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Urban Flood Risk Generation under Climate-Incompatible Urban Development: An Integrated Analysis of the April 2026 Jahrom Flash Flood

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ABSTRACT

This study analyzes the April 2026 Jahrom flash flood through an integrated framework combining hydrological, infrastructural, urban-development, sediment-transport and resilience assessments. Using field observations (26-28 March 2026), documentary evidence, intensity-duration-frequency (IDF) analysis, concentration-time calculations, stormwater-network data and evaluations of channel capacity and culvert performance, the research examines how short-duration extreme rainfall interacts with watershed characteristics and climate-incompatible urban development to generate urban flood risk. Results show that rainfall intensities of 70-90 mm/hr (15-minute intervals) and 45-70 mm/hr (30-minute intervals), combined with clay-marl soils and subbasin concentration times of 9-30 minutes, produced a rapid hydrological response that activated southern ephemeral channels and delivered large runoff volumes into the city. Urban development within channel beds, channel narrowing to 30-50% of natural capacity, altered slopes, blocked flow paths and interference of utilities with drainage channels significantly reduced conveyance capacity, causing even moderate rainfall to result in widespread inundation. Infrastructure malfunction, including culvert failure, hydraulic bottlenecks at bridges, and severe sediment deposition, further amplified damages. Sediment-laden flows originating from eroded foothill orchards and disturbed slopes blocked channels and intensified flood impacts.Resilience assessment revealed weaknesses across physical, infrastructural, institutional and social dimensions, limiting early warning, coordination, and crisis response. The findings demonstrate that flood risk in semiarid cities emerges from interactions among climatic hazards, urban development, infrastructure dysfunction, sediment dynamics and governance capacity. The study proposes policy strategies including restoration of natural flow paths, redesign of stormwater networks, sediment-management measures, institutional reforms, and climate-compatible urban planning to reduce flood risk.

Keywords:

Urban Resilience; Semi-arid Cities; Extreme Rainfall; Watershed Response; Sediment-laden Floods; Infrastructure Vulnerability

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1. Introduction

Urban flash floods have emerged in recent decades as one of the most critical hazards affecting dry and semi-arid climates. Climate change, the increasing frequency of short-duration extreme rainfall events, and urban development incompatible with the natural characteristics of watersheds have caused even moderate return-period events to evolve into widespread urban crises. Under such conditions, flood risk is not merely a function of rainfall intensity; rather, it is the outcome of interactions among hydrological processes, urban development, infrastructure performance, and governance capacity.

The April 2026 Jahrom flood represents one of the most destructive and complex flood events of the past four decades in southern Iran. Within a short period, it exposed extensive parts of the city to inundation, overtopping of channels, damage to critical infrastructure, large-scale sediment transport, and disruption of urban systems. This flood occurred following intense convective rainstorm precipitation, the simultaneous activation of southern, southwestern, and southeastern channels, and the entry of large volumes of runoff into the urban area. Concurrent with the event, field surveys were conducted from 26 to 28 March 2026, during which flood-entry pathways, infrastructure failure points, channel conditions, sediment transport and deposition patterns, hydraulic blockages, and urban development patterns were systematically documented. These field data, combined with documentary and technical information, constitute the primary basis for the analyses presented in this study.

The Jahrom flood demonstrated that under climate change conditions, urban floods cannot be interpreted solely as the consequence of intense rainfall; rather, such events result from complex interactions between natural hazards and human-induced vulnerabilities within natural and urban environments. In this study, "urban flood-risk generation" refers to the process through which interactions among watershed characteristics, urban development, infrastructure performance, and institutional capacity transform a natural hazard into an urban crisis. From this perspective, flood risk is not simply the outcome of an extreme event, but the product of interactions between natural processes and human interventions that determine the severity and spatial extent of damages.

According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2022), rising atmospheric temperatures and increased moisture-holding capacity have intensified the frequency and severity of short-duration extreme rainfall events; in semi-arid watersheds with short concentration times, these events rapidly evolve into flash floods. In recent years, the research literature has shifted from a sole focus on hydrological analyses toward integrated frameworks for risk management and urban resilience, an approach that highlights the simultaneous role of hydrological processes, urban development, infrastructure performance, and governance in shaping flood risk (Rözer et al., 2022; Azadgar et al., 2024).

Globally, the Sendai Framework for Disaster Risk Reduction (2015–2030), reports of the United Nations Office for Disaster Risk Reduction (UNDRR), and UN-Habitat emphasize that disaster risk reduction requires an integrated approach encompassing physical, infrastructural, institutional, social, and environmental dimensions. Within this framework, urban resilience is not limited to post-crisis recovery capacity; it also includes the ability of cities to anticipate, prepare for, absorb, respond to, and recover from hazards. The Jahrom flood demonstrated that under climate change conditions, urban flood risk is not driven solely by extreme rainfall, but emerges from interactions between natural processes and human interventions. It also showed that weaknesses in institutional dimensions—particularly the absence of an effective early-warning system, limited inter-sectoral coordination, and insufficient social preparedness—combined with physical and environmental vulnerabilities, can significantly amplify flood impacts. This finding aligns with recent urban resilience studies that identify institutional capacity, governance, inter-sectoral coordination, and adaptive capability as key components of flood-risk reduction within the disaster management cycle (Lopes et al., 2025).

Although numerous studies on urban flooding have been conducted in Iran in recent years, most have focused on hydrological analyses, peak-flow estimation, flood zoning, or hydraulic modeling. Internationally, although recent studies emphasize the importance of urban resilience, risk governance, and integrated approaches, few have examined the process of urban flood-risk generation through

simultaneous analysis of watershed hydrology, climate-incompatible urban development, infrastructure performance, sediment transport, and institutional resilience, particularly in semi-arid cities (Azadgar et al., 2024; Lopes et al., 2025). Therefore, developing an integrated analytical framework to explain the mechanisms of urban flood-risk generation remains a major research gap.

Flash floods in dry and semi-arid regions represent one of the most prominent manifestations of the interaction between climate change and watershed hydrological characteristics. According to IPCC (2022) reports, rising temperatures and increased atmospheric moisture-holding capacity have intensified the frequency and severity of short-duration extreme rainfall events. In dry and semi-arid climates, the geomorphological and hydrological characteristics of watersheds cause short-duration intense rainfall systems, under the influence of climate change, to generate highly rapid and voluminous flood responses. This feature is particularly significant in southern Iran, especially in cities developed on active alluvial fans and ephemeral channels, where it strongly influences watershed hydrological behavior.

