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Assessing and Mapping Spatial Variation Characteristics of Natural Hazards in Pakistan

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Abstract: One nation with the highest risk of climate catastrophes is Pakistan. Pakistan's geographical nature makes it susceptible to natural hazards. Pakistan is facing regional differences in terms of climate change. The frequency and intensity of natural hazards due to climate change vary from place to place. There is an urgent need to recognize the spatial variations in natural hazards inside the country. To address such problems, it might be useful to map out the areas that need resources to increase resilience and accomplish adaptability. Therefore, the main goal of this research was to create a district-level map that illustrates the multi-hazard zones of various regions in Pakistan. In order to comprehend the geographical differences in climate change and natural hazards across Pakistan, this study examines the relevant literature and data currently available regarding the occurrence of natural hazards in the past. Firstly, a district-level comprehensive database of Pakistan's five natural hazards (floods, droughts, earthquakes, heatwaves, and landslides) was created. Through consultation with specialists in related areas, hazard and weighting factors for a specific hazard were specified based on the structured district-level historical disaster database of Pakistan. After that, individual and multi-hazard ratings were computed for each district. Then, using estimated multi-hazard scores, the districts of Pakistan were classified into four zones. Finally, a map of Pakistan's multi-hazard zones was created per district. The study results are essential and significant for policymakers to consider when making decisions on disaster management techniques, that is, when organizing disaster preparedness, mitigation, and prevention plans.

Keywords: natural hazards; climate change; spatial analysis; multi-hazard zoning; Pakistan

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1. Introduction

If global warming increases by 1.5 °C in the near future, it will surely intensify a variety of climatic catastrophes and present several natural hazards to ecosystems and humans [1]. The impacts and hazards associated with climate change are growing more complex and challenging to control. Hundreds of millions of people's livelihoods, food security, and nutrition are already negatively impacted by climate change, particularly in low- and mid-latitude regions [2–4]. Natural catastrophes, such as floods, droughts, tsunamis, storms, and tornadoes, often occur due to global climate change [5–7]. By 2050, Pakistan and the northern regions of India and China are anticipated to experience greater water stress [1,8–10]. Due to climatic extremes, including floods, droughts, and heatwaves, farmers in Pakistan see reductions in agricultural yields and an increase in crop diseases [11]. By 2100, Hyderabad, Jacobabad, Bahawalnagar, and Bahawalpur are expected to be the warmest cities in Pakistan, with average temperatures between 29.9 °C and 32 °C [12]. According to research on Pakistan, poor agricultural communities are among the greatest sufferers of climatic changes [13]. One of the nations with the highest risk of natural disasters is Pakistan [14]. According to observations, various regions of Pakistan are experiencing distinct climatic stress, with the north particularly vulnerable to snowstorms, landslides, avalanches, and floods. Flooding hazards are more prevalent in the center and mid-river basins, whereas drought risks are more prevalent in southern Punjab, Sindh, and Baluchistan [14]. One of the most serious environmental hazards is flooding brought on by global climate change, which Pakistan has seen over the last ten years [15,16]. Over the past decade, the frequency and severity of climatic catastrophes in Pakistan have increased, including droughts, floods, and heatwaves [17]. Pakistan was listed as the eighth-most flood-prone nation in 2010, 2011, 2012, and 2015 [3,14] and ranks eighth among the countries that are very susceptible to climatic changes and their effects [5,18]. Between 1999 and 2018, Pakistan was the fifth-most severely hit nation worldwide by extreme weather occurrences [19].

Identifying the regions where catastrophic climate threats are most likely to occur is a pressing need [20,21]. The relevant literature states that historical data are often used to build hazard-specific zoning maps [22,23]. Multi-hazard zoning maps display the regions exposed to different risks and the spatial differences in natural hazards within a region. The decision making of the authorities in charge of hazard mitigation and readiness depends on them [24]. The literature emphasizes how important it is to confront hazards jointly [25]. Multi-hazard assessment is essential to making the world safer in the twenty-first century. However, simultaneously evaluating many hazards and their various controlling elements is a complicated issue [26]. Many academics are concentrating on single hazards with many regulating variables [27–29]. However, many areas of the globe may experience many hazards at once [30–32]. A single hazard map may sometimes be perplexing for planners and policymakers as it neglects risks due to other catastrophes in the areas. A multi-hazard plan also offers all necessary data and triggers the mechanisms simultaneously [30]. There have not been many multi-hazard assessment studies conducted in Pakistan. There are some zoning maps available for specific hazards that have no comprehensive or well-structured historical records. Evaluating several hazards in various parts of the nation has not been carried out properly. Concerning natural disasters, in particular, Pakistani disaster management primarily focuses on relief and rescue operations, with little focus on procedures of hazard recognition, assessment, and management, as well as hazard preparedness [33]. It raises the likelihood that society, particularly the poor, will be vulnerable. The absence of early warning systems, or at least timely ones, poor consciousness, and, most importantly, numerous communities are exposed to catastrophes caused by humans and natural disasters due to a lack of cooperation among numerous government institutions [33,34]. Pakistan's geographic location renders it susceptible to climate change, as numerous Asian nations are struggling to develop sustainably and ecologically, owing to resource reduction, manufacturing growth, enhancement of urban areas, and commercial growth [11,35,36]. The glaciers in the Himalayas are melting at a pace quicker than in the past [37], sudden rainstorms, unpredictably high flood levels, droughts, temperature fluctuations, and a shortage of water sources [5], storms, hurricanes, landslides, earthquakes, and extreme heat [38] are the severe repercussions of climatic changes in Pakistan. Finding susceptible locations requires understanding spatial changes using a multi-hazard map at the district level [39].

The research emphasizes Pakistan's susceptibility and physical exposure to natural hazards, such as earthquakes, landslides, heatwaves, floods, and droughts. Additionally, a multi-hazard map will be proposed to pinpoint regions that are very sensitive to the severe effects of climatic changes. The outcomes of the research paper will highlight the spatial variations in natural hazards individually and collectively in the multi-hazard map based on different combinations between these natural hazards. These maps will help to show the highly affected areas by the discussed natural hazards in the past. Moreover, the outcomes will assist policymakers and future researchers in recognizing the hotspots from the perspective of these natural hazards.

Pakistan is a country in the southwest of Asia; the Arabian Sea borders the south and the steep Himalayas, Hindukush, and Karakorum are in the north. The cancer tropic is located in the south of the country. Pakistan is situated among latitudes of 23° N to 37° N and longitudes of 60° E to 77° E. More than 220 million people live there, and a higher proportion is vulnerable to climate change [11]. Most of Pakistan is dry to semi-arid climatically, with substantial regional and temporal fluctuation in climatic characteristics [40]. The monsoon rains, Pakistan's primary hydro-meteorological resource, account for 59% of the country's annual rainfall; snow and ice make up the majority of the Greater Himalayan region's winter precipitation above 35° N [41]. The rivers remain perennial throughout the year because of the help of snow melt [42]. Only a small portion of the coast in the south and southeast has a coastal climate [43]. The mountainous region in the north has a climate that may range from humid to dry [44]. The climate in between is often tropical continental in type [41].

Figure 1 is a geographical map of Pakistan showing the topographical characteristics of Pakistan. Pakistan's diverse topography separates the country into six main areas: the Northern High Mountainous Region, the Western Low Mountainous Region, the Baluchistan Plateau, the Potohar Uplands, and the Punjab and Sindh fertile plains [45]. Parts of the Hindukush, the Karakoram Range, and the Karakoram (Gilgit), Hindukush (Chitral), and Himalayas (Murree, Naran, etc.) are found in the northern highlands [46]. This region includes well-known peaks, such as K2 (Mount Godwin Austen, at 8611 m, the second-highest peak in the world) [47]. K2 is a part of the Karakoram Range and that is how its name was derived [48]. Western Mountains comprise four mountain systems (Koh-e-Safed, Waziristan, Sulaiman, and Kirther) [49].

Figure 1. Geographical Map of Pakistan.

2. Climate Change and Natural Hazards in Pakistan

The climate of Pakistan is generally tropical continental, with a wide range of temperatures and rainfall; the majority of the country is dry to semi-arid [50]. Over the last several decades, Asia's rainfall variability has risen spatially, seasonally, and yearly. Along Pakistan's coastal regions and dry plains, decreasing trends in rainfall patterns have also been seen [51]. Given its anticipated effects on the environment of vulnerable nations, the topic of climatic changes has been highly prominent throughout the last couple of decades on a worldwide basis [52]. Pakistan has a wide variety of geographical landscapes that confront various difficulties owing to climate change [53]. Latitudinal location, closeness to the sea, rugged terrain, continentality, maritime impact in the far south, plant cover, and soil composition are the variables causing diversity in Pakistan's climates [54]. Based on the Task Force on Climate Change's report [55], Pakistan is vulnerable to a range of natural disasters, including cyclones, earthquakes, floods, and droughts. Over the last several decades, extreme weather occurrences have risen in number, regularity, and intensity. Pakistan will also experience the worst effects of climate change as a result of its declining hydrological reserves, fast glacier melting, floods, and droughts [56]. By 2020, until 2050, Pakistan's temperature will increase from 0.9 to 1.5 °C. From 1998 to 2002, Pakistan faced significantly damaging droughts [57]. The problem is worse in Pakistan due to the nation's lengthy history of uncontrolled growth, which has severely influenced the socioeconomic structure of the nation, particularly in metropolitan areas [58]. Pakistan's low adaptive capacity has repeatedly threatened the ecosystem, biodiversity, and human communities due to the country's high poverty rate, limited financial resources, absence of physical resources, and continuing dangerous climatic events, e.g., temperature variations, flooding, and sweating glaciers [38]. Pakistan is one of the top-10 countries most impacted by climate change, with underprivileged people who are particularly vulnerable to its negative consequences, according to statistics from the global vulnerability index [34]. The effects of climate change have significantly impacted Pakistan, and this increased susceptibility of the nation to the threat of changing climate it is commonly recognized [12,17,59,60]. Over the years 1961–2010, Pakistan saw a rise in average mean and maximum temperatures of 0.5 °C and 0.8 °C, respectively [12]. In particular, the northern areas situated at greater altitudes are predicted to suffer heightened surface air temperature (5.8 °C), even if the future temperature rise is estimated to be more than the world average [61]. Agriculture-based economies (such as Pakistan) are more vulnerable to climate change due to their unique location, demographic patterns, socioeconomic characteristics, and lack of adaptation ability [62]. Therefore, knowledge of future climate change is necessary to evaluate its expected effects and develop policies resulting in quick adaptation and mitigation measures. Figure 2, from the Pakistan Meteorological Department, depicts the different climatic zones of the country; most of Pakistan has arid weather. A tiny portion of the north is characterized by high humidity. Less than 250 mm of rain falls each year throughout the whole of Sindh, the majority of Baluchistan, significant portions of Punjab, and the central regions of the Northern Areas. Spatial changes in rainfall patterns linked to changes in the area's overall atmospheric circulation make up the majority of climatic variations [44,50].

Due to little rainfall in the area and other socioeconomic factors, Pakistan's Sindh and Baluchistan regions regularly experience droughts [40]. In Pakistan, recurrent droughts impact various industries, including agriculture, forestry, cattle, fisheries, banking, energy, transportation, inflation, and unemployment [63]. Droughts have been more frequent and intense over the last 20 years, with the worst affecting Punjab province's economy the most from 1998 to 2001 [64]. Every ten years, this slow-motion tragedy strikes the nation for 2–3 years [40]. Arid and semi-arid regions comprise 88% of Pakistan's total land area of 79.6 million hectares. According to the studies, just 9% of Pakistan's land faces more rain than 508 mm annually, 22% receives between 254 and 508 mm, and 69% receives less than 254 mm [65]. In the second quarter of the year, Pakistan had a recent drought (April–June 2022), when less than typical (−25.13%) precipitation was observed over Pakistan [66]. The ongoing increase in temperature and changing climatic patterns are expected to result in longer and more severe droughts in the future [7]. The country's rainfall patterns are shifting owing to climate change; some years, there is more rain during wet periods and less rain during dry spells, which leads to drought conditions [67]. Therefore, predicting droughts is crucial for providing early warning and preparing the most vulnerable areas for the effects of droughts. This research work seeks the spatial distribution of droughts between 1950 and 2022 to provide the country's citizens with a clear representation of the drought-affected regions. Pakistan is subjected to various natural and man-made disasters because of the diversity and geographical variance in geology, geography, and weather [68,69]. Due to the effects of climate change, Pakistan's wet and dry seasons have undergone a significant alteration. The nation now experiences more heavy rain during wet spells and sparse rainfall during dry spells [70]. The most catastrophic natural catastrophe in Pakistan is floods, which disastrously impact infrastructure, natural resources, and human life [71]. During July through September, tropical monsoon depression systems originating from the Bay of Bengal often cause floods in Pakistan. Floods from rivers primarily harm areas along the Indus plain, whereas hill torrents often affect areas with hills in Pakistan's northern and western regions [72]. Landslide susceptibility varies from area to region in Pakistan based on factors, such as surface geology, moisture availability, closeness to seismically active zones, and slope angle [73,74]. Landslides frequently occur in Pakistan and are primarily caused by natural factors, such as rain or moisture, earthquake activity, and floods. Human-induced factors, such as degrading forest cover, terracing, and increasing human intervention over vulnerable slopes, frequently intensify these natural factors [75]. Larsen et al. [76] noted, in their research, that most of Pakistan's regions, particularly Kashmir, the Northern Areas, and parts of the province of Khyber Pakhtunkhwa, are exposed to and prone to landslides brought on by the climate. High deforestation rates, farming, and haphazard building are other significant factors contributing to a rise in landslide incidents in mountain ranges with vulnerable soil types [77]. In the aforementioned locations, there are typically small-scale, localized landslide hazards. Climate, slope, land cover, and lithology may all have a role in the incidence of landslides in the Pakistani Himalayan area, ranging from minor occurrences to almost heavy land sliding [78,79]. The Hindukush, Himalayas, and Karakorum mountain ranges are the most geologically susceptible to landslides [44]. Additionally, it was calculated that nearly 30% of all landslides worldwide only occur in the Himalayan mountain chain [80]. According to the global trend, the average annual temperature across Pakistan rose by 0.6 C during the last century [81]. Given that many Asian countries are striving to develop sustainably and environmentally as a result of resource depletion, industrial expansion, urbanization, and economic growth, Pakistan's geographic location makes it vulnerable to the consequences of climate change [35]. Pakistan may be at risk for economic, social, and environmental growth due to the severe effects of climate change [82]. According to the Intergovernmental Panel on Climatic Change, the area where Pakistan is situated is anticipated to see somewhat larger temperature rises than the average worldwide increase [83,84]. Particularly during the previous ten years, Pakistan has had a high frequency of heatwaves. The experts on climate change believe that global warming is to blame for this temperature's fluctuating intensity [85]. According to [86], temperatures have increased since 1961, and Sindh, Baluchistan, and Punjab are seeing an increase in the number of days with temperatures exceeding 40 °C. This clearly shows why this region is regarded as the most vulnerable to increasing heatwaves [87]. The regional thrust faults that have an east–west trend are often linked to earthquakes in Pakistan [88]. The earthquake-prone regions in Pakistan are the Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT), and Main Boundary Thrust (MBT) [89]. The Chaman and Ornach-Nal Fault Zones (800–900 km), which constitute the western edge of the Indian Plate, are the primary source of seismicity in and around Quetta, Pakistan, which connects the western Himalayas in the north with the Makran subduction zone in the southwest [90].

A comparison of the susceptibility of South Asian countries to several climate disasters, such as sea-level rise, glacier retreat, temperature increase, floods, and drought, is provided in the aforementioned Table 1, which shows that compared to other South Asian nations, Pakistan has higher climatic risks. Table 1 shows that Pakistan, India, and Bangladesh are all susceptible to various climate dangers.

