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Classification of Iraqi Children According to Their Nutritional Status Using Fuzzy Logic

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Abstract

In this paper we build a fuzzy classification system for classifying the nutritional status of children under 5 years old in Iraq using the Mamdani method based on input variables such as weight and height to determine the nutritional status of the child. Also, Classifying the nutritional status faces a difficult challenge in the medical field due to uncertainty and ambiguity in the variables and attributes that determine the categories of nutritional status for children, which are relied upon in medical diagnosis to determine the types of malnutrition problems and identify the categories or groups suffering from malnutrition to determine the risks faced by each group or category of children. Malnutrition in children is one of the most important contributing factors to diseases and mortality. This research aims to develop a fuzzy classification system to assist in classifying the nutritional status of children under the age of five in Iraq using fuzzy logic, the fuzzy rules in the classification are derived from the Mamdani method. Therefore, by classifying the nutritional status of children more accurately, we reduce the chances of misdiagnosis and provide them with appropriate treatment more precisely to improve the health level of children and build a society more immunity and a good level of health.

The Cluster Sampling size is 16,487 observations for children under 5 years old in Iraq, consisting of 8,427 males and 8,060 females. The sample was divided into 12 age categories. The results showed that age categories less than 2, 4, 6, and 8 months had a underweight of approximately 30%. On the other hand, the age categories from 8 months to less than 2 years had a overweight of approximately 30%. While for the rest of the children in the other age groups, they had a normal nutritional status.

Paper type: Research paper
Keywords: Fuzzy Logic, Fuzzy Classification, Nutritional Status, Mamdani Method, Defuzzification

❖ **This research is taken from a master's thesis.**

1.Introduction

Classification is considered an important topic in statistics as it deals with how to handle real data and how to classify it into categorical groups. This classification forms the basis for making more accurate statistical decisions, rather than relying solely on raw data. There are several methods used in this field, including cluster analysis, nearest neighbour analysis, as well as classification using fuzzy sets, such as the Mamdani Method.

1.1 Literature review

Given the importance of the topic, several researchers have conducted different studies. Mohammed (2011) classified children in Iraq under the age of 6 years based on their nutritional status using data for 2006, and body mass index (BMI) was used for the classification process. On the other hand, Permatasari et al (2017) presented a nutritional status classification system for children using a fuzzy inference system (FIS) with the Mamdani method he concluded nine fuzzy rules through which they classified the nutritional status of children. Moktar et al (2018) evaluated weight deficiency among children using a fuzzy logic approach with the Mamdani method and concluded that the Mamdani method was effective due to its flexibility in controlling inputs and outputs. Mohammed (2020) assessed the nutritional status of children under 5 years old in Iraq in 2018 and compared the results with those from 2006 they concluded that there is an improvement in the nutritional status of children. Hedawi and Hatim (2020) assessed the nutritional status of children under 5 years old in the Najaf province, studying the impact of various social, demographic, maternal educational, and economic characteristics, as well as breastfeeding, on the nutritional status of children. Faradisa et al (2022) developed a system that automatically determines the value and category of body mass index (BMI) using fuzzy logic to monitor nutritional status, and tested the BMI with five attributes in the system (very low, low, normal, high, obese), which matched manual calculations.

In 1965 Lotfi Zadeh introduced the theory of fuzzy sets, and he applied multi-valued logic and introduced the concept of fuzzy logic. Hooda and Raich (2017) this transformation from classical logic which represents only true or false and the values of one or zero, into a multi-valued, between zero and one, in order to make inferences and reasoning in uncertain conditions.

Azevedo et al. (2011) with the presence of uncertain and fuzzy attributes, it is not possible to achieve precise classification. To deal with for these uncertain attributes are addressed through the study of fuzzy sets. Permatasari et al. (2017) in dealing with uncertain and fuzzy attributes, the aim is to provide a description that is acceptable and analyzable. This results in the occurrence of multiple characteristics within a single fuzzy set, leading to ambiguity in classification. Therefore, the tool of classification using fuzzy sets is robust in handling uncertain or ambiguous terms, providing consistent and straightforward solutions to real problems (Azevedo et al, 2011).