Under such conditions, urban resilience emerges as the primary theoretical framework for analyzing climate-related hazards. In the literature of the IPCC, UN-Habitat, UNDRR, and the 100 Resilient Cities (100RC) program, urban resilience is defined as the ability of a city to anticipate, absorb, adapt to, and recover from extreme events. This framework emphasizes that flood management is effective only when physical, infrastructural, institutional, social, and environmental dimensions operate in an integrated manner to prevent the transformation of a natural hazard into a human-induced disaster. Physical resilience refers to the quality of stormwater drainage networks, the hydraulic capacity of channels, the adequacy of culverts, and the presence of natural flow paths; infrastructural resilience relates to the performance of bridges, culverts, channels, and flow-conveyance structures; institutional resilience encompasses governance, inter-sectoral coordination, early-warning systems, and crisis decision-making; social resilience emphasizes public awareness, collective behavior, community preparedness, and trust in official warnings; and environmental resilience is grounded in the preservation of channels, sustainable land management, sediment control, and protection of natural flow pathways.

In the global literature, climate-incompatible urban development is recognized as one of the primary drivers of flood-risk amplification. When urban expansion occurs without regard to watershed dynamics, flow pathways, and hydraulic capacity, extreme climatic events rapidly transform from natural phenomena into human-induced disasters. This pattern is described through three key concepts: floodplain encroachment, hydraulic bottlenecking, and disrupted hydro-ecological connectivity.

In semi-arid regions, these patterns combine with another phenomenon that is less emphasized in the global literature but highly influential in southern Iran: sediment-laden flash floods. Severe slope erosion, disturbed soils in foothill orchards, and the absence of sediment-control mechanisms cause substantial volumes of mud, sand, fine sediments, and rocky debris to enter urban areas and block flow pathways. This phenomenon reflects weaknesses in environmental resilience and sediment management and plays a major role in amplifying flash-flood damages.

According to the Sendai Framework for Disaster Risk Reduction (2015–2030), urban flood risk is not solely a function of hazard; exposure and vulnerability play decisive roles in transforming a natural event into a human-induced disaster. This study employs an integrated conceptual model that maps the causal chain of risk generation in semi-arid cities. To clarify the mechanisms of urban flood-risk generation, Figure 1 presents the matrix conceptual model developed in this study. The model illustrates how climate drivers, urban development patterns, infrastructure conditions, and flood impacts interact across four vulnerability levels, demonstrating the pathways through which a rainfall event can evolve into an urban disaster or, under adequate adaptive capacity, lead to risk reduction and urban resilience.

Figure 1. Matrix conceptual model of urban flood risk, illustrating the interaction between climate drivers, urban development, infrastructure conditions, and flood impacts across four vulnerability levels (high exposure, structural vulnerability, institutional weakness, and adaptive capacity).

The matrix conceptual model presented in Figure 1 organizes the causal structure of urban flood-risk generation into four interconnected components: climate drivers, urban development patterns, infrastructure conditions, and resulting flood impacts. Each component is mapped across four vulnerability levels (high exposure, structural vulnerability, institutional weakness, and adaptive

capacity), showing how climatic hazards interact with human-induced conditions to escalate or reduce flood risk. The climate driver dimension captures short-duration extreme rainfall and watershed hydrological behavior; the urban development dimension reflects encroachment on natural drainage systems, hydraulic bottlenecking, and disrupted hydro-ecological connectivity; the infrastructure dimension represents culvert performance, channel capacity, and flow-conveyance efficiency; and the flood impact dimension illustrates how these interactions shape inundation patterns, damage severity, and sediment-laden flows. By structuring these relationships within a matrix, the model supports the analytical framework of this study by providing a systematic basis for examining how hydrological processes, climate-incompatible development, infrastructure malfunction, sediment dynamics, and resilience conditions collectively generate urban flood risk in semi-arid cities.

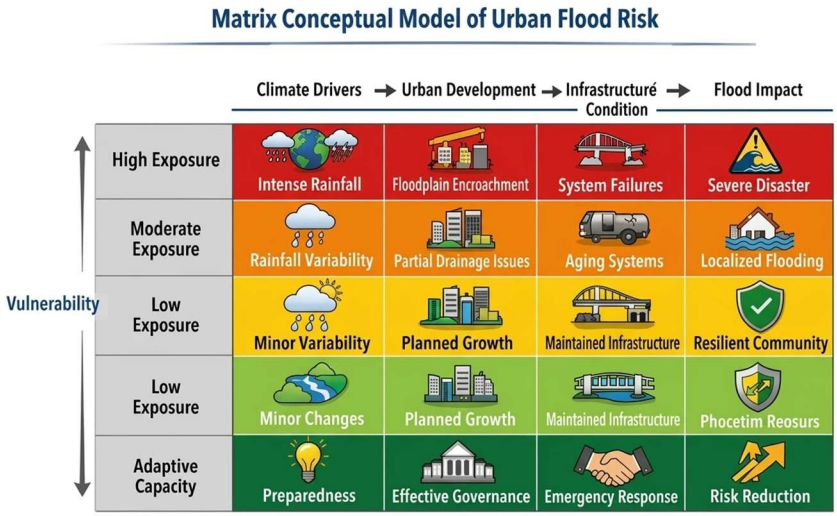


Figure 1: Matrix conceptual model of urban flood risk, illustrating the interaction between climate drivers, urban development, infrastructure conditions, and flood impacts across four vulnerability levels (high exposure, structural vulnerability, institutional weakness, and adaptive capacity)

This model demonstrates that urban flood risk is the product of a complex system and can only be effectively managed when physical, infrastructural, institutional, social, and environmental dimensions operate in an integrated manner. The theoretical framework of this study is grounded in this logic and enables systematic analysis of interactions among climatic hazards, urban development, and managerial capacity.

