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Sam Froze Jiee

Kai Joo Lim

Daryl Sin Choon Vui

Dina Peter Marius

Nurul Syafiqah Illyana

Anisah Jantim

Extreme Weather and Melioidosis: An Endemic Tropical Disease in the Penampang District of Sabah, Malaysia

Sam Froze Jiee [a,*], Kai Joo Lim [a], Daryl S. Choon Vui [b], Dina P. Marius [b], Nurul S. Illyana [b], Anisah Jantim [c]

[a] Department of Disease Control, Penampang District Health Office, Sabah State Health Department, Ministry of Health, Malaysia
[b] Communicable Disease Control and Surveillance Unit, Department of Disease Control, Penampang District Health Office, Ministry of Health, Malaysia
[c] Penampang District Health Office, Ministry of Health, Malaysia

Abstract

Background: **Melioidosis is a fatal, but preventable communicable disease that is endemic in several parts of the world, including the state of Sabah, Malaysia, which is located in the northern part of Borneo Island. Flooding is one of the most regular natural disasters affecting some parts of Malaysia, including Sabah. The main aim of this study was to determine if rainfall and floods were significant risk factors contributing to the substantial burden of melioidosis in the Penampang district from 2015 to 2020.**

Method: **We analyzed 64 culture-confirmed cases of melioidosis in the Penampang district, Sabah, between 2015 and 2020 to determine if rainfall and floods were significant risk factors that contributed to the substantial burden of melioidosis. Fisher's exact test was used to examine for associations between risk factors and melioidosis mortality. We used Poisson regression to calculate the incidence rate ratio for melioidosis cases based on different risk factors.**

Results: **There was a linear association between rainfall and floods with cases of melioidosis. Our Poisson regression results indicated that the number of melioidosis cases was 1.002 times greater with every 1 mm increase of rainfall and 2.203 times greater with every flood event. There was a linear association between cases of melioidosis with rainfall and floods, with most patients having comorbidities.**

Conclusion: **Prevention of melioidosis in the Penampang district should primarily focus on avoiding direct contact with soil or contaminated water, especially during or after extreme weather events. Continuous and community-empowered health education targeting the high-risk group is essential, as flash floods in certain parts of the state and districts are seasonal and unpredictable.**

Keywords: Melioidosis, Extreme weather, Heavy rainfalls, Malaysia

1. Introduction

Melioidosis is predominantly a disease in tropical climates. Whitmore and Krishnaswami first discovered the disease in 1912 [1]. In some parts of the world, melioidosis is seasonal and frequently occurs during the tropical monsoon season [2]. Other meteorological events, such as disasters, increase the incidence rate. Since its discovery in Malaysia, several localities have been categorized as endemic, including the state of Sabah [3]. There were reported cases in livestock and wild animals. Existing studies defined an incubation period of between 1 and 21 days in the 25% of cases where exposure is defined [4]. In a particular area, exposure to mud and the water's surface can be seasonal depending on agricultural practices such as paddy and vegetable farming.

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* Corresponding author.
E-mail address: samfrozejiee@gmail.com (S.F. Jiee).

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Globally, melioidosis is considered a major neglected tropical disease [5]. Furthermore, there could be a significant disparity between the actual number of cases and the number of reported cases. If not prevented, those with socioeconomic disadvantages are more likely to be hospitalized in an intensive care unit due to melioidosis bacteremia [6]. Melioidosis is a public health issue mainly in Southeast Asia, India and Australia, whereby some localities have been declared endemic due to disease incidence and the presence of *Burkholderia pseudomallei* from soil sampling surveillance [7,8]. Worldwide studies, including those conducted in Peninsular Malaysia's northern region, revealed a significant increase in the average medical cost of melioidosis therapy [9,10]. According to a modelling research study published in 2016, around 165,000 persons globally are infected with melioidosis each year [11]. The case fatality rate varies from 10 to 50% depending on the severity the of illness [12].

