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The contribution of dry indoor built environment on the spread of Coronavirus: Data from various Indian states

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ABSTRACT

Coronavirus spread is more serious in urban metropolitan cities compared to rural areas. It is observed from the data on the infection rate available in the various sources that the cold and dry conditions accelerate the spread of coronavirus. In the present work, the existing theory of respiratory droplet drying is used to propose the mechanism of virus spread under various climates and the indoor environment conditions which plays a greater role in the virus spread. This concept is assessed using four major parameters such as population density, climate severity, the volume of indoor spaces, and air-conditioning usage which affect the infection spread and mortality using the data available for various states of India. Further, it is analysed using the data from various states in India along with the respective climatic conditions. It is found that under some indoor scenarios, the coronaviruses present in the respiratory droplets become active due to size reduction that occurs both in sessile and airborne droplet nuclei causing an increase in the spread. Understanding this mechanism will be very useful to take the necessary steps to reduce the rate of transmission by initiating corrective measures and maintaining the required conditions in the indoor built environment.

1. Introduction

Immediately after the 100th anniversary of Spanish flu (WHO, 2018), the deadliest outbreak in the recorded history, wherein approximately 50 million people were killed which is more than the death toll from the First World War, now the new corona pandemic is threatening the entire world. The other major pandemics during the 20th century were Asian flu (1957 − 58), and Hong Kong flu (1968 − 69) which killed 1–4 million people during each era. In the last two decades, the epidemics of infectious diseases are occurring more often and spreading faster and further than ever. The reason is due to change in the lifestyle that leads to climate change leading to a biological imbalance in the system and thus we continuously learn about the unpredictable power of nature. There were witnesses for several new viral diseases Ebola, Lassa fever, Yellow fever, Crimean-Congo hemorrhagic fever, Zika, Cholera, Monkeypox, Plague, Chikungunya, Dengue, Avian influenza A (H7N9), HPAI A (H7N9), Swine flu, etc., which have emerged and created a huge threat to all developed, developing and underdeveloped nations. There are several means (air, water, flies, mosquitoes, etc.,) through which the contagious diseases could spread to human beings. Coronavirus Disease 2019 (COVID 19), Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS) viruses belong to the same CORONA family virus with a size range of 80–160 nanometres. Several questions have been raised by the world community about the mechanism of the COVID 19 transmission.

There has been some suggestion by the authorities that the most effective approach to prevent the transmission of COVID 19 among the population are: keeping social distance and washing hands. The rationale for such a policy is that virus transmission occurs through direct contact and droplet transmission, and public health professionals believe that using facial masks and gloves is an efficient way in preventing virus spread. It is a general belief that population density is an important parameter in deciding the spread of the COVID-19 virus; however, it is observed that the virus spread is less in densely populated areas in India such as Bihar, Chandigarh, Haryana, Kerala and Puducherry. Hence it is clear from the statistical study, that population density is not the only major parameter and it is one of the major parameters governing the spread of COVID-19 virus. In India, Six cities (Mumbai, Delhi, Ahmedabad, Chennai, Pune, and Kolkata) account for 50 % of all reported cases in the country. Lakshadweep is the only region that has not reported any single case (Wikipedia, 2020a) in India. Kay (2020) has prepared a comprehensive international database of

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large COVID-19 infection clusters or super spreading events in the spread of coronavirus for February and March 2020. The commonality of the outbreak observed by him is that all the infections were indoor with people closely packed. The main sources of infections are home, workplace, public transport, social gathering, and restaurants. Top 50 outbreaks have happened in the prison, religious houses, meat packing facilities, weddings, funerals, business networking events, call centers, and choir. Outbreaks happened outdoor is a small percentage of around 10 %. The author has also mentioned that studies have to be done on the effect of indoor conditions such as temperature and RH in the spread of the virus. The various other factors are classified as:

- **Minimum Infectious dose of virus**: A minimum dose of about 1000 SARS COV2 infectious virus particles is required to start a pathogenesis cascade that can cause new infection (Kay, 2020). The successful infection is a product of the dosage of virus and time for exposure. A person can get infected by a strong dose of a virus for a shorter period or a weak dose of the virus for a longer period. For example if 1000 virus particle is required for infection it can happen by 10 particles in 100 min or by 100 particles in 10 min.
- **Number of droplets released and speed of release**: A cough by a person releases about 3000 droplets at 50 mph, a sneeze releases 30,000 droplets at 200 mph and during the breath, about 5000 droplets are released at very low velocity (Bromage, 2020). The droplets released by sneeze and cough can travel a longer distance and stay in the air for a longer period of time (Chen, Zhang, Wei, Yen, & Li, 2020).
- **Age of the infected person**: The amount of the virus released depends on the age of the infected person. It is lesser if the age is less than 20. It increases up to 40 and then decreases with age. When the viral load builds up the person becomes symptomatic (Bromage, 2020).
- **Enclosed environments**: Any crowded indoor environment with poor air circulation and high density of people with high breathing and panting due to physical activity of the infected person such as loud talking, laughing, singing, dancing and playing has resulted in an increase in breathing rate and the number of droplets released causing high spread rate (Bromage, 2020; Chen et al., 2020).
- **Social and large public gathering**: Physical contact between the individuals as part of social and public gathering procedures such as hugging, handshaking, kissing also has resulted in fomite transmission.

