Mathematical analysis of Surface spread of COVID 19 and disinfection using Drones

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Abstract:
The world is facing the COVID-19 pandemic threat, In this work epidemiological analysis is carried out using Susceptible Carrier Infection Recovery (SCIR)model and the effect of drone based disinfectant spray in the public places are analyzed .The mathematical models are now fundamental tools in perception of the infectious diseases and helps in planning the control measures to prevent the spread of the disease. The reproduction number where analyzed on the disease spread pattern using SCIR Model. The effect of corona virus in Indian cities where studied before and after the drone disinfectant spray. It is found that after the sanitization operation, the infection and carrier cases are reduced. This model helps in analyzing the steps involved to curtail the spread of infection further.

Key words: COVID 19. DRONES, SANITISING, SCIR MODELLING, EPIDEMIC MODELLING.

1.Introduction

COVID-19 (coronavirus disease 2019) is a public health emergency of international concern. WHO declared COVID-19 as a global pandemic On 11 March 2020. COVID-19 is acknowledged as illness caused by a novel coronavirus known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Around 4170424 people are affected, in almost all territories worldwide and killed almost 287399 people worldwide. World Health Organisation (WHO) declared the outbreak of COVID-19 a global pandemic. It does not have an effective vaccine or an exact and effective treatment scheme[1,2,3]. It shows a destructive effect especially in individuals with weak immune systems. The advent of COVID-19 has hindered the normal societal and trade practices around the world. With concerns existing around the pandemic, there is a need to limit the chance of infection. The infection is transmitted in many cases through respiratory droplets, direct contact with cases and through contaminated surfaces. The virus persists on public surfaces for varied period of time; it gets easily inactivated by the use of chemical disinfectants[4,5].

The Administration in various Cities have taken significant measures to sanitize the major cities, especially the public spaces which are considered risk prone areas for local spread of virus. Cities have adopted numerous approaches to disinfect the public spaces including the bus terminals, railway stations, streets, markets, etc. Cities are taking up innovative approaches for disinfection of public places deploying workers.The disinfectant are sprayed in all corners of the city to keep it safe from any kind of infection. Some cities have deployed 1,200 workers for, door-to-door garbage collection in the morning hours. Sanitation workers are deployed across the city after sundown to spray disinfectants. Sanitization of whole city is under way usingf, anti-larva spray and disinfectant spray. City Administration have ensured disinfection of all public places in the city using jetting Machines. Vehicles and ground workers can do only ground floor spraying activities. . But these processes are laborious when repeated throughout the year and results in fatigue of the workers. It is also found to cause allergic effects on the workers. Cities are taking up innovative approaches for disinfection of public places using sodium hypochlorite. Our Cities have a lot of apartments and high risers with multiple floors. Latest technologies and autonomous machines are playing lead role in responding to COVID-19 pandemic. However, in this war against this invisible enemy, drones play a key role by helping authorities and people in different ways to prevent further spread of the coronavirus outbreak[6,7,8,14,15]

Drones can fly up to 150 meters which is more than 400 feet. During a pandemic, drones offer a lot of advantages. For one, they can minimize human interactions—preventing viral transmission. In addition, they can speed up transport by as much as 50% compared with regular vehicle road transport. Drones can also be used to reach remote areas more easily and quickly than standard modes of transportation. Throughout the world, med tech innovators and scientific researchers are coming together to find innovative ways to use drones to fight COVID-19[16,17,18,19].

Cities that implemented such measures earlier had greater delays in reaching infection peak and had lower peak mortality rates. The current pandemic has created plenty of anxiety. There is need of Mathematical models to predict and know how a disease spreads. Inevitably different epidemic models are applied to different cases. In country like India where population size is sufficiently large and fixed, where people immunity is less, almost all infected people are infectious and vice versa, we use a deterministic model. However, when dealing with small groups the probability element must be taken into account and so stochastic models are used. Recently it is found the novel coronavirus undergoes asymptomatic period at the beginning of the disease. In the course of this time, this carrier can harbour the virus and spread the disease to their fellow being without exhibiting any symptoms. Hence there is a need to add another class of people to the model. These individuals once afflicted, are proficient enough of passing on the disease while exhibiting no symptoms are the carrier class. Hence S-I-R model is changed to S-C-I-R model. The carrier class is vital for the spread of the disease. Even the most accurate mathematical models are not competent enough to predict the current pandemic. But mathematical modelling played a great role in handling severe epidemics[20,21,9,10,11,12].

