 doi:10.20944/preprints202211.0148.v1

Article

Diffusion and Prediction of Covid-19 Pandemic: Limits of Models and Strategies to Improve Outlook and Preparedness to Face Next Pandemics

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Abstract

One of the most important problems in the presence of epidemics and pandemics is an accurate prediction and preparedness. Scholars and experts argue that future pandemics and/or epidemics are almost inevitable events and is not whether next pandemics will happen, but when a new heath emergency will emerge. Epidemiologic models for prediction of Coronavirus Disease 2019 (COVID-19) have shown many limitations because of unpredictable dynamics of the new viral agent SARS-CoV-2 in environment and society. The main goals of this study are twofold: first, the analysis of anthropogenic activities and factors that may trigger pandemic threats; second, the planning of new directions for strategies to reduce risks that a pandemic threat emerges and/or in the initial phase to reduce vast diffusion and negative impact of new viral agents that can generate hazards and problems in public health, environment and socioeconomic systems. In particular, the investigation and understanding of sources and driving factors concerning the emergence and diffusion of new pandemics have critical aspects for strategic actions of forecast, prevention and preparation of effective policy responses to cope with next pandemic crises and health emergencies. Insights here endeavor, whenever possible, to clarify these problems to increase the knowledge of the sources and factor determining the emergence of new viral agents in order to design optimal response policies to face next pandemic diseases similar to COVID-19.

Keywords: COVID-19 pandemic; Infectious diseases; Global diffusion; Environmental factors; Compartmental models; Epidemiologic models; Outlook; Prediction; Preparedness; Surveillance; Health policy; Crisis management; Strategies

1. INTRODUCTION

In 2022 we are still in the throes of negative effects of the pandemic of Coronavirus Disease 2019 (COVID-19), an infectious illness emerged with the Severe Acute Respiratory Syndrome Coronavirus 2 or SARS-CoV-2 virus (Chowdhury et al., 2022; Coccia, 2020, 2022, 2022a, 2022b; Bontempi et al., 2021; Bontempi and Coccia, 2021; Johns Hopkins Center for System Science and Engineering, 2022; Núñez-Delgado et al., 2021).

A vital aspect for public health and security of nations is predicting next pandemic to design appropriate strategies of crisis management based on policy responses, pharmaceutical and non-pharmaceutical interventions to stop

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and/or mitigate, whenever possible, that a new virus emerges, spreads and infects a lot of people (Coccia, 2022a, 2022b). The prediction of next pandemics involves different aspects, such as to understand how new viral agents emerge, behave and mute to design and implement effective policy responses for reducing socioeconomic impact (Coccia, 2021a). In this context, governments largely relied on epidemiological models of predicted COVID-19 cases and/or deaths to guide the application of effective and timely containment policies and vast vaccination campaigns (Alsobhi, 2023; Keshavamurthy et al., 2022). However, epidemiologic models for prediction of COVID-19 have shown many limitations because of unpredictable dynamics of SARS-CoV-2 in environment and society (Rosenfeld and Tibshirani, 2021). In the presence of manifold limitations of epidemiologic models of pandemic prediction for SARS-CoV-2 and its mutations, one of the critical activities of nations and their institutions is to examine sources and driving factors of new infectious diseases having potential elements to generate a pandemic. The impact of human activities on the development of COVID-19 plays a vital role to prevent, whenever possible, new hazardous viral agents and prepare optimal strategies of crisis management to guide effective and timely processes of decision-making for stopping transmission dynamics in society (Coccia, 2021, 2021a, 2022c; Khandia et al., 2022). In fact, governments should prepare, *ex-ante*, response policies for facing pandemic threats of new viral agents that can generate main negative effects in society (cf., Groh, 2014).

Hence, since the forecasting of pandemics in the short and long run using current epidemiologic models, as all human activity of prediction, has manifold shortcomings and can provide misleading results, the main goals of this study are twofold: first, the analysis of anthropogenic activities and factors that may trigger pandemic threats; the planning of optimal strategies to reduce the hazards and risks of emergence of pandemic threat and/or in the initial phase to reduce negative impact associated with the emergence and diffusion of new viruses that can generate problems on public health, environment and socioeconomic systems. In particular, the investigation and

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understanding of sources and driving factors concerning the emergence and diffusion of new pandemics have critical aspects for designing appropriate strategic actions of prevision, prevention and planning of effective policy responses to improve preparedness to cope with next pandemic crises and health emergencies (Coccia, 2022c; Dai et al., 2022; Krechetov et al., 2022; Kuvvetli et al., 2021; Liu et al., 2022; Šušteršič et al., 2021). Hence, this study endeavors, whenever possible, to clarify these problems to increase the knowledge of the sources and factor determining the emergence of new viral agents in order to design optimal response policies to face next pandemic diseases similar to COVID-19 (Farazmand, 2001, 2014).

2. STUDY DESIGN AND METHODOLOGY

The method of inquiry is based on a research process to search in the existing scientific literature the factors determining pandemic threat and its diffusion for planning and preventing next pandemic crises and systematically design and implement optimal policy responses to cope with health emergencies.

