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Extreme weather events induced mortalities in Jammu and Kashmir, India during 2010-2022

MUKHTAR AHMED, SONAM LOTUS, BAPPA DAS*, FAROOQ AHMAD BHAT,
AMIR HASSAN KICHLOO and SHIVINDER SINGH**

India Meteorological Department, MoES, Meteorological Centre Srinagar – 190 015

**Indian Council of Agricultural Research (Central Coastal Agricultural Research Institute Goa India – 403 402*

***India Meteorological Department MoES, Meteorological Centre Chandigarh – 160 036*

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e mail : mukhtarssc@gmail.com

सार – 2010-2022 के दौरान भारत के जम्मू और कश्मीर में प्रचंड मौसम की घटनाओं (EWEs) से बढती मृत्यु दर पर एक अध्ययन किया गया है। वर्तमान अध्ययन में, हमने भारत मौसम विज्ञान विभाग, जम्मू-कश्मीर के 10 स्टेशनों में 2010 से 2022 की अवधि के दौरान भारी वर्षा, भारी हिमपात, तड़ित/गर्ज के साथ तूफ़ान, ओला वृष्टि और प्रचंड वायु की आवृत्ति का उपयोग किया। प्रत्येक जिले के लिए इन प्रचंड मौसम की घटनाओं के कारण होने वाली मौतों का विवरण मौतों विज्ञान केंद्र श्रीनगर से एकत्र किया गया। प्रत्येक स्टेशन के लिए प्रत्येक माह की औसत मासिक वर्षा और वर्षा के दिनों की संख्या की गणना 40 वर्षों के आंकड़ों (1982 से 2022) के आधार पर की गई। पिछले 12 वर्षों के दौरान (2010-2022), 31 दिसंबर 2022 तक जम्मू-कश्मीर में कुल 2863 प्रचंड मौसम की घटनाएं हुई जिनसे 552 मौतें हुई। विभिन्न प्रचंड मौसम की घटनाओं में, तड़ित (1942) और भारी वर्षा (409) की घटनाएं अधिक बार हुई। जब हम प्रति घटना मृत्यु दर की तुलना करते हैं, तो भारी हिमपात किसी भी अन्य प्रचंड मौसम की घटनाओं की तुलना में अधिक विनाशकारी था। अन्य प्रचंड घटनाओं की तुलना में भारी हिमपात के कारण प्रति घटना मृत्यु दर सबसे अधिक (4.33) थी, हालांकि भारी वर्षा (409), अचानक बाढ़ (168) और तड़ित (1942) की तुलना में भारी हिमपात की घटनाओं की संख्या कम (42) है। प्रचंड मौसम की घटनाओं के जिलावार नतीजों से पता चलता है कि भारी हिमपात के कारण सबसे ज्यादा मौतें कुपवाड़ा, बांदीपोरा, बारामूला और गांदरबल में हुई। इसी तरह अचानक बाढ़ से किश्तवाड़, अनंतनाग, गांदरबल और डोडा में सबसे ज्यादा मौतें हुई। पियर्सन सहसंबंध परिणामों से पता चलता है कि भारी वर्षा (0.77) और भारी हिमपात (0.69) (P मान P<0.01 पर महत्वपूर्ण) और उसके बाद अचानक बाढ़ (0.492) (P मान P 0.05 पर महत्वपूर्ण) के लिए कुल मौतों का उच्चतम सहसंबंध है। भारी हिमपात और तूफान (0.584) (P मान P <0.05 पर महत्वपूर्ण) के बीच नकारात्मक सहसंबंध परिणाम देखा गया। वर्तमान अध्ययन से पता चलता है कि, समग्र रूप से केंद्र शासित प्रदेश के लिए, भारी वर्षा और भारी हिमपात मृत्यु दर का कारण बनने वाली दो प्रमुख आपदाएं रही हैं, हालांकि अचानक बाढ़, गर्ज के साथ तूफान और तूफानों को महत्व दिया जा रहा है। प्रवृत्ति विश्लेषण परिणामों से यह भी पता चलता है कि पिछले कुछ वर्षों में विशेष रूप से अचानक बाढ़ (R^2 मूल्य 0.434) और तूफान (R^2 मूल्य 0.371) के कारणमृत्यु दर में उल्लेखनीय वृद्धि हुई है।

ABSTRACT. A study has been conducted on Extreme Weather Events (EWEs) induced mortalities in Jammu and Kashmir, India during 2010-2022. In the present study, we used the frequency of heavy rain, heavy snow, lightning/thunderstorm, Hailstorm and squall during the period 2010 to 2022 of 10 stations of J&K from India Meteorological Department. The mortalities occurred due to these extreme weather events for each district were collected from the Meteorological Centre Srinagar. The mean monthly precipitation and number of rainy days for each month was calculated for each station based on 40 years data (1982 to 2022). During the past 12 years, (2010-2022) a total of 2863 EWEs occurred over J&K in which 552 deaths occurred till 31st December 2022. Among the various EWEs, lightning (1942) and heavy rainfall (409) events were more frequent. When we compare the mortality per event, the heavy snow was more destructive compared to any other EWEs. The mortality per event due to heavy snow was highest (4.33) as compared to other extreme events, although the number of events of heavy snow is less (42) as compared to heavy rain (409), flash floods (168) and lightning (1942). District wise results of EWEs results revealed the highest deaths due to heavy snow were observed over Kupwara, Bandipora, Baramulla and Ganderbal. Similarly for flash floods, the highest deaths were observed over Kishtwar, Anantnag, Ganderbaland Doda. The Pearson correlation results revealed highest correlation of total deaths for heavy rain (0.77) and heavy snow (0.69) (significant at p value $p<0.01$) followed by flash floods (0.492) (significant at p value $p<0.05$). Negative correlation result was observed between heavy snow and windstorm (0.584) (significant at p value $p<0.05$). The present study has shown that, for the union territory as a whole, the heavy rain and heavy snow have been two major disasters causing mortality, though flashfloods, thunderstorms and windstorms are gaining importance. The trend analysis results also revealed that there is a significant increase in mortality over the years particularly due to flash floods (R^2 value 0.434) and windstorm (R^2 value 0.371).

