

DYNAMIC STOCHASTIC MODELLING OF COVID-19 AMONGST DISPLACED POPULATIONS IN IRAQ

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Abstract: The prevalence of covid-19 also rapidly increased among displaced populations in Iraq, emphasizing the identification of important solutions in this regard. Therefore, this paper, spreading of covid-19 was modelled, using stochasticity within the “susceptible-infected recovered” (SIR) model, incorporating deterministic differential equation. The Itô's formula was used for expressing “stochastic SIR dynamics.” It has been proved from this study, that stochastic SIR has an effective global significant solution $I(t)$. This study aims to explore the spreading of covid-19 among displaced population in Iraq from period of 13-08-2020 to 13-09-2020. The results obtained show that stochastic noise introduction within the deterministic model for spreading of covid-19 prevent the cause of associated disease. Computer simulation was also used for illustrating the results. This study has also been effective in providing important practical as well as theoretical implications.

1. INTRODUCTION

In December 2019, in Wuhan a novel strand of Coronavirus was identified. The disease resulted in causing severe and fatal respiratory syndrome named as Covid-19. Since then, the world health organization (WHO) declared it as pandemic on March 11. Soon after its prevalence is gradually spread to many countries globally [13, 27]. Iraq was also affected by Covid-19. In this regard, millions of people were forced by the national governments to stay in isolation and other difficult conditions. As this disease was growing rapidly all around the world. In the

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absence of availability of any proper vaccine or medication, self-quarantine, social distancing and wearing of a face mask were identified as the effective and widely implemented strategies to control and mitigate the pandemic. In this context, the mathematical models were required to assess the transmission of disease and other associated aspects. It also involved death, recovery, or other important parameters in different countries and for different specific regions of low to high reported cases of Covid-19. Different measures were taken by different measures that were important to control the specific disease. Many modelling approaches were also used by the researchers' utilizing datasets through real incidents from the affected countries and have investigated distinct characteristics as a function of distinct parameters of the outbreak. It is imperative that mathematical models were formulated to construct insights and make predictions regarding Covid-19 so that effective policies and control strategies can be planned [4, 23, 24].

The massive displacement in Iraq is rooted in historical reasoning. Violence, political crisis, and conflicts have caused severe issues in the country. The Islamic State of Iraq and the Levant (ISIL) along with other armed groups added to the crisis with forced evacuation [26]. Notably, the displacement catastrophe in Iraq is not only enormous but given the instability and continuous conflicts, individuals faced repeated disturbances [12]. Thus, the complexity of the displacement in Iraq led to a humanitarian emergency. This is due to the severe impact of conflict and displacement on communities. Other than physically being displaced from their homes and communities, individuals were confronted with disturbances in their social connections and loss of trust [16]. As discussed by Strang, et al. [26], social capital is built on the basis of social connections and trust which are regarded as vital for well-being of a community. Community functioning requires strategies to enhance social capital. Consequently, a community that is severely affected by conflict and displacement, the development of social network is pivotal to recover from the damages and reestablish a sense of belonging [25].

In this regard, it is highly critical to understand the significance of strategies in humanitarian response. The mechanisms and resources used by communities to rebuild social networks can vary across communities due to the different challenges they encounter. This study aims to assess the dynamic stochastic modelling of Covid-19 among the displaced population in Iraq.

The contribution of the study is based on the 1) utilization of dynamic stochastic modelling and 2) investigation of displaced populations in Iraq and 3) providing meaningful implications for the migration community. The understanding of social dynamics among displaced population can provide important insights for integration of the affected individuals and development of conflict prevention strategies. Therefore, the present study intends to offer value in terms of designing effective intervention policies and community functioning. This research work presents the review of the literature in the next section and the detailed methodology is elucidated in the third section. The fourth section covers the results followed by a comprehensive discussion, highlighting the implications, and acknowledging the limitations.