Accordingly, this study aims to provide an integrated analysis of the process of urban flood-risk generation by selecting the April 2026 Jahrom flood as a case study. Using field, documentary, hydrological, infrastructural, and stormwater master plan data, the study examines interactions among watershed hydrological characteristics, urban development, infrastructure performance, sediment transport, and multiple dimensions of urban resilience within a unified analytical framework. Moreover, the proposed framework can serve as a basis for analyzing similar events, supporting decision-making, and developing climate-compatible policies in semi-arid cities. To achieve this objective, the study pursues five main goals:

- analyzing rainfall system characteristics and the role of short-duration extreme rainfall, intensity–duration–frequency (IDF) curves, and sub-basin concentration time in generating flash floods;
- examining the role of climate-incompatible urban development, including construction within channel beds, reduced channel capacity, altered natural slopes, blocked flow paths, and conversion of drainage channels, in increasing flood risk;

- evaluating the performance of urban infrastructure, including bridges, culverts, channels, stormwater drainage networks, hydraulic bottlenecks, and interference of critical utilities with flow paths, in amplifying flood damages;
- analyzing the role of slope erosion, sediment transport, and sediment deposition in blocking flow paths and increasing flood damages;
- assessing urban resilience across physical, infrastructural, institutional, and social dimensions, and proposing climate-compatible policy strategies for reducing flood risk over short-, medium-, and long-term horizons.

2. Data and Methodology

The methodological framework of this study is based on an integrated five-stage approach that enables simultaneous analysis of watershed behavior, infrastructure performance, urban development patterns, and governance capacity:

(1) analysis of the rainfall system and extraction of intensity–duration–frequency indicators;
(2) hydrological analysis based on concentration time and short-duration rainfall behavior;
(3) hydraulic analysis focusing on flow bottlenecks and infrastructure failure;
(4) urban development analysis assessing human interventions in natural flow paths;
(5) urban resilience assessment across physical, infrastructural, institutional, and social dimensions.

The city of Jahrom is located in the southern part of Fars Province within a semi-arid climate zone, a setting that, due to its climatic and hydrological characteristics, exhibits high sensitivity to extreme events. The city's position along the southern foothills of the Zagros Mountains and its proximity to active alluvial fans cause runoff generated by intense rainfall to enter the urban area rapidly. This topographic configuration, combined with the physical expansion of the city into natural flow paths, has significantly increased flood risk.

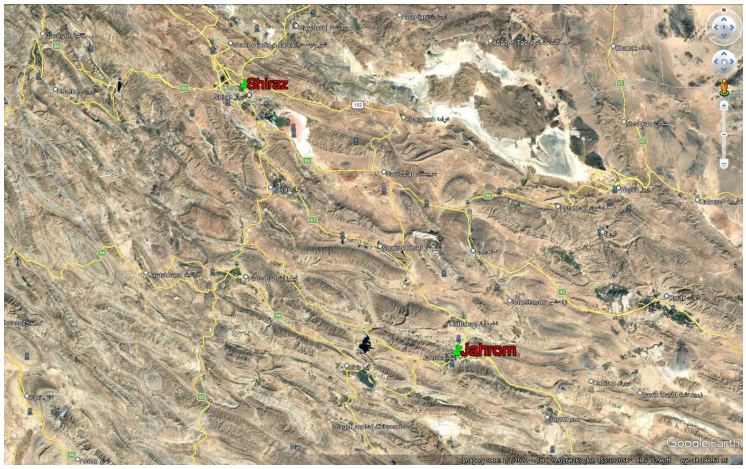


Figure 2. Study Area and Geographic Context

In this study, nineteen primary drainage channels that convey runoff from the southern, southwestern, and southeastern highlands into the urban area were identified and analyzed. Field investigations indicate that many ephemeral channels have been obstructed or narrowed due to urban development, reducing their natural hydraulic capacity for conveying runoff.

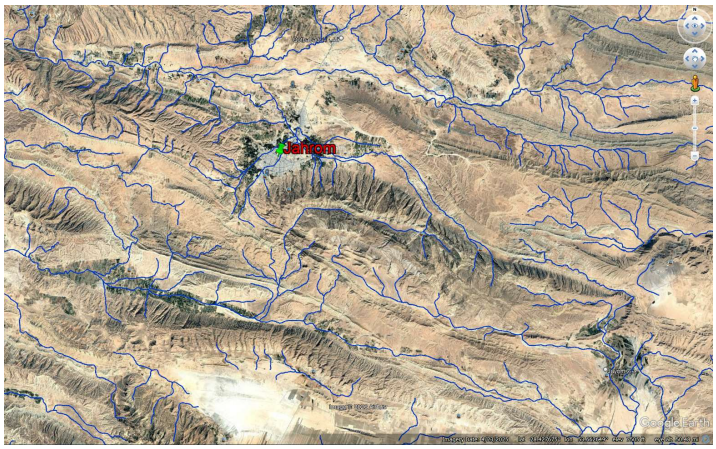


Figure 3. Regional Drainage Network

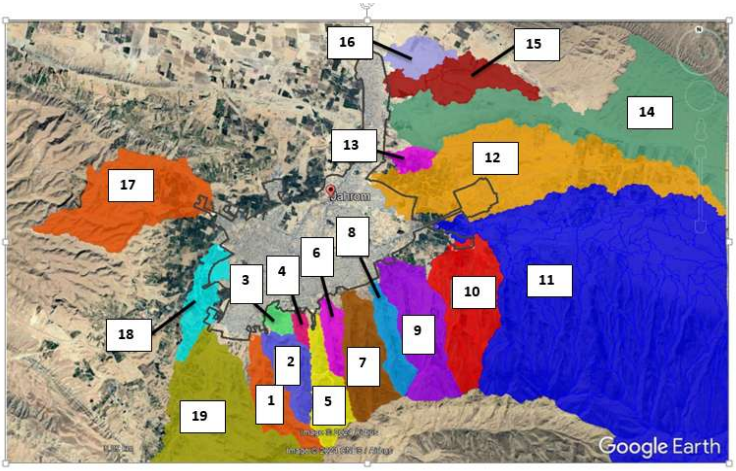


Figure 4. Base Map of the Watersheds Under Study

The geological structure of Jahrom consists of Precambrian, Cretaceous, and Tertiary formations and Quaternary alluvial deposits. The southern and southwestern parts of the city lie on the Gachsaran and Aghajari formations, clay–evaporitic units with very low permeability that rapidly reach surface saturation during extreme events. Within the urban area, soils are predominantly clay–marl, with highly limited infiltration capacity; therefore, most rainfall, particularly during short-duration events, is converted into runoff.

