reviewed paper

Integrating Socio-Economic Data in Spatial Analysis: An Exposure Analysis Method for Planning Urban Risk Mitigation

Neysa Setiadi, Hannes Taubenböck, Sonja Raupp, Jörn Birkmann

(M.Sc. Neysa Setiadi, United Nations University, UNU-EHS, UN Campus, Hermann-Ehlers-Str. 10, 53113 Bonn, Germany, setiadi@ehs.unu.edu)

(Dr. Hannes Taubenböck, German Aerospace Center (DLR), German Remote Sensing Data Center (DFD), Oberpfaffenhofen, 82234 Wessling, Germany and Julius-Maximilians-University of Würzburg, Geographical Institute, Earth Observation, 97074 Würzburg, Germany, hannes.taubenboeck@dlr.de)

(Sonja Raupp, United Nations University UNU-EHS, UN Campus, Hermann-Ehlers-Str. 10, 53113 Bonn, Germany, raupp@vie.unu.edu)

(Dr. Jörn Birkmann, United Nations University UNU-EHS, UN Campus, Hermann-Ehlers-Str. 10, 53113 Bonn, Germany, birkmann@ehs.unu.edu) (Title Firstname Givenname, Institution of Author 1, Address, e-mail)

1 ABSTRACT

For disaster risk management and risk-based urban planning, time-dependent knowledge on the spatial distribution of various social groups is of critical importance. However, in a highly dynamic urbanizing world data are mostly outdated, generalized, not area-wide, not reliable or even not existing. This paper explores the potential of interdisciplinary integration of social science and remote sensing to deal with the problem of area-wide and up-to-date information derivation of the spatial distribution of population, and especially the vulnerable groups. The integration of conventional socio-economic data (census and household survey data) with the structural information of the urban landscape extracted from remotely sensed data aims at assessing dynamic exposure of various social groups. The analysis was done for the case study in the tsunami and earthquake prone coastal city of Padang, West Sumatra, Indonesia. The information generated is particularly useful for giving an additional insight for urban planners, how land use and urban development shape the exposure of various social groups to natural hazards.

2 BACKGROUND AND RATIONALE OF THE STUDY

In light of global environmental change, building a safe environment for urban areas should be more emphasized. Two decades ago, an analysis of the world´s 100 most populous cities found that 78% were exposed to one of four major natural hazards-earthquakes, tsunamis, volcanoes, and windstorms (not including flooding)- and 45% faced being struck by more than one. In developing countries alone, 86% face more than one threat (Degg, 1992). For development of effective disaster risk reduction measures, vulnerability assessment is crucial. It should consider exposed, susceptible elements (e.g. population or various social groups) and coping capacities, which determine the expected harm resulting from a given hazardous event (Birkmann, 2006).

An exposure analysis that provides accurate and detailed information about distribution of population and various social groups in relation to the existing hazards is an important initial phase in vulnerability assessment. It serves as a basis for planning disaster risk mitigation, e.g. evacuation planning (short- to medium-term) or exposure reduction by means of land use planning (medium- to long-term). Due to the dynamic in urban activity pattern, spatiotemporal variation of population is a crucial component regarding vulnerability. A time-geography approach to spatial behaviour has long been developed by researchers (Hägerstrand, 1970; Pred, 1981). Presently, it has already been operationalized using various highly developed GIS-tools and methodologies and used in planning, e.g. development of transportation network, access to public services and infrastructures.

Since the 1970s, remote sensing estimation of residential population has been applied more frequently, as an increasing amount of spaceborne satellite data have become available (Elvidge et al. 1997; Lo, 2001; Sutton et al., 1997, Harvey, 2002; Li & Weng 2005; Taubenböck, Roth & Dech, 2007; Liu & Herold 2007; Lo, 1986; Lu et al., 2006; Schneiderbauer & Ehrlich, 2007; Mesev, 2003). The most recent study of Khomaruddin et al. (2008) shows the potential of Census data to derive weights for population distribution day and night by land use type, which is suitable for broadscale analysis (e.g. nation-wide). On the other hand, Taubenböck et al. (2008) presents capabilities of high resolution satellite data (Ikonos) to assess day and night urban population on building level which is suitable for the small-scale and heterogenous urban context. The method used is an object-oriented, hierarchical classification methodology, on very fine resolution. However, the result has not yet indicated the spatial distribution of the vulnerable social groups.

The study presented in this paper attempts to further develop the methodology used by Taubenböck et al. (2008) and Khomaruddin et al. (2008), emphasizing more on the socio-economic characteristics and daily activity pattern of the individuals / households. Analysis of conventional census data and household survey is conducted to build a model of population distribution that is combined with spatial data. In doing so, the identification of vulnerable social groups in various building - land use types is made possible.