Further, it is understood from various data and literature that cold and dry conditions accelerate the rate of spread of coronavirus (Casanova, Soyoung, Rutala, Weber, & Sobsey, 2010; Chin, Chu, Perera, & Hui, 2020; Stephanie, 2019; Taylor, 2020a, 2020b). This infers that climate severity is an important parameter in the spread of the virus. Hence the major objective of the present work is to propose the mechanism of virus spread under various climates and the indoor environment conditions maintained through the existing theory of respiratory droplet drying. Further, it is aimed to perform a statistical study on the dependence of mortality and infection in the Indian States with respect to four major parameters such as population density, climate severity, volume of indoor spaces, and air-conditioning usage based on monthly data for March and April. This study is done to confirm whether the trend and correlation from the analysis support for the drying of respiratory droplets under dry conditions proposed in the present work. Understanding the mechanism of production of dry pockets in various indoor air environments by the heating, ventilating and air conditioning (HVAC) systems is very essential to take appropriate measures and to reduce the rate of transmission.

2. Methodology

The mechanism of drying of respiratory droplets and transmission

potential is explained initially using the various sources available in the literature. The present work shows how the conventional cooling and heating mechanism in the indoor environment creates the possible drying potential for the respiratory droplet using the psychrometric chart for different climatic zones such as (i) hot and humid zone, (ii) cold and humid zone (iii) cold and dry zone (iv) hot and dry zone. The effect of this drying potential on the size reduction of the droplets and its effect on the spreading of viruses is also analysed.

In order to assess the concept proposed, the number of infected persons and the mortality from several states of India where different climatic conditions prevail during March and April, 2020, are compared using the selected parameters. The population density is one of the parameter chosen as there is a general agreement that the population density is the reason for its spread. The effect of climate severity in a particular state is brought through the parameters such as monthly average relative humidity, monthly average peak temperature, and monthly average minimum temperature. In any country, 40 % of the total power generated is utilized in the building sector in which 50 % of the energy is utilized for building air-conditioning. Hence 20 percent of the total energy generated in the country is used by the HVAC system. Hence the parameter energy utilisation is considered as another parameter which is proportional to the dry pocket creation during the period of analysis through the HVAC system. Power infrastructure (Wikipedia, 2020b), is also used as a parameter to indicate the volume of the contained indoor built environment in the state. Population density, power generation capacity (POSOCO, 2020), and CORONA infection and mortality data (Wikipedia, 2020a) were taken from Wikipedia and the weather details taken from the ISHRAE weather data (ISHRAE Weather data, 2017). The limitation of the analysis is there may be other unknown parameters which may also influence the spread of coronavirus which are not considered in the present analysis. Further, there is a drawback of using the average state-wise data in the analysis due to the possibility of mixed climatic zone prevailing in different places in the same state. A statistical study is thus performed on the dependence of mortality and infection in the Indian states with respect to four major parameters such as population density, climate severity (RH and minimum and maximum temperature), the volume of indoor spaces, and air-conditioning usage based on monthly data for March and April. The correlations obtained from the statistical analysis are well discussed to check whether it supports the concept of respiratory droplet drying under various climatic conditions proposed using the psychrometric chart.

3. Drying of respiratory droplets and transmission potential

Respiratory droplets are produced by the atomization of human secretions along the air passage from the lungs during coughing and sneezing. Respiratory droplet contains water and salts such as potassium and sodium chloride. For the infected person, the respiratory droplet additionally contains the viruses (Condair USA, 2020). These droplets with high humidity and at human body temperature while traveling in the air initially undergo size reduction due to the drying of water content if the surrounding air humidity and temperature are very low and finally it becomes the droplet nucleus. The size of the droplet will not undergo size reduction if the surrounding is in high temperature and high humidity due to less potential difference for heat and mass transfer. The virus in the droplet nucleus is less active if the size remains larger with more water content. The droplet coming from the infected person will be initially at the body temperature of 37 °C. When it tries to attain equilibrium with the surrounding lower temperature the heat available from the droplet itself will be utilized for evaporation. When the surrounding air is dry (low Relative humidity) and cold, the size of the particle is reduced by combined heat and mass transfer (Chen, Liu, Lin, & Chen, 2015; Liu, Wei, Li, & Ooi, 2016; Yunyun, Xiaosong, & Xuelai, 2016). In hot and dry conditions the heat transfer potential is less, however, the mass transfer potential is high. The mass

transfer effect will be more pronounced when the relative humidity is very low. If the surrounding air is humid, water cannot evaporate and the droplet size is not reduced. Water content in the particle plays an important role in diluting the virus so that it is less active and less harmful. Also, the salt (sodium chloride and potassium chloride) in the respiratory droplet is hygroscopic and acts as a desiccant to absorb the moisture from the humid air to increase the size of the droplets. The virus gets diluted with water content and become less active. Thus, a humid environment naturally makes the virus less active (Condair USA, 2020). Further, in hot and humid conditions, the mucus membrane in the respiratory tract will be wet which will humidify and dilute the droplet nuclei. However in dry locations, the mucus membrane becomes dry and the fluid over lining the cells becomes more viscous and the little hair CILIA which normally protects our lungs from deep settling of particle, cannot filter out the virus. After entering the lungs, the virus can cross the one cell layer separating the air path in the lungs and the blood path, and it can infect the blood very easily.

4. Transmission potential of COVID virus in various climatic zones

The respiratory droplets released during coughing and sneezing of the infected patient may have a size spectrum ranging from 0.3 microns to 1000 microns. The heavier droplets settle to the floor faster while the particles of lesser size are suspended in the air. These suspended droplets initially have a temperature of 37 °C and the relative humidity may be assumed to be in the range of 80 %, 70 %, and 60 % (DC1, DC2, and DC3) as shown in the Psychometric chart in Fig. 1. In this section, how the droplets are dried and size gets reduced under various climatic and the indoor conditions is demonstrated.

