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Changes in human-nature relations during pandemic outbreaks: a big data analysis

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HIGHLIGHTS
• This study examines changes in human-nature relations during pandemic outbreaks.
• Big data analysis was applied to global news related to SARS, Swine flu, MERS, and Ebola.
• Big data analysis can support the analysis of pandemic impacts on cultural ecosystem services.
• Regulating and supporting ecosystem services may be less recognized and valued by the public.
• The media’s human-centric views signal a challenge to adapt to nature-based solutions.

GRAPHICAL ABSTRACT

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ABSTRACT
Pandemic outbreaks can cause diverse impacts on society by altering human-nature relations. This study analyzed these relational changes during the severe acute respiratory syndrome (SARS), Swine flu, Middle East respiratory syndrome (MERS), and Ebola outbreaks by applying machine learning and big data analyses of global news articles. The results showed that social-ecological systems play vital roles in analyzing indirect pandemic impacts. Herein, major pandemic impacts, including reduced use of cultural ecosystem services, can be analyzed by big data analyses at the global scale. All the identified pandemic impacts herein were linked to provisioning and cultural ecosystem services, implying that these ecosystem services might be more recognized or valued more by the public than regulating and supporting ecosystem services. Further, the pandemic impacts were presented with human-centric views, indicating a challenge to adapting nature-based solutions to mitigate the risk of future pandemic emergences. These findings will advance the current knowledge of diverse pandemic impacts and human-nature relations.

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1. Introduction
Pandemic outbreaks can have devastating impacts on human well-being (Di Marco et al., 2020; McCloskey et al., 2020; Naidoo and Fisher, 2020; Remuzzi and Remuzzi, 2020). Historically, several pandemic diseases have emerged globally, including severe acute
respiratory syndrome (SARS), swine flu, Middle East respiratory syndrome (MERS), and Ebola (Di Marco et al., 2020; Feldmann and Geisbert, 2011; Li et al., 2005; Nelson et al., 2015). Currently, COVID-19 is rapidly altering health, economic, and environmental systems worldwide (Chakraborty and Maity, 2020; McCloskey et al., 2020; Remuzzi and Remuzzi, 2020; Zambrano-Monserrate et al., 2020). To date, the major impacts of this pandemic include the deterioration of both human health and economies (Bonaccorsi et al., 2020; Chakraborty and Maity, 2020; Naidoo and Fisher, 2020; Pike et al., 2014). However, these impacts do not encompass all the impacts of COVID-19. Pandemic outbreaks have the ability to change human-nature relations, such as our direct access to nature (Slater et al., 2014). However, these impacts do not encompass all the impacts of COVID-19. Pandemic outbreaks have the ability to change human-nature relations, such as our direct access to nature (Slater et al., 2014) and diverse economic activities that rely on and influence nature (Bonaccorsi et al., 2020; Chakraborty and Maity, 2020). These changes can ultimately alter the public’s well-being as it relies heavily on the diverse contribution of nature to people (Díaz et al., 2018; Millennium Ecosystem Assessment, 2005). Therefore, it is vital to investigate the pandemic’s impacts from a human-nature relations perspective in order to further our understanding of the impacts that pandemics inflict on our society.

Big-data analyses have been increasingly applied to investigate the impact of pandemics. Characterized by high volume, high velocity, and high variety (Chen and Zhang, 2014; Goodchild, 2013; Saligain, 2017), big data has the potential to support pandemic analyses that could not be efficiently conducted using conventional data. For example, Twitter data can support a real-time analysis of the public’s attention and perception related to the 2009 H1N1 (Ahmed et al., 2019; Chew and Eysenbach, 2010) and Ebola outbreaks (Odlum and Yoon, 2015). Social media image services, such as Instagram and Flickr, can be used to analyze the public’s fears and sentiments related to the Ebola outbreak (Seltzer et al., 2015). Further, news data have been applied to analyze outbreaks, including H1N1 and SARS (Hoffman and Justicz, 2016; Tian and Stewart, 2005). These studies focus on the application of big data to monitor the emergence of pandemic outbreaks and analyze public perception related to them. However, there is a lack of big data applications regarding pandemic impacts from a human-nature relation perspective, even though it has the potential to reveal empirical evidence of diverse pandemic impacts and could provide new insights regarding complex the human-nature relations.

