STUDY FLASH FLOOD CHARACTERISTICS IN NASIRI RIVER, WEST SERAM MALUKU

Bunchhun Moeung[1*], Adam Pamudji Rahardjo[1], Istiarto[1]
[1]Department of Civil and Environmental Engineering, Faculty of Engineering,
Universitas Gadjah Mada
[*]Email: moeung@mail.ugm.ac.id

Abstrak

Curah hujan dengan intensitas tinggidapat menghasilkan banjir bandang, khususnya di daerah pegunungan dengan kemiringan curam dengan kawasan pemukiman di dalamnya, sehingga mengakibatkan korban lebih besar, kerusakan infrastruktur ekstrem, penurunan hasil pertanian dan kerugian ekonomi yang luar biasa. Dengan keberadaan bukit-bukit dan lereng terjal di daerah hulu, desa Nasiri mengalami banjir bandang setiap tahun, terutama pada tahun 2012, yang memicu kerusakan besar pada permukiman yang berada di tepi kanan dan kiri sungai. Penelitian ini bertujuan untuk menggunakan model hujan-aliran, yang dikembangkan oleh Miyata (2014), untuk mensimulasikan karakteristik banjir bandang di Daerah Aliran Sungai Nasiri dengan luas daerah tangkapan air 10,48 Km^2 dan panjang alur sungai utama 4,62 Km. Penelitian ini akan membandingkan hasil yang disimulasikan dengan hasil penelitian sebelumnya dan untuk menganalisis data topografi. Hasil simulasi menunjukkan adanya perbedaan antara waktu puncak banjir hasil simulasi baru dan hasil studi sebelumnya walaupun simulasi menggunakan nilai kekasaran permukaan dan kapasitas infiltrasi yang sama namun menggunakan sumber data topografi yang berbeda. Perbedaan sumber data topografi menyebabkanadanya perbedaan pola arah aliran limpasan pada sel-sel lereng yang mengalir ke saluran aliran.

Abstract

Highintensity rainfall produces flash floods, particularly on mountainous area with steep slope withsome urban areas, which resulted in greater casualties, extreme infrastructure damages, agricultural products decreasing and tremendous economic losses. Covering by hills and steep slope in upstream area, Nasiri village experienced flash flood every year, especially in 2012, which provoked large destruction to settlements located on the right and left bank of river. This study aims to verify rainfall-runoff model, developed by Miyata (2014), by simulating flash flood characteristics in Nasiri watershed with catchment area of 10.48 km^2 and river length of 4.62 km. Sub-objectives of this research are to compare the simulated results with previous study and to analyze the topographical data. The simulated results show the presence ofdifferent values of time to peak between that of new simulation and that of previous study even though the surface roughness and infiltration parameter values are the same but with different sources of topographical data used. The last causes differentcell flow direction pattern for slope runoff flowing to the stream channel.

Keywords: *flash flood, Nasiri watershed, rainfall-runoff model*

INTRODUCTION

Indonesia is highly prone to climate change and climate vulnerability that triggered the intensive rainfall almost every year. The intensive rainfall produced flash floods, particularly in mountainous and urban area, which resulted in greater casualties and tremendous economic losses. In 2012, flash flood occurred in Nasiri village, Maluku province, which provoked large destruction to settlements located on the right and left bank of river Widowati (2017). Because of topographical condition with steep slope and sediment erodible, it is very predictable that flash flood will occur again in near future. Non-structural measures system comprises such as monitoring and warning facilities, warning platforms, evacuation plans, organization systems, knowledge dissemination, training and exercises (Yao et al., 2016). Surface runoff prediction using hydrologic models was considered very significant among all aforementioned non-structural countermeasures to support decisions on water resources management (Khalid et al., 2016). Therefore, a hydrologic modelling is used to simulate flash flood characteristics, namely Grid-Based Hydrology-Hydraulic Rainfall-Runoff modelling, developed by Miyata et al. (2014).

