Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 04, April, 2023

Flood Sedimentology for Future Floods Mitigation in North Luwu, Sulawesi, Indonesia

Adi Maulana [1, 2*], Miswar Tumpu [1], Indah Putri Indriani [1, 3], Iswandi Utama [4]

[1] *Magister of Disaster Management Study Program, Graduate School of Hasanuddin University, Makassar, Indonesia.*

[2] *Department of Geological Engineering, Hasanuddin University, Makassar, Indonesia.*

[3] *Government of North Luwu Regency, Indonesia.*

[4] *Centre for Disaster Study, Hasanuddin University, Makassar, Indonesia.*

Received 12 December 2022; Revised 26 February 2023; Accepted 08 March 2023; Published 01 April 2023

Abstract

A sedimentological study after the flash floods that hit North Luwu on July 13, 2020, has been carried out on three affected rivers, namely the Masamba River, the Radda River, and the Binuang River. The study aims to determine the sedimentological impact of the 2020 flash flood disaster, including sedimentation rate, annual bedload sediment volume, and total sediments, which will be used as a reference for future mitigation consideration. The study is based on fieldwork for data collection and laboratory analysis. The results of field measurements and laboratory analysis are then processed by calculating the sedimentation rate at the annual discharge, the bedload sediment volume, and the total estimated sediment accumulated by the flash flood. Sedimentation rate analysis was performed using the Ackers-White formula, and flood delineation was processed using HEC-RAS software. The climatological data from the climatology station at Andi Djemma Airport were used to calculate the river discharge. It is estimated that the volume of bedload sediment in the Binuang River is 16,194,168 m^3/year, that of the Masamba River is 7,852,061 m^3/year, and that of the Radda River is 4,003,011 m^3/year. The volume of sediment brought by flash flood sedimentation in the Radda River is 9,141,608.39 m^3, while that in the Masamba River is 55,131,761.29 m^3, and that in the Binuang River is 136,838,603.61 m^3. The total estimated sedimentation generated by the flash flood on the three rivers on July 13, 2020, is 222,476,966 m^3. Based on the study, zonation for vulnerability levels is designed for a future mitigation scheme. The zonation can be classified into three zones: 1) the highly affected zone; 2) the moderately affected zone; and 3) the least affected zone, with special purposes in each zone. It is strongly recommended that future disaster settlement and infrastructure reconstruction policies be based on this zone to reduce disaster risk.

Keywords: Sedimentation; Flash Flood; Mitigation; North Luwu; South Sulawesi.

1. Introduction

One of the dominant types of disasters occurring in the territory of Indonesia are floods and flash floods, which cause a lot of material loss and casualties [1]. Flash floods have occurred several times in South Sulawesi, and the flash flood-prone area is widely distributed in South Sulawesi and flash floods are one of the most destructive natural hazards, causing significant economic losses [2–7]. Flooding in the region is commonly caused by high-intensity storms that cause ephemeral watercourses to overflow [8–10]. Despite their importance, flash floods were poorly known until recently due to problems in monitoring [11, 12], attributable mostly to the time and spatial scales at which they occur as

* Corresponding author: adi-maulana@unhas.ac.id

http://dx.doi.org/10.28991/CEJ-2023-09-04-011

well as the inability of standard observational networks to accurately assess their properties [13, 14]. In recent years, published post-flood surveys that emphasize the above problem [15], describing hydrometeorological conditions, as well as catchment and societal responses, have been the primary vehicle for filling this documentation gap.

Although post-flood surveys are event-based, they allow for the observation of the hydrological behavior of catchments (e.g., peak discharge or debris content) in the face of extreme meteorological forcing, when (as many authors put it) the majority of surface runoff paths are active [16–18]. This method elucidates features of watershed behavior, such as the impact of land use, human intervention, and catchment intrinsic qualities [18, 19]. Existing inventories have increased the qualitative and quantitative information on the hydrometeorological aspects of the examined events by utilizing the results of post-flood surveys [20, 21].

One that attracts the most attention is the flash flood that hit North Luwu, especially Masamba City and its surroundings, in June 2020. The flash floods were caused by an overflowing flow of water mixed with debris and sediment in three river flows, namely the Masamba River, Binuang River, and Radda River. The flash floods have caused serious damage to settlements, infrastructure, and agricultural areas. The flow of scrapped materials carried by the flash floods resulted in thousands of houses being submerged and 4,000 families affected, along with dozens of people dying and several residents being declared missing [22–24]. The geological condition of the Masamba area is composed of an alluvial plain covering an area of approximately 40 × 20 km^2, forming a lowlands morphology known as the Depression Zone, according to Simandjuntak et al. (1991) [25]. Based on the report of the Local Disaster Management Unit of North Luwu, the distribution of sedimentation material due to flash floods was found in six sub-districts, namely Masamba, Sabbang, Baebunda, South Baebunta, Malangke, and West Malangke. Masamba and Baebunta sub-districts are the areas that are most severely affected by high-runoff floods. This condition is exacerbated by the density of settlements and the many road infrastructures and public facilities in these two sub-districts. The purpose of this study is to evaluate the sedimentological impact of the 2020 flash flood disaster, including sedimentation rate, annual bedload sediment volume, and total sediments accumulated in the three affected rivers, namely the Binuang, Radda, and Masamba Rivers (Figure 1). The result will be significant data for proposing a future mitigation scheme.

