ILKOM Jurnal Ilmiah Vol. 15, No. 1, April 2023, pp. 21-31
Accredited 2nd by RISTEKBRIN No. 200/M/KPT/2020; E-ISSN 2548-7779 | P-ISSN 2087-1716

Research Article

Fuzzy C-Means with Borda Algorithm in Cluster Determination System for Food Prone Areas in Aceh Utara

Mutammimul Ula [a,1,*]; Munirul Ula [a,2]; Desvina Yulisda [a,3]; Susanti [a,4]
[a] *Universitas Malikussaleh, Jl. Medan-Banda Aceh, Cot Teungku Nie, Reuleut, Aceh Utara, 24355, Indonesia*
[1] *mutammimul@unimal.ac.id;* [2] *munirul@unimal.ac.id;* [3] *desvina.yulisda@unimal.ac.id;* [4]*susanti212118@gmail.com*
* *Corresponding author*

Article history: Received October 11, 2022; Revised November 08, 2022; Accepted January 21, 2023; Available online April 07, 2023

Abstract

In this research, the clustering of food prone areas in Aceh Utama is based on the Index Ketahanan Pangan (IKP) indicators compiled by Badan Ketahanan Pangan (BKP) using Fuzzy C-Means (FCM) and Borda algorithms. The fuzzy C-Means algorithm was used to classify food-prone areas with three clusters: very prone, moderately prone, and prone. The Borda algorithm was used to choose the most prone area from very prone clusters, which are considered urgently to be followed up by decision-makers. Based on the research results, it was found that in the aspect of food availability, four sub-districts are moderately prone, 10 are prone, and 13 are very prone. Regarding food affordability, it found that 12 sub-districts are moderately prone, seven are prone, and eight are very prone. Regarding food utilization, one sub-district is moderately prone, three are prone, and 23 are very prone. The results of voting using the Borda algorithm in very prone clusters are obtained Sawang District from the aspect of food availability, Syamtalira Aron District from the aspect of food affordability, and Lapang District from the aspect of food utilization. The clustering system is built based on the web using the PHP programming language.

Keywords: Food Prone Areas; Clustering; Fuzzy C-Means; Borda; Website.

Introduction

Indonesia's position in the 2020th Global Food Security Index is at 65th position out of 113 countries (Global Food Security Index in 2020), experiencing a decline in 2019 to position 62. Indonesia's position in several aspects could be in better position. In the food affordability aspect, Indonesia is at the 55th position, in the food availability aspect is at the 34th position, in food quality and safety are at the 89th position, and natural resources and resilience are at the 109th position. This result indicates that one or several aspects of food still need to be fulfilled. Indonesia's efforts in alleviating food-prone areas continue to be carried out, starting with compiling a Food Security and Vulnerability Atlas (FSVA) as a roadmap for intervening in various programs because it can show locations or areas that are resistant to food prone. Strengthening food supply, distributing and reserving food, and developing diversification and the local food industry [1].

Each district needs to be evaluated so the government can decide which areas should be prioritized for a follow-up to achieve equitable food security distribution. It is required to divide the areas into several groups with the same characteristics and map them. The criteria required for the clustering process are used as an evaluation [2]. In this research, the authors used Fuzzy C-Means and Borda methods in grouping food prone areas in Aceh Utara's sub-district based on criteria according to the Indeks Ketahanan Pangan (IKP), which has been compiled by the Badan Ketahanan Pangan (BKP) of Kementerian Pertanian Indonesia. The two methods will be implemented into a web-based system.

Several previous pieces of research on Fuzzy C-Means, including research conducted by Rahakbauw, et al., apply Fuzzy C-Means Clustering in determining scholarships [3]. Salat, et al., applying Fuzzy C-Means Clustering in image segmentation [4]. Nurjanah, et al, implemented Fuzzy C-Means in clustering rice varieties [5]. Rouza et al, applied Fuzzy C-Means in the clustering of UKM in Rokan Hulu district [6]. Research conducted by Suwarso, also uses Fuzzy C-Means in clustering rice fields in Indonesia [7].

http://dx.doi.org/10.33096/ilkom.v15i1.1481.21-31

In this research, Fuzzy C-Means was implemented to cluster food prone areas in Aceh Utara. The results of the cluster from Fuzzy C-Means calculation were carried out by voting using Borda Algorithm in very prone, moderately prone, and prone areas based on three criteria, namely aspects of food affordability, food utilization, and food availability. With this research, it is hoped that the relevant agencies can consider it in making a further decision.

