

# Increased Risk of Legionella Pneumonia as Community-acquired Pneumonia after Heavy Rainfall in 2018 in West Japan

Miho Mitsui (✉ [32134miho@gmail.com](mailto:32134miho@gmail.com))

Kurashiki Central Hospital: Kurashiki Chuo Byoin <https://orcid.org/0000-0002-3110-4705>

**Akihiro Ito**

Kurashiki Central Hospital: Kurashiki Chuo Byoin

**Tadashi Ishida**

Kurashiki Central Hospital: Kurashiki Chuo Byoin

**Hiromasa Tachibana**

National Hospital Organization Minami Kyoto Hospital

**Yosuke Nakanishi**

Kurashiki Central Hospital: Kurashiki Chuo Byoin

**Akio Yamazaki**

Shiga University of Medical Science: Shiga Ika Daigaku

**Yasuyoshi Washio**

Research Institute for Disease of the Chest, Graduate School of Medical science, Kyushu University

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## Research

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# Abstract

**Background:** Japan experienced a heavy rainfall event from June 28 to July 8, 2018, and many casualties were caused by both heavy rainfall and flooding. Few studies have investigated patients' characteristics and causative pathogens of community-acquired pneumonia before and after heavy rainfall events. The aim of the present study was to evaluate the causative pathogens and clinical characteristics of hospitalised patients with community-acquired pneumonia before and after the heavy rainfall event using prospective cohort data.

**Methods:** The study was divided into two periods: July to November 2013-2017 (pre heavy rainfall) and July to November 2018 (post heavy rainfall). The patients' clinical characteristic and causative pathogens before and after the heavy rainfall were investigated. Regarding the causative pathogens, precipitation and seasonal patterns were adjusted.

**Results:** There were no significant differences in the number and clinical characteristics of patients pre and post heavy rainfall. However, the frequency of *Legionella* pneumonia was significantly higher after than before the heavy rainfall event (8.9% vs 3.0%,  $P = 0.02$ ) and remained significant after adjusting for precipitation and season. Three of 7 *Legionella* pneumonia patients engaged in reconstruction work and 2 *Legionella* pneumonia patients had soil exposure.

**Conclusions:** An increased risk of *Legionella* pneumonia after not only rainfall and serious flooding, but also following recovery work or soil exposure should be considered.

**Trial registration:** A prospective epidemiological study for patients with pneumonia in a single center in Japan, UMIN000004353. Registered 7 October 2010, [https://upload.umin.ac.jp/cgi-open-bin/ctr\\_e/ctr\\_view.cgi?recptno=R000005195](https://upload.umin.ac.jp/cgi-open-bin/ctr_e/ctr_view.cgi?recptno=R000005195)

## Background

Pneumonia is one of the most problematic infectious diseases worldwide because of its high morbidity and mortality. The number of patients hospitalised with pneumonia is much higher than that of patients hospitalised with other respiratory diseases such as bronchial asthma, bronchitis, chronic obstructive pulmonary disease (COPD), and lung cancer [1].

Previous reports demonstrated that acute respiratory infections are a major cause of disease after hydrologic events such as tropical cyclones, typhoons, and other heavy rainfall-related events [2–6], and numbers of both outpatients and inpatients with pneumonia increase after such disasters [7, 8]. Regarding the aetiology of pneumonia, the rate of *Haemophilus influenzae* infection was significantly higher after tsunami and earthquake disasters [7]. Both contact with floodwaters and post-flooding cleaning were reported to increase the risk of respiratory infections [4].

Western Japan experienced a heavy rainfall event from June 28 to July 8, 2018. This event was called the “west Japan heavy rainfall,” and it caused significant flood damage in Kurashiki city, where our hospital is located. Few studies have investigated patients’ characteristics and causative pathogens of CAP before and after this heavy rainfall event. Thus, the aim of this study was to investigate the frequency of CAP and any differences in causative pathogens before and after the west Japan heavy rainfall event using a prospective cohort database.

