BAREKENG: Journal of Mathematics and Its Applications
December 2023 Volume 17 Issue 4 Page 2411–2420
P-ISSN: 1978-7227 E-ISSN: 2615-3017
https://doi.org/10.30598/barekengvol17iss4pp2411-2420

CLUSTERING OF FOOD SECURITY IN PAPUA ISLAND: WITH AN OPTIMIZED SPATIAL FUZZY CLUSTERING APPROACH

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ABSTRACT

Food needs are primary needs that must be met by everyone to maintain their survival. The condition of stable food security is still not evenly distributed throughout Indonesia. Papua Island is one of the regions that has low food security conditions. In identifying the characteristics of food security in Papua Island, it can be done using cluster analysis. The cluster analysis method used in this research is classical FGWC and FGWC with optimization of HHO. This method has considered the spatial element in the grouping process. The purpose of this study is to classify the level of food security in Papua Island and determine the effectiveness of using optimization in FGWC. Based on the evaluation results, it was found that the FGWC-HHO method was the most optimal method with a total of 3 clusters. Cluster 3 consists of 18 regencies is a cluster with a low level of food security, so this cluster can be used as a priority in handling the problem of food security which is still low in Papua Island.

Article History:

Received: 26th August 2023
Revised: 22nd October 2023
Accepted: 21st November 2023

Keywords:

FGWC;
Food Security;
Optimization.

How to cite this article:

R. A. Pasaribu and E. T. Astuti., "CLUSTERING OF FOOD SECURITY IN PAPUA ISLAND: WITH AN OPTIMIZED SPATIAL FUZZY CLUSTERING APPROACH," *BAREKENG: J. Math. & App.*, vol. 17, iss. 4, pp. 2411-2420, December, 2023.

Journal homepage: *https://ojs3.unpatti.ac.id/index.php/barekeng/*
Journal e-mail: *barekeng.math@yahoo.com; barekeng.journal@mail.unpatti.ac.id*

Research Article · Open Access

1. INTRODUCTION

Food is a basic human need that must be met at any time both in terms of quantity and quality, therefore it is very important to create a strong and stable food security system. Fulfilling food needs is a human right that must be fulfilled because it has a very important role in nation [1] building. Fulfillment of food needs at the regional level up to the individual which includes availability, access, and good use of food can create a sustainable food security system. Food security is a major issue in the development of a country, because it has a role as the main target of development and the economy [2]. In line with this, [3] stated that development is a factor that cannot be separated in realizing food security in a region.

In Indonesia, the condition of evenly distributed food security cannot be achieved completely. The results of research conducted by The Economist Intelligence Unit (EIU) in 2020 Indonesia's food security rating has decreased compared to 2019. In 2020 Indonesia is ranked 65 out of 113 countries with a food security score of 59.5. This value has decreased when compared to 2019, Indonesia's food security score was 62.6 and was ranked 62 out of 113 countries [4]. The National Food Security Agency (BKP) is targeting a prevalence value of under-consumption of 6.2 in 2020 [5]. However, this target has yet to be achieved, BPS recorded the prevalence value of insufficient consumption by the Indonesian population in 2020 at 8.34. These results indicate that there are still areas in Indonesia that have not achieved a good level of food security.

In general, Papua Island is known to still have a low level of food security. This can be seen from the 2020 Food Security Index values. Papua Province and West Papua Province have respective values of 35.48 and 46.05. This makes the provinces of Papua and West Papua fall into the range of priorities 1 and 2 in handling food security issues. This can also be seen from the level of calorie and protein consumption in the Papuan population which is still below the set standards [5].

The diversity of geographical conditions, climate, regional potential has a variant effect in the results of food security. The differences between these regions are spatial problems caused by geographical factors that affect food security [6]. This has also been proven from several related studies inferentially in identifying spatial influences on food security in Indonesia [7], [8], [6]. Therefore, a statistical method is also needed that takes into account geographical location or observational location factors in identifying the characteristics of food security in a region [9].

