Scaling behavior of COVID 19 across the World and in India

H S Mukunda
Retired Professor, Indian Institute of Science,
Fire and Combustion Research Centre, Jain (deemed-to-be-university), Bangalore
(hsm.cgpl@gmail.com)
[under review with Current Science]
June 24 2020

Abstract

This article addresses the development of COVID 19 pandemic over the last five months and seeks to answer two principal questions: How high would be the infections in any country before flattening and decrease? And why there are significant differences in the death per infection in different countries. Using the data from various countries, a social distancing parameter (m^2/person) has been used to identify what appears to be a "universal" behavior leading to the maximum infections (cases per million, *C/M*) at "zero distancing" of 9000 per million population. Further, the observation that a large number of nations living in tropical climates, *poor, deprived* or otherwise have had much less death per million *(D/M)* compared to the nations in relatively rich upper and lower latitudes has been pursued to seek a latitude based index that can explain the broad behavior. The behavior is captured in terms of a relationship $D/M \sim \exp[C_0 \text{ Lat,}°/90°]$ and $D/M \sim (C/M)^{1.5}$. Exceptions like Ecuador, Mexico and Brazil on the one side and Iceland, South Korea, Taiwan, Belarus and a few others on the other side are also discussed. The same approach is used for studying India. A state-wise study shows that Orissa and Bihar stand out with very low *D/C* apart from the better known Kerala state. The behavior with latitude shows no specific pattern indicating relative uniformity of the population in India for COVID response. The relationship of *D/M* with *C/M* within India is similar to what has been found for other countries.

The deviations that occur on the subject of deaths/million in India and elsewhere are suggestive of the difference between inherent immunity and viral load. In urban centres of all countries, both *C/M* and *D/M* are controlled by viral overload overcoming the inherent immunity. In countries with latitudes far from equator where the immunity is not high, *D/M* is large or small depending on isolation helped by testing and early attention to the infected.

This article also includes observations on social distancing and use of masks based on the movement of vapors due to natural breathing that are considered more appropriate to account for asymptomatic cases.

Finally, even though there will continue to be increases in the cases and deaths beyond this time, because the spread of the disease has already been extensive with many countries indicating flattening of the growth, the broad conclusions obtained here will remain unaffected.

Key words: Scaling laws for COVID 19; coronavirus spread; Deaths due to COVID 19

1. Background

The beginning and spread of the COVID-19 pandemic has been discussed in a large number of scholarly articles over the last three months, most of which are posted in WHO website. While a full scale review of these articles would be both impossible and not meaningful, a cursory examination showed that there did not seem to be any overlap with the aims and objectives of the current work. The questions posed here and the approach chosen do not involve the variation in the nature of virus, a subject that has been studied and discussed with no definitive conclusions, as yet. It is also felt that the key factors influencing the spread of the pandemic, namely, basic immunity and viral load caused by social mixing have such enormous variability that it may be appropriate to seek answers to the questions posed that already embed these aspects in the data on infections and deaths in various parts of the World.

One set of studies on the prediction of the size of the problem and the time duration for which it might last was very attractive during the early period of the pandemic since this was thought to offer strategies for countries to plan the infrastructure. Batista [1] set out a SIR (Susceptible-Infected-Recovered) model, opened up the MATLAB code for wide use. This got more support from its description by Luo [2] and drew attention of media in India. Also the work of Singh and Adhikari [3] became relevant to a media that appeared anxious for any science based predictions. The code by Batista [1] became very popular for users amongst various countries to try out the predictions for their own countries. The results of this code depend on the data because the parameters of the model are derived from the data until that point of time. Hence the predictions could change after every few days since the parameters of the model are optimized using the data. An examination of the parameters shown against the plots obtained on different dates showed that the results of the key parameters like reproduction number, β, for instance keep changing, in fact by large amounts as seen from [1]. Also the parameters varied widely depending on the countries and there appeared no way to justify the changes. These implied that the method might be no more than a curve-fit, even if what was adopted was the solution of differential equations meant for infectious diseases. This implied clearly that the spread of the disease was beyond what the simple model accounted for.

In the light of the above, it was thought important to understand the data from other perspectives before conceptualizing an appropriate predictive model. Fortunately, data from India was posted on the Government of India dash board (https://coronaindia.github.io/#dashboardSection) and the data was set out into excel format to enable data manipulation. The data from International scene was available from World in data coronavirus (https://ourworldindata.org/coronavirus) in excel format itself. Both these have been very valuable in pursuing the studies set out in this article.

2. Social distancing, Masks and Isolation index

Over the last five months after the outbreak of COVD-19, social distancing and use of masks have been strongly recommended to avoid infection and the use of masks mandatory in public places. The extent of social distancing – one to several meters, and the nature of masks – N95 class, fabric based two layer, three layer with and without shield have been considered and internet is replete with experiences and advise. Focusing on the social distancing aspect, the behavior of breath during inhalation and exhalation, the trajectory of the mucus during cough or sneeze have been studied over a time [4-8]. The emphasis on cough and sneezing seems to have been much more in these studies. Fluid dynamic simulations of coughing and sneezing have been used to argue that the recommended 1 m social distancing is very inadequate since the droplets from cough or sneeze have a long reach of nearly 3 to 5 m due to ejection velocities of 5 m/s. Based on these studies, a minimum of 2 m of social distancing has been advised.

The documented cases of COVID-19 in Singapore with associated investigations [9] and also in other countries seem to present alternate routes to inception and spread: (a) the softest of these being in the same place within a few hours of another person or more than one with pre-symptomatic conditions containing the virus, (b) the next level being in a music choir group with social distancing arrangements, but where some loud singing was a part of the event, (c) very high levels of close interaction of being around a circular relatively small size table for an extended lunch either at home or in a hotel. In each of these cases, there have been many cases cited in literature (these are not specifically cited here since a simple google search reveals so many cases and studies).

The implication of these observations is that the virus will get transmitted in the atmosphere with more relative ease than appreciated. Natural slow breathing generates moisture laden vapor that contains many species. It is also to be noted that coronavirus is about 80 to 120 nm in size and exhaled breath contains near saturated (relative humidity of 95 %) water vapor. The vapor droplets have been characterized as about 2 to 10 microns in size [7]. The virus that is carried by the vapor drop is so small in size that it will move with local wind currents as though it is also a fluid for, one uses even larger sized trackers (of a few microns size) as discussed in a TSI manual [10], for instance. Consistent with the observations in this study [7], it is hypothesized that natural breath also can spread coronavirus. It is important to note that the velocities associated with natural nasal breathing are 0.3 to 1 m/s and the vapor is at about 37 °C as it exits the body. If the surrounding temperature is lower than this, as it usually is (20 to 28 °C), the tendency for the vapor is to move up in a plume that may also be present around the body (one can see the excellent shadowgraph videos cited in ref. 4] also form larger condensates such as fine drops. If under these circumstances, the ambient wind is about 0.3 to 1 m/s, as will be the case with light winds or even from active air conditioning systems, the virus laden vapor and tiny drops can move around the area of several square meters from the position the person is breathing. The accumulation can be enhanced by the creation of vortices (for instances Karman vortices left behind by people moving around) that can trap the vapor. While these are simple basic arguments from fluid mechanics, experimental data on measurements reported by Lio et al [11] in hospitals in Wuhan and other evidence and discussion by Lewis [12] indicate to *strong possibilities* of coronavirus being present in the atmosphere where one or some of the persons may have the virus in them even though *they are asymptomatic*. The data from [11] shows that the virus complex with water seems to have two sets of sizes – 0.25 to 1 micron and > 2.5 micron. These values are so small that filtering them is extraordinarily difficult. What this means is that if one is an environment which could have coronavirus, *the presence of a mask that is most usually porous to this range of particle sizes would be of little help*. If one were to ask as to what quality of mask should one wear, it will turn out to be surgical mask or at the next level, N95 class mask. Breathing through either of these masks is not particularly pleasant because the pressure drop per unit area would be so significant that much exertion is required for inhaling fresh air. Of course, these would be tolerated because of the necessity of a situation like in a surgical theatre and for not too long a period. This would lead to a further question what "fun" would it be to wear such mask in a group setting (party is perhaps the other word)? Thus, if one is wearing a two or three fabric cloth covered mask that has a visible pore size, in all likelihood, it would not be able to filter the virus filled vapor.

Thus, transmission from asymptomatic cases with natural breathing even without speech is entirely possible. At this stage, it is also pertinent to point out that just because one is present in an unknown environment that is suspected to laden with coronavirus, it is not necessary that one would get infected. To get infected would need a situation where the individual immunity is unable to bear the viral load. Since it never evident to anybody who is asymptomatic and may be carrying a virus that could be infectious, one needs to protect oneself and others by imposing on oneself certain obligations. And it is not a sure approach to avoid infection and the simple and sure way to avoid infection would be to practice social distancing in the true sense of the word – with minimal-most contact with the society, very close to being in self-quarantine.

The term social distancing is in fact directly connected to population density. In fact, it is the inverse of population density – social distancing defined as a **m/person** can be interpreted as **m^2/person** as the space must be provided all around. Population density is defined as population per unit area. Inverse of this is area per unit population or really, area per person. A question that arises is whether the population density *of a nation* is the most appropriate parameter of choice for seeking relations with the rise of infections. Since the population density across any nation varies significantly because of enormous urbanization into a smaller number of clusters (that has occurred over the last three decades along with population increase in most countries), the population density that matters is that corresponding to the urban clusters. This deduction is somewhat elementary if we note that it is these urban clusters that have contributed most to the rise of infections compared to rural counterpart in almost every country. The cities also have significant medical infrastructure to which patients and others arrive and their inter-mixing (as against social distancing) could be expected to lead to enhanced infection rate. The parameter chosen would therefore be the effective population density or effective social distancing parameter (SDP, for short).

3. Effective parameters, infection and deaths

This leads naturally to the broader question of whether SDP can be related to rise of infections (called *confirmed cases* or just *cases*) and deaths due to infections. Being infected because a certain magnitude of virus enters the body is perhaps inescapable. Such persons later may turn out to remain asymptomatic because their immune system has the ability to overcome the virus or they may be mildly asymptomatic, meaning having mild symptoms characterizing the disease and these never reach aggravating proportions. For some, particularly those who may have comorbidities like diabetes and/or blood pressure, the immune system may be unable to contain the virus leading to serious disorder and death. Hence population density alone cannot describe the *death-to-case* ratio. If a just-infected person is isolated and provided necessary medical support (usually ventilator to provide enhanced oxygen fraction), the chances of recovery are considered high. But the most crucial feature in recovery or even not getting seriously infected is the immunity. It is sometimes thought that the immunity required for battling with coronavirus may be naturally embedded in communities that have had to deal with malaria, dengue and such other diseases central to tropical climates. A cursory examination of the deaths per case data over the countries across the globe indicates that many countries in Africa and South-east Asia with poor to moderate medical infrastructure (economically poor as well) and countries in Indian sub-continent have had much smaller deaths per million (D/M) than the relatively rich nations in Europe and North America. This appears striking and begs explanation. It was thought that a simple approach would be to identify the countries by their latitude and examine the data on this basis. It is anticipated that one would need to add an imposed *isolation index* to explain observations related to some countries like Iceland and South Korea that are far removed from equator and the benefits that this would give (in addition) in reducing the death-to-case ratio to countries like Singapore that already enjoy tropical climate and hence larger natural immunity. What is to follow treats the subject of *cases* using effective social distancing parameter (SDP) based on effective population density and examining the D/M using latitude as the controlling feature.

4. Un-aggregated and aggregated data

In order to understand the behavior of the relationship of cases with population density, the data of several European countries was chosen. Table 1 shows these data updated as on 12th June 2020 as also some other countries for the purposes of comparison.

Table 1 Details on COVID-19 cases and deaths, 12th June 2020

Country	Population million	Pesrons/ km²	No. Cases	*C/M*	Deaths	*D/M*	*D/C*
			Europe				
Austria	9	107	17034	1893	674	74.9	0.040
Belarus	**9.54**	**47**	**51816**	5431	**293**	30.7	0.006
Belgium	12	383	59711	4976	9636	803.0	0.161
Bulgaria	7	64	2993	428	167	23.9	0.056
Denmark	5.8	137	12035	2075	593	102.2	0.049
Finland	5.5	18	7064	1284	325	59.1	0.046
France	65	123	156000	2400	29346	451.5	0.188
Germany	84	237	187000	2226	8851	105.4	0.047
Greece	11	82	3088	281	183	16.6	0.059
Hungary	10	108	4039	404	553	55.3	0.137
Italy	60	206	236000	3933	34167	569.5	0.145
Netherlands	17	488	48251	2838	6044	355.5	0.125
Norway	5.4	14	8608	1594	242	44.8	0.028
Portugal	10	112	35910	3591	1504	150.4	0.042
Romania	19	85	21182	1115	1369	72.1	0.065
Russia	146	8	502000	3438	6532	44.7	0.013
Slovakia	5.5	114	1541	280	28	5.1	0.018
Slovenia	2.1	103	1488	709	109	51.9	0.073
Spain	47	93	243000	5170	27136	577.4	0.112
Sweden	10	25	48288	4829	4814	481.4	0.100
Switzerland	8.6	214	31044	3610	1675	194.8	0.054
			Others				
Ireland	5	72	25238	5048	1703	340.6	0.067
UK	56	281	291000	5196	41279	737.1	0.142
USA	**331**	**36**	**2060000**	6224	**115000**	347.4	0.056
Singapore	**5.9**	**8358**	**39387**	6676	**25**	4.2	0.001
South Korea	**51.3**	**527**	**12003**	234	**277**	5.4	0.023
Japan	**127**	**348**	**17292**	137	**920**	7.3	0.053
Taiwan	**24**	**673**	**443**	18	**7**	0.3	0.016
India	**1380**	**382**	**287000**	208	**8102**	5.9	0.028
Karnataka	**64**	**321**	**6245**	98	**61**	1.0	0.010
Bangalore	**12**	**5455**	**600**	50	**15**	1.3	0.025

C/M = Cases per million; *D/M* = Deaths/million; *D/C* = Deaths/Cases

During the spread of COVID-19 cases, Belgium was being highlighted as having a large number of cases and deaths (even on per million population basis) partly perhaps related to having the World Health Organization's European Union related office. It is a small country with quarter of the population of Spain and yet the cases per million (C/M) are comparable and number of deaths per million (D/M) is larger. Just as a matter of contrast, Bangalore city has a population of comparable magnitude with a population density fourteen times that of Belgium with superior COVID performance. In the case of Singapore, C/M is as large as 6676 (highest in the list), but D/C is the lowest of all countries. Taiwan, a country with very much larger population than Singapore has the smallest number of cases and the lowest number of deaths.

