International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-6, March 2020

The Changes of Runoff with DEM Resolution Variations

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Abstract: Currently there has been a research gap in providing sufficient and reliable data for the estimation of surface runoff from ungauged catchment in Batang Kuranji watershed, City of Padang, West Sumatera, Indonesia. The need for such data arose from the fact that land cover changes occur rapidly in the past 20 years, and flash flood and river degradation have been experienced at an alarming scale. However, due to lack of discharge data from upstream catchment, modelling catchment response to the effect of land use changes is hampered. Field measurement is difficult due to accessibility to river tributaries in the upstream catchment. Therefore, the use of digital satellite images and digital elevation model is studied with various DEM (Digital Elevation Model) resolutions for the first time in this catchment. This catchment is situated from 95 to 1858 m above sea level with an annual rainfall of 3440 mm. This watershed is classified as steep with a watershed that has a slope of more than 40% reaching 37.01% of the entire Kuranji watershed area. This study used 30 m and 8 m DEM. Secondary data were gathered from satellite images such as MODIS (MODerate resolution Imaging Spectroradiometer) Land Use. Precipitation data were gathered from three rain gauging stations in or nearby the catchment. Stream geometry data were obtained from the Provincial Office for River Management. Annual discharge and 100-year discharge are calculated using rainfall data for the past 20 years. Runoff discharge was calculated using rational method and SCS (Soil Conservation Services) method. Overall, computed discharge decreases as DEM resolution decreases with percentage varies between 0.98% to 1.76%. The biggest difference between DEM of 30 m and 8 m was shown by the Rational method. However, the difference between years is inconsistent with methods used with no significant pattern. Using the rational method, the biggest difference was by 18.73 m3/s, making up 1.76%. With SCS-CN, however, the biggest difference was 14 m3/s or 1.32% and the smallest was 0.98%. Validation with field measurement suggests that the 8-m DEM varies only 0.16% with actual discharge. Therefore, in the Kuranji catchment, the SCS method coupled with 8-m DEM was found to be accurate for the estimation of surface runoff.

Keywords: DEM, Land use, Runoff discharge.

I. INTRODUCTION

Padang City in West Sumatra, Indonesia has experienced a shift in urban development and rapid population growth over in last decade. The population of Padang City was 1.6 million in 2010. Population growth for 5 years increased by 8% to 1.8 million (www.padangkota.bps.go.id) in 2015. This has led to population growth and hence growing demands for public transportation facilities, residential areas and other supporting facilities. In current global issues in climate change, Padang is facing serious problems in hydro-climatologic related disasters.

In the past 20 years, Batang Kuranji watershed has experienced numerous problems related to hydrology. A massive flash flood in the Year 2012 and continuous river bed degradation has taken serious concerns on the health of the watershed. Yet, there has been a research gap in providing sufficient and reliable data for the estimation of surface runoff from ungauged catchment in Batang Kuranji watershed, City of Padang, West Sumatera, Indonesia. Due to lack of discharge data from upstream catchment, modelling catchment response to the effect of land use changes is hampered

Numerical models can be used to predict runoff as an insight to catchment response to various environmental changes. HEC-HMS is one of the hydrological models in the past that has been able to estimate runoff with various accuracy between regions [1], [2], [3], [4]. Inputs required are Digital Elevation Model (DEM), precipitation, stream networks, land use, and other catchment conditions. DEM may be obtained in various resolutions. With adequate sub catchment arrangements, the results may give both quantitative and qualitative information on hydrologic response of catchments.

Climate change in recent years has been intensively studied as a major cause of flood frequency [5], [6], [7]. Understanding global and regional climate conditions over a longer period is more important than local or catchment scale. Furthermore, [5], [6], [7] recommended that characteristics of flood must be understood by its causal mechanisms and dominant processes over statistical approaches alone [5]. Climate change would change flood peak discharges. Specifically, an increase in convective precipitation at a small catchment may growth maximum flood discharge [6]. Similarly, atmospheric conditions particularly rainfall will change magnitude of floods. Moreover, they highlighted that apart from the atmosphere, river systems and catchment land use changes are also attributed with the magnitude of flooding [7].

