GIS-based ranking and categorization of potential impact on drought as disaster mitigation effort in Bandung Barat Regency (KBB) using Simple Additive Weighting (SAW)

Y H Chrisnanto, F Renaldi*, N Z Afasyari and A I Hadiana

Computer Science Department, Faculty of Science and Informatics, Universitas Jenderal Achmad Yani, Jl. Terusan Jenderal Sudirman, Cimahi 40526, Indonesia

*faiza.renaldi@unjani.ac.id

Abstract. Drought is a disaster that has a significant impact on agriculture, economics, health and the environment, and many other aspects of life all including Kabupaten Bandung Barat (KBB), Indonesia. The Regional Disaster Management Agency (BPBD) of KBB shows that in 2018, over 92,780 houses in 47 villages were affected by drought. This study aims to predict which area in KBB will be impacted by drought using Geographical Information System (GIS). Previous studies have shown much evidence that GIS will work, but none were done in Indonesia. We use the Simple Additive Weighting (SAW) method to create the ranking, categorization, and information on potential droughts. The method analyses historical drought impact, rainfall densities, water resources, rivers, and lakes availability, and settlement area. At the end of this study, we successfully categorize 162 villages into 4 categories. Accuracy on the result is also tested using real data from 2018, which resulted in 70.21% accuracy out compared to all 47 villages that were affected in 2018. An increase in accuracy of 72.50% also highlighted when comparing the result of very high potential and high potential area affected by drought with the 2018 data. Furthermore, a convincing 100% accuracy was obtained when comparing the top-10 data of very high potential in droughts and 2018 data. As our future recommendation, We suggest more parameters to be included in the calculations and also to use a 3-dimensional GIS approach as a tool to visualize the information.

1. Introduction
Drought is a disaster related to the availability of water which is far below the daily needs of human life [1]. It has a significant impact on agriculture [2], economics [3], including health and the environment [4]. The same case happens in Indonesia. As an agricultural country with tropical weather which only consists of dry and rainy seasons, drought can be an obstacle to agricultural production, which has an impact on the economy and changes in the environment that affect human health in the local area. Data from the Regional Disaster Management Agency (BPBD) of West KBB shows that in 2018, over 92,780 houses in 47 villages were affected by drought (water shortage) [5]. KBB is a regency in West Java with a lot of nature tourism. Consequently, it has a higher potential of drought compared to other flat-surfaced regencies. Things were getting worsen by the fact that most of the water resources are set afar from those villages/settlements, thus creating more operational difficulties of transporting the water to all the townships.
Judging from the visible effects of drought in Indonesia especially within the KBB, we compelled it is necessary to take measures to reduce the impact. Implementations of IT in this area, especially Geographical Information System (GIS) has been to be able to visualize the information while in the end can give a clear understanding of spatially based information on the possibility of drought within a dry season [6]. Researches with the results of system [7,8], models [9], or framework [10] of GIS-Based systems has been suggested to reduce the risks of drought systems. The benefits of GIS in general is to provide information that approaches real-world conditions, predicts an outcome and strategic planning [11]. GIS is essential in storing, manipulating, analyzing, re-displaying natural conditions with the help of attribute and spatial data. It also can be integrated with other computer systems at functional and network levels [12]. However, information about the drought in the KBB area, is still lacking at this time, especially spatial data or maps that can display a full spectrum of information. Based on this fact, BPBD of KBB has been dealing with the same problem throughout the years, which is the difficulty of mapping the areas that have the potential to be affected by drought. This situation has been hitting the local government hard enough, hence the priority call–out to this problem is needed. Early investigation showed that BPBD had not yet carried out a regional categorization technique specifically to map potential areas affected by drought based on existing data. It is a very crucial information, as it can be a reference for strategic decision making in overcoming drought disasters related to countermeasures for the drought that will occur again soon. The categorization technique has been known to be able to map information and carry out a certain priority value and recommend action that should be carried out [13].