Key words – Extreme weather events, Heavy rain, Thunderstorm/lightning and disaster management.

1. Introduction

The frequency of Extreme weather Events (EWEs), such as heavy rains/flash floods, heat waves, cold waves, tropical cyclones, floods and thunderstorms has increased in recent decades. These events have affected the entire world, including the Indian subcontinent resulted in the loss of life, property, and other assets (Bjerge and Trifkovic, 2018; Mahapatra *et al*., 2018; Murari *et al*., 2015). Annual EWEs increased by 18% from 2007 to 2016 compared to the previous decade (1997-2006) (Ray *et al*., 2019a). Goswami *et al*., (2006) has shown a significant rising trend in the frequency and magnitude of extreme rain events (EREs) over central India during 1951-2000. To effectively track such events, accurate and timely monitoring and forecasting of heavy rains, tropical cyclones, thunderstorms, hailstorms, cloudburst, drought, heat and cold waves, *etc*. is highly vital. Before going into the impact details of such events, one has to know the basic definitions of each of these events.

Extreme weather Events (EWE's) : The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. In many cases, a weather or climate event with high impact is also deemed as extreme event.

(*i*) *Heavy Rain* : If a station receives 64.5-115.5 mm of rain in 24 hours. The precipitation is referred to as heavy rain.

(*ii*) *Heavy Snow* : If a station receives >30 cm of snowfall in a 24-hour period. The snowfall is referred to as heavy snow.

(*iii*) *Cloud burst* : If a location or station receives 10 cm of rain in 1 hour. The relatively tiny scale in space and time makes cloud bursts particularly challenging to anticipate. Cloud bursts do happen on plains, but due to orography, they tend to happen more frequently in mountainous and hilly areas.

(*iv*) *Thunderstorm/Lightning* : A thunderstorm, often referred to as an electrical storm or a lightning storm, is a type of storm that is defined by the presence of lightning and the audible sound of thunder that is produced when lightning strikes the Earth's atmosphere. Thundershowers are the name for relatively weak thunderstorms. A cumulonimbus is a form of cloud where thunderstorms develop. Strong winds are typically present along with them, and heavy rain, snow, sleet, or hail is frequently produced. Nevertheless, some thunderstorms result in little to no precipitation at all. A squall line, often known as a succession of thunderstorms, can form or become a rainband.

(*v*) *Hailstorm* : Solid precipitation in the form of ice balls with sizes of 5 to 50 mm or even larger.

(*vi*) *Squall* : Squally weather refers to persistent types of high gusty winds (mean wind speed not less than 20 knots) accompanied by rain or sometimes occurring or frequent squalls with rain. Such circumstances are related to low pressure systems or the beginning and intensification of the monsoon.

(*vii*) *Heat wave* : Heat wave need not be considered, normally till maximum temperature of a station reaches at least 40 ºC for Plains and at least 30 ºC for Hilly regions.

(*a*) Based on departure from Normal

Heat Wave : Departure from normal is 4.5 °C to 6.4 °C

Severe Heat Wave : Departure from normal is > 6.4 °C

(*b*) Based on actual maximum temperature

Heat Wave : If the actual maximum temperature of a station reaches ≥ 45 °C.

Severe Heat Wave : If the actual maximum temperature of a station reaches ≥ 47 °C.

(*viii*) *Cold wave* : Minimum temperature of a station reaches at least ≤ 10 °C for Plains and ≤ 0 °C for Hilly regions.

(*a*) *Based on departure from Normal*

Cold Wave : Departure from normal is -4.5 °C to -6.4 °C

Severe Cold Wave : Departure from normal is > - 6.4 °C

(*b*) *Based on actual minimum temp (plains)*

Cold Wave : If the actual minimum temperature of a station reaches ≤ 4.5 °C

Severe cold Wave : If the actual minimum temperature of a station reaches ≤ 2.0 °C

De *et al.*, in 2005 has compiled the Extreme Weather Events over India in the last 100 years. Singh *et al.*, in 2005 studied Spatio-Temporal Distribution of Extreme Weather Events in India. The main conclusions of the study are that the state of Maharashtra experiences Flooding, hailstorms, and lighting most frequently. The frequency of cold waves is highest in Bihar. The state of Andhra Pradesh experiences the most cyclone landfalls. The Uttar Pradesh has the most frequent dust storms. The state of Rajasthan experiences the highest frequency of heatwaves. In Assam, the frequency of squalls is at all-time high. In West Bengal, thunderstorms are most frequent. The greatest incidence rates are not always found in the highest mortality rates. For instance, while Orissa leads in cyclone fatalities, AP leads in cyclone occurrences.

In 2019, an unusual increase in EWEs was observed. In the summer of 2019, 73 heat waves were recorded, compared to 17 in the normal year (average from 1986 to 2016). Rainfall was deficient up until the end of July during Monsoon Season 2019, and it was also very unevenly distributed, with many districts reporting deficient rainfall. Excessive precipitation during the second half of the 2019 Monsoon (August and September 2019) caused flooding in central India.

