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CLINICAL DECISION SUPPORT INFORMATION SYSTEM FOR RISK EVALUATION OF KIDNEY FUNCTIONING

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Abstract

The disturbed lifestyle is responsible for various human health-related issues, and one of them is Hypertension. The uncontrolled Hypertension is largely responsible for kidney performance. The neglected approach to major symptoms caused by the disturbed performance of kidney provides a platform for chronic kidney disease. Chronic Kidney Disease (CKD) is a progressive and multifactorial disorder that poses a major global public health challenge. Early diagnosis and risk assessment remain difficult due to the gradual progression of the disease and the inherent uncertainty in clinical parameters. In this article, we explore Kidney risk assessment to make the patient aware of its current status.

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1. Introduction

Chronic Kidney Disease (CKD) is a long-term and progressive disorder characterized by persistent abnormalities in renal structure or function, leading to impaired filtration, metabolic imbalance, and increased systemic complications. Clinically, Chronic Kidney Disease is identified by sustained reductions in estimated glomerular filtration rate (eGFR), albuminuria, or structural kidney damage lasting longer than three months [1, 2]. The global prevalence of Chronic Kidney Disease has increased substantially over the past decades, affecting nearly 10-15% of the adult population worldwide and contributing significantly to morbidity, mortality, and healthcare expenditure [3, 4]. Chronic Kidney Disease is a complex, multifactorial disease characterized by gradual progression, diagnostic uncertainty, and strong interactions with other chronic conditions. Conventional diagnostic frameworks often struggle to represent these complexities. Soft computing techniques provide a mathematically rigorous yet clinically intuitive approach for Chronic Kidney Disease risk assessment and early diagnosis. A major challenge in Chronic Kidney Disease management is its asymptomatic nature during the early stages. Many patients remain undiagnosed until irreversible renal damage has occurred. The progression of Chronic Kidney Disease is influenced by a complex interaction of demographic, clinical, biochemical, and

lifestyle-related factors such as age, hypertension, diabetes mellitus, dyslipidemia, obesity, smoking habits, and genetic predisposition [5, 6]. These factors interact in nonlinear and uncertain ways, making early diagnosis and accurate risk stratification particularly difficult. Traditional diagnostic approaches in nephrology rely on crisp threshold-based criteria, including fixed cut-off values for eGFR, serum creatinine, and albumin-to-creatinine ratio. While these criteria provide standardized clinical guidance, they often fail to capture gradual transitions between disease stages and the uncertainty inherent in biological measurements [7]. Patients with similar laboratory values may exhibit markedly different disease trajectories due to comorbidities or lifestyle differences, highlighting the limitations of conventional decision models. Soft computing criteria closely mimic human reasoning through their respective components. The linguistic variables and fuzzy computational intelligence introduced by Zadeh [8, 9] have enabled the development of interpretable medical expert systems that integrate quantitative data with expert knowledge.

Recently, Srivastava and Sharma [11] developed a fuzzy risk assessment information system for coronary heart disease, demonstrating how vague clinical parameters and interacting risk factors can be modeled using fuzzy relations and trapezoidal membership functions. One significant contribution in this direction was made by Srivastava, Sharma, and Aparna [15], who developed a fuzzy soft system for arrhythmia classification. Their work combined fuzzy with soft set theory to better manage the ambiguity present in electrocardiogram data and related clinical indicators. Earlier work by Srivastava and Sharma [19] offered a comprehensive overview of soft computing models in medical diagnosis. Their study compared various approaches, including neural networks and hybrid systems, and emphasized the advantages of combining multiple techniques. In the area of kidney disease, Mulik and Jadhav [16] proposed a fuzzy inference system designed to support both diagnosis and treatment planning. Their model incorporated common symptoms and laboratory findings as input variables expressed in linguistic terms. This work strengthened the argument for applying fuzzy expert systems in nephrology. Building upon this line of research, Mondal and Srivastava [17] focused specifically on assessing kidney performance in patients with diabetes. Similarly, Srivastava and Mondal [18] introduced a diabetes diagnostic intelligent information system aimed at improving early detection and classification accuracy.