This study carries out a result of a GIS-Based system of categorizing vulnerable areas affected by drought in KBB. It uses a weighted sum method of Simple Additive Weighting (SAW), using data related to the drought occurred that is initially administered using the spatial processing method by utilizing Quantum GIS as a spatial analysis tool. The result of that will then be weighted to find the order of proneness areas affected by drought.

2. Research methods

After assessing the general views on drought, GIS-based systems, and categorization techniques, we now will go deeply in understanding the research specifically those that have been done in Indonesia. As an archipelago and volcanic country, the GIS-based approach is deemed to be best fit to correctly visualized a set of information. A recent study in Boyolali, Central Java [14] in 2018 was done to determine the potential location of a conservation region, where one area is used as an example or model for other areas to empower communities in and around conservation region. Another study also suggested the use of the SAW method to examine the potential for lightning stricken in Lampung of the island of Sumatra, Indonesia [15]. SAW has also been used to map the location of the slum area in Gorontalo City (of Sulawesi Island) and find areas that have the highest level of necessity to be proposed in the city’s urban spatial plans [16]. Those earlier researches mentioned has justified the use of GIS-based and SAW to solve the problem in Indonesia, thus also applicable to be used within this research.

In this study, five stages were carried out in completing the GIS-based systems including the pre-processing stage (see Figure 1). In the pre-processing stage, we used a manual approach of GIS by combining data in the form of maps, transparent sheet media for overlapping (overlay). Overlay analysis itself is a computerized spatial operation that occurs in two or more coordinated map layers.

In the geoprocessing function, geometric intersection points can be used to combine, modify or update features in the map dataset [17]. Spatial analysis of existing maps is processed in GIS-based tools (QuantumGIS) to retrieve data on maps that will be used in the calculation of a simple additive weighting method. Quantum GIS is an open-source tool, can be used as an alternative (compared to other paid proprietary tools) for GIS processing even though there are still weaknesses in data analysis with vector format that is not able to merge (union) more than two shapefiles [18]. We have initially determined 6 criteria to rank all the analysis per village in KBB, which are: rain densities, drought impact (2018), amount of water resource, total area of per settlement (village), amount of river stream, and amount of lake.
After that, we continue to the first stage of the study, which is to determine the criteria to be used as a reference in decision-making processes. The second stage is to determine the compatibility rating of each alternative on each criterion by codifying each criterion with a certain range. The third step is to create a decision matrix based on criteria (C1), normalize them based on equations that are adjusted to the type of attribute to obtain the normalized matrix R. Finally, the fourth stage is to rank the value (recommendation). Ranking process which acquires by the sum of the normalized matrix multiplication with the weight vector. The largest value is selected as the best alternative (A1). Those results will then be design and developed as a GIS-Based software.

2.1. Pre-processing stage
For rain densities, we use the interpolation method because there is no data of rain densities per village. What we have is data from 3 rain observation post in Bandung, Citeko, and Majalengka. With these 3 data, we estimate values in areas that are not sampled or measured, so a map or distribution of values is made for the entire area of KBB. The three posts are combined based on their respective rainfall data that covers a specific area so that all areas in the KBB can be incorporated in all three areas of each rain observation post, which is assisted with an administrative map of all villages in KBB. Furthermore, polygon these tools are used to determine the scope of the observation (rain) post. To finally retrieve the rain density data per village, we join them using the union tools. For drought data, it is a straightforward action since the data is already available at BPBD. To determine the amount of water resources per village, we manually combine the administrative maps of the KBB area with digitizing the location of springs based on their coordinates. To retrieve the amount of spring water data per village, the Count Point in Polygon tool is used. Map of rivers and lakes are taken from the Rupa Bumi Indonesia (RBI) Map and manually digitized so that they can be divided according to the KBB area. To get the total number of rivers and lakes in the village area, the Joint Attribute by Location tool is used. We also use
the RBI Map to get the total area of the settlement in each village, but for this criterion, we use Union tools.

2.2. Stage 1: Determining the criteria
We determined 6 criteria that were used to initiate the pre-process stage, which include historical data, rain intensity, large and dense, no river flow, far from a lake and water resources. In this stage, we detailed them by explaining what value should be inserted for each criterion and equipped them with a layered map. Table 1 explained the criteria on conformity with primary data and its visualization, which were obtained through interviews with the BPBD of KBB.

