Tech Science Press

Analyzing the Implications of COVID-19 Pandemic through an Intelligent-Computing Technique

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Received: 02 July 2021; Accepted: 03 August 2021

Abstract: The outbreak of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2 virus or COVID-19) disease was declared pandemic by the World Health Organization (WHO) on March 11, 2020. COVID-19 has already affected more than 211 nations. In such a bleak scenario, it becomes imperative to analyze and identify those regions in Saudi Arabia that are at high risk. A preemptive study done in the context of predicting the possible COVID-19 hotspots would facilitate in the implementation of prompt and targeted countermeasures against SARS-CoV-2, thus saving many lives. Working towards this intent, the present study adopts a decision making based methodology of simulation named Analytical Hierarchy Process (AHP), a multi criteria decision making approach, for assessing the risk of COVID-19 in different regions of Saudi Arabia. AHP gives the ability to measure the risks numerically. Moreover, numerical assessments are always effective and easy to understand. Hence, this research endeavour employs Fuzzy based computational method of decision making for its empirical analysis. Findings in the proposed paper suggest that Riyadh and Makkah are the most susceptible regions, implying that if sustained and focused preventive measures are not introduced at the right juncture, the two cities could be the worst afflicted with the infection. The results obtained through Fuzzy based computational method of decision making are highly corroborative and would be very useful for categorizing and assessing the current COVID-19 situation in the Kingdom of Saudi Arabia. More specifically, identifying the cities that are likely to be COVID-19 hotspots would help the country's health and medical fraternity to reinforce intensive containment strategies to counter the ills of the pandemic in such regions.

Keywords: COVID-19; Saudi Arabian regions; risk assessment; dynamics of infection; fuzzy AHP

1 Introduction

As the virus grips the countries, transcending the borders and geographical regions, the world is looking for any possible escape routes. With no medication that can serve as certified treatment and no vaccine to render people immune to the virus, the COVID-19 pandemic has wreaked havoc on both the health and economic well-being of millions in the world [1,2]. Having spread the virus, researchers now face COVID-19 pandemic-related problems. In its efforts to contain the magnitude of the Coronavirus pandemic, Saudi Arabia has already initiated highly effective precautionary measures [3]. In this row, our empirical study will be a significant contribution to the various preventive strategies introduced by the medical fraternity and the government.

The experts opine that the most effective strategy to break the chain of the spread of Coronavirus is to identify the susceptible regions, the possible hotspots, and introduce preemptive measures to control the contagion. In this league, we have identified the vulnerable regions in Saudi Arabia that are likely to be severely affected by the pandemic. Our research is premised on the data collated from literature surveys, media websites, and medical reports [4,5]. The analysis of the available resources in this context points to several causes that could be major risk factors for the spread of COVID-19 in Saudi Arabia. For example, one of the main risk factors, as medical experts have noted, is that people in KSA are not as safe as they could be. Those with a weak immune system are at a higher risk of infection; hence, urgent medical intervention is required to ensure stronger immunity and better wellbeing of the people. Besides, to further our empirical base, we also perused numerous studies that focused specifically on integrating digital technology with health issues in the Kingdom of Saudi Arabia. The key literature in this context includes:

Arpin et al. [5] presented a modeling and estimation paper discussing the cardiovascular surgery burden in Saudi Arabia. The paper talks about the future growth as well as categorizes the burden of surgeries in Saudi Arabian healthcare organizations. Yet another study in this league by Rachah et al. [6] presented a computational model for assessing the risk of mass gatherings during an epidemic. The paper presented the situation of mass gatherings at the Olympic Games, FIFA world cup, Hajj, etc. The study selected Hajj as a case study and used Data-Driven computational model to assess the risk of any type of epidemic in mass gatherings. Moreover, the paper effectively discusses the interaction of self-awareness into infection spreading and portrays a link between them. The study illustrates the importance of self-awareness and also proposes effective countermeasures by imposing self-restrictions on ourselves. Furthermore, another similar study by Rorres et al. [7] and Chimmula et al. [8] also portrays the self-awareness in infection spread and proposes a model to adopt self-awareness to prevent the spread of infection.

Various KSA regions have different environments, populations, ratios of density, and ratios between men, women, and children [9,10]. Besides, resources in the KSA regions are also different, including hospitals, doctors' local clinics. Given this backdrop, the main purpose of our analysis is to identify, categorize and thereafter prioritize the regions of KSA which are at high risk and could be the most vulnerable targets of Coronavirus [11–13]. Such a research initiative would also be an effective alternative to the paranoia and confusion amongst people regarding the spread of the pandemic [14–17]. With the help of the Multi-Criteria Decision Making (MCDM) methodology, the authors have chosen and tested the high-risk COVID-19 states [18,19]. MCDM is Operation Research's utmost significant branch through which people take nuanced decisions on any issue. It is a deep learning based artificial intelligence inherited methodology which is used to choose options in an automated neuroscience scenario. Several researchers are already employing many of the MCDM Models [20,21]. All these MCDM Models are based on decision-making problem behavior [22,23]. People select the best alternatives in the MCDM method. Such MCDM methods have recently been used in the economic, environmental, and social contexts as well.

