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Assessing the Impact of Anthropogenic Factors on Flash Floods in a Coastal City of Saudi Arabia

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Abstract In recent years, coastal cities around the world have been facing an increase in flash floods, causing catastrophic effects on people, properties, and socioeconomic activities. However, the existing literature on this topic focuses disproportionately on the natural factors that trigger floods, such as hydrological, geotechnical, and environmental factors. To achieve a more comprehensive and effective understanding and management of floods, it is crucial to also consider the human factors that contribute to floods and their mitigation strategies. This study employs an expert-based Analytic Hierarchy Process (AHP) model to assess the human factors that contribute to flash floods in Jeddah, Saudi Arabia. The findings reveal that the highest-ranked factor contributing to flash floods was the inadequate open drainage systems (IODS) (29%), followed closely by the presence of impermeable surfaces (IS) (25%) and topography flattening (TF) (21%). Infrastructure failure (IF) and vegetation clearance (VC) were the least-rated factors, with priority weights of 17% and 7%, respectively. The study recommends stormwater management (SM) and the provision of open drains (POD) to mitigate flash flood risks in the study area and similar geographical regions resulting from anthropological factors contributing to flash floods. This study can help decision-makers to understand flash flood causes and design appropriate prevention measures.

Keywords Analytic Hierarchy Process, Flood Assessment, Flash Floods, Anthropological Factors

1. Introduction

Floods are among the most catastrophic natural disasters, destroying millions of lives and properties. They occur when the natural and artificial drainage networks have exceeded their absorptive capacity, causing sudden and high discharge from the outlets into the built-up areas [1]. Flash flood disasters are one of the major threats to human lives, economies, and infrastructures. Globally, out of 9,697 people were killed by natural disasters in 2017, and floods alone account for 37.9%, closely followed by storms (37.6%) and earthquakes (6.6%) [2, p. 3]. Apart from natural factors such as heavy precipitation, storm surges and hurricanes, and low elevation, floods are intensified by rapid urbanization, deforestation, infrastructure failures, and climate change [3-7]. Studies on the impacts of urbanization on hydrographical processes associate IS and VC with triggering floods [7-8]. Similarly, floods are likely to increase due to unplanned urban expansion [9-11].

Saudi Arabia is experiencing rapid urban and infrastructural transformation, with eight out of every ten persons dwelling in cities [12]. Although the country is located in a hyper-arid region, with little precipitation of nearly 52.5 mm per annum and high temperatures ranging from 43–46 ℃, it is susceptible to recurrent flash floods disasters that cause several deaths, injuries, economic loss, and outbreak of diseases and epidemics [13, 14]. Flash floods have killed at least 280 people in the last two decades (Figure 1) and caused economic losses of around 450 USD, making it the most devastating disaster after epidemics [15].

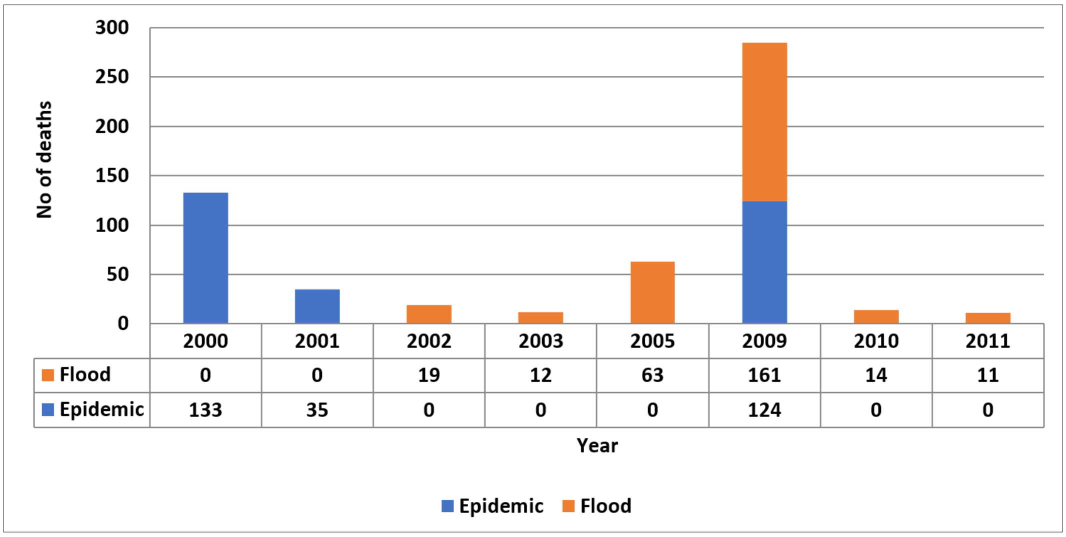


Figure 1. Major natural disasters experienced by Saudi Arabia, 2000-2011 (modified from Alshehri et al. [29; p. 1814])

The coastal cities of Dammam and Jeddah have recently been experiencing severe flash floods that drench homes, streets, and schools and disrupt the residents' daily lives. Flash flood events are the most recurring and costliest natural disasters affecting both cities. In 2009 and 2011, flash floods destroyed infrastructure and properties worth 3 billion USD in Jeddah [16]. They are triggered by a combination of natural factors and anthropogenic activities such as the presence of IS, topography flattened (TF), as well vegetation clearance (VC) [1, 7, 16, 17].

