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Environmental Protection Policy and the Emergence of New Diseases: A Global Empirical Analysis of the Pre- and Post-industrial Era

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ABSTRACT

Background: Proper biodiversity conservation and strategies for sustainability in environmental and public health are essential measures for addressing the problems of water-related and zoonotic-caused pandemics. It is generally assumed that a resurgence in an epidemic disease is directly linked to negligence in environmental protection policies, but there are sparse scientific publications supporting the claim.

Methods: To address this issue, we collected data on the global pre- and post-industrialization scenarios and subjected it to multivariate analyses to investigate the relationship between the lack of proper environmental protection and the emergence of new diseases.

Result: Our investigations found a statistically significant association between the loss of wildlife habitat and the emergence of novel diseases. The study also revealed that wildlife-related zoonotic disorders caused more than 220 million deaths amongst global pandemics. More than 30 million deaths were attributed to waterborne diseases due to improper waste management and wastewater treatment. Thus, it is recommended that other environmental parameters (*e.g.,* pollution phase) need to be investigated to fully understand the complex relationship between environmental protection and emergence of new zoonotic diseases.

Key words: Emerging disease, Environment protection, Pandemic, Waste management, Wildlife habitat.

INTRODUCTION

The environment exerts a significant role in determining human physical, biological, social and mental wellbeing (Abdallah *et al*., 2017; Davis and Sharp, 2020). Biodiversity conservation is a crucial component of environmental sustainability, which plays a pivotal role in maintaining ecological balance and ensuring healthy as well as functioning ecosystems. However, the emergence of industrialization in the 19th century brought along a myriad of environmental challenges, such as deforestation and deterioration in air and water quality, resulting in an inevitable ecological damage due to forest destruction and consequently a rise in infectious diseases from zoonotic pathogens.

In the late 19th and early 20th centuries, governments across the world realized that policy development and promulgation of laws and regulations for protecting wildlife and nature-reserves were necessary. As a result, manifold summits and conferences were held to address the most challenging environmental problems requiring international attention. Davis and Sharp (2020) advocated the "One Health" concept as an inclusive approach to solving continuously complex global health challenges, considering the interconnectedness of human, animal and environmental health. Many invertebrate animals dwelling in our immediate vicinity are of epidemiological importance as they play important roles in transmitting pathogenic diseases to humans (Musoke *et al*., 2016).

About 25% of diseases devastating the world today occur due to prolonged exposure to environmental pollution (Musoke *et al*., 2016; Davis and Sharp, 2020). Besides, epidemiologists and environmental health scientists endeavored to understand historical trends of diseases and appraise therapeutic and preventive measures to develop appropriate policy and decision-making. However, little attention was given to assessing the relationship between environmental protection policy and the emergence of new

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diseases. Here, we identified and analyzed the key drivers contributing to the relationship and implored appropriate remedial and preventive actions to be taken.

Materials and Methods

This study was conducted at the Department of Environmental Science and Engineering, Hohai University, Nanjing, PR. China, from February 2020 to August 2021. The study's methodology was based on the employment of secondary data sources. Table 1 summarizes the sources of information used in the analyses. In order to obtain reliable data, we introduced two criteria, namely, data verification and data validation. To verify each set of the received data, we arranged the data in a chronological list based on originality date and source conformity. We also separated the qualitative and quantitative data sets; a data cleaning analysis was conducted to remove the irregular and inconsistent data sets. Finally, we compared the two data sets (old and new) for verification.

For data validation, before analysis, data obtained from various sources were collated, transformed and configured to suit the employed analytical approach (Indika, 2011). In this study, about 89% of the data obtained were valid. Pearson correlation was used to determine the relationship among different variables. The probability level of certainty is accepted at a 95% confidence limit (CL) or $\alpha = 0.05$. Calculations were performed using a Statistical Package for Social Sciences (SPSS) version 22 (IBM, Armonk, NY) and a Microsoft Excel 2013 program (Microsoft, Redmond, WA).

Results and Discussion

We analyzed the world's eight major forest ecosystems with a total landmass of 9,353,946 km^2 in the post-industrialization period. The results revealed an estimated 11,537 (0.12%) km^2 of wildlife habitat loss, with the highest in South America's Amazon Forest (84%), followed by the Congo Rainforest in Africa (10%) and the lowest in the Asian Kinabalu National Park and the Daintree Forest of Australia (0.01% each) (Table 2). Loss of wildlife habitat is significantly correlated with an increase in mortalities ($r = 0.84$; $p<0.05$) (Fig 1A) as a result of an imbalance in zoonotic pathogen/ wild-animal eco-equilibrium, which subsequently led to the emergence of new (virulent) diseases in the human population. However, no associations were observed between time intervals of pandemics and changes in mortalities, as illustrated in Fig 1B.

