

Urban Flood Management and Zoning under Different Return Periods using the 2D HEC-RAS Simulation

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Abstract: Among natural disasters, floods, earthquakes, and droughts are of particular importance due to the financial and human losses they cause. In fact, natural disasters result from the interaction between human activities and random natural phenomena. This point is especially significant in the case of floods due to the relative concentration of human economic activities in floodplains. Given that floods cause considerable financial and human losses around the world every year, the importance of flood control and damage mitigation becomes evident. Furthermore, identifying inundated land uses is essential for effective urban management and planning strategies. In this study, the HEC-RAS hydraulic simulation model was used to simulate floods with different return periods, predict flow behavior, and perform flood zoning. The GIS (Geographic Information System) was employed as a tool to link flood modeling outputs and calculate the floodplain area for the inundated zones. The case study focuses on the urban flood of the Western Flood Diversion Channel located in Tehran, Iran. Using the 2D HEC-RAS model, floodplains corresponding to various return periods were determined. These were then analyzed in GIS using regional digital elevation model layers to derive the flood extent for each return period. The results indicate that with an increase in the flood return period, the channel is unable to convey the incoming flow, leading to a significant expansion of the floodplain and a greater number of land uses being submerged.

Keywords: Flood zoning, 2D Hydraulic simulation, HEC-RAS, ArcGIS.

I. INTRODUCTION

Urbanization has drastically altered natural hydrological processes, especially in rapidly growing cities where population density and human activities are concentrated (Yereseme et al., 2022). One of the most significant consequences of urban development is the widespread replacement of permeable natural surfaces with impervious

materials such as asphalt, concrete, rooftops, and paved walkways. These modifications disrupt the natural infiltration of rainfall into the soil and increase surface runoff, intensifying the risk of urban flooding (Kumar et al., 2021). In urban watersheds, land-use changes and high-density construction result in altered drainage patterns and reduced infiltration capacities (Suresh et al., 2023). The expansion of cities often outpaces the development of effective stormwater infrastructure. As a result, conventional urban drainage systems (typically designed for lower return periods), become overwhelmed during heavy rainfall events. This can lead to waterlogging, traffic disruption, property damage, and even loss of life (Alamdari & Hogue, 2022). Another major contributor to the increasing frequency and severity of urban flooding is climate change. Shifts in climatic patterns have led to irregular and more intense rainfall events, altering both the spatial and temporal distribution of precipitation. These changes exacerbate the vulnerability of urban areas, especially those situated on floodplains or with outdated drainage networks (Banjara et al., 2024). Moreover, rapid and unplanned urban expansion often encroaches on natural floodplains, wetlands, and waterways (Nguyen et al., 2021). Construction in these sensitive areas reduces the land's capacity to store or absorb excess water during storm events. As a result, even moderate rainfall can cause widespread inundation, especially in low-lying or poorly drained areas. These conditions are further aggravated by land compaction, deforestation, and the removal of vegetation, which all diminish the watershed's natural flood-mitigation capacity (Nsangou et al., 2022).

Urban floods not only pose risks to infrastructure but also threaten public health and safety (Sun et al., 2021). Contaminated floodwaters can spread waterborne diseases, damage sanitation systems, and increase the likelihood of outbreaks (Green et al., 2021). Additionally, the psychological and financial toll on affected populations can be substantial, particularly in socioeconomically vulnerable communities (Chen et al., 2021). Given these risks, it is essential to adopt proactive flood risk management strategies that incorporate advanced modeling and spatial analysis tools (Manandhar et al., 2023). Accurate prediction and delineation of flood-prone areas are crucial for

planning resilient infrastructure, establishing emergency response protocols, and protecting critical urban services and assets (Qi et al., 2021).

Hydraulic and hydrological simulation models, such as the Hydrologic Engineering Center's River Analysis System (HEC-RAS), have emerged as valuable tools for understanding and forecasting flood behavior (Ansarifard et al., 2024). The two-dimensional (2D) capabilities of HEC-RAS enable detailed simulation of overland flow and floodplain inundation, offering greater precision in modeling complex urban environments (Mihu-Pintili et al., 2019). When integrated with Geographic Information Systems (GIS), HEC-RAS becomes even more powerful. GIS facilitates the visualization, analysis, and interpretation of spatial data, making it possible to overlay flood simulation results with land use, infrastructure, and demographic information (Tahmasbinejad et al., 2012). This integration supports more informed decision-making in urban planning and disaster risk reduction. Flood zoning maps generated from 2D hydraulic simulations provide critical input for land-use planning and regulatory frameworks (Ícaga et al., 2016). They help identify areas at high risk of flooding under various return period scenarios, enabling planners to impose development restrictions, design effective drainage systems, and prioritize flood protection measures (Alaghmand et al., 2012).

This study aims to apply the 2D HEC-RAS model in combination with GIS tools to simulate and map urban flood extents under different return periods in the Western Flood Diversion Channel area of Tehran, Iran. By analyzing the spatial distribution of inundation areas and assessing the capacity of the existing drainage infrastructure, the study seeks to provide data-driven insights for flood risk mitigation and sustainable urban development planning. Thus, the primary objective of this research is to evaluate and map urban flood extents under varying return periods using a HEC-RAS integrated with GIS. The study focuses on the Western Flood Diversion Channel in Tehran, aiming to simulate the behavior of floodwaters under different hydrological scenarios. By accurately delineating flood-prone areas and estimating inundation zones, the research provides essential information to support urban flood risk management, infrastructure design, and emergency response planning. The novelty of this study lies in its application of a coupled HEC-RAS 2D and GIS approach in a highly urbanized and complex catchment area. Unlike traditional one-dimensional modeling, the two-dimensional simulation allows for detailed representation of surface water dynamics and overland flow patterns. Furthermore, the integration with high-resolution digital elevation models (DEMs) and spatial land-use data enhances the accuracy of flood mapping. This research also introduces a localized calibration framework tailored to the unique topographic and hydrologic conditions of Tehran, which has not been extensively explored in previous studies. This study addresses a key gap in flood risk assessment in rapidly urbanizing regions exposed to increasing climate variability. Given the growing frequency and severity of urban floods, especially in cities like Tehran where urban planning often overlaps with floodplains, the need for reliable flood modeling tools is more urgent than ever.

II. BACKGROUND

Flood zoning maps play a critical role in floodplain management studies and are extensively used worldwide as foundational datasets in planning and designing infrastructure projects. Today, these maps are considered essential components of engineering and environmental assessments and are routinely reviewed by relevant authorities prior to any investment or implementation of development plans. The concept of flood zoning is based on the premise that the river channel and its adjoining floodplain function as an integrated system. The floodplain is considered an extension of the river that is occasionally utilized during high flow events (Khattak et al., 2016). Accordingly, flood zoning refers to the process of delineating areas within the floodplain for various land-uses and planning purposes. These zones are categorized based on different levels of flood risk, with the objective of regulating land use, guiding sustainable development, and reducing vulnerability to flood hazards (Namara et al., 2022). Flood zones can be used to assess risk levels for property development, define areas eligible for flood insurance, and enforce land-use restrictions in hazard-prone regions. Zoning must be supported by legally enforceable policies derived from hazard maps that clearly identify flood-prone areas and risk categories (Mason et al., 2019).

Flood zoning maps also serve a wide array of practical applications in flood risk management (Wiering & Winnubst, 2019). These include economic feasibility studies for civil infrastructure projects, flood forecasting and early warning systems, emergency response and rescue operations, and flood insurance planning (Khalfallah & Saidi, 2018). One of the most modern and effective methods for generating flood zoning maps involves the use of GIS in combination with advanced hydraulic models (Mason et al., 2019). In this research, a numerical analysis of flood inundation resulting from multiple return periods is carried out using a two-dimensional modeling approach. The extent of inundated areas is quantified for each return period using the HEC-RAS hydraulic simulation model (Alaghmand et al., 2012). This study aims to contribute to urban flood management by providing accurate flood zone maps that can support effective planning, risk mitigation, and infrastructure resilience. In the following section, a review of relevant research efforts in the field of flood management and control is presented, highlighting key methodologies and findings from recent studies that inform and support the current investigation.

Shahiriparsa et al. (2016) applied the HEC-RAS model to determine flood-affected areas in the Jehor River basin in Malaysia for different return periods (2, 25, 50, and 100 years) to analyze flood risk in this region. They identified the Manning's roughness coefficient as the most important factor in determining water surface levels using HEC-RAS. The study further concluded that the primary cause of increased flood damage is the utilization of land near the river rather than the flood frequency itself. Khattak et al. (2016) used the HEC-RAS simulation model to map the floodplain of the Kabul River in Pakistan. In their study, they mapped the study area using the HEC-GEORAS extension in GIS, calculated the river geometry and cross-sections, and then performed floodplain zoning for return periods of 25, 50, and 100 years using the HEC-RAS model.