Sustainable flood control and prevention measures are paramount to minimizing the tremendous impacts of flash floods. The Sustainable Development Goal under target 11.5 highlighted the importance and urgent need to reduce deaths and economic losses resulting from natural disasters [18]. However, flood mitigation and management cannot be effectively achieved without identifying the key human-made factors contributing to flash floods.

Several studies have investigated flood causation factors internationally [19-23] and locally [1, 12, 24, 25, 16]. Despite the increased attention to flood impacts and causes, few studies have investigated the contribution of anthropogenic factors such as IS, VC, inadequate drainage systems (IODS), topography flattening (TF), and infrastructure failures (IF) to flood incidence. Investigating the contribution of these five important anthropogenic factors in flood incidence is the focus of the present study. For example, Du et al. [7] more recently investigated the impact of IS on flood generation and found that asphalt used for road construction and other pavement materials used in landscaping exert more influence on flood triggering. Similarly, Chiesura [25] revealed that vegetation decreases the likelihood of flood generation in an area.

However, few studies have assessed the relative contributions of these five key anthropogenic factors in triggering floods. Therefore, the present study contributes to the literature by bridging this research gap and aids the municipality toward appropriate decision-making in flood mitigation and control. This study employs the AHP mathematical model to assess the extent, to which the aforementioned anthropogenic factors are likely to contribute to flash flood generation in Jeddah, Saudi Arabia. The AHP is a valuable decision-making tool that allows qualitative and quantitative data analysis, as used in several flood-related studies [1, 26-28]. The findings are expected to aid the municipality in decision-making and planning for flood disaster risk reduction and management. The study will also serve as the basis for future research.

2. Materials and Methods

2.1. Study Settings

Jeddah is a coastal city located along the coast of the Red Sea in the western part of Saudi Arabia. The city borders the Red Sea from the west and mountainous terrains (Hijaz mountains) that reach an elevation of nearly 500 m above sea level from the east (Figure 2). It occupies an area stretching 60 km along the shoreline of the Red Sea and 40 km wide. Jeddah is the second largest city and the commercial hub of the country. With a population of 4.08 million in 2016, the city houses one-eighth of the country’s total population [30]. The city’s climate is divided into summer and winter. The summer comes with a high temperature of around 46-47℃ between June and August (Figure 3). Winter temperatures are as low as 8℃, often accompanied by scarce rainfalls of around 20 mm. The city has recently experienced flash floods that have caused many deaths and injuries and damaged infrastructure and properties. Urbanization patterns exacerbate the impact of extreme weather events through the urban heat island effect, making areas hotter compared to surrounding rural landscapes [31].