In this research, we focus on studying one of the important indicators of children's health, which is their nutritional status. Therefore, it is necessary to monitor their nutritional status, as malnutrition in children leads every year to 1.3 million deaths or 45% of all child deaths. The nutritional status of the child has a significant role in the success of human growth in general, and it is considered the golden age of life, and nutrition is an important role in the human life cycle from pregnancy to old age. The highest priority in all societies is given to infants and young children under 5 years of age, as malnutrition in them may interfere with growth and development and may persist until adolescence if not treated early. These age categories are important in society as they represent the nucleus of the community and are the future, as they are important pillars in society.

In this research, we presented a classification of Iraqi children (under the age of 5) based on their nutritional status using linguistic variables such as weight and height. Due to the uncertainty and ambiguity in these variables that determine the nutritional status of children, we opted for fuzzy classification methods.

fuzzy logic is known for its ability to handle uncertain and ambiguous situations, and the Mamdani Method is one of the fuzzy logic approaches. Using this method, we classify Iraqi children under the age of 5 according to their nutritional status.

2. Material and Methods

2.1 Membership function

The membership function is of great importance in the theory of fuzzy sets, as it represents one of the ordered pair members that represents the fuzzy set. Membership functions are used to determine how an element belongs to a fuzzy set. There are several types of functions: (Shi et al, 2009).

a- Triangular Membership Function:

The membership values of elements to the fuzzy set are represented in the form of a linear function, which possesses three basic parameters (bounds) k_1, k_2, k_3. This function can be defined according to the following formula:(Zhang and Liu 2006).

$$\mu_A\ (x;\ k_1, k_2, k_3) = \begin{cases} 0 & x \leq k_1 \\ \frac{x - k_1}{k_2 - k_1} & k_1 < x \leq k_2 \\ \frac{k_3 - x}{k_3 - k_2} & k_2 < x < k_3 \\ 0 & x \geq k_3 \end{cases} \qquad (1)$$

Since $k_1 < k_2 < k_3 \in R$, the graph in figure (1) illustrates the triangular membership function.

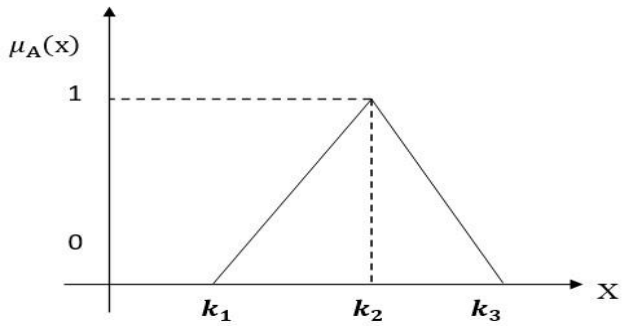

Figure 1: Triangular Membership Function

b- L – Membership Function

This is a special case of a Trapezoidal Membership Function where $k_3 = k_4 = +\infty$. This function can be defined according to the following formula (2). Figure (2) illustrates the plot of the L function (Faradisa et al, 2022).

$$\mu_A(x, k_1, k_2) = \begin{cases} 0 & if\ x \leq k_1 \\ \dfrac{x - k_1}{k_2 - k_1} & if\ k_1 < x < k_2 \\ 1 & if\ x \geq k_2 \end{cases} \qquad (2)$$

c-R –Membership Function

This is a special case of a Trapezoidal Membership Function where $k_1 = k_2 = -\infty$. This function can be defined according to the following formula (3). Figure (3) illustrates the plot of the R function (Faradisa et al, 2022).

$$\mu_A(x, k_3, k_4) = \begin{cases} 1 & if \quad x \leq k_3 \\ \dfrac{k_4 - x}{k_4 - k_3} & if \quad k_3 < x < k_4 \\ 0 & if \quad x \geq k_4 \end{cases} \qquad (3)$$

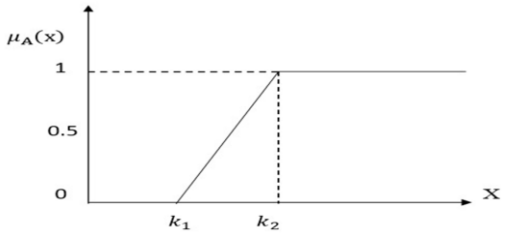

Figure 2: Membership Function L

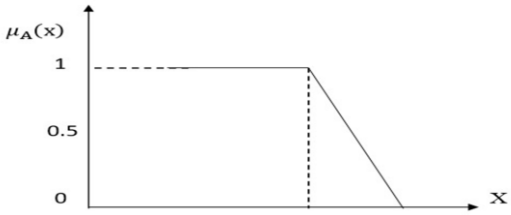

Figure 3: Membership Function R

2.2 Mamdani Method

This method is the most commonly used in making decisions using fuzzy logic and was introduced by Mamdani. It relies on the operations of (min-max). According to this method, the minimum value for each rule is found, then the maximum value for all rules is determined, as in the following steps:(Wulandari et al, 2018)