3 STUDY AREA AND DATASETS

The study area is the coastal city of Padang, West Sumatra, Indonesia. Padang city with almost one million inhabitants is highly exposed to various natural hazards, especially earthquake and tsunami (Borrero et al., 2006; McCloskey et al., 2010). This city represents coastal urban areas in developing countries, which was initially developed through historical intensive trading activities at the coast during colonial times, and therefore, remains having central activities and densely populated areas at the coastal region. The recent strong earthquake events, of which the most recent one occurred in September 2009 with a magnitude of 7.5M (USGS, 2009), and their potential in generating tsunamis have triggered the city to revise their current urban plan and develop the city towards less-exposed areas, moving away from the coast. As one of the baseline information, it is important to show how the current urban structure has influenced the exposure of the population and various social groups to tsunamis. The required information should encompass the quantity of population and its spatiotemporal dynamic, as well as identification of vulnerable social groups, such as women, elderly and children. Presently, spatial data on population are only available at village level and contains no information on the temporal aspect. Therefore, analysis of ancillary data from remote sensing as well as additional surveys are conducted.

High resolution remotely sensed data from the Ikonos sensor, a Digital Surface Model (DSM) and a Digital Terrain Model (DTM) were used to provide area-wide, up-to-date and accurate information on the urban land cover and its spatial structural pattern in a 3-D city model. Additionally, data derived from field work on urban land use are available (Taubenböck et al., 2009a). The information on daily activity pattern obtained from household survey data 2008 (UNU-EHS Household Survey in Padang, 2008) cover an activity diary of about 800 respondents representing different gender groups, main activities and occupations. Additionally, data from the last population Census (BPS, 2000), and additional statistical data of year 2005 from Padang in Figures (BPS, 2006a), Padang`s Sub-Districts in Figures and Village Potential Survey (BPS, 2006b) are available for calculation of population number by social groups as well as concentration of economic activities and public facilities within the study areas, from which the weights for various land use types are derived.

4 CONCEPTUAL FRAMEWORK & METHODOLOGY

An analysis framework was developed to enable estimation of spatial distribution of exposed social groups and was applied for the case study. The starting point of the analysis is the assumption that exposure of social groups to tsunamis varies and influenced by the urban land use. Based on this assumption, the parameters were defined and analysed:

- classification of social groups with regard to vulnerability to tsunamis
- main activities that compose daily activity pattern & particular time of the day to show the temporal dynamic
- linkage between building-land use and daily activity

4.1 Vulnerable Social Groups and Daily Activity Pattern

With regard to tsunamis, the following social groups have been revealed as more vulnerable: women, elderly and children (See e.g. Birkmann et al., 2007). This particularly relate to lower physical capability of these groups to evacuate themselves during an emergency or tsunami events, i.e. low running (evacuation) velocity and stamina. It is important to analyse the population distribution disaggregated for these social groups. Aside from demographic characteristics, there are other parameters to be considered in assessing vulnerability, e.g. households with lower income and marginalized social groups are most likely to have lower access to disaster preparedness interventions such as early warning and training activities, as well as to face more difficulties during recovery process after a disaster event. In this case study, however, the linkage between such parameters with the dynamic spatial distribution have not been explored sufficiently, thus, not integrated yet.

The time geographic model of society potrays individuals and households as following a series of daily paths through time and across space, with their movement at such settings as home, office, school, shops, and sites of discretionary activities such as the church or community center (Pred, 1981). Time-budget studies, in which respondents are asked to keep an activity diary specifying the duration and location of activities, are permitting to emerge a fine-grained picture of the temporal and spatial use of the city (Anderson 1971, Chapin 1974).

In this study, the daily activity was derived from an activity diary from the household survey. It was summarized in three main categories: working activities (occupation in built areas: service, trade, industry), education (school and higher eduction), and other activities (care and social activities). The daily activity pattern was found to be different particularly between women and men, with main activity of working and non-working (Figure 1).

