RESEARCH ARTICLE

Changes in ischemic heart disease mortality at the global level and their associations with natural disasters: A 28-year ecological trend study in 193 countries

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Abstract

Background
Natural disasters are believed to be associated with cardiovascular disease. This study aimed to explore the changes in mortality due to ischemic heart disease (IHD) and their associations with natural disasters at the global level.

Methods
Country-specific data on the impact of natural disasters, rates of mortality due to IHD and years of life lost (YLL) and socioeconomic variables were obtained for 193 countries for the period from 1990 to 2017. An ecological trend study was conducted to estimate the changes in the IHD mortality and YLL rates and their associations with natural disasters (occurrence, casualties and total damage). Correlation analyses and multivariate linear regression were used.

Results
Significant changes were found in the IHD mortality and YLL rates and the occurrence of disasters between the two equal periods (1990 to 2003 and 2004 to 2017) (p<0.001). The bivariate Pearson correlation test revealed that the trend in the occurrence of natural disasters was positively correlated with trends in the IHD mortality and YLL rates among females.
and all individuals (p<0.05) and was marginally correlated among males. Multiple linear regression revealed an independent association between the occurrence of natural disasters and the IHD mortality rate among males, females and all individuals (standardized coefficients = 0.163, 0.357 and 0.241, p<0.05), and similar associations were found for the YLL rate (standardized coefficients = 0.194, 0.233 and 0.189, p<0.05).

Conclusions

Our study demonstrated significant changes in the IHD mortality and YLL rates at the global level and their independent associations with natural disasters. Both males and females were vulnerable to natural disasters. These results provide evidence that can be used to support policy making and resource allocation when responding to disasters and developing strategies to reduce the burden of IHD.

Introduction

Ischemic heart disease (IHD), characterized by insufficient blood flow to the muscle tissue of the heart, is the world’s biggest killer, responsible for 16% of global deaths in 2019 according to the World Health Organization (WHO) [1]. To reduce the IHD burden and improve public health, rather a range of risk factors have been identified, such as high blood pressure, diabetes, and smoking [2]. In recent decades, the accumulating epidemiological and clinical evidence has suggested that natural disasters are associated with IHD [3,4]. A natural disaster is defined by the WHO [5] as an act of nature of sufficient magnitude to create a catastrophic situation. In addition to the well-known acute damage, such as destruction of the physical, biological and social environment, natural disaster can create chronic impacts on health [6]. Every year from 2000–2020, natural disasters have caused approximately 64,000 deaths and affected 197 million people worldwide [7]. To respond to the immediate negative effects of natural disasters on public health, the needs for water, food, shelter and medical interventions have been repeatedly emphasized [8].

In the past two decades, an accumulation of epidemiological and clinical evidence [3,4] has suggested that IHD can be triggered or exacerbated by various kinds of natural disasters, including earthquakes, hurricanes, dust storms, storms, volcanic eruptions, and wildfires. This scientific evidence has increased the recognition of the relationship between IHD and natural disasters. The potential mechanisms underlying this relationship include exposure to environmental contamination, emotional stress and lifestyle changes [9–11]. However, most previous studies focused on the impact of a specific type of natural disaster rather than the integrated impact of all types of natural disasters. For example, a systematic review including 26 studies by Bazoukis et al [3] concluded that earthquakes associated with an increased incidence of acute coronary syndrome and cardiovascular death. We still need solid evidence to confirm the independent association between natural disasters and IHD at the global level.

Recently, the Global Burden of Disease (GBD) Study by the Institute for Health Metrics and Evaluation (IHME) [12] published findings on worldwide country-specific all-cause disease burdens. We collected data the mortality and years of life lost (YLL) rates due to IHD from the GBD study forin two periods (1990–2003 and 2004–2017). We on the impact of natural disasters during the same periods, quantified as the disaster frequency (occurrence) and severity (casualties and total damage). The data on natural disasters come from the Centre for Research on the Epidemiology of Disasters (CRED) [7]. We conducted an ecological trend
study using the above data with the aim of promoting the adoption of appropriate adaptation
measures and strategies to reduce the IHD burden. This study was an initial investigation of
the hypothesis that natural disasters—as an environmental factor—are associated with IHD
mortality and YLL rates.

