Integration of Digital Elevation Model (DEM) and HEC-RAS Hydrodynamic Model for flood routing

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Abstract. The development of computer technology, especially the hydrodynamic modeling package, provides convenience in many things including flood modeling in the river. One of these modeling packages is HEC-RAS Hydrodynamic Model which can be used to simulate both steady flow and unsteady flow. On the other side, the development of Geographic Information System (GIS), is now rapidly evolving for a variety of purposes with a wider range of fields and scope, including the preparation of river geometry data based on Digital Elevation Model (DEM) in Triangulated Irregular Network (TIN) format as the input of the model. The aim of this study is to perform flood routing for determining the river capacity and for estimating the factors that cause floods by integrating TIN data into HEC-RAS Hydrodynamic Model, using Lantikadigo River in Central Sulawesi, Indonesia as a model. In this river, almost every year flooding occurs with fluctuating intensity of inundation. Integrating data is the process of synthesizing geometry data that is processed in the GIS environment as input for the HEC-RAS Model. Data integration provides the effectiveness of the use of simulation time due to input geometry data is done using import data facility when compared manually input geometry data. The results of the study show that the maximum water level of the 1-year return period has exceeded the river bank elevation both on the left and on the right side of the entire segment. The peak discharge of hydrograph for 1-year return period is 55.3 m³/s at the outlet of Lantikadigo Watershed. This means that the average channel capacity is far below the peak discharge. Based on simulation results it can be predicted that the cause of flooding in Lantikadigo River is due to morphological change of river geometry.

1. Introduction

Data plays a very important role in the analysis of various things including for modeling the flow associated with flood routing. Flood routing is a mathematical procedure used to track flow through hydrological systems [1]. In practice, there are two types of flood routing i.e. hydrologic routing and hydraulic routing [2]. Hydrologic routing is only capable of providing information about flow at one point in one part of the river as a function of time [3], so this routing gives less accurate results than hydraulic routing [4]. Flood routing needs to be done related to flood control efforts so as not to cause problems and high risks for the residents of the surrounding communities. In any event of flooding, at any point along the river channel, there will be an increase in water level and will return to normal after the flood receded. The water level of the flood at any point along the river will never be obtained by routine measurements by setting calibration formula and finding discharge [4]. What can be done is to know the hydrograph at one upstream point and do routing at the downstream points.
Associated with the need of flood search, generally the data used is data field measurement results are entered manually into the model used [5]. The weakness of this way is the process of data entry becomes longer and interpolation of data in the model becomes very rough, so it is possible to affect the simulation results. Therefore, to anticipate such problems, it can use Digital Elevation Model (DEM) data in Triangulated Irregular Network (TIN) format, which is processed through Geographic Information System (GIS) analysis [6], [7].

2. Data and Methods

2.1. Study Area
This flood routing was conducted in the downstream reach of Lantikadigo River, along 9475 m. The river covers 503.94 km2 of the watershed area, which situated on the geographic coordinates of 121°16'7.51"E-121°33'1.19"E and 0°47'8.85"N-1°7'7.82"N. The watershed is located in the eastern part of Buol Regency, Central Sulawesi Indonesia as shown in Figure 1. Almost half of the watershed is a flat area with topographic slopes below 10%, especially in the middle and downstream areas. This form of topography leads to meandering river configurations, with a changeable cross-sectional shape.

![Figure 1. Research site at downstream reach of Lantikadigo River](image-url)

2.2. Data
Basically, the DEM data which used to derive river geometry was free obtained from USGS website with a resolution of 30 m. This resolution is considered sufficient to create cross-sectional rivers with good configuration. However, the use of this data should be done carefully, considering the accuracy of interpretation on flat topography tends to be biased due to the limitations of DEM resolution. If this problem is inevitable, DEM data improvement must be performed by combining with better resolution DEM data. It can be obtained either by direct surveying in the study area or by purchasing from an official agency of spatial information (Figure 2).
The next main data needed for the research are the design hydrograph and tidal curve. Both data are used as upstream and downstream boundary condition of HEC-RAS Simulation Model. Design hydrograph is a hydrograph that is analyzed using HEC-HMS Hydrology Model based on certain return period. The main inputs of this hydrology model are rainfall data and watershed morphometry. The rainfall data previously transformed into design rainfall using several frequency analysis methods, such as Normal, Log Normal, Log Pearson, and Gumbell. The selections of those methods are based on statistic parameters of rainfall distribution. The tidal curve is a graph illustrating the relationship between time and sea water level at the river mouth. The data is obtained by direct measurement for 15 days and furthermore transformed to a tidal curve through harmonic analysis.

Figure 2. Digital Elevation Model of study area

Figure 3. Lantikadigo River at downstream reach

2.3. Methods
The main emphasis of this research is on the integration of DEM data on the HEC-RAS Hydrodynamic Model and the analysis of river channel capacity. Integrating data is the process of synthesizing geometry data that is processed in the GIS environment as input for the HEC-RAS Model. River geometry is primarily a cross section of rivers created using DEM-based geographic information systems. The module required for this analysis is HEC-GeoRAS, a set of procedures, tools, and
utilities for processing geospatial data in ArcGIS using a graphical user interface (GUI). The interface allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS [8]. This geometry is further integrated into the HEC RAS Model using import facility on the File Menu in the Main Window of HEC RAS [9].

The hydraulic simulation was performed in the Lantikadogo River from Negeri Lama Village in downstream, Bungkudu Village in the middle to Biau Village in the upper reaches, with 138 cross-sections (Figure 3). Calibration and verification were done by adjusting the simulation results with water level measured [10]. The capacity of the river is evaluated using the model based on the boundary condition in the upstream and downstream reach being modeled. The unsteady simulation is performed by inputting hydrograph at the upstream boundary and tides at the downstream boundary. Based on the simulation result, it can be known as the channel capacity of the river.