Chronic Kidney Disease has increasingly been studied through the lens of machine learning, particularly as researchers seek reliable methods for early detection. Unlike black-box machine learning models, fuzzy systems provide transparent rule structures that enhance clinical trust and interpretability. Chronic Kidney Disease progression is strongly influenced by combined effects such as hypertension–diabetes synergy and age-related decline in renal reserve. Fuzzy computational intelligence models offer a structured approach to encode these interactions using expert-defined relationships. Such relational frameworks have proven effective in other chronic disease risk assessment systems and offer strong potential for nephrology-focused applications. Furthermore, Chronic Kidney Disease is increasingly recognized as a systemic disorder

with strong cardiovascular implications. Patients with Chronic Kidney Disease face a substantially higher risk of cardiovascular events than progression to end-stage renal disease itself [12]. This interconnection highlights the need for integrated diagnostic frameworks capable of jointly assessing renal and cardiovascular risk.

In the present article, we have proposed an intelligent diagnostic system concerning Chronic Kidney performance and the current status of the patients on the basis of their clinical data.

2. Preliminaries

Definition 1. Fuzzy Set: [10] A *fuzzy set* $\mathcal{A}$ on a universe of discourse X is defined as a set of ordered pairs

$$\mathcal{A} = \{(x, \mu_{\mathcal{A}}(x)) \mid x \in X\},$$

where $\mu_{\mathcal{A}} : X \to [0, 1]$ is the membership function of $\mathcal{A}$.

Definition 2. Gaussian Fuzzy Number: [14] A *Gaussian fuzzy membership function* is a smooth and continuous function used to model gradual transitions between membership grades in fuzzy logic systems. For a real-valued variable $x \in X$, the membership function $\mu(x)$ is defined as

$$\mu(x) = \exp\left(-\frac{(x-c)^2}{2\sigma^2}\right),$$

where $c \in \mathbb{R}$ denotes the center of the fuzzy set, corresponding to the point of maximum membership, and $\sigma > 0$ is the spread parameter that controls the width of the function. The membership value $\mu(x)$ lies in the interval $[0, 1]$ and decreases symmetrically as it x moves away from c.

3. Methodology

In the proposed intelligent risk assessment diagnostic system, the combined effect of two interacting risk factors is evaluated through fuzzy computational criteria. We have considered Gaussian fuzzy numbers [13] in order to process the fuzzy computational aspects as per the [11] .

Let $X = (c_X, \sigma_X)$ and $Y = (c_Y, \sigma_Y)$ be two Gaussian fuzzy numbers representing interacting clinical risk factors.

To perform fuzzy multiplication, the α-cut representation of the Gaussian fuzzy numbers is first obtained. For any $\alpha \in (0, 1]$, the α-cut of a Gaussian fuzzy number is defined as the set of all real numbers whose membership values are greater than or equal to α.

Gaussian fuzzy numbers at the α–level

$$X_\alpha = c_X + \sigma_X \sqrt{-2 \ln \alpha}, \qquad Y_\alpha = c_Y + \sigma_Y \sqrt{-2 \ln \alpha}.$$

The fuzzy multiplication of A and B is defined as the product of their respective α–cuts. Accordingly, the α–cut of the product $A \times B$ is given by

$$X_\alpha \times Y_\alpha = \left(c_X + \sigma_X \sqrt{-2\ln\alpha}\right)\left(c_Y + \sigma_Y \sqrt{-2\ln\alpha}\right).$$

Expanding the above expression, we obtain

$$x = c_X c_Y + (c_Y\sigma_X + c_X\sigma_Y)\sqrt{-2\ln\alpha} + \sigma_X\sigma_Y(-2\ln\alpha)$$

$$\mu_{X\times Y}(x) = \exp\left[-\frac{1}{2}\left(\frac{(c_Y\sigma_X + c_X\sigma_Y) - \sqrt{(c_Y\sigma_X + c_X\sigma_Y)^2 + 4\sigma_X\sigma_Y(x - c_X c_Y)}}{2\sigma_X\sigma_Y}\right)^2\right] \tag{3.1}$$

In order to estimate the early risk associated with chronic kidney disease, a mathematical risk assessment function as constructed within the proposed fuzzy information system [11], given by:

$$\mathrm{RA} = \frac{1}{1 + \exp\left(\frac{-\sum_{i=1}^{n} u_i\, x_i}{2}\right)} \tag{3.2}$$

where n is the number of parameters, u_k and x_k are fuzzy relational parameters that govern the proposed intelligent diagnostic system.

