On Classifying the Pandemic: A Potential Contribution of Cluster Analysis for Policymakers

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ABSTRACT

Purpose: The recent pandemic (COVID-19) is considered as the most crucial health misfortune of this century globally. It became the greatest challenge after the second World War. Countries fear the imminent economic and financial crisis leading to recession due to this outbreak. There are countries with no cases reported, clusters of cases, and community transmission with various social measures and varying public health measures depending on the local evolution of virus. This study analyzes the countries based on their common characteristics and COVID-19 spread leading to better policy making

Methodology: To achieve the objective and understand the internal dynamics of the spread, this study employs the kNN clustering technique by using daily data of COVID-19 cases from January 22, 2020 to September 20, 2020.

Findings: Based on the results, four different clusters were identified. These clusters reflect the growth of cases and strategic measures to contain spread. There were 134 countries in the largest cluster while the other 3 clusters had 35,13 and 6 members respectively. The study shows that the governments and the stakeholders including public played a significant role in controlling the spread of COVID-19. The countries which were efficient in devising policies and also implementing them controlled the spread quickly. Therefore, the findings of study deliver important implications for the policymakers.

Originality: The clustering of countries explained in this study will serve the steppingstone for those interested in infectious diseases in general and COVID-19 research in specific.

Implications: Many countries controlled the virus to a larger extent, but it is said that virus has reduced but not ended so it is essential to take great care. The study not only provides substantial evidence and understanding of the pandemic's spread but also proves to be useful for policy makers and other stakeholders.

Keywords: COVID-19, Outbreak, kNN Clustering, Policy.

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1. INTRODUCTION

The novel coronavirus disease (COVID-19) emerged at the end of December 2019 when World Health Organization (WHO) China office received reports about number of pneumonia cases of unknown causes in Wuhan city of China. The awful story of COVID-19 turned more serious as it was declared a pandemic by WHO on March 11, 2020. It was limited to China but then it became a global contagion. Initially referred to as 2019 novel coronavirus (2019-nCoV), it was reported that the virus was caused by severe acute respiratory syndrome coronavirus 2 (SARS-COV2) (Rothan & Byrareddy, 2020) sharing 79.5% of the genetic sequence of SARS and 96.2% homology was same as bat coronavirus (Zhou et al., 2020). By the start of September 2020, 26,964,880 confirmed cases of COVID-19 have been reported including 881,096 deaths across the globe. The epicenter of coronavirus shifted from China to Europe, then to US, and the virus also hit Asian countries recently. When the death toll in Italy surpassed that of China, the lockdown was imposed on the entire country shutting down public places, cinemas, pubs, theatres, and banning weddings and funerals (Aslam, Awan, Khan, Aslam, & Mohmand, 2021). In UK, schools, restaurants, bars and other nonessential stores were closed for nine weeks. Despite unprecedented steps taken by countries to stop the spread of COVID-19, it is reported that most of the developed countries failed in containing the virus. Researchers did their best to help the health agencies and governments through working day and night in making predictions (Arora, Kumar, & Panigrahi, 2020; Awan & Aslam, 2020), checking the sentiments and emotions of the public (Lwin et al., 2020), finding medicines for treatment reducing the effect of the virus (Mitjà & Clotet, 2020) and providing innovative solutions for customers (Alsukaini, Sumra, Khan, & Awan, 2022). One of the major problems during the pandemic times was the spread of fake news regarding pandemic which created panic among people at large (Awan et al., 2022). Similar to COVID-19, fake news are always problematic and reaserch has proved its neagitive effect (Sharif, Awan, & Paracha, 2021). On the other hand, the delay in lockdown in some areas e.g. the UK accompanied by non-serious behavior of the country's leaders in taking precautionary measures led to severe outbreak (Lea, 2020). After lifting complete lockdown, countries are moving towards smart lockdown strategies for controlling its spread. However, the infectious virus has been constantly spreading in developed as well as developing countries. The COVID-19 has largely affected the world in many aspects including economic recession (Awan & Maqsood, 2021; Sharif, Aloui, & Yarovaya, 2020), fragile health systems (Paintsil, 2020) and changes in social behaviors (Aslam, Awan, Syed, Kashif, & Parveen, 2020). Researchers and practitioners need to understand how COVID-19 has spread across different countries and how countries behaved differently. There are obviously some common characteristics and countries can be clustered to analyze their common characteristics which is the aim of current study. The common characteristics if carefully considered can help explore those common reasons that divide this whole world into clusters of countries.

