Calculation of the number of peaks in The Gunung Sewu area using DEMNAS, focal maximum function and slope position classification method

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Abstract. Thousand Hills (Gunung Sewu) is a karst area in the southern Java island, stretches 85 km east to west covering around 1,300 km² and formed by thousands of conical hills. This research aims to calculate the number of peaks in the Gunung Sewu area using focal maximum function and slope position classification. The data for the calculation was the Indonesian national DEM (DEMNAS). It was used in its original spatial resolution at 8.25 m, and the resampled version at 10 m and 16.5 m. The processing consists of detection of peaks, selection of top of hills, and evaluation. Twenty four combinations of window types and size and spatial resolution of DEMNAS were evaluated. The accuracy of the calculation was assessed using ten test areas with 1,576 hills digitized manually. The best function to detect the peaks is a rectangle type window with a width of three pixels with a spatial resolution at 8.25 m. Types of hills can be identified: conical and polygonal hills. The calculation found that there are 27,773 regional peaks, or hills, in the Thousand Hills area. The results were tested using a confusion matrix with overall accuracy is 86.2%.

1. Introduction

The name Gunung Sewu can be literally translated into “thousand hills”. This name implies that there are thousands of hills populated this region. However, there is no official figure on the number of peaks or hills in the area. People simply calling that there are thousands of it.

Gunung Sewu is a karst area formed by thousands of conical hills which stretches 85 km from Gunungkidul regency, Wonogiri regency, to Pacitan regency [1]. The topography of the region consists of karst plateau, alluvial karst, doline, and dry valley [2]. The diversity topography made this area unique. For its uniqueness, this area inaugurated as a Global Geopark in 2015.

UNESCO Global Geoparks are a single, unified geographical area where sites and landscapes of international geological significance that should be managed with a holistic concept [3]. Many aspects of sustainably should be used as a foundation in managing and developing global geoparks. Scientifically, and from an environmental point of view, it is necessary to know how many hills are in the Gunung Sewu area. Based on the decision of ministry Energy and Mineral Resources of Republic Indonesia No. 3045 K/40/MEM/2014 about the decree of Gunung Sewu needed of detail inventory. One of the inventory landscape and hidrology in Gunung Sewu is conical hills. Inventory as conservation and protection activities aimed to prevent damage and support sustainable development and scientific development.
The number of conical hills in Gunung Sewu researched in 1976 is approximately 40,000 hills. There was no investigation on this topic after 1976, however karst area is continually changing because of human and natural activities. It is also important to note that remote sensing technology in that year is not as developed as today. This research aims to calculate the number of hills in the Gunung Sewu area by detect peaks on Digital Elevation Model (DEM).

Gunung Sewu area has been investigated by several researcher, such as Haryono [4] who studied the morphometry characteristics of karst valley networks that developed in the karst area. Morphometry characteristics of karst were interpreted by aerial photographs and field surveys. The typology of the Gunung Sewu karst based on the morphometry of the karst valley network is included in the cockpit karst category or also called conical hills [4]. According to Bastra (1976) in Simanjuntak [5], conical hills in the Gunung Sewu area amounted to be approximately 40,000 hills.

Several studies have also reviewed the methods to detect peaks, one of the researches conducted by Deng and Wilson [6]. They mapped the mountain peak using the MRVBF (Multi-resolution valley bottom flatness) approach. The mountain peaks were defined as high down-slope relief in a local area, steep in this local area, has high elevation in comparison with a large surrounding neighborhood, and doesn't have many competing peaks in this large neighborhood.

In addition, the detection of peaks was studied by Podobnikar [7] who examined automatic methods for detecting regional peaks in the Kamnik Alps, Slovenia mountains by applying spatial analysis on Digital Terrain Model (DTM). The study used Slovenian DTM with a resolution of 12.5 m; 25 m; 100 m. DTM was used to detect peaks based on the size of the average height and distance between peaks based on topographic and morphological criteria. Based on topographic criteria, the local peaks are calculated applying 3 x 3 local moving window or in this research called focal maximum function. Based on morphological criteria, the local peaks are eliminated setting criteria not on the flat areas by combined slope, curvature, and elevation of terrain. The results of the study are the regional peaks at Kamnik Alps. The quality of the results of this study can be proven visually by comparing the list of peaks and heights of these peaks. Then the research was developed by Podobnikar.

