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Marnpyung Jang and Jaeyoung Yoon contributed equally to this work.

Key Points:

- We evaluated the changes in healthcare utilization patterns after 2022 Seoul flood
- The universal health insurance data and a generalized synthetic control were used
- There was an increase in injuries and a decrease in pregnancy related hospital visits after flood

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

C. Han,
cwohan@cnu.ac.kr

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Changes in Healthcare Utilization After the 2022 Seoul Metropolitan Flood: Applying a Generalized Synthetic Control Approach

Marnpyung Jang[1], Jaeyoung Yoon[1], Yeseul Yun[2], Jaiyong Kim[3], Hoyeon Jang[3], Tarik Benmarhnia[4,5], and Changwoo Han[4,6]

[1]Chungnam National University College of Medicine, Daejeon, Korea, [2]NARA Space Technology, Seoul, Korea, [3]Department of Big Data Research and Development, National Health Insurance Service, Wonju, Korea, [4]Scripps Institution of Oceanography, UC San Diego, La Jolla, CA, USA, [5]Inserm, EHESP, Irset (Institut de Recherche en Santé, Environnement et Travail) - UMR_S 1085, Université de Rennes, Rennes, France, [6]Department of Preventive Medicine, Chungnam National University College of Medicine, Daejeon, Korea

Abstract Floods can have adverse health effects and impose a burden on healthcare systems. However, the potential consequences of floods on specific medical causes in densely populated metropolitan cities has not been characterized yet. Therefore, we evaluate the changes in healthcare utilization patterns after the 2022 Seoul flood using nationwide health insurance data. Based on the flood inundation map, districts within the flooded municipalities of Seoul were classified as severe-($n = 12$), mild-($n = 22$), or non-($n = 38$) flood-affected districts. Capitalizing on the timing of the flood as a natural experiment, a generalized synthetic control method was applied to estimate changes in the number of disease-specific hospital visits in flood-affected districts during 2 weeks after the flood. We found excess hospital visits for external injuries (20.2 visits, 95% CI: −6.0, 45.2) and fewer visits for pregnancy and puerperium (−3.0 visits, 95% CI: −5.1, −0.5) in residents of flooded districts. When comparing severe- and non-flood districts, the increase in hospital visits for external injuries (56.2 visits, 95% CI: 17.2, 93.2) and a decrease in hospital visits related to pregnancy and puerperium (−5.3 visits, 95% CI: −8.4, −1.6) were prominent in residents living in severe-flood affected districts. Disease specific analysis showed an increase in hospital visits for injuries to the elbow and forearm, ankle and foot injuries, and chronic lower respiratory diseases in severe-flood-affected districts. However, these impacts were not observed when comparing the mild- and non-flood-affected districts. Our study suggests an immediate and substantial change in medical demand following flood exposure, highlighting the importance of public health responses after flood events.

Plain Language Summary This study evaluated the acute medical demands after a 2022 Seoul Metropolitan City flooding event, highlighting the need for preparedness and response to future flood disasters. We observed an increase in hospital visits related to external injuries and chronic lower respiratory infection and a decrease in pregnancy and puerperium related hospital visits in residents of severely flood-affected districts. However, such changes were not observed in residents of mildly flood-affected districts. Future healthcare management plans following flood should include adjustments to changes in the demand for medical services during and after flood events.

1. Introduction

Unexpected floods may cause health effects in flood-exposed residents, including waterborne (Levy et al., 2016), respiratory (Milojevic et al., 2012), skin (Bandino et al., 2015), and psychological diseases (Huang et al., 2016; Takagi et al., 2021), and external injuries (Bich et al., 2011; Fewtrell & Kay, 2008). For instance, floods caused over 17,000 cases of waterborne diseases in Bangladesh (Qadri et al., 2005) and a 13% increase in hospital admissions for infectious intestinal diseases in Ho Chi Minh City, Vietnam (Phung et al., 2017). An increase in cholera and acute diarrheal infections, as well as skin diseases like dermatitis and wound infections, and respiratory infections were observed among residents affected by the 2022 flood in Pakistan (Manzoor & Adesola, 2022). The prevalence of mental health symptoms among flood-affected individuals in the United Kingdom was five times higher than in the pre-flood period (Paranjothy et al., 2011). There were increased fatalities from vehicle-related drowning or physical trauma during floods in the United States (Jonkman & Kelman, 2005), and individuals in contact with floodwater reported a 17.8 times higher risk of injury in Germany (Schnitzler et al., 2007). Therefore, floods can burden healthcare systems with the increasing demand for medical services (Alderman et al., 2012). Additionally, a public health crisis following a flood can be complex, with the destruction of medical facilities, inadequate supply of medical resources, and interruption of routine medical check-ups (Achour & Price, 2010; Smith & Graffeo, 2005).

Most previous studies on the health effects of floods used self-reported field surveys of flood-exposed residents (Bich et al., 2011; Cummings et al., 2008; Mulder et al., 2019). However, self-reported surveys may have recall and selection biases and do not have detailed medical diagnosis information for multiple medical causes confirmed by healthcare professionals (De Man et al., 2016). Although a few studies have utilized emergency department visit records (Drayna et al., 2010; Lin et al., 2013; Phung et al., 2017) and hospital admission data (Phung et al., 2017), the healthcare utilization information of all hospitals in flood-affected areas has not been utilized. Therefore, a study with advanced methodological study design (e.g., quasi-experimental methods) utilizing detailed medical usage data from the flood-affected region is needed to estimate the causal effect of floods on public health.

Few studies have assessed the public health impact of heavy rainfall event in Korea. Studies with a health insurance database showed an increase in infectious diarrhea, allergic rhinitis, and atopic dermatitis hospital visits within a week after heavy rainfall (S. Kim et al., 2013; Park et al., 2013). Another study based on government disease surveillance data reported increased waterborne diseases, including Vibrio vulnificus septicemia and shigellosis, after heavy rains in Korea during the 2000s (Na et al., 2016). However, previous studies were conducted a decade ago and comprehensive assessments of changes in healthcare utilization for diverse disease outcomes after flooding were not available. Furthermore, evidence regarding the adverse health effects of flooding in major metropolitan cities is limited, even though urbanization has increased the risk of extreme rainfall and subsequent flooding by intensifying moisture convergence through urban heat and densely built building structures (Yang et al., 2021).