Systematic review here is based on a search strategy with the goal of determining drivers of pandemic threats by analyzing selected papers on these topics (Uman, 2011). In this perspective, systematic review here focuses on a method of logic selection of specific literature aimed at minimizing bias in order to produce robust findings to explain drivers of new viral agents and plan strategic actions for supporting decision making of policymakers to cope with pandemics (Clarke, 2011).

In addition, systematic review here also includes a meta-analysis to show quantitative values, data and information from some studies related to these topics (Petticrew and Roberts, 2006). In particular, examining the studies about lab accidents, the reported occurrence of accidents in different labs dealing with biological experiments is reported and discussed. Systematic reviews differ from narrative reviews that are mainly descriptive and focus on a subset

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of studies also generating elements of bias (Clarke, 2011; Uman, 2011). In short, systematic review here endeavors to identify, appraise and synthesize a selected literature to provide main evidence and information to clarify the specific problem of detecting sources of new viral agents and predicting risk factors of pandemic threats for planning optimal strategies of prevention to improve the preparedness of nations to cope with health crises and emergencies.

3. RESULTS

The assessment and prediction of pandemic threats, similar to COVID-19, have vital aspects for prevention and preparedness of nations. In this perspective, the reduction of the risks and hazards for the emergence and diffusion of new viral agents and consequential pandemics has to focus pre-emptively on following measures of control.

3.1 Factors determining a high risk for the emergence of new viral agents

- *Surveillance of wildlife to avoid pandemic emergence and diffusion*

Daszak et al. (2020) argue some risk factors determining the emergence of pandemic threats, such as the interaction between humas and wildlife that can foster the transmission of dangerous pathogens and spillover effects; moreover, wildlife trade in domestic and international markets, with poor measures of control, can reduce biosecurity and increase the emergence of new viral agents. A large literature discusses the conditions leading to the emergence of an epidemic and/or pandemic (Anderson and May, 1991; Dobson and Carper, 1996). For instance, a poor surveillance of wildlife can generate evolutionary phases that specialize a pathogen from animals to humans . This aspect can generate compounding and cascading events that in a large population, new viral agents can infect a lot of individuals with a rapid and widespread transmission. Moreover, persistence of infection depends on manifold factors, such as density of population, level and period of infectivity of hosts, period necessary

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for host to achieve a protective immunity, resistance of pathogen to pharmaceutical treatments, continued existence of new viral agent in regions, though extinctions in local clusters (Wolfe et al., 2007).

- *Biosafety lab risk assessment and protocols to reduce accidents for the emergence and diffusion of new viral agents*

Lab risk assessment and protocols improve biosafety and reduce accidents that increase the probability that a new viral agent spread (Ménard and Trant, 2020). Hellman et al. (1986) show that two percent of accidents are in fabrications rooms and thirteen percent are in research labs. Van Noorden (2013) argue that thirty per cent of a large sample of people working in labs has assisted to serious injury in a period of about 20 years. Ayi and Ho (2018) also report that in Canada about fifteen per cent of people in labs has experienced at least one lesion or mishap. Simmons et al. (2018) reveal that at the Iowa State University (U.S.A.) lab incident are more than 18% of total. Kou et al. (2021) point out that at the University of Minnesota (USA) in a period of five years, scholars reported that the most frequent incidents are the spill of hazardous substances, fire and equipment damages that injure lab personnel (Kou et al., 2021). These case studies reveal that that the escape and diffusion of new viral agents associated with an accident of lab can have a vital role in the emergence of epidemics and pandemics and need accurate monitoring for improving prediction, prevention and preparedness of nations (Coccia, 2022). In particular, the reduction of pandemic threats, from incidents of viral agents in labs, is associated with an accurate activity of lab risk assessment and effective protocols for biosecurity. Li Na et al. (2019) argue that risk assessment in biosafety labs can be performed with different methods, such as scenario analysis, pre-hazard analysis, hazard and operability analysis, fault tree analysis, event tree analysis, matrix analysis, risk mapping, etc. However, source and control measures of risks cannot be general for all labs worldwide and biological risk management system has no fixed modes generalizable for all nations and has to be adapted to the specificity of labs and country

(Coccia, 2022, 2021a). For prevention of epidemics and pandemics, information and data of lab accidents and also safety, should be linked to a national and international surveillance system for real time transmission in order to better coordinate targeted investigations and interventions to improve the safety of labs in the presence of specific needs, threats and global risks for stopping new infectious disease outbreaks (Jia and Yang, 2020).

Hence, laboratory biosafety risk analyses and assessments have to be a recurring critical activity to improve the security of operation of laboratory and minimize incidents of hazardous pathogens and aerosol exposure risk of hazardous viral agents that can lead to the emergence of epidemic and pandemic diseases (Li Na et al., 2019).

- *High air and environmental pollution, and (un)sustainable environment can support pandemic emergence and spread*

One of the factors determining a high risk for the emergence and diffusion of epidemics and pandemics similar to COVID-19 is air and environmental pollution (Coccia, 2020, 2020a). In general, population living in environments with high air pollution has experienced an increased mortality of COVID-19 for rapid diffusion of SARS-CoV-2 (Coccia,2020, 2021b). In fact, high levels of particulate matter and other air pollutants can mix with pathogens generating mutations and resistance of viral agents that increase their transmissibility and infectivity with main negative impact on health of people and socioeconomic systems (Jones and Harrison, 2004; Wei et al., 2018; Zhong et al., 2020; Coccia, 2020, 2021b; 2021c, 2021d; Rosario Denes et al., 2020).