**Table 1.** Criteria of potential drought area.

| Criteria          | Assessment (How to)                                                                 | Visualization          |
|-------------------|------------------------------------------------------------------------------------|------------------------|
| Drought Impacts   | Area which directly suffers from drought with settlements in it (not inhabitant area) | Drought Impacts Map    |
| Rain Densities    | The lower the density, the higher chance of the area to have suffered from drought |
| Settlement Area   | The larger the area, the higher the impact of drought                                | Settlements Area Map   |
| Rivers            | The lesser or inexistence of rivers inside the area, the higher chance of drought   | River Map              |
| Lakes             | The lesser or inexistence of lakes inside the area, the higher chance of drought    | Lakes Map              |
| Water Sources     | The lesser or inexistence of water sources (spring) inside the area, the higher chance of drought | Water Resource Map     |

2.3. Stage 2: Determination of compatibility rating for each alternative criteria
In SAW, we weight each of the criteria to create a certain range of data. These weights and ranges for each criterion are obtained from a series of interviews with stakeholders. To accommodate future changes in each weight, we make them dynamic and can be changed inside the system later. The weighting for the criteria will be further explained in table 2 thought table 4 below.

**Table 2.** Weight and range value on drought impacts and rainfall density criteria.

| DROUGHT IMPACT (PEOPLE) | WEIGHT | RAINFALL DENSITY (MM/YEAR) | WEIGHT |
|--------------------------|--------|---------------------------|--------|
| 0 – 300                  | 1      | 0-2270                    | 1      |
| 301 – 600                | 2      | 2271-2360                 | 2      |
| 601 – 900                | 3      | 2361-2450                 | 3      |
| 901 – 1200               | 4      | 2451-2540                 | 4      |
| 1201 – 500000            | 5      | 2541-2700                 | 5      |

**Table 3.** Weight and range value on settlement areas and river amount criteria.

| SETTLEMENT AREA (KM2) | WEIGHT | RIVERS (AMOUNT) | WEIGHT |
|-----------------------|--------|-----------------|--------|
| 0 – 0.00060000        | 1      | 0-1             | 1      |
| 0.00060001 – 0.00097250| 2      | 2-20            | 2      |
| 0.00097251 – 0.00345770| 3      | 21-40           | 3      |
| 0.00345771 – 0.00594290| 4      | 41-60           | 4      |
| 0.00594291 – 0.09999999| 5      | 61-300          | 5      |
We converted data out of 162 villages that have been established through spatial analysis using QuantumGIS tools (see subsection 2.1) using the weight on the range value following Table 2 through Table 4. The following table 5 contains an example of 7 of 162 data overlay results which are then used as an alternative to the adjusted criteria.

Table 4. Weight and range value on lakes criteria.

| LAKES (AMOUNT) | WEIGHT | WATER RESOURCE (AMOUNT) | WEIGHT |
|----------------|--------|-------------------------|--------|
| 0 – 1          | 1      | 0-1                     | 1      |
| 2 – 3          | 2      | 2-3                     | 2      |
| 4 – 6          | 3      | 4-6                     | 3      |
| 7 – 9          | 4      | 7-9                     | 4      |
| 10 – 15        | 5      | 10-20                   | 5      |

Table 5. Weighted alternatives (villages) according to all the criteria.

| Alternatives | Criteria | C1 | C2 | C3 | C4 | C5 | C6 |
|--------------|----------|----|----|----|----|----|----|
| 3217002      |          | 1  | 1  | 1  | 1  | 2  | 1  |
| 3217003      |          | 1  | 1  | 3  | 1  | 2  | 1  |
| 3217004      |          | 1  | 1  | 2  | 1  | 3  | 5  |
| ...          |          | ...| ...| ...| ...| ...| ...|
| 3217203      |          | 1  | 1  | 4  | 1  | 3  | 1  |

Where:
C1 = Drought impact (people)
C2 = Rainfall densities (mm/year)
C3 = Settlement area (km2)
C4 = Lake(s) per village (amount)
C5 = River(s) per village (amount)
C6 = Water resource(s) per village (amount)

2.4. Making a decision matrix based on criteria and normalization

The previous data from Table 6 that has been matched by category/compatibility rating will be used in the processing of the SAW method. It will be visualized in the form of a matrix. Furthermore, we will do the normalization process based on their type of benefits or costs. The SAW method requires the decision matrix normalization process (X) to a scale that can be compared with all existing alternative ratings [19].

