Lecture Notes in Civil Engineering

Stefanus Adi Kristiawan
Buntara S. Gan
Mohamed Shahin
Akanshu Sharma *Editors*

Proceedings of the 5th International Conference on Rehabilitation and Maintenance in Civil Engineering

ICRMCE 2021, July 8–9, Surakarta, Indonesia

Springer

Lecture Notes in Civil Engineering

Volume 225

Lecture Notes in Civil Engineering (LNCE) publishes the latest developments in Civil Engineering - quickly, informally and in top quality. Though original research reported in proceedings and post-proceedings represents the core of LNCE, edited volumes of exceptionally high quality and interest may also be considered for publication. Volumes published in LNCE embrace all aspects and subfields of, as well as new challenges in, Civil Engineering. Topics in the series include:

- Construction and Structural Mechanics
- Building Materials
- Concrete, Steel and Timber Structures
- Geotechnical Engineering
- Earthquake Engineering
- Coastal Engineering
- Ocean and Offshore Engineering; Ships and Floating Structures
- Hydraulics, Hydrology and Water Resources Engineering
- Environmental Engineering and Sustainability
- Structural Health and Monitoring
- Surveying and Geographical Information Systems
- Indoor Environments
- Transportation and Traffic
- Risk Analysis
- Safety and Security

To submit a proposal or request further information, please contact the appropriate Springer Editor:

- Pierpaolo Riva at pierpaolo.riva@springer.com (Europe and Americas);
- Swati Meherishi at swati.meherishi@springer.com (Asia - except China, and Australia, New Zealand);
- Wayne Hu at wayne.hu@springer.com (China).

All books in the series now indexed by Scopus and EI Compendex database!

More information about this series at https://link.springer.com/bookseries/15087

Stefanus Adi Kristiawan ·
Buntara S. Gan · Mohamed Shahin ·
Akanshu Sharma
Editors

Proceedings of the 5th International Conference on Rehabilitation and Maintenance in Civil Engineering

ICRMCE 2021, July 8–9,
Surakarta, Indonesia

Springer

Digital Repository Universitas Jember

Editors
Stefanus Adi Kristiawan
Department of Civil Engineering
Universitas Sebelas Maret
Surakarta, Indonesia

Buntara S. Gan
College of Engineering
Nihon University
Tokyo, Japan

Mohamed Shahin
Department of Civil Engineering
Curtin University
Perth, WA, Australia

Akanshu Sharma
Institute of Construction Materials
University of Stuttgart
Stuttgart, Germany

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-16-9347-2 ISBN 978-981-16-9348-9 (eBook)
https://doi.org/10.1007/978-981-16-9348-9

© The Editor(s) (if applicable) and The Author(s), under exclusive license
to Springer Nature Singapore Pte Ltd. 2023
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

The International Conference on Rehabilitation and Maintenance in Civil Engineering (ICRMCE) is a triennial conference that aims to provide a forum for researchers, academicians (professors, lecturers, and students), government agencies, consultants, and contractors to exchange experiences, technological advancement, and innovations in the world of civil engineering, specifically in the fields of rehabilitation and maintenance. The previous four ICRMCE conferences took place successfully in 2009, 2012, 2015, and 2018. Hundreds of researchers worldwide attended these events to present their scientific papers in various areas of civil engineering such as material engineering, structural engineering, geotechnical engineering, transportation engineering, and construction management.

This year's conference was organized by Sebelas Maret University in collaboration with Mataram University. The conference was initially scheduled offline in Mataram, Indonesia. However, due to the escalating coronavirus (COVID-19) outbreak and the need for social distancing, we decided to hold the conference online. Some reputable universities and institutions are participating in the current ICRMCE as partners. Among them are Nihon University, University of Stuttgart, National Taiwan University, TU Delft, Hiroshima University, Diponegoro University, Muhammadiyah University of Yogyakarta, Jenderal Soedirman University, University of Jember, UPN Veteran East Java, the National Center for Research on Earthquake Engineering (NCREE) Taiwan, Himpunan Ahli Konstruksi Indonesia (HAKI), and Himpunan Ahli Teknik Tanah Indonesia (HATTI).

The ICRMCE 2021 was successfully held on July 8–9. Presenters who joined this conference came from Japan, Singapore, Malaysia, China, Vietnam, Taiwan, England, the Netherlands, Kuwait, and Indonesia. Furthermore, several outstanding keynote speakers gave a presentation of the state-of-the-art findings in the field of civil engineering. Our esteemed speakers are Prof. Shyh-Jiann Hwang (National Taiwan University), Prof. Buntara Sthenly Gan (Nihon University), Dr. Edgar Bohner (VTT Technical Research Centre of Finland), and Prof. Mohamed Shahin (Curtin University).

In the process of organizing this conference, we received invaluable motivation, advice, and support from several individuals and institutions. I intend to express my gratitude and appreciation to all of them. First, my most profound appreciation goes to all organizing committee members who worked day and night preparing this conference. Special thanks to the conference and media partners for their generous support. We also express our gratitude to Prof. S.A. Kristiawan (Sebelas Maret University), Dr. Ing. Akanshu Sharma (University of Stuttgart), Prof. Mohamed Shahin (Curtin University), and Prof. Buntara Sthenly Gan (Nihon University) for their willingness to serve as the editors of the 5th ICRMCE proceedings.

Halwan Alfisa Saifullah
The 5th ICRMCE Chairman

Preface

Civil engineering infrastructures are the backbone for the continuous development of civilization. Managing these infrastructures is essential in keeping the quality of services they provide to the community. A decline in the performance of key infrastructure will have an impact on the quality of these services, which in turn can cause social and economic problems. A variety of factors affects the performance of infrastructure. In each case, the declining performance of infrastructure requires an appropriate and adaptive response to offer effective solutions. Protection, maintenance, repair, and retrofitting are part of the various solutions that can be implemented. All of these solutions are assisted by technological developments related to repair materials, methodologies, systems, management, and operational efficiency, as well as economic and social considerations.

Infrastructure performance is also inevitably affected by exposure to hazards originating from natural and environmental conditions such as earthquakes, landslides, and floods, among others. Therefore, hazard mitigation is also an interesting topic of discussion. In addition, risk reduction and safety are among the most important issues of infrastructure management. Finally, various perspectives on sustainability in civil engineering are also covered in this conference.

This book is a collection of papers presented at the 5th International Conference on Rehabilitation and Maintenance in Civil Engineering (ICRMCE) 2021 that deals with the issues stated above. The papers are grouped into sequential themes representing the structure of this book:

- Part I: Factors affecting performance of buildings and infrastructures
- Part II: Assessment, protection, maintenance, repair, and retrofitting of buildings and infrastructures
- Part III: Maintenance management of buildings and infrastructures
- Part IV: Hazard mitigation
- Part V: Risk reduction and safety management
- Part VI: Sustainability aspects in transportation engineering
- Part VII: Sustainability aspects in construction projects

- Part VIII: Sustainability aspects in water resources management
- Part IX: Construction materials for sustainable infrastructures

Postgraduate students, researchers, and practitioners who would like to update their knowledge on the topics above will find this book very useful.