Patel et al. (2017) investigated flood zoning in the city of Surat, India, located downstream of the Sardar Sarovar Dam, which experienced its largest flood in 2006. They considered a discharge rate of approximately 25,770 m³/s from the Sardar Sarovar Dam, which was responsible for the major flood disaster in the region. The study included 290 cross-sectional profiles, two hydraulic models, and five flood scenarios along the river to perform one-dimensional modeling. The results of the simulation indicated that the western region of the study area experienced the deepest flooding, with water levels reaching approximately 4 to 5 m. The study further demonstrated that the new HEC-RAS simulation model significantly enhances flood mapping and provides critical insights for flood management planning. Jun et al. (2019) focused on urban runoff management in Tongshan County. In their research, they assessed the capacity of the drainage network to handle floodwaters for different return periods. In addition to analyzing the real capacity of the drainage system, they provided recommendations for optimizing and increasing the channel capacity to better handle floodwaters.

Madhuri et al. (2021) evaluated flood risks for buildings using the HEC-RAS model. Their research examined urban flood risks for buildings in the context of climate change. The study was conducted in the Hyderabad Municipal area in India, where heavy rainfall and resulting floods have caused significant property damage. The researchers utilized the HEC-RAS model to simulate flood depths, identify high-risk areas for buildings, and assess the effectiveness of various flood risk reduction strategies. The study highlights that accurate flood depth simulations and risk modeling are vital for creating detailed flood maps that can assist in better flood management and minimizing infrastructure damage. Jeong et al. (2024) stated that due to the increasing frequency and intensity of floods because of climate change, the preparation of flood zoning maps is important as a non-structural measure. These maps can play a crucial role in preventing and reducing flood damage. The use of two-dimensional flood simulation models, such as FLUMEN and HEC-RAS, for modeling urban floods, especially in areas with complex factors like the presence of buildings and specific land cover characteristics, has been employed in several studies. In this research, the flood simulation results from both FLUMEN and HEC-RAS models were compared, taking into account urban factors and varying roughness coefficients. The study addresses the uncertainties arising from model selection and emphasizes the importance of choosing the right model for urban flood analysis. The findings highlight how the proper model choice can significantly assist in selecting appropriate numerical models for various urban flood scenarios.

III. MATERIALS AND METHODS

A. HEC-RAS Principal

HEC-RAS is advanced hydraulic modeling software developed by the U.S. Army Corps of Engineers. It provides users with the ability to perform both 1D and 2D flow modeling for rivers, streams, and floodplains (Yang et al., 2006). The software is essential for simulating steady and unsteady flow conditions, including flood forecasting, hazard assessment, and infrastructure design (Namara et al., 2022). HEC-RAS also

models sediment transport, bed mobility, and water quality, making it useful for environmental impact studies, river restoration projects, and sediment management (Khalfallah & Saidi, 2018). The addition of 2D capabilities enhances the model's ability to simulate complex flow conditions, especially in urban areas where the flow direction can change rapidly due to obstacles like buildings or complex topography (Alaghmand et al., 2012).

One of HEC-RAS's key features is its ability to analyze river hydraulics and flow dynamics in relation to infrastructure, such as bridges and culverts, by calculating the water surface elevation and flow velocities under various flow conditions (Mason et al., 2019). This is critical for designing flood control structures, assessing flood risk, and evaluating floodplain management. The software integrates with GIS tools, particularly with the HEC-GeoRAS extension, to provide spatial data processing, such as generating cross-sectional profiles, topography, and hydraulic features, which improve the accuracy and reliability of the model (Madhuri et al., 2021). This integration allows for efficient data management and ensures that results are geographically accurate, which is crucial for large-scale flood modeling and infrastructure planning (Jeong et al., 2024). HEC-RAS is widely regarded for its user-friendly interface, flexibility, and accessibility, making it suitable for a wide range of users, including government agencies, consultants, and researchers (Salajegheh et al., 2009). As a free tool, it offers an economical solution for hydraulic modeling. Furthermore, HEC-RAS allows model calibration and validation using field data, ensuring the model accurately reflects real-world conditions (Khalfallah & Saidi, 2018). With its powerful capabilities, HEC-RAS has become a standard tool in hydraulic engineering, flood risk analysis, and environmental management, providing critical insights for mitigating flood hazards and designing resilient water management systems (Yang et al., 2006).

HEC-RAS initially focused on 1D modeling of steady and unsteady flow conditions. In steady-state flow, the flow characteristics at a specific point in the river do not change over time (Salajegheh et al., 2009). For unsteady flow, HEC-RAS models the time-dependent variations in flow, velocity, and water surface elevation, allowing engineers to simulate dynamic river conditions (Alaghmand et al., 2012). Steady-state flow is typically used for floodplain mapping, while unsteady flow modeling is used for flood forecasting, dam break analysis, and flood risk assessments. The 2D capabilities of HEC-RAS provide a more accurate and detailed analysis of river hydraulics. The software incorporates the RAS-Mapper extension, which allows users to model flow over complex, irregular riverbeds, better representing real-world scenarios where flow can change direction and vary across different parts of the river (İcaga et al., 2016). 2D modeling is essential for simulating localized flow behavior such as backwater effects, flow around structures, or floodplains that are not well represented in 1D models (Wiering & Winnubst, 2019).

HEC-RAS includes sediment transport modeling capabilities that allow engineers to predict erosion and sediment deposition processes in rivers and streams (Mason et al., 2019). The software can simulate the movement of sediment particles based on the flow velocity, depth, and sediment characteristics (Namara et al., 2022). This feature is key in designing riverbed

stabilization projects and understanding sediment dynamics (Mondal et al., 2016). The model can also evaluate bed mobility, providing insights into the potential for changes in riverbed elevation due to sediment transport (Raji et al., 2024).

HEC-RAS can be integrated with GIS tools, particularly with the HEC-GeoRAS extension, which allows users to process spatial data and generate geometric inputs for the model. This integration simplifies data management, particularly in large-scale river systems or when working with complex topographic datasets (Namara et al., 2022). GIS integration ensures that model inputs (such as riverbed geometry, land use, and hydraulic features) are spatially accurate, improving the quality of model outputs (Rahman & Ali, 2016). Successful use of HEC-RAS requires careful calibration and validation of the model using field data such as river flow measurements, water surface elevation surveys, and historical flood events (Yang et al., 2006). Calibration ensures that the model accurately represents real-world conditions, while validation helps confirm the model's accuracy in simulating specific events or conditions (Jeong et al., 2024).

B. Differential Equations Governing Flow

The flow of water in open channels such as rivers and floodplains is governed by the Saint-Venant equations, which are a set of partial differential equations derived from the principles of conservation of mass and momentum (Roohi et al., 2020). These equations form the mathematical foundation for hydraulic models like HEC-RAS. There are two main equations: the continuity equation for mass conservation, Eq. 1 and the momentum equation as momentum conservation, Eq. 2 (Magdalena et al., 2024). The Saint-Venant equations consist of the continuity equation and the momentum equation. These equations are fundamental to modeling unsteady open-channel flow, such as during flood routing in rivers (Roohi et al., 2020). Depending on how many terms from the momentum equation are retained during simplification, there are three primary methods used for flood routing in rivers (Saleh et al., 2013):

- *Kinematic Wave*: This method simplifies the Saint-Venant equations by neglecting all the terms in the momentum equation except the gravity and friction slope terms. It assumes that the flow is mainly driven by gravity and resisted by friction, with no effects from pressure, inertia, or acceleration. This approach is suitable for steep channels where backwater effects and inertial forces are negligible.
- *Diffusion Wave*: This method includes the pressure term in addition to the gravity and friction slope terms in the momentum equation, allowing it to simulate backwater effects to some extent. It is more accurate than the kinematic wave model and is suitable for mild-sloped channels where pressure gradients cannot be ignored.
- *Dynamic Wave*: This is the most complete form, using the full Saint-Venant equations without omitting any term from the momentum equation. It accounts for all forces, including inertia and pressure, and is required for highly dynamic flows, such as those with rapidly changing water levels or velocities.

$$q_l = \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} \quad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q^2}{A} \right) + gA \frac{\partial h}{\partial x} + gAQ_f = 0 \quad (2)$$

where, A is cross-sectional flow area (m²), Q is discharge or flow rate (m³/s), x is distance along the channel (m), t is time (s), q_l is lateral inflow per unit length (m²/s), g is gravitational acceleration (9.81 m/s²) and h is flow depth (m). It should be noted that the expanded form Eq. 2, more commonly used as

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q^2}{A} \right) + gA \left[\frac{\partial h}{\partial x} + S_f - S_0 \right] = 0 \quad (3)$$

where, S_f is friction slope and S₀ is bed slope.

The kinematic wave method is the simplest, assuming that the channel bed slope and friction slope are equal, effectively neglecting all other forces such as pressure and inertial effects. This method is suitable for steep, uniform channels where flow is predominantly driven by gravity. The diffusion wave approach adds one more level of complexity by including the pressure gradient term (the water surface slope) in the momentum equation, while still neglecting local and convective acceleration (inertial terms). This allows it to account for mild backwater effects, making it appropriate for gently sloping channels where flow changes gradually. The most comprehensive method is the dynamic wave, which retains all terms in the momentum equation, including inertia and pressure effects. This method is used for modeling unsteady and complex flow situations, such as rapidly rising flood waves, dam breaks, or tidal flows, where full dynamic behavior of the flow must be considered.