4.1. Hot and humid zone

In the hot and humid as well as warm and humid zone regions, the surrounding air has high temperature and humidity, and hence the temperature and humidity potential available for reduction in the size of the droplet is lesser. However, when the air for the indoor environment is conditioned, the air is cooled and dehumidified in the air handling unit and so the potential available for drying S2-RDC (refer in Fig. 1 with Room Design Condition 25 °C, 50 % RH) is more compared to hot and humid outdoor conditions and hence there is a reduction in the size of the droplets in proportion to room temperature and RH setting. Inside a conditioned room due to the drying of respiratory droplets, the virus is active compared to a hot and humid outdoor

environment. The virus is less active in the open spaces of hot and humid conditions as this respiratory droplet nucleus with salt contents, which act as the desiccants absorb the moisture and increase in size due to humidification in the hot and humid conditions. However, in hot and humid conditions, in the air-conditioned indoor environment, where the humidity and temperature are less the virus becomes active due to droplet size reduction. The water content and weight of the respiratory droplet nuclei are reduced and the concentration of virus and salt in the droplet nuclei increases and becomes more active. The reduction in the specific density of the respirator droplet nuclei make it to float and hence become airborne.

4.2. Cold and humid zone

In cold and humid zones (a condition referred as CH0 with 5 °C, 90 % RH), although there is no potential for drying, a small amount of sensible heating from CH0 to CH1 (15 °C, 50 % RH) represented with a drying potential (S1-CH1) and on further heating to comfort temperature CH2, (25 °C, 25 % RH) the droplet drying potential (S2-CH2) increases greatly due to relative humidity of 25 %. Under such circumstances, the sensible heaters used for the heating system of the room will reduce the relative humidity of the room and will lead to the size and weight reduction of the droplet nuclei and increases the virus activity. The droplet nuclei containing the virus may become airborne (Fig. 2). Thus in cold and humid places, the indoor environment with low relative humidity will serve as pockets for virus survival. Thus, the virus can be active in cold and humid regions in these moderately dry pockets mentioned above.

4.3. Cold and dry zone

The cold and dry zone (a condition referred to as CD0 with 5 °C, 40 % RH) is a highly unsafe condition since the drying potential already exists at low temperature. A small sensible heating without humidification, in this case, increases the drying potential CD1 (15 °C, 20 % RH) and further heating will lead to CD2 (25 °C, 10 % RH), which increases the drying potential to a higher level and there is an additional possibility of the virus becoming airborne. In an environment with low humidity and low temperature, due to combined high heat and mass transfer potential leads to fast drying and size reduction of the respiratory droplets and the virus is almost active in all the locations.
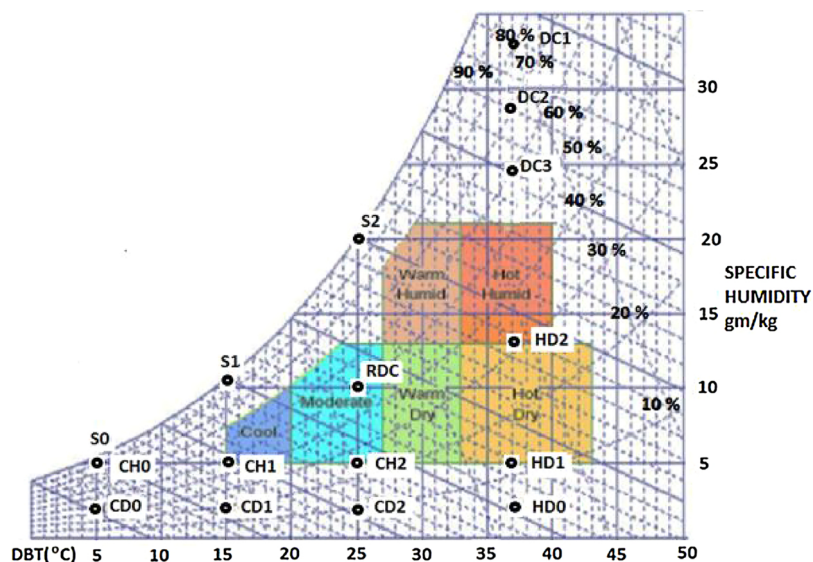

Fig. 1. Coronavirus transmission potential in various climatic zone in Psychrometric chart.
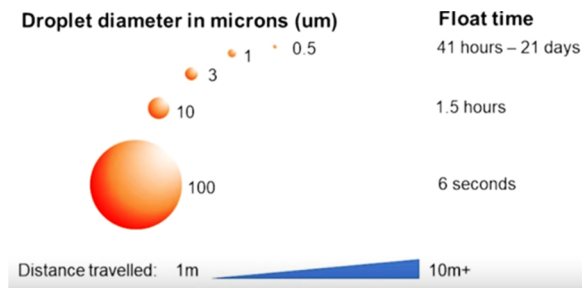
Fig. 2. Respiratory droplets shrink and become airborne when air is dry (Stephanie, 2019).

4.4. Hot and dry zone

In hot and dry climates, the drying potential for the droplet is higher at HD0 and HD1. If a cooling and dehumidification system is used in a hot and dry climate this will increase the drying potential and thus the virus activity to a dangerous level. Cooling with humidification like spray washer will improve the humidity level and will reduce the risk of viral contamination.