Thus, as explicated above, MCDM is highly effective and useful in the context of assessment in between more than one option [24,25]. Categorizing Saudi Arabian regions based on their risk factors for COVID-19 is also a task where machine learning is in demand for taking right decision. To make it easier and effective for researchers and experts, the authors chose MCDM technique because the process involves multi-decision attributes. Various regions and different factors that affect the risk ratio of COVID-19 become a context of multi-dimensional decision-making. Therefore, the authors also adopt the AHP MCDM approach to conduct the assessment in this paper. The approach affords both simplicity and accuracy. Complex computational methodologies create confusion and ambiguity in the readers' minds. Since COVID-19 is a sensitive topic, it is imperative to choose a simple but effective AHP approach for attaining convincing results. It is shown that mostly fuzzy set theories are adopted and utilized to assess ambiguous data inputs and its outcome efficiency is also very high. Fuzzy-based decision-making approaches are dependent and associate attributes. Ambiguity is always present in this type of decision-making. Imprecision is another obstacle that arises in the pathway of fuzzy-based decision-making that is caused due by unquantifiable data, missing data, inaccessible data, and limited irrationality.

The proposed article attempts to classify and prioritize the risk of COVID-19 based on geographical and infrastructural attributes of different Saudi Arabian regions. The proposed study adopts a fuzzy-AHP approach to estimate the level of risk in Saudi Arabian regions. This type of methodology helped us to perform a numerical assessment of the risks. A numerical assessment brings forth precision in the analysis. Precise figures will translate into more convincing data which can be used by future researchers and experts in managing the COVID-19 situation. Moreover, to deliver more clarity in the adopted methodology, the AHP has a systematic assessment pathway that gives an experimental result and validation of those outcomes very efficiently. More significantly, in the context of the benefits of the proposed approach and evaluation, the results discussed in this paper would add to the repository of data that the government and health practitioners refer to for formulating preventive mechanisms against COVID-19 disease. Furthermore, the study's contributions also include the following:

The proposed study provides a specific and unique risk-based categorization and a priority list of different Saudi Arabian regions that will be exceptionally helpful for the healthcare industry in KSA. The biggest advantage of this proposed study is that the evaluated results of a study can be adopted by healthcare experts and the Saudi government to identify high-risk zones and regions. The detection of high-risk regions or zones will help the experts and the Saudi government in applying prompt and targeted preventive measures in most high-risk regions of KSA, thus averting casualties or COVID-19 cases.

The application of evaluated results in this proposed study is highly systematic. The risk ratios of different cities, as specified in the findings of the study, are specific and precise in their readings. Hence the policymakers working on COVID-19 preventive mechanisms can base their decisions on data that is numerical, accurate, and corroborative. Saudi Arabia is a country with a stable economy empowered with fully digitalized and developed healthcare infrastructure. However, the present-day COVID-19 health emergency calls for timely and effective containment strategies to prevent any further loss of lives as well as stem economic loss to the country. The proposed study attempts to evaluate the level of risk in different regions of KSA.

2 Materials and Methods

2.1 COVID-19 Situation in KSA

KSA is a vast country with a thriving economy in the Middle East. However, the COVID-19 outbreak has affected the country most dramatically and the condition is likely to be even worse. COVID-19 cases are on the rise and are increasing day-by-day in various regions of Saudi Arabia (Tab. 1) [26].

Table 1: Current case census in KSA

Sub-regions	Total confirmed cases	Total recovered	Total deaths
Eastern Province (R11)	83287	79203	594
Tabuk (R21)	4631	4502	67
Madinah (R22)	23796	22471	135
Makkah (R23)	83174	79075	1863
Ha'il (R31)	6244	5873	70
Jawf (R32)	1102	1022	31
Northern borders (R33)	1954	1650	68
'Asir (R41)	25781	24713	234
Najran (R42)	5885	5568	16
Jizan (R43)	11618	10367	231
Bahah (R44)	3524	3160	37
Qassim (R51)	12171	11588	134
Riyadh (R52)	69162	66444	1145
Total	338132	323769	4972

Above Tab. 1 and Fig. 1 portrays the situation of confirmed, recovered, and death cases in Saudi Arabian regions. A look at the total death ratio of KSA shows that the percentage ratio is highly low in comparison of confirmed cases, but additionally, it is also true that the infection ratio is growing without any limit in various regions (based on the census). It is shown in this COVID-19 period that the death ratio is always much lower in comparison to the infected ratio and cases. But this type of situation has some of its adverse effects on the country's infrastructure. More number of infected cases and ongoing treatment cases directly affect the healthcare infrastructure of the country. Moreover, the vectors of an infection tell that the infection ratio is continuously growing. This is a major concern for the KSA because currently, the country is working towards achieving Vision 2030. All the key resources of the country including the healthcare infrastructure are currently in the transformation stage. The transformation stage has rendered the KSA's health systems vulnerable, and it would be difficult for the state machinery to cater to the heavy COVID-19 caseload. Hence, unless the country works on quick identification of the most affected or most likely to be affected regions of the KSA due to Coronavirus, more people will suffer. Therefore, a mechanism that is accurate and systematic in its findings is required to assess the high-risk spots in KSA and facilitate the highest safety and security countermeasures [23–26] in them for effective prevention.

