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A Climate Change Calamity: Assessing The Impact Of Flooding On Waterborne Disease Burden In Pakistan

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Abstract

Background: Pakistan ranks among the countries most vulnerable to climate change. In 2022, extreme flooding ravaged the country as a result of unprecedented monsoon rains, resulting in widespread environmental and health devastation. As flooding events can damage water, sanitation and health (WASH) infrastructure, contribute to disaster conditions, and strain healthcare systems, heavy rains can impact waterborne disease transmission and outbreak events. Extreme flooding events are expected to increase in prevalence, severity, and scope as the climate continues to change in the future. This study aims to assess the impact of monsoon seasons and flooding events on waterborne disease burden in Pakistan from 2021 to 2023.

Methods: Epidemiological case data from Pakistan's National Institutes of Health was analyzed to explore the effect of monsoon seasonality and known flooding events (KFEs) on the prevalence of common water-sensitive diseases in Pakistan: acute diarrhea, bloody diarrhea, suspected cholera, and typhoid. Case data was statistically analyzed to assess important differences: between pre-monsoon, monsoon, and post-monsoon seasons, between years 2021 and 2023, and between four-week pre-flood and post-flood periods for all KFEs. Analysis was performed on national and administrative unit scales.

Results: The analysis demonstrated statistically significant differences in case prevalence across pre-monsoon, monsoon, and post-monsoon seasons for most disease types and assessment levels ($p<0.05$). Yearly comparisons of adjusted case estimates (adjusted for reporting scope) demonstrated statistically significant differences between 2021 and 2023 for most disease types and assessment levels ($p<0.05$). Unadjusted comparison of population-adjusted case estimates for all KFEs between 2021 and 2023 demonstrated no significant difference between pre-flood and post-flood four-week periods.

Conclusion: Our analysis indicated that heavy rains and flood conditions significantly impacted the burden of infectious waterborne diseases in Pakistan. The effects of climate change, especially on countries experiencing disproportionate impacts, are imminent. More robust analysis is imperative for strengthening healthcare systems and building resilience against environmental threats, including heavy rains and extreme flooding. Current public data reserves lack important breadth and detail necessary for comprehensive environmental health analysis. Research of this nature may influence political and public health action, protecting communities, promoting resilience, and ensuring health and well-being in the future.

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Glossary of Abbreviations

AJK: Azad Jammu & Kashmir

ARS: Agreed Reporting Site

GB: Gilgit-Baltistan

ICT: Islamabad Capital Territory

IDSR: Integrated Disease Surveillance & Response

KFE: Known Flood Events

KP: Khyber Pakhtunkhwa

NIH: National Institutes of Health

WASH: Water, Sanitation & Hygiene

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Introduction

For over a decade, Pakistan has ranked among the top ten countries with the highest Climate Risk Index (Siddiqui, 2022). Ongoing crises pose an immense challenge for mitigating negative impacts and reducing disaster potential. Although climate impacts in Pakistan are manifested in several different ways, flooding events, often due to unpredictable monsoon rains, are among the most precarious. These demonstrations of climate-driven severe weather have caused or contributed to many health and developmental challenges across the country, especially in recent years. Notably, Pakistan experienced catastrophic flooding throughout 2022, the extent of which is demonstrated in Figure 1. After higher-than-average monsoon rains ravaged the country between early summer and late fall, unprecedented rains left one-third of the country flooded, impacting over 33 million people (Hong et al., 2023; UNICEF, 2023). Recent scientific analysis attributes the severity of Pakistan's 2022 flooding to increasing effects of climate change, solidifying Pakistan's high-ranking disaster risk levels (Center for Disease Philanthropy, 2023; P Lama & Tatu, 2022). While seasonal monsoon cycles are not only expected during the summer months, but also necessary for supporting natural agricultural cycles, the frequency and severity of extreme rain and flooding events are predicted to increase in the future (Burke et al., 2023). Flood implications include property and infrastructural damage, environmental destruction, and both direct and indirect effects on health and well-being; importantly, flooding also influences the spread of infectious disease.

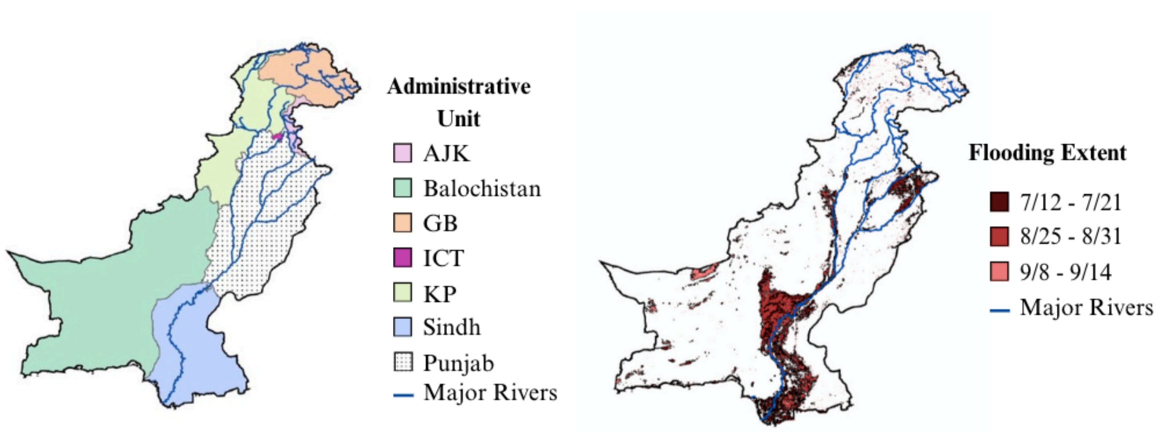

Figure 1. Pakistan's administrative units, major rivers, and the extent of 2022 flooding. Administrative units include Azad Jammu & Kashmir (AJK), Balochistan, Gilgit-Baltistan (GB), Islamabad Capital Territory (ICT), Khyber Pakhtunkhwa (KP), Sindh, and Punjab.

