Delineation of flash flood hazard zones based on morphometric parameters using GIS technique in upper Lematang sub-watershed

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Abstract. The hilly and mountainous topography with high annual rainfall triggered a flash flood in the upper Lematang sub-watershed. The impact caused not only damaged infrastructure, agriculture land, and even fatalities. This research aimed to conduct flash flood hazard zoning based on morphometric parameters using the GIS technique. By extracting the DEM data, it is generated to a slope map, flow direction, flow accumulation, stream order, and watershed boundary. The data were then evaluated to obtain the morphometric parameters. Parameters analyzed using the PCA approach to get the correlation between parameters related to flash flood hazards. Of the 12 parameters, the KMO value is 0.66, and a significant level is 0.001 <0.05 with a sufficient level of intercorrelation. The result of PCA analysis, two factors were obtained with an eigenvalue > 1, and the cumulative percentage of the two factors was able to explain data variations of 87.49%. Finally, using 12 parameters, the upper Lematang sub-watershed area had 48.79% very-high hazard zones of a flash flood, 16.48% high zones, 20.28% moderate zones, and 0.97% low zones, and 13.48% very-low zones. The results of this study can be used in mitigation activities as well as for integrated watershed management.

1. Introduction

The occurrence of a flash flood was a natural phenomenon that occurred in many parts of the worldwide. It was also one of the threats to human safety, damaging the environment and the infrastructure in its path [1]. The definition of a flash flood was the sudden release of large volumes of water because the soil was saturated with water for a short time in minutes to several hours, accompanied by the heavy rain [2].

Analysis of watershed morphometric is measured watershed parameters, including linear aspects, area, and relief, to facilitate the understanding of the geomorphological characteristics, hydrological conditions in responding to climate change, and land-use [3–6].

Utilizing Geographic Information System (GIS) was a helpful tool in evaluating watershed morphometric parameters. Flash flood hazard zonation mapping was necessary for disaster mitigation activities and watershed management information. PCA is a Measure of Sampling Adequacy (MSA) method which is widely used in studies of hydrology, geomorphology and watershed management [7–9]. Thus, this research focused on the flash flood hazard zoning by evaluating morphometric parameters using GIS techniques in the upper Lematang sub-watershed with Principal Component Analysis (PCA) approach.
2. Material and methods

2.1. Study area
Based on hydrologic conditions, the study area was in the upper Lematang sub-watershed with 4,008.9 km². It was a watershed part of the Musi river basin and based on geographic conditions located between 30°30'33.06" S – 40°22'33.37" S and between 103°00'58.48" E - 103°05'53.97" (Figure 1).

![Figure 1. Study area](image)

2.2. Data
This study's data use topographic data on a scale of 1: 50,000 sourced from the Geospatial Information Agency (BIG), Indonesia. The topographic map was created DEM data with a pixel size 25m x 25m processed using the DEM hydro-processing tool in software ILWIS 3.3. Further, the data DEM was generated into slope data, flow direction, flow accumulation, stream order, and sub-watershed boundaries. To obtain the morphometric parameters, including linear aspects, area aspects, and relief aspects, the using equations were calculated, as shown in (Table 1).


Tabel 1. Morphometric parameters equations from linear aspects, areal aspects, and relief aspects

| No | Morphometric parameters | Formula | Source |
|----|-------------------------|---------|--------|
| 1  | Stream order (U)        | Hierarchical rank (analysis by software ILWIS 3.3) | [10] |
| 2  | Stream number (Nu)      | Nu= N1+ N2+...+Nn | [10] |
| 3  | Stream length (Lu)      | Lu= L1+ L2+...+Ln (km) | [10] |
| 4  | Bifurcation ratio (Rb)  | Rb= Nu/Nu+1 | [10] |
| 5  | Mean bifurcation ratio (Rbm) | Rbm = average of bifurcation ratios of all orders | |
| 6  | Length of overland flow (Lo) | Lo= 1/2 D2d | [11] |
| 7  | Basin Length (Lb)       | Lb=1.312(A)0.568 | [12] |
| 8  | Main river length (Lrm) | Analysis by software ILWIS 3.3 (km) | |
| 9  | Area (A)                | Analysis by software ILWIS 3.3 (km2) | |
| 10 | Perimeter (P)           | Analysis by software ILWIS 3.3 (km) | |
| 11 | Drainage density (Dd)   | Dd= Lb/A (km/km2) | [11,13] |
| 12 | Drainage texture (Dt)   | Dt= Nu/P | [11] |
| 13 | Stream frequency (Fs)   | Fs= Nu/A | [11,13] |
| 14 | Elongation ratio (Re)   | Re=1.128 √A/Lb | [12] |
| 15 | Basin relief (R)        | R=H-h Where, H= The maximum height in each sub-watershed, h= The Minimum height in each sub-watershed | [14] |
| 16 | Relief ratio (Rr)       | Rr= H/Lb | [12] |
| 17 | Ruggedness number (Rn)  | Rn= Dd(R/1000) | [15] |