Method

A. Research Scheme

In this research, Fuzzy C-Means and Borda algorithms were used. The research scheme is shown in **Figure 1** below.

Figure 1. Research Scheme

Based on **Figure 1**, this research starts with inputting criteria and village data. The next step is the clustering process with the Fuzzy C-Means algorithm. The third step is after getting the result of the clusters with Fuzzy C-Means; we perform the ranking process using the Borda algorithm. After getting the ranking results using the Borda method, the results are the food prone areas in Aceh Utara.

B. Fuzzy C-Means

Fuzzy C-Means is a fuzzy clustering algorithm with the most frequency used in research. The value of degree of membership is in a pre-determined range, which are: 0 and 1 [8]. The steps of the Fuzzy C-Means algorithm are shown below:

- Input the data to be in *Cluster X*, data in the form of a matrix of size *n* x *m* (*n*, number of data samples; m, attributes of the data). X_{ij}, data sample of-*i* (*i*=1,2...n), attribute of-*j* (*j*=1,2...m) [9].
- Determine the initial conditions: Number of clusters : c; Grade : w; Maximum Iteration : MaxIter; Error Rate : ε*I* ; Initial Objective Function : *Po* = 0; Initial Iteration : t = 1 [10].
- Create a random number μ_{ik}, *i*=1,2...n; *k*=1,2...c; as a form of initial partition matrix U

$$\text{Qi} = \sum_{k}^{c} = 1\mu_{ik} \tag{1}$$

With j=1,2...n Calculate by using formula :

$$\mu_{ik} = \frac{\mu_{ik}}{Q_i} \tag{2}$$

- Calculating the center *Cluster* of-k: V_{kj}, with *k*=1,2...c; and *j*=1,2...m.

$$V_{kj} = \frac{\sum_{i=1}^{n}((\mu_{ik})^{w} X_{ij})}{\sum_{i=1}^{n}(\mu_{ik})^{w}} \tag{3}$$

- Calculating the objective fucntion in iteration of-t, Pt .

$$P_{t=\sum_{1}^{n}=1\sum_{k}^{c}=1([\sum_{j}^{m}=1(X_{ij}-V_{kj})^{2}](\mu ik)^{w})} \tag{4}$$

- Calculating partition matrix changes:

$$\text{M}_{\text{ik}} \frac{[\sum_{j}^{m} = 1(X_{ij} - V_{kj})^{2}]\frac{-1}{w-1}}{\sum_{k}^{c} = 1(X_{ij} - V_{kj})^{2}\frac{-1}{w-1}} \tag{5}$$

- Cheking the stop condition: If: (|Pt-Pt-1|<ϵ_1 or (t >MaxIter) then Stop. Else: t = t + 1, repeat step - 4 [11]. [12].

C. Borda Method

The Borda method is a voting method that can solve problems so decisions can be made in clusters [13]. The implementation of Borda is that decision-makers will rank based on existing alternatives or choices, then process these choices with each given a choice [14]. The Borda method is used to assign a priority rating to a vote. The first-ranked alternative will be rated higher than the next in a pairwise comparison [15].

Results and Discussion

A. Data Criteria

In this research, determining food-prone clusters used Badan Pusat Statistik (BPS) data of Aceh Utara. These data are the criteria for evaluating food security in Aceh Utara in 2020. The indicators used consist of criteria and sub-criteria determined by Badan Pusat Statistik (BPS), which consist of Aspects of Food Availability, Food Affordability, and Food Utilization.

The criteria for the Food Availability aspect are the ratio of the standard area of rice fields to the sub-district area and the ratio of the number of food supply facilities and infrastructure to the number of households. The data are shown in **Table 1**.

Table 1. Data of Food Availability Aspect

No.	Sub District (Alternative)	Aspect of Food Availability	
		Ratio of standard area of rice fields to area of the sub District	*The ratio of the number of food supply facilities and infrastructure to the number of households*
1	Muara Batu	0.261961503	0.06442889
2	Sawang	0.08966593	0.032532306
3	Nisam	0.086886856	0.076700111
4	Nisam Antara	0	0.109484599
5	Banda Baro	0.258087367	0.050912176
.	.	.	.
.	.	.	.
.	.	.	.
25	Seunuddon	0.152340256	0.076455771
26	Tanah Jambo Aye	0.144312186	0.067104876
27	Langkahan	0.09766144	0.054405054

The Aspect of Food Affordability is the ratio of households with the lowest level of welfare to the number of households. The number of households with a low level of welfare is divided by the number of households to obtain data, as in **Table 2**.