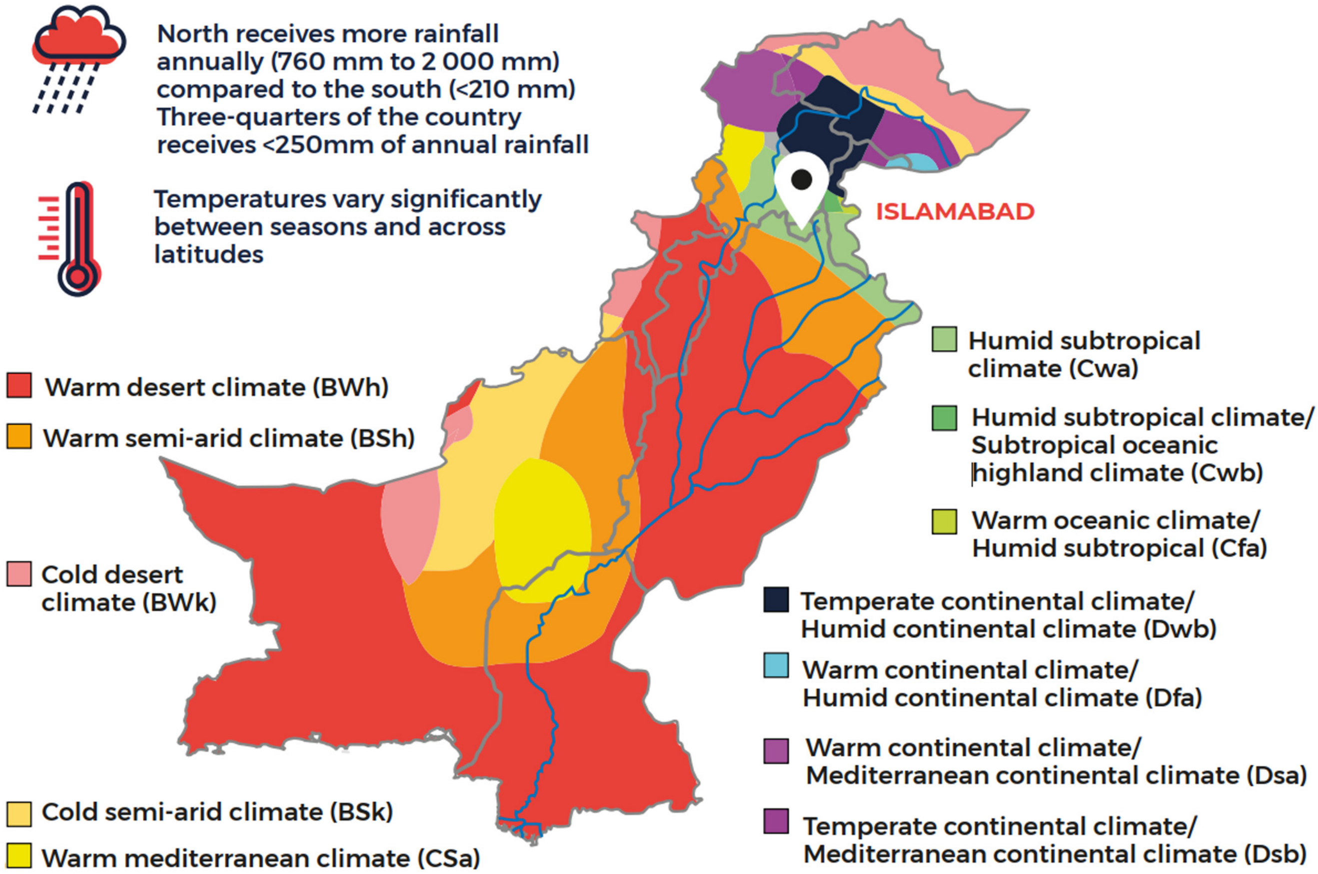

Figure 2. Climatic zones of Pakistan. Source [45].

Table 1. Summary of climate risks for South Asian countries [67].

	Afghanistan	Bangladesh	Bhutan	India	Nepal	Pakistan	Maldives	Sri Lanka
Sea Level Rise	-	High	-	Modest	-	Modest	High	High
Glacier Retreat	High	High	High	High	High	High	-	-
Temperature Increase	-	High	High	High	High	High	Modest	High
Floods more Frequent	-	Likely	High	High	Likely	High		
Drought more Frequent	Likely	High some areas	High	Likely	-	Likely		

3. Methodology

Sources of Data

The data were collected from different databases and from the published literature to supplement the raw data that were already accessible. To comprehend the geographical variability in climate change for Pakistan, we reviewed the pertinent literature. We gathered historical climate hazard records spanning 1950 to 2022 from several data sources to create a multi-hazard zoning map, including Emergency Events Database (EM-DAT) [91]; it compiles crucial core data from a variety of sources, including UN agencies, non-governmental organizations, insurance companies, research institutions, and news agencies, on the occurrence and consequences of over 22,000 catastrophic events that have occurred globally from 1900 to the current day. National Aeronautics and Space Administration Global Landslide Catalog (NASA GLC) [92] was created with the intention of locating landslide occurrences everywhere in the world, regardless of their magnitude, significance, or location. VOLCANO Discovery [93] tracks earthquake events all over the world; World Food

Program GeoNode Integrated Context Analysis-Areas Pakistan (WFPGeoNode-ICA) [94], National Disaster Management Authority (NDMA) [95], NDMA manages the full spectrum of catastrophes by incorporating disaster risk reduction into all stages of development planning. NDMA oversees the Disaster Management Cycle (DMC), which entails Preparedness, Mitigation, Risk Reduction, Relief, and Rehabilitation. Pakistan Meteorological Department (PMD) [96], The Climatic Data Center of PMD, presently keeps digital records of climate data from more than 100 locations around Pakistan, some of which go back more than a century. Geological Survey of Pakistan [97], RS and GIS branch of the Geological Survey of Pakistan is responsible for managing, manipulating, analyzing, modeling, disaster management, risk map analysis, and presenting spatially referenced data. Different online reports, e.g., Relief Web, [98–100], Inventory Maps, and several pieces of literature (i.e., case studies) and different reports from newspapers were also explored to collect information. The primary purpose of using multiple data sources was to overcome the issues related to any missing events at one data source, achieved from the other data source. To do this, we thoroughly compared the data obtained from different sources and competently verified where any missing or conflicting data were observed. Any occurrence that results in ten or more human fatalities, major impacts on the lives of 100 or more people, a state of emergency is proclaimed, or a request for international aid is classified as a disaster by EM-DAT. Smaller-scale incidents that had a terrible effect on the local people are not included in this categorization and documentation procedure. For every district in Pakistan, we thoroughly sorted the catastrophe data; if a disaster struck a district more than once in a year, it was tallied individually for each. We only considered earthquakes, landslides, floods, droughts, and heatwave occurrences since they regularly happen in Pakistan. Since they happen too seldom to be measured in terms of geographic variance between administrative districts, other occurrences, including cyclones, GLOF, epidemics, and hurricanes, were omitted from this research. Additionally, they only appear in a small portion of the nation; there is no spatial occurrence elsewhere.

Table 2 describes the damage and population affected by hazards all over the country; it includes the hazards that caused some loss of life or property. The most frequent climate hazards and disasters include floods, earthquakes, and droughts regarding the number of deaths, persons affected, and total damage. This table shows the records of hazards from 1950 to 2022 obtained from EM-DAT 2022. From the above Table 2, it can be said that earthquakes, floods, and droughts are Pakistan's most severe natural disasters.

Table 2. Disaster records for Pakistan 1950–2022.

Disaster Type	Disaster Sub-Type	Count of Events (No)	Total Deaths (No)	Population Affected (No)	Total Damage in M$
Drought	Not Specified	2	220	6,880,912	401,798
Flood	Not Specified	43	6981	56,876,354	8,049,670
	Flash Flood	25	3595	22,114,350	12,732,011
	Riverine Flood	43	9229	34,967,357	12,268,967
Earthquake	Ground Movement	32	79,925	7,474,537	7,422,549
Landslide	Not Specified	09	222	29,707	18,000
	Avalanche	12	567	4435	-
	Mudslide	02	16	-	-
Extreme Temperature Events	Heatwave	16	2936	80,574	20,603
Storms	Not Specified	06	184	2988	-
	Convicted Storm	17	447	1,002,038	-
	Tropical Storm	06	11,555	2,589,940	2,270,152
Wildfire	Forest Fire	1	4	4004	-

Data source: EM-DAT 2022.

Table 3 provides the total number of events for each natural hazard that has taken place in each district of Pakistan from 1950 to 2022. Due to the diverse geographical nature of Pakistan, the occurrence of these natural hazards is not uniform all over Pakistan. Some districts are more prone to landslides (i.e., Abbottabad, Astore, and Buner), while some are more prone to floods (i.e., Neelum, Shangla, Swat). The total event of the hazards for each district is obtained by adding the number of occurrences of each natural hazard in each district. The maximum number of Natural Hazards occurs in Chitral 92, and Lower Kohistan lies 2nd in the list with 87 natural hazards. District Diamer lies 3rd in the list, with 84 natural hazards. Nankana Sahib is the only district with no natural hazards from the found records. Moreover, Hafizabad, Okara, and Pakpattan are the districts that faced only one natural hazard during 1950–2022. On the basis of the collected data given above in Table 3, an attempt is made to distinguish the district on the basis of natural hazards, which are occurring in them.

Table 3. Historical database for five major natural hazards in Pakistan, showing numbers of events in each district.

Sr. No	Districts	Droughts (a)	Earthquake (c)	Heatwave (e)	Floods (b)	Landsides (d)	Total Events (a + b + c + d + e)
1	Abbottabad	0	4	0	7	25	36
2	Astore	0	7	0	3	39	49
3	Attock	0	3	0	1	17	21
4	Awaran	4	5	0	3	0	12
5	Badin	6	2	4	5	0	17
6	Bagh	0	4	0	4	27	35
7	Bahawalnagar	3	0	7	0	0	10
8	Bahawalpur	2	3	7	5	0	17
9	Bajaur	0	10	0	4	1	15
10	Bannu	0	4	0	3	0	7
11	Barkhan	3	10	3	4	0	20
12	Batagram	0	7	0	6	24	37
13	Bhakkar	2	1	2	4	0	9
14	Bhimber	0	2	0	2	0	4
15	Buner	0	5	0	4	30	39
16	Chagai	9	10	8	2	1	30
17	Chakwal	0	1	7	2	0	10
18	Chaman	5	6	4	6	0	21
19	Charsadda	0	4	0	7	14	25
20	Chitral	3	48	0	7	34	92
21	Chiniot	0	0	0	6	0	6
22	Dadu	7	0	11	11	0	29
23	Dera Bugti	4	8	0	5	0	17
24	Dera Ghazi Khan	3	5	0	9	0	17
25	Dera Ismail Khan	1	2	0	5	1	9
26	Diamer	0	6	0	6	72	84
27	Duki	5	13	0	1	0	19
28	Faisalabad	0	0	3	4	0	7
29	Ghanche	0	2	0	6	35	43
30	Ghizer	0	9	0	4	25	38
31	Ghotki	6	1	4	7	0	18

Table 3. *Cont.*

Sr. No	Districts	Droughts (a)	Earthquake (c)	Heatwave (e)	Floods (b)	Landsides (d)	Total Events (a + b + c + d + e)
32	Gilgit	0	9	0	8	43	60
33	Gujranwala	0	2	6	2	0	10
34	Gujrat	0	1	0	2	0	3
35	Gupis Yasin	0	9	0	4	21	34
36	Gwadar	7	1	4	5	0	17
37	Hafizabad	0	0	0	1	0	1
38	Hangu	0	6	0	2	12	20
39	Haripur	0	5	0	3	26	34
40	Harnai	8	11	0	4	0	23
41	Hattian	0	4	0	3	0	7
42	Haveli	0	3	0	3	29	35
43	Hunza	0	6	0	3	64	73
44	Hyderabad	7	0	8	7	1	23
45	Islamabad	0	3	1	4	0	8
46	Jacobabad	4	1	11	7	0	23
47	Jaffarabad	3	0	0	9	0	12
48	Jamshoro	8	0	4	7	0	19
49	Jhal Magsi	6	1	0	6	0	13
50	Jhang	1	1	0	7	0	9
51	Jhelum	0	2	0	1	0	3
52	Kachhi	5	11	0	3	0	19
53	Kalat	6	5	0	5	0	16
54	Karachi Central	2	1	12	5	0	20
55	Karachi East	2	1	12	7	1	23
56	Karachi South	2	1	12	7	1	23
57	Karachi West	2	1	12	7	0	22
58	Karak	0	3	0	6	13	22
59	Kashmore	4	2	0	6	0	12
60	Kasur	0	1	0	2	0	3
61	Kech	7	3	7	9	0	26
62	Khairpur	6	0	13	7	0	26
63	Khanewal	1	0	0	2	0	3
64	Kharan	8	4	0	2	0	14
65	Kharmang	0	7	0	4	27	38
66	Khushab	1	1	1	2	0	5
67	Khuzdar	3	6	0	9	0	18
68	Khyber Agency	0	5	0	4	13	22
69	Killa Abdullah	5	7	0	6	0	18
70	Killa Saifullah	3	5	0	5	0	13
71	Kohat	0	4	0	3	0	7
72	Kohlu	3	10	0	5	0	18
73	Kolai Pallas	0	10	0	0	0	10
74	Korangi	2	0	12	2	0	16
75	Kotli	0	2	0	2	0	4

Table 3. *Cont.*

Sr. No	Districts	Droughts (a)	Earthquake (c)	Heatwave (e)	Floods (b)	Landsides (d)	Total Events (a + b + c + d + e)
76	Kurram Agency	0	5	0	4	15	24
77	Lahore	0	0	8	7	0	15
78	Lakki Marwat	1	3	0	4	0	8
79	Larkana	5	0	10	7	0	22
80	Lasbela	2	1	4	8	0	15
81	Layyah	1	3	4	5	0	13
82	Lodhran	1	0	6	1	0	8
83	Loralai	2	12	0	4	0	18
84	Lower Dir	0	15	0	4	9	28
85	Lower Kohistan	0	10	0	8	69	87
86	Malakand	0	8	0	5	18	31
87	Malir	2	0	12	4	0	18
88	Mandi Bahauddin	0	0	0	2	0	2
89	Mansehra	0	7	0	5	67	79
90	Mardan	0	6	0	8	0	14
91	Mastung	3	9	0	2	0	14
92	Matiari	5	0	0	4	0	9
93	Mianwali	1	1	8	4	10	24
94	Mirpur Khas	3	0	3	7	11	24
95	Mirpur	0	2	0	6	0	8
96	Mohmand Agency	0	4	0	5	0	9
97	Multan	1	4	12	5	0	22
98	Musakhel	2	8	0	3	0	13
99	Muzaffarabad	0	5	0	6	43	54
100	Muzaffargarh	1	5	4	7	0	17
101	Nagar	0	6	1	3	31	41
102	Nankana Sahib	0	0	0	0	0	0
103	Narowal	0	0	0	5	0	5
104	Naseerabad	4	5	0	9	0	18
105	Naushahro Firoze	4	0	5	4	0	13
106	Nawab Shah	7	0	7	2	0	16
107	Neelum	0	7	0	10	25	42
108	North Waziristan	0	4	0	3	14	21
109	Nowshera	0	5	0	6	12	23
110	Nushki	9	6	0	1	1	17
111	Okara	0	0	0	1	0	1
112	Orakzai agency	0	5	0	3	14	22
113	Pakpattan	1	0	0	0	0	1
114	Panjgur	8	4	6	2	0	20
115	Peshawar	0	5	1	9	0	15
116	Pishin	6	10	4	7	0	27
117	Poonch	0	3	0	2	10	15