2.Methodology

Mathematical modelling has provided an economical means to comprehend the transmission dynamics of diseases. It aids in the ability to choose the most effective and economical interventions aimed at preventing and treating disease. Let us consider four states

Susceptible, Carrier, Infected and Removed for the mathematic SCIR modeling[1]. A fraction of the state individuals will come into contact with carriers and Individuals in the carrier state are capable of infecting others. These asymptomatic carrier state will either come into the infected state or move back to the susceptible state of individuals. Individuals in the infected state are by default, carrier state of individuals. The removed state of individuals comprises of those in the infected state that have either recovered from the disease or died. The flow of the disease are shown in figure 1.

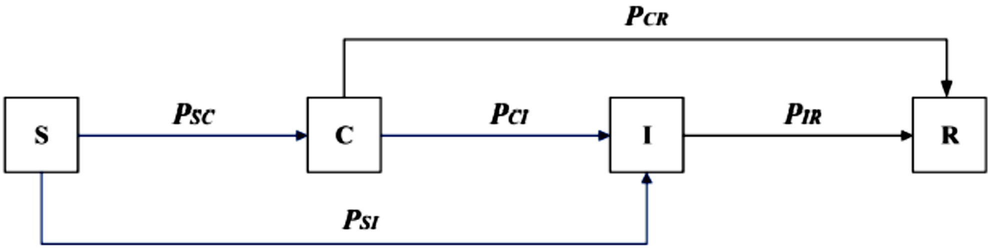

Figure 1 : SCIR model of the disease

The differential equation for the SCIR propagation model is written as

$$\frac{dS(t)}{dt} = -(P_{SC} + P_{SI} + P_{SR})S(t)I(t) \qquad [1]$$

$$\frac{dC(t)}{dt} = \left(P_{SC}\, S(t)I(t) + P_{RC}R(t) - P_{CR}\, C(t) - P_{CI}\, C(t)\right) \qquad [2]$$

$$\frac{dI(t)}{dt} = (P_{CI}\, C(t) + P_{SI}\, S(t)I(t) - P_{IR}\, I(t)) \qquad [3]$$

$$\frac{dR(t)}{dt} = \left(P_{CR}\, C(t) + P_{SR}\, S(t)I(t) + P_{IR}\, I(t) - P_{RC}\, R(t)\right) \qquad [4]$$

The rate of change in the susceptible state, with respect to time, depends on the fraction of people vaccinated and those that return to the susceptible state from the carrier state. Also the asymptomatic individuals belongs to the carrier state, and the natural death of individuals in the susceptible state have to be removed. P_{SC} indicates the probability that the susceptible state individual is in contact with carrier, it is generally referred as the internal carrier contact rate. Similarly, in the carrier state the rate of change depends on the portion of the susceptible state intermingling with the carrier state. But those individuals reverting to the susceptible state, those exiting the carrier state by being infected and also those exiting the carrier state owing to natural death. The variation in the infected class depends on the fraction of carrier individuals being infected. However, the infected state of individuals that either recover or die due to the infection and some individual experience natural death have to be excluded from the infected state individuals. P_{SI} indicates the probability that the susceptible person is infected due to spread referred to as direct infection rate. P_{CI} indicates the probability that the asymptomatic carrier is infected, that is, the carrier infection probability. The change in the recovery class depends on the fraction of individuals vaccinated, the recovered individuals from the infected class and those who die from natural causes. It is assumed that individuals in the state cannot reacquire the disease. P_{IR} indicates the probability that the infected person is recovered termed as acquired immunity rate. P_{CR} indicates the probability that the carrier is recovered directly it refers to the immunity rate.