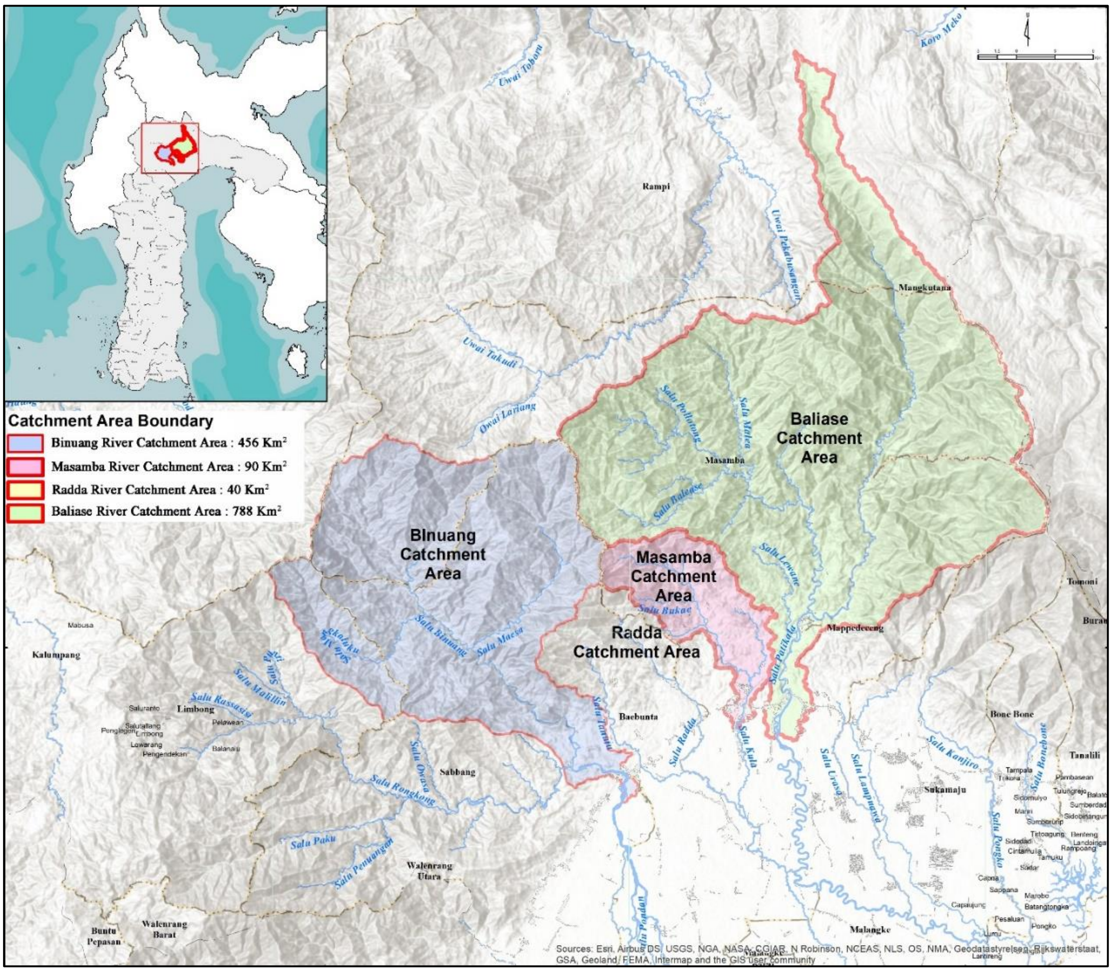


Figure 1. Research map

2. Research Methodology

This research is a series of studies conducted by taking primary data in the field and using secondary data related to the history of flash floods at the research location. The steps from data collection to data processing and analysis in this study can be described as follows:

- Two series of field works were conducted in three overflowing rivers, namely the Masamba River, Binuang River, and Radda River, on August 10, 2020, and November 8, 2020, to collect data, including sedimentological and geomorphic data.
- The data taken includes topographic data using the UAV instrument (Drone Type: DJI Mavic Pro 2 Hasselblad), bedload data, river cross-sectional dimension data, and river flow velocity data, which is used to calculate flow rates.
- Secondary data used include climatological data from the Andi Djemma Airport Climatology Station and information on the chronology of events from the affected community.
- The climatological data from the climatology station at Andi Djemma Airport were analyzed using empirical methods to explain the low discharge of the river.
- The low discharge results will be validated by measuring the partial discharge in the field.
- The discharge data are then used as boundary lines in the upstream part of the sediment transport analysis using HEC-RAS software.
- Sediment transport analysis is conducted empirically based on primary and secondary data and sediment transport analysis methods (the Ackers-White method).
- This method was chosen because it was developed for sediment grain gradation that is almost the same as the sediment in the study location and has hydrodynamic conditions similar to the river in the study area. Grain size analysis was performed using dry sieving and wet sieving methods [26]. Figure 2 shows the research flow in the form of a flowchart.