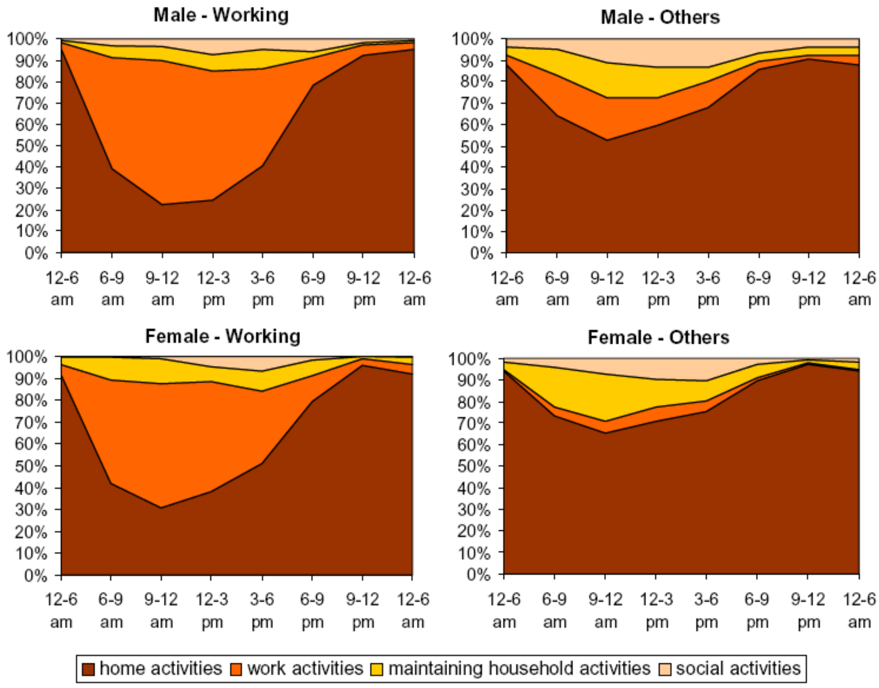

Fig. 1: Daily Activity Pattern of Various Social Groups

For the exposure analysis, three different times over the course of a day were selected to show the temporal dynamic of the daily activities: 9-12 am (morning), 3-6 pm (afternoon), and 12-6 (night).

4.2 Urban Morphology and Daily Activity

Urban morphological analysis seeks to identify distinctive regions in the city according to the functions of tangible land use types and to some extent show the social urban segregation. For the detailed extraction of the small-scale and heterogeneous urban morphology, Ikonos imagery with 4 spectral bands (blue, green, red, nir) and a geometric quality of 1 meter were used. The Digital Surface Model (DSM) and the Digital Terrain Model (DTM) are also available. Additionally, data derived from field work on urban land use were surveyed. The combination of the various data sets provides information on the physical urban morphology of the city, building use and available space for living and working (Figure 2).

Regionalisation is performed to classify areas that contain homogeneous urban morphology parameters (See Taubenböck et al., 2009b). Areas with similar built-up density, building sizes, building heights and building usage are combined citywide as homogeneous sectors (Figure 3). Particularly areas with low built-up density, big building sizes, and high height are mostly representing public buildings.