This research helps identify through clustering technique, globally how the spread of virus is formed. It helps to further explore which parts of the world share common characteristics of the spread and also shed light on what common mechanisms were used to contain the virus. The recommendation of the study helps devise the strategies in areas where the spread is more through replicating the well-established successful practices to contain spread of virus.

2. MATERIALS AND METHODS

Data

For clustering analysis, daily data of 188 countries about confirmed cases of Covid-19 from January 22, 2020, till September 20, 2020 was used for the study. The daily information was collected Center for Systems Science and Engineering (CSSE) at John Hopkins University (JHU) Coronavirus Resource Center.

Methodology

A cluster refers to a collection of objects having similarities with each other, and components of each cluster differ from those of others (ZhAI, Yu, Gao, Yu, & Ding, 2014). Cluster analysis is considered to have strong implications as objects are grouped through different data mining techniques (Jie et al., 2020). Clustering can be applied through different algorithms based on the mode of study and nature of objects to be clustered (Kriegel, Kröger, Sander, & Zimek, 2011). The application of different clustering algorithms based on model (Fraley & Raftery, 1998), density (Rodriguez & Laio, 2014), and partitioning (Ragot, Gillet, & Becker, 2002) are noted in the literature abundantly. It is suggested that K-means clustering algorithm, a commonly used method, has fast convergence and is simple in nature. The traditional K-means algorithm may have problems in determining center point of cluster data (Kanungo et al., 2002). To resolve this problem, kd-tree data structure which is easy to implement was developed. Graph-based clustering is commonly used across different fields in which clusters are modeled as a graph (Novák, Neumann, & Macas, 2010). The clustering graph has nodes representing a particular object of the data set. Further edges represent link between similar nodes while each edge has certain cost which is related to distance between two nodes (Trajcevski, Gunopulos, Aggarwal, & Reddy, 2013).

Multiple studies have been conducted on use of data clustering in medical field, e.g. clustering for the assessment of diabetes physician groups (Greenfield, Kaplan, Kahn, Ninomiya, & Griffith, 2002), obtaining biological information from brain genes (Suo, Liu, Jia, & Yu, 2018) etc. which also became the reason to conduct this study. As far as the field of infectious diseases is concerned, the use of clustering has been very effective as it categorizes different groups of patients and further aid physicians to understand the nature of disease. The current pandemic has attracted attention of researchers to study clusters of coronavirus patients and understand its mode of transmission.

Previous investigation of clustering on COVID-19 was either done within a narrow geographical area or with limited discussion on clustered countries. Hence, there is a need to investigate how clusters of COVID-19 differ across the world. This study aims to explore features of clustered countries of COVID-19 across the world and fills the gap in the literature as none of the studies to date explored the global clustering. The significance lies in identifying infectious clusters which can be isolated from healthy individuals for containing spread of virus. Countries in each cluster share patterns of spreading and containment which is highly significant for containing the virus. Countries where virus has been spreading fast can learn from countries which have contained it with their own unique strategies. The kNN clustering technique is used which follows this section.

MST-kNN Algorithm

For clustering analysis, MST-kNN algorithm is used. kNN clustering is preferred because of multiple benefits. For instance, the outcomes of KNN clustering are easy to justify and it is convenient to implement (Karegowda, Jayaram, & Manjunath, 2012) however, it has higher computation cost as it requires to compute distance of each case and there is no rule for determination of value of K parameter (Zhu, Chen, Hirdes, & Stolee, 2007).

The MST-kNN clustering algorithm is based on the juncture (intersection) of the ends of two nearness (proximity) graphs: MST and kNN. The intersection procedure preserves only those ends among two nodes that are mutual in both proximity graphs. After first application of algorithm, graph with connected components (cc) is generated. MST-kNN algorithm is recursively applied in all components till the number of cc obtained becomes one.

The change in confirmed cases $D_i\ (t)$ between two days are calculated as

$$D_i\ (t) = c_i(t) - c_i(t - \Delta t)$$

Where the confirmed cases on day *t* is represented by $c_i(t)$ and the time interval is Δt.

