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Cold wave induced mortalities in Bangladesh: Spatiotemporal analysis of 20 years' data, 2000–2019

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ABSTRACT

The study aimed to explore the spatiotemporal patterns and characteristics of cold wave mortality in Bangladesh by developing a cold wave dataset using content analysis. Due to the absence of a formal database about cold wave-related mortality in Bangladesh, we first developed a cold wave mortality dataset using content analysis of four (04) leading national daily newspapers' cold wave-related news from 2000 to 2019 and crosschecked with other related reports. Then, we analyzed the data to obtain the spatiotemporal trends and characteristics of cold wave mortality in Bangladesh. A total of 5610 people died in 81 cold wave events (spells) in Bangladesh during the 20 years, with an average of 281 deaths per year. The average duration of cold waves (spells) in Bangladesh was 25.4 days per year, with a statistically significant increasing trend over the period. The highest cold wave mortality rate was found in the Kurigram District; the rate was 163.63 deaths per million people per year. About 58% of cold wave spells and 58.5 % of cold wave mortality occurred in January, followed by December (22%) during the study period. However, cold wave mortality varied from district to district; northwestern districts of Bangladesh were more prone to cold waves and reported a higher mortality rate. During the study period, more children and males died due to cold waves than females in Bangladesh. The study findings serve as a foundation for future research and policy development to establish cold wave management guidelines to reduce the risk of cold wave exposures among vulnerable people in the country.

1. Introduction

It is well known that extreme weather events like cold waves and heat waves in both developing and developed countries are increasing every year, and these events will be more frequent and intense with the increasing climate change scenarios (Ballester et al., 2011; Collins et al., 2013; Diffenbaugh and Scherer, 2011; Field and Barros, 2014; Kirtman et al., 2013; Oudin Åström et al., 2013; Patz et al., 2000; Wang et al., 2016). However, a disproportionate number of studies focus on extreme temperature events (Barnett et al., 2012; Martinez et al., 2018; Seltenrich Nate, 2015), more on heatwaves than cold wave events, especially in developing countries where people are more vulnerable to cold temperatures (Walt and Fitchett, 2021; Wang et al., 2016). The relationship between cold waves and mortality is well established. Prolonged exposure to cold temperatures can lead to direct effects on human health by developing hypothermia, cardiovascular disorders (thrombosis, hypertension), and respiratory infections (pneumonia, influenza) (Chen et al., 2020; Chien et al., 2016; Dadbakhsh et al., 2017; Davídkovová et al., 2014; Gómez-Acebo et al., 2013; Huynen et al., 2001; Kysely et al., 2009; Ma et al., 2013; Miron et al., 2012; Montero et al., 2010; Oudin Åström et al., 2013; Petkova et al., 2021; Revich and Shaposhnikov, 2016; Rocklöv et al., 2014; Sharafkhani et al., 2020; Smith and Sheridan, 2019; Wang et al., 2016). For example, in 2008, the cold wave in subtropical China led to 148,279 deaths and an economic loss of US$ 22.3 billion (Han et al., 2017; Zhou et al., 2014). An analysis of the US National Center for Health Statistics' compressed mortality file showed that from

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1979 to 2004, more than 21,000 people died in natural disasters in the USA; among them, 50 percent accounted for cold wave events (Thacker et al., 2008). However, little literature was found on cold wave frequency and mortality in developing and underdeveloped countries, which are essential for developing their cold wave management policies and plans to reduce the adverse impacts of cold waves in those countries.

Bangladesh, located in South Asia, is ranked as one of the top three disaster-prone countries in the world (INFORM Risk, 2020). It has been frequently encountered by floods, cyclones, storm surges, landslides, droughts, heat waves, and cold waves, resulting in considerable loss of life, livelihoods, and properties. In 2017, extreme weather events killed at least 407 people in Bangladesh and caused an economic loss of about US $2.82 billion (Eckstein et al., 2018). Historically, Bangladesh has been regularly exposed to cold waves, causing severe damage to agricultural production, interruptions of communication, and widespread suffering and deaths of marginal, isolated, and poor people, including children,

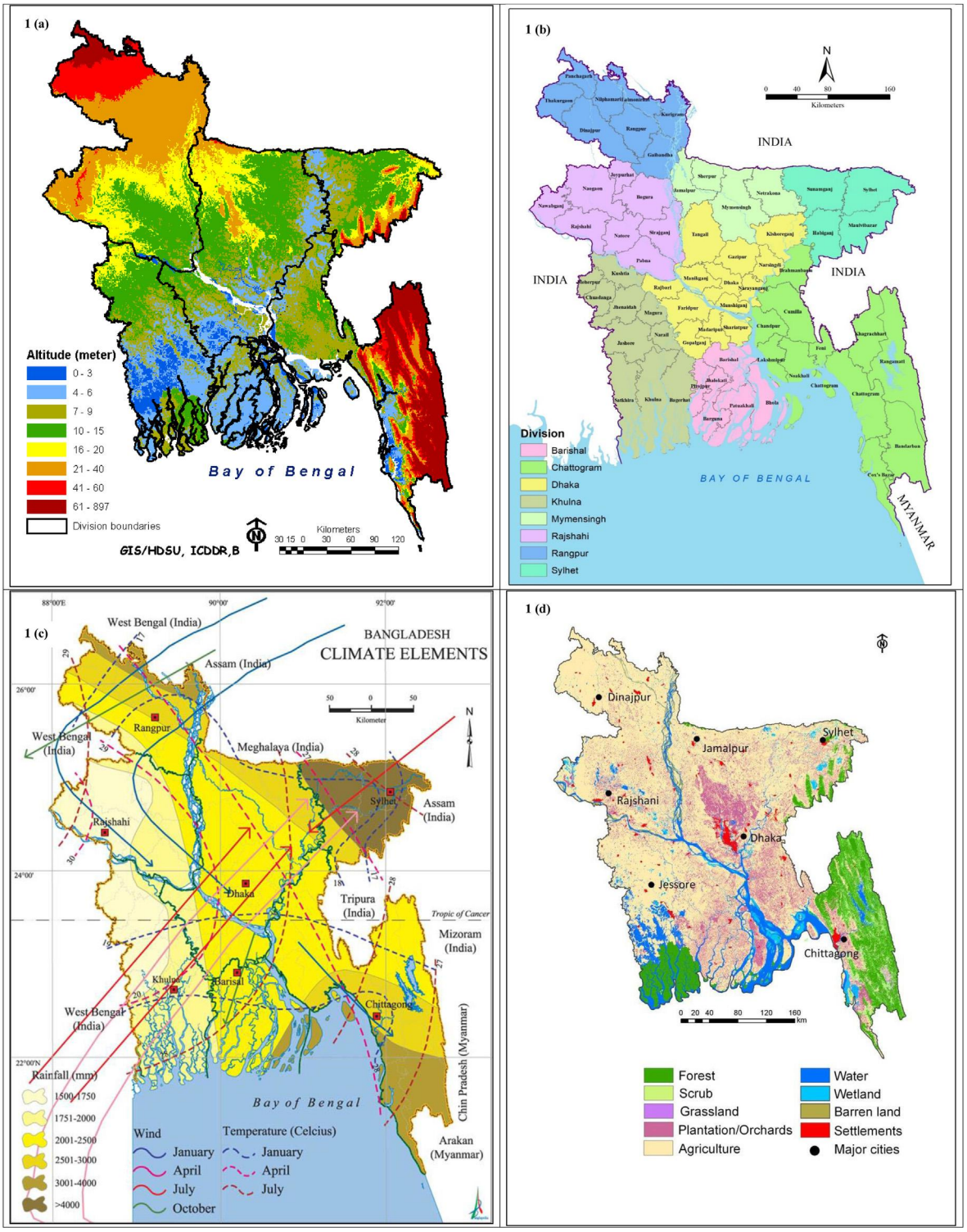

Fig. 1. Maps of Bangladesh. 1(a): Elevation map (Ahsan, 2022); 1(b): Administrative map; 1(c): Climate elements map (Banglapedia, 2021c); 1(d): Land-use map (Reddy et al., 2016).

