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SYNERGISTIC TOXICITY: THE HYDRO-EPIDEMIOLOGICAL CRISIS OF THE 2025 GUJRANWALA FLOODS

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Abstract

The Gujranwala Division of Punjab, Pakistan, which comprises the industrial areas of Gujranwala, Sialkot, and Narowal, is a problematic case study area, where hydrological volatility, industrial non-compliance and the vulnerability of health of the population have intersected. This report gives a descriptive epidemiological and environmental study of the influence of the disastrous August-September 2025 catastrophic floods on gastrointestinal (GI) morbidity. The 2025 crisis in contrast to historical floods that are mainly caused by overflowing rivers was characterized by the so-called toxic cocktail: the inundation of industrial and residential areas by floodwater contaminated with heavy metals (Chromium, Lead, Cadmium, Arsenic) and enteric pathogens (Vibrio cholerae, Salmonella Typhi, Shigella). Based on hydro-climatic data, water quality indicators and disease surveillance notices, this paper outlines the sources of contamination, and quantifies the health burden and criticizes the structural inadequacy of the Water, Sanitation, and Hygiene (WASH) infrastructure. The discussion shows that the floods in this area are not only hydrological risks but complicated toxicological processes when with the help of the heavy metal the intestinal epithelial barrier is weakened, and the waterborne infections are aggravated by the interaction. Our hypothesis is as follows: The synchronization of the flood peaks in both rivers, the Chenab and the Ravi, produced a backwater impact, which halted the urban drainage systems, endangering millions of people with dangerous levels of industrial effluent. This report provides a conclusion to strategic recommendations of hydrological separation and industrial compliance to develop resilience to disasters caused by climate in future.

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1. INTRODUCTION

The intensive urbanization of the Global South has given rise to a new type of disaster, the so-called Na-Tech (Natural-Technological) disaster, when the natural risk causes the technological system failures, which spread hazardous substances into the environment. The Gujranwala Division in Pakistan is a model of this weakness. The division is a home to highly populated but uncontrolled industrial base, with the globally famous leather tanneries and surgical instrument manufacturing in Sialkot and ceramics, textiles and light engineering manufacturing in Gujranwala, located in the interfluvial territory of the Rechna Doab that is the interfluve between the Chenab and Ravi rivers (AIGEO360, 2025). This economic vitality has however been at a very high ecological cost. The natural drains of the region which are also referred to as Nullahs have been intentionally degraded into open sewer pipes to receive the un treated industrial effluent and municipal rubbish. These channels do not carry storm water when the hydrological extremes take place (Khoso et al., 2025). They instead empty a toxic blend of biologic and chemical pollutants in the residential quarters of the most susceptible communities. The floods kill but do not simply drown. The interplay between flood-related mobilization of industrial waste and the epidemic load of waterborne disease forms a challenging problem in the field of the complex public health that the traditional disaster response frameworks are poorly prepared to address (Al-Rashid et al., 2021).

1.2. Historical Context of Hydrological Volatility

In order to determine the intensity of the event in 2025, there is a need to place the event in the hydrological history of the region. Rechna Doab has been characterized by the periodicality of disastrous floods which over the last few decades are reduced, probably due to the strength multiplied by the climate change on the monsoon (Khoso et al., 2025).

Table 1: This Table shows the flood comparison between 2014 and 2022

The 2014 Flood was a watershed moment for the region's disaster management. Discharges at the Marala and Khanki barrages on the River Chenab exceeded 900,000 cusecs, breaching embankments and inundating vast tracts of Gujranwala, Hafizabad, and Mandi Bahauddin (Ali et al., 2019). The floodwaters, carrying heavy silt and debris, destroyed sanitation infrastructure across 1,432 villages, creating conditions ripe for waterborne outbreaks (Assefa & Köhler, 2020).	The 2022 floods touched more than 33 million people in the country due to anomalies caused by climatic factors, although the most severe situation was in the provinces of Sindh and Balochistan (Al-Rashid et al., 2021). The Gujranwala Division, however, was a point of passage of flood peaks heading south. The incident demonstrated the instability of the area drainage; the urban flooding was terrible because of the siltation and clogging of the Nullah Aik, even after the moderate rainfall (Shrivastava et al., 2002).