Surakarta, Indonesia

Stefanus Adi Kristiawan
Chief Editor

Contents

Factors Affecting Performance of Buildings and Infrastructures

Assessment, Protection, Maintenance, Repair, and Retrofitting of Buildings and Infrastructures

Maintenance Management of Buildings and Infrastructures

Hazard Mitigation

Risk Reduction and Safety Management

Sustainability Aspects in Transportation Engineering

Sustainability Aspects in Construction Projects

Sustainability Aspects in Water Resources Management

Construction Materials for Sustainable Infrastructures

Assessment of the Conditioning Factor for Flash Flood Susceptibility Potential Based on Bivariate Statistical Approach in the Wonoboyo Watershed in East Java, Indonesia

Entin Hidayah, Gusfan Halik, and Wiwik Yunarni Widiarti

Abstract Flash floods that occur suddenly, which cause damage to the weirs or embankments, immediately threaten human life. Identifying the causes of a flash flood is very important to reduce its negative impact. This paper examines changes in flash flood disasters in the Wonoboyo watershed based on estimates of flash flood hazard, land-use changes, and rainfall depth distribution patterns. The method of predicting susceptibility to flash flood hazards is based on various environmental factors that are integrated with GIS. Three bivariate statistics consisting of the Statistical Index (SI), Frequency Ratio (FR), and Predictor Rate (FP-PR) model are applied to select the best Flash Susceptibility Index (FFHSI) model. Changes in land use are then explored based on the conditioning factor for a flash flood. In the final stage, the estimation of areal rainfall uses Inverse Distance Weighting (IDW) to describe the position of rain and flash flood events. The best statistical bivariate statistical approach for the FFHSI is FR. Assessment of environmental factors using the FFHSI shows that 21% of the catchment area has moderate to high until very high vulnerability levels. Changes in land cover significantly affect flash floods, especially changes from forest to agricultural land or settlements. The distribution pattern and intensity of rainfall are closely related to the location of the flash flood. This study results can guide future flood mitigation measures.

Keywords Flash flood · FFHS · Land-use change · Rainfall distribution · Wonoboyo watershed

---

E. Hidayah (✉) · G. Halik · W. Y. Widiarti
University of Jember, Jember 68121, Indonesia
e-mail: entin.teknik@unej.ac.id

G. Halik
e-mail: gusfan.teknik@unej.ac.id

W. Y. Widiarti
e-mail: wiwik.teknik@unej.ac.id

S. A. Kristiawan et al. (eds.), *Proceedings of the 5th International Conference on Rehabilitation and Maintenance in Civil Engineering*, Lecture Notes in Civil Engineering 225,
https://doi.org/10.1007/978-981-16-9348-9_49

1 Introduction

Flash floods are local floods that occur suddenly with a high, difficult to predict peak flow [1, 2]. The occurrence of high rainfall intensity triggers flash floods. This kind of flood occurred in the rivers in the Wonoboyo watershed in East Java province. Flash floods in a short time can burst the embankments, damage the infrastructure, and generate runoff that flows over settlements and rice fields in the watershed area [3–7].

In addition to the rainfall, the natural terrain condition is a driving factor of the susceptibility to flash floods. A steep topography drives the water down to the estuary more quickly, endangering the river bed stability [8]. Especially during extreme rain-fall, flooding in this area is unavoidable. Other driving variables of the floods are often meteorological conditions in general, including low atmospheric pressure and land breezes that can cause storms and the entrance of air containing water vapor to the catchment area that produces heavy rains [9]. Furthermore, according to Pradhan [10], both the height and the slope of the hills significantly affect the floods occurrence, namely that steeper slopes resulting in faster flows. Accurate estimation of flood hazard susceptibility is essential to measure the relationship among the various spatial and temporal driving factors.

Furthermore, several studies suggest that changes in land use, distribution, and rain intensity are also the causes of floods. The land-use change in urban areas' growth contributes to increased flash floods [11]. The land-use change induces a hydrological response in the watershed in the form of a higher peak flow rate and a shorter concentration time, increasing the difficulty to avoid flash floods.

Several researchers have used various approaches and environmental factors that affect flash floods to identify the flash flood potentials. The commonly used factors are slope, convergence, Topographic Wetness Index (TWI), profile curvature, river networks, density, and land use. These factors have shown significant results to obtain potential susceptibility [12–15]. On the other hand, some researchers also used the NDVI factor.

In addition to determining the relevant factors, using the proper method is also very important in selecting a capable flash flood hazard model. Previous research has applied several methods including: Analytic Hierarchy Process (AHP) [16–18], decision tree analysis (DT) [15], weight of evidence [19, 20], Statistical Index [21], Entropy Shannon [21], and FR [20, 22]. The decision tree method provides better performance than AHP [12]; however, the decision tree method does not consider the temporal changes of various factors such as SPI, land use, and dynamic NDVI [15]. Compared to other methods, the relatively simple FR method applied in several flash flood studies has shown excellent training and validation results [9, 12, 20]. In addition, the FR method has provided good results for mapping the landslide hazard in the Wonoboyo watershed [23]. SI model gave the highest flood prediction result of 98.72% compared to weighting factors and the Shannon entropy model with predictive rates of 97.6 and 92.42% [21].

Based on the area and recording of flash flood events in the Wonoboyo watershed, this paper aims to develop a flash flood susceptibility map in the Wonoboyo watershed. The best model is obtained by comparing three methods: SI, FR, and FR-PR integration to find a better and more accurate model. Next, the impact of the causes of a flash flood is assessed with changes in land use and the areal rainfall events in the study area.

2 Study Area, Floods, and Flood Inventory Mapping

2.1 Study Area

Wonoboyo watershed, East Java Province, between 113°50′ E and 113°56′ E, and between 7°49′ N and 7°46′ N (Fig. 1) is the study area. This area is topographically hilly, flanked by two mountains, namely Mt. Malang and Mt. Rajekwesi, of which the heights are 1177 and 762 m above sea level, respectively. The watershed covers an area of 3968 ha.

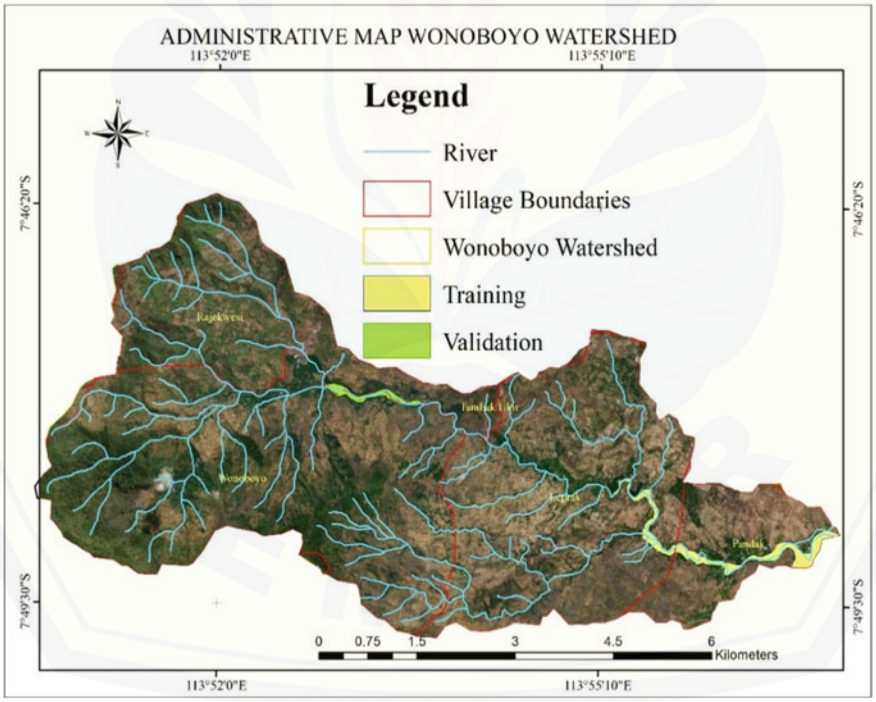


Fig. 1 Study area and flood inventory mapping at Wonoboyo Watershed

The climate has a distinct tropical monsoon with two seasons, namely rainy and dry seasons. The rainy season starts in October and ends in March. The dry season begins in April and ends in September. Based on the Agency of Civil Work of East Java Province, the mean annual rainfall in the study area varies from 460 to 2319 mm.

