Fuzzy Based Decision Making Approach for Evaluating the Severity of COVID-19 Pandemic in Cities of Kingdom of Saudi Arabia

Abdullah Baz¹, * and Hosam Alhakami²

¹Department of Computer Engineering, College of Computer and Information Systems, Umm Al-Qura University, Makkah, Saudi Arabia
²Department of Computer Science, College of Computer and Information Systems, Umm Al-Qura University, Makkah, Saudi Arabia

*Corresponding Author: Abdullah Baz. Email: aobaz01@uqu.edu.sa
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Abstract: The World Health Organization declared COVID-19 a pandemic on March 11, 2020 stating that it is a worldwide danger and requires imminent preventive strategies to minimise the loss of lives. COVID-19 has now affected millions across 211 countries in the world and the numbers continue to rise. The information discharged by the WHO till June 15, 2020 reports 8,063,990 cases of COVID-19. As the world thinks about the lethal malady for which there is yet no immunization or a predefined course of drug, the nations are relentlessly working at the most ideal preventive systems to contain the infection. The Kingdom of Saudi Arabia (KSA) is additionally combating with the COVID-19 danger as the cases announced till June 15, 2020 reached the count of 132,048 with 1,011 deaths. According to the report released by the KSA on June 14, 2020, more than 4,000 cases of COVID-19 pandemic had been registered in the country. Tending to the impending requirement for successful preventive instruments to stem the fatalities caused by the disease, our examination expects to assess the severity of COVID-19 pandemic in cities of KSA. In addition, computational model for evaluating the severity of COVID-19 with the perspective of social influence factor is necessary for controlling the disease. Furthermore, a quantitative evaluation of severity associated with specific regions and cities of KSA would be a more effective reference for the healthcare sector in Saudi Arabia. Further, this paper has taken the Fuzzy Analytic Hierarchy Process (AHP) technique for quantitatively assessing the severity of COVID-19 pandemic in cities of KSA. The discoveries and the proposed structure would be a practical, expeditious and exceptionally precise evaluation system for assessing the severity of the pandemic in the cities of KSA. Hence these urban zones clearly emerge as the COVID-19 hotspots. The cities require suggestive measures of health organizations that must be introduced on a war footing basis to counter the pandemic. The analysis tabulated in our study will assist in mapping the rules and building a systematic structure that is immediate need in the cities with high severity levels due to the pandemic.

Keywords: Kingdom of Saudi Arabia; COVID-19; severity assessment; fuzzy AHP; dynamics of infection

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1 Introduction

The very first case of COVID-19 pandemic was detected in Wuhan, China from unknown source in December 2019. Initially, COVID-19’s seemed more like influenza and the expert’s team did not place it in the league of avian influenza, Severe Acute Respiratory Syndrome (SARS-CoV), and Middle East Respiratory Syndrome Coronavirus (MERS-CoV) [1]. However, when the number of cases rapidly increased due to person to person transmission then, the WHO suggested that novel Coronavirus was far more dangerous than SARS, and MERS-CoV. As per the current status in the world, almost every person is suffering from the COVID-19 pandemic, directly or indirectly; if not by the infection, people are suffering because their lifestyles and incomes have been severely crippled. The pandemic has also affected the mental health and general well-being of people as well. This virus’s spread is harmful and disastrous for any country or region. The current situation in the world is horrifying as COVID-19 afflicts more people with the death toll increasing alarmingly.

Moreover, COVID-19 is much more dangerous because no country has a standard and validated medication or vaccine to contain the virus and cure the patients. Various concepts and methodologies, though, are under research and the specialists across the globe are working on possible breakthroughs in developing a vaccine or an effective drug. Medical and engineering researchers and experts find that the nature of COVID-19 virus is much resilient and its most easy vector for infection is human to human interaction. Practitioners also find that international flight travel, bus travel and unhealthy meat consumption, etc., increases the possibilities of contacting the infection [2]. In the context of corona virus spread, KSA has implemented effective measures and strategies to counteract the threat of COVID-19 [3].

Further in this row, our proposed study will be a definite help to the Saudi researchers and experts in gauging the corona virus spread in KSA’s most populated cities. The data generated by the proposed methodology can be an accurate reckoner for the strategists to launch the best possible containment measures in the densely populated regions, thus reducing the extent of devastation. Different cities in the KSA have varying attributes in terms of men-women ratio, children count, geographical condition, environmental situation, etc. Similarly, availability of resources like hospitals, medical facilities, etc., in KSA also differs from region to region. Hence in the backdrop of these facts, the proposed study tries to bridge the gap between the identification of infected cities based on their risk ratio and prioritizing them for helping cities effectively. This can be done through the empirical analysis profiled in our research which is based on step-wise medical enhancement that the experts can employ.

The study has taken twenty four most populated cities for the research whose population lies between 100,000 to 4,300,000 [4]. Further, four cities have more than 1,000,000 people and twenty cities have between 100,000 and 1,000,000 people. Such an examination activity would likewise be powerful option in contrast to the neurosis and disarray among individuals with respect to the spread of the pandemic. Currently, the most suitable and effective measure against corona spread is identifying the susceptible persons as well as cities and then turn them into a containment zone, and seal all types of activity in the area. Similarly in this study, the authors have identified and selected various infected cities of KSA and then prioritized them accordingly by using the selected methodology. Multi-Criteria-Decision-Making methodology is adopted and implemented for analyzing the various cities and their priority in proposed study [5–7].

MCDM is the most effective and easy way to solve issues related to decision making in different contexts. Many researchers implemented the MCDM technique for various topics [8–10]. Methodologies that are adopted by these studies are based on the behavioral analysis of MCDM technique [11,12]. There are many methods that provide priority through MCDM techniques where there are many methods that are used to identify indicators value in methodology [13,14]. Fuzzy AHP procedure was utilized in this paper to assess the severity of COVID-19 pandemic in Saudi Arabian cities. The remainder of this article is arranged as follows: The subsequent portion is a profile of the regions, states and top populated cities
of Saudi Arabia; The third section portrays the technique for evaluation for example Fuzzy AHP. The fourth section applies the method for obtaining the results. Section five presents the conclusion.