men, and women. Many people die from cold-related illnesses in Bangladesh, such as influenza, diarrhea, pneumonia, and other diseases during cold spells (Express, 2018; Paul, 2019; ReliefWeb, 2006; Star, 2011). For example, according to government reports, in 2019, at least 50 people died due to cold wave-related diseases in Bangladesh (Dhaka Tribune, 2019; Reuters, 2019), and another 24 people were killed in the Nilphamari and Thakurgaon districts of Bangladesh due to the cold wave in 2013 (Star, 2003). However, cold wave morality news is usually restricted to a particular cold wave event or spell for a short time and suffers detailed information about the victims.

Moreover, there is very limited information and literature on cold wave mortality in Bangladesh except in daily newspaper news and some situation reports. A study on the effect of temperature on mortality in rural areas in Bangladesh showed that all-cause deaths increased in low temperatures for 0–13 days after the event. All-causes mortality increased by 3.2% with every 1 °C drop in temperature (Hashizume et al., 2009). Another study found a correlation between infant mortality and low temperature in Matlab Upazila (a smaller unit of the Chadpur District) during 1982–2008 (Babalola et al., 2018). Moreover, some cold-related mortality data from Bangladesh were found in the EM-DAT database, which was inconsistent. In addition, Bangladeshi non-governmental organizations such as the Disaster Forum (DF) and NIRAPAD published some data on cold-related mortality in Bangladesh (Alam et al., 2022).

In conclusion, Bangladesh has no systematic official record of cold wave mortality, unlike the India Meteorological Department (IMD), which collects and preserves mortality data related to disasters, including cold wave mortality data in India (Malik et al., 2020). Thus, we tried to fill this gap by developing a substantial labor-intensive cold wave dataset of Bangladesh from 2000 to 2019 using mainly newspaper content analysis and examining the spatiotemporal changes and characteristics of cold wave mortality in Bangladesh. Evidence from this study will help policymakers and other stakeholders to develop preventive and adaptive policies, plans, and programs for effective and sustainable cold wave management in Bangladesh.

2. Materials and methods

2.1. Study area

Bangladesh — the eighth-most populous country in the world, with an estimated population of 164.69 million in 2020 (World Bank, 2021) (see Appendix, Fig A1) — is also the youngest nation-state in South Asia. The country is situated in the fertile plains of the world's largest river delta, formed by the Brahmaputra River and the Ganges (Padma) River delta and shares its borders with India in the east, west, and north, and has a short border with Myanmar (Burma) in the southeast (Banglapedia, 2021a). Most of the country is a low-lying plain land with an average elevation of 9 m (Fig. 1a), except for the southeast hilly area. Bangladesh is also a small country (148,560 square kilometers) divided into 64 districts under eight administrative divisions: Barisal, Chattogram, Dhaka, Khulna, Mymensingh, Rajshahi, Rangpur, and Sylhet (Fig. 1b). Bangladesh's climate is characterized by heavy rainfall, high temperature, often excessive humidity, and fairly marked seasonal variations as it is located in the tropical monsoon region. The winter season extends from November to February, with very little rainfall (less than 4 percent of the total annual rainfall). During this season, cold air flows eastward from the northwestern part of India and enters Bangladesh through its northwest corner, causing mild to severe cold waves in the country (Banglapedia, 2021b, 2021d) (Fig. 1c). In Bangladesh, the lowest temperature was recorded at 2.6 °C in 2018 and ranged from 2.6 to 7.2 °C between 2000 and 2019, causing severe to moderate cold spells (Table 1). Agriculture is the primary employment sector (48.4%) of the Bangladeshi population and contributes around 17% of GDP. In addition, more than 70% of its land is used for crop production (FAO, 2021 Inland Water Resources and Aquaculture Service) (Fig. 1d).

Table 1
Yearly lowest temperature in Bangladesh (2000–2019).

Year	Lowest Temperature of the Year		
	Day, Date	Temp (°C)	Place (Upazila, District)
2000	Saturday, January 8	5.5	Ishwardi, Pabna
2001	Sunday, January 21	5.2	Sreemangal, Moulvibazar
2002	Saturday, December 21	4	Lalmonirhat
2003	Thursday, January 23	3.4	Rajshahi
2004	Tuesday, December 28	5.2	Sreemangal, Moulvibazar
2005	Friday, February 4	7.2	Sreemangal, Moulvibazar
2006	Monday, January 23	6.6	Sreemangal, Moulvibazar
2007	Wednesday, January 17	4	Sreemangal, Moulvibazar
2008	Friday, February 15	5.2	Sreemangal, Moulvibazar
2009	Tuesday, December 29	6	Ishwardi, Pabna
2010	Tuesday, January 12	5	Sreemangal, Moulvibazar
2011	Wednesday, January 12	4.5	Jashore
2012	Monday, January 23	5.4	Sreemangal, Moulvibazar
2013	Thursday, January 10	3	Saidpur, Nilphamari
2014	Wednesday, January 8	6	Ishwardi, Pabna
2015	Sunday, February 1	5.5	Sreemangal, Moulvibazar
2016	Monday, January 25	6	Gopalgonj
2017	Saturday, January 14	5	Tetulia, Panchagarh
2018	Monday, January 8	2.6	Tetulia, Panchagarh
2019	Tuesday, January 1	4.9	Tetulia, Panchagarh

2.2. Data extraction method

Bangladesh has no official records for cold wave mortality; therefore, we extracted data from the following sources to develop a longitudinal national-scale database.

Primary source: We reviewed four (04) leading national daily newspapers, both print and online versions (2 in Bangla and 2 in English language papers) from November to February (winter season) each year to extract the cold wave mortality data and its attributes using standard data extraction form.

Secondary source: We also reviewed (i) the Monthly Hazard Incident Report published by the Network for Information Response and Preparedness Activities on Disaster (NIRAPAD) (NIRAPAD, 2024), (ii) the Daily Disaster Situation Report published by the Ministry of Disaster Management and Relief, 2024, Government of the People's Republic of Bangladesh (GoB) (Ministry of Disaster Management and Relief, 2024), (iii) International disaster database was published by the Centre for Research on the Epidemiology of Disasters (CRED, 2024), and (iv) Disaster Reports published from Disaster Forum (DF) to crosscheck and validate the mortality data whenever available. A schematic diagram of the mortality database development and the methodology followed in the study is presented in Fig. 2.

National daily newspapers were the prime source of cold wave-related mortality data in this study. Daily maximum and minimum temperature of the winter season, cold wave (spell) duration, and frequency data were collected from the daily disaster situation report published by the Ministry of Disaster Management and Relief, 2024 GoB, and the daily weather forecast issued by Bangladesh Meteorological Department as well as newspapers' daily weather news. At first, a paper form was developed and used to record data and time, location (district), cold wave morality number, gender, and daily maximum and minimum temperature, including the name, page, and column number of the newspapers where the information was found. To avoid duplication, data were first matched with the date of the mortality and demographic variables and then crosschecked against the corresponding location and other entities. Duplicate cases were removed if any overlap happened, and then the final data were transferred in an Excel form for further analysis. During the data collection, we found that many mortality records did not have all the relevant attributes of interest.