2.2 Historical Records of Floods and Flood Inventory Mapping

The historical records of the flood event were obtained from field surveys and various mass media reports. Base on the information gathered, 9 flash floods occurred in two decades. Typically, flash floods used to occur during heavy rain that lasted three days. The events and the impacts of the flash floods are described in Table 1.

The sampling of flash flood events using field observation data. The results in Fig. 1 show that 8859 pixels with a surface area of 44 ha are flood-affected areas with 78% for training and 22% for validation. The pixel size is 30 × 30 m.

3 Methodology

The methodology implemented in this study comprised of the following main steps: (i) determination of flood conditioning factors for flooding; (ii) estimating, evaluating, and mapping the best flash flood susceptibility index by comparing methods: SI, FR, and integrating FR-PR; (iii) statistical analysis of the changes in land covers and analyzing the distribution of rainfall on 6 flood events.

3.1 Flood Condition Factor

Flash flood parameterization is complicated because a flash flood has many causes generally interrelated. For an integrated analysis of the factors that influence a flash flood, it is crucial to determine data collection in essential variables to build a base map representing the conditioning factors for the flash flood in the area under study. Based on previous studies, this study uses 10 factors associated with the flash flood, which are shown in Table 2. [13–15, 19]. The 10 factors are slope, Topography Position Index (TPI), TWI, profile curvature, plan curvature, aspect, convergence index, the density of river networks, land cover, and NDVI. Of the ten factors, 7 geomorphological factors are derived from DEM: slope, TPI, TWI, profile curvature, plan curvature, aspect, and convergence index. Geomorphological data were obtained from the National DEM with a resolution of 8 m × 8 m. 2 other factors, namely land use and NDVI, are derived from Landsat 8 in 2018 and Landsat 7 in 2000, a resolution

Table 1 The historical record on the rainfall depths, the affected villages, and the flood hazards on several flash floods

Flood day evens (rain gauge)			18-Jan-08	31-Jan-16	29-Jan-17	27-Jan-18	25-Jan-19	31-Oct-20
Historical rainfall depth (mm)	Bluncong	D-2	75	0	23	7	0	0
		D-1	7	44	0	67	22	0
		D	27	15	96	190	74	55
		Total	109	59	119	264	96	55
	Wonoboyo	D-2	75	0	0	9	18	0
		D-1	7	50	0	18	17	0
		D	27	150	100	120	50	80
		Total	109	200	100	147	85	80
Exposure village			Wonoboyo and Rajekwesi,	Wonoboyo	Wonoboyo and Leprak	Pandak, Leprak, and Wonoboyo	Wonoboyo	Leprak, and Wonoboyo
Impact of flash flood			The breakdown of the leave, and the overflow of flood into roads and settlements	The breakdown of the leave, and overflow into settlements	The breakdown of the leave and damage to rice fields	The breakdown of the weir, and overflow into the bridge, mosque, and settlement	Small landslide	Overflow into settlement, road, rice field damage

Table 2 Identification driving factors of the flash flood susceptibility

Factor	The preparation procedure of preparation of each factor in Fig. 2 and its relationship with flood susceptibility
Slope (SL)	According to Pradhan [10], slope significantly affects flooding, where steeper slopes produce heavier flow. On the other hand, flat lowlands appear more prone to flooding. The Wonoboyo watershed ranges in slope from 0.008° to 52.602°
Topography position index (TPI)	TPI represents a morphometric index value that describes the difference in height between focused cells and neighboring cells [19]. The TPI value in the Wonoboyo watershed ranges from −11.46 to 10.38
Topographic wetness index (TWI)	The TWI value describes water accumulation's tendency to slope according to gravity, which controls flow direction. A high TWI value indicates that an area is increasingly vulnerable to saturated soil surfaces and areas that have the potential to produce surface runoff [24–26]. Equation (1) is the formula for TWI $TWI = \ln\frac{[As]}{\tan\beta}$ (1) Whereas represents the upstream contribution area, and β represents the slope angle. The TWI value in the Wonoboyo watershed ranges from 3.151 to 19.013
Profile curvature (Prof. C)	Curvature of the profile is a morphometric factor in the form of surface curvature in the vertical plan along the slope [27]. The profile curvature value at the Wonoboyo watershed ranges from −4.209 to 3.516
Plan curvature (Plan C.)	The curvature of the plan is another morphometric factor that affects runoff. This parameter is in the form of a contour line that is formed between the horizontal plane and the ground surface. The value is the difference between the size of the area and the runoff (affects the surface runoff) and those with convergent runoff (the area's infiltration capacity) [9, 10, 27]. The plan curvature value at the Wonoboyo watershed ranges from −4.209 to 4.737
Aspect (A)	Aspect is the direction of the slope. The output raster value is the compass direction of the aspect factor. The aspect factor in the Wonoboyo watershed is grouped into eight classes

(continued)

Table 2 (continued)

Factor	The preparation procedure of preparation of each factor in Fig. 2 and its relationship with flood susceptibility
Coverage index (CI)	CI is a terrain parameter that shows the relief structure as a set of convergence areas (channels) and divergent areas (ridges The CI value ranges from −93.116 to 92.441
River density (RD)	RD affects the level and intensity of flooding significantly. The denser the network and the area around the river, the more prone the area to flooding events [28, 29]. Network density is the division of the flow length (m) to the watershed area (km^2). The RD value ranges from −93.116 to 92.441
Land use (LU)	Land use contributes to infiltration rates in forests and vegetated areas that support infiltration. In contrast, residential areas and grasslands accumulate surface runoff due to impermeable layers that reduce the infiltration capacity. The five land cover classes identified for reclassification are scrubs, followed by plantation area, forest, settlement, and water
Normalized difference vegetation index (NDVI)	NDVI is an index used to measure vegetation characteristics in an area [30]. NDVI can sufficiently represent the decrease in land cover based on the image's local brightness [31]. Equation (2) is a formula to compute NDVI [32] $NDVI = \frac{(NIR - VIS)}{(NIR + VIS)} \quad (2)$ VIS shows the spectral reflectance measurement obtained in the visible wave region in red (band 5). NIR shows the spectral reflectance measurements obtained in the infrared wave region (band 4). The NDVI value ranges from −1 to 1 [33]

of 30 m × 30 m. The river network map is obtained from the delineation of Indonesian Topographical Map data at a scale of 1:25,000. Hydro-climatological data in the form of rain data are obtained from the Bondowoso Technical Operating Unit of Water Resource Management (UPT PSDA) and the Agency of Public Works and Water Resources of Bondowoso Regency.

8 factors in the form of numerical variables are classified into several classes using statistical quantile classification according to the data grid's value [15]. 2 other factors, namely land use and aspect, are nominal variables and are classified based on the feature class.