2 Regions and Cities of Kingdom of Saudi Arabia

Our research was developed by perusing and calculating the data collected through experts, literature surveys, medical, web sites and reports [15,16]. The identification of collected data indicates various risk factors in cities that may be the cause of corona spread in Saudi Arabia. For instance, authors identified that medical experts strongly believe that the immune system of the citizens of KSA is not as strong as it should be to combat the virus [17]. A weak immune system can be easily infected and is less likely to respond to any treatment, thus increasing the danger of mortality. In addition, for providing a more convincing and verified base for the proposed study, the authors selected the relevant literature that combines the medical utilities and conditions with modern technical resources for producing effective outcomes. Notably, Saudi Arabia has five primary regions and 13 states in all [18,19]. Every locale is separated into Governorates and the Area Capitals, which have the status of district.

The total population of KSA is 33,413,660, which represents 0.43% of global population and is ranked 41st worldwide [4,20]. The density ratio is 15.322 per square KM. The average life of male and female in KSA is 75.7 and 74.2, respectively. 83.7% of the population of KSA lives in urban demographical land of country. A study also describes that the 50% of the population in KSA is young and their age lies between 24–54 years [19,20]. The average temperature in summer is 45°C (113°F), but in some special cases the temperature may even rise to 54°C (129°F). On the other hand, in winters, the temperature can be as low as 0°C (32°F) [21]. In spring and other weather, the average temperature of KSA is usually around 29°C (84°F). Condition of rain in KSA is much weaker than any other country in world [19,21].

There are 4 cities with more than a million people in Saudi Arabia; forty five major cities have population between ten thousands and hundred thousand people. Riyadh is the capital and largest city of the KSA. The authors have taken twenty four most populated cities of KSA. This is because more the density of the population of a city, greater are the chances of the pandemic’s spread in it. Further other attributes such as number of hospitals, population, time of lockdown has been kept in mind while opting for these cities. Fig. 1 below describes the hierarchy of twenty four top most populated and vulnerable cities of Saudi Arabia along with their respective states.

![Figure 1: Tree structure of Saudi Arabian regions](image-url)
Population of these twenty four cities is more than one million [4]. Other details of the cities and their respective states have been discussed as follows:

East Region (R1): Eastern Province (R11) is the only state that belongs from the east region of KSA. Eastern Province has the country’s largest land acquisition (259,662 square meters). It is also the third largest populated state of Saudi Arabia with 4,900,325 people. In this Province, six cities have more than 100,000 people. Dammam City (C111), Al Hufuf City (C112), Al Mubarraz City (C113), Hafar Al-Batin City (C114), Al Jubayl City (C115), and Khobar City (C116) have 768602, 293179, 290802, 271642, 237274, and 165799 people, respectively. In the context of resources, this state has 20 hospitals and 2400 beds in terms of medical facilities and is more prepared to handle emergencies due to the pandemic.

West Region (R2): West region of KSA is divided into three main states that are: Tabuk (R21), Madinah (R22) and Makkah (R23). A detailed description of all these states is written below:

- Tabuk (R21)–has 56,399 square meter area in the terms of geographical construction. The population of the state is 910,030. In this Province, there is only Tabuk city (C211) and it has more than 100000 people i.e., 455450. In the context of resources and preparedness for the pandemic, the region has only one main hospital along with 300 beds.

- Madinah (R22) is spread over 58,680 square meter area in the terms of geographical construction. The population of the state is 2,132,679. In this Province, two cities have more than 100,000 people. Yanbu City (C221) and Medina City (C222) have 200161, and 1,300,000 people, respectively. In the context of resources, the region has seven main hospitals along with 3500 beds (approximately).

- Makkah (R23) has an area of 59,131 square meters terms of geographical construction. The population of the state is 8,557,766. In this Province, three cities have more than 100,000 people. Ta'if City (C231), Jeddah City (C232), Makkah City (C233) have 530848, 2867446, and 1323624 people, respectively. In the context of resources, the region has forty main hospitals along with 7000 beds (approximately). This state is also the abode of the largest holy place of Muslims called the Makkah City. Thus the city is at a higher risk of virus spread.

North Region (R3): This region is divided into three main states that are: Ha’il (R31), Jawf (R32) and Northern Borders (R33). A detailed description of all these states is written below:

- Ha’il (R31) has 40,111 square meter area in the terms of geographical construction. The population of the state is 597,144. In this Province, only Ha’il City (C311) has more than 100,000 people with the population of 267005. In the context of resources to deal with contingencies in times of the pandemic, the region has 5 main hospitals along with 1000 beds (approximately).

- Jawf (R32) is spread over 38,692 square meter area in the terms of geographical construction, the population is 508,475. In this Province, two cities have more than 100,000 people. Sakakah City (C321) and Qurayyat City (C322) have 128332, and 102903 people, respectively. In the context of resources, the region has two main hospitals along with 350 beds (approximately).

- Northern Borders (R33) acquire 43,165 square meter area in the terms of geographical construction and the population of the state is 375,310. In this Province, only Arar City (C331) has more than 100,000 people i.e., 148540. The region has 10 main hospitals along with 900 beds (approximately) in all.

South Region (R4): The South region of KSA is divided into four main states that are: ‘Asir (R41), Najran (R42), Jizan (R43) and Bahah (R44). A detailed description of all these states is written below:

- ‘Asir (R41) has an area of 29,611 square meters and the population of the state is 2,211,875. In this Province, two cities have more than 100,000 people. Khamis Mushait City (C411) and Abha City
have 387553, and 210886 people, respectively. In the context of resources, the region has ten main hospitals along with 1250 beds (approximately).

