Flood Risk Assessment in Dili: An Integrated GIS-Based Multi-Criteria Analysis Approaches

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Abstract: An integrated GIS-based multi-criteria approaches was employed to analyze the flood risk assessment which enabled to further construct the accurate maps of flood susceptibility and vulnerability as well as Flood Risk, respectively prior to the recent calamity that struck Timor-Leste, especially the Capital Dili on 4\textsuperscript{th} April 2021. The result of the flood risk index (FRI) categorized into four levels: high 3.36 km\textsuperscript{2} (2\%), was being in the vicinity of rivers, flood plains, lakes, and coasts; moderate to high (18.21 km\textsuperscript{2}, 39\%), low to moderate 20.68 km\textsuperscript{2} (44\%) and low to very low 6.62 km\textsuperscript{2} (14\%). The flood susceptibility Index shows that high flood susceptibility cover area of 11.94km\textsuperscript{2} (8\%), moderate to high: 27.82 km\textsuperscript{2} (19\%), low to moderate: 6.77 km\textsuperscript{2} (5\%), very low: 101.3698 km\textsuperscript{2} (69\%). Most of the potentially susceptible areas of the detected flood were flooded on 4\textsuperscript{th} April 2021.

Keywords: Flood risk assessment, GIS, Map susceptibility, vulnerability, Flood risk index

1. Introduction

The flood events are typically regarded as the most common natural disaster worldwide [1]. Like other flood-prone countries, Timor-Leste has experienced aforesaid events frequently for two decades. However, the most significant live-claimed floods occurred within the last two consecutive years specifically that of recent devastating calamity that took place on 4\textsuperscript{th} April 2021 in the Capital Dili and its surrounding regions. This event is associated with the intense precipitation and strong wind that were triggered by the “Seroja” cyclone. Consequently, losses of more than forty lives; the damages of numerous residential dwellings; commercial buildings and infrastructures; the temporary relocation thousands of households to the nearby shelters; and a few permanent displacements which were resulted by the drastic and sudden flash floods, riverine, lakes and coastal floods during that time. Geographically, Dili located in the northern coast of Timor Island, which is surrounded by higher relief, roughed topography bounded on its eastern, western and southern flanks. The lithology of this highland is predominantly of weathered- and fractured- metamorphic rocks that are covered by moderate to sparse vegetation. The overlain soils and rocks uphill underwent extreme erosion by rapid water runoff downhill through existing natural drainage networks such as gullies and valleys.
and that being dumped into the main river channels, lakes and lowland areas. In addition, it caused the aforementioned ambient to have thickened up with various sizes of unconsolidated sediments which in turn brought the social, economic and livelihood impacts to their inhabitants.

The Dili is situated on top of the alluvial fans that are mainly controlled by fluvial and alluvial systems. Furthermore, the city agglomeration thru uncontrollably urban expansion in recent years, particularly along, across and inside the above mentioned environments led to the narrowing and/or widening of their geometries (i.e., width, length, sinuosity/curvature and depth) for instance rivers and lakes which likely to inhibit the capacity of water discharge during torrential downpour, as a result the vast areas were being inundated and washed out. Nonetheless, the corrective measures of the previous engineering works, namely drainage system and infrastructure including urban planning itself need to be addressed rigorously and wisely in order to withstand other events that are expected to occur in the coming years. There are four major elements obtained in this study such as the risk assessment, flood damage, vulnerability and susceptibility indices. The primary field data acquisition integrated with the secondary data through GIS-based on multi-criteria approaches aided this research to be successfully carried out. Additionally, the detailed elaboration of Remote Sensing (RS) and Geographic Information System (GIS) technologies permitted the researchers to link them with the development of hydrology, particularly in the flood managements which could meet all the requirements of flood prediction, preparation, prevention and damage assessment [2]. The Flood risk mapping which is using the GIS and multi-criteria methods have been applied in various case studies. [3]-[4]. Therefore, the current research aims at investigation and comprehensive flood risk assessment by pinpointing the critical and hazard zones caused by the calamity. The results of this research provide the accurate Maps of Flood Susceptibility and Vulnerability as well as a Flood Risk Map.