$$\frac{dS}{dt} = (1-p)\nu - \beta CS + \gamma_1 C - \nu S \qquad [4]$$

$$\frac{dC}{dt} = \beta CS - \gamma_1 C - \alpha C - \nu C \qquad [5]$$

$$\frac{dI}{dt} = \alpha C - \gamma_2 C - \mu_1 I - \nu I \qquad [6]$$

Hence the final equations is given by equation 4,5 and 6. Where ν *is* the proportion vaccinated, α is the infection rate of carriers, β is the transmission rate, $\gamma_1$is rate at which carriers return to the susceptible class, γ_2 is the infected recovery rate, μ_1 is natural death rate, and μ_2 is rate of death due to infection. The rate of change in the susceptible class, with respect to time, is given by the proportion of people vaccinated, $(1-p)\nu$ [1]. The reproduction number represents the number of secondary infections caused by the average infectious individual. The reproduction number for this model is found by using a method described in the van den Driessche and Watmough, (2002), paper. The variable *x* is used to represent all classes so

$$x = \left(\frac{dS}{dt}, \frac{dC}{dt}, \frac{dI}{dt}\right)^T \qquad [7]$$

Then $F_i(x)$ represent the rate at which new infections appear. While $V_i^+(x)$ and $V_i^-(x)$ are the rates at which individuals enter and leave each class. From this new variables are defined such that $F = \left[\frac{\partial F_i}{\partial x_j}(x_0)\right]$ and $V = \left[\frac{\partial V_i}{\partial x_j}(x_0)\right]$ with $1 \le i, j \le m$; where m represents the number of classes in which individuals are infectious. The reproduction number is then defined as

$$R_0 = \rho(FV^{-1}) \qquad [8]$$

where $\rho(A)$ represents the maximum eigenvalue of matrix *A*. Solving the equation gives the solution as

$$R0 = \beta / \gamma_1 + \alpha + \nu \qquad [9]$$

The reproduction rate R0, is an important index for measuring the transmission of corona virus. R0 is defined as the mean number of subject infected over the disease infection period, in a totally susceptible subjects. The most important conclusions are as follows if the inequality S(0) R0 > 1 holds, then the number of affected population will swiftly decrease .

Hence no pandemic will occur. If S(0) R0 < 1, then pandemic will occur even if there are very few infected population . The size of the pandemics will not rely on the preliminary number of infected subjects, but will rely on the initial portion of susceptibles, S(0), and on R0. Steps that has to taken to avoid pandemics to reduce the initial fraction of susceptibles to S(0) < $\gamma_1 + \alpha + \nu / \beta$. First measure would be to vaccinate the population to prevent the pandemics. But vaccine have not be invented. Other way to achieve the condition S(0) < $\gamma_1 + \alpha + \nu / \beta$, and eradicate the pandemic , is reducing the transmissibility rate β by isolation of infected subjects or social distancing. Further measures include increasing the recovery rate γ by treatment of infectives. But the perfect for the treatment is not developed. Another best way would be reducing the carrier by taking sanitising effort. The sanitising is done effectively using drones[1,13].

Using drones is more advantageous due to the accessibility, which enables them to spray disinfectants on buildings, which is impossible to be done manually. The CK 100 sanitisation drone consists of patented autopilot technology, advanced flight controller system, and is equipped with fuel efficient motors that enables the drone to be deployed for 12 hours a day. It has a payload capacity of 15-20 litres, flight duration of 40-45 minutes, and maximum ceiling height of 450 feet, which is sufficient to disinfect 99 percent of tall buildings across India. Each drone can cover 20 km a day. Spraying Disinfectant in public areas will curb Surface spread to a great degree. The drone based sanitising is shown figure 2. Research based on studies & data obtained from several sanitization operations across the country has indicated a sudden stagnation or dip in the number if cases in the city[16].

Figure 2 :Drone based sanitizing operation

The disinfectant used areS odium hypo-chloride, Sodium Nitrate & Sodium Di Chloro Iso Cynurate with dilution Ratio is 1 : 200 according Ministry of Health guidelines.

3.Results and Discussion

The disinfection was carried in Varanasi and the effect of disinfection was studied in location. Table 1 shows the area covered by the drone, the chemical sprayed in litres in each location and battery cycles charged to run the drones. Almost all main location was covered.

From the table it is found that the drone has covered 753. 4 sq meters , 9 litres of disinfectant was used and 140 battery cycle was used sanitize Varanasi city.

