendations for decision-makers before, during and after an event, a well organised composition of all different perspectives and results along the process chain is necessary, which is realized by storing all project relevant results in a centralized geodatabase. The tool streams all necessary data via internet to an explicitly developed 3D client browser with a multilingual user interface. The client browser enables the user, i.e. the city administration of Padang, rescue teams, etc. to view and analyze tsunami relevant data in 3D at different levels of detail. Due to the low data transfer rates of Indonesia's IT infrastructure, it was essential to develop very efficient multi-resolution techniques for visualizing the DSM (Wahl et al. 2004) and for efficiently mapping GIS data on it (Schneider & Klein 2007). These techniques further improve the geometric representation (Wahl et al. 2008), texturing quality (Schneider & Klein 2008), as well as caching and streaming techniques in such a way that the usability and efficiency of the viewer application within a restricted network infrastructure could be assured while retaining a high rendering quality. The 3D visualization of geospatial data, adapted to the special requirements of hazard management such as tsunami events, offers an effective tool, even for inexperienced GIS users, to interpret geospatial data. This is indispensable if the results should be spread to a wider audience, such as in Padang, with its limited computing and IT infrastructure. The maintenance and update of the geospatial data is very cost-efficient due to its centralized data storage. The tool intends to improve coping capacity in manifold ways: By combining the interdisciplinary research results and visualizing them in a consistent manner (building on the concepts described in Greß & Klein 2009), it enables and supports decision making before, during and after a disastrous event. Before the event, we aim at the correct assessment of various hazard scenarios to quantify exposed susceptible elements and people, to assess their coping capacity and identify potential evacuation bottlenecks. Furthermore, the web application is used as a platform for information dissemination and thus aims to raise awareness and to guide political decisions. This analysis is the basis for recommendations in preparation for an expected disaster. During and after the tsunami event, the platform can be used to spatially plan and manage rescue measures.

The final version of the 3D visualization tool (Figure 10) was developed based on the discussions and results of the Padang Consensus II Workshop. In total, 10 different information layers, i.e. an inundation map integrating the real conditions (buildings, houses) with the visualization option blending and five different vector shapes, i.e. displaying critical features such as schools, were integrated.

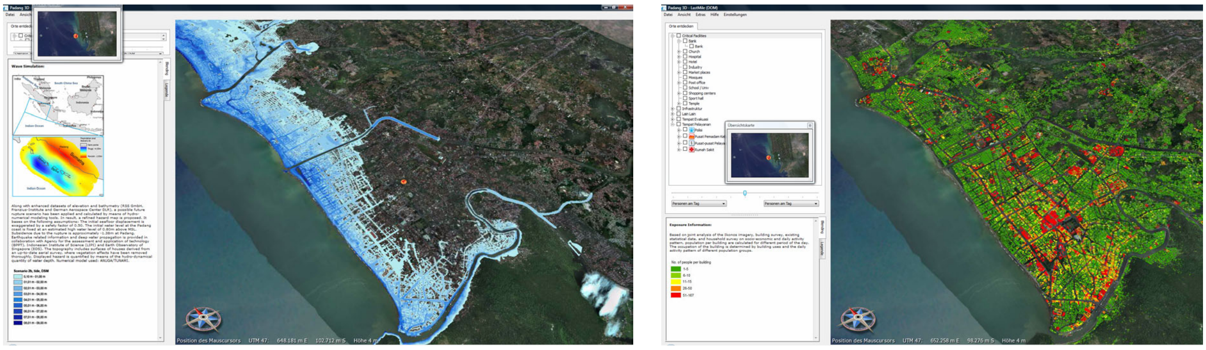


Figure 10. Final Version of the 3D Viewer. On the left the inundation map that integrates the real conditions developed by the Franzius-Institute is shown and on the right the numbers of people per building during day time (exposure information) from the UNU-EHS. In general the viewer consists of 4 windows, a large display window, a small outline map, an information window also containing the legends and an interactive window for the selection of the information content to be displayed (maps and vector)

7 Conclusion

In the last three years the interdisciplinary research project Last-Mile developed a numerical last-mile tsunami early warning and evacuation information system. The scientific core of “Last-Mile – Evacuation” set it’s main research endeavour to develop a system on an microscopic temporal and spatial level, i.e. detailed earth observation data and techniques, highly-resolved unsteady, hydraulic numerical modelling of flooding and tsunami inundation dynamics including numerical evacuation simulations in the urban coastal hinterland for the city of Padang, West Sumatra, Indonesia to achieve by means of a state-of-the-art scientific approach an accurate data base for ongoing disaster prevention planning process.