2. Study Area

Timor-Leste is one of the islands that are located in the outer Banda Arc, easternmost of East Indonesia, between southern and northwestern Indonesia and Australia,
respectively. The study area covers entirely Dili Municipality including Dom-Aleixo, Vera-Cruz and Cristo-Rei (except Metinaro Village) Sub-districts (Fig. 1). The study is subdivided into a square region between latitudes UTM 775000-800000 and longitudes 9045000-9057500 in a total area of 142.85 km². The climate of the study area is generally humid all year round, averaging from 25°C to 33°C. The average rainfall is 100 mm to 300 mm per month between December and May.

3. Methodology

The Integrated GIS-based multi-criteria approaches were employed (Fig. 2) to analyze the flood potential risk areas specifically in this research. This GIS-based multi-criteria approach has been progressively used for flood risk assessment, as it presents several advantages [5].

Two (2) data sources were proposed including primary and secondary data. The former was assessed by using the flood inventory forms through direct field observation, measurement and local interview; meanwhile the latter was obtained by pre-existing data source. The analysis of spatial distribution maps was further performed by means of the GIS platform (ArcGIS) and statistical methods (i.e., Analytical Hierarchy Process, AHP) based on both aforementioned data outlets. The main goal of this study is to provide the Flood Susceptibility Index Map produced by two (2) principal causal factors of relevance thirteen (13) selected criteria of the affected areas. These are conditioning and triggering factors which subdivided into several parameters comprising of the elevation, slope gradient, slope aspects, surface curvature index, surface roughness index, geology, soils, Normalize Difference vegetation index (NDVI), main river proximity, potential coastal and Lake water level rises, drainage density, land use, and land cover; rainfall (precipitation) by Seroja Cyclone, respectively. Moreover, this Flood Susceptibility Index is constructed mainly by secondary data which consisted of 1) Topographic analog, geological and surface soil maps of Dili region; 2) AreoMap in the

![Fig. 2 General Procedure to develop risk map on integrated GIS-based multi-criteria approaches.](image-url)
ESRI ArcGIS via online server; 3) GeoEye-1 imagery; 4) LANDSAT 8 OLI (USGS, 2020); 5) LIDAR-DEM 5m by DNG-MPO-RDTL (2021).

The Rainfall Intensity Map was produced through analysis and processing of rainfall intensity that was acquired from the existing gauge stations in the Dili and surrounding regions such as Dili-EDTL, Railaco, Remexio and Laclo. These four (4) sites data were interpolated to cover precisely the entire research area.

Their locations (between January and April 2021) are described in Figure 3. The elaboration of the Risk Map was undergone by three phases; firstly, the flood susceptibility zone was analyzed based upon two analytical processes, namely the Multi Criteria Analysis (MCA) and Weight Overlay Criteria Map in the GIS platform. The MCA has a multi criteria decision tool, "Analytic Hierarchy Process, AHP" for evaluating the weights of each map criteria. On the other hand, the AHP constructs a hierarchy of decision criteria which has the repetitive comparison processes (formulated as a matrix) between different pairs of different criteria. It was normalized by the paramount criteria pairs and calculated the consistency ratio (it must be lower than 0.1). Additionally, the AHP produced weighting scores of paired criteria that indicated the hierarchy of importance in the selected criteria. The Flood Susceptibility was made after the incorporation of aforesaid determined weighing score and a weighted overlay process.

Secondly, the Flood Vulnerability index map. Vulnerability is the capability of or susceptibility to being physically hurt or damaged. In flooding, there is always the probability of the economy, infrastructure and life being vulnerable. Factors that have influence on vulnerability to flood are land cover and land use, nature of population, degree of built up areas and type of buildings and the ability to forecast and strategize for imminent hazardous event [6]. The vulnerability map in this study was produced by primary source data (field-based) which collected from 468 sites including along rivers, floodplains, coastal areas and lakes. These data were utilized in the form of interpolation in order to produce several empirical flood catalogue maps that consisted of Flood Extent (Distribution) Map, Flood Water Depth Map and Flood Damaged Map. The first map was made on the basis of flooded and non-flooded zones (468 Area of Interests, AOI), while the last two maps was elaborated based on the degree of exposure of ground and/or detailed