Several studies related to flash flood prediction show that grid-based rainfall-runoff model are capable to simulate unsteady flow in various study catchments. Widowati (2017) used GIS-based grid-based distributed rainfall-runoff model to simulate the rainfall-runoff transformation in steep channel of Putih river, Central Java, Indonesia. The numerical simulation using grid-based rainfall-runoff was also applied in Sugoroku catchment, which is an alpine catchment in central Japan(Miyata et al., 2014). Numericalmodel was used to calculate the surface runoff and to derive the flood hydrograph at the return period of 5, 10, 25, 50 and 100 years in Kelantan watershed, Malaysia (Ghorbani et al., 2016). Other researches also indicated the applicability of kinematic overland flow model for flood simulation such as Liu et al. (2009) and Komsai et al. (2015).

This study aims to verify the rainfall-runoff model, developed by Miyata et al. (2014), by simulating flash flood characteristics in Nasiri watershed, Maluku Province. Sub-objectives of this study are to compare the simulated results with previous study and to analyze the topographical data.

METHODOLOGY

Catchment Description

This study is conducted in Nasiri catchment that is located in Nasiri Hamlet, Luhu Village, Huamual Sub-District, West Seram District, Maluku Province (Figure 1). Geographically, it is situated at 3º20’25.80” – 3º20’37.18” (West to East) and 127º56’14.22” – 127º56’27.62” (South to North). The topographical condition throughout the watershed alters from upstream to downstream area. The upstream of watershed is covered by hills with rock and steep slope; moreover, the downstream area is Nasiri hamlet situated near the coastal area with dense population.

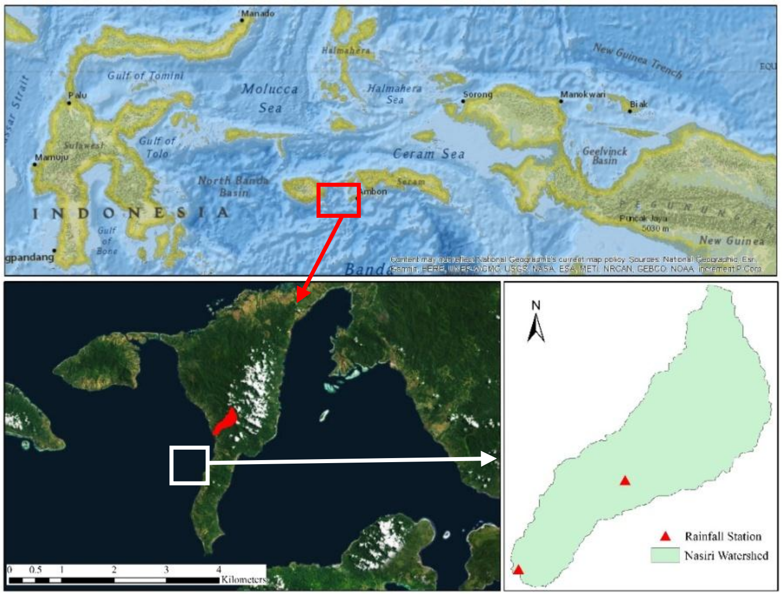

Figure 1. The location of Nasiri catchment

Data Acquisition

Table 1 illustrates the data requirement for inputting to the model, consisting of rainfall data, water level, and topographical data. Rainfall data and water level were obtained from Automatic Rainfall Recorder (ARR) and Automatic Water Level Recorder (AWLR) instrument with 5 minutes time-step. Topographical data, i.e. Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM), was acquired from United States Geological Survey (USGS) with resolution is approximately 30m x 30m.

Table 1. Data requirement for inputting to model

Data	Source	Information
Topography	USGS	Terrain elevation
Rainfall Intensity	ARR	5-minute time-step
Water Level	AWLR	5-minute time-step

Topographical data (Digital Elevation Model) is required as input data for calculation the flow accumulation, stream network, watershed delineation in GRASS GIS. The Shuttle Radar Topography Mission National Geospatial-Intelligence Agency Digital Elevation Model (SRTM NGA DEM) was applied and acquired from United States Geological Survey (USGS) with resolution is approximately 30m x 30m. For previous study, topographical data was SRTM NASA DEM and also obtained from USGS website. Figure 2 depicts comparison of topographical data of previous study and new simulation.