2.3. Principal component analysis (PCA)

PCA was statistical analysis used to reduce a set of variables by declaring the origin variable as a linear combination of factors so that the factors were able to explain the variance of data explained by the originating variable [8,16]. The general form of the equation was.

\[ Z_{ij} = b_1 f_{2j} + b_2 f_{2j} + b_3 f_{3j} + ... b_m f_{mj} + e_{ij} \] (1)

Z was the measured variable, b was the loading factor, f was the score factor, i was the number factor, j was the number of data samples, m was the total number of variables, and e was residual. Of the 18 morphometric parameters were evaluated, 16 parameters were used in factor analysis to identify the structure of the parameters that form it and saw the most significant factors as characteristic hydrologic conditions in each sub-watershed. The data is then interpreted using the Kaiser Mayer Olkin (KMO) correlation matrix. The criteria of KMO score were 0.90s (very good), the 0.80s (good), the 0.70s (good enough), the 0.60s (enough), the 0.50s (very bad), and < the 0.50s (The analysis could not be continued) [17]. Subsequent testing with Barlett’s Test of Sphericity method saw the value of the significance level of < 0.05 [18]. The next step was to factor the parameters to extract the main factor using an eigenvalue > 1 [17]. All stages of the analysis performed using the Jamovi 1.2.22 application.

2.4. Flash flood hazard zonation

In this research, the parameter used was based on the PCA analysis result by show the parameters' correlation values. Zoning of flash flood hazard used a scale of 1 – 5 for all sub-watershed morphometric parameters. The scale values were summed in each sub-watershed and ranked into five flash flood hazard zones (Very high, high, moderate, low, and very low).

3. Result and discussion

3.1. Morphometric parameters of upper Lematang sub-watershed

The maximum height of the upper Lematang sub-watershed with a value of 2,825 masl in the Dempo mountain region, and the minimum height was 36.1 masl. The results of DEM data extraction using
ILWIS 3.3 software obtained slope maps, which are mostly dominated by slope with a flat class with a percentage of 45.51% with a steep level - a very steep total of 22.59%. The flow direction is dominated to the north direction (360°) with 20.15%, and the east direction (90°) percentage of 20.53%. Stream orders consisted of orders 1-6 with a total stream number of 679, and delineation results are obtained 15 sub-watersheds, as shown in (Figure 2).

![Figure 2](image-url)

**Figure 2.** (a) DEM map, (b) Slope in percent map, (c) Aspects map, and (d) stream orders map

**3.1.1. Linear aspects.** The calculation results (Table 2). Stream orders \((U)\) is a hierarchical rank [10]. The stream orders of the upper Lematang sub-watershed consisted of order 1 - 6. Stream number \((Nu)\) was the number of stream orders in each sub-watershed. The values of \(Nu\) ranged from 3 - 125. Stream length \((Lu)\) was the total stream length of all orders in each sub-watershed. The values of \(Lu\) ranged from 20.13 km - 501.94 km. Bifurcation ratio \((Rb)\) was a value determined based on each order's
number of river paths. The higher the $Rb$ value, the region had a rock layer with steep slopes and the distance between narrow valleys bounded by steep walls [10]. The mean bifurcation ratio ($Rbm$) was the average value of $Rb$. There were 13 sub-watersheds with the $Rbm$ value $< 3$, which indicated that the increase in flood water was fast, and the decline was slow. The $Rbm$ values range 3 - 5 were found in SW8 and SW11, which meant the rising and falling water level was not too fast. The length of overland flow ($Lof$) in each sub-watershed was low. The values of $Lof$ 0.26 – 0.46 except SW10 with the value 1.11. That caused the flow increasingly towards the channel, thus potentially for flash floods. The basin length ($Lb$) was the maximum length of the watershed or sub-watershed measured parallel to the main river. The value of the fifteenth $Lb$ of the sub-watershed ranged from 4.58 - 58.50.