Fuzzy Geographically Weighted Clustering (FGWC) is a method that has included geographical or spatial elements in the clustering process. This method was developed by [10]. This method has used population information and distances between regions on the degree of membership of Fuzzy C-Means which makes the clusters formed sensitive to spatial interactions between observation units (geographically aware). However, the FGWC method still has a weakness which lies in the cluster center initialization process, namely the limitation in choosing the initial cluster center value because it is done randomly which causes the FGWC method to easily get stuck in the local optima. This can cause the iteration process to fail to reach the optimum global solution [11]. Therefore, a method for developing FGWC is needed to overcome these weaknesses. One solution that can be used is to use an optimization algorithm to get the optimum global solution. The optimization algorithm that is widely used today is meta-heuristic optimization. This method has a greater chance of reaching a better solution in a shorter time than simple heuristic methods or other optimization algorithms [12]. The metaheuristic algorithm that will be used in this research is Harris-Hawk Optimization (HHO). Measurement of food security is multidimensional, so that appropriate optimization is needed so that the results of the grouping become optimal. HHO optimization can find a superior solution with a stable balance in line with the increase in dimensions (multidimensional). This is because the parameters in HHO optimization are adaptive and time-varying that can allow HHO to handle the problem of searching for local optimal solutions well. This optimization algorithm will be integrated with FGWC to optimize the cluster initialization process. Based on this point, the purpose of this study is to classify the area based on the level of food security on the island of Papua by considering the element of territorial or geographical influence in the grouping process and optimizing the results of grouping.

2. RESEARCH METHODS

2.1 Scope of Research

The scope of this research is all districts/cities in Papua Island. The number of analysis units in this study are 42 districts/cities. The research period is 2020. The analysis used in this study is cluster analysis using the Fuzzy Geographically Weighted Clustering-Harris Hawk Optimization (FGWC-HHO) method. The measurement of food security in this study is based on the four pillars of food security in the 2020 Global Food Security Index (GFSI), and is adjusted to the availability of existing data.

2.2 Data

In this research, we used secondary data obtained from publications by the Central Statistics Agency (BPS) and the Meteorology, Climatology and Geophysics Agency (BMKG) of Papua and West Papua Provinces in 2020. The Global Food Security Index (GFSI) measures food security using four main pillars namely affordability, availability, quality and safety, as well as natural resources and resilience. Affordability measures consumers' ability to buy food, their vulnerability to rising food prices, as well as the programs and policies implemented in the event of a food crisis. Availability measures the adequacy of national food, the risk of supply delays, national capacity to socialize food and research efforts to expand agricultural output. Quality and safety measure the variety and nutritional quality of food and the safety of food conditions. Natural resources and resilience measure exposure to the impacts of climate change, vulnerability to risks of natural resource crises and adaptation in dealing with climate change risks and limitations of natural resources. The variables used in measuring food security are presented in the following table :

Table 1. Variables and References

Variable	Name	References
	Affordability	
X1	Percentage of poor population	[13], [14], [15], [16], [17]
X2	GRDP per capita (thousands of rupiah)	[18]
X3	Ratio of good and moderate roads to area (km/km^2)	[16], [18]
	Availability	
X4	Average calorie consumption (kkal)	[16]
X5	Average protein consumption (grams)	[16]
X6	Percentage of households receiving food assistance (%)	[4]
	Quality and safety	
X7	Percentage of households with a source of clean drinking water (%)	[15], [14], [16]
X8	Percentage of households with access to electricity (%)	[15]
X9	Average length of schooling for girls (years)	[18], [14]
	Natural resources and resilience	
X10	Population growth rate	[19]
X11	Total rainfall (RR)	[4]

2.3 Methods

2.3.1 Fuzzy Geographically Weighted Clustering (FGWC)

Fuzzy Geographically Weighted Clustering (FGWC) was developed by Mason & Jacobson [10]. This method has used population information and distances between regions on the degree of membership of Fuzzy C-Means which makes the clusters formed sensitive to spatial interactions between observation units (geographically aware). The grouping process in the FGWC method is carried out by minimizing the objective function as follows :

$$J(\boldsymbol{U},\boldsymbol{V};\boldsymbol{X}) = \sum_{i-1}^{c} \sum_{k=1}^{n} u_{ik}^{m} \|\boldsymbol{v_i} - \boldsymbol{x_k}\|^2 \quad (1)$$

The cluster center is formulated as follows:

$$\boldsymbol{v_i} = \frac{\sum_{k=1}^{n} u_{ik}^{m} \boldsymbol{x_k}}{\sum_{k=1}^{n} u_{ik}^{m}} \qquad (2)$$

