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Airport risk of importation and exportation of the COVID-19 pandemic

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ABSTRACT

On March 11, 2020, the Director-General of the World Health Organization (WHO) characterized the spread of the coronavirus disease, COVID-19, as a pandemic on the basis of "alarming levels of spread and severity, and by the alarming levels of inaction." Hence, it is urgent and imperative to evaluate the risk of COVID-19 for as many global locations as possible. This study calculates the relative risk of the importation and exportation of the COVID-19 virus. The study's most important contribution is the calculation of the overall relative risk of the importation and exportation of COVID-19 from every airport in local municipalities around the world, based on global spatial and mapping information. Three scenarios of air travel restriction are considered, and the change in the risk of importation and exportation of COVID-19 is calculated. The relative risk of importation and exportation of COVID-19 clearly shows that not only China, Europe, Middle East, and East Asia, but also the U.S., Australia, and countries in northeast Asia and Latin America are subject to risk. Further, a larger reduction in air travel through airports in a large part of the cumulative incidence area would lead to a gradual decrease in the risk flow. Importantly, the exportation risk of the disease from some airports in China, Iran, and European countries has a higher global spread than the importation risk during the pandemic stage. Therefore, every airport, or government with airports in their jurisdiction, should implement strict countermeasures. It is also indispensable for these countries to undertake countermeasures for COVID-19, such as home quarantine within each country and restricting infected or suspected individuals from flying on airplanes.

1. Introduction

In December 2019, China reported cases of a novel coronavirus-infected pneumonia (COVID-19) in local hospitals in Wuhan, Hubei to the World Health Organization (WHO; Haider et al., 2020; Kandel et al., 2020). On January 30, 2020, the WHO declared the outbreak of COVID-19 as a public health emergency of international concern (Kandel et al., 2020). As of March 3, 2020, a total of 90,869 cases had been confirmed globally in 73 countries (World Health Organization, March 11, 2020).

A limited number of studies already exist on the global risk of the COVID-19 outbreak (Haider et al., 2020). For instance, Wu et al. (2020) calculated the risk of spread through international flights compared to domestic flights. Chinazzi et al. (2020) constructed a global meta-population disease transmission model to project the impact of travel limitations on the national and international spread of COVID-19; the results show that the travel quarantine of Wuhan delayed the overall epidemic progression by 3–5 days in mainland China, with a more marked international effect. Chinazzi et al. (2020) also estimated that a reduction of 90% or more in travel to and from China would extend the period during which the importation of cases is greatly reduced.

Other important studies include Bogoch et al. (2020), Gilbert et al. (2020), Lai et al. (2020), and Haider et al. (2020). Bogoch et al. (2020) analyzed international airline passenger trips from ten Chinese cities: Wuhan, Beijing, Shanghai, Kunming, Chengdu, Xiamen, Haikou, Guangzhou, Shenzhen and Hong Kong, and the results show that Taipei, Bangkok, Tokyo, Seoul and Singapore received the highest number of passengers from the aforementioned cities. However, while valuable, Haider et al. (2020), Wu et al. (2020), Chinazzi et al. (2020), and Bogoch et al. (2020) did not evaluate the cumulative risk of importation of COVID-19 in a country and instead focused on specific points of entry.

Gilbert et al. (2020) and Lai et al. (2020) also used air travel data of departures from airports in the affected provinces in China. Gilbert et al. (2020) focused especially on Africa and estimated the risk of importation into each African country and the results show that Egypt, Algeria, and South Africa were the countries at highest importation risk from

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China; their study also assessed the African countries' capacity to detect and respond to COVID-19. Haider et al. (2020) estimated a risk index of COVID-19 transmission from four major cities of China (Wuhan, Beijing, Shanghai, and Guangzhou) based on the number of travelers to destination countries, weighted by the number of confirmed cases in the departed city reported by the WHO; they ranked each country into four quartiles, based on the risk index. Their results show that countries with a higher risk of COVID-19 transmission outside China are Thailand, Cambodia, Malaysia, Canada, and the U.S.

Furthermore, Pinnoti et al. (2020) analyzed importations of COVID-19 that were successfully isolated as well as those leading to onward transmission, while Sun et al. (2020) assessed trends in the epidemiology of COVID-19 and studied the outbreak progression across China by assessing delays between symptom onset and reporting before and after January 18, 2020 as awareness of the outbreak increased. Pinnoti et al. (2020) found a rapid exponential growth of importations from Hubei, combined with a slower growth from the other areas and predicted a rebound of importations from South East Asia. Sun et al. (2020) collected data for 507 patients with COVID-19 reported between January 13 and January 31, 2020 and found that delays between symptom onset and seeking care at a hospital or clinic were longer in Hubei province than in other provinces in mainland China and internationally across the analyzed period.

Similar studies have also focused on other infectious diseases such as the Zika virus (Rocklöv et al., 2020; Luo et al., 2020), yellow fever (Shearer et al., 2018), the influenza virus (Balcan et al., 2009; Lee et al., 2018), Ebola (Marston et al., 2017), SARS (Drake et al., 2006), and others (Leta et al., 2018). Although the target of each study varies, some have common interests, both in terms of the role of airports or airlines in disease transmission (Hsu and Shih, 2010) and using spatial or mapping information for analysis (Leta et al., 2018).