The following are the completion steps using the SAW method:

- Determine C1 which is the only criterion that will be used as a reference in decision making.
- Determine the compatibility rating of each alternative on each criterion.
- Make a decision matrix based on (C1), normalize the matrix based on an equation that is adjusted to the type of attribute (profit attribute or cost attribute) to obtain the normalized matrix R. The formula used to normalize using the following equation (1):

\[
R_{ij} = \begin{cases} 
\frac{X_{ij}}{\text{Max}_i X_{ij}} & \text{if } j \text{ is benefit attribute} \\
\frac{\text{Min}_i X_{ij}}{X_{ij}} & \text{if } j \text{ is cost attribute}
\end{cases}
\]

Where:
Rij = Normalized Rating
Minij = Min Value of each row and column
Maxij = Max Value of each row and column

The result of normalizing data form Table 6 can be seen below:
**Table 6. Normalized data (Matrix R).**

| Alternatives | Criteria | C1 | C2 | C3 | C4 | C5 | C6 |
|--------------|----------|----|----|----|----|----|----|
| 3217002      |         | 0.2| 1  | 0.6| 1  | 2  | 1  |
| 3217003      |         | 0.2| 1  | 0.4| 1  | 2  | 1  |
| 3217004      |         | 0.2| 1  | 1  | 1  | 3  | 5  |
| ...          |         |    |    |    |    |    |    |
| 3217203      |         | 0.2| 2  | 0.6| 1  | 3  | 1  |

The normalization results (R) above are then used to rank weights that have been determined in accordance with the decisions described in the table above. The multiplication results produce the final value of the alternative ($V_i$). The biggest value will be set as a reference for the highest potential drought impact and the lowest value is the lowest potential drought impact reference.

2.5. **Rank recommendation**

We also weight each criterion following their importance level from 0% to 100% making them in a total of 100%. The values were derived from interviews and set by the stakeholder and the system’s users. The following table 7 presents the importance weighting of each criterion.

**Table 7. Importance weight on each criteria.**

| Ci        | Criteria             | Weight | Ci        | Criteria         | Weight |
|-----------|----------------------|--------|-----------|------------------|--------|
| C1        | Drought Impacts      | 30 %   | C4        | Lakes            | 10 %   |
| C2        | Rainfall Densities   | 10 %   | C5        | Rivers           | 10 %   |
| C3        | Settlement Areas     | 20 %   | C6        | Water Resources  | 20 %   |

The weight then will be put inside the ranking formula by multiplying it with the normalized matrix R to get the weighted value that can be sorted from the largest to the smallest value. The final result is viewed as the best alternative ($A_i$) of the solution. The preference value for each alternative ($V_i$) is given as a formula in the following Equation (2):

$$V_i = \sum_{j=1}^{n} W_j R_{ij}$$  \hspace{1cm} (2)

Remarks:

$V_i$ = Final result of one particular alternative  
$W_j$ = Pre-defined importance weight  
$R_{ij}$ = Normalized matrix  
$V_i$ value will be sorted from the biggest one into the smallest one. Table 8 will show the summary of the result:

**Table 8. Rank recommendation of drought impact.**

| Alternative | C1 | C2 | C3 | C4 | C5 | C6 |
|-------------|----|----|----|----|----|----|
| 3217154     | 30 | 6  | 12 | 2.5| 4  | 16 |
| 3217147     | 30 | 6  | 20 | 2.5| 6  | 4  |
| 3217151     | 30 | 4  | 20 | 2.5| 6  | 4  |
| ...         | ...| ...| ...| ...| ...| ...|
| 3217022     | 6  | 2  | 4  | 2.5| 2  | 4  |
3. Results and discussions
The result of our study will be carried out in 2 forms: rankings of possibilities of drought impact in KBB and visualization of the ranking using a GIS-based software.