![Rainfall Intensity (January-March 2021)](image1)

![Rainfall Intensity (Day 01-04 Abril 2021)](image2)

**Fig. 3 Dili and surrounding area rainfall intensity data from January to April 2021.**
land cover gathered from various risk’s elements and the integration flood’s water depth/level by means of statistical analysis and matrix comparison, respectively. Lastly, the construction of the Flood Risk Map by means of spatial overlaying method and statistical matrix pairwise comparison of the Flood Susceptibility Index (FSI) and the Flood Vulnerability Index (FVI) level was concluded. The RISK equation can be presented as follows: RISK = FSI x FVI.

4. Results

4.1. Flood Susceptibility

The Flood susceptibility mapping is essential to characterize potential flood zone development approaches. In this study, flood control and triggered parameters (criteria) were widely selected to generate the flood susceptibility index (Fig. 4) using the multi-criteria analysis (MCA) and weighted overlay criteria map in GIS platform approaches. The CR value that is described here must be lower than 0.1. The relative importance of each criterion was prioritized according to its contribution to flood susceptibility as discussed below. The most predominant flood-caused criteria were environmental factors (0.27), land cover and land-use interference (0.26), rainfall (0.20) proximity of major river channels (0.13), coastal and lakes water level rise (0.1) and drainage density (0.05), respectively. Using these criteria enabled the researchers to categorize the Dili region as high, moderate, low and very low flood susceptibility zones. It explicitly comprises ~11.94 km² (8%) of area coverage which was considered as highly flood susceptibility, the moderate to high flood susceptibility covers ~27.82 km² (19%), low to moderate flood susceptibility occupies ~6.77 km² (5%) and ~101.3698 km² (69%) was very low flood susceptibility, respectively. The former (higher susceptible) were in the river channel, along riverbanks, coastal zones and surrounding lakes. However, the degree of the latter susceptibility zone (moderate-very low) reduced as it extended and distributed its course away from the main flood feeders.

Fig. 4 Flood Susceptibility map of Dili.
4.2 Flood Vulnerability

The flood vulnerability index map was created based on exposure or detailed land use (elements to risk) integrated with flood distribution, flood depth, and damage maps (field based, 468 AOF) by comparison of statistical analysis matrices. The results of the flood vulnerability index map (Fig. 5) were categorized into four levels of vulnerability: high, moderate, low and very low. The Areas of coverage approximately 3.36 km² (2%) are concentrated as high flood vulnerabilities, occur along rivers, and were previously very extensive on both sides of embankments, drainage networks, and lowland areas of the floodplains, along the coast and in the vicinity of lakes. As shown in Fig. 5, moderate to high flood vulnerability is shown in the yellow area. It covers about 16.05 km² (11%). The area of about 28.29 km² (19%) is low to moderate flood vulnerability. With an area of approximately 102.11 km² (68 %), flood vulnerability is very low to low.