3.1. Flowchart of Proposed System The flowchart of the proposed system is given in Figure 1.

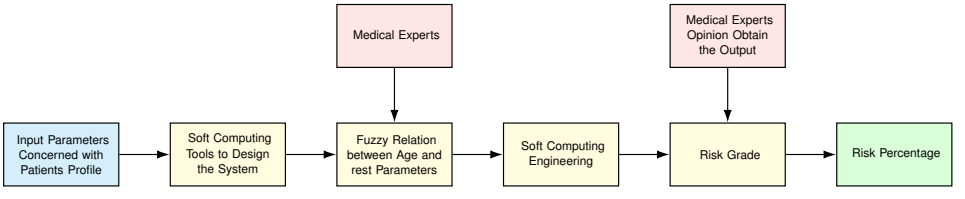

FIGURE 1: Flowchart of Proposed System

3.2. Proposed Algorithm Algorithm 1 presents the workflow of the proposed CKD risk assessment information system.

Algorithm 1: Risk Assessment Algorithm for Chronic Kidney Disease

Input: Patient clinical variables A = {Age, Albumin, Serum Creatinine, eGFR, DBP, SBP, Weight, Water Intake, Urine}, gender, Gaussian parameters (c_i, σ_i), and expert fuzzy relation tables

Output: CKD Risk Percentage

begin

Define n clinical input variables A_i;

foreach *clinical variable* A_i **do**

Assign linguistic categories based on medical ranges;

Convert A_i into Gaussian fuzzy number $G_i = (c_i, \sigma_i)$ using $\mu(x) = \exp\left(-\frac{(x-c_i)^2}{2\sigma_i^2}\right)$;

foreach *interaction between Age and* A_j **do**

Compute α–cut representation of Gaussian fuzzy numbers;

Perform fuzzy multiplication using Gaussian product formulation;

Obtain interaction membership value u_j;

foreach *interaction between Age and* A_j **do**

Determine fuzzy relational value x_j from expert-defined fuzzy relation tables;

Compute cumulative fuzzy score:

$$S = \sum_{j=1}^{8} u_j \, x_j$$

;

Evaluate CKD risk using sigmoid risk function:

$$RA = \frac{1}{1 + \exp\left(-\frac{S}{2}\right)}$$

;

Convert to percentage:

$$\text{Risk}\% = RA \times 100$$

Validate final risk with medical expert knowledge;

return CKD Risk Percentage;

3.3. Risk Factors for Risk Assessment Fuzzy Information System of Chronic Kidney Disease To design the risk assessment information system, we have identified 9 risk factors namely age, albumin, serum creatinine, eGFR, diastolic blood pressure, systolic blood pressure, weight, water intake, and urine that affect the kidney function. These risk factors have been designed with the help of Gaussian membership function.

3.3.1. Age Age refers to the chronological stage of an individual's life that reflects cumulative biological changes that influence renal structure and function.

We classify the levels of age in 5 linguistic variables as shows in Table 1:

TABLE 1: Age

Fuzzy Set	Range(years)
Very young	0 - 25
Young	18 – 40
Mid-Aged	30 – 55
Old	45 - 70
Very old	65 and above

3.3.2. Albumin Albumin is a vital blood protein whose presence and concentration provide insight into renal health and function.

We classify albumin levels into 5 linguistic variables as shows in Table 2:

TABLE 2: Albumin

Fuzzy Set	Range(g/dL)
Very low	2.5 and below
Low	2.3 – 3.8
Normal	3.2 – 5.0
High	4.5 – 5.8
Very High	5.2 and above

3.3.3. Serum Creatinine Serum creatinine is defined as a biochemical marker measured in the blood that reflects the kidneys' ability to filter and eliminate waste products generated from normal muscle metabolism.