**Table 2. Linear aspects**

| Sub-watershed | Morphometric parameters |
|---------------|-------------------------|
|               | $Nu$ | $Lu$ | $Rbm$ | $Lof$ | $Lb$ |
| SW1           | 21.00 | 92.37 | 1.10 | 0.27 | 24.54 |
| SW2           | 19.00 | 85.43 | 1.72 | 0.26 | 24.03 |
| SW3           | 65.00 | 279.94 | 2.00 | 0.34 | 39.95 |
| SW4           | 93.00 | 311.37 | 2.84 | 0.30 | 45.46 |
| SW5           | 51.00 | 213.08 | 1.67 | 0.36 | 33.39 |
| SW6           | 63.00 | 227.15 | 2.18 | 0.32 | 36.74 |
| SW7           | 33.00 | 147.46 | 2.37 | 0.37 | 26.52 |
| SW8           | 61.00 | 200.14 | 3.47 | 0.43 | 28.96 |
| SW9           | 29.00 | 103.80 | 1.61 | 0.41 | 20.63 |
| SW10          | 3.00  | 20.13  | 2.00 | 1.11 | 4.58  |
| SW11          | 67.00 | 267.89 | 4.37 | 0.28 | 44.07 |
| SW12          | 23.00 | 76.64  | 2.11 | 0.26 | 22.13 |
| SW13          | 125.00 | 501.94 | 2.20 | 0.31 | 58.50 |
| SW14          | 13.00 | 35.93  | 1.34 | 0.46 | 10.48 |
| SW15          | 13.00 | 42.40  | 1.13 | 0.38 | 12.80 |

3.1.2. Areal aspects. Calculation results (Table 3). Area ($A$) was an area, and perimeter ($P$) was a perimeter of sub-watershed. The DEM analysis results, 15 sub-watersheds were obtained with an area ranging from 9.03 km$^2$ – 800.84 km$^2$, and a perimeter was ranging 14.48 km – 199.11 km. Drainage density ($Dd$) was the ratio between the total river length of each order to the sub-watershed area. The higher the river's density, the more water was accommodated in the river [11,13]. The ratio of $Dd$ in each sub-watershed was between 0.51 - 0.93. The value of $Dd$ for all sub-watersheds classified as low except SW10 with a moderate density level of 2.23. It indicated the condition of subsurface materials was waterproof, dense vegetation and mountainous relief. Stream frequency ($Fs$) was the number of river segments in all orders in a watershed divided by the watershed [13]. The value of $Fs$ in each sub-watershed was low. It indicates that low permeability, low infiltration capacity, and water-resistant rocks, so that surface flow becomes high in each sub-watershed. Drainage texture ($Dt$) and drainage texture ratio ($Rt$) were crucial in the morphometric analysis and the value of it in each sub-watershed depending on lithology, infiltration capacity, and relief aspects [19]. A high $Rt$ value indicated the potential for erosion hazard and high surface runoff. The value of $Rt$ in sub-watersheds was low $< 1$, it indicated that the amount of erosion and surface runoff was small. The elongation ratio ($Re$) was a sub-watershed form factor obtained from the elongation ratio, which was defined as the ratio of the diameter of a circle with the same area as the length of the sub-watershed. For various types of climate and geology, The value of $Re$ generally ranging from 0.6 - 1.0. It was typical for values close to 1 that the sub-basin had very low relief, while the values of 0.6 - 1.0 had the mountain ridges and hills with steep slopes [10]. The value of $Re$ on each sub-watershed ranged from 0.55 - 0.74, and it indicated that the sub-watershed has mountainous relief and hills with steep slopes.
Table 3. Areal aspects