Table 3. *Cont.*

Sr. No	Districts	Droughts (a)	Earthquake (c)	Heatwave (e)	Floods (b)	Landsides (d)	Total Events (a + b + c + d + e)
118	Qambar Shahdadkot	8	2	0	7	0	17
119	Quetta	6	9	4	5	0	24
120	Rahim Yar Khan	2	2	13	4	0	21
121	Rajanpur	2	8	0	9	0	19
122	Rawalpindi	0	2	2	7	35	46
123	Rondu	0	7	0	0	0	7
124	Sahiwal	1	0	0	1	0	2
125	Sanghar	6	0	4	4	0	14
126	Sargodha	0	1	6	2	0	9
127	Shaheed Benazirabad	6	0	0	4	0	10
128	Shaheed Sikandarabad	6	0	0	1	0	7
129	Shangla	0	8	0	10	35	53
130	Sheikhupura	0	1	0	2	0	3
131	Sherani	3	2	0	3	0	8
132	Shigar	0	7	0	3	29	39
133	Shikarpur	4	1	0	7	0	12
134	Sialkot	0	0	0	8	0	8
135	Sibbi	6	7	11	6	0	30
136	Skardu	0	3	0	5	25	33
137	Sohbatpur	3	8	0	7	0	18
138	South Waziristan	0	1	0	2	0	3
139	Sudhnutti	0	3	0	4	0	7
140	Sujawal	0	0	0	3	0	3
141	Sukkur	4	0	13	6	1	24
142	Swabi	0	4	0	6	15	25
143	Swat	0	43	0	11	24	78
144	Tando Allahyar	4	0	0	4	0	8
145	Tando Muhammad Khan	5	0	0	4	0	9
146	Tangier	0	6	0	0	0	6
147	Tank	2	1	0	2	0	5
148	Tharparkar	9	1	8	3	0	21
149	Thatta	8	0	5	7	0	20
150	Toba Tek Singh	0	0	0	3	0	3
151	Torghar	0	8	0	10	22	40
152	Umerkot	8	0	5	3	0	16
153	Upper Dir	0	34	0	9	31	74
154	Upper Kohistan	0	9	0	3	0	12
155	Vehari	1	0	5	1	0	7
156	Washuk	9	10	0	1	0	20
157	Zhob	4	8	0	5	0	17
158	Ziarat	0	10	0	5	0	15

4. Results

4.1. Hazard and Weighting Factors for Droughts

Firstly, after the computation of the total events of droughts for each district, the frequency intervals were chosen so that the data would be evenly distributed. This frequency classification helps distinguish the districts based on the number of past drought occurrences. In this way, the districts that frequently face droughts were differentiated from those that rarely face this catastrophe. This frequency distribution provides an idea about the districts that are likely to experience droughts in the future. After that, drought hazard weighting factors were assigned for each district. The allocation of these ratings is based on the number of occurrences of droughts within the limits of a certain frequency. The districts that have never experienced a drought are assigned a weighted value of 1. For each subsequent class of frequency, 0.1 is progressively added to the previous weighting factor. The intensity of the effects of previous droughts and their frequency of recurrence are used to determine the hazard factors for a specific region. A hazard factor of 3 (for lower frequency) or 5 (for higher frequency) is assigned to districts that have experienced such events at least once, while 1 is given to districts that have not experienced any drought event. The allocation of these drought hazard factors helps to differentiate depending upon the severity of these events. After that, hazard scores are computed by product of allocated weighting and hazard factors [20,101,102]. Table 4 lists the frequency classes of drought episodes along with the associated hazard and weighting factors. Accordingly, weighting and drought hazard factors were allocated based on the frequency classes or the total number of occurrences for each district. Additionally, as indicated in Table 4, drought hazard ratings for districts are calculated by multiplying the weighting and hazard factors for related occurrences.

Table 4. Calculation of Drought Hazard score based on weighting and hazard factors.

Droughts Frequency	Number Districts	Weighting Factor	Hazard Factor	Hazard Score (Weighting Factor × Hazard Factor)
0	75	1	1	1
1–2.	27	1.1	3	3.3
3–4.	22	1.2	3	3.6
5–6.	18	1.3	5	6.5
7–8.	12	1.4	5	7
9–above	4	1.5	5	7.5

Following the determination of hazard scores for each district, the scores for the droughts were categorized into five groups. These categories include nil for places where there have been no droughts in the last 72 years, while the succeeding categories include locations that have had mild, moderate, high, and extreme droughts. The cumulative drought-hazard ratings were categorized using an even-interval approach. A drought-hazard zoning map was created using the data from Table A1 (provided in Appendix A). This table consists of the districts that fall into different drought-hazard zones. The table indicates that four districts, including Chaghai, Nushki, Tharparkar, and Washuk, are severely drought affected.

The drought hazard map in Figure 3 shows the districts in which the droughts occurred in the past. It also differentiates the districts based on drought-hazard scores, which are calculated according to the information in Table 4. From Figure 3, it can be observed that most of the districts in Baluchistan and Sindh are vulnerable or prone to droughts. In comparison, there is less threat of droughts in upper Punjab and KPK (Khyber Pakhtunkhwa) provinces. Baluchistan is vulnerable to droughts because of its dry environment, rocky topography, and a high degree of rainfall fluctuation. Further, the lack of effective drought-mitigation strategies has increased the effects of the drought on society. The province's agriculture and economy are more susceptible to harmful effects since there is inadequate monitoring and mitigation for droughts in this region. Sindh is particularly susceptible to drought danger because of its desert environment. Most of the rainfall occurs in the monsoon season, and there are no proper dams or storage to save this monsoon water. Therefore, both provinces face water scarcity issues, which usually prevail in drought conditions.

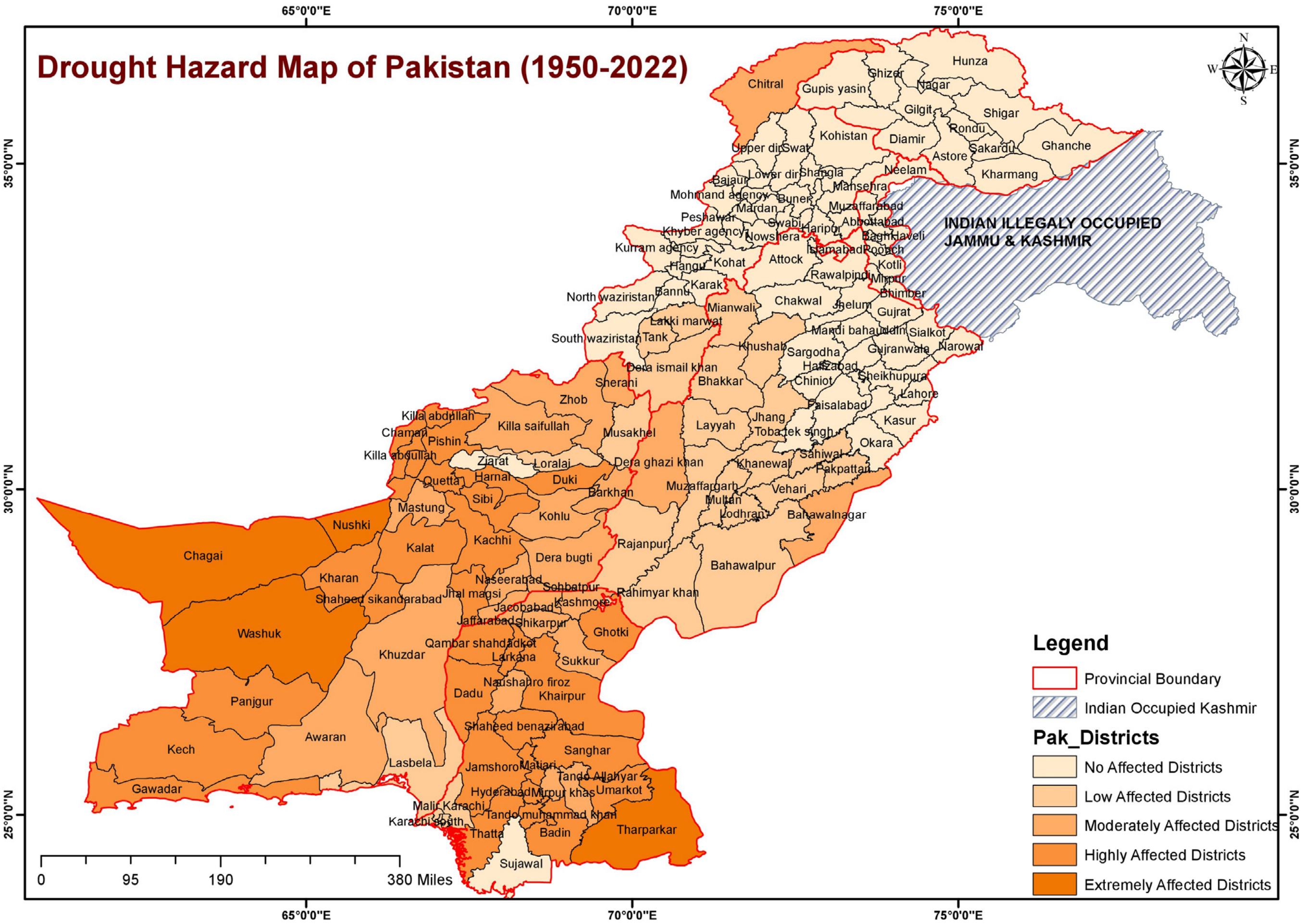

Figure 3. Drought Hazard Map of Pakistan 1950–2022.

4.2. Hazard and Weighting Factors for Floods

The frequency intervals were set so the data would be evenly dispersed; these frequency intervals differentiated the districts on the basis of the number of occurrences of floods. Flood-hazard ratings were initially assigned for each district. These weighting factors are related to the frequency of flood event occurrence. The districts with a weighted value of 1 are those that have never experienced flooding. Additionally, 0.1 is progressively added to the prior weighting factor for each subsequent frequency class. The intensity of the effects of previous floods and their frequency of recurrence are used to determine the weighting factors for a certain district. As a result, districts that have not experienced such incidents at least once are given a hazard factor of 1, whereas districts that have seen such events are given hazard factors of 3 (for less frequency) or 5 (for greater frequency). Table 5 lists the frequency classes of flood occurrences and associated weighting and hazard variables. Therefore, based on comparable frequency classes or the number of occurrences and severity of floods, hazard, and weighting factors were allocated in Table 5. The hazard scores were then computed by multiplying the categorized hazard and weighting factors for floods.

Table 5. Calculation of flood-hazard score based on weighting and hazard factors.

Floods Frequency	Number Districts	Weighting Factor	Hazard Factor	Hazard Score (Weighting Factor × Hazard Factor)
0	6	1	1	1
1–2.	32	1.1	3	3.3
3–4.	46	1.2	3	3.6
5–6.	34	1.3	5	6.5
7–8.	27	1.4	5	7
9–above	13	1.5	5	7.5

The flood-hazard scores were divided into five categories after the computation of the risk ratings for each district. These groups include nil for districts where there have been no floods in the prior 72 years, while the other categories consist of low, moderate, and severely flood-affected regions. Cumulative flood-hazard ratings were assigned using an even-interval categorization scheme. Based on the information from Table A2 (provided in Appendix A), a map of flood hazards was created. The districts located in each flood zone are categorized in this table and indicate that thirteen districts, including Dadu, Dera Ghazi Khan, Jaffarabad, Kech, Khuzdar, Naseerabad, Neelum, Peshawar, Rajanpur, Shangla, Swat, Torghar, and Upper Dir, are located in the flood zone that is most severely impacted.

Figure 4 describes that the districts along river Sindh mostly undergo floods. Most of the flood-prone districts lie in the province of Sindh and South Punjab. In these districts, most riverine floods occur during the monsoon season, while district kech of Baluchistan and some northern districts of province KPK undergo flash flooding. A few districts of Gilgit Biltistan are also severely prone to floods: flash floods or glacier lake outburst flooding. Floods in all provinces of Pakistan are mainly due to changes in trends of high rainfall in the monsoon season due to climate change. Torrential monsoon rains caused the worst flooding Pakistan has seen in recent history. Flash flooding occurs in KPK due to extensive rainfall, continuous rainfall for more than a week, and melting glaciers due to increasing temperature trends. The provinces of Sindh and Punjab mostly face riverine flooding due to the high discharge of water in rivers during the monsoon season. There are limited facilities to store monsoon rainwater, which flows directly to the Arabian Sea through these provinces. As these provinces have plane topography, the rainwater during the monsoon season struggles to flow downward and causes flooding situations.

4.3. Hazard and Weighting Factor Landslides

After the computation of the total events of landslides for each district, the frequency intervals were initially set so the data would be evenly distributed before assigning landslide-hazard ratings for all districts. There were vast variations in the number of landslides for different districts. Thus, nine frequency classifications were established. The districts that a landslide has never impacted have a weighted factor of 1. For each subsequent class of frequency, 0.1 is progressively added to the previous weighting factor. A district's risk variables are determined by the historical frequency and effect of landslides, as well as their severity. A hazard factor of 3 (for less frequency) or 5 (for higher frequency) is assigned to districts that have experienced such events at least once, while 1 is given to districts that have not experienced any landslide event. Table 6 lists several landslide frequency classes along with the related hazard and weighting factors. Consequently, landslide hazard and weighting factors were distributed based on the frequency classes or the total number of incidents for each district and their intensity.

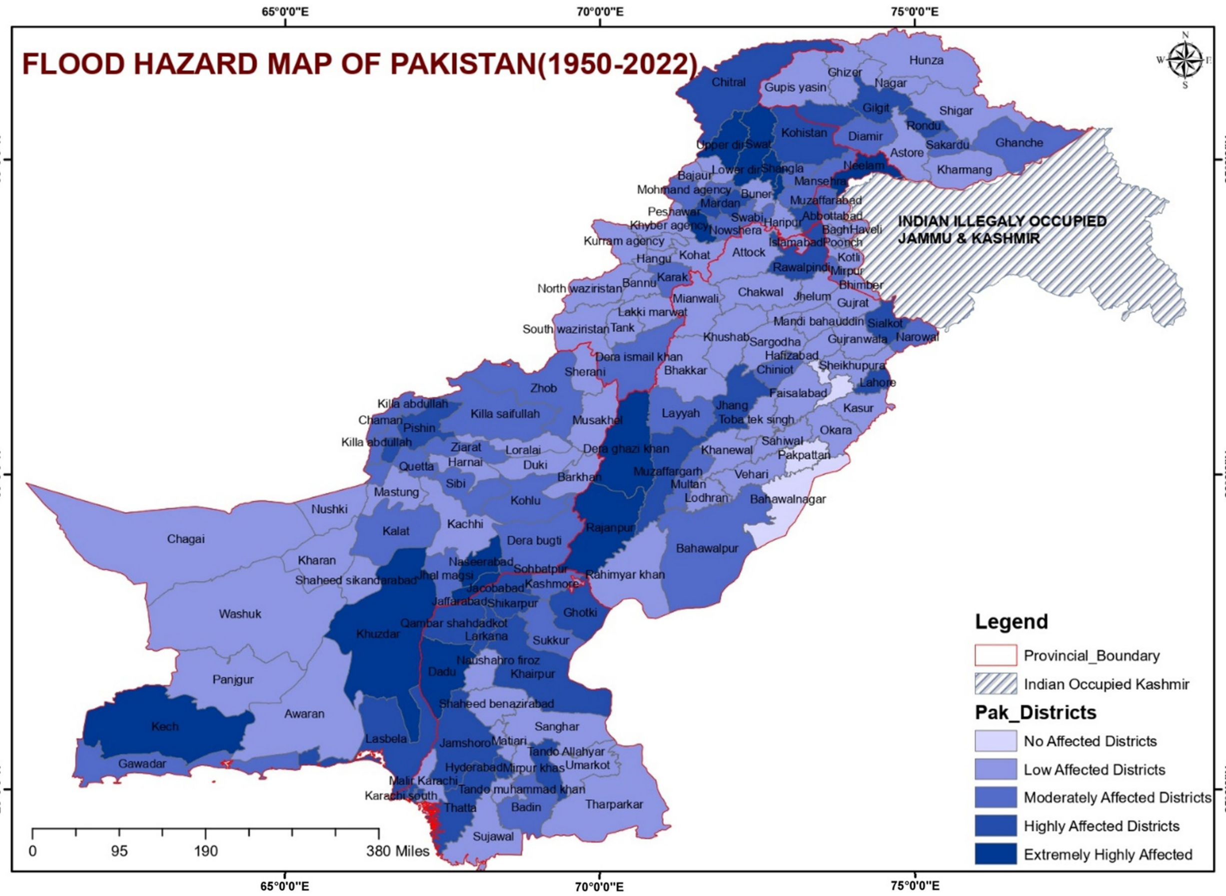

Figure 4. Flood-Hazard Map of Pakistan 1950–2022.