1.3. The 2025 Monsoon Anomaly

The hydrological problem that appears to be one of a kind is the flood episode in August-September 2025, the synchronization of peaks. Contrary to the past years when the peak of the floods in the major rivers was staggered, 2025 had simultaneous High to Exceptionally high floods in the Chenab and Ravi rivers (Khan et al., 2018). This coincidence caused a drastic backwater effect and in effect sealing the drainage outlets of the division tributaries. The resultant overflow was not, of relatively pure river water, but of the expelled contents of the Nullahs themselves--black sludge-laden water in which the industrial effluent of the past dry months was stacked up (Bilal et al., 2025).

1.4 Objectives of the Study

The primary objective of this study is to assess the environmental health risks of the 2025 floods in Gujranwala Division, focusing on water

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contamination by heavy metals and pathogens. This will help understand their impact on human health and inform mitigation strategies.

2. Methodology

The paper applies the retrospective epidemiological and environmental assessment design, which synthesis is based on various data to form an overall image of the health crisis after the flood. The analysis combines both quantitative data of water quality and the frequency of the disease with qualitative evaluation of the infrastructure breakdown and the reaction of the institutions. The evaluation period is the acute phase of the flood (August 15- September 30, 2025) and immediate post-flood recovery phase (October- December 2025), and it will be based on the data of 2014 and 2022 to compare the two periods.

2.1. Data Sources and Acquisition

A stratified set of primary and secondary data was used to obtain information:

- **Hydro-Climatic Data:** Rainfall records, river discharge rates (cusecs), and flood peak timings were obtained from the Pakistan Meteorological Department (PMD) and the Flood Forecasting Division (FFD) reports.[14] Satellite imagery analysis (Sentinel-1 SAR) was utilized to delineate flood extent and inundation duration in Sialkot and Narowal (NDMA, 2025).
- **Water Quality Indices:** Physicochemical and biological water quality data were synthesized from environmental monitoring reports conducted by the Environmental Sampling groundwater in Gujranwala and Sialkot [23] and humanitarian rapid assessment following floods parameters of interest were, pH, Total Dissolved Solids (TDS), Biological Oxygen Demand (BOD), Fecal Coliforms and concentrations of heavy metals (Cr, Pb, As, Cd, Ni) (Afzal et al., 2024).
- **Epidemiological Surveillance:** Data on morbidity was combined based on the Integrated Disease Surveillance and Response (IDSR) system: Acute Watery Diarrhea (AWD), Cholera (suspected and confirmed), Typhoid and Hepatitis A/E. Specific attention was paid to the priority diseases based on the Integrated Disease Surveillance and Response (IDSR) system: Acute Watery Diarrhea (AWD), Cholera (suspected and confirmed), Typhoid and Hepatitis A/E (Nisar et al., 2024).
- **Infrastructure and Demographics:** UNICEF profiles of underserved areas [4] and urban development reports of Sialkot and Gujranwala provided data on the location of slums, the WASH infrastructure coverage, and the industrial zoning (Shah, Hussain & Ahmed, 2020).

2.2. Analytical Framework

The study is in the form of a "Source-Pathway-Receptor" model. The Source includes tanneries, ceramics, and sewage, focusing on the identification of the sources of the contaminants and the hydrological stimuli such as flood peaks. The Pathway involves transport analysis, including Nullah overflow, groundwater percolation, and the backwater effect. The Receptor component evaluates human exposures, both oral and dermal, and assesses the end result of exposure, including morbidity and mortality.

3. Results I: The Hydrological Failure and Nullah Dynamics

The precipitation patterns of 2025 monsoon were marked with a clear change. The Pakistan Meteorological Department (PMD) documented the occurrence of the Heavy to very heavy precipitation on the upper catchments of the Chenab and Ravi rivers in the end of August. Sialkot and Jammu districts recorded 629.4 mm and 296.0 mm precipitation respectively in a 24 hour period ending on August 27, 2025. This was the most heavy precipitation in the upper catchments of the Chenab and Ravi rivers which drain the Piedmont areas of the Jammu hills, which contain the Flood Peaks synchronization: This phase involves synchronizing all centralized brokers to ensure commitment to the agreed speed limit during any phase of flooding (Darbandi et al., 2025).