We classify serum creatinine levels into 6 linguistic variables as shows in Table 3:

TABLE 3: Serum Creatinine

Fuzzy Set	Range(mg/dL)
Low	0.8 and below
Normal	0.5 – 1.4
Slightly High	1.1 – 1.8
Moderately High	1.5 – 2.3
High	2.0 – 2.8
Very High	2.5 and above

3.3.4. Estimated Glomerular Filtration Rate Estimated glomerular filtration rate (eGFR) is a clinically derived measure that represents how effectively the kidneys filter waste products from the blood over a given period of time. It is calculated using serum creatinine levels in combination with factors such as age and sex to provide an overall estimate of renal filtration capacity.

We classify the eGFR levels into 5 linguistic variables as shows in Table 4:

Table 4: Estimated Glomerular Filtration Rate

Fuzzy Set	Range(mL/min/1.73m^2)
Very Severe	30 and below
Severe	25 – 55
Moderate	50 – 70
Mild	65 – 95
Normal	90 and above

3.3.5. Diastolic Blood Pressure Diastolic blood pressure refers to the level of arterial pressure maintained when the heart relaxes between beats, reflecting the baseline load placed on the vascular system and kidneys.

We classify the diastolic blood pressure levels into 5 linguistic variables as shows in Table 5:

Table 5: Diastolic Blood Pressure

Fuzzy Set	Range(mmHg)
Very low	60 and below
Low	55 – 75
Normal	70 – 85
High	80 – 100
Very High	95 and above

3.3.6. Systolic Blood Pressure Systolic blood pressure refers to the peak pressure exerted on the arterial walls when the heart contracts and pumps blood, reflecting the force that directly influences renal circulation.

We classify the systolic blood pressure levels into 5 linguistic variables as shows in Table 6:

3.3.7. Weight Weight refers to an individual's body mass as a clinical indicator that reflects nutritional status, fluid balance, and overall metabolic health.

We classify the weight levels into 5 linguistic variables as shows in Table 7:

3.3.8. Water Intake Water intake refers to the amount of fluid consumed daily that supports the ability of the kidneys to regulate body fluids, maintain electrolyte balance, and eliminate metabolic waste through urine.

We classify the water intake levels into 5 linguistic variables as shows in Table 8:

Table 6: Systolic Blood Pressure

Fuzzy Set	Range(mmHg)
Very low	100 and below
Low	85 – 120
Normal	105 – 135
High	130 – 170
Very High	165 and above

Table 7: Weight

Fuzzy Set	Range(Kg)
Very low	50 and below
Low	40 – 60
Normal	55 – 80
High	75 – 95
Very High	90 and above

Table 8: Water Intake

Fuzzy Set	Range(L/day)
Very low	1.0 and below
Low	0.5 – 1.5
Normal	1.5 – 3.5
High	2.5 – 4.5
Very High	4.0 and above

3.3.9. Urine Urine is the fluid output produced by the kidneys that reflects their ability to filter blood, regulate fluid balance, and remove metabolic waste products from the body.

We classify the levels of urine in 5 linguistic variables as shows in Table 9:

Table 9: Urine

Fuzzy Set	Range(L/day)
Very low	0.2 and below
Low	0.2 – 0.5
Normal	0.5 – 2.0
High	2.0 – 3.0
Very High	3.0 and above

4. Fuzzy Relations for Risk Assessment Information System of Chronic Kidney Disease (Male)

In this section, we construct fuzzy relational matrices to represent the interrelationships among the identified risk factors for male and female patients. These factors were finalized in consultation with nephrology expert Dr. Amaresh Singh.

The appropriate Fuzzy sets were employed to categorize the entries of the Fuzzy relation matrices = (Low(L), 0.32), (Normal(N), 0.54), (High(H), 0.85) and hedges are defined as Very(V) = $(\mu_x)^2$, Extremely(E) = $(\mu_x)^4$, Slightly(S) = $(\mu_x)^{\frac{1}{2}}$, Average(A) = $(\mu_x)^{\frac{1}{3}}$

The fuzzy relations for males are as follows:

Table 10: Fuzzy Relation Between Age (Male) and Albumin

Age	**Albumin**				
	VL	L	N	H	VH
VY	M	L	VL	VL	L
Y	H	SH	AM	L	L
MA	EH	VH	M	L	VL
O	EH	VH	SM	SH	M
VO	EH	VH	H	SH	AM

Table 11: Fuzzy Relation Between Age (Male) and Serum Creatinine

Age	**Serum Creatinine**					
	L	N	SH	MH	H	VH
VY	VL	VL	L	M	SH	H
Y	VL	L	M	AM	H	VH
MA	L	M	AM	SH	VH	EH
O	M	AM	SH	H	VH	EH
VO	AM	SH	H	VH	EH	EH