India, with its very large population amongst democratic countries (the choice of democratic countries has the specific implication that imposition of regulations like lockdown and social distancing can remain not well-followed compared to countries like China, for instance) has a very small C/M and a low D/C. Many countries in Europe show a large D/C compared to several others within the European union. Small countries like Slovakia, Slovenia, Bulgaria and Greece, and even Portugal show small number of deaths, D/M and moderate D/C compared to larger countries like Italy, Spain and France. These data show features that are not easy to relate to a single or a specific set of parameters. Population density can be connected to the infection rise unless social distancing becomes very effective. While a national population index may have very much to do with the country's performance, it is not quite the key parameter that causes infection rise due to reduced social distancing (or social mixing) that occurs much more in high density population areas in cities. This is strikingly clear if we compare Belgium and Bangalore city, both of which have the same population with widely differing population densities with Bangalore showing a very small fraction of both infections and deaths, despite Bangalore having higher population density.

Therefore, the issue of population density has to be addressed taking note of the fact that it is the urban centers that contribute to the infections and the actual population density that matters belongs to the urban centers. Table 2 shows the details of the disease for Italy.

Table 2: The COVID 19 details for Italy as on 15 May 2020.

Italy	Area	Popln	Popln den	Cases	Deaths	*C/M*	*D/M*
	mil-km^2	million	persons/km^2				
Total	0.3	60.5	201.7	223000	31368	3686	518
Unaggregated with 8 regions separately examined							
Lombardy	0.024	10.1	420.8	83820	15298	8299	1515
Piedmont	0.025	4.4	176.0	29209	3493	6638	794
Emila-Rom	0.022	4.4	200.0	27056	3930	6149	893
Veneto	0.002	4.9	2450.0	18845	1733	3846	354
Tuscany	0.023	3.7	160.9	9849	973	2662	263
Liguir	0.0054	1.5	277.8	8995	1329	5997	886
Lazio	0.172	5.9	34.3	7291	595	1236	101
Marche	0.0094	1.5	159.6	6603	974	4402	649
Aggregated - Lombardy + Piedmont and Veneto combined							
L+P+V	0.051	19.4	380.4	131874	20524	6798	1058
Emila-Rom	0.022	4.4	200.0	27056	3930	6149	893
Tuscany	0.023	3.7	160.9	9849	973	2662	263
Liguir	0.0054	1.5	277.8	8995	1329	5997	886
Lazio	0.172	5.9	34.3	7291	595	1236	101
Marche	0.0094	1.5	159.6	6603	974	4402	649

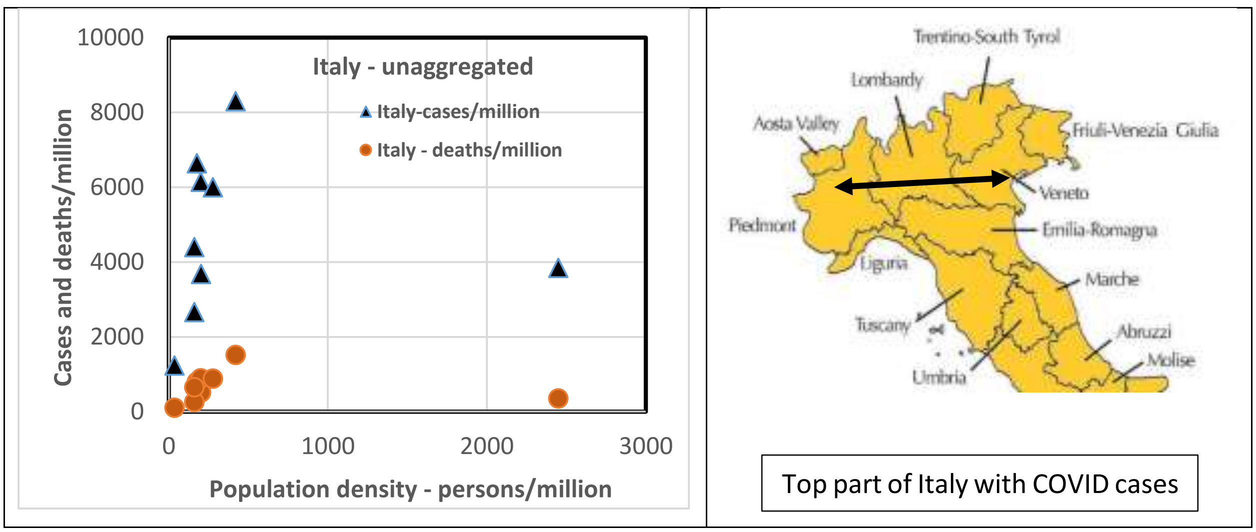

Figure 1: The COVID-19 cases and deaths per million with population density of regions in Table 2. On the right is the map of the region of ITALY with significant COVD-19.

Figure 1 shows the plot containing *C/M* and *D/M* of the region with the local population density. Though there is some order in the data, the specific data corresponding to Veneto falls out of the pattern. If we examine the map of Italy as shown on the right of Figure 1, it is contiguous with Lombardy that experienced the largest number of COVID cases and deaths.

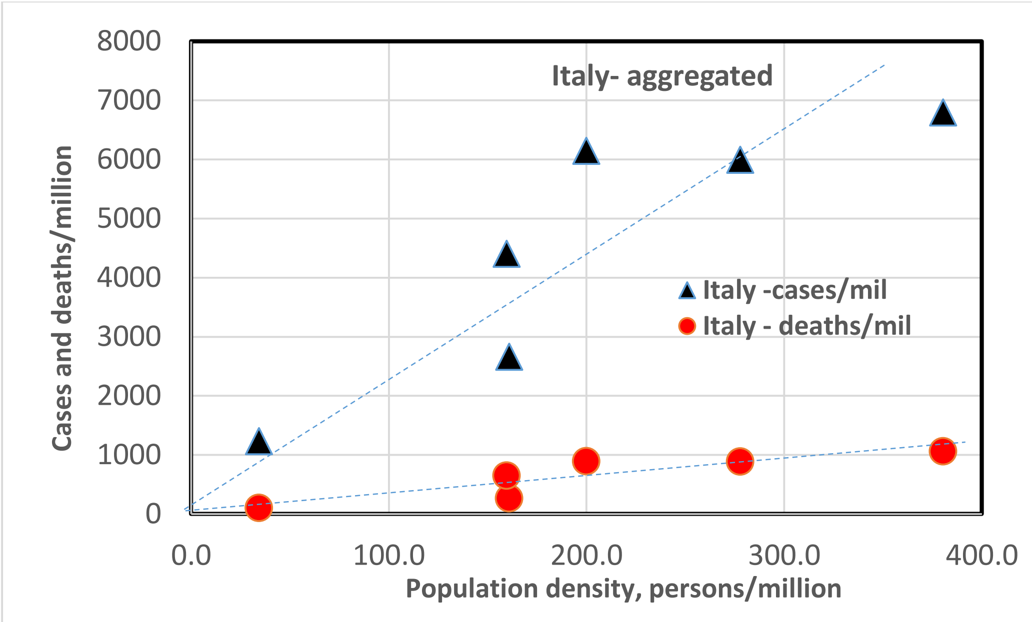

Figure 2: Plot of cases and deaths per million with regional population density on the aggregated basis.

Therefore, the three contiguous regions were combined and the result of aggregating the regions is set out in Figure 2. It appears that the relationship with local population density appears much better.

5. Identification of Social Distance Parameter (SDP)

To pursue the idea of SDP, the data for most countries available in World in coronavirus data was downloaded for study. The data is arranged in an alphabetical order for about 60 countries in Tables 3 a, 3b, and 3c. The five columns after the country have the population, the COVID cases, cases per million population (*C/M*), number of COVID deaths and deaths per million population (*D/M*) and the ratio, deaths-to-case (*D/C*). This is followed by the name of the capital city or the city (or cities) with large population and high population density that has experienced the pandemic (Sao Paulo and Rio de Geneiro in Brazil, Santiago and Valparaiso in Chile, Milano and Venice in Italy their capital city). Next are indicated the effective population and area contributing to the spread of the disease. These two columns are difficult to fill in and need a careful study of the spread of the disease in the concerned city or area. In order to minimize the arbitrariness, a few small countries where the variation across the city cannot be considered significant are considered. These will be described presently. Singapore is a city with a population of 5.7 million and an area of about 730 km^2 and so, a population density of 7917 persons/ km^2. We define a social distancing parameter SDP, as

SDP = 1/(population density*10)/(area of diffusion of coronavirus)

The reference area of spread of virus due to normal exhalation and speech is chosen as 1 m^2. The factor 10 in the denominator is chosen so that when applied to the highest density situation of coronavirus transmission the SDP translates to a value of 1. Though this constant is arbitrary, it is only a scaling factor. It would amount to using a square of 3.2 m size. This parameter works out to 1.26. Similar ideas are applied to other countries also. In the case of smaller countries such as Congo, Cuba, Kenya, Laos, Madgascar, Myanmar, Paraguay, Sri lanka, Thailand, and Vietnam, SDP takes on a large value – 3.6 indicating that the social distancing is the upper limit and the spread of infection is very small. Between these two ends, most other countries take on the SDP parameter. When these were put together on a plot, the data showed a scatter of the placement of the points. At this stage, knowing the points occupied by the ends – at near 1 and at near 3.6, the choice of the

Table 3a. Data on countries with effective parameters and (SDP)

Country	**Popln**	Cases	*C/M*	Deaths	*D/M*	*D/C*	**City**	Eff-popl	Eff area	Pop-den	SDP
	milln							**milln**	**km²**	**per/km²**	
Argentina	45.2	8371	185	382	8.5	0.046	Buenos Aires	1.00	350	2857	3.5
Australia	25	7204	288	102	4.1	0.014	Sydney	5.30	1850	2865	3.5
Austria	9	17005	1889	673	74.8	0.040	Vienna	1.90	530	3585	2.8
Belarus	**9.54**	**51066**	5353	**288**	30.2	0.006	**Minsk**	**3.5**	**590**	5932	1.7
Belgium	12	59569	4964	9619	801.6	0.161	Brussels	1.25	220	5682	1.8
Brazil	212	775000	3656	39797	187.7	0.051	Sao, Rio	13.00	2800	4643	2.2
Bulgaria	7	2993	428	167	23.9	0.056	Sofia	1.30	445	2921	3.4
Cambodia	1.5	126	84	0	0	0.0	Phenom Penh	1.5	540	2778	3.6
Chile	19	148000	7789	2475	130.3	0.017	San, Val	7.00	810	8642	1.2
China	1408	83057	59	4634	3.3	0.056	Wuhan	10.00	3600	2778	3.6
Colombia	51	43682	857	1433	28.1	0.033	Bogotá	11.00	3600	3056	3.3
Congo	90	4390	49	96	1.1	0.022	Kinshasa	12.00	4300	2791	3.6
Cuba	11	2211	201	83	7.5	0.038	Havana	5.50	1980	2778	3.6
Denmark	5.8	12016	2072	593	102.2	0.049	Copenhagen	1.25	340	3676	2.7
Ecuador	18	44440	2469	3720	206.7	0.084	Guayaquil	2.70	685	3942	2.5
Egypt	102	38284	375	1342	13.2	0.035	Cairo	10.00	3450	2899	3.5
Finland	5.5	7040	1280	324	58.9	0.046	Helsinki	0.70	215	3256	3.1
France	65	155000	2385	29319	451.1	0.189	Paris	2.20	570	3860	2.6
Germany	84	187000	2226	8845	105.3	0.047	Berlin	3.80	892	3800	2.6
Greece	10	3068	307	183	18.3	0.060	Athens	0.70	245	2857	3.5
Guyana	0.8	156	195	12	15.0	0.077	Georgetown	0.20	70	2857	3.5
Hungary	10	4039	404	553	55.3	0.137	Budapest	1.70	590	2881	3.5

Table 3b: Data on countries with effective parameters and SDP

Country	Popln	Cases	*C/M*	Deaths	*D/M*	*D/C*	City	Eff-popl	Eff area	Pop-den	SDP
	million							milln	km²	per/ km²	
India	1380	287000	208	8102	5.9	0.028	All-	400.0	140000	2857	3.5
Indonesia	273	34316	126	1959	7.2	0.057	Jakarta	11.00	4000	2750	3.6
Iran	84	178000	2119	8506	101.3	0.048	Teheran	10.00	2700	3704	2.7
Ireland	5	25231	5046	1695	339.0	0.067	Dublin	**1.90**	330	5758	1.7
Italy	60	236000	3933	34114	568.6	0.145	Milan,Venice	**1.50**	310	4839	2.1
Japan	126	17251	137	919	7.3	0.053	Tokyo	14.00	5000	2800	3.6
Kenya	54	3094	57	89	1.6	0.029	Nairobi	4.40	1600	2750	3.6
Laos	7.2	19	3	0	0	0	Vientiane	0.36	130	2769	3.6
Madagascar	28	1138	41	9	0.3	0.008	Tananarive	1.70	620	2742	3.6
Malaysia	33	8338	253	118	3.6	0.014	K-Lumpur	**1.80**	630	2857	3.5
Mexico	129	124000	961	14649	113.6	0.118	Mexico City	**9.00**	2900	3103	3.2
Myanmar	55	248	5	6	0.1	0.024	Rangoon	**5.20**	1850	2811	3.6
Netherlands	17	48087	2829	6042	355.4	0.126	Amsterdam	**0.90**	220	4091	2.4
Norway	5.4	8594	1591	239	44.3	0.028	Oslo	0.70	205	3415	2.9
Panama	4.3	17889	4160	413	96.0	0.023	Panama City	0.90	180	5000	2.0
Paraguay	7.1	1202	169	11	1.5	0.009	Asunción	0.50	180	2778	3.6
Peru	33	209000	6333	5903	178.9	0.028	Lima	9.00	1300	6923	1.4
Philippines	109	23732	218	1027	9.4	0.043	Manila	13.00	4700	2766	3.6
Portugal	10	35600	3560	1497	149.7	0.042	Lisbon	**0.50**	110	4545	2.2
Romania	19	20945	1102	1360	71.6	0.065	Bucharest	**2.00**	625	3200	3.1