Moreover, several authors argued that newspapers often underreport the mortality and injury cases related to extreme weather events (Dlamini, 2009; Mills et al., 2008; Trengove and Jandrell, 2015). However, Mills et al. (2008) and Brázdil et al. (2021) pointed out that newspaper

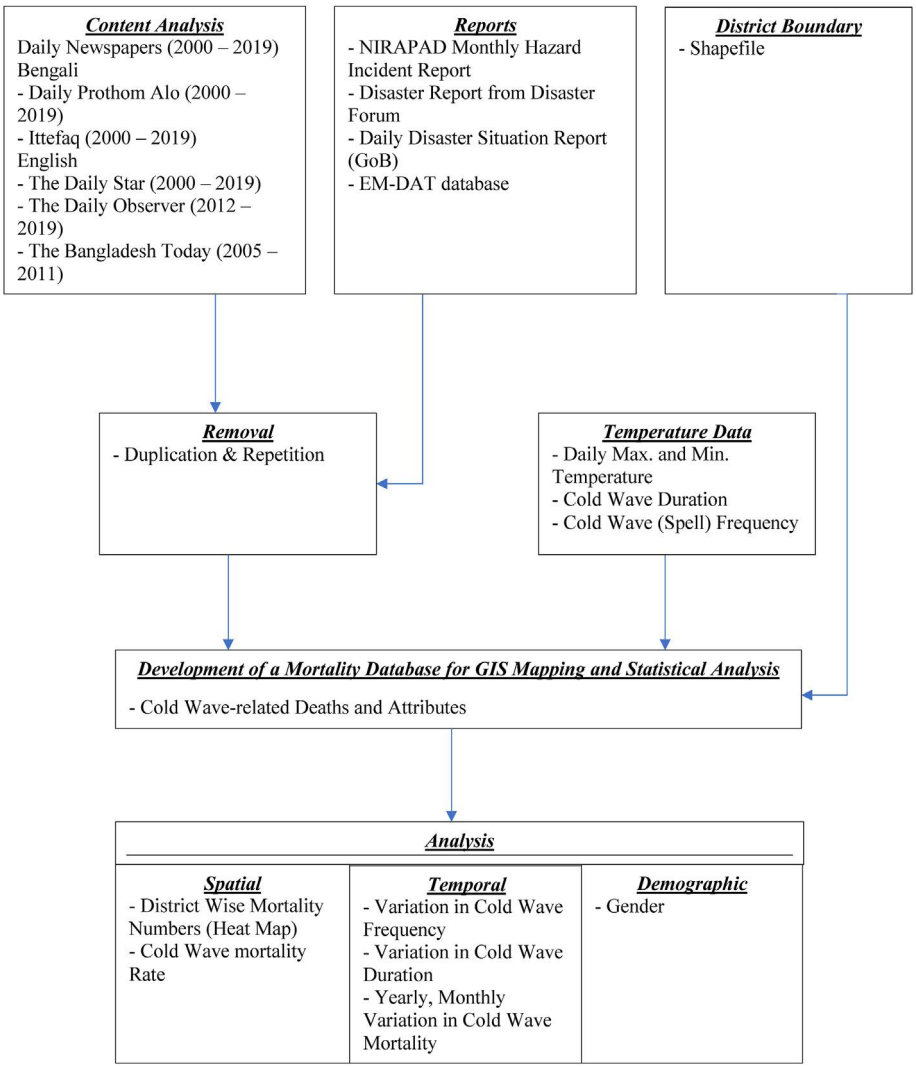

Fig. 2. A schematic diagram of the cold wave mortality database development and the methodology followed in the study.

articles are the most important sources of information when there are no official records, especially for natural disasters and extreme events. Besides, a similar data collection technique was applied to study lightning fatalities in Bangladesh by Dewan et al. (2017) and Holle et al. (2019) and fatalities related to extreme weather conditions in the Czech Republic by Brázdil et al. (2021). Apart from this, district-wise population and area data were collected from the 2001 and 2011 Population & Housing Census of Bangladesh and the estimated population of 2021. The average population for the study period was calculated using the mean population of these three census years.

2.3. Measures

According to IFRC, "A cold wave, sometimes known as a cold snap or deep freeze, is a weather event involving cooling the air, or the invasion of very cold air, over a large area. It is marked by a drop of average temperature well below the averages of a region" (Cold Waves IFRC, 2022). Though temperature ranges for defining cold waves, vary from region to region in Bangladesh, cold waves are defined into four categories: (i) mild coldwave (8–10 ^{O}C), (ii) moderate coldwave (6–8 °C), (iii) severe coldwave (4–6 °C) and (iv), very severe coldwave (<4 °C), based on the normal daily temperature of an area (BBC News, 2020; Care Bangladesh, 2010; Jugantor, 2020; Paul, 2019; The Daily Jugantor, 2020; The Daily Prothomalo, 2016). The average maximum daily temperature was 29 °C, and the average minimum daily temperature was 10.5 °C in the winter season of Bangladesh from 2000 to 2019 (see Appendix, Fig A2).

Cold wave frequency, duration, and deaths in Bangladesh from 2000 to 2019 were documented in the study. Cold wave frequency was measured by the number of cold wave spells that occurred in a year, and cold wave duration in a year was measured by the total number of days of all cold waves that happened that year. The mortality rate due to cold waves was calculated by dividing the number of deaths by the total population of the districts and multiplying by one million. Thus, cold wave mortality rates have been calculated as follows:

$$MR = [(N / P) \times 1,000,000] / n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Here,

MR is the cold wave mortality rate (per million population per year),

N is the number of cold wave mortalities reported,

P is the average total population likely to be affected by cold waves (i.e., this population is an average of the decadal census for 2001, 2011, and the estimated population 2021 district-wise and whole), and

N is the number of years (study period from 2000 to 2019).

Three types of mortality rates were calculated: (i) year-specific mortality rates, (ii) period-specific mortality rates, and (iii) mortality rates for the study period. Moreover, mortality density was calculated by dividing the number of deaths by the total area (in kilometers) of the districts.

2.4. Statistical analysis

Univariate and bivariate analyses were conducted to present the results. Univariate analysis was performed to present levels and trends in the mortality numbers, mortality rates, mortality densities, cold wave frequencies, and durations of cold waves. Bivariate analysis (Mann-Kendall test and Spearman's rho test) was conducted to estimate the linear trends in mortality numbers and rates with cold wave durations and times (statistical significance was set at 0.05). Statistical analyses were done using SPSS 25 and Microsoft Excel 2016 software. Moreover, the spatial distribution of cold wave mortality was shown in the maps using ArcGIS 10.5 software, which will help to find out the most affected areas in Bangladesh.

3. Results and discussion

3.1. Variation in cold wave frequency

During the study period (2000–2019), 81 cold wave events (cold wave spells) happened in Bangladesh, with an average of 4.05 events per year. The highest eight cold wave events were experienced in 2010, whereas the lowest, only one cold wave event, happened in 2007 in Bangladesh. Overall, a slightly increasing trend in cold wave frequency was found during the study period. However, this trend is statistically nonsignificant (Fig. 3). About 58 % of cold wave events happened in January, followed by December (22.22 %) during 2000–2019. Between 1978 and 2014, India — the neighboring country of Bangladesh — suffered from 606 cold wave events, and Uttar Pradesh state experienced the highest number of cold wave events (Malik et al., 2020). As one of the most vulnerable countries to climate change, Bangladesh is expected to face downward changes in cold indices at higher specific warming levels (Khan et al., 2020), which might cause an increase in cold wave events in the future. The northern and northwestern districts generally experienced more cold wave events than the other parts of the country. Higher cold wave events over these areas may result in relatively higher elevation and, most importantly, the intrusion of cold winter air from northwestern India (Banglapedia, 2021e).