## Methods

### Study design and setting

A prospective cohort study was conducted to investigate the clinical characteristics of hospitalised pneumonia patients beginning in October 2010 in Kurashiki Central Hospital, a 1,166-bed tertiary hospital in Okayama Prefecture, Japan (UMIN000004353). In particular, CAP patients who were admitted between 2013 and 2018 were analysed. CAP was defined as recommended by the Infectious Diseases Society of America/American Thoracic Society guidelines [9]. These guidelines required any of the following: presence of infiltrate on chest imaging; some clinical symptoms (cough, sputum production, fever, dyspnoea, and pleuritic chest pain); and physical findings of coarse crackles on auscultation and elevated inflammatory biomarkers, including C-reactive protein and white blood cell count on laboratory testing. The exclusion criteria were age < 15 years and nursing and healthcare-associated pneumonia (NHCAP). NHCAP patients were classified according to the Japanese Respiratory Society guidelines [10]. Patient information (age, sex, underlying medical problems, antibiotic therapy, pneumonia severity, mortality rate) and causative pathogens were evaluated. Pneumonia severity was evaluated based on the CURB-65 [11] and the Pneumonia Severity Index (PSI) [12]. Patients’ clinical characteristics and causative pathogens before and after the west Japan heavy rainfall event were compared using prospective cohort data.

This study was performed as part of a clinical study of pneumonia (trial registration: UMIN000004353), and it was approved by the institutional review board of Kurashiki Central Hospital (approval number 3379). All patients gave their informed consent to participate in this study. The research was conducted according to the principles of the World Medical Association Declaration of Helsinki.

### Details of the heavy rainfall event in western Japan

Severe flooding occurred during the so-called west Japan heavy rainfall event between June 28 and July 8, 2018. Due to the influence of the seasonal rain front and typhoons, this storm produced record-breaking heavy rainfall nationwide, particularly in western Japan. In the Chugoku and Shikoku regions, including Okayama Prefecture, there was approximately two to three times the normal rainfall for the whole of July based on averages from 1982 to 2018 [13]. A total of 123 observation points in Japan recorded the maximum 72-hour precipitation amount, and Kurashiki city was included among them [13].

The rainfall amount was 270.5 mm just over the period of July 5 to 7, whereas rainfall for all of July was 323.5 mm in Kurashiki city. This is 2.8 times the average rainfall for this period of 115 mm. Subsequent river flooding and landslides occurred in many areas of Japan. A total of 223 persons died, and 8 were declared missing nationwide; in Kurashiki city alone, there were 52 victims [14].

In addition, the heavy rainfall caused the Oda River, which is a tributary of the Takahashi River that runs through Kurashiki city, to flood and subsequently breach its banks. As a result, Mabi town in Kurashiki city, which is located 10 km from our hospital, was wholly under water (Fig. 1). Patients affected by the flood visited our hospital because it is the largest hospital covering the affected area.

After the heavy rain, many people came to assist with reconstruction work from inside and outside the affected area. There were 17,287 volunteers in July, and 4,640 to 24,958 volunteers worked from August to November. They removed mud and debris from houses still standing and helped clear the significant wreckage. The removal of major debris in the Mabi town area to a temporary depot was completed on August 25, 2018, but work at the temporary depot has been on-going.

## Study period

To investigate the impact of the disaster on hospitalised CAP patients, the study period covered the period from July 1 to November 30 in 2018 for the reasons described below, and the data were compared for the same period from 2013 to 2017.

The first reason for the chosen study period was the effect of influenza virus as a causative pathogen in CAP. Klein et al. reported that bacterial coinfection with influenza is common in admitted patients, and that the most common causative bacteria is *Streptococcus pneumoniae*, followed by *Staphylococcus aureus* [15]. In Japan, influenza virus activity increases from December to March. Since it was necessary to exclude the effect of coinfection with influenza virus, the period spanning week 47 to week 15 was omitted [16].

The second reason for the chosen study period was that it was necessary to evaluate patients who had engaged in reconstruction work, primarily that involving the removal of rubble, earth, and sand after several months. After the west Japan heavy rainfall event, the Kurashiki municipal office announced the completion of primary debris removal on August 25, although work at the temporary debris storage facilities continued after that date. An estimated 5,000 to 25,000 volunteers participated in the clean-up from July to November.

## Microbiologic investigation

To identify causative pathogens, sputum and blood samples were used for culture and serology, as well as a urinary antigen test to detect *S. pneumoniae* and *Legionella pneumophila* serogroup 1. Other *Legionella* species were identified using culture on Wadowsky-Yee-Okuda- $\alpha$  medium. Causative

pathogens were defined based on a previous report [17] if the following criteria were met: (1) positive sputum culture of more than 1 + on a qualitative test or  $10^5$  on a quantitative test, with reference to the sputum Gram stain; (2) positive blood culture (excluding contaminating normal skin flora); (3) positive pleural fluid culture; (4) positive urinary antigen test for *S. pneumoniae* and *L. pneumophila*; (5) seroconversion or 4-fold increase in antibodies against *Mycoplasma pneumoniae* and *Chlamydothila pneumoniae*; and (6)  $\geq 1:320$  on a single antibody test for *M. pneumoniae* PA antibody (FUJIREBIO, Tokyo, Japan) or a cut-off index of  $\geq 2.0$  on a *C. pneumoniae* IgM antibody test using the Hitazyme assay (Hitachi Chemical, Tokyo, Japan).