Figure 1 presents a schematic comparison of hydrographs resulting from routing a flood wave using the dynamic-wave and kinematic-wave approaches. The figure illustrates how the two methods respond to the same inflow conditions over time. The dynamic wave, by accounting for all terms in the Saint-Venant equations (including inertia, pressure gradients, and resistance), produces a hydrograph that more accurately reflects the real behavior of the flood wave as it propagates through the channel. This typically results in a smoother, more delayed outflow curve, with a broader peak and attenuated response. So, the kinematic wave method, which simplifies the momentum equation by neglecting inertial and pressure effects, leads to a more abrupt and sharper hydrograph. It tends to propagate the wave faster and with less attenuation, often overestimating peak flows and underestimating lag time. This schematic effectively highlights the limitations of using kinematic-wave approximations in cases where dynamic flow behavior significantly affects wave translation and attenuation. Also, Figure 2 compares various flood routing solutions for a rapidly rising wave moving through a prismatic channel with a trapezoidal cross-section. The top panel shows the inflow and outflow hydrographs at a location 40 km downstream. It compares results from the full Saint-Venant equations (dynamic wave) and two alternative diffusive-wave equivalent models: the Kinematic wave Corrected for Dynamic effects (KCD) and the Generalized Kinematic (GK) model.

The KCD model incorporates dynamic effects by using depth-discharge (y - Q) conversions and wave celerity computed with the Jones formula, improving its accuracy over the simple kinematic model. The GK model, while also a diffusive-wave equivalent, calculates y - Q relationships and wave speed using the steady-state rating curve, making it less responsive to transient conditions. The bottom panel of Figure 2 displays the rating curves (i.e., relationships between flow depth and discharge) at a location 20 km downstream. These curves illustrate how each method captures the hysteresis effect (the difference between rising and falling limbs of the hydrograph) in unsteady flow. The dynamic wave solution shows a distinct loop, indicating the lag between depth and discharge due to unsteady effects. The KCD model follows this behavior more closely than the GK model, which tends to revert to a steady-state relationship.

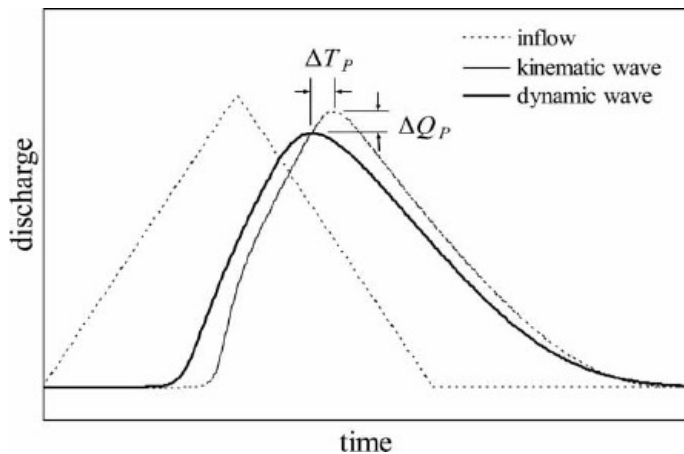


Fig. 1 Comparison of outflow hydrographs showing dynamic vs. kinematic wave routing impacts (Lee & Huang, 2012)

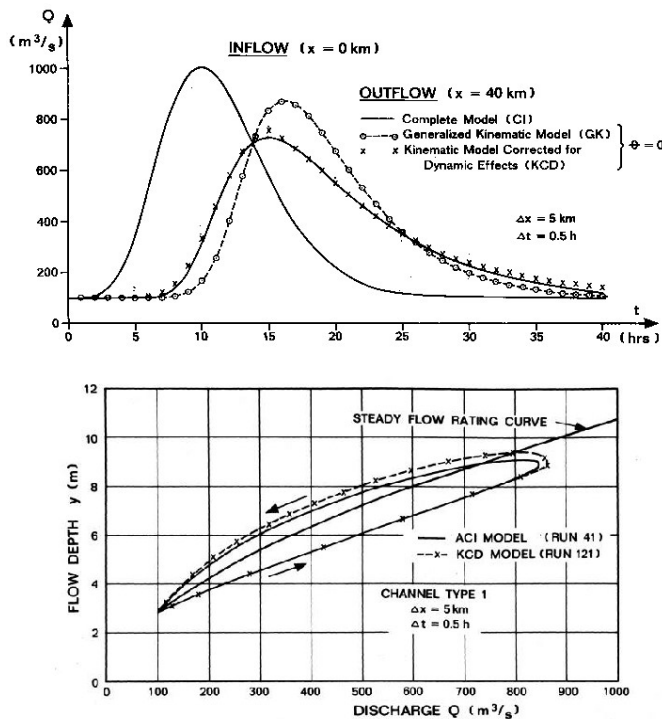


Fig. 2 Routing performance of full dynamic and diffusive models for a fast-rising wave in a trapezoidal channel (Weinmann, 1977)

C. Study Area and Location

Tehran, the capital city of Iran, is located in the north-central part of the country at the southern foothills of the Alborz Mountains. It lies between latitudes $35^{\circ}35'N$ to $35^{\circ}50'N$ and longitudes $51^{\circ}10'E$ to $51^{\circ}35'E$. With an average elevation of about 1,200m above sea level in the city center, Tehran exhibits significant variation in elevation, rising to over 1,800m in the northern districts and descending to around 1,000m in the southern suburbs (Shafiee & Azadi, 2007). This strategic location between the mountains and the central Iranian plateau contributes to Tehran's unique environmental and urban characteristics (Ghassemi, 2023). Tehran experiences a semi-arid to Mediterranean-influenced climate characterized by hot, dry summers and cool, wet winters (Khanlari & Mokhtari, 2012). Average annual precipitation is approximately 230-250 mm, primarily falling between November and April. Summers, particularly from June to August, are dry and hot with average daily temperatures often exceeding $35^{\circ}C$, while winters can be cold, especially in the elevated northern areas, where snow is not uncommon. The climatic gradient between the northern and southern parts of the city, due to topographical differences, results in microclimatic zones within Tehran (Iran Meteorological Organization, 2024).

Tehran's topography is shaped by the dramatic slope descending from the Alborz Mountains in the north to the plains of Varamin in the south. The northern districts, such as Shemiran, are located at higher elevations with steep terrain, while the southern parts, including areas like Rey, lie on relatively flat and lower-lying plains (Ghayoumian et al., 2009). This elevation gradient not only affects urban planning and infrastructure but also results in noticeable differences in temperature, air quality, and vegetation across the city. The northern parts are generally cooler and greener, while the southern areas are warmer and more arid (Khanlari & Mokhtari, 2012). Tehran's geomorphological setting includes mountainous terrain, foothill zones, alluvial fans, and flat plains. The city is intersected by several seasonal rivers and dry valleys known as ravines or kanats, many of which originate in the Alborz Mountains. Over time, these natural features have been significantly altered by urban development. Notable geomorphologic formations such as the Tochal Mountain Range provide not only a natural boundary but also influence local weather patterns through orographic effects and the retention of snowpack, which historically served as a water source (Aghanabati, 2012).

Tehran lies at the junction of the Central Iranian microplate and the southern margin of the Eurasian plate. This tectonic setting has resulted in a complex geological structure dominated by folded and faulted sedimentary rocks of Mesozoic and Cenozoic age (Hosseini et al., 2017). The northern mountainous areas consist primarily of limestones, marls, and volcanic rocks, while the southern plains are underlain by alluvial deposits and fine-grained sediments. The presence of multiple fault lines, including the North Tehran Fault and Mosha Fault, make the region seismically active and prone to earthquakes (Aghanabati, 2012). The soils in Tehran vary significantly across the city, primarily due to differences in elevation, geological history, and sediment transport processes (Ghayoumian et al., 2009).