Drying of the respiratory droplet due to heat and mass transfer potential existing in various zones mentioned above moves the droplet nuclei to the region of low specific density as explained in the psychrometric chart so that they become lighter, buoyed up and become airborne.

5. Results and discussion

It is understood from the theory of respiratory droplets drying under various climatic zones that the virus is very active in cold and dry environment irrespective of conditioned or non-conditioned space (Taylor, 2020b). Hence this climatic zone has the most vulnerable transmission potential for the coronavirus even in the outdoor environment. In the other zones, based on the condition maintained by the HVAC systems the transmission potential will differ.

The various states and the union territories in India are shown in Fig. 3 and the climatic zones prevailing in India in various regions are shown in Fig. 4. Table 1 shows the population density, climatic severity (monthly average RH, maximum temperature, minimum temperature for March and April), the volume of the indoor built environment (power infrastructure), air-conditioning usage (energy utilisation for March and April), and the infection and mortality (for March and April) for various states in India. Tables 2 and 3 show the correlation and regression obtained for infection and mortality respectively for March, 2020 and Tables 4 and 5 show the correlation and regression obtained for infection and mortality respectively for April, 2020. It is seen from the Tables 2–5, that there is a high correlation exists between power infrastructure and energy utilisation with the number of infections and mortality during both March and April. Among the parameters considered for climate severity, monthly average relative humidity correlates better than the monthly average peak temperature, and monthly average minimum temperature with infection and mortality. The negative correlation for the average RH, represent that the decrease in RH increases the number of infection and mortality. Similar results have been reported by various researchers (Chan et al., 2011; Jingyuan, Ke, Kai, & Weifeng, 2020; Yueling et al., 2020). This confirms that the decrease in RH which increases the drying potential causes the increase in viral spread. Hence it is understood that humidity will play a major role than the temperature, as the mass transfer potential for the respiratory droplets will be high at low humid conditions. It is also a well-known fact than for any drying phenomenon, mass transfer is the major influencing factor than the heat transfer. The effect of population density is the least from the correlation due to lock down and social distancing procedure. This will play a major role if the lockdown is released in the state.

Figs. 5–7 are drawn from the data obtained from the official website sources and illustrate the states with high, medium, and low transmission spread respectively during the period between January and April. Fig. 5 shows that among the various states given under high spread, the major areas of Maharashtra, Gujarat, Madhya Pradesh, and Rajasthan are situated under hot and dry zone as shown in Fig. 4. The infection rate is very high during March and April 2020 in these states. Among these states, the spread rate is the highest in Maharashtra as all the three factors such as air conditioning usage; dry condition and population density are more favorable for the virus spread. The rate of infection is showing a near-vertical growth in the recent days despite the lockdown throughout the country since 25th March 2020. Further, Delhi and Uttar Pradesh being in the composite zone, the weather is dry during the reported months of March and April, and hence the infection and mortality is very high. Hence for these states, unless there is control through medicine, the present stringent action of lockdown is the only solution until the south-west monsoon begins and the hot summer effect decreases in the middle of July particularly in the cities like Bombay and Delhi.

The other three states, Tamil Nadu, Andhra Pradesh and Telangana showed in the high spread category are coming under warm and humid region. These southern states in India are located near the equator (8 °N to 18 °N). Though most of these regions are humid, during March (End) and April, the sun position is straight to these states that leads to large usage of the HVAC system. Hence the spread rate is very high. However, questions may arise that in the neighboring states of Kerala and Karnataka, the high spread rate is not reported which is due to the following reason:

In all these states the major spread is reported in the capital city where the air conditioning system usage is the highest. In Karnataka, Bangalore, the capital city is located at a higher altitude (partial hill station) and hence the air-conditioner usage is less and avoided the high spread. The state Kerala normally referred to as "God's own place" because of its lush greenery (full of forests, mountains, and backwater regions) and breath-taking sceneries. This makes the whole state in a comfort condition compared to neighboring state Tamil Nadu. Hence the air-conditioner usage is less and high virus spread is not reported. The spread rate in the three southern states, Tamil Nadu, Andhra Pradesh, and Telangana, does not increase appreciably after the extended lockdown period. Being the lockdown period since 25th March, the spread due to the indoor environment is very minimal. The open hot outdoor environment is not conducive for the virus spread. However, the summer will continue till the end of August. Hence it is very difficult to allow offices with the air-conditioned indoor built environment to start their function until this period. However, in these 3 states, the movement of the public in the outdoor environment and the non-air-conditioned indoor environments (factory sites) is not very critical. Hence in addition to keeping social distancing and following other precautionary measures, minimising the air-conditioning usage till the end of August is essential to reduce the spread rate in indoor environment.

Fig. 6 shows that among the medium spread states, Kerala, Karnataka, West Bengal, and Jammu and Kashmir are the 4 states showing a comparatively higher spread rate. Among these Kerala and Karnataka are in the southern states which are supposed to be in the earlier category and the reason for not coming under a very high spread rate as in Tamil Nadu is already explained. Besides, it is observed that in Kerala during the initial spread period, the rate of spread is high and it declined at the beginning of April. It is one of the states in India where a considerable percentage of the population is working in the Gulf countries and every weekend the passengers flying from Gulf region to Kerala are very high. So the spread through aircraft passengers was high initially (due to high occupant density). Jammu and Kashmir being a very cold place, the need for space heating is essential. Mostly in these regions space heating without humidification is being adopted. Hence

Fig. 3. Various states and union territories of India.