In line with the aforementioned studies, land use changes has an important roles because of its wide interactions with many hydrologic parameters. Land use alteration and management has been known to influence catchment hydrology due to changes in evapotranspiration, infiltration, antecedent soil moisture, and surface and subsurface storage that eventually change surface runoff and stream flow [8]. Nevertheless, the direct connection is difficult to disentangle because the processes are very complex on a long time scale. Interception and infiltration of rainfall which ultimately

Revised Manuscript Received on March 10, 2020.

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changes water runoff is one of catchment responses that is influenced by the mechanism of land use change. Several studies in the past have quantified the impact of land use change on hydrological conditions in the catchment and regional scale. The conversion of savannah into agricultural land and urban areas in Dano, Burkina Faso is strongly associated to an increase of stream discharge by 17%, mainly due to high flows, and a decrease in evapotranspiration by 5% [9]. A forest decline of 30% In a tropical forest of amazon resulted in an average annual flow of 24% [10]. A 10% clear cutting in a forest in a small catchment in Sweden results in an increase in peak flow by 5-10% [11]. However, the presence of other factors such as climate and catchment conditions makes the relationship between land use changes and stream flow being not straight forward.

The impact of land use changes on stream flow is influenced by climatic conditions and the geomorphological conditions of the catchment. A model study in Italy found that an increase in forests and urban areas and a decrease in cultivation areas had slightly changed runoff and then reduced peak flow and total volume, even though they identified problems in the performance of the model [12]. Consideration should be given to the characteristics of rainfall and catchment conditions, including land surface in studying the impact of land use change on floods. The intensity and duration of rain on catchment scale are the most important factors in runoff and stream flow volume, and the impact of land use change can be observed immediately downstream of the catchment. [13].

Field observations through remote sensing and GIS technology have been used to estimate land use change. The use of satellite data since the 21st century is becoming more common because it is one of the most economical and efficient ways to quantitatively display changes in land use over a wide area and time scale. Datasets used to classify land use/land cover are mainly Landsat [14], [15], MODIS [16], [17], Sentinel [18], [19], SPOT [20], [21], IKONOS [22], [23]. The big advantages of Landsat are fine spatial resolution and longer data availability than MODIS and Sentinel (Landsat in 30 m, MODIS in 500 m, Sentinel in 100 m), but the biggest challenge that impedes its implementation is cloud cover. Both SPOT and IKONOS are available commercially at very fine spatial resolution, 20 m and 4 m respectively. These land use information, coupled with hydrologic models, can be used to estimate the effects of land use changes on hydrologic response of catchments over a certain period.

II. METHODS

A. Study Area

The Batang Kuranji watershed in the north is bordered by the Singkarak watershed, in the east with the Sumani watershed, in the west with the Batang Air Dingin watershed and the Indonesian Ocean, in the south with the Batang Arau watershed. Geographically, the Batang Kuranji watershed is located at 0°48'-0°56' S and 100°21'-100°33' E, with elevation of 0-1,858 masl. The Kuranji stem is the main river in the Batang Kuranji watershed which originates on Mount Sakai. The source of the water comes from the Padang Janiah River, Padang Karuah River and Limau Manih River.

The area of Kuranji watershed is around 22470 ha which extends to the administrative area of Padang City and Solok Regency. The upstream part of the Batang Kuranji watershed is around 7,875 hectares, including conservation areas and protected forests.

Fig. 1. Kuranji catchment.