In Jammu and Kashmir, flash floods, cloudbursts, and unusually high temperatures have killed livestock, damaged infrastructure, and killed dozens of people, all of which are seen as manifestations of global warming and human-caused climate change. In both 2018 and 2019, the first week of November saw early snowfall. It caused widespread devastation in the horticulture industry. This was followed by cold winters in 2019 and 2020. The temperature dropped to -15 °C in the South Kashmir district of Shopian. The month of March, which is considered the wettest in terms of rainfall, was nearly 10 degrees warmer than previous years, resulting in early snow melt in alpine landscapes. Between May and July 2022, the region experienced its wettest months, which led to 12 flash floods in the environmentally sensitive Kashmir Valley, which resulted in the loss of life as well as damage to crops and other assets. 2022 has thus far been a year of extremes, from protracted dry spells to an abundance of rainfall.

Due to complex topography and altitude-dependent climate, mountain region is highly vulnerable to extreme rainfall events and cloudbursts. These abrupt and sudden sharp weather fluctuations can cause long term flood and short term floods as well as outbursts in the mountainous region (Nandargi and Dhar, 2011). Cloudbursts and associated flash floods are regular and frequent disasters in the Himalaya region (Thayyen *et al.*, 2013). Kedrnath disaster (June 2013), Rudraprayag cloudburst (September

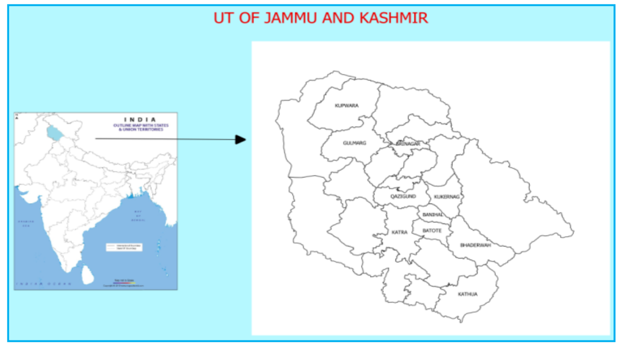


Fig. 1. Map of the study area and location of stations over Jammu & Kashmir

TABLE 1

Latitude and Longitude of the stations

Location of station	Coordinates		Altitude AMSL (m)
	Lat. (N)	Long. (E)	
Srinagar	34° 03′	74° 48′	1587
Qazigund	33° 35′	75° 09′	1690
Kokernag	33° 35′	75° 18′	1678
Kupwara	34° 01′	74° 15′	1609
Gulmarg	34° 03′	74° 23′	2650
Jammu	32° 55′	74° 52′	367
Katra	32° 58′	74° 55′	1170
Banihal	33° 25′	75° 11′	1477
Bhaderwah	32° 58′	75° 43′	1688
Batote	33° 06′	75° 49′	1452

TABLE 2

Mean monthly and Average annual Rainfall (mm) with number of Rainy days over different stations of Kashmir Division

Month	Srinagar		Kupwara		Qazigund		Pahlgam		Gulmarg	
	Rainfall	No. of Rainy days	Rainfall	No. of Rainy days	Rainfall	No. of Rainy days	Rainfall	No. of Rainy days	Rainfall	No. of Rainy days
January	53.9	4.9	92.5	7.4	143.2	7.3	120.3	7.9	158.2	8.4
February	81.9	5.9	128.3	9.4	172.7	8.4	139.2	8.9	223.5	10.8
March	117.6	7.9	190.9	10.4	192.4	9.3	198.0	10.9	251.7	12.2
April	90.8	6.9	151.4	9.2	115.8	7.9	141.6	9.9	168.6	11.0
May	71.0	6.2	95.8	7.3	106.4	7.9	129.9	9.9	153.3	10.9
June	42.0	3.9	54.3	4.7	69.7	5.4	88.0	8.5	103.7	8.7
July	68.9	5.2	90.9	6.3	115.2	7.1	109.1	9.0	110.8	9.4
August	61.2	5.5	72.2	5.2	91.1	5.7	109.8	9.0	93.0	8.0
September	29.0	2.6	34.8	2.9	62.5	3.6	81.4	6.5	62.4	5.5
October	27.8	2.0	43.6	3.1	42.2	2.7	46.2	3.7	50.3	3.6
November	28.7	2.0	45.8	3.2	44.9	2.5	42.9	2.9	55.7	3.4
December	46.0	3.2	68.6	4.9	79.1	4.6	75.1	4.9	103.8	5.3
Annual	**721.8**	**56.3**	**1069**	**74.2**	**1235**	**72.5**	**1281.5**	**91.9**	**1535.0**	**97.5**
Standard Deviation	27.77	1.94	47.34	2.59	47.98	2.30	43.76	2.59	64.59	3.01
Standard Error	8.02	0.56	13.67	0.75	13.85	0.66	12.63	0.75	18.64	0.87

2012), Manali cloudburst (July 2011), Leh cloud burst and floods of Kashmir 2014 are a few of the major cloudburst events notable for causing great damage to human lives and infrastructure.

According to a study by Ugnar *et al*., 1999, losses from extreme weather events are rapidly rising, especially in the last decade of the twentieth century. However, the increased losses could be the result of either an increase in the frequency of extreme weather events or the greater susceptibility of cities, towns, and the accompanying infrastructure and installations that have expanded rapidly to meet the demands of a growing population.

In the past, few studies were conducted to examine the trends of EWEs-related mortalities in Jammu and Kashmir, and many of these studies dealt with only one type of extreme weather event.It is thus necessary to study and explore all major types of EWEs over the last 10 to 15 years in order to develop better disaster management programmes and policy planning. Keeping in mind the increased frequency of EWEs and mortality as a result of these events, these events must be thoroughly investigated.