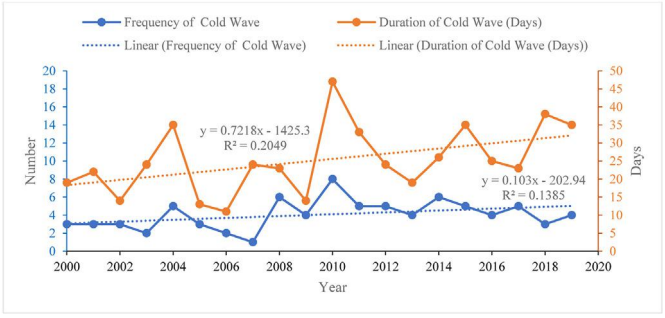

Fig. 3. Frequency and duration of cold wave in Bangladesh (2000–2019).

3.2. Variation in cold wave duration

From 2000 to 2019, the total duration of cold waves in Bangladesh was 508 days, with an average of 25.4 days per year. The maximum duration of cold waves was 47 days in 2010, whereas the minimum duration of cold waves was 11 days in 2006. In addition, a statistically significant increasing trend in cold wave duration was found between 2000 and 2019 (Fig. 3), which is in agreement with the findings of Khan et al. (2020). However, the duration of cold waves may vary from place to place depending on geographical and meteorological characteristics; for example, Jiang et al. (2012) found that cold wave duration significantly decreased in China during 1957–2009. The reduction is much higher in northern China than in southern China.

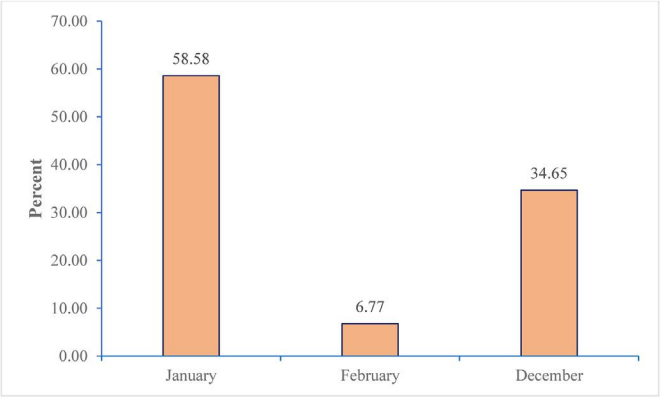

Fig. 5. Monthly variation of cold wave mortality in Bangladesh (2011–2019) (n = 1212).

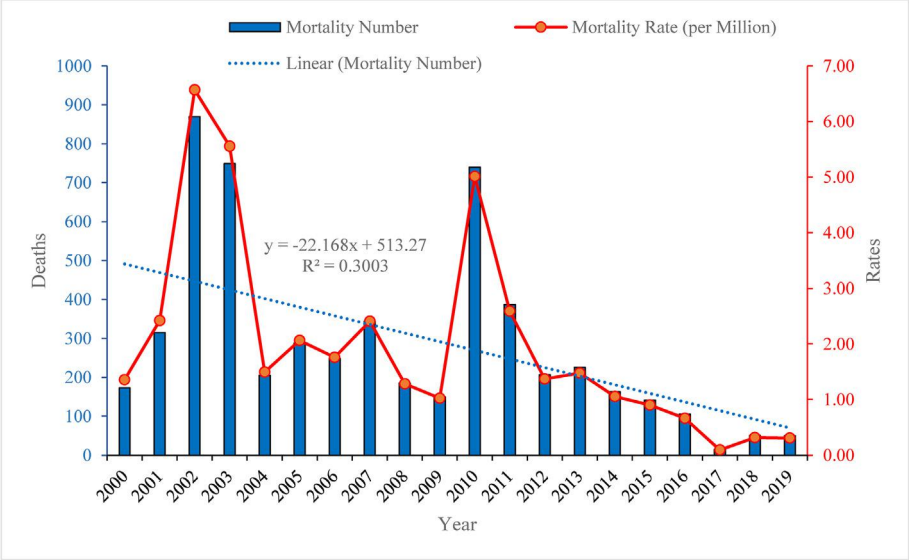

Fig. 4. Mortality number and mortality rates of the population for cold wave in Bangladesh from 2000 to 2019 (n = 5610). Note: Year-wise total population data of Bangladesh were collected from the World Bank population database (Population, Total - Bangladesh | Data, 2022).

Table 2
District-wise distribution of cold wave mortality number, mortality rate, and mortality density with rank in Bangladesh (2005–2019).