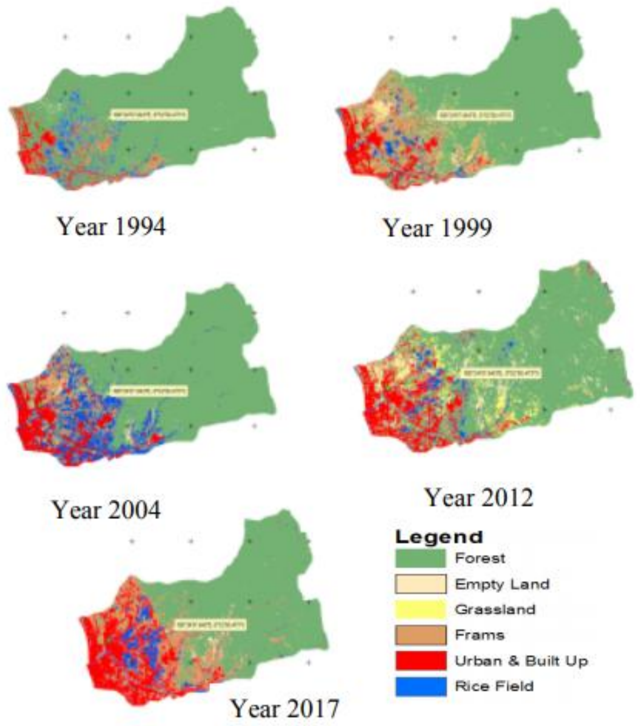

Fig. 2. Land cover in 1994, 1999, 2004, 2012 and 2017.

B. River networks identification

There are two methods used to identify river networks. The first method is to use a topographic map from the Provincial Office Development Plan (Bappeda Provinsi Sumatera Barat). The second method is from DEM (Digital Elevation Model) in 30 m and 8 m resolution from GDEM ASTER (Global Digital Elevation Model-Advanced Spaceborne Thermal Emission and Reflection Radiometer).

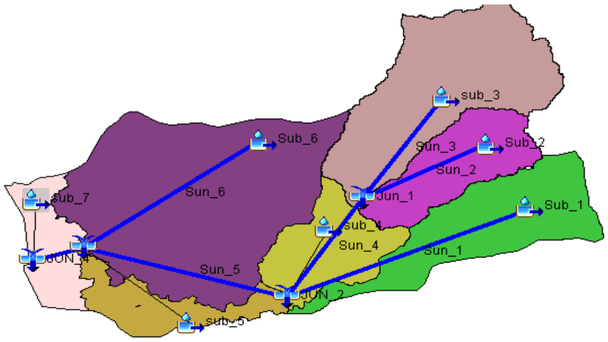

Fig. 3. Hec-HMS sub-catchment delineation.

C. Identification of land use changes

MODIS Land cover from 1994 to 2017 (MOD12Q1) in 500 m resolution (0.5^0 x 0.5^0) was used to analyze land use. There are 6 land cover classes identified by MODIS Land cover. Land use changes were presented as time series, and its changes were computed time to time. Field work was carried out to verify treaty between MODIS data and Provincial Office of Development Plan data.

D. Hidrology analysis

There are two types of DEM resolution used in this study. The 8-m resolution was acquired from DEMNAS of Indonesian Geospatial Body (www. http://tides.big.go.id/DEMNAS/DEMNAS.php) available for Indonesian-wide. The 30-m DEM was acquired from ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model) available at: (https://search.earthdata.nasa.gov/search/) for all the globe. Hydrologic analysis was performed to calculate maximum daily precipitation, intensity, and discharge at the catchment. Precipitation data were collected from rainfall stations in and around the catchment. Precipitation data are available from year 1992 to 2017. Raw data were obtained from Regional Office for River Management of Sumatera V. Based on rainfall records, this shows that in general the Province of West Sumatra has annual rainfall above 3500 mm, except in 2015 during El Nino at which most regions indicated precipitation of below average [24]. Four standard distribution functions are used to analyze Precipitation data according to the Indonesian Code for Drainage Planning, namely Normal, Log-Normal, Pearson Log III and Gumbel. Discharge was computed using two methods: Rational method and SCS method simulated by HEC-HMS package [25], [26]. Runoff coefficients were calculated based on existing land use.

III. RESULT AND DISCUSSION

Precipitation analysis was carried for return periods up to 100 years. Table 1 indicate that maximum daily precipitation for 100 year return period was 350.30 mm. Stream discharge for the flood model are calculated using this data. Land use data in year 1994 were used as base point to estimate average catchment runoff coefficient. Catchment was dominated by primary forest (61.2%) and housing (24%) (Fig. 4).