Table 1: Hot zones in Varanasi were the drone operation were carried out

Zone	**Location**	**Area coverage**	**Chemicals used**	**Battery cycle (sorti)**
1	Madhanpuraand its areas	53.22	7	10
2	Murugayyatollaand its areas	29.46	3	5
3	Pitarkundaand its areas	29.63	5	10
4	Dhanialpurand its areas	43.1	5	8
5	Shivpurand itsareas (Hospital)	58.9	4	10
6	Shivpurgarden areas	3.46	1.5	4
7	Parmanandpurand its areas	40.3	4	6
8	VikasbhavanKajori	71.5	6	10
9	BhimNagar park	73.1	6	10
10	Gangapur-registryoffice	58.1	6	8
11	GangapurMarket	5.61	1.5	2
12	Madhanpura–2rd time	23.9	5	6
13	SapthSagarMandi	58	5.5	7
14	Patrakarpuram	64.5	5.5	10
15	Municipal Corporation	67.7	10	16
16	Police Line	73	14	18
Total		**753.48**	**89**	**140**

The Drone is filled with the chemical solution consisting of 1% Sodium Hypochlorite , [NaOCl]. Further, the drone is calibrated and set ready to fly. Later the drones are flown using a remote-control device by the experienced drone pilots in the planned flight path, simultaneously spraying the sanitizer through its four Nozzles. After every flight (lasting approximately 15 to 20minutes) the drones are called back for refilling the Chemical and replacing the battery pack. The drones are then moved to then next location to resume the flying/spraying. The flight path of the drones and the area covered are controlled and recorded in a handheld device with GIS maps on the back end which is plugged to the remote controller.

The vehicles used for drone operations are fitted with GPS and GSM based wireless cameras using which the entire movement of drones and their operations are centrally monitored from the Kashi Integrated Command and Control Centre, now converted to COVID-19 War Room. The figure 6 below shows the map of distance covered by the drone in the hot spot areas.