To examine the pandemic impacts, this study analyzed changes in human-nature relations during the SARS, swine flu, MERS, and Ebola outbreaks with the research question: “How do human-nature relations change during global pandemic outbreaks?” Using machine learning techniques, the big data of 20,221 news articles worldwide related to the pandemic outbreaks and nature were examined. In order to comprehensively interpret the big data analysis results, a content analysis was conducted based on the conceptual frameworks of ecosystem services (Guerry et al., 2015; Millennium Ecosystem Assessment, 2005), nature’s contributions to people (Díaz et al., 2018), ecological footprints (Hoekstra and Wiedmann, 2014), and social-ecological systems (Folke, 2006; Young et al., 2006). The findings herein will provide several insights that may advance our understanding of pandemic impacts and human-nature relations, including the potential of big data analysis to support investigating pandemic impacts on cultural ecosystem services at a global level, diverse relations between ecosystem services and social systems, and a potential challenge to adapting nature-based solutions to mitigate the risk of future pandemic emergencies.

2. Methods

2.1. Data collection

Global news articles related to pandemics and nature were collected in April 2020 from Factiva, which is a global news database (Factiva, 2020). To search for pandemic news articles related to nature, search terms were established by investigating key environmental topics categorized by Mongabay, which is a news media platform that focuses on diverse conservation issues related to forests, wildlife, oceans, and the conservation sector (Mongabay, 2020). The established search terms were: “[Pandemic name] AND (Agriculture OR Energy OR ‘Palm Oil’ OR Animal” OR Wildlife OR Mammal” OR Conservation OR ‘Climate Change’ OR Deforestation OR Forest” OR Rainforest” OR ‘Indigenous People”’ OR Ocean”). Here, [Pandemic name] was interchanged with SARS, Swine flu, MERS, and Ebola to provide four search results for each pandemic outbreak. Having defined the scope, these terms did not allow us to cover all possible nature-related words. However, these terms did enable us to cover keywords linked to the major global environmental issues identified by Mongabay, which is specialized in reporting these issues. Moreover, only English articles were collected to ensure that each article was examined consistently using the machine learning techniques. Consequently, the studied articles were not in different languages. Nevertheless, the English articles covered major pandemic issues globally. For each pandemic, a year with the largest number of news articles was identified. Then, all the news articles published in that year using our search terms were collected. As a result, the collected text data obtained 11,846 SARS-related articles published in 2003, 9,414 Swine flu-related articles in 2009, 585 MERS-related articles in 2012, and 16,203 Ebola-related articles in 2014 (Fig. 1). These articles concerned various locations in the world where the pandemic outbreaks emerged, as well as the locations where news articles were reported (Fig. 2).

2.2. Text classification

Text classification was utilized to separate nature-related articles from non-nature articles for each pandemic (Fig. 1). Text classification is a supervised machine learning method that enables the classification of a massive amount of text data, including identifying spam emails (Bird et al., 2009). Training data for classification models were established by reviewing the collected articles for each pandemic outbreak. This training data consisted of two types of data: input data (x) and output data (y). The input data were the collected pandemic-related news articles or a corpus of news texts. The text data used for the text classification were prepared by tokenization, lower casing, removing stop words, and lemmatization (Bird et al., 2009). Vectorization of the text data was based on the term frequency-inverted document frequency (TF-IDF) approach. Meanwhile, the output data were developed as a discrete variable that showed whether pandemic-related articles were also related to nature (nature-related, where y = 1) or not (non-nature-related, where y = 0). Thus, these training data enabled a machine to learn how to classify nature-related articles based on the function: y = f(x). Training data for the SARS-classification model had 470 nature-related and 470 non-nature-related articles. That for the Swine flu model consisted of 412 nature-related and 412 non-nature-related articles. The training data for the MERS model contained 51 nature-related and 51 non-nature-related articles. Finally, those for the Ebola model had 1045 nature-related and 1045 non-nature-related articles. To train each pandemic model, 67% of the training data were used for model training, and the remaining 33% were used to validate the classification results. All models were developed using the Naive Bayes classifier. The validation results showed that the SARS classification model achieved 88% accuracy, identifying 6096 nature-related articles. With 86% accuracy, the Swine flu model identified 5133 nature-related articles. The MERS model had 97% accuracy, finding 350 nature-related articles, and the Ebola model had 92% accuracy, identifying 8642 nature-related articles. Scikit-learn and Python were used for text classification (Pedregosa et al., 2011).

