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RESEARCH ARTICLE

Spatial and Quantitative Analysis of Historical Pollution Incidents: Sulfur Dioxide Emissions from Copper Smelting during Japan's Modernization Era

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ABSTRACT

During Japan's modernization and westernization over a century ago, copper mining and smelting became a key export industry. However, the resulting sulfur dioxide emissions caused significant damage to crops and forests. Due to the limited availability of historical environmental records, this study utilizes the atmospheric dispersion simulation tool AIST-ADMER, developed by the National Institute of Advanced Industrial Science and Technology, to reconstruct pollution patterns associated with the Besshi Copper Mine in Ehime Prefecture. We assess the plausibility of the simulated dispersion patterns by examining their correlation with historical records of environmental damage and compensation. The results reveal a moderate correlation between simulated sulfur dioxide concentrations and compensation levels, whereas the correlation with recorded damage is relatively weak. Regression analysis further indicates that compensation amounts are significantly associated with both concentration levels and the proportion of forest land use. Applying this model to counterfactual scenarios, we estimate that relocating the smelting facilities to alternative sites, such as a coastal onshore site or a mountainous inland area which could have increased compensation payments by approximately three and five times, respectively. These findings shed light on how corporate decisions shaped responses to environmental damage and compensation, highlighting the complex trade-offs companies faced in managing pollution under evolving social and environmental pressures. This research fills a significant gap in the literature by establishing a quantitative framework that links simulated pollution patterns with historical evidence, enabling a deeper understanding of past environmental impacts and corporate responses.

Introduction

There is much to learn from environmental history, especially regarding historical pollution incidents [1–4]. They reveal the importance of early investigation and response, the necessity of appropriate compensation, and the wide-ranging impacts on local communities [5–10]. Simultaneously, such cases often suffer from gaps in scientific understanding and underdeveloped observation systems at the time of the incidents, making it difficult to grasp the full extent of pollution. Records of damage and compensation are often fragmentary, making it challenging to construct a comprehensive picture. As a result, there has been little quantitative research on historical pollution incidents. By quantitatively reconstructing such an incident, this study re-evaluates the relationships among pollution, damage, and compensation, an approach that is novel in historical pollution research.

This study examines the sulfur dioxide emissions from the Besshi Copper Mine during Japan's Edo (1603–1868) early modern era, Meiji (1868-1912), and Taishō (1912–1926) modernization periods. Using a simplified air pollution simulation, we compared the modelled outputs with historical records of damage to agriculture

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and forestry and compensation to analyze the spatial and quantitative relationships among pollution, harm, and redress.

During the Meiji and Taishō eras, the Besshi Copper Mine, alongside Ashio, Kosaka, and Hitachi, was one of the four major copper mines that contributed to Japan's modernization. However, sulfur dioxide gas released during the smelting process causes significant damage to local agriculture and forestry. While smelting had originally been conducted in the mountains near the mine during the early modern Edo period (Kyu-Besshi area, i.e., the former Besshi area), its relocation to Sōbiraki in Niihama, closer to the coast, with an increased production in the mid-Meiji period, marked the beginning of more serious environmental damage. In response to the growing protests from nearby farmers, the smelter was moved in 1904 (Meiji 37) to Shisakajima Island, an island in the Seto Inland Sea. However, the damage spread more widely as production increased. Ultimately, the mine operator and farmers in four counties in the eastern region of Ehime Prefecture entered into agreements, and the operator paid compensation. The introduction of technologies to recover and utilize sulfur eventually ended the pollution problem in 1939 (Shōwa 14).

This case is significant as one of Japan's earliest industrial pollution incidents, which set a precedent for future environmental disputes. For example, farmers affected by the Hitachi Copper Mine later visited Besshi to study how stakeholders had addressed environmental pollution, social damage, and compensation. Long-standing negotiations between the mine operator and farmers culminated in compensation agreements. These can be interpreted as outcomes of Coasean bargaining, where parties negotiate a resolution based on the assignment of property rights and mutual interests [11–13].

The socio-economic aspects of air pollution incidents at the Besshi Copper Mine have been explored primarily in the fields of management and environmental history (we do not discuss here the literature in the field of geology and mining and metal engineering). Scholars in management history examine corporate events related to mine pollution and analyze the significance of managerial decisions. For instance, Sueoka discusses the contrasting perspectives of Hirose Saihei, a prominent reformer of the Besshi Copper Mine and the first Director-General of the Sumitomo group, and the second Director-General, Iba Teigo, known for his thoughtful character [14–16]. When Iba proposed relocating the mine's smelting facility to Shisakajima Island, approximately 20 km from the coast, Hirose opposed the idea, viewing it as wasteful and potentially hazardous, claiming that compensation would be the best remedy. Finally, after examining several options including locating in Niihama as well as Kyu-Besshi, the mine owner and the owner of the Sumitomo group, Sumitomo Tomoito, supported Iba's decision to move the facility to Shisakajima.