2.2 Regions of Saudi Arabia

Saudi Arabia is distributed into five main regions and 13 sub-regions [9]. Each region is divided into governorates and the region capitals, which have the status of the municipality and are headed by the mayors. The population of the country is estimated to be 33,091,113 and the density ratio is 15.322 per square km [10]. The life expectancy of males and females is 75.7 and 74.2 years, respectively. Further, 83.8% of the total population is urban. More than 50% of the total population lies between the age group of 25–54 years [11–13]. A range of deserts and contains the 250,001 square meter Rub 'al Khali ("Empty Quarter") in the southeastern portion of the country, the world's biggest contiguous sand desert.
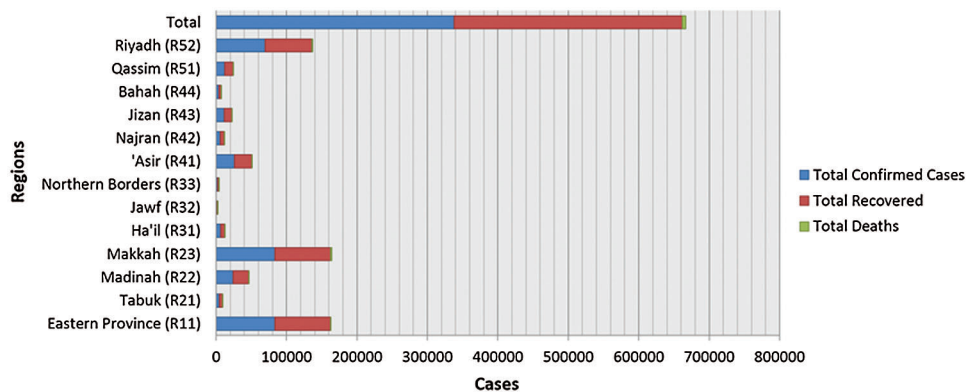
Figure 1: Graphical representation of current census

Normal summer temperatures are about 45°C (113°F) but can reach as high as 54°C (129°F). In the winter the temperature seldom drops below 0°C (32°F) [12,13]. In the spring and autumn, the climate is temperate, temperatures hover about 29°C (84°F). The annual rainfall is extremely poor [14,15]. Further, Fig. 2 represents the regions of KSA, and details of each region have been discussed as follows:

East Region (R1): The Eastern region has only one state namely, the Eastern Province (R11). It is the largest state of KSA in terms of area (259,662 square meters). After Riyadh and Makkah, it is the third most populous region with a population of 4,900,325. The population count is 3,140,362 Saudi citizens, and 1,759,963 foreign nationals [16,17]. The region contributes 15.05 percent of Saudi Arabia's total population. The density ratio of the state is 19/square meters. This state has twenty main hospitals with 2400 beds (approximately) that can help treat the COVID-19 patients. Further, due to high business activity, this state is at high risk due to the COVID-19 pandemic.

West Region (R2): The Western region has three states: Tabuk (R21), Madinah (R22) and Makkah (R23). Details of each state have been discussed as follows:

Tabuk (R21) has a 56,399 square meter area and the population of the state is 910,030. The region accounts for 5.56% of the whole population of Saudi Arabia. The density ratio of the state is 16/square meters. This state has one main hospital with 300 beds (approximately) to deal with the emergencies of the pandemic. Further, due to very low business activity, this state is at low risk due to the COVID-19 pandemic.

Madinah (R22) has a 58,680 square meter area and the population of the state is 2,132,679. The region accounts for 9.84% of the whole population of Saudi Arabia. The density ratio of the state is 36/square meters. This state has seven main hospitals with 3500 beds (approximately). Madinah is the revered pilgrimage visited by many from all corners of the world and is also a business hub. Thus, this state is also at high risk due to the COVID-19 pandemic.

Makkah (R23) has a 59,131 square meter area and the population of the state is 8,557,766. The region accounts for 30.26% of the whole population of Saudi Arabia. The density ratio of the state is 140/square meters. This state has forty main hospitals with 7000 beds (approximately) that can help treat the afflicted. Further, due to highly frequent pilgrim footfall and business activity, this state is a very high risk due to the COVID-19 pandemic.