**Materials and methods**

**Study design**

This study was an ecological analysis designed to explore the association between trends in the
annual mean natural disaster impact and the IHD mortality and YLL rates from 1990 to 2017
in 193 countries, including all populations. The annual mean was calculated for each variable
with original data from the two equal periods (1990–2003 and 2004–2017). The trends in the
variables in the two periods were calculated with the following formula:

\[
\text{Variable trend} = \frac{\text{variable mean} (2004–2017) - \text{variable mean} (1990–2003)}{}
\]

Trends were replaced by 0 for variable with unavailable data. All the original data for each
variable were collected from the same 193 countries. A list of the countries included is pro-
vided as supplemental information. Countries missing any data were excluded. The data that
support the findings of this study are available from the corresponding author upon reasonable
request.

**Patient and public involvement**

Since our study was a population-based ecological trend study using data accessible from open
sources and no identification of individuals was involved in the recruitment or conduct of the
study, the need to obtain informed consent from participants and approval were waived by the
research ethics committees of the People’s Hospital of Deyang City.

**Variable definition and data collection**

The analysis of trends in variables relied on original data from two periods, namely, 1990–
2003 and 2004–2017, which were obtained from open sources, including the CRED, the GBD
Study, the World Bank and the Food and Agriculture Organization of the United Nations
(FAO).

**Independent variables—impact of natural disasters.** The impacts of natural disasters
were quantified as the occurrence, casualties and total damage; this information was obtained
from the Emergency Events Database [10] (EM-DAT) of the CRED—a WHO Collaborating
Centre since 1980. The EM-DAT contains essential core data on the annual occurrence and
effects of natural disasters worldwide from 1900 to the present. Natural disasters include the
main categories of catastrophic events, including geophysical, meteorological, hydrological,
climatological, biological and extraterrestrial disasters. For a disaster to be entered into the
EM-DAT database, at least one of the following criteria must be met: (1) ten or more people
reported dead, (2) one hundred or more people reported affected, (3) declaration of a state of
emergency, and (4) call for international assistance. The variables of natural disaster exposure
were defined as follows:

- **Occurrence (per year):** The average annual number of natural disasters in each country.
- **Casualties (per 100,000 per year):** The average annual number of deaths, injuries, people
  left homeless, and affected people requiring immediate assistance due to the natural disaster,
  i.e., requiring basic survival resources such as food, water, shelter, sanitation and immediate
  medical assistance.
Total damage (US$1000 per year): The value of all damage and economic losses directly or indirectly related to the disaster. The information may include a breakdown of the figures by sector: social, infrastructure, production, environment and other (when available).

**Independent variables—confounding variables.** Another 10 variables were collected as confounding factors from two sources: the World Bank and the FAO. The following seven variables came from the World Bank [13]: life expectancy (in years for males, females and both sexes), gross domestic product (GDP) per capita (constant 2010 US$), industry (value added, constant 2010 US$), government expenditure on education (% of GDP), CO$_2$ emissions (metric tons per capita), urban population (%), and trade (% of GDP). Additionally, the population of each country was obtained from the World Bank as a weighting factor for multivariate regression. The following three variables came from the FAO [14]: tobacco consumption per capita (kg), alcohol consumption per capita (kg), and fat and meat consumption per capita (kg).

**Dependent variables—mortality and YLL due to IHD.** IHD has been consistently defined as an underlying cause of death across ICD revisions (most recently, the ICD-10 I20–I25 and ICD-9 410–414) [15]. The GBD Study was the source of the data on the IHD mortality and YLL rates, which are essential for evaluating the burden of IHD and for planning prevention programs. The GBD Study provides data on mortality and YLL rates from 1990 to 2017 for males, females and both sexes [12]. These dependent variables are defined as follows:

- Death (per 100,000 population per year): annual IHD deaths per 100,000 population of interest (all ages) in that year.
- YLL (per 100,000 population per year): the total product of multiplying IHD deaths by the standard life expectancy at the age of death in years per 100,000 population of interest (all ages) in that year.

**Statistical analysis**

Statistical analyses were conducted for 193 countries using IBM SPSS version 22 (IBM, Armonk, New York, USA), and a p value < 0.05 was considered to be statistically significant. Nonnormally distributed continuous variables are presented as medians and quartiles.

The Wilcoxon signed-rank test, a nonparametric test, was used to assess the distributions of the two groups of variables representing the impacts of natural disasters and the IHD mortality and YLL rates. The bivariate Pearson correlation test was used to quantify associations between trends in natural disaster impacts and IHD mortality and YLL rates. The correlations were visualized as a world map of trends with Quantum Geographic Information Systems (QGIS) (OSGeo, Beaverton, OR, USA).