This study focuses on COVID-19 to calculate the relative risk of importation and exportation of the virus; the methodologies are based on existing studies. Although the existing studies analyzed the importation risk of COVID-19 from China to Europe, Africa, or the other countries, COVID-19 is currently regarded as a global pandemic disease and every city or country has the potential to be not only the epicenter but also a destination of disease spread via the global mobility of people around the world. Therefore, the most important contribution of this study is its assessment of both importation and exportation risk of COVID-19 spread via air travel from/to world airports based on the confirmed disease, air travel, and population data. Moreover, the change in the risk of importation is based on global spatial and mapping information. On March 11, 2020, the Director-General of the WHO (2020) characterized the COVID-19 situation as a pandemic on the basis of "alarming levels of spread and severity, and by the alarming levels of inaction." It is therefore urgent to consider and evaluate the risk of the spread of COVID-19 not only from a specific country such as China or Italy, but also from any other global location.

2. Methodology

The risks of importation and exportation of COVID-19 were calculated based on origin–destination (OD) annual air travel flows (Fig. 1). The annual air travel flows used in this study were estimated based on Huang et al. (2013) model, where passenger flows between 1491 airports on 644,406 unique routes were computed based on a dataset of network characteristics, city population, and local area GDP obtained from a variety of sources [the Airline Origin and Destination Survey, EuroStat, and the Official Aviation Guide (OAG; www.oag.com); Huang et al., 2013].

Fig. 2 shows the data on the population, airport location, and confirmed cases of COVID-19. WorldPop (www.worldpop.org) provided the mosaiced 1 km resolution global database based on Tatem (2017) and Lloyd et al. (2019) methodology. The confirmed case data of COVID-19 include all confirmed cases recorded until March 14, 2020, as provided by the Johns Hopkins Center for Systems Science and Engineering, 2020; these data were also used by Haider et al. (2020), Chinazzi et al. (2020), and Gilbert et al. (2020).

The detailed calculation methodology is based on Gilbert et al. (2020) and is as follows. Risk flow (γ_{od}) from origin to destination is calculated by:

$$\gamma_{od} = \frac{e_o n_o A_{od}}{\sum_j e_j n_j} \tag{1}$$

where n_o is the travel flow from the origin (o), and the cumulative incidence (e_o) is calculated as the total number of confirmed cases per municipality where airports are located, divided by the municipal population. A_{od} is the probability of traveling from origin (o) to destination (d), conditioned on traveling internationally.

The exportation risk from origin (o) is then:

$$R_o = \sum_j \gamma_{od} \tag{2}$$

Similarly, the importation risk to destination (d) from any origin is:

$$R_d = \sum_i \gamma_{od} \tag{3}$$

where both these relative risks are normalized to 1.

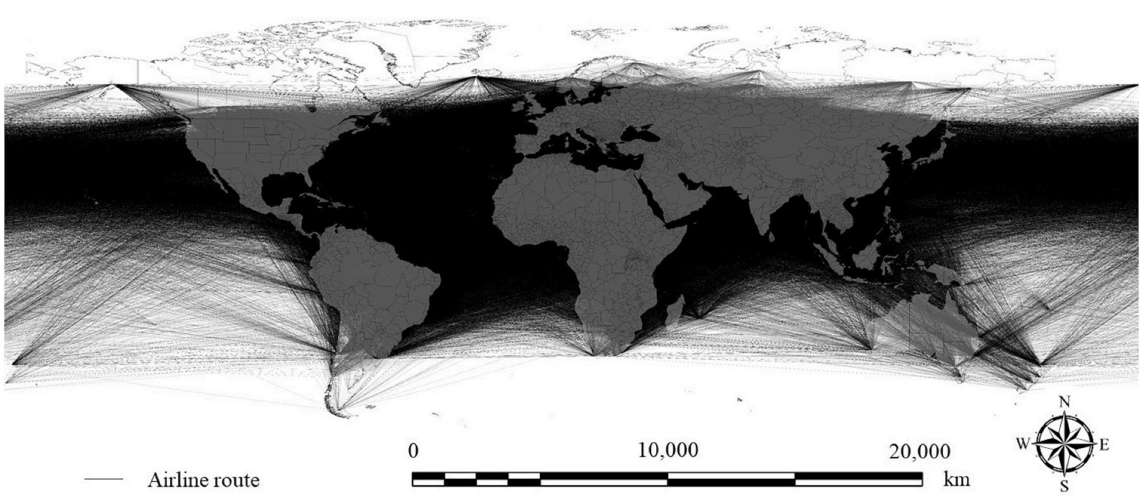

Fig. 1. Annual air travel flows around the world.

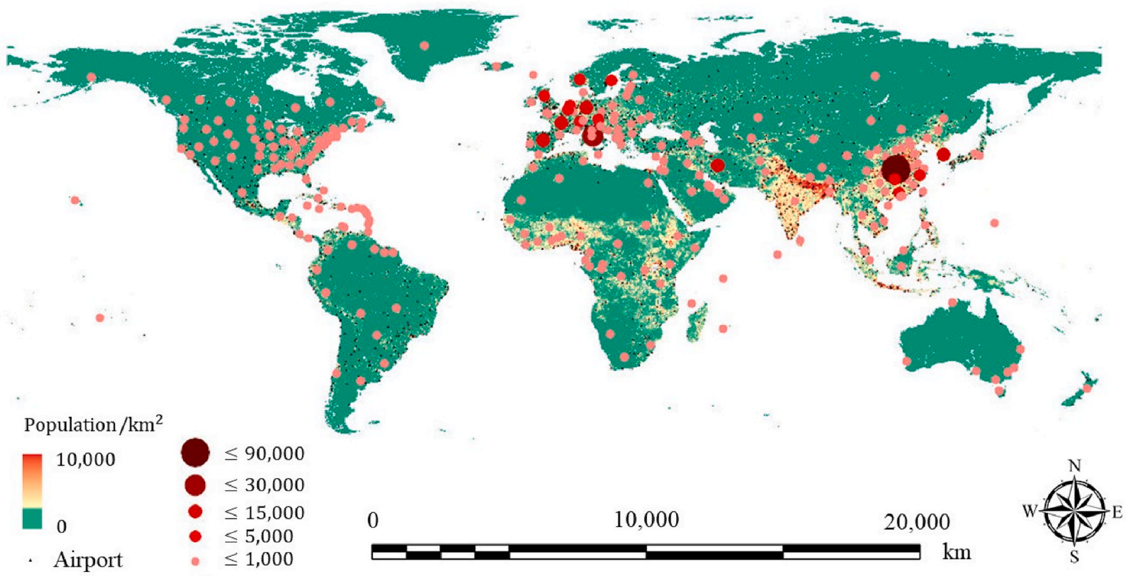

Fig. 2. Population, airport locations, and confirmed global cases of COVID-19 until March 14, 2020.