Fig. 2 Maps of flood hazard susceptible conditioning factors, **a** S, **b** TPI, **c** TWI, **d** Prof. C, **e** Plan C. **f** A, **g** CI, **h** RD, **i** LU, **j** NDVI

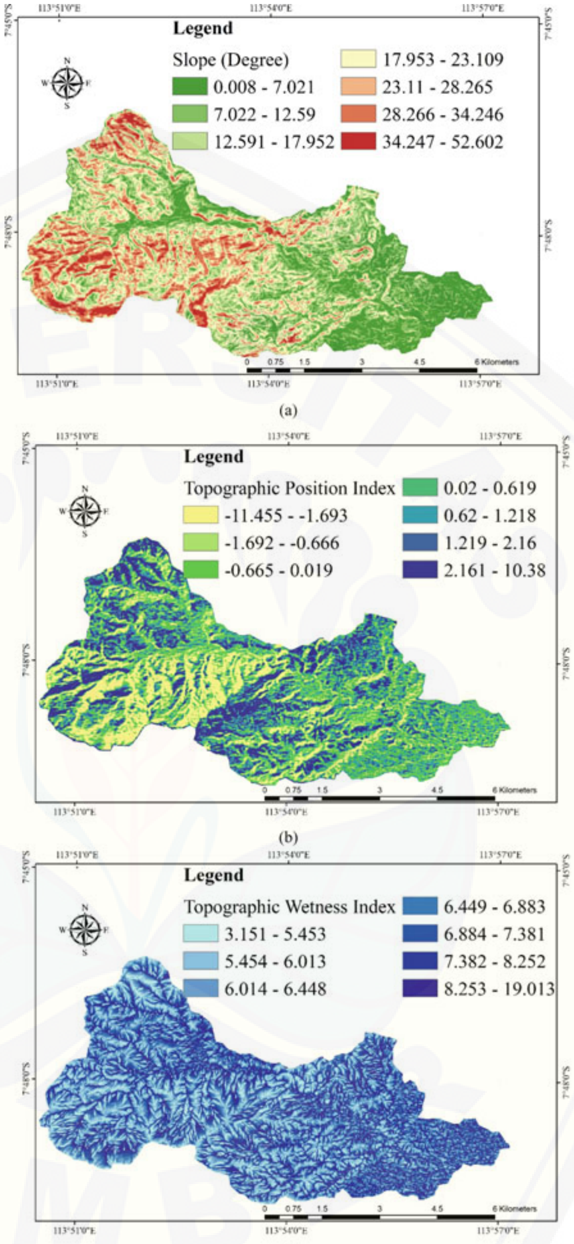
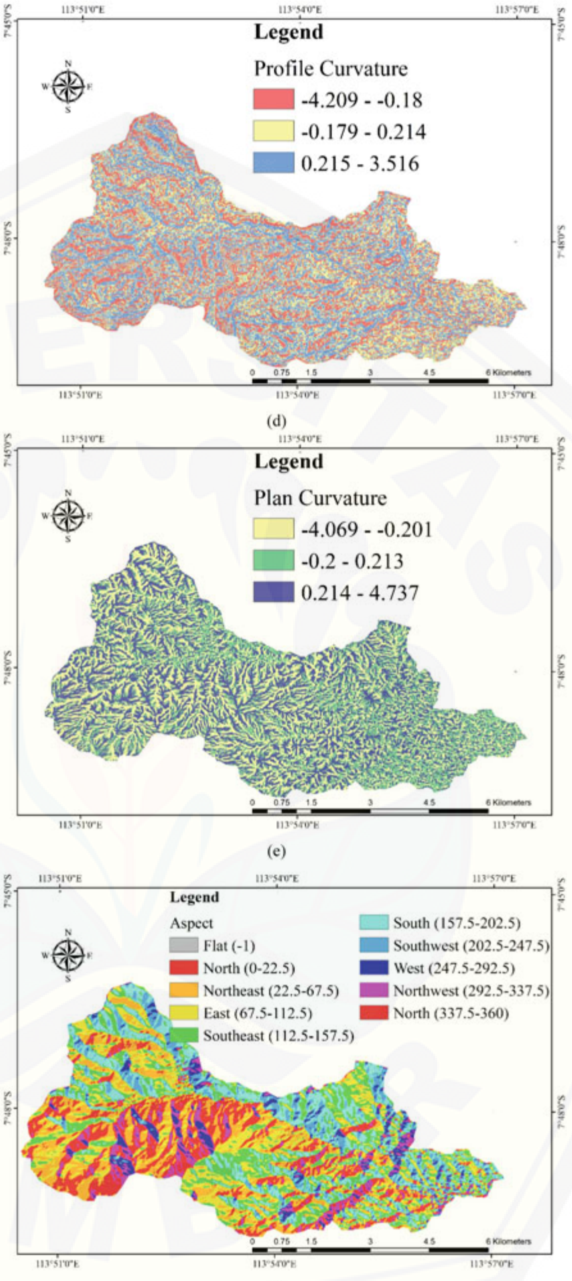


Fig. 2 (continued)

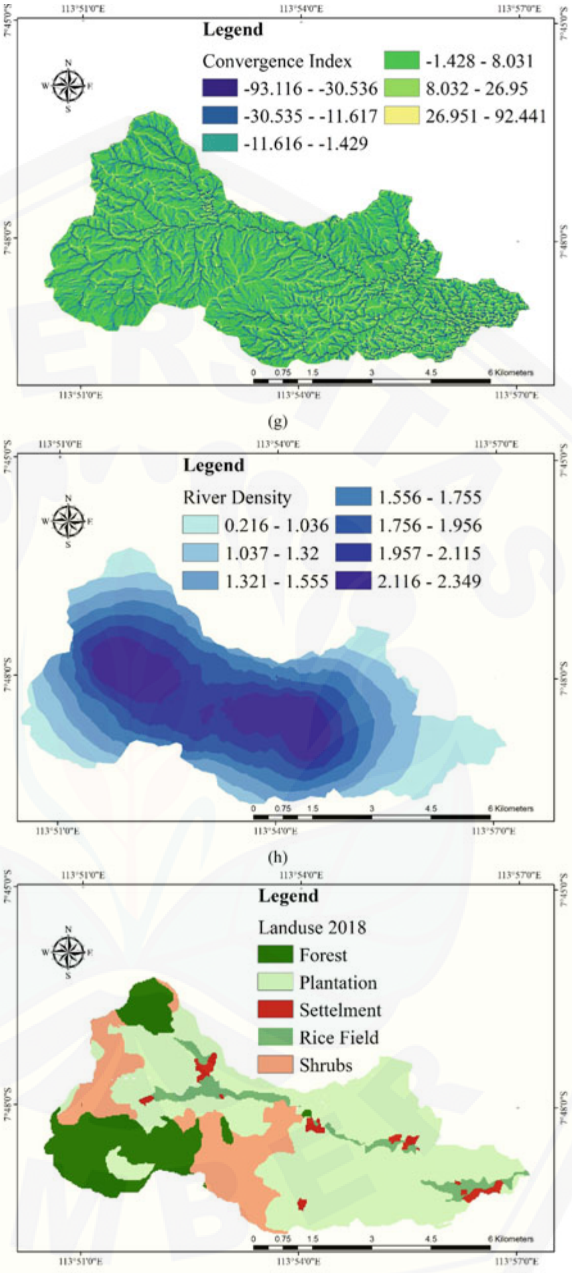


(d)

(e)

(f)

Fig. 2 (continued)