Multivariate linear regression was used to investigate the associations between the trends in the dependent variables (trends in mortality and YLL due to IHD for males, females and both sexes) and independent variables (trends in natural disaster impacts, i.e., occurrence, casualties and total damage, and confounding variables) with the criteria for entry and removal of F = 0.05 and 0.1, respectively. Multivariate linear regression was conducted with stepwise methodology (Wald) and weighting by the average population size from 1990–2017. Coefficients with 95% confidence intervals (95% CIs) and p values are reported for the variables included in the multivariate linear regression. Additionally, standardized coefficients were calculated to evaluate the size of the effect for all variables. All analyses were performed separately for males, females and both sexes. To confirm the robustness of the findings, different analyses (bivariate Pearson correlation test and multivariate linear regression) were conducted by subgroup (males, females and both sexes) or with different analytical methods with or without confounding variables.
Role of the funding source

The funders of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

The descriptive statistics for natural disaster and IHD rates are summarized separately for two equal periods (1990–2003 and 2004–2017), and the trends in both periods are presented (Table 1). The Wilcoxon signed-rank test revealed that the two groups of variables representing the impact of natural disasters and the IHD rates significantly differed from each other (p < 0.05). Densely populated geographic regions (including East, South and Southeast Asia) experienced significant increases in the occurrence of natural disasters in recent decades that were accompanied by increases in the IHD mortality and YLL rates. Significant decreases in the occurrence of natural disasters were observed in North America and Western Europe that were accompanied by decreases in the IHD mortality and YLL rates (Fig 1).

The correlations between natural disasters and the rate of mortality and YLL due to IHD are summarized in Table 2. The occurrence of natural disasters was positively and significantly correlated with the mortality and YLL rates among females and both sexes (p < 0.05) and marginally correlated with these rates among males, as shown in the trend maps (Fig 1).

The results of multivariate linear regression among males are shown in Table 3. In the stepwise multivariate linear regression weighted by population, the occurrence of and total damage caused by natural disasters were independently and significantly associated with the mortality rate (standardized $\beta = 0.163$ and 0.205, respectively, p < 0.05) after adjusting for confounding variables. A considerable variance of 64.2% was explained by the mortality model among males. Associations of the occurrence of and total damage caused by natural disasters were found in the YLL model (standardized $\beta = 0.194$ and 0.245, respectively, p < 0.05), with an explained variance of 58.8%.

The results of multivariate linear regression among females are shown in Table 4. In the stepwise multivariate linear regression weighted by population, the occurrence of and total damage caused by natural disasters were still independently and significantly associated with the mortality rate (standardized $\beta = 0.357$ and 0.159, respectively, p < 0.01) after adjusting for confounding variables. A considerable variance of 64.2% was explained by the mortality model among females. Associations of the occurrence of and total damage caused by natural disasters were found in the YLL model (standardized $\beta = 0.194$ and 0.245, respectively, p < 0.05), with an explained variance of 58.8%.

Table 1. Summary statistics for natural disaster impacts and mortality and YLL rates due to IHD during two periods in 193 countries.

| Natural disasters | 1990 to 2003 | 2004 to 2017 | Trend | P value* |
|-------------------|-------------|-------------|-------|---------|
| Occurrence, median (IQR) | 0.86(1.8) | 1.13(3.47) | 0.12(0.61) | 0.000 |
| Casualties, median (IQR) | 4.29×10^6(6.38×10^6) | 2.06×10^5(2.05×10^5) | -20.43(1.91×10^3) | 0.001 |
| Total damage, median (IQR) | 1.20×10^4(8.40×10^4) | 1.65×10^4(1.49×10^4) | 0(4.74×10^4) | 0.019 |
| Deaths | | | | |
| Male, median (IQR) | 100.63(132.9) | 104.41(92.35) | -2.32(34.19) | 0.011 |
| Female, median (IQR) | 74.96(102.4) | 80.62(72.0) | -3.58(25.46) | 0.003 |
| Both, median (IQR) | 90.24(118.25) | 94.36(81.78) | -2.79(29.7) | 0.009 |
| YLL | | | | |
| Male, median (IQR) | 2.32×10^5(2.52×10^5) | 2.09×10^5(1.75×10^5) | -148.32(799.92) | 0.000 |
| Female, median (IQR) | 1.48×10^5(1.36×10^5) | 1.26×10^5(1.15×10^5) | -146.43(522.85) | 0.000 |
| Both, median (IQR) | 1.90×10^5(1.90×10^5) | 1.73×10^5(1.45×10^5) | -132.93(621.11) | 0.000 |

*Wilcoxon Signed-Rank Test.