Table 3c: Data on countries with effective parameters and SDP

Country	Popln	Cases	*C/M*	Deaths	*D/M*	*D/C*	City	Eff-popl	Eff area	Pop-den	SDP
	milln							milln	km²	per/km²	
Russia	146	502000	3438	6532	44.7	0.013	Moscow	**14**	3100.0	4516	2.2
Saudi Arabia	35	11200	320	819	23.4	0.073	Mecca	1.7	600.0	2833	3.5
Singapore	5.7	38965	6836	25	4.4	0.001	Singapore	5.7	720.0	7917	1.3
Slovakia	5.5	1533	**279**	28	**5.1**	0.018	Bratislava V	**0.12**	**42.0**	**2881**	3.5
Slovenia	2.1	1488	**709**	109	**51.9**	0.073	Ljubljana	**0.28**	**92.0**	**3043**	3.3
South Africa	59	55421	939	1210	20.5	0.022	Johannesburg	5.6	1800.0	3111	3.2
South Korea	51	11947	234	276	**5.4**	0.023	Daegu	**2.5**	**880.0**	**2841**	3.5
Spain	47	242000	5149	27136	577.4	0.112	Madrid	**3.2**	560.0	5714	1.8
Sri Lanka	21.7	1869	86	11	0.5	0.006	**Colombo**	**0.4**	**120.0**	2750	3.6
Suriname	0.6	144	240	2	3.3	0.014	Paramaribo	0.24	85.0	2824	3.5
Sweden	10	46814	4681	4795	479.5	0.102	Stockholm	**1.0**	185.0	5405	1.9
Switzerland	8.6	31011	3606	1675	194.8	0.054	Zürich	**0.42**	91.0	4615	2.2
Thailand	70	3125	45	58	0.8	0.019	Bangkok	8.3	3000.0	2767	3.6
Turkey	82	173000	2110	4746	57.9	0.027	Istambul	15.00	4000.0	3750	2.7
UK	56	290000	5179	41128	734.4	0.142	London	**9.00**	1550.0	5806	1.7
USA	328	2040000	6220	115000	350.6	0.056	New York	**8.30**	**1220.0**	**6803**	1.5
Vietnam	97	333	3	0	0.0	0.000	Hanoi	8.00	2850.0	2807	3.6

effective population and area consistent was made with the way the spread of the disease occurred in each of the countries where the details were available (these have been available for small and large countries on Wikipedia and other documents and constitute reading that is enlightening).

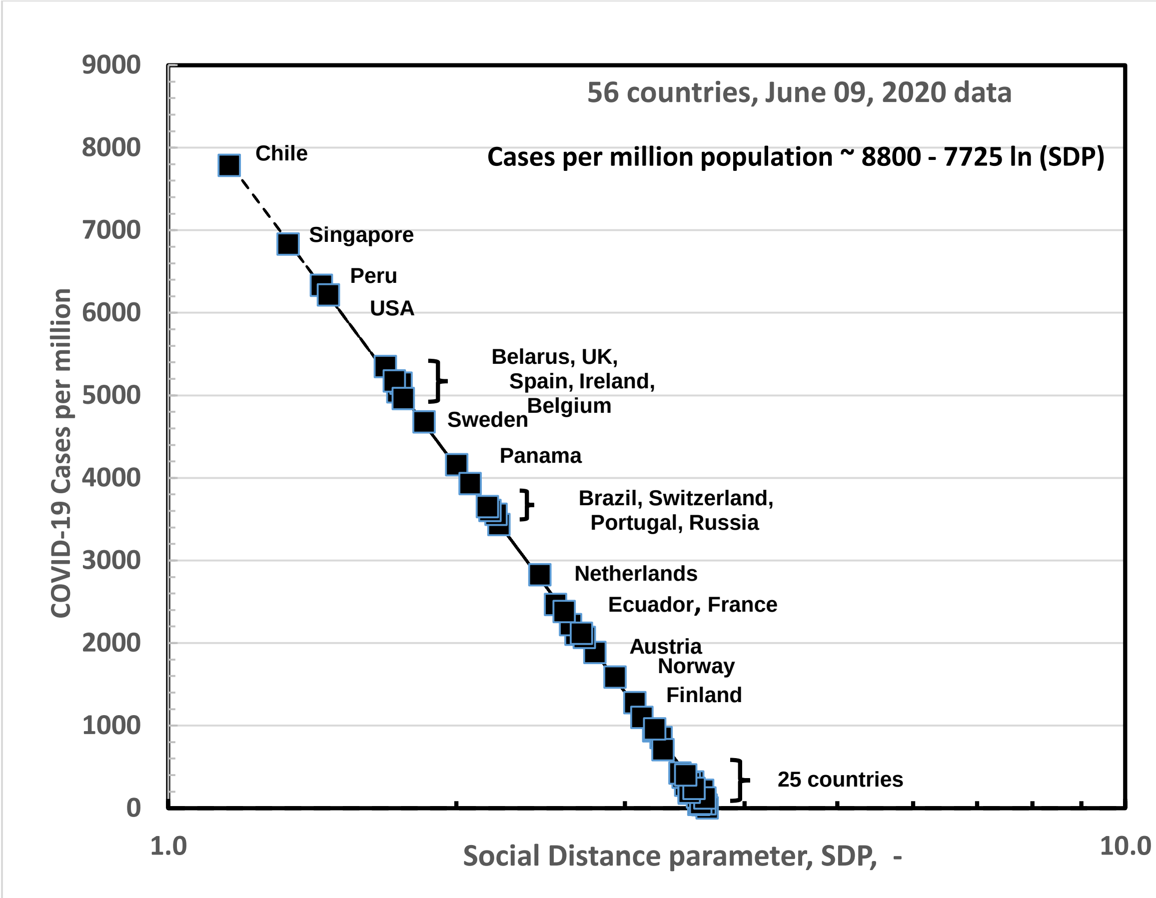

Figure 3: The plot of COVID *C/M* as a function of SDP for 56 countries.

The net result is that for the parameters chosen, the behavior would be like in Figure 3. This plot may appear too smooth and made up (!). It is not indeed so. Changes in the choice of the effective population and area will cause shift of the points across (since *C/M* is a known value). Only when a broad pattern was seen, adjustments were made to the effective parameters to cause lateral shift of the points to lie on this curve *fixed at top and bottom regions*. The details of the choice of parameters are set out in Tables 3a-c are set out to help get an appropriate picture of the behavior. The plot can be condensed into a correlation

Cases per million (*C/M*) = 8800 – 7725 ln (SDP)

Thus when SDP is 1, the number of cases per million turns out to be 8800. This implies that infections in any country will reach close to 0.1 % of the population. At this time, Chile seems to be close to this value with other countries like Singapore, Peru, USA, Belarus, UK, Spain, Ireland

Belgium in the following. It is indicated that many countries have already flattened the COVID curve and hence it is speculated that these values may not change substantially, certainly not beyond about 10 % of this value.

6. Deaths per million (*D/M*) and Latitude of the country

It was described in section 3 that the issue of COVID deaths should be treated differently from infections (or cases). The argument is that the virus that would be floating around in the atmosphere would be breathed in by a passing individual and could get eliminated through system immunity depending on the viral load; it is the difference between the viral load and the system immunity that decides future progress of the disease in the individual. Keeping the viral load low can be helped by social distancing during the stage of inception, and social isolation beyond this stage. Such a social isolation may be quarantine or hospitalization with suitable medical care. The fact that an individual recovers from the disease is quite strongly dependent on the intrinsic immunity. Further, even with good immunity, with high viral load that is generally experienced in COVID care hospitals, one can get seriously infected. What more, even the doctors and nurses can get affected with the imposing viral load if there is the slightest shortfall in protective gear, or way of managing with the protective gear.

The inference is that natural immunity plays an important role in the process of the development of infection in an individual. There have been suggestions in blogs indicating that those who have suffered malaria and such other tropical diseases may have greater immunity against coronavirus. This suggestion has not been pursued in the literature and will be discussed here. The data on the deaths due to coronavirus documented in World in coronavirus data was therefore examined.

Table 4a constructed from these data shows the countries and states with *zero deaths* due to coronavirus. Four countries in Africa, three in South east Asia and several states in India with small to reasonable population size show this extraordinary behavior. It is considered important to take these data into account even though they may not be "so very well known". Vietnam and Uganda have large population with reasonable high mean densities that ensuring coronavirus deaths at zero

Table 4a: Data of coronavirus cases with *zero deaths* (14 June 2020)

Region	Country	Lat, °	Cases	Deaths	*C/M*	*D/M*	populn, miln	PD
Africa	**Uganda**	**0.35**	**694**	**0**	**15.2**	**0**	**45.7**	**214**
Africa	**Eritrea**	**15.3**	**65**	**0**	**18.3**	**0**	**3.5**	**44**
Africa	**Namibia**	**22.5**	**32**	**0**	**12.6**	**0**	**2.5**	**3**
Africa	**Timor**	8.5	**24**	**0**	**18.2**	**0**	**1.3**	**87**
S-E Asia	**Cambodia**	**11.5**	**128**	**0**	**7.7**	**0**	**16.7**	**91**
S-E Asia	**Laos**	18	**19**	**0**	**2.6**	**0**	**7.3**	**30**
S-E Asia	**Vietnam**	21.1	**334**	**0**	**3.4**	**0**	**97.3**	**308**
India	**Andaman-Nicobar**	**11.7**	**38**	**0**	**84.4**	**0**	**0.5**	**46**
India	**Goa (India)**	15.3	**564**	**0**	**322.3**	**0**	**1.8**	**485**
India	**Dadra Nagar+**	**20.3**	**36**	**0**	**85.7**	**0**	**0.4**	**715**
India	**Manipur**	**24.8**	**458**	**0**	**152.7**	**0**	**3.0**	**140**
India	**Nagaland**	**25.7**	**112**	**0**	**48.7**	**0**	**2.3**	**105**
India	**Sikkim**	**27.3**	**68**	**0**	**97.1**	**0**	**0.7**	**385**
India	**Arunachal P**	**27.8**	**91**	**0**	**53.5**	**0**	**1.7**	**19**

C/M, D/M **= cases and deaths per million, PD = Population density (persons/km^2)**

is a difficult proposition. This is also true of the several states in India (like Goa with high population and density) where ensuring that population follow regulations is not always an ensured feature. All these countries and states in India like Arunachal Pradesh, Sikkim and Nagaland with a high latitude have had malaria in addition to other diseases to varying degrees. It is hypothesized that suffering some tropical diseases like Malaria and dengue as well as receiving mosquito bites over a period would have provided enough immunity to the people to deal with coronavirus.

The fact that hydroxychloroquine has been suggested to help improve the recovery of patients with coronavirus (sometimes, in addition to drugs that help other tropical diseases) in recent times is supportive of this hypothesis. Latitude is the single strongest indicator of the presence of these diseases in these countries and so it constitutes as the single most important factor that characterizes the immunity. Exceptions to this hypothesis that are seen with some countries like Ecuador, Peru and Brazil will be discussed later.

The proposition is pursued with the data on countries with a small non-zero *D/M* next. After a careful consideration of the data for 160 countries excepting the seven above, it was found that the contribution to scatter by small countries that have long continuous borders, more particularly in the middle region of Africa is such that unless they are grouped, it would be difficult to understand the behavior.

Consequently, several of the countries within a small range of latitudes and smaller population could be grouped together. For instance, neighboring countries in Africa with latitudes between 0 to 6° - Gabon, Cameroon, Nigeria, Central African Republic, Democratic republic of Congo, Congo, and Equatorial Guinea were grouped together as Africa -1, determining the total number of cases and deaths, total population of the region to derive the mean properties. They were assigned a mean latitude as well.

Table 4b: Data on coronavirus for many other countries, 14 June 2020.

Country	Lat, °	Cases	Deaths	*C/M*	*D/M*	*D/C*	populn, miln	PD
Gabon	0.4	3463	22	959	9.9	0.006	2.2	7.9
Cameroon	4	8681	171	208	6.4	0.020	26.5	50.9
Nigeria	6	15181	399	39	1.9	0.026	206.1	209.6
Central Afri_Rep	4	2044	7	135	1.4	0.003	4.8	7.5
Democratic Rep_Congo	4	4724	106	26	1.2	0.022	89.6	35.9
Congo	4.2	745	24	96	4.3	0.032	5.5	15.4
Equatorial Guinea	1	1306	12	743	8.6	0.009	1.4	45.2
MeanAfrica - 1	4	36144	741	107	2.2	0.021	336.2	
Ecuador	2.2	46356	3874	2117	219.6	0.084	17.6	66.9
Togo	6.1	525	13	47	1.6	0.025	8.3	143.4
Benin	6.5	388	5	16	0.4	0.013	12.1	99.1
Ghana	5.5	11118	48	219	1.5	0.004	31.1	126.7
Liberia	6.3	421	32	52	6.3	0.076	5.1	49.1
Cote d'Ivoire	6.9	4684	45	92	1.7	0.010	26.4	76.4
Sierra Leone	8.5	1132	51	92	6.4	0.045	8.0	104.7
Guinea	9.5	4426	24	249	1.8	0.005	13.1	51.8
Guinea-Bissau	11.9	1460	15	596	7.6	0.010	2.0	66.2
Burkina Faso	12.2	892	53	40	2.5	0.059	20.9	70.2
Mali	12.7	1752	101	52	5.0	0.058	20.3	15.2
Gambia	13.3	28	1	10	0.4	0.036	2.4	207.6
Senegal	14.7	4851	52	187	3.1	0.011	16.7	82.3
Mauritania	18.1	1572	81	51	17.4	0.052	4.6	4.3
Mean Africa - 2	10	33249	521	194	3.0	0.016	171.0	
Cyprus	35.2	980	18	1119	20.6	0.018	0.9	127.7
Malta	35.9	646	9	1463	20.4	0.014	0.44	1454.0
Greece	37	3112	183	299	17.6	0.059	10.4	83.5
Albania	41.3	1464	36	509	12.5	0.025	2.9	104.9
Macedonia	42	3895	179	1870	85.9	0.046	2.1	82.6
Mean - Greece+	37	10097	425	605	25.4	0.042	16.7	
Malaysia	3	8445	120	229	3.7	0.014	32.4	96.3
Indonesia	6	37420	2091	137	7.6	0.056	273.5	145.7
Timor	8.5	24	0	18	0.0	0.000	1.3	87.2
S E Asia, 1 - 8	7	45889	2211	167	8.0	0.048	274.8	

PD = Population density (persons/km²)

Table 4b to d show the details of most of the countries considered. These contain data corresponding to 37 countries and 16 regions which constitute the mean of several countries whose details are in the above tables (these indicated by the name of the country with a + sign after it).