North Region (R3): The Northern region has three regions: Ha'il (R31), Jawf (R32), and Northern Borders (R33). Information of respective regions has e been deliberated as follows:
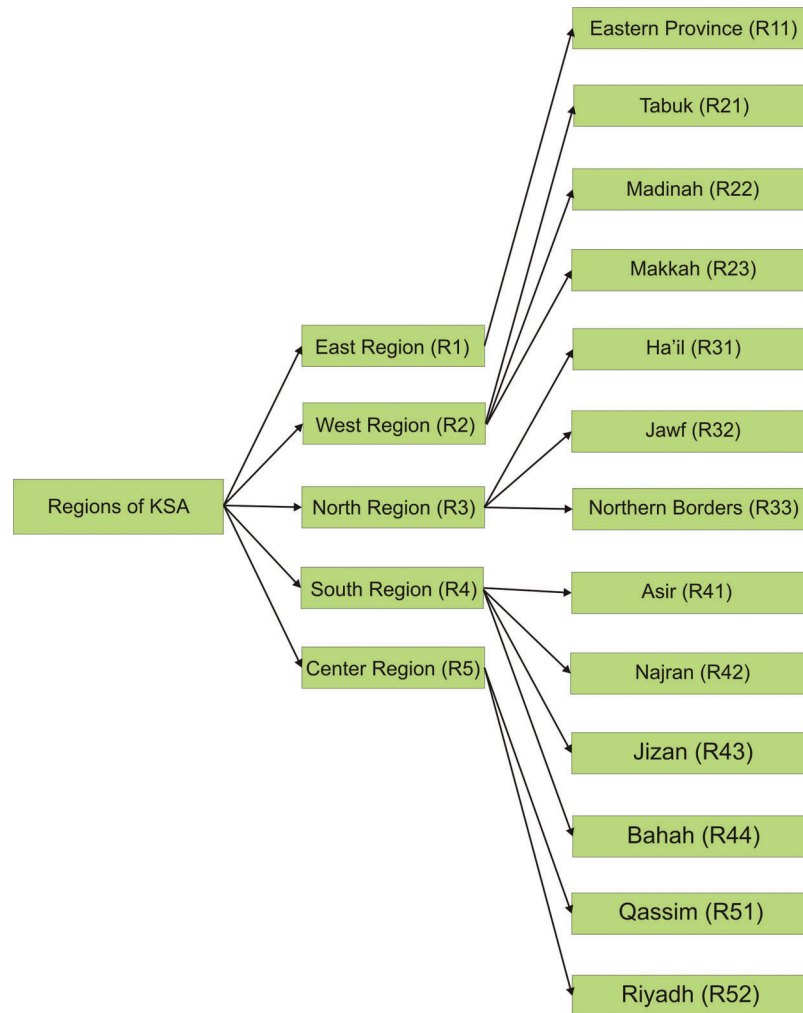
Figure 2: Tree structure of Saudi Arabia regions

Ha'il (R31) has a 40,111 square meter area and the population of the state is 597,144. The state accounts for 3.56% of the whole population of Saudi Arabia. The density ratio of the state is 15/square meters. This state has 5 main hospitals with 1000 beds (approximately). The state has relatively less business activity, hence can be classified in a low-risk zone that is unlikely to be affected by the pandemic.

Jawf (R32) has a 38,692 square meter area and the populationof the state is 508,475. The region accounts for 2.24% of the whole population of Saudi Arabia. The density ratio of the state is 11.4/square meter. This state has two main hospitals with 350 beds (approximately) that can help handle the pandemic. Further, due to low business activity, this state comes in the low-risk category.

Northern Borders (R33) has a 43,165 square meter area and the population of the state is 375,310. The region accounts for 5.06% of the whole population of Saudi Arabia. The density ratio of the state is 8.7/ square meter. This state has 10 main hospitals with 900 beds (approximately). This state is also at low risk due to the COVID-19 pandemic.

South Region (R4): The Southern region has four states: 'Asir (R41), Najran (R42), Jizan (R43), and Bahah (R44). Information of respective region have been deliberated as follows:

'Asir (R41) has a 29,611square meter area and the population of the state is 2,211,875. The region accounts for 15.06% of the whole population of Saudi Arabia. The density ratio of the state is 65/square meters. This state has ten main hospitals with 1250 beds (approximately). Due to the mountains, rainfall, cold temperature [18,19], and high business activity, this state falls under the high-risk zone and is most likely to be affected by the pandemic.

Najran (R42) has a 57,727 square meter area and population of state is 505,652. The region accounts for 3.06% of the whole population of Saudi Arabia. The density ratio of the state is 8.8/square meter. This state has three main hospitals with 500 beds (approximately). Due to low business activity, this state falls under the low risk category.

Jizan (R43) has 4,506 square meter area and population of state is 1,567,547. The region accounts for 7.84% of the whole population of Saudi Arabia. The density ratio of the state is 350/square meter. This state has eight main hospitals with 3000 beds (approximately). Further, due to high business activity, this state is at high risk of contacting the COVID-19 pandemic.

Bahah (R44) has 3,831 square meter area and population of state is 476,172. The state accounts for 4.06% of the whole population of Saudi Arabia. The density ratio of the state is 120/square meter. This state has two main hospitals with 400 beds (approximately) that can be helpful for handling the pandemic. High business activity in the state makes it a vulnerable target of COVID-19 pandemic.