Table 2. Data of Food Affordability Aspect

No.	Sub District (Alternative)	Aspect of Food Affordability	
		The ratio of the number of households with the lowest level of welfare to the number of households	*Villages with poor road quality*
1	Muara Batu	0.135698	0.50000
2	Sawang	0.371231	0.56410
3	Nisam	0.651951	0.58621
4	Nisam Antara	0.549253	0.50000
5	Banda Baro	0.28723	0.55556
.	.	.	.
.	.	.	.
.	.	.	.
25	Seunuddon	0.471477	0.57576
26	Tanah Jambo Aye	0.396449	0.02128
27	Langkahan	0.233591	0.391304

The criteria for Food Utilization Aspects is the ratio of households without access to clean water to the number of households; this criterion requires data on the types of water sources used by the citizens, then the data is divided by the number of households. This research used data on the ratio of the number of villagers per health worker to population density; this data was obtained from the results of dividing the number of health workers and the number of households then divided by population density, as shown in **Table 3**.

Table 3. Data of Food Utilization Aspects

No.	Sub District (Alternative)	Aspect of Food Utilization	
		Ratio of the number of households without access to clean water to the number of households	***Ratio of village population per health worker to population density***
1	Muara Batu	0.008908686	0.940517
2	Sawang	0.099863976	4.690854
3	Nisam	0.056410256	1.443806
4	Nisam Antara	0.008539189	0.937556
5	Banda Baro	0.151463725	0.542949
.	.	.	.
.	.	.	.
.	.	.	.
25	Seunuddon	0.176026078	1.572344
26	Tanah Jambo Aye	0.064455999	1.234697
27	Langkahan	0.133731134	2.315692

B. Fuzzy C-Means Calculation Results

- ***Aspect of Food Availability***

The first step of Fuzzy C-Means on the aspect of food availability is to determine the X matrix in the form of m x n, where m is the attribute data and n is the number of alternative data.

$$Xij = \begin{bmatrix} 0.26196 & 0.06443 \\ 0.08967 & 0.03253 \\ 0.08689 & 0.07670 \\ 0 & 0.10948 \\ 0.25809 & 0.05091 \\ \vdots & \vdots \\ \vdots & \vdots \\ 0.14431 & 0.06710 \\ 0.09766 & 0.05441 \end{bmatrix}$$

The second step is to determine the initial conditions, where: Number of *Cluster* (c) =3, Grade (w)= 2, Maximum Iteration: 0.01, *Error Rate (e)= 0,* Initial Objective Function *P0 = 1.* The third step is to create random numbers μ_{ik} with i = number of alternative data and k = number of cluster, where n x k is the size that forms the initial partition matrix U, as shown in **Table 4**.

Table 4. Initial Partition

No.	Initial Partition (μ_{ik})			Total
	k1	***k2***	***k3***	
1	0.344064	0.250748203	0.4051881	1
2	0.38700	0.001505311	0.611491	1
3	0.277411	0.358988636	0.36360	1
4	0.191146	0.304668697	0.5041857	1
5	0.172379	0.109292454	0.7183281	1
.	.	.	.	.
.	.	.	.	.

No.	Initial Partition (μ_{ik})			Total
	k1	k2	k3	
.	.	.	.	.
25	0.197975	0.341240489	0.4607848	1
26	0.448633	0.344231391	0.2071353	1
27	0.019159	0.274083177	0.7067574	1

The fourth step is the calculation for the center *Cluster* (V_{kj}). Details of the calculation process for the first data on Cluster 1 is: $(\mu_{11})^2$= $(0.344064)^2$= 0.118379817. Details of the calculation process for the second data on Cluster 1 is:$(\mu_{21})^2$= $(0.38700)^2$= 0.149771847. Details of the calculation process for the third data in Cluster 1 is:$(\mu_{31})^2$= $(0.277411)^2$= 0.076956721. Calculate all data variables using the procedure above as much as sub-district data in Cluster 1, then summarize each Cluster.

Cluster 1 :

$$\sum_{i=1}^{27}(\mu_{i,1})^2 = (\mu_{1,1})^2 + (\mu_{2,1})^2 + (\mu_{3,1})^2 + (\mu_{4,1})^2 + (\mu_{5,1})^2 + \cdots + (\mu_{25,1})^2 + (\mu_{26,1})^2 + (\mu_{27,1})^2$$

$= 0.118379817 + 0.149771847 + 0.076956721 + 0.036536644 + 0.029714673 + \ldots + 0.039194 + 0.201271826 + 0.000367084 = 2.178202588.$

The results of the overall calculation of the data in Cluster 1 are shown in **Table 5**.

