Nguyen and Liou *Geoscience Letters* (2024) 11:9
https://doi.org/10.1186/s40562-024-00322-0

Geoscience Letters

RESEARCH LETTER

Open Access

Rethinking our world: a perspective on a cleaner globe emerging from reduced anthropogenic activities

Kim-Anh Nguyen[1,2] and Yuei-An Liou[3*]

Abstract

Stringent measures, such as lockdowns, were implemented to curb the virus's spread, leading to reduced pollution levels and environmental improvements at various geographic scales, from cities to regions and nations. Such positive effects have been found and reported for regional scales, but not for a global scale till nowadays. This study aims to fill the gap by uncovering the modifications of global spatiotemporal eco-environmental vulnerability patterns between pre-pandemic (2016) and amid-pandemic (2020) periods. By analyzing various factors influencing the eco-environmental health or geo-health, such as human activities, climate change, and ecological dynamics, we seek to understand the intricate relationships and dynamics within these influential factors. We examined six categories of environmental vulnerability, which encompassed socioeconomics, land resources, natural hazards, hydrometeorology, and topography, using a five-dimensional stressor framework. Our analysis revealed a significant decrease in vulnerability levels across all categories, except for the very low level increased by 78.5% globally. These findings emphasize the detrimental impact of human activities on the global environment. They underscore the urgency of implementing spatial management strategies that prioritize sustainable geo-health development and foster a more resilient Earth.

Keywords Global eco-environment vulnerability, Spatiotemporal changes, Nature and human impacts, COVID-19, Lockdown, Land-based eco-environment, Geo-health

Introduction

The global environment is undergoing deterioration due to a combination of human actions and natural variations (Tilman 1999; Tilman and Lehman 2001). Concurrently, urbanization has been shown to diminish, if not impede, the ecological services provided by greenspaces (Tran and Liou 2024; Nguyen and Liou 2024) and elevate the susceptibility to flash flood in mountainous regions (Hoang and Liou 2024). Understanding the magnitude and spatial distribution of the eco-environmental vulnerability caused by natural changes and human-made impacts is a crucial step in safeguarding the geo-health. Nguyen and Liou (2019a) presented a global assessment framework to evaluate and visualize the eco-environmental vulnerability from human and natural disturbances by using freely accessible global datasets. Give the scope of our study, the term "eco-environmental vulnerability is defined as the risk of damage to the natural environment or particular ecosystem because of any disturbances, including internal physical/structural features and external dynamics (Nguyen et al. 2016). Their study showed that in 2016 Asia was the most vulnerable region with China and India as the two leading countries. It has

*Correspondence:
Yuei-An Liou
yueian@csrsr.ncu.edu.tw
[1] Institute of Geography, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet Rd., Cau Giay, Hanoi 100 000, Vietnam
[2] Graduate University of Science and Technology, Vietnam Academy of Science and Technology, Hanoi 100000, Vietnam
[3] Center for Space and Remote Sensing Research, National Central University, 300, Jhongda Rd., Jhongli District, Taoyuan 32001, Taiwan, ROC

been suggested that the COVID-19 pandemic has benefited the environment and climate by reducing human disturbances relating to lockdown measures (UNECE, Coll 2020). According to the report by the World Economic Forum (WEF), as of April 7, 2020, about half of the world's population was under some form of lockdown, with more than 3.9 billion people in more than 90 countries experienced some form of lockdown globally, and their mobility was restricted by respective governments to control COVID-19 transmission (World Economic Forum 2020). Due to the lockdown, various industries, business and transportation were significantly reduced or halted, resulting in an apparent reduction of greenhouse gas emissions, as vehicles and airplanes, which are major sources of greenhouse gas emissions (GHG), were used less frequently (Henriques 2020). As a result, the environment has been improved overall (Saadat et al. 2020; Hu et al. 2021; Goel et al. 2020; Chen et al; 2023). Moreover, Liou et al. (2023) illustrated that a substantial decline in premature deaths and welfare costs around 97,390 and over USD 74 billion, respectively. This reduction was attributed to improvements in air quality resulting from the COVID-19 lockdown measures.

To explore the change in eco-environmental vulnerability status, global freely accessible dataset that contains variables derived from satellite data is utilized in the current study. GIS modelling, analytic hierarchy process (AHP), and spatial analysis are applied for the change and vulnerability assessment (Nguyen et al. 2019). This type of quantitative method was developed and based on individual GIS-layer with variables considered and weighted overlaid to generate the eco-environmental vulnerability synthesis map (Fernández and Lutz. 2010; Liou et al. 2017; Nguyen and Liou 2019a; Nguyen et al. 2021). To date, these assessment methods have been applied to different environmental issues to assess the spatial patterns of affected status by different factors (Halpern et al. 2008; Halpern et al. 2009; Ban and Alder. 2008; Micheli et al. 2013) or natural hazard processes (Wu et al. 2022; Sansare and Mhaske. 2020; Chen 2022). These methods and study results are helpful to identify and classify the hotspots areas, and understand which stressors have the most dominating impact, and in turn, are useful to design the mitigation strategies for decision-making and environmental protection management (Halpern et al. 2009; Dai et al. 2001; Rashed and Weeks 2003; Eastman et al. 1993; Yin and Li 2001).

The impact of COVID-19 on the eco-environmental quality is examined in this study by evaluating the differences between eco-environmental vulnerability in 2020 during pandemic with its pre-pandemic status, as evaluated in a previous study presented in 2016 (Nguyen and Liou 2019a). To ensure fair comparison and consistent outcomes, we use the same data sources as earlier study but updated to 2020, and apply the same methodology. The results of our analysis can provide insights into the changes in the global inland's eco-environment and offer suggestions for sustainable and resilient eco-environmental strategies. As the COVID-19 pandemic represents a significant global experiment in reducing human impacts on the natural eco-environment, our assessment results will reveal outcomes relevant to both direct and indirect socio-economic and eco-environmental factors for a healthier earth.