District	Division	Area (km^2)	Average population (in million)	Mortality (2005–2019)		Mortality rate (2005–2019) (per million people)		Mortality density (2005–2019)	
				Number	Rank	Rate	Rank	Density	Rank
Bagerhat	Khulna	3959	1.56671	24	29	15.32	23	0.006062	39
Bandarban	Chattogram	4479	0.38515	4	50	10.39	32	0.000893	57
Barguna	Barishal	1831	0.91811	14	35	15.25	24	0.007646	33
Barishal	Barishal	2785	2.48543	62	13	24.95	17	0.022262	18
Bhola	Barishal	3403	1.84564	65	12	35.22	12	0.019101	21
Bogura	Rajshahi	2920	3.43898	60	14	17.45	21	0.020548	19
Brahmanbaria	Chittagong	1927	2.95192	26	26	8.81	38	0.013492	23
Chandpur	Chattogram	1704	2.53875	8	44	3.15	45	0.004695	44
Chapainawabganj	Rajshahi	1703	1.69195	9	43	5.32	41	0.005285	40
Chattogram	Chattogram	5283	7.73950	0	61	0.00	61	0.000000	61
Chuadanga	Khulna	1177	1.14505	122	5	106.55	2	0.103653	2
Coxsbazar	Chattogram	2492	2.34757	2	56	0.85	56	0.000803	59
Cumilla	Chattogram	3085	5.51395	4	51	0.73	57	0.001297	54
Dhaka	Dhaka	1464	11.45107	11	39	0.96	55	0.007514	34
Dinajpur	Rangpur	3438	3.02099	77	10	25.49	16	0.022397	17
Faridpur	Dhaka	2073	1.95681	47	17	24.02	18	0.022672	16
Feni	Chattogram	928	1.47725	1	57	0.68	58	0.001078	56
Gaibandha	Rangpur	2179	2.49748	98	7	39.24	9	0.044975	8
Gazipur	Dhaka	1800	3.16060	4	52	1.27	54	0.002222	50
Gopalganj	Dhaka	1490	1.22790	11	40	8.96	37	0.007383	35
Habiganj	Sylhet	2637	2.16222	24	30	11.10	30	0.009101	31
Jamalpur	Dhaka	2032	2.37096	69	11	29.10	14	0.033957	12
Jashore	Khulna	2567	2.80603	50	15	17.82	20	0.019478	20
Jhalokati	Barishal	749	0.71830	17	32	23.67	19	0.022697	15
Jhenaidah	Khulna	1961	1.82060	5	47	2.75	47	0.002550	48
Joypurhat	Rajshahi	965	0.93415	10	41	10.70	31	0.010363	28
Khagrachhari	Chattogram	2700	0.62586	1	58	1.60	52	0.000370	60
Khulna	Khulna	4394	2.44917	32	23	13.07	29	0.007283	36
Kishoreganj	Dhaka	2689	3.05162	31	24	10.16	33	0.011528	25
Kurigram	Rangpur	2296	2.10845	345	1	163.63	1	0.150261	1
Kushtia	Khulna	1601	2.00166	30	25	14.99	25	0.018738	22
Lakshmipur	Chattogram	1456	1.81403	0	62	0.00	62	0.000000	62
Lalmonirhat	Rangpur	1241	1.28848	48	16	37.25	11	0.038678	10
Madaripur	Dhaka	1145	1.23510	12	38	9.72	35	0.010480	27
Magura	Khulna	1049	0.94458	5	48	5.29	42	0.004766	43
Manikganj	Dhaka	1379	1.43932	10	42	6.95	40	0.007252	37
Meherpur	Khulna	716	0.66561	40	18	60.10	6	0.055866	6
Moulvibazar	Sylhet	2799	1.95181	26	27	13.32	28	0.009289	30
Munshiganj	Dhaka	955	1.46954	3	54	2.04	51	0.003141	47
Mymensingh	Dhaka	4363	5.32600	16	33	3.00	46	0.003667	46
Naogaon	Rajshahi	3436	2.65617	37	21	13.93	27	0.010768	26
Narail	Khulna	990	0.75871	0	63	0.00	63	0.000000	63
Narayanganj	Dhaka	700	2.87072	1	59	0.35	60	0.001429	53
Narsingdi	Dhaka	1141	2.26864	1	60	0.44	59	0.000876	58
Natore	Rajshahi	1896	1.72800	25	28	14.47	26	0.013186	24
Netrokona	Dhaka	2810	2.32561	5	49	2.15	50	0.001779	52
Nilphamari	Rangpur	1580	1.86997	139	4	74.33	4	0.087975	3
Noakhali	Chattogram	3601	3.16144	7	46	2.21	49	0.001944	51
Pabna	Rajshahi	2372	2.57282	98	8	38.09	10	0.041315	9
Panchagarh	Rangpur	1405	1.00395	40	19	39.84	8	0.028470	14
Patuakhali	Barishal	3221	1.60655	16	34	9.96	34	0.004967	42
Pirojpur	Barishal	1308	1.16344	40	20	34.38	13	0.030581	13
Rajbari	Dhaka	1119	1.06756	8	45	7.49	39	0.007149	38
Rajshahi	Rajshahi	2407	2.62736	119	6	45.29	7	0.049439	7
Rangamati	Chattogram	6116	0.59805	0	64	0.00	64	0.000000	64
Rangpur	Rangpur	2368	2.95418	189	2	63.98	5	0.079814	5
Satkhira	Khulna	3858	2.04522	35	22	17.11	22	0.009072	32
Shariatpur	Dhaka	1182	1.20771	3	55	2.48	48	0.002538	49
Sherpur	Dhaka	1364	1.41496	13	37	9.19	36	0.009531	29
Sirajganj	Rajshahi	2498	3.16610	87	9	27.48	15	0.034828	11
Sunamganj	Sylhet	3670	2.52424	4	53	1.58	53	0.001090	55
Sylhet	Sylhet	3490	3.46592	18	31	5.19	43	0.005158	41
Tangail	Dhaka	3414	3.66693	14	36	3.82	44	0.004101	45
Thakurgaon	Rangpur	1810	1.42414	146	3	102.52	3	0.080663	4
BANGLADESH		**147,570**	**146.6927**	**3298**		**22.48**		**0.022348**	

3.3. Cold wave mortality in Bangladesh

3.3.1. Yearly variation

Annual counts for cold wave mortality and mortality rate in Bangladesh from 2000 to 2019 are presented in Fig. 4. During this period, 5610 deaths were recorded due to cold wave-related illnesses, with an average of 280.5 deaths per year. The annual cold waves-related mortality rate varied from 6.57 to 0.09 per million people, with an average of 1.99 deaths per million people. A statistically significant linear decline trend ($R^2 = 0.30$; $P = 0.012$) was found in cold wave mortality numbers

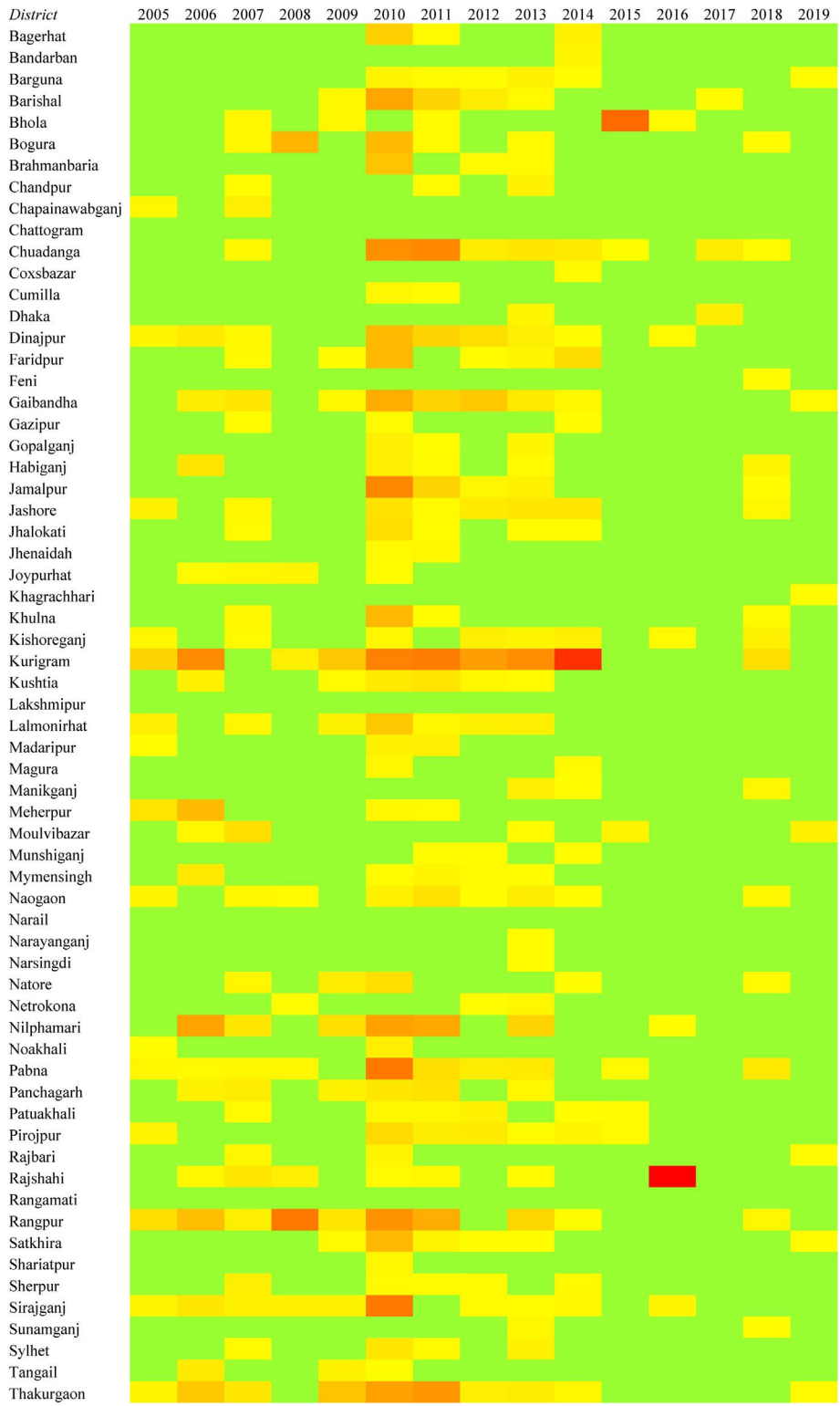

Fig. 6. Heat map of the cold wave mortality in Bangladesh (2005–2019). The number of mortality increases from light green to yellow to red (range: 0 to 94).

