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Flood risk analysis and mapping in Gorontalo city, Indonesia, using high resolution Google Earth's imagery

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Short abstract: We found that Google Earth (2010) images obtained freely from internet are very efficient for risk assessment. About 101 hectares of the area studied were considered high risk, while 200 ha were at medium risk. The high risk areas were located in the settlements. The river embankments (dikes) built along the river for mitigation purposes are built on flood plains. Land utilization should be tightly controlled using strict urban planning legislation.

Keywords: risk, flood, Bone River, Gorontalo, Google Earth.

Introduction

Almost every year, Gorontalo city and its vicinity experiences flooding from Bone and Tamalate rivers. Before 1996, the accident did not have significant impact to inhabitants. However, flooding tends to be severe, with a notable record being in 2002. The most recent serious inundation was in 2006. To avoid such disastrous accidents, mitigation planning is required. The first step to establishing a suitable risk mitigation plan requires evaluation of flood hazard and risk along the two rivers.

It is widely understood that Gorontalo is a flood-prone area since it lies in the central basin of North Sulawesi. The city has been built on alluvial plains and the Bolango River alluvial fan. The city is surrounded by hilly to mountainous terrain, making it particularly vulnerable to flooding (Tjahjono *et al.* 2009). Mapping and study of flood hazard was conducted by Bappedalda Gorontalo (Municipal Board for Environmental Assessment of Gorontalo) in 2007, using a geomorphological approach based on 2006 Landsat data. The study suggested that anthropogenic factors – uncontrolled land use change, appalling drainage and waste management – contributed significantly to increasing flood risk. Hidiya (2011) indicated a significant trend on land use change of Lower Bone Watershed. In the site, forests, rice fields and uplands have been replaced by mixed garden and settlements. The study concluded that urban planning has a major role in avoiding damage and fatalities in the future.

Spatial planning or mitigation planning at municipal level requires detailed spatial data or imagery. With the remoteness of most Indonesian middle sized cities, appropriate scale data is not available. This even occurs in most Eastern Indonesian regencies (*kabupatens*), due to many reasons including availability of high resolution remote sensing data. Availability of high resolution data sources such as Google Earth leads to diminishing gaps on some locations. This paper discusses the use of high-resolution Google Earth image to provide a detailed flood risk map, based on the work of Bappedalda Gorontalo.

Methods

Gorontalo Municipal is geographically located in 0° 32' 00.79" N and 123° 03' 35.42" E and at the seashore of Tomini Gulf, Northern Sulawesi. In this research, Google Earth data dated 6th March 2010 were used. Digitizing was done online using Google Earth digitizing facilities. Visual interpretation on land use and landforms employed common interpretation keys such as tone, texture, shape and association.

Flood hazard map of Bappedalda Gorontalo was used as an input to estimate risks associated with vulnerability and risk elements of land use. Risk was calculated using the definition of Thouret (1994) as follows: $R = H \times V \times E$, where R = risk, H = hazard, V = vulnerability, and E = risk elements (or exposure). Study site was focused along Bone and Tamalate Rivers which are covered by high resolution imagery.

In this research, simple scoring was implemented to obtain risk levels (Table 1, 2, and 3). The hazard levels were classified into high, moderate and low.

Flood Hazard	Score
High	3
moderate	2
Low	1

Tab. 1 – Scoring for flood hazard.

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Vulnerability	Score
Built areas, river channel	3
Agriculture (rice & upland fields)	2
Others	1

Tab. 2 – Scoring for vulnerability.

Risk Elements	Score
Settlements (built areas)	3
Rice fields	2
Upland fields	1
Mixed gardens	1
Forest and scrubs, river channel	0

Tab. 3 – Scoring for risk elements.

Risks were classified into three categories based on intervals calculated from range divided by designated risk classes, i.e. (27–0)/3 = 9. Risk classes are described in Table 4.

Risk categories	Range
High	>18-27
Moderate	>9-18
Low	0-9

Tab. 4 – Classification of risk.

Results and Discussion

It appears that spatial distribution of hazard levels was closely related to landforms. Highest level could be found in flood plains of the rivers. Areas with highest level of hazard were usually flooded every year in the rainy season; inundation frequency is about 7–10 times every decade. Meanwhile, a moderate level of hazard was attributed generally to older alluvial plains with frequency of 3-6 times/decade (Bappedalda Gorontalo, 2007). However, we should mention here that magnitude of inundation tends to increase in recent years and induces substantial cost to local inhabitants who live along the river.

In this research, vulnerability was solely determined by land use data. Google Earth images provide the possibility to derive detailed and up-to-date land use information. Using the imagery, 5 major land use classes could be retrieved, i.e. built-up (dominated by settlements), rice fields, upland (dry) fields, mixed gardens, forest/shrub. Land use delineation on flood-prone areas concluded that built-up (settlement) areas covered 408.9 ha, which was the largest among land use classes. After settlements, mixed garden (380.5 ha), upland fields (364.5 ha), and rice fields (142.5 ha) were the most abundant. Each land use class was then assigned a designated score and serves as a risk element to obtain overall vulnerability.

