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Original Article

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Spatial Accessibility of Health Facilities and Implications for Nutrition and Health Emergency Preparedness in Flood-Affected Districts of Pakistan: A GIS-Based Ecological Study

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Abstract

Background: Climate-induced flooding poses a significant threat to health systems by disrupting access to healthcare, emergency referrals, and essential nutrition services. Pakistan experiences recurrent monsoon floods that disproportionately affect vulnerable populations, highlighting the need for evidence-based preparedness planning. Spatial accessibility analysis offers a valuable approach for identifying districts where limited healthcare access may compromise emergency response and continuity of nutrition and public health services. This study assessed the spatial accessibility of health facilities in flood-affected districts of Pakistan and identified priority areas for disaster preparedness. **Methods:** An ecological cross-sectional study was conducted using publicly available secondary datasets. Geographic Information System (GIS) techniques were applied to integrate district flood status, mapped health facility locations, and population data. District-level health-site density per 10,000 population, nearest-hospital distance, and population burden were calculated. Flood-affected and non-flood-affected districts were compared using descriptive statistics, Wilcoxon rank-sum tests, and Welch's t-tests. A composite preparedness priority score incorporating flood exposure, population burden, health facility density, and geographic accessibility was developed to identify districts requiring enhanced preparedness. **Results:** Flood-affected districts did not demonstrate uniformly lower health-facility density than non-flood-affected districts. Instead, considerable geographic heterogeneity was observed. While flood-affected districts generally had higher median health-site density and shorter median distance to the nearest hospital, several districts exhibited substantial preparedness gaps due to high population burden, limited population-standardized facility availability, and reduced geographic accessibility. Faisalabad, Muzaffargarh, Bahawalpur, Gujranwala, Multan, Nushki, Rajanpur, and Khairpur emerged as the highest-priority districts for preparedness interventions. The findings indicate that preparedness planning based solely on flood exposure may overlook districts with critical healthcare accessibility constraints. **Conclusion:** Integrating geospatial accessibility indicators with flood exposure and population burden provides a practical framework for prioritizing disaster preparedness in Pakistan. The identified priority districts should be considered for strengthening referral systems, deployment of mobile health and nutrition teams, pre-positioning of emergency medical and nutrition supplies, and improving continuity of essential health and nutrition services before future monsoon seasons. GIS-based evidence can support climate-resilient health and nutrition planning and contribute to more equitable emergency preparedness in disaster-prone settings.

Introduction

Climate change has emerged as one of the most significant threats to global public health, increasing the frequency, intensity, and severity of floods, heatwaves, droughts, and other extreme weather events that challenge health systems worldwide. Among these hazards, floods account for the largest proportion of climate-related disasters, causing widespread mortality, displacement, destruction of infrastructure, and disruption of essential healthcare services, particularly in low- and middle-income countries (LMICs) [1,2]. Beyond their immediate physical impacts, floods increase the burden of communicable diseases, interrupt maternal and child healthcare, compromise immunization programs, reduce access to essential medicines, and adversely affect food security and nutritional status among vulnerable populations [1,3].

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Pakistan is recognized as one of the country's most vulnerable to climate-induced disasters because of its geographical diversity, rapid urbanization, socioeconomic inequalities, and increasing climate variability. The unprecedented monsoon floods of 2022 affected approximately 33 million people across 85 calamity-hit districts, resulting in more than 1,700 deaths, widespread displacement, extensive destruction of health infrastructure, and major disruption of routine health services [4,5]. The Post-Disaster Needs Assessment further documented severe damage to health facilities, roads, water supply systems, and sanitation infrastructure, demonstrating that flood emergencies have consequences extending far beyond the immediate disaster period [6]. More recently, the Pakistan Meteorological Department reported that 2024 was the seventh wettest year during the previous six decades, with annual rainfall 31% above the long-term average and national mean temperature 0.71°C above normal, indicating an increasing likelihood of recurrent climate-related emergencies [7]. These trends underscore the need to strengthen climate-resilient health systems and disaster preparedness strategies before future flood events occur.

Floods influence health through multiple interconnected pathways. Damage to transportation networks and healthcare infrastructure limits physical access to health facilities, delays emergency referrals, interrupts routine immunization, maternal and newborn care, and continuity of treatment for chronic diseases. Simultaneously, contaminated water sources, overcrowded shelters, inadequate sanitation, and disruption of food systems increase the incidence of diarrheal diseases, vector-borne infections, acute respiratory illnesses, and undernutrition, particularly among children under five years of age and pregnant and lactating women [1,8,9]. These combined effects highlight that disaster preparedness should encompass not only emergency medical response but also the continuity of essential nutrition and primary healthcare services.