Climate-driven flooding events often impact the spread of infectious disease through damage or strain on water, sanitation, and hygiene (WASH) infrastructure. In Pakistan, which already faces immense WASH challenges, disaster conditions can contribute to ongoing microbial transmission (Cooper, 2018). During the monsoon season, which can range from June to September, an influx of precipitation places additional demands on water and sanitation infrastructure, contributing to instances of overload, contamination, and water stagnation (World Bank CCKP, n.d.). These heavy rains and flood events impact water quality, availability, and distribution through designated and non-designated channels, implicating access to clean and safe drinking water. This interruption of clean water supplies can promote conditions for the outbreak and spread of infectious disease (Okaka & Odhiambo, 2018). Research suggests that flooding influences pathogen transport and transmission through multiple pathways, including microbial contamination of surface waters, high flow velocities, and lengthened or increased transport of solids. Similarly, when water excess and inundation intersects with ineffective water and sanitation management, stagnant water presents an environment for microbial pathogens to live, multiply, and persist (Kraay et al., 2020). These pathways can impact the breadth of pathogen distribution and spread, the duration in which microbes remain infectious, and the introduction of infectious pathogens into additional water sources (Collender et al., 2016).

The primary aim of this research is to explore the influence of Pakistan's seasonal monsoons, heavy rains, and known flooding events on the burden of waterborne diseases across the country. As climate change progresses, extreme flooding events, such as those observed in 2022, will become more prevalent and severe (Tabari, 2020). To appropriately plan and build public health response capacity, the impacts of flooding and water-related climate phenomena must be understood. Research of this nature may identify opportunities for data supplementation, research improvement, and resilience-building to combat future flooding and disease risks in the wake of inevitable consequences of climate change.

Flooding and WASH Infrastructure in Pakistan

The transmission of waterborne diseases, deemed preventable by the World Health Organization, is directly influenced by inappropriately managed or inadequate WASH systems and services, including those in South Asia (World Health Organization, 2013). Following disastrous early-2010 flooding in Pakistan, poor hygiene and disaster conditions contributed to increased and ongoing transmission of multiple disease types (Baqir et al., 2012). During flood events, water contamination and demands on WASH infrastructure are exacerbated, often amplifying the risk potential of bacterial and viral pathogen spread. These effects are often most pronounced in humanitarian response settings that follow disasters, where displacement and overcrowding, coupled with resource stress, strain WASH infrastructure and further facilitate the spread of infectious disease (British Red Cross, n.d.). In addition to flooding and climate stressors such as drought and earthquakes, Pakistan also faces instances of conflict-driven internal displacement (CGIAR, 2024; UNICEF, n.d.). Vulnerability, in these instances, often compounds. When the environment, WASH infrastructure, the healthcare system, or any combination of these systems becomes vulnerable, the instability accompanying stressors can wreak havoc on health.

Pakistan's WASH challenges are multifaceted. In addition to lacking infrastructure, water pollution continues to pose additional public health threats across the country (Noor et al., 2023). Throughout the country, drinking water quality is not comprehensively monitored nor effectively managed, resulting in extremely poor access to clean drinking water (Azizullah et al., 2011). In Pakistan's cities, drinking water contamination is among the most pressing issues, whereas rural communities struggle with water access (Noor et al., 2023). Pakistan's climate, which is prone to both drought and heavy precipitation, contributes to existing management barriers. Further complicating WASH-related challenges, open defecation practices are common in Pakistan, which can directly release infectious pathogens into water systems and sources (UNICEF, n.d.).Though international and national partners continue to improve WASH infrastructure and water-related conditions in Pakistan, including the Ministry of Climate Change, Sanitation and Water for All, and the Clean Green Pakistan program, challenges persist (SWA, 2020).

Flooding and Waterborne Infectious Diseases in Pakistan

When waterways and water infrastructure are compromised, such as after flooding events, pathogens that are transmitted through waterborne transmission or water-related channels may spread more easily. In Pakistan, many waterborne diseases are endemic even during dry seasons, such as cholera, hepatitis, typhoid, diarrhea, and gastroenteritis (Qamar et al., 2022). Due to increased contamination potential from poor infrastructure, the burden of these diseases is often greatest in rural areas, such as Pakistan's southern provinces. Conversely, in some areas such as populated urban city centers, transmission risk may be more attributable to the widespread consumption of untreated or contaminated water (Ishaque et al., 2024). In many instances, flood-related contamination results from sewage or agricultural runoff, introducing pathogens into drinking water sources (CDC, 2022).

Following 2022's devastating floods, when Pakistan's health system was already strained due to increased demand, water-related conditions presented an entirely new challenge. In many cases, these ailments impacted groups experiencing disproportionate risks, such as children, those experiencing food disparities, and populations experiencing displacement (Saifi et al., 2022). In conjunction with WASH-related challenges experienced during emergency events, disasters resulting in displacement and overcrowding facilitate extensive pathogen dissemination in the event of a waterborne disease outbreak (Manzoor & Adesola, 2022).

Without appropriate management, detection, and treatment, these waterborne diseases present severe health risks, with symptoms ranging from gastrointestinal discomfort to life-threatening conditions. Often, these infections cause symptoms such as headache, lethargy, stomach pain, loss of appetite, dehydration, diarrhea (acute or bloody), and fever (National Park Service, 2018). The risk of severe complications, including death, is elevated for disproportionately impacted groups (CDC, 2020). For some infections, such as cholera, recovery is dependent on access to clean drinking water and adequate re-hydration resources. Research demonstrates that the containment of climate-sensitive infectious diseases, such as waterborne infection, is becoming more challenging as climate change consequences continue to disproportionately impact low- and middle-income countries, whose resources are already strained (Dimitrova et al., 2023).

To assess the impacts of infectious disease across Pakistan, the National Institutes of Health (NIH), Islamabad Pakistan conducts regular surveillance and monitoring of many infectious diseases, including acute diarrhea, bloody diarrhea, suspected cholera, and typhoid. Data is publicly reported through NIH's Integrated Disease Surveillance and Response (IDSR) bulletin, conducted by NIH's Field Epidemiology and Disease Surveillance Division (NIH Pakistan, n.d.). The data provides imperative context and useful information for understanding the nature of infectious disease across the country.

Methods

To assess the impact of heavy rains and flooding on waterborne disease burden in Pakistan, publicly available epidemiological health data from 2021 to 2023 was analyzed. Pakistan NIH's Integrated Disease Surveillance & Response (IDSR) Weekly Bulletin data served as the primary source of data, providing weekly case estimates for various infectious disease types. All statistical analysis was conducted via SAS Studio.

Data Collection and Preparation

I. Epidemiological Health Data

Four diseases of interest were identified for this assessment. Diseases were chosen from available IDSR reporting categories based on waterborne significance, potential transmission sensitivity preceding or following flooding events, and completeness of data and reporting across the three-year reporting period (2021 to 2023). The four disease types included in the analysis were acute diarrhea (non-cholera), bloody diarrhea, suspected cholera, and typhoid. Weekly case estimates for the four disease types of interest were transcribed from all available IDSR Weekly Bulletin reports between 2021 and 2023. Publicly available data begins Week 21 of 2021, with reporting through the end of 2023.

