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People exposure and land use damage estimation caused by tsunami using numerical modelling and GIS approaches (Case study: South Coast of Java – Indonesia)

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For tsunami risk analysis information about the number of exposed people and about the land-use in the endangered areas are important input parameters. Data on people distribution could help to manage the evacuation planning and mitigate the people loss by tsunami. Land-use and potential damages are relevant for rehabilitation management

The aim of the paper is to present methodologies and tools to generate the above mentioned missing information before a disaster happens. Based on this, governmental authorities can prepare and calculate how many people are living in the affected area, how many people could be evacuated, and how to perform adequate land use planning to mitigate the disaster impact. For the disaster response phase, the local government will be supported to plan and manage the evacuation process more efficiently. For the recovery phase, government will be provided by estimates on the amount and type of potential damages.

This research analyzes the estimation of people at risk and potential land-use damage estimation by tsunamis in the South Coast of Java, Indonesia. Combinations of numerical modelling and Geographic Information System (GIS) approaches have been applied in this research. There are three scenarios for tsunami simulations generated by earthquake magnitude Mw 8.5 with different locations of the epicentres.

TUNAMI-N1 model has been applied to determine the tsunami wave height in the coastal area. Validation of tsunami modelling has been performed using Aceh Tsunami 2004 data.

Inundation modelling was applied to the study area and the results were combined with the people distribution map and land-use data to estimate people at risk and land-use damage by tsunami.

People distribution maps during day time and night time were derived.

The results of this research will be integrated in an information system, which in future can be applied on the level of the local government to better mitigate the impact of tsunami disaster and provide tools for an improved tsunami risk assessment for decision makers at the local level.

Method

To reach the described goals four methodological steps have been developed. The first is the tsunami inundation modelling. A combination between Tunami N1 (Imamura, et al. (2006)) and modification of Federici, et al. (2006) formula was conducted in this research.

This means that tsunami modelling results, which are valid for the calculation of expected wave heights at the coastline, are combined with empirically derived relationships, which are newly developed to calculate the tsunami inundation.

Tsunami wave heights at coastlines have then been used as input in the Federici formula to calculate the inundation area. The modification of the Federici formula is replacing the land use condition as a reducing tsunami wave factor with tsunami wave height and inundation reduction caused by distance from the coast.

The maximum wave heights from TUNAMI-N1 are used as input values (Ru) to inundation modelling using the Federici formula as shown in equation (1):

$$W = \varepsilon . Ru - Z \qquad (1)$$

Where,

ε = Roughness parameters
Ru = Maximum wave height at the coast
Z = height of the ground (from DEM SRTM)

If $W > 0$	inundation	pixel = 1	wet
If $W < 0$	no inundation	pixel = 0	dry

Validation of proposed inundation calculation was done based on inundation mapping using post disaster Landsat data (USGS, 2004). The validated model was then used to calculate the potential inundation area in the study area. The second part is deriving the people distribution maps in study area. Generally population distribution is representative for administrative units, far too coarse to adequately calculate amount of people affected. An improvement of spatial resolution of population the database is presented here. The population data from census sources are commonly made available per political or administrative unit (Schneiderbauer, 2007). In Indonesia, the people distributions data is represented at village level. In fact, people are doing activity in certain land uses within the representative census data at village level. The combination of people distribution data from census and detailed land use information (derived from Indonesian topographic map at 1: 25.000 scale) is used to disaggregate and down-scale population distribution. For example, distribution of people in a settlement area in one village will be different than in a paddy field area in that village which is not reflected in census population data. The proportion (weighting) of people in the different land-use areas is needed in this analysis. This is a critical value to estimate people distribution based on detailed land use information (Gallego, 2007). For the south coast of Java, this proportion is calculated based on people activity during day and night time within the assigned land use classes. The distribution factors to calculate population distribution at day and night time per land use is derived from national statistical data (BPS, 2006). Hereof percentages of people working in certain land use classes (e.g. agriculture, industry) are derived and have been used as weighting / distribution factor. This data also will be used to calculate the land use damage estimation.