Maintaining access to nutrition services during emergencies has become an increasingly important component of resilient health systems. Essential interventions such as infant and young child feeding counselling, growth monitoring, micronutrient supplementation, community-based management of acute malnutrition, maternal nutrition services, and nutrition surveillance depend upon accessible and functional health facilities [10]. Disruptions to these services during floods may exacerbate childhood wasting, micronutrient deficiencies, food insecurity, and maternal health risks, particularly in underserved and geographically isolated communities. Consequently, improving spatial accessibility to health facilities contributes not only to emergency healthcare delivery but also to the continuity of nutrition interventions and achievement of Universal Health Coverage and the Sustainable Development Goals.

Geographic Information Systems (GIS) have become indispensable tools for assessing spatial accessibility to healthcare services and supporting evidence-informed public health planning. By integrating health facility locations, population distribution, hazard exposure, and administrative boundaries, GIS enables identification of underserved populations, assessment of geographic inequalities, and prioritization of areas requiring additional health resources [11]. Previous studies conducted in Pakistan have shown that household vulnerability to flood-related health risks is strongly influenced by socioeconomic conditions, access to healthcare, water and sanitation services, and geographic distance to health facilities [12,13]. Nevertheless, most available studies have focused on household vulnerability or post-disaster impacts rather than evaluating district-level spatial accessibility of health facilities using nationally available geospatial datasets.

Global frameworks similarly emphasize strengthening health systems to withstand climate-related emergencies. The World Health Organization Operational Framework for Building Climate-Resilient and Low Carbon Health Systems recommends integrating climate adaptation into health infrastructure, surveillance, emergency preparedness, and service delivery to ensure continuity of essential healthcare during disasters [3]. Likewise, the Sendai Framework for Disaster Risk Reduction 2015–2030 advocates risk-informed planning, resilient infrastructure, and evidence-based decision-making to reduce disaster-related health losses [14]. These international frameworks recognize that effective preparedness requires combining hazard information with health system capacity and service accessibility rather than relying solely on hazard exposure.

Despite Pakistan's repeated experience with severe flooding, district-level evidence integrating flood exposure with spatial accessibility of health facilities remains limited. Preparedness planning often identifies flood-prone districts without simultaneously considering population burden, health facility distribution, and geographic access to referral hospitals. Such approaches may overlook districts where relatively limited healthcare accessibility could substantially compromise emergency response despite moderate flood exposure. Furthermore, few studies have translated publicly available geospatial datasets into practical preparedness tools for district-level decision-making.

The present study addresses this evidence gap by conducting a district-level ecological assessment of spatial accessibility to mapped health facilities in flood-affected districts of Pakistan using publicly available secondary datasets. The study evaluates health-site density per 10,000 population, geographic proximity to hospitals, and population burden to develop a composite preparedness prioritization framework for flood-prone districts. Rather than assessing health facility functionality or quality of care, this study provides an evidence-based geospatial approach for identifying districts where limited healthcare accessibility may constrain emergency response and continuity of essential health and nutrition services.

The findings are expected to support national and provincial disaster management authorities, health planners, and development partners in strengthening climate-resilient health systems through targeted preparedness interventions.

By identifying districts where high population burden overlaps with limited health facility accessibility, the study provides evidence to inform pre-positioning of mobile health and nutrition teams, strengthening referral systems, improving emergency logistics, and ensuring continuity of essential health and nutrition services before future monsoon emergencies.

Materials and Methods

❖ Study Design

An ecological cross-sectional study was conducted using publicly available secondary geospatial datasets to assess district-level spatial accessibility to health facilities in flood-affected districts of Pakistan. The district served as the unit of analysis, and Geographic Information System (GIS)-based techniques were employed to integrate health facility locations, district boundaries, flood status, and population data. The study focused on baseline spatial accessibility and preparedness rather than evaluating health facility functionality during flood emergencies.

❖ Study Area

The study covered all administrative districts of Pakistan, including Punjab, Sindh, Khyber Pakhtunkhwa, Balochistan, Gilgit-Baltistan, Azad Jammu and Kashmir (AJ&K), and Islamabad Capital Territory (ICT). Districts were categorized as flood-affected or non-flood-affected according to the National Disaster Management Authority (NDMA) flood classification incorporated into the district geospatial dataset. The analysis aimed to compare accessibility indicators between flood-affected and non-flood-affected districts while identifying districts requiring priority preparedness interventions.