3.1. Possibilities of drought impact
The top-10 of our rank recommendation are Sariwangi (SAW value: 70.5), Rende (68.5), Mandalamukti (66.5), Ganjarsari (66.0), Tenjolaut (64.5), Gunungmasigit (62.5), Wangunjaya (60.5), Sindangkerta (60.5), Cisomang Barat (60.5), and Mandalasari (60.5). These are likely to have drought problems. While the bottom-10 are Buniagara (26.5), Cipangeran (26.5), Cimareme (24.5), Cimanggu (24.5), Padalarang (24.5), Cicangkang Girang (24.5), Galanggang (22.5), Singajaya (22.5), Batujajar Barat (22.5), and Budiharja (20.5). These are all the areas that are unlikely to have a drought. We also categorized those villages into 4 categories of very high potential (to experience droughts), high potential, average potential, and low potential. Based on the calculation starting from the pre-process stage up until the SAW method, 10 villages fall into the category of very high potential for drought, 30 villages with high potential, 102 villages average potential and 20 villages with low potential of drought.

To validate our calculation, we compare the final result in our study to the previous event that has happened which is in 2018. As mention in the introduction section, there were 48 villages impacted by the drought. We compared the 2018 data of 48 villagers with our top-48 data to measure the accuracy of our SAW methods (see Figure 2). It is found that 33 out of 47 villages were matched (marked with green color in Figure 2), to create an accuracy of 70.21%. This can be considered as moderate-to-high accuracy. If we were to use the findings from our SAW methods which are 10 villages of very high potential and 30 of high potential, we will see a different result. Out of the very high potential result (10 villages), we struck a very convincing 100% accuracy, which means that all the villages were indeed suffered from very high droughts in 2018. While for the total of very high potential and high potential, we have an accuracy of 72.50% (29 villages are accurate out of 40 villages), also in the area of moderate-to-high accuracy.
Figure 2. Comparison between ranking using SAW and real data 2018.

3.2. GIS-based software

We visualized the system on the SAW method starting from defining the criteria until visualization of rank recommendation. The users of the systems are the logistics department and the mitigation department. The latter is the central user of this system as they are the ones who create plans and simulate all the criteria to recommend areas to observe in terms of droughts soon.
Figure 3. GIS software of overlay map (right) and visualization of drought potential (left).

As depicted in Figure 3, for the overlay map, we can see the information of settlements, lakes, rivers, and rainfall densities and a visualization of drought potential maps in KBB. We accommodate the stakeholders and users with a dynamic value of decision weight to create more possibilities for adjusting the value for simulation purposes (see figure 4). This feature will create a chance to fine-tune the accuracy level within the systems to achieve better accuracy.

Figure 4. GIS software of dynamic value (adjustable) of decision weight.

4. Conclusions
In this study, the calculation of droughts potential using the SAW method was not a straightforward situation since some spatial analytical techniques need to apply in the pre-processing stage. We have analyzed 162 villages in KBB which resulted in 10 villages that were found to have a very high potential for drought, 30 villages with high potential, 102 villages average potential and 20 villages with low potential of drought. We have a 100% accuracy in terms of predicting severe droughts (very high potential), while we also have a 72.50% accuracy in our total calculation of very high and high drought potential compared to what has happened in 2018 (real reference data from BPBD of KBB). Lastly, there is a 70.21% accuracy if we compare our rank recommendation to the real data of all the impacted villages (47 of them) in KBB in 2018. The challenge on how to increase the accuracy has been solved and made available in the systems by providing a dynamic parameter feature which allows user to change the weight of each criterion and also in the decision criteria. Furthermore, we also suggest to further study this by adding more criteria such as contour level, soil water volume, soil texture (for permeate level), and recharge area.