in the conditioned space, the dry pockets may arise leading to high spread. In West Bengal, despite the presence of the city Calcutta, one of the thickly populated cities next to Bombay and Delhi, the spread rate is comparatively less. This is due to the location in the northeast region of the country, where the Himalayan base effect will provide better climatic conditions, and hence the usage of air-conditioner is less. The states of Punjab and Haryana also benefited by Himalaya and these states have the major rivers originated from Himalaya. However in these two states during May the humidity level will be the lowest and hence there is a possibility of increasing trend in May if the lockdown is released. The other 3 states shown under this medium spread category and the majority of the states shown under the low spread category

(Fig. 7) are located in the North East region of India where the weather is either composite or warm and humid. Since the average temperature is less, the requirement for air-conditioner is minimal which is also seen from the electricity consumption. The possibility of spread is also in the outdoor environment when the dry climatic condition prevails. The solutions suggested to reduce the spread are (i) prevention of re-circulation of contaminated air (ii) proper use of air filtration technology in the return air system of the HVAC system and (iii) to maintain higher temperatures and relative humidity in the indoor environment without compromising the comfort. Further, it is suggested to avoid spending long hours in the closed dry environment until the corona spread is controlled.
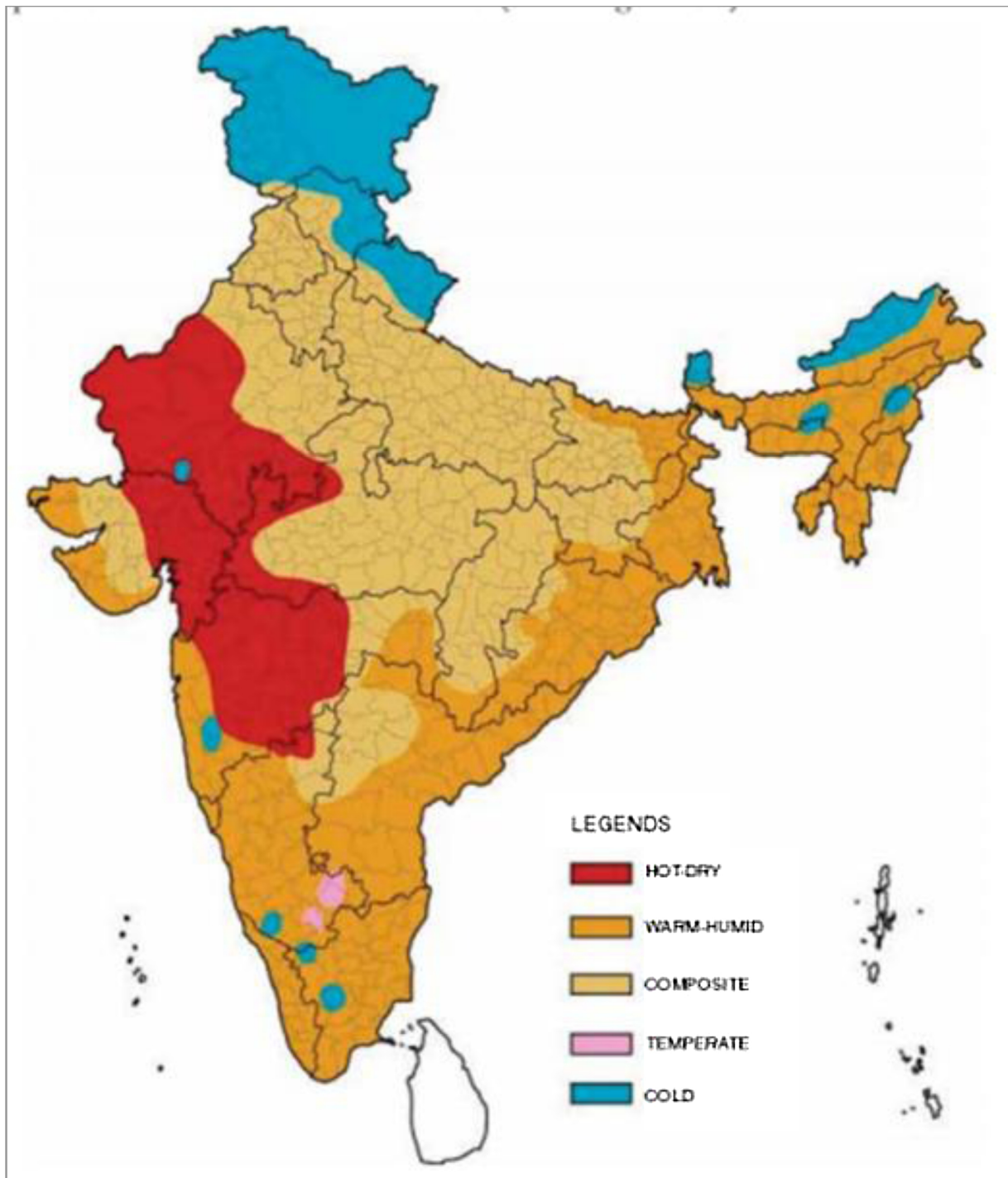
Fig. 4. Climatic zones for various states of India.

6. Conclusion

In the present work, the concept of respiratory droplet drying under various climatic conditions was explained. The variation of the severity relating to the drying potential of the respiratory droplet under different indoor environment conditions is demonstrated with a psychrometric chart. The population density, climate severity, power infrastructure, and energy utilization that represent the use of the HVAC system for all the major states in India are compared with the infection spread rate. The major conclusion arrived and the recommendations made are summarised below.