Case counts were collected on the administrative unit level to allow for regional and province-specific assessment. Pakistan consists of four provinces (Balochistan, Khyber Pakhtunkhwa (KP), Punjab, and Sindh), one federal territory (the Islamabad Capital Territory (ICT)), and two administrative territories (Azad Jammu and Kashmir (AJK) and Gilgit-Baltistan (GB)). All administrative units were included in the analysis, with the exception of Punjab, which was excluded due to substantially inconsistent reporting and incomplete data over the course of the study period. Case estimates from all administrative units included in the analysis were aggregated for Pakistan estimates and country-wide assessment.

Each IDSR report reflects that given week's received reports from agreed reporting sites (ARS) across the country, as demonstrated in Figure 2. In addition to the transcription of case counts, the number of reports received from each administrative unit for each IDSR reporting week was also recorded for adjustment purposes in this analysis.

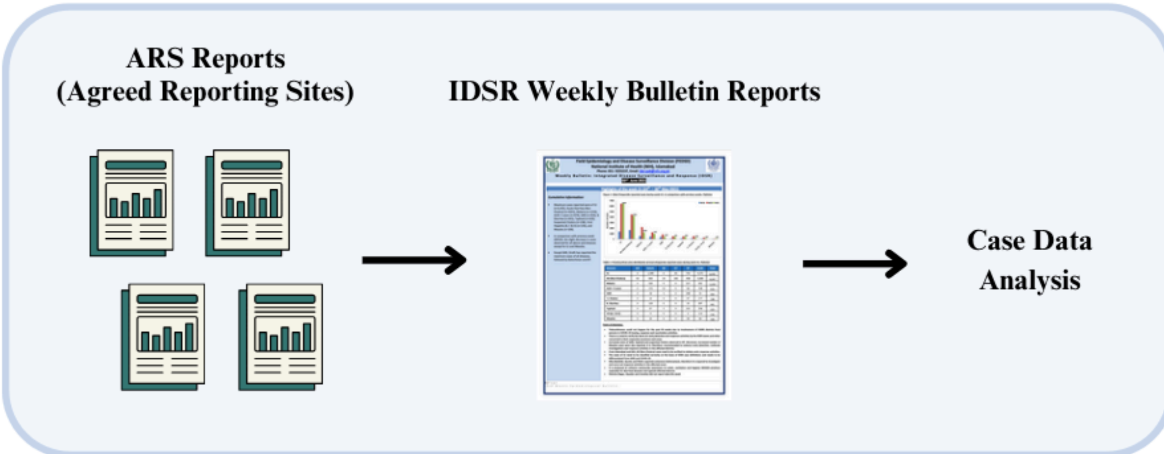

Figure 2. Visual description of epidemiological case report data collection and analysis from NIH Pakistan's public data sources.

Reporting was inconsistent across the study period. 17 weeks of data were available for 2021, between Week 21 and Week 52. Nine weeks of data were available for 2022, from Week 2 to Week 16. Thirty-two weeks of data were available for 2023, from Week 16 to Week 52. In total, 58 IDSR reports were integrated for comprehensive analysis. A description of accessible IDSR data is available in Supplementary Table 1 and Supplementary Table 2, found in the Appendix.

II. Known Flood Events

Known Flood Event (KFE) data was collected from online news and climate reporting sources, including FloodList and available accounts of flooding in Pakistan (FloodList, n.d.). Floods were only included in the analysis if the specific date of flooding was identifiable or explicitly indicated. All identified KFEs from 2021 to 2023 were considered for analysis. Out of 30 identified KFEs, 14 were deemed eligible for analysis. KFEs were excluded if the data pre-flood, post-flood, or during both periods was missing or insufficient for analysis. A summary of all KFEs (included and excluded) for the 2021-2023 period is available in Supplementary Table 3, found in the Appendix.

III. Pakistan Population Data

Pakistan population data was collected for data adjustment purposes. Census data was identified from the Government of Pakistan's Bureau of Statistics, which provided 2017 estimates for Pakistan's four provinces (Balochistan, KP, Punjab, and Sindh), as well as Pakistan's federal territory (ICT) (Pakistan Bureau of Statistics, n.d.). We also identified the 2017 population estimates for Pakistan's administrative territories (AJK and GB), which both reported independently through their own statistical agencies (AJ&K Bureau of Statistics, n.d.; Government of Gilgit Baltistan, n.d.). An additional Census was conducted for Pakistani provinces in 2023. To complement 2023 IDSR data, population estimates were updated for Pakistan's four provinces (Balochistan, KP, Sindh, and Punjab). Estimates beyond 2017 were not available for AJK and GB, so 2017 estimates were maintained.

Analysis

I. Seasonality: Pre-Monsoon Season, Monsoon Season, and Post-Monsoon Season

To begin the analysis, IDSR data was used to assess the difference in case report data over the course of the year, with an emphasis on monsoon seasonality. Disease case counts for the four diseases of interest were compared "Pre-Monsoon Season" (January - May), "During Monsoon Season" (June - September), and "Post-Monsoon Season" (October - December) for each calendar year, 2021 to 2023 (World Bank CCKP, n.d.). As the number of observations for some categorical samples was below the threshold to meet normality assumptions ($N<30$), a non-parametric Kruskal-Wallis test was used to determine if there were statistically significant differences between the three seasons. Since there was no direct comparison between years, there was no correction for the number of reports received per week; crude weekly case report estimates were assessed. Given the lack of consistent reporting across the three-year period, including differences in ARS sites and number of reports received each week, the seasons were deemed independent.

II. Disease Prevalence: Comparison Between 2021 and 2023

To understand potential differences in reporting and changes in disease prevalence across the study period, IDSR data was analyzed to compare case estimates between 2021 and 2023. We excluded 2022 from the year-to-year comparison due to incomplete and missing data, which was insufficient for meaningful analysis. To control for potential differences in reporting between 2021 and 2023, the weekly IDSR case estimates were adjusted to reflect the number of ARS reports contributing to that week's IDSR estimate. For example, the weekly case estimate for each disease type in any given administrative unit was divided by the number of reports received from that administrative unit for that specific week (as indicated in the IDSR report). Once adjusted, the number of cases per ARS report per week were compared using a non-parametric Wilcoxon Rank-Sum Test. Normality assumptions were not met due to insufficient sample sizes ($N<30$). Week 16 of 2023 was excluded from this analysis due to insufficient ARS compliance reporting from some provinces, such that the IDSR case estimate could not be adjusted by the number of reports received.