| Sub-watershed | Morphometric parameters |
|---------------|-------------------------|
|               | A  | P  | Dd | Dt | Rt | Fs | Re |
| SW1           | 173.57 | 88.58 | 0.53 | 0.06 | 0.24 | 0.12 | 0.61 |
| SW2           | 167.18 | 89.66 | 0.51 | 0.06 | 0.21 | 0.11 | 0.61 |
| SW3           | 409.19 | 98.17 | 0.68 | 0.11 | 0.66 | 0.16 | 0.57 |
| SW4           | 513.72 | 149.02 | 0.61 | 0.11 | 0.62 | 0.18 | 0.56 |
| SW5           | 298.41 | 107.67 | 0.71 | 0.12 | 0.47 | 0.17 | 0.58 |
| SW6           | 353.09 | 117.44 | 0.64 | 0.11 | 0.54 | 0.18 | 0.58 |
| SW7           | 198.86 | 83.10 | 0.74 | 0.12 | 0.40 | 0.17 | 0.60 |
| SW8           | 232.29 | 93.55 | 0.86 | 0.23 | 0.65 | 0.26 | 0.59 |
| SW9           | 127.81 | 98.56 | 0.81 | 0.18 | 0.39 | 0.23 | 0.62 |
| SW10          | 9.03  | 14.48 | 2.23 | 0.74 | 0.21 | 0.33 | 0.74 |
| SW11          | 486.36 | 148.63 | 0.55 | 0.08 | 0.45 | 0.14 | 0.56 |
| SW12          | 144.63 | 69.22 | 0.53 | 0.08 | 0.33 | 0.16 | 0.61 |
| SW13          | 800.84 | 193.11 | 0.63 | 0.10 | 0.65 | 0.16 | 0.55 |
| SW14          | 38.79  | 50.31 | 0.93 | 0.31 | 0.26 | 0.34 | 0.67 |
| SW15          | 55.15  | 42.83 | 0.77 | 0.18 | 0.30 | 0.24 | 0.65 |

3.1.3. Relief aspects. Basin relief (R) was the height difference between the maximum and minimum heights. R-value of the fifteenth sub-watersheds ranged from 59 masl - 2457.1 masl. Relief ratio (Rr) was the ratio of R to sub-watershed length [12]. The value of Rr ranged from 3.53 – 98.19. The Ruggedness number (Rn) of the fifteenth sub-watersheds ranged from 0.04 – 1.76. The high Rn value indicated the terrain structure’s complexity associated with watershed relief and drainage density, which showed that the sub-watershed is vulnerable to erosion [8].

Table 4. Relief aspects

| Sub-watershed | Morphometric parameters |
|---------------|-------------------------|
|               | R  | Rr | Rn |
| SW1           | 131.40 | 5.35 | 0.07 |
| SW2           | 300.00 | 12.49 | 0.15 |
| SW3           | 2102.00 | 52.62 | 1.44 |
| SW4           | 2325.50 | 51.15 | 1.41 |
| SW5           | 2307.10 | 69.09 | 1.65 |
| SW6           | 2457.10 | 66.88 | 1.58 |
| SW7           | 1941.70 | 73.23 | 1.44 |
| SW8           | 2041.70 | 70.49 | 1.76 |
| SW9           | 2025.50 | 98.19 | 1.64 |
| SW10          | 202.00 | 44.10 | 0.45 |
| SW11          | 1178.70 | 30.40 | 1.11 |
| SW12          | 78.20  | 3.53  | 0.05 |
| SW13          | 1778.20 | 50.31 | 0.93 |
| SW14          | 55.15  | 42.83 | 0.77 |
| SW15          | 63.80  | 4.99  | 0.05 |