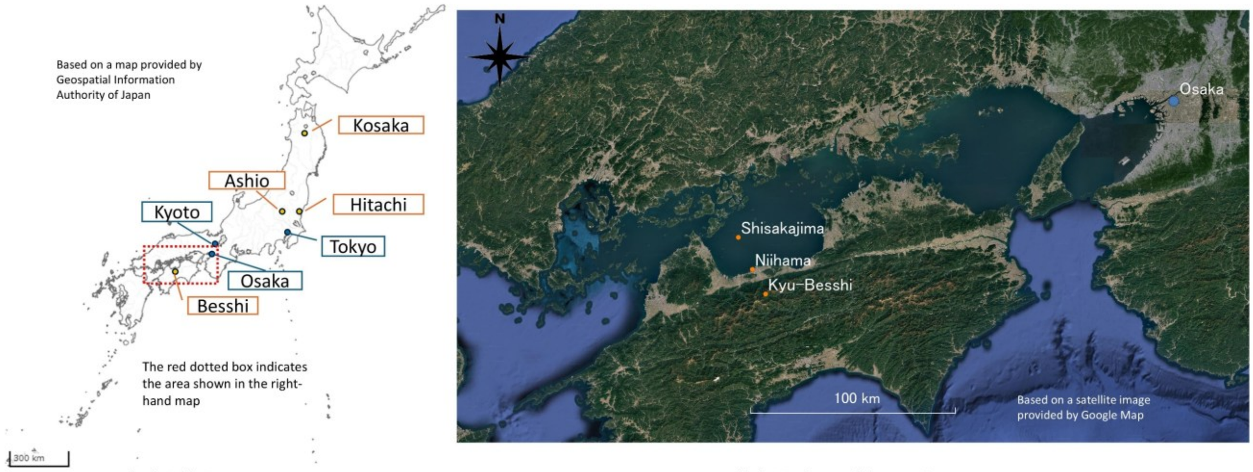
In contrast, environmental history research focuses on the social dynamics among polluters, victims, and the government. Sugai interprets these interactions as indicative of Japan's controlled capitalist development, where state-led capitalism prioritized the interests of industrialists over those of local farmers [17,18]. Although the government facilitated negotiations between victims and polluters to arrange compensation, its primary aim was to safeguard mine owners' interests and maintain the momentum of national economic expansion.

While previous studies, including historical investigations of copper mining and industry in Japan, provide valuable historical insights [19,20], they often rely on intuitive explanations and lack rigorous quantitative evaluations. This study aims to address this gap by using simulation techniques to uncover the causal relationships between pollution, damage, and compensation, an approach akin to historical environmental forensics.

Materials and Methods

Study Area

The study area is located on Shikoku Island and its nearby small islands in Japan (Figure 1). The region lies in a temperate climate zone and includes part of the Seto Inland Sea. In 2009, the average temperature recorded at the Niihama meteorological station in the study area was 17.0 °C, and annual rainfall was 1,297.5 mm. The area comprises forests, agricultural land, residential areas, industrial zones, and coastal waters.



(a) All Japan map (b) Related locations

Figure 1. Location of the Besshi Copper Mine and smelting facilities: (a) major copper mines in modern Japan, major cities, and the study area and (b) the locations of the smelting facilities of the Besshi Copper Mine.

Data Analysis

The atmospheric dispersion model ADMER (Atmospheric Dispersion Model for Exposure and Risk Assessment, https://riss.aist.go.jp/admer/) version 3.5 was used to estimate the atmospheric concentration of sulfur dioxide gas in each scenario. ADMER is a Gaussian plume-type dispersion model developed at the National Institute of Advanced Industrial Science and Technology (AIST) in Japan. It can estimate monthly or annual mean concentrations at 1.0 m above the ground in any region in Japan, with a relatively high spatial resolution (100 m to 5 km grids) [21,22]. ADMER has been applied to many chemical exposure and risk assessments [23–25].