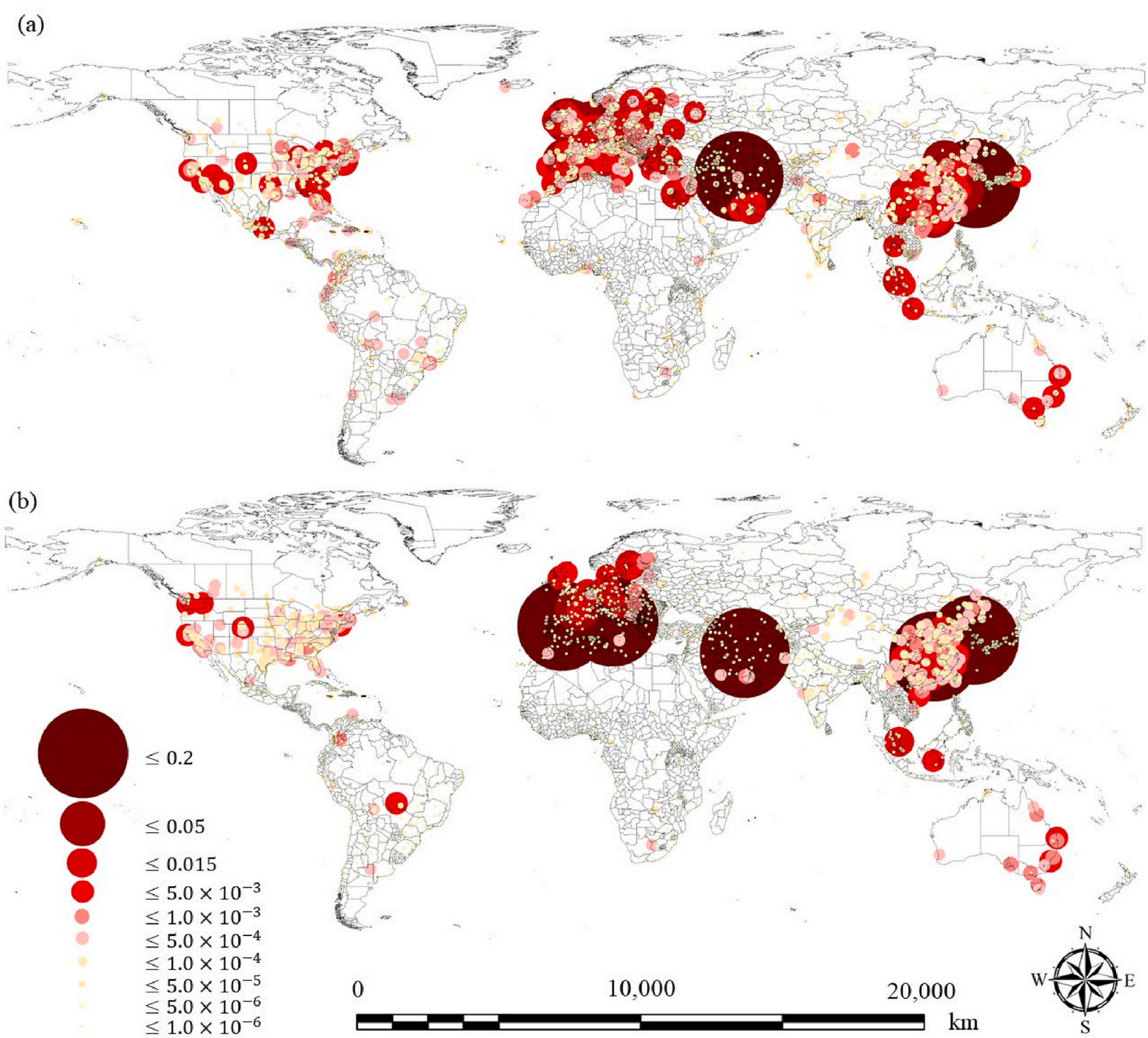

Fig. 3. Relative risk of importation (a) and exportation (b) (Unit: %).

3. Results

Figs. 3–6 show the results of the risk flow and the relative risk of importation and exportation of COVID-19 via airports. Fig. 3 shows the relative risk of importation and exportation of each airport and Fig. 4 shows the summarized values for each country. Fig. 3 shows that some airports, including in China and Iran, have a higher risk of both importation and exportation than other airports, while some airports in Europe, especially Italy, have a higher risk of exportation than of importation. Moreover, the U.S. seems to have more airports with a relative risk of importation than with relative risk of exportation. This means that although the U.S. did not show a high number of cumulative confirmed cases relative to the population on March 14, 2020, it has potential relative risk to import the pandemic disease.

The top five countries with relative risk of importation of COVID-19 shown in Fig. 4 are South Korea, China, U.K., Iran, and Spain, and those with exportation relative risk are Italy, South Korea, China, Iran, and Spain. Fig. 4 also clearly indicates that not only China, Europe, Middle East, and East Asia, but also various other countries such as the U.S., Australia, northeast Asian countries, and Latin America are exposed to risk to some extent.