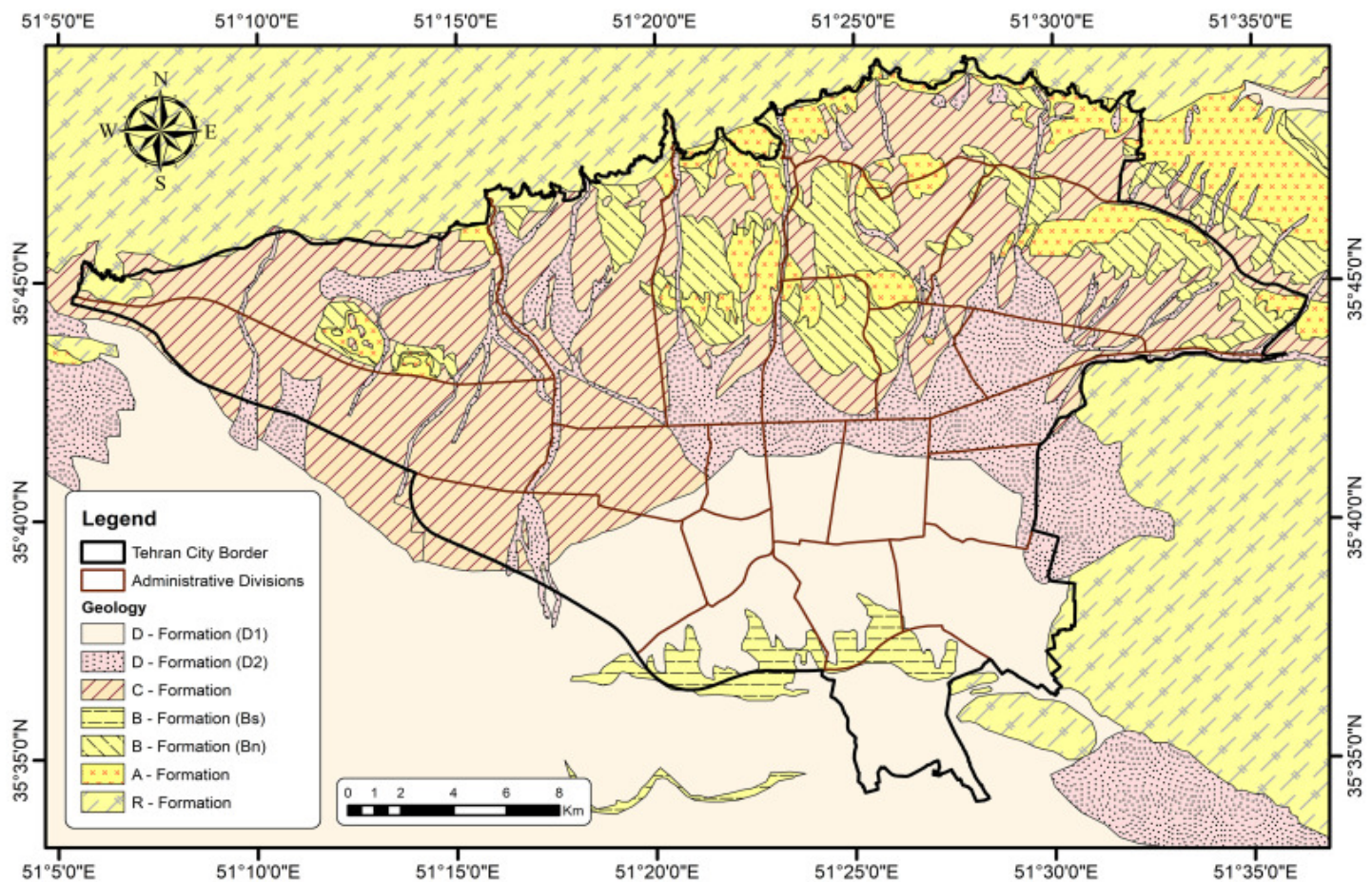


Fig. 3 Geological map of Tehran (Abbasnejadfar et al., 2023)

In the northern regions, coarse alluvial soils dominate, providing better drainage and stability. Conversely, the southern parts of Tehran are characterized by fine silty and clayey soils, which are more prone to compaction and liquefaction during seismic activity (Aghanabati, 2012). These variations in soil properties have direct implications for building design, land use planning, and risk assessment. Figure 3 illustrates the geological map of Tehran.

The Kan River can be considered one of the primary and most important drainage outlets in Tehran County. Recognized as the most significant river in Tehran, the Kan River receives flow from several major tributaries along its course (Aghanabati, 2012). The Western Flood Diversion Canal serves as the most important inflow to the river, acting as a collector for various streams and canals, including Darakeh, Khoshkheh, Abdolabad, Tappeh Neyzar, Behroud, Farahzad, Moradabad, Shahin, and others. Additional inflows to the Kan River include the Zarnow watercourse and the Fath Canal (Lord et al., 2021). In this study, the Western Flood Diversion Basin is selected for detailed analysis. This basin includes approximately 120 km of open channel, of which an 8.5km segment located in western urban Tehran is specifically examined. The study aims to delineate flood inundation extents and identify flood-prone areas under different return periods. Figures 4 illustrate the spatial position of the study area in relation to Tehran's urban districts, as well as the specific location of the flood diversion system. The flood hazard zoning area of Tehran examined in this study spans from

Goftegoo Park to the Kan River, covering the floodplain area associated with the Western Flood Diversion system.

The Western Flood Diversion Canal of Tehran is a major engineered drainage infrastructure designed to mitigate flood risks in the western urban districts of the city. It serves as a critical flood control system by collecting and conveying surface runoff and stormwater from several upstream tributaries and watersheds. The canal was constructed in response to increasing urban development, which has reduced natural infiltration and increased the volume and velocity of stormwater. By channeling excess water away from densely populated and economically important areas, the system helps protect critical infrastructure, residential zones, and transportation networks from flash floods and urban waterlogging. Hydrologically, the canal acts as a main collector for various rivers and ephemeral streams descending from the Alborz Mountains, such as the Darakeh, Farahzad, Moradabad, and Behroud streams. These tributaries typically experience high runoff volumes during intense seasonal rainfalls, particularly in the late autumn and early spring. The Western Flood Diversion Canal integrates these flows and directs them southward toward the Kan River, which ultimately conveys the water further downstream. Along its course, the canal includes both open-channel segments and covered concrete conduits, equipped with flow regulation structures to manage discharge capacity during peak storm events. The canal is also significant in urban planning and environmental management. It intersects multiple urban neighborhoods and passes through areas with high

population density, necessitating careful maintenance and regular monitoring to ensure safety and operational efficiency. Moreover, as the city expands westward, the canal plays an increasingly important role in controlling urban runoff, reducing soil erosion, and minimizing the risk of waterborne pollution entering downstream ecosystems. Its presence emphasizes the need for integrated flood risk management strategies that combine engineered infrastructure with watershed conservation and sustainable urban drainage practices.

D. Required Data and Methodology

For the purpose of two-dimensional hydraulic modeling using HEC-RAS, a high-resolution topographic map of the study area was required as an essential input. Since a complete topographic map of Tehran County was available, the DEM of the entire region was first imported into the ArcGIS environment. The study area was then extracted from the full DEM using spatial tools. This clipped DEM was exported and loaded into the HEC-RAS model through the RAS-Mapper interface (Figure 5). The main map used in this study had a scale of 1:1000, while the map specific to the canal was available at a finer scale of 1:500. These two maps were overlaid in ArcGIS to ensure spatial alignment and accuracy before being imported into the hydraulic model.

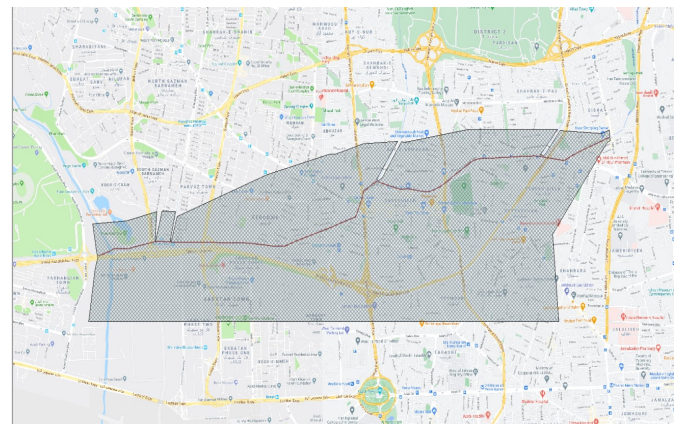


Fig. 5 Model created with mesh and boundary conditions for 2D hydraulic simulation in HEC-RAS

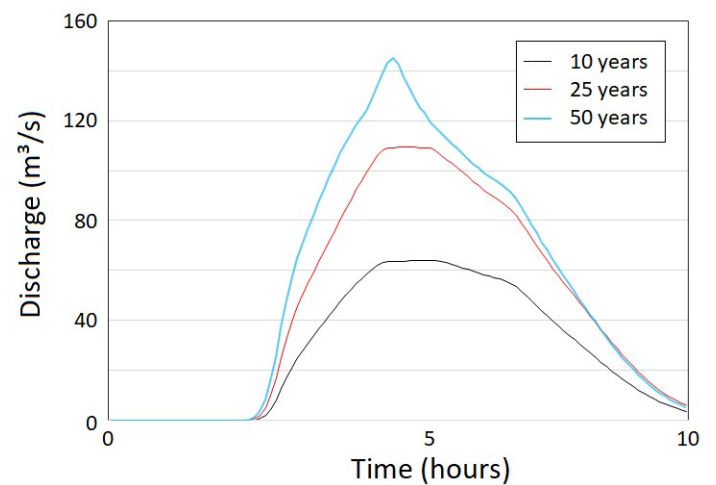


Fig. 6 Inflow hydrographs for various return periods used in the 2D HEC-RAS model

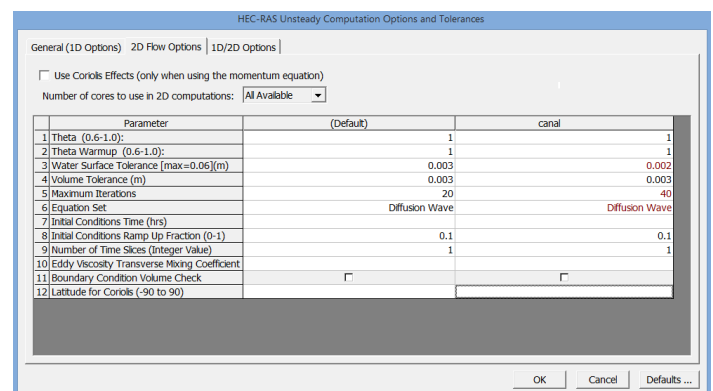


Fig. 7 Configured parameters for stabilizing the HEC-RAS hydraulic model

Additionally, hydrological input data such as inflow hydrographs for various return periods were utilized for upstream boundary conditions. Sub-catchment inflows and local tributary hydrographs were used to define lateral boundary conditions, while normal depth was applied at the downstream boundary. All spatial and hydrologic data were georeferenced and calibrated appropriately for model use.