In this study, the horizontal resolution was set to 30 arcseconds in latitude and 45 arcseconds in longitude (approximately 1 km × 1 km), covering the computational domain with 90 grid cells in latitude and 100 grid cells in longitude. The values for each meteorological element required for the calculation (wind speed, wind direction, precipitation) in each grid cell were computed using the pre-processing function in ADMER from the hourly data of automatic weather reporting stations located within the study area. Simulations were conducted using the meteorological conditions of 2009, which was considered a representative average year for recent years (given that the study area includes both land and sea, the most influential meteorological factor affecting air pollution is likely the land-sea breeze. Since the coastline has remained relatively unchanged between the 19th century and recent years, we assume that the general patterns of land-sea wind have also remained broadly consistent over this period). Estimated sulfur dioxide emissions were calculated based on historical copper production levels [26]: approximately 2,664 tons SO_2 emissions per year during the Edo period (before 1868), when smelting was carried out at the former Besshi (Kyu-Besshi) area; 26,550 tons per year during the Meiji period (1868–1912), when operations were relocated to the Niihama-Sōbiraki facility; and 119,600 tons per year during the Taishō period (1912–1926), when smelting took place at the Shisakajima Island plant. The assumed smokestack heights for the simulations were 20.145 meters for both the Edo and Meiji periods, based on the height of a remaining smokestack constructed in the same era, and 108 meters for the Taishō period, which reflects the actual smokestack height. Table 1 shows the annual average values of wind speed and precipitation across the entire computational domain, as well as the most frequent wind direction across the entire computational domain throughout the year. The other parameter settings used for the simulation are presented in Table 1.

Table 1. Summary of data and parameter settings used for simulation. The table presents the meteorological data and the parameter settings for the pollutant (SO_2) in the dispersion simulation.

Meteorological data	The parameter settings for the pollutant (SO_2) in the dispersion simulation
Average wind speed: 2.05 m/s	Dry deposition velocity: 0.48×10^{-2} (m/s)
Average daily precipitation: 4.01 mm/day	Decomposition coefficient: 1.5 (%/hr)
Most frequent wind direction: Southwest-West	Washout ratio: 300

Data on damage and compensation were drawn from Isshiki (1926) [27], who compiled figures for affected areas and compensation amounts by municipality. For this study, we used data on compensation prior to 1910 (Meiji 43). Due to the scarcity of land use data around 1900, we used data from 1976, assuming that early 20th-century patterns resembled those of the late 20th century [28]. We conducted correlation analysis among dispersion concentrations, damage rates, and compensation rate, as well as ordinary regression analyses in which compensation rate was the dependent variable and concentrations and land-use variables were the independent variables. The estimated model was used to conduct what-if analyses under alternative scenarios. The flowchart in Figure 2 illustrates the steps undertaken in this study.

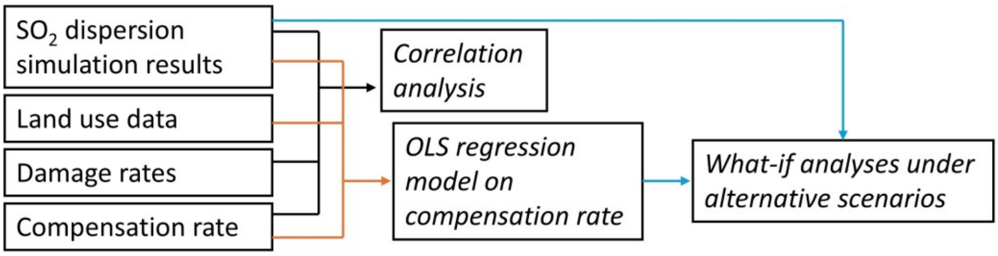


Figure 2. The flowchart of this study, summarizes the data used and the analyses conducted.

Results

When comparing the Edo (mid-19th century), Meiji (late 19th century), and Taishō (early 20th century) periods, the analysis applies today's regulatory thresholds for sulfur dioxide in Japan: above 0.04 ppm (shown in orange) and between 0.004 ppm and 0.04 ppm (shown in light orange) as average concentrations. Based on these thresholds, it is clear that the area affected by sulfur dioxide expanded markedly over time (Figure 3). The zone of damage shifted from a limited portion of the Shikoku Mountains to include the coastal region of Niihama and eventually extended to the Takanawa Peninsula, where Ochi County is located. This suggests that relocating the smelting site to Shisakajima achieved its intended purpose of reducing damage to land areas.