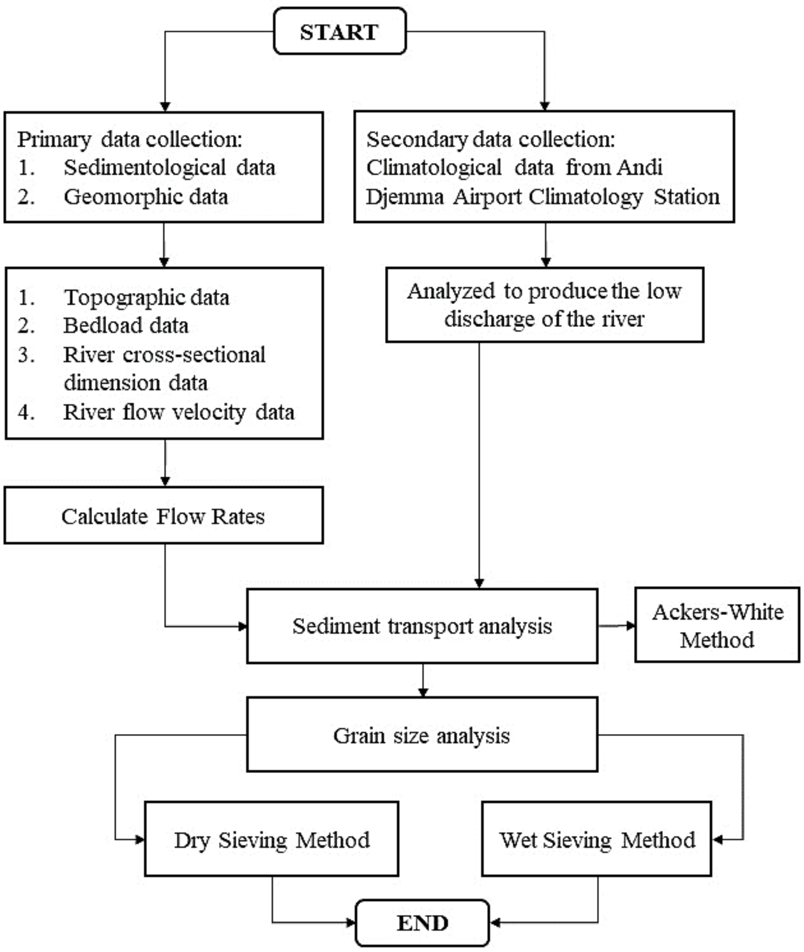


Figure 2. Flowchart of the research methodology

3. Results and Discussion

3.1. Sedimentation Rate Estimation

The analysis of the three rivers profiles was carried out using the HEC-RAS 5.0.7 mathematical modeling program (Hydrologic Engineering Center's - River Analysis System) [27]. An analysis of the cross-sectional capacity of the river is carried out on the current river conditions to determine the river depth, current power, flow velocity, and shear stress in each river segment. The value generated from the simulation results will be used to calculate the rate of sedimentation in the three rivers. In order to compare the sedimentation rate, we collected data at two different times, namely August 10, 2020, and November 8, 2020. The sedimentation rate of the Binuang River on August 10, 2020, suggests that the partial discharge that flows at that time is 32 m^3/s with a total sediment discharge of 1,35 m^3/s (Table 1), while on November 8, 2020, the partial discharge was 28 m^3/s with a total sediment discharge of 0.432 m^3/s (Table 1). Based on this, it can be concluded that from August 10, 2020, to November 8, 2020, the bedload sediment in the Binuang River decreased.

Table 1. Sedimentation rate of Binuang River on August 10, 2020 and 8 November

	Q (m^3/sec.)	32.0
	Depth (m)	1.30
	Gradient slope	0.04
	D_{35} (mm)	0.30
August 10, 2020	n	0.030
	qs (m^3/sec.)	0.007247
	River width (m)	185
	qs (m^3/sec.)	1.34066
	Total qs (m^3/sec.)	1.350
	Q (m^3/sec.)	28.0
	Depth (m)	1.0
	Gradient slope	0.03
	D_{35} (mm)	0.1
November 8, 2020	n	0.030
	qs (m^3/sec.)	0.0025
	River width (m)	164.0
	qs (m^3/sec.)	0.4
	Total qs (m^3/sec.)	0.432

Sedimentation rate estimation from Radda River on August 10, 2020 showed that the partial discharge flowing at that time was 3.8 m^3/s with a total sediment discharge of 0.341 m^3/s (Table 2) while on November 8, 2020, it is calculated that the partial discharge was 4 m^3/s with a total sediment discharge of 0.163 m^3/s. These results suggest that the bedload sediment in Radda River experienced a decreasing trend.