2. Study area and data collection

The study was conducted for union territory of J&K, both at the UT level and district level (20 districts). Each district faces distinct EWEs due to its geography. In the present study, we used the frequency of heavy rain, heavy snow, lightning & thunderstorms, Hailstorm and squall during the period 2010 to 2022 of 10 stations of J&K from the India Meteorological Department (Fig. 1 & Table 1). The weather data of other stations is not available as no observatory is there. The mortalities occurred due to these extreme weather events for each district were collected from the Meteorological Centre Srinagar. The data on mortality for each Extreme Weather Event is compiled after the information shared by Govt. officials on Newspapers, Press releases, electronic and social media.

3. Data analysis

For the above study, 12 years data of extreme weather events and mortality data were used for entire Jammu and Kashmir. Deaths due to different extreme weather events and deaths for different districts due to EWEs were plotted on Microsoft excel sheet. Pearson

TABLE 3

Mean monthly and Average annual Rainfall (mm) with number of Rainy days over different stations of Jammu Division

Month	Jammu		Katra		Banihal		Batote		Baderwah	
	Rainfall	No. of Rainy days	Rainfall	No. of Rainy days	Rainfall	No. of Rainy days	Rainfall	No. of Rainy days	Rainfall	No. of Rainy days
January	62.2	3.3	110.3	4.9	175.1	7.0	176.8	6.6	125.3	6.8
February	71.2	4.1	131.2	5.7	226.8	8.6	226.8	8.5	170.9	8.5
March	68.0	4.1	141.7	6.7	243.3	9.8	227.2	8.9	171.5	8.6
April	42.7	2.9	75.0	4.4	123.7	7.4	129.3	7.2	123.8	7.6
May	27.0	2.9	61.3	4.4	94.9	7.2	103.2	7.2	94.1	7.4
June	96.5	5.9	137.2	7.2	45.7	4.3	91.4	6.8	74.8	7.1
July	416.9	12.7	589.6	17.1	93.4	6.6	179.6	10.0	141.0	9.8
August	353.0	11.9	635.1	17.3	97.7	6.1	149.1	9.2	121.0	9.3
September	137.4	5.8	199.6	8.1	67.3	3.8	98.0	4.8	92.2	4.9
October	22.6	1.6	35.2	5.4	40.9	2.4	40.9	2.9	38.8	2.6
November	8.5	0.8	23.4	1.6	50.5	2.6	45.5	2.3	36.9	2.4
December	32.7	2.0	58.7	2.8	96.9	4.7	95.8	4.4	72.5	3.9
Annual	**1338.6**	**58.1**	**2198.3**	**82.7**	**1350.1**	**70.5**	**1562.2**	**78.7**	**1262.6**	**78.5**
Standard Deviation	133.15	3.81	206.93	5.03	67.98	2.33	62.75	2.49	45.08	2.54
Standard Error	38.44	1.10	59.73	1.45	19.62	0.67	18.11	0.72	13.01	0.73

Correlation was carried out using SPSS software. Simple excel was used to see the trends over different years for individual Extreme Weather Event. Spatial comparison between the districts for frequency of different EWEs was also carried out by generating a GIS (Geographic Information System) map using ESRI ArcGIS software.

4. Results and discussion

The mean monthly precipitation and number of rainy days for each month was calculated for each station based on 40 years data (1982 to 2022). The results revealed highest standard deviation (SD 206.93) for Katra and the least for Srinagar (SD 27.77) station. The highest standard deviation for Katra is due to the fact that the area is influenced by both Western disturbances (WD) during winter and SW Monsoon during the Monsoon Period. Moreover the mean rainfall of different months for Katra station is highly erratic with a maximum value of 635.7 mm in the month of August and a minimum value of 23.4 mm in the month of November. Stations, *viz*., Srinagar, Kupwara, Gulmarg, Qazigund and Pahlgam is mainly affected by Western disturbances during November to April while the stations Jammu, Katra, Banihal, Batote and Baderwah are mainly affected by the South West Monsoon. Similarly, the mean number of rainy days was highest for Gulmarg (97.5) and Pahlgam (91.9) and lowest for Srinagar (56.3) and Jammu (58.1) with SD values 3.01, 2.59, 1.94 and 3.81 respectively. (Tables 2&3). A rainy day has been differentiated as a day with rainfall of ≥ 2.5 mm**.** Similar results were observed by Dimri *et al*., 2015 and Bhutiyani *et al*., 2016 were they found that winter climate of north-western Himalaya is determined largely by Mid-latitude westerlies (western disturbances) from October to May) and by Indian Summer Monsoon (ISM) from June to September. Similar results were reported by Ahmed *et al*., 2022 were they found the significant influence of western disturbances over stations of Kashmir division as compared to stations of Jammu division during November to April.

The results of Innovative trend analysis showed highest reduction in Precipitation during the month of March for all the stations. The decline was highest in Kupwara (slope value -4.116) followed by Qazigund (-3.160). Similar declining trends were also observed for

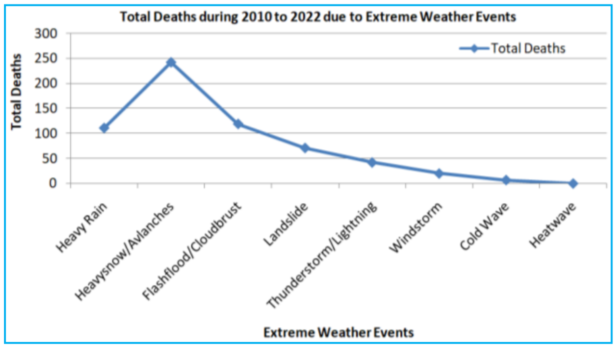


Fig. 2. Deaths due to different EWEs in Jammu & Kashmir

TABLE 4

Precipitation trends for different months and Seasons of stations using Innovative trend analysis (JF- January and February-Winter Season), (MAM- March, April and May-Pre-Monsoon Season), (JJAS- June, July, August and September-Monsoon Season), (OND- October, November and December-Post-Monsoon Season)