3.2 Pre-emptively measures of control for the widespread diffusion of new viral agents

- *Strengthening the early warning system with effective contract tracing system*

An effective contact tracing system and timely isolation can reduce transmission dynamics of infectious diseases within and between different outbreak areas (Wells et al., 2020). This dual strategy plays a basic aspect to stop the spread of infectious diseases having a latent pre-symptomatic phase (Coccia, 2020). Moreover, an effective contact tracing system, with a "bidirectional" approach , can reduce the spread of novel viral agents in society and improve a timely healthcare of infected individuals to reduce severe side effects and also deaths (Bradshaw et al., 2021; Yalaman et al., 2021).

- *Effective governance improves prevention and preparedness to face pandemic threats.*

Effective governance can support prevention and preparedness to pandemic threats with constant investments to reinforce: surveillance of the interaction of human society with wildlife, protocols for biosafety laboratory risk assessment, health system human resources and management, new technology that reduces human exposure to new vital agents and opportunities for a pandemic virus to emerge, effective early warning system and rapid containment actions to stop rapid diffusion of viral agents. In short, good institutions and governance, human resources with high expertise and available new technology in health sector and overall socioeconomic system only can improve the prediction of a new virus and preparedness to face pandemic crisis like COVID-19 (Coccia, 2021a, 2022b; Sagan et al., 2020). Benati and Coccia (2022) show that, during the first wave of COVID-19 pandemic, some Italian regions have implemented appropriate policy responses based on widespread testing of symptomatic and asymptomatic individuals associated with a timely isolation of infected people, reducing total deaths and negative effects in society. Benati and Coccia (2022a) also show the positive effects of good governance for supporting optimal policy responses towards the COVID-pandemic with a timely vaccination directed to reduce negative pandemic impact in society.

Figure 1 shows critical risk factors for the emergence and diffusion of future pandemics.

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Factors determining emergence and rapid diffusion of pandemics

– Factors determining a high risk for the emergence of new viral agents

- Poor surveillance of wildlife and high interaction of humans with wildlife
- Incomplete biosafety protocols in labs, increasing probability of accidents
- High air and environmental pollution support atmospheric stability for emergence and diffusion of new viral agents that mix with particular matter acquiring resistance and high infectivity and rapid transmission in polluted cities having a high density of people with deteriorated immune systems

– Poor pre-emptively measures of control for reducing the widespread diffusion of new viral agents

- Ineffective contact tracing systems and scarce team for epidemiological investigations
- Bad governance of nations leading to poor health systems

Figure 1. Factors that increase the opportunities for a pandemic virus to emerge and spread

4. POLICY IMPLICATIONS: LIMITS OF COVID-19 PREDICTION MODELS AND STRATEGIC ACTIONS FOR FORECASTING AND PREVENTING PANDEMIC THREATS

Epidemic forecasting plays a vital role to improve the surveillance for pandemic risks, protect public health and cope with future pandemic threats (Johansson et al., 2019; Ajelli et al., 2018). In the presence of COVID-19, scholars suggest different models for epidemic tracking and forecasting (Rosenfeld and Tibshirani, 2021). Reinhart et al. (2021) have done many efforts in the construction and maintenance of an open repository of real-time and geographically detailed COVID-19 indicators in the United States. This repository provides main information about COVID-19, such as confirmed cases, hospitalizations, deaths, fatality rates, etc. McDonald et al. (2021) endeavor to explain if a set of indicators can improve the accuracy of COVID-19 short-term forecasting and hot spot detection models in spatial regions. However, pandemic tracking and forecasting models have also some

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problematic points, such as data generation process is a critical aspect for downstream applications, in addition human behavior and its impact on the progression of epidemics are hard to measure and to model. Moreover, COVID-19 diffusion has shown rapid peaks and then infections abruptly fall, regardless measures of control. In fact, unlike predictions of different epidemiologic models, the reduction of control measures for COVID-19 did not generate a rapid take off of infections (Wieland, 2020). One of the main problems of epidemiologic models applied for COVID-19 is due to high overestimation of deaths (Allen, 2022; Briggs and Littlejohn, 2021; Korolev, 2021). This limitation of current models for pandemic prediction is the assumption of a constant reproductive number, whereas in real contexts it changes over the course of time (Korolev, 2021). Additionally, a lot of models do not consider that the deaths of COVID-19 have a skewed distribution towards elderly and susceptible people with comorbidities (Chen et al., 2022). Appropriate prediction models of infectious diseases, like COVID-19, should be age-dependent. Another critical limitation of epidemiological model applied for COVID-19 is the reductionism approach that did not consider the behavioral change of people in the presence of a pandemic (Mohammadi et al., 2022). In fact, many epidemiologic models do not consider that people, with the fear to be infected and/or of die with new infections, can adapt the behaviour to new situation taking provident actions to protect themselves and survive (Stangier et al., 2022). For instance in the US economy, the reduction of consumer mobility is due to mainly to private responses rather than public obligations (Goolsbee and Syverson, 2021). Finally, susceptible-infectious-removed (SIR), Susceptible-Exposed-Infected-Recovered-Dead (SEIRD) and other epidemiologic models focus mainly on stable and short-run variables, whereas factors driving the pandemic have dynamic change over time. As a consequence, in general epidemiologic models cannot provide reliable long-run forecasting of pandemic that is an ideal goal as all forecasting activities, because limits are due to the interaction of manifold and complex factors.