in Bangladesh during this period. However, no statistically significant correlation was found between morality number and cold wave frequency or duration in Bangladesh. Alam et al. found that, on average, 104 cold-related deaths occurred in Bangladesh from 2009 to 2021 (Alam et al., 2022). Ironically, cold waves cause many excess deaths all over the globe. During 1978–2014, 8520 people lost their lives due to cold waves in India, with an average of 230 deaths per year and about 75 percent of total cold wave mortalities reported in Bihar (44%) and Uttar Pradesh (31%) states (Malik et al., 2020). In 1987, a cold wave caused 274 excess deaths in the Czech Republic; in 2006, Moscow's cold wave resulted in over 370 excess deaths (Yang et al., 2019). Thacker et al. found that 10, 827 cold-related deaths occurred in the USA from 1987 to 2004, with an average of 637 deaths per year (Thacker et al., 2008).

3.3.2. *Monthly variation*

Usually, in Bangladesh, the dry winter season starts in November and

ends in February. The temperature starts dropping sharply from December and remains low until mid-February; therefore, most of the cold wave events happen in December and January (Banglapedia, 2021d). About 58.5 % of the total cold wave mortality was reported in January, followed by December (37%) from 2011 to 2019 (Fig. 5). Like Bangladesh, in India, nearly 72 percent of total mortality was reported in January, followed by December (25 percent) from 1978 to 2014 (Malik et al., 2020).

3.3.3. District-wise variation

Due to the lack of district-wise mortality attributes in the data sources, only 74.83 percent of total reported mortality cases (2468 out of 3298) were segregated by district during 2005–2019 to evaluate the district-wise spatiotemporal distribution and changes in cold wave mortality numbers, rate, and density. During this period, the highest mortality number, rate, and density due to cold waves were found in the Kurigram District in the Rangpur Division. In contrast, no cold wave related mortality was seen in the Chattogram, Lakshmipur, Narail, and Rangamati districts in Bangladesh (Table 2). The second highest cold wave mortality rate at 7.10 per million per year was found in the Chuadanga District, followed by the Thakurgaon District (6.83 per million per year). The heat map of the cold wave mortality by district in Bangladesh (2005–2019) is shown in Fig. 6. The highest number of cold wave mortality (730) by district was recorded in 2010, followed by 357 mortality in 2011. In addition, these six districts, Kurigram, Rangpur, Thakurgaon, Nilphamari, Chuadanga, and Rajshahi, experienced 42.94% of the total cold wave mortality in Bangladesh from 2005 to 2019. The cold wave mortality number sharply declined from 2015 to 2019 compared to earlier years. This decline in mortality may result in improving the early warning system for cold waves and increasing preparedness to deal with cold waves in Bangladesh (WB, 2017).

Fig. 7 illustrates the periodic distribution of cold wave mortality rate by district in Bangladesh. During 2005–2009, the Meherpur District had the highest cold wave mortality rate (10.12 deaths per million per year), followed by Kurigram (8.06 deaths per million per year) and Thakurgaon districts (7.72 deaths per million per year). From 2010 to 2014, the highest cold wave mortality rate (49.6 deaths per million per year) was found in the Kurigram District, whereas the Rajshahi District experienced the maximum cold wave mortality rate (18.8 deaths per million per year) during 2015–2019. Overall, the northwestern districts had a relatively higher cold wave mortality rate, while the southeastern districts had a relatively lower cold wave mortality rate in Bangladesh during the study period.

Table 3 shows the spatial distribution of changes in the mortality rate

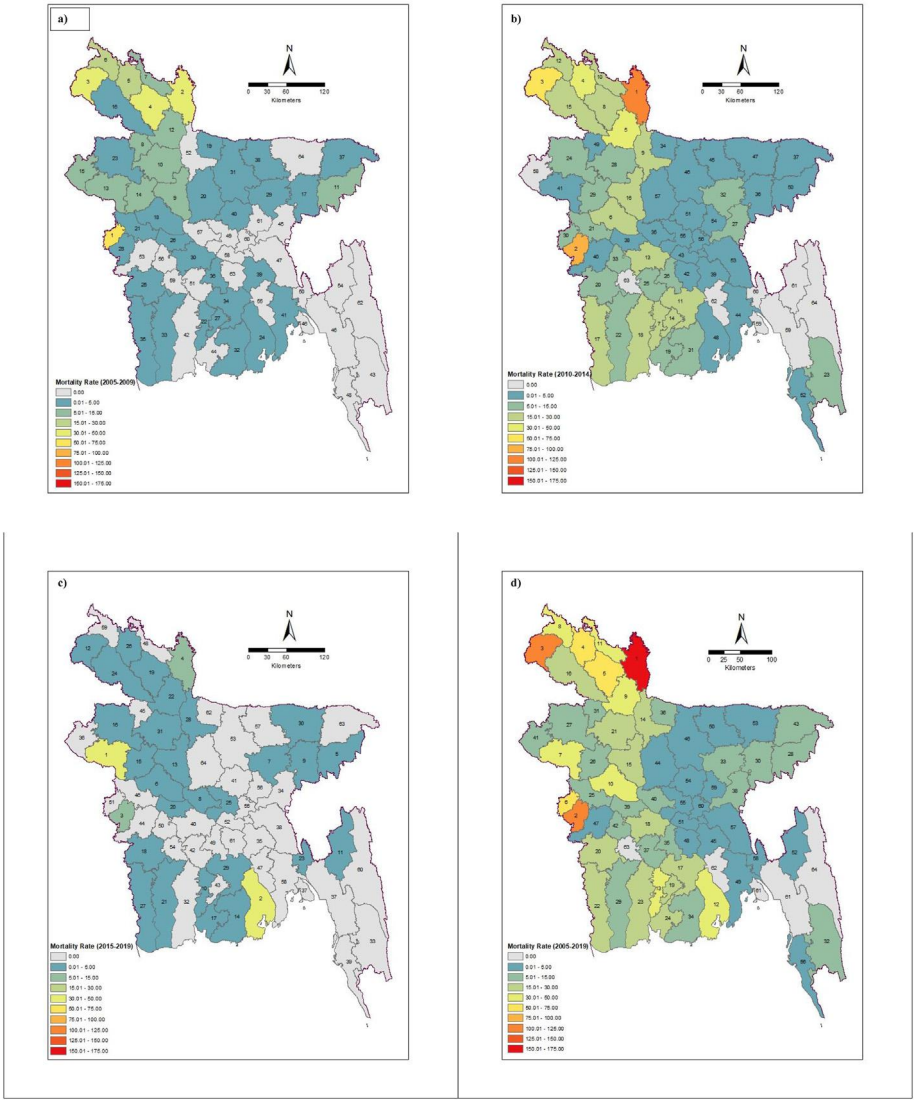

Fig. 7. Distribution of cold wave mortality rate (per million) by district in Bangladesh, (a) during 2005–2009, (b) during 2011–2014, (c) during 2015–2019, and (d) during 2000–2019. Mortality rate ranks by district are numbered. Color shading in scale ranges from the lowest rate in yellow to the highest rate in red.