From 8 to 9 August 2022, a flood caused by heavy rainfall affected the central region of South Korea, including Seoul Metropolitan City. Seoul experienced daily cumulative rainfall of up to 381.5 mm and an hourly maximum rainfall of 141.5 mm, the highest observed precipitation in Korean meteorological records (Korea Research Institute for Human Settlements, 2022). The Southern part of Seoul was particularly affected, with over 100 mm of rainfall per hour, leading to the flooding of rivers and inundation of subway stations, roads, cars, and houses. The deluge resulted in 17 fatalities and 2 missing persons, and the estimated property damages were 315.4 billion South Korean Won (241.87 million USD), including 409.7 ha of agricultural land loss and 34,000 livestock deaths (The Government of the Republic of Korea, 2023).

Therefore, this study analyzed the changes in healthcare utilization patterns of residents affected by the 2022 Seoul flood. We compared hospital visit patterns among residents in flooded and non-flooded districts in Seoul using National Health Insurance data coupled with fine-scale flood inundation information. This analysis of changes in healthcare utilization patterns can provide information on healthcare services required by residents who experience flooding events.

2. Materials and Methods

2.1. Flooded Districts

The districts flooded during the 2022 Seoul Metropolitan flood (8–9 August) were defined following the flood inundation trace map created by the Seoul Metropolitan government using the data collected by district offices. Preliminary investigations were conducted within 10 days after the flood, typically involving on-site visits to assess flood damage. Comprehensive investigations were followed using a Global Positioning System, electronic theodolites, in-person surveys, and a review of meteorological data and media reports (Goo et al., 2011). The flooded area was defined as area where the flooding depth exceeds 0.3 m and those that have received disaster relief funds or insurance payouts after the flood (Figure 1; Figure S1 in Supporting Information S1).

Using a flood-inundation trace map, we selected four flood-affected municipalities in Seoul (Yeongdeungpo, Dongjak, Gwanak, and Seocho). The proportion of the inundated area per building area in each district was calculated. Based on the median inundated levels (4.63%), the districts within the affected municipalities were categorized as severe-(12 districts; where the proportion of the inundated area was 15% or more), mild-(22

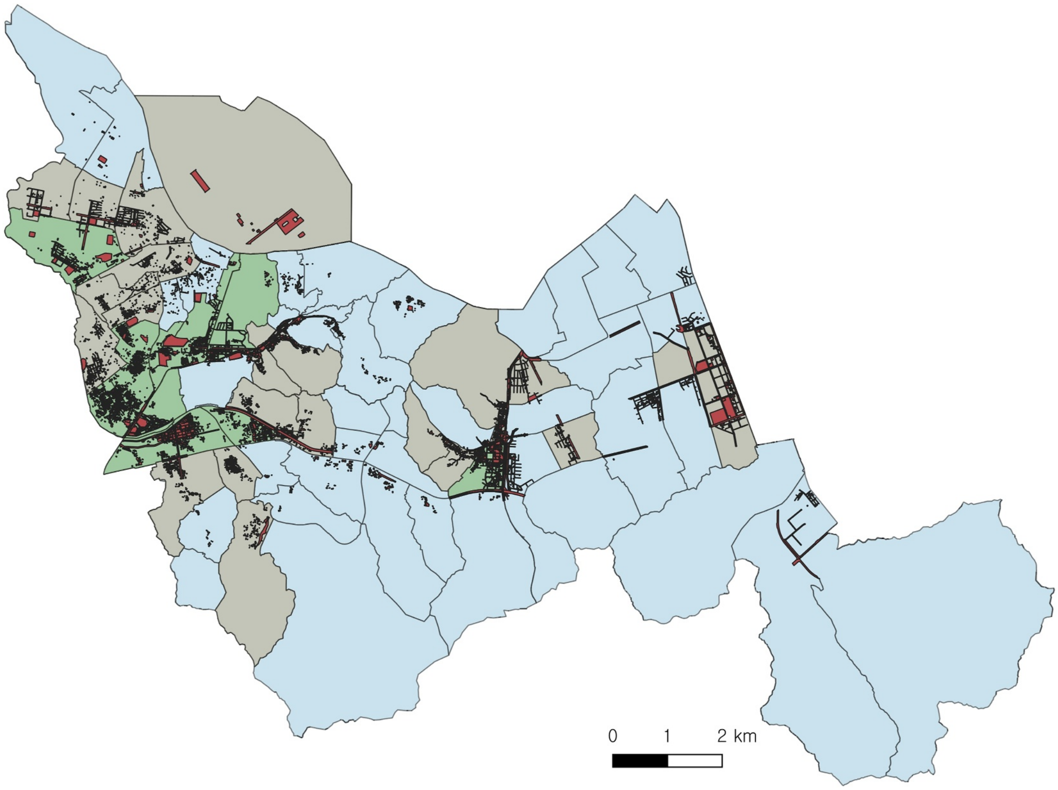

Figure 1. Map of the study region. Seventy-two districts within four flood-affected municipalities of Seoul (Yeongdeungpo, Dongjak, Gwanak, and Seocho) were classified into three classes based on the degree of inundation. Green-, gray-, and blue-colored areas represent the severe-, mild-, and non-flood affected districts, respectively. Red colored regions are area with flood inundation.

districts; where the proportion ranged from more than 5% to less than 15%), or non-(38 districts; where the proportion was less than 5%) flood-affected districts (Figure 1).

2.2. Hospital Use Data

District-level hospital visit information for major and specific disease categories was obtained from the National Health Insurance Service (NHIS). From birth to death, all hospital visit information for the entire Korean population is stored in a single database, the National Health Insurance Database (Kyoung & Kim, 2022). In collaboration with the NHIS, all hospital visit data for residents in the districts within the four flood-affected municipalities were acquired from June to August 2022. Hospital visits for major and specific disease categories were defined based on primary diagnostic code information using the International Classification of Diseases 10th Revision (ICD-10) codes. This study was exempted from review by the Chungnam University Institutional Review Board (IRB no: 202307 SB 096 01) because this study used de-identified data provided by the NHIS.

2.3. Statistical Analysis

The number of hospital visits in flood-affected (both severe and mild) and unaffected districts was compared using the generalized synthetic control method which is well-suited to assess the causal effects of climate-related hazards (Sheridan et al., 2022). A detailed discussion of the method was presented in a previous paper (Xu, 2017).