4.3 Flood Risk

The Flood Risk Map was developed eventually through the integration of previous two maps i.e., Susceptibility and Vulnerability Maps. It will be considered as an essential tool for future Land Use Planning in the inundated zones (5). The overall accuracy of this map was classified into four classes of risk index ranging from very low to high flood risk index zones. The high Flood Risk Index (FRI) zone covers approximately 3% that is equivalent to 1.32 km² of the study area including those of rivers and lakes proximity ambient which represents red color hue on the map. The small portion of lowland areas fell into this category as well due to lack of urban planning (overpopulated/city agglomeration) such as inadequate drainage systems, inapt management of settlement construction, industrial waste and uncontrollable rocks/soils excavation of the hilly areas (e.g., principal contribution to the erosion and sedimentation rates). The results showed that the following areas are specifically located within this zone including Kasnafar Beduku, Fomento, Fatu-Hada, Aitarak Laran, Maloa, Caicoli, Bidau, Maufelu, Akanunu, Mota Kiik, Halidolar, Ailoklaran-Hera (Naval) and Beraca-Hera. The Moderate FRI zone on the other part expands across the vast areas that represent 18.21 km² or roughly 39% of the research area.
Fig. 6 Flood risk Map of Dili.
which is indicated as yellow color shades that encompassing the Tasi – Tolu, the Central of Dili, Akanunu and the Hera Central (i.e., Mota Ki’ik, Ailoklaran, Halidolar and Beraca). This zone is likely shifting to higher risk in several exceptional cases. Lastly the low and very low FRI zones cover 20.68 km² (44%) and 6.62 km² (14%) which are shown by green color tones (pine green and forest green). They occupy unaffected foothill areas, suburban and urban elevated lands/highlands, horticultural and agricultural lands (e.g., Halidolar, Hera), those distal to the main flood feeders (e.g., river and lakes) and highlands/uphill, respectively. These areas were left untouched because of its elevation, distance and reduction of flow capacity during flooding. However, the former could potentially create low to moderate risk in certain situations. The flood Risk Map is shown in Fig. 6.

5. Discussion

The flood susceptibility index was determined using secondary source and was created based on two analytical processes Multi Criteria Analysis (MCA) and Weighted Overlay Criteria Map in GIS approaches. These methods demonstrated that it’s an extremely effective in this study. The fact that most of the potentially susceptible areas of the detected flood were flooded on 4th April 2021.

The raw data from primary sources or fields (Fig.7) were collected from 468 flood sites along rivers, floodplains, coasts, and around lakes, including non-flood sites. The flood vulnerability index maps created by them show that several types of floods have occurred, including river floods, flash floods, coastal floods, and lake floods. These types of floods occurred individually or in conjunction with other floods simultaneously and/or in succession. The susceptible flood zone pointed out in this paper is presumed to have been caused by various factors such as the following.

a) Many trigger and adjustment factors are involved along rivers. Before the heavy precipitation, the river spread very wide on both sides. During the unusual weather conditions of the Cyclone Seroja, large amounts of water were supplied to existing drainage networks and lowlands. After that, excessive drainage and spillage occurred in the area.

In general, the shape of a river is characterized by the width, depth, curvature, etc. of the channel. And then, it is determined by the rugged terrain. Such surrounding terrain can cause extreme erosion along the river itself. As a result, relative subsidence occurs around the river. It is designated here that the design of civil engineering structures such as river embankments and the design of bridges that are not based on geological knowledge may have increased the damage this time. For example, blockages of tree, debris, and deposits on bridges would be a good example. Roads will also impede the flow of water, depending on where they are installed, and will cause high river levels at some points. In addition, deforestation results in the deprivation of water retention in the mountains, resulting in rainfall, soils and sands, and even timbers flowing into rivers at once. Such deforestation, uncontrollable rock quarrying, excavation for construction purposes in adjacent canyons (e.g. roads and houses) and land reclamation with sediments will continue from a geological point of view. We need to have considered them on the basis of geological knowledge.

b) Floodplains were damaged by dense urbanization and lack of urban planning systems. Due to the increasing urbanization
and densely populated residential areas of Dili, even small flood areas will increase the affected population and economic loss. In the future, such floods are expected to increase along with global warming.

We need to reconsider the urban planning systems toward the future flood disasters. Furthermore, we start to consider a long-term urban plan on the basis of geological studies as follows. Dili is located in an alluvial fan, which is a fan-shaped land formed by the movement of rivers and the supply of earth and sand in a fan shape. Even if a bank is constructed along a river flowing through such an alluvial fan, the river would be immediately filled with the supplied soils and sands. As a result, the river will move to the side. When a bank is constructed along a river in such an alluvial fan, that is, when the river channel is fixed by the embankment, it is necessary to frequently remove the soils and sands supplied from the mountains to the riverbed. Failure to excavate such riverbeds will reclaim rivers and increase flood damage. When controlling rivers in city planning, it is necessary to devise a long-term city plan based on geological knowledge.

