Preliminary Studies of Sediment Transport and River Silning Modeling for Flood Potential Using SWAT and HEC-RAS Models (Case Study: Citarik Sub Watershed)

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Abstract. The Citarik sub watershed is one of the priority sub watersheds in the Upper Citarum watershed. The sustainability of this sub watershed has an important role in maintaining the sustainability of the Citarum watershed, but this sub watershed has experienced a lot of hydrological function degradation. Increasing population and economic activity have resulted in massive changes in land use which is the main issue of this problem. Indications of damage are felt by increasing the maximum extreme discharge, as well as increasing the value of the coefficient of water runoff, giving rise to the phenomenon of flooding in the rainy season, this phenomenon is exacerbated by sedimentation and silting of rivers, which from year to year this flood phenomenon is getting worse and causing a lot of economic losses. Therefore, we need a hydrological and hydraulics modeling of the Citarik Sub watershed which aims to predict sedimentation, river siltation, and their effect on flood potential using QSWAT and HEC-RAS. To produce a good model that maximized all the available data and solved the problems effectively, a preliminary study is needed first. The scope of the preliminary study includes defining the potential problems and analyzing the data avalability of the research location, especially the data that needed to be the input for QSWAT and HEC-RAS model so the validity can be maximalized and represent the actual condition. The results of the preliminary study stated that the Citarik sub watershed is a potential area for further study and modeling because it has many problems ranging from critical land, flooding to sedimentation and has sufficient data availability to develope a model.

Keywords: *Citarik; HEC-RAS; preliminary study; shallowing; SWAT; sedimentation.*

1 Introduction

The function of the upstream watershed (watershed) as a water catchment area is very important in maintaining the availability of water in the watershed as a whole and has a protective function for the downstream watershed. The Upper Watershed generally functions as a conservation area that is managed to maintain the environmental conditions of the Watershed so that it is not degraded, which can be indicated, among other things, from the condition of the vegetation cover of the watershed land, water quality, ability to store water (discharge), and rainfall.

The Citarik sub watershed is one of the priority sub watersheds in the Upper Citarum watershed. The area of critical non-forest land in this sub watershed reaches 5,511 Ha covering 5 sub-districts, while for non-critical forest land it reaches 1,866 Ha in 3 sub-districts[6]. The main factor for the increase in critical land is land conversion, it is noted that from 2013 to 2021 non-agricultural areas have increased by 21,095.57 Ha and forest has decreased by 21,237 Ha, this has resulted in the land cover index being 49.28[6]. Changes in land use also affect the value of the runoff coefficient and the amount of sediment formed, the Citarik Sub watershed has an average value of an increase in the runoff coefficient value of 51.86% per year, Haryanto in [6] and the amount of sediment reaches 63,012 tonnes/year in 2018, PUSAIR in [6]. The Citarik sub watershed is one of the locations where flooding occurs every year, especially in the Rancaekek, Majalaya, and Baleendah Sub-Districts. It was recorded that in 2021 there were 111 flood incidents in 22 sub-districts, with a potential impact of 1,832, and inundation ranging from 0.5 to 2 m. BBWS in [6].

For this reason, we need a hydrological and hydraulics modeling that aims to predict sedimentation, silting of rivers, and their effect on potential flooding that occurs due to critical land, the fruit of unsustainable land conversion[16]. It is hoped that the model will be able to predict the amount of sedimentation, siltation, and their effect on flood potential in the next few years, as well as be able to provide the best scenario so that future problems can be anticipated and become a consideration for long-term policy making.

Hydrological modeling was carried out using the SWAT (Soil and Water Assessment Tools) model[17], then the output from the SWAT model in the form of discharge and sediment data was used as the HEC-RAS (Hydrologic Engineering Center-River Analysis System) model input for further analysis related to hydraulics[8]. HEC-RAS will produce erosion and sedimentation models complete with their location and cross-sectional changes, as well as being able to simulate floods that will occur[8].The model is calibrated using historical data, then validated using sampling data. Data that needs to be sampled include debit, sediment, and TSS data.

Prior to modeling, a preliminary study is needed to look at the state of the area, potential problems, and data availability, so that research will be more focused by maximizing the availability of existing data to solve specific problems at the research location.

2 Methodology

2.1 Data Collection

The data used in this study are secondary and primary data. Secondary data is used to calibrate the model, while primary data is used to validate the model. Among the secondary data are spatial data, land use, soil characteristics, climatology, DEM (Digital Elevation Model), sedimentation, discharge, and river dimensions. While the primary data is in the form of direct sampling related to the discharge and the amount of floating sediment.