Table 2. Sedimentation rate of Radda River on August 10, 2020 and 8 November 2020

	Q (m^3/sec.)	3.8
	Depth (m)	0.3
	Gradient slope	0.2
	D_{35} (mm)	0.9
August 10, 2020	n	0.0
	qs (m^3/sec.)	0.0
	River width (m)	50.0
	qs (m^3/sec.)	0.3
	Total qs (m^3/sec.)	0.341
	Q (m^3/sec.)	4.0
	Depth (m)	0.3
	Gradient slope	0.2
	D_{35} (mm)	0.2
November 8, 2020	n	0.030
	qs (m^3/sec.)	0.003
	River width (m)	48.0
	qs (m^3/sec.)	0.16
	Total qs (m^3/sec.)	0.163

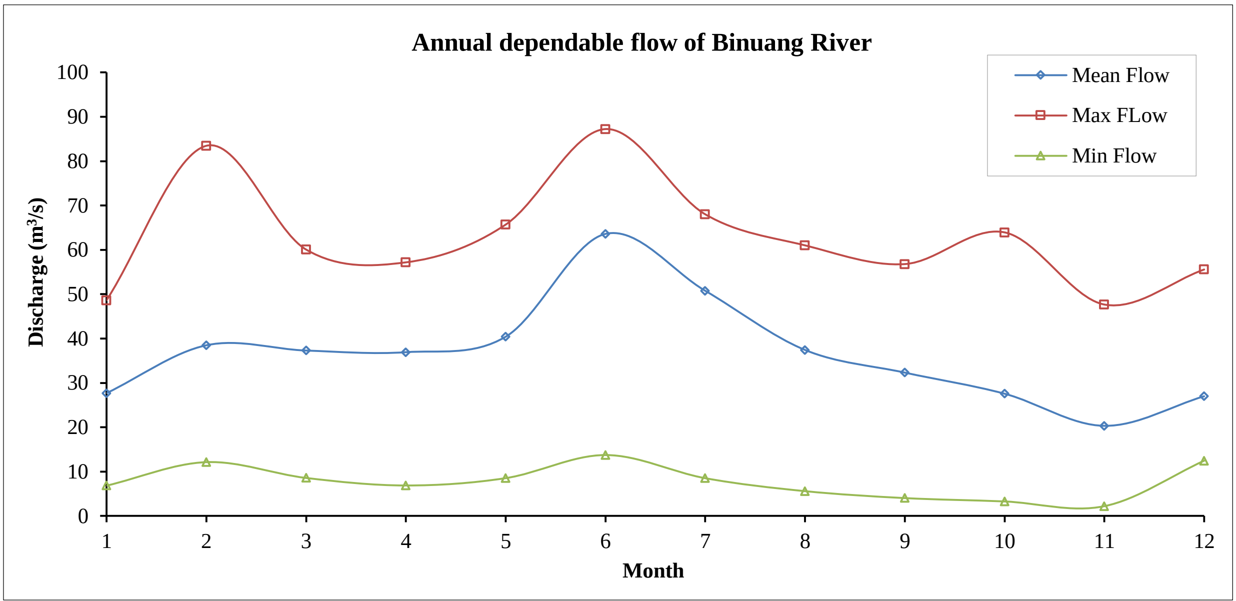
Estimation of Masamba River sedimentation rate on August 10, 2020 showed that the partial discharge flowing at that time was 7 m^3/s with a total sediment discharge of 0.031 m^3/s (Table 3). The measurement results on November 8, 2020 showed that the partial discharge was 4 m^3/s with a total sediment discharge of 0.024 m^3/s. It is shown from the data that from 10 August 2020 to 8 November 2020, the bedload sediment in Masamba River has a decreasing trend.

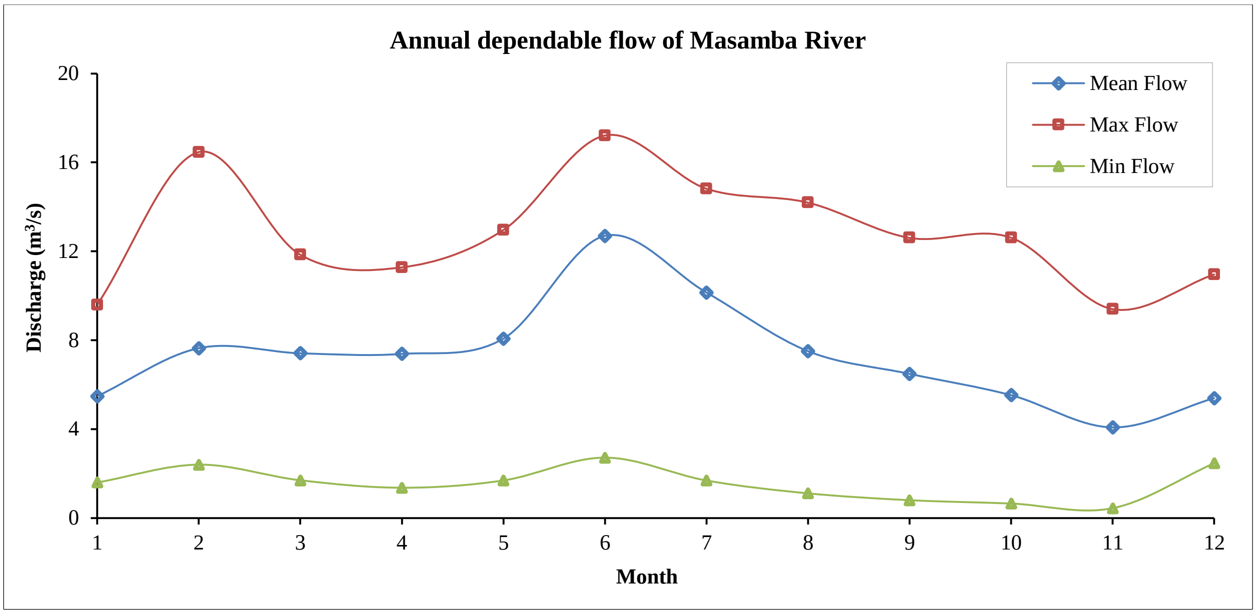
Table 3. Sedimentation rate of Masamba River on August 10, 2020 and 8 November 2020