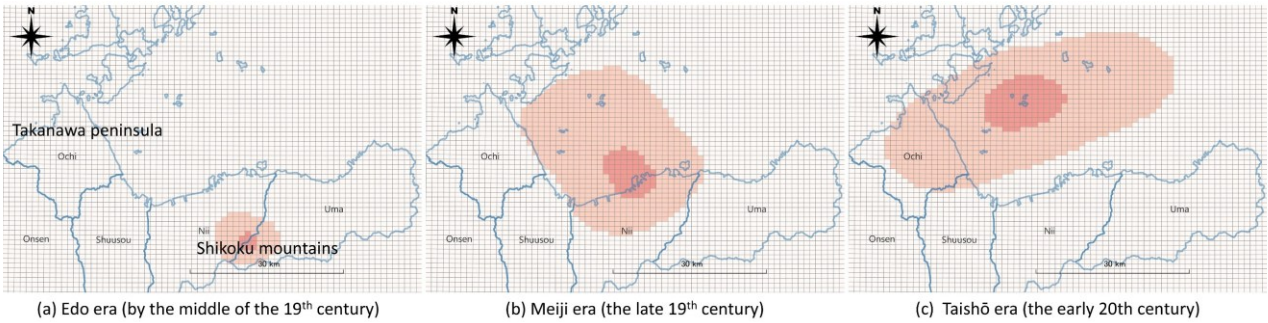


Figure 3. Dispersion of SO_2 in three eras (>0.04 ppm: orange color/ 0.004 – 0.04 ppm: light orange color).

To examine the relationship between atmospheric dispersion concentrations, environmental damage, and compensation during the Taishō period (early 20th century), correlation and regression analyses were conducted using spatial units of approximately 1 km × 1 km. As shown in Table 2, the correlations between the dispersion concentrations and damage rates for rice paddies, crop fields, and forests—measured as the ratio of damaged area to total village area, were relatively weak (r = 0.18, -0.07, and 0.15, respectively). In contrast, the correlation between the dispersion concentration and the amount of compensation per unit area of each village was moderately strong (r = 0.57). To further examine the detailed relationships between atmospheric dispersion and compensation, we conducted ordinary least squares (OLS) regressions, taking compensation per hectare as the dependent variable and the average atmospheric concentration estimated using ADMER and land-use-related variables, such as paddy field ratio, crop field ratio, orchard ratio, other tree crops ratio, and forest ratio, as independent variables. As shown in Table 3, we found a statistically significant ($p < 0.1$) correlation between compensation values and sulphur dioxide concentration, rice paddy field, orchard field, and forest ratios. While the sulfur dioxide variable has a positive coefficient, the ratios of several agricultural and forestry land uses have negative coefficients.

Table 2. Correlation analysis among dispersion concentration, damage rates, and compensation rate (n = 401). This table presents the correlation coefficients among the variables.

	Dispersion concentration	Rice paddy field (damage rate)	Crop field (damage rate)	Forest (damage rate)	Compensation Rate (1/1000 jpy per ha)
Dispersion concentration	1.00				
Rice paddy field	0.18	1.00			
Crop field	-0.07	-0.35	1.00		
Forest	0.15	-0.37	0.51	1.00	
Compensation	0.57	0.39	0.18	0.00	1.00

Table 3. OLS regression result on compensation values (initial model) (n = 1,409). This table presents the results of an OLS regression in which compensation values are the dependent variable and SO_2 concentration and land-use variables are the independent variables.

	Coefficient	Std. err.	t	p-value
SO_2 concentration (ppm)	1,597,356.0	55,161.5	28.96	0.000
Rice paddy field ratio	-1,809.7	1,010.4	-1.79	0.073
Crop field ratio	-3,370.9	4,223.0	-0.8	0.425
Orchard ratio	-2,446.6	1,118.6	-2.19	0.029
Other tree crops ratio	27,048.3	68,681.0	0.39	0.694
Forest ratio	-4,169.1	650.1	-6.41	0.000
Constant	2,311.4	619.8	3.73	0.000

We further conducted a regression analysis using rice paddy field and forest ratios, which were statistically significant, as independent variables. As orchards are a relatively new category in this region, we did not include this category in the analysis. We found that the coefficient for the rice paddy field variable became insignificant this time. Therefore, we decided to include only the forest ratio as an additional independent variable in our final model. (Table 4).