Step1: fuzzification

Fuzzification: is the process of converting numerical inputs into fuzzy numbers using membership functions for use in a fuzzy system (Wulandari et al, 2018).

Step2: Creating fuzzy rules

Hooda and Raich (2017) Fuzzy rules are a set of linguistic expressions that describe how a decision should be made regarding the classification of inputs or the control of outputs. All input combinations should be considered when creating rules. The rules contain fuzzy IF-THEN statements, and the IF part can have multiple conditions using the fuzzy "AND" operator (Ross, 2009).

Step3: Aggregate results for all outputs

In this step, the outputs are merged for each case. In the fuzzy rule in the first part of the IF where there are multiple conditions linked by the fuzzy operator "and", the minimum operator is used. In the case of a single observation give the same result or inference for the fuzzy rule, the fuzzy operator "or" is used, represented by the maximum operator (Ross, 2009).

Step4: Defuzzification

To obtain a clear final result that gives us a single non-fuzzy value for the class or category, the process of defuzzification is used. Defuzzification is the process of converting fuzzy numbers (outputs) into crisp values, and there are several methods, one of which is the center of mass method. This is done according to the following equation:(Wulandari et al, 2018)

$$z = \frac{\sum_{j=1}^{n} z_j \mu(z_j)}{\sum_{j=1}^{n} \mu(z_j)} \qquad (4)$$

Where z represents the final output after defuzzification.

Where $\mu(z_j)$ is the membership value of z_j to the fuzzy set or category. Figure (4) illustrates the four steps of the Mamdani method (Permatasari et al, 2017).

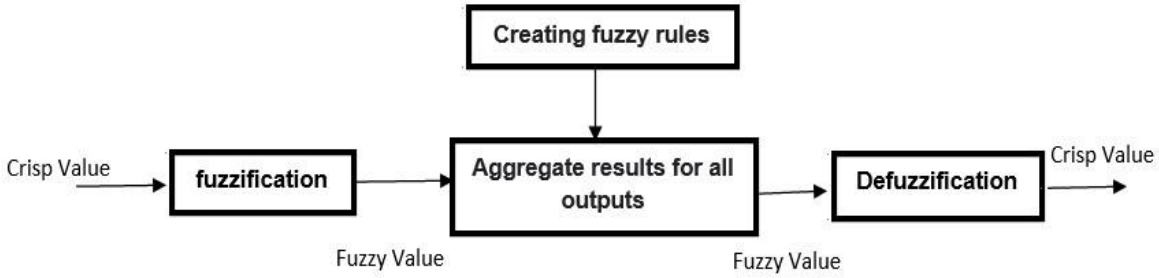

Figure 4: Steps of Mamdani Method

2.3 Case Study

This case study focuses on classifying the nutritional status of children under the age of 5 years in Iraq based on data obtained through the multiple indicator cluster survey 6 (MICS6) conducted in 2018 by the central Statistical Organization in Iraq in collaboration with the Ministry of Health and the World Health Organization. Data was collected on 16,689 children under the age of 5, including 8,532 males and 8,157 females. Table (1) presents the data divided into 12 age categories according to the age variable.

Table 1: Represents a description of the data for Iraqi children in 2018.