Melioidosis is endemic in Malaysia; and its incidence rate varies according to state and localities. Melioidosis incidence rate climbed from 0.55 cases per 100,000 population to 2.60 cases per 100,000 population in three years (2011−2013), according to data issued by the Sabah State Health Department [13]. At the same time, the frequency of flash floods has grown over the last five years, with an average of 1−3 incidents each year in the Penampang district. Penampang is situated in the northern part of Borneo Island, with an area of 424.73 square kilometers and a total population of 153,300 (estimated for the year 2020). It is inhabited by people from various ethnic groups, namely: Kadazan, Dusun, Chinese, Bajau, and Malay. Geographically, Penampang is divided into eight subdistricts, with two-thirds being suburban and rural areas. The size of the cultivated areas in Penampang is 757.47 ha, indicating that Penampang makes a significant contribution to the farming industry in Sabah. Like other rural parts of Malaysia, rice and vegetable farming occur in several areas of the Penampang district. Thus, exposure to mud and surface water is consistent throughout the year. Exposure to mud and surface water is occasionally affected by environmental changes such as heavy downpours and floods. These extreme weather events potentially lead to increases in infectious diseases such as melioidosis and leptospirosis. Malaysia is a tropical country with an average rainfall of 3085.5 mm annually. It has two monsoon seasons: the Southwest Monsoon (April−September) and the Northeast Monsoon (October-March) [14]. Rainfalls are relatively high throughout the state of Sabah, including the Penampang district, with average rainfall ranging from 2965.1mm (the year 2016) to 5115.6 mm (the year 2020) for the years 2015−2020 [15].

There are several established risk factors for melioidosis including socio-demographic characteristics (ie. age and gender), socioeconomic status (ie. occupation) and clinical risk factors (diabetes mellitus and hypertension). Yet, there was a need for an epidemiological assessment to determine if environmental factors contributed to the increased burden of melioidosis. The problems in diagnostic capabilities, as well as the bad prognosis from delayed treatment, force us to increase our preventive efforts. The ecological distribution of *Burkholderia pseudomallei* bacteria, which causes melioidosis, in the Borneo parts of Malaysia remains unclear. Understanding the risk factors of melioidosis transmission will allow us to design the most appropriate preventive activities adapted to the Penampang district and Borneo Island. Better prevention will reduce disease burden. Health officials can improve the health system's performance with more data about the needs and expectations for the health sector's response to melioidosis. The main aim of this study was to determine the influence of rainfall and flash floods on the incidence rate of melioidosis in the Penampang district of Sabah.

2. Methods

2.1. Study population and data collection procedure

This was a health facility-based retrospective study on all confirmed cases of melioidosis in the Penampang district, state of Sabah, Malaysia. We analyzed data for all confirmed melioidosis cases registered under the Disease Control Section of the Penampang Health District Office from 2015 until 2020. Rainfall statistics and flood data were obtained from the Meteorological Department and Environmental Health Section of the Penampang District Health Office. Melioidosis is a notifiable disease in Malaysia; thus, all clinically suspected and confirmed cases are reported to the District Health Office. Tertiary centers are responsible for the diagnostic and curative aspects of the disease. The melioidosis cases were confirmed by culture and serology. Average monthly and annual rainfall data for Penampang were obtained from the Malaysian Meteorological Department and the Environmental Health Unit of the Penampang Health Office. The five crucial components for our data collection were sociodemographic characteristics, medical history, disease outcome (mortality), rainfall, and flooding. For the occupation category, indoor occupations

Table 1. Demographic characteristics of melioidosis cases and mortality among cases.

Variables	Melioidosis cases		Mortality Frequency		*p-value*
	Number	%	Number	%	
Total	64	100	16	25	
Age (yrs)					0.473
10 and below	4	6.3	2	12.5	
11 to 30	3	4.7	1	6.2	
31 to 50	19	29.7	6	37.5	
51 to 70	28	43.8	5	31.3	
70 and above	10	16.6	2	12.5	
Mean (SD)	50.90 ± 18.90		47.38 ± 22.82		
Median (IQR)	54.00 (42.00−61.75)		48.50 (37.50−64.50)		
Gender					0.276
Male	42	65.6	12	75.0	
Female	22	34.4	4	25.0	
Ethnicity					0.714
KDMR[a]	26	40.6	8	50.0	
Chinese	21	32.8	4	25.0	
Other native groups	13	20.3	2	12.5	
Non-citizen	4	6.3	2	12.5	
Citizenship					0.258
Malaysian	60	93.8	14	87.5	
Non-citizen	4	6.3	2	12.5	
Occupation type					0.218
Indoor	12	18.8	2	12.5	
Outdoor	16	25.0	4	25.0	
Pensioner	4	6.3	0	0.0	
Housewife	7	10.9	0	0.0	
Unemployed	21	32.8	8	50.0	
Students/Children	4	6.3	2	12.5	
Comorbidity[c]					
Diabetes	28	47.5	5	31.3	0.383
Hypertension	21	35.5	5	31.3	0.568
CRF[b]	5	8.5	1	6.3	0.633
Alcoholism	5	8.5	2	12.5	0.367
Without comorbid	24		3	18.9	0.565