2.2 Developing Models

The SWAT model was built by classifying pieces of areas in the watershed into HRU (Hydrologic Response Units) with certain values based on topography, soil type, and land use data[7]. This model uses DEM data as its base map and is used to delineate subcatchment areas and determine outlet points. Then the model is inputted with climatological data in the form of rainfall, temperature, wind speed, humidity, and sunshine duration.

The HEC-RAS model is composed of three main parts, namely geometry, discharge and quality. Geometry data is created by generating DEM maps using the RAS Mapper tool. Discharge data is obtained from the river discharge hydrograph, to increase the accuracy, rain and temperature data are added. River quality data in this case only focuses on sediment and TSS. Sediment data and downstream discharge are inputted in the form of a Rating Curve, and for sediment, sediment gradation data is required.

2.3 Sampling

Sampling will be carried out in the period May - June 2023. The sampling method refers to the applicable SNI, the data sampled are discharge data[15] , sediment data[14], and TSS data[13].

Table 1 Sampling Point Coordinates

Point	Location	Coordinate		Distance (m)
		X	Y	
1	Upstream	107.89	-6.96	0
2	Upstream	107.87	-6.97	3609
3	Upstream	107.83	-6.97	5539.2
4	Middle Stream	107.80	-6.98	5550
5	Middle Stream	107.80	-6.99	2120

Point	Location	Coordinate		Distance (m)
		X	Y	
6	Middle Stream	107.76	-7.01	4400
7	Down Stream	107.75	-7.00	2607
8	Down Stream	107.71	-6.99	5072

Sampling was carried out at 8 points along the Citarik River Figure 3, the determination of the sampling points was adjusted to the SNI criteria used. SNI-8066-2015 is used to measure discharge, taking drift sedimentation using SNI-3414-2008, bottom sediment ASTM D 887-13, sieve analysis SNI ASTM C136-2012, and gravimetric measurements in the lab based on SNI-3962-2018.

2.4 Calibration and Validation

Calibration and Validation are carried out using the same method, namely NSE (Nash-Sucliffe Efficiency) which differs only in the data. Calibration is done with historical data and if the NSE is not appropriate, readjustments can be made. Validation is done by sampling data, if it is valid then the model can be used to predict future phenomena, if not then vice versa.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right] \quad (1)$$

NSE is calculated using the evaluated constituent values (*Y*) either observation or simulation in a certain order (*i*) with a certain total number of safeguards (*n*). NSE values range from 0 to 1 with the criteria as shown in Table 2. If the NSE is negative, the model cannot be accepted[10].

Table 2 Statistical Score Criteria for NSE[10]

Criteria	NSE
Very good	0.75 < NSE < 1.00
Good	0.65 < NSE < 0.75
Satisfying	0.50 < NSE < 0.65
Less satisfactory	NSE <= 0.50

2.5 Running Scenario

The SWAT parameters that will be varied are the Land Use Parameter, which will carry out existing land use, land use according to the 2029 RPJMN, and predictions of 2029 land use with a linear regression of land change that occurs from 2012 – 2020.

The HEC-RAS model was run with two variations, namely variations in the existing state and the state after sedimentation occurred. Because SWAT is the input of the HEC-RAS discharge data, the SWAT variation will also add to the HEC-RAS variation.

3 Location Overview

The Citarik sub watershed is the easternmost sub watershed of the Citarum watershed. Astronomically it is located at the coordinates 6 ° 55 'S - 7 ° 05' S and between 107 ° 50' E - 107 ° 40' E and is administratively located in Bandung Regency, Sumedang Regency and Garut Regency. Demographics can be seen in **Table 3**.

Table 3 Citarik Sub watershed Demographic Data[4] [5]

No	District	Sub District	Population (People)	Area (km^2/sq.km)	Population Density (Population /km^2)	Growth Rate 2020 - 2022 (%)
1	Sumedang	Cimanggung	88,940	55.55	2,182	1.63
2		Pamulihan	63,542	50.7	1,098	2.55
3		Tanjung Sari	87,520	44.86	2,457	2.23
4	Bandung	Majalaya	162,658	25.36	6,365	0.63
5		Nagreg	60,488	49.3	1,204	1.77
6		Paseh	139,939	51.03	2,702	1.36
7		Cikancung	100,031	40.14	2,447	1.7
8		Cicalengka	125,079	35.99	3,430	1.19
9		Rancaekek	189,801	45.25	4,141	1.15
10		Solokan Jeruk	88,829	24.01	3,652	1.17
Average			110,682.7	42.219	2,967.8	1.538
Total			1,106,827	422.19		

Geographically, this sub watershed is located within the Bandung basin which is mostly surrounded by quatemary volcanic mountains and surface runoff eventually flows into the Citarum River. The northern part of the Citarik Sub watershed is bordered by Mount Geulis, the northeastern part is limited by Mount Kareumbi, the eastern part is limited by Mount Calancang and Mount Bujung, while the southeast and south are limited by Mount Madalawangi.