Podobnikar [8] also proposed the automatic method for detecting peaks and delineation of peak shapes in the Kamnik Alps, Slovenia mountains. The study uses the Slovenian Digital Elevation Model (DEM) data with a resolution of 12.5 m; 25 m; 100 m. DEM data was processed into two parts. First, detected regional and global peaks based on topographic, morphological, and climbing criteria based on the International Mountaineering and Climbing Federation (UIAA). Second, classified the shape of the peaks and analyzed the area around the peaks based on morphological criteria to determine the shape of the peak. The results of this study are regional peaks and global peaks in the Kamnik Alps and the shape of regional peaks is sharp, blunt, and oblong.

Other studies proved that DEM can be used to detect ridge areas, one of them is proposed by Weiss [9]. The study classifies Mt. Hood, Oregon and the western slopes of the Cascades into six and ten criteria. The classification uses the Topographic Position Index (TPI) method. TPI is the height difference on DEM cells with the average height value in the neighborhood. TPI value is used to classify an area into six criteria with the slope position classification method. The six criteria for slope position classification are ridges, upper slopes, middle slopes, flat slopes, lower slopes, and valleys. TPI value is also used to classify an area into ten criteria using the landform analysis method. The results of the landform analysis are canyon criteria, middle slope drainage, highland drainage, U-shaped valleys, flat areas, open slopes, upper slopes, local hills in the valley, local hills in the plains, and ridge.

Based on previous studies, there are some differences in this study. This study uses the National DEM (DEMNAS) to detect peaks and count the number of hills in the Gunung Sewu area. The spatial raster analysis method used named the focal maximum function and slope position classification. The preliminary study was conducted by Siddiq [10].
2. Method

2.1. Characteristic of procedure

Characteristic of the procedure to calculate the number of peaks in Gunung Sewu is detected peaks. Hill is defined based on topographic and morphological criteria. Hill based on topographic criteria is defined as an area that is higher than the neighborhood [11]. This criterion is realized by applying the focal maximum function method to calculate the highest elevation in the neighborhood area called local peaks. Hill based on morphological criteria is defined based on slope and elevation in neighborhood area [12]. These criteria are realized by applying the slope position classification method researched by Weiss [9]. The slope position classification method classifies landscapes into six classes based on the Topographic Position Index (TPI) and slope values, one of which is the ridge. The ridge is used to select a local peaks that is not the top of a hill based on morphological criteria.

2.2. Case-study area and data

The study area of this research is the Gunung Sewu complex with an area of approximately 1,300 km². It stretches 85 km from Gunungkidul, Wonogiri, to Pacitan Regency [1]. Geomorphologically, the existence of conical hills in this region was used as a reference in delineating the boundary of the Gunung Sewu area. The boundary also refers to the previous study [1]. The boundary of the Gunung Sewu area is presented in Figure 1. This study used nine DEMNAS with a spatial resolution of 8.25 m, which were downloaded from http://tides.big.go.id/DEMNAS/. The availability of DEMNAS makes this research possible.

![Location of the Gunung Sewu area](Figure 1)

Figure 1. Location of the Gunung Sewu area.

The original spatial resolution of 8.25 m, along with the resampled ones. It was resampled to 10 m and 16.5 m. Resampling aims to find the best-fit raster data that illustrate the topography of Gunung Sewu. The nearest neighbor algorithm was chosen as a resampling method to make it closely similar to the original one. The DEM with three different spatial resolutions of 8.25 m, 10 m, and 16.5 m were used to detect peaks.
2.3. Detection of local peaks
Detection of the peaks was done by the focal maximum function and conditional evaluation method. Focal functions are raster functions that compare one pixel to its neighboring pixels to check a certain condition [12]. On the three DEM versions, a window of focal maximum function was run to check and get the highest elevation inside the window. Pixel with the highest elevation is temporarily assigned as local peaks. Window with different sizes and types produced different results.

