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Topographic Runoff Accumulation and Potential Waterlogging Mapping in Arid Suburban Plains Using TWI: A Case Study of Suluq and Jardina, Southern Benghazi, Libya

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ABSTRACT

This research investigates topographic runoff accumulation and potential waterlogging susceptibility across, low relief suburban plains of Suluq and Jardina in southern Benghazi, Libya. By integrating USGS Digital Elevation Models (DEM), D8 flow routing algorithms, and Topographic Wetness Index (TWI) mapping with Open Street Map infrastructure inventories, a practical geospatial framework was established to couple terrain morphology directly with urban risk evaluation. The empirical findings indicate that favourable macro topographic drainage conditions generally prevail, with the vast majority of the landscape situated within low TWI categories. Nevertheless, subtle micro topographic depressions generate critical localized pooling hazards. Specifically, the combined High and Very High runoff accumulation zones total area of 318.75 ha in Suluq (in the High and Very High class) and 70.61 ha in Jardina (in the High and Very High class). These severe tiers directly intersect a combined total of 120 vulnerable structures in western Suluq (91 in High and 29 in Very High) and 11 structural units in central western Jardina (7 in High and 4 in Very High). By explicitly isolating these topographic accumulation nodes, the applied methodology provides municipal engineers with empirical metrics to evaluate surface water pooling potential, noting that the index reflects terrain driven saturation

rather than hydrodynamic flood depth modeling.

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Keywords: : (TWI), Topographic runoff accumulation, Potential waterlogging, Arid suburban plains, Suluq, Jardina, Terrain saturation mapping.

Introduction

In arid and semiarid regions, high intensity convective storms trigger rapid, un-attenuated hydrological responses governed by surface crusting, sparse vegetation, and inherently low soil permeability. Over recent decades, this natural susceptibility has been severely intensified by uncoordinated suburban encroachment upon low-gradient desert fringes, where permeable soils are sealed beneath artificial concrete and asphalt, disrupting natural runoff redistribution.

In north-eastern Libya, the suburban and coastal plains extending south of Benghazi specifically the municipal sectors of Suluq and Jardina exhibit a deceptively subdued topography. While these flat expanses appear structurally secure during normal conditions, they function as expansive hydraulic collection zones during episodic meteorological extremes. Sheet runoff shed from regional highs migrates across flat pediments until impeded by unengineered roadway embankments and localized micro depressions, producing persistent surface water pooling that disrupts transportation networks, damages municipal infrastructure, and affects residential quarters long after precipitation ceases.

Consequently, municipal management has historically relied on reactive post event maintenance rather than predictive planning. While terrain driven geospatial modelling leveraging digital elevation models (DEMs) offers a viable alternative in ungauged basins, conventional regional flood studies often apply hydrotopographic indices passively without accounting for localized micro topography or coupling hazard zones directly with urban infrastructure.

This creates a distinct research gap, standard regional hydrological models fail to capture subtle micro topographic variations in low relief pediments, leading to distorted representations of overland flow concentration, while failing to provide asset level exposure metrics for actionable municipal planning.

To bridge this operational and methodological gap, this study presents a terrain driven geospatial diagnostic framework that integrates 30 m USGS SRTM Digital Elevation Models, deterministic D8 flow routing algorithms, and Topographic Wetness Index (TWI) mapping with OpenStreetMap (OSM) infrastructure inventories. The primary novel contribution of this research lies in coupling terrain derived surface saturation potential directly with asset level structural exposure in

a data scarce environment. Rather than attempting hydrodynamic flood depth modeling in the absence of hydrometeorological gauging, this research isolates localized topographic accumulation nodes, providing municipal engineers with empirical metrics to execute targeted, cost effective structural interventions in ungauged arid suburban plains.