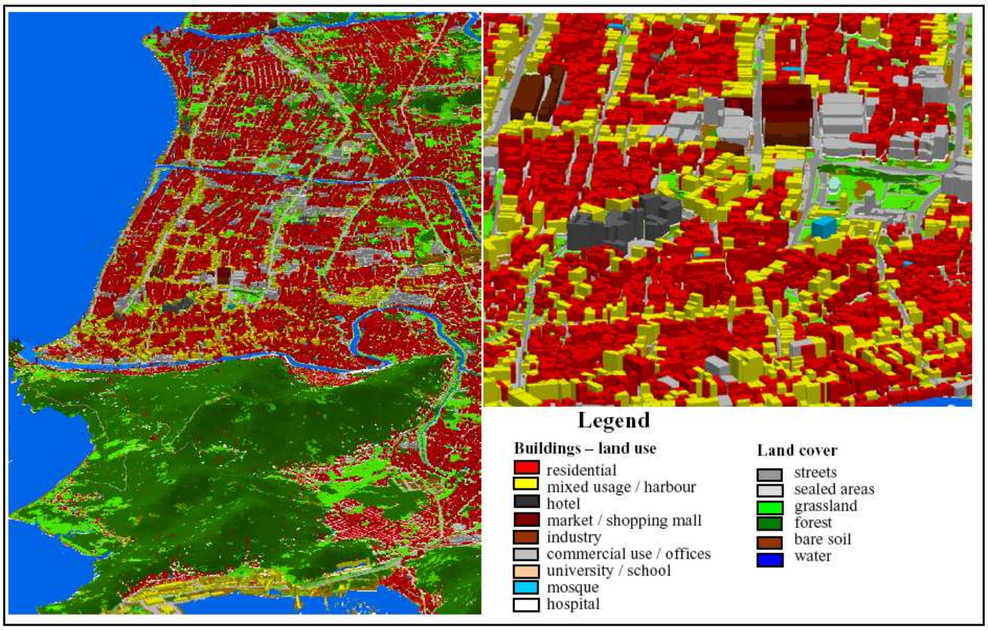

Fig. 2: Building - Land Use of the Study Area in Padang City

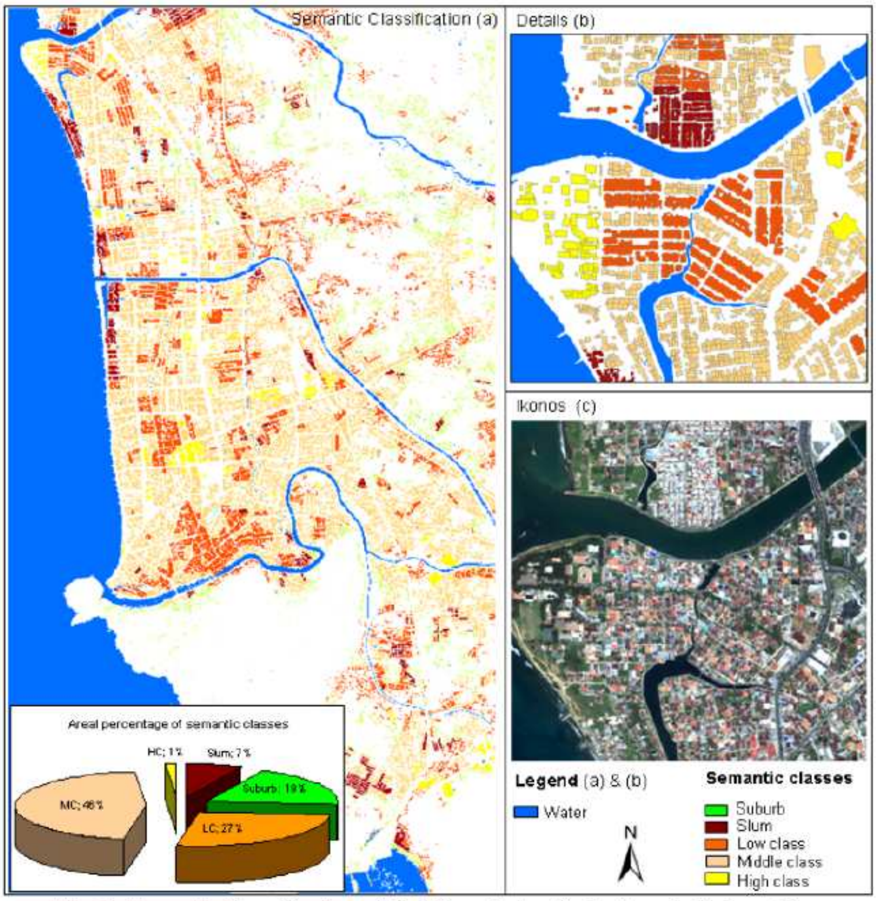

Fig. 3: Semantic Classification of Buildings in the Study Area in Padang City

The correlation between the static elements of physical urban structures with the socio-economic parameters of the people was tested. The findings proved that socio-economic characteristics like household income level and price of housing correlate to some extent with physical urban patterns and thus enable extrapolation on the complete urban landscape (See Taubenböck et al, 2009b). The classification of the physical urban structures are particularly used for the residential buildings. For the working activities, the building-land use is summarized in several main categories which match the activities of the population from the Population Census and Household survey data, namely office, commercial, and industrial buildings.

4.3 Development of weighting

Similar with the methodology used by Khomaruddin et al. (2008), weights are derived from the available socio-economic data to calculate population distribution in the study area, but putting more emphasize on the social groups and their daily activity pattern. The important parameters are the main activity, occupation of the social groups and their mobility (to what extent the individuals travel to conduct their daily activities). For the purpose of our analysis, mobility is defined as whether or not the daily activities are performed at home/neighbourhood (in the residential buildings) or in public facilities and buildings where economic and business activities are concentrated in the city. The overall analysis framework is presented in a simplified manner in the following figure (Figure 4), showing the example of the activities of female population.