Fisher's Exact test was carried out for the associations of age category, gender, ethnicity, citizenship, occupation category, and comorbid with melioidosis mortality.

[a] KDMR= Kadazan, Dusun, Murut and Rungus (Native ethnic group of Sabah).

[b] CRF = Chronic Renal Failure.

[c] Comorbidity = Several cases had multiple comorbidities. Thus, the percentage for type of comorbid did not include those without comorbid.

refers to those who work in the office (desk job) or from home, as well as administration and retail. This study included teachers, clerks, waiters, shop assistants, mechanics and online businesspeople. Those involved in outdoor occupations were blue-collar job employees, drivers, field technicians and farmers. Their job requires them to spend lengthy amounts of time outdoors. For ethnic group category, KDMR refers to one of the largest native ethnic groups in Sabah namely Kadazan, Dusun, Murut and Rungus.

2.2. Statistical analysis

First, data were manually entered into Microsoft Excel before proceeding with analysis using Statistical Package for the Social Sciences (SPSS), version 28. Descriptive analysis was carried out to obtain basic features of the data in this study (frequency, percentage, mean, median, and standard deviation). Fisher's exact test was used to investigate associations between risk factors and disease outcomes (mortality from melioidosis). Poisson regression using age-specific population sizes as offsets was applied to the model. We also tested for age-dependencies in the incidences of disease cases. Since there was an excess of zeroes in the numbers of cases and death, zero-inflated Poisson regression was also applied, if it predicted our response variable better than a standard Poisson model. Sample size estimation was done by using G*Power 3.1 software. For all the statistical tests, a p-value of less than 0.05 was considered statistically significant. Total rainfall of 300mm and above per month was considered heavy rain for the state of Sabah for this analysis [16]. The number of melioidosis cases in an

endemic area could increase up to 50% after a heavy rain season/month, and possibly much more after a flood [17].

2.3. Ethical considerations

The privacy and confidentiality of the patients' records were ensured. Ethical approval was obtained from the Medical Research and Ethics Committee of the Ministry of Health, Malaysia [NMRR-21-395-58802 (IIR)].

3. Results

3.1. Demographics

A total of 64 melioidosis cases (lab culture-confirmed) were reported from 2015 to 2020 (Table 1), with 16 deaths among these cases. The mean age of the cases was 50.90 ± 18.90 years old, with an age range of 5 months old to 82 years old. The majority were within the age range of 51–70 years old [28 cases (43.8%)]. Seven cases (11.1%) were below 30 years old. The vast majority were male (65.6%), and from the KDMR ethnic group (41.3%). Only 4 cases (6.3%) were non-citizens of Malaysia. A total of 22 cases (34.9%) were pensioners/unemployed during the time of diagnosis, followed by 16 cases (25.4%) whose job scope involved outdoor activities (heavy machinery vehicle drivers, field technicians, construction workers, and tourist guides).

Among the patients with comorbidities, a total of 28 (47.5%) had diabetes mellitus, followed by 21 (36.5%) with hypertension, and the remaining had chronic renal failure (8.5%) and alcoholism (8.5%). Based on the registered address, approximately 60% of the cases were from the suburban and rural areas of the Penampang district. Among the mortality cases, their mean age was 47.38 (SD = 22.82). Fisher's exact test indicated that the socio-demographic characteristics and comorbidities did not affect the disease outcome (mortality) in this study.