Table 5. Center Cluster 1 Calculation Results

i	$(\mu_{1,1})^2(X_{i,1})$	$(\mu_{1,1})^2(X_{i,2})$
1	0.031010955	0.00762708
2	0.013429432	0.004872423
3	0.006686528	0.005902589
4	0	0.0040002
5	0.007668982	0.002748324
.	.	.
.	.	.
.	.	.
25	0.005970824	0.002996608
26	0.029045977	0.013506321
27	0.000035849	0.0000199712
$\sum_{i=1}^{n}((\mu_{ik})^w X_{ij})$	0.462125334	0.178659296

With the formula and steps above, calculate the center of Clusters 2 and Cluster 3. The result of V shown as below:

$$V = \begin{bmatrix} 0.212159024 & 0.082021432 \\ 0.208936355 & 0.08523858 \\ 0.190024254 & 0.081166537 \end{bmatrix}$$

The fifth step is to calculate the Objectivity Function. In cluster 1, the details of the calculation process for the first data on the first attribute is: $(X_{11} - V_{11})^2 = (0.26196 - 0.212159)^2 = 0.002480287$. Details of the calculation process for the first data on the second attribute is: $(X_{12} - V_{12})^2 = (0.06443 - 0.082021432)^2 =$ 0.000309498.

So :

$$\left[\sum_j^m = 1(X_{ij} - V_{kj})^2\right](\mu ik)^w = [(X_{11} - V_{11})^2 + (X_{12} - V_{12})^2](\mu_{11})^2$$
$$= (0.002480287+0.000309498)(0.344064)^2$$
$$= 0.000330254182716$$

With the steps above, calculations are processed up to the 27th data in 3 Clusters with the following equation and the results are shown in **Table 6**.

$$L1 = \left[\sum_j^2 = 1(X_{ij} - V_{1j})^2\right](\mu_{i1})^w$$
$$L2 = \left[\sum_j^2 = 1(X_{ij} - V_{2j})^2\right](\mu_{i2})^w$$

L3 = $\left[\sum_j^2 = 1\left(X_{ij} - V_{3j}\right)^2\right](\mu_{i3})^w$
LT = $\sum_k^{c3} = 1(\left[\sum_j^2 = 1\left(X_{ij} - V_{kj}\right)^2\right](\mu_{ik})^w$

Table 6. Objectivity Function Calculations

L1	L2	L3	LT
0.000330254	0.000208229	0.000895607	0.001434090
0.002614078	0.000000049	0.004650489	0.007264616
0.001209870	0.002165067	0.001408949	0.004783886
0.001672124	0.004057473	0.009382928	0.015112525
0.000065937	0.000093024	0.002456560	0.002615521
.	.	.	.
.	.	.	.
.	.	.	.
0.000141461	0.000486387	0.000306228	0.000934076
0.000971277	0.000625926	0.000098138	0.001695341
0.000005092	0.000937852	0.004618965	0.005561910
		Total	0.2807528081

The objectivity function in the first iteration is (P_1)= 0.2807528081. The sixth step is to calculate the change in the new partition matrix, which the results are shown in Table 7.

$$\mu_{11} = \frac{358.4506227}{849.9587494} = 0.421727081.$$

Table 7. New Partition

μ_{ik}		
0.421727081	0.36259876	0.21567416
0.291558111	0.29928022	0.40916166
0.28365168	0.29791002	0.4184383
0.305406778	0.31592294	0.37867028
0.42282171	0.38010148	0.19707681
.	.	.
.	.	.
.	.	.
0.217260156	0.23905107	0.54368877
0.239181987	0.25620211	0.5046159
0.282433364	0.29386279	0.42370385

The last step is to check the stop condition.

P_1= 0.2807528081
P_0= 0
$|P_1 - P_0|$ = $|0.2807528081 - 0|$

The value $|P_1 - P_0|$ > Error Value (0,01). Then the process continues in the second, third, fourth iteration... n, and repeat the step 4 dan so on until the error value stabilizes or falls below than 0.01. In this research, the iteration stops until the 7th iteration. From this iteration, we can find the result of the final partition matrix, as shown in **Table 8**.