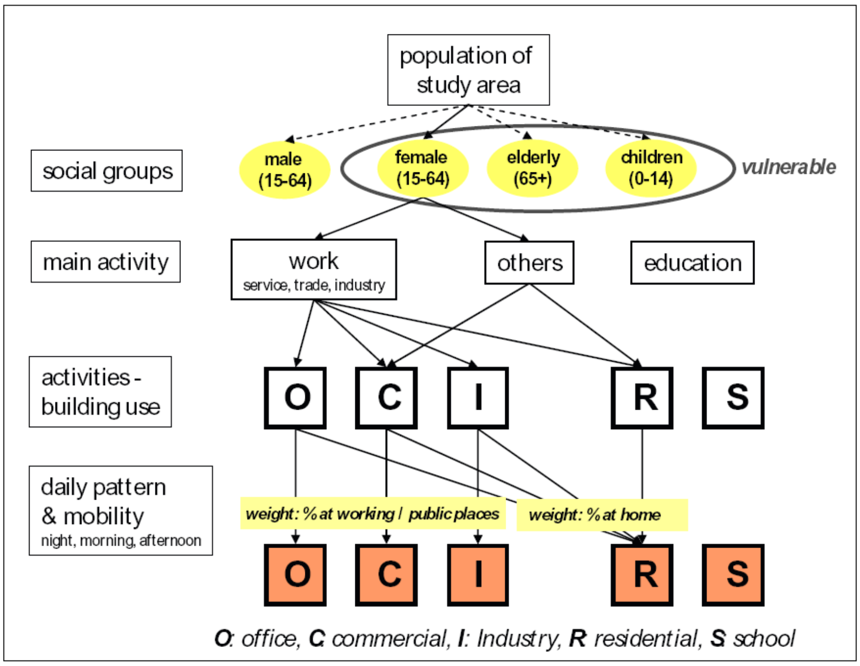

Fig. 4: Analyis Framework

During the analysis, some additional assumptions for the weights had to be made due to inexistence of information e.g. activities in the mosques and in public facilities. However, this involved relatively small part of the total population and did not change the results significantly.

5 RESULTS

Basically we observe and quantify high concentration of people in the urban center during morning and afternoon, while at nighttime the people are more equally distributed. During daytime we measure higher exposure of the total population due to the fact that more people linger in the urban core near the coastline. The analysis results of population distribution show that there is an immense spatial shift in population distribution for non residential areas between day- and nightime, and slightly less during the afternoon time (Figure 5). The non-residential areas are mostly located in the city center and along the main roads, where the economic and business activities are concentrated. Thus, the spatial pattern of vulnerability transforms significantly over the course of a day and e. g. with immense impact on the situation for evacuation in case of tsunami events (Lämmel et al., 2008).

Disaggregated analysis on vulnerable social groups show in general similar pattern with the total population, nevertheless different weighting in activities of various social groups show noticable variation. Overall, the activities outside house (residential buildings) of the vulnerable groups is lower due to the fact that the proportion of working female (29.4%) and working elderly population (40.3%) is much less than the working male population (63.9%). Additionally, the household survey showed that the proportion of working activities of the working vulnerable population that are conducted at home is higher compared to of the male population. This variation has implication on the population shift during the day of vulnerable and male population, as well as difficulties that these social groups would face in evacuation during emergency events. More vulnerable population stay in residential areas during the morning and afternoon time, while increasing male population are concentrated in the non-residential areas during the day. In terms of evacuation, it indicates difficulties lower access of the vulnerable population to the main roads (evacuation routes) in the dense residential areas with mostly narrow street networks, while the concentrated population in the city center and along the main roads might already initiate traffic jam Moreover, some punctual variations in different building – land use types are also visible for the vulnerable groups as can be seen in Figure 6 below. In this example, the low proportion of vulnerable groups working in the industrial sector (20.5%) show variation in changes during the day, compared to changes in university, where participation of vulnerable groups is higher (55.1%). Such disaggregated information of vulnerable groups is also significant in e.g. hospital buildings, that consist of almost 90% vulnerable people.