The membership matrix before geographic modification can be formulated as follows :

$$\boldsymbol{u_{ik}} = \frac{\mathbf{1}}{\sum_{j=1}^{c} \left(\frac{\|\boldsymbol{v_i} - \boldsymbol{x_k}\|}{\|\boldsymbol{v_j} - \boldsymbol{x_k}\|} \right)^{\frac{2}{m-1}}} \qquad (3)$$

with :

U = membership matrix
V = cluster center matrix
X = point data matrix
m = fuzziness value
u_{ik} = membership matrix elements
$\boldsymbol{v_i}$ = i-th cluster center vector
$\boldsymbol{x_k}$ = k-th data points vector
c = number of clusters

Then reformulation is carried out by substituting **Equation (2)** into **Equation (1)**, and substituting **Equation (3)** into **Equation (1)**, resulting in two formulations of the objective function as follows :

$$J_{FGWC}(\boldsymbol{V}; \boldsymbol{X}) = \sum_{i=1}^{c} \sum_{k=1}^{n} \frac{\|\boldsymbol{v_i} - \boldsymbol{x_k}\|^2}{\left(\sum_{j=1}^{C} \left(\frac{\|\boldsymbol{v_i} - \boldsymbol{x_k}\|}{\|\boldsymbol{v_j} - \boldsymbol{x_k}\|} \right)^{\frac{2}{m-1}} \right)^{m}} \qquad (4)$$

where **V** is the cluster center matrix, **X** is the data matrix, $\boldsymbol{v_i}$ is the cluster center, m is the fuzziness value and $\boldsymbol{x_k}$ is the data point.

$$J_{FGWC}(\boldsymbol{U}; \boldsymbol{X}) = \sum_{i=1}^{c} \sum_{k=1}^{n} u_{ik}^{m} \left\| \frac{\sum_{k=1}^{n} u_{ik}^{m} \boldsymbol{x_k}}{\sum_{k=1}^{n} u_{ik}^{m}} - \boldsymbol{x_k} \right\| \qquad (5)$$

where **U** is the membership matrix, **X** is the data matrix, $\boldsymbol{v_i}$ is the cluster center vector, m is the fuzziness value and $\boldsymbol{x_k}$ is the data point vector. Evaluation of the results of fuzzy clustering can use a validity index, one of which is the partition index or the SC index **[20]**.

2.3.2 Harris-Hawk Optimization (HHO)

Harris hawk optimization (HHO) is a metaheuristic algorithm that can be used to deal with optimization problems **[21]**. HHO is inspired by the cooperative behavior and style of Harris's hawk in hunting prey in the form of rabbits **[22]**. HHO has very good performance and is computationally efficient **[23]**. Hunting patterns and prey behavior are mathematically formulated to develop this optimization algorithm. There are two phases in this optimization method, namely the exploration and exploitation phase.

In the exploration phase, harris' hawks waits and observes the situation and prey in a random position. There are two strategies considered based on the value of the opportunity (q) which is a random number (0.1) for each position. If q < 0.5 means between Harris's eagles in a position close to prey and if q ≥ 0.5 means that between Harris's eagles are in a random position. This condition can be formulated in the following **Equation (6)**:

$$X(t+1) = \begin{cases} X_{rand}(t) - r_1 |X_{rand}(t) - 2r_2 X(t)| & q \geq 0,5 \\ X_{rabbit}(t) - X_m(t) - r_3 \big(LB + r_4(UB - LB)\big) & q < 0,5 \end{cases} \qquad (6)$$

where $X(t+1)$ is the position vector of hawks in the next iteration t, $X_{rabbit}(t)$ is the position vector of rabbit, $X(t)$ is the current position vector of hawks, r_1, r_2, r_3, r_4, and q are random number inside (0,1), which are updated in each iteration, LB and UB show the upper and lower bounds variable, $X_{rand}(t)$ is a randomly selected hawk from current population, and $X_m(t)$ is the average position of the current population of hawks. The average position of hawks is attained using **Equation (7)**:

$$X_m(t) = \frac{1}{N}\sum_{i=1}^{N} X_i(t) \tag{7}$$

where $X_i(t)$ indicates the location of each hawk in iteration t and N denotes the total number of hawks.