2.3. Topic modeling

Topic modeling was utilized to identify existing topics among the nature-related articles identified from the text classification (Fig. 1).
Topic modeling is an unsupervised machine learning method (Jacobi et al., 2016) that allows the identification of latent patterns of word occurrence in the word distribution of massive text data. In this study, topic modeling was conducted based on non-negative matrix factorization (NMF) (Lee and Seung, 1999) because the NMF method requires the determination of only a few parameters, thus achieving more stable...
and coherent modeling outcomes (Belford et al., 2018; Greene and Cross, 2017). The number of topics in each pandemic topic model was chosen by the number \(k\) generating the highest mean topic coherence using the Word2Vec tool (Greene and Cross, 2017; Mikolov et al., 2013). The Word2Vec tool computes the semantic similarity between term vectors (e.g., semantic similarity between the meanings of “animal” and “cat”) by analyzing all terms included in a large quantity. Consequently, a topic can obtain a high coherence when high semantic similarity exists among the keywords of the topic. To determine \(k\) for each topic model, the coherence of the pandemic topic model was measured as (Greene and Cross, 2017):

\[
\text{coh}(t_h) = \frac{1}{\binom{k}{2}} \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \cos (v_i, v_j). 
\]  

(1)

where \(z\) is the number of top-ranked keywords in a topic (e.g., the top 10 keywords supporting a topic of “livestock”), \(t_h\) represents a single topic (e.g., “livestock”) with topic index \(h\), and \(v\) represents a unique pair of term vectors. The mean coherence of topic modeling was calculated by:

\[
\text{coh}(T) = \frac{1}{k-1} \text{coh}(t_h),
\]  

(2)

where \(k\) is the number of topics in the model, and \(t_h\) is a single topic. In this study, topic coherence was compared with a range of \(k\) between 1 and 30 (Fig. 3). The analysis of coherence results found that \(k\) ranged between 23 and 30 for all pandemic topic models. After \(k\) was determined for each pandemic topic model, the selected topics were further reviewed by investigating the topics’ relevance to nature. Note that some identified topics did not focus on nature. These outcomes existed not only because that the text classification models achieved only 86% to 97% accuracy in classifying nature-related articles from non-nature-related articles (as addressed in Section 2.2) but also because the main topics of some articles focused on prevention issues, such as recommendations to wear a mask and wash hands regularly, and new quarantine requirements for international travelers. Even if these articles were related to nature by analyzing virus origins and animal reservoirs, these topics were excluded from the content analysis. Here, again, Scikit-learn and Python were employed to conduct topic modeling for each pandemic outbreak (Pedregosa et al., 2011).