Table 6. Calculation of Landslide-Hazard score based on weighting and hazard factors.

Landslide Frequency	Number Districts	Weighting Factor	Hazard Factor	Hazard Score (Weighting Factor × Hazard Factor)
0	108	1	1	1
1–5.	8	1.1	3	3.3
6–10.	3	1.2	3	3.6
11–15.	10	1.3	3	3.9
16–20	2	1.4	5	7
21–25	8	1.5	5	7.5
26–30	6	1.6	5	8
31–35	6	1.7	5	8.5
36–above	7	1.8	5	9

The landslide-hazard scores were divided into five categories after the computation of the hazard scores for each district. These groups include nil for the districts where no landslide happened in the past 72 years, and the preceding categories consist of low, moderate, high, and extremely landslide-affected areas). The cumulative landslide weighting factors were categorized using an even-interval approach. In response, a landslide-hazard zoning map was created using the data from Table A3 (provided in Appendix A). The districts in each landslide-hazard zone are included in this table. The table indicates that the significantly impacted landslide zones include thirteen districts, including Astore, Chitral, Diamer, Ghanche, Gilgit, Hunza, Lower Kohistan, Mansehra, Muzaffarabad, Nagar, Rawalpindi, Shangla, and Upper Dir.

Landslide occurrence mainly depends upon the topographical nature of the ground. In Pakistan, landslides occur in a few districts, as seen in Figure 5. Most of the country is safe from this catastrophe of nature. Figure 5 shows that some northern districts in the KPK province and the entire Gilgit Baltistan experience landslides. This is because the Himalaya Mountain range is made up of younger, tectonically unstable geological formations that are often exposed to powerful earthquakes. The Himalayas and Hindukush area are a treasure from nature to Pakistan, but unplanned development activity, a lack of land planning, the building of dwellings, and deforestation have weakened the mountain, which has become the main cause of landslides. Moreover, the location of Gilgit Baltistan is likely to face these events due to certain unique rainfall conditions or earthquakes.

Figure 5. Landslide-Hazard Map of Pakistan 1950–2022.

4.4. Hazard and Weighting Factors for Earthquake

To rate the hazards of earthquakes in each district, firstly, the frequency intervals were determined so that the data should be uniformly distributed. Due to a large number of earthquakes, seven classes of frequency were taken. A weighting factor of 1 is given to the districts that have not been affected by any earthquake in the past. Further, 0.1 is gradually added in the preceding weighting factor for every next frequency class. Hazard factors are determined for a certain district from the magnitude of prior earthquake impacts as well as their frequency of recurrence. A hazard factor of 3 (for less frequency) or 5 (for higher frequency) is assigned to districts that have experienced such events at least once, while 1 is given to districts where no earthquake event occurs. Additionally, as indicated in

Table 7, earthquake-hazard ratings for every district are determined by multiplying the weighting and hazard factors for related occurrences.

Table 7. Calculation of Earthquakes-Hazard score based on weighting and hazard factors.

Earthquakes Frequency (≥M6)	Number Districts	Weighting Factor	Hazard Factor	Hazard Score (Weighting Factor × Hazard Factor)
0	37	1	1	1
1–2.	35	1.1	3	3.3
3–4.	23	1.2	3	3.6
5–6.	22	1.3	4	5.2
7–8.	17	1.4	4	5.6
9–10.	15	1.5	5	7.5
11–12.	3	1.6	5	8
13–above	6	1.7	5	8.5

After calculating each district's hazard scores, the earthquake-hazard scores were classified into five categories. These categories contain nil for the districts where no earthquake happened in the past 72 years, and the preceding categories consist of low, moderate, high, and extremely earthquake-affected areas. The cumulative earthquake-hazard ratings were categorized using an even-interval approach. In response, an earthquake-hazard zoning map was created using the data from Table A4 (provided in Appendix A). The districts in each seismic hazard zone are included in Table A4 and show that nine districts (Chitral, Duki, Harnai, Kachhi, Loralai, Lower Dir, Muzaffarabad, Swat, and Upper Dir) lie in the extremely affected earthquake zone.

Pakistan lies on a number of fault lines, and the country's earthquake activity is mostly centered in its northern and western regions. According to Figure 6, the north-western districts of Baluchistan and the northern districts of KPK provinces have faced the most earthquakes. Further, the Districts of Gilgit Baltistan and Azad Kashmir have faced several earthquakes in the past. The capital city of Pakistan has faced many earthquakes in the past, as it lies on five significant fault lines that run through Islamabad and can produce powerful earthquakes. Due to several active faults and high seismic belts bordering numerous active plates, Pakistan has a history of numerous major earthquakes, and its diverse areas (east-northern districts) of Baluchistan, KPK, and Gilgit Baltistan are at high seismic risk. In terms of geology, Pakistan is between the Indian and Eurasian tectonic plates. Punjab and Sindh are located on the northwest edge of the Indian plate, whereas Khyber-Pakhtunkhwa and Baluchistan are located on the Eurasian plate. Azad Kashmir and the Northern Areas are vulnerable to powerful earthquakes since they are located where two tectonic plates intersect.

4.5. Hazard and Weighting Factors for Heatwave

To assign heatwave-hazard scores for all districts, firstly, the frequency intervals were determined so that the data should be uniformly distributed. Due to a large number of heatwaves, eight classes of frequency were taken. A weighting factor of 1 is given to the districts that have not been affected by any heatwave in the past 72 years. Further, 0.1 is gradually added in the preceding weighting factor for every next frequency class. The intensity of prior heatwave effects and their recurrence frequency are used to determine the hazard factors for each district. A hazard factor of 3 (for less frequency) or 5 (for higher frequency) is assigned to districts that have experienced such events at least once, while 1 is given to districts that have not experienced them. Table 8 displays several heatwave frequency classifications together with the related weighting and hazard factors. Additionally, heatwave-hazard ratings for districts are determined by multiplying the hazard and weighting factors for related occurrences, as seen in Table 8.

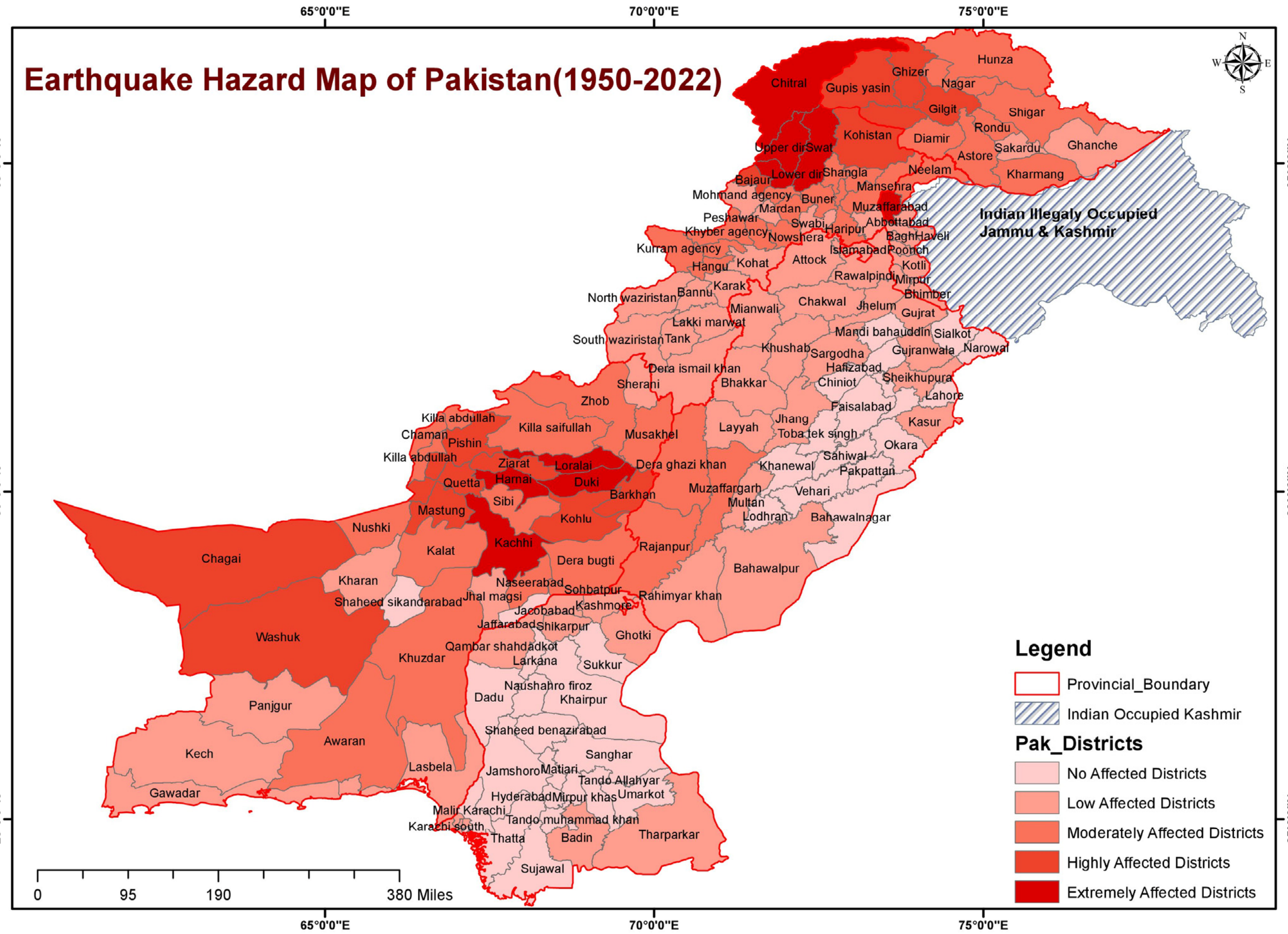

Figure 6. Earthquake-Hazard Map of Pakistan 1950–2022.

Table 8. Calculation of Drought Hazard score based on weighting and hazard factors.

Heatwave Frequency	Number Districts	Weighting Factor	Hazard Factor	Hazard Score (Weighting Factor × Hazard Factor)
0	106	1	1	1
1–2.	6	1.1	2	2.2
3–4.	14	1.2	3	3.6
5–6.	8	1.3	4	5.2
7–8.	7	1.4	5	7
9–10.	5	1.5	5	7.5
11–12.	9	1.6	5	8
13–above	3	1.7	5	8.5

After calculating the hazard scores for each district, the heatwave-hazard scores were classified into five categories. These categories contain nil for the districts where no heatwave happened in the past 72 years, and the preceding categories consist of low, moderate, high, and extremely heatwave-affected areas. The cumulative heatwave-hazard ratings were categorized using an even-interval approach. A heatwave-hazard zoning map was created based on the data supplied by Table A5 (provided in Appendix A). This table lists the districts lying in different heatwave-hazard zones. It shows that fourteen districts (Dadu, Jacobabad, Khairpur, Korangi, Malir, Rahim Yar Khan, Sibbi, Sukkur, Karachi

Central, Karachi East, Karachi South, and Karachi West) lie in the extremely affected heatwave zone.

As discussed above, Pakistan is facing the problem of a rise in average temperature due to climate change. Heatwaves in Pakistan are now becoming more common day by day. Figure 7 shows that most of the districts of south Punjab and several districts of Sindh face heatwaves. Further, the biggest city in Pakistan, Karachi, is experiencing heatwaves. District Chaghi and Kech of Baluchistan were also highly affected by heatwaves in the past. In many Pakistani cities, rapid and unsustainable development has intensified the impact of urban heatwaves. Deforestation is also a major cause of heatwaves in Pakistan. Further, global climatic change trends are a major cause of increasing trends of heatwaves in Pakistan.

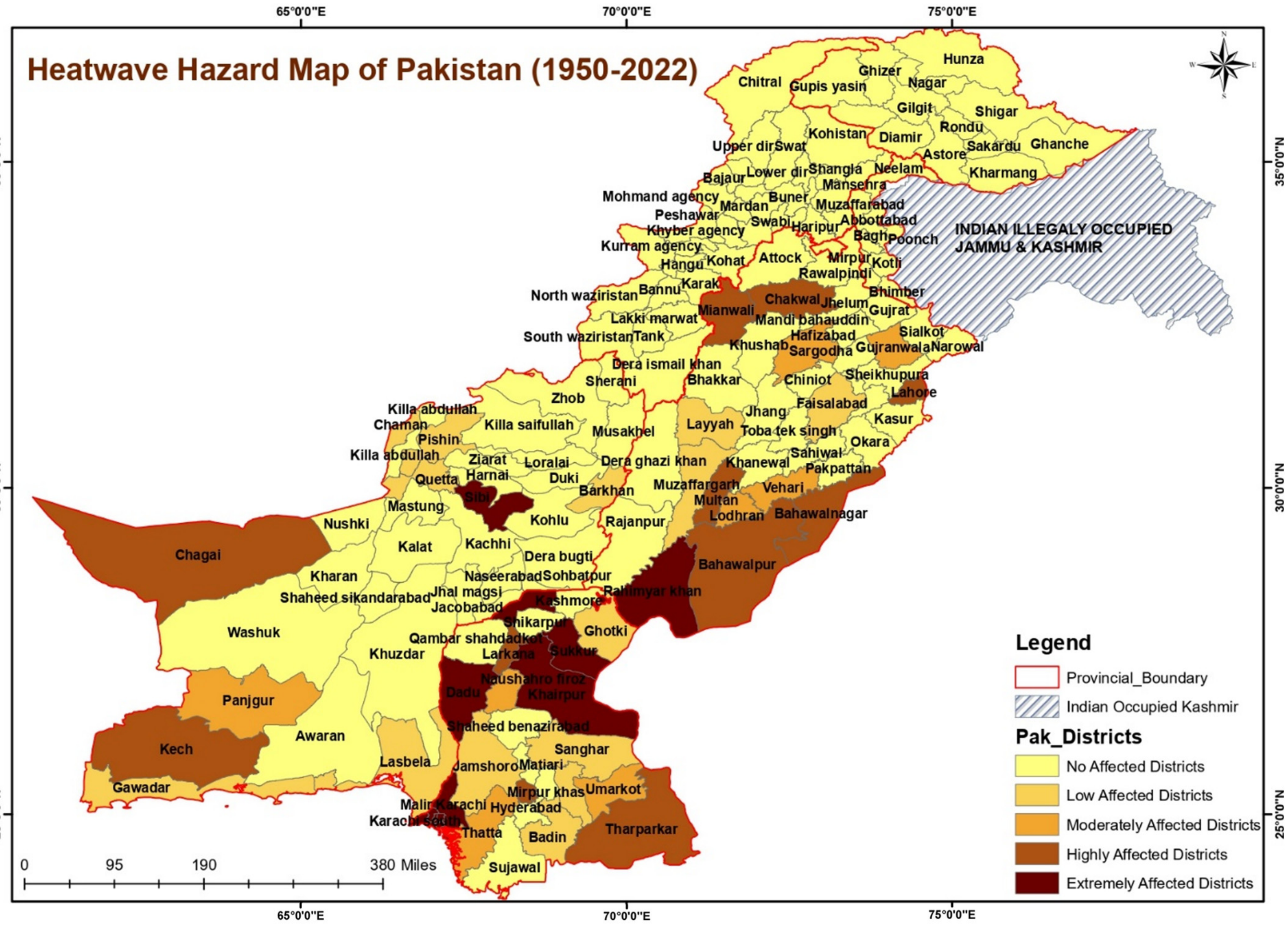

Figure 7. Heatwave-Hazard Map of Pakistan 1950–2022.