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confounding variables. A variance of 71.3% was explained by the mortality model among females. A similar association with natural disaster occurrence was found in the YLL model (standardized $\beta = 0.233$ and 0.207, respectively, $p < 0.01$), with an explained variance of 64.0%.

The results of multivariate linear regression for both sexes are shown in Table 5. Unsurprisingly, in the stepwise multivariate linear regression weighted by population, the occurrence of

![Fig 1. Map of trends in natural disasters and IHD from 1990 to 2017 in 193 countries.](https://doi.org/10.1371/journal.pone.0254459.g001)

Table 2. Correlations of natural disaster impact, mortality due to IHD and YLL due to IHD during two periods in 193 countries.

|                | Occurrence | Casualties | Total damage |
|----------------|------------|------------|--------------|
|                | R*         | P value    | R            | P value    | R            | P value    |
| Males          |            |            |              |            |              |            |
| Deaths         | 0.138      | 0.055      | -0.101       | 0.163      | -0.04        | 0.577      |
| YLL            | 0.128      | 0.076      | -0.083       | 0.25       | -0.032       | 0.659      |
| Females        |            |            |              |            |              |            |
| Deaths         | 0.204      | 0.004      | -0.119       | 0.1        | -0.061       | 0.396      |
| YLL            | 0.162      | 0.025      | -0.104       | 0.149      | -0.041       | 0.573      |
| Total          |            |            |              |            |              |            |
| Deaths         | 0.174      | 0.016      | -0.112       | 0.120      | -0.052       | 0.476      |
| YLL            | 0.146      | 0.043      | -0.094       | 0.194      | -0.036       | 0.618      |

*R*Pearson’s correlation.

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Table 3. Multivariate linear regression-derived coefficients for the associations of natural disasters and socioeconomic variables with IHD mortality and YLL rates among males from 1990 to 2017 in 193 countries, weighted by population.

| Factor                  | Coefficient (95% CI) | Standardized Coefficient | P value | Coefficient (95% CI) | Standardized Coefficient | P value |
|-------------------------|-----------------------|---------------------------|---------|-----------------------|---------------------------|---------|
| Natural disasters       |                       |                           |         |                       |                           |         |
| Occurrence              | 1.679(0.04–3.314)     | 0.163                     | 0.044   | 40.027(7.703–72.351)  | 0.194                     | 0.016   |
| Casualties              | NA                                  | 0.176                     | 0.178   | NA                                  | 0.09                     | 0.453   |
| Total damage            | 8.45×10^{-7}(3.22×10^{-7} – 1.37×10^{-5}) | 0.205                     | 0.002   | 2.038×10^{-5}(1.05×10^{-5} – 3.02×10^{-5}) | 0.245                     | 0.000   |
| Fat and meat consumption| NA                                  | -0.059                    | 0.362   | NA                                  | -0.053                    | 0.438   |
| Tobacco use             | 1.615(0.721–2.508)     | 0.165                     | 0.000   | 26.703(7.649–45.758) | 0.135                     | 0.006   |
| Alcohol consumption     | 0.388(0.081–0.696)     | 0.139                     | 0.014   | NA                                  | 0.034                     | 0.543   |
| GDP per capita          | -0.007(-0.009–0.006)   | -0.659                    | 0.000   | -0.146(-0.174–0.118) | -0.645                    | 0.000   |
| Life expectancy (male)  | -2.215(-3.872–0.557)   | -0.129                    | 0.009   | -42.485(-76.613–8.357) | -0.123                    | 0.015   |
| Education expenditure (% of GDP) | NA                       | -0.027                   | 0.567   | NA                                  | 0.002                     | 0.965   |
| Urban population (% of total) | 0.87(0.05–1.69)            | 0.154                     | 0.038   | NA                                  | 0.133                     | 0.121   |
| CO₂ emissions           | NA                                  | 0.105                     | 0.258   | 127.111(56.381–197.841) | 0.271                    | 0.000   |
| Trade (% of GDP)        | NA                                  | 0.041                     | 0.373   | NA                                  | 0.02                     | 0.68    |
| Industry                | 0.011(0.003–0.018)      | 0.235                     | 0.004   | NA                                  | 0.143                     | 0.103   |

*Stepwise method was used; R² = 0.642, F = 40.847, p = 0.000.
*Stepwise method was used; R² = 0.588, F = 43.696, p = 0.000.
*Not applicable for variables not included as predictors.

