Development of Highland Vegetable Commodity Areas Through Multi-Criteria Decision Making (MCDM) Analysis and Geographic Information Systems

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Abstract. The highlands in Central Java have a major contribution to meet the national demand for vegetables. However, competition for these lands by non-agricultural sectors or for the production of other agricultural commodities could lead to a decline in vegetable production. The research aimed to spatially analyze the land suitability and availability for highland vegetable commodities. It also aimed to analyze the land potential for the development of vegetable commodity areas. The research was carried out in Banjarnegara and Wonosobo Regencies, at an altitude of more than 700 meters above sea level, from July to December 2020. The methodology used was Multi-Criteria Decision Making with Analytical Hierarchy Process structure and map overlay, using ArcGIS ver. 10.5. The results showed that land which is suitable for the highland vegetable commodities was at 33.52%, it was dominated by a class of moderately suitable (S2). Furthermore, the suitable and available land for vegetable cultivation covers an area of 16.03 %. Finally, there were 9,911.2 hectares of land that had not been optimally used and had the potential to become a development area for highland vegetable commodities in the future.

1. Introduction
The increase in human population has an impact on increasing the need for land as a residential area and for food production. Furthermore, it significantly affects food security and linearly affects the area of available agricultural land [1,2]. The decrease in the agricultural land area does not only occur in lowlands with a tendency to be close to the center of cities, as it also occurs in highlands, which occupy an area of only 7.3 percent of the potential agricultural land area in Indonesia [3]. In the agricultural sector, highlands are majorly used in the horticulture sub-sector, especially for vegetable production. Vegetables have strategic roles in humans, namely, as food sources with high nutrients, vitamins, and minerals, as raw materials for agricultural or agro-industrial products, as sources of state income and foreign exchange in support of economic growth, and as sources of business opportunities in both upstream and downstream industries.

The contribution of vegetable commodities to economic growth has not received much attention, even though their marketing provides business opportunities for the young generation. With technological adaptive characteristics, these commodities provide more financial benefits in a shorter period compared to other agricultural commodities [4]. The high demand in terms of quantity and quality due to increased awareness of consuming vegetables has not been fully met by domestic production. Therefore, the rate of import is still greater compared to exports [5]. This condition is caused by several
factors. At the practical level of agricultural area development, land availability is one of the inhibiting factors [6]. At the same time, low efficiency and productivity are affected by land suitability, agrotechnological factors, and conservation efforts [7,8]. Various factors need to be considered before developing agricultural areas in mountainous regions to ensure that there is an efficient and sustainable use of land. They include plant types and growth requirements, elevation factors, and conservation efforts.

Java Island has the most significant contribution to national vegetable production, while Central Java Province is the most significant contributor of commodities like onions, garlic, potatoes, cauliflower, carrots, and chilies [9]. However, the high potential for vegetable production in the highlands of Central Java is constantly being challenged due to the increased use of land by the tourism, housing, industrial, and other non-agricultural sectors. The northern area of the research location has a function as a protected area, upstream of the Serayu River, and as a cultural heritage area. This implies the need for strict land-use regulations to achieve efficiency by taking into account the level of land suitability. At a practical level, vegetable productivity is affected by several factors that tend to be dynamic and have a complexity level that has to be measured with certainty [10,11]. Therefore, a multi-criteria approach is needed in decision making to optimize productivity.

Multi-Criteria Decision Making (MCDM) is a system of approach that refers to a comprehensive perspective of solving complex problems such as those of the agricultural sector [12]. Based on this background, the research objectives were to spatially analyze the land suitability for vegetable commodities using the criteria weighting method, land availability for vegetable commodities, and the land potential for developing vegetable commodity areas in the highlands of Central Java.

2. Methods

2.1. Location and time of research
This research was conducted in the Highlands of Central Java Province that could achieve self-sufficiency in the horticulture sub-sector, especially in the development of vegetable commodities. Moreover, the horticulture center was located in the Dieng Plateau area. The research location constituted the Banjarnegar and Wonosobo Regencies which were at more than 700 meters above sea level. Based on this height, there are seven sub-districts in Banjarnegar Regency and eight in Wonosobo Regency. The research was conducted from July to December 2020.