In this regard the project took microscopic temporal and spatial inundation dynamics into account and additionally assessed the physical-technical susceptibility and the socio-economic vulnerability of the population with the objective to mitigate human and material losses due to possible tsunamis threats. By means of discrete multi-agent techniques risk-based, time- and site-dependent forecasts of the evacuation behaviour of the population and the flow of traffic in large parts of the road system in the urban coastal strip have been simulated and concurrently linked with the other components to come up with both achieve essential knowledge on how to evacuate the city most effectively and obtain vital insights in which locations to establish and construct vertical evacuation shelters.

The vulnerability analysis in context of evacuation particularly focusing on the social dimension revealed some important aspects and challenges that the people at risk are facing, which should be considered in planning effective evacuation. The study within the project has proven that it is also possible and beneficial to combine the social with the physical parameters, as well as analysis methodologies for social data with engineering and remote sensing analysis methodologies. Vulnerability indicators and maps have been generated to support planning activities as well as to monitor continuously the effectiveness of the evacuation plan that is being developed in the city of Padang. It is necessary to test the applicability, develop further and adjust these tools to the current development together with the local actors.

The so-called Padang Consensus Process (PCP) has been actively supported from all partnering institutions within the “Last-Mile – Evacuation” project. In this framework two main workshops (Aug. 2008, Apr. 2010) have been supported in technical scope and scientific contents. The main results based on the workshops and input from other scientists have been recently agreed on 21 April 2010 after taking into account all processes and input from scientists and attendees of the 2nd workshop to recommend the use of the so-called Official Tsunami Hazard Map for Padang on the basis of the best available geodata set. This particular Official Tsunami Hazard Map for Padang is solely based on the outcome of the collaborative research approach originating from the Indonesian and German partnering institutions within the framework of “Last-Mile – Evacuation”. The validation of Map 3 as the official tsunami hazard map as the highly demanded planning and preparedness basis is now recommended towards the address of the Mayor’s Regulation (Peraturan Walikota, Perwako) in order to proceed with the development of a community friendly evacuation plan by involving relevant stakeholders. We thus conclude that the main objectives of the in 2007 envisaged scientific endeavours and focussed political implementations have been accomplished from our perspective, but also from the viewpoints of local as well as national partnering institutions.

Remote sensing proved to be independent, area-wide and up-to-date for the derivation of highly resolved geoinformation. However, the develop methods even allow to derive indirectly information on socio-economic parameters of the people living there. Furthermore, the Last-Mile project intended to prepare the city of Padang on awaited future natural hazards, but the earthquake in September 2009 allowed us to provide within hours and days to provide geometrically and thematically highly resolved information for situation assessment after the quake and preparation of rescue teams.

The evacuation analysis demonstrated that in some areas the expected evacuation time is higher than 40 minutes. Those areas are to be considered as highly endangered, where the situation could be improved by shelters for vertical evacuation. An analysis of the street utilization during an evacuation run indicates which streets could be considered as major evacuation routes. It is important that those streets are clear of obstacles during an evacuation. Another important finding of the evacuation analysis is, that locations for shelters should be carefully selected otherwise it could happen that the evacuation time increases because of additional queues on the streets. In general problem shelters should not be clustered but allocated corresponding to the demand and they should not be located too far away from the shore, so that evacuees from the coastal area have enough time to reach them.

Furthermore, the results are combined and presented in a 3-D Viewer. The tool intends to improve coping capacity in manifold ways: Since it combines the interdisciplinary research results and visualizes them in a consistent manner (building on the concepts described in Greß & Klein 2009), it enables to support decision making before, during and after a disastrous event. In addition the results of Last-mile are actively contributed to the Padang consensus process by many workshops and meetings with decision-makers and stakeholders in Padang.

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