III. Known Flood Events: Pre-Flood and Post-Flood Analysis

To better understand the impact of known flooding events on infectious disease prevalence across Pakistan, KFE data was assessed. For each disease included in the analysis, the case estimates pre-flood and post-flood were compared, with a four-week data inclusion threshold for both pre-flood and post-flood periods. The threshold was chosen based on the nature of waterborne disease transmission and infection timing, supported by data availability. Research suggests that although outbreak events may begin and disease incidence may increase as early as one week post-flood, especially in the event of acute disease, infectious disease outbreak events typically occur up to four weeks post-flood (Yavarian et al., 2019). Additional effects can last as long as eight weeks post-food (Wang et al., 2023). For the assessment, case estimates from all IDSR reports available within each four-week period were averaged. To allow for flood comparison across administrative units and account for potential differences in case estimates, IDSR case estimate data was adjusted by population. Pre-flood and post-flood averages were divided by the population estimate of the administrative data in which the data originated, then multiplied by 100,000 to produce estimates reflecting the mean number of cases/100,000 population. When adjusting for population, 2017 Pakistani census estimates were used for all 2021 and 2022 flood events. The total population estimate for Pakistan-wide assessment only includes the administrative units included in this analysis (reflecting the exclusion of Punjab). For 2023 floods, Pakistan's 2023 census estimates were used for all available administrative units: Balochistan, KP, Sindh, and ICT. The most recent estimates available, 2017 estimates, were maintained for AJK and GB adjustments. Once adjusted, all 14 KFEs included were analyzed together using a paired design. To assess differences, a non-parametric t-test equivalent, the Wilcoxon Signed Rank test, was used. Parametric assumptions were not met due to insufficient sample size ($N<30$). A paired design was adopted to account for the paired nature of pre-flood and post-flood estimates for each KFE. Additional tests were performed for 2021 and 2023 only.

Results

A comparative analysis between pre-monsoon season, monsoon season, and post-monsoon season is described in Table 1. Across each administrative unit, the analysis demonstrated statistically significant differences in the mean number of cases per week for at least one disease of interest across monsoon seasons. On a country level, cases of acute diarrhea ($p = 0.047$) and suspected cholera ($p < 0.001$) significantly differed across seasons, with the highest mean number of cases per week occurring during the monsoon season. Similarly, all four diseases of interest significantly differed across seasons in AJK, Balochistan, and GB ($p < 0.05$). The mean number of cases per week was almost always the highest during the monsoon season in AJK and Balochistan, with the exception of suspected cholera in Balochistan, which was highest during the post-monsoon season. For all four diseases in GB, the highest average number of cases per week occurred during the post-monsoon season. In ICT, the mean number of cases per week significantly differed for acute diarrhea ($p = 0.016$) and suspected cholera ($p = 0.027$). Cases of acute diarrhea were highest during the monsoon season, while cases of cholera were highest during the pre-monsoon season. In KP, the mean number of cases per week significantly differed between seasons for bloody cholera ($p = 0.030$) and typhoid ($p = 0.023$), with the highest case counts during the monsoon season. In Sindh, the mean number of cases per week significantly differed across seasons only for acute diarrhea ($p = 0.049$), with the highest number of cases during the monsoon season.

Table 1. Differences in the average number of cases per week between pre-monsoon season (January - May), monsoon season (June - September), and post-monsoon season (October - December) for the entire 2021 - 2023 monitoring period

Assessment Level, 2021-2023	**Pre-Season** cases/week (mean)	**Monsoons** cases/week (mean)	**Post-Season** cases/week (mean)	**p**† (DF = 2)
Pakistan*				
Acute Diarrhea	16,239	56,578	43,668	0.047
Bloody Diarrhea	1,436	4,480	4,132	0.122
Suspected Cholera	363	516	579	<0.001
Typhoid	1,039	2,627	2,359	0.057
AJK				
Acute Diarrhea	112	1,328	783	0.034
Bloody Diarrhea	7	79	39	0.021
Suspected Cholera	10	48	32	0.022
Typhoid	2	58	25	<0.001
Balochistan				
Acute Diarrhea	1,425	4,848	4,633	0.016
Bloody Diarrhea	359	1,242	1,236	0.029
Suspected Cholera	56	198	251	<0.001
Typhoid	187	656	628	0.003
Gilgit-Baltistan				
Acute Diarrhea	8	159	240	<0.001
Bloody Diarrhea	2	17	29	<0.001
Suspected Cholera	2	30	38	<0.001
Typhoid	2	18	27	<0.001
ICT				
Acute Diarrhea	189	235	118	0.016
Bloody Diarrhea	5	5	4	0.383
Suspected Cholera	7	2	2	0.027
Typhoid	1	2	2	0.894
KP				
Acute Diarrhea	6,548	18,045	12,192	0.070
Bloody Diarrhea	373	791	600	0.030
Suspected Cholera	159	127	117	0.301
Typhoid	462	859	577	0.023
Sindh				
Acute Diarrhea	7,958	31,964	25,700	0.049
Bloody Diarrhea	691	2,274	2,224	0.186
Suspected Cholera	130	110	139	0.429
Typhoid	385	1,003	1,100	0.072

* Punjab excluded due to insufficient data
† P-value for Kruskal-Wallis Test

After the number of cases reported in IDSR weekly bulletins was adjusted by the number of ARS reports received from each administrative unit each week, a comparative analysis demonstrated significant differences between 2021 and 2023. To contextualize these differences, Figure 3 represents the monthly mean adjusted case estimates (cases per ARS report received), demonstrating not only adjusted case estimates, but also differences in IDSR reporting between 2021, 2022, and 2023. Statistical analysis demonstrated significant differences for almost all disease types across all administrative units, as described in Table 2. There were statistically significant differences in adjusted case estimates between 2021 and 2023 for all diseases at every level ($p<0.05$), with the exception of typhoid in GB, Sindh, and at a Pakistan-wide assessment level, acute diarrhea in ICT, and bloody diarrhea in ICT and KP. In almost all instances, the mean number of cases per ARS report was higher in 2023 compared to 2021, with the exception of suspected cholera and typhoid in ICT, KP, Sindh, and on a Pakistan-wide assessment level, as well as bloody diarrhea in KP. Across all assessment levels, the mean number of cases of acute diarrhea per ARS report was higher in 2023.