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The improvement of pandemic forecasting can be done by focusing on key components described in table 1.

Table 1. Elements for improving pandemic forecasting and tracking

□	Electronic Medical Records (EMR)
	The accurate analytics of real-time data can improve the forecasting of pandemic dynamics. *Electronic Medical Records* (EMR) has a high potential for real-time surveillance streams of infections and deaths related to pandemic of new viral agents similar to SARS-CoV-2
□	Different phases of epidemic surveillance need different analytic techniques and approach.
	In the inter-pandemic phase, the monitoring of data streams and consequential events worldwide can avoid compounding and cascading events, such as species jumping, mutations and high diffusion of viral agents. *In the containment phase*, a threat of a new viral agent has to be intensely monitored, assessed, and contained. A real-time analytics can provide reliable estimation of critical epidemiological parameters for assessing and predicting with accuracy pandemic trend.

In general, since the pandemic forecasting in the long run provides uncertain results, countries can direct their efforts on pre-emptively strategic actions to increase R&D investments in new technology, organized infrastructures in health sector, equipment, and education of human resources, associated with international collaboration, for improving activities of prevention and preparedness in crisis management to cope timely with to unforeseen pandemics to reduce main socioeconomic and health problems (Coccia, 2021).

In general, strategies of countries for unforeseen pandemic crisis should be preventive health policies to minimize risk factors associated with the emergence and evolution of new pandemic virus (Bundy et al., 2017; Seeger et al., 1998; cf., Mahmoudi and Xiong, 2022).

In particular, strategies of pandemic forecasting and prevention can focus on following vital aspects of a specific task force:

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- Analytics for detecting factors determining pandemic threat
- Plan of strategies to reduce occurrences of diffusion of new viral agents, to predict and prevent pandemics.
- Design of policies to mitigate negative impact of outbreaks, endeavoring to contain and stop diffusion in local contexts.

This general strategy in practice has to design and implement three main strategic actions.

Firstly, the reduction of interaction with wildlife and/or appropriate protections in hazardous environments (e.g., mines) for reducing human exposure of people to animals inducing a pandemic virus to emerge (e.g. spillover form wildlife).

Secondly, a strategic action has to improve the warning system and prompt containment interventions in the initial phase of outbreak that could prevent chains of transmission. An effective early warning systems in the international community can ensure timely detection of suspected cases in humans. Laboratories have to receive all data, information and clinical specimens for assessing risk factors of a pandemic threat in society and communicate timely appropriate actions to remove or minimize a diffusion from local to global environments, such as selected restrictions in hot spots and similar places (Coccia, 2021e; Tsiotas et al., 2020; Warren et al., 2021). International institutions and countries have to coordinate of global health policies to minimize risks of pandemic threat or crisis.

Thirdly, governments have to support public and private research labs for drug discoveries, such as effective antiviral and vaccines, to decrease the spread of novel viral agent (Coccia, 2021, 2021a). These innovative drugs to face health emergency should be delivered to all countries with equity to reduce the takeoff of pandemic and the generation of new variants that feed the evolution of pandemic for a longer period (Benati and Coccia, 2022, 2022a; Crow et al., 2018; Coccia, 2021a; 2022e, 2022f). R&D investments have to be directed to new vaccines that provide a general and long-run protection of people against novel viral agents and their variants (Coccia, 2020, 2022a, 2022b, 2022d, 2022; Kapitsinis, 2020; Williams et al. 2020).

Overall, then, in turbulent (complex and uncertain) environment, R&D investments and good governance can improve preparedness of countries and reduce opportunities of human exposure to hazardous pathogens and risk factors that a pandemic virus to emerge, strengthening the early warning systems and effective policy responses based on non-pharmaceutical and pharmaceutical interventions that decrease/stop transmissibility among humans and/or delay its international spread (Coccia, 2020, 2021, 2022c).

5. CONCLUSIONS

Lessons learned of COVID-19 suggest that governments have to plan strategies and public polies to forecast, prevent and prepare to cope with future infectious diseases of novel viruses to mitigate deterioration of public health and economies (Coccia, 2021; Newby et al., 2020; Sirois and Owens, 2021; Whittaker et al., 2021). In worldwide context an effective crisis management is based, more and more, on an international collaboration in science and public health for timely sharing of data and sample for accurate analytics of novel viral agents for appropriate policy responses that contain hazardous pathogens in local communities and avoid the spread between countries and as consequence generating global socioeconomic shocks (Coccia, 2020).