Table- I: Maximum daily precipitation

Return Period (year)	Maximum daily precipitation (mm)
100	350.30
50	312.60
25	270.60
10	223.30
5	182.80
2	118.30

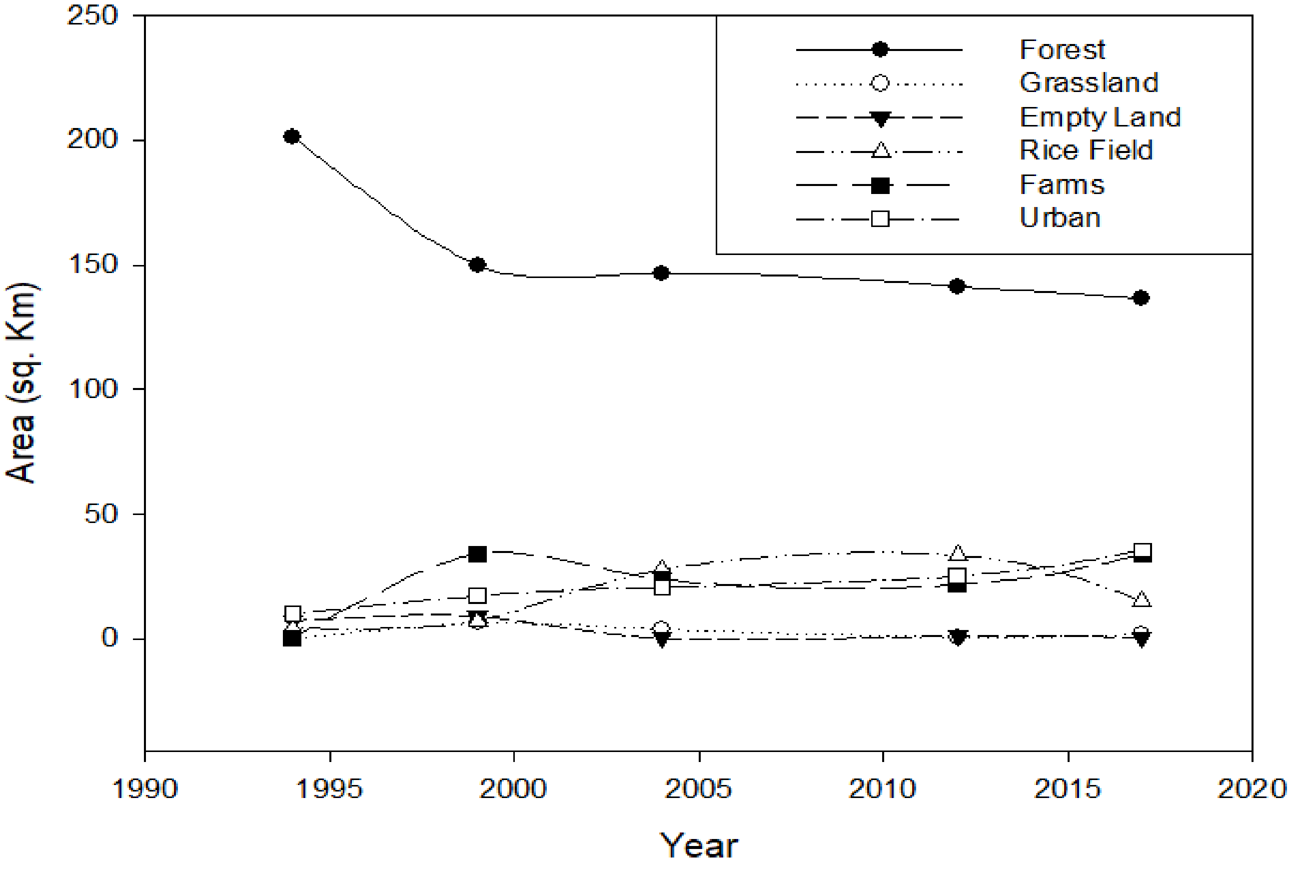

Fig. 4. Land use changes from year 1994 to 2017.