Materials and methods

Assessment framework

We have utilized the framework developed and presented by Nguyen and Liou (2019a, 2019b) to quantify the global eco-environmental vulnerability status for the year 2020. The same five-dimensional stressors and sixteen indicators used in the previous study were used, but updated data and satellite products from 2020 were utilized. The eco-environmental vulnerability was classified into six levels as in the previous study: very low, low, medium, medium high, high and very high levels. Quantifying the vulnerability level is helpful to identifying regions that require prioritized environmental protection management, particularly from a top-down perspective at the global, continental, and national scales. The formulae (1,2) were used to compute the sum of weights for the indicators:

$$\mathrm{GEV} = \sum_{1}^{4} B_i * W_i \tag{1}$$

$$B_i = \sum\nolimits_{1}^{nBi} C_i * w_i \tag{2}$$

In this equation, GEV denotes the global eco-environmental vulnerability where a higher GEV value indicates greater vulnerability. B_i is the ith group determinant factor, W_i is the weight of the ith group determinant factor, C_i is the ith indicator, w_i is the weight of the ith variable, and nB_i is the number of indicators in a group determinant factor B_i introduced in Table 1 (Nguyen and Liou 2019a). The weights for the indicators are the same as those used in the previous assessment as shown in Table 2.

Comparison and analysis the eco-environmental change

To ensure fair and consistent comparison, we classified global eco-environmental vulnerability levels for both pre-pandemic (2016) and amid-pandemic (2020) using the same standard and statistical and scoring methods.

Table 1 Indicators used to evaluate global eco-environmental vulnerability including data description, and brief explanation of their roles

Major disturbance determinants	Indicators	Role in environment profile
Hydrometeorology (B_1)	Soil moisture (C_1)	Soil moisture is vitally important in controlling the exchange of water and heat energy between land surface and atmosphere through evapotranspiration and as a key variable to define flood control, soil erosion, and slope failure
	Precipitation (C_2)	Precipitation is important for soil and plant growth and useful for determination of weather patterns regarding to early warning of drought and flood
	Temperature (C_3)	Average global air temperature is useful to classify weather patterns in combination with precipitation and soil moisture
	Distance from hydrological network (C_4)	Availability of surface water is important for environment especially in urban cities for cooling heat island effect
Socioeconomics (B_2)	Population (C_5)	Population plays an important role in eco-environmental vulnerability assessment since it contributes to determine human pressure on eco-environment. In general, more people and higher population density likely cause heavier pressure on environment resulting in higher vulnerability
	Income (C_6)	This indicator shows average income of each country from high to low income (highly developed countries to developing countries). In general, in the developing countries, the eco-environment is likely to be disturbed more than developed countries since they are on the fast growing processes of urbanization and industrialization. Income also reflects the education level as well as public awareness of eco-environmental protection
	Distance from urbanized areas (C_7)	This indicator determines the influence from the urban by spatial distance. Exposure from urban affected the eco-environment by the stress from the city like pollution from vehicles and air condition, and trash from households, and wastewater. It is likely that the farther from the urban the better the eco-environment
Land resource (B_3)	Land use/land cover (LULC) (C_8)	LULC is an important determinant of eco-environmental vulnerability due to its contribution to and general influence on environmental quality. The areas without or with less vegetation cover are more vulnerable than the dense vegetation areas. Impervious surface materials conserve more heat during the day and release it more slowly at night than natural materials like soil or vegetation
	Normalized Difference Vegetation Index (NDVI) (C_9)	NDVI is a crucial indicator to measure the greenness of vegetation and vegetation plays an important role in maintaining good eco-environment. Regions that are less or without vegetation may cope with higher vulnerability
Natural hazards (B_4)	Drought (C_{10}) Tropical cyclones (C_{11}) Landslides (C_{12}) Flood (C_{13})	These indicators determine the areas constantly affected by natural hazards resulting in environmental decline
Topography (*B5*)	DEM (C_{14})	DEM plays an important role in defining topographic condition, determining the features of land surface such as incoming solar radiation, tree types, and potential exposure to hazards like landslide, and drought
	Slope constraint (C_{15})	Slope constraint is a factor influencing land-use decision and the item "Land utilization possibilities". The influence of terrain on erosion is great important. Steeper slopes are also associated with shallower soils in general and with a higher risk for soil degradation and landslides
	Slope aspect (C_{16})	Slope aspect and topographic position contribute to define annual mean temperature, potential energy incoming and evapotranspiration. Resulting in vegetation structure, ground moisture, snow retention, plant communities and surface temperature are all characteristics influenced by aspect

Table 1 (continued)

Modified and adapted from Nguyen and Liou 2019a

Table 2 Weightings of group indicators and indicators used for the calculation of global eco-environmental vulnerability

Group variables/factors (B_i)	Global weight (W_i)	Variables/factors (C_j)	Local weight (w_j)
B_1. Hydrometeorology	0.169	C_1 Soil moisture	0.384
		C_2 Precipitation	0.300
		C_3 Temperate	0.191
		C_4 Distances from hydrological network	0.125
B_2. Society–economics	0.242	C_5 Population	0.557
		C_6 Income	0.320
		C_7 Distances from urbanized areas	0.123
B_3. Land resources	0.070	C_8 LULC	0.667
		C_9 NDVI	0.333
B_4. Natural hazards	0.395	C_{10} Drought	0.250
		C_{11} Tropical cyclone	0.250
		C_{12} Landslide	0.250
		C_{13} Flood	0.250
B_5. Topography	0.123	C_{14} DEM	0.557
		C_{15} Slope constraint	0.320
		C_{16} Slope aspect	0.123

Modified and adapted from Nguyen and Liou 2019a, b. Consistency ratio of assessment is 0.007

A positive or negative score represents increased or decreased in human- or nature-made disturbance, respectively. We categorized the vulnerability scores/trends into different levels, such as very high decreasing, high decreasing, low decreasing, very low decreasing and neither decreasing nor increasing.