In the exploitation phase, the Harris hawks perform the surprise pounce by attacking the intended prey detected in the previous phase. The prey always try to escape from threatening situations. Suppose thar r is the chance of prey in successfully escaping (r < 0.5) or not successfully (r ≥ 0.5). Whatever the prey does, the hawks will perform a hard or soft besiege to catch the prey. To model this strategy and enable the HHO to switch between soft and hard besiege processes, the E parameter is utilized. In this regard, when |E| ≥ 0.5, the soft besiege happens, and when |E| < 0.5, the hard besiege occurs.

The soft besiege happens when r ≥ 0.5 and |E| ≥ 0.5. This condition can be formulated in the following **Equation (8)** and **Equation (9)**:

$$X(t+1) = \Delta X(t) - E|JX_{rabbit}(t) - X(t)| \tag{8}$$

$$\Delta X(t) = X_{rabbit} - X(t) \tag{9}$$

where $\Delta X(t)$ is the difference between the position vector of the rabbit and the current location in iteration t, r_5 is a random number inside (0,1) and $J = 2(1 - r_5)$ represents the random jump strength of the rabbit throughout the escaping procedure. The J value changes randomly in each iteration to simulate the nature of rabbit motions.

The hard besiege happens when r ≥ 0.5 and |E| < 0.5, the prey is so exhausted and it has a low escaping energy. In this situation, the current positions are updated using **Equation (10)**:

$$X(t+1) = X_{rabbit}(t) - E|\Delta X(t)| \tag{10}$$

3. RESULTS AND DISCUSSION

3.1 Food security in Papua Island

An overview of the condition of food security in Papua Island is presented by displaying the average value, standard deviation, minimum and maximum value of each variable used.

Table 2. Minimum, Maximum, Mean and Standard Deviation Values for Each Variable

Variable	Mean	Standard Deviation	Minimum	Maxsimum
X1	27.15	8.93	10.03	41.76
X2	57652.02	78419.30	6851	471690
X3	0.02	0.03	0	0.15
X4	1922.61	244.86	1446.17	2627.74
X5	48.77	12.36	21.27	80.51
X6	2.21	4.02	0	16.51
X7	40.54	29.45	0.29	96.62
X8	79.33	22.05	12.98	99.99
X9	5.87	2.94	0.90	11.31
X10	4.25	2.86	0.58	15.96
X11	2837.78	1204.85	1051.40	7092.50

Based on **Table 2**, it can be seen that food security in Papua Island has not yet reached ideal or evenly distributed conditions. This can be seen from the high level of poverty, low income, inadequate road access. According to **[24]** poverty has a close correlation with food insecurity. Regions with high levels of poverty result in reduced ability of people to buy food. On the other hand, areas with low poverty rates reflect the purchasing power of the people who are good at fulfilling their food needs. Apart from that, from the income side, regions or households that have low income levels are more vulnerable to experiencing food shortages and unequal access **[25]**. Consumption levels of calories and protein are also not up to the standards set, food assistance is not evenly distributed and access to electricity and clean water is still low. According to FAO, in order to utilize optimal nutritional intake, households must have access to sources of clean drinking water. The availability of access to electricity is also an indicator of the welfare of a region, because it can encourage economic activity which will have an impact on the condition of food security in the region [26]. The low education level of women also affects the quality of food consumed. According to Food Security Agency of Indonesia, the education level of women, especially mothers and child caregivers, greatly influences the health and nutritional status of family members [26]. Unfavorable demographic and geographical conditions can be seen from the high population growth and the impact of climate change. Rapid population growth will also increase the demand for food [4]. This is in accordance with the theory of [27] which states that food growth is like an arithmetic progression and population growth is like a geometric progression. This means that along with the increase in population and population growth, the need for food also increases, so that population growth that is not matched by the amount of food supply, the area will be vulnerable to food. Vulnerability to climate change can be seen through the amount of rainfall, which can result in loss of crop yields and a decrease in food supply at any given time.

3.2 Results of the Grouping Analysis of Food Security in Papua Island

In this research, we were grouping by considering the geographical elements (FGWC) in the grouping process and optimizing to achieve optimal grouping results. Based on Figure 1, it can be seen that the SC index values between the FGWC and FGWC-HHO methods differ significantly. The smaller the SC index value, the better the grouping results obtained. In Figure 1, it also shows that the SC index value of the FGWC-HHO method is smaller than the SC index value of the FGWC method without optimization. These results indicate that the FGWC development method with optimization is able to provide more optimal grouping results.