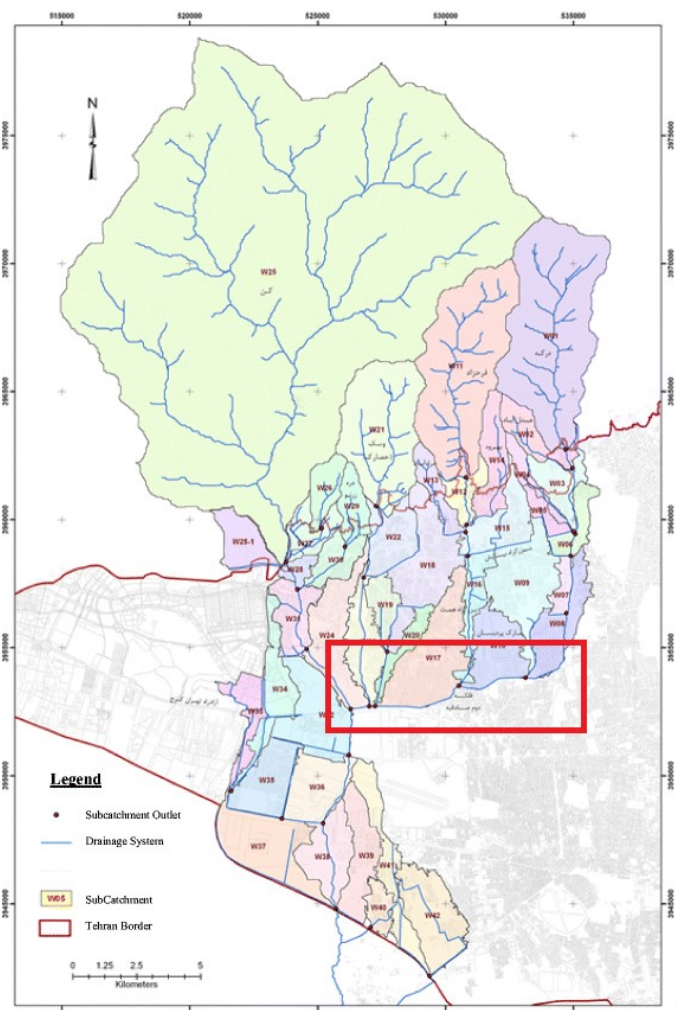


Fig. 4 Location of the study area and the West Flood Diversion Channel in Tehran Province (adapted from Yazdi, 2018)

The geometric setup of the 2D hydraulic model was conducted in the HEC-RAS environment. A computational mesh was generated for the entire study domain using the RAS-Mapper tool. Manning's roughness coefficients were assigned based on land cover and channel characteristics. For each defined return period, corresponding inflow hydrographs were applied at the upstream boundary. The mesh structure was refined iteratively, and boundary conditions were explicitly set for the Main River, sub-channels, and diversion flows. Model simulations were performed under unsteady flow conditions to represent dynamic flood scenarios. To assess model stability and ensure convergence, sensitivity analyses were conducted on mesh size and time-step parameters. Through this analysis, a mesh resolution of 5m (in both D_x and D_y directions) was found to provide reliable results without significant computational cost. The inflow hydrographs for different return periods used in the simulations are shown in Figure 6. Finally, model parameters such as tolerances, iteration controls, and solver settings were fine-tuned to enhance numerical stability. As shown in Figure 7, these calibrated settings ensured the accuracy and reliability of the simulation outcomes. Outputs included water surface elevations, inundation extents, and velocity fields across the domain. The finalized hydraulic model offers a reliable tool for flood hazard mapping and mitigation planning in the Western Flood Diversion Canal region of Tehran.

IV. RESULTS AND DISCUSSION

Upon completion of geometric data entry and model configuration for the Western Flood Diversion Canal in the HEC-RAS 2D simulation environment, a comprehensive sensitivity analysis was conducted on mesh resolution and calibration parameters to ensure numerical stability and accuracy of the hydraulic model. Following model setup, unsteady flow simulations were executed for multiple flood return periods (e.g., 10-, 25-, and 50-year events), producing spatially and temporally distributed outputs, including water depth, flow velocity, and inundation extent. Using the RAS-Mapper visualization tool, flood inundation maps were generated for each return period and overlaid with high-resolution satellite imagery of the study area. This allowed for a clear visual assessment of flood spread across various land use zones. Urban features such as buildings, roadways, and critical infrastructure were cross-referenced with the inundation extents to identify assets at risk under each flood scenario.

The output results, including flood depth and velocity maps, were exported in raster format and imported into ArcGIS for further spatial analysis. GIS tools were utilized to quantify the area of inundation for each return period. For instance, as shown in Figure 8, the 50-year floodplain clearly exceeds the design capacity of the diversion canal, inundating surrounding urban and semi-urban areas. This indicates a significant overflow risk for extreme events. Figure 9 displays the corresponding flow velocity map for the 50-year scenario. While velocities remained low in most sections, localized peaks reaching 2 m/s were observed, particularly near channel transitions and constrictions. These zones represent hotspots for erosion and structural damage, necessitating targeted mitigation measures. The simulation outputs indicate that under 25- and 50-year return

periods, the canal infrastructure is inadequate for safely conveying floodwaters, and the adjacent urban areas are highly vulnerable to inundation. To mitigate future flood risks and potential damages, strategic interventions such as expanding channel capacity, constructing flood detention basins, or implementing nature-based solutions, should be considered. These actions are critical to enhancing the flood resilience of the western districts of Tehran, especially in areas where risk to human life and infrastructure is most pronounced (see Figure 10).

A significant advantage of the HEC-RAS 2D model is its capability to provide detailed hydraulic information, such as water surface elevation (WSE) and flow depth at any selected cross-section. In this study, multiple cross-sections were defined along the length of the diversion canal. For each section, WSE values and flow depths were extracted, as shown in Figure 11, offering insight into channel behavior during peak flows. Additionally, a longitudinal water surface profile was generated to assess spatial changes in flow elevation relative to the canal bed. This analysis helped identify potential overtopping zones and areas requiring structural reinforcement or redesign. The inundation extents for each return period were also exported as Shapefiles and imported into ArcGIS to conduct surface area calculations. As displayed in Figure 12, floodplain boundaries were clearly delineated for all modeled scenarios, providing a robust basis for spatial analysis. Using ArcGIS spatial analysis tools, the surface area of each floodplain was quantified. These results are summarized in Table 1, which reveals a clear positive correlation between return period and inundated area (i.e., larger floods result in greater surface coverage). Figure 13 illustrates this trend graphically, reinforcing the relationship between return period magnitude and flood hazard severity in the study area.

Furthermore, the integration of land use data within the GIS environment enabled a detailed impact assessment of flood hazards on critical urban functions. Water depth data for each pixel within inundated zones was extracted and overlaid with layers representing land use categories, road networks, and infrastructure facilities. This allowed for accurate identification of flood-affected assets under different return periods. Based on the vulnerability and estimated value of each land use type, such as residential areas, commercial establishments, public buildings, and utility infrastructure; a damage estimation was carried out. Figure 14 illustrates the land use types impacted under the 50-year flood scenario, identifying zones at highest risk of economic and social disruption. These findings demonstrate that the current capacity of the Western Flood Diversion Canal is insufficient to handle high-magnitude flood events. Immediate attention is required to prioritize mitigation measures aimed at reducing exposure, enhancing canal capacity, and increasing the resilience of surrounding urban and peri-urban areas. The integration of hydraulic modeling with geospatial analysis has proven critical in identifying vulnerable zones and informing future flood risk management strategies for western Tehran.

The results of this study provide essential insights for future flood risk assessments and management strategies in the Western Flood Diversion Canal area. Given the significant urban development in the vicinity of the canal and the increasing risk of extreme flood events due to climate change and urbanization, understanding flood inundation dynamics is crucial. The detailed analysis of flood extent, flow velocity, and water surface

elevation under various return periods highlights the urgent need for infrastructure improvements and strategic flood mitigation measures. These findings not only inform flood management practices but also provide a foundation for future studies that aim to optimize canal capacity, develop sustainable flood prevention solutions, and assess the long-term impact of flooding on urban infrastructure and human safety. Furthermore, the integration of hydraulic modeling with GIS-based spatial analysis opens new avenues for more comprehensive, data-driven flood management. This approach allows for a deeper understanding of flood

hazards, offering a tool for urban planners, engineers, and decision-makers to identify at-risk areas and prioritize interventions. The methodology applied in this study can serve as a model for similar flood risk analyses in other regions facing comparable challenges. Future studies can build upon these results by exploring more refined simulation scenarios, incorporating climate change projections, and evaluating the effectiveness of potential flood control interventions to better prepare urban areas for future flood events.