Validation

Validation of the global eco-environmental vulnerability map is crucial. In an earlier study, $PM_{2.5}$ data derived from the MIRS product were used. However, since MIRS data are no longer available in 2020, we used $PM_{2.5}$ data derived from MODIS. We eliminated dust using the same process as the $PM_{2.5}$ derived from the MIRS product. During the validation phase, we located 230 random points, and their vulnerability values were calculated and compared with the $PM_{2.5}$ values at the corresponding locations.

Results

Change in cumulative impact

Figure 1 shows (a) the change in the global eco-environmental vulnerability during the study period from 2016 to 2020, as well as the percentage of all six vulnerability levels considered in the study for those years. Ice-covered land (i.e. Greenland) and sea ice area are excluded for comparison, because sea ice cannot be considered in the assessment. All the vulnerability levels except the very low vulnerability level under the scenario of improving eco-environmental condition exhibit a decreasing trend, with the percentage of eco-environmental vulnerability at the very low level increasing by approximately 78.5% over the 5-year study timespan (Fig. 1a, b). The improvement of the eco-environment appears in all continents, particular in Asia, Africa and America. Globally, a decrease in vulnerability levels indicates a positive impact of COVID-19 on the environment. In the previous study conducted by Nguyen and Liou (2019a), it was found that Asia and Africa were identified as the most vulnerable continents, with China and India as the two most vulnerable countries. Interestingly, the current results indicate that China and India have experienced significant improvement in their environment due to lockdown measures, resulting in temporary slowdowns or halts. As a result, deforestation rates have decreased or slowed down, as seen in satellite images from NASA/USGS's Landsat and ESA's Sentinel-2 satellites, along with a reduction in the environmental pollution. For instance, Singh et al. (2020) reported a significant reduction in $PM_{2.5}$ and PM_{10} (by ~ 40–60%), and NO_2 (by ~ 30–70%) and CO (by ~ 20–40%) across the 134 cities in India during the lockdown.

Figure 2 shows the trend of eco-environmental vulnerability evolution. Overall, there has been a decreasing

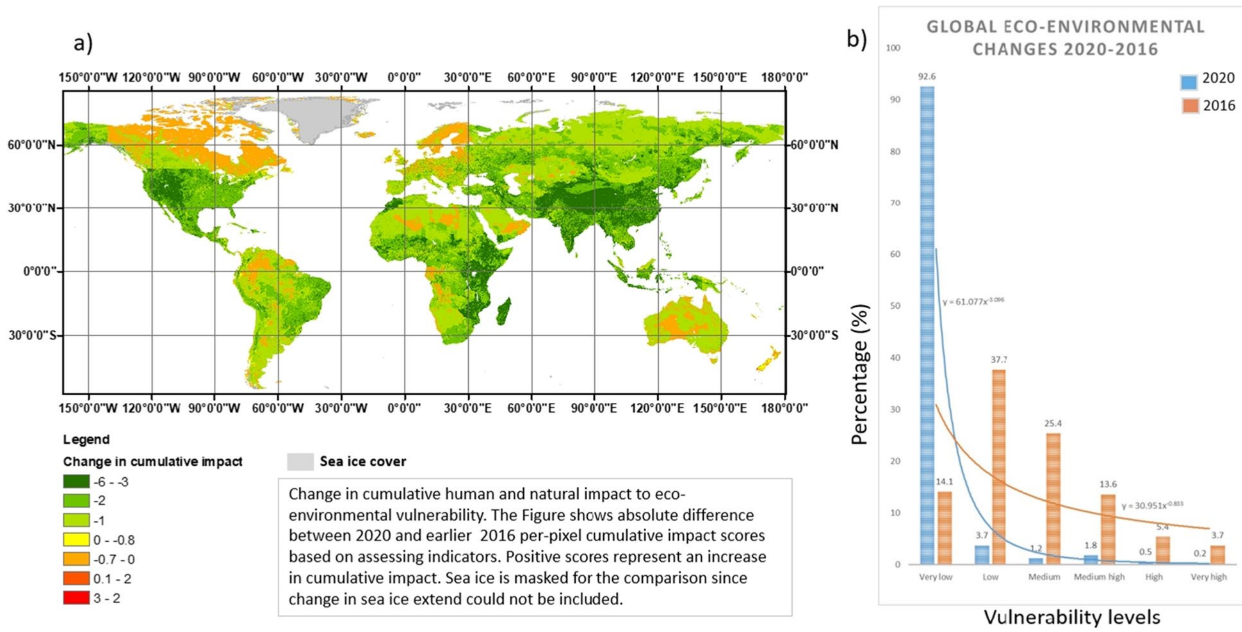

Fig. 1 Global eco-environmental vulnerability patterns and changes (2020–2016)