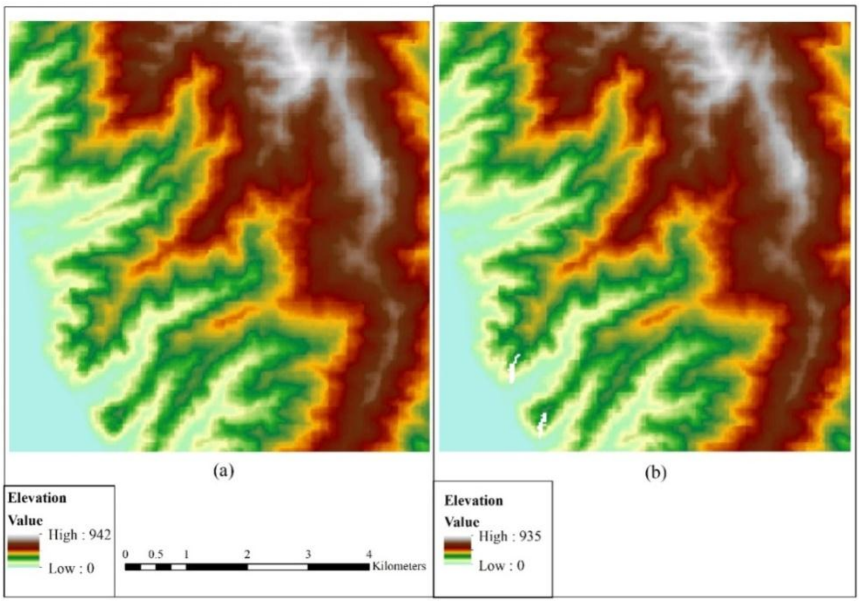

Figure 2. Comparison of topography map of study area: (a) previous study and (b) new simulation

Rainfall intensity data were obtained from Automatic Rainfall Recorder (ARR) station, situating at upstream and downstream of watershed (Figure 1). Water level data were received from Automatic Water Level Recorder (AWLR) instrument which is located at downstream of catchment. Both instruments were installed by Universitas Gadjah Mada (UGM). The water level data were used to generate to observed discharge using rating curve equation for Nasiri catchment (Primahessa et al., 2017), as shown in following equation:

$$Q = 0.0011 \times h^{2.39} \quad (1)$$

where Q is observed discharge (m^3/s)
h is rise of water level (cm)

The rainfall events were selected to simulate flow hydrographs, consisting of three events such as 19 April 2016, 03 May 2016 and 12 November 2016.

Model Description

The grid-based rainfall-runoff model, developed by Miyata et al. (2014), is used to simulate runoff in study catchment during the short intense storm event. The simulation model comprises such as hillslope and stream segment. Figure 3 illustrates the schematic of simulation model in hillslope segment. The hillslope segment was divided into 10 x 10 m grids, which the grid with lowest elevation within the neighboring 8 grids was defined as flow direction (Figure 4). The outputs from hillslope segment were used as input to stream channel and continuously flow to main output of catchment. In each grid, the soil was divided into 2 layers consisting of A-layer and B-layer. A-layer received water that infiltrated from soil surface and became ground water flow into B-layer. The ground water in the B-layer enabled to percolate to deep layer, however, the ground water in deep layer was assumed not to return neither to the hillslope nor the stream segment.

 ISSN: 2459-9727

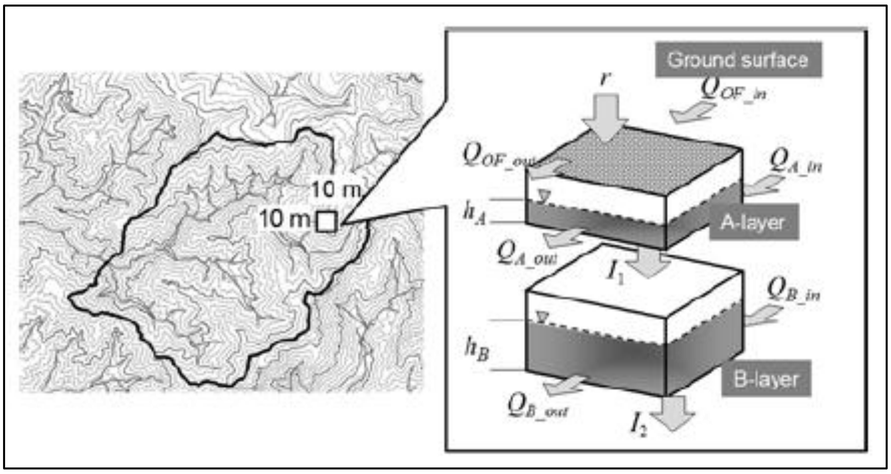

Figure 3. Schematic illustration of simulation model in hill slope segment (Miyata et al., 2014)