## Statistical analysis

Continuous variables are expressed as medians and interquartile range, whereas categorical variables are presented as percentages. Continuous variables were analysed using the non-parametric Mann-Whitney *U*-test, and categorical variables were compared using Fisher's exact test. Regarding the comparison of hospitalised pneumonia patients from 2013 to 2017 and 2018, the data were evaluated using Poisson regression analysis. An interrupted time series analysis and segmented Poisson regression with offset terms to detect changes in levels were performed. The rate of causative pathogens per month was also evaluated if the causative pathogens showed significant differences. Autocorrelation was tested using the autocorrelation function and partial autocorrelation function, with a threshold of 0.2. Previous studies reported that CAP patients with *S. pneumoniae* are more numerous in winter and that those with *L. pneumophila* are the most numerous in summer [18]. In addition, increased precipitation is associated with an increased risk for legionellosis [19–21]. Therefore, seasonality was adjusted based on Fourier terms, and the model was adjusted by monthly rainfall. As mentioned above, the duration of the intervention was determined to be between July and November 2018. A *P* value  $< 0.05$  was considered significant. Analyses were performed using R software (version 3.0.3, Vienna, Austria).

## Results

### Patients' characteristics

Of the 1,347 patients admitted from 2013 to 2018, a total of 482 were included in the present study, which was divided into two periods, from 2013–2017 and 2018. The study flowchart is shown in Fig. 2. All 482 patients were included for analysis, with 79 patients in the 2018 (post-disaster) group and 403 patients in the 2013–2017 (pre-disaster) group. Table 1 shows the clinical characteristics of patients in the pre- and post-disaster groups. Males comprised approximately 70% of the subjects. The most common comorbidity was COPD. There were no significant differences in age or other comorbidities between the two groups. The CURB-65 scores, PSI, and 30-day mortality rates between the two groups also showed no significant differences (Table 2).

Table 1  
 Characteristics of community-acquired pneumonia patients before and after  
 the west Japan heavy rainfall event

	<b>2013-2017<sup>a</sup></b>	<b>2018<sup>a</sup></b>	<b><i>P</i>value</b>
	<b>Pre heavy rainfall</b>	<b>Post heavy rainfall</b>	
	<b>(n = 403)</b>	<b>(n = 79)</b>	
Cases (per year)	80.6	79	0.82
Age (years)	76 [69.0–83.0]	77 [39.5–83.5]	0.79
Males	281 (69.7)	56 (70.9)	0.89
Current smoker	57 (14.1)	9 (11.4)	0.60
Comorbidities			
COPD	89 (22.1)	21 (26.6)	0.38
Interstitial pneumonia	31 (7.7)	6 (7.6)	1.00
Bronchial asthma	53 (13.1)	11(13.9)	0.86
Diabetes mellitus	80 (19.9)	16 (20.3)	1.00
Chronic heart disease	120 (29.7)	19(24.0)	0.34
Chronic renal disease	32 (7.9)	4 (5.0)	0.49
Malignant disease	29 (7.1)	7 (8.8)	0.64
Data are presented as medians [interquartile range] or n (%).			
<i>COPD</i> chronic obstructive pulmonary disease			
<sup>a</sup> Includes the period from July to November			

Table 2

Severity and prognosis of community-acquired pneumonia before and after the west Japan heavy rainfall event