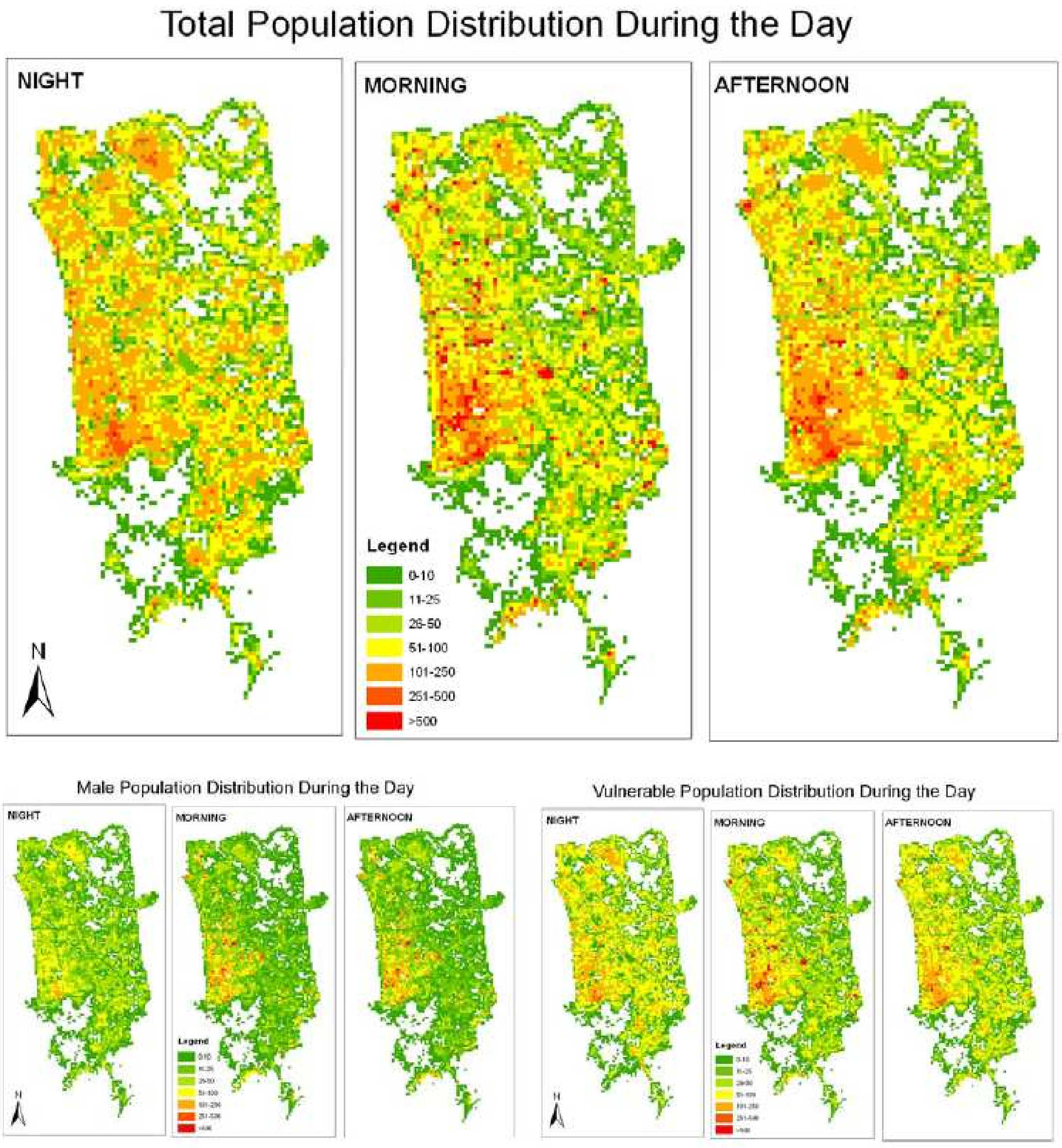

Fig. 5: Distribution of Population by Daytime (Visualization of Summary in Grids 100mx100m)

To check the accuracy of the basis population (night population in the residential areas) of our calculation, the results were compared with the available population data of year 2005 in the villages, where the study area is located (BPS, 2006b). The total population in the study area coverage within the selected villages is summed up to 428,452, including 275,845 vulnerable population, while the total population in the residential buildings based on our calculation is 387,450, of which 257,682 are vulnerable population. The comparison shows that a difference of about 10%, nevertheless, our calculation generated the same magnitude of population as well as vulnerable population. Comparison was also done using single household data from the household survey, showing that the proportion of vulnerable population at building level is on average similar, but vary at the building level with the standard deviation of 20%. This also conforms to variations at the household level from the analysis of Census Population Data (BPS, 2000). Accuracy analysis of the population distribution in the morning and afternoon time at the building level was not possible, since there is no validation data available.

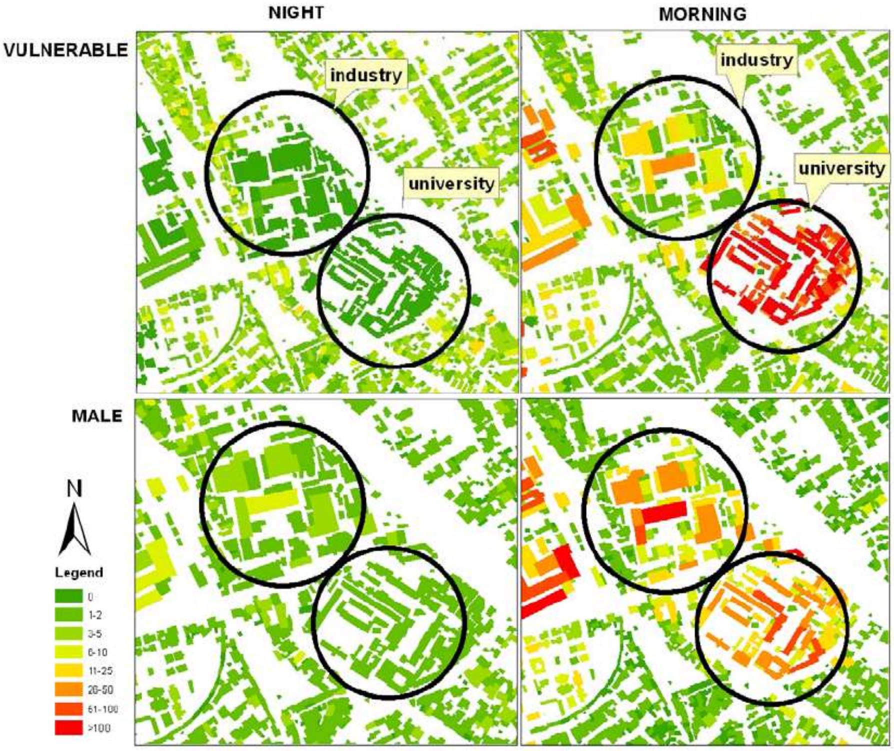

Fig. 6: Variation in Distribution Different Building-Land Use by Daytime and Social Groups

