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We regret for any errors or omissions that we may have unintentionally made.

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PREFACE

The International Seminar on Water Related Risk Management, held in Jakarta, Indonesia from 15 to 17 July 2011 were attended by experts, Scientiest, Practitioners and Profesionals on water resources, Coastal and other related sectors.

The discussions of the seminar had covered the entire aspects of water related risk management including risks contained in flood/drought , coastal , groundwater and urban drainage as well as socio-econonic aspects, involving likely notified profesionals with numerous models, scientific and empirical deliberation, as well as field experience exposures.

The overall presentations, discussions and debates during seminar concluded that the outputs will undoubtedly contribute to remarkable concepts, strategies, lessons learned, and sharing of experiences on the water related disastrous phenomena and it's risks, particulary on the enviromentally sound technologies and sustainable practices on the year to come. Based on this fact, I believe that the proceeding of this seminar will be valuable document in solving the problems of water related disaster and reducing the impact of water related risk.

I would like to thank the organizing committee, reviewer and writers, seniors and all members of HATHI for enormous supports to the seminar. May God bless you all.

Pitoyo Subandrio

Chairman,
The Organizing Committe
July 17th, 2011

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Urban Drainage and Water Supply

Integrated Coastal Vulnerability Assessment Model for Bali Island

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Abstract: *Vulnerability is defined as the extent to which a population or an ecosystem is liable to be affected by a hazard event . A Numerical assessment measures the probability of physical changes based on analysis of physical and human-interference variables. The approach model attempts to combine susceptibility with the ability of the system to adapt and to cope with these problems. Vulnerability indexes provide a measurement of vulnerability potential affected by natural and human induced sea level rise that likewise may contribute to or trigger an increasingly vulnerability.*

The vulnerability assessment method integrates two variables, namely physical and human influence variables that include also the influence of culture and traditional wisdom is expected to be a more integrated assessment model for the estimation of coast vulnerability. By including human induced activity into the vulnerability assessment model, more objective vulnerability indexes to improve management in coping with affected sea level rise, and preparation of strategy, anticipation and adaptation to climate change will be resulted. The application of the coastal vulnerability assessment model in Bali showed that both physical and human-interference variables had affected the coastal vulnerability of the island.

Keywords: *vulnerability assessment, coastal vulnerability indexes, physical variables, human interference variables, Bali Island*

1. INTRODUCTION

Indonesia as an island nation and with a coast line of approximately 95.181 km, the fourth longest in the world (Rompas, 2010), is extremely vulnerable to sea level rise (UNEP, 2006). The vulnerability is aggravated by the population residing these coastal areas, i.e. approximately 60% of the total population lives at a radius of 50 km within the coastline (Idris 2002). Sea level rise in Indonesia reaches an average of 5-10 mm per annum (MMAF, 2009). This sea level rise is relatively small, but in the long range this increase will be of high significance causing serious impact to coastal damages. When adaptation attempts are not carried out and population growth not controlled, the scenario of one meter sea level rise in a time span of 100 years ahead may cause erosion and a shoreline retreat of 50 m (IPCC, 2007). This serious condition of erosion may decrease coastal areas in Indonesia by approximately 4,759 ha per year, and millions of people have to be evacuated to higher grounds (MMAF, 2009). Sea level rise and other related effects are estimated to cause serious impact to coastal areas along the north coast of Java, small islands like Bali, east coast of Sumatera, south coast of Kalimantan, southwest coast of Sulawesi, some coastal areas in West Papua (ADB, 2001).

Sea level rise as impact of global warming has become a serious threat to coastal communities, infrastructure and eco-system (Kaiser, 2007), and exacerbate to coastal areas (1) coastal erosion, (2) inundated coastal plains, (3) tidal flooding, (4) salt intrusion into groundwater layer (Kana et al, 2004; Leatherman, 1989), (5) increase of flood frequency and intensity, (6) change of sea current and destruction of mangrove forests, and (7) disappearance of small islands (Gornitz, 2000). Other induced impacts are the decrease of productive agricultural land and the slow down of industrial and business activities due to damaged infrastructure (MMAF, 2009). Coastal zones are therefore the most vulnerable areas to sea level rise (IPCC, 2001).

This study intends to put forth a model of vulnerability assessment to sea level rise and was tested on beach vulnerability in Bali. It is expected that this study may come out with a more realistic assessment model that shall not only illustrate physical vulnerability but also socio-economic and environmental vulnerability. Development of this model may result (1) coastal vulnerability maps depicting areas of high vulnerability for reference of policy makers, planners and stake-holders in anticipating impacts of climate change, and in preparing strategy, anticipation and adaptation to these impacts, (2) priority in coping with impact in accordance with area vulnerability, and (3) most vulnerable and dominant parameter used in the adaptation plan to impact of sea level rise.