From 430 BC to today, the world has experienced 28 different pandemics caused by 12 different classes of pathogenic bacterial and viral *spp* (Fig 2). *Variola major* virus, the cause of smallpox, remained in humans for the most extended period (62% longer of all pandemics duration) while RNA virus 1 was the shortest (0.05%) (Table 3). The highest mortality stems from the bubonic plague (caused by *Yersinia pestis*), which, although not very highly virulent

Table 1: The study's data and sources.

Data	Reference/URL
Pre-industrialization (before 1800 AD)	Ibeji (2011); Stanbridge (2016); Horgan (2016); Harper (2017); Horgan (2019);https:// standfortrees.org/why-forests/
Post-industrialization	Kumar (2016);https://www.tusk.org/the-challenge/habitat-loss/?gclid; Mwenda (2019); Wikipedia (2020a); https://data.worldbank.org/
Record of global pandemics from 430 BC to March, 2021	Rosenwald (n.d.); WHO (2008);https://www.who.int/data/mortality/country-profile
Water stress index	Acciona (n.d.); Joshi (n.d.); WWF (n.d.)

AD: After (Christ) death; BC: Before christ.

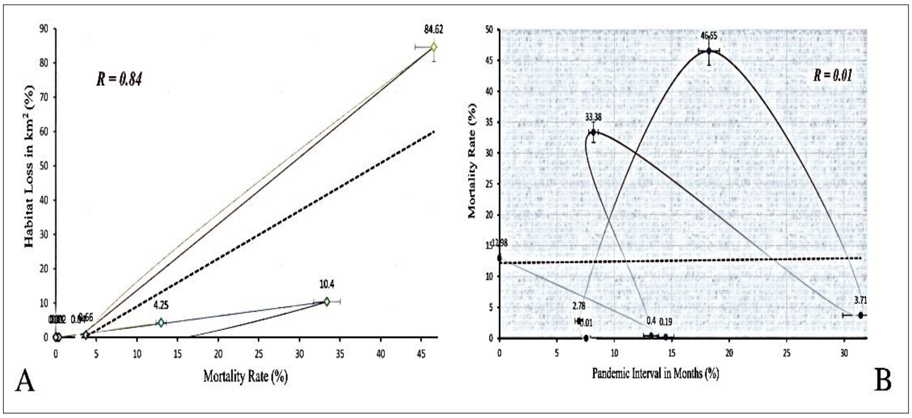

Fig 1: Post-industrialization period (after 1800 AD); relationship between (A) wildlife habitat loss and increase in mortality and between (B) pandemic interval and mortality rate
- km^2: kilometer square.

Table 2: Post-industrialization (after 1800 AD), wildlife habitat destruction, period, global pandemics duration and mortalities incurred.

Biome/forest	Area (km^2)	Wildlife habitat loss/ year (m^2)	Non-human host	Pathogen	Period (years)	Pandemic duration (months)	Mortality	Reference
Valdivian temperate rainforest	248,100	490,000,000	Black rat/flea	Bubonic bacterium (*Yersinia pestis*)	0	540	14,000,000	Horgan (2016); Kumar (2016)
Daintree forest	1,200	1,200,000	Mosquito (*Aedes aegypti*)	Yellow fever virus	23	132	200,000	WHO (2019); Finger (2011); Kumar (2016); WHO (2008)
Sundarbans	10,000	2,670,000	Aves	Influenza A virus (H2N2)	11	37	3,000,000	Kumar (2016); Debnath *et al.,* (2018)
Amazon	7,000,000	9,762,000,000	Pig	H1N1 Influenza A virus	29	27	50,200,000	Wikipedia (2020a); Kumar (2016)
Tongass	68,062	75,600,000	Wildlife	H3N2 Virus	50	24	4,000,000	Kumar (2016)
Congo rainforest	2,023,428	1,200,000,000	Chimpanzee	HIV	13	468	36,000,000	Mwenda (2019); Kumar (2016)
The tropical rainforest of Xishuangbanna	19,223	4,330,000	Bat/civet/pangolin	SARS-CoV	21	115	428,210	Zhu (1992); Kumar (2016); Little (2020)
Kinabalu National Park	754	980,000	Wild animal	Ebola virus	12	24	11,325	Paul (2012); Kumar (2016)

km^2: Square kilometer; m^2: Square meter.