The average confirmed cases $E(C_i)$ of any country$_i$ over a period of time is defined as:

$$E(C_i) = \frac{1}{n}\sum_{t=1}^{n} C_i(t)$$

And the Pearson's coefficient is calculated by using the 'Equation 3' given below:

$$\rho_{ij} = \sqrt{\frac{E(C_iC_j) - E(C_i)E(C_j)}{\sqrt{Var(C_i)Var(C_j)}}}$$

Where, C_i *and* C_j are changes in confirmed cases of country *i* and *j*.

The algorithm entails a distance matrix *d* as input encompassing the distance between *n* objects.

To calculate the weight in the network, the coefficient of correlation to capture the distance among all pairs of indices in the correlation matrix was altered, as proposed by (Mantegna, 1999; Mantegna & Stanley, 1999).

The transformation function for the distance can be expressed as:

$$d_{ij} = \sqrt{2(1 - \rho_{ij})}$$

By using 'Equation 4', a distance matrix of (188×188) for all countries was obtained. Then, the next steps are performed, i.e.

a. computes complete graph (CG) representing data, with one *node* for each object, one *edge* per pair of objects, and *cost* of edge equaling distance between objects obtained from distance matrix $d_{i,j}$.
b. compute MST graph using Prim's algorithm (Prim, 1957) and using complete graph as input
c. compute kNN graph through complete graph as input and determining value of *k* according to $k = min\{\lfloor \ln(n) \rfloor; \min k \mid kNN\ graph\ is\ connected\}$
d. perform intersection of edges of both MST and kNN graphs that will produce a graph with cc≥1 connected components
e. evaluate numbers cc in graph produced. If cc=1, algorithm stops. If cc>1, steps 1-4 are repeatedly applied in each cc of graph and
f. when the algorithm stops in above step in any recursion, union of the graphs produced by the application of the MST-kNN algorithm in each recursion is performed.

For the purpose of analysis, the R packages "*mstknnclust*" and "*igraph*" were used in this study.

3. RESULTS

Through KNN clustering technique, four clusters were identified in total. The cluster number and size are documented in Table 1. The largest cluster consists of 134 countries followed by 35,13 and 6 members in 2nd, 3rd and 4th cluster respectively. Through kNN clustering technique, a total of four clusters were identified. The cluster number and size of each cluster are documented in Table 1. The largest cluster consists of 134 countries followed by 35, 13 and 6 members in 2nd, 3rd and 4th cluster respectively.

Table 1. Cluster Number and Sizes

Cluster Number	Clusters Size
1	134
2	35
3	13
4	6

The detailed membership of each cluster is presented in Figure 1 and the detailed list of membership is given in Appendix A. Each cluster is represented with a unique color in Figure 1. The members of Cluster 1 can be identified in the brown, whereas cluster 2 is represented by light blue color comprising 35 countries. The third cluster consists of 13 countries and represented with green color whereas fourth cluster, the smallest with 6 countries is represented with yellow color.