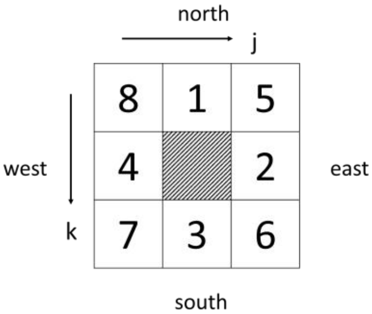

Figure 4. Flow direction to the neighboring eight grid (Miyata et al., 2014)

Watershed and Stream Delineation

Watershed delineation can be conducted using many programs such as ArcGIS, GRASS GIS, etc. The process of watershed delineation in GRASS GIS is considered using sequential steps such as UTM zone conversion, set region, depressionless, flow direction and accumulation, raster resampling, watershed analysis and watershed creation. After that, raster calculator operation is used to crop preferable watershed and stream network. The last step is to export the Stream01 to ESRI ASCII format for using in rainfall-runoff model. Setting minimum size of exterior watershed in watershed analysis operation may affect to number of sub-watersheds and tributaries. Moreover, determining the outlet point of watershed provides variation of watershed shape as well.

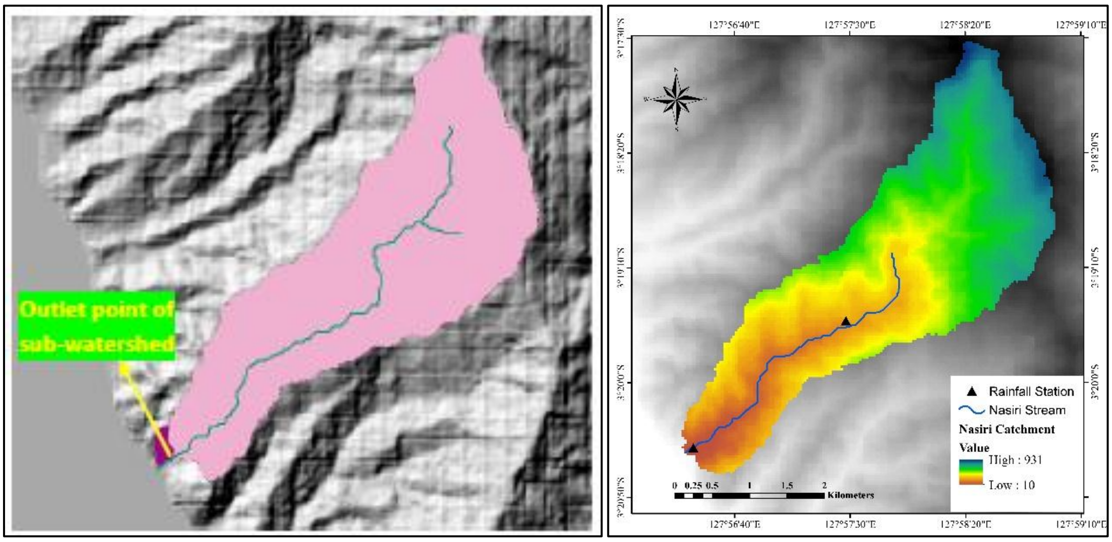

Figure 5. Comparison of Nasiri watershed and stream network: previous study (left) and new simulation (right)

Figure 5 illustrates the comparison of watershed boundary and stream network of Nasiri watershed for previous study and new simulation. The catchment area is approximately of 10.48 km^2 with river length of 4.62 km, comparing to previous study with catchment area of 10.45 km^2. The watershed is converted to ASCII format and used as input data for rainfall-runoff model. After delineation, stream network in this watershed is only one, comparing to previous study that watershed was divided into 3 sub-watersheds with 3 tributaries, to facilitate rainfall-runoff model during simulation. The watershed also consists of slope of all grid cells, except the stream grid cells, which is distinguished by elevation of each grid cell.