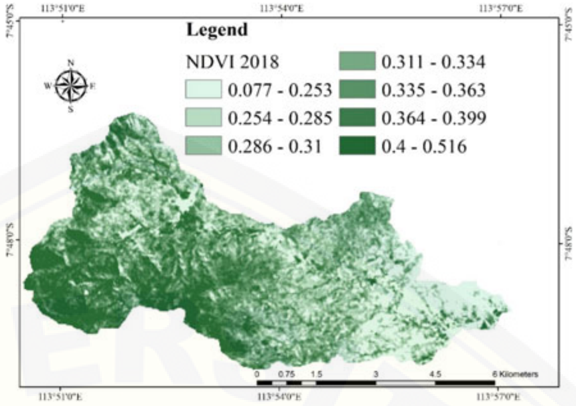


(g)

(h)

(i)

Fig. 2 (continued)



(j)

3.2 *Estimation of the Flash Floods Hazard Susceptibility Index*

The estimation of flash flood hazard is based on statistical observations between the inventory of flood events and the flood conditioning factors. This stage comprises four steps (1) Weighting each class's factors using various statistics bivariate methods. The weights for each class of geomorphological and environmental factors are computed by using GIS, resulting in FFHSI values. (2) The validation of the model is carried out by comparing the Area Under Curve (AUC) values between the flash flood hazard susceptibility predicted by the model with the actual flash flood locations from the field survey. The values of the indices were then grouped into six intensity classes by using natural break reclassification.

Statistical Index

The SI model is a bivariate statistical approach introduced by Van Westen [34] Initially, this model was to estimate landslide hazards. Recently, this model has been developed to be applied to flash flood hazard areas [9, 12]. The SI method describes the weight value for the parameter class in the form of the natural logarithm of the flash flood density in that class divided by the flash flood density across the map. The equation used is as in Eq. 3 [34]:

$$W_{ij} = \ln(\frac{D_{ij}}{D}) = \ln\frac{\left(\frac{L_{ij}}{L_T}\right)}{\left(\frac{P_{ij}}{P_L}\right)} \tag{3}$$

whereas W_{ij} is the weight assigned to class i given from factor *j;* D_{ij} is the flash flood density in class i from factor *j; D shows the totalflash flood density on the entire map;* L_{ij} *is the number of pixels with flash floo*ding in class i from factor j; L_T is the total number of flash floods on the entire map; P_{ij} is the number of pixels in class i of parameter j, and P_L is the total number of pixels on the entire map.

The results of the calculation can be interpreted that if the value of W_{ij} is positive, it indicates a viable and strong relationship between the class and the flash flooding distribution. The higher the score, the stronger the relationship. Conversely, if the W_{ij} value is negative, there is no correlation between the class and the occurrence of flooding. Furthermore, the FFHSI value can be calculated by adding all the weights for the number generated as in Eq. 4.

$$FFHSI_{SI} = \sum\nolimits_{R=1}^{R=n} W_{ij} \tag{4}$$

Frequency Ratio and Predictor Rate Method

The frequency ratio method was used in [9, 10] to estimate the probabilistic relationship between dependent variables and the independent variables and to determine the weighting coefficient values in each flood-related variable class Eq. 5 shows a formula used to estimate the values in Frequency Ratio.

$$FR = \left(F_i \Big/ \sum\nolimits_{i-1}^{m} F_i\right) / \left(A_j \Big/ \sum\nolimits_{j=1}^{n} A_j\right) \tag{5}$$

where F_i is the number of pixels with flash floods for each class of each factor; A_j is the number of pixels for each class of each factor; m is the number of classes in the F_i factor; n is the number of factors in the study area [35]. The FR value interpretation shows that if the value is more than 1, there is a correlation between the class and the occurrence of flooding. The higher the value, the stronger the relationship.

Based on the calculations for the FR sole conditioning factor, FFHSI can be calculated by aggregating the FR of all factors by using Eq. 6:

$$FFHSI_{FR} = \sum\nolimits_{\mathrm{j=1}}^{n} FR \tag{6}$$

The next step is to calculate the relative frequency (RF) using Eq. 7 by normalizing the FR value (probability value range {0–1}).

$$RF = \frac{(FR_{ij})}{\left(\sum_{i=1}^{m} FR_{ij}\right)} \tag{7}$$

In RF, all factors have the same weight; FR-PR integration considers the disadvantages of these. Weights using the level predictor (PR) are calculated by assessing each flood conditioning factor with the training data set in Eq. 8 [34]

$$PR = \frac{(RF_{max} - RF_{min})}{(RF_{max} - RF_{min})_{Min}} \tag{8}$$

Furthermore, the FFHSI value is the sum of the results of each FP-PR factor with each RF class as in Eq. 9.

$$FFHSI_{PR} = \sum (PR \times RF) \tag{9}$$

3.3 Preparation of Datasets for Training and Validation

This stage evaluates and compares the training and prediction capability. The last step includes validating the model based on statistical metrics such as percentage of sensitivity, and specify, as shown in Eqs. 10 and 11.

The sensitivity indicates the proportion of incidents correctly classified as flash floods. Accuracy means the balance of incidents correctly classified as flash floods and correctly classified as non-flash-floods.

$$sensitivity(y) = \frac{TP}{TP + FN} \tag{10}$$

$$specifity(x) = \frac{TN}{FP + TN} \tag{11}$$

where TP (True Positive) and TN (True Negative) indicate correctly classified incidents and FP (False Positive) and FN (False Negative) indicate wrongly classified incidents [13]. The ROC plot is a sensitivity versus specificity graph, statistically unaffected by prevalence. It is calculated by estimating the parameters for the infinity limit. The Area Under the Curve (AUC) is estimated from the ROC curve as Eqs. (12) show the overall performance of the vulnerability model [36]. An AUC value that is close to 1.0 indicates that the model is very good and can classify the flash flood area correctly.

$$AUC = \sum\nolimits_{i=1}^{n+1} \frac{1}{2}\sqrt{(x_i - x_{i+1})^2 \times (y_i - y_{i+1})} \tag{12}$$

3.4 Estimation of Rain Spatial Distribution by Using IDW

Rainfall is the main factor that causes flash floods. The higher the rainfall intensity, the higher the flooding potential will be. For a study on the causes of flash floods in an area, spatial rain distribution is essential for describing the locations where the flash floods occurred. The spatial rain distribution is estimated by using Inverse Distance Weighting (IDW) method [36]. IDW is a spatial interpolation method suitable for the prediction of rainfall possibility [37]. Besides, estimates of mean regional rainfall using the IDW method are slightly better than the forecast resulting in the other three ways (ANUDEM, Spline, and Kriging). The IDW method is also easier to implement in GIS [38]. IDW interpolation determines cell values using a weighted combination of a set of sample points. The weight is a function of the inverse distance. The data recorded by these devices are used to estimate mean regional rainfall. The study focused on determining flash flood causes. The estimate of spatial rainfall distribution in various times of occurrence (in Table 1) of flash floods occurrences is used to identify the effect of rainfall on the flash floods historically.

4 Result and Discussions

4.1 Assessment of FFHS from SI, FR, and FR-PR

In this paper, the potential of the flash floods on the Wonoboyo watershed has been assessed by using SI, FR, and FP-PR a bivariate statistical approach integrated with geospatial techniques. These methods are used to find a correlation between a flash flood in its causes.