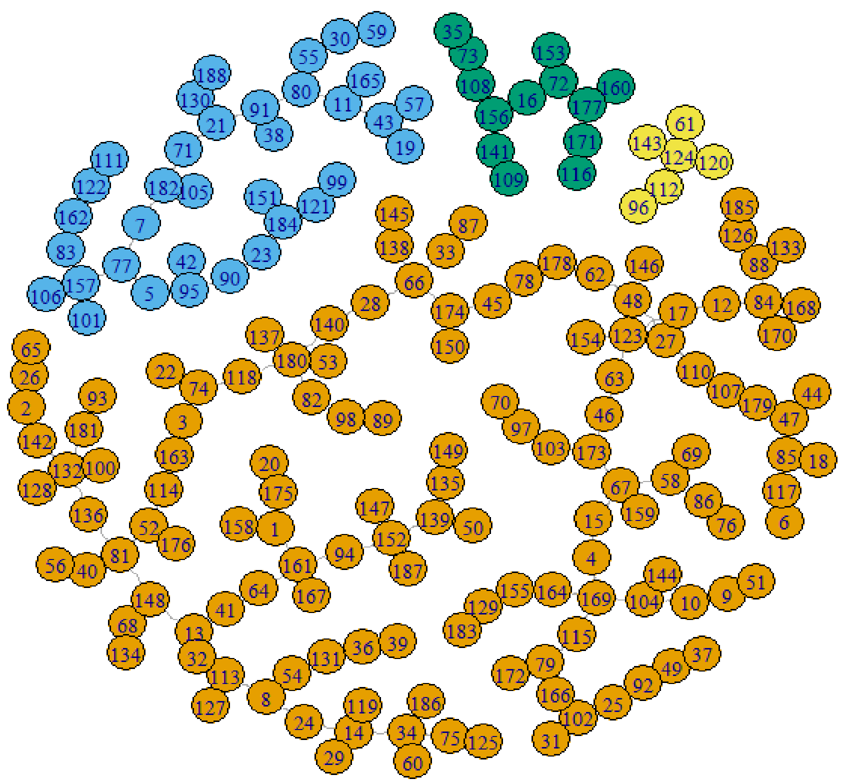

Figure 1. Clusters of COVID-19 Confirmed cases (22-Jan-2020 to 20-Sep-2020).

The smallest cluster (yellow color), named as cluster four comprises of countries having least COVID-19 cases or who retained to normal life after controlling the virus completely. New Zealand has only 1,815 cases with 25 deaths by September 20, 2020. In March 2020, when there were only 100 cases of COVID-19 in New Zealand, the government decided to impose strict lockdown and closure of borders. There was clear communication of SOPs by government's platforms and higher testing also helped New Zealand to contain the virus (Baker, Kvalsvig, Verrall, & Wellington, 2020). In the same vein, Fiji also contained the virus through lockdown and use of proper SOPs as it reported only 32 cases with two deaths by September 20, 2020 (Dahal

& Wagle, 2020). The unique geographical advantage and strict measures by government in containing virus made countries to fall in this cluster. The other countries falling in this cluster include Laos, Mauritius, MS Zaandam, and Saint Kitts and Nevis. They supposedly had similar strategies which made them fall in the same region. Also, less imported cases in these regions as the air and land travel was prohibited made them contain the virus effectively. Like the actions taken by Lao Government, the early response of Mauritius towards the pandemic started with stringent lockdown which resulted in reduction in new cases. From January, screening of people started at airports by the government of Mauritius (Chan Sun & Lan Cheong Wah, 2020). The Prime Minister of Mauritius established communication cell in his office to regularly monitor the cases and address public. Further, the government also collaborated with all stakeholders including ministries of commerce and health to deal with containment of virus (Farseev, Chu-Farseeva, Yang, & Loo, 2020). The well-established healthcare system of Mauritius aided in containing the virus in the early weeks of pandemic (Gilbert et al., 2020; Sun & Wah, 2020). The similarities between countries include in this cluster reveal that early response of government was highly effective in containing the virus. Specifically, the active communication of the government officials and engagement with communities to create awareness among people helped in containing virus. A coordinated pattern among different sectors such as commerce, security and healthcare sector can be seen among New Zeeland, Fiji and Mauritius and other countries in this cluster which is termed as a reason they fall in the same cluster.

The third cluster (green color) comprises of 13 countries, which comparatively tackled the pandemic well as compared to the first and second cluster where devastated loss was noticed. Sri Lanka, an island with no land borders took early warnings of WHO for implementing strict lockdown of two months through military assistance (Wickramaarachchi & Perera, 2020). The state funded health care system of Sri Lanka is best equipped to deal with pandemic (Bhutta, Basnyat, Saha, & Laxminarayan, 2020). By September 20, 2020, Sri Lanka reported 3,299 confirmed cases and only 13 deaths, which was only possible due to the timely decision of lockdown as compared to the first world countries like US and UK. However, easing restrictions resulted in hype of COVID-19 cases after which Sri Lanka closed schools again and halted reopening of boarders (Weerasinghe, 2020). With excellent health care system and early measures to quarantine short- and long-term travelers, Singapore has been comparatively successful in maintaining fatalities low, but still has higher infection rate in foreign worker dormitories (Woo, 2020). A 14-day quarantine policy for visitors, submission of travel history details and denying short-term visitors helped Singapore in tracing and containing COVID-19 (Ng et al., 2020). The same pattern was followed by UAE which has world class health care system in tackling the virus. UAE took early measures to impose lockdown and shut borders to control the spread (Ehtesham, Almas, Akbar, Niaz, & Zia, 2020). Besides this, deployment of technology through virtual doctors and use of robots for sanitization aided in containing virus in the country (Nasajpour et al., 2020). Similar patterns of preventive measures were noted among other countries in this cluster.