(42.9%), spread across a vast geographical region. At the same time, the more lethal Ebola virus killed less than 12,000 people due to its limited transmissibility. Notably, no correlations were observed between pathogen persistence and the interval of pandemics (Fig 3A). Yet, there is a weak relationship (r = 0.27) between the duration of pandemics and fatalities (Fig 3B). More so, mortality rates depend on both the virulence of the pathogen and the ease of its transmission, *i.e.,* a pathogen of relatively low virulence but with a rapid means of transmission can cause more mortality compared to a highly lethal pathogen with limited transmission capability. More often, underlying health history and social status exacerbate the situation.

The majority of diseases ravaged the globe ranging from the ancient Plague of Athens in 430 BC to the current COVID-19 pandemic, are limited to five continents, namely, Africa, Asia, Australia, Europe and North America, but not South America or Antarctica (Table 4). The highest relative cumulative death toll is in Asia (36.4%), closely followed by Europe (34.9%). Australia has the lowest mortality rate and the shortest duration of a pandemic. It is interesting to note that in the pre-industrialization era, pandemics were attributed to infections from three types of pathogens, namely, *Salmonella typhi*, *Variola major* virus and *Yersinia pestis*. The latter accounted for 68.4% of all deaths during this period (Table 5), with only smallpox (caused by *Variola major* virus) considered to have been completely eradicated (Kumar, 2016; US CDC, 2020).

While the Sustainable Development Goals (SDGs) No. 6 of the United Nations emphasized that industrial technologies, recent wave of economic globalization and infrastructural development have led to a growing health concern (Spier, 2011; Ibrahim *et al.*, 2021). The findings in this study also showcased the need for global natural habitat

Table 3: Duration of the pandemics caused by pathogenic organisms of interest and resulting mortality.

Pathogenic organism	Pandemic duration (years)	Percent total pandemic duration	Mortality	Percent total mortality	Reference
Yersinia pestis	112.00	14.43	139,100,000	42.88	Horgan (2016); Rosen (2007)
Ebola virus	2.00	0.26	11,325	0.001	Anonymous (n.d.)
H1N1 virus	2.25	0.29	50,200,000	15.48	Rosenwald (n.d.)
H2N2 virus	3.08	0.40	3,000,000	0.92	Rosenwald (n.d.)
H3N2 virus	2.00	0.26	4,000,000	1.23	Rosenwald (n.d.)
RNA virus 1	0.42	0.05	40,000	0.01	Jarus (n.d.)
Salmonella typhi	4.00	0.52	100,000	0.03	Littman (2009)
SARS - CoV	9.58	1.23	428,210	0.13	Little (2020)
Unidentified	15.00	1.93	500,000	0.15	Rosenwald (n.d.)
Vibrio cholerae	94.00	12.11	33,007,165	10.18	Acciona (n.d.); Joshi (n.d.)
Variola major virus	482.00	62.09	57,800,000	17.82	Horgan (2016); Rosenwald (n.d.)
Virus (HIV)	39.00	5.02	36,000,000	11.10	Rosenwald (n.d.)
Yellow fever virus	11.00	1.42	200,000	0.06	WHO (2019); Finger (2011); WHO (2018)