Figs. 5 and 6 show the risk flow of importation and exportation, or, in other words, the expected number of people infected by COVID-19. Fig. 5 shows the risk flow of importation and exportation of each airport and Fig. 6 shows the summarized values of the risk flow by each country. Fig. 5 indicates that, while airports with the highest risk flow of importation are in East Asia near mainland China where the first case was confirmed, the airports with high exportation risk flow are located not only in mainland China and East Asia, but also in the Middle East and Europe, especially near Italy. This confirms that COVID-19 is a pandemic rather than an epidemic disease. The top five countries having the risk flow of importation and exportation of COVID-19 shown in Fig. 6 are the same as the top five countries of relative risk. Although the risk flows of each airport in the U.S. are not high, as shown in Fig. 5, the summarized total value in the U.S. is high, as shown in Fig. 6. This is because the U.S. has a large number of airports and a large population that is susceptible to COVID-19. Fig. 6 also shows that some countries such as the U.S. and Brazil seem to have a larger amount of risk flow of importation than that of exportation. This indicates that those countries are more likely to import infected people rather than export them. Therefore, many airports, or governments with jurisdiction over airports, need to implement strict countermeasures to reduce air travel for the benefit of their own citizens as well as for the global population.

4. Scenario simulation

Chinazzi et al. (2020) indicated that it is difficult to calculate the exact level of risk and transmissibility reduction brought about by

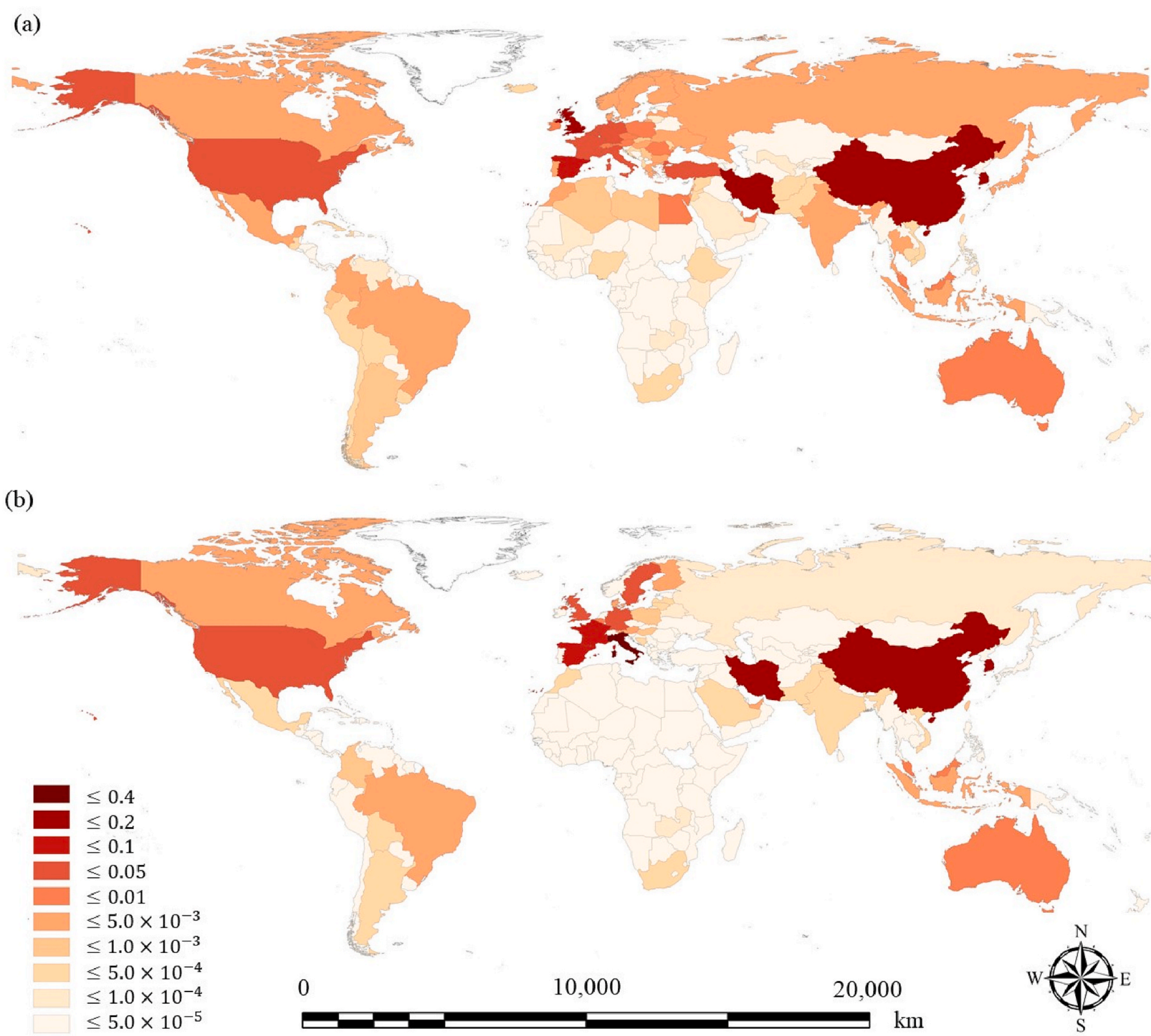

Fig. 4. Relative risk of importation (a) and exportation (b) summarized by country (Unit: %).