### 2.4. Content analysis

Content analysis was used to examine all topics identified from topic modeling (Fig. 1). Each of these topics was examined as a sampling unit for the content analysis. By reviewing all the topics related to the studied outbreaks, three groups of categories were established: 1) virus-related categories, 2) nature-related categories, and 3) categories of changes in human-nature relations. First, the virus-related categories were established based on news contents related to the SARS, Swine flu, MERS, and Ebola outbreaks, wherein the final categories included “cure”, “emergence”, “origin”, “other diseases”, “prevention”, and “transmission”. Second, the nature-related categories represented the nature component of the topics, including the final categories of “agriculture”, “animal experiment”, “animal reservoir”, “livestock”, “medicine”, “oil”, “oil and crops”, “other diseases”, “pet”, “tourism”, “virus”, “wildlife trade”, and “zoo”. Third, the categories of changes in human-nature relations included nature’s positive contributions to people (N+), nature’s negative contributions to people (N−), people’s positive contributions to nature (P+), and people’s negative contributions to nature (P−) (Fig. 4). These human–nature relations were intertwined with various frameworks, such as ecosystem services (N+) (Guerry et al., 2015; Millennium Ecosystem Assessment, 2005), nature’s contributions to people (N+ and N−) (Díaz et al., 2018), conservation (P+), ecological footprint (P−) (Hoekstra and Wiedmann, 2014), and social-ecological systems (N+, N−, P+, and P−) (Folke, 2006; Young et al., 2006). Changes in these human–nature relations during the pandemic outbreaks were examined as an increase ([N−]-[N+] or decrease ([N+]-[N−]) of these relations. When multiple categories were related to
a topic, the most relevant category was selected based on the main messages and focus of the news article.

3. Results and discussion

The results herein revealed various topics highlighted in the global news media (Fig. 5 and Supplementary Information). Specifically, many topics focused on nature’s negative contributions to people (N−), wherein most of these topics (43 topics) concentrated on an increase in nature’s negative contributions to people ([N−]↗). Despite the large topic number, these topics were only grouped into three categories of changes in human-nature relations. The dominant category, “virus,” indicated an increase in the SARS, Swine flu, MERS, and Ebola viruses by discussing their emergence, potential origins, or transmission. This category was observed in all pandemics. Another category was “other diseases,” illustrating other disease outbreaks that were compared with the pandemic outbreaks, which included the Spanish flu, bird flu, or mad cow disease. “Animal reservoir” illustrated the roles of domestic and/or wild animals (e.g., camels, fruit bats, and pigs) in transmitting pandemic diseases. Notably, only two topics focused on a decrease in nature’s negative contributions to people ([N−]↘), wherein they were categorized as “virus,” and addressed the prevention of viral contagion through enhanced monitoring systems (e.g., increased inspection).

The results also revealed multiple topics related to nature’s positive contributions to people (N+), wherein 26 topics focused on a decrease in nature’s positive contributions to people ([N+]↘). These topics represented the reduction of various ecosystem services during the SARS, Swine flu, MARS, and Ebola outbreaks. These ecosystem services were either provisioning or cultural ecosystem services. Provisioning services included reduced product consumption related to “agriculture”, “livestock”, and “wildlife”, owing to import bans by governments, reduced consumer demand, and/or reduced food supply. These changes not only affected the agricultural sector in developed countries (e.g., the Swine flu in North America) but also caused food security issues in developing countries (e.g., Ebola in West Africa). In addition, the topic of “livestock” was dominantly observed in the Swine flu model, while “wildlife trade” was identified for the SARS and Ebola outbreaks. A decreased use of “crops” was caused by reduced feedstock consumption.

Fig. 4. Framework of human-nature relations applied. These relations correspond to multiple frameworks of human-nature relations. Pandemic impacts were analyzed in terms of a decrease (\(\downarrow\)) or an increase (\(\uparrow\)) of these relations.