	Srinagar	Qazigund	Kupwara	Jammu	Katra	Baderwah
Months/Seasons	Trend Slope	Trend Slope	Trend Slope	Trend Slope	Trend Slope	Trend Slope
January	**0.638***	-0.073	0.354	-0.157	**-0.917***	**-0.737***
February	**1.040***	-0.043	**1.958***	**-0.752***	**-0.648***	**1.058***
March	**-1.568***	**-3.160***	**-4.116***	**0.548***	-0.364	**-1.941***
April	**-0.288***	-0.300	**-1.038***	**-0.498***	**-1.669***	**-1.296***
May	**-0.941***	**-2.221***	**-0.813***	**-0.671***	0.092	**-1.671***
June	-0.061	0.189	-0.006	**1.724***	**3.379***	**1.120***
July	0.246	**-1.936***	**-0.684***	**-2.032***	**-6.686***	-0.555
August	**-0.406***	**-1.468***	**-1.019***	1.198	**-2.024***	-0.718
September	**1.183***	**1.878***	-0.022	0.035	0.192	-0.049
October	**-0.808***	**-1.025***	**-0.539***	**0.221***	**-0.167***	**-0.709***
November	-0.066	**-0.461***	**0.379***	**-0.288***	**-0.517***	**-0.727***
December	**-1.978***	**-1.764***	**-1.764***	**-0.871***	**-1.795***	**-1.532***
JF	**0.839***	-0.058	**1.156***	**-0.454***	**-0.783***	0.160
MAM	**-0.932***	**-1.894***	**-1.989***	-0.207	**-0.647***	**-1.636***
JJAS	**0.241***	-0.334	**-0.433***	0.231	**-1.285***	-0.050
OND	**-0.951***	**-1.083***	**-0.641***	**-0.313***	**-0.827***	**-0.989***
Annual	**-0.251***	**-0.865***	**-0.609***	-0.129	**-0.927***	**-0.646***

* Significant at the 0.05 level (2-tailed), ** Significant at the 0.01 level (2-tailed).

TABLE 5 (a)

Total mortality caused by various extreme weather events (EWEs) during 2010-2022

Category	No. of events	Share % of each event	Mortalities (Number)	Share % of each event	Mortality Per event
Heavy Rain	409	14.3	111	20.10	0.27
Heavy Snow	42	1.47	182	32.97	4.33
Flash floods	168	5.90	119	21.55	0.70
Lightning	1942	67.83	42	7.60	0.021
Windstorm	31	1.08	20	3.62	0.64
Landslides	186	6.5	71	12.86	0.38
Heat wave	48	1.67	0	0.0	0
Cold wave	37	1.3	7	1.26	0.18
Total	2863	100	552	100	0.19