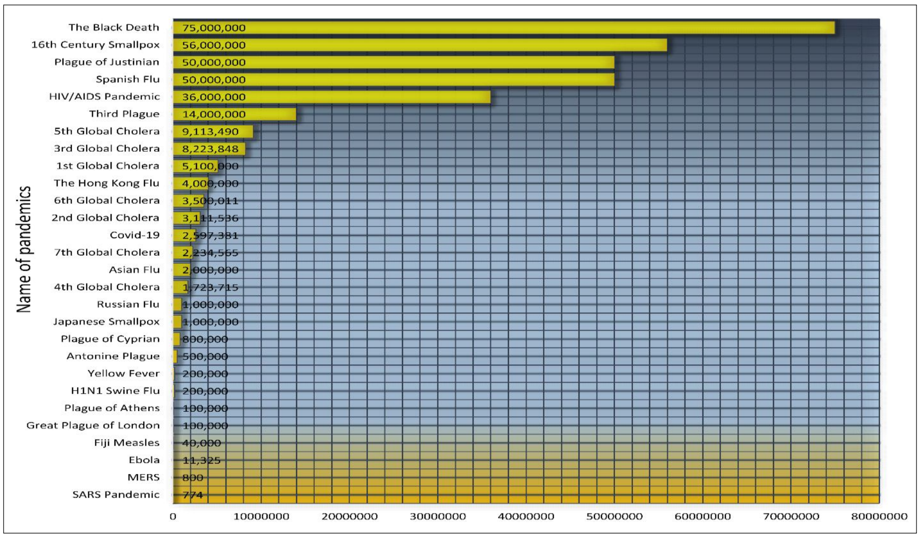

Fig 2: Twenty-eight world's pandemics and their recorded mortality (430 BC - 2021 AD)
Source: Horgan (2016); Sowards (2018); WHO (2019); US CDC, (2020); Rosenwald (n.d.).

conservation as the complexity in the nexus between wildlife habitat loss and pathogen spreads was majorly identified by the rise of industrialization in the late eighteenth and early nineteenth centuries (Spier, 2011). In those days, high morbidity and mortality were mostly due to poor sanitation, unsafe water supply and lack of understanding of the causes of infectious diseases.

Post-industrialization anthropogenic activities resulted in natural habitat encroachment, are negatively impacting the pre-existing natural ecological systems and compelling closer contact of wild animals with the intruding human population. For instance, in the 1950s, the natural forest coverage in Xishuangbanna, PR China, was >50% of the total area; however, by 1978, the coverage decreased to 34% and the natural forests have continuously been destroyed to make way for shifting cultivation and rubber tree plantation (Zhu, 1992). Consequently, the interaction between humans and wild animals in the forests increases,

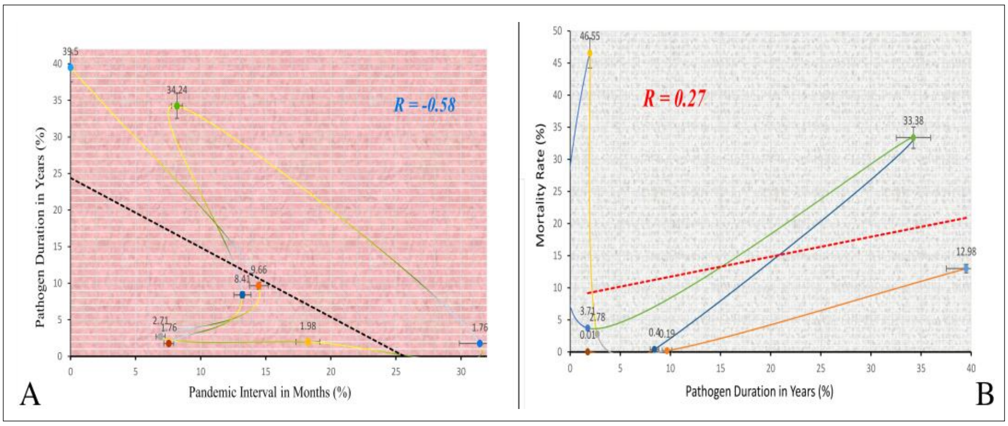

Fig 3: Post-industrialization period (after 1800 AD); relationship (A) between pathogen persistence and pandemic interval and (B) between pathogen persistence and mortalities.

Table 4: Pandemic duration and percent mortality in five continents during the post-industrial period.

Region	Percent mortality	Pandemic duration (months)	Percent pandemic duration	Reference
Africa	11.41	864	21	Horgan (2016); Rosenwald (n.d.)
Asia	36.41	1,652	41	WHO (2019); Finger (2011); Rosenwald (n.d.); Sowards (2018)
Australia	0.01	5	0.01	Rosenwald (n.d.)
Europe	34.85	543	14	Rosenwald (n.d.); Jarus (n.d.)
North America	17.33	972	24	Rosenwald (n.d.)
Antarctica	NA	NA	ND	-
South America	NA	NA	ND	-

NA: No report available; ND: Data could not be detected for some reasons.

Table 5: Global pandemics during the pre-industrial period (before 1800 AD).