Severity score	2013-2017 <sup>a</sup>	2018 <sup>a</sup>	P value
	Pre heavy rainfall	Post heavy rainfall	
	(n = 403)	(n = 79)	
CURB-65	36 (8.9)	7 (8.9)	0.29
0	129 (32.0)	30 (38.0)	
1	134 (33.3)	25 (31.6)	
2	85 (21.1)	10 (12.7)	
3	18 (4.5)	7 (8.9)	
4	1 (0.2)	0	
5			
PSI score (points)	95 [76–117]	99 [78–117]	0.31
PSI class			0.30
I	10 (2.5)	0	
II	56 (13.9)	9 (11.4)	
III	116 (28.8)	18 (22.8)	
IV	170 (42.2)	43 (54.4)	
V	51 (12.7)	9 (11.4)	
ICU admission	29 (7.2)	11(13.9)	0.07
30-day mortality	19 (4.7)	3 (3.8)	1.00
Data are presented as medians [interquartile range] or n (%)			
<i>CURB-65</i> confusion, urea > 7 mmol/L, respiratory rate ≥ 30 breaths/min, low blood pressure (systolic < 90 mmHg or diastolic ≤ 60 mmHg), and age ≥ 65 years, <i>ICU</i> intensive care unit, <i>PSI</i> Pneumonia Severity Score			
<sup>a</sup> Includes the period from July to November			

## Aetiology of pneumonia

Table 3 shows a comparison of the distribution of causative pathogens between the pre- and post-disaster groups. The most common causative pathogen was *S. pneumoniae* in both groups, followed by *H. influenzae* in the pre-disaster and *L. pneumophila* in the post-disaster groups. Only the prevalence of *L. pneumophila* increased significantly post-disaster.

Table 3  
Aetiology of community-acquired pneumonia before and after the west Japan heavy rainfall event

	2013-2017 <sup>a</sup> Pre heavy rainfall (n = 403)	2018 <sup>a</sup> Post heavy rainfall (n = 79)	P value
<i>Streptococcus pneumoniae</i>	87 (21)	19 (24)	0.66
<i>Haemophilus influenzae</i>	18 (4.5)	4 (5.0)	0.77
<i>Streptococcus anginosus</i> group	12 (3.0)	0	0.23
<i>Legionella pneumophila</i>	12 (3.0)	7 (8.9)	0.02
<i>Staphylococcus aureus</i>	11 (2.7)	1 (1.3)	0.70
<i>Moraxella catarrhalis</i>	9 (2.2)	3 (3.8)	0.43
Anaerobes	8 (2.0)	0	0.36
<i>Mycoplasma pneumoniae</i>	6 (1.5)	0	0.60
<i>Pseudomonas aeruginosa</i>	6 (1.5)	0	0.60
<i>Klebsiella pneumoniae</i>	5 (1.2)	1 (1.3)	1.00
<i>Streptococcus</i> species	5 (1.2)	0	1.00
<i>Enterobacter</i> species	0	1 (1.3)	0.16
Unknown	226 (56.0)	45 (56.9)	0.90
Data are presented as n (%)			
<sup>a</sup> Includes the period from July to November			

## Legionella pneumonia patients after adjusting for seasonal patterns and precipitation

After adjusting for seasonal patterns and precipitation in each month, the number of *Legionella* pneumonia patients was also significantly higher post-disaster than pre-disaster (estimate 1.344; standard error 0.464;  $P = 0.004$ ). The locations and exposure of risk for *Legionella* infection were

investigated for all of the *Legionella* pneumonia patients after the heavy rainfall event. Residence and exposure associated with reconstruction work or contaminated soil of *Legionella* pneumonia patients post-disaster are shown in Fig. 3. Three of 7 (42.9%) *Legionella* pneumonia patients were engaged in reconstruction work.

## Discussion

In the present study, the effects of the disaster on the frequency and causative pathogens of CAP were examined. There were no significant differences in the number of admissions and clinical characteristics pre- and post-disaster. However, regarding the causative pathogens, there were significantly more patients with *Legionella* pneumonia post-disaster than pre-disaster, although there were no significant differences in the number of patients with CAP caused by other pathogens.

Some studies have reported that the number of patients with respiratory infections increases after a natural disaster [7, 8, 24, 25]. Among these studies, one examining the Great East Japan earthquake in 2011 reported a 5-fold increase in the number of pneumonia hospitalisations compared with the usual number, along with an increased risk of death due to pneumonia [7]. Pneumonia deaths increased significantly during the 1st through 12th week after the earthquake and tsunami [7, 26]. The authors of that study suggested that the tsunami increased the risk of pneumonia death. Regarding flooding-related disasters, there are some reports of increases in the occurrence of acute respiratory infections [2–4]. These reports included patients who were outpatients and had symptoms but had not been diagnosed with pneumonia. In the present study, there was no significant increase in the number of hospitalised patients in 2018 when compared with the pre-disaster period. One reason for this difference could be that the rainfall occurred in summer, and upper respiratory tract infections or outpatients with pneumonia were not analysed.