Fig. 5. Changes in human-nature relations highlighted in the global news media during the severe acute respiratory syndrome (SARS), Swine flu, Middle East respiratory syndrome (MERS), and Ebola outbreaks. [N−]↗ indicates an increase in nature’s negative contributions to people during the pandemic outbreaks. [N−]↘ denotes a decrease in nature’s negative contributions to people. [N+]↘ shows a decrease in nature’s positive contributions to people, and [N+]↗ shows an increase in nature’s positive contributions to people. (The sources of virus images: CDC/Alissa Eckert, MSMI; Dan Higgins, MAMS; Frederick Murphy; E. Palmer; and R.E. Bates).
for livestock businesses (e.g., the hog industry), and a decreased use of “oil” resulted from a reduced demand for crude oil due to pandemic impacts on international travelers and airlines. Meanwhile, reduced use of cultural ecosystem services included restricting people’s relations with “pets”, such as dogs and cats, owing to the pets’ potential infection and transmission of the viruses. “Tourism” represented reduced tourism in nature, such as Safari, parks, and islands, linked with prevention of the viruses. Specifically, “Zoo” indicated reduced visitors to a zoo during the SARS outbreak, affecting the financial capacity of the zoo to feed animals. Conversely, 11 topics represented an increase in nature’s positive contributions to people ([N+]/↘). “Medicine” showed use of pharmaceutical materials or viruses to develop medicine or vaccines for the pandemic viruses. “Animal experiments” indicated the use of animals in laboratories to test vaccines, such as monkeys and mice. “Livestock” indicated an expected increase in pork exports from Brazil, as many countries banned pork imports from Mexico where Swine flu infections occurred.

These findings provided the following insights: 1) social-ecological systems can play important roles in examining diverse indirect pandemic impacts; 2) impacts on cultural ecosystem services are major pandemic impacts, wherein big data analyses can support analyzing these impacts at a global scale; 3) provisioning and cultural ecosystem services are more closely linked with social systems than regulating and supporting ecosystem services; and 4) the news media’s human-centric views of human-nature relations imply a potential challenge to adapt to nature-based solutions to mitigate the risk of future pandemic emergence.

First, many indirect impacts of the pandemic outbreaks were determined by diverse feedback between ecological and social systems. The results showed that provisioning ecosystem services were reduced by the Swine flu, SARS, and Ebola outbreaks (Fig. 5). However, reducing these ecosystem services had different impacts on social systems because these viruses are associated with different natural reservoirs (or ecological systems), and these natural reservoirs are linked to different social systems. Being spread by hogs (Nelson et al., 2015), Swine flu substantially affected social systems related to the hog industry and other sectors providing feedstock for hogs. As they were considered to be carried by wildlife animals, such as fruit bats (Feldmann and Geisbert, 2011; Li et al., 2005), the SARS and Ebola outbreaks dominantly affected social systems related to wildlife, such as Safari tourism and wildlife trade. In addition, food supply was restricted by the Swine flu and Ebola outbreaks. However, their impacts differed between advanced and advancing countries (or social systems) as advanced countries are linked with multiple food systems (or ecological systems), and advancing countries rely on a few vulnerable food systems. The Swine flu outbreak affected the hog industry in developed countries, such as Canada, but it did not cause food security issues in those countries. Meanwhile, the Ebola outbreak hampered food security in West Africa, as these countries have limited food-provisioning ecosystems. These findings highlight that the framework of social and ecological systems play important roles in analyzing indirect pandemic impacts on our society. These findings are supported by COVID-19 studies in the literature in that COVID-19 impacts on food security can be influenced by the availability of different social systems, such as online food delivery systems, a system to measure food safety, and Industry 4.0 technologies supporting real-time monitoring of food supply chains (Galanakis, 2020; Galanakis et al., 2020; Rizou et al., 2020).

Second, reduced access to cultural ecosystem services was one of the major pandemic impacts identified by the global news media, wherein big data analyses exhibited the potential to support analyzing these cultural impacts globally. As it is critical to understand how pandemic’s impact human health and economic activities, which are the major pandemic impacts, these impacts are a primary focus of various pandemic studies (Bonaccorsi et al., 2020; Pike et al., 2014) and the main focus of the global news media (e.g., virus [N−]/↗ and agriculture [N+]/\) (Fig. 5). However, the results herein revealed that pandemic outbreaks reduce people’s access to cultural ecosystem services by restricting their relations with companion animals (e.g., cats, dogs, and zoo animals) and nature (e.g., national parks and islands, and safari parks). These cultural ecosystem services significantly contribute to human well-being, such as improving mental health (Wells, 2009; Wolf and Robbins, 2015). Therefore, it is necessary to integrate pandemic impacts on cultural ecosystem services to analyze the overall pandemic impacts on human well-being. However, measuring cultural ecosystem services is often challenging as there is a lack of empirical evidence (Hernández-Morcillo et al., 2013), particularly at the global scale. This study illustrates that big data analysis can be used to obtain this empirical evidence at a global level.

