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Spatio-temporal Analysis of Multi-Hazard in Pokhara Metropolitan City, Nepal

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Abstract

In the recent decade, rapid urbanization and population growth at an alarming rate in Pokhara Metropolitan City have exposed it to multiple hazards. Multi-hazards study addressed several hazards, and identifying risk became essential for urban planning and preparedness. This study examined the spatial and temporal trends of multi-hazards (urban fire, flood, landslides, forest fire, and earthquake) incidents between 2018 to 2024, in ward-wise, monthly, and seasonal terms through a quantitative approach using ArcGIS for hotspots, R language for trend visualizations, and Chi-Square to measure significance in PMC. The findings reveal fire-related incidents dominating, while earth and water-related hazards are slightly lower. Spatial mapping highlights wards (17,6, 18, 24, 25) located in the northwestern region highly concentrated hazard zones. Temporal analysis indicates, April and July months peaked the incident counts, and the spring season, with moderate correlation (R^2=0.4189), generates more incidents. Chi-square (X^2 = 59.15, df = 18, α = 0.05) confirms the significance of season in the frequency of hazards. Overall, hazards distribution within PMC is uneven across wards, indicating a temporal pattern for incident occurrences. The findings offer insights for local government and stakeholders for interventions on focusing preparedness and hazard analysis.

Keywords: *Urban fire, Landslide, Chi-Square, Quaternary, GIS-mapping, Heat map*

Introduction

Mountainous regions worldwide suffer from various hazards, amplified by a growing population, rapid urbanization, and climate change (Khatakho et al., 2021; Poudel, 2025). Recent studies have highlighted the rise in human and economic loss contributed by weather-related activities driven by population growth, particularly in developing countries, resulting in heavy economic damages (Bouwer 2010; Independent Evaluation Group, 2006; Poudel, 2021). Similarly, the Asian region experienced multi-hazard incidents, accounting for 44% in the last 123 years (Lee et al., 2023).

Maplecroft's Climate Change Vulnerability Index has ranked Nepal in fourth position in terms of vulnerability (UNICEF Nepal, 2017). The fragile geology and mountainous topography with unexpected regional weather patterns increases possibility of multi-hazards in Nepal (Disaster Preparedness Network Nepal, 2022; MoHA, 2024). Between 2018 to 2024, approximately 32,375 minor and major disaster events like fire, earthquake, and landslides are recorded, claiming 3,672 people's lives, whereas 446 people went missing (MoHA, 2024). Nepal recorded 1,116 fire incidents, claiming 16 lives, 145 injuries, damaging properties and livestock losses, and causing losses over Rs. 499 million within the period of July 16 to 15 December, 2024 (The Kathmandu Post, 2025). Considering the above incidents, national policy on disaster has underperformed in terms of risk reduction, mostly affected by inadequate community engagement, lack of transparency and accountability, and weak inclusion of local-level governments (Gautam, 2024; Acharya et al., 2025).

The calcareous deposition formed during the late Quaternary period, monsoon climate, and Himalayan tectonics govern the valley and its surroundings to a possible disaster-prone area (Fort et al., 2018). A study on the 2012 flood in Pokhara, highlighted the future potential for glacier-lake outburst flood and landslides, urging necessity of an early-warning system in such hydrological and geomorphic conditions (Fischer et al., 2021; Fischer et al., 2022). Pokhara has experienced rapid urbanization and population growth at an alarming rate established in geo-environmentally fragile zones, for which illegal mining of gravel and unplanned construction boosting for hazards risks (Rimal et al., 2015; Poudel & Shrestha, 2025). Multi-hazard risk assessment is essential to overcome the limitations of single-hazard analysis (Liu et al., 2016). It provides an insight for urban planners, local governments, and stakeholders on the implementation of an early-warning system, updating disaster management planning, resource allocation, and resilience building.

Several studies addressed specific hazards like floods (Fischer et al., 2023; Fischer et al., 2022), seismic hazards (Baruwal et al., 2020; Schwanghart et al., 2015), and landslides (Gurung et al., 2021; Dhungana & Maharjan, 2023). Few attempts have been made to integrate the multi-hazards study, delineated within the Seti River watershed, largely occupied by the Pokhara valley (Rimal et al., 2015). Building on these insights, this study investigates multiple hazards such as urban fire, forest fire, landslides, floods, and earthquake risk in Pokhara Metropolitan City (PMC). It addresses the research gap through the documentation of recent incidents from 2018 to 2024. Therefore, the study analyzes the spatial-temporal trends of hazards from 2018 to 2024, and illustrates the spatial distribution of multiple hazards in Pokhara Metropolitan City (PMC).