❖ Data Sources

Secondary datasets were obtained from publicly available national sources. District administrative boundaries and flood-status classifications were derived from the district shapefile used in the analysis. Health facility locations were extracted from the Pakistan Health Sites dataset, which provides georeferenced information on hospitals and other health facilities across Pakistan. Population denominators were obtained from the Pakistan Tehsil–District Census dataset based on the 2017 Population and Housing Census and harmonized to district administrative boundaries. Additional contextual information on flood impacts, climate variability, and district characteristics was obtained from the National Disaster Management Authority (NDMA), Pakistan Meteorological Department (PMD), and Pakistan Bureau of Statistics (PBS).

❖ Variables

The primary outcome variable was district-level health-site density, calculated as the number of mapped health facilities per 10,000 population. Secondary accessibility indicators included hospital density per 10,000 population, total mapped health facilities, total mapped hospitals, district population, district area, and centroid-to-nearest mapped hospital distance (km). Flood status (flood-affected or non-flood-affected) was considered the principal exposure variable.

To support preparedness planning, a composite preparedness priority score was developed by integrating four indicators: district flood status, population burden, health-site density, and geographic distance to the nearest mapped hospital. Higher scores indicated districts requiring greater preparedness attention due to overlapping accessibility constraints and population vulnerability.

Table 1. Characteristics of the Study Variables

Variable	Definition	Unit
Flood status	District classified as flood-affected or non-flood-affected	Binary
Population	District population (2017 Census)	Number
Known health sites	Total mapped health facilities	Count
Hospitals	Total mapped hospitals	Count
Health-site density	Health facilities per 10,000 population	Per 10,000 population
Hospital density	Hospitals per 10,000 population	Per 10,000 population
Nearest health site distance	Euclidean distance from district centroid to nearest health facility	km
Nearest hospital distance	Euclidean distance from district centroid to nearest hospital	km
Preparedness priority score	Composite score based on flood status, accessibility, and population burden	Continuous

❖ Spatial Analysis

Spatial analyses were conducted using Geographic Information System (GIS) methods to characterize health facility accessibility across Pakistan. Health facility point locations were spatially assigned to district polygons to determine district-level facility counts. Health-site density was standardized using district population denominators to enable comparisons across districts with varying population sizes.

Geographic accessibility was assessed by calculating the straight-line (Euclidean) distance from each district centroid

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to the nearest mapped hospital. Although Euclidean distance does not account for transportation networks or travel time, it provides a practical geographic proxy for district-level referral accessibility and preparedness screening. Choropleth maps were generated to visualize the spatial distribution of health-site density, hospital accessibility, and preparedness priority across Pakistan.

❖ Statistical Analysis

Descriptive statistics were calculated for all study variables using means, medians, standard deviations, interquartile ranges, and frequency distributions. Accessibility indicators were compared between flood-affected and non-flood-affected districts using the Wilcoxon rank-sum (Mann–Whitney U) test because several variables demonstrated skewed distributions. Welch's independent t-test was additionally performed to compare group means while accounting for unequal variances.

Scatterplots, boxplots, and choropleth maps were used to examine spatial and distributional patterns. Exploratory regression analyses were performed to assess associations between flood status and accessibility indicators; however, these analyses were considered supportive rather than inferential because the ecological study design precludes causal interpretation. Statistical significance was assessed using a two-sided p-value of <0.05.

Ethical Considerations

The study utilized publicly available, anonymized secondary datasets containing no individual-level or identifiable information. Consequently, informed consent was not required, and formal ethical review was not necessary under institutional guidelines for secondary analyses of publicly available data. All datasets were used in accordance with their respective data-sharing policies, and appropriate acknowledgment was provided to the original data sources.