RESULTS AND DISCUSSIONS

The hydrographs in Nasiri watershed are simulated on 19 April 2016, 03 May 2016 and 12 November 2016. Figure 6 depicts the simulated and observed flow hydrograph of 19 April 2016 event. The roughness coefficient and infiltration rate values for this event are 0.7 and 22 mm/hr respectively. The peak of rainfall is 42.67 mm at t = 85 minute. The hydrograph of new simulation starts rising at t = 100 minute and the peak discharge is 1.19 m^3/s at t = 130 minute. For previous study, the hydrograph identically rises at t = 120 minute with the peak discharge value of 1.11 m^3/s at t = 175 minute, while the peak discharge of observed data is 0.78 m^3/s at t = 160 minute. The peak discharge values of new simulation and previous study are not significantly different but the peak times of both hydrograph are different in 45 minutes.

The observed and simulated flow hydrograph of 03 May 2016 event is illustrated in Figure 7. The parameter values of roughness coefficient and infiltration rate are 0.7 and 21 mm/hr respectively. It can be observed that the rainfall intensity is peak at t = 35 minute with value of 54.86 mm. The peak discharge of new simulation is 1.81 m^3/s at t = 70 minute. The hydrograph shows the value of previous study peak discharge is 1.92 m^3/s at t = 105 minute, comparing to observed flow with peak discharge and time of 1.89 m^3/s and 115 minute, respectively. It can be said that the difference between peak discharge of new simulation and previous study is 35 minutes.

Figure 8 shows the observed and simulated flow hydrograph of 12 November 2016 event. The roughness coefficient and infiltration rate values used in this event are 0.5 and 18 mm/hr respectively. The rainfall intensity is peak at t = 55 minute with peak value of 48.76 mm. In addition, the peak discharge of new simulation is 4.06 m^3/s at t = 90 minute, while the observed flow is peak at t = 95 minute with peak discharge value of 3.81 m^3/s. More significantly, the peak discharge in previous study is 3.71 m^3/s at t = 110 minute. The result shows that new simulation discharge are not much different from observed value comparing to previous study result, which the difference between the peak discharges are 25 minutes.