Materials and methods

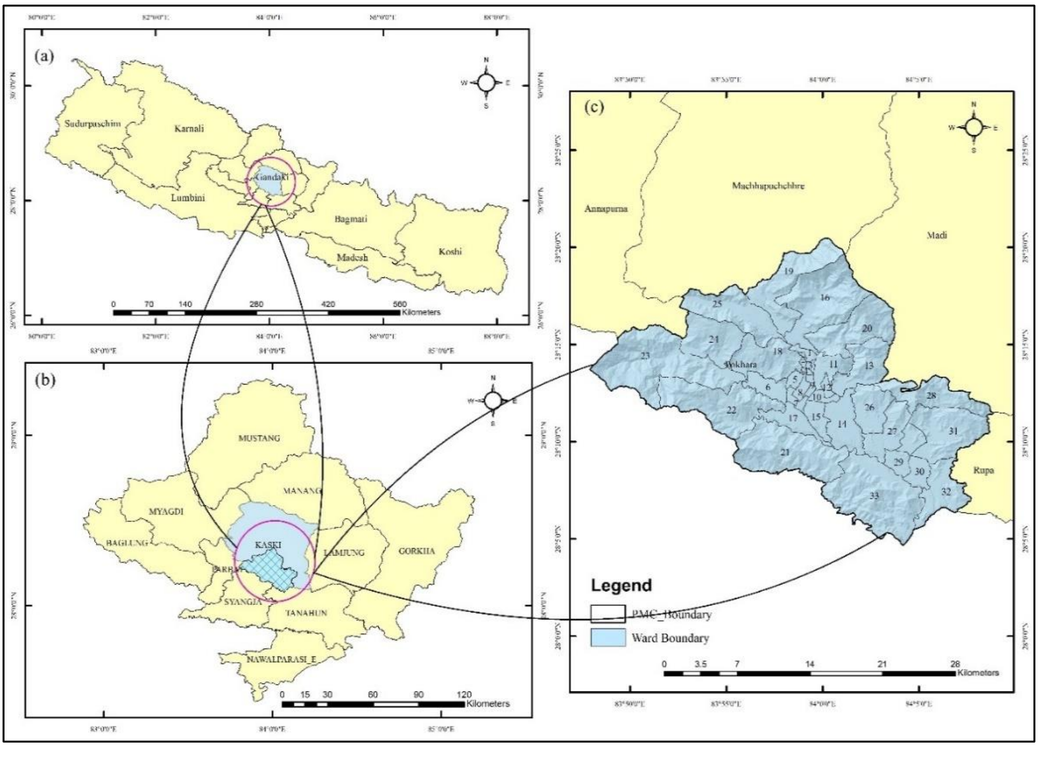
This study adopts a spatio-temporal quantitative approach fully based on secondary data available at the Nepal Disaster Risk Reduction Portal (http://www.drrportal.gov.np/). The data consists of five hazards that occurred within PMC, namely earthquake, forest fire, flood, landslides, and urban fire, selected in terms of impactful having high severity. Each incident was allocated to its respective wards before assessment.

Study area

Pokhara Metropolitan City (PMC) served as the study area (Figure 1). During the medieval period (1100, 1255, 1344 C.E.) in Nepal, three major earthquakes greater than 8 magnitudes causing huge landslides and debris flows filling the valleys with thick tens of meter layers of sediment, resulting into today's formation (Schwanghart et al., 2015). Pokhara Metropolitan City comprises an area of 464.24 km^2, allocated into 33 wards, in Kaski district, serving as the capital of Gandaki province. PMC ranges from a minimum altitude of 502 meters (Kotre) to a maximum altitude of 2651 meters (Armala), geographically expanded between 28°04″39.91′ N to 28°20″27.75′ North Latitude and 83°47″54.35′ E to 84°08″52.07′ East Longitude (Pokharel et al., 2025). As per NSO (2021), the population of PMC is 513,504 with a density of 1,106 people per square kilometers, predominate by age group of 20-24 (53,355).