Set	Age			Sum
		Female	Male	
Set1	2 Months	228	239	467
Set2	4 Months	296	320	616
Set3	6 Months	314	272	586
Set4	8 Months	268	292	560
Set5	10 Months	268	292	560
Set6	12 Months	203	247	450
Set7	16 Months	554	546	1100
Set8	20 Months	524	579	1103
Set9	24 Months	477	507	984
Set10	3 years	1498	1610	3108
Set11	4 years	1786	1809	3595
Set12	5 years	1644	1714	3358
Sum		8060	8427	16487
Missing observations and recording errors		97	105	202
Sum		8157	8532	16689

The variables studied for classifying the nutritional status include the child's weight as a linguistic variable denoted by the symbol X, with linguistic limits (x_1 represents Scrawny, x_2 represents Light, x_3 represents normal, x_4 represents obese, x_5 represents very obese), and the child's height as a linguistic variable denoted by the symbol Y, with linguistic limits (y_1 represents stunted, y_2 represents short, y_3 represents normal, y_4 represents tall, y_5 represents very tall) (input variables). The classification categories are the body mass index (BMI) and its linguistic limits (malnutrition, underweight, normal, overweight, obesity) (output variable).

The MAMDANI method for classifying the nutritional status of children involves four main sequential steps and is implemented using the R programming language through the frbs package. These steps are as follows:

Step1: fuzzification

The membership functions are built according to the age categories, where for the first year, there are six functions every two months, for the second year, there are three functions every four months, and for the third, fourth, and fifth years, there is one function per year. The input data is fuzzified using the triangular membership function, as well as the L and R

functions. In our current study, we will select the parameters for classifying children's nutritional status based on the World Health Organization's tables (https://www.who.int). The fuzzification functions for the variable Y, for age category less than two months for males, are as follows, as adopted in the mathematical formulas (1, 2, 3):

$$\mu_A y_1(y;\ 50.8, 52.8) = \begin{cases} 1 & y \leq 50.8 \\ \frac{52.8 - y}{52.8 - 50.8} & 50.8 < y < 52.8 \\ 0 & y \geq 52.8 \end{cases} \quad (5)$$

$$\mu_A y_2(y;\ 50.8, 52.8, 54.7) = \begin{cases} 0 & y \leq 50.8 \\ \frac{y - 50.8}{52.8 - 50.8} & 50.8 < y \leq 52.8 \\ \frac{54.7 - y}{54.7 - 52.8} & 52.8 < y < 54.7 \\ 0 & y \geq 54.7 \end{cases} \quad (6)$$

$$\mu_A y_3(y;\ 52.8, 54.7, 56.7) = \begin{cases} 0 & y \leq 52.8 \\ \frac{y - 52.8}{54.7 - 52.8} & 52.8 < y \leq 54.7 \\ \frac{56.7 - y}{56.7 - 54.7} & 54.7 < y < 56.7 \\ 0 & y \geq 56.7 \end{cases} \quad (7)$$

$$\mu_A y_4(y;\ 54.7, 56.7, 58.6) = \begin{cases} 0 & y \leq 54.7 \\ \frac{y - 54.7}{56.7 - 54.7} & 54.7 < y \leq 56.7 \\ \frac{58.6 - y}{58.6 - 56.7} & 56.7 < y < 58.6 \\ 0 & y \geq 58.6 \end{cases} \quad (8)$$

$$\mu_A y_5(y;\ 56.7, 58.6) = \begin{cases} 0 & y \leq 56.7 \\ \frac{y - 56.7}{58.6 - 56.7} & 56.7 < y < 58.6 \\ 1 & y \geq 58.6 \end{cases} \quad (9)$$

Figure (5) represents the membership function for the variable of length based on the nutritional status data of Iraqi children under two months of age.

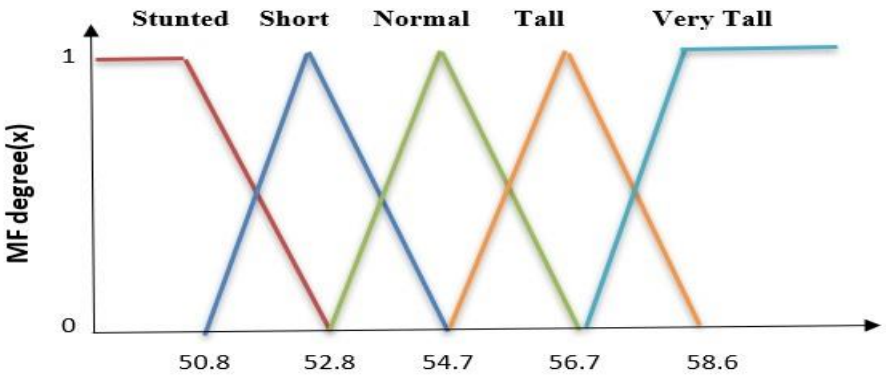

Figure 5: the membership functions for the length variable Y

The horizontal axis represents the input values which is the length variable, while the vertical axis represents the degree of membership for the input value of the length variable. To apply the fuzzification functions for variable X for males under the age of two months, the following mathematical formulas (1,2,3) were adopted:

$$\mu_A \boldsymbol{x_1}(x;\ 3.4, 3.9) = \begin{cases} 1 & x \leq 3.4 \\ \frac{3.9 - x}{3.9 - 3.4} & 3.4 < x < 3.9 \\ 0 & x \geq 3.9 \end{cases} \quad (10)$$

$$\mu_A \mathbf{x_2}(x;\ 3.4,3.9,4.5\ ) = \begin{cases} 0 & x \leq 3.4 \\ \frac{x - 3.4}{3.9 - 3.4} & 3.4 < x \leq 3.9 \\ \frac{4.5 - x}{4.5 - 3.9} & 3.9 < x < 4.5 \\ 0 & x \geq 4.5 \end{cases} \quad (11)$$

$$\mu_A x_3(x;\ 3.9,4.5,5.1\ ) = \begin{cases} 0 & x \leq 3.9 \\ \frac{x - 3.9}{4.5 - 3.9} & 3.9 < x \leq 4.5 \\ \frac{5.1 - x}{5.1 - 4.5} & 4.5 < x < 5.1 \\ 0 & x \geq 5.1 \end{cases} \quad (12)$$

$$\mu_A x_4(x;\ 4.5,5.1,5.8\ ) = \begin{cases} 0 & x \leq 4.5 \\ \frac{x - 4.5}{5.1 - 4.5} & 4.5 < x \leq 5.1 \\ \frac{5.8 - x}{5.8 - 5.1} & 5.1 < x < 5.8 \\ 0 & x \geq 5.8 \end{cases} \quad (13)$$

$$\mu_A x_5\ (x;\ 5.1,5.8\ ) = \begin{cases} 0 & x \leq 5.1 \\ \frac{x - 5.1}{5.8 - 5.1} & 5.1 < x < 5.8 \\ 1 & x \geq 5.8 \end{cases} \quad (14)$$

Figure (6) represents the membership function for the weight variable based on the nutritional status data of Iraqi children under the age of two months.

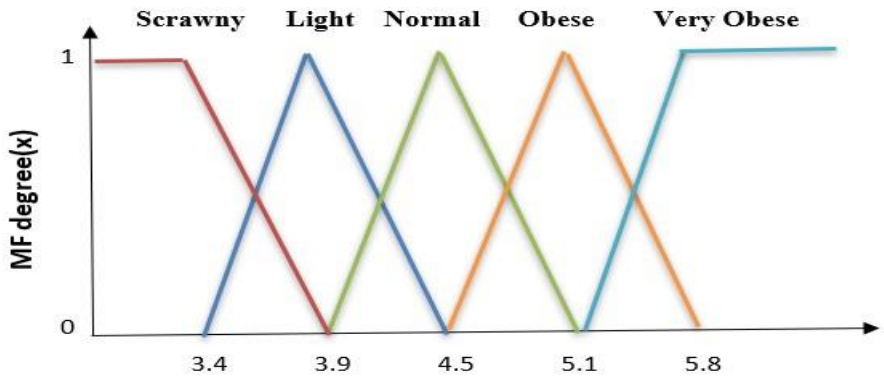

Figure 6: the membership function for the weight variable X

The horizontal axis represents the input value, which is the weight variable, while the vertical axis represents the degree of membership for the input value of the weight variable. Similarly, the remaining age categories for both males and females are fuzzified using the tables of the World Health Organization (https://www.who.int).

Step2: Creating fuzzy rules

In this study, rules are created to express the relationship between the inputs (weight and height) and the outputs (nutritional status). Based on Table 2, which illustrates the creation of rules for classifying nutritional status, a total of 25 fuzzy rules were inferred.