The most common causative pathogen of CAP after the heavy rainfall event was *S. pneumoniae*, similar to our previous report [17]. There was a significant increase in the number of pneumonia cases due to *Legionella* after the west Japan heavy rainfall event, although the total number of pneumonia patients and patients with other causative pathogens did not increase significantly. A previous study reported that the frequency of *H. influenzae* as a causative pathogen of pneumonia increased after the Great East Japan earthquake, but the frequency of *L. pneumophila* was not significantly changed [7].

The following causes likely led to the increased prevalence of *Legionella* pneumonia from July to November of 2018. First, the increase in precipitation appeared to affect the number of cases of *Legionella* pneumonia. This possibility is supported by some reports indicating that not only a wet and humid environment, but also precipitation is significantly associated with increased rates of legionellosis [20, 21, 23, 27]. The risk of legionellosis is significantly associated with increased rainfall 6–10 days before disease onset. This association was explained by observations showing that rainfall increases

organic sediments and contamination with other microbes [21]. Another report suggested that vehicles could produce aerosols that contain *Legionella* as a result of driving on wet road surfaces [23].

However, in the present study, the number of *Legionella* pneumonia patients was significantly greater after adjusting for seasons and precipitation. Engaging in reconstruction work and soil exposure after the disaster were thought to have led to a higher risk of *Legionella* pneumonia. Van Heijnsbergen et al. reported that garden soil serves as a reservoir of *Legionella* bacteria. They detected *Legionella* over a period of 1 year in some locations in the Netherlands. There was no difference in temperature or precipitation between the soils in which *Legionella* bacteria were isolated, and *Legionella* was detected throughout the year. They concluded that *Legionella* bacteria can survive in soil over a long period of time [28]. Wallis et al. reported a case of legionellosis in which the patient's sputum specimen was positive for *L. pneumophila* SG1, and the same genotype of *L. pneumophila* was detected in soil of the patient's workplace [29]. In this case, soil was considered the source of infection [29]. In Japan, there have been some reports of *Legionella* pneumonia in workers engaged in recovery efforts after a disaster. One case involved a patient doing decontamination work after the Great East Japan earthquake; this work included removal of the top layer of soil in mountainous areas and cleaning roads and roofs of residential buildings using high-pressure water [30]. In another study, Oda et al. reported a case of *Legionella* pneumonia diagnosed several days after the patient was working to remove rubble, earth, and sand dust after the west Japan heavy rainfall event [31]. One can hypothesise that the increased chance of inhaling *Legionella*-containing aerosols from the soil after the disaster was one of the causes of the increase in *Legionella* pneumonia cases. In the present study, 3 patients had been engaged in reconstruction work, and 2 patients had been exposed to garden soil. These results and those of other studies thus suggest that reconstruction work and soil exposure increase the risk of *Legionella* pneumonia after a natural disaster.

The present study has some limitations. First, this was a single-institution study, and it is unclear whether similar results would be obtained in other areas. Therefore, it is difficult to conclude with certainty that the prevalence of *Legionella* pneumonia increased as a result of the overall effect of the heavy rainfall event. Second, data were collected only from patients who came to our hospital. The heavy rainfall event occurred over a large area, and many volunteers engaged in reconstruction work. Some of these individuals came from other prefectures and returned home after their work was completed. In case of illness, they would have visited a local hospital other than ours. Therefore, we may have underestimated the incidence of reconstruction work-related pneumonia because it was not possible to identify those patients who had visited other hospitals. Third, a urinary antigen test that detects only *L. pneumophila* serogroup 1 was used [32]. When patients are likely to have *Legionella* pneumonia diagnosed based on clinical data, other *L. pneumophila* serogroups are checked via sputum culture in addition to the urinary antigen test, but sometimes it is not possible to identify the pathogen. It should be noted that it has not been conclusively determined whether *Legionella* infection is associated with recovery work, since no genetic analyses have been performed on bacteria isolated from patients or soil.

On the other hand, the present study did have some strengths. First, the prospective pneumonia data were compared with data from after the west Japan heavy rainfall event, and there are no reports specific to CAP similar to the present study published to date. Second, the large number of beds and large medical care area of our hospital made it possible to cover a reasonable number of patients, even though the study was conducted at a single centre.