3.2. Factor analysis (FA)

3.2.1. Correlation matrix. Before conducting stage analysis of the FA, the parameters were analyzed using the Pearson correlation matrix to make it easier to understand the correlation between
morphometric parameters. Based on the value of the correlation coefficient ($r^2$) if, $r^2 > 0.9$ meant the parameter had a strong correlation, $r^2 > 0.75$ good correlation, $r^2 > 0.6$ moderate correlation, and $r^2 < 0.5$ bad correlation [8]. The results of the analysis of the relationship between parameters (Table 5). Area ($A$) correlated strongly with $Nu$, $Lu$, and $Lb$ and correlates well with parameter $Rt$ and $Re$. $Nu$ correlated strongly with $Lu$ and $Lb$ and correlated well with $Rt$ and $Re$. $Lu$ correlated strongly with $Rt$ and $Re$. $Lb$ correlated strongly with $Re$. Parameter of $RL$ and $Rbm$ had a bad correlation to all parameters. $Lof$ correlated strongly with $Dd$ and $Dt$ and correlated well with $Fs$ and $Re$. $Dd$ correlated strongly with $Dt$ and correlated well with $Fs$ and $Re$. $Rt$ correlated well with $R$. $Fs$ correlated well with $Re$. The value of inverse correlation (-) meant an increase in the value of a parameter made the value of other parameters to decrease and vice versa. While the direct correlation (+) meant an increase in the parameter's value, it made other parameters increase in the correlated parameters.

### Table 5. Correlation matrix of 15 morphometric parameters

|     | $A$ | $Nu$ | $Lu$ | $RL$ | $Rbm$ | $Lof$ | $Lb$ | $Dd$ | $Dt$ | $Rt$ | $Fs$ | $Re$ | $R$ | $Rr$ | $Rn$ |
|-----|-----|------|------|------|------|-------|------|------|------|------|------|------|-----|------|-----|
| $A$ | 1.00|      |      |      |      |       |      |      |      |      |      |      |     |      |     |
| $Nu$| 0.97| 1.00 |      |      |      |       |      |      |      |      |      |      |     |      |     |
| $Lu$| 0.99| 0.99 | 1.00 |      |      |       |      |      |      |      |      |      |     |      |     |
| $RL$| 0.05| 0.03 | 0.00 | 1.00 |      |       |      |      |      |      |      |      |     |      |     |
| $Rbm$| 0.47| 0.50 | 0.47 | 0.43 | 1.00 |       |      |      |      |      |      |      |     |      |     |
| $Lof$| -0.42| -0.38 | -0.37 | -0.12 | -0.09 | 1.00 |       |      |      |      |      |      |     |      |     |
| $Lb$| 0.98| 0.95 | 0.96 | 0.06 | 0.50 | -0.55 | 1.00 |       |      |      |      |      |     |      |     |
| $Dd$| -0.42| -0.38 | -0.37 | -0.12 | -0.09 | 1.00 | -0.55 | 1.00 |       |      |      |      |     |      |     |
| $Dt$| -0.47| -0.41 | -0.42 | -0.09 | -0.10 | 0.99 | -0.60 | 0.99 | 1.00 |       |      |      |     |      |     |
| $Rt$| 0.78| 0.88 | 0.85 | -0.10 | -0.52 | -0.31 | 0.81 | -0.31 | -0.34 | 1.00 |       |      |     |      |     |
| $Fs$| -0.51| -0.37 | -0.43 | 0.00 | -0.14 | 0.75 | -0.62 | 0.75 | 0.83 | -0.22 | 1.00 |       |     |      |     |
| $Re$| -0.81| -0.80 | -0.80 | -0.09 | -0.42 | 0.81 | -0.91 | 0.81 | 0.85 | -0.73 | 0.76 | 1.00 |     |      |     |
| $R$ | 0.58| 0.69 | 0.67 | 0.01 | 0.39 | -0.23 | 0.65 | -0.23 | -0.29 | 0.78 | -0.21 | -0.65 | 1.00 |     |      |
| $Rr$| 0.14| 0.27 | 0.26 | 0.13 | 0.24 | 0.14 | 0.20 | 0.14 | 0.08 | 0.41 | 0.09 | -0.22 | 0.84 | 1.00 |     |
| $Rn$| 0.44| 0.57 | 0.55 | 0.01 | 0.36 | -0.08 | 0.50 | -0.08 | -0.14 | 0.72 | -0.07 | -0.51 | 0.97 | 0.92 | 1.00 |