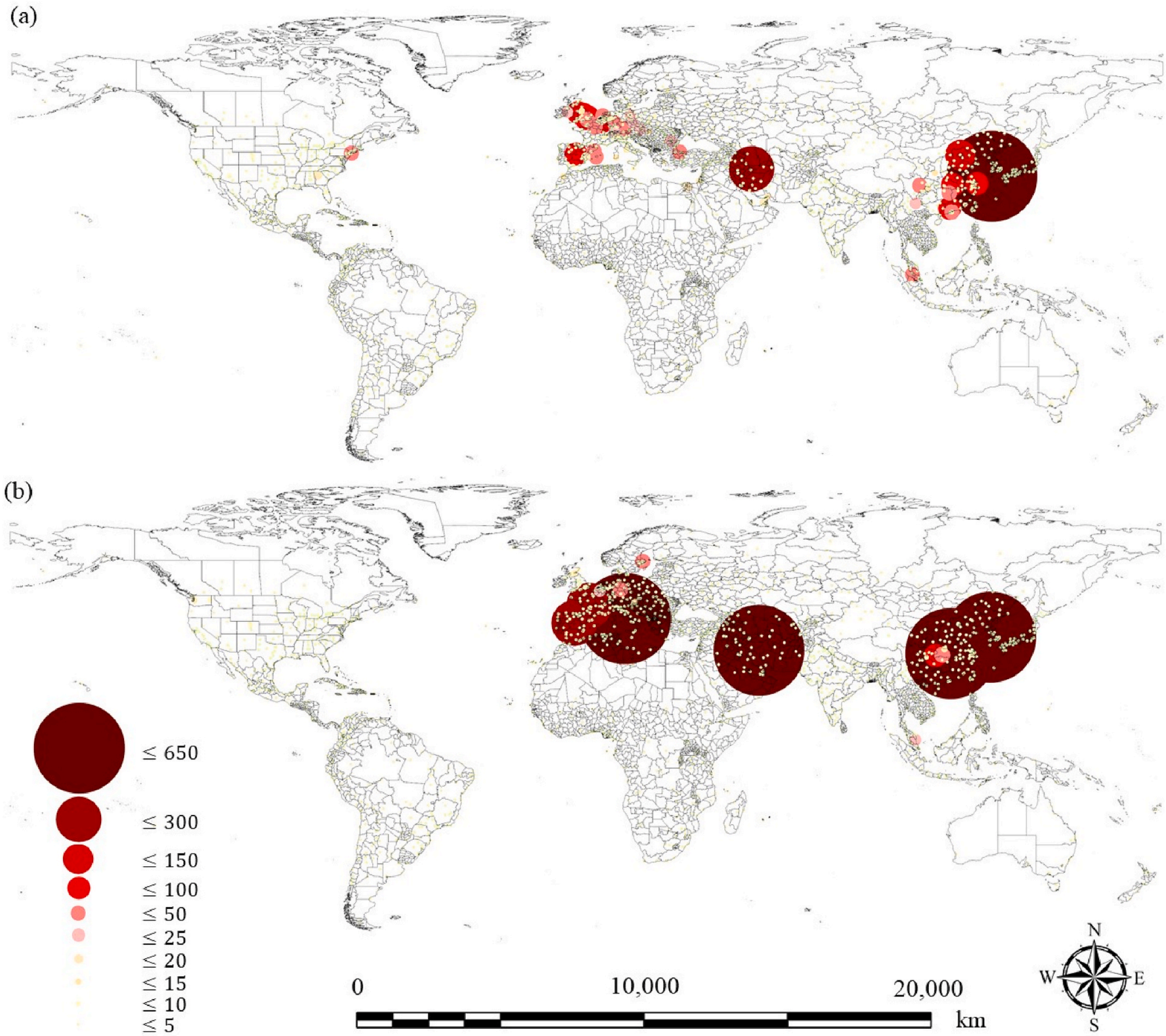

Fig. 5. Risk flow of importation (a) and exportation (b) (Unit: persons).

international travel restrictions. However, due to the travel bans imposed by several countries, it is still useful to consider some scenarios to analyze the countermeasures for the spread of the COVID-19 pandemic through airport and airline travel restrictions.

In this study, three scenarios for importation and exportation risk are considered, and the change in the risk flow of importation and exportation of COVID-19 is calculated. Hence, all airports are first classified into quartiles based on the cumulative COVID-19 incidence of the area in which each airport is located.

In scenario 1, the change in transmissibility of the disease is considered by changing the transmissibility rate from 1 to 0.5 from the status quo. Scenario 2 considers that air travel from the airports located in the 1st quartile area (i.e., the highest 25% of the cumulative incidence area) is reduced by 90%, that of those in the 2nd quartile area is reduced by 60%, and that of those in the 3rd quartile area is reduced by 30%, without a change in transmissibility of the disease. Scenario 3 changes the transmissibility rate from 1 to 0.5 from scenario 2.

Fig. 7 shows the results of the change in the risk flow of importation and exportation by scenario. Apparently, when air travel from an airport in the high cumulative incidence area is reduced by a larger percentage, the risk flow decreases gradually. However, even when the strictest reduction countermeasure is implemented, the risk flow of importation and exportation in China, Iran, the U.S., and some countries in Europe still exists. However, as many countries can reduce the risk flow of importation and exportation, the pandemic disease still prevails in some areas. This means that it is more indispensable for these countries to undertake countermeasures for COVID-19 such as home quarantine.

5. Conclusion

This study calculated the overall relative risk of importation and exportation of COVID-19 from/to every airport in local municipalities around the world based on existing studies and global spatial and mapping information. At the pandemic stage, the risk of exportation is as important as the risk of importation. This study examines both risks; it is more necessary to reduce the exportation risk than the importation risk from the perspective of risk flow.

This study also conducts a basic simulation for three scenarios, and the results show that risk flow of importation and exportation in specific areas still exists even after executing the strictest reduction countermeasures. This indicates the necessity of reducing air travel as much as possible; specifically, more than a 90% reduction is necessary in areas of high cumulative incidence. Therefore, flights must be minimized and politics should play a significant role in restricting travel to benefit individual countries as well as global health.