6 CONCLUSION AND OUTLOOK

The study presented above shows that detailed analysis on population distribution for high resolution exposure analysis is made possible through the combination of remote sensing analysis and conventional socio-economic data of census and household surveys. In spite of high level of details of the information, the analysis method can be easily understood and implemented for continuous updating by the local risk managers and urban planners, in contrast to complex modelling analysis. It provides an overview of “who”, “when”, “where”, as a basis information for risk managers and urban planners to develop effective mitigation strategies such as evacuation planning. Moreover, the analysis results can easily be linked and overlayed with data on tsunami as well as other hazards to assess exposure. For longer-term urban development planning, it would also be interesting to develop a set of scenarios for the analysis, e.g. how the population distribution would change if urban activities would be intensified in areas away from the coast. In case more comprehensive and detailed data on mobility or transportation pattern would be available, such analysis can be further developed and include more complexity. However, this also implies assessment on how much added-value it would bring and its applicability.

7 ACKNOWLEDGEMENT

The authors would like to thank the German Education and Research Ministry (BMBF), who funded the study in scope of special Programme “Geotechnologies” - Early Warning Systems in Earth Management. Sponsorship Code: 03G0643A-E.

8 REFERENCES

ANDERSON, J.: Space – Time Budgets and Activity Studies in Urban Geography and Planning. In: Environment and Planning, Vol. 3, Issue 4, pp. 353-368. 1971.

BIRKMANN, J., FERNANDO, N., HETTIGE, S., AMARASINGHE, S., JAYASINGAM, T., PARANAGAMA, D., NANDANA, M.D.A., NAßL, M., VOIGT, S., GROTE, U., ENGEL, S., SCHRAVEN, B., WOLFERTZ, J.: Rapid vulnerability assessment. SOURCE Publication Series of UNU-EHS, No. 7, 2007.

BIRKMANN, J.: Measuring Vulnerability to Promote Disaster-Resilient Societies: Conceptual Frameworks and Definitions. In: Birkmann, J. (Ed.): Measuring Vulnerability to Natural Hazards, pp. 9-53. United Nations University Press. Tokyo, 2006.