Center Region (R5): The Central region has two states: Qassim (R51) and Riyadh (R52).

Details of each state have been discussed as follows:

Qassim (R51) has 22,412 square meter area and population of state is 1,215,858. The region accounts for 11.06% of the whole population of Saudi Arabia. The density ratio of the state is 54/square meter. This state has ten main hospitals with 1200 beds (approximately). Further, due to high pilgrims and business activity, this state is at high risk due to COVID-19 pandemic.

Riyadh (R52) is the capital and second largest state of the country. It has 156,080 square meter area and population of the state is 8,216,284. The state accounts for 28.06% of the whole population of Saudi Arabia. The density ratio of the state is 53/square meters. This state has thirty-eight main hospitals with 6000 beds (approximately). Further, due to very high pilgrims and business activity, this state at very high risk due to the COVID-19 pandemic.

The authors applied the adopted MCDM methodology to the regions mentioned above to obtain the risk ratio of these regions. The findings of the study can be used by experts to prevent the spread of Coronavirus in KSA.

2.3 Methodology

The adopted methodology fuzzy AHP is an MCDM approach that works on the hierarchical model like Fig. 2 [26,27]. These hierarchal models are associated with various layers based on the levels in the work and assessment criteria. In the context of their layered architecture, the first and most prior layer of hierarchy tells about the main attribute of the research domain. Then, the next layers show the factor and sub-factors of the topic that is relatable and inherited from each other, respectively. After identifying the appropriate hierarchy for assessment, the next step of the examiners is to find the triangular fuzzy value that helps in building the Triangular Fuzzy Number (TFN) used for creating a pair-wise comparison matrix. Triangular Fuzzy membership value for pair-wise comparison was employed by Yu et al. [27].

Baz et al. [22] used the Fuzzy AHP algorithm for evaluating the effectiveness of the healthcare system. In this paper, we adopted TFN because they make calculation of membership functions easy and align with fuzzy data. The TFN lies between 0 and 1. The linguistic values are divided as equally important, weakly important etc., and precise values are shown as numeric 1, 2, … 9., its membership function values are

calculated. The mathematical Eqs. (1)–(4) are used for converting the numerical data into TFN [28,29]. Φ_{ij} is calculated depending upon the geometric mean of the specialists' observation for a particular similarity. TFN [Φ_{ij}] is calculated as:

$$\Phi_{ij} = (A_{ij}, Bi_{ij}, C_{ij}) \tag{1}$$

where $A_{ij} \leq Bi_{ij} \leq C_{ij}$

$$A_{ij} = min(J_{ijd}) \tag{2}$$

$$Bi_{ij} = (J_{ij1}, J_{ij2}, J_{ij3})^{\frac{1}{x}} \tag{3}$$

$$and \ C_{ij} = max(J_{ijd}) \tag{4}$$

The geometric mean is calculated by multiplying and adding two fuzzy numbers and in Eqs. (2) and (4) d stands for summarized data that is taken as observation for calculating TFN values. Eqs. (5)–(7) are used to calculate geometric mean. Consider two TFNs, P1 and P2, P1 = (A1, B1, C1) and P2 = (A2, B2, C2). We calculated the geometric means by these mathematical statements:

$$(A_1, B_1, C_1) + (A_2, B_2, C_2) = (A_1 + A_2, B_1 + B_2, C_2 + C_2) \tag{5}$$

$$(A_1, B_1, C_1) \times (A_2, B_2, C_2) = (A_1 \times A_2, B_1 \times B_2, C_1 \times C_2) \tag{6}$$

$$(A_1, B_1, C_1)^{-1} = \left(\frac{1}{C_1}, \frac{1}{B_1}, \frac{1}{A1} \right) \tag{7}$$

In the above equations, Jijk displays the comparative importance of the rating provided by the expert k between two criteria. Where, I and j represent a pair of parameters that experts' evaluate. In addition, defuzzification is performed after the building of the comparison matrix to generate a quantifiable value based on the measured TFN values. This is done by using the Eqs. (8)–(10) called the alpha cut method [30,31].

$$\mu\alpha, \ \beta(\eta ij) = [\beta.\eta\alpha(Lij) + (1 - \beta).\eta\alpha(Hij)] \tag{8}$$

where, $0 \leq \alpha \leq 1$ and $0 \leq \beta \leq 1$

Such that,

$$\eta\alpha(Lij) = (Mij - Lij).\alpha + Lij \tag{9}$$

$$\eta\alpha(Hij) = Hij - (Hij - Mij).\alpha \tag{10}$$

where α and β are used for experts' choices in those equations. Those two values range from 0 to 1. Precise sets $\ddot{y}\alpha, \beta$ ($\tilde{A}$) are basically defined whether or not an element is a member of the set. Eq. (11) presents a single pair-wise matrix for comparisons.