Table 4c: Data on coronavirus for more countries, 14 June 2020.

Country	Lat, °	Cases	Deaths	*C/M*	*D/M*	*D/C*	populn, milln	PD
Kosovo	42.6	1326	31	686	16.0	0.023	1.9	159.0
Bulgaria	42.7	3191	172	459	24.8	0.054	6.9	65.2
Bosnia_Herzegovina	43.9	2893	163	882	49.7	0.056	3.3	68.5
Romania	44.33	21679	1349	1127	70.1	0.062	19.2	85.1
Serbia	44.7	12251	253	1800	37.2	0.021	6.8	80.3
Croatia	45.9	2251	107	548	26.1	0.048	4.1	73.7
Slovenia	46	1492	109	718	52.4	0.073	2.1	102.6
Hungary	47	4064	559	421	57.9	0.138	9.7	108.0
Moldova	47	11459	398	2841	98.7	0.035	4.0	123.7
Slovakia	48.6	1545	28	283	5.1	0.018	5.5	113.1
Mean- Romania+	46	62151	3169	978	49.9	0.051	63.5	
San Salvador	13.7	3603	72	555	11.1	0.020	6.49	307.8
Guatemala city	14.6	8982	351	501	19.6	0.039	17.92	157.8
Belmopan	17.25	20	2	50	5.0	0.100	0.40	16.4
Tegusigalpa	14.1	8132	306	821	30.9	0.038	9.90	82.8
Managua	12.1	1464	55	221	8.3	0.038	6.62	51.7
San Jose	10	1662	12	326	2.4	0.007	5.09	96.1
Panama City	8	20059	429	4649	99.4	0.021	4.31	55.1
Bogota	4.7	48746	1592	958	31.3	0.033	50.88	44.2
Caracas	10.5	2904	24	102	0.8	0.008	28.44	36.3
Paramaribo	5	196	3	334	5.1	0.015	0.59	3.6
Georgetown	6	159	12	202	15.3	0.075	0.79	4.0
Port of Spain	10.6	117	8	84	5.7	0.068	1.40	266.9
S-America -1	12	96044	2866	723	21.6	0.030	132.83	
Peru	12	225000	6498	6824	197.1	0.029	32.97	25.1
Bolivia	17.5	16929	559	1450	47.9	0.033	11.67	10.2
Chile	33.5	167000	3101	8736	162.2	0.019	19.12	24.3
S-America2	30	408929	10158	6413	159.3	0.025	63.76	

Table 4d: Data on coronavirus for more countries, 14 June 2020

Country	Lat, °	Cases	Deaths	Cases/ million	Deaths/ million	Deaths/ cases	populn, million	populn_ density
USA	40.7	2120000	117000	5022	353.5	0.055	331.00	35.6
Brazil	23.5	851000	42791	1764	201.3	0.050	212.56	25.0
India	25	309000	8884	105	6.4	0.029	1380.0	450.4
Singapore	1	40197	26	5463	4.4	0.001	5.9	7915.7
China	30.6	83132	4634	58	3.2	0.056	1439.3	147.7
Portugal	38	36463	1512	3019	148.3	0.041	10.2	112.4
Spain	40	244000	27136	5035	580.4	0.111	46.8	93.1
Italy	45	237000	34301	3807	567.3	0.145	60.5	205.9
Switzerland	47	31094	1677	3543	193.8	0.054	8.7	214.2
France	48	157000	29389	2226	450.2	0.187	65.3	122.6
Austria	48.2	17078	677	1827	75.2	0.040	9.0	106.7
Ukraine	50.4	30506	880	486	20.1	0.029	43.7	77.4
Belgium	50.8	59918	9650	4948	832.6	0.161	11.6	375.6
Canada	52	98410	8107	2271	214.8	0.082	37.7	4.0
Germany	52	187000	8867	2136	105.8	0.047	83.8	237.0
Netherlands	52	48640	6057	2652	353.5	0.125	17.1	508.5
UK	52	294000	41662	3847	613.7	0.142	67.9	272.9
Ireland	53	25295	1705	5002	345.3	0.067	4.9	69.9
Belarus	53.7	53241	303	3931	32.1	0.006	9.4	46.9
Russia	55	520000	6829	2422	46.8	0.013	145.9	8.8
Denmark	55.9	12139	597	1966	103.1	0.049	5.8	136.5
Finland	59	7087	325	1191	58.7	0.046	5.5	18.1
Norway	59	8628	242	1541	44.6	0.028	5.4	14.5
Sweden	59	50931	4874	3351	482.6	0.096	10.1	24.7
Iceland	64	1808	10	5286	29.3	0.006	0.34	3.4

A total of 159 countries has been covered. Table 4b to d show the details of most of the countries considered. These contain data corresponding to 37 countries and 16 regions which constitute the mean of several countries whose details are in the above tables (these indicated by the name of the principal country with a + sign after it). A total of 159 countries has been covered.

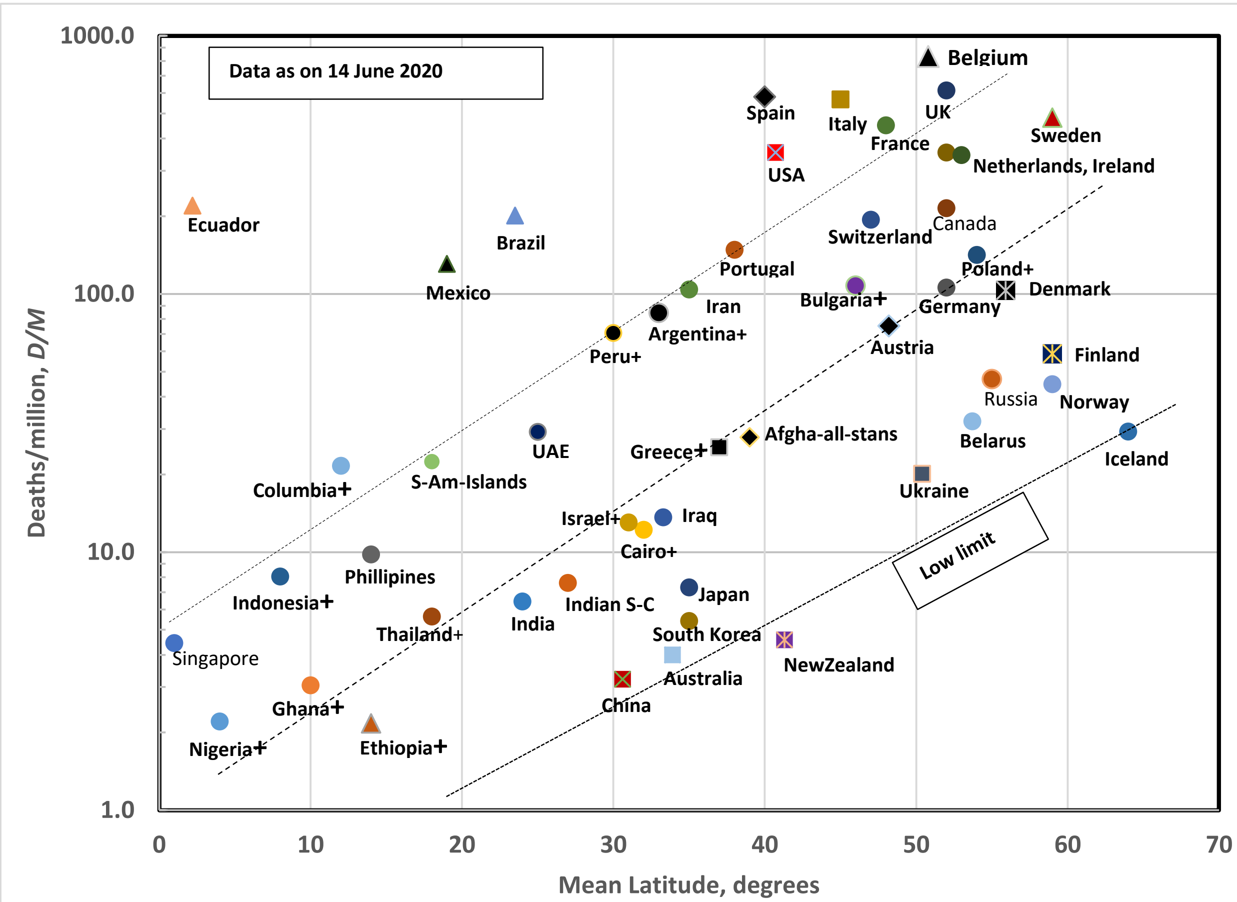

Figure 4: The data of deaths per million vs. Mean latitude of the country

For some countries like Chile, the choice of latitude is not so easy as the country covers a latitude varies from 17 to 56° (south). What has been used is the latitude of Santiago, its capital at 33.4°.

The data of deaths per million with latitude are set out in Figure 4. The broad trend of increased D/M with increase in latitude is clear. Changes in D/M are over three orders with latitude change from 0 to 64°. This implies that that those who countries closer to the equator would experience much less coronavirus related deaths compared to the countries far from equator. This figure is important and needs to be explained.

We consider countries at the two ends of the spectrum. The D/M in three regions with more than 35 countries in Africa (Nigeria+, Ghana+, Ethiopia+) with a large population (~ 500 million) show values that are the lowest. It certainly cannot be stated that these countries are well equipped with needed medical care even it is stated that they have the experience of having handled Swine flu, Ebola and others. It is the present author's contention that the immunities that these people have acquired having suffered the tropical diseases has led naturally to a low COVID related D/M. No other explanation seems to explain this behavior. Singapore has shown a very low D/M even though its C/M is very large (see fourth row in Table 4d). While appropriate measures were taken to attend to testing and treatment, the magnitude of the D/M is so small that it is reasonable to assume that the intrinsic immunity was high. This is consistent with the zero death due to COVID in other south east Asian countries. Similar explanation holds good for Indian sub-continent, particularly because the population size is very large (~1500 million). India that has a D/M of 6.4 may increase with rise in infections after the lockdown was formally declared relaxed, but will be within the broad band indicated in Figure 4. China can exert social distancing measures like few other countries can. Japan and South Korea have population that is very disciplined and have introduced social distancing measures, contact tracing and isolation all of which have helped bring down their D/M. In the case of New Zealand, it is inferred that similar measures have helped the low death count; Australia is further helped by its population being spread out and containment in the select urban locations (like Sidney and surrounding areas) kept the death count low. The better performance of Ukraine is related to measures like in other countries with the country's president taking direct responsibility for some time (and changing the heath minister to ensure better performance). Even so, better immunity of Ukrainian population must have played a significant part (the reasons for this are not yet clear) in lower D/M even though their latitude is high. Iceland is another country with small population and low population density that has a low D/M of 29. Considering that it is an isolated island and it is easy to stop international entry and impose social distancing measures, the performance of Iceland can be considered good. The fact that death rate is not as low as some of the African and south east Asian countries is indicative of an immunity level comparable to that in middle Europe. This is also consistent with the population being largely Nordic.

The most curious of the countries is Belarus and has also an interesting input. The president of the country dismissed the outlook and reality on coronavirus outside the country and did not issue any related safety measures in the country. This was commented upon in late March by WHO and others [14]. While some population was concerned with the situation and observed self-quarantine and social distancing measures on their own, it is appropriate to conclude that there would have been large scale social mixing. Yet, their D/M is about 20 and D/C of 0.008 (close to 0.006 at this time) which is very low considering the extent of social mixing. Further, D/M for Russia is also is about 48, much more than Belarus, but much lower than what the general trend would indicate (about 100). The D/C for Russia is also low (0.013), much lower than for several other countries. While there have been arguments on whether these values are really true because reportedly, more than hundred doctors and front line medical staff have died in Russia due to lack of protective equipment [15], these values are accepted here as the declared values have been set out in World in Coronavirus data. Also, it is taken that substantial deviations would have come to light over a period of time. The key point is that both with Belarus and Russia, the death rates are much lower compared to other countries (see Tables 4c and 4d – even smaller countries like Slovakia and Slovenia have double or more than double D/C values). Undoubtedly, these communities must have a *high enough intrinsic immunity* to maintain such low D/M and D/C.

An entirely opposite situation of a country with no Government based lockdown but with self-managed social distancing belongs to Sweden. Based on the directions by its top epidemiologist, Dr. Anders Tegnell, the country did not impose lockdown and closing of borders and suggested that people observe social distancing as a part of their social life. The situation was so much appreciated by the people then that his picture was used a tattoo by his fans! However, two months into the pandemic, the performance of Sweden is towards the top end of D/M and while the Government itself is defending the decision, Dr. Tegnell has admitted that he was perhaps wrong [16]. If they had followed the lockdown procedures like other Nordic countries, they would have saved close to 5000 lives! Clearly, Swedish people seem to have a much lower immunity compared to those in Belarus and the risk of abandoning social distancing and lockdown measures has been staggering. Belgium that has the largest D/M (830) is the other extreme case of complete social mixing and creating a viral overload on the patients. While the Governmental defense of the high D/M of Belgium is related to counting procedure in which it is claimed that the count of those dead in care homes perhaps with other diseases is responsible for the high death count, the fact that the actual numbers have not changed over a time is taken to imply that these numbers are considered correct. An arguably more *appropriate reason* appears from a newsletter of Jewish telegraphic agency [17] which has the following quote: **The estimate for Antwerp's Jews is "higher than the general population due to social interactions"; the higher infection rate "makes sense, because Antwerp Jews all know each other, each synagogue is an extended family," Michael Freilich, a Modern Orthodox lawmaker from Antwerp, told JTA. "If the average Belgian person has a circles of 15 close friends and family," he said, "then with Antwerp Jews it's 150 people."** Similar arguments are set out why UK Jews are represented much higher in deaths than their population index. Also, it appears that the Jewish *purim* festival that involves significant congregations could have been responsible for larger spread of the coronavirus amongst the community and others who came into contact with them unwittingly. The high D/M in the UK is strongly linked to initial assertion of the herd immunity route (in an approach more relaxed than the one adopted in Sweden) that led to high infection rates and the inability of the medical care system to deal with this over a time and then the institution of a subsequent long lockdown. Italy, Spain and France had early problems of the infection and the delayed response to the instituting testing and social distancing measures. Also, it is important to point out that the nature of the spread of virus was being understood over the critical period in Europe during which the spread was indeed very significant. All these was compounded by the response of the citizens to the lockdown that always is not the same in liberal societies as with the response in countries like China.