Figure 1

Location map of study area (a) Map of Nepal with seven provinces (b) Gandaki province with 11 districts (c) Pokhara Metropolitan City (study area) with neighboring municipalities.

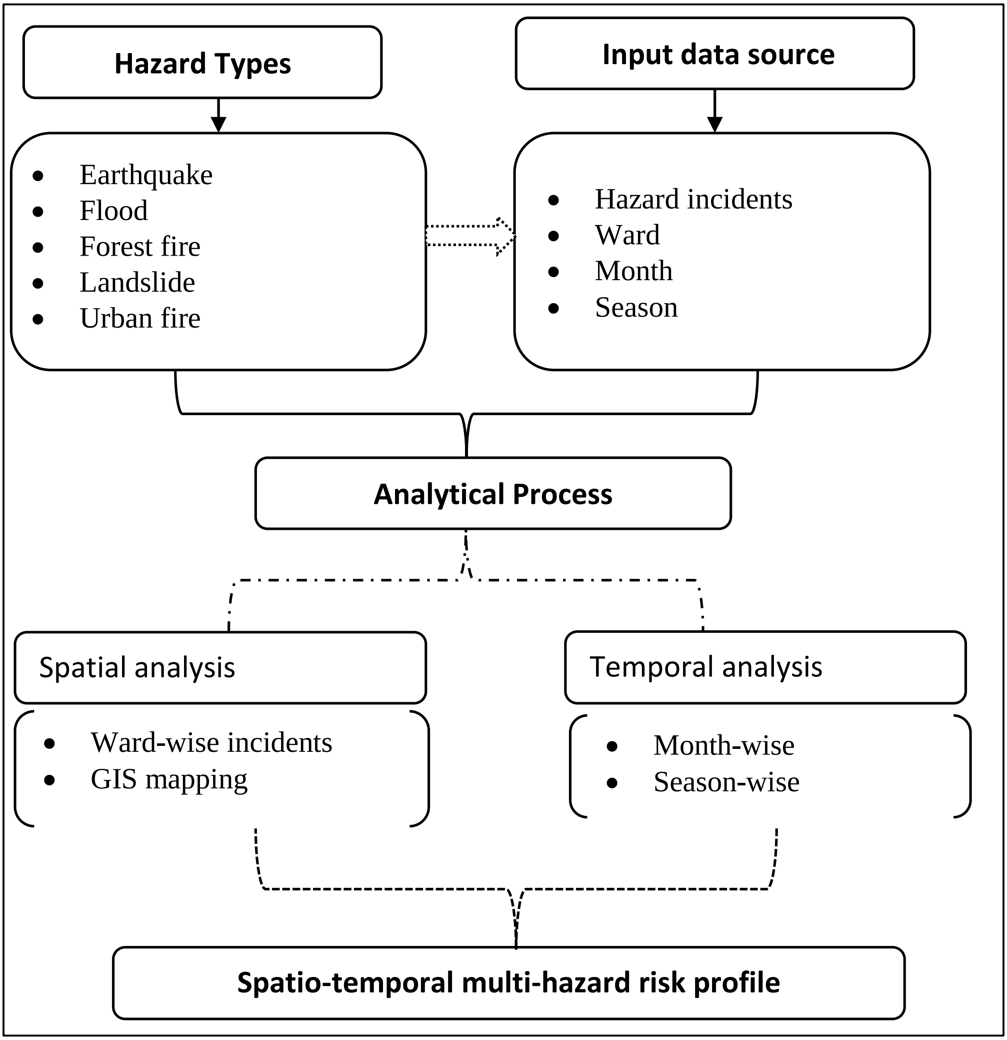


Study framework

This study framework (Figure 2) assesses the spatial and temporal hazard in PMC event took between 2018 to 2024. For study, five types of hazards, predominantly occurred having higher impact in PMC are selected, namely earthquake, forest fire, flood, landslides, and urban fire. Further, analyzed on the basis of municipal wards, monthly, and season wise, to profile the risk in PMC.