2. LITERATURE REVIEW

Foreseeing and understanding the influence of novel Covid-19 have gained huge significance because of its important global health implications. In accordance with the reports of September 18, 2020, there were almost 30,356, 725 individuals who were diagnosed with Covid-19. In December 2019, there were almost 950, 625

fatalities that were reported since the initial cases were determined in the city of Wuhan China [28, 29]. However, it highlighted the continuous and utmost need for the continuous efforts and vigilance for the mitigation of virus and its prevalence globally. According to Worldometer [29], the global data also reveals that the number of people who were infected with coronavirus persisted to increase even though the prevalence of effective prevention strategies. Coronavirus was infiltrating every aspect of life. It not only damaged the global economy but also cause huge destruction in both natural and manufactured environments. The influence of pandemic varies in accordance with different regions. In this regard, some countries experienced more severe consequences as compared to the other countries [3, 29]. However, in individual countries there were substantial variations in the level of infections in different provinces. This highlighted the heterogeneous nature of the effects of pandemic. However, it also emphasized the requirement for tailored strategies and response so that the diverse challenges could be addressed that were prevailing in distinct geographical areas. In this regard, a huge amount of work was undertaken to model the spread of Covid-19 which was hugely confined to the ordinary differential equations [32]. However, the existing models lacked considerations for the inherent randomness associated with the transmission of Covid-19. For this purpose, different researchers have also introduced SIR model assumption “dynamic stochastic modelling” [6]. This approach seeks to inculcate and evaluate the influence of unpredictable factors which are effective to recognize the stochastic nature of the transmission dynamics of this virus. The dynamic stochastic model of Covid-19 involves the utilization of statistical and mathematical techniques so that the evolving and uncertain nature of pandemic can be captured. Researchers are also of the view that the dynamic stochastic model of Covid-19 plays an important role in enhancing and understanding the critical nature of the Covid-19 pandemic. Apart from accurate or meaningful predictions, this model also aids in the informed decision-making and planning of public health. As this model contributes in uncertainty quantification, as a result this model adequately provides a measure of uncertainty [19]. Therefore, it also enables the effective quantification of risks related to distinct scenario of pandemic.

The research by Zhang, et al. [31] also studied the prediction of Covid-19 outbreak in China on the basis of new stochastic model. In this regard, a novel stochastic model was proposed that aimed to account for the unique transmission dynamics of Covid-19. In their research, the effects of intervention measures were also analysed that were implemented in Mainland China. The results of their study depicted that instead of deviation, there was a huge quantity of “asymptomatic virus carriers”. It was also observed that a virus carrier with the symptoms were twice more likely to transfer the disease to others as compared to an asymptomatic carrier. However, their research also concluded that the rate of virus transmission was reduced significantly after the implementation of control measures in China Mainland. Olabode, et al. [18] also studied the deterministic and stochastic models for the epidemic dynamics of Covid-19 in Wuhan China. In their research, it was explained that the stochastic model was constructed through the system of ordinary differential equations (ODEs). These are formulated with constant parameters. Their research depicted that both the infected and exposed classes play a significant role in shaping the epidemic dynamics of Covid-19 in Wuhan China. Moreover, the numerical simulations in their research also revealed that the second wave of ongoing pandemic was likely to occur if the control or prevention strategies were not implemented adequately. These studies confirm the

effective and rapid utilization of dynamic stochastic model for predicting Covid-19. Other than these there are many other studies which focused on the effective utilization of this model in drawing the required results. Due to the effective and increased probability of results accuracy, the stochastic model is widely implemented to predict Covid-19 outbreaks and other associated concerns [5, 22, 30]. Researchers He, et al. [7] depicted that through the implementation of Stochastic dynamic model, the outbreaks of Covid were predicted effectively. In their research it was indicated that the simulations attained through the results of this model showed that the newly confirmed cases will continue to decrease, and the total confirmed cases will also reach the peak around the end of February 2020 in accordance with the current measures of control.

3. METHOD

The prevalence of covid-19 pandemic varied in different regions, especially within the context of displaced individuals. In the past, ordinary differential equations were used for determining the covid-19 spread, whereas no focus was given on the inherent randomness within the context of covid-19 spread among displaced people in Iraq. Therefore, in this research paper, the impacts of environmental noise introduction within the context covid-19 among displaced individuals in Iraq, was determined, by using a “susceptible-infected-recovered” (SIR) model. Equation 1 shows the SIR model assumption for this study.

$$\frac{dI(t)}{dt} = aS(t)I(t) - bI(t) \quad e.q.(1)$$

For this study, the “stochastic differential equations (SDEs)” are taken in the following forms:

$$dX(t) = f(X(t), t)dt + g(X(t), t)dW(t) \quad e.q.(2)$$

In this regard, $f(X(t), t)dt$ is considered as the function of drift coefficient, while $g(X(t), t)$, is considered as a diffusion. The integral formula for e.q. (2) is presented in e.q. (3).