## Conclusions

There was a significant increase in the number of pneumonia cases due to *Legionella* after the west Japan heavy rainfall event, although the total number of pneumonia patients and patients with other causative pathogens did not increase significantly. The present data suggest an association between *Legionella* pneumonia and being engaged in recovery work or soil exposure after such a natural disaster. Therefore, it is important to take preventive measures such as wearing masks and gloves when engaging in reconstruction work or being exposed to soil after floods.

## Abbreviations

COPD: chronic obstructive pulmonary disease

CAP: community-acquired pneumonia

NHCAP: nursing and healthcare-associated pneumonia

PSI: Pneumonia Severity Index

## Declarations

## Ethics approval and consent to participate

This study was approved by the institutional review board of Kurashiki Central Hospital. All patients gave informed consent to participate in this study.

## Consent for publication

Not applicable.

## Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

# Competing interests

The authors declare they have no actual or potential competing financial interests.

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# Authors' contributions

MM served as the principal author, had full access to all data in the study, and takes responsibility for the integrity and accuracy of the data and data analysis. MM and AI contributed to study conception and design; MM, AI, TI, HT, YN, AY, and YW contributed to acquisition of data; MM, AI, TI, and HT contributed to analysis and interpretation of data; MM, AI, TI, HT, YN, AY, and YW contributed to drafting and revision of the manuscript and approval of the final version to be submitted for consideration for publication.