August 10, 2020	Q (m^3/sec.)	7.0
	Depth (m)	0.5
	Gradient slope	0.0
	D_{35} (mm)	0.1
	n	0.0
	qs (m^3/sec.)	0.0
	River width (m)	63.0
	qs (m^3/sec.)	0.031
	Total qs (m^3/sec.)	0.031
November 8, 2020	Q (m^3/sec.)	4.0
	Depth (m)	0.5
	Gradient slope	0.0
	D_{35} (mm)	0.1
	n	0.0
	qs (m^3/sec.)	0.0
	River width (m)	62.0
	qs (m^3/sec.)	0.0
	Total qs (m^3/sec.)	0.024

3.2. Dependable Flow

One of criteria to represent water surface investigation is a dependable flow which is defined as the amount of discharge that available to meet water need with calculated risk of failure [26]. It is observed that annual flow series shows periodicity over the years. The dependable flow used to carry out analysis of periodicity using up current data. Graphics below showing the dependable flow from the river that affected by flash flood (Figure 2).





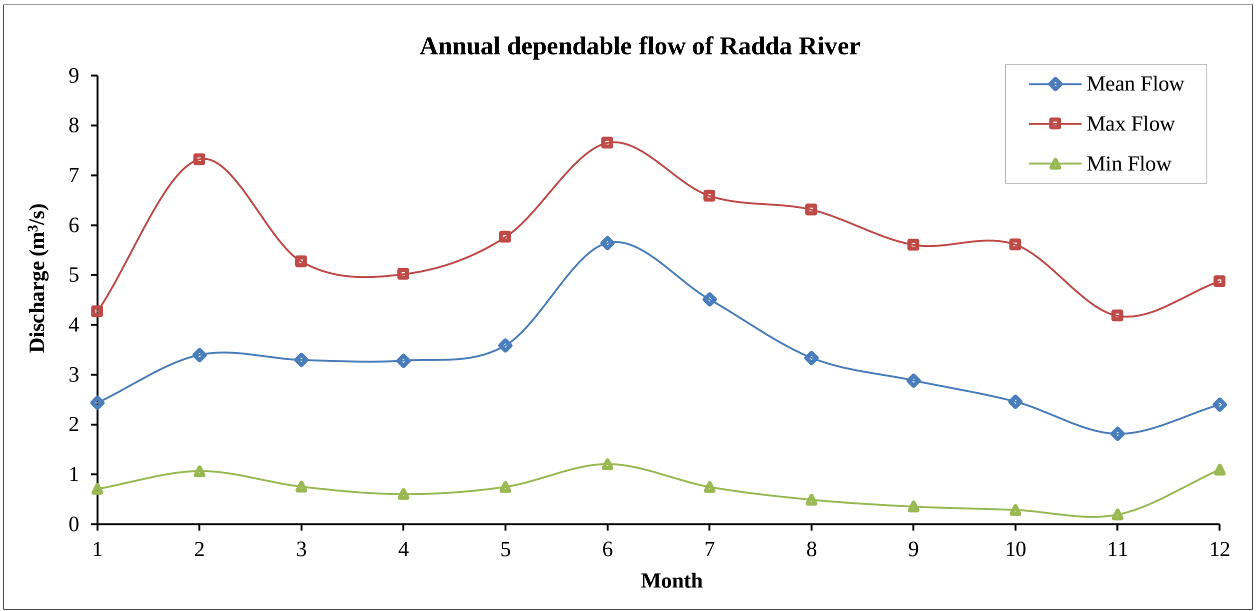


Figure 3. Annual dependable flow from 3 rivers that affected by flash flood

3.3. Annual Bedload Sediment Estimation

From the results of the dependable discharge analysis combined with the percentage of sediment discharge, the estimated volume of annual bedload sediment can be calculated. It is estimated that the total annual bedload sediment in Binuang River is 16,194,168 m^3/year whereas in Radda River is 4,003,011 m^3/year and Masamba River is 7,852,061 m^3/year (Table 4).