3.2.2. Interpretation of parameters morphometric. From the results of the correlation analysis of morphometric parameters (Table 5), parameters that had a good - strong relationship was $A$, $Nu$, $Lu$, $Lof$, $Lb$, $Dd$, $Dt$, $Fs$, $Re$, $R$, $Rr$, and $Rn$. From the thirteen parameters, data interpretation was carried out using KMO and Bartlett's Test which aimed to measure the level of correlation between parameters regarding whether or not FA was appropriate. Based on the test results, FA could not be continued because the lowest Measure of Sampling Adequacy (MSA) value of 0.21 was found in the $Rr$ parameter and the overall KMO value was 0.45. MSA values ranged from 0 - 1 and this test was used to assess the intercorrelation between parameters [20]. Furthermore, to increase the correlation between parameters, the $Rr$ parameter was omitted and the analysis results obtained the lowest MSA value of 0.53, the overall KMO value was 0.66 with a significant 0.001 <0.005 (Table 6). Based on these values, the FA analysis was feasible to do.
Table 6. KMO Measure of Sampling Adequacy and Bartlett's Test of Sphericity of morphometric parameters in the upper Lematang sub-watershed.

| Morphometric parameters | A  | Nu  | Lu  | Lof | Lb  | Dd  | Dt  | Rt  | Fs  | Re  | R   | Rn  | KMO  | Bartlett's Test |
|--------------------------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------------------|
| MSA                      | 0.60 | 0.78 | 0.70 | 0.70 | 0.65 | 0.66 | 0.64 | 0.62 | 0.54 | 0.77 | 0.63 | 0.53 | 0.54 | 0.77           |

3.2.3. Principal component analysis (PCA). Using eigenvalue <1, there were two main component factors and extracted well and truly perfectly represent the problem. The result of the rotated component loadings of morphometric parameters using maximum variance (Table 7). The first factor consisted of Rt, Nu, Lu, R, A, Lb, and Rn with eigenvalue 7.78, and 64.84% explained these parameters' variance. The second factor consisting of Dt, Dd, Lof, Fs, and Re with eigenvalue 2.72 and 22.64% was able to explain these parameters' variance. Overall the two factors were able to explain the diversity of data by 87.49%.

Table 7. Rotated component loadings of morphometric parameters.

| Parameters | Component |
|------------|-----------|
|            | 1         | 2         |
| Rt         | 0.92      | -0.16     |
| Nu         | 0.91      | -0.29     |
| Lu         | 0.90      | -0.30     |
| R          | 0.87      | -0.06     |
| A          | 0.83      | -0.38     |
| Lb         | 0.83      | -0.51     |
| Rn         | 0.81      | 0.10      |
| Dt         | -0.18     | 0.97      |
| Dd         | -0.13     | 0.96      |
| Lof        | -0.14     | 0.96      |
| Fs         | -0.17     | 0.85      |
| Re         | -0.66     | 0.74      |

| Eigenvalue | 7.78 | 2.72 |

| % of Variance | 64.84 | 22.64 |
|Cumulative %   | 64.84 | 87.49 |

3.3. Flash flood hazard zonation
From the results of the analysis of the PCA approach, obtained parameters that had a strong correlation—very strong consisting of parameters Rt, Nu, Lu, R, A, Lb, Rn, Dt, Dd, Lof, Fs, and Re. Based on the results of the FA, in delineating the hazards of flash floods using these 12 parameters. Furthermore, to get a flash flood hazard class, each parameter in each sub-watershed was explained using a scale of 1-5 then summed and created a flash flood hazard zone based on the scale of the hazard level (Table 8). The results of the calculation there were 4 sub-watersheds (SW3, SW4, SW8, and SW13) had a very high level of flash flood hazard zones, 3 sub-watersheds (SW5, SW6, dan SW10) had a high level of flash flood hazard zones, 3 sub-watersheds (SW7, SW9, and SW11) had a moderate flood hazard zones, 1 sub-watershed (SW14) had a low-level flash flood hazard zone, and 3 sub-watersheds (SW2, SW12, and SW15) had a very low level of flash flood hazard zone (Figure 3).
Table 8. The level of flash flood hazard in 15 sub-watersheds