2.2. Method of collecting data
The primary data were obtained through weighted interviews with the criteria of land suitability for vegetable commodities. Furthermore, the weight of the criteria for the suitability of vegetable land was determined based on the opinion of seven experts from the Directorate General of Horticulture, Center for Research and Development of Agricultural Land Resources (BBSDLP), Center for Agricultural Technology Studies (BPTP) Central Java, Agriculture, Fisheries and Food Security Office, and also from academics. The use of experts in the weighting criteria could produce more appropriate criteria, because of their expertise in knowing specifically the characteristics of the research area [13].

Land suitability parameters include biophysical suitability factors such as soil type, elevation, slope, rainfall, temperature, and humidity. Social suitability factors include land use, distance to markets, and access roads. Secondary data in the form of spatial data on soil biophysical parameters were obtained from a 1:50,000 scale soil map sourced from BBSDLP. Furthermore, climatic data, including rainfall, temperature, and humidity, were obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). Topographic data were obtained from topographic maps at a scale of 1:25,000 that were sourced from the Indonesian Geospatial Information Agency (BIG). Also, land use data were obtained from the Ministry of Environment and Forestry (KLHK), while spatial data on spatial patterns were obtained from the Regional Spatial Plan (RTRW) of Banjarnegar and Wonosobo Regencies with a scale of 1:50,000.
2.3. Data analysis method
Land suitability was analyzed using Multi-Criteria Decision Making (MCDM) with Multiple Analysis Decision Making (MADM) structure. Furthermore, it was analyzed using map overlay with Microsoft office and ArcGIS ver 10.5. The weighting of the criteria element scores was carried out using the Analytical Hierarchy Process (AHP) method on a scale of one to nine in a pairwise comparison and the form of a matrix. Moreover, the matrix describes the dominating and dominated priorities between one criterion element and another [14]. The opinions of seven multidisciplinary experts were first checked for consistency and combined using a geometric mean which was then processed using the AHP procedure. Each criterion element of the biophysical and social parameters was assigned a score between 0 and 10 depending on the level of importance; thus, the ranking was determined. The weighted scores of the criteria elements and the results of the pairwise comparison assessment were then used to obtain a GIS model and overlay the map to obtain a map of the land suitability for vegetable commodities. The land suitability class for the vegetable commodities was categorized into four, namely, highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N), based on the equations [11,15] as follows:

\[ S = \sum_{i=1}^{n} w_i x_i \]

where, \( S \) = land suitability, \( w_i \) = weight of land suitability criteria, \( x_i \) = sub-criteria score, and \( n \) = number of land suitability criteria.

The result of the land suitability class is complemented by each limiting factor. The Highly suitable class (S1) is characterized by no or only minor limiting factors to a sustained application that will not significantly reduce the productivity. Limiting factors in the land which in the aggregate are moderately severe for sustained application called moderately suitable (S2). Marginally suitable land (S3) is characterized by limitations which in the aggregate are severe for sustained application and reduce productivity. Not suitable class (N) is indicated by land’s qualities that are so severe as to preclude successful sustained use of the kind under consideration[16,17].

In conducting land suitability analysis, lands that serve natural purposes like those for water bodies, steep walls, settlements, and rock outcrops are separated and not considered. Therefore, the existing land available for consideration is used for the development of horticultural areas such as dryland agriculture areas and rice fields. The overlay of land suitability for vegetable commodities and land availability produces the availability of land suitable for cultivating vegetable commodities, either those currently cultivated or land that is still available to be cultivated as a vegetable area development.

3. Results and Discussion
The classification of biophysical and social parameters was grouped into nine criteria that have been scored by experts. There were six soil orders, including Andisols, Inceptisols, Alfisols, Oxisols, Ultisols, and Entisols, and eight soil great groups at the research location. Characterization and evaluation of the soil which include soil type, texture, and gleying processes helped to assess their constraints and potentials for crop production [18,19]. The largest soil great groups were Hapludands (44.57%), Dystrudepts (19.56), and Hapludalfs (15.27%), while other soil types were found in areas less than eight percent of the total available land. Furthermore, the highest score of 10 was given to the Soil Great Group, Hapludands, which was included in the Andisols order, derived from the primary material of volcanic ash. The results are in line with Widiatmaka [11] and Haryati [20], which showed that most of the vegetable cultivation in the highlands occurs in fertile Andisols and is in areas affected by volcanic activity, whether active or inactive.