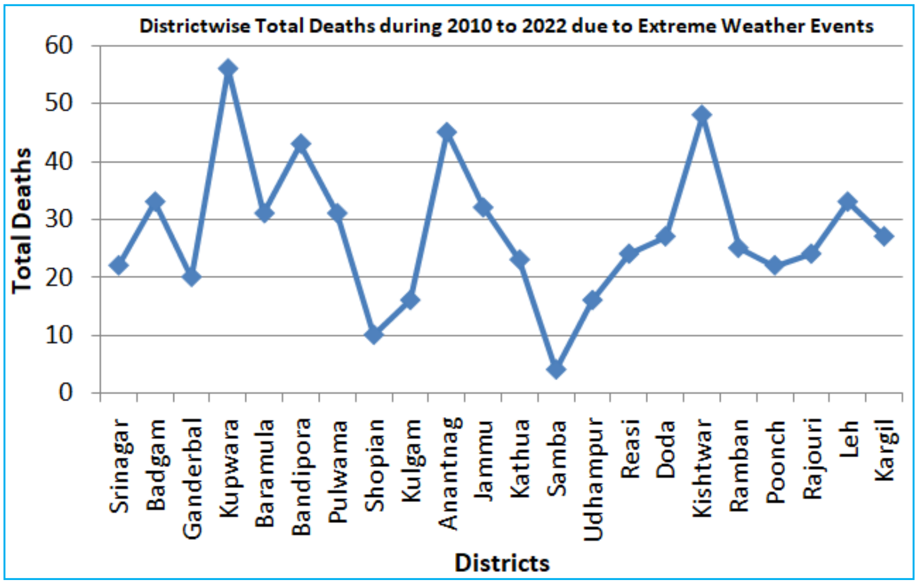


Fig. 3. Deaths due to different EWEs over different districts of Jammu & Kashmir

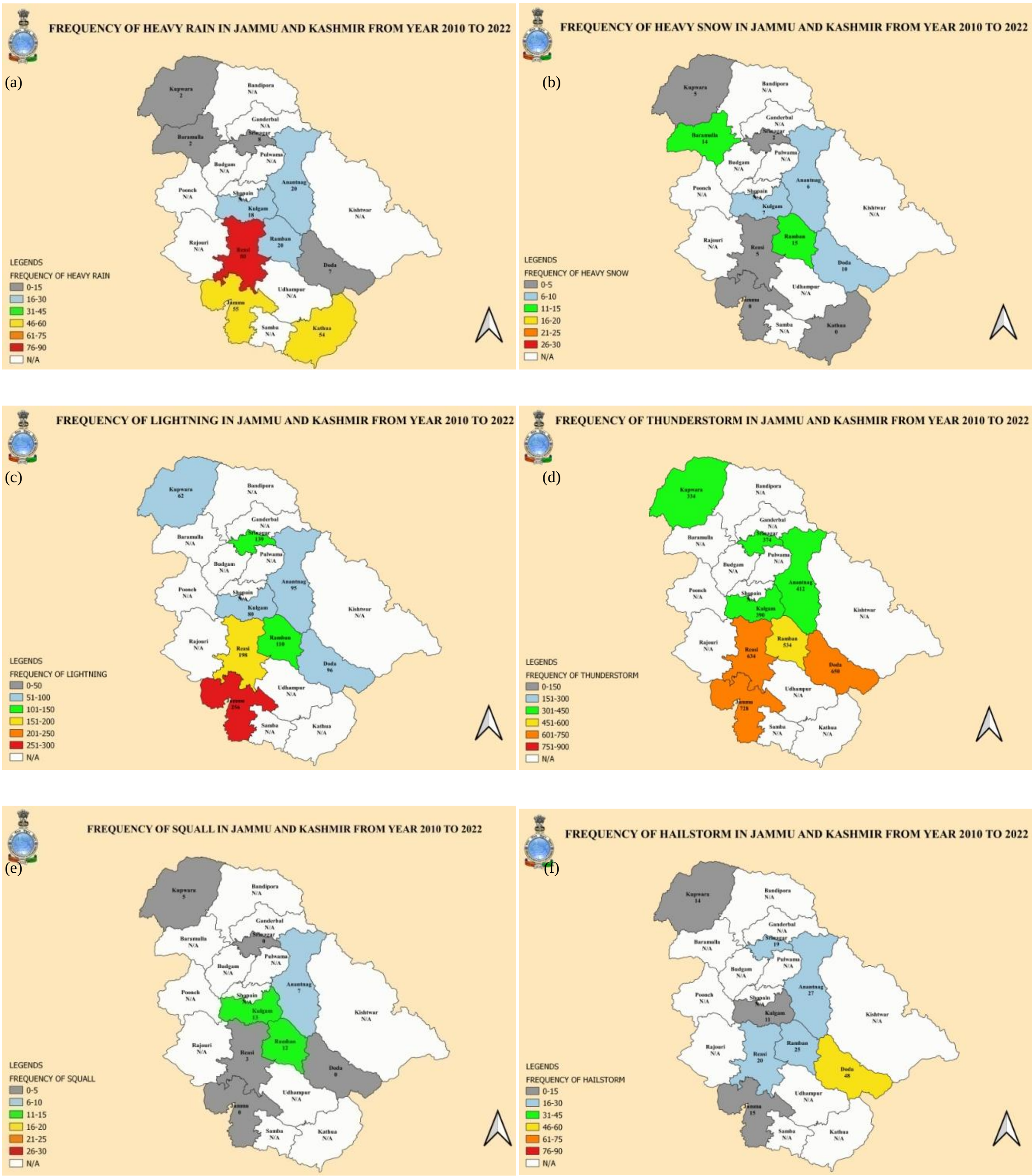
TABLE 5 (b)

Total Mortality wise in different districts in descending order for each extreme weather event during 2010-2022

Extreme weather Events (EWE)	Districts (arranged mortality wise, in descending order)
Heavy Rain	Jammu, Srinagar, Anantnag, Kathua
Heavy Snow	Kupwara, Bandipora, Baramulla, Ganderbal
Flash floods	Kishtwar, Anantnag, Ganderbal, Doda
Thunderstorm/Lightning	Rajouri, Kathua, Badgam, Ramban
Windstorm	Kulgam, Pulwama, Kupwara, Bandipora
Landslides	Doda, Ramban, Poonch, Badgam
Heat wave	Nil
Cold wave	Baramulla, Anantnag, Kathua

Jammu and Katra station in July month with significantly decreasing trends with slope value -2.032 and -6.680 mm/year respectively. There is marginal rise in Precipitation trends during the month of September for Srinagar and Qazigund. The seasonal analysis showed significantly decreasing trends with p value < 0.05 for all the stations during Pre Monsoon (March, April and May) and Post Monsoon (October, November and December) season. The annual Precipitation trend analysis also showed decreasing significant trends for all the stations. (Table 4). Bhutiyani *et al*. (2010) also studied precipitation trends in the northwest Himalayas and did not found any trends in precipitation during the winter season. Decreasing trends in monsoon and winter rainy days over all the stations were also observed by Kumar and Jain in 2010. Decreasing trends in winter precipitation were also observed by Kumar and Jain, 2010; Dimri and Dash, 2012.

During the past 12 years, (2010-2022) a total of 2863 extreme weather events occurred over J&K in which 552 deaths were observedtill 31st December 2022. Among the various extreme weather events, lightning (1942) and heavy rainfall (409) events were more frequent. When we compare the mortality per event, the heavy snow was more destructive compared to any other EWEs. The mortality per event due to heavy snow was highest (4.33) as compared to other extreme events, although the number of events of heavy snow was less (42) as compared to heavy rain (409), flash floods (168) and lightning (1942). Similarly 31 windstorm events caused 20 deaths, followed by landslides (71 deaths) and flash floods (119 deaths) for



Figs. 4(a-f). Frequency of different Extreme weather events over different districts of Jammu and Kashmir during 2010-2022. A-Heavy Rain, B- Heavy Snow, C-Lightning Flash floods, D-Thunderstorm, E–Windstorm, F-Hailstorm

186 and 168 events respectively. District wise results of EWEs results revealed the highest deaths due to heavy snow occurred in Kupwara, Bandipora, Baramulla and Ganderbal. Similarly for flash floods, highest deaths were occurred over Kishtwar, Anantnag, Ganderbal and Doda.