Table 4 Slope Classification[12]

Class	Classification	Area (Ha)	%
0% - 8%	Gently Sloping	64.91	50.38
8% - 15%	Moderately Sloping	56.2	43.62
15% - 25%	Moderately Steep	7.63	5.92
25% - 45%	Steep	0.09	0.07
> 45%	Very Steep	0.00	0.00
	Total	128.84	100.00

The upstream Citarik River flows through wavy morphological units, hilly to mountainous. The geological conditions of the Citarik sub watershed are identified into two categories of deposits, namely:

1. Sediments from the Old Kwater Volcano, and volcanic products that are not decomposed, are difficult to distinguish in several locations because they are weathered, predominately pumice tuff, containing tuffaceous sand, lapilli, bombs, breccias, lava, lapili, and agglomerates. Most of it is water passable, through the cavities between grains.

2. Alluvial deposits consist of river deposits and lake deposits, besides that there are alluvial volcanic facies, consisting of tuffaceous clay, tuffaceous sandstone, and breccia inserts. Its nature is slightly pass water until it passes water, through the cavities between grains.

Citarik River itself has a length of 40.59 km, with varying widths and depths. Citarik River water originates from the Situ Cisanti spring, flowing up to Sapan and into the Citarum River, so that it is one of the upstream areas of the Citarum River. The Citarik River has many tributaries, including the Cimande River, Wirama River, Cibedah River, Cisungalah River, Ciburaleng River, Cimanggung River, Cipanaruban River, Cihanyawar River, and Cimulu River.

The Citarik sub watershed is one of the priority sub watersheds in the Citarum watershed because it has various problems and its important role because it is in the upstream area, among the problems are critical land, flooding, erosion and sedimentation. The Citarik sub watershed has a very critical non-forest area of 5,511 ha and 1,866 for critical non-forest land[6]. Flood Citarik River resulted in the flooding of parts of Rancaekek District and Solokanjeruk District. Meanwhile, floods in Majalaya and Baleendah Districts originate from the Citarum River with a potential impact of up to 1,832 and an inundation range of 0.5 to 2 meters. (BBWS Citarum in [6] Sedimentation reached 63,012 tonnes/year PUSAIR in [11].

4 Data Availibility Analysis

This research will build SWAT and HEC-RAS models from secondary and historical data. The following is a display of the available and obtained data to be used, especially those needed to develop the SWAT and HEC-RAS models.

4.1 DEM and SHP data

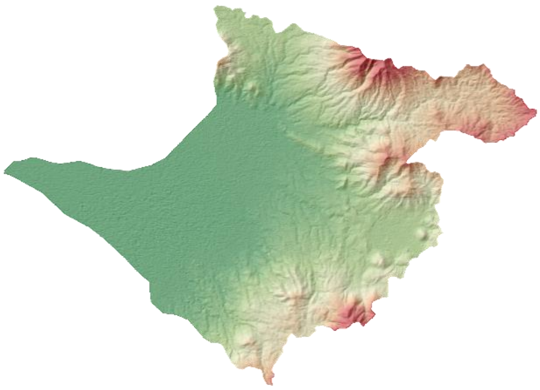

Figure 1 *DEM Map of Citarik Sub watershed* [2]

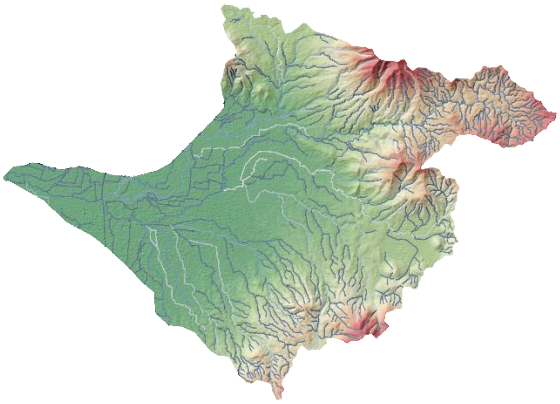

Figure 2 *River Map of Citarik Sub watershed* [2]

Digital Elevation Model (DEM) data use for QSWAT as the base layer to create sub watershed and generate the slope data. While in HEC-RAS this data use for creating the geometric data and generate river bathymetry and slope data.