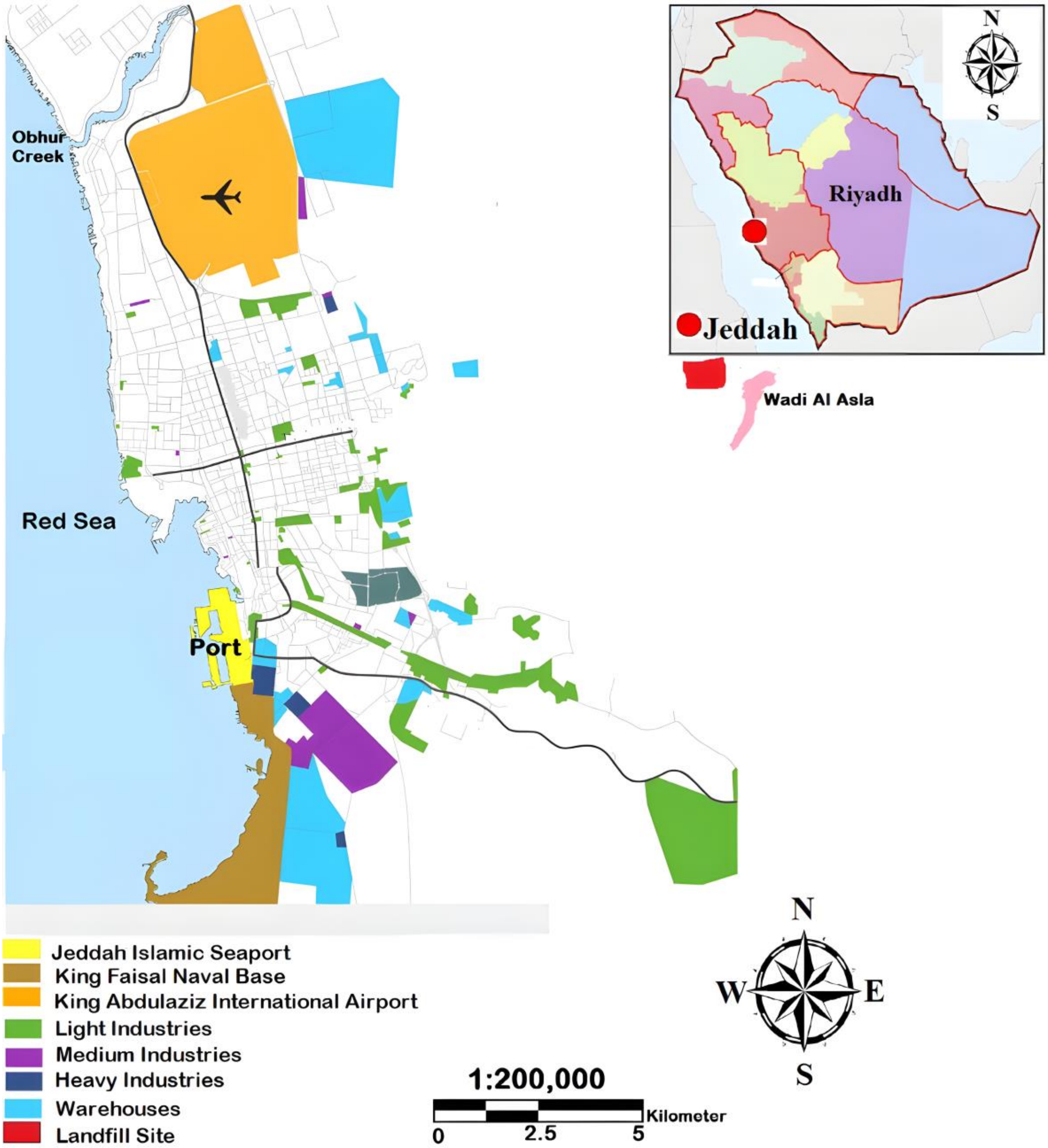
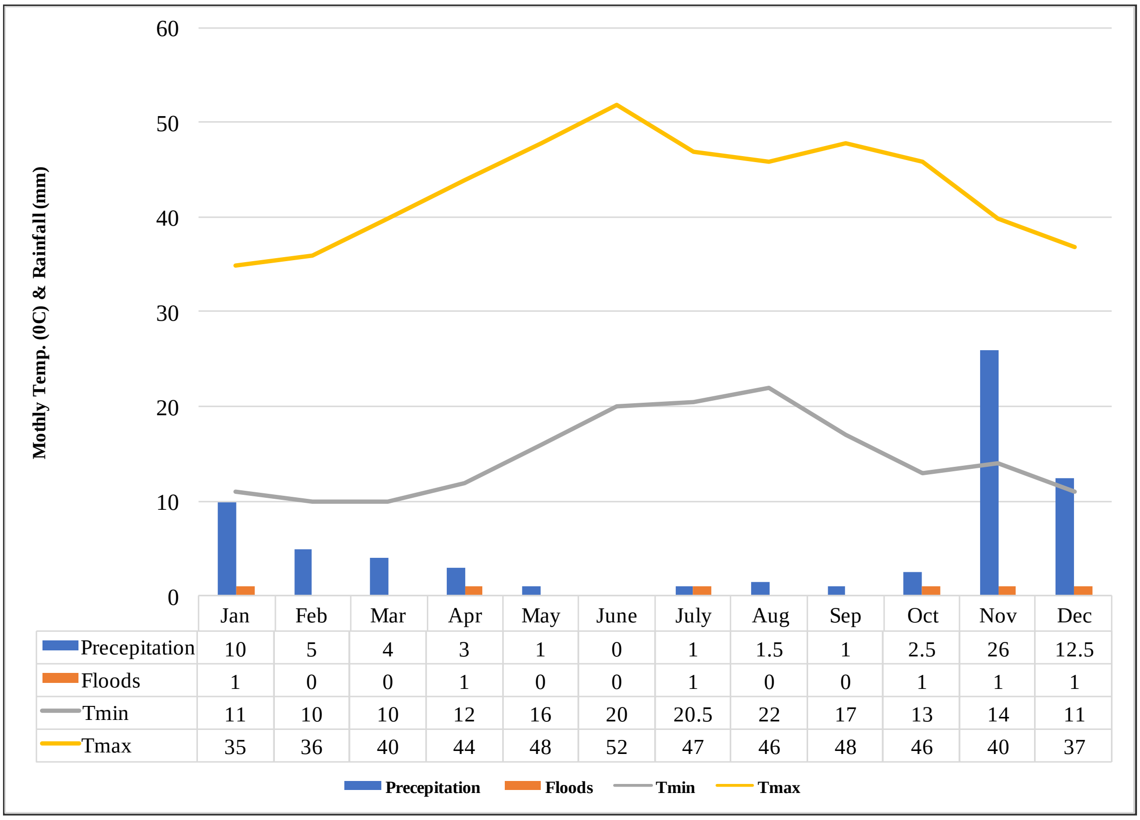


Figure 2. Map of Jeddah city bordering the Red Sea (Source: Author)



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Precepitation	10	5	4	3	1	0	1	1.5	1	2.5	26	12.5
Floods	1	0	0	1	0	0	1	0	0	1	1	1
Tmin	11	10	10	12	16	20	20.5	22	17	13	14	11
Tmax	35	36	40	44	48	52	47	46	48	46	40	37

Figure 3. Maximum, average, and minimum monthly air temperature (^{0}C), rainfall (mm), and number of recorded flash flood events in Jeddah city (Adapted from Tekeli [32])

2.1.1. Urbanization Pattern

Jeddah has undergone rapid urban expansion over the past few decades, driven by population growth, economic diversification, and its role as a tourism and religious pilgrimage hub. Urban growth primarily follows a north-south axis along the coast, constrained by the Red Sea on the west and the Hijaz mountains on the east. New residential developments, especially in northern areas, and coastal land reclamation projects are shaping the city’s skyline. However, this rapid urbanization has placed considerable strain on infrastructure, such as water management systems and transportation networks, which struggle to keep pace with growth [31, 32].