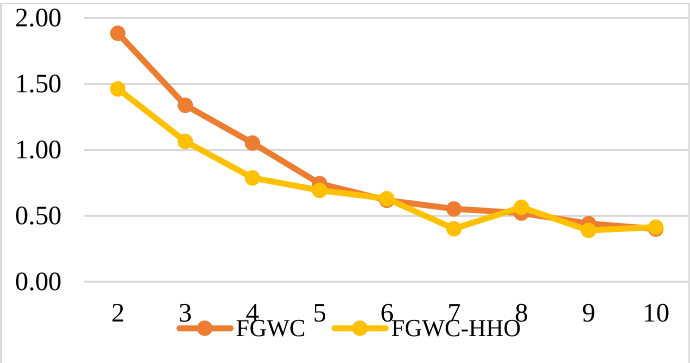
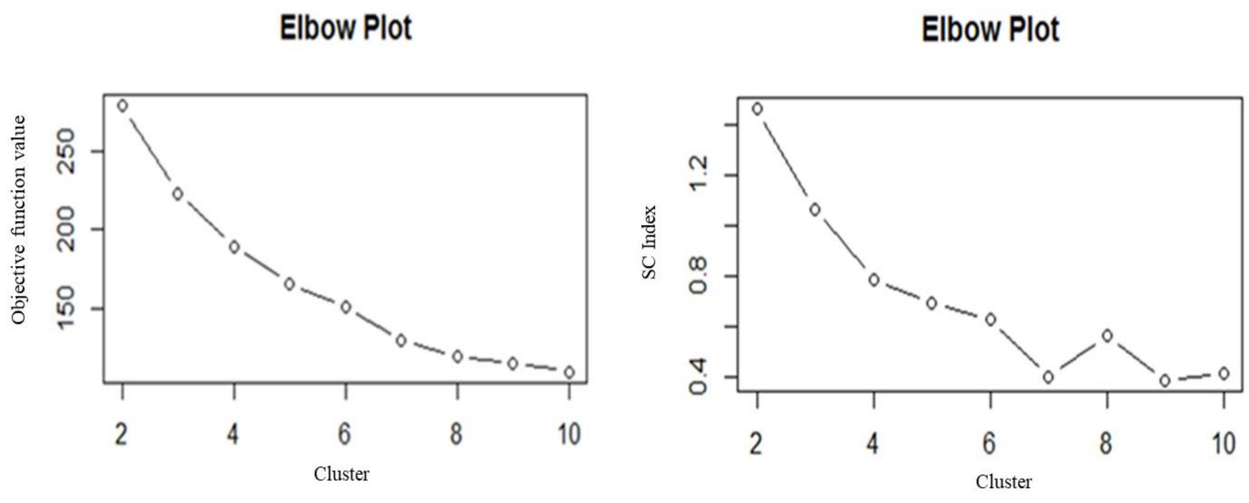


Figure 1. FGWC and FGWC-HHO SC index values

This result is in line with the findings obtained by Heidari [22]. In their research, found that HHO optimization can find superior solutions with a stable balance as the dimensions (multidimensional) increase. This is because the parameters in HHO optimization are adaptive and time-varying which allows HHO to handle the problem of finding local optimal solutions well. Determination of the number of clusters was carried out using the elbow method by testing 2 to 10 clusters. The angled plot is a two-dimensional plot, namely the x and y axes. The x-axis is the number of clusters and the y-axis is the value of the evaluation criteria. The evaluation criteria used are the value of the objective function and the SC index. The optimal number of clusters is located at the point where the slope of the line changes significantly [28]. The following is the result of the angled plot that is formed.



(a) (b)

Figure 2. Elbow plot, (a) objective function value, (b) SC index

Based on Figure 2, it can be seen that the SC Index value decreases with the increase in the number of clusters. The most significant decrease occurred at cluster points 2 to 3 and then the decline relatively decreased in the number of clusters thereafter. Based on these results, it can be concluded that point 3 is an elbow point that describes the optimal number of clusters. After obtaining the optimal number of clusters, the next step is to group them using the FGWC HHO method and the number of clusters is 3. The following presents the results of grouping food security using the FGWC-HHO method.