References
[1] Wilhite D A 2000 Chapter 1 Drought as a Natural Hazard: Concepts and Definitions Drought Mitigation Center Faculty Publications 1(1) 3-18
[2] Ding Y, Hayes M J and Widhalm M 2011 Measuring economic impacts of drought: a review and discussion Disaster Prevention and Management: An International Journal 20(4) 434-446
[3] Salami H, Shahnosshi N and Thomson K J 2009 The economic impacts of drought on the economy of Iran: An integration of linear programming and macroeconometric modelling approaches Ecological Economics 68(4) 1032-1039
[4] McMichael A J, Friel S, Nyong A and Corvalan C 2008 Global environmental change and health: impacts, inequalities, and the health sector Bmj 336(7637) 191-194
[5] Satti S R and Jacobs J M 2004 A GIS-based model to estimate the regionally distributed drought water demand *Agricultural Water Management* **66**(1) 1-13

[6] Tao J, Zhongfa Z and Shui C 2011 Drought monitoring and analysing on typical karst ecological fragile area based on GIS *Procedia Environmental Sciences* **10** 2091-2096

[7] Suryabhagavan K V 2017 GIS-based climate variability and drought characterization in Ethiopia over three decades *Weather and climate extremes* **15** 11-23

[8] Valencia J, Monserrate F, Casteleyn S, Bax V, Francesconi W and Quintero M 2020 A GIS-based methodological framework to identify superficial water sources and their corresponding conduction paths for gravity-driven irrigation systems in developing countries *Agricultural Water Management* **232**(1) 1-9

[9] Ayalew L, Yamagishi H and Ugawa N 2004 Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, *Japan Landslides* **1**(1) 73-81

[10] Lumban Batu J A J and Fibriani C 2017 Analysis of Determination of Flood Evacuation Locations by Using Geographic Information Systems and Simple Additive Weighting Methods (Case Study: Surakarta City) *Jurnal Teknologi Informasi dan Ilmu Komputer (JTIK)* **4**(2) 127-135

[11] Ahaliki B 2018 Geographical Information System (GIS) Mapping Location of Slum Settlement Infrastructure Facilities in Gorontalo City with Analysis of SAW Method *Jurnal Teknologi Informasi Indonesia* **3**(1) 18-22

[12] Arumsari Y and Joko S Y 2018 Geographic Information System Design for Recommended Conservation Area Model by Implementing Simple Additive Weighting (SAW) Method in Boyolali Regency *Indonesian Journal of Modeling and Computing* **2**(2) 55-63

[13] Cokrowibowo S and Ismail 2017 Analysis of Determination of Outlet Locations Using Geographic Information Systems and Simple Additive Weighting Case Study: Outlet Kalla Automotive *PROSIDING – Kajian Ilmiah Dosen Sulbar* **1**(4) 192-209

[14] Husodo H S 2018 “Water shortage in West Bandung affected 90.000 citizens,” Pikiran Rakyat, 28 2018 [Online] Retrieved from: https://www.pikiran-rakyat.com/ [Accessed on: 14 9 2019]

[15] Malczewski J and Rinner C 2015 Multicriteria Decision Analysis in Geographic Information System (New York: Springer Science)

[16] Menke K, Smith R, Pirelli L and Hoesen J V 2016 *Mastering QGIS* Second Edition (Birmingham: Packt Publishing Ltd.)

[17] Sugiyono and Agani N 2016 Digital Map Model of Lightning Stranger by Using the SAW (Simple Additive Weighting) Method Case Study in Lampung Province *Jurnal Telematika MKOM* **4**(1) 90-96

[18] Yunarto and Sukristiyanti 2016 Geographic Information System Location Rating Potential Landslide Evacuation Using Simple Additive Weighting Method Case Study: Garut Regency *Prosiding Pemaparan Hasil Penelitian Puslit Geoteknologi – LIPI 2016* **2**(20) 74-86

[19] Yin Y, Zhang X, Lin D, Yu H and Shi P 2014 GEPIC-VR model: a GIS-based tool for regional crop drought risk assessment *Agricultural Water Management* **144** 107-119