The unregulated expansion of urban areas has led to challenges in environmental management, including reduced green spaces, increased pollution, and poor drainage systems, which make the city vulnerable to flash floods. Efforts to mitigate these issues include urban heat island mitigation strategies and investments in infrastructure resilience, but challenges remain in effectively managing the balance between rapid urbanization and sustainable development [32].

2.1.2. Geological Setting

Jeddah comprises three major geological components: the Tertiary sediments and lavas, the Neoproterozoic bedrock complex, and the Holocene sediments and Sabkhas. The Tertiary sediments are found in the city's eastern part and are covered by basaltic lavas. Similarly, the Neoproterozoic rocks lay in some parts of the city's eastern area, typically coated by the hills of the Red Sea and pediments. They are composed of volcanic rocks encroached by plutonic rocks. Then the Holocene component is characterized by marine sediments and corals. It includes the Wadi (valley) alluvium, the basaltic lava flows, the Sabkha sediments, and the Aeolian sands beside the floodplains and bedrock.

2.1.3. Hydrology

Jeddah's hydrology is shaped by a diverse range of topographic and physiographic features that play a crucial role in the city's water dynamics. The climate conditions, particularly temperature and rainfall, also have a significant impact on the hydraulic response of Jeddah's watersheds, determining how water flows and accumulates within the region. These climatic conditions are influenced by multiple air masses that converge over the area, creating distinct rainfall patterns. Consequently, rainfall emerges as the primary factor affecting the hydraulic characteristics of the city's basins. Key aspects of rainfall, such as its duration, spatial and temporal distribution, intensity, and recurrence intervals (return cycles), directly influence the hydrological behavior of these basins, affecting flood risks, water storage, and drainage capacities within Jeddah’s urban environment. Understanding these interactions is essential for effective water resource management and flood mitigation strategies in the city.

2.2. Data Collection and Analysis

Data collection for this study included a thorough review of existing literature and an expert-based questionnaire survey, both of which were integral to achieving the study objectives. Initially, a comprehensive desktop review of relevant literature provided insight into various anthropogenic factors contributing to flood occurrences worldwide. This literature review enabled the authors to compile a broad list of factors associated with flood risks. Subsequently, a brainstorming session with subject matter experts allowed the researchers to refine and prioritize these factors, focusing on five primary contributors to flash floods specific to the study area. To gather primary data, the study employed an expert-based survey using Saaty's scale of relative importance, where experts ranked the relative contribution of each identified factor to flood risks in Jeddah.

Utilizing Saaty's scale offered a structured and quantifiable means of capturing expert judgments on the significance of each factor. This approach is recognized as a reliable method for data collection, particularly valuable for identifying, prioritizing, and understanding complex phenomena such as natural disasters by drawing on the knowledge of highly experienced professionals [33, 34]. This study utilized eight experts on the subject under investigation, which is adequate considering that prior studies have also used eight [35], nine [27, 36], ten [37, 38], and sixteen experts [39]. As revealed by Saaty and Özdemir [39], using a few well-experienced experts is acceptable to achieve valid and reliable results.

The questionnaire design was adopted from similar prior studies [1] and structured into two parts. The first part consisted of the socio-demographic characteristics of the experts, including their education level, occupation, years of experience, and level of knowledge on the subject. The second part covered experts' judgment about the extent to which the five anthropogenic factors contribute to flash floods, the degree of influence of each factor, and its impacts. The majority of the questions were structured as close-ended, with responses required on Saaty's 9-point rating scale: 1 (equal importance) to 9 (extreme preference) as illustrated in Table 1, the experts' judgments were then compiled into a pairwise comparison matrix. The data were analyzed using AHP with the aid of Microsoft Excel software.

2.2.1. AHP Model

The AHP is a structured mathematical model that deals with complex decision elements by structuring them into a structural hierarchy. It is implemented based on three basic principles: decomposition, relative judgment, and synthesis of priorities [40]. The technique organizes and evaluates criteria/alternatives based on a hierarchy of multifaceted elements, as illustrated in Figure 4. It offers an efficient quantitative decision-making tool to handle multifaceted and unstructured decision problems. It allows an enhanced, easier, and well-organized structure for finding appropriate criteria/alternatives and computing their relative weights [1].

The process allows incorporating judgments with intangible qualitative and tangible quantitative criteria. Therefore, these steps help decision-makers determine the elements that best contribute to resolving a problem. The fundamental purpose of AHP is to judge decision criteria and alternatives for a specific goal, such as causes of flood occurrence and mitigation strategies.

Once the hierarchy was established, the respondents were asked to evaluate the relative influence of each pair of factors using a pair-wise comparison and processed it mathematically as shown in the Appendix. For example, the impervious surfaces vs. inadequate open drainage system are adjudged at a time. Hence, the decision process using AHP is abridged in four fundamental steps: creating a decision hierarchy; determining the relative influence/importance of criteria under investigation; evaluating each alternative and computing its global weight for each criterion, and checking the consistency of the subjective assessments [41]. To ensure the consistency of the experts' rankings, checking data reliability is essential, and the Consistency Ratio (CR) of ≤ 0.1 was set as an acceptable level of reliability in the AHP methodology.

