Simulation of Batang Agam River Capabilities as Effect of Land-Use Changes

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Abstract: Batang Agam River is one of the rivers in West Sumatra Province that crosses Bukittinggi City, Agam Regency, Payakumbuh City and Limapuluh Kota Regency. The river is ± 60 Kilometers length with headwaters in Bukittinggi city and empties into Batang Sinamar in Limapuluh Kota Regency. With growth development of Bukit Tinggi, so that existing lands such as rice fields and other fields have changed functions into built-up land such as housing, offices, trade and so on. This resulted an increasement of surface runoff coefficient (coefficient C) and flow rate, which resulted in frequent flooding of Batang agam. These will induced flood, for example on 10 December 2018 flood which inundating SDN 18 Koto Tangah in Jorong Uba and 9 February 2020 flood which inundated 6 Hectare of rice fields in Kamang Hilia. To find out the magnitude of changes in land use and flood discharge that occurred in the Batang Agam watershed, a comparison of land use in 2011 with 2019 and flood discharge that occurred in 2011 with 2019. After calculating the results of the flood discharge calculation, the flood discharge was simulated using HEC-RAS software with a 5-year return period to get the overflowing water level and the area of the puddle. From the calculation results obtained an increase in the runoff coefficient value from 0.35 to 0.467, this resulted in a significant increase in flood discharge in each return period and the modeling carried out obtained the results of the maximum flood height reaching 3.13 m from the riverbed, this height is close to the flood height observed in the field, which is as high as 3.03 m.

Keywords: Batang Agam, Landuse changed, Flood, HEC RAS simulation

1. Introduction

The growth of region generally creates changes in land use patterns from their original conditions. Urban development approach that often emphasizes value of economic growth often creates problems in environmental conditions. Land ability to absorb rainwater was decreased and intensity of rainfall today that increase due to global warming put pressure on the city's ability to release runoff into drainage. Condition was exacerbated by diminishing capacity of river services as drainage due to increase of natural sedimentation and municipal sewage discharges. Bukittinggi is one of the 18 cities which administratively part of West Sumatra province. Geographically, the city was located between 100°20' - 100°25' East Longitude and between 00°16' - 00° 20' South Latitude with an altitude of 780 - 950 meters above sea level [1]. Bukittinggi have some rivers, namely Batang Tambuo in the east, Batang Sianok which flows in the west and the Batang Agam river which has an upstream in urban areas.

Population growth of Bukittinggi was very rapid. Based on statistical data in 2004, population reached 120,491 people with a growth rate 1.82 percent [2]. The increase of population was directly proportional to the increase in drainage flow and decrease in water catchment areas. Based on Bukittinggi topographic, Batang Agam was one of receiving water bodies from drainage channels in Bukittinggi. As a receiving water body, Batang Agam is faced with the classic problem of drainage in an area with a high population density. Service capacity of Batang Agam river from Bukittinggi city outlet macro drainage system was expected to capable with the discharge from the existing drainage system. Ability of this service is one of important part to realizing safety and comfort for the city from flooding that occurred at of the rainy season peak. Land use changed that was occurred in the city due to increasing population growth and settlements, resulting ability of land that reduced to absorbing water. This has an impact on increasing the surface runoff which must be accommodated by the drainage system.

This study will review percentage increase of discharge that occurred in Batang Agam river on recent years. Ratio of discharge will be differentiated based on coefficient C in each year. Variation of flood discharge will be determined using Hydrological analysis for several years. Flood modelling will be carried out using HEC-RAS, so that can be seen inundation and flood heights are.