Table 3
Spatial distribution of changes in the cold wave mortality rate in Bangladesh. The average population for 2005–2011 was calculated using the 2001 and 2011 census data, whereas the average population for 2012–2019 was calculated using the 2011 census and 2021 estimated population data.

District	2005–2011			2012–2019			Change in mortality rate over the period	Trend
	No. of death	Ave. population	Mortality rate (per million people/year)	No. of death	Ave. population	Mortality rate (per million people/year)		
Bagerhat	19	1512560.5	1.79	5	1,575,545	0.40	−1.40	Decrease
Bandarban	0	343227.5	0.00	4	428667.5	1.17	1.17	**Increase**
Barguna	6	870667.5	0.98	8	952890.5	1.05	0.06	**Increase**
Barishal	52	2340138.5	3.17	10	2,550,155	0.49	−2.68	Decrease
Bhola	8	1,739,956	0.66	57	1916897.5	3.72	3.06	**Increase**
Bogura	57	3,206,965	2.54	3	3,651,937	0.10	−2.44	Decrease
Brahmanbaria	22	2,619,376	1.20	4	3,228,749	0.15	−1.04	Decrease
Chandpur	3	2343623.5	0.18	5	2,672,509	0.23	0.05	**Increase**
Chapainawabganj	9	1536421.5	0.84	0	1825260.5	0.00	−0.84	Decrease
Chattogram	0	7,114,246	0.00	0	8,303,176	0.00	0.00	No change
Chuadanga	88	1068072.5	11.77	34	1214007.5	3.50	−8.27	Decrease
Coxsbazar	0	2031849.5	0.00	2	2,634,495	0.09	0.09	**Increase**
Cumilla	4	4991422.5	0.11	0	5,973,144	0.00	−0.11	Decrease
Dhaka	0	10277602.5	0.00	11	12920988.5	0.11	0.11	**Increase**
Dinajpur	56	2,816,489	2.84	21	3,210,064	0.82	−2.02	Decrease
Faridpur	29	1834719.5	2.26	18	2056984.5	1.09	−1.16	Decrease
Feni	0	1338877.5	0.00	1	1595685.5	0.08	0.08	**Increase**
Gaibandha	65	2,258,718	4.11	33	2677127.5	1.54	−2.57	Decrease
Gazipur	3	2717901.5	0.16	1	3,724,956	0.03	−0.12	Decrease
Gopalganj	7	1,168,844	0.86	4	1259207.5	0.40	−0.46	Decrease
Habiganj	18	1,923,333	1.34	6	2364500.5	0.32	−1.02	Decrease
Jamalpur	60	2199941.5	3.90	9	2,502,837	0.45	−3.45	Decrease
Jashore	21	2618050.5	1.15	29	2973273.5	1.22	0.07	**Increase**
Jhalokati	15	688,450	3.11	2	730334.5	0.34	−2.77	Decrease
Jhenaidah	5	1,675,397	0.43	0	1,941,152	0.00	−0.43	Decrease
Joypurhat	10	880,232	1.62	0	977,884	0.00	−1.62	Decrease
Khagrachhari	0	569790.5	0.00	1	675958.5	0.18	0.18	**Increase**
Khulna	30	2,348,749	1.82	2	2484263.5	0.10	−1.72	Decrease
Kishoreganj	8	2753430.5	0.42	23	3279953.5	0.88	0.46	**Increase**
Kurigram	179	1,930,673	13.24	166	2266636.5	9.15	−4.09	Decrease
Kushtia	25	1843496.5	1.94	5	2,132,419	0.29	−1.64	Decrease
Lakshmipur	0	1609544.5	0.00	0	1,976,094	0.00	0.00	No change
Lalmonirhat	37	1,182,721	4.47	11	1378049.5	1.00	−3.47	Decrease
Madaripur	12	1156150.5	1.48	0	1,279,476	0.00	−1.48	Decrease
Magura	3	871,365	0.49	2	1004709.5	0.25	−0.24	Decrease
Manikganj	0	1338973.5	0.00	10	1516433.5	0.82	0.82	**Increase**
Meherpur	40	623,411	9.17	0	702,696	0.00	−9.17	Decrease
Moulvibazar	15	1,765,718	1.21	11	2,121,531	0.65	−0.57	Decrease
Munshiganj	1	1,369,816	0.10	2	1,557,330	0.16	0.06	**Increase**
Mymensingh	13	4,799,999	0.39	3	5,744,136	0.07	−0.32	Decrease
Naogaon	25	2,495,756	1.43	12	2788578.5	0.54	−0.89	Decrease
Narail	0	710057.5	0.00	0	788,834	0.00	0.00	No change
Narayanganj	0	2561082.5	0.00	1	3219108.5	0.04	0.04	**Increase**
Narsingdi	0	2,060,464	0.00	1	2,454,972	0.05	0.05	**Increase**
Natore	22	1614004.5	1.95	3	1831336.5	0.20	−1.74	Decrease
Netrokona	1	2,108,915	0.07	4	2,494,321	0.20	0.13	**Increase**
Nilphamari	122	1702960.5	10.23	17	2019115.5	1.05	−9.18	Decrease
Noakhali	7	2842663.5	0.35	0	3453541.5	0.00	−0.35	Decrease
Pabna	73	2349724.5	4.44	25	2771089.5	1.13	−3.31	Decrease
Panchagarh	37	911,920	5.80	3	1,087,822	0.34	−5.45	Decrease
Patuakhali	8	1498317.5	0.76	8	1,679,427	0.60	−0.17	**Increase**
Pirojpur	25	1112162.5	3.21	15	1189628.5	1.58	−1.64	Decrease
Rajbari	7	1,000,842	1.00	1	1,125,389	0.11	−0.89	Decrease
Rajshahi	23	2441035.5	1.35	96	2797598.5	4.29	2.94	**Increase**
Rangamati	0	552080.5	0.00	0	642989.5	0.00	0.00	No change
Rangpur	170	2711763.5	8.96	19	3,160,043	0.75	−8.20	Decrease
Satkhira	32	1925331.5	2.37	3	2135479.5	0.18	−2.20	Decrease
Shariatpur	3	1,119,062	0.38	0	1,270,412	0.00	−0.38	Decrease
Sherpur	9	1318933.5	0.97	4	1482662.5	0.34	−0.64	Decrease
Sirajganj	77	2895651.5	3.80	10	3402244.5	0.37	−3.43	Decrease
Sunamganj	0	2,240,853	0.00	4	2,779,484	0.18	0.18	**Increase**
Sylhet	13	2,994,877	0.62	5	3,921,094	0.16	−0.46	Decrease
Tangail	14	3447889.5	0.58	0	3855041.5	0.00	−0.58	Decrease
Thakurgaon	128	1,302,209	14.04	18	1,529,021	1.47	−12.57	Decrease
BANGLADESH	**2340**	**134,199,480**	**2.49**	**958**	**157861348.5**	**0.76**	**−1.73**	**Decrease**

of cold waves in Bangladesh. The changes in mortality rate were calculated by comparing the mortality rate per year of two different periods, 2005–2011 and 2012–2019. The highest decline in mortality rate was found in the Thakurgaon District, about 12.57 per million people per year, followed by Nilphamari and Meherpur districts, which experienced a decrease in the mortality rate of 9.18 and 9.17, respectively, during the periods. On the other hand, the highest increase in mortality rate was found in the Bhola District, at about 3.06 per million per year, followed by Rajshahi and Bandarban districts. Further studies are needed to investigate the underlying factors that cause the shifting of mortality rates from one district to another. However, several health conditions, i.e., cardiovascular dysfunction and pre-existing chronic obstructive pulmonary disease (COPD), and socioeconomic factors such as poor housing, poor utility facilities, and poverty, might modify the mortality risk of cold waves (Achebak et al., 2019; Arbuthnott et al., 2018; Chen et al., 2020; Kysely et al., 2009; Rocklöv et al., 2014).