BORRERO, J.C., SIEH, K., CHLIEH, M., SYNOLAKIS, C.E. : Tsunami inundation model of western Sumatra. In: PNAS, Vol. 103, No. 52, pp. 19673-10677. 2006.
CHAPIN, F.S: Human Activity Patterns in the City: Things People Do in Time and in Space. John Wiley and Sons. New York,1974.
DEGG, M.: Natural Disasters: Recent Trends and Future Prospects. In: Geography, Vol. 77, Issue 3, pp. 198-209. 1992.
ELVIDGE C. K., BAUGH E., KIHN H., KROEHL E.D., DAVIS, C.: Relation between satellite observed visible-near infrared emissions, population, economic activity and electric power consumption. In: International Journal of Remote Sensing, Vol. 18, pp 1373-1379. 1997.
HÄGERSTRAND, T.: What About People in Regional Science? In: Regional Science Association Papers, Vol. 24, pp. 7-21. 1970.
HARVEY, J. T.: Population estimation models based on individual TM pixels. In: Photogrammetric Engineering and Remote Sensing, 68, pp. 1181–1192. 2002.
KHOMARUDDIN, M.R., STRUNZ, G., POST, J., ZOßENDER, K., LUDWIG, R.: Spatial improvement of information on population distribution using GIS approaches: An input for tsunami people exposure assessment. In: International Conference on Tsunami Warning (ICTW), Bali, Indonesia, November 12-14, 2008.
KWAN, M., LEE, J.: Geovizualization of Human Activity Patterns Using 3D GIS: A Time-Geographic Approach. In: Goodchild, M.F., Janelle, D.G. (Eds.): Spatially Integrated Social Science, Chapter 3. Oxford University Press. Oxford, 2004.
LÄMMEL, L., RIESER, M., NAGEL, K., TAUBENBÖCK, H., STRUNZ, G., GOSEBERG, N., SCHLURMANN, T., KLÜPFEL, H., SETIADI, N., BIRKMANN, J.: Emergency Preparedness in the case of a Tsunami –Evacuation Analysis and Traffic Optimization for the Indonesian city of Padang, Proc. of the 4th Interantional Conference on Pedestrian and Evacuation Dynamics, Wuppertal, Germany, 2008.
LI, G. & WENG, Q.: Using Landsat ETM+ imagery to measure population density in Indianapolis, Indiana, USA. In: Photogrammetric Engineering and Remote Sensing, Vol. 71, pp. 947–958. 2005.
LIU, X., HEROLD, M.: Estimating population distributions in urban areas. In: Urban Remote Sensing, pp. 269-290. CRC Press/Taylor&Francis. London, 2007.
LO, C.P.: Accuracy of population estimation from medium-scale aerial photography. In: Photogrammetric Engineering and Remote Sensing, Vol. 52, pp. 1859–1869. 1986.
LO, C.P.: Modeling the population of China using DMSP operational linescan system nighttime data. In: Photogrammetric Engineering and Remote Sensing, Vol. 67, pp. 1037–1047. 2001.
LU, D., WENIG, Q., LI, G: Residential population estimation using a remote sensing derived impervious surface approach. In: International Journal of Remote Sensing, Vol. 27, Issue 16, pp. 3553-3570. 2006.
Mc CLOSKEY, J., LANGE, D., TILMAN, F., NALBANT, S.S., BELL, A.F., NATAWIDJAJA, D.H., RIETBROCK, A.: The September 2009 Padang earthquake. In: Nature Geoscience, Vol. 3, No. 2, pp. 70-71. 2010.
MESEV, V.: Remotely Sensed Cities. Taylor & Francis, London, 2003.
PRED, A. (Ed.): Space and Time in Geography – Essays Dedicated to Torsten Hägerstrand. CWK Gleerup. Lund, 1981.
SCHNEIDERBAUER, S. & EHRLICH, D.: EO data supported population density estimation at fine resolution – test case rural Zimbabwe. In: Zeug, G. & Pesaresi, M. (Eds): Global Monitoring for Security and Stability (GMOSS). Integrated Scientific and Technological Research Supporting Security Aspects of the European Union, JRC Scientific and Technical Reports, EUR 23033, pp. 194 – 209. 2007.
STATISTICS INDONESIA (BPS): Padang Dalam Angka (Padang in Figures) 2006. BPS. Padang, 2006a.
STATISTICS INDONESIA (BPS): Padang Kecamatan Dalam Angka (Padang´s Sub-Districts in Figures) 2006. BPS. Padang, 2006b.
STATISTICS INDONESIA (BPS): Population Census 2000. BPS. Jakarta, 2000.
STATISTICS INDONESIA (BPS): Village Potential Survey 2006. BPS. Jakarta, 2006.
SUTTON, P., ROBERTS, D., ELVIDGE, C.D., MEIJ, H.: A comparison of nighttime satellite imagery and population density for the continental United States. In: Photogrammetric Engineering and Remote Sensing, Vol. 63, pp. 1303–1313. 1997.
TAUBENBÖCK, H., GOSEBERG, N., SETIADI, N., LÄMMEL, G., MODER, F., OCZIPKA, M., KLÜPFEL, H., WAHL, R., SCHLURMANN, T., STRUNZ, G., BIRKMANN, J., NAGEL, K., SIEGERT, F., LEHMANN, F., DECH, S.,
GRESS, A., KLEIN, R.: Last-Mile preparation for a potential disaster – Interdisciplinary approach towards tsunami early warning and an evacuation information system for the coastal city of Padang, Indonesia. In: Natural Hazards and Earth System Sciences, Vol. 9, pp. 1509-1528. 2009a.
TAUBENBÖCK, H., POST, J., ROTH, A., STRUNZ, G., KIEFL, R., DECH, S., ISMAIL, F.: Multi-scale assessment of population distribution utilizing remotely sensed data – The case study Padang, West Sumatra, Indonesia. In: International Conference on Tsunami Warning (ICTW), Bali, Indonesia, November 12-14, 2008.
TAUBENBÖCK, H., ROTH, A., DECH, S.: Linking structural urban characteristics derived from high resolution satellite data to population distribution. In: Coors, V., Rumor, M., Fendel, E.M., Zlatanova, S. (Eds): Urban and Regional Data Management. pp. 35-45. Taylor & Francis, London, 2007.
TAUBENBÖCK, H., WURM, M., SETIADI, N., GEBERT, N., ROTH, A., STRUNZ, G., BIRKMANN, J., DECH, S.: Integrating Remote Sensing and Social Science – The correlation of urban morphology with socioeconomic parameters. In: Urban Remote Sensing Joint Event, pp. 7. Shanghai, China, 2009b. U.S. GEOLOGICAL SURVEY (USGS): Earthquake Details Southern Sumatra, Indonesia, September 30, 2009 (http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/us2009mebz.php). 2009.
UNITED NATIONS UNIVERSITY INSTITUTE FOR ENVIRONMENT AND HUMAN SECURITY (UNU-EHS): Household Survey on Socio-Economic Vulnerability to Tsunamis in Padang City. 2008.