Figure 1. Flood Conditions in Bukittinggi City February 1, 2022

2. Methods

Comprehensive review of the current and future trends of real-time flood forecasting modeling in urban drainage systems was conducted [3] . The results show that the combination of various sources of real-time rainfall measurements and the inclusion of other real-time data such as soil moisture, wind flow patterns, evaporation, fluvial flow and infiltration should be further investigated in real-time flood forecasting models. Study that subjected to evaluated why the detention pond system was identified as the most successful water reduction based Sustainable Drainage System was conducted. Case study was located in a residential area of Gibside View, Winlaton, Gateshead, UK. This research shows how detention ponds should be re-located to the already inadequate drainage system [4]. Investigation with flood scenario using an experimental scale facility of urban roads and manhole networks was conducted [5]. Several hydraulic conditions were investigated in various road configurations and resulting a new set of data such as discharge values, flow exchange, energy loss and discharge coefficients that can be used as benchmarks and to calibrate and validate numerical models. River Analysis Modeling (HEC-RAS) combined with SWMM to observe detailed and spatial flood reduction rates in the city of Chittagong, Bangladesh [6]. Results showed that model can be used to make decisions needed for flood reduction and to build a distributed Rain Water Harvesting system in the study area. Comparison of flood risk management approaches in the UK and China was studied [7]. Actions individual countries are also taking to address these issues. Results provide suggestions for strategic research plans and proposed ways to address knowledge gaps in flood management. Study to determine the main challenges and problems in implementing e-flows at different scales by analyzing policies and practices in China was conducted [8]. Results indicating that there was gap between science and the implementation of e-flows. It was found that environmentally sound drainage is a term that is used more by the government, rather than applied in its implementation. Geographic Information System (GIS) technology in analyzing the height of inundation due to flooding has been carried out [9]. Analysis of flood inundation on Batang Mahat river involving three contributing factors, namely flood inundation by dams and creeks, changes in land use and rainfall data. Land use change from 1994 was analyzed from the Landsat and EVI (Enhanced Vegetation Index) time series. Analysis show that the overflow dam at a height of 80 m is unlikely to be the main reason, because the maximum flood height occurs at 92 m. On the other hand, flooding may be caused by narrowing of the channel in the river. The flood inundation model using the channel narrowing scenario shows the similarity of the inundation to the affected area. Land conversion from forest to oil plantations is also thought to increase runoff and also contribute to flooding. Hydraulic simulation using HEC RAS for simulating flood conditions based on land use maps has been carried out [10]. Research was conducted by simulating existing land use scheme and predictions to describe the catchment condition of the Batang Arau area in Padang city. Numerical modeling study on flow patterns in the Batang Mahat river was also conducted [11]. Flow rate used in model was obtained from hydrological analysis with daily rainfall data in the Batang Mahat sub-watershed. Study found that locations with increased riverbed elevation tend to provide potential for flooding and inundation in area. Study also provide direction for further reviews to pay attention to changes in land characteristics that have the potential to provide sediment supply to the river as a component that caused flooding.

Topographic maps, land use maps, rainfall data, and Batang Agam River geometry data were used as data to conducted the research. Rainfall data was obtained from the Canduang station post which was obtained from the PSDA Office of West Sumatra Province. Land use data was obtained by the Public Works and Spatial Planning Office of Bukittinggi in 2011 and 2019 and river geometry data was obtained by BWS Sumatra V. The discharge coefficient C is defined as the ratio of peak runoff to rainfall intensity, this factor is the most decisive variable for calculating flood discharge. The main factors that influence C are soil infiltration rate or percentage of impermeable land, land slope, land cover crops and rainfall intensity. Surface impermeability, soil properties and conditions, groundwater, soil density, soil porosity, and sediment depression. Land use was defined as a form of human intervention (interference) on land in order to meet the needs of life, both material and spiritual. The amount of rainfall that can cause flooding is also strongly influenced by the amount of land use. Changes in land use are unavoidable because rapid population growth causes the ratio between population and agricultural land to be unbalanced [12]. Changes in land use that often occur are the conversion of forest and agricultural land into built-up areas, especially settlements. The increase in the built space causes the surface run off to also increase due to the smaller infiltration. The volume of surface runoff results in higher flood/runoff discharges, causing flooding problems in urban areas. The above conditions also apply to the case of the city of Bukittinggi where there has been a change in land cover in the Catchment area as can be seen in Figure 2. Hydrological variables describe the size of hydrological phenomena, such as daily average discharge, hourly average rainfall and so on. In hydrological analysis to get good conclusions, hydrological data can be expressed as statistical variables. To obtain this rain plan, the probability distribution of Normal, Gumbel, Log Normal and Log Person Type III is usually used, to choose a distribution that fits the existing data and to get a convincing calculation result or no one meets the requirements using a probability distribution, then usually tested using the Chikuadrat method and the Smirnovkolomogorof method [13]. In addition to the suitability test, testing was also carried out on the confidence limit of the data with a 95% confidence level. Next, an analysis of the planned rain will be used to calculate the flood discharge for a certain period. In addition to hydrological variables, hydraulic variables must also be considered. In hydraulic analysis, three-dimensional flow is simplified to one-dimensional flow because in field conditions, one-dimensional flow rarely occurred by ignoring changes in vertical and transverse velocity with respect to longitudinal velocity. Rainfall data used is the average daily maximum rainfall with a return period of 15 years, namely in 2006 to 2020 from Canduang station. Analysis of rainfall design was calculated by several Probability Distribution methods, namely Normal, Log Normal, Gumbel, and Log Pearson Type III. Validation flood discharge design using observation method in field as a control on the results of the calculation obtained from rain data. Observations location was carried out in Nagari Koto Laweh, Tilatang Kamang District, Agam Regency, where located at 0°14'31"S 100°23'48"E. Hydraulics modeling was carried out using the HEC-RAS 5.0.7 application. Model was used with unsteady flow condition with the manning coefficient (n) = 0.03. Validation was done by comparing suitability of model results with real flood conditions that occurred.