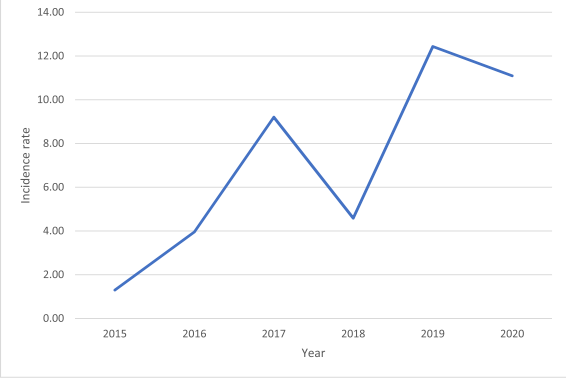

Fig. 1. Incidence rate (per 100,000 population) of melioidosis based on disease notification in Penampang district, Sabah, Malaysia from the year 2015 until 2020.

3.2. Incidence rate of melioidosis, rainfall, and floods

Throughout 2015–2020, the incidence rate of Melioidosis has increased dramatically (Fig. 1). The incidence rate for the year 2015 was 1.30 per 100,000 population, 3.96 per 100,000 population in 2016, 9.20 per 100,000 population in 2017, 4.59 per 100,000 population in 2018, 12.43 per 100,000 population in 2019 and 11.09 per 100,000 population in the year 2020. Most of the cases (based on onset) were detected at the middle and end of the year (Fig. 2). The mean rainfall was in the lower range from February to May, and gradually increased from July until the end of the year (Fig. 3). Consequently, floods mainly occurred in the middle and end of the month, increasing in frequency from one year to another.

3.3. Rainfall and flood influence on melioidosis

We utilized a Poisson regression model with the dependent variable of melioidosis cases in the form of counts. We selected rainfall amount and flood-prone areas in the Penampang district as independent variables. Meteorological data on rainfall amount was obtained from the Malaysia Meteorology Department from January 2015 until December 2020. In this data, the mean rainfall amount was 329.1mm (5.4–869.9). The dispersion parameter estimated with the Pearson's Chi-Square test statistic and degrees of freedom was 1.054 (near 1). This indicated that the assumption in Poisson regression that there was equidispersion of data (and not overdispersion) was met. In addition, predictors in the inflation model were not statistically significant.

Trends based on Poisson regression analysis showed a statistically significant association of rainfall amounts and flood frequency with melioidosis cases in the Penampang district [IRR = 1.002 (95% CI: 1.001–1.003), p = .0.06; IRR = 2.203 (95% CI: 1.256–3.864), p = .06; respectively, Table 2]. As indicated in Figs. 3 and 4, there was a drastic increase in melioidosis cases and deaths over five years. Predictors in the zero inflation Poisson regression model were not statistically significant. The Incidence Rate Ratio (IRR) reflects the change in the dependent variable as a percentage increase or decrease. The direction of the change in the

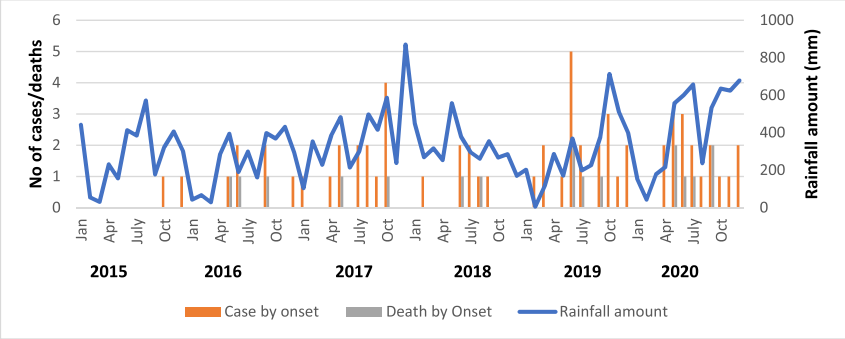

Fig. 2. Monthly trend of melioidosis cases and deaths influenced by mean rainfall by month from 2015 to 2020.

dependent variable is determined by whether or not the IRR is greater or less than one (ie. IRR>1 indicates a percentage increase in the dependent variable). There is a 0.2% increase in melioidosis cases for every extra 1mm of rainfall. On top of this, the number of melioidosis cases will be 2.203 times greater for each flood-prone area in the Penampang district. In other words, there is a 20.3% increase in melioidosis cases for each flood-prone area in the Penampang district.