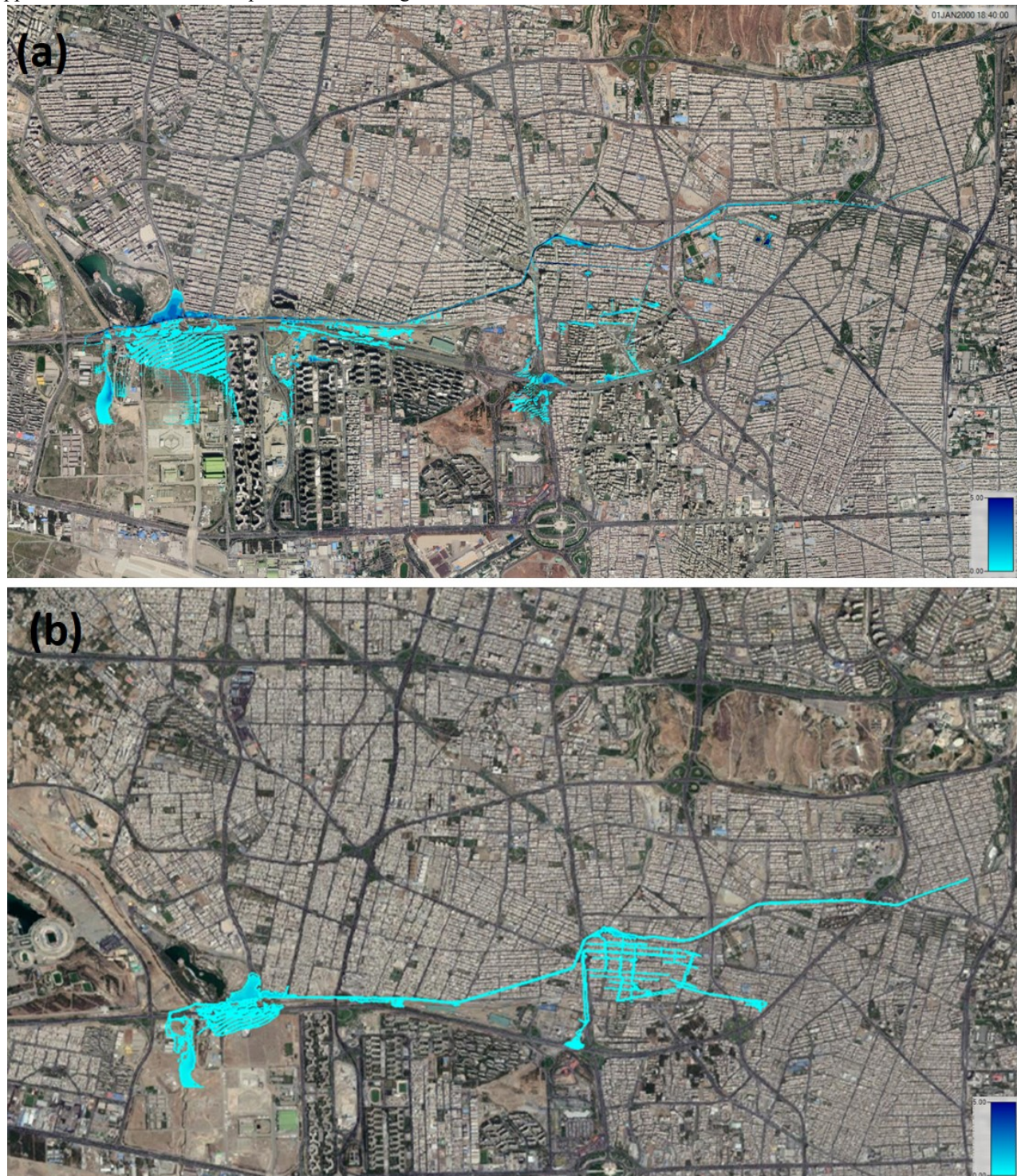


Fig. 8 Significant floodplain overflow risk: (a) 50-year, (b) 25-year

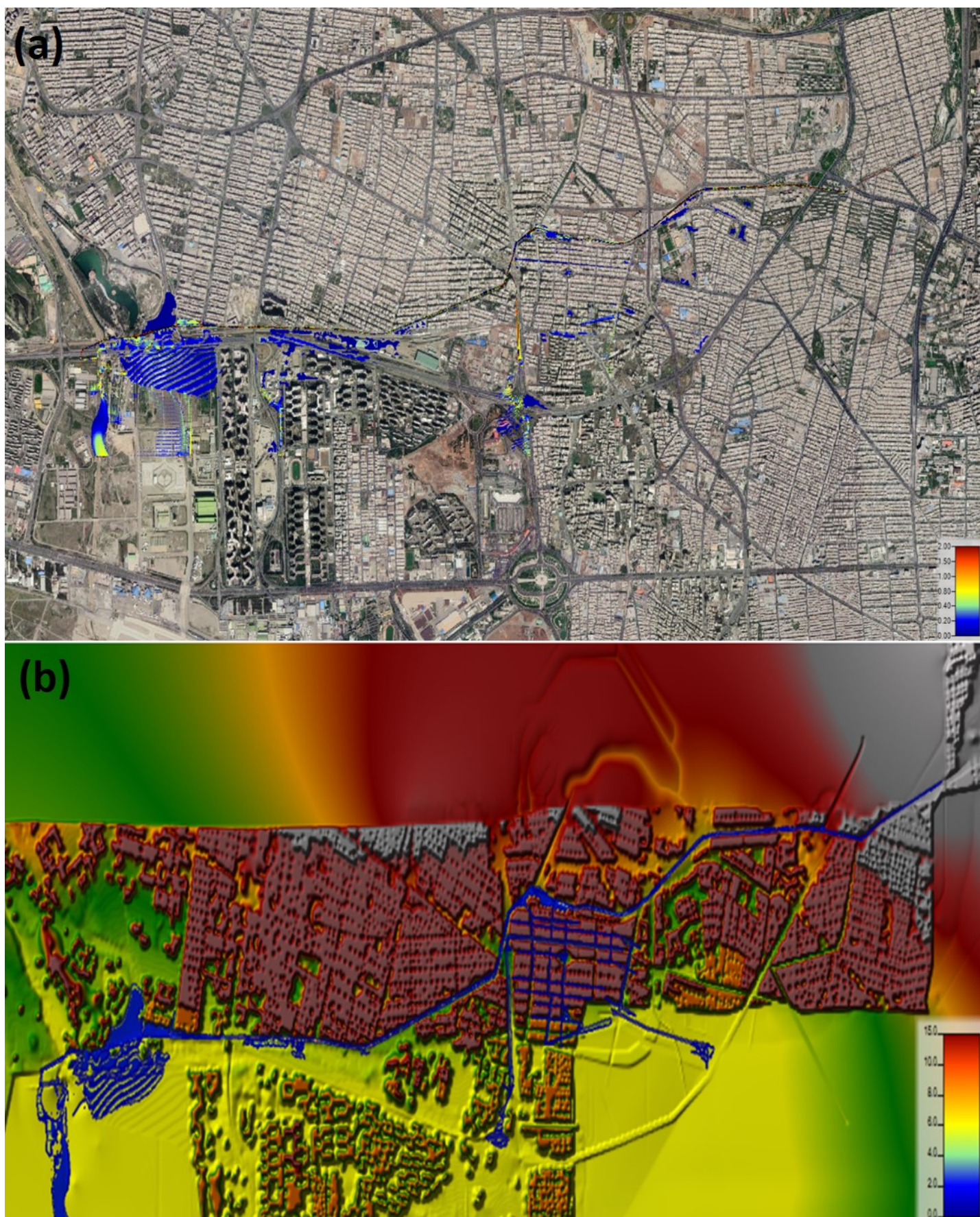


Fig. 9 Floodplain of velocity delineation based on return periods: (a) 50-year, (b) 25-year