Table 1. The 9-point Saaty's scale of preference (Source: [42])

Scale	Definition	Description
1	Equally important	Both criteria contribute equally to the objective
3	Moderately important	One criterion is moderately more important than the other
5	Strongly important	One criterion has strong importance over the other
7	Very strongly important	One criterion is very strongly more important than the other
9	Extremely important	One criterion is of extreme importance compared to the other
Scale 2, 4, 6 and 8	Intermediary values	Used to represent intermediate importance between neighboring judgments when necessary
Reciprocals	If criterion i is assigned a score in comparison to criterion j, then j is assigned the reciprocal score	

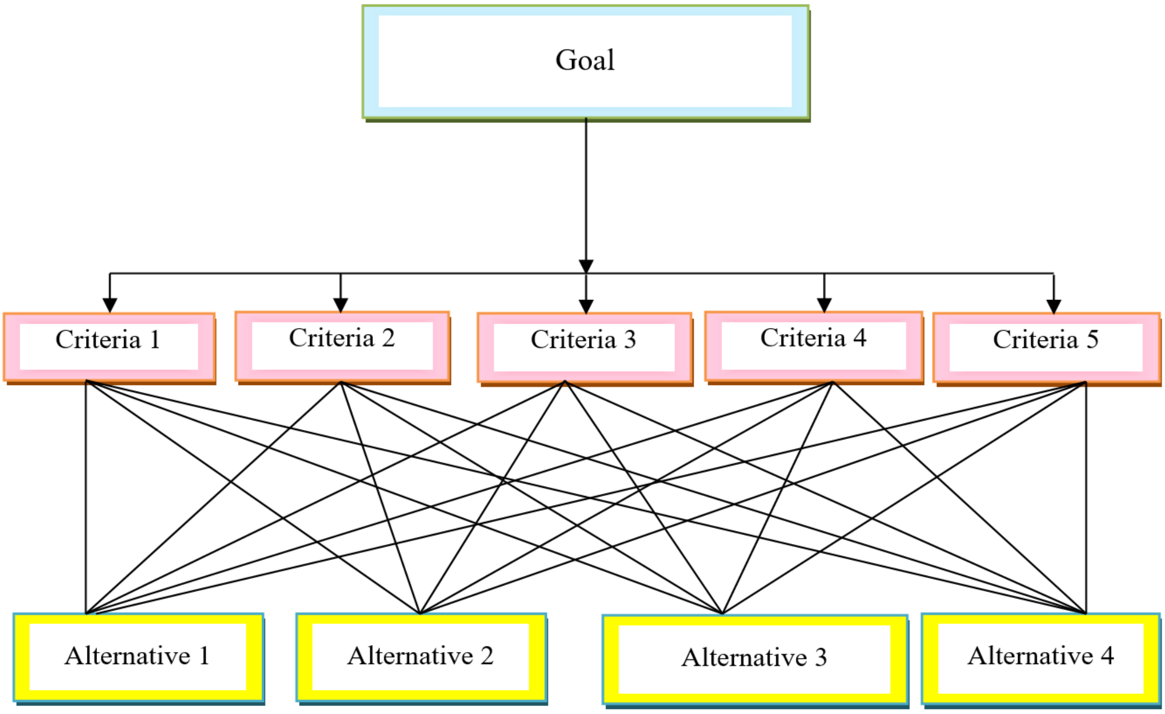


Figure 4. The general structure of the AHP (Source: authors)

In the first step of the hierarchy (Figure 4), the decision is fragmented into its criteria and denoted in a hierarchical chart of no less than three levels (goal, criteria, and alternatives). The power of AHP to deal with quantitative and qualitative data analysis makes it a perfect technique for prioritizing multifaceted decision problems. Each decision element is assigned a numerical value in Saaty's scale of preference so that it can numerically be compared with other elements in the pair-wise comparison matrix table. Thus, it is conducted mathematically as summarized in Equation 1 below:

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} & a_{14} & \cdots\cdots & a_{1n} \\ 1/a_{12} & 1 & 1/a_{13} & 1/a_{14} & \cdots\cdots & 1/a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & 1/a_{4n} & \cdots\cdots & 1 \end{pmatrix} \quad (1)$$

The experts' numerical judgments were aggregated to obtain priority weights that accurately reflect the combined single consensus opinion. In this study, Geometric Mean Method (GMM) was employed to aggregate the experts' ratings. GMM was selected for its appropriateness in pair-wise comparison rankings [42]. In a similar manner, within the resulting pairwise comparison matrix, GMM can preserve the reciprocal property necessary for the mathematical framework of AHP. Several prior studies have employed GMM in combining the respondents' rankings [43, 20, 21, 1, 44]. The GMM ($\prod$) is mathematically expressed as the root of the product of numbers presented in Equation (2).

$$\left(\prod_{i=n}^{n} x_i\right)^{\frac{1}{n}} = \sqrt[n]{x_1 x_2 \cdots\cdots x_n} \quad (2)$$

Where,
$\prod$ = geometric mean
n = number of values
x_i = value to average

The final stage of the AHP begins by normalizing and finding the relative weights for each set of pair-wise comparison elements.

2.2.2. Goals, Criteria, & Alternatives

Goal

The primary goal of the present study is to assess the impact of anthropogenic factors on flash floods in Jeddah city. This involves understanding how human activities and infrastructure decisions contribute to flood risks and evaluating strategies for effective mitigation.