In this study, the generalized synthetic control method estimates what the number of hospital visits would have been in flooded areas if the flood (treatment) had not occurred. To do this, data from multiple control (non-flooded) areas are combined using weighting and an interactive fixed-effect model to create a synthetic control district that closely mimics the pre-flood hospital visit patterns of each flooded district (Nianogo et al., 2023;

Table 1
Estimated Changes in the Number of Hospital Visits for Major Disease Categories Among Residents in Flood-Affected Districts Compared to Non-Flood-Affected Districts During the 2 Weeks Following the Flood

Major disease categories	ICD-10 code	Cumulative number of hospital visits 2 weeks before the flood (baseline)	Changes in number of hospital visits 0–2 weeks after the flood	Percent changes in hospital visits 0–2 weeks after the flood compared to the baseline
Certain infectious and parasitic diseases	A00-B99	551.9	−1.7 (−19.4, 11.0)	−0.3 (−3.5, 2.0)
Neoplasm	C00-D48	452.8	−4.2 (−14.7, 7.1)	−0.9 (−3.2, 1.6)
Endocrine, nutritional and metabolic diseases	E00-E90	712.6	−14.3 (−28.4, 5.7)	−2.0 (−4.0, 0.8)
Mental and behavioral disorders	F00-F99	559.3	6.9 (−4.2, 20.6)	1.2 (−0.8, 3.7)
Diseases of the nervous system	G00-G99	263.9	−0.2 (−8.2, 9.3)	−0.1 (−3.1, 3.5)
Diseases of the eye and the ear	H00-H95	1008.6	−6.4 (−32.8, 16.8)	−0.6 (−3.3, 1.7)
Diseases of the circulatory system	I00-I99	1033.1	−3.0 (−26.3, 30.2)	−0.3 (−2.5, 2.9)
Diseases of the respiratory system	J00-J99	1578.6	17.0 (−21.6, 57.2)	1.1 (−1.4, 3.6)
Diseases of the digestive system	K00-K93	778.6	−2.7 (−21.8, 14.3)	−0.3 (−2.8, 1.8)
Diseases of the skin and subcutaneous tissue	L00-L99	817.1	−11.9 (−26.1, 4.4)	−1.5 (−3.2, 0.5)
Diseases of the musculoskeletal system and connective tissue	M00-M99	2160.5	16.9 (−16.1, 57)	0.8 (−0.7, 2.6)
Diseases of the genitourinary system	N00-N99	843.3	2.5 (−16.5, 17.7)	0.3 (−2.0, 2.1)
Pregnancy, childbirth, and the puerperium	O00-O99	19.7	−3.0 (−5.1, −0.5)	−15.2 (−25.9, −2.5)
Injury, poisoning, and certain other consequences of external causes	S00-T98	962.5	20.2 (−6.0, 45.2)	2.1 (−0.6, 4.7)

Sheridan et al., 2022). If the synthetic control is comparable to the hospital visit patterns of the flooded area before the flood, the post-flood hospital visits patterns of the synthetic control can be used to estimate the counterfactual hospital visits in the flooded area (Nianogo et al., 2023; Sheridan et al., 2022).

Considering the timing of the event as random (i.e., independent from the health outcomes under study), there is a vast existing literature using quasi-experimental approaches to infer causal effects of natural disasters on public health (Sheridan et al., 2022). It is possible to estimate causal effects under specific identification assumptions under the potential outcomes framework. Specifically, we ensured that: (a) geographical units eligible for the pool of control groups have not been exposed to the flooding event (as demonstrated in the flooded district section); (b) differences in the hospital visits between the treated units and the obtained synthetic control groups before the flood were null or close to 0 (equivalent to the parallel trend assumption in the difference-in-difference analysis), and (c) no other shocks coincidently took place during the flood event (i.e., common shock assumption) (Nianogo et al., 2023; Sheridan et al., 2022). These causal identification assumptions being met, we can use our estimates (difference between observed and counterfactual number of hospital visits after the flood) to infer the causal effects of the flood event on the outcomes of interest.

For the main analysis, we defined the pre-treatment period from 1 June to 7 August 2022 (68 days before the flood), and the post-treatment period from 8 to 21 August 2022 (14 days since the flood started). The average treatment effect of the treated (ATT) (changes in the number of hospital visits in the flooded districts) was calculated as the difference between the treated and estimated synthetic control groups after the flood. For this study, the number of cumulative changes in hospital visits for each flooded districts during zero to 2 weeks after the flood was compared to the generated synthetic control using the R software "gsynth" package (Xu, 2017).

First, we compared the number of hospital visits for large disease categories (based on the ICD-10 code categories listed in Table 1) between the flooded (severe- and mild-flood-affected) and non-flooded districts. Subsequently, we compared severe- and mild-flood-affected districts to non-flooded districts to evaluate the dose-response relationship between the degree of flood damage and changes in the number of hospital visits. Based on previous studies reporting the associations between flooding and infectious diseases, psychological disorders, respiratory diseases, and external injuries (Bandino et al., 2015; Bich et al., 2011; Fewtrell & Kay, 2008; Huang et al., 2016; Milojevic et al., 2012; Takagi et al., 2021), we conducted disease-specific analyses within each of these categories.

Several sensitivity and stratification analyses were conducted. First, we used different definitions of flooded districts [severe- (six districts; the proportion of the inundated area was 20% or more) and mild-flood-affected districts (28 districts; where the proportion ranged from more than 5% to less than 20%)]. Second, stratification analysis by gender and age groups (ages 0–14, 15–64, and ≥65) were conducted for large disease categories to evaluate effect modification with demographic characteristics. Third, we set an artificial time point one year before the 2022 Seoul flood (8 August 2021) and performed a negative control analysis with the expectation of null results. All analyses were performed using SAS (version 9.4) and R software (version 4.2.1).

3. Results

Table 1 and Figure S2 in Supporting Information S1 compare the number of hospital visits for major disease categories between the flooded (severe- and mild-) and non-flooded districts. The initial 2 weeks following the flood resulted in excess hospital visits for external injuries (20.2 visits, 95% confidence interval [CI]: −6.0, 45.2) and fewer visits for pregnancy, childbirth, and puerperium (−3.0 visits, 95% CI: −5.1, −0.5) among residents of flood-affected districts.