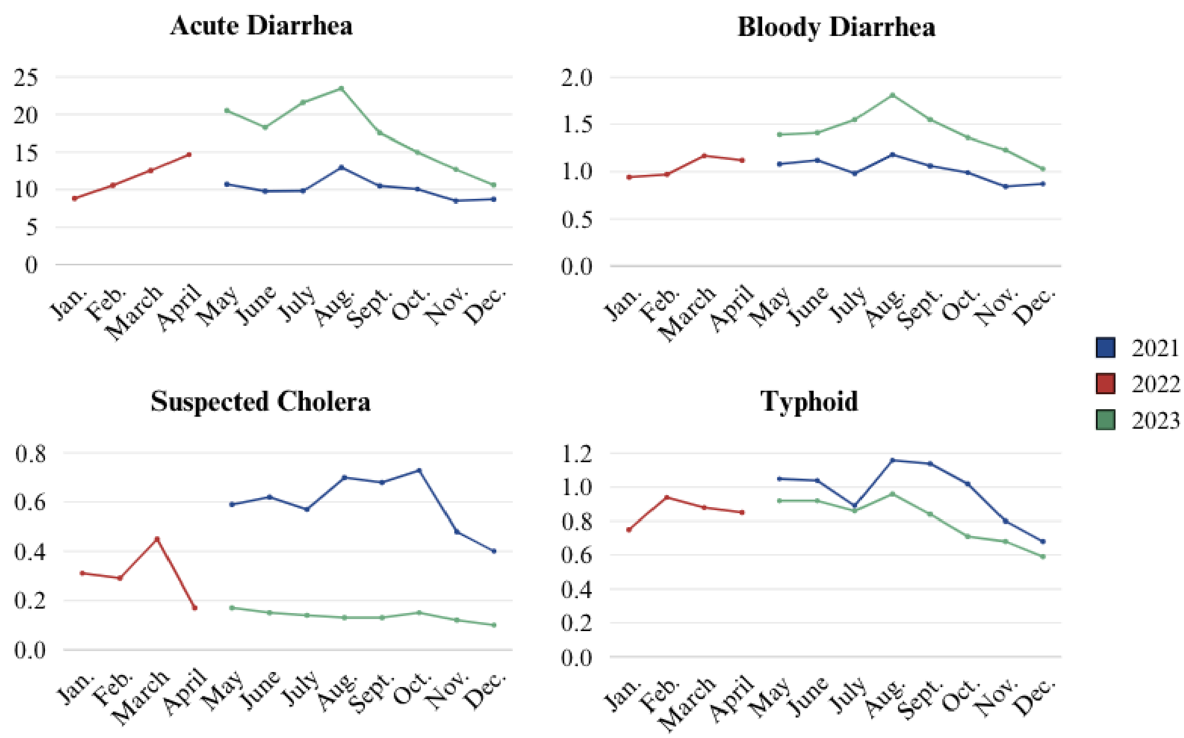

Figure 3. Monthly average of adjusted cases (cases per ARS report) across Pakistan, 2021-2023.

Table 2. Differences in number of weekly IDSR cases per ARS report between 2021 and 2023

Assessment Level	2021 mean ± std	2023 mean ± std	p†
Pakistan*			
Acute Diarrhea	10.00 ± 2.22	17.63 ± 4.82	<0.001
Bloody Diarrhea	1.00 ± 0.20	1.45 ± 0.28	<0.001
Suspected Cholera	0.58 ± 0.18	0.14 ± 0.03	<0.001
Typhoid	0.95 ± 0.25	0.81 ± 0.18	0.095
Azad Jammu Kashmir			
Acute Diarrhea	1.69 ± 0.80	5.07 ± 1.90	<0.001
Bloody Diarrhea	0.10 ± 0.15	0.28 ± 0.12	<0.001
Suspected Cholera	0.00 ± 0.00	0.19 ± 0.09	<0.001
Typhoid	0.07 ± 0.11	0.20 ± 0.25	0.002
Balochistan			
Acute Diarrhea	5.69 ± 1.46	9.21 ± 2.42	<0.001
Bloody Diarrhea	1.25 ± 0.34	2.44 ± 0.56	<0.001
Suspected Cholera	0.27 ± 0.19	0.42 ± 0.18	0.004
Typhoid	0.85 ± 0.37	1.24 ± 0.40	<0.001
Gilgit-Baltistan			
Acute Diarrhea	0.59 ± 0.42	2.87 ± 2.17	<0.001
Bloody Diarrhea	0.14 ± 0.15	0.30 ± 0.23	0.004
Suspected Cholera	0.22 ± 0.16	0.54 ± 0.53	0.014
Typhoid	0.27 ± 0.25	0.29 ± 0.27	0.593
Islamabad Capital Territory			
Acute Diarrhea	7.66 ± 2.93	12.35 ± 11.68	0.653
Bloody Diarrhea	0.19 ± 0.20	0.25 ± 0.31	0.948
Cholera	0.13 ± 0.21	0.11 ± 0.38	0.024
Typhoid	0.23 ± 0.18	0.02 ± 0.04	<0.001
Khyber Pakhtunkhwa			
Acute Diarrhea	11.65 ± 5.68	17.16 ± 6.72	0.007
Bloody Diarrhea	0.79 ± 0.46	0.75 ± 0.25	0.653
Suspected Cholera	0.70 ± 0.41	0.07 ± 0.08	<0.001
Typhoid	1.30 ± 0.67	0.74 ± 0.06	<0.001
Sindh			
Acute Diarrhea	14.97 ± 3.52	24.94 ± 5.66	<0.001
Bloody Diarrhea	1.30 ± 0.28	1.89 ± 0.35	<0.001
Suspected Cholera	0.92 ± 0.29	0.04 ± 0.03	<0.001
Typhoid	1.00 ± 0.31	0.86 ± 0.21	0.155

* Punjab excluded due to insufficient data
† P-value for Wilcoxon Rank-Sum Test

After adjusting for population differences between administrative units, Pakistan-wide assessment of associations between mean four-week pre-flood and mean four-week post-flood cases/100,000 population showed no statistically significant differences for all known KFEs, as demonstrated in Table 3. Based on assessment data, more often than not, the mean number of cases/100,000 population increased post-flood. In many instances, the analysis demonstrated similarity between pre-flood and post-flood cases/100,000 (p values close to 1.00).