- The results inferred that the spread rate is directly proportional to the energy utilisation in all the states, which could be avoided by proper usage of HVAC systems with a higher set temperature as much as possible for the necessary comfort and the relative humidity in the range of 50–60% in the indoor environment in addition to the other recommended measures.
- It is concluded from the present study that the region with low humidity has a higher spread potential even in the outdoor environment. Hence, in the high spread states like Maharashtra, Gujarat, Madhya Pradesh, Rajasthan, and Delhi with hot and dry weather conditions, the spread may continue till the middle of July when the effect of hot summer decreases and the south-west

Table 1

NUMBER OF COVID 19 INFECTION & MORTALITY FOR MARCH & APRIL AND THE VALUES OF INFLUENCING PARAMETERS CONSIDERED.

STATE	INFECTION		MORTALITY		POPULATION DENSITY	ENERGY UTILISATION		POWER INFRA	MARCH			APRIL		
	INFECTION MARCH	INFECTION APRIL	MORTALITY MARCH	MORTALITY APRIL		ENERGY Utilisation March	ENERGY Utilisation April		Tmin	Tmax	RH	Tmin	Tmax	RH
	No of people	No of people	No of people	No of people	No of people per sq km	Mega Unit	Mega Unit	GIGA WATT	ºC	ºC	%	ºC	ºC	%
Gujarat	33	2591	5	107	308	9418	7784	29.43	12	40	38	21	42	40
Madhya Pradesh	13	1839	5	78	236	6158	5471	16.55	15	39	30	20	41	29
Maharashtra	78	6352	11	272	929	13649	11680	38.4	18	37	44	22	37	45
Rajasthan	74	1890	0	27	200	5806	4874	17.22	14	38	34	18	43	30
Arunachal Pradesh	0	22	0	0	17	18	12	0.257	15	29	65	20	28	85
Jammu and Kashmir	37	390	2	3	56	1496	1271	2.67	1	22	69	6	28	65
Assam	0	36	0	1	398	246	207	1.37	13	33	78	14	37	71
Bihar	13	163	1	1	918	2166	2320	6.384	11	40	55	18	42	49
Chandigarh	13	14	0	0	9258	91	76	0.124	9	28	77	11	36	64
Chhattisgarh	8	28	0	0	189	2487	2229	13.66	17	41	47	21	42	40
Delhi	86	2290	0	50	868	1692	1640	8.346	11	36	56	19	43	37
Haryana	40	232	0	3	573	2862	2519	8.79	13	37	54	16	45	47
Himachal Pradesh	2	38	1	0	123	675	402	4.42	7	29	76	15	37	67
Jharkhand	0	55	0	3	414	725	698	2.68	15	35	60	19	40	42
Ladakh	13	5	0	0	56	302	305	2.67	3	20	69	6	26	65
Punjab	37	240	4	12	551	2707	2391	10.59	7	35	65	9	39	53
Uttar Pradesh	101	1503	0	24	829	7226	7956	15.721	13	37	53	19	42	46
Uttarakhand	7	40	0	0	189	856	626	3.17	6	30	62	13	36	50
Karnataka	57	314	3	10	319	7438	6122	15.27	19	35	50	19	37	56
Kerala	219	177	3	0	860	2382	2054	4.12	23	35	74	24	35	78
Manipur	1	1	0	0	128	19	16	0.21	7	30	64	15	29	79
Meghalya	0	11	1	1	132	67	54	0.387	0	23	77	5	23	70
Mizoram	1	0	0	0	52	20	16	0.12	16	34	63	18	35	69
Nagaland	0	0	0	0	119	18	17	0.14	9	31	65	14	33	73
Tamil Nadu	71	1612	1	19	555	9586	7289	23.104	21	37	74	25	38	71
Telangana	69	915	6	20	308	7133	4799	9.539	21	37	57	23	40	47
West Bengal	19	495	5	10	1028	3829	3657	9.563	20	39	65	20	40	70
Andaman and Nicobar Islands	10	2	0	0	46	15	20	0.05	22	33	78	24	34	77
Andhra Pradesh	40	915	0	29	308	5767	4785	13.69	20	37	68	24	37	73
Goa	5	2	0	0	394	287	241	0.4	20	35	77	24	34	72
Odisha	3	57	0	0	270	2272	2061	9.04	21	38	71	21	39	73
Puducherry	1	6	0	0	2547	214	149	0.334	23	33	75	25	35	76
Tripura	0	2	0	0	350	135	114	0.64	15	37	65	17	37	71

Table 2

Correlation and regression for infection – March 2020.

PARAMETERS	CORRELATION COEFFICIENT	Equation Coefficients	Standard Error	t Statistics	P-value
Intercept	–	2.671364	115.7166	0.023085	0.981758
POPULATION DENSITY	−0.00172	0.000589	0.00477	0.123542	0.902628
ENERGY CONSUMPTION	0.472524	0.012966	0.00776	1.670846	0.106748
ENERGY INFRASTRUCTURE	0.383954	−2.73817	3.063893	−0.89369	0.379686
MONTHLY AVERAGE MINIMUM TEMPERATURE	0.293757	0.810451	2.021811	0.400854	0.691803
MONTHLY AVERAGE MAXIMUM TEMPERATURE	0.239065	−0.27871	2.776279	−0.10039	0.920806
MONTHLY AVERAGE RELATIVE HUMIDITY	−0.17106	0.177031	0.923104	0.191778	0.849406

Table 3

Correlation and regression for mortality – March 2020.