A combination of three parameters was evaluated: window types, window size, and pixel size. Two types of windows were tested, the rectangle and circle. The rectangle window is the most commonly used while the circle window is representing conical hills. In the rectangle window, the size was set at 3, 5, 7, and 9 pixels. The circle window used a radius of 3, 5, 7, and 9. Three different spatial resolution of DEM were employed: the 8.25, 10, and 16.5m. In total there were 24 combinations of window types and sizes, and spatial resolution.

Based on the highest value in evaluated by a window, it is then determined which cell is the peak. A pixel which has the highest elevation inside a window and equal to the DEM value indicated that the pixel is a peak. A conditional evaluation was applied to test whether the peak is in a hill or not using the expression:

\[ \text{Con ("DEMNAS" == "Focal Function", " DEMNAS")} \]

The expression tested if the DEMNAS pixel value is the same as the FocalFunction pixel value. If the output is true, then the DEMNAS pixel value represents the peak. These peaks are the highest pixel inside the window. It is called the local peaks.

2.4. Evaluation of local peaks
Twenty-four combinations of parameters were used to produce a variety of local peaks. In addition, all 24 parameter combinations were evaluated. The accuracy of the calculation was assessed against 10 test areas. In these test areas, 1,576 test points representing peaks were digitized on-screen based on aerial photographs, high resolution satellite imagery, and ESRI aerial photographs. The distribution of the test area in the Gunung Sewu area is illustrated in Figure 2.
These ten test areas spread over the Gunung Sewu. They represent various hill models, like conical and polygonal. They also cover residential areas, to test the ability of the function and DEM in discriminating elevation of the houses and actual hills. Test points and local peaks were compared to obtain the most suitable combination. The suitability of the combinations of parameters was determined by calculating the difference between the local peaks and test points. The accuracy of the calculation was assessed against 10 test areas. After an evaluation, it was found that one combination was found better: a 3 cell rectangle window with a pixel size of 8.25 m. This combination can detect small hills that are not detected by others.

2.5. Topographic Position Index (TPI)
One of the morphological hill criteria is defined based on differences in height with the neighborhood area. The difference in height with the surrounding area is processed by the TPI method proposed by Weiss [9]. The TPI method calculates the difference of height in a DEM cell with the average height values which is represented by a window formulated in Reu et al [13] as follows:

\[ TPI = z_0 - \bar{z} \] (1)

Here \( z_0 \) is the height value of the center cell DEM in a window and \( \bar{z} \) is the average height value in a window. The value \( \bar{z} \) is affected by the size and type of window selected. Therefore, the window that best suits the topography of the Gunung Sewu area was chosen, a 3 cell radius circle window with a pixel size of 8.25 m DEM. The combination is chosen manually by identification of the result because it is the most represent the hills topography of Gunung Sewu rather than a 3 cell rectangle window. The TPI value is a height difference which is representing the landscape classification described in Figure 3.

A positive TPI value indicates that the cell is higher than the neighborhood. A TPI value close to zero indicates that the cell is a flat area or an area with a constant slope. A negative TPI value indicates that the cell is lower than the neighbor.
2.6. Slope position classification

The height difference with the neighborhood has been represented by TPI. TPI is combined with a slope to define morphological hill criteria. The method is named as the slope position classification method. This method classifies six landscape classes based on the Topographic Position Index (TPI) and slope values, namely ridge, upper slope, middle slope, flats slope, lower slope, and valley [14]. The classification is explained in detail in Table 1.