This study is limited as it only collected static data at a certain stage of the pandemic disease; relative data were not up to date. Scenario analyses are also approximate due to data limitations and limited

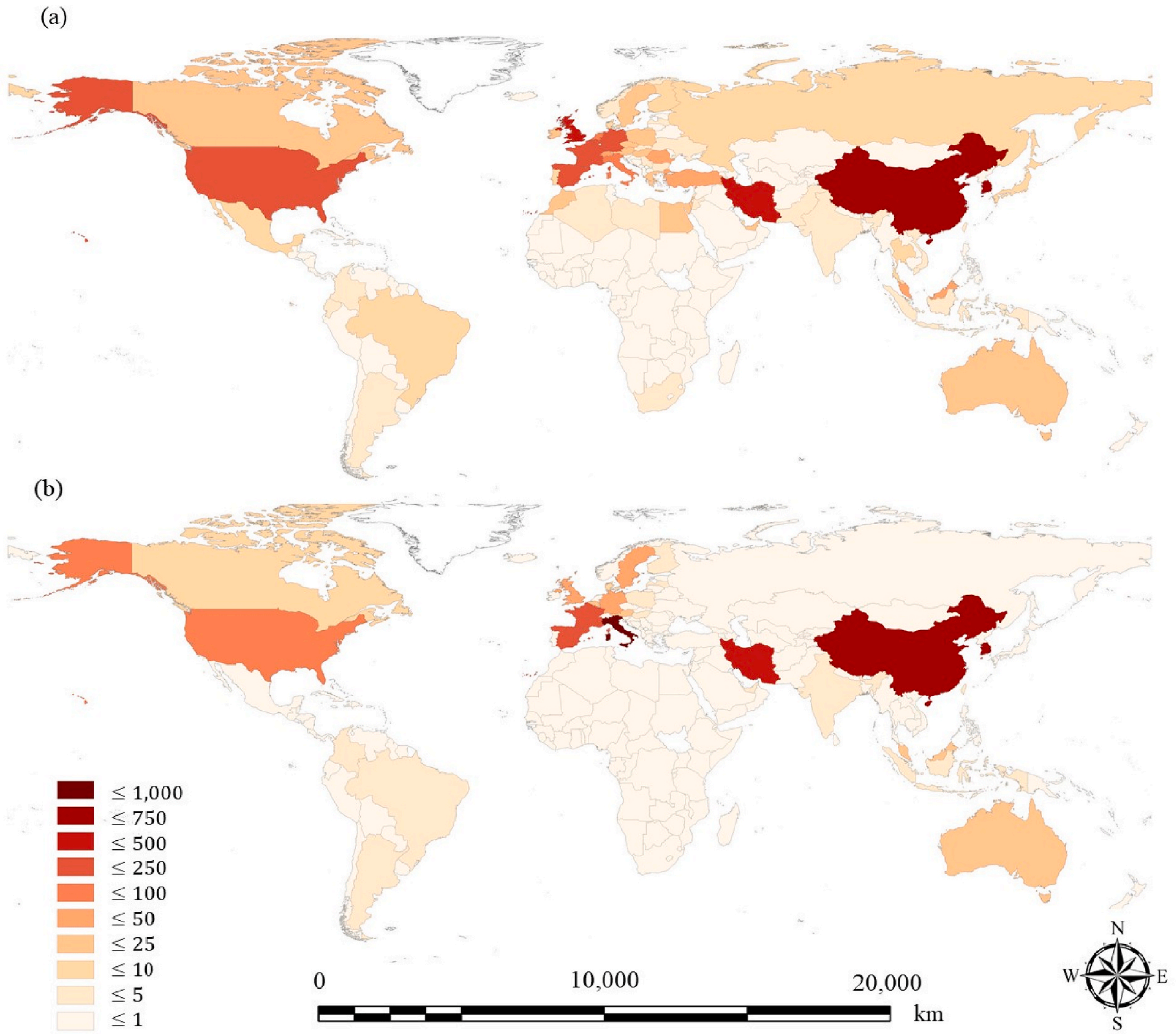

Fig. 6. Risk flow of importation (a) and exportation (b) summarized by country (Unit: persons).

scientific clarity on how the pandemic disease is transmitted between people. Information and data were continuously changing throughout the period of this study, which was undertaken during the course of the pandemic. Therefore, ongoing analyses similar to this study with updated information and data are necessary for further comparison with the actual situation.

Moreover, many OD trips involve intermediate stops at major hubs, such as Dubai and Singapore. Therefore, the risks for importing or exporting the virus from one of these hubs would be greater than our predictions. In addition, even if a country reduces direct flights from a high-risk city, unless indirect travel is also reduced, related countermeasures may not be particularly effective.

For further study, it is necessary to assess not only direct connections, but also indirect connections to Wuhan and Hubei, considering each city's characteristics. Although the analysis of this study considers the population density in each area, factors of tourists' or visitors' flows via various transportation as well as business connections of people and products through supply chains must be considered.