- Najran (R42) has an area of 57,727 square meters. The population of the state is 505,652. In this Province, only Najran City (C421) has more than 100,000 people with the population of 258,573. The region has three main hospitals along with 500 beds (approximately).

- Jizan (R43) has an area of 4,506 square meters and the population of the state is 1,567,547. In this Province, only Jizan City (C431) has more than 100,000 people with a population of 105,198. The region has eight main hospitals along with 3000 beds (approximately).

- Bahah (R44) acquires 3,831 square meter area in the terms of geographical construction. The population of the state is 476,172. This Province has no more than 100,000 people in a single city. In the context of resources to manage the emergencies of the pandemic, the region has two main hospitals along with 400 beds (approximately).

Center Region (R5): The central region of KSA is divided into two main states that are: Qassim (R51) and Riyadh (R52). A detailed description of all these states is written below:

- Qassim (R51) has an area of 22,412 square meters and the state’s population is 1,215,858. In this Province, only Buraydah City (C511) has more than 100,000 people with a population of 391,336. The region has ten main hospitals along with 1200 beds (approximately).

- Riyadh (R52) is a central point and capital of the country with an area of 156,080 square meters. The total population is 8,216,284. In this Province, three cities have more than 100,000 people. Al Kharj City (C521), Sultanah City (C522), and Riyadh City (C523) have 425300, 946,697, and 4,205,961 people, respectively. The region has thirty eight main hospitals along with 6000 beds (approximately).

3 Methodology Followed

The adopted methodology for assessment is Fuzzy-AHP (Analytical Hierarchy Process). Fuzzy-AHP is a MCDM approach that works on a hierarchal tree and provides accurate and effective results [22,23]. In addition, first step for assessment through this methodology is to construct a hierarchy of various factors that need to be assessed by fuzzy-AHP. The factors to be assessed in this study have already been tabulated in Fig. 1. The factors have been converted into the values of Triangular Fuzzy Numbers (TFN) for calculation. Thereafter, pair-wise comparison matrix has been constructed by using Eqs. (1)–(4) [24–26]. This type of procedure for assessment was adopted from Kumar et al. [27].

Agrawal et al. [28] have also used the fuzzy-AHP methodology for analyzing the healthcare issues and factors effectively. For this proposed study, authors adopted the TFN value for effective and easy calculation process. TFN value always lies between 0 and 1 [29–31]. In addition, linguistic values of lower, medium and upper limit are divided through numeric values: 1, 2, 3…..9. Value of $\Phi_{ij}$ is evaluated via geometrical mean process of experts’ opinion. Equations that are used in calculation are:

\[ \Phi_{ij} = (X_{ij}, Y_{ij}, Z_{ij}) \]  \hspace{1cm} (1)
\[ X_{ij} = \min (J_{ij1}) \]  \hspace{1cm} (2)
\[ Y_{ij} = (J_{ij1}, J_{ij2}, J_{ij3})^{\frac{1}{3}} \]  \hspace{1cm} (3)
and \( Z_i = \max(J_{ijk}) \) \( (4) \)

The geometric mean is determined by duplicating and including two fuzzy numbers. Scientific articulations (5–7) are utilized to compute geometric mean. We determined the geometric methods by these scientific explanations:

\[
(X_1, Y_1, Z_1) + (X_2, Y_2, Z_2) = (X_1 + X_2, Y_1 + Y_2, Z_1 + Z_2)
\]

\[
(X_1, Y_1, Z_1) \times (X_2, Y_2, Z_2) = (X_1 \times X_2, Y_1 \times Y_2, Z_1 \times Z_2)
\]

\[
(X_1, Y_1, Z_1)^{-1} = \left( \frac{1}{Z_1}, \frac{1}{Y_1}, \frac{1}{X_1} \right)
\]

\( J_{ijk} \) illustrates the significance of the expert’s opinion \( k \). Additionally, \( I \) and \( J \) represent the parameters experimented by experts. Further, defuzzification process is evaluated after constructing comparison pair matrix and converting the TFN values. All these processes are evaluated through Eqs. (8)–(10) \[32,33\].

\[
\mu_{\alpha, \beta}(\eta_{ij}) = [\beta \eta(X_{ij}) + (1 - \beta) \eta(Z_{ij})]
\]

\( \eta(X_{ij}) = (Z_{ij} - X_{ij}) \alpha + X_{ij} \) \( \eta(Z_{ij}) = Z_{ij} - (Z_{ij} - Y_{ij}) \alpha \)

where \( 0 \leq \alpha \leq 1 \) and \( 0 \leq \beta \leq 1 \)

Equation (12) is based on straightforward vector change, in which \( I \) corresponds to the unit network. By applying scientific proclamations (1–12), the loads of explicit models might be procured against the various potential rules.
4 Data Analysis and Results

AHP procedure is used to construct judgment in multi criteria situation. In the recent years it is evident and clearly displayed that many researchers and experts are using AHP methodology for constructing precise decision on calculated and evaluated results [10–12, 33–35]. This is a significant strategy ordinarily utilized by the experts to finish a need based investigation. To manage the delays and ambiguities that might arise due to the experts’ choices, we opted for an improved type of AHP, which is known as the fuzzy AHP. In the context of COVID-19 pandemic, there is no specific treatment yet and each expert is doing his/her best to treat the victims.