Table 3. The Results of Grouping The Levels of District/City Food Security

Cluster	Districts/Cities	Amount
1	Jayapura City, Sorong City, Manokwari, Sorong	4 districts/cities
2	Biak Numfor, Boven Digoel, Fakfak, Jayapura, Kaimana, Keerom, Kepulauan Yapen, Mamberamo Raya, Manokwari Selatan, Maybrat, Merauke, Mimika, Nabire, Raja Ampat, Sarmi, Sorong Selatan, Supiori, Teluk Bintuni, Teluk Wondama, Waropen	20 districts
3	Asmat, Deiyai, Dogiyai, Intan Jaya, Jayawijaya, Lanny Jaya, Mamberamo Tengah, Mappi, Nduga, Paniai, Pegunungan Arfak, Pegunungan Bintang, Puncak, Puncak Jaya, Tambrauw, Tolikara, Yahukimo, Yalimo	18 districts

Based on the Table 3 above it is known that cluster 1 consists of 4 districts/cities, cluster 2 consists of 20 districts and cluster 3 consists of 18 districts.

3.3 Identification of Characteristic Clusters of Food Security in Papua Island

To find out the characteristics of the clusters formed from the results grouping using the FGWC-HHO method used the average value of each indicator in each cluster that was formed. The following table displays the average value of each indicator according to the four pillars of food security used.

Table 4. The Average Value of The Food Affordability Pillar Variable

Cluster	Affordability		
	Percentage Of Poor Population	GRDP Per Capita	Road Ratio In Good Condition
1	**18.4425**	84939	**0.0769**
2	22.4600	**87271.05**	0.0178
3	34.3039	18678.22	0.0072

Based on Table 4, cluster 1 is the cluster with the highest level of food affordability, cluster 2 has a moderate level of food security and cluster 3 is the cluster with the lowest level of food affordability. Cluster 1 has the lowest average value of the poor population and has adequate road access which is reflected in the high number of road ratios in good and moderate conditions to the area. Cluster 2 has the highest PDRB per capita value compared to other clusters. Cluster 3 has the highest average percentage value of the poor, the lowest per capita GRDP, and the ratio of the road is in good condition and is currently lowest compared to other clusters. The low number of poor people and high per capita income indicate good conditions of food affordability. In addition, adequate road infrastructure factors also help in the distribution of food.

Table 5. The Average Value of The Food Availability Pillar Variable

Cluster	Availability		
	Average Calorie Consumption	Average Protein Consumption	Percentage Of Food Aid Recipients
1	1869.92	55.81	**11.49**
2	**2002**	**57.37**	1.72
3	1846.12	37.64	0.69

Based on Table 5, cluster 1 has an average percentage of households receiving food assistance which is higher than the other clusters. Cluster 2 has an average value of calorie and protein consumption that is higher than the other clusters. Cluster 3 has the lowest average consumption of calories and protein as well as food assistance compared to other clusters. Based on this information, cluster 2 is the cluster with the highest level of food availability while cluster 3 becomes the cluster with the lowest level of food availability. The number of calories and protein consumed can describe the level of population nutritional adequacy. A good level of nutritional adequacy is also one indicator that shows the level of welfare of the population. Residents who have good nutritional adequacy rates and have met the established standards have a good level of welfare.

Table 6. The Average Value of The Food Quality and Food Safety Pillar Variable

Cluster	Quality And Safety		
	Access To Clean Water	Access To Electricity	Length Of Female Education
1	**83.88**	**99.33**	**9.53**
2	55.39	92.02	7.76
3	14.40	60.78	2.97

Based on Table 6, cluster 1 has an average value of the percentage of households with sources of clean drinking water, access to electricity and the average length of schooling for girls is higher than the other clusters, this indicates that cluster 1 has better quality and food security. While cluster 3 has the lowest average value on all indicators used in measuring food quality and safety. This shows that areas included in cluster 3 have a low level of food quality and safety. The availability of access to clean water that consistently plays a very important role in achieving food security, especially in maintaining food quality and safety. Households that have adequate electricity access can make food storage safer and keep food durable and hygienic. Mothers who have a high level of education have sufficient knowledge related to the provision of quality and safe food.