Comparing severe- and non-flood-affected districts showed an increase in hospital visits related to external injuries (56.2 visits, 95% CI: 17.2, 93.2) and a decrease in hospital visits related to pregnancy and childbirth (−5.3 visits, 95% CI: −8.4, −1.6) among residents of severe-flood affected districts during the 2 weeks after the flood (Table 2 and Figure 2). These changes correspond to 6.1% and −30.1% changes of hospital visits related to external injuries and pregnancy and childbirth, respectively, when compared to the number of hospital visits occurred during the 2 weeks before the flood. However, these changes were not observed when hospital visits patterns of residents within the mild- and non-flood-affected districts were compared (Table 2 and Figure S3 in Supporting Information S1).

Detailed disease-specific analyses comparing number of hospital visits among residents living in severe flood-affected and non-flood-affected districts are presented in Table 3 and Figure 3. An increase in hospital visits due to injuries to the elbow and forearm (9.9 visits, 95% CI: 2.6, 17.8), injuries to the wrist and hand (9.4 visits, 95% CI: 1.9, 26.9), and injuries to the ankle and foot (15.7 visits, 95% CI: 2.4, 27.9) was observed in residents living in severe flood-affected districts in the 2 weeks following the flood. Additionally, there was an increase in hospital visits related to chronic lower respiratory diseases (14.1 visits, 95% CI: 0.8, 28.0) and other viral diseases (13.9 visits, 95% CI: −3.1, 22.3). When comparing mild- and non-flood-affected districts, an increase in hospital visits due to injuries to the knee and lower leg (8.5 visits, 95% CI: 0.8, 17.7) was observed. However, there were no changes in other disease categories following flooding (Table S1 and Figure S4 in Supporting Information S1).

Stratification analysis showed the differential effect of the flood on health care utilization by demographic characteristics of the flood-affected residents (Tables S2–S6 and Figures S5–S7 in Supporting Information S1). When comparing severe- and non-flood-affected districts, men showed a greater increase in hospital visits for external injuries compared to women (men: 36.3 visits, 95% CI: 17.8, 58.7; women: 15.0 visits, 95% CI: −9.4, 41.3) (Tables S2 and S3 and Figures S5 and S6 in Supporting Information S1). In age group-specific analysis, residents aged 15–64 in severe flood-affected districts showed changes in hospital visits related to certain infections and parasitic diseases (28.5 visits, 95% CI: 9.7, 44.5), diseases of the respiratory system (34.0 visits, 95% CI: 8.1, 61.8), pregnancy, childbirth, and puerperium (−5.3 visits, 95% CI: −8.4, −1.6), and external injuries (43.7 visits, 95% CI: 12.1, 73.5) in the 2 weeks following the flood (Table S5 and Figure S7 in Supporting

Table 2
Estimated Changes in the Number of Hospital Visits for Major Disease Categories Among Residents in Severe- and Mild-Flood-Affected Districts Compared to Non-Flood-Affected Districts During the 2 Weeks Following the Flood

Major disease categories	ICD-10 code	Cumulative number of hospital visits 2 weeks before the flood (baseline)	Changes in number of hospital visits 0–2 weeks after the flood	Percent changes in hospital visits 0–2 weeks after the flood compared to the baseline
Comparison between severe- and non-flood affected districts				
Certain infectious and parasitic diseases	A00-B99	558.6	12.7 (−9.9, 31.0)	2.3 (−1.8, 5.5)
Neoplasm	C00-D48	437.9	−0.7 (−14.6, 15.5)	−0.2 (−3.3, 3.5)
Endocrine, nutritional, and metabolic diseases	E00-E90	654.0	−17.8 (−37.6, 7.5)	−2.7 (−5.7, 1.1)
Mental and behavioral disorders	F00-F99	518.9	2.9 (−14.2, 23.4)	0.6 (−2.7, 4.5)
Diseases of the nervous system	G00-G99	262.6	−3.2 (−15.0, 10.2)	−1.2 (−5.7, 3.9)
Diseases of the eye and the ear	H00-H95	928.2	−10.7 (−49.0, 33.0)	−1.2 (−5.3, 3.6)
Diseases of the circulatory system	I00-I99	1002.3	0.1 (−34.7, 43.8)	0.0 (−3.5, 4.4)
Diseases of the respiratory system	J00-J99	1549.0	41.5 (−10.0, 95.2)	2.7 (−0.6, 6.1)
Diseases of the digestive system	K00-K93	776.8	−10.4 (−37.6, 14.0)	−1.3 (−4.8, 1.8)
Diseases of the skin and subcutaneous tissue	L00-L99	767.8	−13.7 (−34.2, 10.8)	−1.8 (−4.5, 1.4)
Diseases of the musculoskeletal system and connective tissue	M00-M99	2089.2	2.3 (−45.9, 52.0)	0.1 (−2.2, 2.5)
Diseases of the genitourinary system	N00-N99	785.2	4.1 (−21.5, 27.6)	0.5 (−2.7, 3.5)
Pregnancy, childbirth, and the puerperium	O00-O99	17.6	−5.3 (−8.4, −1.6)	−30.1 (−47.7, −9.1)
Injury, poisoning, and certain other consequences of external causes	S00-T98	924.2	56.2 (17.2, 93.2)	6.1 (1.9, 10.1)
Comparison between mild- and non-flood-affected districts				
Certain infectious and parasitic diseases	A00-B99	548.3	−9.5 (−29.6, 3.6)	−1.7 (−5.4, 0.7)
Neoplasm	C00-D48	460.9	−6.1 (−17.8, 6.6)	−1.3 (−3.9, 1.4)
Endocrine, nutritional, and metabolic diseases	E00-E90	744.5	−12.4 (−28.9, 10.1)	−1.7 (−3.9, 1.4)
Mental and behavioral disorders	F00-F99	581.4	9.7 (−4.7, 25.1)	1.7 (−0.8, 4.3)
Diseases of the nervous system	G00-G99	264.6	1.4 (−8.0, 11.8)	0.5 (−3.0, 4.5)
Diseases of the eye and the ear	H00-H95	1052.5	−4.8 (−37.0, 22.5)	−0.5 (−3.5, 2.1)
Diseases of the circulatory system	I00-I99	1049.9	−4.7 (−32.2, 33.5)	−0.4 (−3.1, 3.2)
Diseases of the respiratory system	J00-J99	1594.8	3.7 (−35.1, 46.8)	0.2 (−2.2, 2.9)