A score of nine was given to the Soil Great Group, Eutrudepts, which was included in the Inceptisols order, and Hapludalfs, which were then included in the Alfisols order. Eutrudepts have vertical characteristics, with fractures \( \geq 0.5 \) cm wide and \( \geq 30 \) cm deep, while Hapludalfs have lytic contact within 50 cm of the mineral soil surface [21]. Another orders of Inceptisols and Dystrudepts were given a lower score of eight because of their lower fertility and saturation levels. The soil great group
Endoaquents from the Entisols order had a score of eight with base saturation characteristics of less than 50% at a depth of 20-50 cm from the soil surface. Furthermore, the group had no characteristic horizon, was not coarse-textured from any albic material or horizon, and had a high fertility level. Other Entisols orders found in the research area were Udorthents, which had a lower score of four, with the characteristics of being developed from young alluvium material and having a layered arrangement with irregular organic C levels.

The soil great group Hapludults belonged to the order Ultisols which was classified as acidic soil. However, it was suitable for agricultural purposes; after treatment with organic matter, fertilizers, as with proper fertilization, it got a score of six. Apart from the Ultisols order, the Oxisols order was also a productive acid land for agricultural areas. Hapluodixs, which are part of the Oxisols order, was given a score of five with the characteristic of having a clay content of 40% or more in the fraction of fine soil between mineral soil surfaces [21].

Altitude is an important factor in vegetable cultivation as it affects plant growth. The higher a place is, the greater the tendency for a change in the intensity and spectrum of light, causing a decrease in temperature and an increase in humidity [22]. The research location was grouped into four, with the largest area being at an altitude of 700-1000 m asl and constituting 40.36% of the total available land. This region had the most cultivated vegetable commodities; therefore, it was given a score of 10. Additionally, scores 9 and 8 were given to the areas with altitude > 1000-1300 and > 1300-2000 m asl, which occupied the next largest area. Finally, the area at an altitude of more than 2000 m asl with an area of 5.34% was not given a score because it was a protected area.

The slope condition at the research location with the largest area was rather steep, steep, and gently sloping. Meanwhile, the optimum condition for vegetable cultivation is an area with a flat to gentle slope; therefore, there was a decrease in score levels from flat to steep areas. Steeper slopes are more costly and labor-intensive to manage, including water management, and are more prone to erosion hazards. An area with a slope > 40% is given a zero score because it is not a cultivated.

Rainfall intensity in the research area was in the range of 700 to 3000 mm/year. This condition was ideal for cultivating vegetable commodities; therefore, it was given a score of 10. Extreme rainfall would damage plant growth, and when the condition of the agricultural land is steep and does not have terracing contours, the soil would be more susceptible to rain flow. The higher rainfall caused production costs to increase, especially for the purchase of pesticides and a decrease in production. Apart from rainfall, the temperature had a significant influence on the growth of vegetable crops. Around July and August, there is often frost in the Dieng Plateau, with temperatures reaching a critical point of zero degrees and sometimes even -8 °C [23]. Meanwhile, the normal temperature range in the research area was between 8-23 °C, with the widest area, which constituted 45.84% of the land area, being at a temperature of 20-23 °C.

The optimum temperature for vegetable growth is in the range of 16-18 °C; therefore, the research area was given a score of 10. A score of eight is given at temperatures > 14-16 °C and > 18-20 °C. Temperatures that are lower or higher than these sub-criteria could cause metabolic disorders and inhibit growth [22]. Temperatures also show a positive gradient to rainfall [24]. One of the problems in developing vegetable commodities such as potatoes in medium plains as a solution to minimizing environmental damage in the highlands is high temperatures, which could reduce tuber production. In the post-harvest handling process, high temperatures could also cause vegetables to spoil quickly due to low humidity levels. The entire research area was at a humidity of 82-83%, which was ideal for vegetable growth. Moreover, rainfall, soil type, and transpiration rate determine soil moisture and water availability for plant growth [25]. The high intensity of the sun would cause an increase in the rate of evaporation; therefore, humidity would be lower and have an impact on the soil condition, making it getting drier and inhibiting the growth of vegetable crops.