4.6. Multi-Hazard Score of Individual Districts

The basic purpose of this research is to produce a multi-hazard map showing spatial variations in natural hazards in the past. We computed the total multi-hazard scores by adding district-wise hazard scores for five hazards. We then classified the multi-hazard scores for all districts into four categories: low, moderate, high, and extreme. An even-interval classification system was used for cumulative multi-hazard ratings for all 158 districts of Pakistan, as given in Table 9. A maximum multi-hazard score of 28.6 was for the districts Chaghi and Chitral. Chaghi is the most vulnerable to natural hazards due to less precipitation and its vulnerability to earthquakes, while a large number of landslides and floods in Chitral district gave it the highest value on this list. Moreover, Nankana Sahib has the lowest value of 5 for the multi-hazard score as it has not faced any natural hazard for the period of 1950–2022.

Table 9. Calculation of District-wise Multi-Hazard Score.

Sr. No	Districts	Droughts (a)	Floods (b)	Earthquake (c)	Landsides (d)	Heatwave (e)	Multi-Hazard Score (a + b + c + d + e)
1	Abbottabad	1	7	3.6	7.5	0	20.1
2	Astore	1	3.6	5.6	9	1	20.2
3	Attock	1	3.3	3.6	7	1	15.9
4	Awaran	3.6	3.6	5.2	1	1	14.4
5	Badin	6.5	6.5	3.3	1	3.6	20.9
6	Bagh	1	3.6	3.6	8	1	17.2
7	Bahawalnagar	3.6	1	1	1	7	13.6
8	Bahawalpur	3.3	6.5	3.6	1	7	21.4
9	Bajaur	1	3.6	7.5	3.3	1	16.4
10	Bannu	1	3.6	3.6	1	1	10.2
11	Barkhan	3.6	3.6	7.5	1	3.6	19.3
12	Batagram	1	6.5	5.6	7.5	1	21.6
13	Bhakkar	3.3	3.6	3.3	1	2.2	13.4
14	Bhimber	1	3.3	3.3	1	1	9.6
15	Buner	1	3.6	5.2	8	1	18.8
16	Chagai	7.5	3.3	7.5	3.3	7	28.6
17	Chakwal	1	3.3	3.3	1	7	15.6
18	Chaman	6.5	6.5	5.2	1	3.6	22.8
19	Charsadda	1	7	3.6	3.9	1	16.5
20	Chitral	3.6	7	0	8.5	1	20.1
21	Chiniot	1	6.5	1	1	1	10.5
22	Dadu	7	8	1	1	8	25
23	Dera Bugti	3.6	6.5	5.6	1	1	17.7
24	Dera Ghazi Khan	3.6	7.5	5.2	1	1	18.3
25	Dera Ismail Khan	3.3	6.5	3.3	3.3	1	17.4
26	Diamer	1	6.5	5.2	9	1	22.7
27	Duki	6.5	3.3	8.5	1	1	20.3
28	Faisalabad	1	3.6	1	1	3.6	10.2
29	Ghanche	1	6.5	3.3	8.5	1	20.3
30	Ghizer	1	3.6	7.5	7.5	1	20.6
31	Ghotki	6.5	7	3.3	1	3.6	21.4
32	Gilgit	1	7	7.5	9	1	25.5
33	Gujranwala	1	3.3	3.3	1	5.2	13.8
34	Gujrat	1	3.3	3.3	1	1	9.6
35	Gupis Yasin	1	3.6	7.5	7.5	1	20.6
36	Gwadar	7	6.5	3.3	1	3.6	21.4
37	Hafizabad	1	3.3	1	1	1	7.3
38	Hangu	1	3.3	5.2	3.9	1	14.4
39	Haripur	1	3.6	5.2	8	1	18.8
40	Harnai	7	3.6	8	1	1	20.6
41	Hattian	1	3.6	3.6	1	1	10.2
42	Haveli	1	3.6	3.6	8	1	17.2

Table 9. *Cont.*

Sr. No	Districts	Droughts (a)	Floods (b)	Earthquake (c)	Landsides (d)	Heatwave (e)	Multi-Hazard Score (a + b + c + d + e)
43	Hunza	1	3.6	5.2	9	1	19.8
44	Hyderabad	7	7	1	3.3	7.5	25.8
45	Islamabad	1	3.6	3.6	1	2.2	11.4
46	Jacobabad	3.6	7	3.3	1	8	22.9
47	Jaffarabad	3.6	7.5	1	1	1	14.1
48	Jamshoro	7	7	1	1	3.6	19.6
49	Jhal Magsi	6.5	6.5	3.3	1	1	18.3
50	Jhang	3.3	7	3.3	1	1	15.6
51	Jhelum	1	3.3	3.3	1	1	9.6
52	Kachhi	6.5	3.6	8	1	1	20.1
53	Kalat	6.5	6.5	5.2	1	1	20.2
54	Karachi Central	3.3	6.5	3.3	1	8	22.1
55	Karachi East	3.3	7	3.3	3.3	8	24.9
56	Karachi South	3.3	7	3.3	3.3	8	24.9
57	Karachi West	3.3	7	3.3	1	8	22.6
58	Karak	1	6.5	3.6	3.9	1	16
59	Kashmore	3.6	6.5	3.3	1	1	15.4
60	Kasur	1	3.3	3.3	1	1	9.6
61	Kech	7	7.5	3.6	1	7	26.1
62	Khairpur	6.5	7	1	1	8.5	24
63	Khanewal	3.3	3.3	1	1	1	9.6
64	Kharan	7	3.3	3.6	1	1	15.9
65	Kharmang	1	3.6	5.6	8	1	19.2
66	Khushab	3.3	3.3	3.3	1	2.2	13.1
67	Khuzdar	3.6	7.5	5.2	1	1	18.3
68	Khyber Agency	1	3.6	5.2	3.9	1	14.7
69	Killa Abdullah	6.5	6.5	5.6	1	1	20.6
70	Killa Saifullah	3.6	6.5	5.2	1	1	17.3
71	Kohat	1	3.6	3.6	1	1	10.2
72	Kohlu	3.6	6.5	7.5	1	1	19.6
73	Kolai Pallas	1	1	7.5	1	1	11.5
74	Korangi	3.3	3.3	1	1	8	16.6
75	Kotli	1	3.3	3.3	1	1	9.6
76	Kurram Agency	1	3.6	5.2	3.9	1	14.7
77	Lahore	1	7	1	1	7	17
78	Lakki Marwat	3.3	3.6	3.6	1	1	12.5
79	Larkana	6.5	7	1	1	7.5	23
80	Lasbela	3.3	7	3.3	1	3.6	18.2
81	Layyah	3.3	6.5	3.6	1	3.6	18
82	Lodhran	3.3	3.3	1	1	5.2	13.8
83	Loralai	3.3	3.6	8	1	1	16.9
84	Lower Dir	1	3.6	0	3.6	1	9.2
85	Lower Kohistan	1	7	7.5	9	1	25.5
86	Malakand	1	6.5	5.6	7	1	21.1

Table 9. *Cont.*

Sr. No	Districts	Droughts (a)	Floods (b)	Earthquake (c)	Landsides (d)	Heatwave (e)	Multi-Hazard Score (a + b + c + d + e)
87	Malir	3.3	3.6	1	1	8	16.9
88	Mandi Bahauddin	1	3.3	1	1	1	7.3
89	Mansehra	1	6.5	5.6	9	1	23.1
90	Mardan	1	7	5.2	1	1	15.2
91	Mastung	3.6	3.3	7.5	1	1	16.4
92	Matiari	6.5	3.6	1	1	1	13.1
93	Mianwali	3.3	3.6	3.3	3.6	7	20.8
94	Mirpur Khas	3.6	7	1	3.9	3.6	19.1
95	Mirpur	1	6.5	3.3	1	1	12.8
96	Mohmand Agency	1	6.5	3.6	1	1	13.1
97	Multan	3.3	6.5	3.6	1	7.5	21.9
98	Musakhel	3.3	3.6	5.6	1	1	14.5
99	Muzaffarabad	1	6.5	5.2	9	1	22.7
100	Muzaffargarh	3.3	7	5.2	1	3.6	20.1
101	Nagar	1	3.6	5.2	8.5	2.2	20.5
102	Nankana Sahib	1	1	1	1	1	5
103	Narowal	1	6.5	1	1	1	10.5
104	Naseerabad	3.6	7.5	5.2	1	1	18.3
105	Naushahro Firoze	3.6	3.6	1	1	5.2	14.4
106	Nawab Shah	7	3.3	1	1	7.5	19.8
107	Neelum	1	7.5	5.6	7.5	1	22.6
108	North Waziristan	1	3.6	3.6	3.9	1	13.1
109	Nowshera	1	6.5	5.2	3.9	1	17.6
110	Nushki	7.5	3.3	5.2	3.3	1	20.3
111	Okara	1	3.3	1	1	1	7.3
112	Orakzai agency	1	3.6	5.2	3.9	1	14.7
113	Pakpattan	3.3	1	1	1	1	7.3
114	Panjgur	7	3.3	3.6	1	5.2	20.1
115	Peshawar	1	7.5	5.2	1	2.2	16.9
116	Pishin	6.5	7	7.5	1	3.6	25.6
117	Poonch	1	3.3	3.6	3.6	1	12.5
118	Qambar Shahdadkot	7	7	3.3	1	1	19.3
119	Quetta	6.5	6.5	7.5	1	3.6	25.1
120	Rahim Yar Khan	3.3	3.6	3.3	1	8.5	19.7
121	Rajanpur	3.3	7.5	5.6	1	1	18.4
122	Rawalpindi	1	7	3.3	8.5	2.2	22
123	Rondu	1	1	5.6	1	1	9.6
124	Sahiwal	3.3	3.3	1	1	1	9.6
125	Sanghar	6.5	3.6	1	1	3.6	15.7
126	Sargodha	1	3.3	3.3	1	5.2	13.8
127	Shaheed Benazirabad	6.5	3.6	1	1	1	13.1
128	Shaheed Sikandarabad	6.5	3.3	1	1	1	12.8
129	Shangla	1	7.5	5.6	8.5	1	23.6
130	Sheikhupura	1	3.3	3.3	1	1	9.6

Table 9. *Cont.*

Sr. No	Districts	Droughts (a)	Floods (b)	Earthquake (c)	Landsides (d)	Heatwave (e)	Multi-Hazard Score (a + b + c + d + e)
131	Sherani	3.6	3.6	3.3	1	1	12.5
132	Shigar	1	3.6	5.6	8	1	19.2
133	Shikarpur	3.6	7	3.3	1	1	15.9
134	Sialkot	1	7	1	1	1	11
135	Sibbi	6.5	6.5	5.6	1	8	27.6
136	Skardu	1	6.5	3.6	7.5	1	19.6
137	Sohbatpur	3.6	7	5.6	1	1	18.2
138	South Waziristan	1	3.3	3.3	1	1	9.6
139	Sudhnutti	1	3.6	3.6	1	1	10.2
140	Sujawal	1	3.6	1	1	1	7.6
141	Sukkur	3.6	6.5	1	3.3	8.5	22.9
142	Swabi	1	6.5	3.6	3.9	1	16
143	Swat	1	8	0	7.5	1	17.5
144	Tando Allahyar	3.6	3.6	1	1	1	10.2
145	Tando Muhammad Khan	6.5	3.6	1	1	1	13.1
146	Tangir	1	1	5.2	1	1	9.2
147	Tank	3.3	3.3	3.3	1	1	11.9
148	Tharparkar	7.5	3.6	3.3	1	7.5	22.9
149	Thatta	7	7	1	1	5.2	21.2
150	Toba Tek Singh	1	3.6	1	1	1	7.6
151	Torghar	1	7.5	5.6	7.5	1	22.6
152	Umerkot	7	3.6	1	1	5.2	17.8
153	Upper Dir	1	7.5	0	8.5	1	18
154	Upper Kohistan	1	3.6	7.5	1	1	14.1
155	Vehari	3.3	3.3	1	1	5.2	13.8
156	Washuk	7.5	3.3	7.5	1	1	20.3
157	Zhob	3.6	6.5	5.6	1	1	17.7
158	Ziarat	1	6.5	7.5	1	1	17

4.7. Spatial Variations and a Multi-Hazard Map of Pakistan

For each hazard, district-level hazard scores are first computed. Then, these hazard scores of droughts, floods, heatwaves, landslides, and earthquakes are added to find a cumulative multi-hazard score. Hazard factors are ranked according to how often they occur and how badly they affect a certain area. Multi-hazard scores were rated on a 4-point scale, with 1 denoting no risk and 4 denoting significant risk. After calculating each district's multi-hazard ratings, the scores were divided into four groups. These groups include low, moderate, high, and extremely multi-hazard-affected areas. The system of categorization for cumulative multi-hazard ratings was even-interval. As a result, a multi-hazard zoning map was created using the data in Table 10. This table lists the districts lying in different multi-hazard zones. Table 10 shows that seven districts (Hafizabad, Mandi Bahauddin, Nankana Sahib, Okara, Pakpattan, Sujawal, and Toba Tek Singh) lie in the less-affected multi-hazard zone, while fifteen districts, namely Chagai, Chitral, Dadu, Gilgit, Hyderabad, Karachi East, Karachi South, Kech, Lower Kohistan, Muzaffarabad, Pishin, Quetta, Sibbi, Swat, and Upper Dir, lie in the extremely affected multi-hazard zone.

Table 10. District-wise Multi-Hazard Zones.