C1 C2 … Cn

$$\ddot{y}\alpha, \beta(\tilde{A}) = \ddot{y}\alpha, \beta[\tilde{a}ij] = \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} \begin{bmatrix} 1 & \ddot{y}\alpha, \beta(\tilde{a}11) & \dots & \ddot{y}\alpha, \beta(\tilde{a}1i) \\ 1/\ddot{y}\alpha, \beta(\tilde{a}21) & 1 & \dots & \ddot{y}\alpha, \beta(\tilde{a}2i) \\ . & . & & . \\ . & . & & . \\ 1/\ddot{y}\alpha, \beta(\tilde{a}j1) & 1/\ddot{y}\alpha, \beta(\tilde{a}j2) & \dots & 1 \end{bmatrix} \tag{11}$$

The next step is to evaluate the pair-wise comparison matrix's eigenvalue and eigenvector. Assume that μ denotes the eigenvector while λ denotes the eigenvalue of fuzzy pair-wise comparison matrix ηij (Eq. (12)).

$$[\mu\alpha, \beta(\eta ij) - \lambda I].\mu = 0 \tag{12}$$

Eq. (12) is based on linear vector transformation, in which I represent the unit matrix. By applying Eqs. (1)–(12), the weights of specific criteria may be acquired against all the other possible criteria.

3 Data Analysis and Results

3.1 Statistical Findings

Analytic Hierarchy Process (AHP) is used to evaluate a common choice in a set of judgments, but most of the experts have found that fuzzy-based AHP is more accurate in giving their weights precise decisions [22–25]. This is an important method commonly used by decision-makers to complete a priority analysis. This method is helpful in deep learning and is effectively utilized in neural network-related issues. The current use of this method in the proposed article is highly appropriate and effective as it simulates the possible effective decision options for the experts in KSA and through these options, they can propose their future countermeasures against the pandemic. To deal with the hesitations and vagueness of the experts' decision, the contributors of this article adopted an improved form of AHP, which is called the fuzzy AHP. More specifically, in the context of the COVID-19 pandemic, there is no confirm treatment and every expert is doing his/her best to treat the afflicted.

In such a critical scenario, the decision-making process plays a key role during a patient's treatment. This method is also the best choice for locking the infection dynamics. In this row, we have done the risk assessment and the severity levels of each state of the Saudi Arabia. Moreover, this contribution is aimed at evaluating the risk of COVID-19 pandemic in Saudi Arabian regions, with the aid of experts' inputs. For assessing the risk, authors have taken the opinions of 25 experts from the various areas of research institutes and hospitals. Furthermore, with the help of Eqs. (1)–(3), authors converted the linguistic data into numeric data and Fuzzy numbers in triangular form. Fig. 2 shows the regions and sub-regions at Levels 1 and 2, respectively. Thereafter, the aggregated fuzzy pair-wise comparison matrixes that are constructed have been shown in Tabs. 2–6. After constructing the fuzzy pair-wise comparison matrices, Eqs. (4)–(6) are used for defuzzification. Further, Eq. (7) is used to evaluate the single pair-wise comparison matrix (Crisp set). In the next step, we evaluated the consistency ratio of each matrix [26,27]. Eq. (8) is used to calculate the eigenvalue and eigenvector. With the help of Eqs. (9)–(12), the authors assessed the defuzzified values and local weights of each group that are shown in Tabs. 7–11. Finally, Tab. 12 shows the dependent weights of each region through the hierarchy.

To analyze the evaluated results by describing the above Tab. 13, it can be seen that Riyadh and Makkah are the high-risk regions in KSA with 16.10 and 13.58 percent ratio of risk, respectively. Similarly, Tubuk and Northern Border are less and low risk regions with 4.19 and 3.00 percentage of risk ratio. The analytical view on this type of results tells that Riyadh and Makkah are both at highest risk due to their large population and infrastructure complexities according to authors' evaluation. Thus, this type of analysis portrays an immense need for efficacious preventive measures in the specified high-risk ratio regions. Additionally, risk ratio for every region in between Riyadh and Northern Border regions has been determined. This result can be adopted by the experts to assess the outcome for these cities and create appropriate policies to contain COVID-19.

Table 2: Pair wise comparison matrix for Saudi Arabian main regions

	R1	R2	R3	R4	R5
East region (R1)	1.00000, 1.00000, 1.00000	0.31256, 0.45487, 0.62658	0.88569, 0.92658, 0.93665	0.22563, 0.30255, 0.42563	0.22256, 0.33556, 0.51525
West region (R2)	–	1.00000, 1.00000, 1.00000	2.15447, 3.12566, 4.24475	0.25568, 0.36785, 0.59362	0.69256, 1.11115, 1.52568
North region (R3)	–	–	1.00000, 1.00000, 1.00000	0.35586, 0.53658, 0.98556	0.47854, 0.53658, 0.81585
South region (R4)	–	–	–	1.00000, 1.00000, 1.00000	0.89556, 1.15857, 1.39556
Center region (R5)	–	–	–	–	1.00000, 1.00000, 1.00000