Criteria (Flood-Contributing Factors)

The criteria represent the key factors driving floods in Jeddah, reflecting the direct and indirect consequences of urban activities. These criteria are:

- Impermeable Surfaces (IS)

With rapid urbanization, natural landscapes are frequently replaced by IS such as asphalt, concrete, and other construction materials. These surfaces prevent rainwater from infiltrating into the ground, significantly reducing natural water absorption. As a result, rainwater quickly accumulates on the surface, increasing the volume and speed of runoff flowing into drainage systems. This sudden surge leads to peak discharge, especially during heavy rainfall, which can overwhelm urban stormwater systems and cause flooding. The lack of natural absorption also limits groundwater recharge, which can have broader environmental impacts. Managing the expansion of IS through green infrastructure, such as permeable pavements and green roofs, can help mitigate these effects.

- Vegetation Clearance (VC)

Clearing vegetation for urban development reduces the land’s natural capacity to retain water, making it more susceptible to rapid runoff during rainfall. Vegetation, including trees, shrubs, and grasses, plays a vital role in absorbing rainfall and slowing down runoff through root systems that bind the soil. When vegetation is removed, soil becomes exposed and more vulnerable to erosion, which can lead to sediment buildup in rivers and drainage systems, further increasing the risk of flooding. Additionally, without the natural buffering effect provided by plants, water flows more rapidly across the landscape, contributing to the erosion of land and infrastructure and raising the risk of landslides in sloped areas.

- Inadequate Open Drainage Systems (IODS)

Effective SM requires well-maintained drainage systems that can quickly convey water away from populated areas. However, in many urban settings, drainage infrastructure is either insufficient or absent, leading to frequent water stagnation and flooding during heavy rain. In Jeddah, for example, multiple flood events have been attributed to poorly designed or clogged drainage systems, which fail to divert water efficiently. Without adequate open drainage systems, stormwater can pool in low-lying areas, damaging properties and creating health hazards due to stagnant water. Regular maintenance and expansion of drainage capacity are essential to prevent blockages and ensure effective SM, especially as rainfall intensity and urban density increase.

- Topography Flattening (TF)

Construction activities often involve leveling natural landforms, a process known as TF, to prepare sites for building and infrastructure projects. This alteration disrupts the natural flow paths of water, which would typically follow slopes or contours of the land. Flattened topography reduces the land’s natural ability to direct water toward drainage basins or other low-lying areas, creating conditions that increase the likelihood of water pooling and flash flooding. Additionally, topographic modifications can increase runoff velocity by reducing the friction that vegetation and varied terrain provide. Proper planning and careful consideration of the landscape’s natural features can help maintain effective water flow patterns and reduce flood risk.

- Infrastructure Failure (IF)

Flood-prevention infrastructure, such as dams, levees, and drainage channels, plays a critical role in managing water flow and reducing flood risks. However, infrastructure failure can lead to catastrophic flooding during extreme weather events. Aging structures, poor maintenance, or insufficient capacity to handle intense rainfall can cause these systems to fail, releasing large volumes of water unexpectedly. For example, a breached dam can lead to downstream flooding, endangering lives and property. Infrastructure failure not only exacerbates the immediate effects of a flood but also complicates recovery efforts, as damaged infrastructure can hinder access to essential services. Ensuring that flood-prevention structures are regularly inspected, maintained, and upgraded to withstand extreme conditions is essential for minimizing the risk of infrastructure-related flooding disasters.

Alternatives (Flood Mitigation Strategies)

The alternatives represent possible strategies to mitigate the impact of floods by addressing the contributing factors. The strategies are:

- Land Use Planning (LUP)

Effective LUP involves setting regulations to manage construction and development activities, particularly in areas prone to flooding. This includes restricting or carefully controlling new developments in floodplain regions to minimize the risk of flood damage. Preserving green spaces is also a crucial aspect of LUP, as these areas help absorb rainwater, reduce runoff, and maintain natural water balance within urban environments. Integrating natural landscapes into urban planning not only mitigates flood risks but also enhances biodiversity, supports ecosystem services, and improves the aesthetic quality of urban areas. By prioritizing sustainable land use, cities can create resilient landscapes that reduce flood vulnerability and promote a balanced urban ecosystem.

- Tree Planting (TP)

TP initiatives involve reintroducing vegetation in urban and suburban areas to restore the natural ability of soil and plants to retain water, thereby reducing surface runoff. Trees and other vegetation intercept rainfall, allowing it to percolate slowly into the ground rather than flowing directly into stormwater systems. This natural retention helps to stabilize soil, minimizing erosion and sediment displacement, which can clog waterways and exacerbate flooding. Additionally, tree roots create soil structure that improves infiltration, which is essential in areas with compacted or impervious surfaces. By enhancing groundwater recharge and reducing the volume and velocity of runoff, TP is a key component in sustainable flood management practices.

- Provision of Open Drains (POD)

The establishment or upgrading of open drainage systems is vital for efficient SM, as these systems provide designated pathways for water to flow away from urban areas quickly during heavy rainfall events. Open drains facilitate the rapid evacuation of stormwater, preventing water from accumulating on roads and other infrastructure where it could lead to flooding and property damage. Upgraded drainage systems with sufficient capacity are essential in areas experiencing increased rainfall due to climate change or urban expansion. Regular maintenance of open drains is also critical, as debris and sediment can clog these systems, reducing their efficiency and leading to water stagnation that can foster mosquito breeding and degrade water quality.