The second cluster (light blue color) comprised 35 countries including India, Iraq and Argentina as prominent victims of COVID-19. Having population of 1.3 billion, India has been facing gravest challenges despite taking initial measures at early stage of outbreak (Patrikar, Poojary, Basannar, Faujdar, & Kunte, 2020). It started with cancelling all visit and business visas, shutting down boarders and imposing lockdown in more than 35 administrative units on 21st March when it had 600 verified COVID-19 cases (Ambikapathy & Krishnamurthy, 2020). Despite these early measures, India could not curtail outbreak with 5,562,663 cases and 88,965 deaths by September 20, 2020 making it among top four worst hit countries (Aslam et al., 2021; Patrikar et al., 2020). It could be because of high population density, improper application of SOPs and poor health care system that India could not benefit from lockdown. Like India, Argentina also took very early measures at the start of pandemic, but its struggle has been the longest in the world (Awan & Aslam, 2020; Gemelli, 2020). On 20th March 2020 when the country had only 50 cases, Argentina imposed total lockdown of economy and public places along with compulsory quarantine and closure of schools. Despite having robust healthcare system, Argentina was not capable to tackle outbreak at large scale (Baron, Aznar, Monterubbianesi, & Martínez-López, 2020). By September 20, 2020, Argentina reported 640,147 cases with more than 13,482 deaths. This resembles India in terms of early lockdown and shutting or borders but lack of public cooperation in following SOPs made both countries big victims of the virus (Yilmazkuday, 2021). Another country which falls in second cluster having India and Argentina's pattern is Iraq. First case was identified in Najaf City on February 24, 2020, which led to curfew, lockdown and closure of borders in main pilgrimage centers of Iraq (Mikhael & Al-Jumaili, 2020). The religious establishment of country united with the government to contain COVID-19 by closing religious places and Friday sermons (Habib, AlKanan, & Mohammed, 2020). By September 20, 2020, Iraq reported 322,856 cases with more than 8,625 deaths. The reason behind failure of early measures against COVID-19 in Iraq was lack of public compliance to SOPs and poor health care system of a war-torn country. There are 1.3 million Internally Displaced People (IDPs) in Iraq who are most are living in open unhygienic areas without following SOPs (Dempster et al., 2020). In the midst of pandemic, these IDPs are the most vulnerable and they may collapse the already weak healthcare system of the country. What makes India, Argentina and Iraq fall in one cluster is the government's prompt action unlike those of UK and USA, but lack of public compliance and vulnerable heath care system failed in containing the virus. Other countries in this cluster are believed facing similar issues and hence fell in the same cluster.

Main countries included in the first cluster (brown color) are United Kingdom, Turkey, Canada, United States of America, and Japan (McKibbin & Fernando, 2021). Geographically widespread across the globe, these countries share similar pattern. Two main highly affected countries in the cluster are USA and UK which were supposed to be the best prepared countries to deal with this pandemic (Pollock, Roderick, Cheng, & Pankhania, 2020). However, they turned to be the major failures with 7,046,216 deaths in USA and 398,625 deaths in UK. These countries failed to detect and track cases at earlier stage which ultimately led to outbreak (Geldsetzer, 2020). Another similarity between these countries was the national policy in dealing COVID-19 as USA left testing up to states while UK remained in chaos for developing smartphone app to deal with the detection (Welfens, 2020). Unlike USA and UK, the first cluster also contains Canada and Japan who have handled COVID-19 comparatively well. At early stage of COVID-19, there had been daily visitors between USA and Canada which escalated cases in both countries which became a reason of sharing the same cluster, however, the political response to handle COVID-19 was major difference between these two countries (Pennycook, McPhetres, Bago, & Rand, 2020). With population of 37 million, Canada reported 145,415 cases and 9,228 deaths by September 20, 2020. Canada has 2,784.13 per million cases with 229.53 deaths per million whereas USA has higher cases per million i.e., 8,441.99 with 391.04 deaths per million as of September 20, 2020. UK reported 4187.55 cases per million and 650.08 deaths per million in the same period which shows that mortality rate in UK is higher in comparison with Canada and USA (Vaid, Cakan, & Bhandari, 2020). The similarity in infectious rate in these countries and others made them to lie in the same cluster.