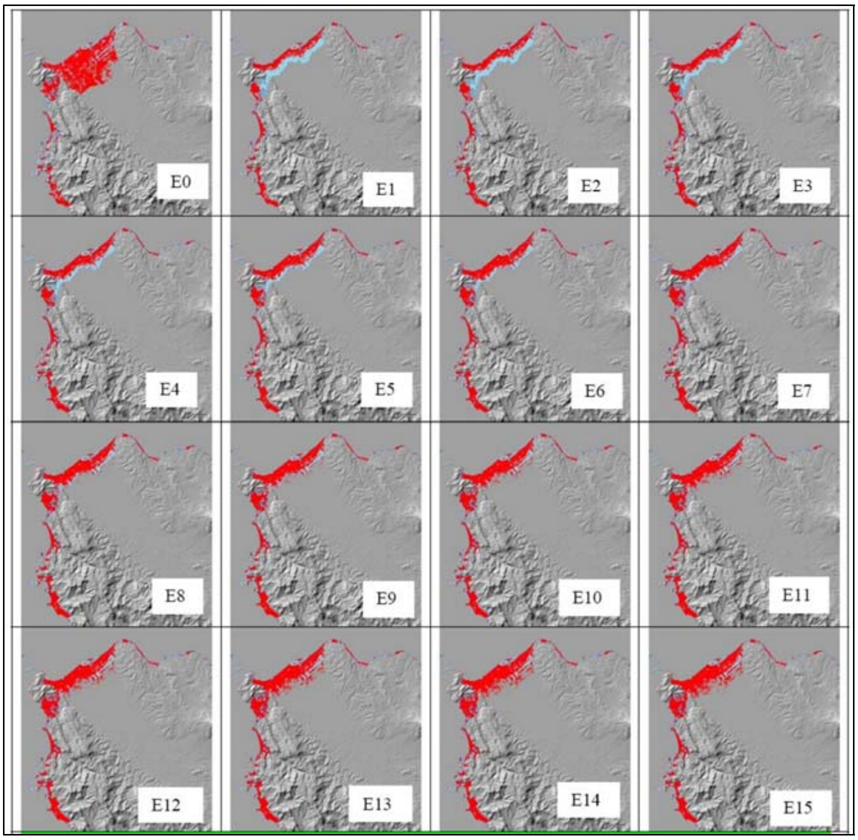
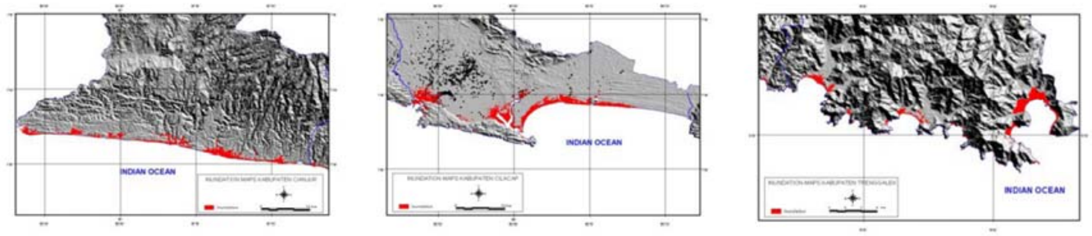


Figure 1. The validation of tsunami inundation base on Federici, et al. (2006) modification.



(a) Cianjur Scenario 1 (b). Cilacap Scenario 2 (c). Trenggalek Scenario 3

Exposed People

Province	Districts	People exposure in scenario					
		Scenario 1		Scenario 2		Scenario 3	
		Day	Night	Day	Night	Day	Night
West Java	Cianjur	15496	16647	1555	1056	337	350
	Garut	4762	5066	582	710	64	62
	Tasikmalaya	6646	8511	1062	1637	9	42
	Ciamis	1229	584	4629	2707	226	30
Central Java	Cilacap	3505	1642	34746	61168	2544	1202
	Kebumen	88	15	2774	1425	262	43
	Purworejo	0	0	1073	615	169	119
DI Yogyakarta	Kulon Progo	403	171	2978	2283	1539	985
	Bantul	219	208	2551	2226	289	265
	Gunung Kidul	0	0	0	0	250	212
East Java	Pacitan	222	47	638	101	7881	6068
	Trenggalek	84	142	98	141	13341	14096