$$X(t) = X_0 + \int_{t_0}^t f(X(s), s)ds + \int_{t_0}^t g(X(s), s)dW(s) \quad e.q. (3)$$

Different theorems were also used within the context of this study to fulfil the proposed aim of this study, as discussed below:

3.1 Itô's formula

Theorem 1

E.q. (4) was used as the Itô's chain or formula for this study, inspired by Kareem and Al-Azzawi [11].

$$dF(X_t, t) = \left[\frac{\partial F}{\partial t} + \frac{\partial F}{\partial X_t} f + \frac{1}{2} \frac{\partial^2 F}{\partial X_t^2} g^2 \right] dt + \frac{\partial F}{\partial X_t} g dW_t \quad e.q. (4)$$

3.2 The SDE SIR Model for Covid-19 Spread among Displaced People

E.q. (5) shows the SDE SIR model for this study, to determine the spread of covid-19 among displaced people in context of Iraq.

$$dI(t) = (aS(t)I(t) - (p + \gamma)I(t))dt + \sigma S(t)I(t)dW_t \quad e.q. (5)$$

Table 3.1 shows the parameters for this model.

Table 3.1. Parameters.

Parameters	Description
$S(t)$	whole population of displaced people at (t) time
t	Time parameter
$I(t)$	Active infections' number at (t) time
$dS(t), dI(t)$ and $dRm(t)$	Change within states at t
$Rm(t)$	Total number of recoveries and deaths at (t) time
a	Coefficient of disease transmission
dW_t	Increment within Weiner process
γ	Rate at which individuals are cured
ρ	death rate/ capita
R_e	Basic no. of reproduction for "deterministic model"
R_e^S	Basic number of reproductions for "stochastic model"
N_{total}	The populations of S_0 and I_0 regions are the initial infections number
σ	Parameter which is used for modelling the stochastic within evolution

3.3 Non-negative Solution Presence

Before beginning the investigation of SDE SIR model's dynamic behaviour, for covid-19 (eq (5)), it was essential to ensure that no global solution was available in this regard. In order to ensure these characteristics, theorem 2 was considered.

Theorem 2

For every provided initial value $0 = I_0 \in (0, N)$, the covid-19 model of SDE SIR was found to have a non-negative solution at global level. Therefore, it was easy to show that:

$$LV(x) \leq \frac{\rho+\gamma}{x} + \frac{dN}{N-x} + \sigma^2 N^2 \left(\frac{1}{x} + \frac{1}{N-x} \right) \leq CV(x) \quad e.q. (6)$$

3.4 Extinction

Within the context of displaced population systems' dynamic behaviour, it was essential to consider the situations, required to die out covid-19. In general terms, extinction of the disease was also focused.

Theorem 3.1 and 3.2

Inspired by the study of Kareem and Al-Azzawi [11] theorems 3.1 and 3.2 were taken into account within the context of extinction of covid-19 for this study. Within the context of theorem 3.1, the basic reproduction number for SDE was found to be:

$$R_e^S = \frac{aN}{(\rho+\gamma)} - \frac{\sigma^2 N^2}{2(\rho+\gamma)} = R_e - \frac{\sigma^2 N^2}{2(\rho+\gamma)} < 1 \text{ and } \sigma^2 \leq \frac{a}{N} \quad e.q. (7)$$

In this regard, the solution for SDE model was:

$$\lim_{t \rightarrow \infty} \sup \frac{1}{t} \log(I(t)) \leq aN - \rho - \gamma - 0.5\sigma^2 N^2 < 0 \quad e.q. (8)$$

However, for theorem 3.2, the basic reproduction number for SDE was stated to be:

$$R_e^S = \frac{aN}{(\rho+\gamma)} - \frac{\sigma^2 N^2}{2(\rho+\gamma)} = R_e - \frac{\sigma^2 N^2}{2(\rho+\gamma)} > 1 \quad e.q. (9)$$

Its solutions were:

$$\lim_{t \rightarrow \infty} \sup I(t) \geq \xi \quad e.q. (10)$$

4. RESULTS

In order to comprehend the impact of promoting environmental stochasticity within the SDE system (e.q. (5)), focusing on the system stability as well as disease extinction, the spread of covid-19 within the context of displaced population in Iraq, was considered. The required data was collected from the Health Ministry of Iraq and other associated reports. Table 4.1 shows the covid-19 spread among the displaced populations in Iraq.

The total population considered for this purpose was 403,977,492 and σ was equal to 0.0001.