Quality Assurance

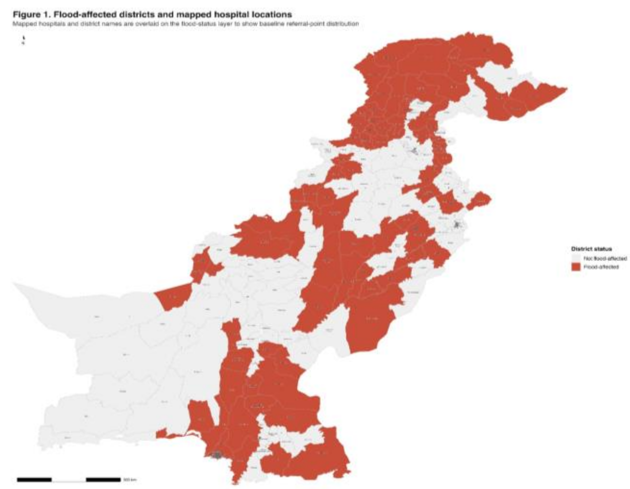
To ensure analytical consistency, district population denominators were harmonized with administrative boundaries before calculating standardized accessibility indicators. Districts with unavailable population denominators were excluded from density-based analyses but remained available for descriptive mapping where appropriate. Data cleaning procedures included verification of district names, boundary harmonization, assessment of missing values, and validation of spatial joins between health facility records and district polygons. Priority rankings and accessibility indicators were independently cross-checked against generated analytical outputs to improve reproducibility and reduce potential processing errors.

Results

❖ District Characteristics

The analysis included all administrative districts of Pakistan classified as either flood-affected or non-flood-affected based on the 2022 National Disaster Management Authority flood classification. District-level health facility records, population denominators, and spatial accessibility indicators were successfully integrated to generate a national geospatial database for preparedness assessment. Districts without matched population denominators were excluded from population-standardized analyses but remained available for descriptive mapping and accessibility assessment.

Figure 1: Flood-affected districts across Pakistan



Provincial Distribution of Health Facilities

Substantial variation in health facility availability and geographic accessibility was observed across provinces and territories (Table 2). Flood-affected districts in Sindh contained the largest number of mapped health facilities (1,068 facilities and 516 hospitals), reflecting the province's large population and concentration of health services. In contrast, Khyber Pakhtunkhwa contained the greatest number of flood-affected districts (n = 27), while Balochistan demonstrated the greatest geographic remoteness, with a median nearest-hospital distance of 64.29 km among flood-affected districts.

Punjab showed relatively similar health facility densities between flood-affected and non-flood-affected districts (0.03 health facilities per 10,000 population), although median hospital accessibility was lower in flood-affected districts (21.32 km versus 15.94 km). Sindh demonstrated comparatively higher health-site density among flood-affected districts (0.06 facilities per 10,000 population), whereas Islamabad Capital Territory exhibited the highest health facility density and shortest median hospital distance (0.21 km), reflecting its highly urbanized setting.

Table 2. Provincial Comparison of Health Facility Accessibility by Flood Status

Province	Flood status	Districts	Population	Health Sites	Hospitals	Health Sites/10,000	Hospitals/10,000	Median Hospital Distance (km)
AJ&K	Flood	6	9,444	10	8	1.06	0.00	16.26
AJ&K	Non-flood	4	–	1	1	–	–	26.80
Balochistan	Flood	8	4,358,200	31	19	0.01	0.01	64.29
Balochistan	Non-flood	28	8,424,934	10	10	0.00	0.00	83.79
Khyber Pakhtunkhwa	Flood	27	29,954,099	149	67	0.02	0.01	23.85
Khyber Pakhtunkhwa	Non-flood	10	5,213,260	22	8	0.00	0.00	46.17
Punjab	Flood	17	51,109,339	350	229	0.03	0.02	21.32
Punjab	Non-flood	19	58,903,103	604	348	0.03	0.02	15.94
Sindh	Flood	19	34,775,960	1068	516	0.06	0.05	23.17
Sindh	Non-flood	11	12,020,922	183	80	0.02	0.02	21.11
ICT	Non-flood	1	2,006,572	122	51	0.61	0.25	0.21

Comparison Between Flood-Affected and Non-Flood-Affected Districts

District-level comparisons revealed significant differences between flood-affected and non-flood-affected districts for several accessibility indicators (Table 3). Flood-affected districts contained a higher median number of mapped health facilities (median = 4) than non-flood-affected districts (median = 1). Similarly, the median number of mapped hospitals was greater in flood-affected districts (median = 2) compared with non-flood-affected districts (median = 0).

Health-site density per 10,000 population was significantly higher in flood-affected districts (median = 0.03) than in non-flood-affected districts (median = 0.01) (Wilcoxon p = 0.005). Hospital density also demonstrated a significant difference between the two groups (median = 0.02 versus 0.00 hospitals per 10,000 population; Wilcoxon p = 0.013). These findings indicate that flood-affected districts were not uniformly characterized by lower mapped facility availability.