Figure 2

Conceptual framework of the study



Data analysis

The study analyzed multi-hazards (earthquake, forest fire, flood, landslides, and urban fire) of PMC by year, month, season, and municipal ward-wise. R language and Excel were used for the visualization and summarization of data. Grouping analysis (mapping clusters toolset) was performed in ArcGIS 10.4, identifying hotspots of hazards. A Chi-Square test with a 4 X 7 likelihood structure examined seasonal variation, examining the significance of hazards depending on season in PMC (2018-2024). Formula for Chi-Square test:

$$x^2 = \sum \frac{(0 - E)^2}{E}$$

Here, O = Observed value, and E = Expected value.

Similarly, $E = \frac{RT \times CT}{N}$

RT = Row total, and CT = Column total

degree of freedom (df) = (r - 1) (c - 1), setting the level of significance (α) at 0.05 (95% confidence level).

Results and discussion

Overview of hazards in PMC

The data recorded 453 incidents that took place between 2018 to 2024 in PMC, dominated by urban fire (294) as a major hazard, followed by landslides with 72 incidents, and forest fire contributing 61 incidents (Table 1). Flood occurred 24 times, and an earthquake appeared twice within these seven years. From the given data, it concludes severe dominance of fire- related hazards than water and earth related hazards comparatively lower frequency in PMC, indicating higher risk of fire related events.

Table 1

Number of hazards events took place between 2018-2024, PMC

Category	Incidents
Earthquake	2
Fire (Urban)	294
Flood	24
Forest fire	61
Landslide	72
Total	453

Source: DRR Portal Nepal (http://www.drrportal.gov.np/, 2025), compiled by Author.

Spatial distribution of hazard across wards of PMC

Spatial distribution of hazards shows an uneven concentration of incidents across PMC throughout period of seven years from 2018 to 2024 (Table 2). Total 37 incidents recorded in 2018 with ward-18 accounted higher (4). In next year (2019), incidents slightly decrease recording 34 incidents. After that, hazards in PMC increases till 2021, witnessing sharp downfall in number following next year recording 41 incidents. However, the rising trends start from 2023 to till. On average, ward-18 and 17 recorded higher incidents (4.3, and 3.9, respectively). Figure 3, provides the clear picturesque of concertation of hazards, red color indicating "Very High" clustering wards, orange with "High", light green with "Moderate", and dark green "Low". The results show northwest of PMC highly risk zones in term of hazards, whereas central commercial zones indicate low risk area of hazards assessed in the study.

Table 2

Spatial distribution of disaster incidents across the wards of PMC (2018-2024)

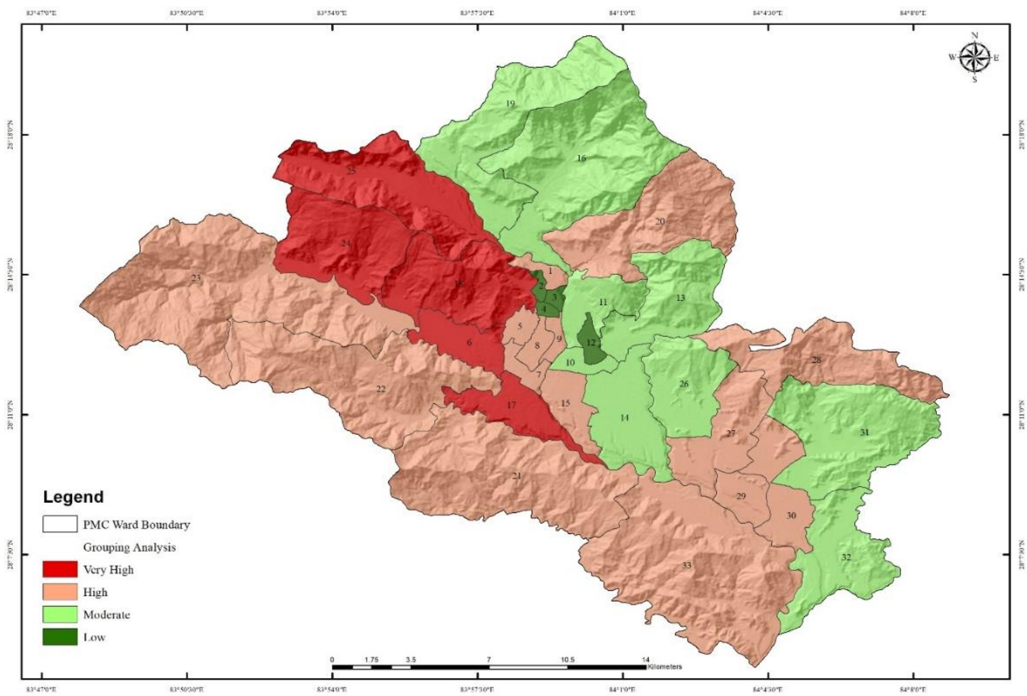
Ward no.	2018	2019	2020	2021	2022	2023	2024	Average
1	2	0	0	2	1	1	3	1.3
2	1	0	0	1	0	1	2	0.7
3	0	1	1	0	0	0	1	0.4
4	1	0	0	0	1	0	2	0.6
5	3	0	3	1	1	1	3	1.7
6	2	4	2	3	2	3	5	3.0
7	2	0	1	1	2	1	2	1.3
8	3	1	0	1	3	2	2	1.7
9	2	2	2	1	3	1	1	1.7
10	0	1	1	0	2	6	6	2.3
11	1	3	4	7	0	5	3	3.3
12	0	0	0	1	1	0	3	0.7
13	1	0	3	3	3	2	4	2.3
14	0	2	1	1	2	4	5	2.1
15	1	0	0	0	1	2	3	1.0
16	2	2	2	3	1	2	7	2.7
17	0	1	6	2	2	6	10	3.9
18	4	3	2	4	0	7	10	4.3
19	1	0	3	4	0	3	7	2.6
20	0	0	1	3	0	3	2	1.3
21	0	1	1	0	1	1	5	1.3