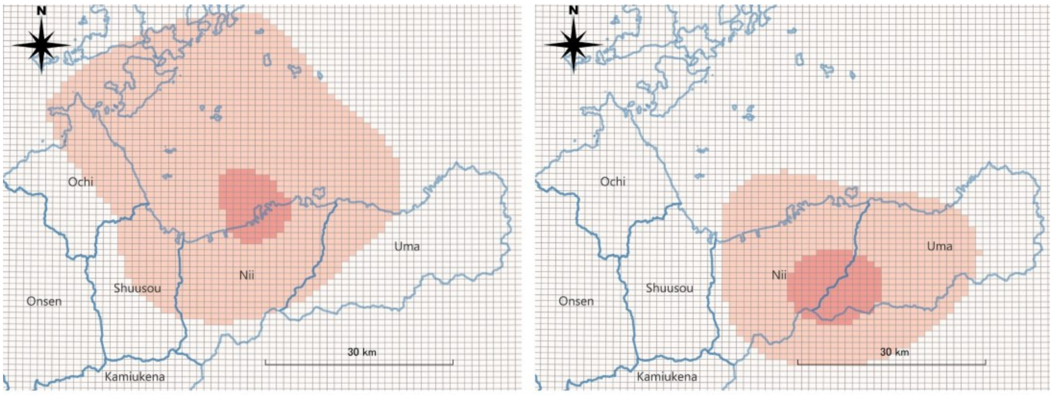
Table 4. OLS regression on compensation values (final model) (n = 1,409). This table presents the results of an OLS regression in which compensation values are the dependent variable and SO_2 concentration and forest ratio are the independent variables.

	Coefficient	Std. err.	t	p-value
SO_2 concentration (ppm)	1,598,994.0	55,052.6	29.04	0.000
Forest ratio	-2,991.2	386.7	-7.74	0.000
constant	1,113.0	333.4	3.34	0.001

Discussion

The correlation between dispersion concentrations and the damaged areas of rice paddies, crop fields, and forests was relatively weak (r = 0.18, -0.07, and 0.15, respectively). This weak correlation may be due to two factors: the use of the ratio of damaged area to total village area (rather than to the area of each land category within the village) as the damage indicator, and the ecological and agricultural/forestry diversity across the regions, which may obscure or confound the underlying relationships. In contrast, a moderate correlation was observed between the dispersion concentration and the amount of compensation per unit area of each village (r = 0.57), suggesting a more consistent relationship in this case. The OLS regression provides a relatively accurate prediction of compensation values (adjusted $R^2 = 0.45$ for both the initial and final models). As expected, the air concentration of sulfur dioxide had a positive relationship with compensation. Unexpectedly, the more land used for agriculture or forestry, the less compensation was paid. This may be because the farmers themselves distributed the total amount of compensation from the mine [27]. They may have allocated more resources to resource-poor communities than to those with greater resources. The maximum concentrations of sulfur dioxide over land during the Meiji and Taishō periods (0.967 ppm) exceeded the levels recorded during the Yokkaichi Asthma incident (0.075 ppm) in 1963–1964, one of Japan's four major pollution cases. This finding suggests that pollution during these earlier periods likely had severe impacts not only on agriculture and forestry but also on human health [29].

If we have sufficient confidence in the estimated OLS model, we can estimate compensation values under hypothetical scenarios. Based on historical debates among the mine managers in the early 20th century, we estimated compensation amounts for alternative cases in which the smelters were not relocated to Shisakajima Island but remained either in Niihama on the coast or at Kyu-Besshi in the mountainous region. These estimates were derived using the model in Table 4. For comparison, we also estimated the compensation values for the actual case of Shisakajima. In all three scenarios, we assumed that the operator constructed a smokestack 108 m high, the same height as the one built on Shisakajima. Figure 4 shows how SO_2 would have dispersed according to our model if the mine operator had set up smelters in Niihama or Kyu-Besshi with the same levels of production (i.e., emissions). We calculated the compensation values for the respective cases based on our model (Figure 5). The mine would have paid 3.2 times or 5.6 times more compensation if the operator had located their smelter in Niihama or Kyu-Besshi rather than Shisakajima. Otherwise, the operator must significantly reduce production levels.



(a) The Niihama case (b) The Kyu-Besshi case

Figure 4. What-if analyses of cases where the smelting facility was located in alternative sites (>0.04 ppm: orange; 0.004–0.04 ppm: light orange): (a) the dispersion pattern if the smelting facility was located in Niihama, and panel and (b) the dispersion pattern if the facility was located in Kyu-Besshi.