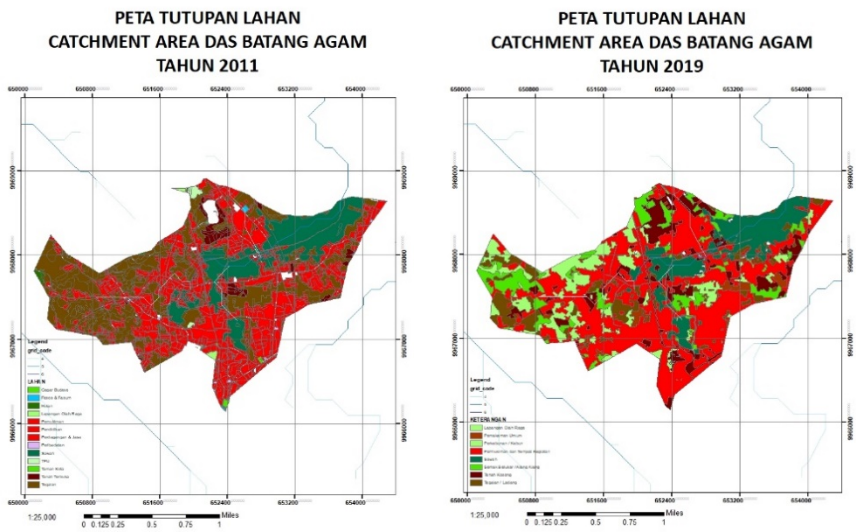


Figure 2. Coverland Map of Batang Agam Watershed Catchment Area

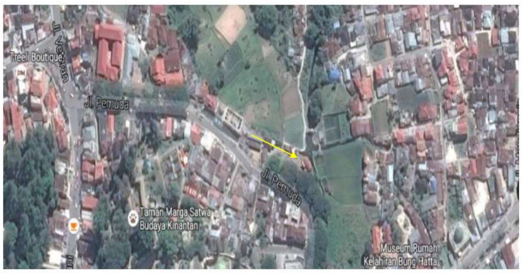


Figure 3. Upperstream of Batang Agam River and Existing Detention Storage

Figure 4. Existing Condition of Batang Agam River Upstream

3. Result and Discussion

Results of rainfall design analysis as seen in table 1. Distribution test was used to determine whether the chosen probability distribution equation can represent the statistical distribution of the analyzed data sample. The results of the calculations on this probability distribution test are in Table 2.