- Stormwater Management (SM)

SM encompasses a range of solutions designed to capture, store, and control the flow of runoff during and after rainfall events. Techniques such as retention basins collect stormwater and gradually release it to avoid overwhelming drainage systems, while infiltration trenches allow water to percolate into the soil, recharging groundwater and reducing runoff. Urban reservoirs serve as storage facilities for excess stormwater, which can then be repurposed for non-potable uses such as irrigation. Collectively, these SM systems help mitigate flood risks by controlling the volume and speed of runoff entering natural and built water systems. Incorporating these solutions within urban planning supports sustainable water management and enhances urban resilience against extreme weather events.

This systematic breakdown aligns the study's goal with the criteria for assessing flood risks and identifies alternatives for mitigating the impact of anthropogenic activities. By using these structured elements, the study ensures a comprehensive evaluation of the factors contributing to flash floods and the effectiveness of mitigation strategies. Therefore, the output's validity was assessed using the generated relative weights of the pair-wise comparison matrix. For instance, if the value of a computed matrix with a tolerable consistency judgment is A, the pair-wise comparison’s weight is computed using Equation (3) below:

$$AW = \lambda_{max} \ W \tag{3}$$

Where $\lambda_{\max}$ represents the principal eigenvalue of a consistent matrix A. Consistency Index (CI) and Consistency Ratio (CR) were computed to determine the consistency of the experts' rankings. Equation (4) was used in calculating the CR:

$$C = \frac{CI}{RI} \tag{4}$$

The random index (RI) reflects the values for matrices of size n, obtained from Table 2, which is a standardized table created by randomly generating values for n criteria. Consequently, the random inconsistency index is calculated by finding the average consistency index from reciprocal matrices generated using the 9-point preference scale shown in Table 1. The CR is only tolerable if it does not exceed a threshold value of 0.1 (10%), as earlier mentioned.

Table 2. Random inconsistency index (adapted from Saaty [44])

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3. Judgment matrix on the influences of human-made flash flood contributing factors for Jeddah city

	Anthropogenic flash flood contributing factors	IS	VC	IODS	TF	IF	Priority weights
IS	Impervious surfaces	1.00	2.51	0.17	2.29	2.52	0.25
VC	Vegetation clearance	0.38	1.00	0.23	0.36	0.36	0.07
IODS	Inadequate open drainage systems	3.05	3.02	1.00	1.09	1.06	0.29
TF	Topography flattening	1.23	2.79	0.60	1.00	1.51	0.21
IF	Infrastructure failure	0.28	2.73	0.94	0.66	1.00	0.17
Inconsistency ratio = 0.09							

Table 4. Judgment matrix on the importance of flash flood reduction alternatives

	Flash flood reduction alternatives	LUP	TP	POD	SWM	Priority weights
LUP	Land use planning	1.00	2.15	1.17	0.26	0.20
TP	Tree-planting	0.38	1.00	0.16	0.13	0.07
POD	Provision of open drains	3.09	3.04	1.00	0.73	0.35
SWM	Stormwater management	2.41	3.03	1.38	1.00	0.38
Inconsistency ratio = 0.06						

3. Results

The current section presents the outcome of the AHP pair-wise comparison matrix of the five main flood contributing factors and four flood mitigation alternatives based on the aggregated weights of all the experts generated using the GM computation (Table 3).

Analysis of the results reveals that an inadequate open drainage system is the most human-made flash flood contributing criterion among others in triggering flash floods with a weight of 29%, followed closely by the presence of IS and TF with weights of 25% and 21%, respectively. On the other hand, the least rated human-made flash floods contributing factors are VC with a weight of 7% and IF at 17%.

Similarly, the experts were requested to rate certain flash flood-reducing alternatives that can help reduce flash flood disaster risks in the study area using the 9-point scale of relative importance. The experts also believed that SM and POD are the most effective approaches to reducing flash flood incidence in the study area (38% and 35%), followed distantly by LUP and TP with weight scores of 0.20% and 0.07%, respectively (Table 4).

4. Discussion and Recommendations

A relative comparison of the human-made flash flood triggering factors considered in the present study underscores the high importance attached to the inadequate open drainage systems (29%), the presence of impervious surfaces (25%), and topography flattening (21%) criteria across the board as shown in Table 3. These findings corroborate a prior study that reported a lack of adequate open drainage systems as one of the major causes of flash flooding in Jeddah [16]. The authors reported that three major catchments: Wadi Methweb, Wadi Asheer, and Al-Khumra, lack open drainage systems to connect them with the southern channel, which caused severe floods in Wadi Methweb in 2009. Similarly, the study has revealed the presence of impervious surfaces as one of the major floods triggering factors in the area. This situation is exacerbated by rapid urban expansions along valleys, floodplains, and the channel downstream that have become the order of the day in Jeddah [16]. Jeddah and Mumbai, Jakarta, and Bangkok have revealed the lack of adequate drainage systems, impervious surfaces, and topography flattening as one of the key anthropogenic factors triggering flash floods [45, 46].

Moreover, this finding supports a prior study that reported impervious surfaces directly impacting runoff and peak discharge [7]. The United Nations Population Division projected that by 2050, over 95% of the increase in the global urban population would occur in developing nations [47]. Therefore, rapid urban growth is massively increasing the proportion of impervious surfaces, exacerbating the risks and menace of urban floods [47].