Table 12: Fuzzy Relation Between Age (Male) and eGFR

Age	**eGFR**				
	VS	S	Mi	M	N
VY	H	SH	M	L	VL
Y	VH	H	AM	M	L
MA	EH	VH	SH	AM	M
O	EH	EH	H	SH	AM
VO	EH	EH	VH	H	SH

Table 13: Fuzzy Relation Between Age (Male) and DBP

Age	**DBP**				
	VL	L	N	H	VH
VY	M	L	VL	L	M
Y	L	VL	VL	SH	H
MA	L	VL	VL	H	H
O	H	SH	M	VH	vH
VO	VH	H	AM	VH	EH

Table 14: Fuzzy Relation Between Age (Male) and SBP

Age	**SBP**				
	VL	L	N	H	VH
VY	M	L	VL	L	SM
Y	M	L	VL	M	SH
MA	AM	M	L	SH	VH
O	SH	M	M	H	VH
VO	H	SH	M	VH	EH

Table 15: Fuzzy Relation Between Age (Male) and Weight

Age	Weight				
	VL	L	N	H	VH
VY	L	VL	VL	L	M
Y	M	L	VL	M	SH
MA	AM	M	L	SH	H
O	SH	M	M	H	VH
VO	H	SH	M	VH	EH

Table 16: Fuzzy Relation Between Age (Male) and Water Intake

Age	Water Intake				
	VL	L	N	H	VH
VY	M	L	VL	L	M
Y	AM	M	VL	L	SH
MA	SH	M	L	M	H
O	H	SH	M	H	VH
VO	VH	H	M	VH	EH

Table 17: Fuzzy Relation Between Age (Male) and Urine

Age	Urine				
	VL	L	N	H	VH
VY	M	L	VL	L	M
Y	AM	M	VL	L	SH
MA	SH	M	L	M	H
O	H	SH	M	H	VH
VO	VH	H	M	VH	EH

Fuzzy relations for female are as follows:

Table 18: Fuzzy Relation Between Age (Female) and Albumin

Age	Albumin				
	VL	L	N	H	VH
VY	M	L	VL	VL	L
Y	AM	M	VL	L	M
MA	SH	M	L	M	H
O	H	SH	M	H	VH
VO	VH	H	M	VH	EH

Table 19: Fuzzy Relation Between Age (Female) and Serum Creatinine

Age	Serum Creatinine					
	L	N	SH	MH	H	VH
VY	VL	VL	L	M	AM	SH
Y	VL	L	M	AM	SH	H
MA	L	M	AM	SH	H	VH
O	M	AM	SH	H	VH	EH
VO	AM	SH	H	VH	EH	EH