Table 7. The Average Value of The Food Natural Resources and Resilience Pillar Variable

Cluster	Natural Resources and Resilience	
	Population Growth Rate	Rainfall Amount
1	4.10	**3132.57**
2	**3.35**	2816.76
3	5.27	2795.63

Based on Table 7, cluster 1 is an area that has the highest average rainfall compared to other clusters. Cluster 2 has a lower average population growth value than the other clusters. Cluster 3 has an average population growth rate that is higher and the amount of rainfall in a year. Based on this information, cluster 2 is the highest cluster with the highest resistance while cluster 3 is the lowest resistance cluster. Rapid population growth will increase demand for food and tighten the food system. Increased demand for food must be balanced with the availability and affordability of food to be able to meet the needs of food demand. Extreme climate change can also interfere with food availability and threaten food security.

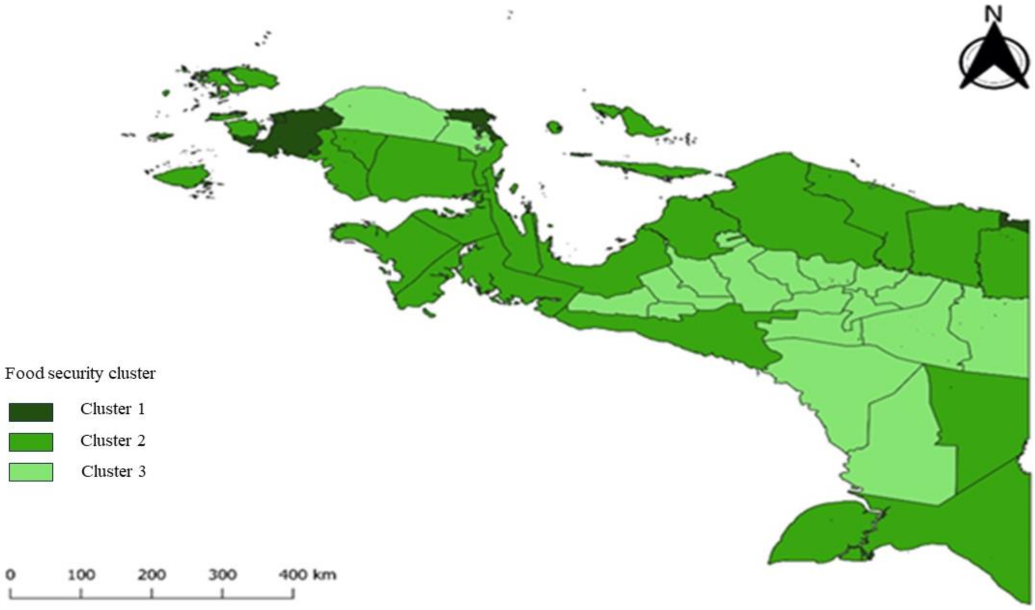


Figure 3. The results of grouping food security levels in Papua Island

Based on the grouping results, cluster 1 is a cluster with a high level of food security, cluster 2 is a cluster with a moderate level of food security and cluster 3 is a cluster with a low level of food security. Based on **Figure 3**, it can be seen that areas with moderate and low levels of food security are close to one another. This means that regions that have a moderate level of food security are also among areas that have a moderate level of food security as well. Likewise, regions that have a low level of food security are also among areas that have a low level of food security. This indicates that there is an influence of inter-regional linkages based on the condition of food security in Papua Island. Based on this information, it is expected to be able to help the government in identifying areas that are the point of food vulnerability, so that the policy program can be on target.

4. CONCLUSIONS

The results of a comparative evaluation between the FGWC and FGWC-HHO methods using the SC validity index showed that the FGWC-HHO method was superior to the FGWC method without optimization. The grouping of districts/cities in Papua Island based on the characteristics of food security using the FGWC-HHO method obtained a total of 3 clusters with high, medium and low food security characteristics. The group of districts/cities with a high level of food security consists of Jayapura City, Sorong City, Manokwari and Sorong, while the remaining 20 districts belong to the district group with a moderate level of food security and 18 districts with a low level of food security. Regencies that are members of cluster 3 are a priority in handling the problem of food security which is still low in Papua Island. The pillar of food affordability is a priority in handling food security problems in this cluster. The regencies that is a member of this cluster has high poverty level, low income, and lack of road access. Therefore, government policies are expected to focus on eradicating poverty, improving the economy of the community and the development of road infrastructure to realize equitable food security.

ACKNOWLEDGMENT

Acknowledgments are conveyed to the Central Bureau of Statistics who have provided educational scholarships at the STIS Statistics Polytechnic to the author and all friends and relatives who have provided support to the author.

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