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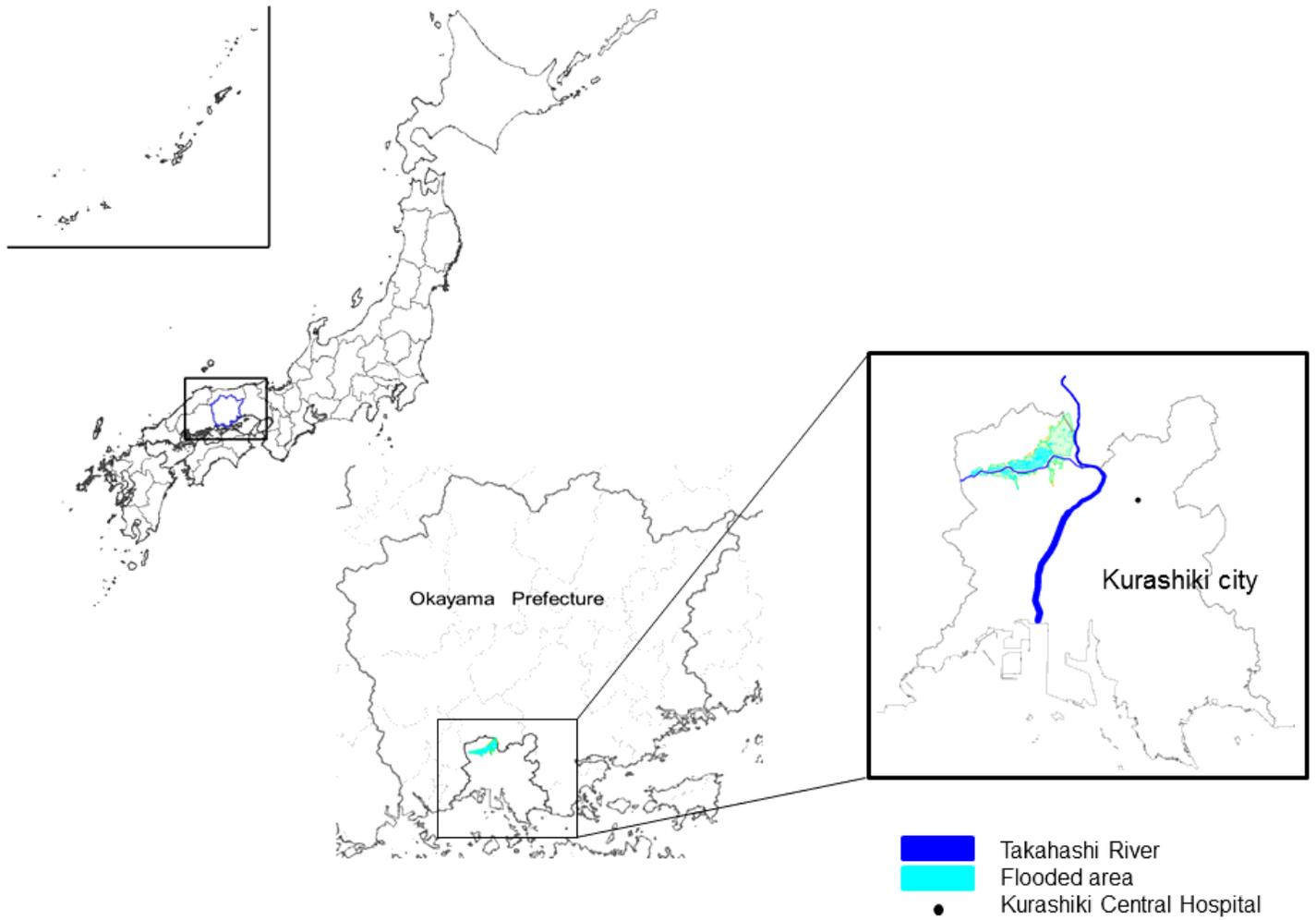
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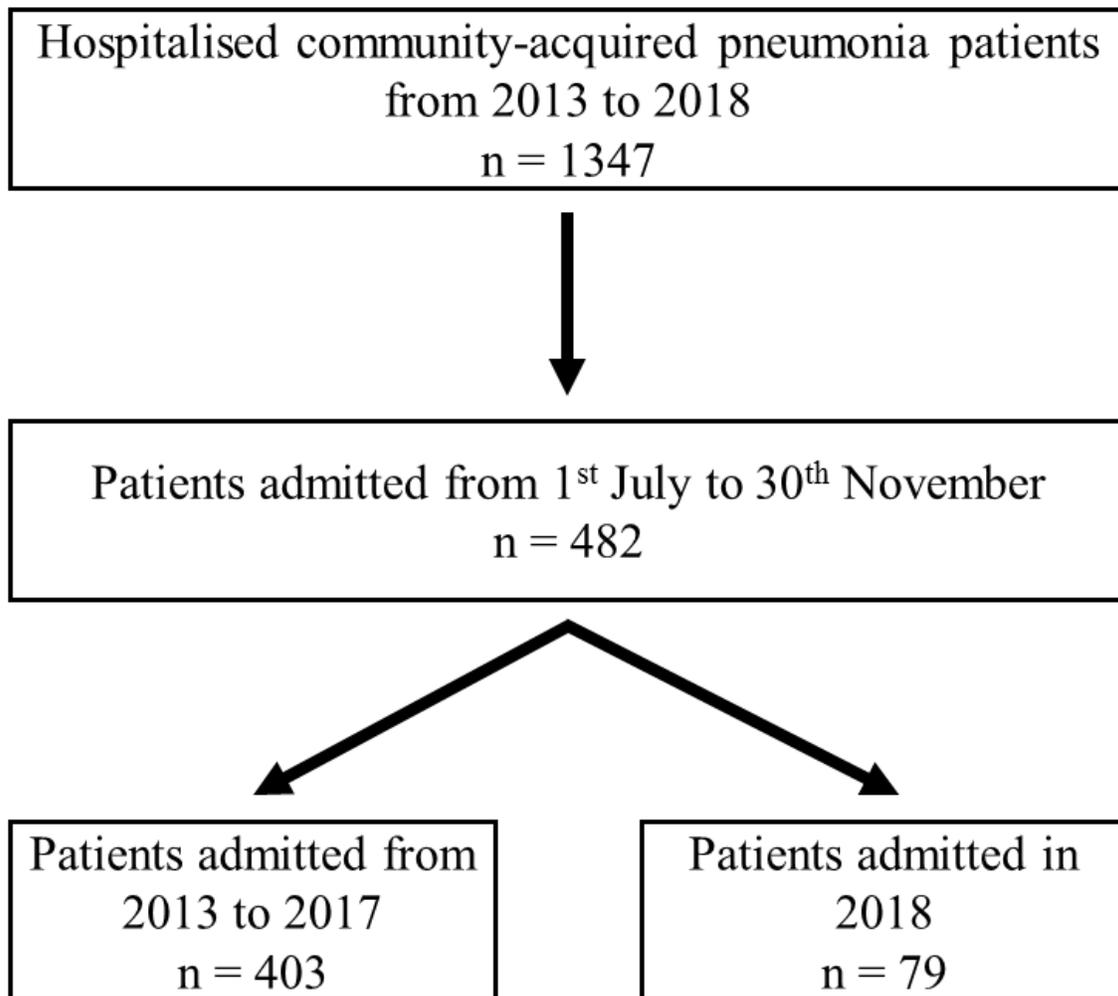
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## Figures