Table 4. Total annual estimation of bedload sediment in Binuang River, Radda River dan Masamba River

River	Description (m^3/sec.)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec	Sediment volume
Binuang	Mean monthly discharge	27.69	38.49	37.30	36.93	40.41	63.59	50.77	37.43	32.33	27.57	20.33	27.00	16,194,168 (m^3/year)
	Sedimentation rate	0.39	0.54	0.52	0.52	0.57	0.89	0.71	0.52	0.45	0.39	0.28	0.38	
Masamba	Mean monthly discharge	5.48	7.64	7.41	7.38	8.07	12.69	10.15	7.51	6.49	5.53	4.08	5.39	7,852,061 (m^3/year)
	Sedimentation rate	0.19	0.26	0.25	0.25	0.27	0.43	0.34	0.26	0.22	0.19	0.14	0.18	
Radda	Mean monthly discharge	2.44	3.40	3.29	3.28	3.59	5.64	4.51	3.34	2.88	2.46	1.81	2.40	4,003,011 (m^3/year)
	Sedimentation rate	0.09	0.13	0.13	0.13	0.14	0.22	0.18	0.13	0.11	0.10	0.07	0.09	

3.4. Sediment Volume Estimation Due to Flash Floods

By using spatial analysis, the area affected by the flash floods in July 2020 can be delineated. This data is then multiplied by the sediment thickness measured in the field so that the volume of sediment from the flash flood can be calculated. The results of sedimentation volume due to flash floods on the three rivers are presented in Table 5. It is shown that the sediment thickness in the three rivers ranges from 1- 5 meters. The total sediment volume in Radda River is 9,141,608.39 m^3, whereas the sediment thickness in Masamba River is 55,131,761.29 m^3, and the thickness of sediment in Radda River is about 136,838,603.61 m^3. Based on the results, the total volume of sediment due to the 2020 flash floods reached 222,476,966 m^3.

Table 5. The total volume of sediment material after flash flood

River	Zone	Delineation area (m^2)	Sediment thickness (m)	Sediment volume (m^3)	Total sediment volume (m^3)
	Green	2,798,310.7	0-1	2,798,310.73	
Radda	Yellow	3,174,770.2	1-3	9,524,310.58	
	Red	3,637,196.1	3-5	18,185,980.56	
	Total			30,508,601.87	
	Green	3,511,105.03	0-1	3,511,105.03	
Masamba	Yellow	6,236,683.40	1-3	18,710,050.21	222,478,966.76
	Red	6,582,121.21	3-5	32,910,606.04	
	Total			55,131,761.29	
	Green	7,608,276.85	0-1	7,608,276.85	
Binuang	Yellow	21,983,882.23	1-3	65,951,646.70	
	Red	12,655,736.01	3-5	63,278,680.06	
	Total			136,838,603.61	

3.5. Implication for Future Mitigation Scheme

The results have shown that huge amounts of sediment have been accumulated due to flash flood sedimentation in the three rivers. The volume of sediment accumulated can be used to determine the level of vulnerability. In order to design future mitigation schemes, a zonation for vulnerability level is made, which is based on the area that has been inundated by the sediment brought by the flash flood. The zonation is classified into three categories as follows: 1) highly affected zone; 2) moderately affected zone; 3) lowly affected zone (Figure 3). The highly affected zone (high hazard) is highlighted by a red area on the zonation map, whereas the moderately affected zone (moderate hazard) is in yellow and the lowly affected zone (low hazard) is in green. Highly affected zones should only be utilized for green open space and should not be used for any settlement or other vital public building such as a hospital, office, market, or mall. Moderately affected zones can be used for agriculture, transportation infrastructure, sparsely populated settlements, and worship places such as mosques and churches. Lastly, lowly affected areas can be used for densely populated settlements, educational and health facilities, trade centers, markets, hospitals, and other public infrastructure. This zonation should be used as a reference for spatial planning design, especially for future settlement and infrastructure reconstruction policies after disasters.