Table 3. Unadjusted associations between mean pre-flood and post-flood cases/100,000 population for Known Flood Events (KFEs)

Assessment Level	**Pre-KFE** mean ± std	**Post-KFE** mean ± std	**p**†
2021 & 2023 Combined			
Pakistan*			
Acute Diarrhea	29.10 ± 29.52	27.27 ± 25.40	0.801
Bloody Diarrhea	1.63 ± 1.45	1.65 ± 1.37	0.358
Suspected Cholera	0.50 ± 0.43	0.58 ± 0.48	0.119
Typhoid	1.50 ± 0.97	1.52 ± 0.85	0.715
2021			
Pakistan*			
Acute Diarrhea	8.24 ± 2.71	9.03 ± 1.92	0.383
Bloody Diarrhea	0.72 ± 0.61	0.78 ± 0.58	0.109
Suspected Cholera	0.49 ± 0.20	0.57 ± 0.26	0.195
Typhoid	0.99 ± 0.74	0.94 ± 0.42	1.00
2023			
Pakistan*			
Acute Diarrhea	65.76 ± 14.22	58.56 ± 13.19	0.625
Bloody Diarrhea	3.23 ± 1.09	3.22 ± 0.88	1.00
Suspected Cholera	0.55 ± 0.73	0.60 ± 0.80	1.00
Typhoid	2.41 ± 0.68	2.40 ± 0.60	1.00

* Punjab excluded due to insufficient data
† P-value for Wilcoxon Signed Rank Test

Discussion

Interpretations

Extreme flooding events affect health through multiple pathways: environmental destruction, damage to health infrastructure, the promotion of conditions that increase disease risk and susceptibility, and strained capacity for response and mitigation efforts. Although a change in waterborne disease prevalence can not be attributed to known flood events based on this assessment, the analysis presented significant impacts of monsoon seasonality on the prevalence of acute diarrhea, bloody diarrhea, suspected cholera, and typhoid across Pakistan. Similarly, the analysis demonstrated significant differences in case prevalence across different study years, potentially reflecting underlying differences in weather, climate, and public health surveillance efforts throughout the duration of this study period. The data and research show that waterborne disease burden is typically highest during the monsoon season, when heavy rains and flooding events are more likely to occur.

Like any disaster, the impacts of flooding are not uniform across Pakistan. After adjusting for the number of reports received, the weekly cases per ARS report show the highest disease prevalence in Sindh, both in 2021 and 2023 (Table 2). Similarly, without any adjustment, out of all administrative units included in the analysis, Sindh demonstrated the highest number of weekly cases, accounting for roughly one third to one half of all cases in Pakistan for each disease type. As seen in Figure 1, the 2022 floods highly affected Sindh, which experienced severe impacts. High disease prevalence, coupled with high flood risk or climate vulnerability, may place additional strain on important public health resources. In regions where flooding is more common or more severe, the monsoon seasons may warrant public health concern. Research suggests that increased disease incidence and outbreaks can limit resources available for not only disease management, but also clinical and public health; high disease burdens can limit operational capacity, redirect resources, and exacerbate existing health challenges (Colzani, 2019). In areas uniquely affected by flooding and subsequent impacts on infectious disease, these effects may have significant implications.

Over the study period, based on the number of ARS reports received each week, public health surveillance efforts improved in Pakistan. Even after adjusting for the number of reports received per ARS for each IDSR Weekly Bulletin, which intended to account for potential differences in disease surveillance and monitoring from 2021 to 2023, there were statistically significant differences in reported disease prevalence for all four diseases of interest between 2021 and 2023. Many health and environmental factors may have contributed to this difference, including overall surveillance improvements over the course of the study period. Since the increased number of ARS reports could not explain this difference alone, there may have been significant improvements in monitoring capacity at each ARS site. Importantly, the ongoing impacts of COVID-19 and the resource strains across the healthcare industry may have impacted surveillance capacity in 2021, resulting in fewer reported cases of each waterborne disease. Regardless, these case estimates are likely an underestimation of true disease burden across Pakistan, supporting the need for more comprehensive health surveillance, monitoring, and reporting for research and development purposes. Beyond surveillance, there were likely differences in climate, seasonality, and environmental factors between 2021 and 2023. For example, precipitation rates differed drastically between 2021 and 2023, as demonstrated in Figure 4. A future assessment of adjusted associations, in which additional variables such as temperature and precipitation are accounted for, may provide important insights into environmental factors impacting waterborne disease burden.

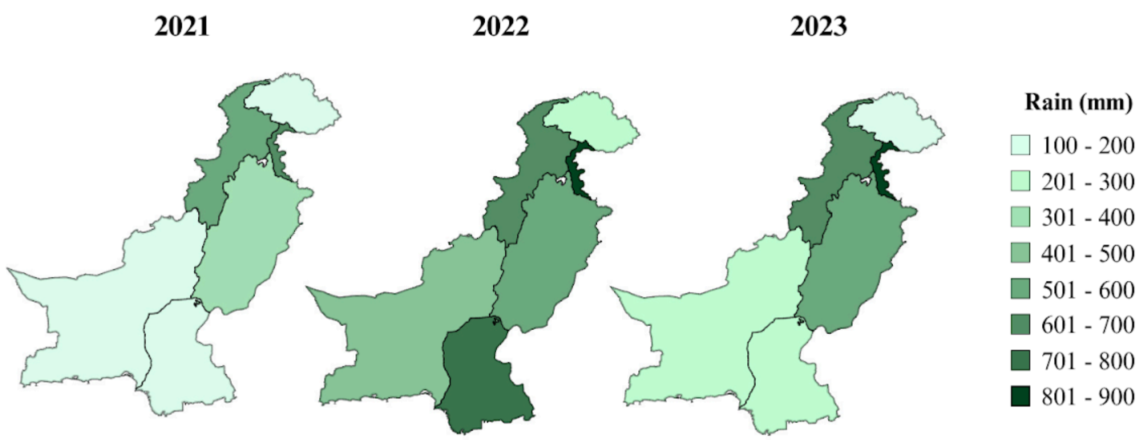

Figure 4. Annual area-weighted rainfall in Pakistan (mm), years 2021 to 2023.

While the analysis suggests that disease prevalence increases during the monsoon season, there were no statistically significant differences in disease prevalence during the four-week periods before and after known flooding events. The lack of significance across the pre-flood and post-flood KFE analysis may be explained by the possibility of flood overlap, such that the pre-flood period of one KFE may capture the post-flood period of a preceding KFE, especially during rainier seasons. Research demonstrates that waterborne diseases are associated with floods via indirect and direct pathogen transport, with the highest odds of morbidity two to four weeks following a flood event (Wang et al., 2023). This phenomenon was not reflected in the results of this analysis, possibly due to data and research limitations, especially during the year of known flooding devastation, 2022. With an analysis at this scale, using disease estimates at the level of the administrative unit may also hide or underestimate impacts of flooding on a local or regional scale. The impact of the KFEs may have been more significant if assessed on a different scale, providing an additional opportunity for more targeted research in the future.