| Sub-watershed | A  | Nu | Lu | Lof | Lb | Dd | Dt | R | Fs | Re | Rn | R  | Sum | Hazard level |
|---------------|----|----|----|-----|----|----|----|---|----|----|----|----|-----|--------------|
| SW1           | 2  | 1  | 1  | 2   | 1  | 1  | 1  | 2 | 1  | 1  | 1  | 15 |    | Very low     |
| SW2           | 1  | 1  | 1  | 1   | 2  | 1  | 1  | 1 | 2  | 1  | 1  | 14 |    | Very low     |
| SW3           | 3  | 3  | 3  | 1   | 4  | 1  | 1  | 5 | 2  | 1  | 5  | 5  | 34 |    | Very high    |
| SW4           | 4  | 4  | 4  | 1   | 4  | 1  | 1  | 5 | 2  | 1  | 4  | 5  | 36 |    | Very high    |
| SW5           | 2  | 2  | 3  | 1   | 3  | 1  | 1  | 3 | 2  | 1  | 5  | 5  | 29 |    | High         |
| SW6           | 3  | 3  | 3  | 1   | 3  | 1  | 1  | 4 | 2  | 1  | 5  | 5  | 32 |    | High         |
| SW7           | 2  | 2  | 2  | 1   | 3  | 1  | 1  | 3 | 2  | 2  | 5  | 4  | 28 |    | Moderate     |
| SW8           | 2  | 3  | 2  | 2   | 3  | 2  | 2  | 5 | 4  | 2  | 5  | 5  | 37 |    | Very high    |
| SW9           | 1  | 2  | 1  | 1   | 2  | 1  | 1  | 3 | 2  | 1  | 3  | 5  | 25 |    | Moderate     |
| SW10          | 1  | 1  | 1  | 1   | 5  | 1  | 1  | 5 | 5  | 2  | 1  | 5  | 33 |    | High         |
| SW11          | 4  | 3  | 3  | 1   | 4  | 1  | 1  | 3 | 1  | 2  | 2  | 3  | 27 |    | Moderate     |
| SW12          | 1  | 1  | 1  | 1   | 2  | 1  | 1  | 2 | 2  | 1  | 1  | 16 |    | Very low     |
| SW13          | 5  | 5  | 5  | 1   | 5  | 1  | 1  | 5 | 1  | 1  | 4  | 4  | 38 |    | Very high    |
| SW14          | 1  | 1  | 1  | 2   | 1  | 2  | 1  | 5 | 4  | 1  | 1  | 22 |    | Low          |
| SW15          | 1  | 1  | 1  | 1   | 1  | 1  | 1  | 2 | 3  | 1  | 1  | 17 |    | Very low     |

Figure 3. Map of flash flood hazard zones in upper Lematang sub-watersheds
4. Conclusions
The quantitative analysis of the morphometric parameters of the upper Lematang sub-watershed obtained 15 parameters consisting of \(Nu, Lu, Rbm, Lof, A, P, Lb, Dd, Dt, Rt, Fs, Re, R, Rr,\) and \(Rn\). From the 15 parameters, the analysis results using the PCA approach using eigenvalue > 1 obtained two factors that were directly related to the flash flood hazard. The first factor consisted of \(Rt, Nu, Lu, R, A, Lb,\) dan \(Rn\) parameters with strong-very strong correlation (0.81 – 0.92). The second factor had a fairly strong-very strong correlation with values ranging from 0.74 - 0.97 consisting of \(Dt, Dd, Lof, Fs,\) and \(Re\) parameters. These two factors were able to explain the diversity of data by 87.49%. Finally, using the 12 parameters, a ranking was made based on a scale of 1-5 on each morphometric parameter, and then it was added up in each sub-watershed. Based on it summed result, a very high zone of flash flood hazard was found in the SW3, SW4, SW8, and SW13 sub-watersheds, the high zones were in the SW5, SW6, and SW10 sub-watersheds. The moderate zones were in the SW7, SW9, and SW11 sub-watersheds, the low zone was in the SW14 sub-watershed, and the very-low zones were in the SW1, SW2, SW12, and SW15 sub-watersheds.

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