3.1. Synchronization of Flood Peaks

The timely alignment of the floods in the transboundary rivers was a critical issue in the severity of the 2025 floods.

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- **River Chenab:** The discharge at Marala Headworks surged to "Exceptionally High" flood levels, exceeding 400,000 cusecs, driven by the inflows from the Jammu region (NDMA, 2025).
- **River Ravi:** Simultaneously, the River Ravi, usually a dormant channel during non-monsoon months, experienced high flows (Shahdara: 217,660 cusecs) due to releases from India and local catchment rains (Zhu et al., 2024).
- **River Sutlej:** The Sutlej River also reached "Exceptionally High" flood levels at Ganda Singh Wala (261,053 cusecs) (Shrivastava *et al.*, 2002).

These concurrent enlargement of the great rivers formed a hydraulic barrier. The tributaries (Nullahs) which empty into these rivers had their sources blocked by the overflowing water in the principal water courses.

3.2. The Failure of the Nullah Network

The natural streams on which the internal drainage of the Gujranwala Division depends are: Nullah Aik, Nullah Palkhu, Nullah Bhaid and Nullah Deg. Anthropogenic interventions have essential interfered with these streams (Shah et al., 2020).

3.2.1 Nullah Aik and Palkhu (Sialkot)

Passing through the middle of Sialkot, Nullah Aik and Palkhu are the main channels of storm water as well as industrial effluents. As the Chenab swelled, it prevented Nullah Aik from discharging. The water backed up, causing the levels within the city to rise rapidly. The hydraulic pressure caused breaches in the weak embankments near Sambrial and within Sialkot city limits (Assefa & Köhler, 2020). Years of solid waste dumping and siltation have caused enormous drains in the flow capacity of these nullahs. Historical data suggests the bed levels have risen by several feet due to the deposition of tannery sludge and municipal waste. During the 2025 event, this reduced cross-sectional area forced the water to overtop the banks at much lower discharge rates than in previous decades (Ali et al., 2022). The overflow inundated residential colonies like Model Town, Defense Road, and industrial estates. Inundation depths reached 3-4 feet in urban centers, submerging ground-floor sanitary fittings and contaminating underground water storage tanks (Zhang et al., 2024).

3.2.2 Nullah Deg (Narowal/Gujranwala)

One Nullah Deg, which was the most ferocious, destroyed the agricultural belt. The floodwaters here were heavily laden with agricultural runoff and sewage. In 2025, the overflow of Nullah Deg was the primary driver of the contamination of rural tube wells in Narowal and Pasrur tehsils, leading to immediate clusters of gastroenteritis (AIGEO360, 2025).

4. Results II: Environmental Toxicology

The 2025 floods were not hydrological vectors; they were chemical solutions. The flood unlocked many drainage systems and soil of accumulating industrial toxins that had been stored in the drainage system and soil during the dry season.

4.1 The Chemical Contaminants: A Toxic Inventory

4.1.1 Chromium (Cr) - The Sialkot Signature

The leather industry of Sialkot is a huge contributor to the pollution of chromium. Although the city is in the process of changing to the Sialkot Tannery Zone (STZ), hundreds of tanneries are situated in the city or release pre-treated effluent into Nullah Aik. Pre-flood groundwater analysis of Sialkot has revealed that the levels of Cr are 0.01-0.19 mg/L. Nevertheless, the surface water and mixed aquifer samples that were taken post-flood were reported to have a concentrate of 1.8 - 9.8 mg/L, consisting of 36-196 times the exceedance of the WHO limit of 0.05 mg/L (Zhang et al., 2024). The high velocity of floodwaters scoured the bed of Nullah Aik, re-suspending the chromium-rich sludge that had settled there. This "first flush" effect meant that the initial wave of floodwater entering homes was the most toxic (Ackland et al., 2015).

4.1.2 Lead (Pb) and Cadmium (Cd) - The Gujranwala Profile

The toxicological profile of Gujranwala city is different with its variety of industries such as ceramics, sanitary ware, and engineering. Groundwater near industrial drains in Gujranwala

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has shown Lead (Pb) concentrations up to 1.17 mg/L (Standard: 0.01 mg/L) and Cadmium (Cd) levels significantly elevated. Zone 2 (Engineering industries) recorded the highest mean levels of Cd (0.331 mg/L) and Pb (0.573 mg/L) (Ehsan et al., 2025). Samples from inundated areas displayed EC values exceeding 3000 µS/cm, indicating a hypersaline solution caused by the dissolution of industrial salts (chlorides, sulfates) and heavy metals (AIGEO360, 2025).