Table 20: Fuzzy Relation Between Age (Female) and eGFR

Age	eGFR				
	VS	S	Mo	Mi	N
VY	H	SH	M	L	VL
Y	VH	H	AM	M	VL
MA	EH	VH	SH	AM	L
O	EH	EH	H	SH	M
VO	EH	EH	VH	H	AM

Table 21: Fuzzy Relation Between Age (Female) and DBP

Age	DBP				
	VL	L	N	H	VH
VY	M	L	VL	L	M
Y	AM	M	VL	M	SH
MA	SH	M	L	SH	H
O	H	SH	M	H	VH
VO	VH	H	M	VH	EH

Table 22: Fuzzy Relation Between Age (Female) and SBP

Age	SBP				
	VL	L	N	H	VH
VY	M	L	VL	L	M
Y	AM	L	VL	M	SH
MA	SH	M	L	SH	H
O	H	SH	M	H	VH
VO	VH	H	M	VH	EH

Table 23: Fuzzy Relation Between Age (Female) and Weight

Age	Weight				
	VL	L	N	H	VH
VY	L	VL	VL	L	M
Y	M	L	VL	M	SH
MA	AM	M	L	SH	H
O	SH	M	M	H	VH
VO	H	SH	M	VH	EH

Table 24: Fuzzy Relation Between Age (Female) and Water Intake

Age	Water Intake				
	VL	L	N	H	VH
VY	M	L	VL	L	M
Y	AM	M	VL	L	SH
MA	SH	M	L	M	H
O	H	SH	M	H	VH
VO	VH	H	M	VH	EH

Table 25: Fuzzy Relation Between Age (Female) and Urine

Age	Urine				
	VL	L	N	H	VH
VY	M	L	VL	L	M
Y	AM	M	VL	L	SH
MA	SH	M	L	M	H
O	H	SH	M	H	VH
VO	VH	H	M	VH	EH

5. Results and Discussion

In order to assess the computational intelligence of the proposed system, we have considered the medical data of the four patients for illustration.

Case 1 The patient's Age = 25 years, Gender = male, Albumin = 3.2 g/dL, Serum Creatinine = 7.8 mg/dL, eGFR = 9.2147, Diastolic Blood Pressure = 80 mmHg, Systolic Blood Pressure = 170 mmHg, Weight = 45 kg, WI = 1.2 L/day, and Urine = 0.9 L/day.

Based on the primary stage of the Information System introduced in Section (algorithm), Gaussian fuzzy numbers corresponding to Age, Albumin, Serum Creatinine, eGFR, DBP, SBP, Weight, Water Intake, and Urine are developed and detailed below.

Age = [29, 11], Albumin = [3.05, 0.75], Serum Creatinine = [5.75, 3.25], eGFR = [17.5, 12.5], DBP = [77.5, 7.5], SBP = [177.5, 12.5] Weight = [50, 10], WI = [1.0, 0.5], Urine = [1.25, 0.75]

Employing the formulations given in equation (3.1), the membership values of the product u_i of Gaussian fuzzy numbers are evaluated for the male population.

$\mu_{Age\times Alb} = 0.9878$, $\mu_{Age\times SC} = 0.9791$, $\mu_{Age\times eGFR} = 0.8433$, $\mu_{Age\times DBP} = 0.9726$, $\mu_{Age\times SBP} = 0.9242$, $\mu_{Age\times Wt} = 0.9198$, $\mu_{Age\times WI} = 0.9992$, $\mu_{Age\times Urine} = 0.9116$.

By using the fuzzy relation tables 10, 11, 12, 13, 14, 15, 16 and 17, we calculate the value of x_i.

Fuzzy relational value for age and albumin, which is slightly high for the patient in case 1, is denoted as $x_1 = 0.9219$,

Fuzzy relational value for age and serum creatinine, which is extremely high for the patient in case 1, is denoted as $x_2 = 0.5220$,

and similarly, $x_3 = 0.7225$, $x_4 = 0.1024$, $x_5 = 0.9219$, $x_6 = 0.32$, $x_7 = 0.52$, $x_8 = 0.1024$.

Next, we evaluate $\sum_{k=1}^{8} u_i x_i$ in the Risk Assessment Function (3.2) using the computed values of u_i and the fuzzy relational values of x_i, and determine the corresponding risk grade according to the procedure described in the algorithm, as presented below.

$\sum_{k=1}^{8} u_i x_i$

$= 0.9878(0.9219) + 0.9791(0.5222) + 0.8433(0.7225) + 0.9726(0.1024) + 0.9242(0.9219) + 0.9198(0.3200) + 0.9992(0.5200) + 0.9116(0.1024) = 3.8900$

Risk Grade $= \frac{1}{1+\exp\left(\frac{-3.8900}{2}\right)}$

$=0.8749$

The calculated risk grade for chronic kidney disease in the concerned person is 87.49%, and adopting a kidney-supportive diet combined with regular exercise could help lower this risk.

Case 2 The patient's Age = 30 years, Gender = female, Albumin = 2.9 g/dL, Serum Creatinine = 2.1 mg/dL, eGFR = 34.9206, Diastolic Blood Pressure = 70 mmHg, Systolic Blood Pressure = 130 mmHg, Weight = 48 kg, WI = 2.5 L/day, and Urine = 2.2 L/day.