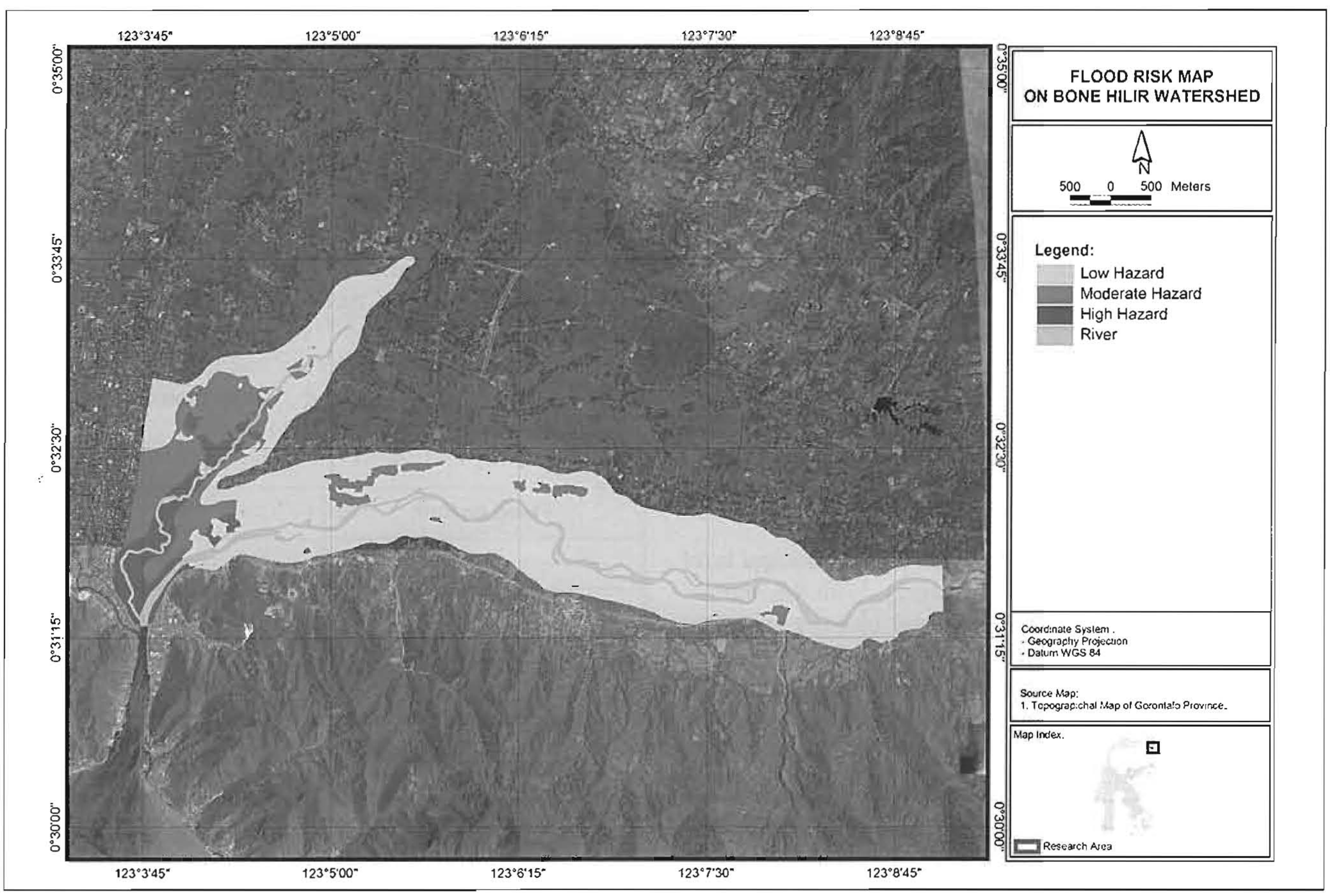

Fig. 1 – Bone River flood risk map, Gorontalo, Indonesia.

Using simple Boolean overlay in GIS, flood risk of the site was calculated. The result indicated that highest risk areas were the least abundant, covering around 101.7 ha. These areas were to be found on Tamalate and Bone River banks, especially in the estuary. Most of the study area was categorized as low risk (1187.6 ha) with following land uses: upland (dry) fields, mixed garden, rice fields and settlements. Moderate risk (about 200.3 ha) was located in settlements and some in rice fields (Fig. 1). As most of the medium to high risk areas are to be found in built-up areas, the local government has already built dikes to limit the impact of most flood events. These are appropriate for all but exceptional events which may overflow them. It should be noted here that these dikes have not been built on the edge of flood plains, but in the middle. In these cases, if urban development takes place behind the dikes, but within the flood plains, the risk is significantly higher – here, during exceptional events, these urban areas will most likely flooded very rapidly after the dikes are overflowed.

The Google Earth image presented below shows the narrowing part of Bone River, near the estuary. This point pays an attention and further research is needed to determine its contribution to flooding. Restricting the width of the river body would dramatically change the river bed, and a slight increase of water flow could raise water level which, in turn, may create flooding. The situation could be even worse if the tidal influence is also taken into account; however, we cannot currently evaluate this impact due to the limited data available.

Conclusion

Newly acquired data (6th March 2010) available through Google Earth was beneficial to assessing flood risk and provided the possibility of deriving detailed land use of a remote area in Indonesia. In particular, land use information was required as a contributing factor to risk elements (exposure).

This study demonstrates that freely available high resolution imagery were advantageous to assist mitigation and hazard-related planning in remote areas. Availability to such data should help reduce damages and casualties in future flooding events.

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