In contrast, the active alluvial fans and young alluvial deposits upstream contain coarse-grained and gravelly sediments that create concentrated, high-velocity flow pathways, directing runoff rapidly toward the urban area. The combination of very low-permeability clay–marl soils in the city and steep slopes with coarse sediments upstream drastically reduces watershed concentration time, creating conditions in which even 15- to 30-minute rainfall bursts can generate flash flooding in less than one hour.

The data used in this study were collected from a combination of documentary, station-based, field, and urban sources. Core datasets include meteorological records, intensity–duration–frequency (IDF) curves, geological and soil information, land-use maps, surface-water network data, channel capacities, culvert conditions, and existing flow pathways.

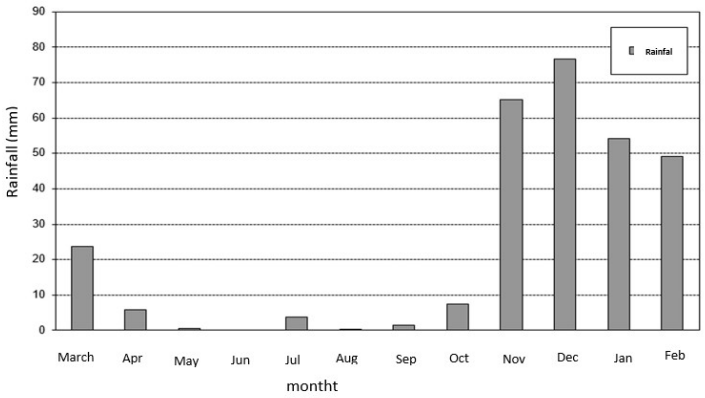


Figure 5. Monthly Rainfall Averages

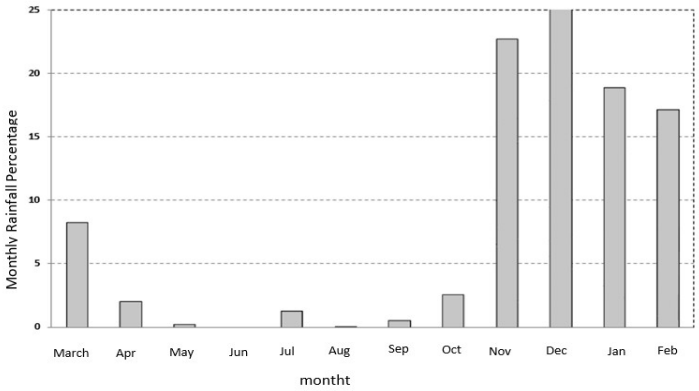


Figure 6. Monthly Rainfall Percentages

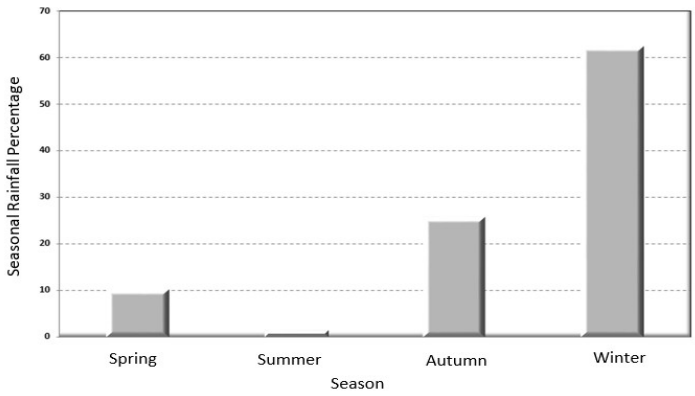


Figure 7. Seasonal Rainfall Percentages

Table 1. Goodness-of-Fit Tests for Selected Statistical Distributions of Annual Rainfall in Jahrom

Station	Distribution	k-s	Distribution	k-s	Distribution	k-s
Jahrom	Generalized Pareto	0.075	Generalized Extreme Value	0.079	Ln-Normal	0.110
	Log-Logistic	0.077	Normal	0.082	Log10-Normal	0.113
	Uniform	0.079	Generalized Logistic	0.093	Exponential	0.238

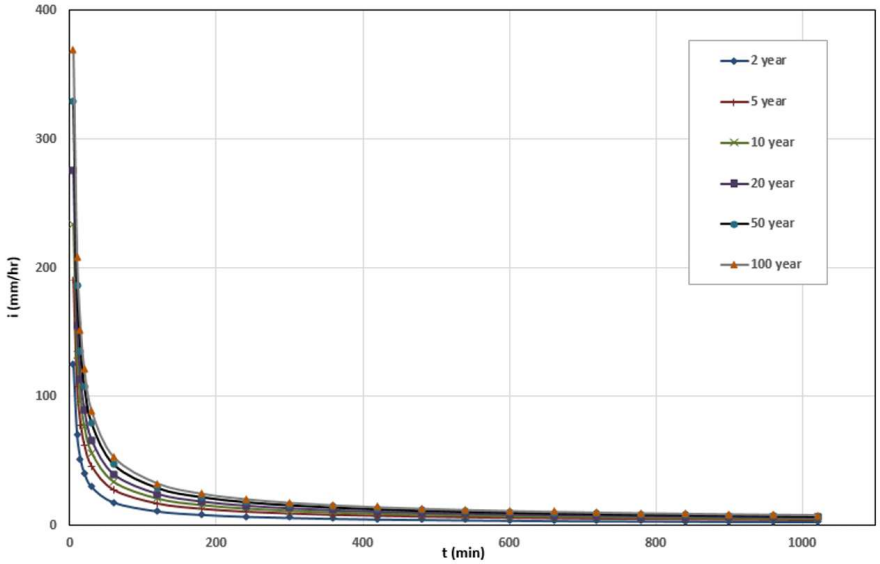


Figure 8. IDF Curves Derived Using the Ghahreman Equation (Ghahreman, 1999)

To complement documentary data, a field survey was conducted from 26 to 28 March 2026. This survey documented direct evidence of channel blockages, narrowed flow paths, and infrastructure failure points, and was incorporated as empirical data alongside official sources.