Based on the primary stage of the Information System introduced in Section (algorithm), Gaussian fuzzy numbers corresponding to Age, Albumin, Serum Creatinine, eGFR, DBP, SBP, Weight, Water Intake, and Urine are developed and detailed below.

Age = [29, 11], Albumin = [3.05, 0.75], Serum Creatinine = [1.9, 0.4], eGFR = [40, 15], DBP = [65, 10], SBP = [120, 15] Weight = [50, 10], WI = [2.5, 1], Urine = [2.5, 0.5]

Employing the formulations given in equation (3.1) the membership values of the product u_i of Gaussian fuzzy numbers are evaluated for the male population.

$\mu_{Age\times Alb} = 0.9997$, $\mu_{Age\times SC} = 0.9726$, $\mu_{Age\times eGFR} = 0.9914$, $\mu_{Age\times DBP} = 0.9784$, $\mu_{Age\times SBP} = 0.9730$, $\mu_{Age\times Wt} = 0.9999$, $\mu_{Age\times WI} = 0.9990$, $\mu_{Age\times Urine} = 0.9876$.

By using the fuzzy relation tables 18, 19, 20, 21, 22, 23, 24 and 25, we calculate the value of x_i.

Fuzzy relational value for age and albumin, which is medium for the patient in case 2, is denoted as $x_1 = 0.5400$,

Fuzzy relational value for age and serum creatinine, which is average medium for the patient in case 2, is denoted as $x_2 = 0.8143$.

and similarly, $x_3 = 0.8500$, $x_4 = 0.5400$, $x_5 = 0.1024$, $x_6 = 0.32$, $x_7 = 0.1024$, $x_8 = 0.3200$.

Next, we evaluate $\sum_{k=1}^{8} u_i x_i$ in the Risk Assessment Function (3.2) using the computed values of u_i and the fuzzy relational values of x_i, and determine the corresponding risk grade according to the procedure described in the algorithm, as presented below.

$\sum_{k=1}^{8} u_i x_i$

$= 0.9997(0.5400) + 0.9726(0.8143) + 0.9914(0.8500) + 0.9784(0.5400) +$

$0.9730(0.1024) + 0.9999(0.3200) + 0.9990(0.1024) + 0.9876(0.3200) = 3.54078$

Risk Grade = 0.8545

The calculated risk grade for chronic kidney disease in the concerned person is 85.45%, and adopting a kidney-supportive diet combined with regular exercise could help lower this risk.

Case 3 The patient's Age = 70 years, Gender = male, Albumin = 3.0 g/dL, Serum Creatinine = 1.8 mg/dL, eGFR = 41.0494, Diastolic Blood Pressure = 70 mmHg, Systolic Blood Pressure = 180 mmHg, Weight = 76 kg, WI = 2.0 L/day, and Urine = 1.6 L/day.

Based on the primary stage of the Information System introduced in Section (algorithm), Gaussian fuzzy numbers corresponding to Age, Albumin, Serum Creatinine, eGFR, DBP, SBP, Weight, Water Intake, and Urine are developed and detailed below.

Age = [77.5, 12.5], Albumin = [3.05, 0.75], Serum Creatinine = [1.9, 0.4], eGFR = [40, 15], DBP = [65, 10], SBP = [177.5, 12.5], Weight = [72.5, 7.5], WI = [2.5, 1], Urine = [1.25, 0.75]

Employing the formulations given in equation (3.1), the membership values of the product u_i of Gaussian fuzzy numbers are evaluated for the male population.

$\mu_{Age\times Alb} = 0.9611$, $\mu_{Age\times SC} = 0.9220$, $\mu_{Age\times eGFR} = 0.9905$, $\mu_{Age\times DBP} = 0.9962$, $\mu_{Age\times SBP} = 0.9340$, $\mu_{Age\times Wt} = 0.9795$, $\mu_{Age\times WI} = 0.8708$, $\mu_{Age\times Urine} = 0.9802$.

By using the fuzzy relation tables 10, 11, 12, 13, 14, 15, 16 and 17, we calculate the value of x_i.

$x_1 = 0.7225$, $x_2 = 0.7225$, $x_3 = 0.5222$, $x_4 = 0.8500$, $x_5 = 0.5222$, $x_6 = 0.5400$, $x_7 = 0.5400$, $x_8 = 0.5400$.