Table 2: Fuzzy rule of classification of toddler nutritional status

		Weight (kg)				
Height (cm)		**Scrawny**	**Light**	**Normal**	**Obese**	**Very Obese**
	Stunted	Underweight	Normal	Obesity	Obesity	Obesity
	Short	Malnutrition	Underweight	Overweight	Obesity	Obesity
	Normal	Malnutrition	Underweight	Normal	Overweight	Obesity
	Tall	Malnutrition	Malnutrition	Underweight	Overweight	Obesity
	Very Tall	Malnutrition	Malnutrition	Underweight	Normal	Overweight

After aggregating the results for all outputs and applying defuzzification using the center of mass method, a clear final result is obtained that gives a single non-fuzzy value for the class or category. Table (3) illustrates the weight, length, and nutritional status classification of male infants under two months of age, using the Mamdani method. The same process was applied for the rest of the age categories, as well as for females and males.

Table 3: presents the results of nutritional status classification for male Iraqi children under the age of two months.

No.	X	Y	Classification Results	
1	4.80	36.00	Z_5	Obesity
2	9.30	52.40	Z_5	Obesity
3	5.40	41.20	Z_5	Obesity
⋮	⋮	⋮	⋮	
237	3.90	60.70	Z_1	Malnutrition
238	2.50	50.10	Z_2	Underweight
239	2.60	51.80	Z_2	Underweight

3.Discussion of Results

After applying the Mamdani method to all age categories for males and females, the final results are presented in Tables (4, 5). Table (4) shows the number of male children in each category of nutritional status and the percentage of each category for all age categories. The results showed that the majority of children in the age categories less than 4, 6, 8 months suffered from Underweight with percentages of 41.6%, 37.9%, and 30.1% respectively. Moreover, the majority of children in the age categories less than 2, 10, 12, 16, 20, 24 months suffered from overweight with percentages of 31.4%, 32.5%, 35.2%, 26.4%, 28.7%, and 29.8% respectively. Finally, the majority of children in the age categories less than 3, 4, 5 years had normal weight with percentages of 33%, 36.5%, and 32.7% respectively.

Table4: Results of the number and percentage of children classified according to nutritional status for all age categories and for males

Age	Malnutrition		Underweight		Normal		Overweight		Obesity	
	N	Per%	N	Per%	N	Per%	N	Per %	N	Per%
Less than 2 Months	13	5.4	70	29.3	54	22.6	75	31.4	27	11.3
Less than 4 Months	31	9.7	133	41.6	79	24.7	52	16.3	25	7.8
Less than 6 Months	26	9.6	103	37.9	56	20.6	63	23.2	24	8.8
Less than 8 Months	13	4.5	88	30.1	62	21.2	88	30.1	41	14.0
Less than 10 Months	14	4.8	74	25.3	65	22.3	95	32.5	44	15.1
Less than 12 Months	8	3.2	54	21.9	56	22.7	87	35.2	42	17.0
Less than 16 Months	20	3.7	116	21.2	139	25.5	144	26.4	127	23.3
Less than 20 Months	6	1.0	112	19.3	146	25.2	166	28.7	149	25.7
Less than 24 Months	10	2.0	103	20.3	131	25.8	151	29.8	112	22.1
Less than 3 years	18	1.1	457	28.4	532	33.0	298	18.5	305	18.9
Less than 4 years	27	1.5	486	26.9	660	36.5	397	21.9	239	13.2
Less than 5 years	24	1.4	512	29.9	560	32.7	396	23.1	222	13.0
Sum	210	2.5	2308	27.4	2540	30.1	2012	23.9	1357	16.1

Table (5) shows the number of female children in each category of nutritional status and the percentage of each category for all age categories. The results showed that the majority of children in the age categories less than 4 and 6 months suffer from Underweight with percentages of 40.5% and 35.7%, respectively. However, the majority of children in the age categories less than 2, 8, 10, 12, 16, 20, and 24 months suffer from Overweight with percentages of 32.5%, 30.6%, 29.5%, 42.9%, 31.8%, 28.8%, and 27.5%, respectively. The majority of children in the age categories less than 3 and 4 years have normal weight with percentages of 31.3% and 34.3%, respectively. The majority of children in the age categories less than 5 years suffer from Underweight with a percentage of 34.3%.