In such a varied scenario, fuzzy-AHP method plays an even more significant role in treatment procedure against COVID-19. The procedure has the ability to produce and evaluate the sensitivity and priority of infection dynamics. To achieve the desired goals, the authors assessed the risk and severity of every categorized region of KSA. Furthermore, this proposed study’s intent is to provide a severity assessment of Saudi cities. This was evaluated by the authors on the basis of the experts’ opinions. We have taken the opinions of 25 experts for this assessment. Further, through the Eqs. (1)–(12) described in the methodology section of this paper, we constructed Tabs. 1–11 of comparison pair-wise matrix and evaluated the ranking of hierarchy described in Fig. 1.

| Table 1: Saudi Arabian main regions at level 1 |
|-----------------------------------------------|
| R1    | R2         | R3         | R4         | R5         |
| East Region (R1)                             |
| 1.0000 | 0.3130,0.4400,0.6250 | 0.8730,0.9010,0.9470 | 0.2260,0.2930,0.4170 | 0.2580,0.3390,0.5060 |
| West Region (R2)                             |
| –      | 1.0000,1.0000,1.0000 | 2.0450,3.1700,4.2330 | 0.2670,0.3660,0.5910 | 0.6910,1.0060,1.5120 |
| North Region (R3)                            |
| –      | –          | 1.0000,1.0000,1.0000 | 0.3670,0.5250,0.9660 | 0.3600,0.5220,0.8070 |
| South Region (R4)                            |
| –      | –          | –          | 1.0000,1.0000,1.0000 | 0.8960,1.1490,1.3900 |
| Center Region (R5)                           |
| –      | –          | –          | –          | 1.0000,1.0000,1.0000 |

| Table 2: Saudi Arabian west regions at level 2 |
|-----------------------------------------------|
| R21   | R22         | R23         |
| Tabuk (R21) | 1.0000,1.0000,1.0000 | 0.6900,0.8860,1.1000 | 0.2260,0.2760,0.3570 |
| Madinah (R22) | –          | 1.0000,1.0000,1.0000 | 0.3050,0.3890,0.5610 |
| Makkah (R23) | –          | –          | 1.0000,1.0000,1.0000 |

| Table 3: Saudi Arabian north regions at level 2 |
|-----------------------------------------------|
| R31   | R32         | R33         |
| Ha’il (R31) | 1.0000,1.0000,1.0000 | 0.6950,0.9500,1.3460 | 1.1490,1.4390,1.6960 |
| Jawf (R32) | –          | 1.0000,1.0000,1.0000 | 1.1930,1.5830,2.1500 |
| Northern Borders (R33) | –          | –          | 1.0000,1.0000,1.0000 |
| Table 4: Saudi Arabian south regions at level 2 |
|-----------------------------------------------|
| **R41** | **R42** | **R43** | **R44** |
| 'Asir (R41) | 1.0000, 1.0000, 1.0000 | 1.0781, 1.5990, 2.1130 | 0.8210, 1.1120, 1.6150 | 0.5670, 0.7130, 0.8740 |
| Najran (R42) | – | 1.0000, 1.0000, 1.0000 | 0.3230, 0.4480, 0.6050 | 0.2580, 0.3170, 0.4170 |
| Jizan (R43) | – | – | 1.0000, 1.0000, 1.0000 | 0.6660, 1.0560, 1.5430 |
| Bahah (R44) | – | – | – | 1.0000, 1.0000, 1.0000 |

| Table 5: Saudi Arabian central regions at level 2 |
|-----------------------------------------------|
| **R51** | **R52** |
| Qassim (R51) | 1.0000, 1.0000, 1.0000 | 0.3130, 0.4400, 0.6250 |
| Riyadh (R52) | – | 1.0000, 1.0000, 1.0000 |

| Table 6: Eastern province cities at level 3 |
|-----------------------------------------------|
| **C111** | **C112** | **C113** | **C114** | **C115** | **C116** |
| Dammam City (C111) | 1.0000, 1.0000, 1.0000 | 1.0000, 1.5157, 1.9331 | 0.4896, 0.6372, 1.0000 | 0.4152, 0.5743, 1.0000 | 0.2215, 0.3936, 0.5661 | 0.3146, 0.4610, 0.8705 |
| Al Hufuf City (C112) | – | 1.0000, 1.0000, 1.0000 | 0.3009, 0.5386, 1.0000 | 1.5518, 0.5836, 1.0000 | 1.0000, 1.5836, 1.1791 |
| Al Mubarraz City (C113) | – | – | 1.0000, 1.0000, 1.0000 | 1.0000, 1.5518, 1.0000 | 1.0000, 1.5836, 1.1791 |
| Hafar Al-Batin City (C114) | – | – | – | 1.0000, 1.0000, 1.0000 | 1.0000, 1.5836, 1.1791 |
| Al Jubayl City (C115) | – | – | – | – | 1.0000, 1.0000, 1.0000 | 1.0000, 1.0000, 1.0000 |
| Khobar City (C116) | – | – | – | – | – | 1.0000, 1.0000, 1.0000 |
For developing a fuzzy pair-wise correlation matrix, conditions (4–6) are utilized for defuzzification. In the subsequent stage, we assessed the consistency ratio of each matrix [13,14,24,25,34–36]. Eq. (8) is utilized to compute the eigenvalue and eigenvector. With the assistance of Eqs. (1)–(8), we evaluated the defuzzified values of each matrix that are depicted from Tabs. 12–22 and Figs. 2–12. In addition, Tab. 23 shows the dependent weights of Saudi Arabian regions through the hierarchy. With the help of Tab. 23 and Tabs. 17–22, we estimated dependent weights of Saudi Arabian cities through the hierarchy in Tab. 24. Finally, normalized weights and final ranking of the Saudi Arabian regions and cities was obtained. This has been shown in Tab. 25, Fig. 13 and Tab. 26, Fig. 14, respectively.
Table 12: Local weights for Saudi Arabia’s main regions at level 1

| Region          | R1   | R2   | R3   | R4   | R5   | Weights |
|-----------------|------|------|------|------|------|---------|
| East Region (R1)| 1.0000 | 0.4540 | 0.9060 | 0.3070 | 0.3600 | 0.0950  |
| West Region (R2)| 2.2020 | 1.0000 | 3.1550 | 0.3970 | 1.0540 | 0.2290  |
| North Region (R3)| 1.1040 | 0.3170 | 1.0000 | 0.5960 | 0.5530 | 0.1190  |
| South Region (R4)| 3.2560 | 2.5170 | 1.6790 | 1.0000 | 1.1460 | 0.3230  |
| Center Region (R5)| 2.7760 | 0.9490 | 1.8080 | 0.8730 | 1.0000 | 0.2340  |
| C.R. = 0.0410     |      |      |      |      |      |         |