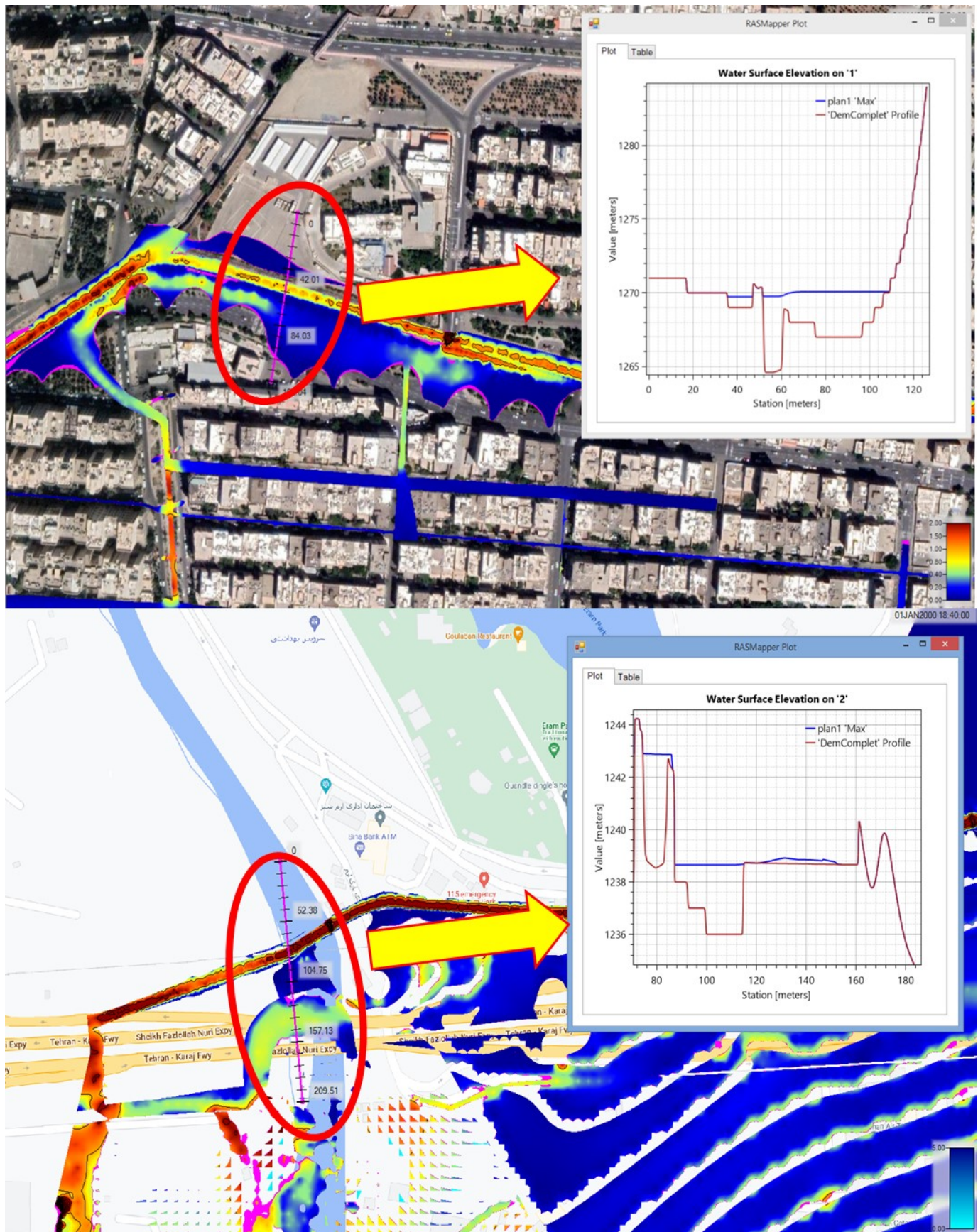


Fig. 10 Display of water surface elevation for the drawn cross-sections in the 2D simulation model

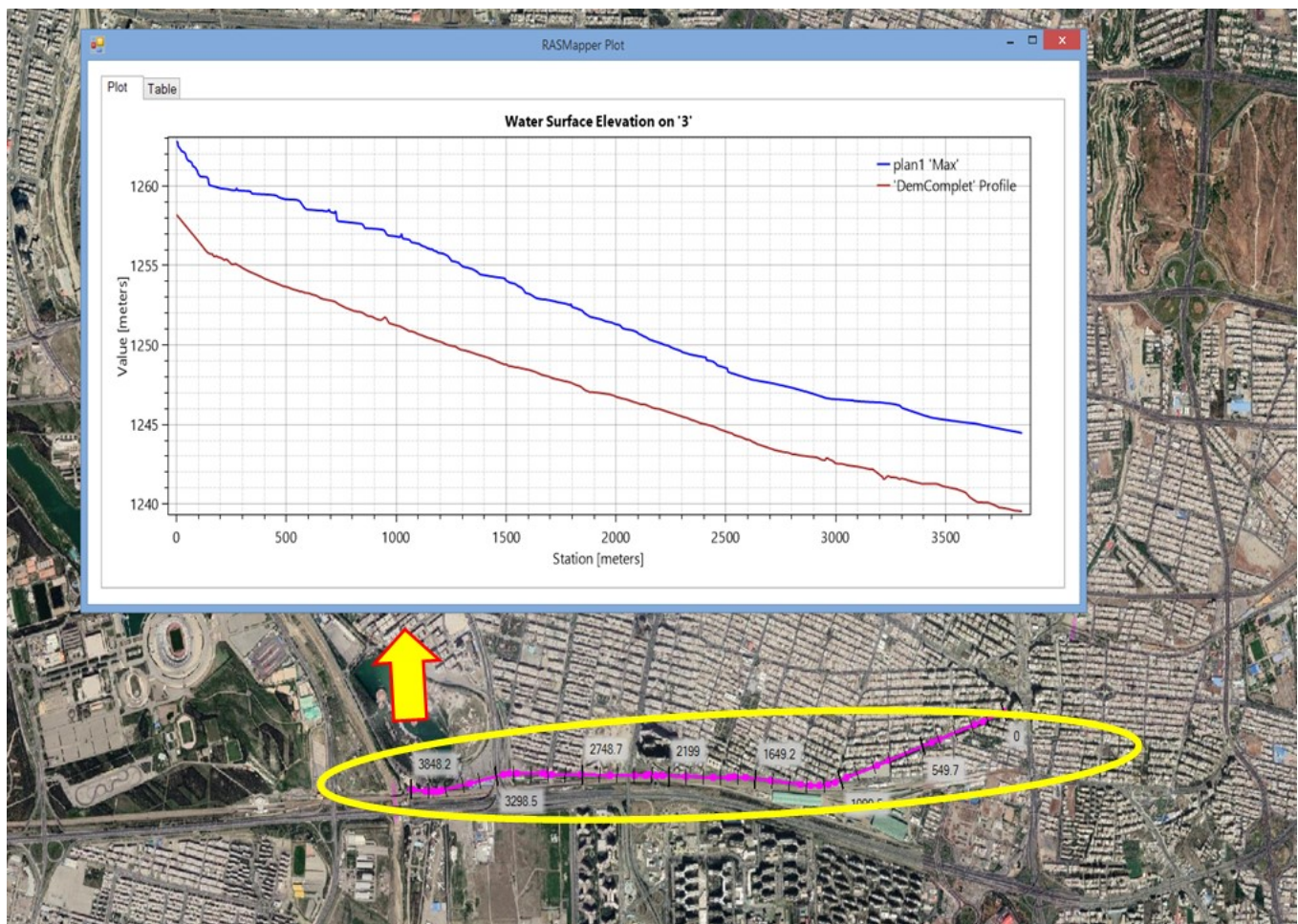


Fig. 11 Longitudinal profile drawn in the 2D HEC-RAS simulation model

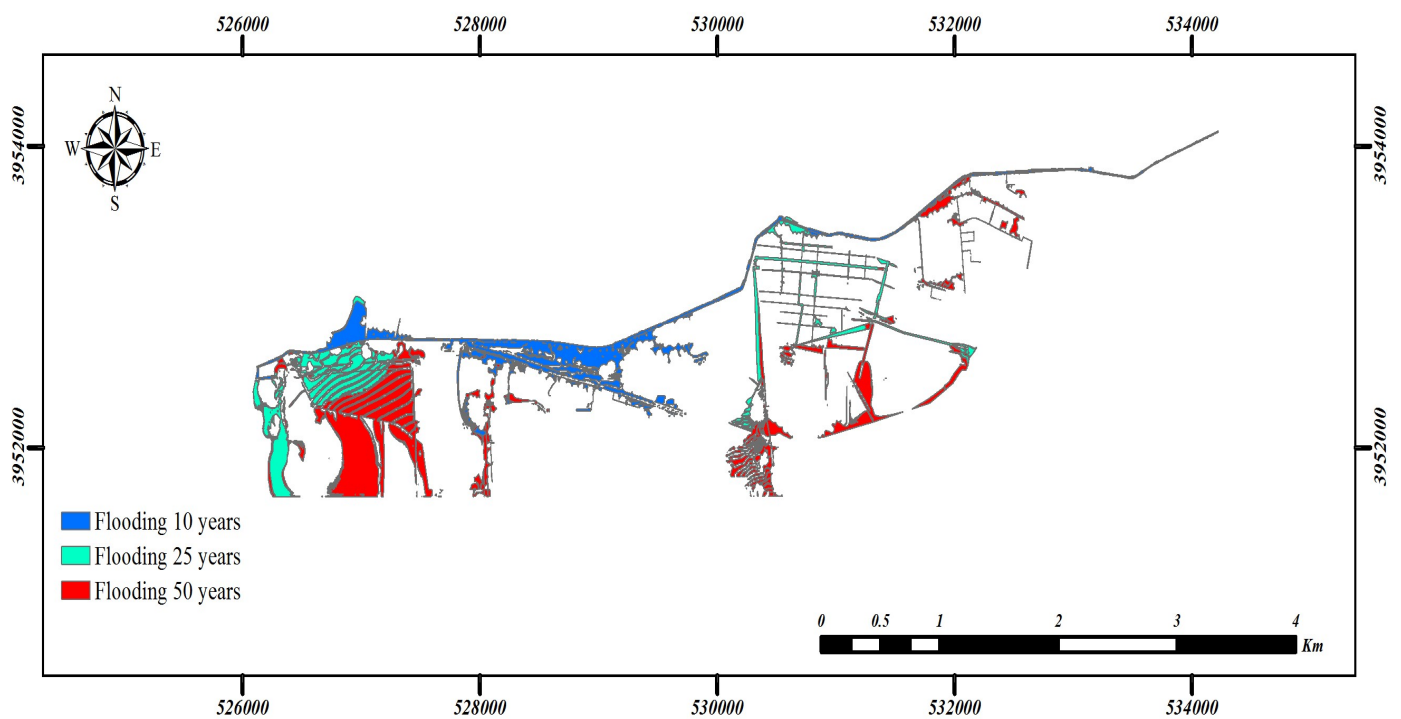


Fig. 12 Floodplain delineation for different return periods imported into the GIS software