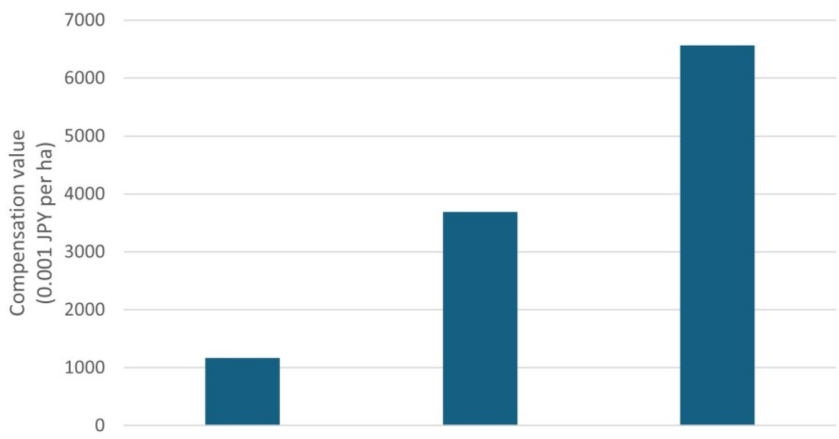


Figure 5. Estimated compensation values are presented for the cases in which the smelting facility was located in Shisakajima, Niihama, and Kyu-Besshi. The estimation is based on the model of Table 4.

The spatial distribution of compensation in each case is shown in Figures 6. The darker meshes indicate that the compensation values would be more than 5 JPY per ha in those areas (note that significant inflation has occurred over the past 100 years, substantially affecting the value of the Japanese yen). The light-dark meshes indicate that the value would be less than 5 JPY. In the cases of Niihama and Kyu-Besshi, the darker meshed areas cover larger areas than in the case of Shisakajima.

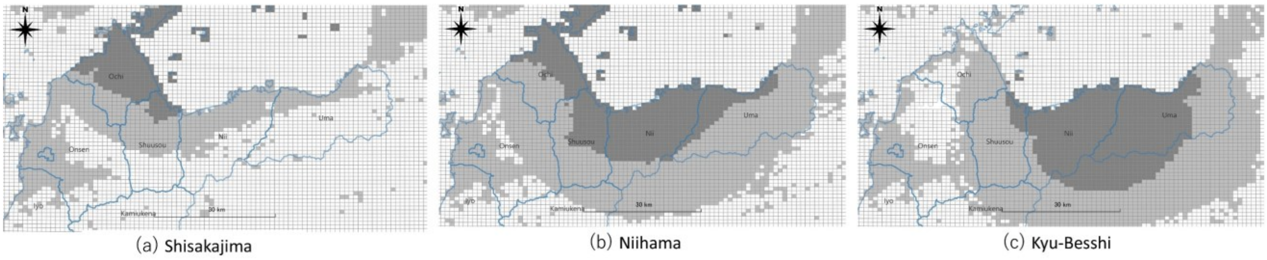


Figure 6. Distribution of compensation (>5 JPY per ha: dark meshes; <5 JPY per ha: light–dark meshes). This figure shows the respective compensation patterns for the cases in which the smelting facility was located in (a) Shisakajima, (b) Niihama, and (c) Kyu-Besshi.

The predictive ability of these models is limited. Further improvements to the model are needed, particularly to enhance its ability to predict damage patterns. One key limitation is the use of contemporary land-use data rather than data from the actual pollution period. Another limitation is that the analysis used modern meteorological data, assuming that climatic conditions have not changed significantly over the past one to two centuries. Addressing these issues will improve the accuracy and historical validity of this analysis. We also plan to extend our research to include comparative studies of the other three major copper mines in Japan. By examining differences in corporate behavior shaped by managerial resources, environmental conditions, and the adoption of technological innovations, we aim to reinterpret the nature of historical pollution and corporate responses during Japan's modernization period [30–34].

Conclusions

This study demonstrated that atmospheric dispersion simulations can be effectively combined with historical records to quantitatively reconstruct the relationships among pollution, environmental damage, and compensation in a historical context. By applying the estimated regression model, we found that early corporate decisions to relocate smelting facilities significantly reduced compensation obligations by directing pollution primarily over the sea rather than over inhabited or cultivated land areas. This highlights the extent to which corporate responses to pollution shape the spatial distribution of environmental burdens and redress among affected populations. The accuracy of the compensation estimation model should be enhanced in future research to improve the robustness of quantitative assessments. While this study focuses on a single copper mine that generated substantial pollution during Japan's modernization, future research should extend this approach to other mines to examine how different operations responded to pollution. Our approach shows that simulation-based analysis offers a promising method for reconstructing past pollution incidents in both spatial and quantitative terms. This methodology not only provides new insights into the dynamics of historical pollution but also helps evoke vivid and real-world images of how such incidents unfolded and were addressed.