Table 4.1. Covid-19 spread in displaced population in Iraq.

Date	New Cases among displaced population	Active cases among displaced population	New Deaths among displaced population	New Recoveries among displaced population	R_e	R_s
13-08- 2020	3840	591	52	2666	2.205882352	0.367648234
14-08- 2020	4012	625	67	2920	2.007360320	0.334560052
15-08- 2020	4292	591	75	2570	2.266717037	0.377786171
16-08- 2020	4347	570	74	2673	2.182611858	0.363768642
17-08- 2020	3201	604	93	3570	1.637107775	0.272851294
18-08- 2020	4575	573	81	2894	2.015451796	0.335908631
19-08- 2020	4092	581	84	2528	2.295332822	0.382555546
20-08- 2020	3994	613	86	2830	2.056202878	0.34270047
21-08- 2020	4287	586	74	3245	1.806684733	0.301114121
22-08- 2020	3964	636	71	2946	1.988730526	0.331455086
23-08- 2020	3290	660	73	3015	1.941119378	0.323519895
24-08- 2020	3643	537	90	3981	1.473839351	0.245639891
25-08- 2020	3961	573	76	3370	1.739634676	0.289939112
26-08- 2020	3836	594	71	3453	1.701644922	0.283607485
27-08- 2020	3650	565	71	3793	1.551991722	0.258665286
28-08- 2020	4176	581	73	3864	1.523229245	0.253871540
29-08- 2020	3833	578	76	4145	1.4207909006	0.236798476
30-08- 2020	3730	541	67	3861	1.527494907	0.254582483
31-08- 2020	3756	578	82	3720	1.576872535	0.262812088
1-09- 2020	3403	520	80	3870	1.518218622	0.253036435
2-09- 2020	3945	526	77	3731	1.57480314	0.262467191
3-09- 2020	4754	497	73	3551	1.65471593	0.275785988
4-09- 2020	5025	493	83	3610	1.623815967	0.270635994
5-09- 2020	4643	522	62	3890	1.737116386	0.472574150
6-09- 2020	3650	506	91	3300	1.769389562	0.294898825
7-09- 2020	4313	533	75	4298	1.371115173	0.228519194
8-09- 2020	4893	563	67	3464	1.698273421	0.28304556
9-09- 2020	4242	541	74	3668	1.602564102	0.267094016
10-09- 2020	4596	540	81	3823	1.53609830	0.256016383
11-09- 2020	4253	565	66	3578	1.645639056	0.274273176
12-09- 2020	4105	563	61	3886	1.52014187	0.25335697
13-09- 2020	3530	563	70	3423	1.716738196	0.286122022

The average of the associated parameters was determined from 13- 08 -2020 to 13- 09- 2020. Finally, the obtained average was substituted within equation 5 for this study and the following equation is attained:

$$dI(t) = (2481.5624)I(t)dt + 100I(t)dW_t, I(0) = 1 \quad \text{e.q. (11)}$$

Therefore, as per the Itô's formula, the following solution is obtained:

$$I(t) = \exp [-2518.4374t + 100W_t] \quad \text{e.q. (12)}$$

Thus, from theorem 3.1, it can be concluded that any initial value $I(0)$ is equal to $I_0 \in (0.100000)$ and equation 11 is obeyed as:

$$\lim_{t \rightarrow \infty} \sup \frac{1}{t} \log(I(t)) \leq -2518.4374$$

This states that $I(t)$ will be zero exponentially, when the probability is stated to be one. However, in other context, for the SIR model (eq (1)), the basic number of reproductions was:

$$Re > 1.$$

The “Euler Maruyama method (EM),” was used for computer simulation and figure 4.1 was attained, showing the covid-19 extinction.

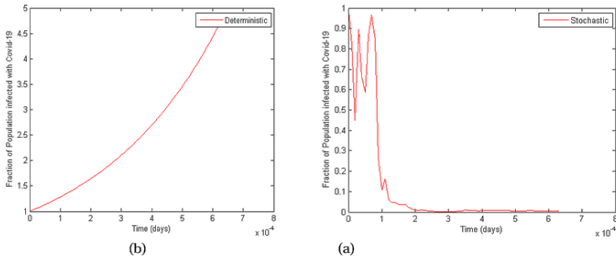


Figure 4.1. Path $I(t)$ computer simulation, utilizing EM model (eq (11)). Figure 4.1(a) shows “deterministic SIR model” and (b) shows “SDE SIR model.”