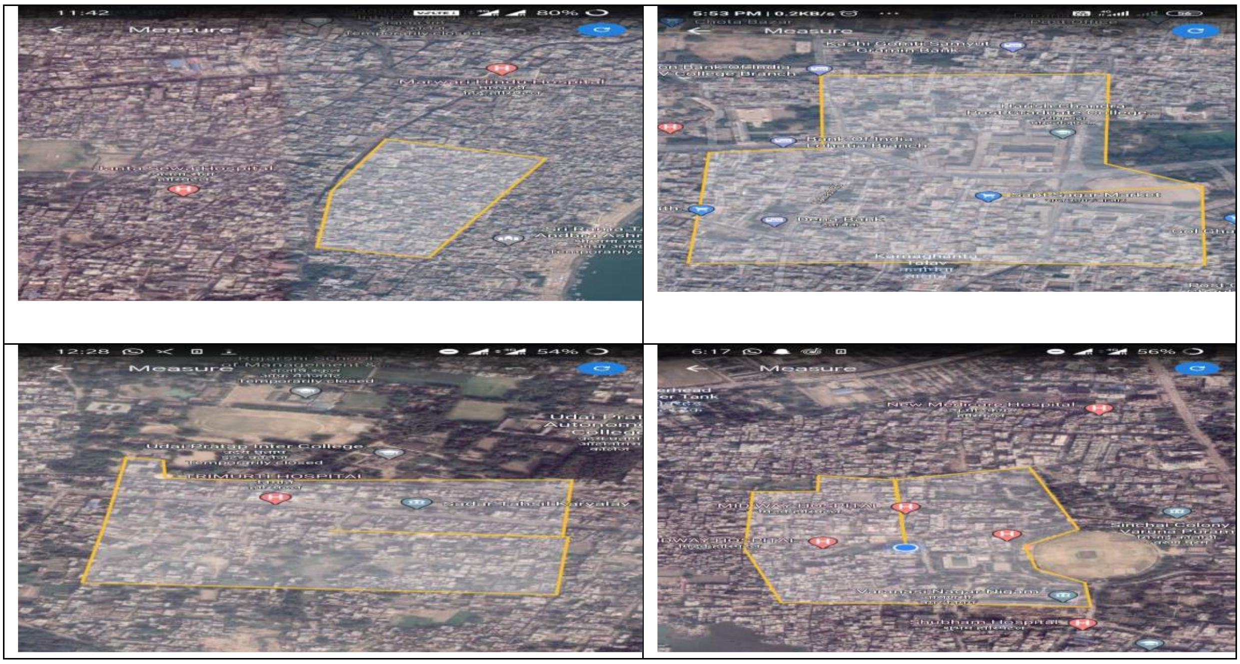

Figure 3: The sample areas covered the drones during the sanitiising operation

The statistics of the city was studied after and before the sanitising operation was performed. The graph in figure 4 shows the average individuals in susceptible, carrier and infectious cases in Varanasi before sanitising It is found from the graph the mean case were 2 before sanitising operations .After the sanitising operation was performed the average case came down below. The graph in figure 5 depicts the average individuals in susceptible, carrier and infectious cases in Varanasi after sanitising

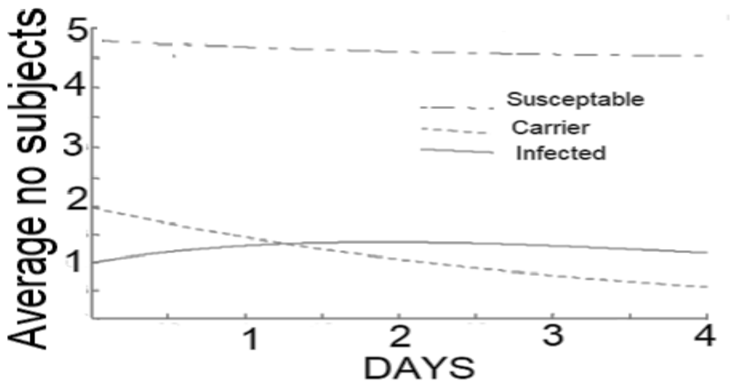

Figure 4: Average no of individuals in different class before sanitising

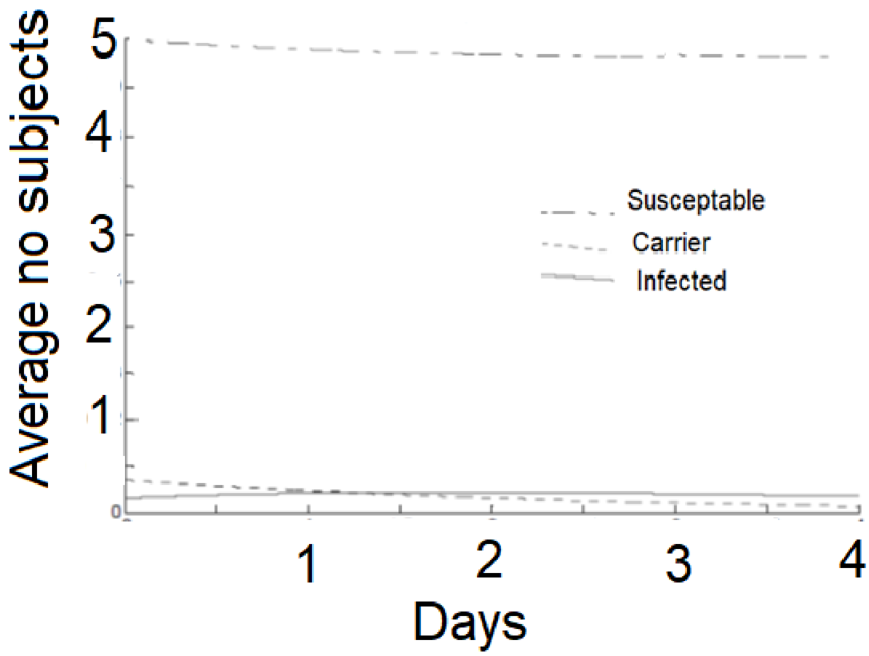

Figure 5: Average no of individuals in different class before sanitising

Hence it is found that, until preventive vaccination and proper drugs are available for curing the COVID19 , sanitizing is the best control measure .The sanitizing using Drones were effective in reducing the infectious and carrier cases.

4.Conclusion

It is found using mathematical model, the control measure to prevent spread of corono virus is to reduce the reproduction number of the model. It could be reduced by vaccination, increasing the immunity of the individuals in a population, social distancing , finding proper drugs and sanitizing. In the case study it was found that drone based sanitizing was effective in containing the spread of the disease.

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