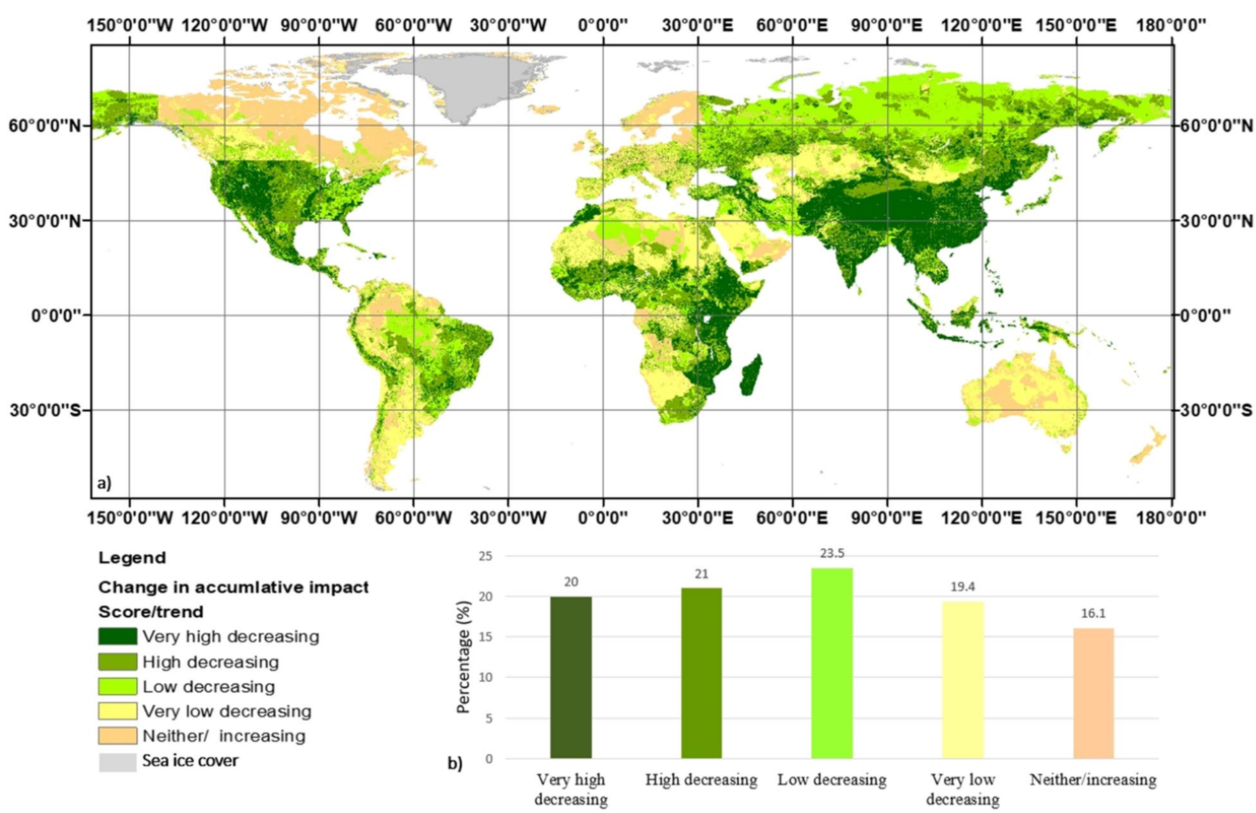

Fig. 2 Difference in vulnerability between current (as of 2020) and previous (2016) in accumulative impact scores based on the input indicators in the timeframe 2016–2020. This is the result of overlaid pixel score of 2020–2016. Positive score is defined as increasing impact and negative score is defined as decreasing impact (trend)

trend in the vulnerability worldwide from 2016 to 2020. About 41% of the global inland areas experienced a very high or high decreasing trend in vulnerability, with the most significant decreases seen in Asia, Africa, and America. A decreasing trend appears more obvious in Asia, Africa and America. In contrast, only 16.1% of global inland areas showed neither decreasing nor increasing trends, as seen in Fig. 2b. The largest decrease in vulnerability were observed in China and India, East Africa and America where very high and high vulnerabilities were identified in the 2016 assessment (Nguyen and Liou 2019a). Oceania, North Africa, high-latitude regions, and part of European countries showed a patchy mix of decreased and increased vulnerability. It is worth noting that the change in accumulative impacts correlated with spread of COVID-19. By examining the distribution of COVID-19 cases and lockdown measures on the map in 2020. (Dailymail.Co.UK), a strong link can be observed between the regions of lockdown and trend of eco-environmental status.

Current cumulative impact

Figure 3 presents a global eco-environmental vulnerability (GEV) map. The map highlights three hotspots in Asia, Africa, and America, represented by A, B, and C, respectively. Six levels of vulnerability have been defined ranging from very low to very high, with each vulnerability category's percentage distribution based on the number of pixels (where 1 pixel = 0.083 degree).

Regarding the comparison of the GEV values between 2016 (Fig. 4) and 2020 (Fig. 3), it is clearly seen that there was a reduced trend with mean values 2.17 and 0.78 in 2016 and 2020, respectively (standard deviations were 0.63 and 0.55 in 2016 and 2020, respectively). In addition, min and max values in 2016 were 0.84 and 5.0, respectively, while min and max values of GEV in 2020 were 0.26 and 0.39, respectively. This reduction trend in GEV value is due to the contribution of COVID-19 pandemic.

Validation

To validate the results of the global vulnerability map in 2020, 230 random points were selected and their values were compared with the $PM_{2.5}$ values at the same spatial locations in the same year. Spatial correlation coefficients were computed and results showed a significant correlation of 0.84 between the global maps and $PM_{2.5}$ (Fig. 5). Notably, to remove noise from the $PM_{2.5}$ data, dust was eliminated when comparing it to the global maps.