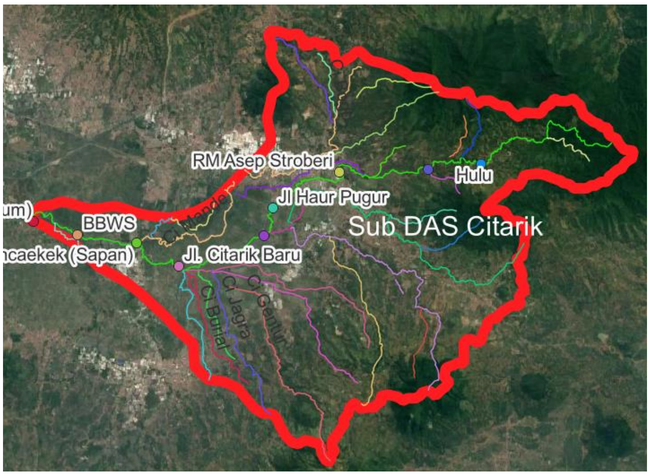

Figure 3 *River Map and Sampling Points*[2] [11]

River Map in shape file data form used in QSWAT as the guideline for making the sub watershed river path. While in HEC-RAS use for making river path and reach in geometric data.

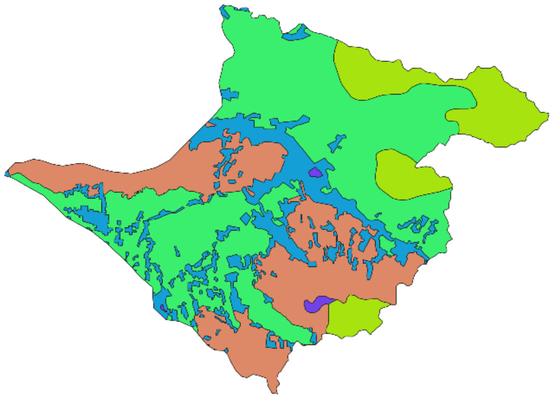

Figure 4 *Citarik Sub watershed Land Use Map*[11] **blue: residential; orange: plantations; purple: fields; green: rice fields; yellow green: forest*

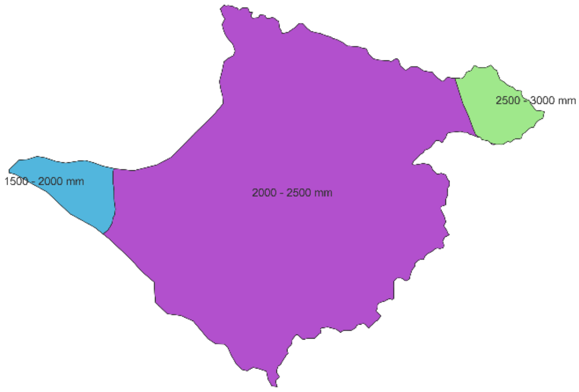

Figure 5 *Rain Map of Citarik Sub watershed* [11]

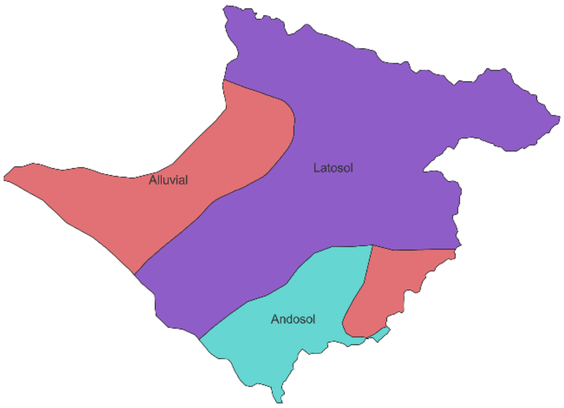

Figure 6 *Map of Citarik sub watershed soil types*[11]

Shapefile of land use and soil types data used for QSWAT model to create the HRU (Hydrologic Respond Unit), while the rain data use as the additional input data in QSWAT.