Table 2
Continued

Major disease categories	ICD-10 code	Cumulative number of hospital visits 2 weeks before the flood (baseline)	Changes in number of hospital visits 0–2 weeks after the flood	Percent changes in hospital visits 0–2 weeks after the flood compared to the baseline
Diseases of the digestive system	K00-K93	779.6	1.5 (−19.5, 20.9)	0.2 (−2.5, 2.7)
Diseases of the skin and subcutaneous tissue	L00-L99	843.9	−10.9 (−28.3, 6.8)	−1.3 (−3.4, 0.8)
Diseases of the musculoskeletal system and connective tissue	M00-M99	2199.4	26.4 (−8.9, 69.7)	1.2 (−0.4, 3.2)
Diseases of the genitourinary system	N00-N99	875.0	1.4 (−19.4, 20.3)	0.2 (−2.2, 2.3)
Pregnancy, childbirth, and the puerperium	O00-O99	20.9	−1.8 (−4.2, 1.3)	−8.6 (−20.1, 6.2)
Injury, poisoning, and certain other consequences of external causes	S00-T98	983.4	0.6 (−29.5, 29.6)	0.1 (−3.0, 3.0)

Information S1). However, these changes were not observed in stratification analyses when hospital visit patterns of residents within the mild- and non-flood-affected districts were compared.

The sensitivity analysis with different definitions of severe- and mild-flood-affected districts showed similar results as in the main analyses (Tables S7 and S8 in Supporting Information S1). Two weeks following the flood showed an increase in hospital visits related to external injuries (63.7 visits, 95% CI: 9.2, 115) and a decrease in visits related to pregnancy and puerperium (−6.0 visits, 95% CI: −10.2, −1.3) in severely flood-affected districts, while no significant changes were found in mildly affected districts. Additionally, a null association was found in a falsification test with a random event set 1 year (8 August 2021) before the Seoul flood as expected (Table S9 in Supporting Information S1).

4. Discussion

Residents who experienced the 2022 Seoul metropolitan flood showed an increase in hospital visits for external injuries and a decline in hospital visits related to pregnancy and puerperium. Disease-specific analysis revealed increased visits for several diseases within external injuries and chronic lower respiratory diseases. We found a dose-response relationship between the degree of flood damage and changes in hospital visit patterns.

Over the past decade, property damage caused by heavy rainfall has accounted for a significant proportion of the costs associated with natural disasters in Korea. For example, heavy rainfall events caused financial losses of 40.5 billion KRW (South Korean Won, 30.4 million USD) in 2021, comprising 61.5% of the total economic damage caused by natural disasters (Korean Ministry of the Interior and Safety, 2022). Given the projected increase in rainfall and flooding under possible future climate change (Van Aalst, 2006), assessing the potential health burden of flood events is crucial to respond to future events.

Previous studies used large-scale administrative units to define flood-affected and non-affected regions. In Korean studies, the entire country is divided into 16 administrative units to determine which residents are exposed to heavy rainfall (S. Kim et al., 2013; Na et al., 2016; Park et al., 2013). Similarly, a Taiwanese study divided Taiwan into 22 subregions (Huang et al., 2016). These low spatial resolutions may be related to exposure misclassification, incorrectly identifying residents exposed to heavy rainfall or flood events. Moreover, previous studies focused on the relationship between floods and one or two specific types of diseases (Cummings et al., 2008; Drayna et al., 2010; Lin et al., 2013; Wade et al., 2004). As floods are related to various health outcomes (Du et al., 2010; Paterson et al., 2018), a comprehensive assessment of the relationship between floods and diverse illnesses can help to understand their actual health impacts on the population.

Our study evaluated temporal changes in healthcare utilization patterns before and after the flood event among residents living in flood-affected and non-flood-affected districts based on nationwide health insurance database.