These leave behind three major exceptions: Ecuador, Mexico and Brazil. Issues related to Ecuador in terms of its poor response have been discussed in some detail [18]. The central issue was allowing opportunities for enormous social mixing much after the pandemic had entered the country (3 weeks after it entered) by allowing for a soccer game attended by 17000 fans. Even after the Government declared a state of emergency and compulsory social isolation, it never got implemented in practice. The fact that the city had a large number of slums with large population density did not help any control either. The number of COVID infections rose rapidly and the medical care system got saturated quickly, leading to a viral overload on the population. This led to D/M much higher than what would have been experienced if the standard social distancing procedures had been followed at an earlier time. Issues related to Brazil are even more clear. The president himself has been seen promoting social mixing and disregarding all inputs of its evils from experts and other members of the Government. It would have been possible to bring down the D/M had the lockdown and social distancing procedures been put in place at an early enough time. Mexico has had problems not too different from Belarus – with its president demonstrating social mixing and describing that religious faith would cure the pandemic and allowing international travel that led to a situation that could be more alarming than what has turned out to be [19]. Because the population resides in tropical climate and they had Swine flu some ten years back, the immunity levels have helped a natural containment of deaths per million which is now at 200 which is large, but not large enough like those in Europe. Figure 4 contains three dotted lines. The two lines covering many of the countries can be characterized by a curve fit:

$$\boldsymbol{D/M}\ \textbf{(upper)} = \textbf{4.4 e}^{\textbf{8.4 Lat°/90°}};\quad \boldsymbol{D/M}\ \textbf{(lower)} = \textbf{1.0 e}^{\textbf{8.4 Lat°/90°}}$$

The data of many countries will fall between these two estimates. If one were to ask a question as to what would be the minimum *D/M*, the line drawn from about 20° latitude and through the data of Iceland (because it has the largest latitude and deployed measures to control coronavirus spread and yet experienced a *D/M* of 29) was considered the most appropriate estimate for COVID related deaths per million): $\boldsymbol{D/M}\ \textbf{(lowest } \boldsymbol{D/M}\textbf{)} \approx \textbf{3.2 e}^{\textbf{3.2 Lat°/90°}}$

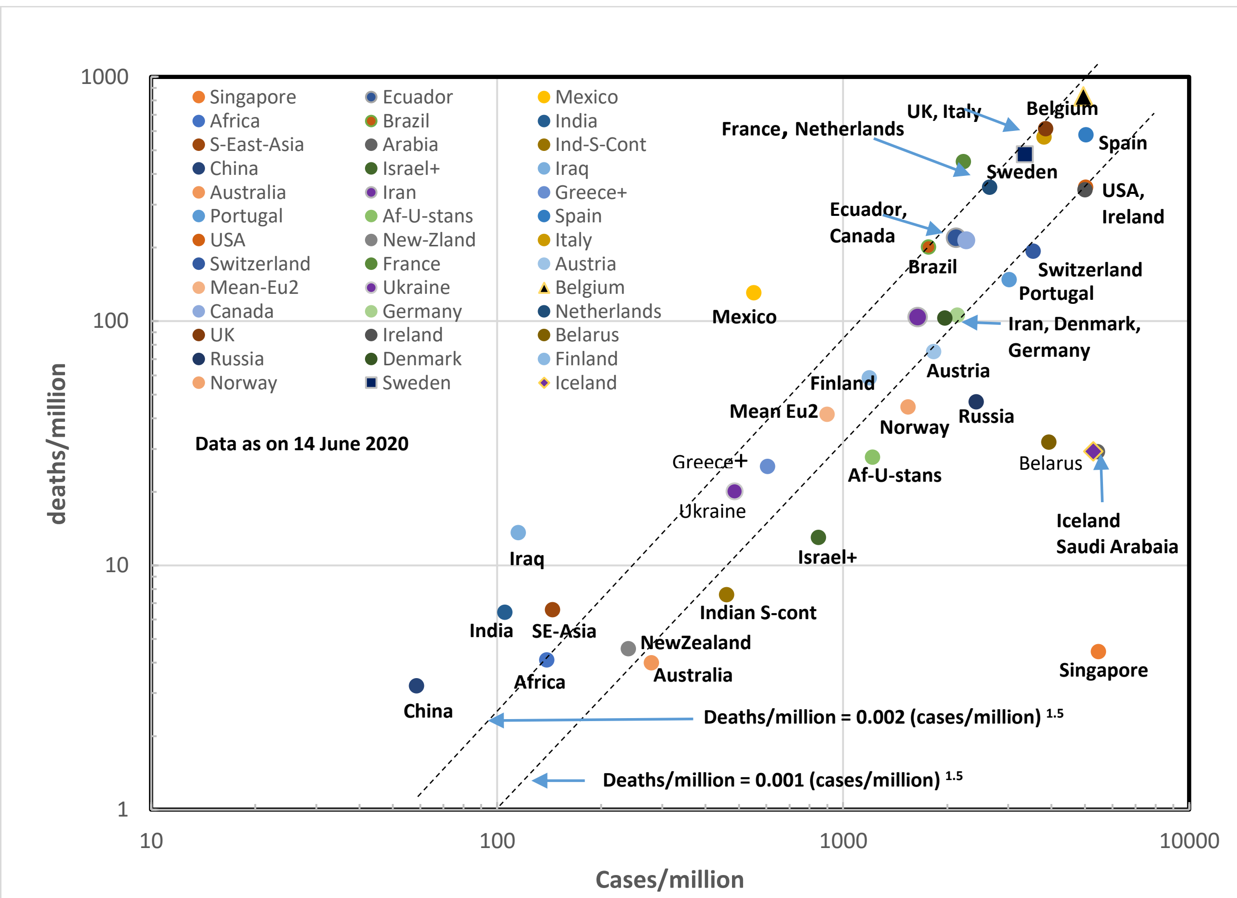

Figure 5: Deaths per million with cases per million with aggregation for all the countries.

In order to assess the D/C behavior, a plot of D/M vs. C/M is set out in Figure 5. One might wonder why D/C itself is not set out against C/M in a plot. It turns out that such a plot is not as easily decipherable as the current plot. Like in the case of Figure 4, countries appear in the plot somewhat similarly, albeit with some changes. For instance, Ecuador and Brazil that appeared as outliers on the plot (Figure 4), appear here close to the mean behavior. This means that they would be close to the mean behavior even in the earlier plot provided the infection was reasonably well controlled. A question on the use of C/M that is current may be brought up since this changes with time and would the curve above change as well. There will be changes. Since the values of D/M are also likely to change, the shift of several of the points where the virus is still spreading as in the case of USA and India (and also a few others), the points will shift towards right bringing them to within the range of data. Also such changes will be small since the progress of cases is already very large. Like in the earlier case, the behavior of D/M with C/M can be set as:

$$\boldsymbol{D/M \sim \mathrm{A}\ (C/M)^{1.5}}$$

While one might expect D/M to scale linearly with C/M, in the above equation with dimensionless quantities, the exponent is much larger than 1 and indicates to the way the disease affects the D/M. The load of coronavirus becomes an overload when C/M is larger because the viral concentration becomes much larger in an environment with patients even with all the care that may be exercised in terms of protection equipment and air-conditioning systems in the ICU, etc. In fact, in many countries that includes Italy, Spain, Ecuador, Brazil reports indicate inability to provide protection for the patients and on occasions to medical staff as well. Thus the D/M scales with C/M in a non-linear way. The constant A is 0.0014 for many countries and 0.002 for others. For some it is about 0.0017. There are some countries for which D/M is much lower than what this curve-fit indicates. In the cause of these countries, the approach chosen for in the early detection of the patents and isolating them or treating them sufficiently early has resulted in lower death rate.

7. The Indian case study

It is thought appropriate to consider the Indian situation on coronavirus with its various states having large population. The data with some states with zero deaths during the pandemic was set out in Table 4a. The data of many other large states is set out in Table 5. As can be seen from the table, the states that have the lowest D/C and C/M are Orissa and Bihar. Kerala that has been

Table 5: Data of India and Indian states on cases and deaths, 19 June 2020

State/UT	Popln, million	Lat,°	Cases	*C/M*	Deaths	*D/M*	*D/C*	Area, km²	PD, per/km²
Orissa	46	19.4	4512	98	11	0.24	0.002	155707	295
Bihar	121.7	25.6	7025	58	44	0.36	0.006	99200	1227
KER	35	8.5	2794	80	21	0.60	0.008	38863	901
TN	81	13.1	52334	646	625	7.72	0.012	130058	623
Haryana	26.0	28.5	9218	354	134	5.15	0.015	44212	588
J & K	15	34	5555	370	71	4.73	0.013	2336	6421
KAR	68	13	7944	117	114	1.68	0.014	191791	355
AP	54	15.8	7518	139	92	1.70	0.012	160205	337
Punjab	31	31.6	3615	117	83	2.68	0.023	50362	616
Rajasthan	77.0	26.9	13857	180	323	4.19	0.023	342239	225
Delhi	19.0	28.6	49979	2630	1969	103.63	0.039	1484	12803
UP	223.0	27.2	15181	68	465	2.09	0.031	243286	917
TEL	40	17.3	6027	151	195	4.88	0.032	112077	357
Maharashtra	124.9	19.1	120504	964	5751	46.03	0.048	307713	406
MP	83	22.7	11426	138	486	5.86	0.043	308252	269
WB	99	22.6	12735	129	518	5.23	0.041	88752	1115
Gujarat	69.0	23	25601	371	1591	23.06	0.062	196024	352
Al India	1350	20	380532	282	12573	9.31	0.033	3287000	411
Mumbai	33.0	19.1	90787	2751	3289	99.67	0.036	2000	16500
Pune	7.3	18.5	12888	1765	588	80.55	0.046	7256	1006
Bangalore	12.3	13	862	70	52	4.23	0.060	741	16599

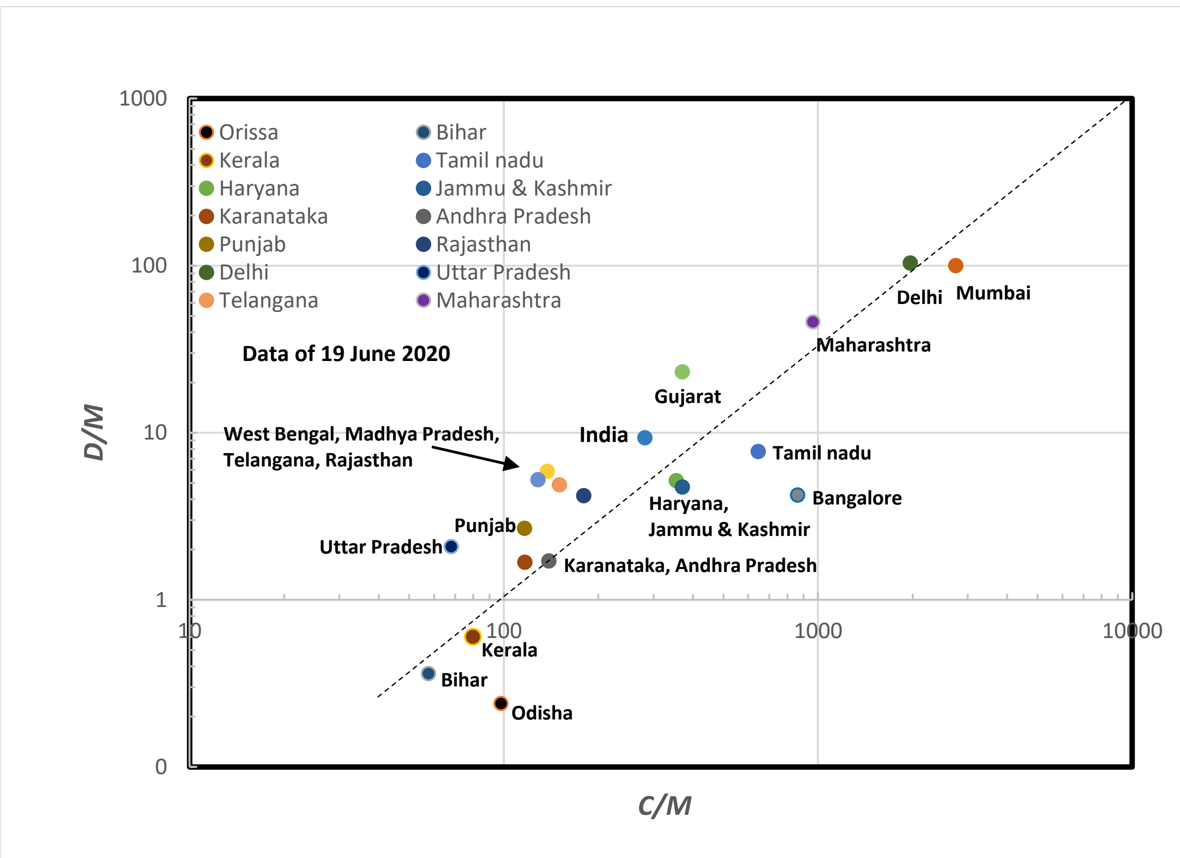

Figure 6 The plot of death/million with cases/million for many states in India

discussed much more in the media comes later. It is particularly interesting to note that both of the states have not been the known states in terms of development index. Being the focus of intense media attention, Maharashtra, Delhi, Gujarat and Tamil nadu have had very large number of cases in their urban centres – Mumbai, Delhi, Ahmadabad, and Chennai. The most striking feature is the low D/C ratio all across the states even in the major urban centres.