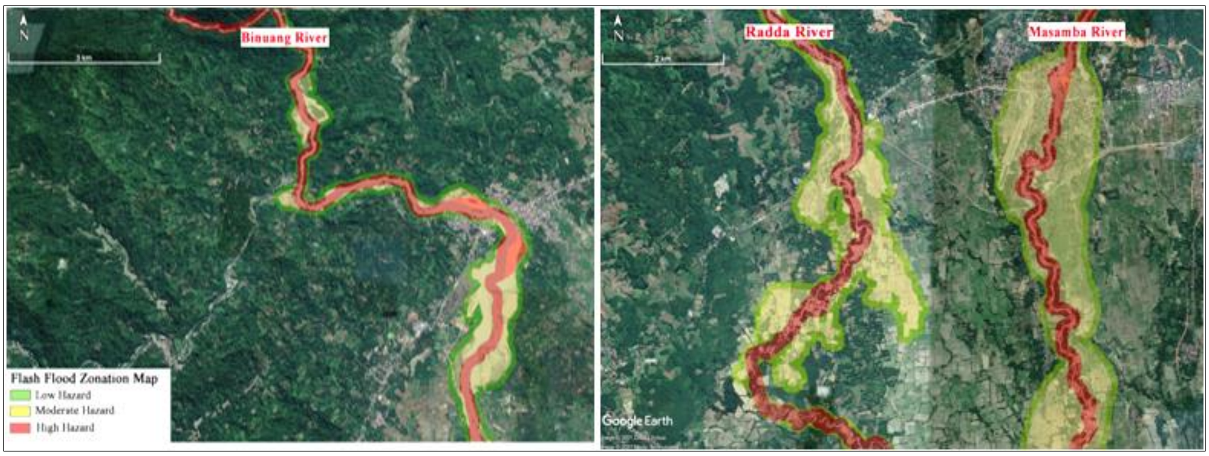


Figure 4. Zonation map that affected by the flash flood divided into 3 zones

4. Conclusion

It is estimated that the volume of Binuang River bedload sediment is 16,194,168 m^3/year, while the Masamba River is 7,852,061 m^3/year and the Radda River is 4,003,011 m^3/year. The volume of material accumulated by flash flood sedimentation in the Radda River is 9,141,608.39 m^3, whereas in the Masamba River is 55,131,761.29 m^3 and in Binuang River is 136,838,603.61. The total estimated sedimentation caused by flash floods in the three rivers is 222,476,966 m^3. For future mitigation schemes, zonation for vulnerability level is designed and classified into three categories: 1) highly affected zone; 2) moderately affected zone; 3) lowly affected zone. Highly affected zones should only be limitedly utilized for green open space and should not be used for any settlement or other vital public building such as a hospital, office, market, or mall. Moderately affected zones can be used for agriculture, transportation infrastructure, sparsely populated settlements, and worship places, whereas lowly affected areas can be used for densely populated settlements, educational and health facilities, trade centers, markets, hospitals, and other public infrastructure. It is strongly suggested that future settlement and infrastructure reconstruction policies after disasters should be based on this zonation to reduce disaster risk.

5. Declarations

5.1. Author Contributions

Conceptualization, A.M., M.T., and I.P.I.; methodology, A.M., M.T., and I.U.; validation, A.M., I.U., and M.T.; formal analysis, A.M., M.T., I.P.I., and I.U.; investigation, M.T., I.P.I., and I.U.; resources, A.M., M.T., I.P.I., and I.U.; writing—original draft preparation, A.M. and M.T.; writing—review and editing, I.P.I. and M.T.; project administration, I.U. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

Data sharing is not applicable to this article.

5.3. Funding and Acknowledgements

We would like to express our gratitude to Bappelitbangda Staff of North Luwu Regency and local people in Binuang, Radda and Masamba River for their support during field work.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Ackers, P., & White, W. R. (1973). Sediment transport: new approach and analysis. Journal of the Hydraulics Division, 99(11), 2041-2060. doi:10.1061/JYCEAJ.0003791.

[2] Maulana, A. (2019). Geological constraints for disaster mitigation model in South Sulawesi. Journal of Physics: Conference Series, 1341(5), 52004. doi:10.1088/1742-6596/1341/5/052004.

[3] Ahilan, S., Guan, M., Wright, N., Sleigh, A., Allen, D., Arthur, S., Haynes, H., & Krivtsov, V. (2019). Modelling the long-term suspended sedimentological effects on stormwater pond performance in an urban catchment. Journal of Hydrology, 571, 805–818. doi:10.1016/j.jhydrol.2019.02.002.

[4] Ahilan, S., Guan, M., Sleigh, A., Wright, N., & Chang, H. (2016). The influence of floodplain restoration on flow and sediment dynamics in an urban river. Journal of Flood Risk Management, 11(S2), 1-16. doi:10.1111/jfr3.12251.

[5] Paredes, J. M., Ocampo, S. M., Foix, N., Olazábal, S. X., Valle, M. N., Montes, A., & Allard, J. O. (2021). Geomorphic and Sedimentological Impact of the 2017 Flash Flood Event in the City of Comodoro Rivadavia (Central Patagonia, Argentina). Advances in Geomorphology and Quaternary Studies in Argentina, Springer Earth System Sciences. Springer, Cham, Switzerland. doi:10.1007/978-3-030-66161-8_1.

[6] Scorpio, V., Crema, S., Marra, F., Righini, M., Ciccarese, G., Borga, M., Cavalli, M., Corsini, A., Marchi, L., Surian, N., & Comiti, F. (2018). Basin-scale analysis of the geomorphic effectiveness of flash floods: A study in the northern Apennines (Italy). Science of the Total Environment, 640–641, 337–351. doi:10.1016/j.scitotenv.2018.05.252.

[7] Righini, M., Surian, N., Wohl, E., Marchi, L., Comiti, F., Amponsah, W., & Borga, M. (2017). Geomorphic response to an extreme flood in two Mediterranean rivers (northeastern Sardinia, Italy): Analysis of controlling factors. Geomorphology, 290, 184–199. doi:10.1016/j.geomorph.2017.04.014.

[8] Burke, L., & Spalding, M. (2022). Shoreline protection by the world's coral reefs: Mapping the benefits to people, assets, and infrastructure. Marine Policy, 146, 105311. doi:10.1016/j.marpol.2022.105311.