Concerning topography flattening, this study's third-ranked flash flood contributing factor, some national [1, 25] and international [21] studies have also ranked it as one of the significant floods triggering factors. Topography flattening occurs due to urban transformation and relevant construction activities, where the natural landforms are altered and flattened for construction and pavement purposes. Smooth flat surfaces trigger flash floods, decreasing the concentration and infiltration time of rainwater because of the reduction in flow velocity, thereby increasing the likelihood of flood occurrence in an area.

Also, the experts reported that stormwater management and building adequate drainage systems are the most preferable flash flood reduction alternatives. With global scores of 38% and 35%, respectively, stormwater management and drainage systems are almost twofold greater than land use planning (20%) and fivefold greater than the tree planting (7%) approaches. Thus, both approaches should be accorded the highest priorities for flash flood management in Jeddah. Similar studies by Zhang et al. [48] and World Bank [46] have highlighted the importance of stormwater management in flood control in Beijing, China and Tokyo, respectively. The authors indicate that stormwater management projects help achieve runoff reduction, flood control, and stormwater utilization [48, 47]. Thus, Stormwater management allows urban areas to mitigate the impact of flood disasters and relevant environmental changes. Integrated stormwater management and modern drainage infrastructure are essential to mitigate these risks, as demonstrated by successful flood control initiatives in cities like Beijing and Tokyo [46].

Based on the above mentioned, when assessing the human-made flash flood contributing factors holistically, inadequate open drainage systems, impervious surfaces, and flattened topography are identified as the major anthropogenic flash flood causative factors. This study’s methodology, demonstrating the analytical strength of AHP as a decision-making model, is thus capable of offering consistent and vital information to flood management agencies in reducing flash flood disasters in the study area. Similarly, the study's methodology, criteria, and alternatives can be replicable to any geographical area facing similar global flood challenges.

5. Conclusions

The present study found that inadequate open drainage systems, impervious surfaces, and topography flattening during construction projects are the three major human factors contributing to flash floods in Jeddah city. These findings have some important practical implications. Exploring expert opinions concerning anthropogenic factors contributing to flash floods and the likely reduction alternatives could offer basic understanding and valuable information to policymakers, officials, and experts working in disaster management agencies such as the General Directorate of Civil Defense and related agencies. Furthermore, the likely impacts of urban development and its associated construction activities on triggering floods should be considered. Also, there is the need for strategizing, developing, and enforcing flood hazard management activities that will guide any construction project and create awareness concerning the menace of human causes of flood disasters. Therefore, the concerned authorities, such as the Ministry of Municipal and Rural Affairs, in partnership with the General Directorate of Civil Defense, the Presidency of Meteorology and Environment, and construction companies, should ensure that construction projects are resistant and adaptive to floods. There is also the need for educational institutions and relevant non-governmental organizations to enlighten the public concerning the human causes of flash flood disaster risks and promote positive attitudes towards abstaining from any activity that could trigger flood disasters.

The AHP as a decision-making model thus provides an efficient platform for disaster management agencies and experts from multidisciplinary backgrounds to collaborate seamlessly in addressing and curtailing the occurrence of flash floods and associated natural hazards. With growing interest in flood management issues, adopting the AHP's capabilities in disaster decision-making is important. Understanding the major anthropogenic factors contributing to floods in the study area and similar locations will facilitate the concerned authorities in taking effective measures to reduce damages to lives, economy, and properties. Therefore, the findings from the present study underscore critical insights for other coastal cities grappling with similar urbanization challenges and flood risks such as Mumbai, Jakarta, and Bangkok. Collaborative governance and public awareness campaigns are critical to ensuring sustainable urban development and community resilience against future flooding events. The 2012-2013 report of the State of the World Cities stated that the 21st century cities strive to reduce the menace of all kinds of disasters and vulnerability for all people and develop resilience to any unfavorable forces of nature.

Appendix: Questionnaire Sample

Table 1. Comparison of the Flash Flood Triggering Factors

Question: With respect to flash flood occurrence, **which factor is more likely to trigger flash flood events?**										
Factor 1	Extremely favors (9)	Very strong favors (7)	Strongly favors (5)	Slightly favors (3)	Equal (1)	Slightly favors (3)	Strongly favors (5)	Very strong favors (7)	Extremely favors (9)	**Factor 2**
Impervious surfaces										Vegetations clearance
Impervious surfaces										Inadequate open drainage systems
Impervious surfaces										Topography flattening
Impervious surfaces										Infrastructure failure
Vegetations clearance										Absence of open drainage systems
Vegetations clearance										Topography flattened
Vegetations clearance										Infrastructure failure
Inadequate open drainage systems										Topography flattened
Inadequate open drainage systems										Infrastructure failure
Topography flattening										Infrastructure failure

Table 2. Comparison of the Alternatives

Question: With respect to **flash flood reduction, which alternative is most preferable?**										
Factor 1	Extremely favors (9)	Very strong favors (7)	Strongly favors (5)	Slightly favors (3)	Equal (1)	Slightly favors (3)	Strongly favors (5)	Very strong favors (7)	Extremely favors (9)	**Factor 2**
Land use planning										Tree planting
Land use planning										Provision open drains
Land use planning										Stormwater management
Tree planting										Provision open drains
Tree planting										Stormwater management
Provision open drains										Stormwater management

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