| Class of slope position classification | TPI and slope |
|---------------------------------------|---------------|
| Ridge                                 | TPI > 1 STDEV |
| Upper slope                           | TPI > 0.5 STDEV; TPI ≤ 1 STDEV |
| Middle slope                          | TPI > -0.5 STDEV; TPI < 0.5 STDEV; slope > 5° |
| Flats slope                           | TPI ≥ -0.5 STDEV; TPI ≤ 0.5 STDEV; slope ≤ 5° |
| Lower slope                           | TPI ≥ -1 STDEV; TPI < 0.5 STDEV |
| Valley                                | TPI < -1.0 STDEV |

Landscapes are classified based on the comparison of the TPI in a cell and the mean in that cell multiplied by -1; -0.5; 0.5; 1 of the standard deviation (STDEV). The comparison determines which cell belongs to which class. Slope classes in the middle and flat areas are determined based on the slope value of the cell. If the slope value of a cell > 5°, then the cell is included in the middle slope. Otherwise, the cell is a flat area.

2.7. Selection of regional peaks

The ridge class is used to select local peaks that are not the top of hills, based on morphological criteria. Some peaks might have errors. A hill with one ridge might have two peaks, while it should have one hill represented by one peak. A hill should have one peak [6]. This situation is different from the hills which have several peaks because there are several ridges. Therefore, among the several peaks, one of the highest peaks was chosen. The highest peak is called regional peaks.

2.8. Accuracy evaluation

Regional peaks were evaluated with the test points in 10 test areas. The overall accuracy was calculated by comparing the number of regional peaks with the number of test points. Besides being compared with aerial photo data, regional peaks were evaluated with the results of field surveys. The classification accuracy-test uses the confusion matrix method. The confusion matrix is a matrix that compares each classification category between ground truth with the results of classification automatically [15]. The confusion matrix compared the hill and not hill categories between regional peaks and ground truth. Ground truth is obtained from field surveys based on the natural appearance of hills or no hills. There are 66 ground truths in Panggang and Tepus Districts, Gunungkidul Regency.
Characteristics of evaluated the classification accuracy based on the value of omission, commission, producer’s accuracy, user’s accuracy, and overall accuracy. It is based on the remote sensing classification accuracy assessment of Lillesand and Kiefer [16]. The overall accuracy was used to determine whether the classification results are accepted or not. If the value is ≥85%, the classification results are accepted. If the value is <85%, the classification results are not accepted and it is necessary to repeat the steps of evaluated local peaks and test points to obtain a combination of parameters that suits the Gunung Sewu area.

3. Result and discussion

3.1. Local peaks
Local peaks in this study are defined as the highest points of an area based on the topographic criteria. Local peaks obtained from the focal maximum function method with 24 combinations of parameters. Based on these 24 combinations, the number of detected local peaks is detailed in Figure 4.

Based on Figure 4, local peaks in the Gunung Sewu area are between 7,733 to 39,946. The average number of local peaks is 28,755 points. Combination number 13 (circle window with radii 3, and pixel size 8.25 m) can detect small hills that are not detected by a larger window and pixel size parameter combinations. The criteria for local hills detected are a series of hills with several local peaks, cone hills with one local peak, and the highest point on a flat or flat area. These criteria are illustrated in Figure 5.
Sometimes the highest point calculated in the processing is not the peak of a hill. The yellow points in Figure 5a and 5b represent peaks. On the other hand, the yellow point in Figure 5c is not peak. It is just a higher elevation in a flat area. The accuracy of the calculation was assessed against 10 test areas. The number of local peaks and test points is explained in Table 2.