Multi Hazards Scores	Multi Hazards Zone	Districts
1.0–8.0	**Low**	**N = 7** Hafizabad, Mandi Bahauddin, Nankana Sahib, Okara, Pakpattan, Sujawal and Toba Tek Singh
8.1–16.0	Moderate	**N = 59** Attock, Awaran, Bahawalnagar, Bannu, Bhakkar, Bhimber, Chakwal, Chiniot, Faisalabad, Gujranwala, Gujrat, Hangu, Hattian, Islamabad, Jaffarabad, Jhang, Jhelum, Karak, Kashmore, Kasur, Khanewal, Kharan, Khushab, Khyber Agency, Kohat, Kolai Pallas, Kotli, Kurram Agency, Lakki Marwat, Lodhran, Mardan, Matiari, Mirpur, Mohmand Agency, Musakhel, Narowal, Naushahro Firoze, North Waziristan, Orakzai agency, Poonch, Rondu, Sahiwal, Sanghar, Sargodha, Shaheed Benazirabad, Shaheed Sikandarabad, Sheikhupura, Sherani, Shikarpur, Sialkot, South Waziristan, Sudhnutti, Swabi, Tando Allahyar, Tando Muhammad Khan, Tangir, Tank, Upper Kohistan, Vehari
16.1–24.0	High	**N = 77** Abbottabad, Astore, Badin, Bagh, Bahawalpur, Bajaur, Barkhan, Batagram, Buner, Chaman, Charsadda, Dera Bugti, Dera Ghazi Khan, Dera Ismail Khan, Diamer, Duki, Ghanche, Ghizer, Ghotki, Gupis Yasin, Gwadar, Haripur, Harnai, Haveli, Hunza, Jacobabad, Jamshoro, Jhal Magsi, Kachhi, Kalat, Karachi Central, Karachi West, Khairpur, Kharmang, Khuzdar, Killa Abdullah, Killa Saifullah, Kohlu, Korangi, Lahore, Larkana, Lasbela, Layyah, Loralai, Lower Dir, Malakand, Malir, Mansehra, Mastung, Mianwali, Mirpur Khas, Multan, Muzaffargarh, Nagar, Naseerabad, Nawab Shah, Neelum, Nowshera, Nushki, Panjgur, Peshawar, Qambar Shahdadkot, Rahim Yar Khan, Rajanpur, Rawalpindi, Shangla, Shigar, Skardu, Sohbatpur, Sukkur, Tharparkar, Thatta, Torghar, Umerkot, Washuk, Zhob, Ziarat
24.1–Above	Extreme	**N = 15** Chagai, Chitral, Dadu, Gilgit, Hyderabad, Karachi East, Karachi South, Kech, Lower Kohistan, Muzaffarabad, Pishin, Quetta, Sibbi, Swat, Upper Dir

Figure 8 is a pictorial representation of the frequency of occurrence and severity of these multiple hazards in different districts of Pakistan. District Kech and the western district of Baluchistan, Northern districts of province Sindh, northern districts of KPK, and some districts in Gilgit Biltistan lie in the Extremely Affected Zone, while most of the northeastern districts of the province of Punjab lie in the lowest-affected zone by these multi-hazards. The high values of multi-hazards for the districts in the province are mainly due to frequent heatwaves and floods. The districts of Baluchistan have high multi-hazard scores due to frequent droughts, while the districts in KPK and Gilgit Baltistan have high values of multi-hazard scores due to frequent landslides and earthquakes.

4.8. Different Combinations of Hazards

It is also important to discuss which types of hazards occur in specific districts, to observe whether a specific district is experiencing all five natural hazards discussed in this research work or whether it is experiencing any one, two, three, or four natural hazards combination. Further, it is important to know which one, two, three, or four hazards are occurring in a specific district. This section will discuss the districts, if any, which are impacted by only one, two, three, four, or all five natural hazards. For this purpose, different combinations between these five natural hazards were derived. These combinations are presented in Figure 9. This figure describes all possible combinations between the natural hazards. All 158 districts of Pakistan were further categorized based on these combinations. These districts are pictorially presented in Figure 10.

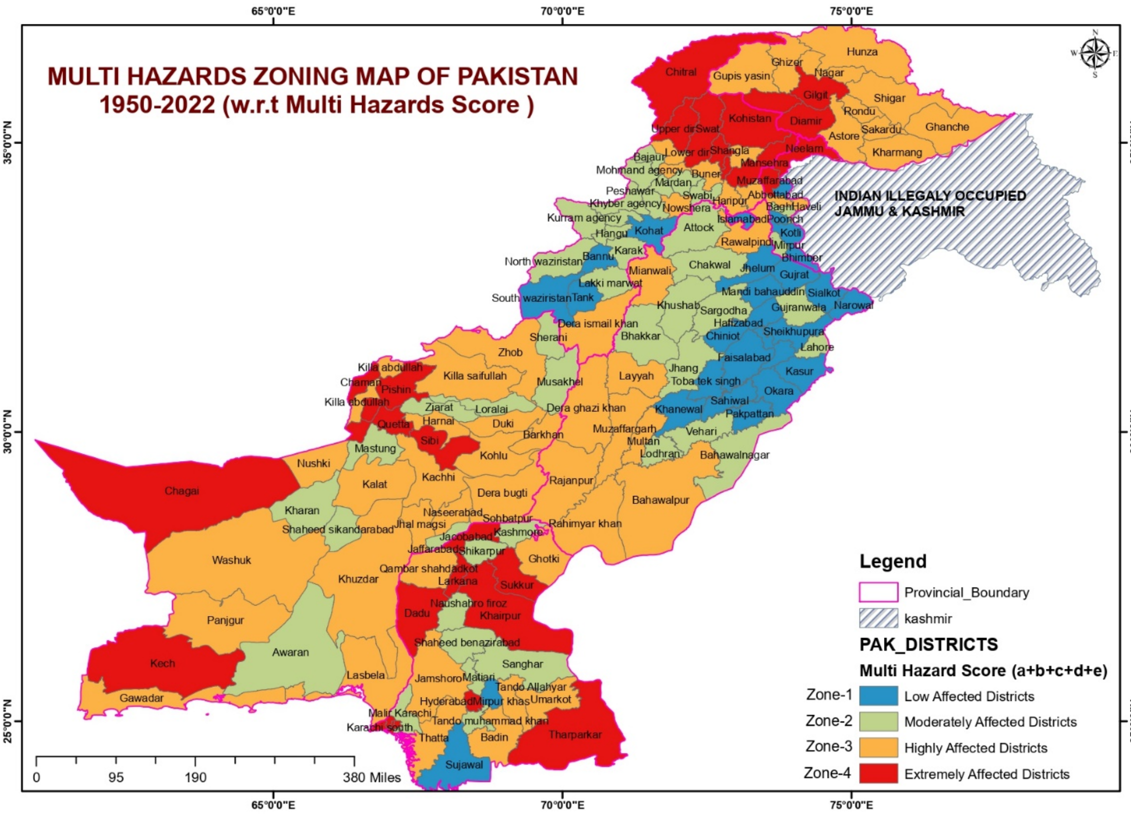

Figure 8. Multi-Hazard Zoning Map of Pakistan 1950–2022 regarding Hazard Score.

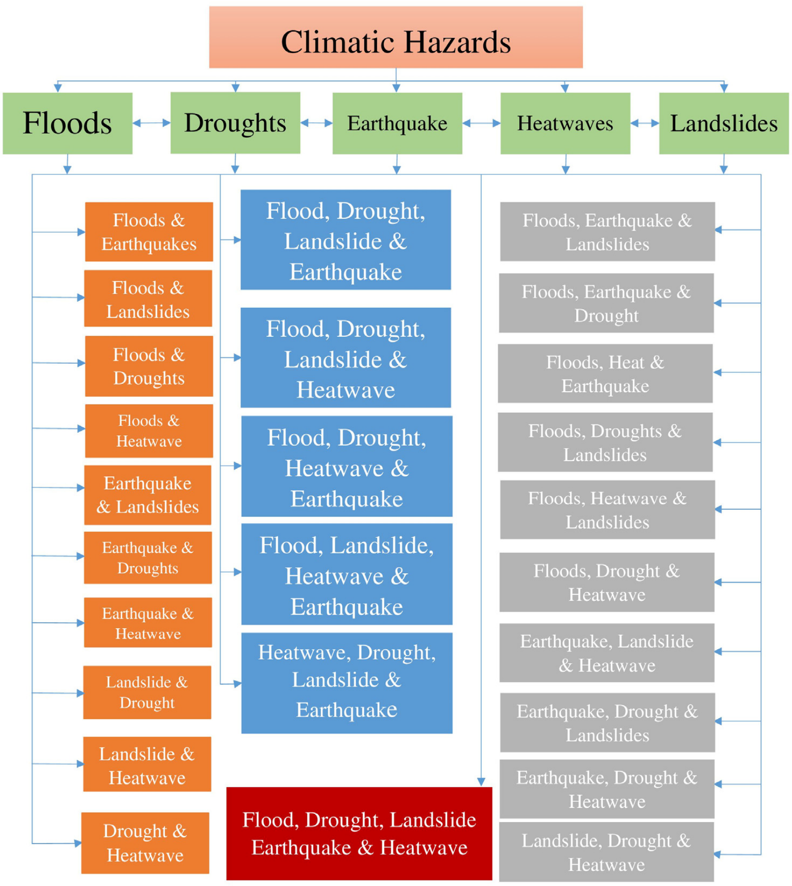

Figure 9. Different combinations of hazards chart under study.

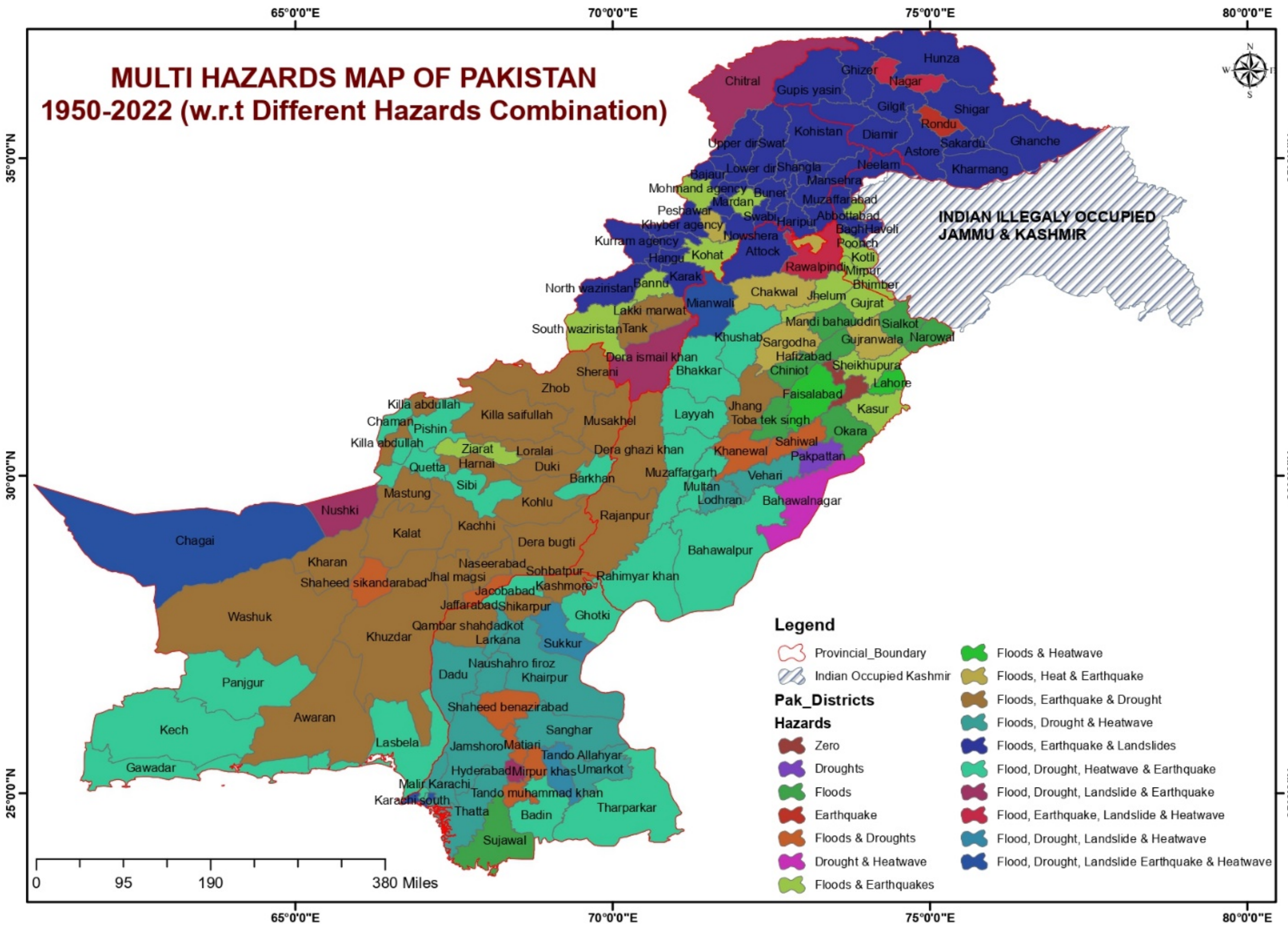

Figure 10. Multi-Hazard Map of Pakistan 1950–2022 with regard to Hazard Combinations.

Figure 10 shows different districts of Pakistan, which are experiencing several natural hazards. Most of the districts of Gilgit Baltistan are facing Floods, Earthquakes, and Landslides, while most of the districts of Baluchistan are experiencing Floods, Earthquakes, and Drought. The central districts of Sindh are facing Floods, Droughts, Landslides, and heatwaves. The districts of south Punjab are experiencing floods and heatwaves.

5. Discussion

Pakistan has a vast latitudinal range, with a significant amount of seasonal rainfall variation. Every season, certain parts of the nation experience extreme dryness and are, thus, at risk of drought. The areas will be engulfed in drought conditions if succeeding seasons fail to provide considerable precipitation. The nation is often affected by these circumstances, particularly in the south [103]. All of Sindh, a portion of Northeast Balochistan around Sibi and Kalat, coastal regions of Balochistan, and the western portion of Balochistan near Nokundi stay dry for more than half of the year when the location is seen in the perspective of the % driest times. Every four to five years, Pakistan's rainfall patterns indicate severe drought danger [104]. Moreover, in the study of drought monitoring for a period of 1983 to 2010, the districts Chagai, Kharan, Gawadar, Awaran, Kech from Baluchistan province and Dadu, Sakhar, Khairpur, Nawab Shah, Jacobabad, Shikarpur, Nowshehro Feroz, and Larkana from Sindh were categorized as severely affected by droughts. From previous studies, i.e., Naz et al., Sheikh, and Shumaila-Sadiq [103–105], it can be assessed that droughts in Pakistan are mainly due to less and uneven rainfall. Due to their unexpected nature, droughts are a natural calamity that affect broad regions and people [106]. Sindh and Baluchistan are the two provinces that experience the worst droughts, according to the meteorological drought intensity map. However, it is clear from the map that Punjab and KPK are now also drought-affected regions.

Our findings are consistent with the following on the severity of meteorological droughts in Sindh and Balochistan [65]. These provinces are especially susceptible to droughts since they are in a hyper-arid climate zone. Ahmad et al. [107] draw the conclusion from their study that repeated droughts and overuse of groundwater are to blame for the significant fall in the water table in the severely afflicted regions. Seasonal droughts in Pakistan are significantly impacted by changes in precipitation brought by large-scale meteorological phenomena, including monsoons and western disturbances, caused by global warming [108]. This is due to increased precipitation in monsoons over a few places in the north and a reduction in monsoons across areas of the country's southern and western regions, which have traditionally been more susceptible to droughts [108,109]. This study recognized that the districts Chagai, Nushki, Tharparkar, and Washuk are mostly affected by droughts. As droughts are mainly caused due to less precipitation, there is a need to take special steps, such as water supply, through irrigation channels to meet this water deficiency.