4. Discussion

Melioidosis can be a fatal, but preventable communicable disease. It remains a disease of public health importance and a significant environmental infectious disease in Borneo Island, including the district of Penampang. The incidence rate of melioidosis in Penampang (11.09 per 100,000 population reported in 2020) is comparable to other parts of Malaysia and the world. It is lower than the one observed in Kedah (16.35 per 100,000 people in 2010), Malaysia's biggest rice producer. But it is considerably higher than the modelling estimate by Limmathurotsakul et al., who estimated that 5.0 per 100,000 population is at danger worldwide [11,18]. Endemic countries with melioidosis carry a high economic burden [19]. A high mortality rate that results in productivity losses is a massive drawback for socio-economically disadvantaged people.

A significant and important finding in our study was that extreme weather events (heavy rainfall and flooding) remain one of the most critical determinants of melioidosis. The correlation between weather and the incidence of Melioidosis has been reported in several parts of the world, including Thailand, Australia, and the peninsular part of Malaysia [18,20]. We reported that extreme weather events were an essential determinant for melioidosis. Flooding is one of the most common natural disasters affecting Malaysia during the annual monsoon season. The occurrence of flash floods is seasonal in the Penampang district of Sabah. One of the leading causes of flash floods is heavy and excessive rainfall, which is more rain than the ground can absorb. Heavy rain and flooding are devastating events that disturb the soil structure and bring the *Burkholderia pseudomallei* to the surface.

Worldwide studies have shown that one of the principal risk factors of melioidosis is occupation, predominantly being employed in farming and forestry [21,22]. Over the past ten years, most cases of melioidosis were reported in the farming, fishing, and forestry industry (2−25% of cases), followed by the construction and trucking industry (3−18% of cases) [23]. Similarly, our analysis revealed that most of the cases were reported among those who spent a significant amount of time outdoors and were constantly in direct contact with soil. Extreme weather events are often associated with health issues such as diarrheal diseases, vector-borne diseases, and skin rashes. According to the World Meteorological Organization, the population of tropical and developing countries is at the highest risk of health crisis post extreme weather events due to rapid population growth and urbanization [24]. The most common transmission mode for *Burkholderia pseudomallei* is direct contact with contaminated soil or water through subcutaneous inoculation, especially when there is an open wound on the skin [25]. Infection can also be acquired via dust particles or water droplets inhalation and ingesting contaminated water. Person-to-person and zoonotic spread are uncommon. Approximately two-thirds of the reported cases resided in suburban and rural areas. Nevertheless, assessment of lifestyle behaviour can be included in future studies involving communicable diseases.

From the perspective of industry, melioidosis can be a tropical occupation hazard. Employees exposed to soil are entitled to personal protective equipment

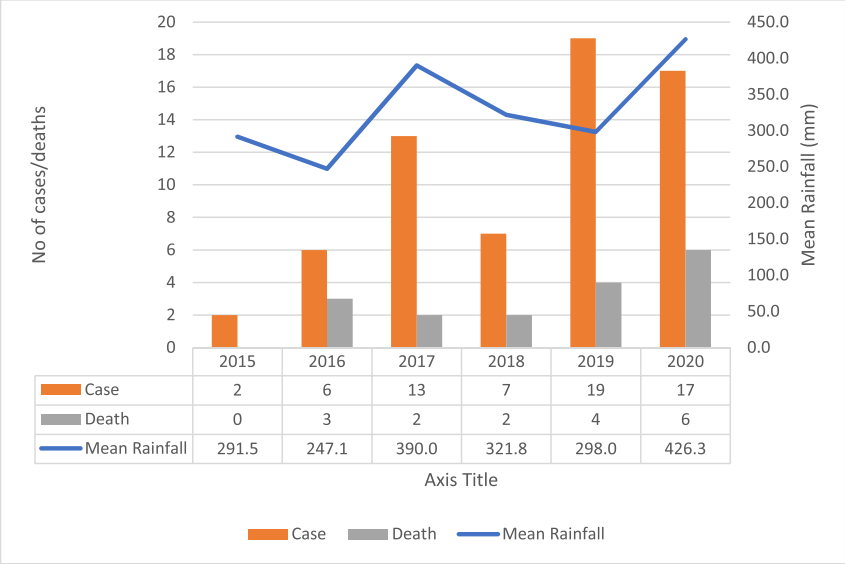

Fig. 3. Trend of melioidosis cases and deaths influenced by mean rainfall from 2015 to 2020.

such as boots and gloves. Medical surveillance is needed to monitor the health status of every employee to ensure their well-being and to keep them at low risk for non-communicable and infectious diseases. The gold standard for diagnosing acute and chronic melioidosis is a bacteriology blood test [26]. Thus, it is essential for health facilities in endemic localities to have strong laboratory support. Enhancing the existing disease surveillance systems to target specific diseases or syndromes allows us to make timely responses against diseases of public health concern. Effective surveillance is essential in localities with a high burden of melioidosis. Public health teams need to identify the most common transmission mode of *Burkholderia pseudomallei* in their respective localities/regions.