The relationship of D/M with latitude was first examined. It turned out that the plot showed no specific trend indicating that the population appears to be mixed, quite consistent with the expectation of large scale travel between regions with migrants contributing to it. The variation of D/M vs. C/ M from the above data was considered next. Figure 6 shows such a plot. The variation of the data is along the lines that were obtained with international data. These also seem to have a scaling law with an exponent of 1.5. The curve-fit is $\boldsymbol{D/M = 0.001\ (C/M)^{1.5}}$. The constant for the data of the world was 0.0014 to 0.002 instead of 0.001. In fact, even in the above plot, it can be seen that the constant for all India is about 2.

It is useful to discuss the results for many states shown in Figure 6. Orissa (or Odisha) with its lowest D/M is related intense proactive actions towards social distancing, isolation and attention to suspected cases also helped by intrinsic immunity. The attention paid in Bihar was perhaps not as intense as in Orissa, but its intrinsic immunity must have been high. In both states, there was a problem of enormous influx of migrants and yet the performance in terms of C/M and D/M is remarkable. Any explanation other than intrinsic immunity seems too difficult to justify. The performance of Kerala has been discussed and highlighted in the media extensively (to an extent more than the attention provided to the performance of Odisha). Both Kerala and Karnataka deployed modern techniques of early identification, contact tracing to make decisions on home isolation, quarantining, or hospitalization of possible patients. Knowing that the problem of the pandemic could be a long-drawn matter much to the anguish of all concerned, application of these techniques that have also been used in Singapore and South Korea extensively will be invaluable.

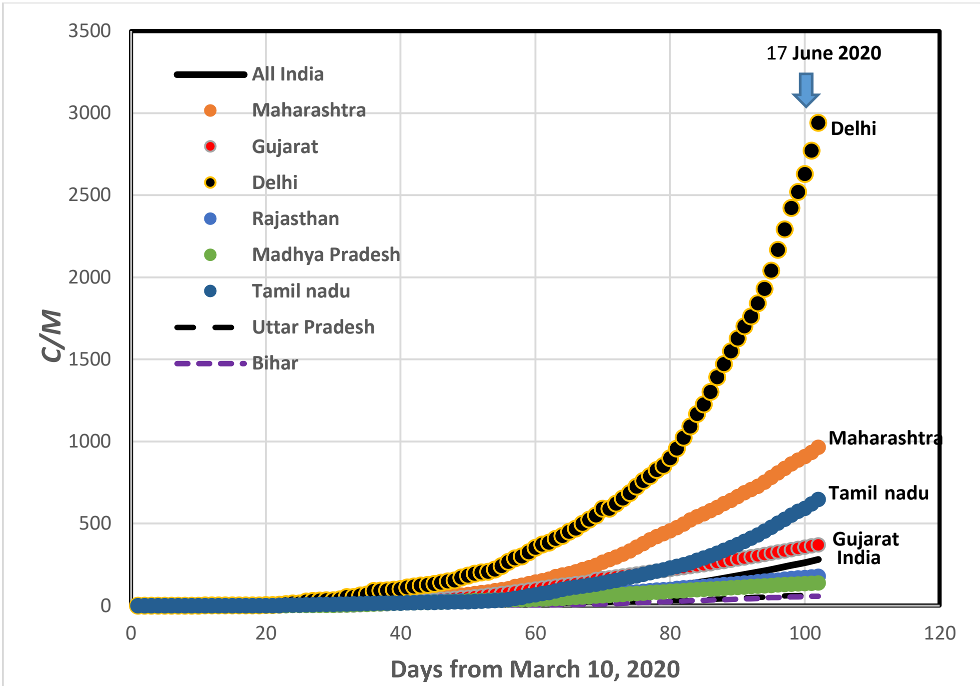

Figure 7: The coronavirus *C/M* for several Indian states

Many other states that are above the line have had issues of viral overload due to large growth of infections with time as can be seen from Figure 7 that shows the *C/M* vs days from March 10 2020, the date from which the data were recorded. The slope of these curves seems to indicate that the time for control of the pandemic (what is classically termed as R ratio becoming less than 1, this implying that it requires more than one infected person to infect a new person) is still far away. To get a possible assessment of this, dimensionless quantities involving the ratios of active-to-total cases [A/T], recovered-total cases [R/T] and (recovered + deaths)-to-total cases [R + D]/T are set out in Figure 8. One can notice that while the active cases in proportion to total cases come down, the proportion of recovered will increase. The intersection of the two lines (the recovered including the dead to determine the status) with the lines moving in opposite directions with the crossover at around 0.5 that could be expected to occur after 85 days from start (this would mean 02 June 2020) which is when it actually occurred. The point being made is that over the scale of the population (of COVID cases) of 200,000, surprises in this trend will be small. This plot also provides for determining how long after can one expect to have gained control over the disease. This can hopefully happen when the recovery (+dead) reached about 0.9 or so. Beyond this, sporadic cases may come up and can be handled as any other disease. This does not mean that over the course of time significant infections cannot come up (for understandable or not-so understandable reasons) leading to demand for significant medical care.

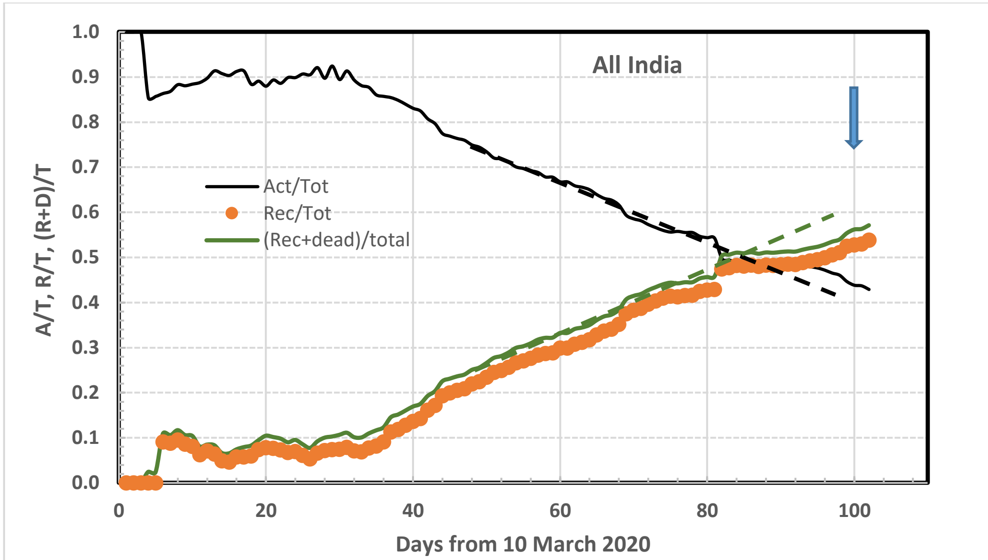

Figure 8: The plot of various ratios with total cases for the 102 days

The example of the surprises (substantial) of the progress of the disease in a region is provided by Kerala. Figure 9 presents the data for Kerala. It can be observed from Figure 9 that after 60 days

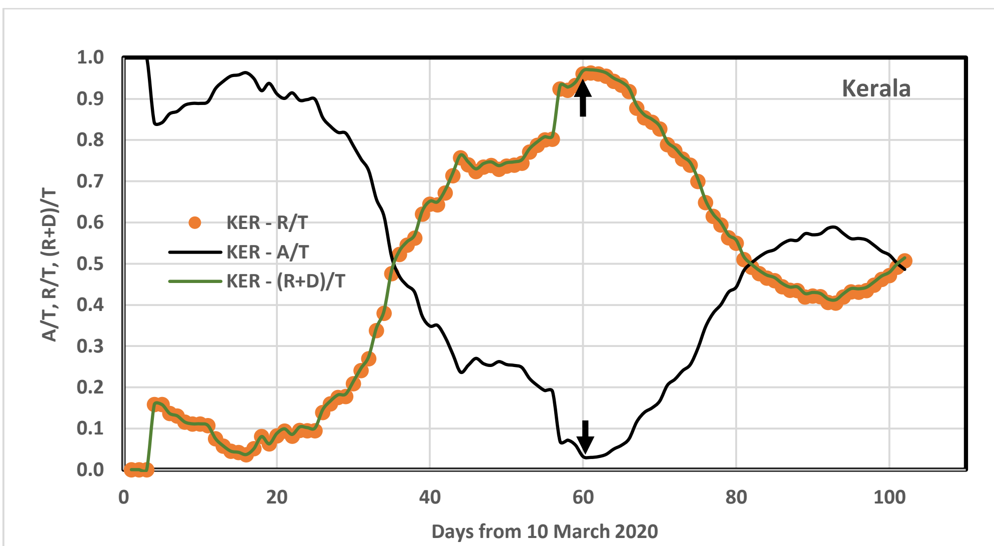

Figure 9: The plot of the ratios with total cases over time from 10 March 2020

from start (5th August 2020) the recoveries had reached 94 % and the cases increased over the course of the next 30 days and the recovery rates have crossed 50 % after 100 days. Since the population was not very high, such changes can be expected.

8. Cases and *D/C* with time

It is instructive to compare the way the cases have developed over time as it describes the strategies that were used to saturate them and ensure that fresh cases are small. Figures 10a, b show the plot of cases *normalized by an estimate of the peak value* to enable a visual examination of the variation of the development of cases. The choices in some cases like Taiwan and Vietnam are justified on the basis of the saturation of cases. The choice of the peak value was made by examining the enhancement of cases on a daily basis over ten days.

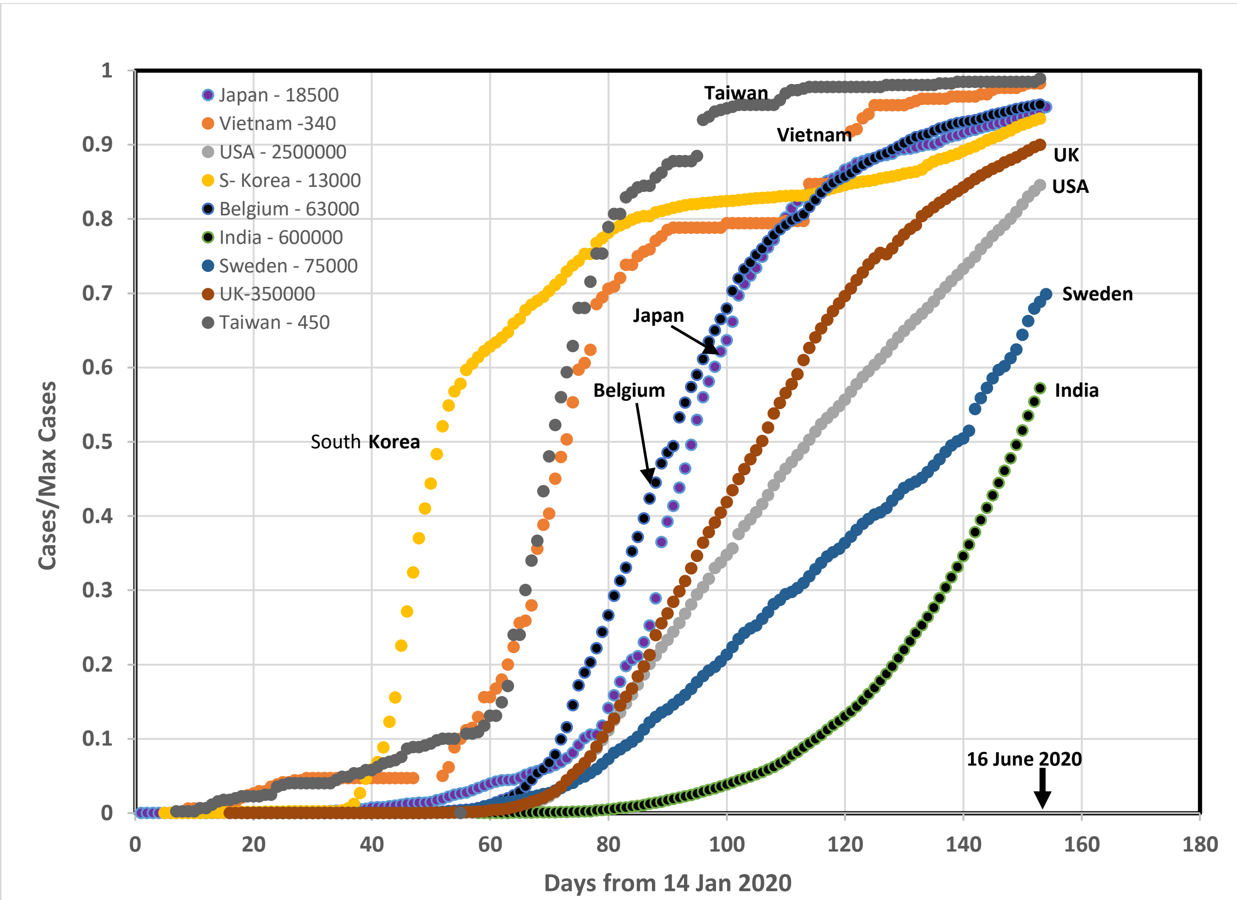

Figure 10a: Plot of cases normalized by an estimate of the maximum with days for some countries

It is not suggested that the variation shown will remain unaltered over time, but the qualitative variation will not be affected and it will be instructive to examine the behavior.