Table- II: Coefficient of land cover in Sub Watershed, SCS CN Method in HEC-HMS

No	Sub Watershed	1994	1999	2004	2012	2017
		CN	CN	CN	CN	CN
1	Sub 1	71.59	71.62	71.88	71.56	71.80
2	Sub 2	71.01	71.15	71.05	71.10	71.13
3	Sub 3	71.02	71.06	71.08	71.06	71.09
4	Sub 4	71.82	73.64	74.71	72.42	73.29
5	Sub 5	76.84	79.91	83.45	80.67	84.53
6	Sub 6	73.45	75.80	77.11	80.02	77.97
7	Sub 7	78.92	84.27	83.35	86.58	86.56

Figure 4 shows that while area for housing and farms increased steadily, forest decreased at the same extent through to 2017. These three land use types dominate the catchment area. Due to higher runoff coefficient, the increase of these areas results in increased discharge from year 1994 to 2017 in all methods used, regardless of DEM resolutions. However, since year 2014, MODIS Land cover did not release land use data, and hence, we used Landsat 7 and 8 for land use assessment. In Kuranji catchment, Landsat categorized four land cover classes, *i.e.* forest, urban and built up, farms, and water bodies such as river and wetlands. Landsat datasets from year 1994 were used to re-classify MODIS data for current use. Six land use classes in MODIS Land cover (Forest, Grassland, Empty Land, Rice Field, Farms, and Urban & Built Up).

DEM Resolutions Slightly affect discharge in the catchment. Using DEM resolutions of 8 M, maximum discharge using Q_{50} and Q_{100} are 947 and 1061 m3/s, respectively. for DEM of 30 m, Q_{50} and Q_{100} are 961 and 1077 M3/S, respectively. Overall, using two methods (Rational and SCS) DEM of 30 m results in higher discharge at all return periods with a difference of 10-15 m3/s than that of the 8-m resolution. as expected, discharge increased continuously from year 1994 to 2017. Our findings disagree with [27], [28] since these studies employ more variable DEM resolutions. On the other hand, other studies suggested that runoff discharge is not sensitive [29] nor consistently affected [30], [31] by DEM resolution. Other factors also intervene such as number of rainy days [32].

Table- III: Discharge using rational method

Tahun	C	A (Km^2)	Q DEM 8m (m3/dt)			Q DEM 30m (m3/dt)		
			5	50	100	5	50	100
1994	0.404	119.82	544.49	931.15	1043.55	551.53	943.19	1057.04
1999	0.406		548.25	937.59	1050.76	555.30	949.65	1064.27
2004	0.407		548.40	937.85	1051.05	556.81	952.22	1067.16
2012	0.411		554.33	947.98	1062.41	564.10	964.70	1081.14
2017	0.412		553.87	947.19	1061.52	562.29	961.59	1077.66

For both 8 m and 30 m DEM, peak flow occurs at 4th hour (Fig. 5 and 6). Figure 5 shows that peak time is not sensitive to input precipitation, since higher precipitation from Year 1994 To 2017 results in similar runoff patterns. This figure is consistent with DEM resolution, as 30-m DEM and 8-m DEM produce the same runoff peak. This study agrees with [32] in other study found that as DEM resolution is coarser, peak flow decreases [31].