Discussion

The patterns of eco-environmental vulnerability change over the timeframe from 2016 to 2020 show an improved signal of eco-environmental vulnerability level worldwide. This improvement of vulnerability level is highly associated with decreasing human activities due to COVID-19 pandemic, with lockdown-measure implemented in many parts of world. This study offered a unique concept for global eco-environmental monitoring using freely accessible global dataset. Its outcomes alert not only the public, but also private sectors to the evolution and signatures of environmental conditions due to human-made and natural disturbances, as well as the improved inland's environment owing to the COVID-19 pandemic. It should be noted that the input data for assessment may consist of uncertainties since there may be inconsistencies in the data used in the study, possibly

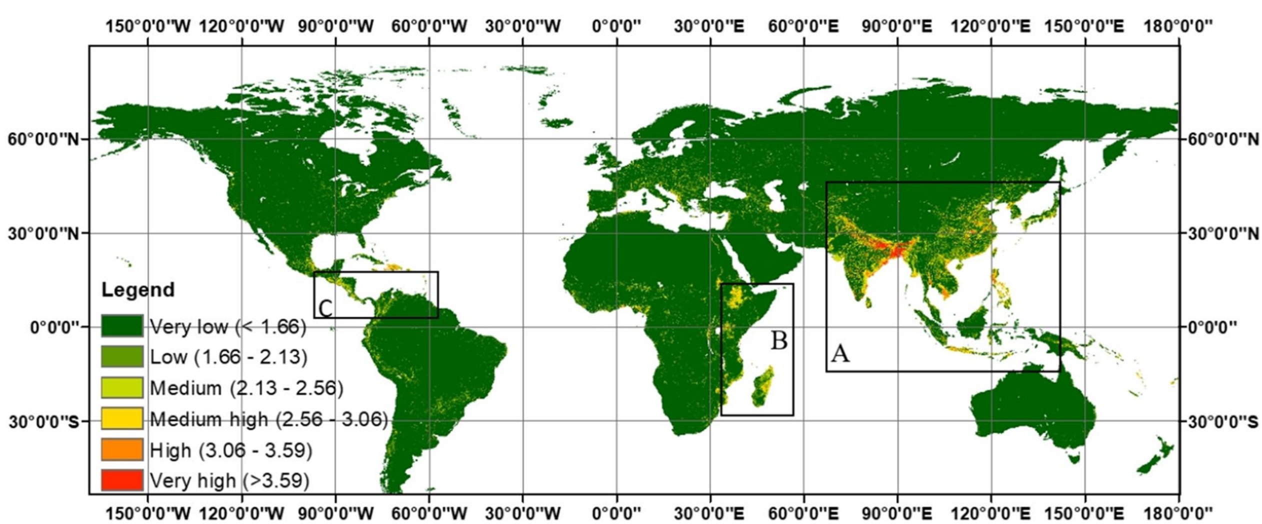

Fig. 3 Global eco-environmental vulnerability and hotspots A, B, C in continents

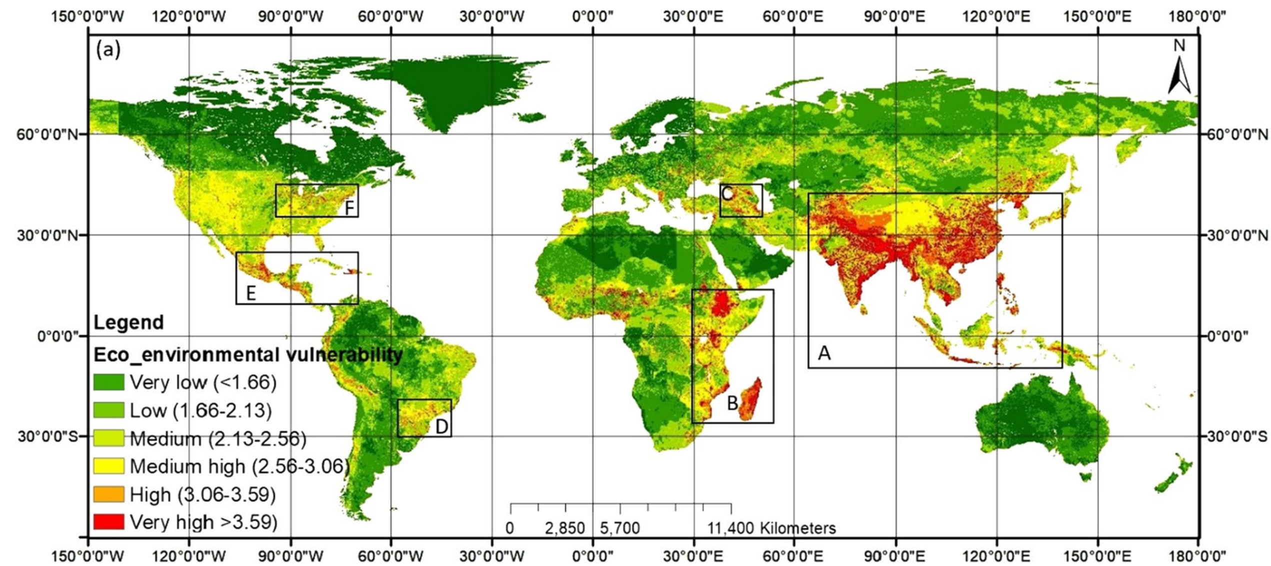

Fig. 4 Global eco-environmental vulnerability map and hotspots A, B, C in continents in 2016