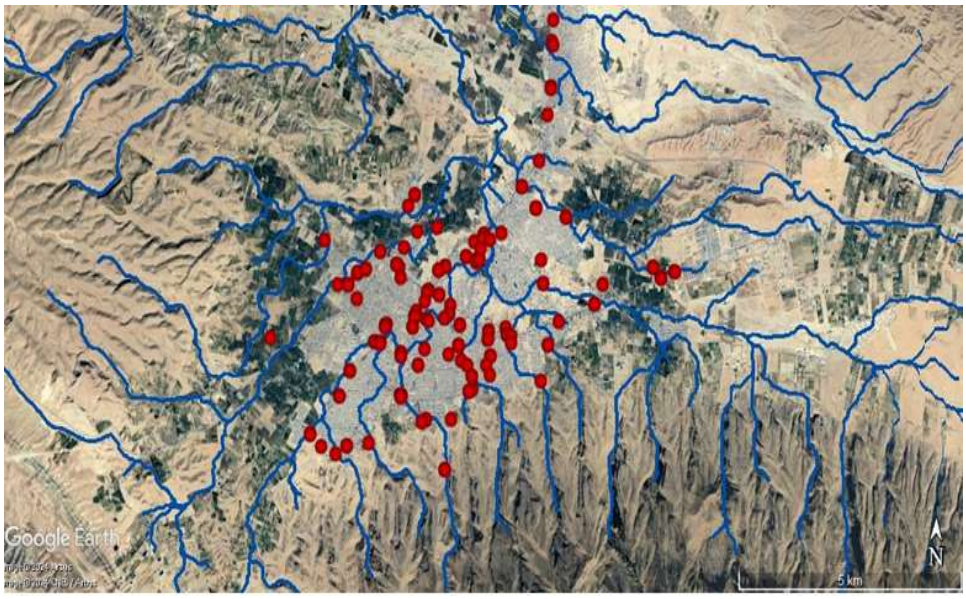


Figure 9. Critical and Problematic Points in Jahrom's Surface-Water Network

The methodology of this research is based on integrating analytical, physical, institutional, and empirical approaches to examine the dynamics of urban flood-risk generation in Jahrom. In the first stage, hydrological analysis was conducted using meteorological data, IDF curves derived from the Ghahreman equation (Ghahreman, 1999), and extreme rainfall information. This analysis enabled the examination of short-duration intense rainfall behavior, the estimation of sub-basin concentration time (TC), and the calculation of runoff generated by 15- to 30-minute rainfall events, forming the foundation for explaining the rapid hydrological response of the watershed under semi-arid conditions.

Subsequently, hydraulic analysis was performed using surface-water network data, channel capacities, culvert conditions, and existing flow pathways. This analysis evaluated the performance of stormwater infrastructure under extreme events and identified bottlenecks, hydraulic constraints, and blockages contributing to flood intensification. Findings indicated that channel narrowing, obstruction of ephemeral streams, and malfunctioning flow-conveyance structures played decisive roles in increasing flood severity.

Urban development analysis focused on land-use patterns, physical expansion, and construction within sensitive zones. This component examined the role of building within channel beds, development on active alluvial fans, and conversion of natural flow paths in increasing flood risk. The analysis showed that climate-incompatible urban development significantly reduced the watershed's natural capacity to convey runoff, facilitating the transformation of an extreme rainfall event into an urban crisis.

Exposure and vulnerability analysis was conducted using population data, asset density, and the spatial distribution of infrastructure within sensitive zones. This analysis demonstrated that the concentration of population and urban assets within natural flow pathways increased exposure to flooding and played a major role in amplifying damages.

Finally, urban resilience was assessed across four dimensions: physical, infrastructural, institutional, and social. This assessment employed a resilience matrix and revealed structural, managerial, and social weaknesses in the city's capacity to cope with flash-flood events. The integration of these approaches enabled simultaneous analysis of watershed hydrological behavior, infrastructure performance, urban development patterns, and institutional capacity, providing a unified framework for explaining the process of urban flood-risk generation.

Due to data limitations, this study employed a field-based validation approach. Temporal–spatial matching of rainfall data, flood-entry pathways, infrastructure failure points, sediment deposition patterns, and field observations served as the primary validation criteria. This method is widely accepted in flash-flood studies in semi-arid regions as a reliable alternative to numerical modeling (Lin et al., 2023; Rahman et al., 2022; Lopes et al., 2025).

3. Results

The April 2026 Jahrom flood represents a prominent example of flash-flood events in semi-arid climates, an event in which the interaction between a convective rainstorm system, the hydrological characteristics of the watershed, and the city's physical–infrastructural conditions produced a widespread urban crisis. Analysis of rainfall data indicates that the primary trigger of the flood was the extremely high rainfall intensity over short time intervals. Although the 24-hour total rainfall exceeded 80 mm at several stations, the 15- to 30-minute peaks were the main drivers of extreme runoff generation and the activation of ephemeral channels, a behavior fully consistent with the pattern of short-duration extreme rainfall reported by the IPCC (2022) for dry regions. This finding demonstrates that in semi-arid climates, rainfall intensity over short intervals, not daily totals, is the determining factor in flood behavior.

3.1. Short-Duration Rainfall Intensit.

Table 2. Rainfall Intensity Across Different Time Intervals

Rainfall Duration	Rainfall Intensity (mm/hr)
15 minutes	70–90
30 minutes	45–70
60 minutes	25–45
24 hours	80–90

As shown in Table 2, rainfall intensities reached 70–90 mm/hr over 15-minute intervals and 45–70 mm/hr over 30-minute intervals, indicating extremely rapid hydrological response conditions. These short-duration peaks far exceeded the thresholds typically associated with flash-flood generation in semi-arid watersheds. In contrast, the 24-hour total rainfall (80–90 mm) was not the primary driver of the event, confirming that short-interval intensities played the dominant role in activating ephemeral channels and producing high-velocity runoff. 3.2. Concentration Time of Sub-basins The second key factor in the formation of the flood was the very low concentration time of Jahrom's watersheds. The general south-to-north and northeast slope of the city, the short length of drainage channels, and the very low permeability of clay–marl soils caused runoff originating from the southern, southwestern, and southeastern highlands to enter the urban area within a very short period. These conditions reduced the time between the onset of rainfall and the arrival of the flood peak to less than one hour, effectively eliminating the window for warning issuance, institutional response, and neighborhood evacuation. Numerical analysis of concentration time showed that the sub-basins feeding the city have concentration times ranging between 9 and 30 minutes, values that closely match field observations indicating the "arrival of the peak in less than one hour." This finding demonstrates that low concentration time is one of the most influential factors in transforming short-duration rainfall bursts into flash floods.