2. LITERATURE REVIEW

Coastal vulnerability is defined as : (1) the extent to which a population or an ecosystem is liable to be affected by a hazard event and be capable of coping with the hazard (UNEP, 2006); (2) the sensitivity of an eco-system and coastal community, individually or as a group to disaster, a condition triggered by a social-economic and environmental system, implies the capability of adaptation in coping with disaster in terms of carrying out preventive measures (Kaiser, 2007); and (3) sensitivity of a community and eco-system to susceptibility of loss and the capability of recovery (Kim et al, 2009). A hazard can maintain a hazard or become more dangerous changing into a disaster. Such depending on the level of vulnerability, particularly if hazard event interacts with human-interfered activity (Kim et al, 2009).

Almost all of these assessment methods stresses upon physical aspects only causing a separation between physical and socio-economic aspects (Nicholls and Small, 2002), and for a long time vulnerability assessment had particularly discussed the physical aspects. However, in recent years some studies had resulted more integrated vulnerability assessment methods that considered both physical and socio-economic/human-interference aspects. These combined variables produced an integrated and complete vulnerability index system (Boruff et al, 2005).

Indicators are defined as the value obtained from several parameters that provides information and the illustration of a phenomena or the environment (OECD, 2003 following Kim et al, 2009). Indicator based vulnerability assessment provides a probability of explaining confusing and intangible reality in one single value. This can be done by reducing these confusing and intangible parameters or application of statistical analysis by a panel of experts (Kim et al, 2009).

3. METHODOLOGY

3.1. Vulnerability Assessment Typology

The indicator based coastal vulnerability assessment model attempts to account for resulting an index of coastal vulnerability to assess and estimate the risk of coastal area to hazards and its capability of coping with these hazards. From the many models of vulnerability assessment and the indexes resulted, vulnerability indexes can be divided into three types: (1) based on physical parameters ; (2) based on combined physical and social parameters ; and (3) based on combined physical, socio-economic , and environmental parameters . The first type initiated the currently used coastal vulnerability indexes as publicized by Gornitzt et al (1991), and the model of vulnerability assessment putting forth physical parameters is used as reference in other types of coastal vulnerability assessment model.

3.1.1. Physical Vulnerability

The physical variable based coastal vulnerability assessment method is related with the segmentation method ranking coastal segments according to semi-quantitative index. The Coastal Vulnerability Index is an example of one of the vulnerability assessment methods only concerned with physical influence. This method measures and ranks indexes based on parameters such as geo-morphology, coastal slope, sea level rise, erosion or accretion of coastline, tidal waves, and average wave height. This vulnerability index was developed by the United States Geological Survey (Thieler and Hammer-Klose,1999). On the contrary, vulnerability assessment based on the human-interference variable uses socio-economic variables as its main component of analysis.

3.1.2. **Integrated Vulnerability Model**

The vulnerability model involving all influential factors of coastal vulnerability, namely physical, socio-economic and environmental variables, is presently considered as the most complete model. By including the cultural parameter, this model is regarded as an integrated vulnerability assessment model and the conceptual coastal vulnerability assessment model used in this study.
The seven parameters proposed in the vulnerability assessment concept include: (1) coastal protection structure, (2) sediment controller, (3) coastal vegetation, (4) land-use, (5) groundwater consumption, (6) population rate, and (7) local tradition, see Table 1.

Table 1 Variable and range of indicator used in deciding the vulnerability index

No.	Variable	Very low	Low	Moderate	High	Very High
1.	Geomorphology	Steep slope	Medium slope	Sand dune	Rock and gravel beach	Sand, coral, mud beach, delta, and mangrove
2	Shoreline change	>2	1.0 – 2.0	-1.0 – 1.0	-2.0 - -1,0	< -2.0
3	Coastal slope	> 1.2	1,2 - 0.9	0.9 - 0.6	0.6 – 0.3	< 0.3
4.	Sea level rise	< 1.8	1.81 – 2.5	2.51 – 3.0	3.01 – 3.4	>3.4
5.	Tidal Range	> 6.0	4.0- 6.0	2.0 – 4.0	1.0 – 2.0	<1.0
6.	Wave height	<1.1	1.1 – 2.0	2.01 – 2.25	2.26 - 2.60	>2.60

Source **:** Pendleton et al (2010)