The DEM and shapefile data in Citarik sub watershed are available and can be use in QSWAT and HEC-RAS model. But for soil types and land use shape file data doesn't have good novelty, the latest data is only 2017. This greatly affects the validity of the model, especially land use data which is quite sensitive and changes every year

4.2 Climatology Data

The Citarik sub watershed has a tropical climate influenced by monsoons, which can be differentiated between the rainy season and the dry season. The rainy season occurs from November to April and the dry season from May to October. Rainfall ranges from 22.3 to 431.9 mm, with an average value of 224 mm. The amount of rain per month is at least 2 days, some reach 26 days, but on average it occurs for 18 days. The duration of sunlight in the Citarik watershed ranges from 2.9 to 6.8 hours, with an average value of 4.7 hours. These data are required for QSWAT model input to interpret the climate which will become the river discharge water source.

Table 5 Citarik Sub watershed Climatological Data[3] [4]

Parameter	Min	Max	Avg
Temperature (º)	16.8	36.2	26.4
Humidity (%)	36	100	78
District Wind (knots)	0	16	1,9
Air Pressure (mb)	917.3	1016	963.4
Rainfall (mm)	22.3	431.9	224
Number of Rainy Days (days)	2	26	18
Solar Illumination (hours)	2.9	6.8	4.7

4.3 Land Change Data

West Java Province itself has a Spatial and Territorial Plan (RTRW) for 2027 and 2036. But the fact is that since 2012 the types of uses related to Mining, Paddy Fields and Dry Land Agriculture have passed the stipulated RTRW, but as the years go by the use of paddy fields is decreasing and in 2021 it is close to the specified RTRW, but the use for mining and dry land agriculture continues to increase.

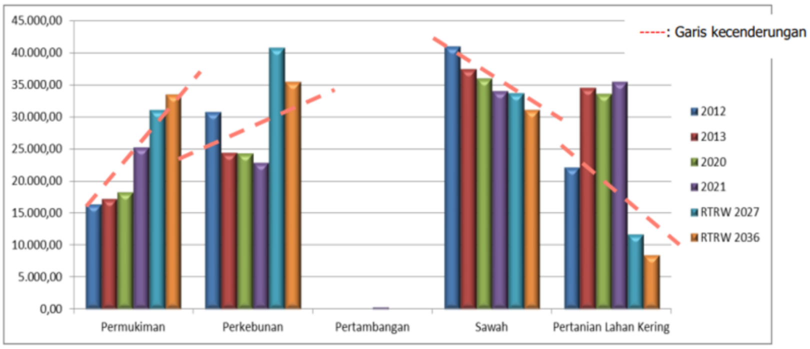

Figure 7 Land Change in Bandung Regency[6]

In the period 2013 to 2021 the non-agricultural area increased by 21,095.57 Ha and the forest decreased by 21,237 Ha, this resulted in the land cover index being 49.28. Forest destruction causes the carrying capacity of forests to decrease. The existence of 11,690 Ha of critical and very critical forest adds to the run off of 58.49 million m3/year or 2 m^3/second which is equivalent to the clean water needs of 1.7 million people assuming a water need of 150 liters/person/day. Bapelitbangda, D.ESDM, and BPN West Java Province in [6].

The percentage of forest in the Citarik sub watershed in 2021 is very small, some of which are in the Majalaya (0.01), Nagreg (0.16), Paseh (0.25), Cikancung (0.08), Cicalengka (0.00), Rancaekek (0.00), and Solokan Jeruk (0.00), IKPLHD Team in [6].

Changes in land cover certainly affect the runoff coefficient that occurs, where there is a significant increase in the runoff coefficient value in the Citarik Sub watershed from year to year as the population increases and land conversion occurs. Citarik experienced an increase in runoff coefficient from 0.019 to 0.122 in 1993 and increased again to 0.229 in 2002, Haryanto, Edi Tri in [6].

The change of land use can be use for the scenario in QSWAT to create different HRU and also the river discharge and rating curve which is became the input of HEC-RAS, so the HEC-RAS will also has the same number of scenario as QSWAT.

4.4 Discharge Data

Discharge data is obtained by means of an ordinary water gauge station located at Solokan Jerik District to the Citarik bridge with coordinates 6°59'36.50"S

107°43'25.00"E. The water survey post was established in 2017 with a catchment area of 1035.8 km^2 and an elevation of +655 m. This data use to calibrate the rating curve data that create by QSWAT model.