PARAMETERS	CORRELATION COEFFICIENT	Equation Coefficients	Standard Error	t Statistics	P-value
Intercept	–	3.396697	5.317348	0.638795	0.528544
POPULATION DENSITY	−0.0517	2.86E-05	0.000218	0.130923	0.896844
ENERGY CONSUMPTION	0.712565	0.000508	0.000359	1.415175	0.168884
ENERGY INFRASTRUCTURE	0.676659	0.011646	0.14164	0.082224	0.935099
MONTHLY AVERAGE MINIMUM TEMPERATURE	0.172597	0.017182	0.092909	0.184937	0.854713
MONTHLY AVERAGE MAXIMUM TEMPERATURE	0.268529	−0.08752	0.128009	−0.68371	0.500205
MONTHLY AVERAGE RELATIVE HUMIDITY	−0.42332	−0.01331	0.042265	−0.31488	0.755363

Table 4
Correlation and regression for infection – April 2020.

PARAMETERS	CORRELATION COEFFICIENT	Equation Coefficients	Standard Error	t Statistics	P-value
Intercept	–	3760.109	1804.579	2.083648	0.047164
POPULATION DENSITY	−0.03426	0.088106	0.075022	1.1744	0.25088
ENERGY CONSUMPTION	0.820265	0.002284	0.130835	0.017454	0.986208
ENERGY INFRASTRUCTURE	0.855729	113.4438	43.37033	2.6157	0.014631
MONTHLY AVERAGE MINIMUM TEMPERATURE	0.278017	39.35471	30.12666	1.306309	0.202886
MONTHLY AVERAGE MAXIMUM TEMPERATURE	0.307947	−92.0743	39.65627	−2.32181	0.028343
MONTHLY AVERAGE RELATIVE HUMIDITY	−0.49483	−23.3569	13.08283	−1.78531	0.085882

Table 5
Correlation and regression for mortality – April 2020.

| PARAMETERS	CORRELATION COEFFICIENT	Equation Coefficients	Standard Error	t Statistics	P-value
Intercept	–	172.8396	81.60525	2.117996	0.043894
POPULATION DENSITY	−0.02078	0.004332	0.003393	1.277016	0.212884
ENERGY CONSUMPTION	0.745251	−0.00453	0.005917	−0.76517	0.451059
ENERGY INFRASTRUCTURE	0.801233	6.002379	1.961258	3.060473	0.005079
MONTHLY AVERAGE MINIMUM TEMPERATURE	0.23006	1.720643	1.362364	1.262984	0.217805
MONTHLY AVERAGE MAXIMUM TEMPERATURE	0.208234	−4.65567	1.793304	−2.59614	0.015304
MONTHLY AVERAGE RELATIVE HUMIDITY	−0.41814	−0.88092	0.591621	−1.48899	0.148519
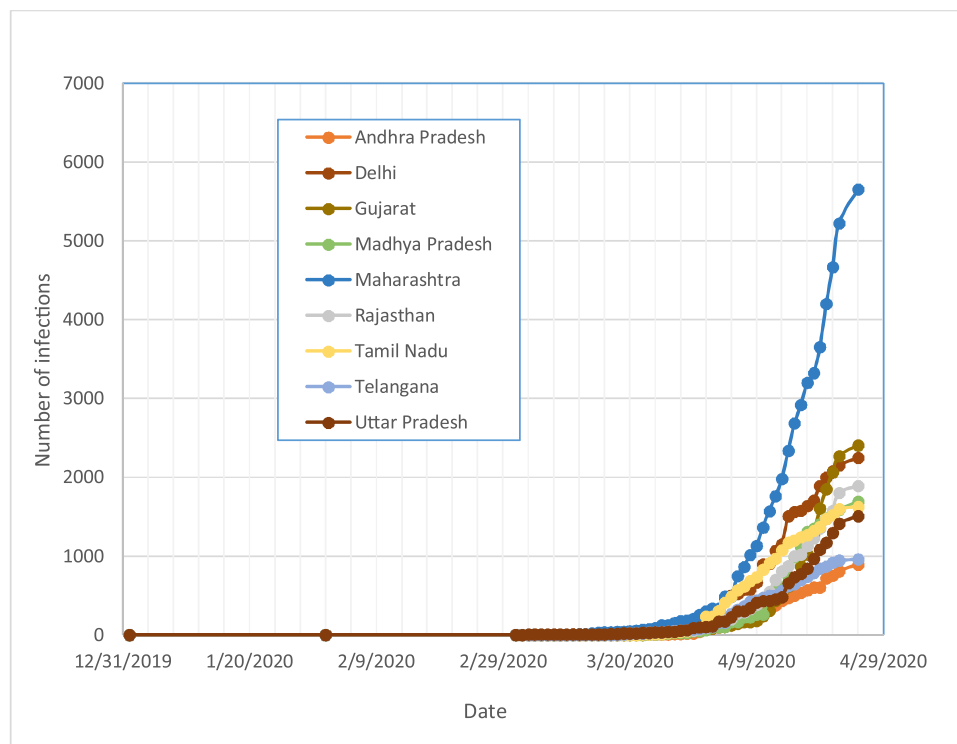
Fig. 5. Indian states with a high rate of spread.

monsoon is in full effect. Hence the existing lockdown cannot be released till Mid-July in those states particularly in the cities like Bombay and Delhi.

- In the southern Indian states, the spread rate due to the outdoor environment is very low. As the summer intensity increases, the effect due to the outdoor environment will further decrease. However, the increase in the use of air-conditioners in the built indoor environment may increase the spread rate. In these states, as summer continues till end of, August, proper measures should be taken while using HVAC systems with the correct set conditions mentioned particularly in the cities like Chennai.