Table 2 Variable of human interference in deciding coastal vulnerability

No.	Variable	Very Low	Low	Moderate	High	Very High
	Human Interference					
1.	Coastal structures	>50 %	30-50%	20-30 %	5-20%	< 5%
2	Sediment controller	< 20%	20-40%	40-60%	60-80%	>80%
3	Coastal vegetation	>50 %	30-50%	20-30 %	5-20%	< 5%
4.	Land-use	Protected forest	Un-used land	settlement	Agri-culture, fishery	Tourism
5.	Groundwater consumption	<20%	20-30%	30-40%	40-50%	>50%
6.	Population rate	<100	100-500	500-1000	1000-5000	>5000
7	Local culture	>5	3-5	2-3	1-2	<1

Adapted from Oyzurt et al (2008)

3.2. Calculation of Coastal Vulnerability Index

The coastal vulnerability index for physical and human-interference parameters is measured by the assessment model following Gornitz et al (1994), Thieler and Hammar-Klose (1999), Doukakis (2005), Oyzurt et al (2008), and Pendleton et al (2010). First step of this measurement includes the determination of the weighting value as shown on Table 3. The vulnerability value of each parameter indicates influence of respective parameter from range 1 (lowest vulnerability rate) to range 5 (highest vulnerability rate).

Table 3 Parameter Value to Vulnerability Rate

No.	Affect of Parameter to Vulnerability	Value
1.	Very Low	0-1
2.	Low	1-2
3.	Moderate	2-3
4.	High	3-4
5.	Very High	4-5

The CVI is measured based on geometric average as shown by the Equations (1) and (2) below:

$$CVI = \sqrt[n]{\prod_{i-1}^{n} Xi} \quad (1)$$

or

$$CVI = \sqrt[n]{X1\ x\ X2\ x\ X3\ x \ldots \ldots Xn} \quad (2)$$

Where CVI is coastal vulnerability index; x_i :i- parameter; and n is number of parameters

Coastal Vulnerability Index for the physical factor (CVI_P) is calculated based on the number of parameters n = 6, namely X_1 = coastal geo-morphology, X_2 = rate of shoreline change, X_3 = coastal slope, X_4 = rate of sea level rise, X_5 = average tidal range, and X_6 = average wave height. Similar method is used to calculate the CVI for human-interference factor (CVI_H) based on the number of parameter n=7, in this case X_1= coastal protection structures, X_2=sediment controller, X_3= coastal vegetation, X_4= land-use, X_5= groundwater consumption, X_6= population rate, and X_7= local tradition. Results of vulnerability index calculation show a rate between 0 and 5, indicating a vulnerability rate from the lowest to the highest for each coastal segment. A coastal area with CVI 5 is considered as very vulnerable to sea level rise and is depicted on Table 4 below:

Table 4 Index rate and Level of Vulnerability

No.	Coastal Vulnerability Level	*Vulnerability Index Rate*
1.	Very Low	$0 \leq CVI < 1$
2.	Low	$1 \leq CVI < 2$
3.	Moderate	$2 \leq CVI < 3$
4.	High	$3 \leq CVI < 4$
5.	Very High	$4 \leq CVI < 5$

4. RESULTS AND DISCUSSION

4.1. Data

This study has selected 4 beach segments in south Bali, i.e. Sanur and Nusa Dua beaches on the east side, and Kuta and Tanah Lot on the west side. Another 4 beach segments were selected in north Bali namely on the west side the beaches Pemutaran and Lovina, and on the east side the Tejakula and Tulambem beaches.

4.2. Analysis

4.2.1. Coastal Vulnerability in South Bali

The beach segment at Sanur as presented in Table 5, resulted the CVI_P and CVI_H rates, of respectively 3.12 and 2.65. These high indexes indicate the high vulnerability rate with physical factor more dominant than the human-interference factor. The sandy and sloping beach geo-morphology of Sanur Beach contributes highly to the coastal vulnerability. Moreover, vulnerability of this beach segment is aggravated by the parameters of human-interference, land-use for tourism, population rate, and groundwater consumption, although local tradition and coastal vegetation are contributing largely to the reduce of coastal vulnerability at Sanur. The Nusa Dua Beach with CVI_P and CVI_H respectively 3.13 and 2.70, show a coastal vulnerability higher than at Sanur. These indexes are resulted by the geo-morphological conditions, coastal slope and tidal range. However, the parameter of human-interference is quite similar with the parameter at Sanur Beach. On the contrary, land-use at Nusa Dua shows a higher contribution to coastal vulnerability than that of Sanur Beach.