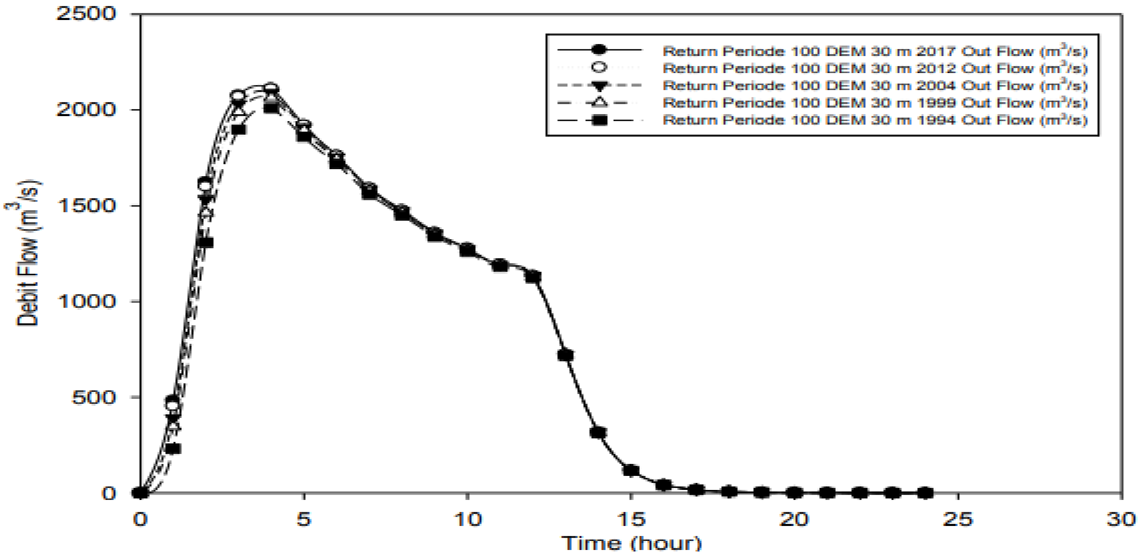

Fig. 5. Hydrograph with return period of 100y using SCS CN, DEM 30m

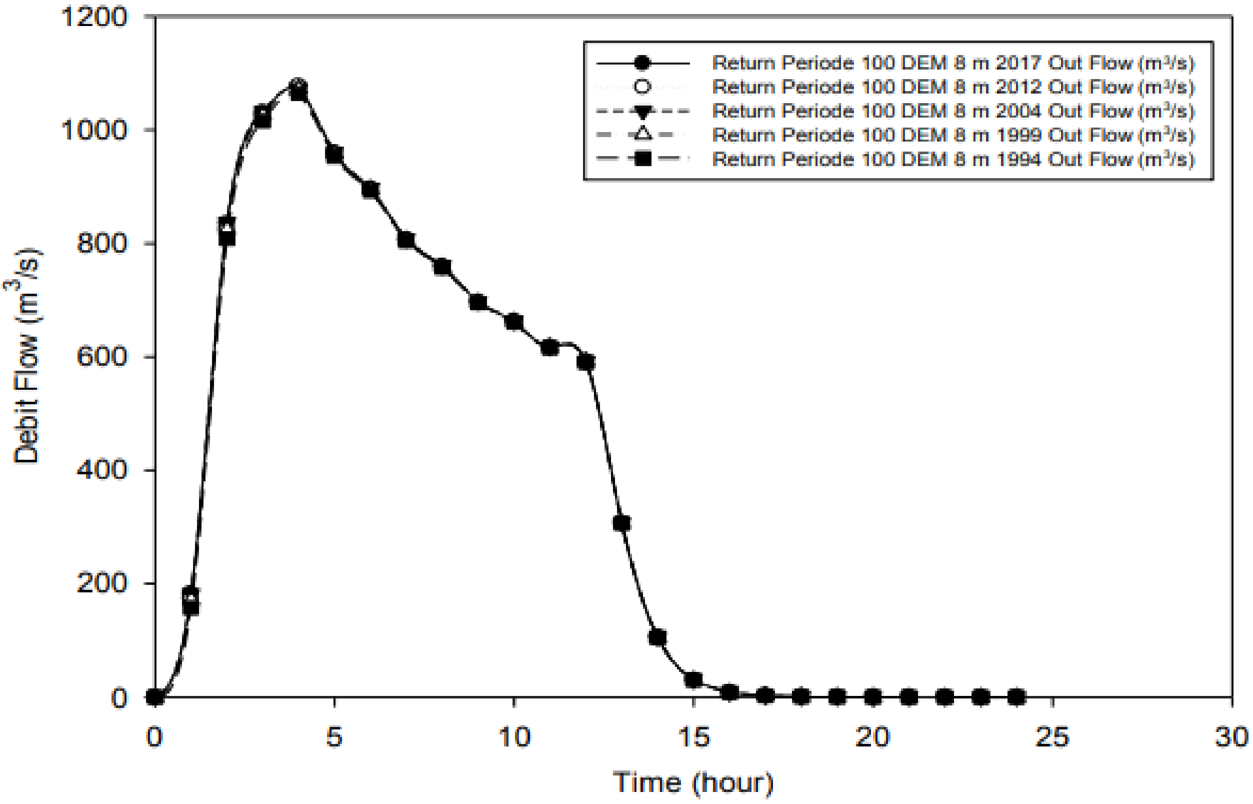

Fig. 6. Hydrograph with return period of 100y, with SCS CN, DEM 8 m.