22	1	0	2	5	1	3	3	2.1
23	1	1	0	3	2	2	7	2.3
24	0	1	2	1	3	5	8	2.9
25	1	2	2	8	3	3	5	3.4
26	2	0	3	3	0	3	3	2.0
27	0	1	1	2	0	1	5	1.4
28	0	1	2	4	1	2	0	1.4
29	0	1	2	1	2	3	3	1.7
30	2	1	1	1	2	3	2	1.7
31	1	3	2	4	0	2	4	2.3
32	3	1	1	2	1	3	5	2.3
33	0	1	1	3	0	1	1	1.0
Total	37	34	52	75	41	82	132	64.7

Source: DRR Portal Nepal (http://www.drrportal.gov.np/, 2025), compiled by Author.

Figure 3

Mapping clusters of hazards in PMC (2018-2024)



Month wise distribution of hazards

The heatmap generated from R Language, demonstrate unevenly fluctuating throughout the year (Figure 4) and table 3 depicts overall datasets marking total 453 incidents recorded within PMC between 2018 to 2024. The number of incidents recorded during January (37) to February (32) consists low to moderate events, except for rare peak like 2021 and 2023 of February. From March (37) to April (69), a sharp rise recorded in hazards, particularly in 2021 and 2024, peaking the chart, whereas incidents slightly dip during May. On the other hand, June displays moderate level of hazards occurrence, while July explodes throughout the study period except 2019 (zero incident). August and September shows mixed intensity, producing moderate to slightly higher incidents, while October (15) generally stays calms amounts lowest incidents. Remaining others (November with 33, and December with 41), indicates the rise in waves of incidents, especially during 2023 and 2024. Overall, the study signifies the significance of seasons in driving the highest and lowest number of incidents, indicating weather factors crucial roles.