The Kuta Beach shows vulnerability indexes exceeding the indexes of Sanur as well as Nusa Dua, namely with CVI_P and CVI_H showing 3.25 and 3.13. Although the geo-morphology and tidal range is the same as with Sanur Beach, coastal slope at Kuta is flatter than at Sanur and Nusa Dua. Wave height at Kuta Beach is also higher and increases the vulnerability rate. The high rate of CVI_H at Kuta Beach, particularly caused by the densely population, land-use, groundwater consumption, scarcity of coastal vegetation, existence of *Ngurah Rai* airport runway, and other types of coastal protection structures contribute highly to the coastal vulnerability. These coastal protection structures along Kuta beach are causing negative impact to the beach condition. Human-interference is very dominant at Kuta and much higher than the physical influence. Coastal vulnerability at Kuta is thus become more vulnerable due to human interference.

Table 5 Coastal Vulnerability Index in South Bali

Parameter	South Coast of Bali			
	Sanur Beach	Nusa Dua Beach	Kuta Beach	Tanah Lot Beach
Physical Parameter				
Geomorphology	4.5	4.5	4.5	1.5
Shoreline change	3.5	3.5	3	2.5
Coastal slope	4.5	4,	5	1.5
Sea level rise	2.5	2.5	2.5	2.5
Tidal range	3.5	4	3.5	3.5
Wave height	1.5	1.5	2	3.5
Physical CVI	**3.12**	**3.13**	**3.25**	**2.35**
Human Interference Parameter				
Coastal protection	1.5	1.5	2.5	1.5
Sediment controller	2.5	2.5	2.5	2.5
Coastal vegetation	2.5	2.5	3.0	2.5
Land-use	4.0	4.5	4.0	4.0
Groundwater consumption	3.5	3,5	3,5	1,5
Population rate	3,5	3.5	4.5	2.5
Local culture	2.0	2.0	2.0	2.0
Human Interference CVI	**2.65**	**2.70**	**3.03**	**2.23**
Integrated CVI	**2.87**	**2.91**	**3.13**	**2.29**

On the contrary, the beach segment at Tanah Lot shows CVI_P and CVI_H rates of respectively 2.35 and 2.23 that indicate moderate vulnerability and the lowest among the other beach segments of south Bali. The steep geo-morphology and coastal slope are contributing highly to the reduce of coastal vulnerability, and therefore in overall the coast of Tanah Lot is much more reliable to global sea level rise. The larger and higher waves than that of the other beach segments are of no influence to its coastal vulnerability. Additionally, human-interference vulnerability index at Tanah Lot is very low which is due to the scare population, low groundwater consumption and the intense cultural contribution. Thus, these parameters are increasing the resilience to the impacts of sea level rise.

4.2.2. **Vulnerability in North Bali**

Physical condition of the geomorphology and coastal slope at *Pemuteran* Beach shows a low vulnerability index, namely CVI_P = 2.32 (see Table 6). Due to being surrounded by mangrove and conservation forests, the human-interference parameter in West Bali is very dominant showing a CVI_H rate of 1.28; lowest vulnerability index of the study area. Local tradition in the area is very dominant and environmentalists supported by national as well as international organizations are holding an active role in preserving the tradition. The Lovina Beach which is closely located to *Singaraja,* capital of the area, is a prime tourist resort on the north coast and shows highest vulnerability assessment rates, namely CVI_P and CVI_H respectively 2.56 and 2.01. The physical condition of the geomorphology and coastal slope is a dominant index of vulnerability, whereas land-use and urban population rate are cause to the higher vulnerability index.

The beaches of *Tejakula* and *Tulamben* on the east side of the northern coast of Bali show very low physical and human-interference vulnerability assessment indexes, CVI_P is 1.76 and 2.07, respectively, while CVI_H is 1.35 and 1.77 respectively. The physical parameters such as steep sloping beaches are a protection and prevention to the impact of sea level rise making both beaches more stable. The use of land as tourist resort and coastal protection structures at *Tulamben* is a dominant contribution to the human-interference vulnerability index on the east side of the northern coast of Bali.