Nevertheless, the results may still support the planning decisions of policy makers for developing disease management strategies, and the decisions of ordinary people in changing their behavior with respect to air travel. For instance, it is indispensable for infected or suspected individuals to avoid flying to reduce the actual risk. Many countermeasures to prevent the spread of COVID-19 have been implemented by air companies and the International Air Transport Association (IATA, 2020). According to IATA (2020), transport flights are categorized into three levels: high-risk flights, medium-risk flights, and low-risk flights, and differentiated prevention and control measures are applied after a comprehensive evaluation of the outbreak at the place of origin of the flights, whether the aircraft is equipped with high efficiency particulate air filters, and other indicators such as load factors, flight time, and mission of the flights. It is also important for passengers not to travel when they are ill and if they experience symptoms suggestive of respiratory illness during or after a trip; they must seek medical attention and share their travel history with their health care provider or medical doctor. Furthermore, national and local governments should provide clear instructions and countermeasures for their people to reduce the actual risk of importation and exportation of COVID-19.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

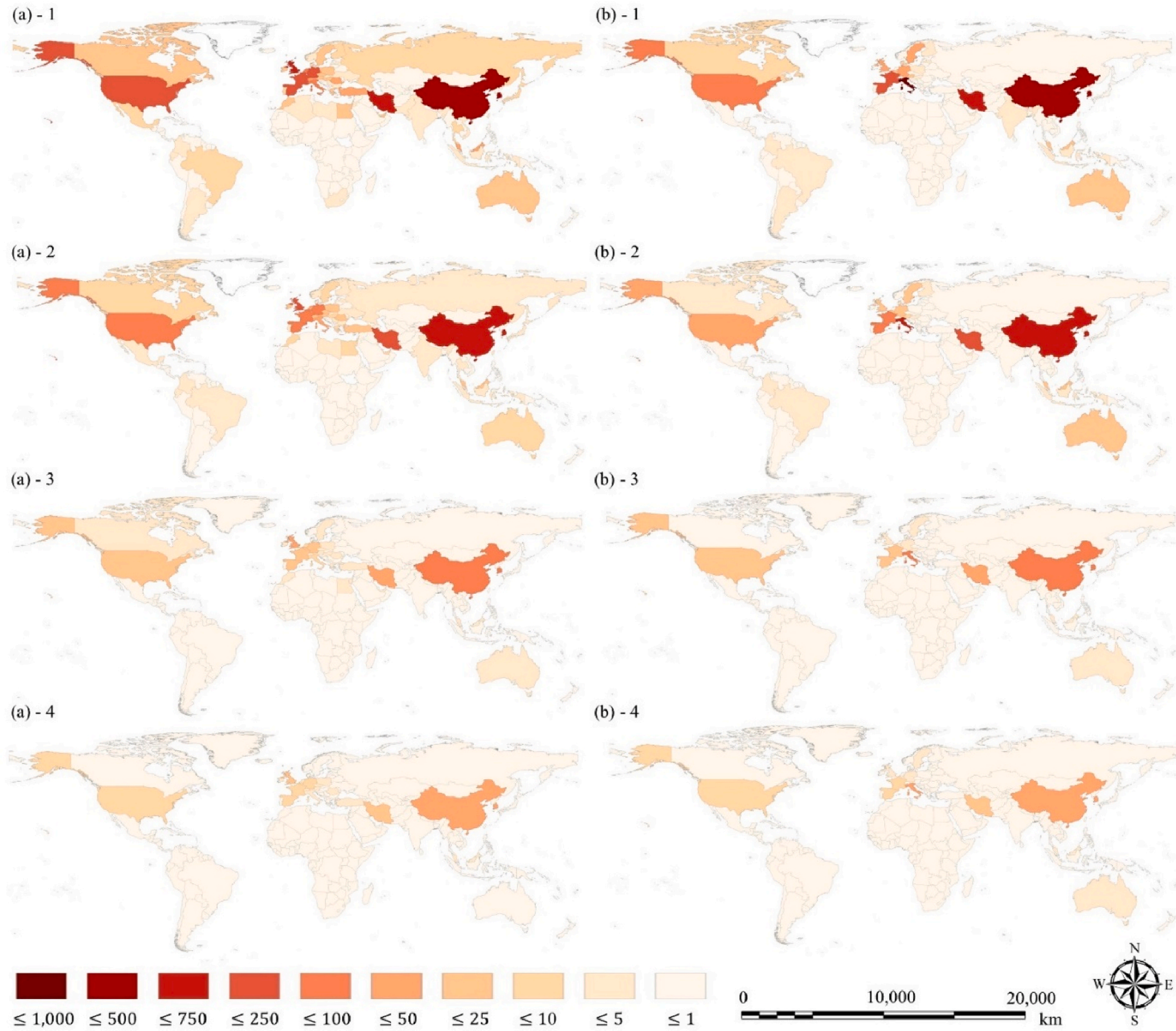

Fig. 7. Change of importation (a) and exportation (b) risk flow per scenario (Unit: persons).
Notes: 0. status quo; 1. scenario 1; 2. scenario 2; 3. scenario 3.

the work reported in this paper.

CRediT authorship contribution statement

Hiroki Nakamura: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Shunsuke Managi:** Conceptualization, Supervision, Project administration.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tranpol.2020.06.018.

References

Balcan, D., Hu, H., Goncalves, B., et al., 2009. Seasonal transmission potential and activity peaks of the new influenza A(H1N1): a Monte Carlo likelihood analysis based on human mobility. BMC Med. 7 (45) https://doi.org/10.1186/1741-7015-7-45.

Bogoch, I.I., Watts, A., Thomas-Bachli, A., Huber, C., Kraemer, M.U.G., Khan, K., 2020. Potential for global spread of a novel coronavirus from China. J. Trav. Med. 27 (2), 1–3. https://doi.org/10.1093/jtm/taaa011.

Chinazzi, M., Davis, J.T., Ajelli, M., et al., 2020. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. Science 9757 (March), 1–12. https://doi.org/10.1126/science.aba9757.

Drake, J.M., Chew, S.K., Ma, S., 2006. Societal learning in epidemics: intervention effectiveness during the 2003 SARS outbreak in Singapore. PloS One 1 (1), e20. https://doi.org/10.1371/journal.pone.0000020.