Table 4.2. Covid-19 spreading among displaced population in Iraq.

Date	New nCases among displaced population	Active cases among displaced population	New Deaths among displaced population	New Recoveries among displaced population	R_e	R_e^s
13-08- 2020	3840	591	52	2666	2.205882352	2.205882352
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18-08- 2020	4575	573	81	2894	2.015451796	1.998656364
19-08- 2020	4092	581	84	2528	2.295332822	2.276205048
20-08- 2020	3994	613	86	2830	2.056202878	2.039067854
21-08- 2020	4287	586	74	3245	1.806684733	1.791629027
22-08- 2020	3964	636	71	2946	1.988730526	1.972157772
23-08- 2020	3290	660	73	3015	1.941119378	1.924943385
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31-08- 2020	3756	578	82	3720	1.576872535	1.563731931
1-09- 2020	3403	520	80	3870	1.518218622	1.505566800
2-09- 2020	3945	526	77	3731	1.57480314	1.56167978
3-09- 2020	4754	497	73	3551	1.65471593	1.64092663
4-09- 2020	5025	493	83	3610	1.623815967	1.610284167
5-09- 2020	4643	522	62	3890	1.737116386	1.724470964
6-09- 2020	3650	506	91	3300	1.769389562	1.754644644
7-09- 2020	4313	533	75	4298	1.371115173	1.359689213
8-09- 2020	4893	563	67	3464	1.698273421	1.684121142
9-09- 2020	4242	541	74	3668	1.602564102	1.589209401
10-09- 2020	4596	540	81	3823	1.53609830	1.523297490
11-09- 2020	4253	565	66	3578	1.645639056	1.631925397
12-09- 2020	4105	563	61	3886	1.52014187	1.507473150
13-09- 2020	3530	563	70	3423	1.716738196	1.702432044

Table 4.2 shows covid-19 spread among displaced population in Iraq, focusing on basic number of reproductions, for the stochastic and deterministic model, when the incorporated total population 40397491 and σ was equal to 0.0001.

The average of the associated parameters was determined from 13- 08 -2020 to 13- 09- 2020. Finally, the obtained average was substituted within equation 5 for this study and the following equation is attained:

$$dI(t) = (2481.5624)I(t)dt + 100I(t)dW_t, I(0) = 1 \quad \text{e.q. (13)}$$

Therefore, as per the Itô's formula, the following solution is obtained:

$$I(t) = \exp [2518.4374t + 10W_t] \quad \text{e.q. (14)}$$

$$\xi = \frac{1}{\sigma^2} (\sqrt{a^2 - 2\sigma^2(\rho + \gamma)} - (a - \sigma^2\sigma N)) = 382762.64$$

Thus, from theorem 3.2, it can be concluded that any initial value $I(0)$ is equal to $I_0 \in (0.100000)$ and equation 13 is obeyed as:

$$\lim_{t \rightarrow \infty} \inf I(t) \leq 382762.64 \leq \lim_{t \rightarrow \infty} \sup I(t)$$

The “Euler Maruyama method (EM),” was used for computer simulation and figure 4.2 was attained, showing the covid-19 extinction.

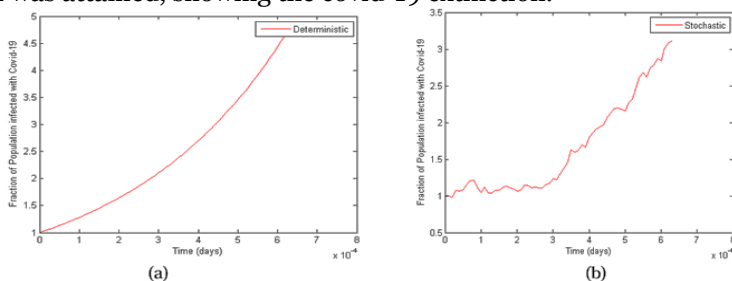


Figure 4.2. Path $I(t)$ computer simulation, utilizing EM model (eq (11)). Figure 4.1(a) shows “deterministic SIR model” and (b) shows “SDE SIR model.”