As shown in Table 3, concentration times across the nineteen sub-basins range from 6 to 32 minutes in most cases, with several basins exhibiting even shorter response times (e.g., 9.9–23.8 minutes in Sub-basin 7 and 7–38 minutes in Sub-basin 19). These values indicate extremely rapid watershed response conditions typical of semi-arid environments with steep slopes and short flow paths. The combination of high slopes (up to 76%) and short channel lengths (as low as 0.42 km) significantly reduces travel time, allowing runoff generated by short-duration rainfall bursts to reach the urban area in less than one hour. This numerical evidence supports the field observations and confirms that low concentration time was a decisive factor in transforming short-interval rainfall peaks into a flash-flood event.

Table 3. Concentration Time of Sub-basins

Sub basin	Flow Path Length (km)	Average Slope (%)	Concentration Time (min)
1	5.85–10.05	41–52	18–27
2	4.42–9.72	29–47	17–31
3	5.02	20	21.9
4	4.20	31	19.5
5	5.40–8.50	55–57	15–20
6	8.30	48	24.6
7	2.15–7.05	21–60	9.9–23.8
8	11.77	55	30.2
9	3.62–12.12	15–76	26–32
10	0.42–9.62	4–54	6–24
11	13.4–7.5	5–19	19–113
12	4.25–16.52	5–12	15–109
13	6.75	10.9	38.6
14	6.80–10.27	6–72	11–31
15	5.70–11.70	7–9	27–91
16	1.05–9.15	5–6	9–62
17	3.67–6.55	14–35	13–33
18	5.10–10.22	6–8	25–68
19	0.52–10.27	11–43	7–38

3.2. Spatial–Temporal Behavior of the Rainfall System

The convective rainstorm nature of the system represented the third defining characteristic of the event. Convective instabilities produced intense rainfall with high spatial variability across the county, such that

certain locations, particularly the city of Jahrom, experienced very large volumes of runoff within a short period, while other areas received substantially lower rainfall. This spatial heterogeneity placed additional pressure on the stormwater drainage network and caused the limited capacity of channels and culverts to become saturated rapidly. This spatial–temporal behavior of rainfall is a defining feature of flash floods in semi-arid climates and demonstrates the high vulnerability of urban drainage networks to events with uneven spatial distribution.

3.3. Flood Entry Pathways into the Urban Area

Field surveys showed that the flood entered the urban area through three primary pathways. The first pathway comprised the ephemeral channels in the southern, southwestern, and southeastern highlands, which were rapidly activated due to rainfall intensity and low concentration time. Blockages caused by construction, reduced hydraulic width, and altered natural slopes forced flows out of their main pathways and into residential neighborhoods. The second pathway comprised the active alluvial fans in the south and southwest, which generate concentrated, high-velocity flows during extreme events. Urban development in these areas, classified as high-risk development in the IPCC literature, caused runoff to enter the city without diversion routes. The third pathway comprised the intersections between the stormwater drainage network and blocked flow pathways in the central and southern parts of the city, where accumulated runoff entered neighborhoods and caused severe inundation. These findings indicate that flood entry pathways were shaped by a combination of natural factors and human interventions.

3.4. Failure of Urban Infrastructure

The April 2026 flood demonstrated that urban infrastructure not only lacked the capacity to manage extreme runoff but also acted as a damage-amplifying factor. Insufficient culvert capacity, the placement of culverts at bottleneck locations, and rapid blockage of inlets caused flow to stop or divert at several critical points. Bridges, due to undersized hydraulic openings, acted as hydraulic barriers and increased upstream water levels. The drainage network, due to improper slope design, limited capacity, and the absence of alternative flow routes, failed to convey runoff effectively. Extensive sediment deposition in channels and blockages caused by construction further disrupted stormwater conveyance. These findings show that infrastructural weakness was one of the primary drivers of damage amplification.

3.5. The Role of Climate-Incompatible Urban Development

A significant portion of flood damages resulted from climate-incompatible urban development patterns. Construction within channel beds, narrowing of flow paths, development on active alluvial fans, land-use change within floodplains, and inappropriate placement of infrastructure reduced the watershed's natural capacity to manage runoff and caused even moderate rainfall to produce widespread inundation. This finding indicates that urban development without regard to watershed dynamics is one of the most important factors in transforming a natural event into an urban crisis.

3.6. Assessment of Urban Resilience

Urban resilience analysis for Jahrom shows that weaknesses across four main dimensions contributed to damage amplification. In the physical dimension, narrow channels and construction within drainage pathways reduced natural conveyance capacity. In the infrastructural dimension, poor performance of bridges and culverts caused flow blockages and increased upstream water levels. In the institutional dimension, a lack of inter-sectoral coordination and weak early-warning systems eliminated opportunities for effective response. In the social dimension, low public awareness and limited trust in official warnings reduced community preparedness. These findings show that Jahrom's urban resilience against flash floods suffers from structural weaknesses across multiple dimensions.

The combined findings of this section indicate that the April 2026 Jahrom flood resulted from the synergy of three main components:

1. short-duration extreme rainfall with very high intensity that rapidly eliminated natural infiltration and storage capacity;
2. very low concentration time in the southern and southwestern sub-basins, causing runoff to reach the urban area in less than one hour and eliminating the window for institutional response;
3. structural weaknesses and climate-incompatible urban development that blocked natural flow pathways and left the stormwater drainage network highly vulnerable to extreme rainfall.

These findings emphasize that the April 2026 flood was not merely a hydrological event but a multi-factor crisis, one whose recurrence can only be prevented through the simultaneous reform of physical, infrastructural, and institutional systems. These results form the basis for the Discussion section presented next.