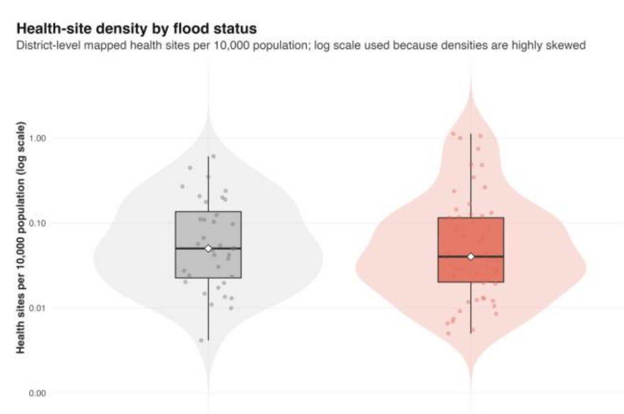
Table 3. Comparison of Spatial Accessibility Indicators Between Flood-Affected and Non-Flood-Affected Districts

Indicator	Flood-affected	Non-flood	Wilcoxon p-value	Welch t-test p-value
Known health sites (median)	4	1	0.001	0.310
Hospitals (median)	2	0	0.002	0.366
Health sites/10,000 population	0.03	0.01	0.005	0.067
Hospitals/10,000 population	0.02	0.00	0.013	0.097
Nearest health site distance (km)	22.05	33.57	0.020	0.003
Nearest hospital distance (km)	24.25	33.65	0.060	0.006

Spatial Accessibility to Hospitals

Geographic accessibility analysis demonstrated important differences in hospital proximity. Flood-affected districts had a shorter median distance to the nearest mapped hospital (24.25 km) than non-flood-affected districts (33.65 km). Welch's t-test also demonstrated a statistically significant difference in mean nearest-hospital distance (34.72 km versus 54.50 km; p = 0.006), suggesting that although some flood-affected districts possessed relatively good geographic access, considerable variability remained across the country. Remote districts, particularly in Balochistan and parts of Gilgit-Baltistan, continued to experience substantially longer travel distances to hospital services than densely populated districts in Punjab and Sindh. Health-site density by flood status mentioned below.

Figure 2: Health-site density by flood status



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Preparedness Priority Assessment

The composite preparedness assessment demonstrated that flood exposure alone did not adequately identify districts requiring intervention. Instead, districts with overlapping characteristics—including high population burden, lower population-standardized health facility density, and relatively poor geographic accessibility—were identified as priority areas for preparedness planning.

The highest-priority districts included Faisalabad, Muzaffargarh, Bahawalpur, Gujranwala, Multan, Nushki, Rajanpur, Khairpur, Okara, and Dera Ghazi Khan. These districts combined large population burden with comparatively constrained accessibility indicators, suggesting that they may require strengthened referral systems, emergency logistics, and enhanced preparedness before future monsoon seasons.

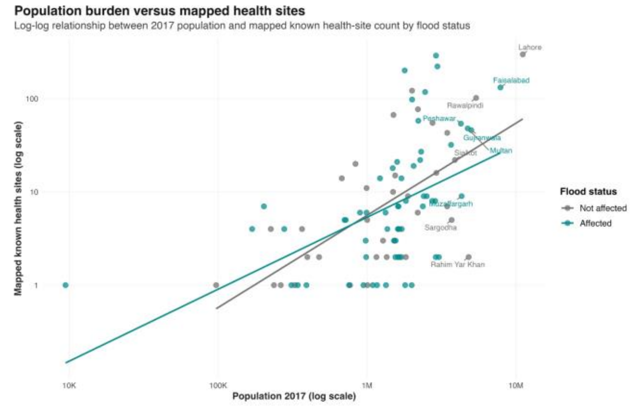
Table 4. Highest-Priority Districts for Flood Preparedness

Rank	District	Province	Priority Considerations
1	Faisalabad	Punjab	High population burden and moderate facility density
2	Muzaffargarh	Punjab	Flood exposure and accessibility constraints
3	Bahawalpur	Punjab	Large catchment population
4	Gujranwala	Punjab	Population pressure
5	Multan	Punjab	Referral demand
6	Nushki	Balochistan	Geographic remoteness
7	Rajanpur	Punjab	Flood vulnerability
8	Khairpur	Sindh	Flood-prone population
9	Okara	Punjab	Moderate accessibility
10	Dera Ghazi Khan	Punjab	Combined accessibility and flood risk

Statistical Findings

Non-parametric analyses demonstrated statistically significant distributional differences between flood-affected and non-flood-affected districts for mapped health facilities (Wilcoxon $p = 0.001$), mapped hospitals ($p = 0.002$), health-site density ($p = 0.005$), and hospital density ($p = 0.013$). Mean nearest-health-site distance also differed significantly between the two groups (Welch's t-test $p = 0.003$), while mean nearest-hospital distance remained significantly shorter among flood-affected districts ($p = 0.006$). Population burden versus mapped health sites mentioned in figure 3.