Pandemic	Period	Source of infection	Pathogenic organism	Mortality	Reference
Plague of Athens	430-426 BC	Pathogen-contaminated water supply	*Salmonella typhi*	100,000	Littman (2009)
		Total		100,000	
Plague of Cyprian	250-270 CE	NA	*Variola major virus*	800,000	Horgan (2016)
Japanese smallpox	735-737 CE	NA	*Variola major virus*	1,000,000	Sowards (2018)
16th century smallpox	1520-1600	NA	*Variola major virus*	56,000,000	Jarus (n.d.)
		Total		57,800,000	
Plague of Justinian	541-542 CE	Black rat/flea	*Yersinia pestis*	50,000,000	Rosen (2007)
The black death	1347-1352 CE	Black rat/flea	*Yersinia pestis*	75,000,000	Anonymous (n.d.a); Mark (2020)
Great plague of London	1665-1666	Black rat/flea	*Yersinia pestis*	100,000	Cohn (2003)
		Total		125,100,000	

BC: Before christ; CE: Common/christian Era; NA: not available.

paving a way for the possible emergence of new diseases. When the effects of industrialization and urbanization on forests and human health were realized, various governments developed regulations for wildlife protection, urban hygiene, sanitation and appropriate housing facilities. For instance, in the USA, the Endangered Species Act (ESA) was passed by Congress in 1973 as a policy to conserve forests and wildlife (Ballotpedia, n.d.).

Notably, among the 324 $\times$ 10^6 mortalities caused by global pandemics, 68% are due to wildlife-related zoonotic diseases. Our study reveals that, in South America's Amazon Forest alone, 9,762 km^2 of forest are lost every year and this has been linked to the deaths of millions of people, mainly caused by zoonotic diseases. In Africa Congo Rainforest, more than 30% of deaths from zoonotic diseases are linked to the loss of 12,000 km^2 of wild animals' habitats. Our survey reveals that >10% of the total deaths caused by global pandemics from 430 BC to 2021 were from water-related diseases, accounting for >33 $\times$ 10^6 deaths. However, another critical source of epidemics is vector-borne pathogens. In Africa during 2013-Yellow-fever, an acute viral hemorrhagic disease transmitted by infected mosquitoes was responsible for 84,000-170,000 severe cases and 29,000 - 60,000 deaths (WHO, 2019). In particular, *Aedes aegypti* is a vector for not only the yellow fever virus but also that of dengue fever, chikungunya, Zika fever and Mayaro viruses.

Furthermore, water stress exists whenever annual water supply of a given region decreases to <170,000,0000 cm^3/person, approximately between eight and nine glasses of water per day (Acciona, n.d.). The UN reported that one in six persons on this planet experiences this situation, which is a global situation that is becoming increasingly acute (Acciona, n.d.). The problem of water stress is especially evident in sub-Saharan African countries (Kyne, 2015; Wikipedia, 2020b). Many communities still rely on rainwater due to the inaccessibility of potable water (Abebe, 2020; Angela *et al.*, 2019). Water shortages facilitate the proliferation of re-emerging diseases, such as Lassa fever in some parts of Africa, stemming from stored water contaminated with urine/feces of infected Mastomys rodents (WHO, 2018; Joshi, n.d.). Therefore, the positive impacts of environmental protection policies would never be overemphasized, as the rapid expansion of human activities in agriculture and industry led to the development and implementation of the policies by both government and private sectors. These policies are vital in thwarting threats of anthropogenic activities on ecosystems and, more importantly, ameliorating existing damages and preventing further abuse of the planet's fragile ecosystems (Bhaurah, 2020).

CONCLUSION

This study demonstrated a strong connection between negligence in environmental protection policies and the emergence of new diseases globally. Among the causative pathogens, *Yersinia pestis* (cause of bubonic plague) was the most fatal pathogenic agent accounting for 40% of deaths from all the pandemics that scourged the world from 430 BC to the present day. The persistence of a pathogenic agent had a significant impact on mortalities. Although waterborne pathogens constitute a major cause of diseases, yet, water stress on the other hand could be a giant contributing factor. Therefore, it is imperative that "all hands should be on deck" to maintain a sustainable utilization of the existing natural resources and biodiversity conservation, bearing in mind that future generations may not share this mindset. Although our study focused on forest habitats, future studies should examine other portions of the ecosystem, such as the ocean, desert and mountains, so that a holistic picture of the relationships among all other components of an ecosystem and human health will be of paramount concerned.

Conflict of interest: None.

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