Table 5: Results of the number and percentage of children classified according to nutritional status for all age categories of females

Age	Malnutrition		Underweight		Normal		Overweight		Obesity	
	N	Per%	N	Per%	N	Per%	N	Per%	N	Per%
Less than 2 Months	15	6.6	57	25.0	45	19.7	74	32.5	37	16.2
Less than 4 Months	33	11.1	120	40.5	68	32.0	54	18.2	21	7.1
Less than 6 Months	17	5.4	112	35.7	69	22.0	89	28.3	27	8.6
Less than 8 Months	17	6.3	67	25.0	67	25.0	82	30.6	35	13.1
Less than 10 Months	14	5.2	67	25.0	65	24.3	79	29.5	43	16.0
Less than 12 Months	4	2.0	40	19.7	43	21.2	87	42.9	29	14.3
Less than 16 Months	6	1.1	106	19.1	131	23.6	176	31.8	135	24.4
Less than 20 Months	9	1.7	76	14.5	136	26.0	151	28.8	152	29.0
Less than 24 Months	7	1.5	103	21.6	129	27.0	131	27.5	107	22.4
Less than 3 years	14	0.9	448	29.9	469	31.3	272	18.2	295	19.7
Less than 4 years	22	1.2	527	29.5	613	34.3	383	21.4	241	13.5
Less than 5 years	29	1.8	564	34.3	535	32.5	325	19.8	191	11.6
Sum	187	2.3	2287	28.4	2370	29.4	1903	23.6	1313	16.3

4. Conclusion

We can use fuzzy classification with the Mamdani method to classify the nutritional status of children under 5 years old using linguistic variables as inputs representing weight and height, and the output being the child's nutritional status classification, represented by the body mass index (BMI) indicator consisting of five categories: malnutrition, underweight, normal, overweight, and obesity. Based on fuzzy logic and the Mamdani method, we derived 25 fuzzy rules to determine the category of each child under 5 years old. We found that the majority of children from birth to the age of 8 months suffer from underweight, while the majority of children from 8 to 24 months suffer from overweight. Finally, we found that the majority of children aged 3 to 5 years have a normal weight.

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تصنيف أطفال العراق حسب الحالة التغذوية باستعمال المنطق الضبابي

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مستخلص البحث

قدمنا هذا البحث لبناء نظام تصنيف ضبابي لتصنيف الحالة التغذوية للأطفال العراق دون 5 سنوات باستخدام طريقة Mamdani بالاعتماد على متغيرات الادخال الوزن والطول لتحديد الحالة التغذوية للطفل والتصنيف للحالة التغذوية يواجه تحديا صعبا في المجال الطبي بسبب حالة عدم التأكد والغموض في المتغيرات والصفات التي تحدد فئات الحالة التغذوية للأطفال والتي يعتمد عليها التشخيص الطبي في تحديد نوع الامراض المتعلقة في مشاكل سوء التغذية لمعرفة الفئات او المجموعات التي تعاني من سوء التغذية لتحديد المخاطر التي تتعرض لها كل مجموعة او فئة من الأطفال حيث أن سوء التغذية لدى الاطفال تكون من اهم العوامل المساهمة في الأمراض والوفاة. يهدف هذا البحث الى وضع نظام تصنيف ضبابي للمساعدة في تصنيف الحالة التغذوية للأطفال العراق دون سن الخامسة باستخدام المنطق الضبابي حيث تُستمد القواعد الضبابية في التصنيف من طريقة مامداني Mamdani Method وبالتالي بتصنيف للحالة التغذوية لأطفال بشكل أكثر دقة نقلل من فرص التشخيص الخاطئ وتقديم العلاج الملائم لهم بدقة أكثر للارتقاء بالمستوى الصحي للأطفال لبناء مجتمع أكثر مناعة وذات مستوى صحي جيد.

استخدم هذا البحث عينة عنقودية بحجم 16487 مشاهدة من الأطفال العراق دون 5 سنوات، 8427 ذكور، 8060 اناث، قسمت حسب العمر الى 12 فئة او مجموعة. وكانت نتائج هذه الدراسة ان الفئات العمرية اقل من 2، 4، 6، 8 شهر يعانون من نقص في الوزن بنسبة تجاوزت تقريبا 30%، بينما الفئات العمرية 8 شهر الى اقل من سنتين كانوا يعانون من زيادة في الوزن بنسبة تقريبا 30%، اما باقي الاطفال في الفئات العمرية الاخرى ذات حالة تغذوية طبيعية.

نوع البحث: بحث تطبيقي

الكلمات الرئيسة: المنطق الضبابي، التصنيف الضبابي، الحالة التغذوية، طريقة مامديني، إزالة التضبيب.

❖ **البحث مستل من رسالة ماجستير.**