In the SI method, all factors are calculated to obtain the resultant weight for each conditioning factor, as shown in Fig. 3. The slope factor in classes 1 and 2 has a positive value, and the lower the class, the stronger the value. TPI in classes 2–4 shows positive values. TWI has positive scores in grades 4–7, and the higher the class, the stronger the relationship. The curvature of the profile with the curvature of the plan has the opposite positive value strength. Aspects have positive values in classes 6, 7, 8, and 10. Convergent in class 1 and 2 has a positive and strong value in class 1. River density indicates that the lower the class, the stronger the relationship. The use of paddy fields and settlements has a strong positive value. The

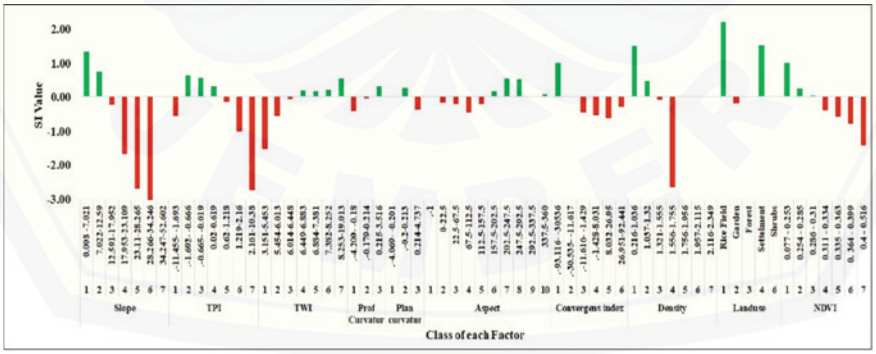


Fig. 3 The computed SI value variations for each class of the conditioning factors

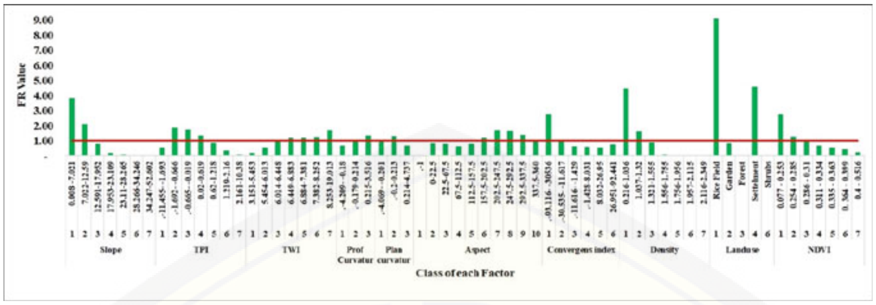


Fig. 4 The computed FR value variations for each class of the conditioning factors

NDVI in classes 1 and 3 had positive scores, and the lower the score, the stronger the relationship.

The FR method applied to measure the prediction capability from selected flash flood driving factors is shown in Fig. 4. Figure 4 shows that the dominant factors that drive flash floods are land use, followed by aspect. The other six other factors (river density, TWI, slope, NDVI, TPI, convergence index) have equal importance. The land-use factor is very closely related to flash flood occurrence. It mainly occurs in the rice fields and settlements class because it has the two highest FR values.

The map in Fig. 5 shows the estimation and identification of flash flood potentials. The map shows that the most susceptible areas to flash floods are the ones with the lowest slopes. The lower the slope, river density, NDVI, and convergence index, the higher the flash flooding potential.

Figure 5 shows a graph of the FR-PR method applied to measure the FP-PR of the selected flash flood driving factors. It shows the dominant factors that cause flash floods are density (3.76), land use (3.73), followed slope (3.26). The other six factors are NDVI (2.14), Convergence index (2.13), TPI (1.59), Prof Curvature (1.38), TWI (1.26), Plan Curvature (1.23), and Aspect. (1.00).

Figure 6 and 7 show a graphical comparison of the hazard levels for each model. The FR and FR-PR models have almost the same hazard pattern at moderate to high

Fig. 5 Flash flood conditioning factors from predictor rate

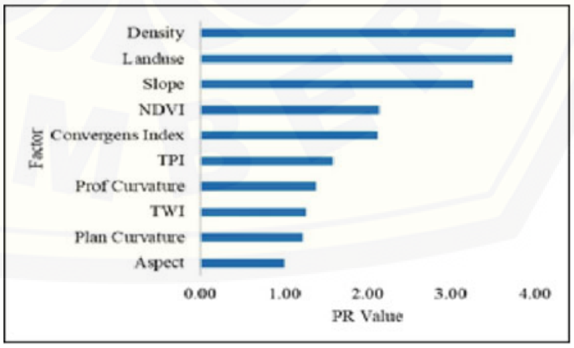
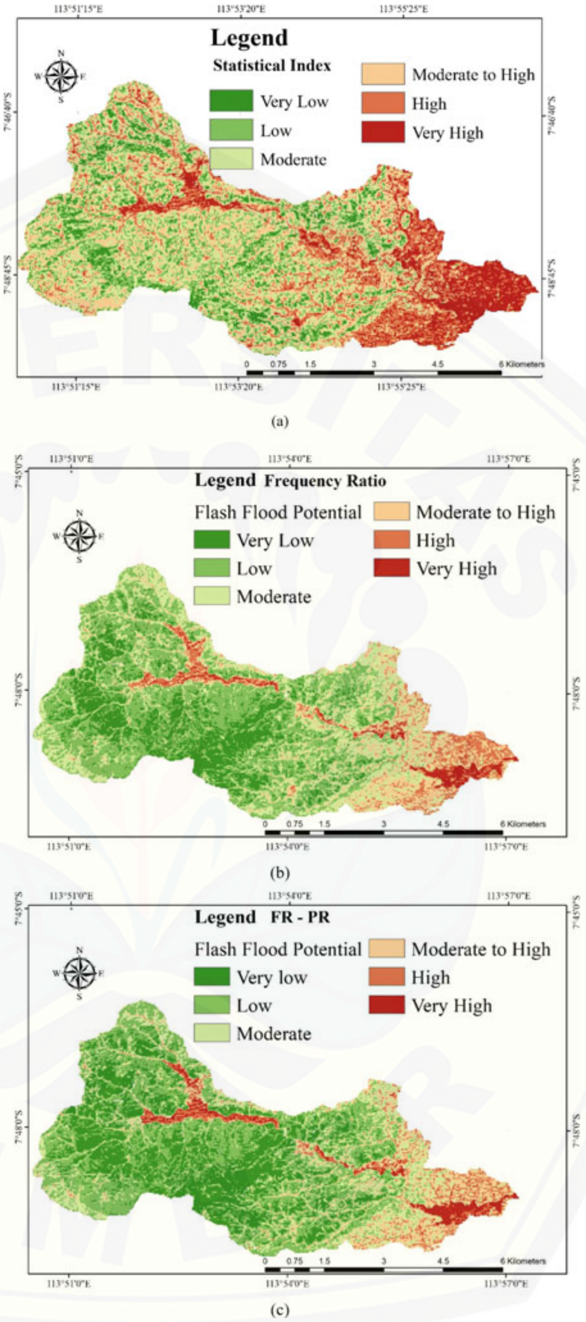


Fig. 6 Map of FFHSI at Wonoboyo Watershed with method: **a** SI, **b** FR, and **c** FR-PR