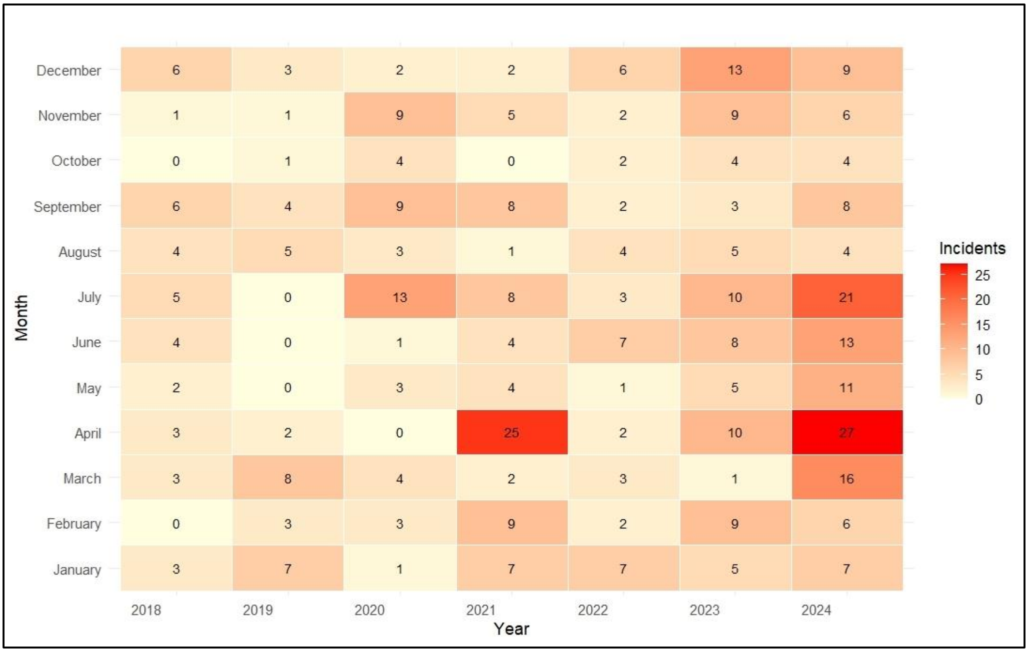
Table 3

Month-wise hazards incidents in PMC (2018-2024)

Month	2018	2019	2020	2021	2022	2023	2024	Total
January	3	7	1	7	7	5	7	37
February	0	3	3	9	2	9	6	32
March	3	8	4	2	3	1	16	37
April	3	2	0	25	2	10	27	69
May	2	0	3	4	1	5	11	26
June	4	0	1	4	7	8	13	37
July	5	0	13	8	3	10	21	60
August	4	5	3	1	4	5	4	26
September	6	4	9	8	2	3	8	40
October	0	1	4	0	2	4	4	15
November	1	1	9	5	2	9	6	33
December	6	3	2	2	6	13	9	41
Total	37	34	52	75	41	82	132	453

Figure 4

Heatmap showing hazards incidents in PMC (2018-2024)



Seasonal distribution of hazards

Seasonal distribution shows a variability in hazard incidence across PMC between 2018 to 2024 (Table 4). Spring season (132) peaked the season chart as higher incidents took place, with highest events (54) in 2024, where R^2=0.4189 showing moderate correlation, indicating hazards count increasing over year (Figure 5). Similarly, summer season (123) displaying mild to moderate number of incidents with strong correlation (R^2=0.6314) suggesting upward trend. Autumn season recorded lowest count (88), reflecting weak correlation (R^2=0.1974) in hazard occurrences. Winter season recorded 110 incidents between 2018 to 2024, moderate to high counts (during 2023) of incidents, having strong correlation (R^2=0.6458). These seasonality pattern, demonstrates the necessity for preparedness plans during specific season.

Additionally, Chi-Square value $X^2 = 59.15$ with df of 18 at $\alpha = 0.05$, found the critical value of 28.869, indicating the rejection of null hypothesis, showing significant relationship between season and hazards.