It can be noted from Figure 10a that the way the cases have increased over time is very different in different countries. The cases in Taiwan increased and reached an early saturation in 70 days (middle of May) compared to most other countries. This has been recognized and considered admirable because this small country very close to China with lot of travel between them [20] could have had issues of the disease over a time (The President of Taiwan, Ms. Tsai Ing Wen, incidentally is also a distinguished academic). Many early stringent actions of testing, isolation and hospitalization were initiated by also curbing international travel into the country. Vietnam also handled it similarly even though it took slightly longer to get to saturation. South Korea had early rise of infections and acted with speed. It was able to bend the curve in about a fortnight. However, the cause for worry remains with the growth rate of infections not coming down significantly. In comparison with South Korea, UK does not appear very different (in terms of slope of the curve) and the number of cases is 25 times larger. Belgium had large tumultuous time during the disease and Sweden that had no lockdown during this period appears to show significant slope and may take very much longer to reach saturation. The saturation of cases for USA is still long way off with the saturation value for the cases upwards of 3.5 million. In the case of India, the slope is the largest for the countries whose data are set out in Figure 10a, and the number of cases may reach a million before saturation is reached. Many other countries from Europe show a behavior that is broadly similar as can be seen in Figure 10b. The smaller countries like Slovakia and Slovenia show very small number of limiting cases compared to larger countries like Spain and France. And, they seem to have reached saturation unlike larger countries.

An interesting question that Governments are faced with would be: When can the lockdown and other measures be relaxed for economy to function and people to exercise freedom of visiting restaurants and shops. The conflict between safety in lockdown and allowing freedom for societal functioning is not easy to resolve for most Governments. One guidance is what can be obtained from the experience of countries who have ventured making the decision to open up. Some countries like Vietnam, Taiwan have allowed freedom even for travel from most countries except some. European countries have issued guidelines for most countries [21] between the middle and end of June 2020 (after 180 to 200 days from the start of the pandemic in the respective countries). What was therefore thought was to set out the data of the slope of the cases/million curve as a function of the current cases/million. The inverse of this slope gives the estimate of the number of days required to reach "infinity", the state of no change. Figure 11a shows the plot of change of cases/day taken over the previous ten days as a function of the cases as on 16 June 2020 for 68 countries.

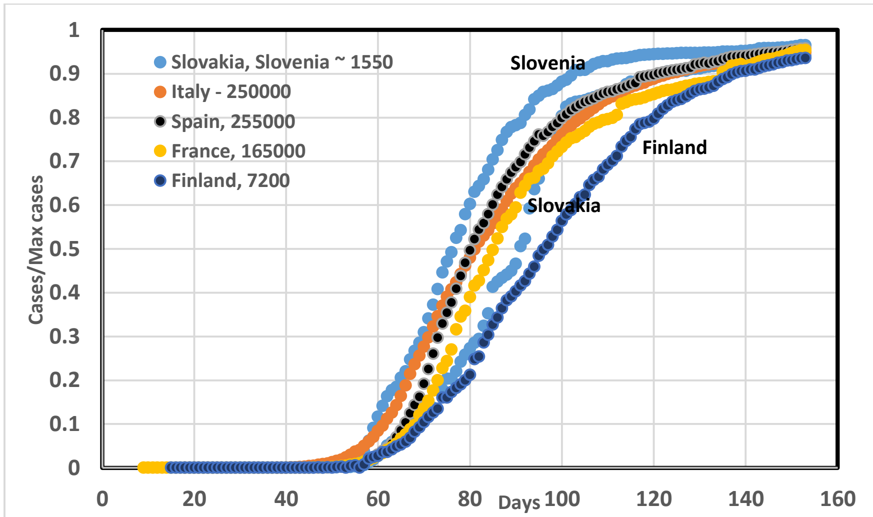

Figure 10b: Cases/Max cases with days for several European countries

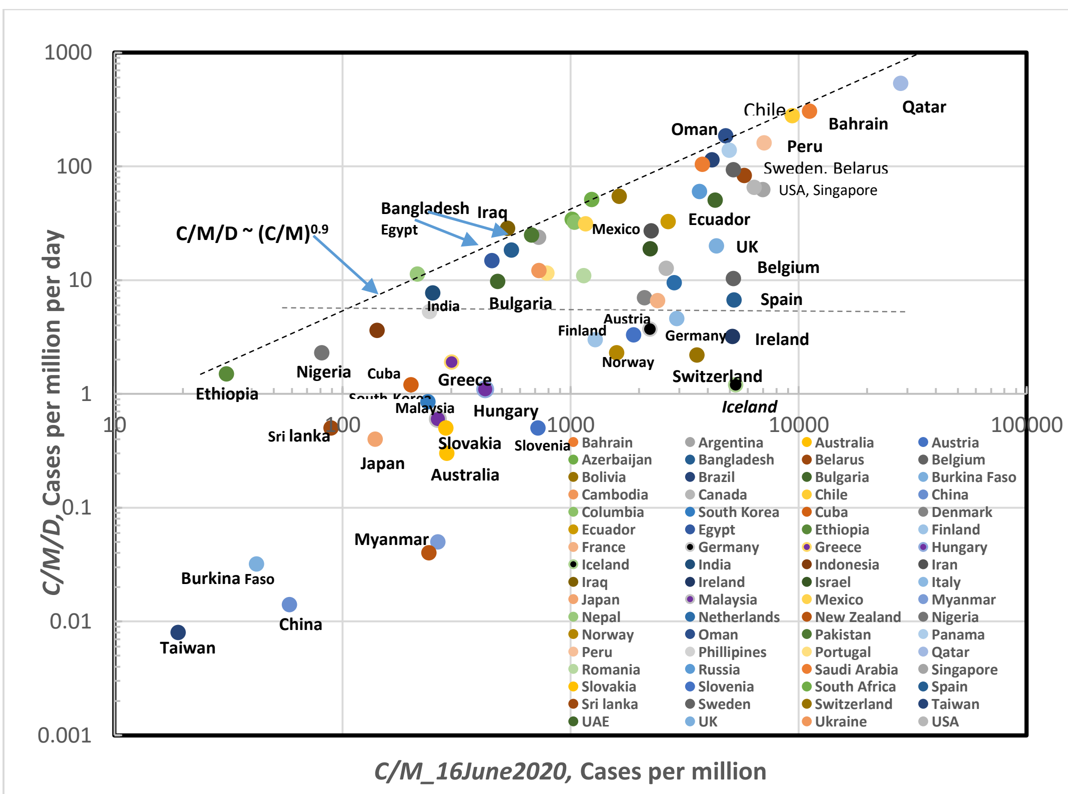

Figure 11a: Cases/million per day on the preceding days with *C/M*

The behavior of the countries in the upper region is correlated by a simple expression shown there; perhaps it does not have any significance. It can be noticed that there are several countries whose case growth rate is less than 0.1 per million per day – Taiwan, China, Burkina Faso, New Zealand and Myanmar which can easily open up without concern of cases going up, for, if it were to happen, it will be taken care by the medical support systems. On the other extreme, those countries in the upper corner – Qatar, Bahrain, Oman, Saudi Arabia, Chile, Peru, Sweden, USA must indeed be careful because in these countries the cases can increase very significantly and D/M is not small in several of these countries. The medical care systems can get overloaded as it has happened and is happening in several pockets in some countries. The rationale for USA opening up is more political than technical. European countries have opened up various activities with each country with its own step-by-step scheme as outlined in the latest Euro-news [21]. This of course can also change over time after experience of the relaxations. For instance, South Korea opened itself up and having found rise in cases, reversed the decision in a day.

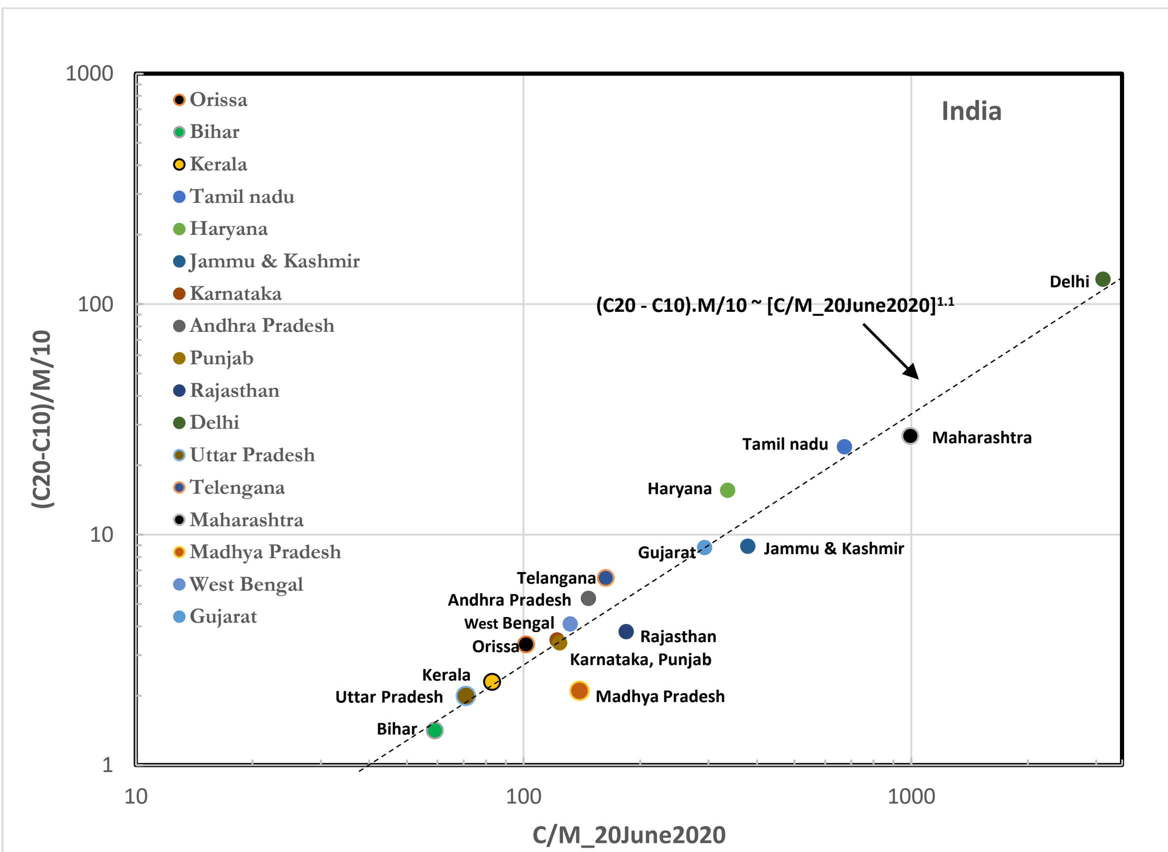

Figure 11b: Cases/million per day on the preceding days with C/M for India

The situation in India using an analysis similar to above is set out in Figure 11b for several states where the pandemic is currently raging. It is useful to know that the very large states, Uttar Pradesh and Bihar have a low growth rate of the cases. The worst affected states are Delhi (union territory), Maharashtra, Tamil nadu on the question of removing lockdown and freedom of travel.

Despite the relatively low growth rates in the states of Uttar Pradesh, Bihar, Orissa and Kerala, there is much apprehension of increase of cases. Even so, most of the country is in semi-lockdown mode, with a large number of local decisions that keep getting changed with time depending the developing situation.

The way the deaths per case (D/C) has varied over time in different countries provides insight into the way the disease was handled over time. Figure 12a shows the variation of D/C for many European countries. It can be seen that the build-up has a relatively "smooth" variation over time.

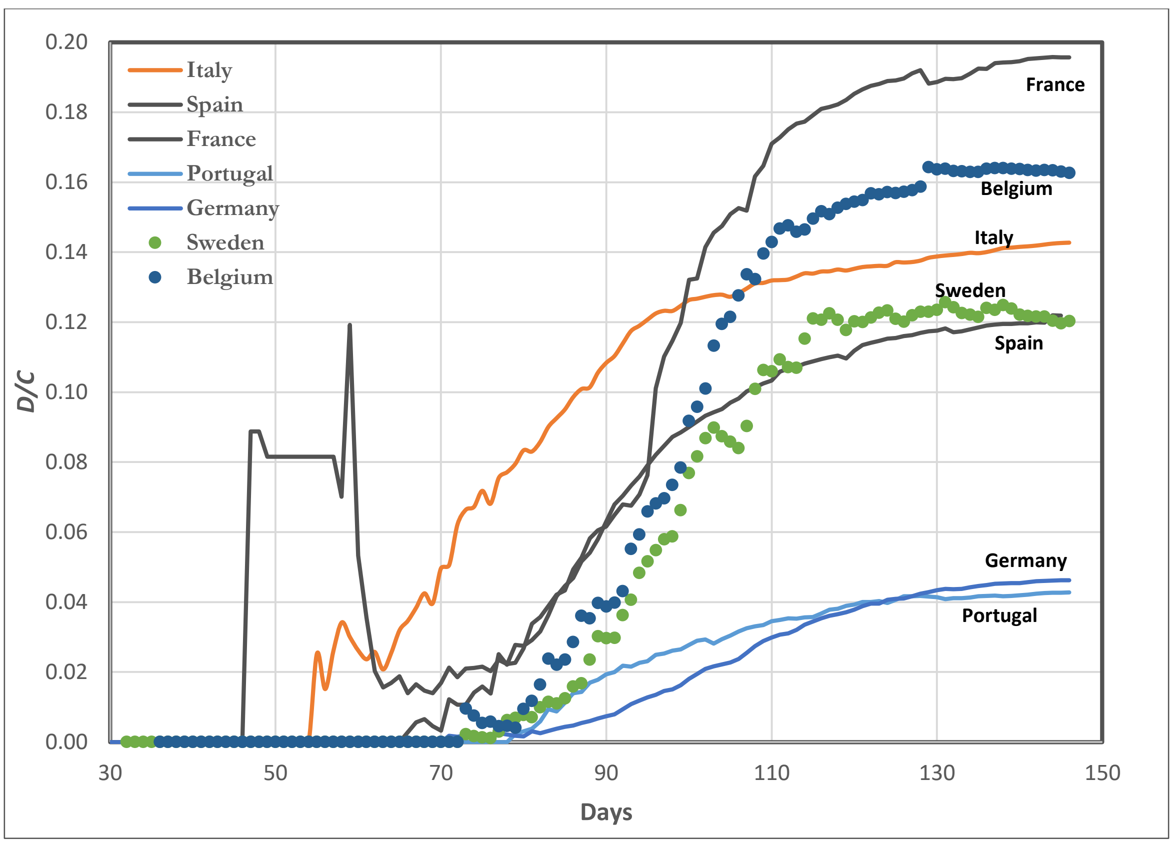

Figure 12a: Variation of deaths-to-case ratio over time for several European countries

Much has been written about Germany that exercised various controls and support systems to limit the death-to-case ratio. Portugal, a relatively small country and does not enjoy the economy or resources of its neighbors has handled the disease to contain the D/C well. It has been indicated that it watched the progress of the pandemic in the neighboring countries and was better prepared to handle the disease.