Considering the difficulties of accurate long-run outlook of pandemic threats, countries have to endeavor to focus their efforts on planning flexible and resilient strategies to minimize the risk factors with policies of prevention and preparedness that a pandemic virus to emerge and spread from wildlife or incidents in labs (Coccia, 2021a; Benati and Coccia, 2022, 2022a). Overall, then, the forecasting, prevention and preparation to health emergencies have to planned by countries with forward-looking policies that improve institutions and public governance in health sectors and not only. The strategies of pandemic preventions have to contains critical aspects of resolution and dissolution to stop, in a short run, diffusion of new viral agents and consequential mutations (Ackoff and Rovin, 2003; Gigerenzer and Todd, 1999; Janssen and van der Voort, 2020; Kahneman et al., 1982; Weible et al., 2020).

Although this study has provided interesting insights to face next pandemics, that are of course tentative, it has several limitations. One of the problems is the difficulty of an accurate prediction of the numbers of reported and unreported cases for the COVID-19 pandemic and similar pandemics for different classes of age (cf., Liu et al., 2021a). A lot of confounding and situational factors should be considered for an accurate forecasting and preparedness of next pandemics. To conclude, the activity of forecasting and prevention in a more and more turbulent world, though considerable science advances is always a terra incognita. Human society needs a sustainable perspective to face a difficult future. Hence, to reduce the emergence of next pandemics and other health emergencies, human society has to be directed towards sustainable communities that respect wildlife, their environment and their natural resources.

REFERENCES

Ackoff RL, Rovin S. 2003. Redesigning Society. Stanford University Press, Stanford

Ajelli M., et al. 2018. The RAPIDD Ebola forecasting challenge: Model description and synthetic data generation. Epidemics 22, 3–12

Alsobh, A. 2023Prediction of COVID-19 Disease by ARIMA Model and Tuning Hyperparameter Through GridSearchCV. Lecture Notes in Networks and Systems 490, pp. 543-551

Anderson, R. M. & May, R. M. 1991. Infectious Diseases of Humans: Dynamics and Control (Oxford Univ. Press, Oxford, UK, 1991).

Ayi, H.-R., Hon, C.-Y. 2018. Safety culture and safety compliance in academic laboratories: A Canadian perspective. J. Chem. Health Saf. 25, 6–12.

Benati I.,Coccia M. 2022. Effective Contact Tracing System Minimizes COVID-19 Related Infections and Deaths: Policy Lessons to Reduce the Impact of Future Pandemic Diseases. Journal of Public Administration and Governance, vol. 12, n. 3, pp. 19-33. DOI: https://doi.org/10.5296/jpag.v12i3.19834

Benati I., Coccia M. 2022a. Global analysis of timely COVID-19 vaccinations: Improving governance to reinforce response policies for pandemic crises. International Journal of Health Governance. https://doi.org/10.1108/IJHG-07-2021-0072

Biggs, A. T. and Littlejohn, L. F., 2021. Revisiting the initial COVID-19 pandemic projections. The Lancet Microbe, 2(3): E91-E92.

Bontempi E., Coccia M., 2021. International trade as critical parameter of COVID-19 spread that outclasses demographic, economic, environmental, and pollution factors, Environmental Research, vol. 201, Article number 111514, https://doi.org/10.1016/j.envres.2021.111514

Bontempi E., Coccia M., Vergalli S., Zanoletti A. 2021. Can commercial trade represent the main indicator of the COVID-19 diffusion due to human-to-human interactions? A comparative analysis between Italy, France, and Spain, Environmental Research, vol. 201, Article number 111529, https://doi.org/10.1016/j.envres.2021.111529

Bradshaw, W.J., Alley, E.C., Huggins, J.H., Lloyd, A.L., Esvelt, K.M. 2021. Bidirectional contact tracing could dramatically improve COVID-19 control. Nature Communications 12(1),232

Bundy J., Pfarrer M. D., Short C. E., Coombs W. T. 2017. Crises and Crisis Management: Integration, Interpretation, and Research Development. Journal of Management, 43 (6): 1661–1692. doi:10.1177/0149206316680030.

Chen, C., So, M., & Liu, F. C. (2022). Assessing government policies' impact on the COVID-19 pandemic and elderly deaths in East Asia. Epidemiology and infection, 150, e161. https://doi.org/10.1017/S0950268822001388

Chowdhury T., Chowdhury H., Bontempi E., Coccia M., Masrur H., Sait S. M., Senjyu T. 2022. Are mega-events super spreaders of infectious diseases similar to COVID-19? A look into Tokyo 2020 Olympics and Paralympics to improve preparedness of next international events. Environmental Science and Pollution Research, https://doi.org/10.1007/s11356-022-22660-2

Clarke J. 2011. What is a systematic review? Evidence-Based Nursing 2011;14:64.

Coccia M. 2020. Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID. Science of The Total Environment, vol. 729, n.138474, https://doi.org/10.1016/j.scitotenv.2020.138474.