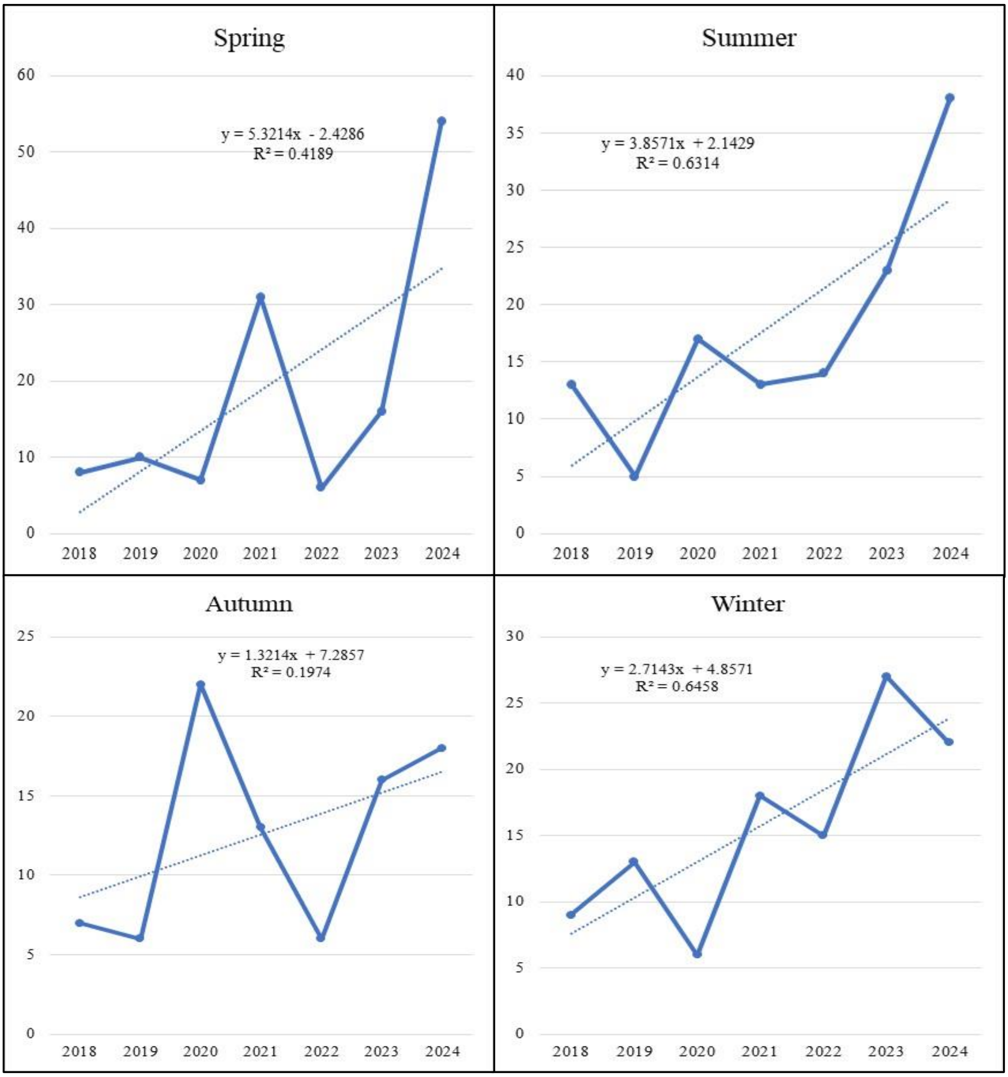
Table 4

Seasonal distribution of incidents in PMC (2018-2024)

Season	2018	2019	2020	2021	2022	2023	2024	Total
Spring	8	10	7	31	6	16	54	132
Summer	13	5	17	13	14	23	38	123
Autumn	7	6	22	13	6	16	18	88
Winter	9	13	6	18	15	27	22	110

Figure 5

Seasonal trends chart of hazards in PMC (2018-2024)



Conclusion

This study examined the multiple hazards in PMC from 2018 to 2024, highlighting the spatial and temporal trends, employing quantitative approach based on secondary data. The integrated data shows urban fire dominance among the hazards (earthquake, flood, landslides, forest fire, and urban fire). Hazard frequency is PMC varies unevenly across wards, ward-18 obtaining higher count of incidents, whilst ward-4 concentrated with lower count. April and July, produced a greater number of incidents, October remaining calm. Seasonally, spring and summer generate most incidents, whilst autumn season recorded fewer count of incidents. Moreover, a statistical test, confirm significance of season in event of hazards frequency.

These findings provide an insight for preparedness during spring and summer, focusing urban fire, landslides, and floods. Early-warning system in hazards specific ward is necessary to mitigate the impact. Strict land use policies for highly risk ward should be imposed for improving the land use pattern, and reducing the dense environment. Multi-hazard mapping should be prioritized in every ward, organizing community-based awareness program. Local governments are required to record every hazard incident digitally, increases feasibility for the future studies. Additionally, the data includes only incidents counts within PMC from 2018 to 2024, categorizing into month, wards, and season for assessment, indicating to focus on socio-economic aspects, population density, and application of advanced machine learning in assessment of multi-hazards.

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