![Figure 5. Different types of local peaks.](image)

*Figure 5. Different types of local peaks.*

| No | Window Type | Pixel Size | A   | B   | C   | D   | E   | F   | G   | H   | I   | J   | Total   |
|----|-------------|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 1  | Rectangle   | 8.25       | 217 | 155 | 210 | 233 | 145 | 173 | 142 | 175 | 145 | 167 | 1,762   |
| 2  | 3 x 3       | 10         | 219 | 158 | 208 | 230 | 141 | 170 | 139 | 177 | 147 | 168 | 1,757   |
| 3  | 16.5        |            | 161 | 117 | 151 | 165 | 116 | 130 | 100 | 141 | 120 | 135 | 1,336   |
| 4  | 8.25        |            | 201 | 148 | 199 | 219 | 137 | 162 | 131 | 160 | 140 | 158 | 1,655   |
| 5  | 5 x 5       | 10         | 196 | 147 | 195 | 214 | 131 | 156 | 128 | 158 | 137 | 154 | 1,616   |
| 6  | 16.5        |            | 92  | 74  | 99  | 111 | 79  | 83  | 71  | 95  | 88  | 91  | 883     |
| 7  | 8.25        |            | 184 | 140 | 184 | 207 | 125 | 147 | 122 | 150 | 133 | 150 | 1,542   |
| 8  | 7 x 7       | 10         | 175 | 134 | 170 | 195 | 123 | 139 | 116 | 145 | 126 | 145 | 1,468   |
| 9  | 16.5        |            | 59  | 50  | 61  | 73  | 56  | 59  | 49  | 65  | 65  | 58  | 595     |
| 10 | 8.25        |            | 171 | 131 | 161 | 184 | 117 | 141 | 112 | 145 | 124 | 142 | 1,428   |
| 11 | 9 x 9       | 10         | 156 | 116 | 152 | 169 | 109 | 125 | 100 | 137 | 114 | 129 | 1,307   |
| 12 | 16.5        |            | 33  | 29  | 39  | 53  | 34  | 38  | 32  | 42  | 39  | 37  | 376     |
| 13 | 8.25        |            | 200 | 147 | 194 | 218 | 134 | 158 | 129 | 159 | 139 | 156 | 1,634   |
| 14 | Circle      | R : 3      | 192 | 145 | 188 | 209 | 131 | 152 | 125 | 156 | 134 | 151 | 1,583   |
| 15 | Circle      | R : 5      | 161 | 117 | 151 | 165 | 116 | 130 | 100 | 141 | 120 | 135 | 1,336   |
| 16 | Circle      | R : 6      | 173 | 129 | 163 | 186 | 116 | 142 | 113 | 146 | 123 | 138 | 1,429   |
The suitability of the combinations of parameters was determined by calculating the difference between the filter result and the test area. From the table, the smallest difference is found in the combination number 13. Combination 14 gave a closer number to the test points, however our visual inspection found that peaks from this combination are deviating from the actual hills.

3.2. Regional peaks
The range of TPI in the Gunung Sewu is from -17.74 to 14.40. Positive TPI indicated that the cell is higher than the neighborhood. If the TPI value is close to the maximum value (14.40), it is an indication that the cell is a peak or ridge. A TPI close to zero is an indication that the cell is a flat area or an area with a constant slope. Negative TPI indicated that the cell is lower than the neighborhood. TPI close to the minimum value (-17.74) indicates that the cell is a valley. TPI value is used to determine landscape classification by the slope position classification method.

The result of the slope position classification is a raster with six landscape classes. The six classes of landscapes are 1 (valley), 2 (lower slope), 3 (flat area), 4 (middle slope), 5 (upper slope), and 6 (ridge). Visualization of the landscape classification is presented in Figure 6a, while the percentage of each landscape class is provided in Figure 6b.

![Figure 6](image.png)

Figure 6. Illustration of landscape classification (a) and percentage of landscape class in the study area (b).

The landscape classes were used to filter out peaks that are not located on top of a hill or not on the ridge. Local peaks are selected based on the point in the ridge called the regional peaks. The best function to detect the local peaks is a rectangle type window with a width of three pixels with a spatial resolution at 8.25 m because it detected the most peaks, 39,946 peaks. The number of regional peaks is 28,432.
hills. The number of local peaks that do not meet the morphological criteria is 11,514 hills. The later are peaks that are located on the flat area or lower slope. In addition, some local peaks are visually hills but based on morphological criteria, the local peaks are classified as the upper slopes.