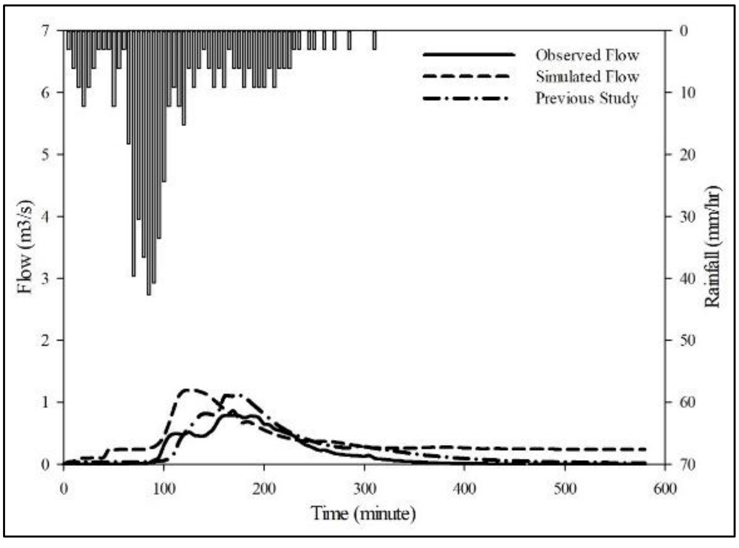

Figure 6. The observed and simulated flow hydrograph of 19 April 2016 event

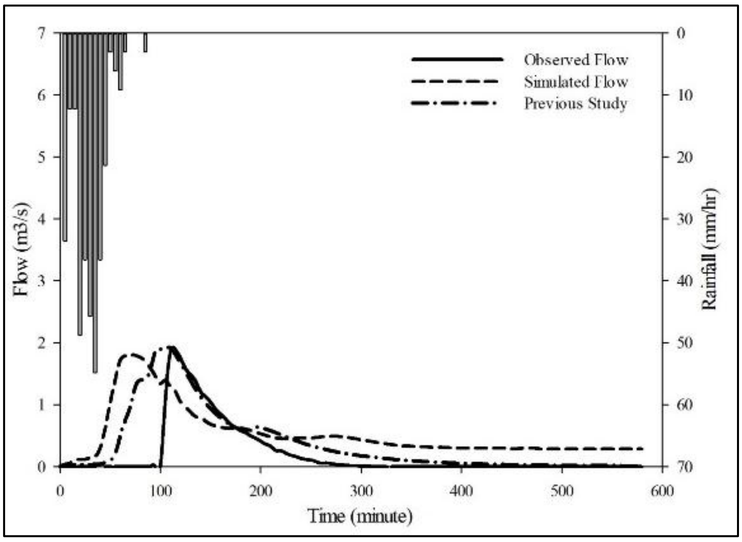

Figure 7. The observed and simulated flow hydrograph of 03 May 2016 event

There are many reasons that are able to cause the peak discharge results of new simulation and previous study significantly different for 19 April 2016 and 03 May 2016 event. The first reason is the effect of topographical data acquired from different sources. In this study, topographical data is SRTM NGA (National Geospatial-Intelligence Agency) DEM type and acquired from USGS website. The elevation throughout the catchment range from 10 m to 931 m. For previous study, SRTM NASA DEM was used to simulate flow hydrograph, with same resolution of 30 m. In case of 03 May 2016 event, the result shows the difference of peak time between observed and simulated flow. This is because the rainfall data used in the rainfall-runoff model is distributed within the watershed, while there was no rainfall at downstream area for this event and the rainfall data was received only from upstream rainfall station. Moreover, the flow data was obtained from downstream station; so that observed flow rose up later than simulated flow.

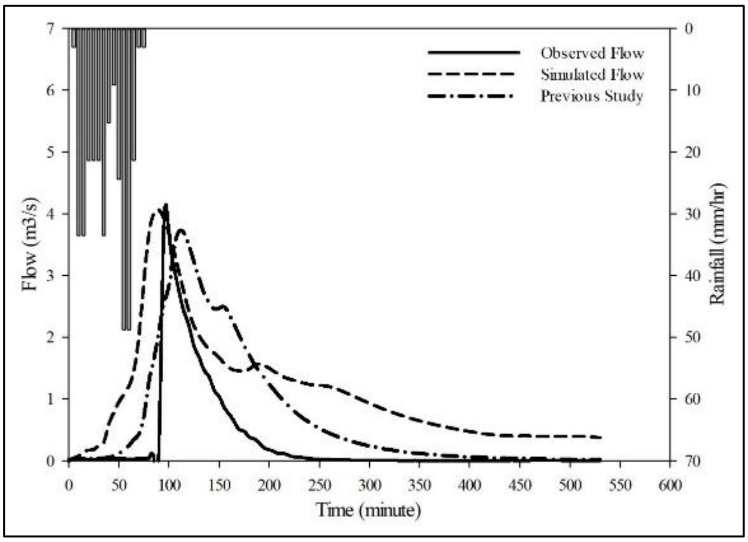

Figure 8. The observed and simulated flow hydrograph of 12 November 2016

More importantly, the last reason can be due to flow direction of slope runoff before entering the stream channel. The flow direction within the neighboring cells that is converted from numbers to direction is illustrated in Figure 4. As shown in Figure 7, the flow direction of both simulations are selected for same position (row number 182 to 188 and column number 373 to 383) and it can be seen that the directions are significantly opposed. For new simulation, the water flow to south-west direction (number 7) before entering to the stream. This is the reason that water flows to stream channel and then outlet point quickly and caused the hydrograph rise to peak immediately. In contrast, the flow direction of previous study is southeast (number 6) before entering to the stream. Consequently, water flows to the outlet point slower than southwest direction. However, the simulated results need to be more accurate by improving the sensitive parameters such as roughness coefficient and infiltration rate.