4.1.3 Arsenic (As) - The Regional Scourge

Floods increase the risk of arsenic contamination in Punjab, although geogenic pollution is a reality in the region. The waterlogging of soils creates anoxic (low oxygen) conditions. This change in redox potential facilitates the release of arsenic from iron-oxide complexes in the soil into the groundwater (Ackland et al., 2015). Studies indicate that over 64% of water samples in Gujranwala are contaminated with arsenic, with post-flood monitoring showing levels between 0.10 - 0.20 mg/L, ten to twenty times the WHO safe limit of 0.01 mg/L (AIGEO360, 2025).

4.2 Microbiological Contamination

The biological quality of water collapsed completely during the flood. Assessments in Gujranwala and Sialkot detected E. coli and fecal coliforms in over 90% of drinking water samples from inundated areas, with the source being the "fecal-oral loop" created by the backflow of sewage into households and the inundation of pit latrines. Unlike chemical contaminants which may dilute over time, biological pathogens can proliferate, and post-monsoon studies show that pathogens persist in biofilms within compromised distribution pipes long after the water recedes (Zohra et al., 2021).

Table 2: Physicochemical and Biological Parameters of Water in Flood-Affected Zones (AIGEO360, 2025)

Parameter	Standard (WHO/NEQS)	Pre-Flood Mean (Groundwater)	Post-Flood Mean (Inundated Zones)	Primary Source	Health Risk
E. coli / Coliforms	0 CFU/100ml	42% positive (Sialkot)	>90% positive	Sewage/Latrine Overflow	Diarrhea, Cholera, Typhoid
Chromium (Cr)	0.05 mg/L	0.01 - 0.19 mg/L	1.8 - 9.8 mg/L	Tannery Effluent (Sialkot)	Carcinogen, GI Irritation
Lead (Pb)	0.01 mg/L	0.05 - 0.15 mg/L	0.30 - 1.17 mg/L	Industrial Runoff (Gujranwala)	Neurotoxicity, Renal Failure
Arsenic (As)	0.01 mg/L	0.05 - 0.10 mg/L	0.10 - 0.20 mg/L	Geogenic + Mobilization	Skin Lesions, Cancer, Immunosuppression
TDS	<1000 mg/L	500 - 800 mg/L	1300 - 2700 mg/L	Saline Effluent Mixing	Osmotic Diarrhea

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5.0. Discussion

The intestinal epithelium is a barrier of significant physical and immunological resistance to pathogens. This has been demonstrated to be actively disrupted by heavy metals, especially Hexavalent Chromium (Cr-VI) and Cadmium (Cd). Cr(VI) is a good oxidizing agent. When it is ingested, it causes the tremendous generation of Reactive Oxygen Species (ROS) in intestinal epithelial cells. The oxidative stress leads to lipid peroxidation of the cell membrane and harms cellular proteins (Xing et al., 2022). Barrier integrity of the gut depends on tight junction proteins (occludin and claudin) that close the gaps between cells. These proteins are down-regulated by heavy metals. Research has indicated that exposure to Cr(VI) causes the activation of the NF-kB (nuclear factor kappa B) signaling pathway and the NLRP3 inflammasome, resulting in the production of pro-inflammatory cytokines (IL-1b, IL-18). This inflammation weakens the tight junctions and forms a "leaky gut." A compromised barrier allows bacteria, endotoxins (LPS), and heavy metals themselves to translocate from the gut lumen into the bloodstream, leading to chronic low-grade inflammation and high vulnerability to sepsis as a consequence of this systemic exposure (Ghosh, Nukavarapu & Jala, 2023).