Table 3: Pair wise comparison matrix for Saudi Arabian western regions

	R21	R22	R23
Tabuk (R21)	1.00000, 1.00000, 1.00000	0.70525, 0.90005, 1.15565	0.23636, 0.24585, 0.36964
Madinah (R22)	–	1.00000, 1.00000, 1.00000	0.31528, 0.39663, 0.57855
Makkah (R23)	–	–	1.00000, 1.00000, 1.00000

Table 4: Pair wise comparison matrix for Saudi Arabian northern regions

	R31	R32	R33
Ha'il (R31)	1.00000, 1.00000, 1.00000	0.88569, 0.92658, 0.93665	0.22563, 0.30255, 0.42563
Jawf (R32)	–	1.00000, 1.00000, 1.00000	1.19252, 1.58556, 2.15554
Northern borders (R33)	–	–	1.00000, 1.00000, 1.00000

Table 5: Pair wise comparison matrix for Saudi Arabian southern regions

	R41	R42	R43	R44
'Asir (R41)	1.00000, 1.00000, 1.00000	0.25568, 0.36785, 0.59362	0.69256, 1.11115, 1.52568	0.56562, 0.71417, 0.87565
Najran (R42)	–	1.00000, 1.00000, 1.00000	0.25568, 0.36785, 0.59362	0.69256, 1.11115, 1.52568
Jizan (R43)	–	–	1.00000, 1.00000, 1.00000	0.66859, 1.05365, 1.54547
Bahah (R44)	–	–	–	1.00000, 1.00000, 1.00000

Table 6: Pair wise comparison matrix for Saudi Arabian central regions

	R51	R52
Qassim (R51)	1.00000, 1.00000, 1.00000	0.35858, 0.49658, 0.68556
Riyadh (R52)	–	1.00000, 1.00000, 1.00000

Table 7: Local weights for Saudi Arabia's main regions

	R1	R2	R3	R4	R5	Weights
East region (R1)	1.00000	0.46585	0.98854	0.35658	0.37584	0.09456
West region (R2)	2.21542	1.00000	3.15696	0.39785	1.15574	0.22890
North region (R3)	1.15598	0.32565	1.00000	0.59555	0.55887	0.11589
South region (R4)	3.25685	2.54574	1.68665	1.00000	1.14856	0.32267
Center region (R5)	2.77696	0.95859	1.81525	0.88557	1.00000	0.23395
C.R. = 0.04112500						

Table 8: Local weights for Saudi Arabian western regions

	R21	R22	R23	Weights
Tabuk (R21)	1.00000	0.89857	0.28556	0.18312
Madinah (R22)	1.12745	1.00000	0.42568	0.22355
Makkah (R23)	3.53652	2.45541	1.00000	0.59257
CR = 0.006102500				

Table 9: Local weights for Saudi Arabian northern regions

	R31	R32	R33	Weights
Ha'il (R31)	1.00000	0.98457	1.35548	0.36365
Jawf (R32)	1.12547	1.00000	1.62569	0.38749
Northern Borders (R33)	0.75625	0.61569	1.00000	0.25365
C.R.= 0.002500621				

3.2 Comparison Analysis

Comparison analysis is a process that indicates and tests the affectivity as well as importance of adopted approach by comparing the present methodology vis-à-vis other similar methodologies. Such an evaluation establishes the efficiency of the methodology used in this paper to assess the risk factors in various regions of Saudi Arabia. To conduct the comparison analysis for the present study, authors performed the same evaluation with different classical AHP methodology (Tab. 13) [18–22].

Table 10: Local weights for Saudi Arabian southern regions

	R41	R42	R43	R44	Weights
'Asir (R41)	1.00000	1.59475	1.16457	0.71657	0.25357
Najran (R42)	0.62569	1.00000	0.45569	0.32691	0.13269
Jizan (R43)	0.85658	0.90527	1.00000	1.16257	0.28263
Bahah (R44)	1.39537	3.05569	0.92567	1.00000	0.33265
CR = 0.0185220110					

Table 11: Local weights for Saudi Arabian central regions

	R51	R52	Weights
Qassim (R51)	1.00000	0.451254	0.31265
Riyadh (R52)	2.255687	1.00000	0.68778
C.R.= 0.0000			

Table 12: Dependent weights of Saudi Arabian regions through the hierarchy

Main regions	Local weights	Sub-regions	Local weights	Overall weights
R1	0.09456	R11	———	0.09456
R2	0.22890	R21	0.18312	0.02564
		R22	0.22355	0.05489
		R23	0.59257	0.14658
R3	0.11589	R31	0.36365	0.04367
		R32	0.38749	0.04685
		R33	0.25365	0.02455
R4	0.32267	R41	0.25357	0.08168
		R42	0.13269	0.04967
		R43	0.28263	0.09258
		R44	0.33265	0.15697
R5	0.23395	R51	0.31265	0.08965
		R52	0.68778	0.15655