3. Result and Discussion

The use of DEM data to create river geometry basically provides many advantages. One of them is the time effectiveness in preparing river geometry data. Besides that the coordinates of the river cross-section can be made more tightly, in accordance with the condition of the river geometry. However, the quality of river cross-section shapes is very dependent on the resolution of the DEM data used. The comparison of result simulation between DEM data and surveyed data of river geometry show that there is no a large differences of channel capacity. The minimum capacity of DEM river geometry is 55.30 m$^3$/s, while the minimum capacity of surveyed river geometry is 57.10 m$^3$/s. The resolution of DEM data affects the quality of channel geometry.

Based on topographic analysis, the Lantikadigo River in this section, especially along approximately 9.47 km (RS1-RS138) has a meandering path as shown in Figure 3. The meander pattern varies with an inner angle of more than 10°. This meanders pattern can be categorized as heavy curves, which can be expressed by the meander index, i.e. the ratio between the total length of the river alignment and the total length of the river curvature. The straight river has a meander index equal to 1. [9]. The higher the river meander index number, the inner bend angle will be smaller and vice versa. In principle, the meander rivers are classified as a river that forms sinus functions, which are divided into two types: irregular meanders and regular meanders. Irregular meander meanders are termed for a river that has an irregular curvature and a regular meander is reserved for a river that has a uniform curvature.

![Figure 4. Longitudinal profile of Lantikadigo River.](image)
The effect of river meander on the flow is the occurrence of flow deflection due to delayed flow on one side of the channel i.e. the outer side of the turn. Obstruction of flow will lead to an increase in water level. The results of research conducted by Mudjiatko (2000) shows the greater the number of meanders index then the higher the level of flow obstruction [11]. Based on the results of this study, it can be concluded that the Lantikadigo River meanders condition is a factor that contributes enough to the flood in the section of Negeri Lama-Bengkudu-Biau, although in the simulation model this factor is neglected. Another influence is the occurrence of the erosion at the outside of the bend and the deposition at the inside of a bend so that in this section the cross-sectional shape is always changing. As a result of field observations, flooding occur on both sides of the river bank precisely located on the channel segment that meanders. Inundated areas are generally residential areas and some are agricultural and plantation areas.

Based on the longitudinal profile, there is also an intensive aggradation found in the meander segment (Figure 4). The aggradations of river bed start from RS.21 to RS.129 along approximately 7353 m. The sedimentation is mainly caused by river meanders, and the rest is the tidal factor in the river mouth [12], 13]. Hydraulically, this phenomenon is confirmed to be the main factor causing floods that occur continuously in recent years in addition to the narrowing of the cross-section at the downstream segment.

Based on the hydraulic simulation conducted on the Negeri Lama-Bengkudu-Biau segment of Lantikadigo River, it can be known the hourly water elevation at each River Station during the simulation time. The water level elevation to be used as a parameter to determine the flood or not in a River Station is the maximum water level. Therefore the parameters that will be discussed and the analysis of flood mitigation are the maximum water level elevation [9].

As shown in Figure 5, almost on all cross sections, the maximum water level for a 1-year return period exceeds the river bank's elevation point either on the left or on the right. The peak hydrograph discharge for the 1-year return period is 55.3 m$^3$/s. This means that the average channel capacity is below the peak discharge, in other words, the river cross-sectional capacity is not able to pass the discharge with a 1 year return period (Figure 6).

Based on the slope of the energy line, from the simulation results is obtained information that the flood Lantikadigo River has a relatively small energy slope that is between 0.00001-0.0001 for the simulation of turn period of 1-100 years in maximum water level. Theoretically, the slope of the
energy line has a great influence on the flow velocity. If the slope of the energy line is low then the flow velocity will be low. If it refers to the mass continuity equation, by giving a constant flow rate (Q), the smaller the flow velocity (V), the wet cross-sectional area (A) becomes larger [14]. This provides information that the increase of the wet cross-sectional area means increased water level elevation. This may be caused by tidal conditions at the downstream boundary, so it is estimated that one of the causes of overflow in the simulation segments.

Previously it was mentioned that on the middle reach of Lantikadigo River, the bed slope tends to be negative. This is thought to be caused by bed aggradations occurring in the downstream segment up to the estuary. Its effect is can happen back water phenomenon, especially at low discharge. Based on field investigation and longitudinal profile mapping, the phenomenon of bed aggradations in the estuary is very intensive. It can be inferred that bed aggradation of the estuary is the effect of significant change of discharge in the dry season and the rainy season and sediment transport factor in the estuary. Based on the geometry and simulation results, it can be predicted that flooding in Lantikadigo River is a factor of morphological change and river geometry such as river morphology. Meander morphology causes flow detention due to blocking of flow on one side of the channel, the occurrence of bed aggradations due to sedimentation as a result of upstream watershed erosion that causes the flow to be slow and the flow transport capability to be low, downstream cross-sectional narrowing and impact a tidal surface in the estuary that causes backwater.

4. Conclusion
Basically, data integration provides the effectiveness of the use of simulation time due to input geometry data is done using import data facility when compared manually input geometry data. Based on the results of the study, It can be seen that the maximum water level of 1-year return period has exceeded the river bank elevation both on the left and on the right side on the entire segment. The peak discharge of hydrograph for 1-year return period is 55.3 m$^3$/s at the outlet of Lantikadigo Watershed. This means that the average channel capacity is far below the peak discharge. Based on simulation results it can be predicted that the cause of flooding in Lantikadigo River is due to morphological change of river geometry.

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