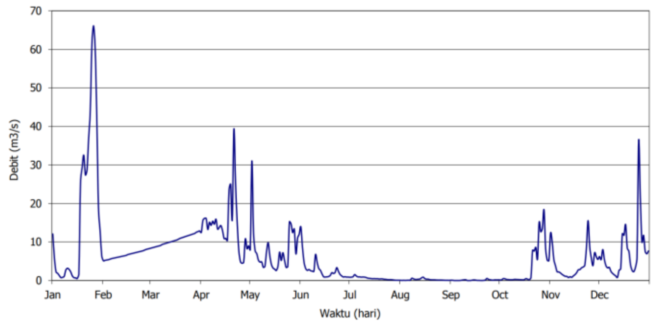

Figure 8 Citarum-Citarik Solokan Jeruk Flow Hydrograph[3]

Flow ranges from 0 to 69.61 m^3/sec, with an annual average of 6.2975 m^3/sec, flow height of 19226 mm, flow/km2 of 6.0799 l/sec, and total flow of 199.14 m^3 (10^6).

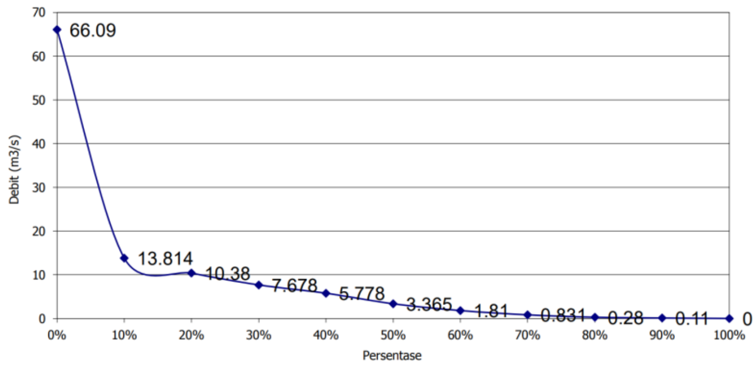

Figure 9 Citarum-Citarik-Solokan Jeruk Duration Curve[3]

4.5 Sedimentation Data

Sedimentation that occurred in the Citarik Sub watershed was only 773 tonnes/year in 2012 with an erosion rate of 1,250 tonnes/ha and an area of erosion hazard level (TBE) of 4,348 ha or equivalent to 16.9% of the Upper Citarum watershed[6]. However, given the rapid land changes that have occurred in the Citarik Sub watershed, it was found that the total sediment in the Citarik Sub watershed reached 63,012 tons/year in 2018, PUSAIR, 2018 in [6]. This data needed to calibrate HEC-RAS sediment model.

Figure 10 Citarum River Erosion and Sedimentation Rate[6]

4.6 Soil Characterization

Table 6 Citarik Watershed SoilGradation Data[1]

No	Parameter	Alluvial	Andosol	Latosol
1	Soil texture	Look	Clay clay	Look dusty
2	Albedo	0.23	0.23	0.23
3	Layer	1	1	1
4	Depth(mm)	250	250	250
5	Sand (%)	11.5	22,3	8,2
6	Dust (%)	36,6	44,4	45.5
7	Clay (%)	50,1	31.5	44,6
8	Organic Material (%)	1, 324	1,964	1,894
9	CEC (meq/100g)	26,069	26,448	25,883
10	Rocks (5)	0	0	0
11	*Bulk Density*(gm/cc)	0.992	0.926	1.007

The Citarik sub watershed is composed of three soil types, namely Alluvial, Latosol, and Andosol. Alluvial is a type of soil that is formed due to sediment, is still young, has not experienced development, medium to high fertility, found in plains and basins. Latosol is a type of soil that has developed to form a horizon, loose to slightly firm in consistency, red to yellow brown in color, found in wet climates, rainfall of more than 300 – 1000 meters, source rock from tuff, volcanic material, and intrusive igneous breccias . Andosol is a mineral soil that has developed profile, rather thick solum, slightly grayish brown to black in color, high organic content, dusty loam texture, crumb structure, friable consistency and oily slippery, medium permeability and sensitive to erosion, volcanic tuff parent rock.[1] Soil data needed to create HRU in QSWAT.

5 Sampling Data

After carrying out data availability analysis, it was found that the available data at the study location was quite potential and from the available data it could also be clearly defined regarding the problems that occurred at that location. However, there are still some data that are not available but are really needed in the HEC-RAS model, namely Bed Sedimentatin Gradation and river bathymetric data. Therefore, it is necessary to do sampling related to the data. In addition, sampling of river discharge and drift sediment data is also needed to create a rating curve and validate the model results.

5.1 Bed Sediment Gradation

This data is needed as sediment data input in the HEC-RAS model. This data was taken with a grab sampler in accordance with ASTM D 887-13 and tested with a sieve shaker based on SNI ASTM C 136-2012 which was adjusted to the availability of sieve sizes in the ITB lab.