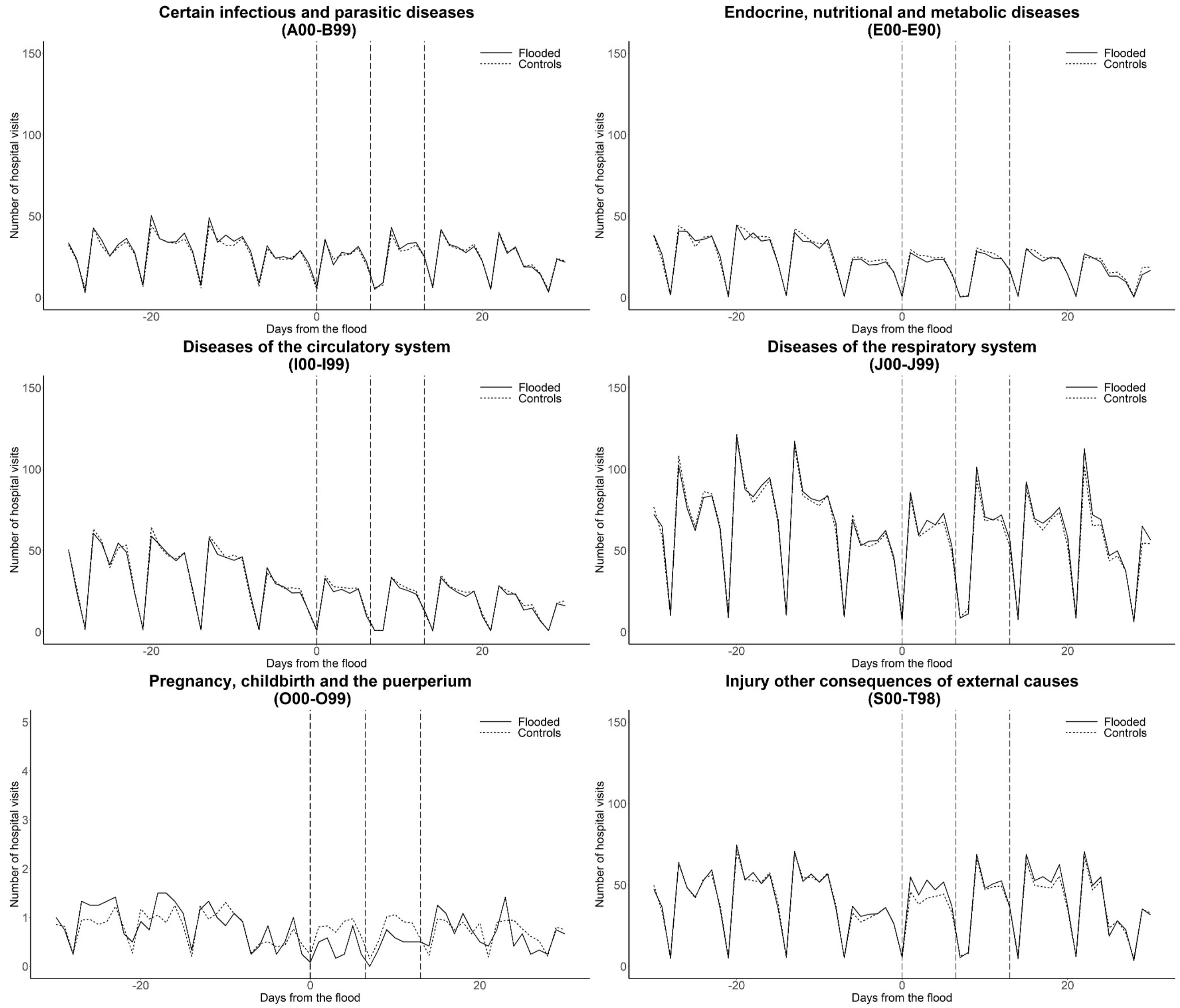

Figure 2. Number of hospital visits in severe- (solid lines) and non-flood-affected (dotted lines, synthetic control) districts. The vertical dashed lines represent the weeks (8 August 2022 to 21 August 2022) after the flood.

As Korea's health insurance data are generated in real-time through reports from certified healthcare providers, the possibilities of recall bias, misdiagnosis, or misreporting can be minimized (J.-A. Kim et al., 2017). By utilizing the flood inundation trace map of Seoul Metropolitan City, this study was able to categorize the flood-exposed and non-exposed residents at the finest administrative unit scale in Korea.

Our study showed increased hospital visits related to external injuries following the 2022 Seoul Metropolitan Flood. The increase was greater among men and residents aged 15–64. During floods, various external injuries, including contusions, punctures, sprains, fractures, and lacerations, can occur. In the United States, sprains, strains, and lacerations are the most commonly reported flood-related injuries (Centers for Disease Control and Prevention, 1993; Doocy et al., 2013). Musculoskeletal injuries are often caused by falls and drowning during flood events (Bich et al., 2011). Lacerations or cuts can occur because of contact with debris or sharp objects in the water, getting caught in trees or structures, or hastily moving the body to avoid emergencies (Cariappa & Khanduri, 2003). Additionally, injuries may occur during cleaning because of sharp debris, shattered glass, or nails. Other external injuries, such as electric shocks, burns, insects and animal bites, may increase following a flood (Diaz, 2007; Noji, 2000).

Table 3
Estimated Changes in the Number of Hospital Visits for Specific Disease Categories Among Residents in Severe-Flood-Affected Districts Compared to Non-Flood-Affected Districts During the 2 Weeks Following the Flood

Specific disease categories	ICD-10 code	Cumulative number of hospital visits 2 weeks before the flood (baseline)	Changes in number of hospital visits 0–2 weeks after the flood	Percent changes in hospital visits 0–2 weeks after the flood compared to the baseline
Certain infectious and parasitic diseases				
Intestinal Infectious Diseases	A00-A09	149.5	3.8 (−7.8, 14.5)	2.5 (−5.2, 9.7)
Other bacterial diseases	A30-A49	9.4	−0.1 (−2.9, 2.5)	−1.1 (−30.9, 26.6)
Other viral diseases	B25-B34	56.2	13.9 (−3.1, 22.3)	24.7 (−5.5, 39.7)
Mycoses	B35-B49	163.4	5.2 (−8.6, 15.8)	3.2 (−5.3, 9.7)
Psychological disease				
Organic, including symptomatic, mental disorders	F00-F09	59.9	−1.7 (−6.6, 4.0)	−2.8 (−11.0, 6.7)
Mental and behavioral disorders due to psychoactive substance use	F10-F19	9.0	−1.2 (−3.3, 0.3)	−13.3 (−36.7, 3.3)
Mood disorders	F30-F39	217.8	4.1 (−6.5, 15.8)	1.9 (−3.0, 7.3)
Neurotic, stress-related, and somatoform disorders	F40-F48	124.3	−0.5 (−7.3, 6.8)	−0.4 (−5.9, 5.5)
Respiratory disease				
Acute upper respiratory infections	J00-J06	606.0	18.2 (−16.2, 53.4)	3.0 (−2.7, 8.8)
Influenza and pneumonia	J09-J18	23.9	−2.4 (−8.9, 3.0)	−10.0 (−37.2, 12.6)
Other acute lower respiratory infections	J20-J22	501.0	0.7 (−36.4, 48.4)	0.1 (−7.3, 9.7)
Other diseases of upper respiratory tract	J30-J39	305.5	−4.9 (−22.2, 16.2)	−1.6 (−7.3, 5.3)
Chronic lower respiratory diseases	J40-J47	99.2	14.1 (0.8, 28.0)	14.2 (0.8, 28.2)
Injury, poisoning and certain other consequences of external causes				
Injuries to the head	S00-S09	45.5	3.0 (−4.4, 9.6)	6.6 (−9.7, 21.1)
Injuries to the neck	S10-S19	46.7	4.8 (−2.2, 12.8)	10.3 (−4.7, 27.4)
Injuries to the thorax	S20-S29	44.8	−3.2 (−10.8, 3.0)	−7.1 (−24.1, 6.7)
Injuries to the abdomen, lower back, lumbar spine and pelvis	S30-S39	125.2	−0.9 (−11.2, 8.3)	−0.7 (−8.9, 6.6)
Injuries to the shoulder and upper arm	S40-S49	63.1	−5.1 (−14.7, 6.5)	−8.1 (−23.3, 10.3)
Injuries to the elbow and forearm	S50-S59	51.8	9.9 (2.6, 17.8)	19.1 (5.0, 34.4)
Injuries to the wrist and hand	S60-S69	142.6	9.4 (1.9, 26.9)	6.6 (1.3, 18.9)
Injuries to the hip and thigh	S70-S79	22.4	1.4 (−3.4, 5.7)	6.2 (−15.2, 25.4)