Coccia M. 2020a. How (Un)sustainable Environments are Related to the Diffusion of COVID-19: The Relation between Coronavirus Disease 2019, Air Pollution, Wind Resource and Energy. Sustainability, 12, 9709; doi:10.3390/su12229709

Coccia M. 2021. Comparative Critical Decisions in Management. In: Farazmand A. (eds), Global Encyclopedia of Public Administration, Public Policy, and Governance. Springer, Cham. https://doi.org/10.1007/978-3-319-31816-5_3969-1

Coccia M. 2021a. Pandemic Prevention: Lessons from COVID-19. Encyclopedia, vol. 1, n. 2, pp. 433-444. doi: 10.3390/encyclopedia1020036

Coccia M. 2021b. High health expenditures and low exposure of population to air pollution as critical factors that can reduce fatality rate in COVID-19 pandemic crisis: a global analysis Environmental Research, vol. 199, Article number 111339, https://doi.org/10.1016/j.envres.2021.111339

Coccia M. 2021c. Effects of the spread of COVID-19 on public health of polluted cities: results of the first wave for explaining the dejà vu in the second wave of COVID-19 pandemic and epidemics of future vital agents. Environmental Science and Pollution Research 28(15), 19147-19154. https://doi.org/10.1007/s11356-020-11662-7

Coccia M. 2021d. The effects of atmospheric stability with low wind speed and of air pollution on the accelerated transmission dynamics of COVID-19. International Journal of Environmental Studies, vol. 78, n. 1, pp. 1-27, https://doi.org/10.1080/00207233.2020.1802937

Coccia M. 2021e. The relation between length of lockdown, numbers of infected people and deaths of COVID-19, and economic growth of countries: Lessons learned to cope with future pandemics similar to COVID-19. Science of The Total Environment, vol. 775, number 145801, https://doi.org/10.1016/j.scitotenv.2021.145801

Coccia M. 2022. Meta-analysis to explain unknown causes of the origins of SARS-COV-2. Environmental Research, vol. 111, Article n. 113062. https://doi.org/10.1016/j.envres.2022.113062

Coccia M. 2022a. Effects of strict containment policies on COVID-19 pandemic crisis: lessons to cope with next pandemic impacts. Environmental Science and Pollution Research, DOI: 10.1007/s11356-022-22024-w, https://doi.org/10.1007/s11356-022-22024-w

Coccia M. 2022b. Improving preparedness for next pandemics: Max level of COVID-19 vaccinations without social impositions to design effective health policy and avoid flawed democracies. Available online 31 May 2022, n. 113566. https://doi.org/10.1016/j.envres.2022.113566

Coccia M. 2022c. Preparedness of countries to face covid-19 pandemic crisis: Strategic positioning and underlying structural factors to support strategies of prevention of pandemic threats. Environmental Research, Volume 203, n. 111678, https://doi.org/10.1016/j.envres.2021.111678.

Coccia M. 2022d. COVID-19 Vaccination is not a Sufficient Public Policy to face Crisis Management of next Pandemic Threats. Public Organization Review, https://doi.org/10.1007/s11115-022-00661-6

Coccia M. 2022e. Optimal levels of vaccination to reduce COVID-19 infected individuals and deaths: A global analysis. Environmental Research, vol. 204, Part C, March 2022, Article number 112314, https://doi.org/10.1016/j.envres.2021.112314

Coccia M. 2022f. COVID-19 pandemic over 2020 (with lockdowns) and 2021 (with vaccinations): similar effects for seasonality and environmental factors. Environmental Research, Volume 208, n. 112711. https://doi.org/10.1016/j.envres.2022.112711

Crow D. A., Albright E. A., Ely T., Koebel, E., Lawhon L. 2018. Do disasters lead to learning? Financial policy change in local government. Review of Policy Research, 35(4), 564–589.

Dai, H., Cao, W., Tong, X. et al. 2022. Global prediction model for COVID-19 pandemic with the characteristics of the multiple peaks and local fluctuations. BMC Med Res Methodol 22, 137 (2022). https://doi.org/10.1186/s12874-022-01604-x

Daszak P., Olival K. J., Li H. 2020. A strategy to prevent future epidemics similar to the 2019-nCoV outbreak, Biosafety and Health, http://dx.doi.org/10.1016/j.bsheal.2020.01.003

Dobson, A. P., Carper, E. R. 1996. Infectious diseases and human population history. Bioscience 46, 115–126 (1996).

Douglas W. Allen (2022) Covid-19 Lockdown Cost/Benefits: A Critical Assessment of the Literature, International Journal of the Economics of Business, 29:1, 1-32, DOI: 10.1080/13571516.2021.1976051

Farazmand A. (ed.) 2001. Handbook of crisis and emergency management. Marcel Dekker, New York.

Farazmand A. (ed.) 2014. Crisis and Emergency Management. Theory and Practice, Second Edition. Routledge.

Gigerenzer G., Todd P. M. 1999. Ecological rationality: the normative study of heuristics. In Gigerenzer Gerd; Todd Peter M. The ABC Research Group (eds.). Ecological Rationality: Intelligence in the World. New York: Oxford University Press. pp. 487–497.

Goolsbee, A. and Syverson, C., 2021. Fear, lockdown, and diversion: Comparing drivers of pandemic economic decline 2020. Journal of Public Economics, 193:104311.

Groh M. 2014. Strategic Management in Times of Crisis. American Journal of Economics and Business Administration. 6 (2): 49–57.