Table 7 Citarik Bed Sediment Gradation

Sieve size (mm)	Retained Percentage (%)							
	1	2	3	4	5	6	7	8
<0,06	0,00	0,00	0,00	2,17	1,86	0,62	1,07	1,05
<0,1	0,11	0,00	0,00	4,85	6,59	6,13	11,76	9,28
<0,2	6,51	0,10	0,00	1,57	1,92	1,28	4,39	10,72
<0,6	1,00	0,07	0,00	51,67	41,51	42,30	67,01	10,51
<0,85	0,50	0,03	0,00	15,37	7,12	17,73	3,05	4,51
<2	3,33	0,30	0,00	19,87	20,42	25,48	6,31	39,83
<6,5	11,06	5,11	0,00	2,73	11,82	4,94	5,35	12,53
<65	77,50	43,31	87,57	1,77	8,76	1,52	1,07	11,57
>65	0,00	51,08	12,43	0,00	0,00	0,00	0,00	0,00

Bed Sediment Gradation data shows that in the upstream area (1, 2, 3) there has been a lot of erosion of river cross sections, in the middle and downstream it shows a lot of sand and silt formed which is formed from the sedimentation process. Where the soil types from smallest to largest sieve size are, respectively, coarse silt, very fine sand, fine sand, medium sand, coarse sand, very coarse sand, granules, pebbles, and cobbles.

5.2 Actual Bathymetry

The HEC-RAS model can be run using bathymetry which is generated from DEM data using the RAS mapper. The data taken in the field is used to validate the model results, whether they are representative and can be used to predict sediment formation or not.