Table 1. Rainfall Design Rate

Return Period (year)	Normal Dist.	Log Normal Dist.	Gumbel Dist.	Log Pearson Type III Dist.
2	79.847	76.539	75.195	78.403
5	99.174	99.184	102.103	99.675
10	109.298	113.606	119.024	112.942
25	119.192	129.645	138.755	124.624
50	127.015	144.073	156.260	133.172
100	133.458	157.073	172.002	140.951

Table 2. Probability Distribution Test

Probability Distribution	Chi Square Test		Smirnov Kolmogorof Test	
	X^2 calc.	X^2 cr	Δp calc.	Δp cr
Normal	8.667	5.991	0.159	0,338
Gumbel	2.667	5.991	0.096	0,338
Log Normal	10.667	5.991	0.106	0,338
Log Pearson Type III	4.667	5.991	0.927	0,338

Based on table 2, the distribution accepted by the two tests is Gumbel distribution. Runoff coefficient value can also be calculated based on the runoff coefficient value table [14]. Based on the map of land cover change in the catchment area of the Batang Agam river basin, change of C coefficient value in 2011 was 0.35 and in 2019 it was increased to 0.467. Data analysis was carried out to obtain surface runoff coefficient which can be seen in table 3. Flood discharge design analysis was carried out using 3 methods, namely the Nakayasu, Synder, and SCS Synthetic Unit Hydrograph Method respectively. Results of this design flood discharge calculation are shown in Table 4. Validation to see suitability of theoretical flood discharge design using observation method in field as a control on the results of the calculation obtained from rain data [15]. Observations location was carried out in Nagari Koto Laweh, Tilatang Kamang District, Agam Regency, where located at 0°14'31"S 100°23'48"E. Calculation was carried out by assuming that river cross section accommodates a maximum discharge equivalent to a 2 year return period discharge at full bank capacity conditions. Maximum flood height measured was obtained as high as 3 meters above the river bed. Using permanent flow hydraulics calculation, flood discharge was obtained, with Q = 35.36 m3/s. This value was closed to theoretical design flood discharge value of the 2-year return period of the Snyder Method, which is 39.46 m^3/s. From this validation, the discharge design of Snyder Method was used as the flood discharge for the simulation. Hydraulics modeling was carried out using the HEC-RAS 5.0.7 application. Model was used with unsteady flow condition with the manning coefficient (n) = 0.03. Validation was done by comparing suitability of model results with real flood conditions that occurred. This condition was obtained from traces measurement of flooding that occurred and interviews with local residents that affected. Based on modeling results, there are similarities that getting with flood incident condition on February 9, 2020 which inundated 6 hectares of rice fields in Kamang Hilir. Simulation showed that flood height at the point under consideration reaches ± 3.13 m from the riverbed. Field observations showed remaining traces of flooding from the condition of the presence of garbage resulting from flooding at an elevation of ± 3.03 from the riverbed stuck in the grass around the river.

Table 3. Runoff coefficient in 2011 and 2019

Type of Land use	2011			2019		
	Area (km^2)	C	A. C	Area (km^2)	C	A. C
Plantation	1,987	0,400	0,795	0,848	0,400	0,339
Dryland farming	0,419	0,100	0,042	1,093	0,100	0,109
Open ground	0,028	0,250	0,007	0,000	0,250	0,000
Ricefield	1,132	0,150	0,170	0,814	0,150	0,122
Moor	2,324	0,200	0,465	0,000	0,200	0,000
Sports field	0,021	0,170	0,003	0,021	0,170	0,003
Housing area	2,330	0,600	1,398	5,574	0,600	3,344
Park	0,000	0,000	0,000	0,002	0,000	0,000
Cultural Heritage	0,003	0,200	0,001	0,003	0,200	0,001
Funeral park	0,009	0,150	0,001	0,023	0,150	0,003

Table 4. Flood Discharge Design Recapitulation

No.	Return Period (Year)	Q design with Synthetic Unit Hydrograph (SUH)					
		Nakayasu		Snyder		SCS	
		2011	2019	2011	2019	2011	2019
1	2	56,887	76,391	39,46	52,989	72,635	97,124
2	5	77,243	103,726	53,58	71,95	98,611	131,857
3	10	79,815	107,18	62,459	83,874	114,971	153,732
4	25	104,971	140,961	72,813	97,778	134,034	179,223
5	50	118,214	158,744	81,999	110,113	150,929	201,813
6	100	130,123	174,737	90,26	121,207	166,11	222,113