Contact with soil is common in outdoor activities. Those with an open wound and in the high-risk group are at risk of contracting melioidosis. Aside from occupation, exposure to *Burkholderia pseudomallei* is most likely from outdoor activities ranging from hobby farming to post-flood cleaning. Post-flood cleaning activities are considered high-risk. In flood-prone areas with melioidosis endemicity, primary prevention involves avoiding exposure to cuts or other trauma with soil or contaminated water. Those with open wounds, trauma, and high-risk groups (the elderly, diabetics) need to avoid post-flood activities that involve direct contact with soil or water. If unavoidable, boots and gloves should be recommended and emphasized. Health education should start in the Temporary Flood Relief Centers. Those who are stranded at home should not be ignored. Health education should be delivered via loudspeaker announcements. This is crucial to prevent melioidosis and other flood-related diseases, like cholera, typhoid fever, and dysentery, as floodwater might contain sewage.

Table 2. Poisson regression analysis of association between meteorology parameters with melioidosis cases from 2015 to 2020 in the penampang district, Sabah, Malaysia.

Meteorology parameters	Std. error	Incidence Rate Ratio IRR (95% CI)	*p-value*[a]
Rainfall amount	0.0007	1.002 (1.001–1.003)	0.006
Flooding	0.2866	2.203 (1.256–3.864)	0.006

CI, confidence interval.
[a] p-value based on Likelihood Ratio test.

Our analysis also reported that melioidosis affected more males than females. This finding was similar to most parts of the world that have a substantial burden of melioidosis [27,28]. It may be attributed to a higher likelihood of males being associated with soil-related occupations and activities, increasing exposure [24]. Females are known to have a healthier lifestyle and are more attentive to health-related information than males [29,30]. Infections of *Burkholderia pseudomallei* can affect all age groups. However, studies indicated that the peak incidence is 40–60 years old, and pediatric melioidosis is less common. A similar finding was reported in our study, whereby most of the cases were within the age range of 30–70. This most active and productive age group contributed to economic development in various sectors ranging from blue-collar workers to executive groups. Approximately two-thirds of the cases being reviewed by Kingsley et al. [31] had at least one risk condition. Insulin

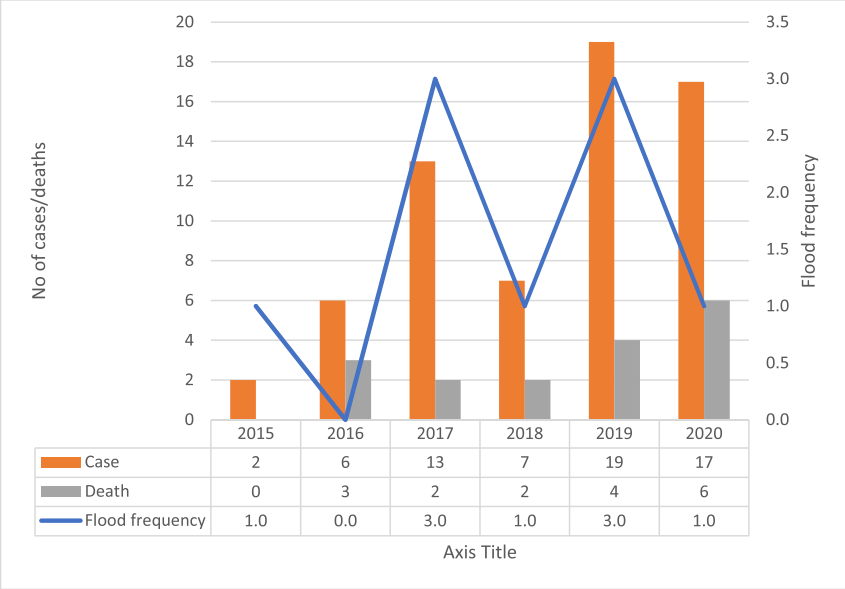

Fig. 4. Trend of melioidosis cases and deaths influenced by flooding from 2015 to 2020.