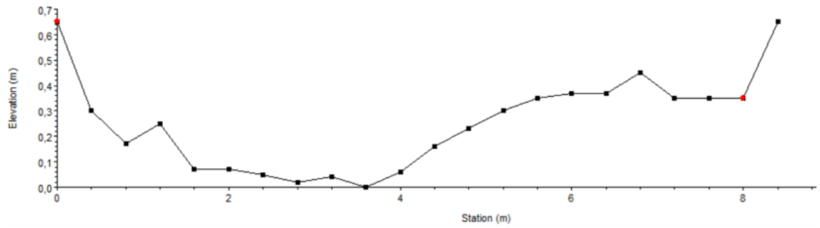

Figure 11 Point 1 Bathymetry

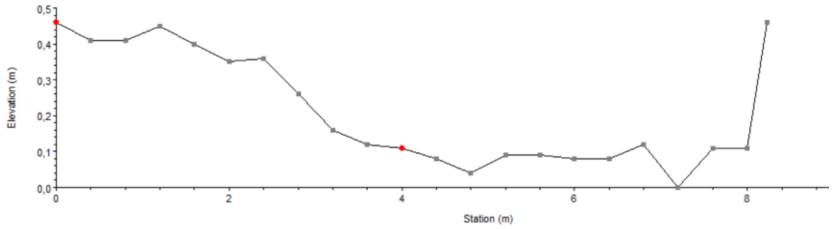

Figure 12 Point 2 Bathymetry

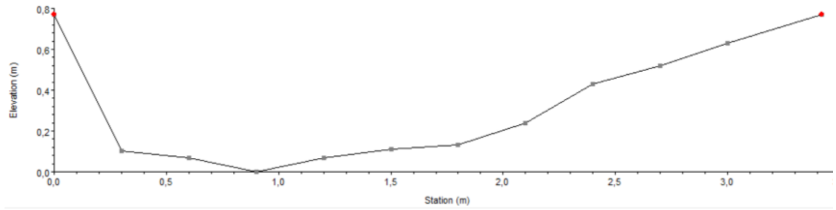

Figure 13 Point 3 Bathymetry

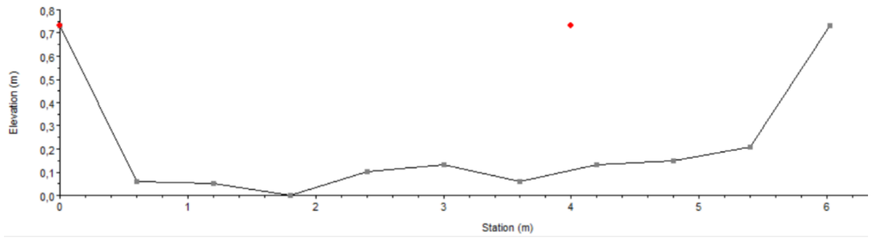

Figure 14 Point 4 Bathymetry

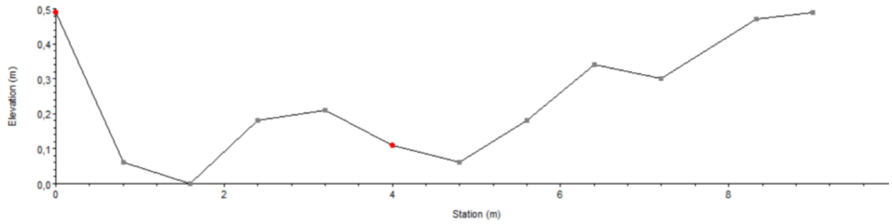

Figure 15 Point 5 Bathymetry

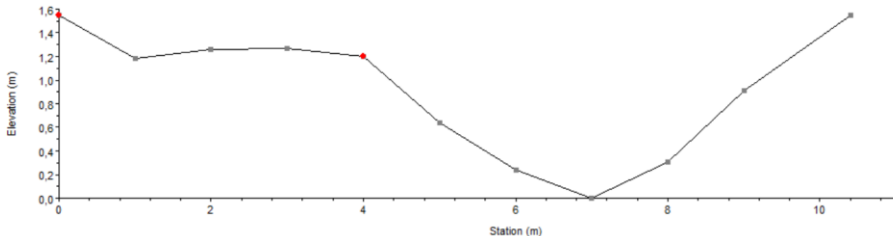

Figure 16 Point 6 Bathymetry

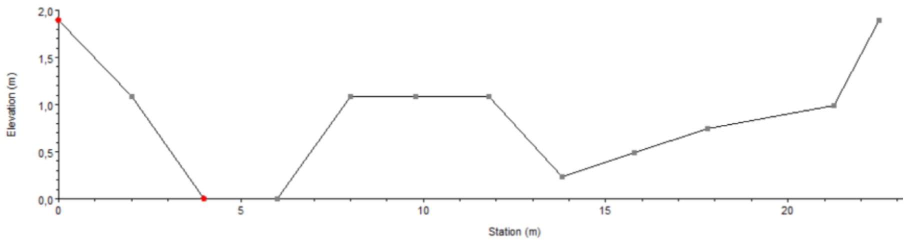

Figure 17 Point 7 Bathymetry

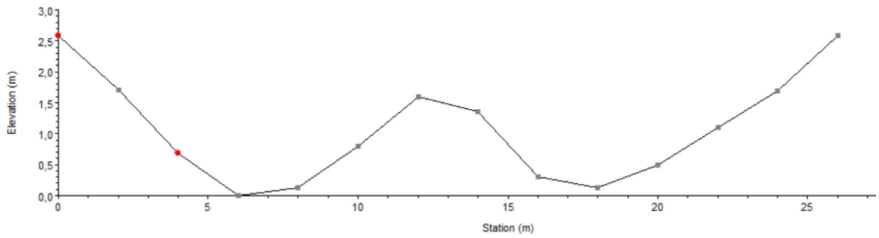

Figure 18 Point 8 Bathymetry

Bathymetry of a river section with a relatively fast flow tends to form deposits on the sides, while those with a relatively slow flow tend to form deposits in the middle. From the existing data it can also be concluded that the cross section of the river from upstream to downstream has undergone significant changes so that it cannot be assumed to be the same.

5.3 Actual Discharge & Floating Sediment

This data is used to validate the results of running the QSWAT model which will be the input to the HEC-RAS model.

Table 8 Citarik Bed Sediment Gradation

Point	Avg. Depth (m)	Min. Depth (m)	Discharge (m^3/s)	Avg. Velocity (m/s)	Perimeter Area (m^2)	Floating Sediment (mg/l)
1	0,435	0,200	0,952	0,274	8,400	0,040
2	0,269	0,010	0,999	0,471	8,230	0,042
3	0,700	0,140	0,863	0,530	3,420	0,019
4	0,631	0,520	1,821	0,533	6,020	0,056
5	0,299	0,020	1,400	0,579	8,330	0,041
6	0,771	0,280	2,164	0,306	10,400	0,112
7	1,254	0,800	6,605	0,268	21,260	0,145
8	1,759	0,880	7,434	0,176	26,000	0,158

The speed upstream is not greater than the speed in the middle stream, this is because there is a fairly high waterfall between points 1 and 2. Overall the speed of the Citarik river is not too extreme, the discharge is quite increasing upstream indicating that there are several tributaries which enters the Citarik River.

6 Conclusion

The Citarik sub watershed is a potential area for further study and modeling because it has many problems ranging from critical land, flooding to sedimentation and also has adequate data availability. Even so, primary data is still needed to complete the model input and validation.

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