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Table 4. Multivariate linear regression-derived coefficients of the associations of natural disasters and socioeconomic variables with IHD mortality and YLL rates among females from 1990 to 2017 in 193 countries, weighted by population.

| Factor                  | Coefficient (95% CI) | Standardized Coefficient | P value | Coefficient (95% CI) | Standardized Coefficient | P value |
|-------------------------|-----------------------|---------------------------|---------|-----------------------|---------------------------|---------|
| Natural disasters       |                       |                           |         |                       |                           |         |
| Occurrence              | 3.24(2.056–4.425)     | 0.357                     | 0.000   | 30.111(9.919–50.302)  | 0.233                     | 0.004   |
| Casualties              | NA                                  | -0.041                    | 0.700   | NA                                  | 0.032                     | 0.787   |
| Total damage            | 5.794×10^{-7}(2.18×10^{-7} – 9.40×10^{-5}) | 0.159                     | 0.002   | 1.078×10^{-5}(4.77×10^{-6} – 1.68×10^{-5}) | 0.207                    | 0.001   |
| Fat and meat consumption| NA                                  | -0.068                    | 0.257   | NA                                  | -0.018                    | 0.768   |
| Tobacco use             | 1.519(0.812–2.226)     | 0.175                     | 0.000   | 20.18(9.053–31.308) | 0.164                     | 0.000   |
| Alcohol consumption     | 0.459(0.24–0.679)      | 0.187                     | 0.000   | NA                                  | 0.07                     | 0.168   |
| GDP per capita          | -0.004(-0.005–0.003)   | -0.413                    | 0.000   | -0.072(-0.088–0.056) | -0.509                    | 0.000   |
| Life expectancy (female) | NA                              | -0.081                    | 0.076   | NA                                  | -0.080                    | 0.109   |
| Education expenditure (% of GDP) | NA                       | -0.013                   | 0.749   | NA                                  | 0.036                     | 0.450   |
| Urban population (% of total) | NA                              | 0.108                    | 0.130   | 12.959(1.751–24.167) | 0.183                     | 0.024   |
| CO₂ emissions           | 5.21(2.47–7.95)        | 0.253                     | 0.000   | 63.54(16.823–110.258) | 0.217                    | 0.008   |
| Trade (% of GDP)        | NA                                  | 0.064                     | 0.114   | NA                                  | 0.046                     | 0.307   |
| Industry                | NA                                  | 0.137                     | 0.080   | NA                                  | 0.119                     | 0.148   |

*Stepwise method was used; R² = 0.713, F = 76.108, p = 0.000.
*Stepwise method was used; R² = 0.588, F = 43.696, p = 0.000.
*Not applicable for variables not included as predictors.

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and total damage due to natural disasters were associated with the mortality rate (standardized $\beta = 0.241$ and 0.192, respectively, $p < 0.01$) after adjusting for confounding variables. A considerable 69.6% of the variance was explained by the mortality model. Similar associations with occurrence and total damage were found in the YLL model (standardized $\beta = 0.189$ and 0.215, respectively, $p < 0.05$), and the model explained 62.5% of the variance.

### Discussion

To the best of our knowledge, this is the first study to demonstrate the associations between trends in natural disasters and IHD mortality and YLL rates at the global level. Both males and females were vulnerable to IHD following natural disasters. This strong and unambiguous association indicates that natural disasters have a significant impact on IHD on a worldwide scale.

IHD is the world’s biggest killer, responsible for 16% of global deaths in 2019 according to the WHO [1]. The measurement of IHD mortality and YLL rates and the identification of the corresponding risk factors are essential for evaluating the burden of IHD, adapting responses and developing prevention and management strategies. Natural disasters, which are undoubtedly one cause of public health crises [5,7], are still not recognized as being as relevant as other well-established risk factors for IHD, such as tobacco use, the harmful use of alcohol, and socioeconomic status. However, there is increasing epidemiological and clinical evidence demonstrating that IHD can be triggered or exacerbated by natural disasters.