4. Discussion

The comprehensive analysis of the April 2026 Jahrom flood demonstrates that this event represents a clear example of the interaction between an extreme natural hazard and human-induced vulnerability, an interaction that the IPCC and UNDRR literature identifies as the primary mechanism through which a hazard transforms into a disaster. Although the convective rainstorm precipitation with extremely high intensity served as the initial trigger of the event, the scale and severity of damages resulted from a combination of structural, managerial, and physical factors that had accumulated over years of urban development in Jahrom. This event showed that in semi-arid climates, flash floods are not driven only by extreme rainfall but are directly shaped by human interventions in natural flow pathways, the quality of stormwater infrastructure, and the effectiveness of institutional crisis management mechanisms. Given the field-based nature of this study, validation was conducted through direct observation of flow pathways, blockage points, sediment transport, and infrastructure failure, which provided a reliable alternative to numerical model outputs.

The findings of this study indicate that urban development in Jahrom over recent decades has occurred without regard to watershed hydrological dynamics and the climatic characteristics of the region. Construction within channel beds, reduction of hydraulic width, development on active alluvial fans, and conversion of floodplains into residential and commercial land uses have significantly reduced the watershed's natural capacity to manage runoff. These development patterns, identified in the IPCC literature as "high-risk development," have caused even moderate rainfall to produce widespread inundation and extreme rainfall to evolve into destructive flash floods. These findings show that climate-incompatible urban development not only reduces the natural capacity of the watershed but also activates the pathways through which a hazard transforms into a disaster, mechanisms recognized in the IPCC literature as major drivers of flash-flood amplification in semi-arid regions.

Although a red-level warning was issued prior to the flood, weaknesses in institutional and managerial mechanisms limited its practical effectiveness. The absence of an efficient early-warning system, weak inter-sectoral coordination, ineffective decision-making structures, and a lack of rapid response protocols prevented crisis management authorities from taking timely and effective action. This situation revealed that Jahrom's institutional resilience to extreme climatic events is very low and requires the redesign of governance mechanisms, improved coordination among agencies, and increased public trust in official warnings. These institutional weaknesses show that even with adequate physical infrastructure, a lack of inter-sectoral coordination and the absence of early-warning systems can severely constrain crisis management effectiveness, a behavior fully consistent with UNDRR findings on the role of governance in flash-flood events.

The Jahrom flood provides several key lessons for flood risk management in semi-arid Iranian cities. First, flood risk management cannot rely solely on physical and infrastructural interventions. This event showed that even robust structures cannot prevent a natural hazard from becoming a disaster without

sufficient institutional and social resilience. Therefore, risk management must be designed within an integrated framework encompassing physical, institutional, social, and climatic dimensions. Second, urban development must be aligned with future climatic conditions. Climate change has increased the frequency and intensity of short-duration extreme rainfall in semi-arid regions, and urban development must be redesigned accordingly. Avoiding construction within natural flow pathways, protecting floodplains, and redesigning channel networks are essential components of climate-compatible development. Third, urban resilience becomes meaningful only when communities, institutions, and infrastructure are strengthened simultaneously. Enhancing risk culture, empowering communities, public education, and strengthening multi-level governance are key factors that can reduce the impacts of extreme events.

Comparison of the Jahrom event with global cases shows that the city's damage pattern resembles that of cities such as Mumbai, Karachi, and Manila, where development within floodplains, channel obstruction, and weak stormwater infrastructure have caused intense rainfall to evolve into urban disasters (e.g., Hallegatte et al., 2013; Jha et al., 2012; UNDRR, 2019). In contrast, cities such as Rotterdam, Copenhagen, and Tokyo have significantly reduced flood risk by adopting urban resilience approaches, redesigning stormwater networks, implementing integrated channel management, and aligning development with climatic conditions (e.g., Ahern, 2011; OECD, 2014; Delta Programme, 2022). This comparison shows that the difference between successful and vulnerable cities lies not in rainfall intensity but in the quality of governance, the protection of natural flow pathways, and climate-compatible urban development, factors that have been neglected in Jahrom over recent decades.

The findings of this study also indicate that reducing flood risk in Jahrom is possible only when urban, infrastructural, and institutional policymaking is implemented in an integrated and phased manner across short-, medium-, and long-term horizons. This phased approach enables control of the risk generation cycle, restoration of the watershed's natural capacity, and strengthening of urban resilience.

In the short term, the primary objective is to restore the minimum hydraulic capacity of the drainage network and reduce immediate risk. Clearing flow pathways of illegal constructions, walls, and encroachments into channel buffers must be carried out by the municipality and the Natural Resources Administration. Dredging channels and drainage pathways to increase runoff conveyance capacity and reduce overtopping risk is the responsibility of the municipality and the Regional Water Authority. Removing hydraulic bottlenecks, including undersized culverts, narrow bridge openings, and flow concentration points, must be undertaken by the Road Maintenance Authority and the municipality. Clearing sediments and debris at the southern entrances of the city, which played a significant role in intensifying the 2026 flood, must be conducted jointly by the Natural Resources Administration, the municipality, and crisis management authorities. Implementing these emergency actions can restore initial network capacity and reduce the likelihood of severe inundation during short-term events.

In the medium term, the focus is on structural reforms of the stormwater network, reforms that must be designed based on extreme climatic scenarios and watershed hydrological behavior. Redesigning the stormwater drainage network to account for short-duration intense rainfall and the low concentration time of the southern sub-basins must be undertaken by the Regional Water Authority and the municipality. Upgrading culverts and increasing bridge capacity at bottleneck locations is the responsibility of the Road Maintenance Authority and the municipality. Creating diversion pathways to manage runoff entering from active alluvial fans must be designed and implemented by the Regional Water Authority and the Natural Resources Administration. Improving drainage network slope design to prevent flow accumulation in the central and southern parts of the city must also be carried out by the municipality. These medium-term actions play a decisive role in reducing physical and infrastructural vulnerability.