Study Problem

Conventional hydrological modelling applied to semiarid, low relief environments such as the suburban plains of Suluq and Jardina faces a major limitation, standard digital elevation models smooth out subtle micro topographic undulations that dictate overland flow paths. Characterized by extensive flat expanses interspersed with localized depressions, these semi urbanized pediments lack defined continuous natural drainage channels. Consequently, sheet flow generated during high intensity storms converges rapidly toward local terminal sinks, exposing road networks and building footprints to persistent waterlogging. Geomorphologically, this pooling hazard is intensified by the strategic location of Suluq and Jardina at the terminal discharge outlets of regional wadi basins (such as Wadi Al Naggar and Wadi Bab) descending from the Al Jabal Al Akhdar highlands against the Al Rajma Escarpment. Applying a refined, cell size scaled TWI model bridges the gap between historical surface pooling anomalies and spatial engineering, providing the empirical baseline needed to design targeted municipal drainage interventions

Study Significance

The significance of this study lies in establishing a reproducible, data driven geospatial framework tailored for ungauged, data scarce suburban environments where hydrometeorological monitoring is lacking. By combining terrain derived moisture potential metrics with open source infrastructure vector data (OpenStreetMap), this research transitions regional hazard mapping into asset level exposure evaluation. The resulting dataset provides civil engineers and municipal planners in southern Benghazi with practical, site specific indicators to identify geometric convergence bottlenecks, optimize transverse culvert locations, and guide urban expansion away from micro-topographic terminal sinks.

Study Objectives

This study aims to achieve the following specific objectives:

- To extract and analyze terrain elevation variations and slope gradients within the flat suburban plains of Suluq and Jardina using available USGS SRTM digital elevation models and geospatial tools.

- To compute and refine the Topographic Wetness Index (TWI) to accurately capture localized surface saturation, convergent flow paths, and runoff accumulation patterns in low gradient arid plains.
- To integrate simulated runoff accumulation zones with OpenStreetMap (OSM) infrastructure databases to map urban exposure and identify vulnerable transportation corridors and building blocks.
- To quantify the spatial impact of runoff accumulation potential on regional assets, providing an actionable, data driven framework for municipal hazard mitigation and urban planning in data-scarce environments.

Study Area

The town of Suluq is geographically situated within the eastern coastal plain, positioned approximately 53 kilometers south of Benghazi city center, extends between longitudes 20° 12′ 40″ E , 20° 18′ 0″ E , and latitudes 31° 38′ 0″ N , 31° 44′ 40″ N (Figure.1). The urban perimeter of the town is documented to occupy a spatial area of approximately 6183ha, the urban fabric is partitioned into seven distinct residential quarters, which are designated as: Al Diplomasi, Al Zohour, Al Ayada, Al Nuaimi, Al Said, Al Hawaza, Al Markaz, and the Residuo Pastoral sector, thereby occupying a highly vulnerable position within the lower deltaic floodplains of the Wadi Bab basin. Historically, the town is recognized as the site harboring the shrine of the historic Libyan resistance leader, Omar Al Mukhtar. From an engineering and water resource perspective, Suluq is distinguished by hosting one of the largest strategic water reservoirs in Libya, known as the Omar Al Mukhtar reservoir [1].

The rural urban community of Jardina is geographically categorized as an administrative sub branch structurally linked to the Suluq municipality within the Benghazi district, extends between longitudes 20° 10′ 40″ E ,20° 12′ 40″E, and latitudes 31° 46′ 40″ N , 31° 49′ 20″ N. Geographically, the settlement is situated approximately 42Km southwest of Benghazi city center and 14 kilometers northwest of Suluq town, thereby occupying a highly vulnerable position within the lower deltaic floodplains of the Wadi Al Naggar basin. The localized built up area is documented to cover a spatial extent of approximately 1284ha, accommodating an expanding residential layout that has been characterized in recent years by unregulated horizontal expansion. Administratively and spatially, the local residential fabric is divided into several informal quarters, including the residential core and adjacent agricultural residential fringes (Figure2).