Extreme rainfall occurrences during the summer monsoon are associated with an increase in sea surface temperature (SST) in the Arabian Sea [110–112]. Extreme precipitation is more likely when the Arabian Sea's high SST enhances the convection process and starts to carry moist air toward the land. Due to their proximity to the shore, the most populous cities in Sindh, Karachi, and Hyderabad are subject to severe floods and windstorms during the significant cyclonic activity in the Arabian Sea [113]. Floods are the most-known climatic hazard in Pakistan. The floods in 2010 and 2022 affected nearly $\frac{3}{4}$ of the country. In Pakistan, during the monsoon season, extreme precipitation events exhibit complex and irregular geographical patterns. The weather in southern Pakistan is warm and becoming much warmer [114]. In the study of Scoccimarro et al. [115], researchers looked at heavy precipitation occurrences in warm climates and projected that towards the end of the twenty-first century, excessive precipitation would occur more often. Ikram et al. [116] also discovered that southern Pakistan's coastal regions, such as Karachi and Badin, are more susceptible to excessive precipitation. The frequency and severity of these catastrophes are predicted to increase due to climate change. The nation is expected to see considerable temperature rises (high confidence), particularly in the snow-covered mountainous north, which would hasten glacier melt and alter the course of the Indus River downstream. Bahawalpur, Faisalabad, Mianwali, Multan, Sargodha, and Rahim Yar Khan were the principal areas in interior Punjab devastated by severe occurrences (drought and flooding) [117]. Understanding the patterns of severe climatic events (such as floods and droughts) and implementing the recommended adaptation techniques are crucial to prevent further occurrences of such extremes. In order to prepare appropriately to lessen the negative effects of these climatic extremes in the future, it would be helpful to understand the climatic extremes (floods and droughts) in Pakistan. The challenge of managing floods in Pakistan calls for both enormous resources and in-depth knowledge of the issue. Due to disparate physiographic, meteorological, hydrologic, demographic, and socioeconomic characteristics, the type of floods varies greatly throughout the country [71]. The increasing trend of precipitation during monsoon seasons is causing flooding in Pakistan and increasing flooding events have been observed during the last two decades. The recent flood in 2022 is the worst example of flood vulnerability in Pakistan due to climatic changes being faced by Pakistan. This study recognized the following 13 districts, Dadu, Dera Ghazi Khan, Jaffarabad, Kech, Khuzdar, Naseerabad, Neelum, Peshawar, Rajanpur, Shangla, Swat, Torghar, and Upper Dir, as extremely affected by floods in the past. The previous trends describe that these districts as well as the districts that lie in the second-most highly affected zone in this study may be categorized at the verge of this catastrophic natural hazard.

Landslides can happen for a variety of reasons, such as environmental factors, including the deterioration of rock over time, flash floods, and rainfall, that can cause rock falls, slope constructions that make the slope weak enough for an earth mass (a combination of mud and rock) to slide downhill, or natural phenomena, such as earthquakes [118,119]. Landslides and mountain or hill slope collapses have a strong link. These landslides are more dangerous for the lowlands because weathering, deforestation, and other human-caused activities make mountainsides more vulnerable [120–122]. The majority of recorded earthquakes in Pakistan's earthquake-prone north are responsible for the majority of the country's landslides, along with heavy rains [123,124]. According to several studies conducted globally, intense rainfall is the primary cause of landslides. Pakistan experiences this problem since the Monsoon season brings the country's heaviest rainfall [125–128]. Due to the large majority of people living near riverbanks, Punjab has also had very few landslides. The Rawalpindi district, which contains the mostly mountainous area of Murree, is an exception to the generally sparsely populated hilly terrains and northeastern region. A massive landslide that blocked the whole Hunza river and built an artificial lake near Attabad in the Hunza valley caused a tragedy in 2010. Thousands of people, however, were forced to abandon their houses because of the flooding. We believe that the analysis in this paper will inspire others to conduct additional research on the impact of climate change, in particular, temperature increases/decreases, along with historical dynamics of rainfall, floods, and seismic activity, etc. This paper identified the regions in Pakistan that are most vulnerable to landslides. Khattak et al. [79] investigated the whole AJK and found that every landslide is close to a river or a road. It is predicted that practically the whole landmass of AJK is susceptible to rains and earthquakes of various magnitudes, and that landslides on steep slopes are also caused by other causes, such as deforestation and road development. This study recognized Astore, Chitral, Diamer, Ghanche, Gilgit, Hunza, Lower Kohistan, Mansehra, Muzaffarabad, Nagar, Rawalpindi, Shangla, and Upper Dir districts as extremely affected by landslides in the past, while the districts of Abbottabad, Attock, Bagh, Batagram, Buner, Ghizer, Gupis Yasin, Haripur, Haveli, Kharmang, Malakand, Neelum, Shigar, Skardu, Swat, and Torghar are categorized as highly affected in the past. According to [129], Pakistan's Kaghan, Karachi, Hyderabad, Sukkar, Kohistan, Kalam, Azad Kashmir, Dir, and Gilgit Baltistan have all had landslides in the past. As a result, landslides may occur across Pakistan's majority of hilly regions in the future. Due to population development and unchecked settlements on or near unstable slopes in hilly locations, landslides have become more frequent in recent years, with a corresponding rise in the number of human casualties and damage to property.

Pakistan is one of the seismically active regions in Asia. It is situated at the confluence of three plate boundaries—the Indian, Eurasian, and Arabian—and has a high density of active faults. Past high-magnitude earthquakes in Pakistan have caused the destruction of infrastructure, property, and lives. The most severe earthquakes resulted in tens of thousands of fatalities in Kashmir in 2005 and Quetta in 1935 [90]. Because major population centers, such as Islamabad, Quetta, Karachi, Muzaffarabad, and Peshawar, are situated on or near significant faults, there is an urgent need to create and execute new construction rules. Additionally, the general population should be made aware of the risk of earthquakes [90]. Pakistan is prone to frequent, destructive earthquakes. Pakistan's northern regions (e.g., Muzaffarabad, Manshera, Abbottabad) and western Pakistan (e.g., Quetta, Ziarat) have frequent earthquakes that have, in the past, resulted in enormous damage [130]. Pakistan's central and eastern regions are thought to be generally secure from significant seismic activity. However, these areas also felt strong shaking from the earthquakes coming from the north and west, suggesting that no part of the nation is immune to these earthquakes [130]. This research work recognized that Chitral, Duki, Harnai, Kachhi, Loralai, Lower Dir, Muzaffarabad, Swat, and Upper Dir are the districts that are extremely affected by earthquakes in Pakistan. Moreover, Astore, Bajaur, Barkhan, Batagram, Chagai, Dera Bugti, Ghizer, Gilgit, Gupis Yasin, Kharmang, Killa Abdullah, Kohlu, Kolai Pallas, Lower Kohistan, Malakand, Mansehra, Mastung, Musakhel, Neelum, Pishin, Quetta, Rajanpur, Rondu, Shangla, Shigar, Sibbi, Sohbatpur, Torghar, Upper Kohistan, Washuk, Zhob, and Ziarat are the districts that lie in the highly affected districts in the past. These districts may be classified as the most-vulnerable districts to earthquakes in future in Pakistan.

Extreme temperature occurrences have drawn much attention in recent years due to their threat to elevated mortality risk. Furthermore, according to climate change projections, there will likely be an increase in the likelihood of very high temperatures occurring in most places in the future [131]. One of the immediate and definite effects of increasing temperatures brought on by global warming is an increase in the frequency and intensity of heatwaves [87]. Therefore, determining the spatial distribution of sensitive zones and developing adaptation and mitigation strategies to increase resistance to growing heatwaves need an examination of the spatial and temporal features of heatwaves and their variations [132]. Zahid and Rasul et al. [133] wrote that Pakistan's heatwaves are defined as having temperatures exceeding 40 °C and 45 °C for a consecutive 5 and 7 days, respectively. Saeed et al. [134] deemed 45 °C or above for five straight days in Pakistan when predicting future heatwaves. Nasim et al. [135] utilized the same criteria but classified heatwaves based on topography, with temperatures 5–6 °C above the mean maximum for 8 straight days. Damage caused by heatwaves depends on several factors, including the length of the peak temperature, the region affected, the temperature at night, etc. Overall, the findings indicated that the southwest region of the nation experienced the nation's most frequent and prolonged heatwaves [87]. According to many studies, Pakistan saw an increase in temperature-related severe occurrences as a result of rising temperatures [81,133,136,137] and neighboring regions [138–142]. Del Rio et al. [143] discovered that between 1965 and 2009, the frequency of severe maximum temperature incidents increased nationwide. Heatwaves often result in fatalities and are Pakistan's main temperature-related worry [144]. Several studies also revealed heatwaves' high implications on Pakistan's public health [145]. Over the years 1980 to 2007, the number of days with extreme heat rose by 31 days [146]. This study classified Dadu, Jacobabad, Karachi Central, Karachi East, Karachi South, Karachi West, Khairpur, Korangi, Malir, Rahim Yar Khan, Sibbi, and Sukkur as extremely affected by heatwaves. Bahawalnagar, Bahawalpur, Chagai, Chakwal, Hyderabad, Kech, Lahore, Larkana, Mianwali, Multan, Nawab Shah, and Tharparkar are the districts that are recognized as highly affected by heatwaves. Most districts lie in southwest Pakistan, which may be considered vulnerable to heatwaves in the future.

The basic purpose of this study was to propose a multi-hazard (drought, floods, earthquake, landslides, and heatwaves) map of Pakistan, depending upon the number of past event occurrences in the past for the period of 1950–2022. For this purpose, an author-based dataset is prepared from the data available from different sources. The multi-hazard study of Pakistan has shown that the districts of Chaghi, Chitral, Dadu, Gilgit, Hyderabad, Karachi East, Karachi South, Kech, Lower Kohistan, Muzaffarabad, Pishin, Quetta, Sibbi, Swat, and Upper Dir were extremely affected by these natural hazards in the past, while the districts of Abbottabad, Astore, Badin, Bagh, Bahawalpur, Bajaur, Barkhan, Batagram, Buner, Chaman, Charsadda, Dera Bugti, Dera Ghazi Khan, Dera Ismail Khan, Diamer, Duki, Ghanche, Ghizer, Ghotki, Gupis Yasin, Gwadar, Haripur, Harnai, Haveli, Hunza, Jacobabad, Jamshoro, Jhal Magsi, Kachhi, Kalat, Karachi Central, Karachi West, Khairpur, Kharmang, Khuzdar, Killa Abdullah, Killa Saifullah, Kohlu, Korangi, Lahore, Larkana, Lasbela, Layyah, Loralai, Lower Dir, Malakand, Malir, Mansehra, Mastung, Mianwali, Mirpur Khas, Multan, Muzaffargarh, Nagar, Naseerabad, Nawab Shah, Neelum, Nowshera, Nushki, Panjgur, Peshawar, Qambar Shahdadkot, Rahim Yar Khan, Rajanpur, Rawalpindi, Shangla, Shigar, Skardu, Sohbatpur, Sukkur, Tharparkar, Thatta, Torghar, Umerkot, Washuk, Zhob, and Ziarat are categorized as highly affected by these natural hazards.

Inter-province comparison for each natural hazard and multi-hazards shows that these natural hazards are diversely distributed among all provinces. Floods affect different districts in all provinces, i.e., Rajanpur, Deraghazi Khan, Muzafar Garh, Sialkot, Rawalpindi, and Lahore in Punjab. Most of the districts in Sindh, i.e., Larkana, Malir, South Karachi, Tando Muhammad Khan, Hyderabad, Dadu, Nushehro Firoz, Qambar Shadad Kot, Ghotki, and Jacobabad, are found to be affected by floods. Some of the districts in the province

Baluchistan, i.e., Kech, Khuzdar, Naseerabad, and Pishin, are hardly hit by floods. Some east-northern districts in KPK, i.e., Chitral, Upper Dir, Sawat, Lower Dir, Shangla, and Peshawar, are threatened by floods. Five districts in Gilgit Baltistan, i.e., Rondo, Gilgit, Sakardu, Ganchi, and Gupis Yasin, are frequently flooded. District Neelum in Kashmir also faces floods usually, while, when observing the results of this study for earthquakes, it is found that no districts in the province Sindh and Punjab are severely affected districts due to earthquakes. Some districts in Baluchistan (Pishin, Loralai, Duki, Harnai, Kachhi, Kohlu, Mastung, Quetta, Chaghi, and Washuk), KPK (Chitral, Upper Dir, Lower Dir, and Sawat), Gilgit Baltistan (Ghizer, Gupis Yasin, Kohistan, and Gilgit), and Kashmir (Muzaffarabad) are experiencing earthquakes consistently. Droughts are specifically hitting most of the districts in Baluchistan and Sindh, while other provinces have no significant effects of droughts. Heatwaves are found to be repeatedly happening in some specific districts in the provinces Punjab (Rahimyar Khan, Bahawalpur, Bahawalnagar, Multan, Mianwali, Chakwal, and Lahor), Sindh (Sukkur, Khairpur, Dadu, Mirpur, Malir, Karachi Central, Karachi East, Karachi South, Karachi West, Khairpur, Korangi), and Baluchistan (Sibi, Kech, and Chaghi). Districts of Punjab, Sindh, and Baluchistan Provinces are not facing any major amount of landslides, while most of the northeastern districts of KPK and nearly all districts of Gilgit-Baltistan are experiencing landslides. The outputs of this study for multi-hazards depict that the province of Punjab has no district that may be extremely vulnerable to multi-hazards. A number of districts in Sindh are vulnerable to multi-hazards. Similarly, the northeastern districts in KPK are also highly vulnerable to multi-hazards. Therefore, there is a dire need to prescribe areal policies to mitigate the diverse nature of these natural hazards.

Predicting multi-hazard susceptibility is a crucial part of a catastrophe risk management strategy. A multi-hazard risk reduction plan that evaluates both the individual risks and their relationships will prove fruitful in Pakistan. This is especially true in view of the geographical nature and spatiotemporal characteristics of all provinces. This study also adds up the information by describing the frequent natural hazards occurring in particular districts, as shown in Figure 10. Special focus should be given to mitigating the specific hazards corresponding to particular districts. According to this study, 14 districts out of 158 are facing Floods, Drought, and Heatwave. Further, 5 districts out of 158 are facing Floods, Heat, and Earthquakes. Floods, Earthquakes, and Droughts are occurring in 28 districts out of 158 districts of the country. Moreover, 38 districts out of 158 districts are facing Floods, Earthquakes, and Landslides. Floods, Drought, Heatwaves, and Earthquakes are occurring in 22 districts and 5 districts are found to be facing all five natural hazards (Flood, Drought, Landslide, Earthquake, and Heatwave) in this study. Almost 20% of the population of Pakistan is exposed to high or very high intensity in the case of seismic hazards, almost 40% in the case of flood hazards, and almost 1% in the case of landslide hazards. Therefore, there is a need to prepare mitigation strategies and planning by keeping a view above statics.

6. Conclusions

(1) Climate change, which is acknowledged as a significant issue in the twenty-first century, affects various regions differently depending on the circumstances, such as geography and socioeconomic status. This paper provides a detailed spatial variation of five natural hazards in Pakistan: drought, floods, earthquakes, heatwaves, and landslides. Climate change has become a major cause behind the increasing trend of these natural hazards in Pakistan.

(2) Pakistan is susceptible to these natural hazards due to its varied topography and climate changes. The occurrences of these natural hazards are unevenly distributed throughout the county. Most of the area of the country is susceptible to these natural hazards.

(3) Annual head-to-head occurrence of natural catastrophes is observed in recent past years all over the country; it is assumed that there will be an increasing frequency and severity of these natural disasters in Pakistan in the future.
(4) Floods are found to be most devastating and damaging for the economy and lives of people in the country. These are occurring in several districts of all provinces in Pakistan. The districts alongside the banks of river Sindh are facing yearly flood conditions during monsoon rainfall.
(5) Several districts of Sindh and Baluchistan provinces faced severe droughts in the past, and their occurrence in future is also likely to be increased due to climate changes, which are impacting the rainfall patterns in these provinces.
(6) Heatwaves are affecting several districts of Sindh, Baluchistan, and Punjab. The increasing trend of temperature subsets means that the frequency and severity of these events will increase in the near future.
(7) Landslides are found to be occurring in northern parts of the country, i.e., several districts of Gilgit Baltistan and Azad Kashmir, as the frequency of the landslides can be triggered by rainfall and increasing trends of the intensity of rainfalls in monsoon may trigger the happening of these landslides.
(8) Real-time monitoring is required to reduce the dangerous impacts of active landslides. Real-time monitoring of landslides may be used to spot signs of significant activity or movement. The surrounding population is always at risk from large active landslides. Massive mass movements should be observed in real time in order to foresee movement and alert the appropriate professionals to the required precautions to minimize damage.
(9) Earthquakes frequently occur in the districts of northern Khyber Pakhtunkhwa, Azad Kashmir, Gilgit Baltistan, and southern districts of Baluchistan. These districts need more resilience practices to mitigate this natural catastrophe.
(10) The results of this research will be very helpful in creating a multi-dimensional strategy that can be used in various districts or regions based on the particular hazards present there.