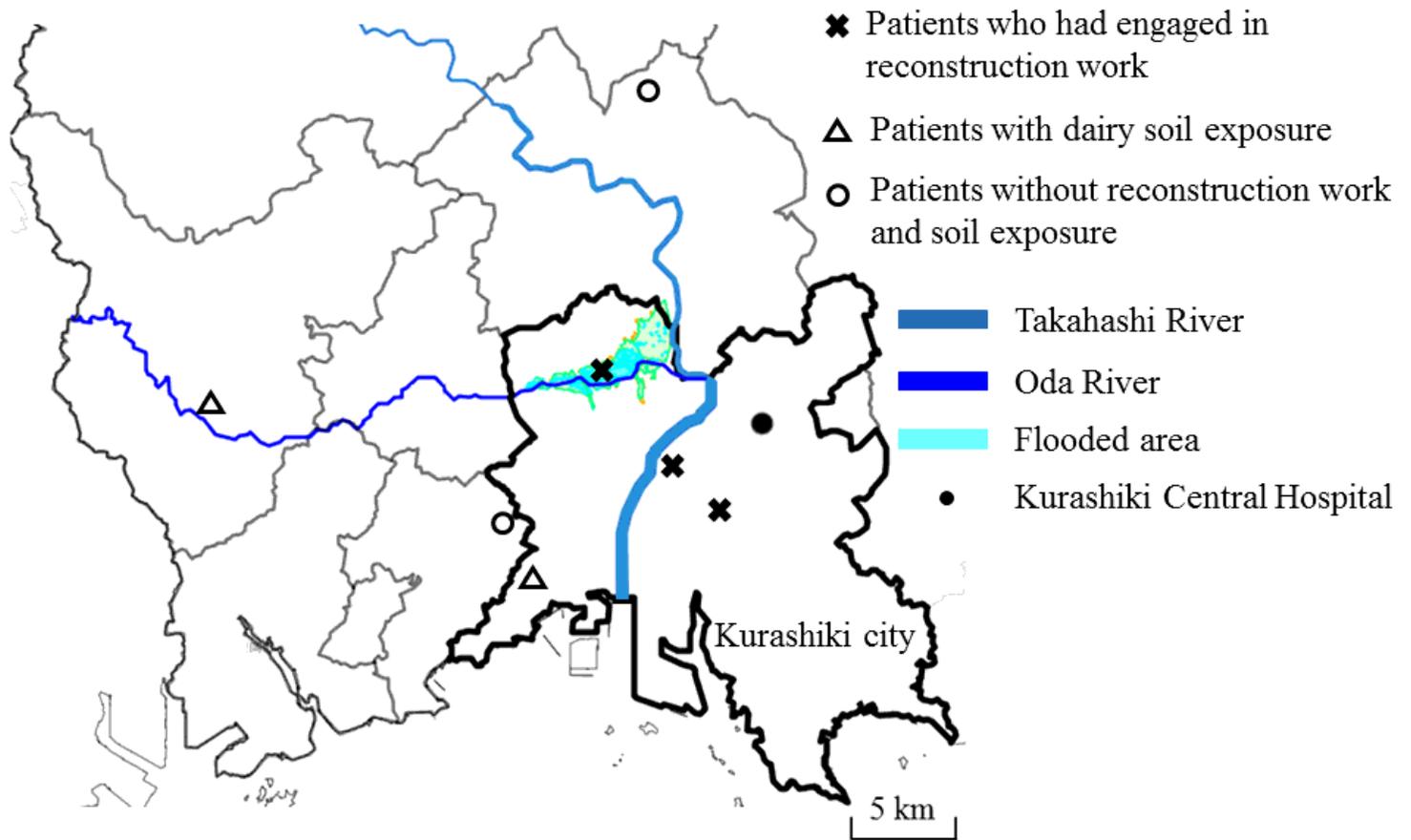
**Figure 1**

Areas affected by the west Japan heavy rainfall event in Okayama Prefecture. Okayama Prefecture is located in central-west Japan, and Kurashiki city is located in the southwestern part of Okayama Prefecture. The Takahashi River is indicated by a blue line, and the flooded area is coloured light blue. The disaster area data were obtained from the Geospatial Information Authority of Japan.



**Figure 2**

Study flowchart.



**Figure 3**

Information regarding all Legionella pneumonia patients after the heavy rainfall event. The Takahashi River and Oda River are indicated by blue lines, and the flooded area is coloured light blue. The disaster area data were obtained from the Geospatial Information Authority of Japan.