Landuse Damage Estimation

Province	Districs	Landuse Damage Estimation								
		Inundation area (scenario 1)			Inundation area (scenario 2)			Inundation area (scenario 3)		
		Total (ha)	Highest	Percent	Total (ha)	Highest	Percent	Total (ha)	Highest	Percent
West Java	Cianjur	3405.7	paddy field	54.50%	558.2	paddy field	59.90%	103.5	paddy field	49.50%
	Garut	2587.3	paddy field	78.30%	184.1	paddy field	57.20%	12.1	beach	52.10%
	Tasikmalaya	1644.1	paddy field	28.60%	257.5	paddy field	28.60%	7.6	water	50.00%
	Ciamis	439.7	paddy field	50.40%	1256.9	paddy field	47.70%	35.4	water	45.50%
Central Java	Cilacap	1415.5	water	48.50%	6524.2	paddy field	59.90%	896.5	water	51.80%
	Kebumen	14.6	water	61.60%	777.7	beach	54.70%	66.1	water	71.20%
	Purworejo	1.2	water	100.00%	745.1	beach	53.00%	118.7	cropland	48.60%
DI Yogyakarta	Kulon Progo	19.5	beach	46.60%	577.1	beach	31.76%	197.4	cropland	22.60%
	Bantul	44.9	paddy field	36.90%	569.5	beach	24.80%	76.9	paddy field	32.90%
	Gunung Kidul	0.5	cropland	100.00%	3.4	cropland	55.90%	11	cropland	42.70%
East Java	Pacitan	12.4	paddy field	22.60%	79.8	paddy field	37.90%	682.4	paddy field	53.60%
	Trenggalek	13.9	beach	58.30%	13.8	beach	58.70%	1216.4	paddy field	36.10%

Figure 2. The result of inundation modelling in the most danger districts, total number of exposed people and land damages estimation

In a third step, the newly derived people density information and land use 1: 25.000 scales data were combined (overlaid) with validated tsunami inundation modelling to derive exposed people and estimate land use damaged in 12 districts in South Coast of Java.

The last and fourth step is a conceptual study to design and implement a risk information tool. It is designed to help local government and reflects the needs of local decision makers handling a simple and robust tool. The tool shall deliver the possibility for the local government to extract information relevant for disaster management planning.

The data that were used in this work are the Digital Elevation Model (DEM), which is based on the Shuttle Radar Topography Mission (SRTM), for tsunami inundation modelling. For the exposure analysis the topographic maps of South Coast of Java, scale 1: 25.000 (Bakosurtanal) and statistical data (Statistical Bureau Indonesia, 2006) were used.

Results and Discussion

The result of the validation is shown in Fig. 1. The proposed modifications of Federici formula for the calculation of tsunami inundation deliver a similar pattern compared to the inundation area from USGS.

Based on this result the Tunami N1 software has been run with three scenario of tsunami source in Indian Ocean. There are 3 different epicentre locations used to calculate the used tsunami scenarios: epicentre's location at 108.192 E, 9.27565 S as scenario 1; at 108.896 E, 9.11123 S as scenario2; and at 109.619 E, 9.02594 S as scenario 3. The result of inundation modeling in the most danger districts, total number of exposed people and land use damage estimation in that three scenarios are shown in the Fig. 2. As can be seen in Fig. 2, the Districts of Cianjur, Cilacap, and Trenggalek are the most affected areas according to estimation results for scenario 1, scenario 2, and scenario 3 respectively. According to the results for scenario 1 the district of Cianjur has 16 villages affected by tsunami inundation.

The village of Jayagiri is showing highest number of people at risk. According to the results presented for scenario 2 the district of Cilacap has 53 villages potentially affected by tsunami inundation with the village of Cilacap at highest risk. In scenario 3 the district of Trenggalek shows 15 villages potentially affected by tsunami inundation with the village of Tasikmadu at highest risk (Fig. 2).

The land-use damage estimation presented here allows quantifying loss of resources and potential monetary losses due to tsunami impact. According to the estimation results from scenario 1, District of Cianjur has 1,858.3 ha paddy field potentially destroyed by tsunami inundation (see Fig. 2). Assuming 4 tons/ha productivity per crop-season, this district will lose 7,433 tons paddy or approximately 7.43 billon rupiah (equal with $US 826,000) at this moment. The example calculation for paddy field can now be extended to the total loss from all land use including the budget calculations for its rehabilitation (Fig. 2).

Finally, the integration of the results into a risk information tool for local decision makers was performed. The derived information is supplied to a risk information tool conceptually developed for 12 districts at the south coast of Java.

The tool is user friendly designed and prepared for standard personal computers available at local governmental institutions.

The tool shall help local government to get information of exposed people and land use damages estimation. In a next step, this tool will be further developed based on user requests.

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