The Vibrio cholerae-Arsenic (As) interaction is one of the most hazardous synergies that should be considered in the context of the Punjab, where the contaminants are both widespread. Vibrio cholerae has incredible evolutionary strategies to achieve survival in adverse conditions. It has the Ars operon house of genes enabling it to pump out arsenic from its cells or to modify it to a less toxic state. V. cholerae can outcompete normal gut bacteria which do not have these resistance mechanisms in an arsenic-rich gut environment (generated by drinking contaminated water), giving the pathogen a competitive edge to colonize the intestine more violently (Bueno et al., 2022). On the same note, arsenic causes weakening of the immune system of the host by suppressing T-cell and macrophage proliferation, which is important in overcoming bacterial infections. Arsenic also modifies intestinal mucosal secretion of cytokines (Shrivastava, Upreti & Chaturvedi, 2003). A combination of a "super-fit" pathogen and an immuno-compromised host means that the infectious dose of cholera can be much lower in populations with exposure to arsenic. Individuals who consume arsenic-contaminated water might develop serious cholera by consuming fewer bacteria than a normal person would need (Bueno et al., 2022).

The human gut microbiome offers a natural protection, the so-called colonization resistance, which does not allow such pathogens as Salmonella and Shigella to enter the human body. This ecosystem is lost by heavy metals. The presence of metals such as Lead (Pb) and Cadmium (Cd) has a strong negative effect on the abundance of advantageous bacteria (Firmicutes, Lactobacillus) and a positive effect on the percentage of pathogenic or opportunistic bacteria (Proteobacteria, E. coli) (Qin et al., 2020). The loss of the beneficial microbiota results in the gut being unable to produce short-chain fatty acids (SCFAs) which feed the gut lining and reduce the luminal pH to eliminate pathogens, providing an open niche that the flood-borne pathogens can exploit (Khoso et al., 2025).

The circumstances of the immediate aftermath of the inundation were characterized by an exponential increase in the number of gastrointestinal cases. Acute Watery Diarrhea (AWD) was the most morbidity burden disease. During the weeks after the flood, Sialkot and Gujranwala hospitals reported a 200-300 percent rise in the number of patients visiting the OPD with a diagnosis of diarrhea compared to the seasonal average. A short-term report on flood-affected districts in Punjab alone (in September 2025) showed that more than 20,945 cases of diarrhea were reported (Darbandi et al., 2025). Reports on outbreaks confirmed cholera clusters in the Sialkot rural belt, with a significant epidemic in the village of Hanjali Mehtabpur (Pasrur Tehsil), where dozens of patients arrived with uncompromisingly dehydrated and rice-water stools (Khoso et al., 2025). A rise in dysentery (bloody diarrhea) was also observed, indicative of invasive pathogens like Shigella or *Entamoeba histolytica*. This is consistent with the "leaky gut"

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mechanism described earlier, where metal-induced barrier damage facilitates bacterial invasion of the intestinal wall (Zhu et al., 2024).

8. Conclusion and Recommendations

The flood event of 2025 in Gujranwala Division was a systemic failure of urban and environmental planning, exacerbated by climate change. The convergence of extreme hydrology with unregulated industrial discharge created a public health hazard that is both acute (cholera, AWD) and chronic (metal toxicity). The "Nullah" network, intended to be the region's safety valve, has become its greatest liability.

8.1. Recommendations for Structural Intervention

1. **Hydrological Separation:** The physical separation of storm water and sewage is the most serious engineering intervention. Interceptor sewers are to be built along the banks of Nullah Aik, Palkhu, and Deg to allow dry-weather flow (sewage/effluent) to be redirected to treatment plants. This will put the nullahs back to their primitive use as flood drains (Saif-Ur-Rehman & Shaukat, 2022).
2. **Accelerated Industrial Compliance:** It has to focus on the completion and full operationalization of the Sialkot Tannery Zone (STZ). In the case of industries that will still stay in the city, the Environmental Protection Agency (EPA) should impose a severe policy of hazardous waste, strictly Zero Liquid Discharge (Al-Rashid et al., 2021).
3. **Resilient WASH Infrastructure:** In peri-urban slums, "flood-proof" WASH solutions are needed. This includes raising the platforms of hand-pumps above the historic high-flood level and sealing the casings of tube wells to prevent contaminant intrusion (Saif-Ur-Rehman & Shaukat, 2022).
4. **Integrated Toxicological Surveillance:** The IDSR system should be enhanced to include toxicological surveillance. Routine water quality monitoring in high-risk zones should test for heavy metals (Cr, Pb, As), not just bacteria, to provide early warning of chemical contamination events (Younas et al., 2022).

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