In the long term, urban policymaking must be fully aligned with future climatic conditions. Prohibiting development within floodplains and natural flow pathways must be enforced through formal regulations by the municipality, the city council, and the Natural Resources Administration. Revising urban development plans with a climate-adaptive approach based on extreme scenarios must be undertaken by the municipality and the Department of Roads and Urban Development. Establishing multi-level early-warning systems capable of predicting short-duration intense rainfall is the responsibility of crisis

management authorities, meteorological agencies, and the municipality. Strengthening multi-level governance to enhance coordination among the municipality, the Road Maintenance Authority, the Regional Water Authority, crisis management agencies, and service delivery organizations must be pursued through stable institutional mechanisms. Enhancing risk culture through public education, preventive communication, and increased trust in official warnings must be carried out by crisis management authorities and local media. These long-term actions can break the risk generation cycle and align urban development with future climatic conditions.

Overall, the policy implications of this study indicate that flood risk management in Jahrom is achievable only through a combination of immediate actions, medium-term structural reforms, and long-term policymaking. An integrated approach, in which the watershed's natural capacity is restored, infrastructure is redesigned based on extreme scenarios, urban development is aligned with climatic conditions, and institutions and communities are empowered, can enhance urban resilience against extreme climatic events and align the city's development trajectory with future conditions. This policy framework demonstrates that sustainable flood risk reduction will be possible only when physical, infrastructural, and institutional reforms are implemented simultaneously and in a coordinated manner.

Despite relying on field data, documentary sources, and multilayered analyses, the present study faces a set of structural limitations that must be considered when interpreting the results and designing future research. These limitations not only affected the accuracy of certain hydrological estimations but also highlight that analyzing flash-flood events in semi-arid climates requires more advanced data infrastructure and modeling capabilities.

The first limitation was the shortage of hydrometric data with sufficient temporal and spatial resolution. Station-level rainfall and runoff data contained temporal gaps, limited spatial coverage, and fluctuations in recording quality, particularly within the short 15- to 30-minute intervals that play a decisive role in flash-flood formation. This condition introduced uncertainty into the estimation of extreme rainfall intensity, sub-basin concentration time, and hydrological runoff behavior. The absence of high-resolution point rainfall data limited the ability to analyze the spatial–temporal variability of the storm system and prevented full reconstruction of rainfall hyetographs at fine scales. As a result, validation relied on field evidence, including peak arrival time, observed flow routes, infrastructure failure points, and sediment accumulation.

The second limitation was the absence of two-dimensional hydraulic modeling for accurately simulating flow behavior within the urban area. The analyses conducted were primarily based on one-dimensional models, simple water balance assessments, and field evidence, an approach suitable for examining general flow patterns but insufficient for capturing spatial details, diversion pathways, runoff concentration points, localized flood behavior, and the fine-scale impacts of urban development. Two-dimensional modeling could have provided a more precise representation of flow behavior at bottleneck locations, culvert blockages, the role of bridges as hydraulic barriers, and flood entry pathways into the urban fabric. The absence of such modeling restricted the analyses to broader trends and reduced the ability to examine flood behavior at micro scales.

The third limitation was the lack of instantaneous discharge measurements in active channels. During the flood event, direct measurement of real-time flow discharge in the southern, southwestern, and southeastern channels was not feasible, and flow intensity was estimated using indirect methods, data extrapolation, field evidence, and recorded images. This condition introduced uncertainty into the analysis of hydraulic flow intensity, flood energy, sediment transport capacity, and dynamic flow behavior. Instantaneous discharge data could have enabled more accurate calibration of hydrological and hydraulic models and improved estimations of peak flow, flood arrival time, and runoff volume. Future research should incorporate high-resolution radar and satellite rainfall data, advanced two-dimensional hydraulic modeling, climate scenario analysis, and multi-criteria decision-making methods to enable a more accurate assessment of flood behavior and urban resilience.

5. Conclusion

The comprehensive analysis of the April 2026 Jahrom flood demonstrates that this event represents a clear example of the transformation of an extreme natural hazard into a human-induced disaster, a process defined in the IPCC and UNDRR literature as the interaction between hazard and vulnerability. Although the convective rainstorm precipitation with extremely high intensity served as the initial trigger of the flood, what transformed this rainfall into an urban crisis was a combination of human-induced factors, including climate-incompatible urban development, weak stormwater drainage infrastructure, and ineffective institutional crisis management mechanisms.

The first key finding of this study is that the short-duration, high-intensity nature of the rainfall, combined with the very low concentration time of the southern sub-basins, caused large volumes of runoff to enter the urban area in less than one hour. Rainfall intensities of 70–90 mm/hr over 15- to 30-minute intervals rapidly eliminated the watershed's natural infiltration and storage capacity and activated ephemeral channels. This behavior indicates that in semi-arid climates, rainfall intensity over short time intervals is the primary driver of flash-flood behavior, and cities with low concentration times are particularly vulnerable to such events.

The second key finding is that climate-incompatible urban development played a decisive role in amplifying damages. Construction within ephemeral channels, reduction of hydraulic width, development on active alluvial fans, land-use change within floodplains, and blockage of natural flow pathways significantly reduced the watershed's natural capacity to manage runoff. The findings show that the severity of flood damages was driven more by reduced natural capacity and infrastructural dysfunction than by rainfall intensity alone.

The third key finding is that Jahrom's urban resilience across physical, infrastructural, institutional, and social dimensions was insufficient. Weak design and placement of stormwater drainage networks, poor performance of bridges and culverts, the absence of alternative flow routes, interference of critical utilities with drainage channels, the lack of an effective early-warning system, limited institutional coordination, and low public trust collectively prevented an effective response to the extreme event. This situation demonstrates that urban resilience becomes meaningful only when infrastructure, institutions, and communities are strengthened simultaneously.

Overall, the April 2026 Jahrom flood underscores that flood risk management in semi-arid cities requires structural reforms, climate-compatible policymaking, and an integrated approach. Redesigning stormwater drainage networks, restoring natural flow pathways, revising urban development policies, strengthening multi-level governance, enhancing risk culture, and empowering communities are essential actions that can halt the cycle of risk generation and align urban development with future climatic conditions. This event demonstrated that without such reforms, future extreme rainfall events may lead to similar or even more severe disasters.

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The authors used AI-based language tools to improve the language, clarity, and readability of the manuscript. All scientific content, interpretations, and conclusions are solely the responsibility of the authors.
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The authors declare that there is no conflict of interest regarding the publication of this article.

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