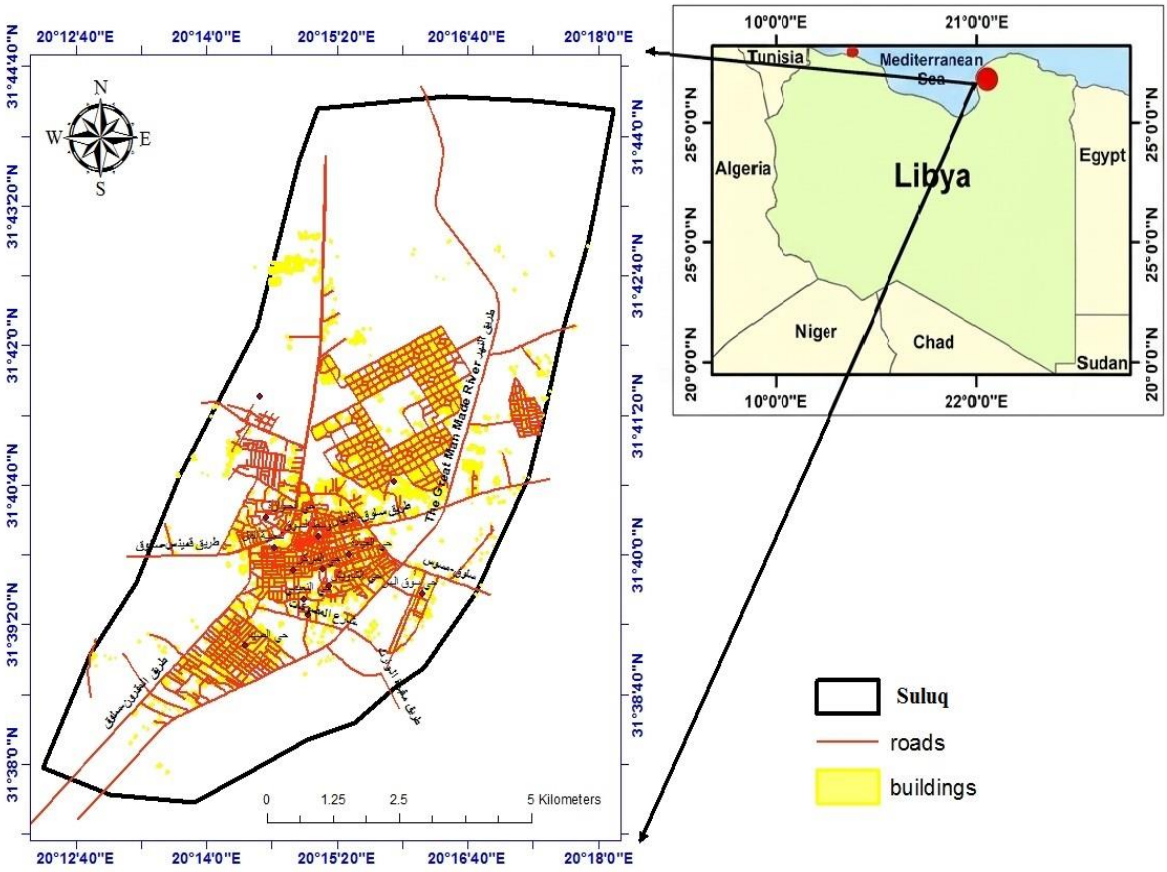


Figure1: Location map of Suluq city.