### Comparison with previous studies

The findings of our research are consistent with observations in previous studies. The association between IHD and geophysical disasters (including earthquakes, volcanic activity and
mass movements) has been well studied. Takiguchi et al. [16] reported significantly increased long-term (3-year) rates of mortality due to acute myocardial infarction (AMI) in both men and women after the Great East Japan Earthquake (2011, Japan). Similar findings were reported by Nakagawa et al. [17] after the Niigata-Chuetsu earthquake (2004, Japan). Niiyama et al. [18] also reported that the incidence of sudden cardiac and unexpected death (SCUD) doubled in the first 4 weeks after the 2011 Japan earthquake and tsunami. In addition, significant relationships were found between the weekly number of SCUDs and seismic activity and frequency. A systematic review of 26 studies by Bazoukis et al. [3] concluded that earthquakes might be associated with increased incidences of acute coronary syndrome and cardiovascular death. In addition to earthquakes, volcanic activity—another type of geophysical disaster—was also reported by Oudin et al. [19] to be associated with death. After the volcanic eruption in Iceland in May 2011, the all-cause mean mortality ratio during the exposure period was 2.42, compared with 2.17 during the control period.

After geophysical disasters, climate-related natural disasters [20] (including biological, hydrological, meteorological and climatological disasters) represent the largest category of natural disasters, and their impacts on health have become a global concern. A series of studies consistently demonstrated the association between climate-related natural disasters and IHD mortality. Using data on 16,559 IHD deaths in the five largest cities in China, Guo et al. [21] found a U-shaped association of death with extreme temperatures, in which both extremely cold and hot temperatures increased IHD mortality from 2004–2008. A similar association was found by Huang et al. [22] between extreme temperature and cardiovascular disease-related YLL. Such associations have been confirmed in high-, middle- and low-income countries [23,24]. More conclusive evidence was provided in a review by Cheng and Su [25]. Their findings suggested that extreme temperature events could be a new risk factor for IHD mortality. In addition to extreme temperature events, other climate-related natural disasters, such as wildfires, dust storms, droughts, snowstorms and hurricanes [26–28], have been confirmed to be associated with increased IHD mortality rates by a series of observational studies. A literature review by Giorgini et al. [4] examined the implications of climate change for public health and concluded that climate change adversely affects the cardiovascular system and that subjects at high risk for cardiovascular diseases are more vulnerable.

**Mechanisms**

Several explanations can be offered for the positive associations found in our study. The first explanation is that natural disasters have a direct impact on physical health, including autonomic system imbalance, hemodynamic disorders, sympathetic and renin angiotensin system activation, oxidative stress and inflammation, and atherosclerosis due to exposure to extreme temperatures, particulate matter (PM), or other harmful substances after natural disasters [4,9,29]. Second, natural disasters have been reported to affect mental health. Increased frequencies of posttraumatic stress disorder, depression, and other mental disorders have been reported following natural disasters [10,29,30].

In addition to direct physical and mental effects on the population, catastrophic natural disasters have also been found to be related to increased exposure to well-established risk factors for IHD, such as hypertension, increased BMI, smoking, alcohol abuse, high blood glucose, high-sodium diets and a lower socioeconomic level (as represented by the GDP per capita) [11,31–33]. Moreover, all these risk factors can be exacerbated by the widespread destruction of infrastructure and hindered access to public health services [33]. Such conditions can cause the risks of IHD morbidity and mortality to increase significantly.
Strengths and limitations of this study

Some advantages of our study merit mention. First, our study provides the first evidence at the global level from 193 countries using two indicators: the mortality rate and the YLL rate. Second, unlike previous observational studies, a series of relevant socioeconomic variables were included in the same set of multivariate linear regression analyses, ensuring the statistical reliability of the results. Third, we studied ecological trends in natural disasters and the burden of IHD in the entire population, thus avoiding the disadvantages of previous studies in which disaster-affected and control populations could not be convincingly identified, especially from a psychosocial perspective. Fourth, the effects of other factors, such as genetics, geography and climate, on IHD could be eliminated with this design, if we assume that the genetics, geography, climate and other population-level factors in a given country remain unchanged. Finally, the the similarity of the results of subgroup analyses and different analytical methods confirms the robustness of our findings.