Gilbert, M., Pullano, G., Pinotti, F., et al., 2020. Preparedness and vulnerability of African countries against importations of COVID-19: a modelling study. Lancet 395 (10227), 871–877. https://doi.org/10.1016/S0140-6736(20)30411-6.

Haider, N., Yavlinsky, A., Simons, D., et al., 2020. Passengers' destinations from China: low risk of novel coronavirus (2019-nCoV) transmission into Africa and South America. Epidemiol. Infect. 148, e41. https://doi.org/10.1017/S0950268820000424.

Huang, Z., Wu, X., Garcia, A.J., Fik, T.J., Tatem, A.J., 2013. An open-access modeled passenger flow matrix for the global air network in 2010. PloS One 8 (5), e64317. https://doi.org/10.1371/journal.pone.0064317.

Hsu, C.I., Shih, H.H., 2010. Transmission and control of an emerging influenza pandemic in a small-world airline network. Accid. Anal. Prev. 42 (1), 93–100. https://doi.org/10.1016/j.aap.2009.07.004.

International Air Transport Association (Iata), 2020. Preventing spread of coronavirus disease 2019 (COVID-19) guideline for airlines. https://www.iata.org/contentassets/7e8b4f8a2ff24bd5a6edcf380c641201/airlines-preventing-spread-of-coronavirus-disease-2019.pdf. (Accessed 2 April 2020) fourth ed.

Johns Hopkins Center for Systems Science and Engineering, 2020. Coronavirus COVID-19 global cases. https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/.bda7594740fd40299423467b48e9ecf6. (Accessed 14 March 2020).

Kandel, N., Chungong, S., Omaar, A., Xing, J., 2020. Health security capacities in the context of COVID-19 outbreak: an analysis of International Health Regulations annual report data from 182 countries. Lancet 395 (10229), 1047–1053. https://doi.org/10.1016/S0140-6736(20)30553-5.

Lai, S., Bogoch, I.I., Watts, A., Khan, K., Li, Z., Tatem, A., 2020. Preliminary risk analysis of 2019 novel coronavirus spread within and beyond China. https://www.worldpop.org/resources/docs/china/WorldPop-coronavirus-spread-risk-analysis-v1-25Jan.pdf. (Accessed 18 March 2020).

Lee, J., Choi, B.Y., Jung, E., 2018. Metapopulation model using commuting flow for national spread of the 2009 H1N1 influenza virus in the Republic of Korea. J. Theor. Biol. 454 (7), 320–329. https://doi.org/10.1016/j.jtbi.2018.06.016.

Leta, S., Beyene, T.J., De Clercq, E.M., Amenu, K., Kraemer, U.G., Revie, C.W., 2018. Global risk mapping for major diseases transmitted by Aedes aegypti and Aedes albopictus. Int. J. Infect. Dis. 67, 25–35. https://doi.org/10.1016/j.ijid.2017.11.026.

Lloyd, C.T., Chamberlain, H., Kerr, D., et al., 2019. Global spatio-temporally harmonised datasets for producing high-resolution gridded population distribution datasets. Big Earth Data 3 (2), 108–139. https://doi.org/10.1080/20964471.2019.1625151.

Luo, X.S., Imai, N., Dorigatti, I., 2020. Quantifying the risk of Zika virus spread in Asia during the 2015–16 epidemic in Latin America and the Caribbean: a modeling study. Trav. Med. Infect. Dis. 33 (January), 101562. https://doi.org/10.1016/j.tmaid.2020.101562.

Marston, B.J., Dokubo, E., van Steelandt, A., et al., 2017. Ebola response impact on public health programs, west Africa, 2014–2017. Emerg. Infect. Dis. 23 (13) https://doi.org/10.3201/eid2313.170727.

Pinotti, F., Domenico, L.D., Ortega, E., et al., 2020. Lessons learnt from 288 COVID-19 international cases: importations over time, effect of interventions, under detection of imported cases. MedRxiv 2, 20027326. https://doi.org/10.1101/2020.02.24.20027326, 24.

Rocklöv, J., Quam, M.B., Sudre, B., et al., 2020. Assessing seasonal risks for the introduction and mosquito-borne spread of Zika virus in Europe. EBioMedicine 9, 250–256. https://doi.org/10.1016/j.ebiom.2016.06.009.

Shearer, F.M., Longbottom, J., Browne, A.J., et al., 2018. Existing and potential infection risk zones of yellow fever worldwide: a modelling analysis. Lancet Glob Health 6 (3), e270–e278. https://doi.org/10.1016/S2214-109X(18)30024-X.

Sun, K., Chen, J., Viboud, C., 2020. Early epidemiological analysis of the coronavirus disease 2019 outbreak based on crowdsourced data: a population-level observational study. Lancet Dig Health 2 (4), PE201–PE208. https://doi.org/10.1016/S2589-7500(20)30026-1.

Tatem, A.J., 2017. WorldPop, open data for spatial demography. Sci Data 4, 170004. https://doi.org/10.1038/sdata.2017.4.

World Health Organization, 2020. Novel coronavirus – situation report 43. www.who.int/docs/default-source/coronaviruse/situation-reports/20200303-sitrep-43-covid-19.pdf?sfvrsn=2c21c09c_2. (Accessed 20 March 2020).

World Health Organization, March 11, 2020. WHO virtual press conference on COVID-19. https://www.who.int/docs/default-source/coronaviruse/transcripts/who-audio-emergencies-coronavirus-press-conference-full-and-final-11mar2020.pdf?sfvrsn=cb432bb3_2. (Accessed 2 April 2020).

Wu, J.T., Leung, K., Leung, G.M., 2020. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. Lancet 395 (10225), 689–697. https://doi.org/10.1016/S0140-6736(20)30260-9.