[9] Barkey, R. A., Malamassam, D., Mukhlisa, A. N., & Nursaputra, M. (2020, October). Land use planning for floods mitigation in Kelara Watershed, South Sulawesi Province, Indonesia. In IOP Conference Series: Earth and Environmental Science Vol. 575, 012132, IOP Publishing. doi:10.1088/1755-1315/575/1/012132.

[10] Kubota, T., Sanchez-Castillo, L., & Soma, A. S. (2017). The Influence of Land Use and Rainfall on Shallow Landslides in Tanralili Sub–watershed, Indonesia. Journal of the Faculty of Agriculture, Kyushu University, 62(1), 171-176. doi:10.5109/1801778.

[11] Montes, A., Rodríguez, S. S., & Domínguez, C. E. (2017). Geomorphology context and characterization of dune fields developed by the southern westerlies at drying Colhué Huapi shallow lake, Patagonia Argentina. Aeolian Research, 28, 58–70. doi:10.1016/j.aeolia.2017.08.001.

[12] Montes, A., Rodríguez, S. S., San Martín, C. N., & Allard, J. O. (2015). Migration of dune fields in coastal canyons of Patagonia. Geomorphology and paleoclimatic implications. Revista de La Sociedad Geológica de España, 28(2), 65–76. (In Spanish).

[13] Magilligan, F. J., Buraas, E. M., & Renshaw, C. E. (2014). The efficacy of stream power and flow duration on geomorphic responses to catastrophic flooding. Geomorphology, 228, 175–188. doi:10.1016/j.geomorph.2014.08.016.

[14] Hooke, J. M. (2015). Variations in flood magnitude-effect relations and the implications for flood risk assessment and river management. Geomorphology, 251, 91–107. doi:10.1016/j.geomorph.2015.05.014.

[15] Hirtz, N. R., & Grizinik, M. (2017). The low flood in the southwest of the city: its evolution from salinization to the flood of March-April 2017. Paredes JM (comp) Comodoro Rivadavia y la catástrofe de, 49-59. (In Spanish).

[16] Hernández, M. A., González, N., & Hernández, L. (2017). Hydrogeology of a Large Oil-and-Gas Basin in Central Patagonia: San Jorge Gulf Basin, Argentina. Springer, Cham, Switzerland. doi:10.1007/978-3-319-52328-6.

[17] Grove, J. R., Croke, J., & Thompson, C. (2013). Quantifying different riverbank erosion processes during an extreme flood event. Earth Surface Processes and Landforms, 38(12), 1393–1406. doi:10.1002/esp.3386.

[18] Froude, M. J., Alexander, J., Barclay, J., & Cole, P. (2017). Interpreting flash flood palaeoflow parameters from antidunes and gravel lenses: An example from Montserrat, West Indies. Sedimentology, 64(7), 1817–1845. doi:10.1111/sed.12375.

[19] Belletti, B., Dufour, S., & Piégay, H. (2014). Regional assessment of the multi-decadal changes in braided rivers capes following large floods (example of 12 reaches in South East of France). Advances in Geosciences, 37, 57–71. doi:10.5194/adgeo-37-57-2014.

[20] Alexander, J., & Cooker, M. J. (2016). Moving boulders in flash floods and estimating flow conditions using boulders in ancient deposits. Sedimentology, 63(6), 1582–1595. doi:10.1111/sed.12274.

[21] Archer, D. R., & Fowler, H. J. (2018). Characterizing flash flood response to intense rainfall and impacts using historical information and gauged data in Britain. Journal of Flood Risk Management, 11, S121–S133. doi:10.1111/jfr3.12187.

[22] Paski, J. A. I., Makmur, E. E. S., Permana, D. S., Nurrahmat, M. H., Praja, A. S., Riama, N. F., & Fitria, W. (2021). Analysis of Multi-Scale Hydrometeorological Triggering Flash Flood Event of the 13 July 2020 in North Luwu, South Sulawesi. IOP Conference Series: Earth and Environmental Science Vol. 893, 012014, IOP Publishing. doi:10.1088/1755-1315/893/1/012014.

[23] Yulihastin, E., Nuryanto, D. E., & Muharsyah, R. (2021). Improvement of Heavy Rainfall Simulated with SST Adjustment Associated with Mesoscale Convective Complexes Related to Severe Flash Flood in Luwu, Sulawesi, Indonesia. Atmosphere, 12(11), 1445. doi:10.3390/atmos12111445.

[24] Thaha, R. ., & Drajat, U. Z. (2023). The Analysis of Post-Flood Disaster Management at North Luwu Regency. International Journal Papier Public Review, 4(1), 51-59. doi:10.47667/ijppr.v4i1.198.

[25] Simandjuntak, T.O., Rusmana, E., Surono dan Supandjono, J.B. (1991). Peta Geologi Lembar Malili, Sulawesi, scale 1: 250.000. Pusat Penelitian dan Pengembangan, Jakarta, Indonesia.

[26] Buchanan, J. B. (1984). Sediment analysis. Methods for the Study of Marine Benthos. Blackwell Scientific Publications, Hoboken, United States.

[27] Brunner, G. W. (2002). HEC-RAS river analysis system: User's manual. Institute for Water Resources, Hydrologic Engineering Center, US Army Corps of Engineers, Washington, United States.