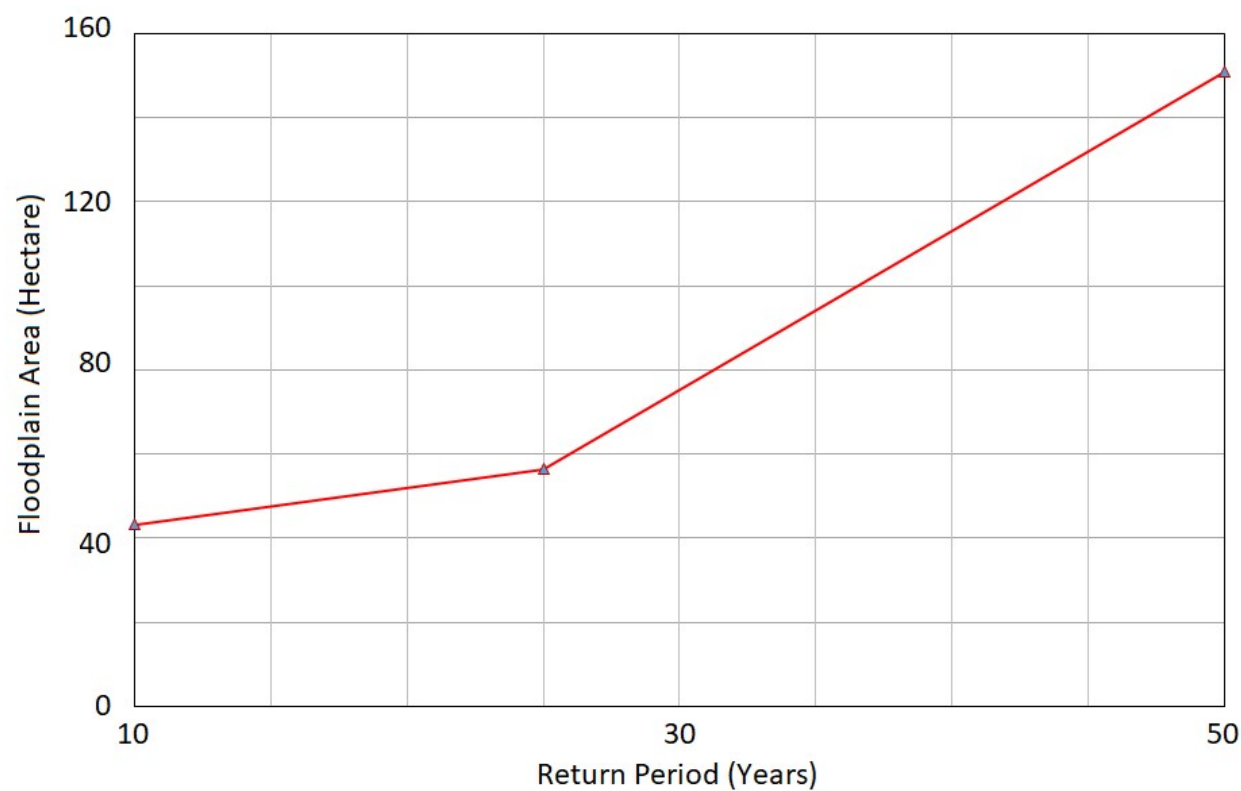


Fig. 13 Return period chart for floodplain area in Tehran

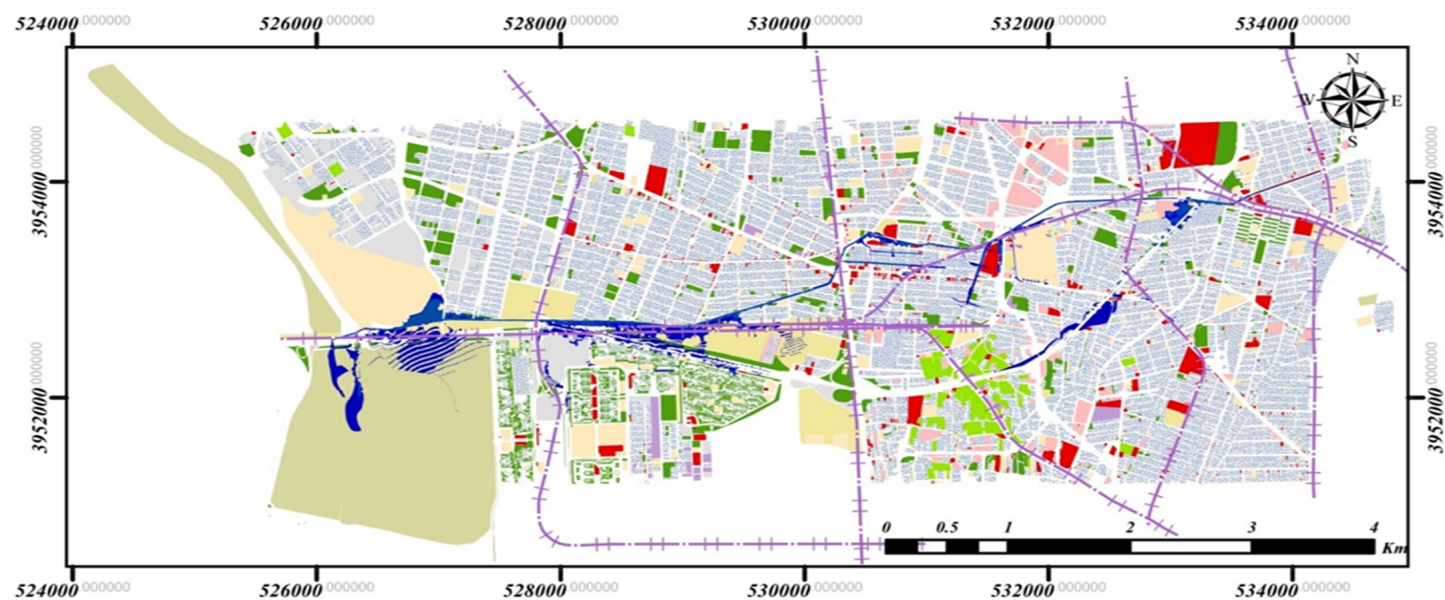


Fig. 14 Flooded areas in the 50-year floodplain delineation

Table 1 Floodplain area for different return periods

Return Period (Years)	Total Area (Hectares)	Total Perimeter (km)
10-Year	43.292	58.344
25-Year	56.427	104.146
50-Year	151.015	261.125

V. CONCLUSION

In this study, the combination of GIS software and the HEC-RAS hydraulic model was utilized to assess the floodplain and flood extents for various return periods within the study area. Additionally, the floodplain areas for each return period were calculated, and the land uses impacted by flooding at different return periods were identified. The analysis revealed that as the return period increases, a larger portion of the land is affected by flooding. Given the urban nature of the area, the expected damage from flooding is significant due to the low permeability of the region. It was observed that the canal under study lacks the capacity to accommodate floodwaters during high return periods, leading to flooding and subsequent damage to urban infrastructure in those scenarios. Based on the results and generated maps, high-risk zones within the canal's vicinity were identified and can be prioritized in urban planning efforts. This study highlights the necessity for both structural and non-structural measures aimed at mitigating flood damage, particularly in flood-prone areas. The findings underscore the need for enhanced flood management strategies, including increasing the canal's capacity, constructing flood detention basins, and implementing nature-based solutions to reduce flood volume and minimize damage to various land uses. The study's results provide crucial information for developing effective flood protection strategies and improving urban resilience against future flood events.

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DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request. No publicly archived dataset was generated.

ETHICS APPROVAL

This study did not involve human participants, personal data, or animal subjects. No specific ethical approval was required.

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AUTHORS' CONTRIBUTIONS

Mohammad Yazdani and Nader Azimi carried out the primary data analysis, contributed to data collection, preprocessing, and interpretation, and prepared the initial draft of the manuscript. Shabnam Sadegi and Zeynep Arslan provided conceptual guidance, critically revised the manuscript, managed the overall project, and approved the final version for publication. All authors reviewed and approved the final manuscript.

CONFLICT OF INTEREST

The authors have not disclosed any competing interests.

USE OF AI

AI tools were not used in data generation, analysis, results, or decision-making.

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