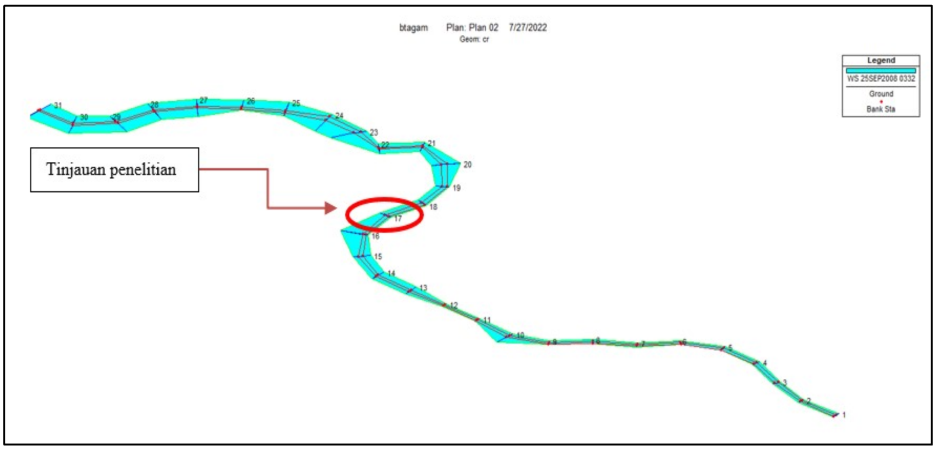
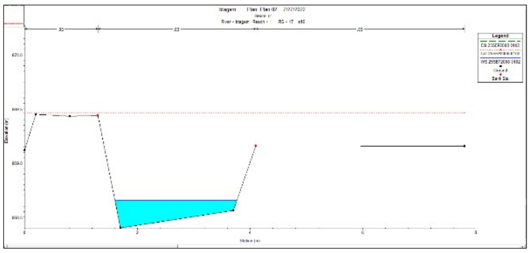
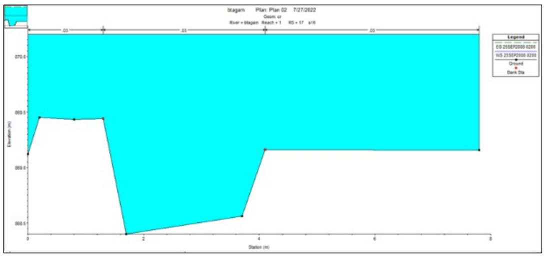


Figure 5. Plan view section of Model



(a)



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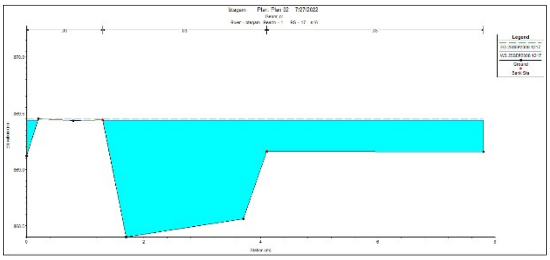

(c)

Figure 6. Water conditions on Sta. S17 Cross Section (a). 1st hour of simulation, (b). at 2nd hour of simulation, flood height reaches 3 m above riverbed, (c). at 12th hour of simulation, flood height reaches 2,2 m above riverbed

4. Conclusions

Based on analysis in 2011 and 2019, it showed that land use in 2011 for settlements reached 25% of the catchment area and increased to 67% in 2019. This condition causes an increase in runoff coefficient from 0.35 to 0.468. Rainfall design for Batang Agam river basin was in return periods of 2, 5,10, 25, 50, and 100 years is 75,195 mm, 102,103 mm, 119,024 mm, 138,755 mm, 156,260 mm, and 172,022mm. This value was obtained from Gumbel Probability Distribution calculation which has been tested with the Chi Square Method and the Smirnov Kolmogorof Method. In 2011 and 2019, with three methods calculation of flood discharge design, there was significant increasing in each return period. Validation carried out on real discharge got Snyder method closest to field discharge state. Flood modeling carried out with HEC-RAS resulted various flood heights at each cross section. Flood height at research point being reviewed reached to 1.3 m height. Model was carried out under unsteady conditions which showed a flood height of 1.3m at the 2nd hour of the simulation. With the results, It is necessary to add water catchment areas, especially in upstream area of the Batang Agam river, as a result of high increasement the amount of land built in recent years.

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