e) In coastal areas, there will be strong winds associated with heavy rains and the reappearance of lowlands due to past river
channel destruction. There were also lagoons that could be affected by higher waves, destroying some areas of these environments. During this flood disaster, we need to study not only the river flood, but also the storm surge as follows. The cyclone due to this flooding has occurred in the Southern Hemisphere and approached Timor Leste from the western region, accompanied by a clockwise rain cloud vortex. In this case, Dili had a strong north wind. Generally, when a low-pressure such as a cyclone approaches, the sea level rises due to the low pressure. In addition, when seawater is blown to the coast by strong winds, the sea level on the coast rises. In this way, when the cyclone approaches, the sea level rises due to low pressure and strong winds. When the high tide time coincides with this, the sea level rises further than normal sea level. Such a phenomenon is called storm surge and poses a threat on the coast. It is possible that such a storm surge occurred along the coast this time as well, and it is necessary to examine in detail the link between floods and storm surges not only as floods in rivers but also as total disaster damages along the coast.

d) Near the lake, heavy rainfall was discharged from the canyons in the surrounding mountainous areas. This flooded and washed away vast areas, killing several people and causing socio-economic losses. It also caused the temporary evacuation of thousands of households.

This detailed study proposed a flood zone area [7] and a land use plan [8] as an early warning system. Figure 6 shows the results, with areas of interest shown in red. Areas shown in red are high areas where potential floods are likely to occur, and areas where potential floods are moderate to high are yellow. This map can help prevent future land use plans and similar flood events in the future. And by using this, it will be possible to build a major early warning system.

6. Conclusion

The flood calamity is reflected as a major natural hazard due to its devastating effects on the affected area that virtually occur in extremely recent rainy season in Dili capital of Timor-Leste. From the data presented in this study, we conclude that: The area that prone to potential flood occurrences are being in the vicinity of rivers, flood plains, lakes, and coasts. The area includes Kasnafar Beduku, Fomento, Fatuhada, Aitarak Laran, Maloa, Caicoli, Bidau, Maufelu, Akanunu, Mota Kiik, Hera Naval.

The principal trigger and adjustment factors that involve in the calamity flooding such as:

- The unusual weather conditions of the Cyclone Seroja
- Environmental (Elevation, Slope gradient, Slope Aspect, Geology, Soil-Textures, Normalized Diff. Vegetation Index, Topographic Roughness Index, and Terrain Curvature Index)
- Lack of urban planning systems.
- The shape of a river
- Inadequate band inequivalent/opposed drainage system
- The design of civil engineering structures such as river embankments and bridges that are not based on geological knowledge.
- Roads also impede the flow of water
- Deforestation
- Uncontrollable rock quarrying, excavation for construction purposes in adjacent canyons (e.g. roads and houses)
- and, land reclamation with sediments.

The flood that occurred affected: infrastructure, urban settlement, government building, schools, Agriculture zone and loss of
life. Furthermore, it causes socio-economic losses and temporary evacuation of thousands of households.

7. Recommendation

According to result obtained, we recommended to all Timorese competent government and institutions or other relatable parts, as fallow:

1. Designing and improvement the existing drainage systems including dams and retaining walls based geological and geomorphological condition to reduce the river-floods (overflowing and cut-banks),

2. Improve the bridges designs and models based on the morphology, drainage pattern and shapes as well as drainage densities, to reduce the blockage materials and overflowed on or around the bridges.

3. To reduce the flash flood in urban areas. We need to be controlling the inadequate small drainage channels and controlling waste management systems, maintenance for pavements to managing runoff surface water. In addition, controlling and socializing land use pattern based on applicable decree laws, controlling disorganized dwellings and regulate the communities to living away at potential risk areas for flooding occurrences such as vicinities of rivers, lakes and coastal area including at the creeks and valleys.

4. To minimize the sedimentation (debris flow deposits) in the lowland areas (foothills especially near the creeks and valleys), need heavily controlling for deforestation of environments (protect the biodiversity alongside or/and on the hills and mountains), controlling the surface excavation as widening-road excavation and dwelling excavation as well as rock quarries.

5. Need a team to monitoring and creating system for flood warning, alert and evacuation.

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References