Figure 2: Graphical representation of local weights for Saudi Arabian main regions

Table 13: Local weights for Saudi Arabian west regions at level 2

| Region  | R21   | R22   | R23   | Weights |
|---------|-------|-------|-------|---------|
| Tabuk (R21) | 1.0000 | 0.8910 | 0.2840 | 0.1830  |
| Madinah (R22) | 1.1230 | 1.0000 | 0.4110 | 0.2240  |
| Makkah (R23) | 3.5220 | 2.4330 | 1.0000 | 0.5930  |
| CR = 0.0062     |      |      |      |         |

Figure 3: Graphical representation of local weights for Saudi Arabian west regions

Table 14: Local weights for Saudi Arabian north regions at level 2

| Region            | R31  | R32  | R33  | Weights |
|-------------------|------|------|------|---------|
| Ha’il (R31)       | 1.0000 | 0.9850 | 1.3580 | 0.3610  |
| Jawf (R32)        | 1.0150 | 1.0000 | 1.6270 | 0.3870  |
| Northern Borders (R33)  | 0.7370 | 0.6150 | 1.0000 | 0.2520  |
| C.R. = 0.0020      |      |      |      |         |
Figure 4: Graphical representation of local weights for Saudi Arabian north regions

Table 15: Local weights for Saudi Arabian south regions at level 2

|        | R41   | R42   | R43   | R44   | Weights |
|--------|-------|-------|-------|-------|---------|
| ‘Asir  | 1.0000| 1.5970| 1.1650| 0.7170| 0.2540  |
| Najran | 0.6260| 1.0000| 0.4560| 0.3270| 0.1300  |
| Jizan  | 0.8590| 1.0000| 1.0800| 0.2830|         |
| Bahah  | 1.3950| 3.0540| 0.9260| 1.0000| 0.3330  |
| CR     | 0.0187|       |       |       |         |

Figure 5: Graphical representation of local weights for Saudi Arabian south regions

Table 16: Local weights for Saudi Arabian central regions at level 2

|        | R51   | R52   | Weights |
|--------|-------|-------|---------|
| Qassim | 1.0000| 0.4540| 0.3120  |
| Riyadh | 2.2020| 1.0000| 0.6880  |
| C.R.   | 0.0000|       |         |

Figure 6: Graphical representation of local weights for Saudi Arabian central regions
Table 17: Local weights for eastern province cities at level 3

| City                  | C111 | C112 | C113 | C114 | C115 | C116 | Local Weights |
|-----------------------|------|------|------|------|------|------|---------------|
| Dammam City (C111)    | 1.000| 1.4912| 0.6910| 0.6410| 0.3027| 0.5268| 0.1037        |
| Al Hufuf City (C112)  | 0.6706| 1.0000| 0.6770| 0.4143| 0.3724| 0.2033| 0.0752        |
| Al Mubarraz City (C113)| 1.4470| 1.4771| 1.0000| 1.2977| 0.4935| 0.8520| 0.1586        |
| Hafar Al-Batin City (C114) | 1.5600| 2.4137| 0.7706| 1.0000| 0.9636| 1.1024| 0.1847        |
| Al Jubayl City (C115) | 3.3036| 2.6853| 2.0263| 1.0378| 1.0000| 0.7172| 0.2369        |
| Khobar City (C116)    | 1.8982| 4.9188| 1.1737| 0.9071| 1.3943| 1.0000| 0.2409        |
| CR = 0.0386           |      |      |      |      |      |      |               |

Figure 7: Graphical representation of local weights for eastern province cities

Table 18: Local weights for madinah province cities

| City                  | C221 | C222 | Local Weights |
|-----------------------|------|------|---------------|
| Yanbu City (C221)     | 1.000| 0.2140| 0.1763        |
| Medina City (C222)    | 4.6729| 1.0000| 0.8237        |
| CR = 0.0000           |      |      |               |

Figure 8: Graphical representation of local weights for madinah province cities

Table 19: Local weights for makkah province cities

| City                  | C231 | C232 | C233 | Local Weights |
|-----------------------|------|------|------|---------------|
| Ta’if City (C231)     | 1.0000| 0.3430| 0.6495| 0.1789        |
| Jeddah City (C232)    | 2.9155| 1.0000| 0.2151| 0.2525        |
| Makkah City (C233)    | 1.5397| 4.649 | 1.0000| 0.5686        |
| CR = 0.0245           |      |      |      |               |
Figure 9: Graphical representation of local weights for Makkah province cities

| C231 | C232 | CR |
|------|------|----|
| Sakakah City (C231) | 1.0000 | 1.8364 | 0.5421 |
| Qurayyat City (C232) | 0.8449 | 1.0000 | 0.4579 |
| CR = 0.0000 |

Figure 10: Graphical representation of local weights for Jawf province cities

| C321 | C322 | CR |
|------|------|----|
| Sakakah City (C321) | 1.0000 | 1.8364 | 0.5421 |
| Qurayyat City (C322) | 0.8449 | 1.0000 | 0.4579 |
| CR = 0.0000 |