Table 3
Continued

Specific disease categories	ICD-10 code	Cumulative number of hospital visits 2 weeks before the flood (baseline)	Changes in number of hospital visits 0–2 weeks after the flood	Percent changes in hospital visits 0–2 weeks after the flood compared to the baseline
Injuries to the knee and lower leg	S80-S89	98.7	6.6 (−3.0, 17.3)	6.7 (−3.0, 17.5)
Injuries to the ankle and foot	S90-S99	163.9	15.7 (2.4, 27.9)	9.6 (1.5, 17.0)

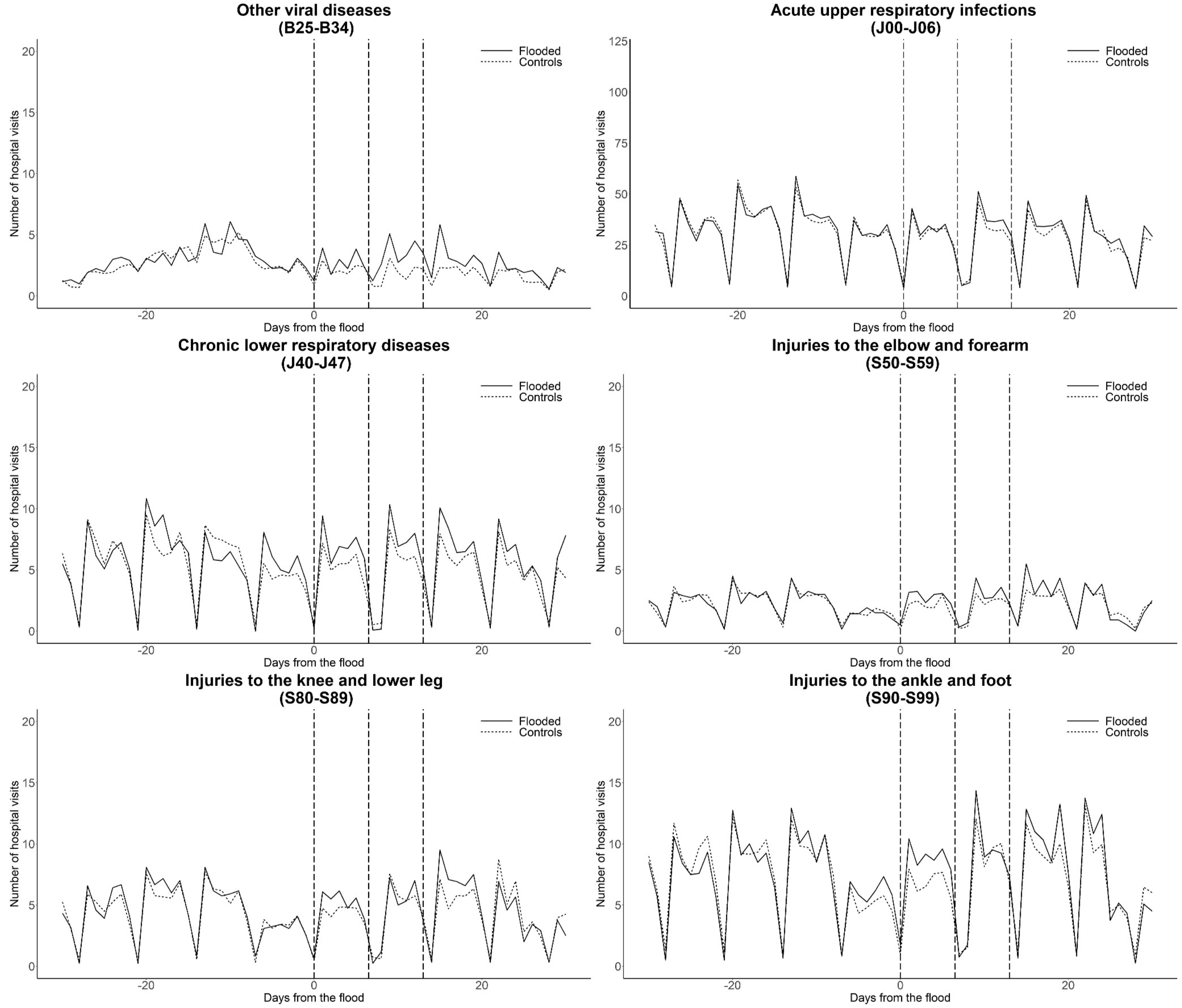

Figure 3. Number of hospital visits for specific disease categories in severe- (solid-lines) and non-flood-affected (dotted-lines, synthetic control) districts. The vertical dashed lines represent the weeks (8 August 2022 to 21 August 2022) after the flood.

A recent study using data from 33 developing countries reported a 1.08 times increased risk of pregnancy loss with gestational flood exposure (He et al., 2024). Injuries, physical and psychological stresses, and inadequate medical service utilization during and after the flood event may increase the risk of pregnancy-related disorders (Mallett & Etzel, 2018; Ochani et al., 2023). Studies in the United States have reported delayed or inadequate prenatal care service after Hurricanes Michael and Katrina (Harville et al., 2021; Pan et al., 2021). Floods may have restricted the mobility of patients (Pan et al., 2021) and resulted in decreased use of healthcare services (Ajibade et al., 2013).

We found a decrease in hospital visits related to pregnancy, childbirth, and puerperium in residents of severely flood-affected districts after the flood. This may indicate disrupted medical service utilization of pregnant women shortly after the flood. Damaged infrastructure and limited accessibility to healthcare facilities after the flood may decrease the hospital visits among pregnant women (Ochani et al., 2023). Because home is generally regarded as secure and safe place (Makwana, 2019), pregnant women with minimal physical and household damage may choose to stay at home after the flood.

Personal and social contexts can determine the extent of health effects on pregnant women exposed to floods (Ajibade et al., 2013; Mallett & Etzel, 2018; Ochani et al., 2023). The risk of pregnancy loss due to gestational flood exposure was found to be higher among women with lower income or education levels (He et al., 2024). A case study focused on the 2011 Lagos flood in Nigeria indicated that the health impacts of floods on pregnant women were particularly severe for those residing in lower-income neighborhoods (Ajibade et al., 2013). Further research is needed to identify the individual and social characteristics of pregnant women that increase vulnerability to health impacts from floods.