deficiency has been found as a significant factor in the association between melioidosis and diabetes mellitus [27]. In Malaysia, type 2 diabetes mellitus is the most frequent co-morbidity linked with melioidosis, as documented in other endemic parts of the world; 38–75% of melioidosis cases were either newly diagnosed or had pre-existing type 2 diabetes mellitus [23]. Our study revealed similar findings, as almost half of the confirmed melioidosis cases were diabetic patients. However, mortality was not influenced by comorbidities. Presently, other co-morbid conditions identified as critical predisposing factors associated with melioidosis include chronic renal diseases, tuberculosis, immune disorders/steroid therapy, chronic heart disease, smoking, chronic alcoholism, and chronic lung diseases [32–34]. A sedentary lifestyle has a particular impact on the development of communicable illnesses. Multiple Community-Based Participatory Research (CBPR) elements reported that the minority ethnic groups of migrants are more prone to diseases due to unhealthy lifestyles [35,36].

Our study reported a higher percentage of melioidosis among the KDMR native ethnic group. Most people from this ethnic group resided in the suburban and rural areas of Penampang and the state of Sabah in general. Studies from all over the world reported that a higher incidence of melioidosis occurred among the countryside population. Investigating the relationship between ethnicity and diseases also exposes a range of disparity and risk factors. This inequality contributed to mortality and morbidity in various conditions, including communicable diseases [2]. Moreover, these inequalities differ according to the ethnic group, with the migrants being among the worst affected. However, the reported cases among the non-citizens in our study were small.

Soil sampling in high-risk areas helps understand the distribution of *Burkholderia pseudomallei*. Blood culture facilities are readily available in most tertiary centers in Malaysia. Health professionals in the primary care settings (government clinics and private practitioners) need to have a high index of clinical suspicion to diagnose and treat melioidosis promptly. Epidemiological information is vital to assist in the differential diagnosis, as almost everyone has direct access to healthcare in Malaysia [37]. Socio-demographic characteristics did not have a significant impact on mortality in our study. A multicenter study with a larger sample size and control population should be conducted in the future to comprehend this issue thoroughly. The geography of the Penampang district is comparable to that of other Borneo Island regions and other tropical developing nations, where heavy rain falls frequently and causes flooding in some areas. Furthermore, the diagnostic capacity of melioidosis remains a challenge in several developing countries. Delayed treatment due to a late diagnosis will worsen the prognosis. To enable a more intensive inter-agency collaborative effort to be made before extreme weather events, it is critical to recognize extreme weather as a risk factor.

We acknowledge that our small sample size might affect the generalizability of these results. However, our results may benefit the healthcare practitioners for implementing primordial and primary interventions. Public health medicine is constantly evolving to keep up with climate change. Primordial and primary prevention has evolved to tackle infectious diseases caused by extreme weather events. The main strength of this study was the utilization of document reviews of all confirmed melioidosis cases. As the disease burden is considered substantial, we had sufficient data to better define the epidemiology of melioidosis, specifically in the Penampang district and the state of Sabah. Moreover, the document review helped us better define melioidosis's risk factors. Hence, its outcome can be used for primordial and primary prevention. Though we had no control over the quality of the documents, we checked for consistency between notification sheets of melioidosis cases from the hospital and the data from the Disease Control Section of the Penampang District Health Office. We assessed the melioidosis notification sheets for relevancy, completeness, and timeliness.

5. Conclusion

Meteorological events not only will lead to the destruction of property, but can also act as powerful determinants of infectious disease. We have demonstrated in our study that *Burkholderia pseudomallei* thrives in areas that are prone to floods. Climate change has resulted in increased unpredictability of weather. Extreme weather events will intensify the disease burden, if an appropriate preventive practice is not in place. Public health authorities must ensure that the population at risk is well-informed about personal protective behaviors against communicable diseases and flood safety measures. In addition, healthcare professionals dealing with the high-risk groups should maintain an appropriately high index of suspicion for melioidosis.

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Conflict of interest

No potential conflict of interest was reported by the authors.

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