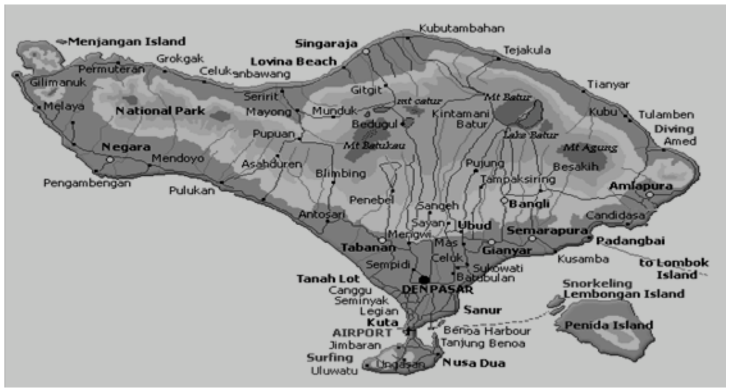

Figure 1 Bali Island

Table 6 Coastal Vulnerability Index of beaches in North Bali

Parameter	North Coast of Bali			
	Pemuteran Beach	Lovina/SGR Beach	Tejakula Beach	Tulamben Beach
Physical Parameter				
Geo-morphology	4.0	4.0	1.5	2.0
Shoreine change	1.5	2.0	1.0	1.0
Coastal slope	3.0	4.0	1.5	3.0
Sea level rise	2.5	2.5	2.5	2.5
Tidal range	3.5	3.5	3.5	3.5
Wave height	1.0	1.0	1.5	1.5
Physical CVI	**2.32**	**2.56**	**1.76**	**2.07**
Human Interference Parameter				
Beach protection	2.5	2.0	1.5	4.0
Sediment controller	1.5	1.5	1.0	1.0
Beach vegetation	1	1.5	1.5	1.5
Land-use	1	4.0	1.5	4.0
Groundwater consumption	1	1.5	1.0	1.0
Population rate	1.5	2.5	1.0	1.5
Culture	1.0	2.0	2.5	1.5
Human Interference CVI	**1.28**	**2.01**	**1.35**	**1.77**
Integrated CVI	**1.31**	**1.51**	**1.24**	**1.91**

4.2.3 **Vulnerability of the Bali Island**

According to the application of the integrated vulnerability assessment model as showed on Table 7, coastal vulnerability in south Bali is much higher than that of the north of Bali. Considering the physical and human interference factors, the high coastal vulnerability in south Bali is quite understandable and supported by actual field conditions. The parameters of geomorphology, coastal slope, tidal range and high waves are causing this high vulnerability index. On the contrary, the human-interference parameter causing negative or positive impact to coastal conditions may be dominant in aggravating or reducing the coastal vulnerability index rate.

Table 7 Summary of Coastal Vulnerability Index of Bali Island

CVI	Bali Island	
	North Coast	South Coast
Physical	2.16	2.96
Human interference	1.57	2.64
Integrated	1.36	2.80

4.3. Discussion

The application of the vulnerability assessment model in the case study of north and south Bali, with respectively four beach segments, can certainly not represent the overall condition of coastal vulnerability in Bali. However, the vulnerability indexes resulted from this assessment model can at least give an illustration of the vulnerability index of both physical and human-interference factors of each beach segment. The index or numerical sum calculated based on this assessment model is an indicator of information on the rate and span of coastal vulnerability. The CVI_P and CVI_H rates resulted from the eight study areas show a conformity with the logical estimated assessment. The case studies in north and south Bali show a relationship between physical and human-interference parameters. For the south Bali, the indicator of high physical vulnerability involves also a high vulnerability of human-interference. On the contrary, for north Bali, the index of physical vulnerability is much larger than the indicator of human interference. A more intensive analysis to be implemented in future, shall concentrate on the determination of dominant variables by linear regression analysis and main component analysis.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

1. Physical and human-interference indicators representing the impact of the interaction between man and the environment that aggravate or reduce coastal vulnerability.
2. Physical and human-interference factors which simultaneously may influence and increase the coastal vulnerability at the Sanur, Nusa Dua, and Kuta Beaches.
3. The human-interference vulnerability indicator of Kuta Beach exceeding its physical vulnerability indicator. The parameters of population and the landing strip at Ngurah Rai are aggravating the vulnerability of Kuta Beach.
4. Coastal vulnerability due to sea level rise in south Bali is higher than the vulnerability in north Bali.

5.2. Recommendations

1. Intensification of the preparation of a coastal data base that shall not only collect physical data, but also gather data on socio-economic and environmental aspects as input of coastal vulnerability assessment.
2. Elaborate base data into coastal information system that useful for coastal vulnerability assessment. GIS for coastal area, is a data source essential in coastal vulnerability assessment which gradually is to be improved by supplementing information on coastal vulnerability and its level of destruction .
3. Programs of step-wise research and development of coastal vulnerability assessment for Java, Bali, and other islands should be set up immediately, so that in certain time period, maps on coastal vulnerability are established and used by planners, coastal management and stakeholders as reference.

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