The periodic distribution of cold wave mortality density by district in Bangladesh is presented in Table 2 (the average population density by district is shown in Fig A2 in the Appendix). From 2005 to 2019, the highest cold wave mortality density was found in the Kurigram District, followed by Chuadanga District. Apart from some exceptions, the northwestern districts had relatively higher cold wave mortality density than the other districts in Bangladesh.

3.3.4. Administrative divisional variation

Fig. 8 illustrates the administrative divisional variation in cold wave mortality in Bangladesh. Nearly one-half (43.84 %) of the cold wave mortality had been reported in the Rangpur Division, followed by Rajshahi (18%) and Khulna (14%) divisions during 2005–2019. Only 2% of mortality cases were found in the Chattogram Division during this period. From 2005 to 2014, the highest cold wave mortality was reported in the Rangpur Division, whereas, from 2015 to 2019, the highest old wave mortality was reported in the Rajshahi Division. Alam et al. also found a similar trend, reporting that 37% of cold wave mortality occurred in the Rangpur Division (Alam et al., 2022).

3.3.5. Gender variation

Several studies have shown that cold wave vulnerability is primarily affected by the socio-economic and living conditions of the people. Moreover, health and nutrition status, health care services, age, and gender also influence the risk of cold wave-related mortality and morbidity (Achebak et al., 2019; Dadbakhsh et al., 2017; Gómez-Acebo et al., 2013; Revich and Shaposhnikov, 2016; Singh et al., 2019; Son et al., 2019). However, our study shows that children were the most vulnerable to the cold wave in Bangladesh, accounting for almost one-half of the total mortality due to cold waves from 2011 to 2019. Moreover, males' mortality rate was more than double that of females during this period (Fig. 9). Alam et al. reported that children and senior citizens are more vulnerable to cold waves in Bangladesh (Alam et al., 2022). Malik et al. (2020) also reported that males are more prone to die in cold waves than females in India. Gómez-Acebo et al. (2013) found that in northern Spain, older people (≥65 years) are more susceptible to cold temperatures, and Revich & Shaposhnikov (2016) also found that the same age groups with circulatory system diseases are at the highest risk of cold wave mortality in Russia. However, several other studies found that the risk of mortality due to cold waves is greater among young people, primarily children, than older people (Achebak et al., 2019; Atsumi et al., 2013; Davídkovová et al., 2014; Son et al., 2011, 2019).

3.4. Implications and limitations of the study

This study examined the spatiotemporal change in cold wave mortality in Bangladesh from 2000 to 2019 by developing a substantial labor-intensive dataset, where information was primarily collected from daily newspapers. Our study provides crucial empirical evidence on the current change in cold wave frequency and mortality in Bangladesh, which has important implications for developing cold wave management policy and plan as well as helping to strengthen cold wave preparedness programs in Bangladesh. Despite the contributions, some limitations of the study are worth mentioning. Firstly, due to the limited information about cold waves in the newspaper, we could not collect all the desirable attributes for the analysis; for example, gender-based data were collected only from 2011 to 2019, and district-wise data were collected from 2005 to 2019. Secondly, not all the mortality cases were reported by newspapers (Dewan et al., 2017; Elsom, 2001; Holle et al., 2005), especially the deaths that occurred in remote rural areas in Bangladesh. Therefore, the original number of deaths due to cold waves may supersede the number found in the study. Finally, this study cannot determine the age-specific and disease-specific causes of cold wave deaths due to insufficient information.

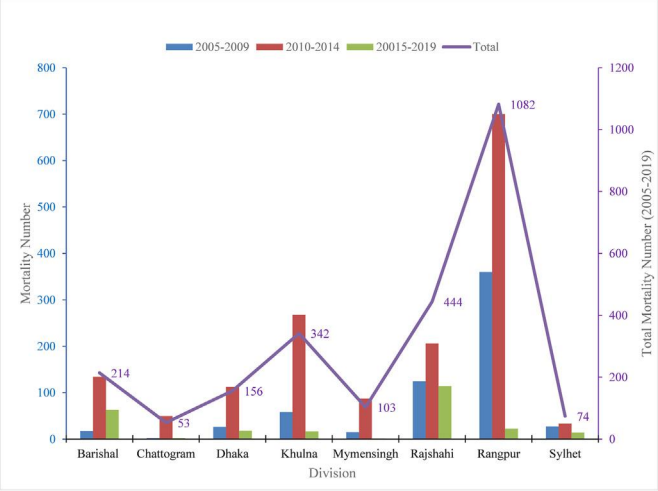

Fig. 8. Divisional variation of cold wave mortality in Bangladesh.

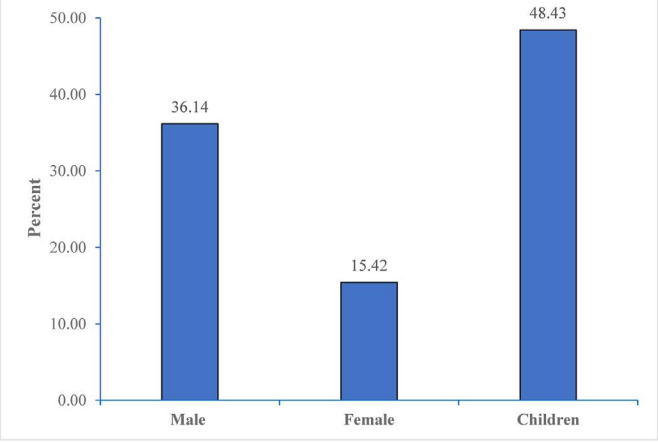

Fig. 9. Gender variation of cold wave mortality in Bangladesh (2011–2019) (n = 830). Males and females are classified when they are 18 years old and above.

4. Conclusion and recommendations

This study investigated the spatiotemporal changes in cold wave mortality in Bangladesh from 2000 to 2019 by developing a dataset using daily newspapers and other sources. Bangladesh encountered 81 cold wave events during this period, resulting in more than 5000 mortality cases, with an average of 280.5 deaths yearly. The maximum mortality due to cold waves was found in the northern and northwestern districts of Bangladesh; however, the mortality rate has reduced significantly in

recent years (2015–2019) compared to the early 2000s. Despite some limitations, the study provides a first step toward a better understanding of the spatiotemporal distribution of cold wave duration and mortality, which provides substantial evidence for developing future cold wave management policies and plans in Bangladesh. However, it is necessary to urgently establish a governmental database on cold wave characteristics, including mortality and morbidity attributes, to monitor the dynamics of cold waves in Bangladesh. Future research should focus on age-specific and disease-specific distributions of cold wave mortality and morbidity in Bangladesh and factors contributing to cold wave mortality and morbidity, which will eventually help to develop an effective public health management policy to reduce the health impacts of cold waves in Bangladesh.

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Ethics approval

Not needed as the database was developed by content analysis (based on secondary information).

Consent to participate

Not applicable.

CRediT authorship contribution statement

Md Khalid Hasan: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tahmina Bintay Younos:** Visualization, Investigation, Data curation, Conceptualization. **Raisa Imran Chowdhury:** Investigation, Conceptualization. **Khalid Bin Masud:** Investigation, Conceptualization. **Pedro Arcos González:** Writing – review & editing, Methodology. **Rafael Castro-Delgado:** Writing – review & editing, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.nhres.2024.01.010.

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