4. CONCLUSION

The outbreak of COVID-19 has created a global health emergency causing not only loss of 961,000 innocent lives but has a deep impact on psychological, social, and economic measures of governments. The policymakers have taken heterogeneous actions in different countries across the world on prevention, surveillance, containment, treatment, coordination etc. The world witnessed transmission of virus ranging from no cases to sporadic nature of spread in different countries. The purpose of this study is to find out the inner dynamics of this spread deploying kNN clustering technique. The analysis was performed on daily information of global COVID cases ranging from January 22, 2020, till September 20, 2020. The kNN results showed that world is divided into four clusters.

This study revealed that even the countries with up to the mark health facilities are badly affected by the pandemic, hence not only improving in health systems but some other factors should be considered to refrain from the spread. It is very important to consider testing asymptomatic cases especially the high-risk countries. In countries with ageing population, extensive testing is recommended along with regular monitoring and reporting to the higher authorities. This will help the concerned authorities to get the updated information about the spread, help analyze the clusters and accordingly devise policies to control the pandemic. No doubt that timely communication is critical in these uncertain times and ministries should strictly direct all media houses to play a positive role. They should not spread rumors or fear among people, but they should educate the population at large. The follow up of affected areas regarding the confirmed cases is another important implication of this study. Isolation is a practice when cases are reported but as in many countries second spell of the virus has already started. The follow up of the previous diagnosed cases can play an important role about the spread. The time frames if people are affected by the virus should be clearly monitored, detailed interviews are to be taken and findings should be reported to the concerned authorities. This somehow will help understand the characteristics of spread in the second phase at many locations.

Research Implications

It is seen that many countries controlled the virus to a larger extent (Awan & Maqsood, 2021; Awan & Aslam, 2020; (Sipra, Aslam, Syed, & Awan, 2021), but it is said that virus has reduced but not ended so it is essential to take great care (Khan, Fatima, Ramayah, Awan, & Kayani, 2021). The study not only provides substantial evidence and understanding of the pandemic's spread but also proves to be useful for policy makers and other stakeholders. The study highlights the use of techniques like cluster analysis to identify the spread of COVID-19 and to be carefully considered for developing effective policies. The clustering technique also helps in providing an analysis for devising preventive measures can be taken to get rid of this deadly virus.

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Appendix A: Clusters and Name of Countries

Cluster	Countries
1	Afghanistan, Albania, Algeria, Andorra, Antigua and Barbuda, Armenia, Australia, Austria, Bahamas, Bahrain, Bangladesh, Barbados, Belgium, Belize, Bhutan, Bosnia an Herzegovina, Brazil, Brunei, Bulgaria, Burkina Faso, Burma, Burundi, Cambodia, Cameroon, Canada, Central African Republic, Chile, China, Comoros, Congo, Brazzaville. Congo Kinshasa, Croatia, Cuba, Cyprus, Czechia, Denmark, Diamond Princess, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, Equatorial Guinea, Estonia, Ethiopia, Finland, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Grenada, Guyana, Haiti, Holy See, Hungary, Iceland, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Korea South, Kosovo, Kuwait, Latvia, Lebanon, Liberia, Liechtenstein, Lithuania, Luxembourg, Malaysia, Malt, Mexico, Moldova, Monaco, Montenegro, Morocco, Mozambique, Netherlands, Nicaragua, Niger, Nigeria, North Macedonia, Norway, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Romania, Rwanda, Saint Lucia, Saint Vincent and the Grenadines, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Sierra Leone, Slovakia, Slovenia, South Sudan, Spain, Sudan, Sweden, Switzerland, Taiwan, Tajikistan, Tanzania, Thailand, Timor Leste, Trinidad and Tobago, Tunisia, Turkey, Uganda, Ukraine, United Kingdom, Uruguay, USA
2	Angola, Argentina, Azerbaijan, Benin, Bolivia, Botswana, Cabo. Verde, Colombia, Costa Rica, Coted Ivoire, El Salvador, Eritrea, Eswatini, Guatemala, Honduras, India, Iraq, Kazakhstan, Kenya, Kyrgyzstan, Lesotho, Libya, Madagascar, Malawi, Mauritania, Namibia, Nepal, Oman, Seychelles, South Africa, Suriname, Syria, Venezuela, West Bank and Gaza, Zimbabwe
3	Belarus, Chad, Guinea, Guinea Bissau, Maldives, Mali, Mongolia, Russia, Singapore, Somalia, Sri Lanka, Togo, United Arab Emirates
4	Fiji, Laos, Mauritius, MS Zaandam, New Zealand, Saint Kitts and Nevis