District wise mortality data over the study area revealed the highest deaths over Kupwara (56), Anantnag (45) and Bandipora (42) over Kashmir Division and Kishtwar (48) and Jammu (33) over Jammu Division [Fig. 3 & Tables 5(a&b)]. The highest mortality over

TABLE 6

Correlation study between Total deaths and different extreme weather event during 2010-2022

	Total Deaths	Heavy Rain	Heavy Snow	Flash flood	Landslide	Thunder-storm	Windstorm	Cold wave
Total Deaths	1	**0.77******	**0.690******	**0.492***	0.266	0.108	0.352	0.167
Heavy Rain		1	0.371	**0.440***	0.352	0.223	0.121	0.221
Heavy Snow			1	-0.019	-0.210	-0.368	**-0.584***	0.021
Flash flood				1	0.605	0.216	-0.285	-0.160
Landslide					1	0.356	-0.178	-0.260
Thunderstorm						1	-0.362	-0.209
Windstorm							1	-0.158
Cold wave								1

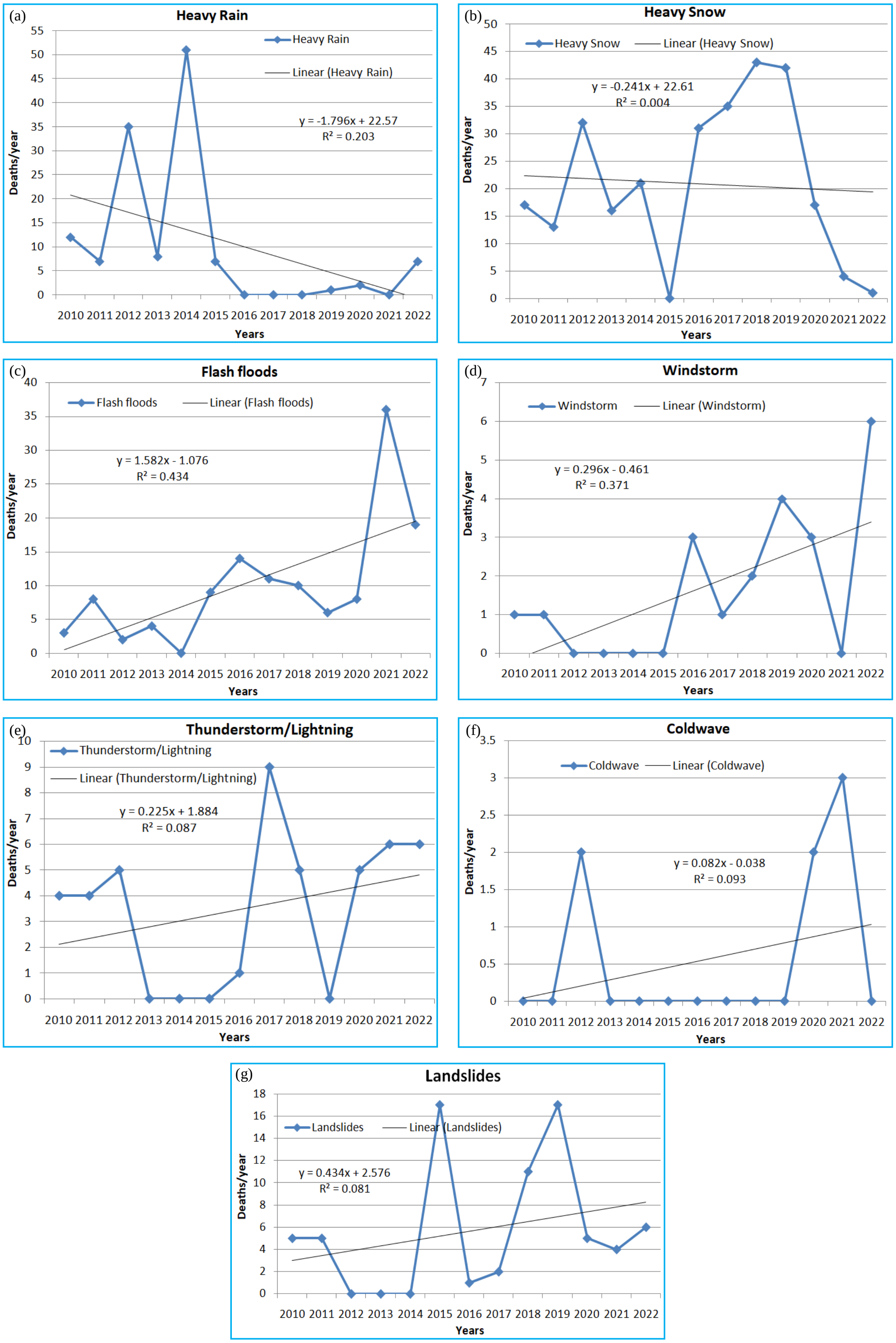
* Correlation is significant at the 0.05 level (2-tailed),
** Correlation is significant at the 0.01 level (2-tailed)

Kupwara and Bandipora district is due to heavy snow/Snow avalanches over extreme higher reaches of the North and Northwestern parts namely Machil, Karnah, Keran, Gurez and Tulail sector. Cloud bursts during the monsoon season, which coincides with Shri Amarnath Ji Yatra, causes more deaths in Anantnag. The high yatr is flow and cloud burst events during monsoon period eventually shoots up the total mortality over Anantnag District as compared to others districts. Due to cloud bursts and landslides, Kishtwar district has significant death rates. Every year, one or two cloud bursts occur during the monsoon season.The deaths over Jammu district is mainly due to flash floods, Landslides and collapsing of Kachha houses. The results also revealed the lowest mortality in Samba district (4).

The frequency of various Extreme Weather Events like heavy rain, heavy snow, cloud bursts, Thunderstorm and lightning, Squall and Hailstorm was also studied and the range of frequencies were used to depict each extreme weather event. The results of frequencies of heavy rainfall revealed the highest frequency for Reasi followed by Jammu and Kathua district. Similarly the highest frequency of thunderstorm and lightning was shown by Jammu, Reasi, Doda and Ramban dist. The highest frequency of heavy snow was observed over Ramban, Baramulla and Kupwara. Similarly the highest frequencyof hailstorm was observed over Doda, Ramban, Anantnag and Srinagar [Figs. 4 (a-f)].