Author Contributions

TT: Conceptualization, Methodology, Investigation, Writing - Review & Editing; **KI**: Software, Investigation, Writing - Review & Editing.

AI Writing Statement

During the preparation of this work the authors used Chat-GPT in order to identify grammatical errors and improve readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflicts of interest

There are no conflicts to declare.

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References

1. Ellis, E.C. Land Use and Ecological Change: a 12,000-Year History. *Annu. Rev. Environ. Resour.* **2021**, *46*, 1–33, doi:10.1146/annurev-environ-012220-010822.
2. Pfister, C.; Wanner, H. *Climate and Society in Europe: the Last Thousand Years*; Haupt Verlag: Bern, 2021; ISBN 3258082340.
3. Søndergaard, J.; Mosbech, A. Mining Pollution in Greenland - the Lesson Learned: a Review of 50 Years of Environmental Studies and Monitoring. *Sci. Total Environ.* **2022**, *812*, 152373.
4. Winter, J. A Historical Perspective Review of the Environmental Pollution. *Sci. Insights* **2024**, *44*, 1253–1261, doi:10.15354/si.24.re916.
5. Stradling, D. *Smokestacks and Progressives: Environmentalists, Engineers, and Air Quality in America, 1881-1951*; Johns Hopkins University Press: Baltimore, 1999; ISBN 0801860830.
6. DuBay, S.; Weeks, B.C.; Davis-Kean, P.E.; Fuldner, C.; Harris, N.C.; Hughes, S.; O'Brien, B.; Perkins, M.; Weyant, C. Measuring Historical Pollution: Natural History Collections as Tools for Public Health and Environmental Justice Research. *Proc. Natl. Acad. Sci.* **2025**, *122*, doi:10.1073/pnas.2403781122.
7. Kobayashi, H. Minamata: How a Policy Maker Addressed a Very Wicked Water Quality Policy Problem. In *Wicked Problems of Water Quality Governance*; Nickum, J.E., Stephan, R.M., Bjornlund, H., Eds.; Routledge: London, 2022; pp. 83–102 ISBN 9781003331438.
8. Nohara, K.; Akiba, S.; Ishizuka, M.; Nakajima, T. What We Have Learned from the Pollution that Occurred in Japan a Half Century Ago. In *Overcoming Environmental Risks to Achieve Sustainable Development Goals. Current Topics in Environmental Health and Preventive Medicine.*; Nakajima, T., Nakamura, K., Nohara, K., Kondoh, A., Eds.; Springer: Singapore, 2022; pp. 55–59 ISBN 978-981-16-6248-5.
9. Otsuka, T. Lessons of Court Decisions on Minamata Disease and Future Actions. In *Overcoming Environmental Risks to Achieve Sustainable Development Goals. Current Topics in Environmental Health and Preventive Medicine*; Nakajima, T., Nakamura, K., Nohara, K., Kondoh, A., Ed.; Springer, 2022; pp. 121–126.
10. Sarker, A. Ecological Perspectives on Water, Food, and Health Security Linkages: the Minamata Case in Japan. *Environ. Sci. Pollut. Res.* **2021**, *28*, 32177–32189, doi:10.1007/s11356-021-14207-8.
11. Coase, R.H. The Problem of Social Cost. *J. Law Econ.* **2013**, *56*, 837–877, doi:10.1086/674872.
12. Spash, C.L. The History of Pollution 'Externalities' in Economic Thought. *Soc. Res. Econ. Discuss. Pap.* **2021**, *01/2021*, doi:10.57938/c61ad395-7a3d-425a-9969-203de844de22.
13. Deryugina, T.; Moore, F.; Tol, R.S.J. Environmental Applications of the Coase Theorem. *Environ. Sci. Policy* **2021**, *120*, 81–88, doi:10.1016/j.envsci.2021.03.001.
14. Sueoka, T. Environmental Issues in Modern Japan and Solution of Air Pollution at the Besshi Copper Mine. *Sumitomo Arch. Bull. (Sumitomo Shiryoukanhou)* **2017**, 132–262.
15. Sumitomo Group Public Affairs Committee Besshi Copper Mine: Heritage of Industrial Modernization. Available online: https://www.sumitomo.gr.jp/english/history/besshidouzan/ (accessed on 4 July 2025).
16. Sumitomo Group Public Affairs Committee Sumitomo Biographies: Director-Generals. Available online: https://www.sumitomo.gr.jp/english/history/person/ (accessed on 4 July 2025).
17. Sugai, M. Four Major Copper Mine Pollution Cases in Japan, the 1890s-1910s (1). *J. Soc. Sci. (Institute Soc. Sci. Univ. Tokyo)* **1979**, *30*, 94–162.
18. Sugai, M. Four Major Copper Mine Pollution Cases in Japan, the 1890s-1910s (2). *J. Soc. Sci. (Institute Soc. Sci. Univ. Tokyo)* **1979**, *30*, 75–150.