- It is also concluded from the present study that the spread rate may reduce in the cold countries in the northern part of the world as summer begins. However, before the next winter starts, it is advisable to modify the kind of heating system adopted to avoid dry conditions in the indoor environment.

- Increasing the fresh air circulation is one of the methods to reduce the spread rate by reducing the viral concentration. However, it should be ensured that the recirculation of air should not help the airborne virus to spread easily in the closed room. Hence, in addition to the existing prevailing measures like wearing masks keeping social distance, and washing hands, it is recommended to bring the
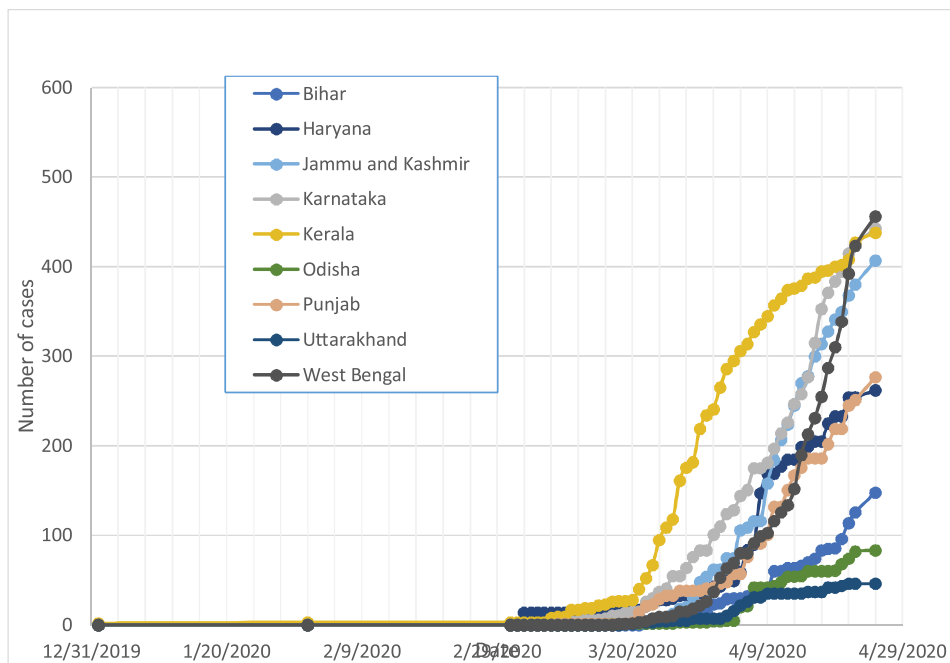
Fig. 6. Indian states with a medium rate of spread.
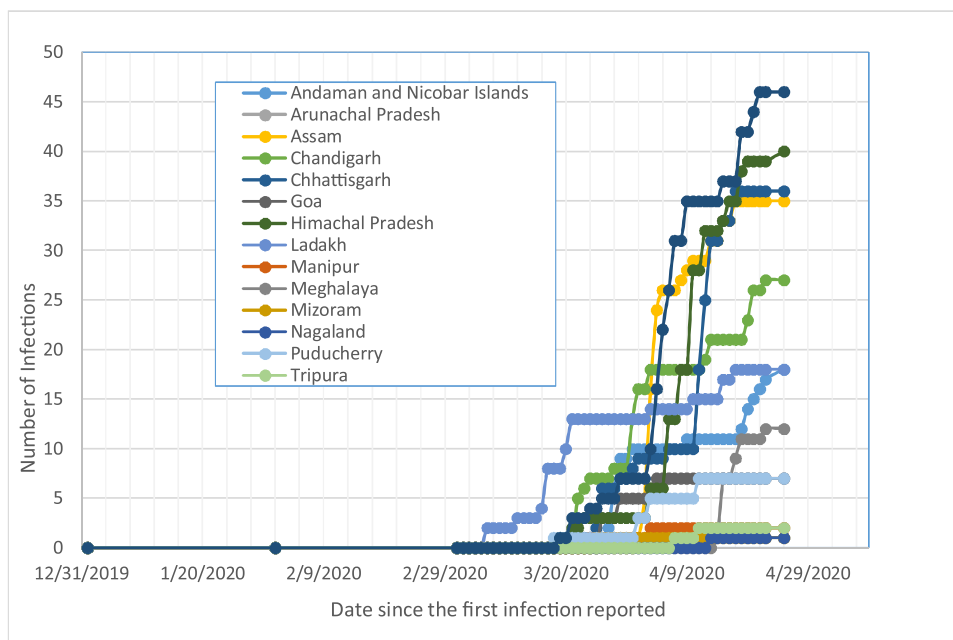

Fig. 7. Indian states with a low rate of spread.

humidity control check as a mandatory measure in the air-conditioning usage in all the indoor environment to reduce the virus transmission due to fast respiratory droplet drying. This must be done in conjuction with supplying clean outdoor air, avoiding air recirculation, proper use of air filtration technology in the return air. Special attention must be paid in high gathering indoor environment such as public buildings, hospitals, care homes, workplace environments, pubic transportation, school etc.

Presently, the humidity control is not available in most of the commercial window, and split type air-conditioners and experimental research outcomes are also not available to prescribe the safe demarcation of the relative humidity in the HVAC systems. Hence, it is

suggested now to set higher temperatures and relative humidity without compromising the comfort. Also, it is advisable to avoid spending long hours in the closed dry environment until the corona spread is controlled.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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