The residents from severely flood-affected districts showed increased hospital visits for chronic lower respiratory disease. Residents aged 15–64 showed increased hospital visits for respiratory diseases. Various studies and reviews have consistently highlighted the correlation between dampness, mold, and chronic respiratory diseases (Clark et al., 2004; Fisk et al., 2010; Heseltine & Rosen, 2009; Mendell Mark et al., 2011; Peirce et al., 2022; Pirhonen et al., 1996). Limited access to medical services or treatments, such as nebulizers and drugs, may explain the increased respiratory symptoms and diseases during and after floods (Robinson et al., 2011). Furthermore, factors that may accompany disasters, such as shortages of food and clean water, physical and psychological stress, can exacerbate preexisting chronic respiratory diseases (Mokdad et al., 2005).

Unlike previous Korean studies, no changes in hospital use for infectious and parasitic diseases were detected after the 2022 Seoul metropolitan flood. Although statistically insignificant, there was an increasing tendency toward hospital use for other viral diseases, as indicated by the disease-specific analysis comparing severe- and non-flood-affected districts (Table 3). In addition, age group-specific analyses showed an increase in hospital visits for infectious and parasitic diseases among residents aged 15–64. The risk of gastrointestinal disease can increase after flooding from inadequate drainage and poorly managed water supply systems (Parkinson, 2003). However, Seoul, which benefits from its relatively well-maintained sewage infrastructure and access to clean drinking water, may exhibit stable patterns in the prevalence of infectious diseases.

In 2011, the Seoul metropolitan government proposed sewer maintenance, pumping station construction, the development of flood forecasting and warning systems, and the introduction of damage insurance programs to respond to localized rainfall and floods (Korean Ministry of the Interior and Safety, 2016). After the 2022 flood, the government planned to establish a flood prevention park by following the example of Japan's comprehensive flood control system in the Neyagawa basin (Ko et al., 2018) and declared the expansion of drainage and storage facilities. The Ministry of Environment introduced a flood management system with smart information and communication technology and AI-based forecasting or warning systems to reduce future casualties (Korea Research Institute for Human Settlements, 2022). However, government-led comprehensive healthcare management plans for flood-affected residents are still lacking in Korea. Future plans should encompass adjustments to changes in the demand for medical services during and after flood events.

For instance, to mitigate the potential risk of external injury or physical trauma, the government should implement preventive measures, including improving evacuation guidelines and educating residents in flood-prone areas. Immediate and coordinated emergency medical services should be provided for external injury patients to prevent further harm (Hirshon et al., 2013). Furthermore, the decrease in medical visits related to pregnancy and chronic diseases following floods observed in this study underscores the importance of managing vulnerable populations needing routine medical checkups. Because delayed prenatal care can significantly harm maternal and fetal health (Dowswell et al., 2010), and interruption of treatment for chronic diseases may cause disease exacerbation and death (Ryan et al., 2015), it will be important to provide guidance to ensure that people who need regular hospital care can continue to receive ongoing management even during disaster situations.

This study has several limitations. First, this study focuses on the acute effects of floods on hospital-use patterns. The flood may cause lagged health effects for weeks to months (Du et al., 2010; Stanke et al., 2012). Diseases showing long-term increases after flooding in previous studies (Du et al., 2010), such as noncommunicable diseases, disabilities, and mental health problems, require further attention in future studies.

While our study focused on acute health impacts attributable to a specific flooding event, recent evidence suggests that repeated exposure to floods can have lasting and long-term impacts as illustrated among communities living in flood-prone areas in Bangladesh (Rerolle et al., 2023). In the context of climate change, extreme weather events are becoming more frequent, and communities can be repeatedly exposed to such hazards. Documenting the long-term health impacts related to living in flood-prone areas in urban areas, including in high-income contexts constitutes an important area of future research.

Second, we have used single method to define the flood affected districts. The flood damage can be measured by various methods (Olesen et al., 2017), but only available objective metric available for this study was inundation map of the Seoul metropolitan government. In addition, the definition of severe- and mild-flood-affected districts were based on the distribution of the proportion of the inundated area of the flood affected districts. However, inundation depth is widely used for flood damage assessments (Merz et al., 2013) and a sensitivity analysis with different threshold values for definition of severe- and mild-flood-affected districts did not change the main results.

Third, the diagnostic information of the health insurance data should be interpreted with caution. The primary aim of the national health insurance system is to facilitate reimbursement rather than pinpointing specific disease outbreaks. Additionally, the NHIS database lacks detailed clinical data, such as laboratory results (Seong et al., 2017). Nevertheless, due to the universal coverage and the quality of the insurance system in Korea, it is plausible that the disease diagnosis and reporting patterns of physicians remained consistent during and after the flood. This consistency allows for a reasonable temporal comparison of healthcare service numbers before and after the flood.

Fourth, due to the study design and data constraints, further stratification analyses to evaluate effect modification for personal and community-level factors (e.g., income levels) were not possible. Considering the disproportionate health effects of flood across different socio-economic status (Ajibade et al., 2013; He et al., 2024), further studies are needed to highlight the individual and communities particularly vulnerable to flood events in terms of their health effects.

5. Conclusion

Our study evaluated the acute medical demands after a 2022 Seoul Metropolitan City flooding event, highlighting the need for preparedness and response to future flood disasters. We observed an increase in hospital visits related to external injuries and chronic lower respiratory infection and a decrease in pregnancy and puerperium in residents of severely flood-affected districts. However, such changes were not observed in residents of mildly flood-affected districts. Future healthcare management plans following flood should encompass adjustments to changes in the demand for medical services during and after flood events.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The National Health insurance data is not publicly available to protect individual privacy, but access to the data could be requested directly at the National Health Insurance Sharing Service homepage (https://nhiss.nhis.or.kr/bd/ay/bdaya001iv.do). The R software version 4.2.1 was used for all analysis (R Core Team, 2021). The "gsynth" R package and example code used in this study is available at package author's personal homepage (https://

yiqingxu.org/packages/gsynth/) (Xu & Liu, 2022). The code used in this study and the flood inundation map from Seoul Metropolitan city open data portal (https://data.seoul.go.kr/dataList/OA-15636/F/1/datasetView.do) are available at author github (Han, 2024).

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