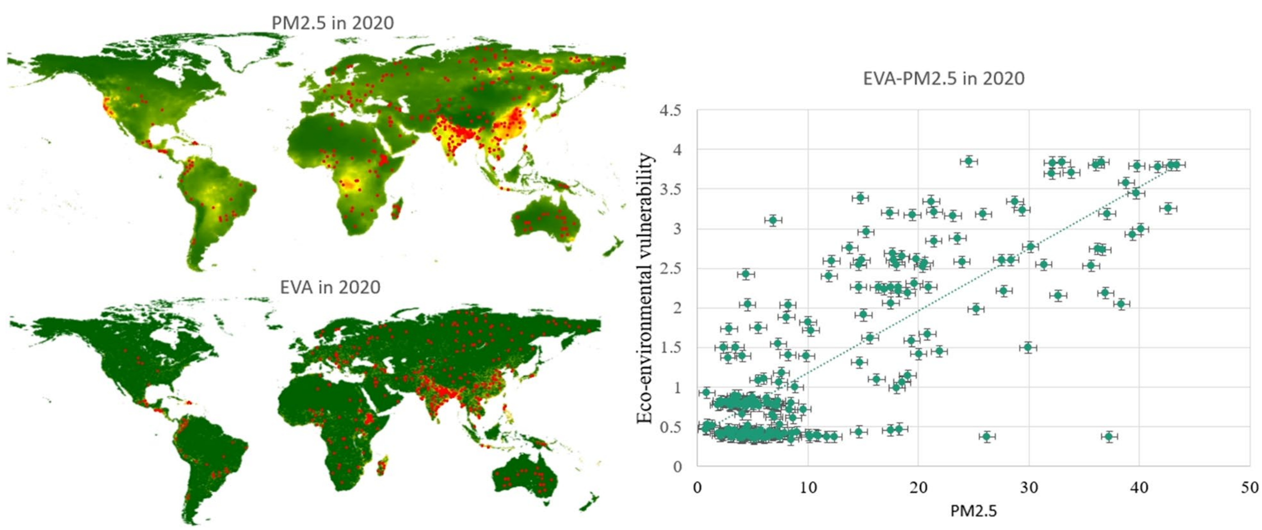

Fig. 5 Comparison between the global eco-environmental vulnerability map and $PM_{2.5}$ distribution in 2020 was conducted, yielding a correlation coefficient of approximately 0.84 for 230 randomly chosen checking points worldwide

due to differences in data collection and inventory in different countries and regions. It is also important to note that there exist other environmental condition assessment indicators or platforms to map the dynamics of eco-environmental vulnerability before and during COVID-19 pandemic, which can provide fundamentally novel understanding of impacts from COVID-19 outspread linking to human impacts on the environment and eco-system.

The vast majority of the inland eco-environment is experiencing significant decreasing vulnerability, indicating a reduction of human impacts on the environment during the lockdown measures. During the lockdown, many countries, particularly in China, USA, and Europe, temporarily stopped industrial operations, and people were locked at home leading to a notable reduction in land-based air pollution. Thus, our findings indicate that there are significant cumulative human impacts on the eco-environment, and the COVID-19 pandemic has pushed many inland regions to restore the eco-environment.

The role of population density in the spatial distribution of global eco-environmental values (GEV) suggests an exploration of how human populations contribute to or are impacted by eco-environmental vulnerability. Higher population density may be associated with increased stress on ecosystems, resource depletion, and higher susceptibility to environmental risks (Tran and Liou 2024). Spatial distribution analysis could involve mapping GEV against population density to identify areas with heightened vulnerability and understand the relationships between human activities and environmental conditions. In the context of the global economy in 2020, the study may be considering how economic factors, particularly vulnerability. Economic activities can impact the environment positively or negatively. The pandemic's effects on the global economy, especially in developing countries, might include disruptions in trade, changes in resource consumption, and shifts in developing priorities. The role of the global economy in lower economic stages of developing countries could involve examining how these nations are disproportionately and how vulnerabilities are exacerbated by economic challenges (Di Pietro 2022; Sanchez-Paramo et al. 2021). The impact of COVID-19 is ununiformed in low-income and minority groups reflecting the role of socio-economic factors in exposure and vulnerability to the virus (Barouki et al. 2021).

The research has some limitations as it did not consider specific statistic on human activities during COVID-19 due to data availability. Nevertheless, based on the information extracted from satellite products and available global dataset, the findings deliver clear message that the global eco-environment can be rapidly improved if human beings adjust their behaviors in an environment-friendly way.

Previously, snapshot of eco-environmental vulnerably due to human and nature disturbances have been used to inform us about the location of hotspots and the need for improvement. The current snapshot (of 2020) and the map showing the change of eco-environmental vulnerability provide a much more comprehensive understanding of how, where, and most importantly, how quickly human activities are affecting/improving the eco-environment.

The change of eco-environmental vulnerability map offers a baseline to guide conservation actions and assessments. However, driving factors may vary between regions depending on behavior intervention, regional policy, and effectiveness of implementation. This may be a consequence of rapid development in anthropogenic process and incomplete solution for the sustainable environment, with a focus on strengthening the economy.

Future research might explore further the link between human factors and the classification of environmentally vulnerable regions, including gender, education levels, societal security, structure of society, level of industrial zones, psychological factors and urbanization. This will help us better understand the interaction better between human and environment to propose smart solutions to restore and maintain the good quality of eco-environment for human well-being (Myers et al. 2013; Galvani et al. 2016; Myers and Patz 2009).

The paragraph presents some limitations and uncertainties associated with the study. It mentions that the use of different datasets for some indicators and different methods for processing them can lead to uncertainty in comparing the results of the 2016 and 2020 eco-environmental vulnerability maps. Additionally, uncertainties related to land use/land cover classification, and GIS spatial analysis can also affect the results. The paragraph acknowledges that these limitations and uncertainties are common in studies of this nature and highlights the importance of this study as the first attempt to assess eco-environmental vulnerability at a global scale and provide a comparison before and after COVID-19. To address these uncertainties, future studies could focus on using more precise and consistent data collection methods and improving the accuracy of land use/land cover classification and GIS spatial analysis.

Uncertainties exist in the study despite the use of the same indicators in the designed framework. For instance, some indicators, such as soil moisture or PM2.5 in 2020, were derived from MODIS data, and the method used to process these indicators was different, resulting in uncertainty in the comparison of the 2016 and 2020 eco-environmental vulnerability maps. Additionally, uncertainties in the land use/land cover classification may lead to mixing patterns of land cover that are not well-distinguished. Moreover, errors may arise during GIS spatial analysis, such as grouping or merging, which can accumulate and further contribute to uncertainties in the results (Crosetto and Tarantola 2001; Selkoe et al. 2009). Nonetheless, this study represents the first attempt to assess eco-environmental vulnerability at the global scale, offering an overall view of the comparison before and after the COVID-19 pandemic.