Hellman, M. A., Savage, E. P. & Keefe, T. J. 1986. Epidemiology of accidents in academic chemistry laboratories. Part 1. Accident data survey. J. Chem. Educ. 63, A267.

Janssen M., van der Voort H. 2020. Agile and adaptive governance in crisis response: Lessons from the COVID-19 pandemic. International Journal of Information Management, vol. 55, Article number 102180

Jia, Peng, Yang, Shujuan, 2020. China needs a national intelligent syndromic surveillance system. Nature Med. 26, 990. https://doi.org/10.1038/s41591-020-0921-5.

Johansson M. A., et al. 2019. An open challenge to advance probabilistic forecasting for dengue epidemics. Proc. Natl. Acad. Sci. U.S.A. 116, 24268–24274.

Johns Hopkins Center for System Science and Engineering, 2022. Coronavirus COVID-19 Global Cases, https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6 (accessed on 4 October 2022).

Jones, A.M., Harrison, R.M., 2004. The effects ofmeteorological factors on atmospheric bio aerosol concentrations-a review. Sci. Total Environ. 326, 151e180.

Kahneman D., Slovic P., Tversky A. 1982. Judgment Under Uncertainty: Heuristics and Biases. Cambridge University Press.

Kapitsinis N. 2020. The underlying factors of the COVID-19 spatially uneven spread. Initial evidence from regions in nine EU countries. Regional Science Policy and Practice, 12(6), pp. 1027-1045

Keshavamurthy, R., Dixon, S., Pazdernik, K.T., Charles, L.E. 2022Predicting infectious disease for biopreparedness and response: A systematic review of machine learning and deep learning approaches. One Health15,100439

Khandia, R., Singhal, S., Alqahtani, T., Kamal, M. A., El-Shall, N. A., Nainu, F., Desingu, P. A., & Dhama, K. (2022). Emergence of SARS-CoV-2 Omicron (B.1.1.529) variant, salient features, high global health concerns and strategies to counter it amid ongoing COVID-19 pandemic. Environmental research, 209, 112816. https://doi.org/10.1016/j.envres.2022.112816

Korolev, I., 2021. Identification and estimation of the SEIRD epidemic model for COVID-19. J. Econometrics, 220(1): 63-85.

Krechetov, M., Esmaieeli Sikaroudi, A.M., Efrat, A. et al. 2022. Prediction and prevention of pandemics via graphical model inference and convex programming. Sci Rep 12, 7599 (2022). https://doi.org/10.1038/s41598-022-11705-8

Kuvvetli Y., Deveci M., Paksoy T., Garg H., 2021. A predictive analytics model for COVID-19 pandemic using artificial neural networks. Decision Analytics Journal, vol. 1, n. 100007, https://doi.org/10.1016/j.dajour.2021.100007.

Li Na, Hu Lingfei, Jin Aijun, Li Jinsong 2019. Biosafety laboratory risk assessment, Journal of Biosafety and Biosecurity, vol. 1, n. 2, pp. 90-92. https://doi.org/10.1016/j.jobb.2019.01.011

Liu Z., Magal P., Webb G. 2021a. Predicting the number of reported and unreported cases for the COVID-19 epidemics in China, South Korea, Italy, France, Germany and United Kingdom. Journal of theoretical biology, 509, 110501. https://doi.org/10.1016/j.jtbi.2020.110501

Liu, X. X., Fong, S. J., Dey, N., Crespo, R. G., & Herrera-Viedma, E. (2021). A new SEAIRD pandemic prediction model with clinical and epidemiological data analysis on COVID-19 outbreak. Applied intelligence (Dordrecht, Netherlands), 51(7), 4162–4198. https://doi.org/10.1007/s10489-020-01938-3

Mahmoudi, J., Xiong, C. 2022. How social distancing, mobility, and preventive policies affect COVID-19 outcomes: Big data-driven evidence from the District of Columbia-Maryland-Virginia (DMV) megaregion. PloS one, 17(2), e0263820. https://doi.org/10.1371/journal.pone.0263820

McDonald D. J. et al., 2021. Can auxiliary indicators improve COVID-19 forecasting and hotspot prediction? Proc. Natl. Acad. Sci. U.S.A. 118, e2111453118 (2021).

Ménard, A. D., Trant, J. F. (2020). A review and critique of academic lab safety research. Nature chemistry, 12(1), 17–25. https://doi.org/10.1038/s41557-019-0375-x

Mohammadi, Z., Cojocaru, M.G., Thommes, E.W. 2022. Human behaviour, NPI and mobility reduction effects on COVID-19 transmission in different countries of the world. BMC Public Health, 22(1),1594

Newby J. M., O'Moore K., Tang S., Christensen H., Faasse K. 2020. Acute mental health responses during the COVID-19 pandemic in Australia. PloS one, 15(7), e0236562. https://doi.org/10.1371/journal.pone.0236562

Núñez-Delgado A., Bontempi E., Coccia M., Kumar M., Farkas K., Domingo, J. L. 2021. SARS-CoV-2 and other pathogenic microorganisms in the environment, Environmental Research, Volume 201, n. 111606, https://doi.org/10.1016/j.envres.2021.111606.