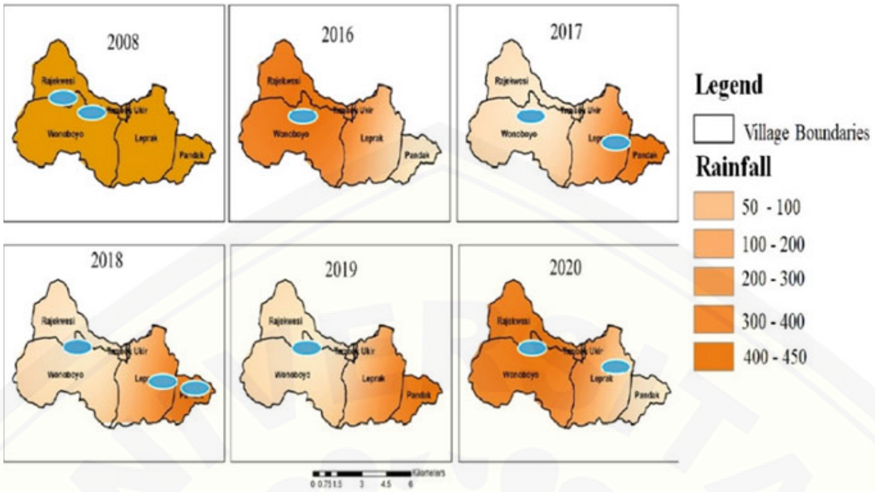


Fig. 7 Comparison of level of hazard between SI, FR, and FP-PR

to very high levels. These two models show that a very low to moderate hazard level has a high percentage value, but has decreased from a moderate to high to very high hazard level. On the other hand, the SI model has small percentage values at very low to moderate hazard levels but shows high percentage values at moderate to high until very high hazard levels downstream of the watershed. In general, from the modeling results, the highest percentage value is found in the FR method with a low hazard level with a value of 38%, while the lowest percentage value is found in the FR method with a very high hazard level with a value of 2%.

4.2 *Validation of Flash Flood Hazard Susceptibility Map*

The validation of the FFHSI model shows that the model has performed well for the SI model and very well for the FR and FR-PR. The AUC value represents this for success curve of 91.06%, and the AUC value for the prediction curve of SI, FR, and FR-PR is 79.38, 90.75, and 90.40, respectively. FR model is the best model from others. Therefore, the prediction of flash flood hazard susceptibility resulting in this the study can be used as a reference for flood disaster management plans for disaster management and decision makers.

Table 3 The change in land use

Land-use	Area (%)		% Change in land use from 2000 conditions
	2000	2018	
Rice field	4.6	4.7	2.84
Plantation	58.5	58.2	−0.5
Forest	17.4	17.3	−1.06
Settlement	1.6	2.0	19.84
Shrubs	17.8	17.8	0.13

4.3 Effect of Change in Land Uses to Flash Floods Occurrences

The change in land cover is analyzed by using a statistical approach. The land-use data of the year 2000 is used as the baseline, and the data of the year 2018 is used to show the change in land use (Table 3).

Of the total Area at Wonoboyo watershed of 4008 ha, the land uses most considerable proportion is for plantations (58%). The land use between 2000 and 2018 does not show any significant change in the total area ratio. The most significant change in land use was the 19.84% increase in settlement, followed by rice fields' rise and the decrease in plantations and forests. Based on Table 2, there is no significant evidence that the change in land use had conditionend the flash floods. Nevertheless, the rise of rice fields and settlements will increase the surface runoff and the infiltration capacity of an area, hence conditionend flooding.

4.4 The Effect of Rainfall on the Flash Floods Occurrence

Figure 7 shows the distribution pattern of rainfall depth and the distribution of six flash flood historical occurrences in 2008, 2016, 2017, 2018, 2019, and 2020. It shows that the distribution of flash flood occurrences is related to the distribution of the rainfall depths. Based on Table 1, the rainfall depth of 55 mm has conditioned the flash floods (Fig. 8).

The flash flood that was triggered by consecutive rainfall for 3 days, as shown in Table 1, would have been worse if one of the variables had become extreme. Based on this study's results, it is essential to consider factors that affect the occurrence of flash floods to determine the proper preparation and mitigation to minimize the risks of future flash floods.

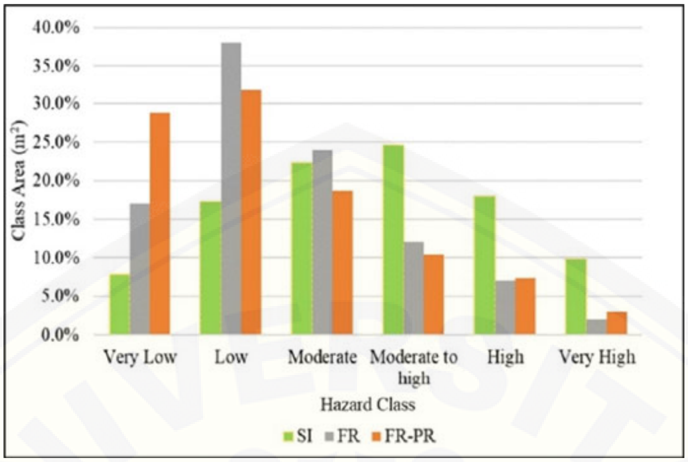


Fig. 8 The rainfall distribution pattern and the flash floods occurrences in Wonoboyo Watershed

5 Conclusions

Based on the comparative analysis of three statistical bivariate methods, the frequency ratio approach is the best method to describe the flash flood potentials, as implied from the AUC model value of 90.75. It is found that land use, the density of river networks, and slope are three dominant factors that conditionend the flash floods. Among the classes in the land-use factor, rice fields and settlement have the most significant effects. As for the factor of the density of the river network, it is found that the denser the river network is, the more susceptible it is to flash floods. Besides, the distribution pattern of rain and the intensity will determine the location of flash floods.

Rain intensity of more than 50 mm per day is the threshold in the occurrence of flash floods. The results of this study can be used as guidelines in the management of watershed spatial planning and steps to minimize the occurrence of flash flood.

References

1. Elkhrachy I (2015) Flash flood hazard mapping using satellite images and GIS tools: a case study of Najran City, Kingdom of Saudi Arabia (KSA). Egypt J Remote Sens Sp Sci 18(2):261–278. https://doi.org/10.1016/j.ejrs.2015.06.007
2. Hapuarachchi HAP, Wang QJ, Pagano TC (2011) A review of advances in flash flood forecasting. Hydrol Process 25(18):2771–2784. https://doi.org/10.1002/hyp.8040
3. Antarafoto (2008) Banjir Desa Wonoboyo, antarafoto
4. BPBD (2016) BPBD Jatim Bantu Korban Banjir dan Tanah Longsor di', BPBD. https://web.bpbd.jatimprov.go.id/2016/02/01/bpbd-jatim-bantu-korban-banjir-dan-tanah-longsor-di-bondowoso/. Accessed Feb 27 2021
5. Beritaekspress (2017) Akibat Banjir, Akses ke Desa Wonoboyo Jatim Lumpuh, beritaekspres