7. Recommendations

1. This study is consistent with historical data and counts the real-time occurrence of natural hazards.
2. It is recommended that future research should focus on investigating the spatiotemporal characteristics of the country. This impacts on changing climatic trends locally and globally on the behaviors of natural hazards.
3. Moreover, the multi-hazard zoning and maps are time-dependent and may be altered as a result of upcoming occurrences of hazards. Therefore, it is suggested that the disaster handling institutes in the country should have to establish a database to store the historical data and all upcoming events.
4. There is a dire need to establish national-level spatial data infrastructure for better hazard risk assessment and planning. Moreover, these types of data should be publicly available for research purposes.
5. The National Disaster Management Authority (NDMA) of Pakistan is advised to make such research findings accessible on its website and adopt them for better decision-making and planning. The multi-hazard map we proposed here can also be used for policy development at the national and sub-national levels to achieve climate adaptation in multi-hazard-active areas.
6. Due to its semi-arid climate, Pakistan might have major effects from minor climatic changes. Food insecurity and more-severe droughts might result from this. Therefore, maintaining land and water resources in the Indus Basin requires a multifaceted strategy.
7. For future similar studies, it is also possible to suitably modify the weighted scores for vulnerability and exposure consideration to take into account the regional circumstances.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. District-wise Drought Zoning.

Droughts Hazard Scores Class	Droughts Hazard Zone	Districts
0–1.0	Nil	**N = 75** Abbottabad, Astore, Attock, Bagh, Bajaur, Bannu, Batagram, Bhimber, Buner, Chakwal, Charsadda, Chiniot, Diamer, Faisalabad, Ghanche, Ghizer, Gilgit, Gujranwala, Gujrat, Gupis Yasin, Hafizabad, Hangu, Haripur, Hattian, Haveli, Hunza, Islamabad, Jhelum, Karak, Kasur, Kharmang, Khyber Agency, Kohat, Kolai Pallas, Kotli, Kurram Agency, Lahore, Lower Dir, Lower Kohistan, Malakand, Mandi Bahauddin, Mansehra, Mardan, Mirpur, Mohmand Agency, Muzaffarabad, Nagar, Nankana Sahib, Narowal, Neelum, North Waziristan, Nowshera, Okara, Orakzai agency, Peshawar, Poonch, Rawalpindi, Rondu, Sargodha, Shangla, Sheikhupura, Shigar, Sialkot, Skardu, South Waziristan, Sudhnutti, Sujawal, Swabi, Swat, Tangir, Toba Tek Singh, Torghar, Upper Dir, Upper Kohistan, Ziarat
1.1–3.5	Low	**N = 27** Bahawalpur, Bhakkar, Dera Ismail Khan, Jhang, Karachi Central, Karachi East, Karachi South, Karachi West, Khanewal, Khushab, Korangi, Lakki Marwat, Lasbela, Layyah, Lodhran, Loralai, Malir, Mianwali, Multan, Musakhel, Muzaffargarh, Pakpattan, Rahim Yar Khan, Rajanpur, Sahiwal, Tank, Vehari
3.6–6.0	Moderate	**N = 18** Badin, Chaman, Duki, Ghotki, Jhal Magsi, Kachhi, Kalat, Khairpur, Killa Abdullah, Larkana, Matiari, Pishin, Quetta, Sanghar, Shaheed Benazirabad, Shaheed Sikandarabad, Sibbi, Tando Muhammad Khan
6.1–7.0	High	**N = 30** Badin, Chaman, Dadu, Duki, Ghotki, Gwadar, Harnai, Hyderabad, Jamshoro, Jhal Magsi, Kachhi, Kalat, Kech, Khairpur, Kharan, Killa Abdullah, Larkana, Matiari, Nawab Shah, Panjgur, Pishin, Qambar Shahdadkot, Quetta, Sanghar, Shaheed Benazirabad, Shaheed Sikandarabad, Sibbi, Tando Muhammad Khan, Thatta, Umerkot
7.1–Above	Extreme	**N = 4** Chagai, Nushki, Tharparkar, Washuk

Table A2. District-wise Flood Zoning.

Floods Hazard Scores Class	Flood Hazard Zone	Districts
0–1.0	Nil	**N = 6** Bahawalnagar, Kolai Pallas, Nankana Sahib, Pakpattan, Rondu, Tangir
1.1–3.5	Low	**N = 32** Attock, Bhimber, Chagai, Chakwal, Duki, Gujranwala, Gujrat, Hafizabad, Hangu, Jhelum, Kasur, Khanewal, Kharan, Khushab, Korangi, Kotli, Lodhran, Mandi Bahauddin, Mastung, Nawab Shah, Nushki, Okara, Panjgur, Poonch, Sahiwal, Sargodha, Shaheed Sikandarabad, Sheikhupura, South Waziristan, Tank, Vehari, Washuk
3.6–6.0	Moderate	**N = 46** Astore, Awaran, Bagh, Bajaur, Bannu, Barkhan, Bhakkar, Buner, Faisalabad, Ghizer, Gupis Yasin, Haripur, Harnai, Hattian, Haveli, Hunza, Islamabad, Kachhi, Kharmang, Khyber Agency, Kohat, Kurram Agency, Lakki Marwat, Loralai, Lower Dir, Malir, Matiari, Mianwali, Musakhel, Nagar, Naushahro Firoze, North Waziristan, Orakzai agency, Rahim Yar Khan, Sanghar, Shaheed Benazirabad, Sherani, Shigar, Sudhnutti, Sujawal, Tando Allahyar, Tando Muhammad Khan, Tharparkar, Toba Tek Singh, Umerkot, Upper Kohistan
6.1–7.0	High	**N = 61** Abbottabad, Badin, Bahawalpur, Batagram, Charsadda, Chiniot, Chitral, Dera Bugti, Dera Ismail Khan, Diamer, Ghanche, Ghotki, Gilgit, Gwadar, Hyderabad, Jacobabad, Jamshoro, Jhal Magsi, Jhang, Kalat, Karachi Central, Karachi East, Karachi South, Karachi West, Karak, Kashmore, Khairpur, Killa Abdullah, Killa Saifullah, Kohlu, Lahore, Larkana, Lasbela, Layyah, Lower Kohistan, Malakand, Mansehra, Mardan, Mirpur Khas, Mirpur, Mohmand Agency, Multan, Muzaffarabad, Muzaffargarh, Narowal, Nowshera, Pishin, Qambar Shahdadkot, Quetta, Rawalpindi, Shikarpur, Sialkot, Sibbi, Skardu, Sohbatpur, Sukkur, Swabi, Thatta, Zhob, Ziarat
7.1–Above	Extreme	**N = 13** Dadu, Dera Ghazi Khan, Jaffarabad, Kech, Khuzdar, Naseerabad, Neelum, Peshawar, Rajanpur, Shangla, Swat, Torghar, Upper Dir

Table A3. District-wise Landslide Zoning.

Landslides Hazard Scores Class	Landslides Hazard Zone	Districts
0–1.0	Nil	**N = 108** Awaran, Badin, Bahawalnagar, Bahawalpur, Bannu, Barkhan, Bhakkar, Bhimber, Chakwal, Chaman, Chiniot, Dadu, Dera Bugti, Dera Ghazi Khan, Duki, Faisalabad, Ghotki, Gujranwala, Gujrat, Gwadar, Hafizabad, Harnai, Hattian, Islamabad, Jacobabad, Jaffarabad, Jamshoro, Jhal Magsi, Jhang, Jhelum, Kachhi, Kalat, Karachi Central, Karachi West, Kashmore, Kasur, Kech, Khairpur, Khanewal, Kharan, Khushab, Khuzdar, Killa Abdullah, Killa Saifullah, Kohat, Kohlu, Kolai Pallas, Korangi, Kotli, Lahore, Lakki Marwat, Larkana, Lasbela, Layyah,, Lodhran, Loralai, Malir, Mandi Bahauddin, Mardan, Mastung, Matiari, Mirpur Khas, Mohmand Agency, Multan, Musakhel, Muzaffargarh, Nankana Sahib, Narowal, Naseerabad, Naushahro Firoze, Nawab Shah, Okara, Pakpattan, Panjgur, Peshawar, Pishin, Qambar Shahdadkot, Quetta, Rahim Yar Khan, Rajanpur, Rondu, Sahiwal, Sanghar, Sargodha, Shaheed Benazirabad, Shaheed Sikandarabad, Sheikhupura, Sherani, Shikarpur, Sialkot, Sibbi, Sohbatpur, South Waziristan, Sudhnutti, Sujawal, Tando Allahyar, Tando Muhammad Khan Tangir, Tank, Tharparkar, Thatta, Toba Tek Singh, Umerkot, Upper Kohistan, Vehari, Washuk, Zhob, Ziarat
1.1–3.5	Low	**N = 8** Bajaur, Chagai, Dera Ismail Khan, Hyderabad, Karachi East, Karachi South, Nushki, Sukkur
3.6–6.0	Moderate	**N = 10** Charsadda, Hangu, Karak, Khyber Agency, Kurram Agency, Mirpur, North Waziristan, Nowshera, Orakzai agency, Swabi
6.1–8.0	High	**N = 16** Abbottabad, Attock, Bagh, Batagram, Buner, Ghizer, Gupis Yasin, Haripur, Haveli, Kharmang, Malakand, Neelum, Shigar, Skardu, Swat, Torghar
8.5–Above	Extreme	**N = 13** Astore, Chitral, Diamer, Ghanche, Gilgit, Hunza, Lower Kohistan, Mansehra, Muzaffarabad, Nagar, Rawalpindi, Shangla, Upper Dir

Table A4. District-wise Earthquake Zoning.

Earthquake Hazard Scores Class	Earthquakes Hazard Zone	Districts
0–1.0	Nil	**N = 37** Bahawalnagar, Chiniot, Dadu, Faisalabad, Hafizabad, Hyderabad, Jaffarabad, Jamshoro, Khairpur, Khanewal, Korangi, Lahore, Larkana, Lodhran, Malir, Mandi Bahauddin, Matiari, Mirpur Khas, Nankana Sahib, Narowal, Naushahro Firoze, Nawab Shah, Okara, Pakpattan, Sahiwal, Sanghar, Shaheed Benazirabad, Shaheed Sikandarabad, Sialkot, Sujawal, Sukkur, Tando Allahyar, Tando Muhammad Khan, Thatta, Toba Tek Singh, Umerkot, Vehari
1.1–3.5	Low	**N = 35** Badin, Bhakkar, Bhimber, Chakwal, Dera Ismail Khan, Ghanche, Ghotki, Gujranwala, Gujrat, Gwadar, Jacobabad, Jhal Magsi, Jhang, Jhelum, Karachi Central, Karachi East, Karachi South, Karachi West, Kashmore, Kasur, Khushab, Kotli, Lasbela, Mianwali, Mirpur, Qambar Shahdadkot, Rahim Yar Khan, Rawalpindi, Sargodha, Sheikhupura, Sherani, Shikarpur, South Waziristan, Tank, Tharparkar
3.6–5.5	Moderate	**N = 45** Abbottabad, Attock, Awaran, Bagh, Bahawalpur, Bannu, Buner, Chaman, Charsadda, Dera Ghazi Khan, Diamer, Hangu, Haripur, Hattian, Haveli, Hunza, Islamabad, Kalat, Karak, Kech, Kharan, Khuzdar, Khyber Agency, Killa Saifullah, Kohat, Kurram Agency, Lakki Marwat, Layyah, Mardan, Mohmand Agency, Multan, Muzaffarabad, Nagar, Naseerabad, North Waziristan, Nowshera, Nushki, Orakzai agency, Panjgur, Peshawar, Poonch, Skardu, Sudhnutti, Swabi, Tangir
5.6–7.5	High	**N = 32** Astore, Bajaur, Barkhan, Batagram, Chagai, Dera Bugti, Ghizer, Gilgit, Gupis Yasin, Kharmang, Killa Abdullah, Kohlu, Kolai Pallas, Lower Kohistan, Malakand, Mansehra, Mastung, Musakhel, Neelum, Pishin, Quetta, Rajanpur, Rondu, Shangla, Shigar, Sibbi, Sohbatpur, Torghar, Upper Kohistan, Washuk, Zhob, Ziarat
8.0–Above	Extreme	**N = 9** Chitral, Duki, Harnai, Kachhi, Loralai, Lower Dir, Muzaffarabad, Swat, Upper Dir

Table A5. District-wise Heatwave Zoning.

Heatwave Hazard Scores Class	Heatwave Hazard Zone	Districts
0–1.0	Nil	**N = 106** Abbottabad, Astore, Attock, Awaran, Bagh, Bajaur, Bannu, Batagram, Bhimber, Buner, Charsadda, Chitral, Chiniot, Dera Bugti, Dera Ghazi Khan, Dera Ismail Khan, Diamer, Duki, Ghanche, Ghizer, Gilgit, Gujrat, Gupis Yasin, Hafizabad, Hangu, Haripur, Harnai, Hattian, Haveli, Hunza, Jaffarabad, Jhal Magsi, Jhang, Jhelum, Kachhi, Kalat, Karak, Kashmore, Kasur, Khanewal, Kharan, Kharmang, Khuzdar, Khyber Agency, Killa Abdullah, Killa Saifullah, Kohat, Kohlu, Kolai Pallas, Kotli, Kurram Agency, Lakki Marwat, Loralai, Lower Dir, Lower Kohistan, Malakand, Mandi Bahauddin, Mansehra, Mardan, Mastung, Matiari, Mirpur, Mohmand Agency, Musakhel, Muzaffarabad, Nankana Sahib, Narowal, Naseerabad, Neelum, North Waziristan, Nowshera, Nushki, Okara, Orakzai agency, Pakpattan, Poonch, Qambar Shahdadkot, Rajanpur, Rondu, Sahiwal, Shaheed Benazirabad, Shaheed Sikandarabad, Shangla, Sheikhupura, Sherani, Shigar, Shikarpur, Sialkot, Skardu, Sohbatpur, South Waziristan, Sudhnutti, Sujawal, Swabi, Swat, Tando Allahyar, Tando Muhammad Khan, Tangir, Tank, Toba Tek Singh, Torghar, Upper Dir, Upper Kohistan, Washuk, Zhob, Ziarat

Table A5. *Cont.*

Heatwave Hazard Scores Class	Heatwave Hazard Zone	Districts
1.1–3.5	Low	**N = 6** Bhakkar, Islamabad, Khushab, Nagar, Peshawar, Rawalpindi
3.6–6.0	Moderate	**N = 22** Badin, Barkhan, Chaman, Faisalabad, Ghotki, Gujranwala, Gwadar, Jamshoro, Lasbela, Layyah, Lodhran, Mirpur Khas, Muzaffargarh, Naushahro Firoze, Panjgur, Pishin, Quetta, Sanghar, Sargodha, Thatta, Umerkot, Vehari
6.1–7.5	High	**N = 12** Bahawalnagar, Bahawalpur, Chagai, Chakwal, Hyderabad, Kech, Lahore, Larkana, Mianwali, Multan, Nawab Shah, Tharparkar
7.6–Above	Extreme	**N = 12** Dadu, Jacobabad, Karachi Central, Karachi East, Karachi South, Karachi West, Khairpur, Korangi, Malir, Rahim Yar Khan, Sibbi, Sukkur

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