A number of regional peaks still contains errors because some ridges still have more than one peaks. One hill should be represented by one peak. A hill that has more than one peak is illustrated in Figure 7.

![Figure 7. Ridge with two peaks.](image)

This is different from the hills which have several peaks because on those hills there are several ridges. Therefore, it needs to be selected by choosing a higher peak than the other peaks on the same hill. The selection used automatic methods for detecting regional peaks. The automatic method combined spatial analysis and spatial database. After being selected, the number of regional peaks in the Gunung Sewu area is 27,773.

Based on the evaluation using the slope position classification method, 27,773 regional peaks are representative of the number of hills in the Gunung Sewu. However, visual inspection shows that some ridges could not be detected as peaks by the focal maximum function. Therefore, it is necessary to know the accuracy of the hill classification results.

### 3.3. Accuracy assessment

Regional peaks are evaluated based test points digitized on high-resolution imagery and field surveys. Comparison of the peaks and the digitization point test on test points presented in Table 3.

| Test site | A  | B  | C  | D  | E  | F  | G  | H  | I  | J  | Total | Accuracy |
|-----------|----|----|----|----|----|----|----|----|----|----|--------|----------|
| Regional  | 149| 147| 176| 185| 93 | 148| 79 | 109| 124| 149| 1,359  | 86.2%    |
| peaks     |    |    |    |    |    |    |    |    |    |    |        |          |
| Test      | 191| 146| 187| 211| 127| 154| 126| 154| 132| 148| 1,576  |          |
| points    |    |    |    |    |    |    |    |    |    |    |        |          |

Based on Table 3, the accuracy of the regional peaks is 86.2%. It means that 86.2% of the peaks are detected and 13.8% is not detected by the process of focal maximum function as peak or several regional hilltops which are hills visually but based on criteria morphology is not a ridge. These regional peaks classified as the upper slope. A visual comparison of the two out of ten test areas is presented in Figure 8.
Figure 8. Visual comparison of classification result (yellow) and test points (red).

In addition, a classification accuracy test and the ground truth data to check the classification result. The ground truth data consists of 66 sample points, of which 39 points are hills and 27 points are not hills. A confusion matrix was used in this assessment. It includes the calculation of omission and commission error, as well as producer’s, user’s, and overall accuracy. The confusion matrix is presented in Table 4, while the detailed calculation is presented in Table 5.

| Classification result | Ground truth data |
|-----------------------|-------------------|
|                       | Hills  | Not hills | Total |
| Hills                 | 36     | 5         | 40    |
| Not hills             | 3      | 22        | 26    |
| Total                 | 39     | 27        | 66    |

Table 4. Confusion matrix of the chosen combination.

| Category | Omission | Comission | Producer’s accuracy | User’s accuracy |
|----------|----------|-----------|---------------------|-----------------|
| Hills    | $3/39 \times 100\% = 7.7\%$ | $5/41 \times 100\% = 12.2\%$ | $36/39 \times 100\% = 92.3\%$ | $36/40 \times 100\% = 87.8\%$ |
| Not hills| $5/27 \times 100\% = 18.5\%$ | $3/25 \times 100\% = 12\%$ | $22/27 \times 100\% = 81.5\%$ | $22/27 \times 100\% = 88\%$ |

Table 5. Detail calculation.

Based on overall accuracy, the classification results is 87.9%, is above the tolerance of 85%. These results indicate that the overall results of the interpretation can be accepted and considered correct.
4. Conclusion

The main objective of this paper is to get an estimate of the number of peaks or hills in the Gunung Sewu area. We use the DEMNAS with a spatial resolution of 8.25 m for the calculation. After a series of tests of 24 combinations of parameters, we found that the best combination to detect the peaks is a focal maximum filter run on the rectangle window with a width of 3 pixels at 8.25 m. A slope position classification method was then applied to filter out peaks that are representing the top of hills. Although it still needs refinement and field checking, we found that there are 27,773 of peaks in the region. They consist of conical and polygonal hills.

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