Beyond the aforementioned limitations, our study has produced the first global eco-environmental vulnerability maps with quantified levels before and during the COVID-19 pandemic. The comparison of these maps reveals significant improvement in environmental conditions worldwide, attributable to lockdown policies. This improvement can be seen as a benefit to the environment at the cost of human welfare and even lives. This raises an interesting question: should human activities be ceased altogether to protect the natural environment and ensure the sustainable development of the world? Our results suggest that urgent and extensive adaptions and transformations of human activities are needed.

Conclusion

This study aimed to assess the changes in global eco-environmental vulnerability during COVID-19 pandemic. We compared the overall status of global eco-environmental vulnerability in 2020 with the result from 2016. To validate our findings, we used global $PM_{2.5}$ data and found a significant correlation coefficient between $PM_{2.5}$ and eco-environmental vulnerability.

Our findings highlight three major points: (1) there was significant improvement in the overall eco-environmental vulnerability status from 2016 to 2020. All continents showed greener patterns of very low vulnerability levels. (2) China and India showed the greatest changes across all vulnerability levels, with evolutionary dynamics in very low and low vulnerability levels. (3) Sixteen indicators contributed to these positives shifts in eco-environmental conditions, while the COVID-19 pandemic played a controlling factor in the short term. If human activities continue to limit their impact on the environment in this way, we can expect a rapid recovery towards a greener trend.

Overall, this study provides important insights into the relationship between human activities and the environment. It highlights the potential benefits of reducing our impact on the environment, even at the cost of sacrificing some human welfare, and the urgent need for larger and deeper adaptations and transformations of human activities towards sustainable development.

If we want to maintain or even accelerate the positive trend in eco-environmental vulnerability, the human activities during the COVID-19 pandemic could serve as a baseline for shaping the impact of human on the eco-environment. The ecological, societal and political lessons learnt during the pandemic have underscored the need for new policies to be informed by the latest scientific findings, in order to improve environmental standards and mitigate the pressures caused by human activities. Moving beyond simply quantifying problems, we must focus on evaluating solutions and taking actions to develop sustainable economic solutions that support and enhance the environment.

Acknowledgements
This research was financially supported by Vietnam Academy of Science and Technology (VAST) via project code VAST01.01/24–25, National Science and Technology Council (NSTC) of Taiwan under the codes 112-2111-M-008-027 and 112-2121-M-008-002, the United States Geological Survey (USGS), and the World Bank. We also acknowledge the FAO for providing global datasets. We would like to express our gratitude to the anonymous reviewers for their constructive comments which helped to improve the quality of the paper.

Author contributions
The research idea was conceived through discussions between K.A.N and Y.A.L. K.A.N collected, processed and analyzed the data while consulting with Y.A.L. K.A.N prepared the initial draft manuscript and Y.A.L provided input to enhance the manuscript. Both authors, Y.A.L and K.A.N, collaborated to finalize the manuscript.

Funding
This research was financially supported by National Science and Technology Council (NSTC) of Taiwan under the codes 112-2111-M-008-027 and 112-2121-M-008-002.

Availability of data and materials
Data will be provided upon request.

Declarations

Competing interests
The authors declare no conflict of interest.

Received: 25 September 2023 Accepted: 4 February 2024
Published online: 27 February 2024

References
Ban N, Alder J (2008) How wild is the ocean? Assessing the intensity of anthropogenic marine activities in British Columbia, Canada. Aquat Conserv 18:55–85
Barouki R, Kogevinas M, Audouze K, Belesova K, Bergman A, Birnbaum L, Boekhold S, Denys S, Desseille C, Drakvik E, Frumkin H, Garric J, Destoumieux-Garzon D, Haines A, Huss A, Jensen G, Karakitsios S, Klanova J, Koskela IM, Laden F, Marano F, Franziska Matthies-Wiesler E, Morris G, Nowacki J, Paloniemi R, Pearce N, Peters A, Rekola A, Sarigiannis D, Šebková K, Slama R, Staatsen B, Tonne C, Vermeulen R, Vineis P; HERA-COVID-19 Working Group (2021) The COVID-19 pandemic and global environmental change: emerging research needs. Environ Int 146:106272. https://doi.org/10.1016/j.envint.2020.106272
Chen Y (2022) Flood hazard zone mapping incorporating geographic information system (GIS) and multi-criteria analysis (MCA) techniques. J Hydrol 612(Part C):128268
Chen Z, Song Y, Li Y, Li Z (2023) Assessing the contaminant reduction effects of the COVID-19 pandemic in China. J Clean Prod 424:138887. https://doi.org/10.1016/j.jclepro.2023.138887
Coll M (2020) Environmental effects of the COVID-19 pandemic from a (marine) ecological perspective. Ethics Sci Environ Polit 20:41–55. https://doi.org/10.3354/esep00192
Crosetto M, Tarantola S (2001) Uncertainty and sensitivity analysis: tools for GIS-based model implementation. Int J Geogr Inf Sci 15(5):415–437
Dai FC, Lee CF, Zhang XH (2001) GIS-based geo-environmental evaluation for urban land-use planning: a case study. Eng Geol 61:257–271
Eastman JR, Kyem P, Toledano J, Jin W (1993) GIS and decision-making. Explorations in Geographic Information Systems, Volume 4, UNITAR United Nations Institute for Training and Research
Fernández DS, Lutz MA (2010) Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. Eng Geol 111(1–4):90–98
Galvani AP, Bauch CT, Anand M, Singer BH, Levin SA (2016) Human–environment interactions in population and ecosystem health. Proc Natl Acad Sci USA 113:14502–14506
Goel A, Raizada A, Bansal K, Gaur N, Abraham J, Yadav A (2020) Profile of patients suspected to be COVID-19: a retrospective analysis of early pandemic data. Cureus 12(8):e10125. https://doi.org/10.7759/cureus.10125
Halpern BS et al (2008) A global map of human impact on marine ecosystems. Science 319:948–952
Halpern BS et al (2009) Global hotspots of land-based impacts to coastal marine ecosystems. Conserv Lett 2:189–196