Figure 11: Graphical representation of local weights for Asir province cities

| C411 | C412 | CR |
|------|------|----|
| Khamis Mushait City (C411) | 1.0000 | 1.1691 | 0.5390 |
| Abha City (C412) | 0.8554 | 1.0000 | 0.4610 |
| CR = 0.0000 |

Figure 12: Graphical representation of local weights for Riyadh province cities

| C521 | C522 | C523 | CR |
|------|------|------|----|
| Al Kharj City (C521) | 1.0000 | 1.3511 | 0.7319 | 0.3316 |
| Sultanah City (C522) | 0.7401 | 1.0000 | 1.1028 | 0.3110 |
| Riyadh City (C523) | 1.3663 | 0.9068 | 1.0000 | 0.3574 |
| CR = 0.0282 |
Al Kharj City (C521)
Sultanah City (C522)
Riyadh City (C523)

Figure 12: Graphical representation of local weights for Riyadh province cities

Table 23: Dependent weights of Saudi Arabian regions through the hierarchy

| Main Regions | Local Weights | Sub-Regions | Local Weights | Overall Weights |
|--------------|---------------|-------------|---------------|----------------|
| R1           | 0.0950        | R11         |               | 0.0950         |
| R2           | 0.2290        | R21         | 0.1830        | 0.0419         |
|              |               | R22         | 0.2240        | 0.0513         |
|              |               | R23         | 0.5930        | 0.1358         |
| R3           | 0.1190        | R31         | 0.3610        | 0.0430         |
|              |               | R32         | 0.3870        | 0.0461         |
|              |               | R33         | 0.2520        | 0.0230         |
| R4           | 0.3230        | R41         | 0.2540        | 0.0820         |
|              |               | R42         | 0.1300        | 0.0420         |
|              |               | R43         | 0.2830        | 0.0914         |
|              |               | R44         | 0.3330        | 0.1076         |
| R5           | 0.2340        | R51         | 0.3120        | 0.0730         |
|              |               | R52         | 0.6880        | 0.1610         |

Table 24: Dependent weights of Saudi Arabian cities through the hierarchy

| Sub- Regions | Dependent Weights | Cities of Saudi Arabia | Local Weights | Overall Weights |
|--------------|-------------------|------------------------|---------------|----------------|
| R11          | 0.0950            | C111                   | 0.1037        | 0.0099         |
|              |                   | C112                   | 0.0752        | 0.0072         |
|              |                   | C113                   | 0.1586        | 0.0151         |
|              |                   | C114                   | 0.1847        | 0.0175         |
|              |                   | C115                   | 0.2369        | 0.0225         |
|              |                   | C116                   | 0.2409        | 0.0229         |
| R21          | 0.0419            | C211                   | –             | 0.0419         |
| R22          | 0.0513            | C221                   | 0.1763        | 0.0091         |
|              |                   | C222                   | 0.8237        | 0.0423         |
| R23          | 0.1358            | C231                   | 0.1789        | 0.0243         |
|              |                   | C232                   | 0.2525        | 0.0343         |
|              |                   | C233                   | 0.5686        | 0.0772         |
Table 24 (continued).

| Sub-Regions | Dependent Weights | Cities of Saudi Arabia | Local Weights | Overall Weights |
|-------------|-------------------|------------------------|---------------|----------------|
| R31         | 0.0430            | C311                   | –             | 0.0430         |
| R32         | 0.0461            | C321                   | 0.5421        | 0.0250         |
|             |                   | C322                   | 0.4579        | 0.0211         |
| R33         | 0.0230            | C331                   | –             | 0.0230         |
| R41         | 0.0820            | C411                   | 0.5390        | 0.0442         |
|             |                   | C412                   | 0.4610        | 0.0378         |
| R42         | 0.0420            | C421                   | –             | 0.0420         |
| R43         | 0.0914            | C431                   | –             | 0.0914         |
| R44         | 0.1076            | –                      | –             | –              |
| R51         | 0.0730            | C511                   | –             | 0.0730         |
| R52         | 0.1610            | C521                   | 0.3316        | 0.0534         |
|             |                   | C522                   | 0.3110        | 0.0501         |
|             |                   | C523                   | 0.3574        | 0.0575         |

Table 25: Overall weight of Saudi Arabian regions and ranks

| Provinces of Saudi Arabia     | Weightages | Percentages | Overall Ranks |
|-------------------------------|------------|-------------|---------------|
| Eastern Province              | 0.0950     | 09.50%      | 4             |
| Tabuk Province                | 0.0419     | 04.19%      | 12            |
| Madinah Province              | 0.0513     | 05.13%      | 8             |
| Makkah Province               | 0.1358     | 13.58%      | 2             |
| Ha’il Province                | 0.0429     | 04.30%      | 10            |
| Jawf Province                 | 0.0460     | 04.61%      | 9             |
| Northern Borders Province     | 0.0299     | 03.00%      | 13            |
| ‘Asir Province                | 0.0820     | 08.20%      | 6             |
| Najran Province               | 0.0419     | 04.20%      | 11            |
| Jizan Province                | 0.0914     | 09.14%      | 5             |
| Bahah Province                | 0.1075     | 10.76%      | 3             |
| Qassim Province               | 0.0730     | 07.30%      | 7             |
| Riyadh Province               | 0.1609     | 16.10%      | 1             |
Figure 13: Graphical representation of final weights for Saudi Arabian regions