In the research area, dry land and mixed dry land were the largest areas followed by plantation areas. Vegetable commodities were mostly found in dryland areas; therefore, a score of 10 was given to those areas because they were the most suitable. In this case, non-irrigated rice fields also had the potential for cultivating vegetable commodities, either as intercropping or alternating crops, when the land was
not planted with rice; therefore, they were given a score of eight. A score of five is assigned to secondary dryland forest, plantation forest, scrub, and open land, which, although currently not a cultivation location, have the potential for regional development. Finally, a zero score is given to water bodies and built-up land that are unlikely to be converted into cultivated land for vegetable commodities.

The highland areas in Banjarnegara and Wonosobo Regencies have relatively good and adequate road access. Therefore, the highest score was given to the nearest road access as a means of transportation, for transporting vegetables because vegetables are easily damaged and do not last long. Likewise, regarding market accessibility, the highest score was given for the closest distance to the market location, which was located in each sub-district center. Transportation plays a vital role in the development of the agricultural sector because adequate access to village roads and markets could reduce the cost of agricultural inputs because agricultural commodity prices are often found due to the high cost of transportation [26]. In addition, market issues, including fluctuations in market prices and instability in output markets, were the most barriers and most concerns to the farmers in the areas [27].

The results of weight calculations using pairwise comparisons presented in table 1 gave a Consistency Ratio (CR) value of 0.072. This value was ≤ 0.1; therefore, the answers from the experts were considered to have consistency and validity. Based on table 1, the highest weight is the type of soil that has a relationship with productivity, soil resistance and was a determining factor for the amount of erosion. The next highest weight was the altitude and slope. On forest land, monoculture and intercropping agriculture on the same slope could cause different rates of erosion. Apart from the type of vegetation, another soil physical characteristic that affects the amount of erosion is the slope. Special attention needs to be given to conservation efforts when vegetables are being cultivated in upland and sloping areas.

Rainfall and temperature obtained weights of 0.096 and 0.077. Furthermore, rainfall in the research area with the greatest slope of > 15-25%, was in the high category, reaching 230 rainy days per year. This vulnerability, when coupled with inappropriate land use, has the potential to trigger landslides. Temperature and humidity had smaller weights because in areas with an altitude > 700 m asl, they did not show a significant difference. Regarding land use, dryland agriculture and forestry are the most common and are not a problem, although, in practice, it is necessary to carry out supervision. Therefore, no land conversion threatens conservation efforts. Dieng Plateau was present in the north of the research area. This plateau is a leading tourist destination due to the adequate road and market access.

**Table 1.** Pairwise comparisons in determining the weights of land suitability criteria.

| Criteria elements A | (a) | (b) | (c) | (d) | (e) | (f) | (g) | (h) | (i) | Weight |
|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
| Soil great group (a) | 1   | 2   | 3   | 6   | 5   | 8   | 4   | 7   | 8   | 0.309  |
| Altitude (b)        | 1/2 | 1   | 2   | 5   | 4   | 7   | 4   | 7   | 8   | 0.233  |
| Slope (c)           | 1/3 | 1/2 | 1   | 3   | 3   | 6   | 2   | 6   | 6   | 0.152  |
| Rainfall (d)        | 1/6 | 1/5 | 1/3 | 1   | 2   | 4   | 3   | 5   | 6   | 0.096  |
| Temperature (e)     | 1/5 | 1/4 | 1/3 | 1/2 | 1   | 3   | 3   | 4   | 5   | 0.077  |
| Humidity (f)        | 1/8 | 1/7 | 1/6 | 1/4 | 1/3 | 1   | 2   | 3   | 4   | 0.044  |
| Land use (g)        | 1/4 | 1/4 | 1/2 | 1/3 | 1/3 | 1/2 | 1   | 3   | 3   | 0.047  |
| Access to market (h)| 1/7 | 1/7 | 1/6 | 1/5 | 1/4 | 1/3 | 1/3 | 1   | 2   | 0.024  |
| Access to road (i)  | 1/8 | 1/8 | 1/6 | 1/6 | 1/5 | 1/4 | 1/3 | 1/2 | 1   | 0.018  |

Consistency vector value (p): 9.833
Consistency index value (CI): (p-n) / (n-1) = (9.833 - 9) / 8 = 0.104
Random index (RI): 1.45
Consistency ratio (CR): CI / RI = 0.072