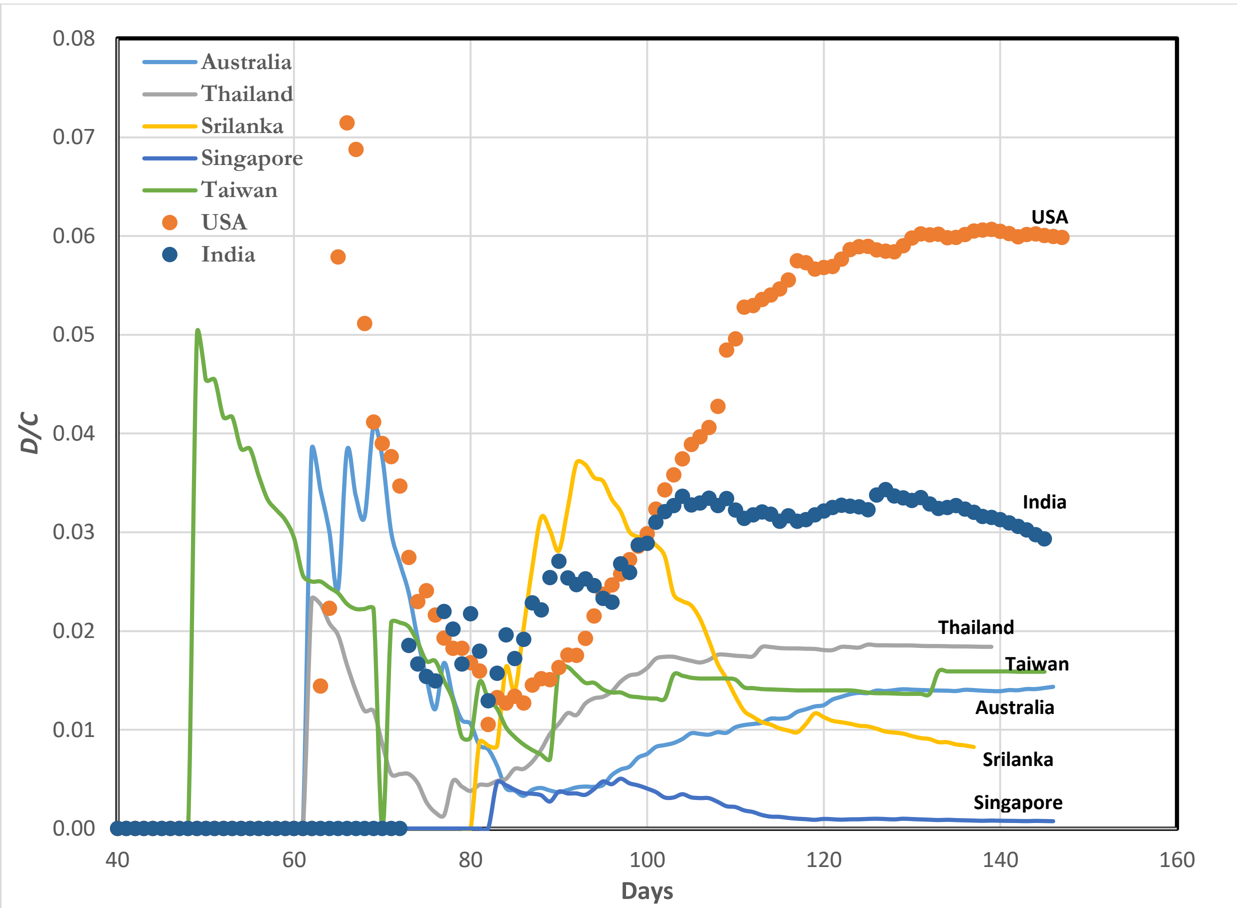

Figure 12b: The plot of D/C with time for several countries.

Figure 12b shows a similar plot for countries that have a different class of variation of D/C. It can be noted that several of these countries have had a sharp rise and then a faster decay (than in the case of European countries) with Singapore showing the smallest of the D/C value – 0.004. Srilanka also has a decreasing death-to-case ratio. India too has a decreasing trend.

USA had an early behavior that is very similar to Australia and Singapore, but there has been a steady rise afterwards. D/C has a reached a steady value (~0.06). What this means is that as the infections keep rising so will deaths increase at this rate.

9. Concluding Remarks

This article has been concerned with an analysis of the issues that have arisen with regard to coronavirus over the last six months all over the World. The analysis is based on the data from World in coronavirus source (https://ourworldindata.org/coronavirus) and the Indian data source (https://coronaindia.github.io/#dashboardSection). The data in tables and figures have different dates principally because during the study some earlier data could not be updated because such updates were unavailable mostly for states within countries. But all the Tables and figures have the dates indicated therein.

a. During the period when the disease was spreading, many bits of advice have been given towards self-protection. One of these that concerns the use of mask has got investigated extensively. While most of them have studied sneezing and coughing as the sources of water droplet borne virus, it is argued here that even normal breathing can create a concentration of virus bearing fine vapor or droplets that can stay in the atmosphere for reasonable times and be carried around due to small air currents caused by the movement of people and inhalation of the air in this environment can bring in the infection. That it may not create any further problem or otherwise depends on the health status of the concerned individual (his immunity). This route is being indicated as the softest and "unobserved" route of infection particularly because there have been many reported asymptomatic cases which later led to hospitalization and the route by which the concerned person(s) received the infection has not been identified in India, Italy and elsewhere. The suggestion therefore is that voluntary isolation most of the time, social distancing by at least a few meters when there is need to meet with others coupled with masks would be an appropriate procedure for safety from coronavirus infection.

b. The question of whether lockdown is needed to deal with infections has been debated and various countries have taken different actions. It has become overwhelmingly clear that imposing lockdown reduced the spread of the disease and allowed better handling of those who got infected. Amongst countries that ignored lockdown and thought differently are

Sweden, Belarus, Brazil, Ecuador and Mexico. The deaths due to the disease have been very large. Countries that sensitively handled the lockdown like Taiwan, Vietnam, Singapore, South Korea, Australia, New Zealand and several countries in Africa have had very small number of deaths due to the disease. India, a large democratic country also handled the lockdown sensitively. USA and UK did not handle it well and the infections and deaths have been large.

c. The question of how many infections per million (*C/M*) of any country is related to an effective social distancing parameter, this parameter being related to the principal city (cities) where the pandemic has grown. The result obtained from a plot of observed C/M with a social distancing parameter (SDP) is that the maximum number of infections is about 9000 per million of the population).

d. The observation that many countries near equator have low deaths per million population (*D/M*) due to coronavirus is connected to their higher level of immunity derived from having experienced tropical diseases like Malaria, Dengue, Chikungunya and others. A plot of *D/M* with latitude shows a three order rise in deaths with latitude changing from 0 to about 64°. A simple correlation is obtained as $\boldsymbol{D/M = A_0 \exp (C_0\ \mathrm{Lat},°/90°)}$ where C_0 = 8.4 and A_0 is 4.4 for one set of countries and 1 for another set of countries. Deviations from this variation with higher values for some countries (Ecuador, Brazil and Mexico) and lower values for some others (Iceland, Belarus, Taiwan, South Korea and a few others) are explained as related to effective actions in the early stages being ignored or taken seriously.

e. A plot of D/M with C/M shows a relationship which appears like a scaling law: $\boldsymbol{D/M \sim A\,(C/M)^{1.5}}$ with **A** ~ 0.0014 to 0.002. The exponent 1.5 is used to explain an observed behavior that when a city centre has an increased number of infections, the death rate also increases very significantly due to viral overload in the environment.

f. The behavior of the coronavirus spread and associated deaths in various states in India follows the general pattern observed in other countries. Some states like Maharashtra, Delhi, Gujarat and Tamil nadu have experienced large number of cases more particularly in the metropolitan cities – Mumbai, New Delhi, Ahmadabad and Chennai. The death per million in India is low and comparable to several other tropical countries. Within India, Orissa, Bihar and Kerala have very low deaths per million

g. One of the important questions as to when to release the lockdown and how much has been of concern to every country. Guidance from the rate of increase of infections in relationship with the current status of the cases suggests that those countries with growth rates of less than about 3 (cases/million/day) is the border line below which the risk involved in opening up the economy is small. Many countries in Europe with the growth rates larger than this have opened up or opening up in stages. Experience over the next several weeks will suggest whether to go back to partial lockdown or allow greater freedom.

h. Finally, it is true that herd immunity must get created. But an unbridled approach leads to a heavy overload on the medical care systems and catastrophe in terms of death count. A calibrated approach to implementing lockdown and release from it is the only correct approach. Such an approach requires sensitive handling of all imperatives.

Final observation: Those of the readers interested in the data may please send an e-mail and the data used in the above work in excel format will be sent for any further study.

10. References.

1. Milan Batista, Estimation of the final size of the coronavirus epidemic by the SIR model, February 2020 https://www.researchgate.net/publication/339311383**;** see also https://www.researchgate.net/publication/339912313_Forecasting_of_final_COVID-19_epidemic_size_200504
2. Jianxi Luo, When will COVID-19 end? Data driven prediction, http://www.sutd.edu.sg**,** 28 April 2020
3. Rajesh Singh and R Adhikari, Age structured impact of social distancing on the COVID-19 epidemic in India [posted on 26 March 2020: https://github.com/rajeshrinet/pyross**]**
4. Tang, J. W., Nicolle, A.D.G., Pantelic, J., Jiang, M., Sekhr, C., Cheong, D. K. W., Tham, K. W., Qualitative real-time schlieren and shadowgraph imaging of human exhaled airflows: an aid to aerosol infection control, PloS ONE, v. 6, 2011; also see: https://video.search.yahoo.com/search/video?p=videos+on+shadowgraph+of+breathing#id=1&vid=0cdbee6fa15ac879a7e1a21357ff619d&action=click
5. Bourouiba, L., Dehandschoewerker, E., and Bush, J. W. M., Violent expiratory events: on coughing and sneezing, J. Fluid Mech, v. 745, pp. 537-563, 2014
6. Scharfman, B.E., Techet, A. H., Bush, J. W. M., and Bourouiba, L., Visualization of sneeze ejecta: steps of fluid fragmentation leading to respiratory droplets, Exp. Fluids, 57:24, 2016
7. Chao, CY H., Wan, M. P., Morawska, L., Johnson, G. R., Ristovski, et al., Characterization of expiration air jets and drop size distributions immediately at the mouth opening, Aerosol Science, 40, pp122 – 133, 2009
8. Dbouk, T and Drikakis, D., On coughing and airborne droplet transmission to humans, Phys. Fluids, 32, 2020
9. Wei, W E, Li, Z., Chiew, C. J., Yong, S. E., Toh, M. P., and Lee, V. J., Pre-asymptomatic transmission of SARS Cov-2, Singapore, Jan 23 – March 26, 2020. DOI: http://dx.doi.org/10.15585/mmwr.mm6914e1

10. TSI manual - https://www.tsi.com/getmedia/9eb5a07b-796b-44cd-9ee7-4adcd2823e90/SeedParticles_2980461?ext=.pdf
11. Liu, Y., Ning, Z., Chen, Y., Guo, M., Liu, Y., Gali, N. K, Sun, L., Duan, Y., Cai, J., Westerdahl, D., Liu, X., Xu, K., and Ho, K-f., Aerodynamic analysis of SARS=CoV-2 in two Wuhan hospitals, Nature, pp. 1-2, 2020
12. Lewis, T., How coronavirus spreads through the air: what we know so far, https://www.scientificamerican.com/article/how-coronavirus-spreads-through-the-air-what-we-know-so-far1/
13. https://www.theguardian.com/world/2020/may/05/why-has-eastern-europe-suffered-less-from-coronavirus-than-the-west, May 05, 2020
14. Praveen, S., https://www.downtoearth.org.in/news/economy/what-s-happening-in-belarus-the-only-european-country-to-not-adopt-social-distancing-71040; also see https://www.cnbc.com/2020/03/31/coronavirus-belarus-urges-citizens-to-drink-vodka-visit-saunas.html
15. Anton Troianovski, https://www.nytimes.com/2020/05/14/world/europe/coronavirus-russia-doctors-hospitals.html
16. Rafaela Lindeberg https://www.bloombergquint.com/politics/sweden-s-pm-hits-back-at-criticism-over-outlier-covid-strategy; see also https://www.bloomberg.com/news/articles/2020-06-03/man-behind-sweden-s-virus-strategy-says-he-got-some-things-wrong
17. Cnaan Liphshisz, https://www.jta.org/2020/03/20/global/antwerp-jewish-community-braces-for-85-infection-rate-and-hundreds-of-deaths-from-coronavirus; see also https://www.jta.org/2020/03/31/global/jews-are-vastly-overrepresented-in-coronavirus-deaths-in-the-uk-here-are-some-theories-why; see also https://www.jta.org/2020/05/05/global/how-the-coronavirus-is-hitting-jewish-communities-worldwide
18. Janhavi Apte, https://www.youngbhartiya.com/article/what-led-to-ecuador-s-unmanageable-covid-19-crisis; see also https://www.youngbhartiya.com/article/un-secretary-general-says-developed-countries-can-learn-from-africa-s-covid-19-response
19. James Pasley, https://www.insider.com/photo-mexico-coronavirus-move-to-phase-three-2020-4#its-healthcare-system-is-also-weak-according-to-the-los-angeles-times-since-becoming-president-andres-manuel-lpez-obrador-cut-healthcare-funding-and-changed-how-hospitals-get-medical-supplies-now-mexico-has-50-as-many-hospital-beds-per-capita-as-the-us-and-a-quarter-as-many-nurses-3
20. James B. Meigs, https://nypost.com/2020/04/25/taiwan-was-the-only-nation-with-a-correct-coronavirus-response/; also see https://www.cbc.ca/news/health/taiwan-covid-19-canada-1.5502194
21. Euronews, https://www.euronews.com/2020/06/15/which-european-countries-have-opened-their-borders-ahead-of-the-summer-holiday-season