Table 8. Last Partition

Last Partition		
0.004935037	0.991717132	0.003347831
0.021646196	0.07830858	0.900045224
0.00040179	0.00142915	0.99816906
0.041337855	0.100185468	0.858476678
0.017258247	0.969302407	0.013439346
.	.	.
.	.	.
.	.	.
0.049411143	0.299060626	0.651528231
0.041853664	0.234761594	0.723384743
0.009639281	0.037053067	0.953307652

Fuzzy C-Means calculation for the aspect of food availability, by taking the highest membership of degree value, the calculation results are shown in **Table 9**.

Table 9. Results of Fuzzy C-Means Calculation Aspects of Food Availability

No.	Sub Districts	Aspect of Food Availability			
		Membership of degree value			*Results*
1	Muara Batu	0.004935037	0.991717132	0.003347831	*Cluster* 2
2	Sawang	0.021646196	0.07830858	0.900045224	*Cluster* 3
3	Nisam	0.00040179	0.00142915	0.99816906	*Cluster* 3
4	Nisam Antara	0.041337855	0.100185468	0.858476678	*Cluster* 3
5	Banda Baro	0.017258247	0.969302407	0.013439346	*Cluster* 2
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
25	Seunuddon	0.049411143	0.299060626	0.651528231	*Cluster* 3
26	Tanah Jambo Aye	0.041853664	0.234761594	0.723384743	*Cluster* 3
27	Langkahan	0.009639281	0.037053067	0.953307652	*Cluster* 3

Cluster 1 = Moderately Prone, *Cluster* 2 = Prone, *Cluster* 3 = Very Prone.

- ***Aspect of Food Affordability***

The results of the Fuzzy C-Means Calculation for the Aspect of Food Affordability are shown in **Table 10**.

Table 10. Results of Fuzzy C-Means Calculation Aspects of Food Affordability

No.	Sub District	Aspect of Food Affordability			
1	Muara Batu	0.170305226	0.564538486	0.265156288	*Cluster* 2
2	Sawang	0.038119709	0.255015869	0.706864422	*Cluster* 3
3	Nisam	0.153939712	0.322325024	0.523735263	*Cluster* 3
4	Nisam Antara	0.15005575	0.408787053	0.441157197	*Cluster* 3
5	Banda Baro	0.056445175	0.451601034	0.491953791	*Cluster* 3
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
25	Seunuddon	0.064454796	0.25119649	0.684348714	*Cluster* 3
26	Tanah Jambo Aye	0.743518859	0.179331983	0.077149158	*Cluster* 1

No.	Sub District	Aspect of Food Affordability			
27	Langkahan	0.131506919	0.802012108	0.066480973	*Cluster* 3

- ***Aspect of Food Utilization***

The results of the Fuzzy C-Means Calculation for the Aspect of Food Utilization are shown in Table 11.

Table 11. Results of Fuzzy C-Means Calculation Aspects of Food Utilization

No.	Sub District	Aspect of Food Utilization			
1	Muara Batu	6.7556E-05	0.00081813	0.99911432	*Cluster* 3
2	Sawang	0.00019053	0.99870573	0.00110374	*Cluster* 2
3	Nisam	0.00130795	0.01969419	0.97899786	*Cluster* 3
4	Nisam Antara	7.0247E-05	0.00084973	0.99908003	*Cluster* 3
5	Banda Baro	0.00124472	0.01303393	0.98572135	*Cluster* 3
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
25	Seunuddon	0.00222038	0.03558685	0.96219277	*Cluster 3*
26	Tanah Jambo Aye	0.00035893	0.00491339	0.99472768	*Cluster 3*
27	Langkahan	0.01007266	0.25136579	0.73856155	*Cluster 3*

The following are the results of the cluster of food prone areas in a graph shown in **Figure 2**.

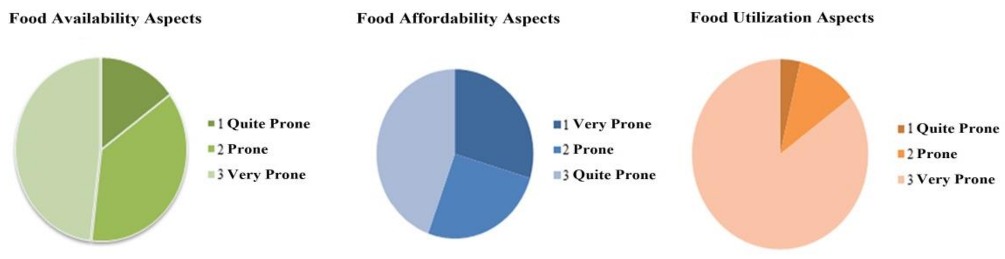

Figure 2. Cluster results diagram for food prone areas using Fuzzy C-Means algorithm

C. Borda Method Calculation Results

Alternative L = (12x0) + (11x0) + (10x2) + (9x0) + (8x0)+ (7x0) + (6x0) + (5x0)+ (4x0) + (3x0) + (2x0)+ (1x0) + (0x1) = 31 .