6. Terbitannews (2020) Akibat Hujan Deras, Banjir dan Longsor Terjadi di Desa Leprak Bondowoso, Terbitannews
7. Faktualnews (2018) 3 Kecamatan di Bondowoso Diterjang Banjir Bandang, faktualnews. https://faktualnews.co/2018/01/28/3-kecamatan-bondowoso-diterjang-banjir-bandang/60730/. Accessed 27 Feb 2021
8. Gaume E, Borga M (2008) Post-flood field investigations in upland catchments after major flash floods: proposal of a methodology and illustrations. J Flood Risk Manag 1(4):175–189. https://doi.org/10.1111/j.1753-318x.2008.00023.x
9. Cao C, Xu P, Wang Y, Chen J, Zheng L, Niu C (2016) Flash flood hazard susceptibility mapping using frequency ratio and statistical index methods in coalmine subsidence areas. Sustainability 8(9) (2016). https://doi.org/10.3390/su8090948
10. Pradhan (2009) Flood susceptible mapping and risk area delineation using logistic regression, GIS and remote sensing. J Spat Hydrol 9(2):1–18
11. Jodar-Abellan A, Valdes-Abellan J, Pla C, Gomariz-Castillo F (2019) Impact of land use changes on flash flood prediction using a sub-daily SWAT model in five Mediterranean ungauged watersheds (SE Spain). Sci Total Environ 657:1578–1591. https://doi.org/10.1016/j.scitotenv.2018.12.034
12. Costache R, Hong H, Pham (2020) QB (711) Comparative assessment of the flash-flood potential within small mountain catchments using bivariate statistics and their novel hybrid integration with machine learning models. Sci Total Environ 711:134514. https://doi.org/10.1016/j.scitotenv.2019.134514
13. Bui DT, Tsangaratos P, Ngo PTT, Pham TD, Pham BT (2019) Flash flood susceptibility modeling using an optimized fuzzy rule based feature selection technique and tree based ensemble methods. Sci Total Environ 668:1038–1054. https://doi.org/10.1016/j.scitotenv.2019.02.422
14. Popa MC et al (2020) Spatial assessment of flash-flood vulnerability in the Moldova river catchment (N Romania) using the FFPI. J Flood Risk Manag 2019:1–10. https://doi.org/10.1111/jfr3.12624
15. Khosravi K et al (2018) A comparative assessment of decision trees algorithms for flash flood susceptibility modeling at Haraz watershed, Northern Iran. Sci Total Environ 627:744–755. https://doi.org/10.1016/j.scitotenv.2018.01.266
16. Lappas I, Kallioras A (2019) Flood susceptibility assessment through GIS-based multi-criteria approach and analytical hierarchy process (AHP) in a River Basin in Central Greece, IRJET, pp 738–751
17. Stefanidis S, Stathis D (2013) Assessment of flood hazard based on natural and anthropogenic factors using analytic hierarchy process (AHP). Nat Hazards 68(2):569–585. https://doi.org/10.1007/s11069-013-0639-5
18. Kazakis N, Kougias I, Patsialis T (2015) Assessment of flood hazard areas at a regional scale using an index-based approach and analytical hierarchy process: application in Rhodope-Evros region, Greece. Sci Total Environ 538:555–563. https://doi.org/10.1016/j.scitotenv.2015.08.055
19. Costache R (2019) Flash-flood potential assessment in the upper and middle sector of Prahova river catchment (Romania). A comparative approach between four hybrid models. Sci Total Environ 659:1115–1134. https://doi.org/10.1016/j.scitotenv.2018.12.397
20. Khosravi K, Nohani E, Maroufinia E, Pourghasemi HR (2016) A GIS-based flood susceptibility assessment and its mapping in Iran: a comparison between frequency ratio and weights-of-evidence bivariate statistical models with multi-criteria decision-making technique. Nat Hazards 83(2):947–987. https://doi.org/10.1007/s11069-016-2357-2
21. Khosravi K, Pourghasemi HR (2016) Flash flood susceptibility analysis and its mapping using different bivariate models in Iran: a comparison between Shannon's entropy, statistical index, and weighting factor models. Environ Monit Assess. https://doi.org/10.1007/s10661-016-5665-9

22. Costache R, Zaharia L (2017) Flash-flood potential assessment and mapping by integrating the weights-of-evidence and frequency ratio statistical methods in GIS environment—case study. Bâsca Chiojdului River Catchment (Romania). J Earth Syst Sci 126(4):1–19. https://doi.org/10.1007/s12040-017-0828-9
23. Efendi D, Hidayah E, Hasanuddin A (2020) U KaRsT, Mapping of landslide susceptible zones by using frequency. Ratios Bluncong 5(1):126–141. https://doi.org/10.30737/ukarst.v3i2
24. Tehrany MS, Pradhan B, Jebur MN (2015) Flood susceptibility analysis and its verification using a novel ensemble support vector machine and frequency ratio method. Stoch Environ Res Risk Assess 29(4):1149–1165. https://doi.org/10.1007/s00477-015-1021-9
25. Beven K (1984) Infiltration into a class of vertically non-uniform soils, Hydrol Sci J 29(4):425–434. https://doi.org/10.1080/02626668409490960
26. Manfreda S, Di Leo M, Sole A (2011) Detection of flood-prone areas using digital elevation models. J Hydrol Eng 16(10):781–790. https://doi.org/10.1061/(asce)he.1943-5584.0000367
27. Duman TY, Can T, Gokceoglu C, Nefeslioglu HA, Sonmez H (2006) Application of logistic regression for landslide susceptibility zoning of Cekmece Area, Istanbul, Turkey. Environ Geol 51(2):241–256. https://doi.org/10.1007/s00254-006-0322-1
28. Fernández DS, Lutz MA (2010) Urban flood Hazard zoning In Tucumán Province, Argentina. Using GIS and multicriteria decision analysis. Eng Geol 111(1–4):90–98. https://doi.org/10.1016/j.enggeo.2009.12.006
29. Glenn EP, Morino K, Nagler PL, Murray RS, Pearlstein S, Hultine KR (2012) Roles of Saltcedar (Tamarix spp.) and capillary rise in salinizing a non-flooding terrace on a flow-regulated Desert River. J Arid Environ 79:56–65. https://doi.org/10.1016/j.jaridenv.2011.11.025
30. Falahnsia AR (2014) Vegetasi dengan metode skoring menggunakan citra satelit di, pp 400–416
31. Ullah K, Zhang J (2020) GIS-based flood hazard mapping using relative frequency ratio method: a case study of Panjkora River Basin, Eastern Hindu Kush, Pakistan. PLoS One 15(3):1–18. https://doi.org/10.1371/journal.pone.0229153
32. Ullah K, Zhang J, Id JZ (2020) GIS-based flood hazard mapping using relative frequency ratio method: a case study of Panjkora River Basin, Eastern Hindu Kush, Pakistan. PLoS 15(3):1–18. https://doi.org/10.1371/journal.pone.0229153
33. Abdulwahid WM, Pradhan B (2017) Landslide vulnerability and risk assessment for multi-hazard scenarios using airborne laser scanning data (LiDAR). Landslides 14(3):1057–1076. https://doi.org/10.1007/s10346-016-0744-0
34. Van Westen CJ, Rengers N, Terlien M (1997) Prediction of the occurrence of slope instability phenomena through GIS-based hazard zonation. https://doi.org/10.1007/s005310050149
35. Regmi AD et al (2014) Application of frequency ratio, statistical index, and weights-of-evidence models and their comparison in landslide susceptibility mapping in Central Nepal Himalaya. Arab J Geosci 7(2):725–742. https://doi.org/10.1007/s12517-012-0807-z
36. Bartier PM, Keller CP (1996) Multivariate interpolation to incorporate thematic surface data using inverse distance weighting (IDW). Comput Geosci 22(7):795–799. https://doi.org/10.1016/0098-3004(96)00021-0
37. Chen FW, Liu CW (2012) Estimation of the spatial rainfall distribution using inverse distance weighting (IDW) in the middle of Taiwan. Paddy Water Environ 10(3):209–222. https://doi.org/10.1007/s10333-012-0319-1
38. Yang X, Xie X, Liu DL, Ji F, Wang L (2015) Spatial interpolation of daily rainfall data for local climate impact assessment over Greater Sydney Region. Adv Meteorol. https://doi.org/10.1155/2015/563629