Next, we evaluate $\sum_{k=1}^{8} u_i x_i$ in the Risk Assessment Function (3.2) using the computed values of u_i and the fuzzy relational values of x_i, and determine the corresponding risk grade according to the procedure described in the algorithm, as presented below.

$\sum_{k=1}^{8} u_i x_i$

$= 0.9911(0.7225) + 0.9220(0.7225) + 0.9905(0.5222) + 0.9962(0.8500) +$

$0.9340(0.5222) + 0.9795(0.5400) + 0.8708(0.5400) + 0.9802(0.5400) = 4.74075$

Risk Grade = 0.9146

The calculated risk grade for chronic kidney disease in the concerned person is 91.46%, and adopting a kidney-supportive diet combined with regular exercise could help lower this risk.

Case 4 The patient's Age = 40 years, Gender = male, Albumin = 3.8 g/dL, Serum Creatinine = 5.6 mg/dL, eGFR = 16.1210, Diastolic Blood Pressure = 110 mmHg, Systolic Blood Pressure = 210 mmHg, Weight = 65 kg, WI = 1.8 L/day, and Urine = 1.6 L/day.

Based on the primary stage of the Information System introduced in Section (algorithm), Gaussian fuzzy numbers corresponding to Age, Albumin, Serum Creatinine, eGFR, DBP, SBP, Weight, Water Intake, and Urine are developed and detailed below.

Age = [42.5, 12.5], Albumin = [4.1, 0.9], Serum Creatinine = [5.75, 3.25], eGFR = [17.5, 12.5], DBP = [107.5, 12.5], SBP = [187.5, 22.5], Weight = [67.5, 12.5], WI = [2.5, 1], Urine = [1.25, 0.75]

Employing the formulations given in equation (3.1), the membership values of the product u_i of Gaussian fuzzy numbers are evaluated for the male population.

$\mu_{Age\times Alb} = 0.9675$, $\mu_{Age\times SC} = 0.9951$, $\mu_{Age\times eGFR} = 0.9908$, $\mu_{Age\times DBP} = 0.9959$, $\mu_{Age\times SBP} = 0.9917$, $\mu_{Age\times Wt} = 0.9808$, $\mu_{Age\times WI} = 0.8789$, $\mu_{Age\times Urine} = 0.9762$.

By using the fuzzy relation tables 10, 11, 12, 13, 14, 15, 16 and 17, we calculate the value of x_i.

$x_1 = 0.5400$,

$x_2 = 0.5222$, $x_3 = 0.5222$, $x_4 = 0.7225$, $x_5 = 0.7225$, $x_6 = 0.8143$, $x_7 = 0.3200$, $x_8 = 0.3200$.

Next, we evaluate $\sum_{k=1}^{8} u_i x_i$ in the Risk Assessment Function (3.2) using the computed values of u_i and the fuzzy relational values of x_i, and determine the corresponding risk grade according to the procedure described in the algorithm, as presented below.

$\sum_{k=1}^{8} u_i x_i$

$= 0.9675(0.5400) + 0.9951(0.5222) + 0.9908(0.5222) + 0.9959(0.7225) +$
$0.9917(0.7225) + 0.9802(0.8143) + 0.9789(0.3200) + 0.9762(0.3200) = 4.74075$

Risk Grade = 0.9011

The calculated risk grade for chronic kidney disease in the concerned person is 90.11%.

The risk of four given patients combined in equation 26.

Table 26: Results

Cases	Case 1	Case 2	Case 3	Case 4
Risk %	87.49	85.45	91.46	90.11

As for illustration, we have shared the computational aspect and risk assessment status demonstrated in accordance with the proposed intelligent system. Similarly, all other data of the remaining patients can be examined.

6. Conclusion

Risk assessment systems support healthcare professionals by improving the precision and clarity of their diagnostic decision-making, thereby strengthening their overall clinical judgment. At the same time, it provides patients with meaningful insight into their present health condition, enabling better awareness and timely medical attention when required. By combining structured risk analysis with accessible system design, the proposed approach bridges the gap between complex medical data and practical healthcare use, ultimately contributing to more informed diagnosis, improved patient understanding, and enhanced quality of medical care.

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