Alternative M = (12x0) + (11x1) + (10x0) + (9x1) + (8x0)+ (7x0) + (6x0) + (5x0)+ (4x1) + (3x0) + (2x1)+ (1x0) + (0x0) = 26.

The results of multiplying the weights in Borda method are shown in **Table 12**.

Table 12. Multiplying Results on Food Availability Aspects

No.	Alternative	Weight													Total
1	A	24	11	0	9	0	0	0	0	0	0	0	0	0	44
2	B	0	0	0	0	8	0	6	5	0	3	0	0	0	22
3	C	12	0	0	9	8	7	0	0	0	0	0	0	0	36

No.	Alternative	Weight													Total
4	D	0	0	0	0	8	7	0	5	4	0	0	0	0	24
5	E	0	0	0	0	0	7	0	0	0	3	2	1	0	13
6	F	12	11	0	0	0	0	0	0	0	3	0	1	0	27
7	G	0	0	0	0	0	0	6	5	0	3	2	0	0	16
8	H	0	0	0	0	0	0	6	5	8	0	0	0	0	19
9	I	0	0	0	0	0	7	0	0	0	0	2	1	0	10
10	J	0	0	0	0	8	0	0	0	0	0	0	1	0	9
11	K	0	0	20	9	0	0	6	0	0	0	0	0	0	35
12	L	0	11	20	0	0	0	0	0	0	0	0	0	0	31
13	M	0	11	0	9	0	0	0	0	4	0	2	0	0	26

The total value indicates that alternative A has the highest score, which is 44. Alternative A (Sawang District) is chosen according to the Cluster voting results that are very prone from the aspect of food availability. Multiplying Results of Food Affordability Aspect see in **Table 13**

Table 13. Multiplying Results of Food Affordability Aspect

No	Alternative	Weight								Total
1	A	7	6	5	4	0	0	0	0	22
2	B	0	0	0	0	3	2	0	0	5
3	C	0	0	0	0	0	2	2	0	4
4	D	7	6	10	0	0	0	0	0	23
5	E	0	0	0	4	0	2	1	0	7
6	F	7	6	5	4	0	0	0	0	22
7	G	7	0	0	0	6	2	0	0	15
8	H	0	6	0	4	3	0	1	0	14

The total value indicates that alternative D has the highest score, which is 23. Alternative D (Syamtalira Aron) is chosen according to the Cluster voting results that are very prone for the aspect of food affordability. Multiplying Results of Food Utilization Aspect see in **Table 14**

Table 14. Multiplying Results of Food Utilization Aspect

No	Alternative	Total
1	A	48
2	B	53
3	C	62
4	D	62
5	E	62
6	F	28
7	G	19
8	H	47
9	I	30
10	J	42
11	K	64
12	L	51
13	M	77
14	N	52
15	O	69
16	P	77
17	Q	21
18	R	21

No	Alternative	Total
19	S	24
20	T	29
21	U	11
22	V	47
23	W	16

The total value indicates that alternative M has the highest score, which is 77. Alternative M (Kecamatan Lapang) is chosen according to the Cluster voting results that are very prone for the aspect of food utilization.

Conclusion

Based on the tested results, it can be concluded that applying the Fuzzy C-Means Clustering method can classify food-prone areas throughout 6 sub-criteria, which are divided into 3 clusters, namely moderately prone, prone, and very prone. The results of the validation value are close to 1, which indicates that C-Means fuzzy clustering has a high level of accuracy. From the 27 sub-districts that clustered by clustering found that in the aspect of food availability, 4 sub-districts are moderately prone, 10 are prone, and 13 are very prone. Aspects of food affordability are 12 sub-districts are moderately prone, 7 are prone, and 8 are very prone. Regarding food utilization, 1 sub-district is moderately prone, 3 are prone, and 23 are very prone. The voting results using the Borda method in the Cluster that very prone obtained that Sawang District from the availability aspect, Syamtalira Aron District from the food affordability aspect, and Lapang District from the food utilization aspect.

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