Table 26: Overall weight of Saudi Arabian cities and ranks

| Top Severe Cities of Saudi Arabia | Weightages | Final Normalized Weights | Percentages | Overall Ranks |
|----------------------------------|------------|--------------------------|-------------|---------------|
| Dammam City                      | 0.0099     | 0.0112                   | 1.12%       | 22            |
| Al Hufuf City                    | 0.0072     | 0.0081                   | 0.81%       | 24            |
| Al Mubarraz City                 | 0.0151     | 0.0171                   | 1.71%       | 21            |
| Hafar Al-Batin City             | 0.0175     | 0.0198                   | 1.98%       | 20            |
| Al Jubayl City                  | 0.0225     | 0.0254                   | 2.54%       | 18            |
| Khobar City                     | 0.0229     | 0.0259                   | 2.59%       | 17            |
| Tabuk City                      | 0.0419     | 0.0473                   | 4.73%       | 11            |
| Yanbu City                      | 0.0091     | 0.0103                   | 1.03%       | 23            |
| Medina City                     | 0.0423     | 0.0478                   | 4.78%       | 9             |
| Ta’if City                      | 0.0243     | 0.0274                   | 2.74%       | 15            |
| Jeddah City                     | 0.0343     | 0.0387                   | 3.87%       | 13            |
| Makkah City                     | 0.0772     | 0.0872                   | 8.72%       | 2             |
| Ha’il City                      | 0.0430     | 0.0486                   | 4.86%       | 8             |
| Sakakah City                    | 0.0250     | 0.0282                   | 2.82%       | 14            |
| Qurayyat City                   | 0.0211     | 0.0238                   | 2.38%       | 19            |
| Arar City                       | 0.0230     | 0.0260                   | 2.60%       | 16            |
| Khamis Mushait City             | 0.0442     | 0.0499                   | 4.99%       | 7             |
| Abha City                       | 0.0378     | 0.0427                   | 4.27%       | 12            |
Table 26 (continued).

| Top Severe Cities of Saudi Arabia | Weightages | Final Normalized Weights | Percentages | Overall Ranks |
|-----------------------------------|------------|--------------------------|-------------|---------------|
| Najran City                        | 0.0420     | 0.0474                   | 4.74%       | 10            |
| Jizan City                         | 0.0914     | 0.1032                   | 10.32%      | 1             |
| Buraydah City                      | 0.0730     | 0.0824                   | 8.24%       | 3             |
| Al Kharj City                      | 0.0534     | 0.0603                   | 6.03%       | 5             |
| Sultanah City                      | 0.0501     | 0.0566                   | 5.66%       | 6             |
| Riyadh City                        | 0.0575     | 0.0649                   | 6.49%       | 4             |
| Dammam City                        | 0.0474     | 0.0530                   | 5.30%       | 7             |
| Al Mubarak City                   | 0.0345     | 0.0393                   | 3.93%       | 9             |
| Al Jubayl City                    | 0.0212     | 0.0244                   | 2.44%       | 11            |
| Al Hufuf City                      | 0.0167     | 0.0192                   | 1.92%       | 12            |
| Yanbu city                         | 0.0112     | 0.0127                   | 1.27%       | 13            |
| Al Qunfudah City                  | 0.0090     | 0.0101                   | 1.01%       | 14            |
| Ta’if City                         | 0.0081     | 0.0090                   | 0.90%       | 15            |
| Yanbu City                         | 0.0078     | 0.0087                   | 0.87%       | 16            |
| Arar City                          | 0.0072     | 0.0080                   | 0.80%       | 17            |
| Hafar Al-Batin City               | 0.0070     | 0.0080                   | 0.80%       | 18            |
| Al Qunfudah City                  | 0.0069     | 0.0077                   | 0.77%       | 19            |
| Al Jurf City                      | 0.0058     | 0.0065                   | 0.65%       | 20            |
| Abha City                          | 0.0056     | 0.0064                   | 0.64%       | 21            |
| Al Qunfudah City                  | 0.0053     | 0.0061                   | 0.61%       | 22            |
| Hafar Al-Batin City               | 0.0051     | 0.0058                   | 0.58%       | 23            |
| Al Jurf City                      | 0.0049     | 0.0057                   | 0.57%       | 24            |
| Abha City                          | 0.0047     | 0.0055                   | 0.55%       | 25            |
| Al Qunfudah City                  | 0.0045     | 0.0053                   | 0.53%       | 26            |
| Hafar Al-Batin City               | 0.0044     | 0.0051                   | 0.51%       | 27            |
| Al Jurf City                      | 0.0042     | 0.0049                   | 0.49%       | 28            |
| Abha City                          | 0.0041     | 0.0048                   | 0.48%       | 29            |
| Al Qunfudah City                  | 0.0039     | 0.0046                   | 0.46%       | 30            |
| Hafar Al-Batin City               | 0.0038     | 0.0045                   | 0.45%       | 31            |
| Al Jurf City                      | 0.0037     | 0.0044                   | 0.44%       | 32            |
| Abha City                          | 0.0036     | 0.0042                   | 0.42%       | 33            |
| Al Qunfudah City                  | 0.0034     | 0.0041                   | 0.41%       | 34            |
| Hafar Al-Batin City               | 0.0033     | 0.0040                   | 0.40%       | 35            |
| Al Jurf City                      | 0.0032     | 0.0038                   | 0.38%       | 36            |
| Abha City                          | 0.0031     | 0.0036                   | 0.36%       | 37            |
| Al Qunfudah City                  | 0.0030     | 0.0035                   | 0.35%       | 38            |
| Hafar Al-Batin City               | 0.0029     | 0.0034                   | 0.34%       | 39            |
| Al Jurf City                      | 0.0028     | 0.0033                   | 0.33%       | 40            |
| Abha City                          | 0.0027     | 0.0032                   | 0.32%       | 41            |
| Al Qunfudah City                  | 0.0026     | 0.0031                   | 0.31%       | 42            |
| Hafar Al-Batin City               | 0.0025     | 0.0030                   | 0.30%       | 43            |
| Al Jurf City                      | 0.0024     | 0.0029                   | 0.29%       | 44            |
| Abha City                          | 0.0023     | 0.0027                   | 0.27%       | 45            |
| Al Qunfudah City                  | 0.0022     | 0.0026                   | 0.26%       | 46            |
| Hafar Al-Batin City               | 0.0021     | 0.0025                   | 0.25%       | 47            |
| Al Jurf City                      | 0.0020     | 0.0023                   | 0.23%       | 48            |
| Abha City                          | 0.0019     | 0.0022                   | 0.22%       | 49            |
| Al Qunfudah City                  | 0.0018     | 0.0021                   | 0.21%       | 50            |
| Hafar Al-Batin City               | 0.0017     | 0.0020                   | 0.20%       | 51            |
| Al Jurf City                      | 0.0016     | 0.0018                   | 0.18%       | 52            |
| Abha City                          | 0.0015     | 0.0017                   | 0.17%       | 53            |
| Al Qunfudah City                  | 0.0014     | 0.0016                   | 0.16%       | 54            |
| Hafar Al-Batin City               | 0.0013     | 0.0015                   | 0.15%       | 55            |
| Al Jurf City                      | 0.0012     | 0.0014                   | 0.14%       | 56            |
| Abha City                          | 0.0011     | 0.0013                   | 0.13%       | 57            |
| Al Qunfudah City                  | 0.0010     | 0.0012                   | 0.12%       | 58            |
| Hafar Al-Batin City               | 0.0009     | 0.0011                   | 0.11%       | 59            |
| Al Jurf City                      | 0.0008     | 0.0009                   | 0.10%       | 60            |
| Abha City                          | 0.0007     | 0.0008                   | 0.09%       | 61            |
| Al Qunfudah City                  | 0.0006     | 0.0007                   | 0.08%       | 62            |
| Hafar Al-Batin City               | 0.0005     | 0.0006                   | 0.07%       | 63            |
| Al Jurf City                      | 0.0004     | 0.0005                   | 0.06%       | 64            |
| Abha City                          | 0.0002     | 0.0003                   | 0.03%       | 65            |
| Al Qunfudah City                  | 0.0001     | 0.0002                   | 0.02%       | 66            |
| Hafar Al-Batin City               | 0.0000     | 0.0000                   | 0.00%       | 67            |