The results of the land suitability analysis for vegetable commodities are presented spatially in figure 1 and quantitatively in table 2 column (b). Figure 1 (a) shows that the dominant land suitability class was moderately suitable (S2) for vegetable cultivation, at 33.52%. Furthermore, unsuitable land covered
2.20% because the location was at the top with an altitude and slope of more than 2000 m asl and 40%, respectively. The unsuitable and constrained areas included water bodies, steep walls, rock outcrops, totalling 22.57%, which means that there was 77.43% of potential land for cultivating vegetable commodities. The area includes 45.19% in the Banjarnegara Regency and 51.49% in the Wonosobo Regency area. Figure 1 (b) shows the availability of land obtained from the maps of the Banjarnegara and Wonosobo District Spatial Planning (RTRW). Meanwhile, the results of the suitability overlay and land availability for vegetable commodities are presented in figure 2.

![Figure 1](image.png)

**Figure 1.** Land suitability and land availability for highland vegetable commodities: (a) land suitability, (b) land availability.

**Table 2.** Land suitability and land availability for highland vegetable commodities.

| Suitability Class | Area of Vegetable Commodities (a) | Land Suitability and Availability (b) | Potential for Vegetable Development (c) |
|-------------------|-----------------------------------|--------------------------------------|---------------------------------------|
|                   | ha                  | %    | ha | %    | ha | %                   |
| S1 (Highly Suitable) | 26,963.36          | 28.70 | 10,023.09 | 10.67 | 1565.56 | 1.67 |
| S2 (Moderately Suitable) | 31,495.85         | 33.52 | 15,064.70 | 16.03 | 6,275.38 | 6.68 |
| S3 (Marginally Suitable) | 14,290.97         | 15.21 | 5,265.26 | 5.60 | 2,070.26 | 2.20 |
| N (Not Suitable) | 2,062.76           | 2.2   | 1,089.21 | 1.16 | - | - |
| Constrain | 19,142.66         | 20.37 | 3,316.76 | 3.53 | - | - |
| Not Available | 59,196.58         | 63.00 | 84,044.40 | 89.45 | 84,044.40 | 89.45 |
| Total | 93,955.60         | 100  | 93,955.60 | 100.00 | 93,955.60 | 100.00 |

In figure 2, areas designated as forest and agricultural areas were not included in the analysis. Furthermore, the Dieng Plateau in the northern region was designated as a protected area to protect the area below, as the upstream of the Serayu River and a cultural heritage area for the Hindu temples. Based on the analysis, it was found that 63% of the land or an area of 59,196.58 ha was not available, and the suitable and available land was majorly in the moderately suitable class (S2).

The potential for vegetable cultivation could be increased by using all the suitable and available land for upland vegetable cultivation. In this case, data on land that has been used for vegetable cultivation, such as paddy fields and dry land, were not re-included. The scrublands included in the forest area were also not taken into account in the analysis. There was 9,911.2 ha or 10.55% of the total land available for the development of vegetable cultivation in the future, which was mainly derived from mixed drylands and open lands that are currently not optimally used. In practical terms, to achieve sustainability, the development of the vegetable cultivation area should refer to the rules for land use and conservation efforts.
4. Conclusion
Land management in the highlands as a location for developing vegetable cultivation areas needs to pay attention to the aspects of land suitability and availability by referring to land use regulations. There were nine criteria used for ascertaining land suitability, namely, soil type, height, slope, rainfall, temperature, humidity, land use, distance to roads, and access to markets. The spatial analysis with a geographic information system based on multi-criteria decision making showed that the land suitability class for vegetable commodities was dominant in moderately suitable conditions (S2), while, unsuitable conditions (N) had the smallest percentage. The land that was not optimally used could be utilized for the development of vegetables. Furthermore, it covered an area of 9,911.2 ha with a varied and dominant land suitability class that was quite suitable or moderate. Given the increasingly limited amount of agricultural land, it was necessary to make land-use engineering efforts and adaptive technology, in order that the needs of vegetables both on a personal, national and global scale could still be fulfilled.

The results on land suitability and availability could be used for future land use planning. However, further analysis related to land suitability for specific types of vegetables needs to be carried out; therefore, land use planning could be more detailed and contribute significantly to increased highland vegetable production.

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