19. Takeda, H. *A History of Copper Industry in Japan*; The University of Tokyo Press: Tokyo, 1987; ISBN 4130460323.

20. Kobata, A. *A Study on the History of Copper Mining in Japan*; Shibunkaku Shuppan: Kyoto, 1993; ISBN 4784207600.

21. Higashino, H.; Kitabayashi, K.; Inoue, K.; Mita, K.; Yonezawa, Y. Development of an Atmospheric Dispersion Model for Exposure and Risk Assessment (ADMER). *J. Japan Soc. Atmos. Environ.* **2003**, *38*, 100–115, doi:https://doi.org/10.11447/sraj.26.41.

22. Higashino, H.; Inoue, K. Development of the Atmospheric Dispersion Model for Exposure and Risk Assessment (ADMER) Ver. 3. *Japanese J. Risk Anal.* **2016**, *26*, 41–46.

23. Inoue, K.; Higashino, H.; Yoshikado, H.; Nakanishi, J. Estimation of Aggregate Population Cancer Risk From Dichloromethane for Japanese Using Atmospheric Dispersion Model. *Environ. Sci.* **2006**, *13*, 59–74.

24. Kishimoto, A.; Cao, H.; Gamo, M. Assessment of Exposure to and Risk Posed by Toluene in Japanese Residents: Combining Exposure from Indoor and Outdoor Sources. *Environ. Sci.* **2006**, *13*, 31–42.

25. Mita, K.; Higashino, H.; Yoshikado, H.; Nakanishi, J. Estimating Ambient Concentration and Cancer Risk for 1,3-Butadiene In Japan. *Environ. Sci.* **2006**, *13*, 1–13.

26. Sumitomo Metal Mining Co., L.; The Editorial Commitee *The History of Sumitomo Besshi Mine (Supplementay Volume)*; 1991.

27. Isshiki, K. *History of Smoke Damage in Eastern Ehime Prefecture*; Shuusou County Smoke Damage Investigation Committee: Nyuugawa-cho, Ehime Prefecture, Japan, 1926.

28. Ministry of Land, Infrastructure, Transport and Tourism. Land Use Third-level Mesh Data. Available online: https://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-L03-a-2021.html (accessed on 19 October 2024).

29. Environmental Restoration and Conservation Agency. Air pollution in Yokkaichi (the early 1960s). Available online: https://www.erca.go.jp/yobou/taiki/rekishi/02_02.html (accessed on 5 July 2025).

30. Takahashi, T.; Nakamura, M.; van Kooten, G.; Vertinsky, I. Rising To The Kyoto Challenge: Is the Response of Canadian Industry Adequate?. *J. Environ. Manage.* **2001**, *63*, doi:10.1006/jema.2001.0467.

31. Nakamura, M.; Takahashi, T.; Vertinsky, I. Why Japanese Firms Choose to Certify: a Study of Managerial Responses to Environmental Issues. *J. Environ. Econ. Manage.* **2001**, *42*, doi:10.1006/jeem.2000.1148.

32. Branzei, O.; Vertinsky, I.; Takahashi, T.; Zhang, W. Corporate Environmentalism Across Cultures: a Comparative Field Study of Chinese and Japanese Executives. *Int. J. Cross Cult. Manag.* **2001**, *1*, doi:10.1177/147059580113003.

33. Takahashi, T. Attitudes of Companies towards Financing Employing Environmental Ratings. *Pap. Environ. Inf. Sci.* **2010**, *ceis24*, 225–230, doi:10.11492/ceispapers.ceis24.0.225.0.

34. Sugita, M.; Takahashi, T. Influence of Corporate Culture on Environmental Management Performance: an Empirical Study of Japanese Firms. *Corp. Soc. Responsib. Environ. Manag.* **2015**, *22*, 182–192, doi:10.1002/csr.1346.