Third, the findings indicate that different types of ecosystem services might have different relations with social systems. All the identified ecosystem services in this study were either provisioning (e.g., agricultural products) or cultural ecosystem services (e.g., nature-based tourism) (Fig. 5). None of these findings represented regulating (e.g., climate regulation by forests) and supporting ecosystem services (e.g., soil nutrients for crops). This implies that social systems might be able to have more immediate impacts on provisioning and cultural ecosystem services than regulating and supporting services. Therefore, the public and, in turn, the news media pay more attention to changes in provisioning and cultural ecosystem services, compared to regulating and supporting ecosystem services, as their understanding of regulating and supporting ecosystem services is limited compared to their understanding of provisioning and cultural ecosystem services. These different interests of the news media for different types of ecosystem services must be considered when managing ecosystem services as this difference could affect ecosystem service management due to the public’s differing support and subsequent valuation of ecosystem services. In addition, these results provide insights for valuation of ecosystem services in that some valuation methods, such as gross ecosystem product (GEP), explicitly count the roles of social systems (e.g. human labor and human-made inputs) when valuing different types of ecosystem services (e.g. regulating vs. provisioning ecosystem services) (Ouyang et al., 2020).

Fourth, the global news media’s views of pandemic outbreaks were human-centric, posing a challenge to integrate nature-based solutions to mitigate the risks of future pandemic emergences. All changes in human-nature relations highlighted by the news media were concerning what people receive from nature (N+ and N−) rather than what people provide to nature (P+ and P−) (Figs. 4 and 5). This lack of the media attention to “what people provide to nature (P+ and P−)” reflects the public’s limited interests in these particular human-nature relations. As a result, these human-centric relations act as an obstacle for adapting nature-based solutions to manage the risk of future pandemic emergence, such as biodiversity conservation (P+). Biodiversity conservation not only prevents the emergence of new infectious diseases from nature by restricting their potential interactions with social systems (Di Marco et al., 2020; Keesing et al., 2010) but also supports conserving unknown medicines in ecosystems (Díaz et al., 2018; Millennium Ecosystem Assessment, 2005) for future pandemic viruses (e.g., medicine [N+]/\). However, the implication of these nature-based solutions would require the public’s interests and support for these approaches to be successfully integrated into policymakers’ decision making. Consequently, the human-centric views of human-nature relations in our society pose a challenge for applying a nature-based solution to managing the risk of future pandemic emergence.

4. Conclusions

This study identified diverse pandemic impacts on human well-being by employing a big data analysis of changes in human-nature relations during the SARS, Swine flu, MERS, and Ebola outbreaks. The findings herein provided empirical evidence for various pandemic impacts, showing that by analyzing social-ecological systems, we can
identify various indirect pandemic impacts on society. In addition to affecting human health and economic activities, impacts on cultural ecosystem services were considered to be major pandemic impacts. Thus, analyzing these impacts is vital, and this study illustrated that big data analysis can support such analysis at a global level. While focusing on provisioning and cultural ecosystem services, the global news media analysis can support such analysis at a global level. While focusing on analyzing these impacts is vital, and this study illustrated that big data system services were considered to be major pandemic impacts. Thus, identify various indirect pandemic impacts on society. In addition to big data sources applicable to pandemic studies, which will enrich our news media data, moreover, future studies can explore other potential big data sources applicable to pandemic studies, which will enrich our understanding of diverse pandemic impacts on human–nature relations.

CRediT authorship contribution statement

Wangal Jaung: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition.

Declaration of competing interest

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

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