5. DISCUSSION

The present research aimed to assess the Dynamic stochastic modelling of covid-19 amongst displaced populations in Iraq. As the displaced population of Iraq was hugely deprived from the basic necessities or health and safety measures. In this regard, the prevalence of Covid-19 was much higher in such displaced population. To cater this issue, the present study has implemented Dynamic stochastic modelling of covid-19 amongst displaced populations in Iraq. The novel stochastic model aims to assess the existence and prevalence of the disease along with its extinction. In this regard, the researchers have also developed a numerical approach for the computation of appropriate solutions for the model [10]. This modelling has been proved to be effective in drawing adequate results and correctly forecasting Covid-19 pandemic. There are many studies which focused on the forecasting of uncertainty resulted due to the prevalence of Covid [1, 9, 30]. According to Mamis and Farazmand [15], the compartmental models hold great significance as a quantitative tool as it enables to predict the course of communicable diseases. The parameters of this model (like how the disease spreads) are uncertain. To deal with this uncertainty, the researchers have widely used stochastic models. Although a common stochastic model through which the uncertainties are treated as random noise is hugely problematic. Research by

Alsakaji, et al. [2], Omar, et al. [20] and Pájaro, et al. [21] also focused on Dynamic stochastic modelling of covid-19. It highlights the significant role played by this model to predict Covid-19 related uncertainties. However, these studies complement the results attained from the present research. The Dynamic stochastic modelling of covid-19 amongst displaced populations in Iraq involved the utilization of statistical and mathematical techniques. In this way, the evolving or unpredictable nature of the virus can be studied efficiently within the specific demographics. As displaced populations faced unique challenges. These includes overcrowded living conditions, lack of proper healthcare access and enhanced mobility [8, 14, 17]. Therefore, the traditional modelling approaches resulted to be insufficient. In this regard, through the inculcation of randomness and consideration of various factors through which the spread of disease is affected, these models seek to provide a more comprehensive understanding regarding the way in which Covid-19 might affect the displaced population. The insights attained through the effort of such modelling can also inform the targeted public health strategies, effective allocation of resources and the policy-related decisions. As a result, this model can also be helpful in mitigating the influence of this virus on the vulnerable population of Iraq.

6. RESEARCH IMPLICATIONS

The present research holds various implications. The dynamic stochastic modelling of Covid-19 concerning the displaced population in Iraq offers significant theoretical implications for considering the unique challenges and dynamics of disease prevalence in such environments. The context of displacement introduces complexities regarding the mobility of population, overcrowded living conditions, limited access to healthcare and potential disruptions concerning the intervention of public health. The theoretical insights attained from modelling also underscores the way these factors interact and contributes to the transmission dynamics of coronavirus. Moreover, the incorporation of stochastic elements also enables for a more realistic representation of the variations and uncertainties in the lives of displaced individuals of Iraq. Considering the theoretical underpinning of Covid-19 prevalence in displaced population can also contribute to the development of targeted strategies of public health. This research also enables to assess the specific vulnerabilities and requirements of this particular demographic group.

Practical implications of this study lie in informing the evidence-based interventions and policies that are tailored to the unique issues faced by this vulnerable group. The insights gained from this study can also ensure the provision of effective resource allocation, deployment of healthcare personnel along with the implementation of effective preventive measures. This can be undertaken in such a way that addresses particular risks related to the displacement of population. The outcome of this model can also help in the identification of optimal vaccination strategies, efficiently allocating the testing resources and formulation of effective targeted public health campaigns. Potential surges can also be predicted through this study concerning the demand in healthcare. It can enable preparedness and timely response against the infectious diseases. The practical implications of this research also lie in enhancing the capacity of public health authorities and humanitarian organizations. The ultimate goal of which is to mitigate the influence of Covid-19 on the displaced population in Iraq.

7. RESEARCH LIMITATIONS

The present study also contains few shortcomings. This research has limited the potential of inculcating expert opinions or insights regarding the Dynamic stochastic modelling of covid-19 amongst displaced populations in Iraq. The concerned experts could be interviewed that have implemented this model. In this way, their direct insights could be attained to draw more valuable results. This research has primarily focused on the displaced population of Iraq which has limited the researcher to assess the potential of this model and its application in other contexts (rather than Iraq). In this way, displaced population from other regions can also be assessed to draw more valuable insights.

8. CONCLUSION

The present research aimed to assess the Dynamic stochastic modelling of covid-19 amongst displaced populations in Iraq. For this purpose, the researcher explored the properties for the consequent stochastic model SIR model for the prevalence of Covid-19. It was attained through first proving that there existed a unique solution that was positive for the given initial value. Furthermore, the researcher also considered the condition needed for the persistence or extinction for the solution $i(t)$. Moreover, the researcher also concluded that the stability of the system can be controlled through the environmental stochasticity.

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