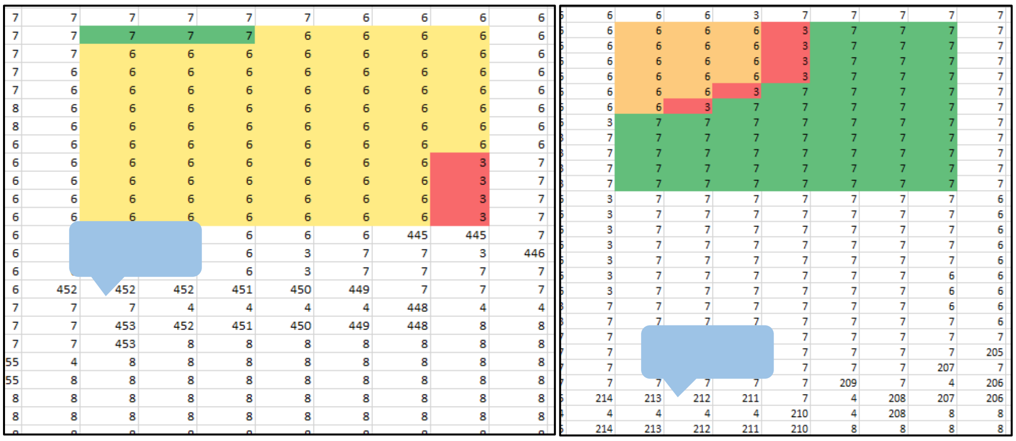

Figure 9. Comparison between flow direction of previous study (left) and new simulation (right)

CONCLUSION AND RECOMMENDATION

Grid-Based Rainfall-Runoff model, developed by Miyata et al., (2014), is used to simulate flash flood characteristics in Nasiri watershed with catchment area of 10.48 km^2. The simulated results show the difference between peak time of new simulation and previous study with similar values of peak discharge due to different sources of topographical data used, rainfall distribution and flow direction from slope runoff to stream channel. It is recommended that average rainfall distribution should be conducted and the study of spatial distribution of roughness coefficient and infiltration rate should be included to obtain accurate results. The simulation of sediment aggradation and early warning time should be conducted for further studies.

REFERENCES

Ghorbani, K., Wayayok, A. and Abdullah, A.F., 2016. Simulation of flood risk area in Kelantan watershed, Malaysia using numerical model. *Jurnal Teknologi*, *78*(1-2).

Khalid, K., Ali, M.F., Rahman, N.F.A., Zainuddin, M.R., Muhamad, N.S., Den, E.M. and Othman, Z., 2016. Surface runoff variation assessment using process-based hydrologic model. *Jurnal Teknologi*, *78*(10-4).

Komsai, A., Liengcharernsit, W. and Kinouchi, T., 2015. Development of Flood Routing Models for Wang River Basin. *ASEAN Engineering Journal Part C* (Vol. 4, No. 1, pp. 16-29).

Liu, J., Feng, J. and Otache, M.Y., 2009. A grid-based kinematic distributed hydrological model for digital river basin. *Advances in Water Resources and Hydraulic Engineering* (pp. 82-87). Springer, Berlin, Heidelberg.

Miyata, S., Fujita, M., Teratani, T and Tsujimoto, H., 2014. Flash Flood due to Local and Intensive Rainfall in an Alpine Catchment.

Primahessa, A., Rahardjo, A., Sujono, J., 2017. Analisis Karakteristik Hujan Penyebab Banjir Pada Sistem Peringatan Dini di Sungai Dengan Kemiringan Curam (Studi Kasus di Dusun Nasiri, Kecamatan Huamual, Kabupaten Seram Bagian Barat). Universitas Gadjah Mada.

Widowati, A.P.A., 2017, January. Hydraulic and Hydrologic Modeling of Steep Channel of Putih River, Magelang District, Central Java Province, Indonesia. *Journal of the Civil Engineering Forum* (Vol. 3, No. 3, pp. 125-134).

Yao, Q., Xie, J., Guo, L., Zhang, X. and Liu, R., 2016. Analysis and evaluation of flash flood disasters: A case of Lingbao county of Henan province in China. *Procedia Engineering*, *154*, pp.835-843.