For research of this nature, it is important to acknowledge that vulnerabilities often compound; the combination of existing WASH challenges, inequitable climate change impacts, and health infrastructure challenges in Pakistan exacerbates the stress experienced by the healthcare system, the environment, the community, and individuals in the event of major flooding and consequent waterborne disease outbreak. Both climate change and WASH-related issues disproportionately impact areas already facing developmental challenges (Government of Canada, 2017; USGLC, 2021), presenting a fundamental challenge to address through improved sustainable development efforts, dedicated public health intervention, and intentional consideration of disproportionate impacts across people and populations.

Research that considers the impact of important climate nuances on human health continues to grow in importance and urgency as climate change progresses. Though climate change research in the field of infectious disease has both increased and improved in recent years, research shows that exploration at this intersection is still lacking (Van de Vuurst & Escobar, 2023). Monsoons are not new in Pakistan, nor is climate change, yet the future impacts of extended monsoon seasons, unpredictable severe weather, and increased vulnerability to the effects of climate change remain broadly unknown (Eckland, 2018). Given the unprecedented nature of these threats, building public health capacity and investing in evidence-based development efforts to address climate change, flooding, water, and sanitation infrastructure is crucial. Ultimately, these imperative efforts will build resilience against potential health fallouts in the event of a disaster, ensuring populations remain protected in the future. From a policy standpoint, research demonstrating the health impacts of climate change may contribute to important policy improvements, including expansion of climate refugee coverage. Climate refugees, who may be displaced due to a plethora of climate-related reasons, including natural disaster, are currently neither recognized nor protected under international refugee law, including protections by the United Nations High Commissioner for Refugees (UNHCR, n.d.). Research may provide political advocacy leverage and evidence-based recommendations, promoting an expansion of intervention, resource allocation, and protection in the future.

Assessing the impact of flooding on infectious disease burden not only underscores the need for comprehensive, targeted monitoring and surveillance of climate and health-related threats, but also provides insight necessary for effectively addressing ongoing climate, WASH, and healthcare challenges, ultimately protecting the health and well-being of communities in Pakistan and beyond.

Limitations

This study has several limitations. First and foremost, weekly case report data from the NIH's public repository are extremely limited, and often inconsistent in reporting frequency and scope. The IDSR Weekly Bulletin contains data beginning Week 21 of 2021, with a collection of reports through the early weeks of 2024. The primary year of interest, 2022, only contains data from January to April, with a lapse in available reports for the following year. No additional sources of case report data, from Pakistan's NIH or external resources, were identified. Given the availability of data, or lack thereof, the range of supported statistical tests was extremely limited. For this analysis, non-parametric tests were required to account for smaller sample sizes and a failure to meet normality assumptions, which are generally less powerful than parametric counterparts. Furthermore, the IDSR reports, which contained all case count and reporting compliance data, were only available in PDF format. Data of interest was manually transcribed from 58 reports, which introduced the potential for manual error. Careful steps were taken to minimize the potential of manual error throughout the data collection and entry process.

Across the IDSR reports, there was a fairly consistent increase in the number of agreed reporting sites and reports received over time. Between 2021 and 2023, there was a considerable difference in the number of ARS reports contributing to IDSR reports each week. Although increased surveillance, data, and monitoring efforts warrant celebration from a public health perspective, the differences were hard to adjust for without more detailed descriptions of reporting circumstances. While compliance information, based on the number of agreed reporting sites and the actual number of reports received each week, was available in weekly bulletin reports, the lack of additional information, including characteristics of the reporting sites and their potential contributions to overall case count estimates, made estimating the significance of differences between 2021 and 2023 estimates difficult due to potential confounding. Adjusting case data on the basis of weekly compliance was not explored in this analysis, given an observed pattern of poor compliance in the early weeks of newly agreed reporting from additional reporting sites.

Furthermore, the data provided in the IDSR Weekly Bulletin reports is fairly limited, as crude case counts are reported without any additional variables or information. The manner in which diseases are bucketed potentially erases important disease nuances, which may impact how disease burden is appropriately assessed, addressed, and managed. In IDSR reports, acute diarrhea and bloody diarrhea are not reported with any specific causative pathogen, as well as no delineation between viral and bacterial origin. Research suggests that climate and flooding may affect these types of disease differently; for example, research demonstrates a positively correlated temperature-diarrhea relationship, with the exception of viral diarrhea (Kraay et al., 2020). Across IDSR reports, no criteria is provided to describe how diseases are classified into each of these reporting categories. Similarly, the reports fail to provide any data to distinguish between incidence and prevalence, such that weekly recovery or new infection trends are impossible to assess. A more detailed account of weekly infectious disease incidence and prevalence, with additional note of important factors such as causative agent, type of diagnosis (for example, symptomatic surveillance, laboratory confirmation), and date of diagnosis, may allow researchers to better design studies that better address specific diseases, specific pathways, and the impact of water and flooding on disease transmission and burden.

Public data availability, in addition to and well beyond the IDSR Weekly Bulletin reports, was generally poor. Adequate flood data, Geographic Information System (GIS) data, epidemiological data, and weather and climate data for Pakistan were either incomplete, insufficient, or completely missing from public data reserves. For example, this analysis fails to consider seasonal rain and precipitation data, which may provide additional information to explain infectious disease patterns or better contextualize monsoon seasonality. The analysis was completed using available data, though additional information and resources may enhance future assessments and provide a more holistic understanding of the impacts of both climate change and flooding on infectious disease transmission and health burdens in Pakistan.

Due to data availability and reporting characteristics, identifying known flood events presented additional challenges. KFE data was only available via news reports and flood lists, which often failed to report the exact date or duration of the flooding events. Among news sources, major flooding events were typically reported in the aftermath of major infrastructural failures or disasters, often resulting in one or more deaths. For example, flood events as a result of heavy monsoon rains and unmanageable water influx were more likely to receive news attention if they resulted in landslides and dangerous flash flooding. Acute flooding events, or floods that did not result in significant damage, may have been severely underreported in public reporting systems. For this reason, the KFEs included in this analysis likely underestimated flood burden in Pakistan between 2021 and 2023. A more robust analysis requires comprehensive cataloging of flood events, including their start date, duration, and scope.