Table- IV: Discharge using Rational method

Rational	2017	2012	2004	1999	1994
Q DEM 30 m	1077.66	1081.14	1067.16	1064.27	1057.04
Q DEM 8m	1061.52	1062.41	1051.05	1050.76	1043.55
Difference	16.14	18.73	16.11	13.51	13.49
%	1.52	1.76	1.53	1.29	1.29

Table- V: Discharge using SCS CN method

M. SCS CN	2017	2012	2004	1999	1994
Q DEM 30m	1076.50	1077.10	1075.20	1073.50	1065.20
Q DEM 8m	1064.20	1065.90	1061.20	1059.90	1054.90
Difference	12.30	11.20	14.00	13.60	10.30
%	1.16	1.05	1.32	1.28	0.98

Table 4 and 5 show that computed discharge decreases as DEM resolution decreases with percentage varies between 0.98% to 1.76%. The biggest difference between DEM of 30 m and 8 m was shown by the Rational method. However, the difference between years is inconsistent with methods used with no significant pattern. Using the rational method, the biggest difference was in 2012 by 18.73 m3/s, making up 1.76%. With SCS-CN, however, the biggest difference was in 2004 (14 m3/s or 1.32%) and the smallest was in 1994 by 0.98%. Hence, in the following section, a validation is conducted between computed discharge and field measurement.

A. Discharge Model Validation

A validation was performed at a cross section downstream flood location. At the site, the channel is lined with brickwork. Several witnesses were interviewed regarding water level at the cross section, and water height was measured. Then a HEC-RAS model was run using two cross sections of 750 m apart. Some trial discharges were simulated to fit water level, and Q during the flood was obtained.

Fig. 7. Validation site with two cross sections for HEC-RAS model.

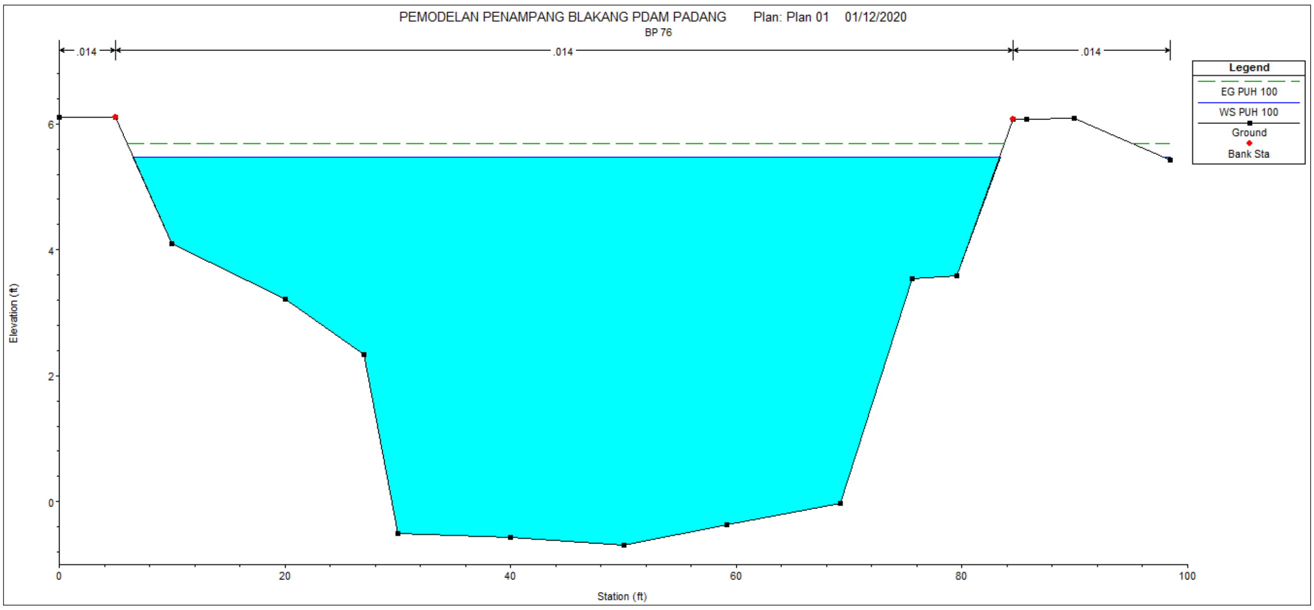

Fig. 8. Cross-section-1.