The difference between classical and fuzzy AHP methodology is very small, but very significant. Addition of fuzzy set theory gives an effective ability to fuzzy AHP methods, whereas the classical AHP methods are not so effective. The evaluated outcomes in Tab. 13 and Fig. 3 of comparison analysis clearly portray that results extracted from both approaches are not so varied. Therefore, it is clearly evident by the outcome that the adopted methodology is highly effective and its results do not provide highly varied results when compared with similar techniques. Further to portray a more categorized and

clear picture of extracted outcomes authors compare the evaluated results percentage ratio with the current case percentage ratio that gives an effective overview about the results discussed in this study. Following Tab. 13 shows the comparison ratio.
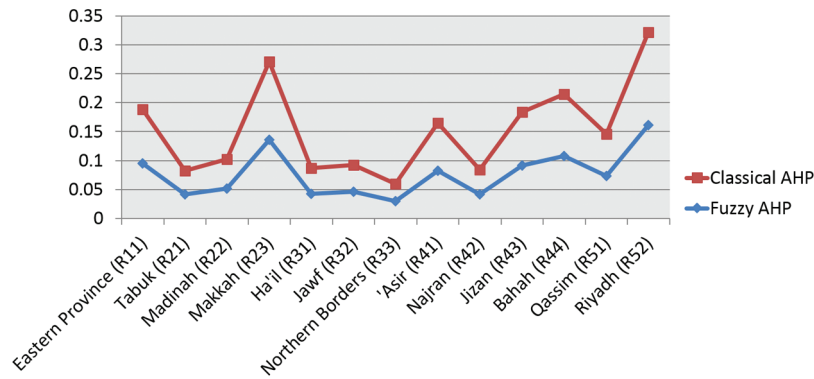

Figure 3: Graph of comparison analysis

Table 13: Comparison between obtained results and current situation

Sub-regions	Obtained results (weights)	Current situation (normalized weights through confirmed cases)
Eastern Province (R11)	0.09456	0.24500
Tabuk (R21)	0.02564	0.01400
Madinah (R22)	0.05489	0.07400
Makkah (R23)	0.14658	0.24700
Ha'il (R31)	0.04367	0.01600
Jawf (R32)	0.04685	0.00330
Northern borders (R33)	0.02455	0.00580
'Asir (R41)	0.08168	0.07620
Najran (R42)	0.04967	0.01740
Jizan (R43)	0.09258	0.03440
Bahah (R44)	0.15697	0.01040
Qassim (R51)	0.08965	0.03600
Riyadh (R52)	0.15655	0.20450

3.3 Limitation of Study

As Saudi Arabia intensifies its efforts to curb the fatal contagion, several risk assessment factors and theories have been dwelt upon and postulated in different research endeavors. It is still a complex and challenging task in KSA to identify and spot high-risk zones. The current scenario of cases in Saudi Arabia and its analysis call for a risk-based region categorization and corona prevention policy development for specific regions based on their geographical and environmental infrastructure. Every

research has its limitations and restrictions. Limitations portray the future possibilities of paper and give ideal potential future research topics to researchers. The limitations of the proposed study are described in the following points:

- Many hybrid MCDM approaches are available and they can produce more efficient results than the fuzzy AHP methodology adopted by us.
- The data and area used for applying methodology are limited and small. Authors strongly believe that the same adopted methodology can produce more efficient outcomes with a large-scale dataset.
- As in the context of the methodology of the paper, α and β are two variables in equations that can affect results. This is another limitation of this study.

4 Conclusions

The numerical assessment gives a complementary advantage to this proposed study because the evaluated quantitative results are simulated versions of the actual situation, approximately. Such an empirical framework would prove to be a reliable milestone to categorize and prevent the spread of COVID-19 in KSA. Moreover, our research investigation attempted to develop a new model for the evaluation of the states at high risk due to the COVID-19 pandemic. The advantage of this new model is that it can objectively and cognitively analyze the spread of Coronavirus in different regions of Saudi Arabia. After collection of data for all the regions, we applied the Fuzzy AHP methodology for finding states that are likely to be under the highest risk category due to COVID-19. Results indicate that Riyadh and Makkah are the most vulnerable targets. The conclusive research evidence drawn from our study seeks to be an effective contribution in the mission of battling against COVID-19 undertaken by the Kingdom of Saudi Arabia. Yet another dimension that can be explored for future research in this context could be the implementation of this computational methodology by employing the SEIR model. Moreover, the present study also focuses on healthcare infrastructures and healthcare population ratios in KSA to get appropriate and relatable effective results. After associating and assessing this type of region-based categorization, the following most concrete and significant outlines are extracted by presented study:

Riyadh and Makkah are the most susceptible regions and must be categorised in the highest possible risk zone in KSA. The presented study gives a comprehensive and systematic step-wise path to assess the level of risk in different regions of KSA that can be further adopted by researchers to facilitate their own ideology of assessment.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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