Importantly, the climate differs across the entirety of Pakistan, as well as surrounding regions. There are variations in the monsoon season across West South Asia, where much of Pakistan's flooding occurs (Ashfaq et al., 2023). As the seasonality of summer monsoon rains becomes harder to predict, well-defined research parameters are harder to identify and employ in flood-related analysis. Conducting analysis on a country-wide level, and even across different administrative units, fails to account for important local differences in geography, hydrology, climate, risk factors, seasonal differences, and resources available for flood preparedness and mitigation. Without comprehensive surveillance and data to reasonably account for these differences on local and regional scales, evidence-based opportunities for targeted or place-based intervention may not be as easily identifiable. Insufficient analysis may not only fail to protect vulnerable areas and populations, but also misallocate resources and public health intervention efforts. Data improvements across the environmental sciences, health sciences, and their intersection may significantly improve research efforts and downstream health outcomes.

Future Research

This analysis serves as an exploratory, country-wide assessment of climate-related flooding on infectious disease prevalence and burden in Pakistan. To better understand the intricacies of climate change impacts on waterborne diseases, more research is necessary. From a climate change perspective, future analyses of this nature may include additional climate predictors, such as temperature, precipitation, or historical patterns of flooding and drought. From a health perspective, future studies may consider additional variables such as the distribution and capacity of WASH infrastructure, the movement or growth of populations and people across Pakistan, or local healthcare capacity, such as ability to appropriately diagnose and report diseases of this nature. From an epidemiological perspective, additional research may consider causative pathogens, concurrent health conditions, or well-defined transmission pathways. Consideration of population demographics and place-based characteristics may alleviate the potential for confounding, as well as identify additional relationships between climate and disease.

While this analysis focused primarily on statistical association, utilization of Geographic Information System (GIS) analysis and more advanced modeling techniques may ameliorate future research efforts. Furthermore, severe flood impacts on a local level may be lost when describing flood impacts at the level of each administrative unit. Research at a smaller scale, such as district-wide or area-based, may provide invaluable insights that better describe local and regional differences, trends, and opportunities for public health improvement.

Conclusion

The 2022 floods in Pakistan demonstrated a unique vulnerability: disease and death attributable to climate change, as unprecedented flooding ravaged the country (Gowen & Bashir, 2023). Climate change undoubtedly impacts communities, individuals, and the systems that are designed to protect them. In Pakistan, extreme monsoon rains contribute to flooding, infrastructural damage, population displacement, and consequently, the spread of infectious waterborne disease. Though this three-year assessment did not present statistical significance between pre-KFE and post-KFE case estimates across most assessment levels, observed health burdens highlight the necessity for research of this nature. From an epidemiological perspective, flood events, especially of such extreme magnitude, impact the environment, infectious disease, and human health. Given the quality and quantity limitations of publicly available data, a more comprehensive understanding of this relationship may be gleaned from a more robust analysis in the future. More comprehensive climate change monitoring, more representative data, and more detailed epidemiological resources are necessary to adequately assess future climate change and health risks. Furthermore, considerations of climate change in infectious disease research may aid in the identification of opportunities for intervention, as well as help direct the most appropriate allocation and distribution of resources. Ultimately, better research can inform strategies to optimize public health response in the event of climate and health emergencies, such as addressing waterborne disease outbreaks in the aftermath of extreme flooding events. Research of this nature underscores the health vulnerabilities associated with extreme flooding and climate change; an expansion of environmental, WASH, and health capacity is necessary to promote resilience and ensure populations remain protected, healthy, and adaptable in the future.

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Appendix

Supplementary Table 1. Description of available IDSR data across Pakistan, number of reports received across yearly reporting periods, 2021-2023

Number of Reports Received		
Reporting Period	**Weeks of Reporting**	**Pakistan***
2021	(N = 17)	
Pre-Monsoons	1	407
Monsoon Season	9	6,423
Post-Monsoons	7	7,338
2022	(N = 9)	
Pre-Monsoons	9	11,349
Monsoon Season	0	-
Post-Monsoons	0	-
2023	(N = 32)	
Pre-Monsoons	1	NA
Monsoons	18	69,768
Post-Monsoons	13	62,037
Total	**N = 58**	**157,322**

* Punjab excluded due to insufficient data.

Supplementary Table 2. Description of available IDSR data by administrative unit, number of reports received across yearly reporting periods, 2021-2023

Number of Reports Received						
Reporting Period	**AJK**	**BAL**	**GB**	**ICT**	**KP**	**SIN**
2021						
Pre-Monsoons	29	111	13	11	52	191
Monsoon Season	251	1,768	306	158	1,830	2,067
Post-Monsoons	192	1,770	213	159	2,937	2,067
2022						
Pre-Monsoons	271	2,741	284	214	4,522	3,317
Monsoon Season	-	-	-	-	-	-
Post-Monsoons	-	-	-	-	-	-
2023						
Pre-Monsoons	NA	NA	NA	NA	NA	NA
Monsoons	5,746	11,365	1,052	363	21,725	29,517
Post-Monsoons	4,364	11,585	2,955	276	19,147	23,710
Total	**10,853**	**29,340**	**4,823**	**1,181**	**50,213**	**60,912**

Supplementary Table 3. Known Flood Events (KFEs) in Pakistan, 2021-2023

Flood Date	**Year**	**Location**	**Inclusion* in Analysis** (*** if included)
Jan. 3	2021	KP	
Jan. 10	2021	AJK	
March 22	2021	KP	
July 11	2021	KP	***
July 15	2021	Balochistan	***
July 18	2021	KP	***
July 20	2021	KP	
July 28	2021	ICT	***
Sept. 3	2021	KP	***
Sept. 3	2021	Sindh	***
Sept. 8	2021	KP	***
Sept. 20	2021	KP	
Sept. 23	2021	Sindh	***
Jan. 20	2022	KP	***
May 7	2022	GB	
July 4	2022	Balochistan	
Aug. 15	2022	Balochistan	
Aug. 15	2022	Sindh	
Aug. 20	2022	Sindh	
March 17	2023	Balochistan	
March 24	2023	KP	
March 29	2023	KP	
April 1	2023	KP	
April 18	2023	KP	
April 29	2023	Balochistan	
June 10	2023	KP	***
June 14	2023	Sindh	***
July 6	2023	KP	***
Sept. 3	2023	KP	***
Sept. 3	2023	AJK	***

* Exclusion due to insufficient data.