Figure 3 Population burden versus mapped health sites



Overall, these findings indicate that health facility accessibility in Pakistan is influenced by population distribution and geographic context rather than flood exposure alone. Consequently, preparedness planning should integrate spatial accessibility, population burden, and referral distance alongside hazard exposure when prioritizing districts for emergency response.

Discussion

The present study addressed the evidence gap identified in the Introduction by providing a district-level geospatial assessment of health facility accessibility in flood-affected districts of Pakistan. Using publicly available GIS datasets, the study demonstrated that flood exposure alone does not adequately explain healthcare accessibility or preparedness. Rather, preparedness is influenced by the interaction between population burden, health facility density, and geographic accessibility. These findings suggest that disaster preparedness planning should extend beyond hazard mapping to incorporate health system accessibility and geographic equity. (No citation required—this summarizes your own findings.)

The findings are consistent with previous studies demonstrating that vulnerability during flood emergencies is determined by multiple interacting factors rather than flood exposure alone. Shah et al. reported that flood-related health vulnerability in Pakistan was strongly associated with healthcare accessibility, socioeconomic conditions, water and sanitation infrastructure, and community resilience rather than hazard occurrence itself [15]. Similarly, Shah et al. demonstrated that rural communities with poor transportation networks and limited access to healthcare experienced disproportionately greater health risks during flood emergencies, emphasizing the importance of spatial accessibility in disaster preparedness [16].

The observed geographic disparities also agree with previous GIS-based healthcare accessibility research. Noor et al. demonstrated that physical accessibility remains one of the strongest determinants of equitable healthcare utilization and recommended integrating geospatial accessibility measures into health planning and resource allocation [17]. Similar conclusions have been reported from flood-prone regions of Bangladesh and India, where geographic barriers significantly reduced access to emergency healthcare services during disasters [18,19].

An important finding of this study was that flood-affected districts generally had higher mapped health facility density than non-flood-affected districts. This observation should not be interpreted as evidence of better preparedness because health facility numbers do not necessarily reflect service functionality, emergency readiness, or continuity of care. The 2022 Pakistan Floods Post-Disaster Needs Assessment reported that many health facilities became damaged or non-functional despite their physical presence, highlighting the importance of resilient infrastructure and emergency preparedness [20].

The shorter median distance to hospitals observed in flood-affected districts should likewise be interpreted cautiously. Geographic proximity alone does not ensure uninterrupted healthcare access during disasters because damaged roads, disrupted transportation networks, and overwhelmed referral systems frequently limit healthcare utilization. The WHO Operational Framework for Building Climate-Resilient and Low Carbon Health Systems recommends strengthening resilient infrastructure, emergency logistics, referral mechanisms, and continuity of essential health services rather than focusing solely on healthcare infrastructure availability [21].

The Introduction highlighted that floods threaten continuity of essential nutrition services, including antenatal care, infant and young child feeding, micronutrient supplementation, growth monitoring, immunization, and management of acute malnutrition. Although nutrition outcomes were not directly assessed in this study, the identified accessibility gaps have important implications for maintaining these services during emergencies. Recent UNICEF and Standing Together for Nutrition reports emphasize that resilient health and nutrition systems are essential for reducing the indirect nutritional consequences of climate-related disasters [22,23].

Overall, the present study addresses the evidence gap identified in the Introduction by demonstrating that preparedness planning should move beyond flood hazard classification to incorporate healthcare accessibility, population burden, and geographic equity. The GIS-based prioritization framework provides an evidence-informed approach for identifying districts where investments in resilient health infrastructure, emergency referral systems, and continuity of essential health and nutrition services are most needed. These findings support the implementation of the WHO Operational Framework for Climate-Resilient Health Systems and the Sendai Framework for Disaster Risk Reduction within Pakistan's disaster preparedness strategies [21,24].

Conflict of Interest: NIL

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Declarations:

Authors' Contribution:

- All Authors Conceptualization, data collection, interpretation, drafting of the manuscript and intellectual revisions
- The authors agree to take responsibility for every facet of the work, making sure that any concerns about its integrity or veracity are thoroughly examined and addressed

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