Petticrew, M., Roberts, H. (2005). Systematic reviews in the social sciences: A practical guide. Malden, MA: Blackwell Publishing.

PStangier, U., Kananian, S., Schüller, J. 2022erceived vulnerability to disease, knowledge about COVID-19, and changes in preventive behavior during lockdown in a German convenience sample. Current Psychology41(10), pp. 7362-7370

Reinhart A. et al., 20221. An open repository of real-time COVID-19 indicators. Proc. Natl. Acad. Sci. U.S.A. 118, e2111452118.

Rosario Denes K.A., Mutz Yhan S., Bernardes Patricia C., Conte-Junior Carlos A., 2020. Relationship between COVID-19 and weather: Case study in a tropical country. International Journal of Hygiene and Environmental Health 229, 113587

Rosenfeld, R., & Tibshirani, R. J. (2021). Epidemic tracking and forecasting: Lessons learned from a tumultuous year. Proceedings of the National Academy of Sciences of the United States of America, 118(51), e2111456118. https://doi.org/10.1073/pnas.2111456118

Sagan A., Thomas S., McKee M., Karanikolos M., Azzopardi-Muscat N., de la Mata I., Figueras J. 2020. COVID-19 and health systems resilience: lessons going forwards, Eurohealth 2020; 26(2).

Seeger M. W., Sellno T. L., Ulmer R. R. 1998. Communication, organization and crisis. Communication Yearbook. 21: 231–275.

Simmons, H. E., Matos, B. & Simpson, S. A. 2017. Analysis of injury data to improve safety and training. J. Chem. Health Saf. 24, 21–28.

Sirois, F. M., & Owens, J. 2021. Factors Associated With Psychological Distress in Health-Care Workers During an Infectious Disease Outbreak: A Rapid Systematic Review of the Evidence. Frontiers in psychiatry, 11, 589545. https://doi.org/10.3389/fpsyt.2020.589545

Šušteršič T, Blagojević A, Cvetković D, Cvetković A, Lorencin I, Šegota SB, Milovanović D, Baskić D, Car Z and Filipović N (2021) Epidemiological Predictive Modeling of COVID-19 Infection: Development, Testing, and Implementation on the Population of the Benelux Union. Front. Public Health 9:727274. doi: 10.3389/fpubh.2021.727274

Tsiotas, Dimitrios; Magafas, Lykourgos. 2020. The Effect of Anti-COVID-19 Policies on the Evolution of the Disease: A Complex Network Analysis of the Successful Case of Greece. Physics 2, no. 2: 325-339. https://doi.org/10.3390/physics2020017

Uman L. S. (2011). Systematic reviews and meta-analyses. Journal of the Canadian Academy of Child and Adolescent Psychiatry = Journal de l'Academie canadienne de psychiatrie de l'enfant et de l'adolescent, 20(1), 57–59.

Van Noorden, R. 2013. Safety survey reveals lab risks. Nature 493, 9–10 (2013).

Warren G. W., Lofstedt R., Wardman J. K. 2021. COVID-19: the winter lockdown strategy in five European nations. Journal of Risk Research 0:0, pages 1-27.

Wei, M., Liu, Houfeng, Chen, Jianmin, Caihong, Xu, Li, Jie, Pengju, Xu, Sun, Ziwen, 2020. Effects of aerosol pollution on PM2.5-associated bacteria in typical inland and coastal cities of northern China during the winter heating season. Environ. Pollut. 262 (2020), 114188. https://doi.org/10.1016/j.envpol.2020.114188.

Weible C.M., Nohrstedt D., Cairney P. et al. 2020. COVID-19 and the policy sciences: initial reactions and perspectives. Policy Sci 53, 225–241.

Whittaker C., Kamaura L. T., Takecian P. L., da Silva Peixoto P., Oikawa M. K., Nishiya A. S., … Sabino E. C. 2021. Three-quarters attack rate of SARS-CoV-2 in the Brazilian Amazon during a largely unmitigated epidemic. Science (New York, N.Y.), 371(6526), 288–292. https://doi.org/10.1126/science.abe9728

Wieland, T., 2020. A phenomenological approach to assessing the effectiveness of COVID-19 related nonpharmaceutical interventions in Germany. Safety Science, 131:104924.

Williams G. A., Ulla Díez S. M., Figueras J., Lessof S. 2020. Translating evidence into policy during the covid-19 pandemic: bridging science and policy (and politics). Eurohealth 2020; 26(2).

Wolfe, N., Dunavan, C. & Diamond, J. 2007. Origins of major human infectious diseases. Nature 447, 279–283 (2007). https://doi.org/10.1038/nature05775

Yuan, D., Gao, W., Liang, S., Yang, S., & Jia, P. (2020). Biosafety threats of the rapidly established labs for SARS-CoV-2 tests in China. Environment international, 143, 105964. https://doi.org/10.1016/j.envint.2020.105964

Zhong, J., Zhang, X., Dong, Y., Wang, Y., Wang, J., Zhang, Y., et al., 2018. Feedback effects of boundary-layer meteorological factors on explosive growth of PM2.5 during winter heavy pollution episodes in Beijing from 2013 to 2016. Atmos. Chem. Phys. 18, 247e258.