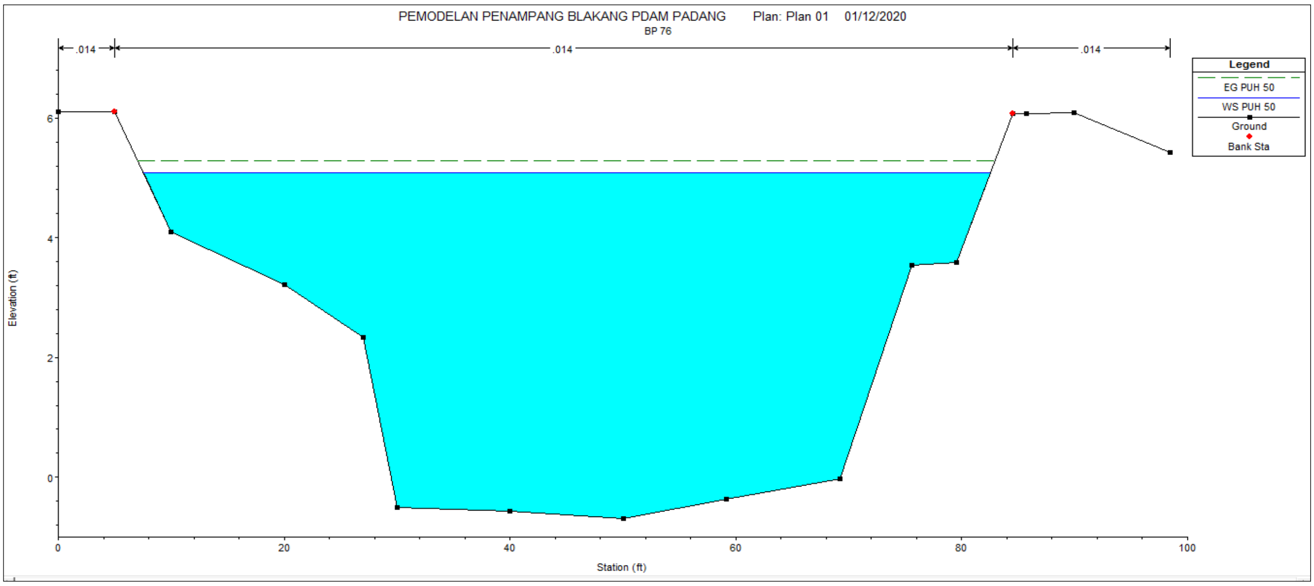

Fig. 9. Cross section-2.

In the cross section 1, a water height of 6.18 m above channel bed was obtained. At cross section-2, water height was 5.78 m above channel bed. The water heights of the two cross sections correspond with a discharge of 1064.2 m3/s. This discharge is 1.7 m3/s less than the 2012 flood or 0.16% using SCS-CN method with 8-m DEM. This considered very accurate.

IV. CONCLUSIONS

Runoff discharge was calculated using rational and SCS HEC-HMS, resulting in 100 year Runoff discharge (2012) of 1081.14 m3/s of rational and 1077.10 m3/s of SCS HEC-HMS for DEM 30 m and 1062.41 m3/s of rational and 1065.90 m3/s of SCS HEC-HMS for DEM 8 m. Due to variations in DEM there was an increase in discharge with the Rational Method between 1.29% - 1.76%, while with the SCS-CN Method, HEC-HMS increased the discharge between 0.98% - 1.32%. A validation using two cross sections downstream the flooded site resulted in flood discharge of 1064.2 m3/s or 0.16% less than that of the SCS-CN method using 8-m DEM. Our model showed that models using SCS-CN coupled with 8-m DEM is a robust and accurate for this catchment scale. However, a more accurate measuring device is needed with variations in catchment scale and topographic variability.

ACKNOWLEDGMENT

Author would like to thank the Padang State Polytechnic for defraying this research.

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