Figure 14: Graphical representation final weights for Saudi Arabian cities

Tab. 25 and Fig. 13 shows that Riyadh with 16.10% and Makkah with 13.58% are most severe regions of contacting the pandemic and might emerge as the possible hotspots of Coronavirus cases. On the other hand, Tabuk with 4.19% and Northern Border with 3% are less severe regions. The minimum severity does not conclude that these regions will not be affected with COVID-19, but due to the higher populations that reside in Riyadh and Makkah, the two cities are at grave risk. Thus, the pace of effectualising containment strategies in these regions needs to be accelerated and must be highly inclusive so that all the residents of the two regions are benefitted at the right time. Further, the evaluated results in the Tab. 26 and Fig. 14 show that Jizan city with 10.32% and Makkah city with 8.72% are at the most severe. On the other hand, Yanbu city with 1.03% and Al Hufuf city with 0.81% are less severe cities. Furthermore, the high prioritized cities can emerge as the potential hotspots for COVID-19 if the preventive measures are not accelerated through effective mechanisms. The pace of effectuating control
techniques in these areas should be quickened and should be exceptionally comprehensive so as to benefit all the affected ones.

5 Conclusion

It is not shocking that Saudi Arabia is also one of the world’s most populous nations; it is the 14th most populated country in the world. Riyadh is the largest city in the country with a population of more than 4 million people, a major contribution to the nation’s entire population. The pandemic COVID-19 spreads rapidly by human to human transmission. Hence, densely populated cities of KSA are obviously at a higher level of risk due to the pandemic. To evaluate the severity of this pandemic in populous cities of KSA, we selected 24 cities and weighted their severity by using Fuzzy AHP methodology. As Saudi Arabia heightens its endeavors to control the deadly disease, a few hazard appraisal components and speculations have been stayed upon and proposed in various research attempts. In any case, our exploration examination endeavored to build up another model for assessment of the states at high risk due to the COVID-19 pandemic.

The upside of this new model is that it can dispassionately and psychologically dissect the spread of Coronavirus in various locales of Saudi Arabia. After an assortment of information for all the districts, authors applied the Fuzzy AHP system for seeing states that are likely as under the most elevated hazard classification due to COVID-19. Results unmistakably show that Jizan City and Makkah City are the most susceptible targets. The decisive research confirmations drawn from our investigation look to be a viable commitment in the Kingdom of Saudi Arabia’s mission of containing COVID-19. The limitation of this work is that only 24 populous cities have been taken in this paper. The severity of the pandemic can be evaluated with big data of other densely populated cities. Furthermore, the proposed approach offers integration of potential approaches that can provide more focus to healthcare services and methods that would efficiently and quickly reduce the spread of COVID-19. The present research has the following practical/ scientific utilities:

- The results from the above computation show that the most vulnerable cities for COVID-19 are Jizan City and Makkah City.
- The proposed research provides a systematic methodology for estimating the severity and could be used as a way for mitigating the risk associated with COVID-19 pandemic.
- With the means to accurately identify the possible Corona hotspots, this research analysis will also aid in reducing the damage caused by the pandemic to a great extent. A timely detection of susceptible zones can help the medical fraternity and the Government to institute quarantine and isolation safeguards at the right juncture and stem the loss of lives due to the contagion.
- The study can be used for enlisting suggestions for managing the impact of COVID-19 in KSA.

The limitations of this work are as follows:

- There are multiple MCDM methods available. Moreover, hybrid methods of MCDM give more precise results than Fuzzy AHP that we have enlisted in our research.
- The dataset used in this work is limited, and the same methodology may give much better results with big datasets.
- Some variables such as $\alpha$ and $\beta$ may affect the results. Hence the consideration of these variables might be reckoned as yet another limitation of this work.
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