Our study has several limitations. The main limitation lies in the intrinsic limitation of the ecological study design (conceptualized as the ecological fallacy), which means that the results obtained from populations cannot be extrapolated to individuals. Another limitation to be considered is that, as shown in the inclusion criteria, the natural disasters included in our study are extremely destructive. Whether natural disasters of lesser severity have similar impacts on IHD is not clear. In addition, most of the confounding factors included in our study were protective or risk factors at the population level. Individual intermediate factors (e.g., blood pressure, blood glucose, BMI) should be included if data are available. Meanwhile, the data we used in this study came from a secondary source, and there might be discrepancies between these data and the actual situation. Finally, our study reflects the associations among trends in variables in the long term, and short-term associations were not investigated.

Further information

The multivariate linear regression analysis in our study suggested that each single-incident increase in the annual natural disaster occurrence was associated with an increase in IHD mortality of approximately 1.679 deaths per 100,000 for men, 3.24 deaths per 100,000 for women and 2.295 deaths per 100,000 for both sexes. Each single-incident increase in the annual natural disaster occurrence was also associated with an increase in the YLL of approximately 40.027 years per 100,000 for males, 30.111 years per 100,000 for females and 31.141 years per 100,000 for both sexes. Furthermore, the trends in total damage caused by natural disasters showed similar associations with IHD. However, considering the inaccuracy of economic loss statistics and the difficulty in calculating them, the occurrence of natural disasters seems to be a better predictor of the burden of IHD. Our study showed that other measures of the severity of natural disasters, including deaths and total number of people affected, were not significantly associated with IHD mortality. This finding suggests that the impact of natural disasters on IHD spreads beyond the directly affected population.

In our study, GDP per capita, which is a measure of a country’s economic output and standard of living, was significantly and negatively associated with IHD mortality and YLL. This finding was consistent with a previous study [33]. In addition, tobacco consumption, an incontrovertible risk factor for CVD, was unsurprisingly significantly and positively associated with mortality and YLL among males, females and both sexes. Interestingly, previous studies have suggested that alcohol has both protective and harmful effects with regard to IHD depending on the amount consumed and the mode of consumption. Our study indicated that alcohol consumption was significantly and positively associated with IHD mortality, suggesting that alcohol consumption in general should be discouraged. Meanwhile, the associations in the
urban population (% of total) varied between men and women. Possible explanations might be that urban men have higher prevalences of high blood pressure, cholesterol, glucose, and heart rate and are less physically active. Similarly, the association of CO2 emissions and YLL due to IHD can be explained as follows: CO2 emissions might serve as a proxy for lifestyle based on energy consumption, as more CO2 emissions mean more energy used, which might lead to an increase in the incidence of cardiovascular risk factors, such as inactivity, high blood pressure, and high blood sugar.

Implications of this study
With regard to the response to public health impacts following natural disasters, emerging guidelines or studies have emphasized the development of specialized interventions for non-communicable diseases in addition to physical trauma therapy, nursing care and infection control [8]. On December 2nd, 2015, the Japanese Circulation Society (JCS), the Japanese Society of Hypertension (JSH), and the Japanese College of Cardiology (JCC) joint working group published the first guidelines for disaster medicine for patients with cardiovascular diseases. Although many studies from local areas have suggested increased IHD morbidity and mortality following all types of natural disasters, the value of our study lies in the fact that it is imperative to increase awareness of the association between the occurrence of natural disasters and IHD. In addition, although the occurrence of natural disasters might be a nonmodifiable and ubiquitous risk factor for IHD, adaptative strategies, such as environmental restoration, psychological interventions, lifestyle improvements and infrastructure reconstruction, can be developed and promoted as part of the response to natural disasters to reduce the IHD disease burden. To achieve these goals, more detailed data on natural disaster exposures, the subsequent health effects and potential mechanisms are particularly needed.

Conclusions
Our ecological study confirmed and quantified the associations between the occurrence of natural disasters and the IHD mortality and YLL rates in 193 countries. Both males and females were vulnerable to IHD following natural disasters. It is imperative to increase awareness of the association between the occurrence of natural disasters and IHD. Our study provides evidence that can be used to support policy making and resource allocation regarding the response to disasters, with the aim of reducing the IHD burden.

Supporting information
S1 File. PLOS One clinical studies checklist.
(DOCX)

S2 File. STROBE checklist v4 combined Plos medicine.
(DOCX)

S3 File. Country list and data uploaded.
(SAV)

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