Henriques M (2020) Will Covid-19 have a lasting impact on the environment. BBC News, London
Hoang D-V, Liou Y-A (2024) Assessing the influence of human activities on flash flood susceptibility in mountainous regions of Vietnam. Ecol Indic 158:111417. https://doi.org/10.1016/j.ecolind.2023.111417
Hu L, Deng WJ, Ying GG, Hong H (2021) Environmental perspective of COVID-19: atmospheric and wastewater environment in relation to pandemic. Ecotoxicol Environ Saf 219:112297. https://doi.org/10.1016/j.ecoenv.2021.112297
Liou Y-A, Nguyen KA, Li M-H (2017) Assessing spatiotemporal eco-environmental vulnerability by Landsat data. Ecol Ind 80:52–65
Liou Y-A, Vo T-H, Nguyen K-A, Terry JP (2023) Air quality improvement following COVID-19 lockdown measures and projected benefits for environmental health. Remote Sens 2023(15):530. https://doi.org/10.3390/rs15020530
Liou Y-A, Tran D-P, Nguyen K-A (2024) Spatio-temporal patterns and driving forces of surface urban heat island in Taiwan. Urban Clim. https://doi.org/10.1016/j.uclim.2024.101806
Micheli F et al (2013) Cumulative human impacts on Mediterranean and Black Sea marine ecosystems: assessing current pressures and opportunities. PLoS ONE 8:e79889
Myers SS, Patz JA (2009) Emerging threats to human health from global environmental change. Annu Rev Environ Resour 34:223–252. https://doi.org/10.1146/annurev.environ.033108.102650
Myers SS, Gaffikin L, Golden CD, Ostfeld RS, Redford KH, Ricketts T et al (2013) Human health impacts of ecosystem alteration. Proc Natl Acad Sci 110(47):18753–18760. https://doi.org/10.1073/pnas.1218656110
Nguyen K-A, Liou Y-A (2019a) Global mapping of eco-environmental vulnerability from human and nature disturbances. Sci Total Environ 664:995–1004
Nguyen K-A, Liou Y-A (2019b) Mapping global eco-environment vulnerability due to human and nature disturbances. MethodsX 6:862–875
Nguyen Q-V, Liou Y-A (2024) Greenspace pattern, meteorology and air pollutant in Taiwan: a multifaceted connection. Sci Total Environ 914:169883. https://doi.org/10.1016/j.scitotenv.2024.169883
Nguyen AK, Liou Y-A, Li M-H, Tran TA (2016) Zoning eco-environmental vulnerability for environmental management and protection. Ecol Indic 69:100–117. https://doi.org/10.1016/j.ecolind.2016.03.026
Nguyen K-A, Liou Y-A, Terry JP (2019) Vulnerability of Vietnam to typhoons: a spatial assessment based on hazards, exposure, and adaptive capacity. Sci Total Environ 682:31–46
Nguyen K-A, Liou Y-A, Vo T-H, Dao D-C, Nguyen H-S (2021) Evaluation of urban greenspace vulnerability to typhoon in Taiwan. Urban for Urban Green. https://doi.org/10.1016/j.ufug.2021.127191
Di Pietro G (2022) Changes in household income during COVID-19: a longitudinal analysis. SN Bus Econ 2:159. https://doi.org/10.1007/s43546-022-00342-y
Rashed T, Weeks J (2003) Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas. Int J Geogr Inf Sci 17(6):547–576. https://doi.org/10.1080/1365881031000114071
Saadat S, Rawtani D, Mustansar C (2020) Environmental perspective of COVID-19. Sci Total Environ 728:138870
Sanchez-Paramo C, Hill R, Mahler DG, Narayan A, Yonzan Y (2021) COVID-19 leaves a legacy of rising poverty and widening inequality. World Bank Blogs, October 07, 2021. https://blogs.worldbank.org/developmenttalk/covid-19-leaves-legacy-rising-poverty-and-widening-inequality
Sansare DA, Mhaske SY (2020) Natural hazard assessment and mapping using remote sensing and QGIS tools for Mumbai city, India. Nat Hazards 100:1117–1136. https://doi.org/10.1007/s11069-019-03852-5
Selkoe KA, Halpern BS, Ebert CM et al (2009) A map of human impacts to a "pristine" coral reef ecosystem, the Papahānaumokuākea Marine National Monument. Coral Reefs 28:635–650. https://doi.org/10.1007/s00338-009-0490-z
Singh N, Tang Y, Ogunseitan OA (2020) Environmentally sustainable management of used personal protective equipment. Environ Sci Technol 54(14):8500–8502
Tilman D (1999) Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. PNAS 96(11):5995–6000
Tilman D, Lehman C (2001) Human-caused environmental change: impacts on plant diversity and evolution. Proc Natl Acad Sci 98(10):5433–5440. https://doi.org/10.1073/pnas.091093198
Tran D-P, Liou Y-A (2024) Creating a spatially continuous air temperature dataset for Taiwan using thermal remote-sensing data and machine learning algorithms. Ecol Ind 158:111469. https://doi.org/10.1016/j.ecolind.2023.111469
World Economic Forum (2020) https://unece.org/covid-19-environment-and-climate-change
Wu Y, Pei C, Wang X, Wang Y, Huang D, Shi S, Shen Z, Li S, He Y, Wang Z, Wang J (2022) Probiotics ameliorates pulmonary inflammation via modulating gut microbiota and rectifying Th17/Treg imbalance in a rat model of PM2.5 induced lung injury. Ecotoxicol Environ Saf 244:114060. https://doi.org/10.1016/j.ecoenv.2022.114060
Yin H, Li C (2001) Human impact on floods and flood disasters on the Yangtze River. Geomorphology 41(2–3):105–109

Publisher's Note