Correlation studies have been done between different Extreme weather events observed over all the stations and No. of Deaths due to each event during 12 years of study using Pearson correlation. The results of the Pearson correlation revealedthat, total deaths are positively correlated with all the extreme weather events, *viz*., heavy rain, heavy snow, flash floods, landslides, thunderstorm, windstorm and cold wave. The Pearson correlation results revealed the highest correlation of total deaths for heavy rain (0.77) and heavy snow (0.69) (significant at p value $p<0.01$) followed by flash floods (0.492) (significant at p value $p<0.05$). (Table 6). Other extreme weather events indicated anon-significant positive association. Heavy snow and windstorm correlated negatively (0.584) ($p<0.05$). Heavy snow also correlated negatively with thunderstorms, landslides, *etc*. (Table 6)

The present study has shown that, for the union territory as a whole, heavy rain and heavy snow have been two major disasters causing mortality, though flash floods, thunderstorms and wind storm are gaining importance. The decreased deaths due to heavy rain and snow are mainly attributed due to better early warning and weather forecasts. [Figs. 5(a-g) & 6, 7]. Many authors have also found similar results and attributed this to better disaster management, better early warning and weather forecasts (MHA, 2011; Mahapatra *et al*., 2018; Mohanty *et al*., 2015). Due to terrain and the sensitivity of hilly residents, weather extremes affect J&K differently. Local nomads, especially the Gujars and Bakerwal tribes, in middle and higher reaches are more susceptible to flash floods, thunderstorms and landslides than those in plains and lower topography. In the case of flash floods, thunderstorm/lightning and landslides, the mortality rates have significantly increased in the last few years as compared to earlier period.Similar resultswere also observed by Kamaljit *et al*., 2021 and Mahapatra *et al*.,



Figs. 5(a-g). Trend analysis of different Extreme weather events in Jammu and Kashmir during 2010-2022. A-Heavy Rain, B- Heavy Snow, C-Flash floods, D-Windstorm, E-Thunderstorm/Lightning, F-Cold wave, G- Landslides

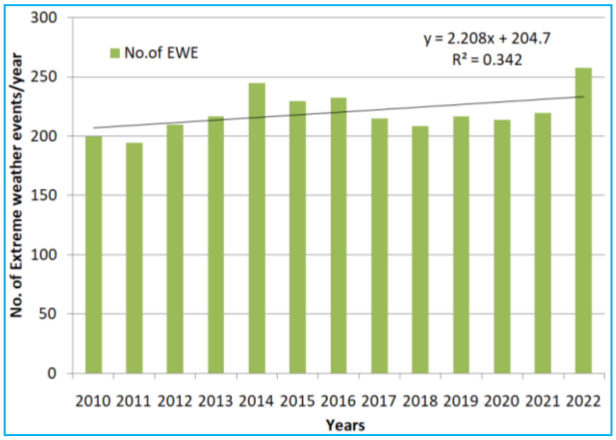


Fig. 6. Trend analysis of the number of Extreme weather events over Jammu and Kashmir during 2010-2022

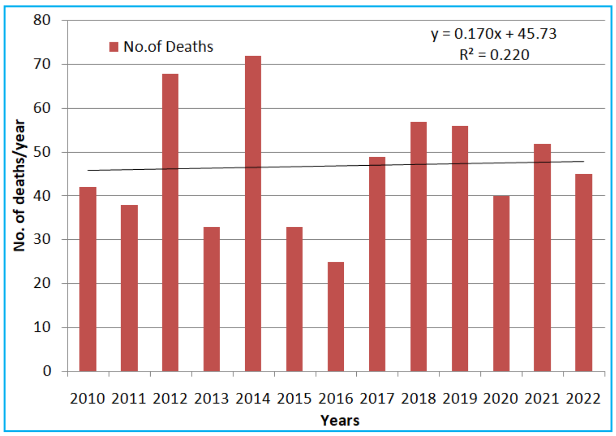


Fig. 7. Trend analysis of the number of deaths due to Extreme weather events over Jammu and Kashmir during 2010-2022

2018, in which they studied mortality due to extreme weather events in India. They have shown that mortalities due to extreme rainfall and tropical cyclones have declined over time, whereas mortalities increased due to lightning and extreme temperatures.

5. Conclusions

The following conclusions were drawn from the above study.

(*i*) During the past 12 years, (2010-2022) a total of 2863 EWEs occurred over J&K in which 552 deaths occurred till ending 2022. Among the various EWEs, lightning (1942) and heavy rainfall (409) events were more frequent.

(*ii*) When we compare the mortality per event, the heavy snow was more destructive compared to any other EWEs. The mortality per event due to heavy snow was highest (4.33) as compared to other extreme events, although the number of events of heavy snow is less (42) as compared to heavy rain (409), flash floods (168) and lightning (1942).

(*iii*) District wise results of EWEs results revealed the highest deaths due to heavy snow occurred over Kupwara, Bandipora, Baramulla and Ganderbal. Flash floods killed most in Kishtwar, Anantnag, Ganderbal and Doda.

(*iv*) The Pearson correlation results revealed the highest correlation of total deaths for heavy rain (0.77) and heavy snow (0.69) (significant at p value $p<0.01$) followed by flash floods (0.492) (significant at p value $p<0.05$). Negative correlation was showed between heavy snow and windstorm (0.584) (significant at p value $p<0.05$).

(v) The present study has shown that, for the union territory as a whole, heavy rain and heavy snow have been two major disasters causing mortality, though flashfloods, thunderstorm and windstorms are gaining importance.

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