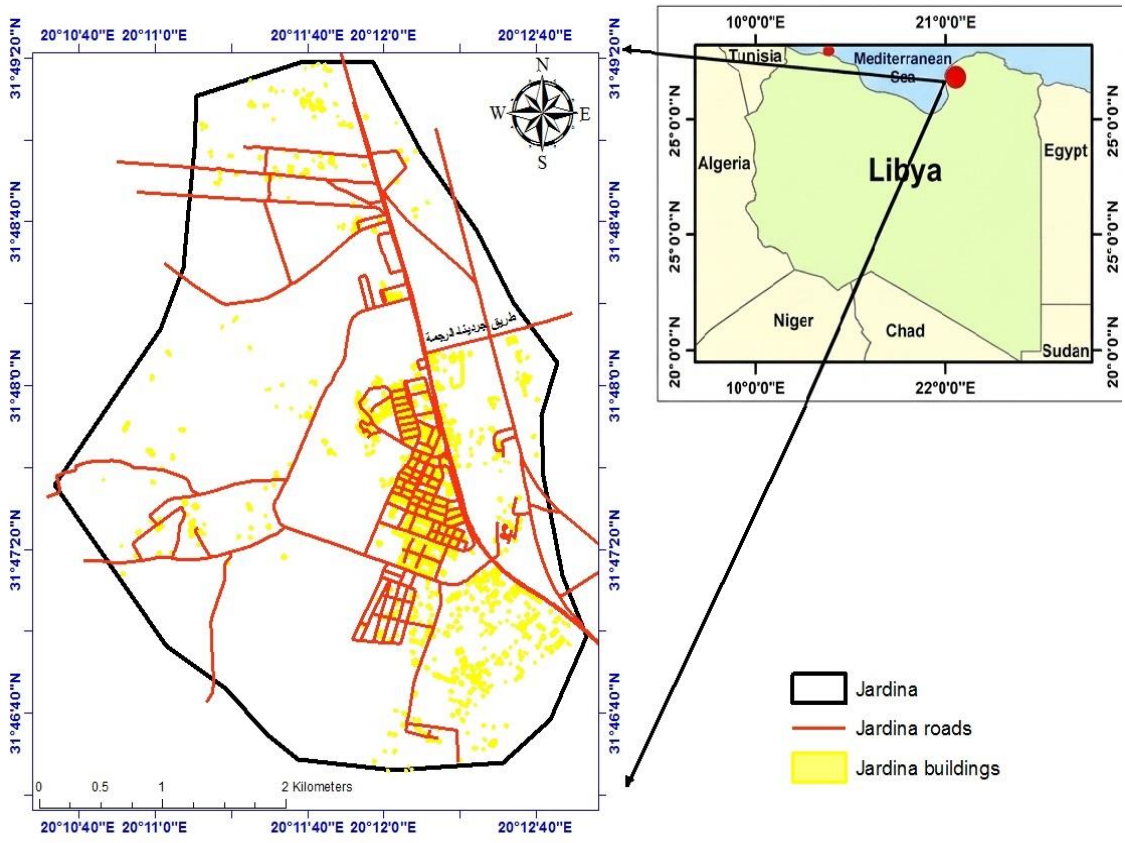


Figure2: Location map of Jardina city.

Previous Studies

The Topographic Wetness Index (TWI) has gained widespread attention in numerous recent studies as an effective geomorphometric and Geographic Information System (GIS) tool for assessing and identifying hazard areas and flood susceptibility degrees. In this context, a study by Latue & Rakuasa (2023)[2] utilized digital elevation model data (DEMNAS) to identify flood-prone areas in Fena Leisela District, Buru Regency, Indonesia, categorizing runoff accumulation potential into low potential covering 92196.09 ha (63.04%), medium potential covering 45769.48 ha (31.29%), and high potential covering 936.12 ha (5.67%), providing vital benchmarks for regional disaster mitigation and management. Additionally, Fitra *et al*. (2024)[3], conducted an assessment of flood vulnerability in Pantai Labu Baru Village, Deli Serdang, North Sumatra, using the Topographic Wetness Index (TWI) derived from Digital Elevation Models (DEM) and Digital Terrain Models (DTM), with findings demonstrating TWI values ranging from -8.3898 to 10.8494, confirming that flat terrain and lower slope angles strongly correlate with higher water accumulation and increased flood susceptibility, thereby serving as an efficient data-driven tool for early warning systems. Furthermore, Adnyana & Wiguna (2025) [4], modeled flood hazards in the Yeh Ho Watershed in Bali, Indonesia, using the TWI methodology normalized on a 0 to-1 interval, categorizing spatial distribution into low (9630.26 ha , 58.3%), medium (4802.66 ha, 29.1%), and high hazard classes (2083.10 ha , 12.6%), identifying Penebel and Selemadeg Timur Districts as priority zones requiring urgent flood mitigation due to flat topography and heavy seasonal rainfall. Moreover, Malik *et al*. (2026)[5], evaluated the Yola Sub-Basin within Nigeria's Upper Benue Trough using high-resolution Shuttle Radar Topography Mission DEM and the D8 algorithm, classifying TWI values ranging from 2.5 in steep uplands to over 18 in low lying floodplains into five susceptibility levels, demonstrating a robust validation with a high matching coefficient (Kappa = 0.85) against historical flood events and established agricultural wetlands (Fadamas. Similarly, the study by Kotaridis (2026)[6], focused on the built environment in the Kassandra region of Greece (with a focus on road infrastructure), where Sentinel-2A satellite imagery and ALOS DEM digital elevation models were used to calculate the Topographic Wetness Index (TWI) to identify areas prone to water accumulation, showing that values exceeding 9 were classified as risk-sensitive, revealing that about 19.5% of the total built environment and 21% of the road network lie within areas susceptible to water accumulation. Building upon this, the study by Aqneber (2026)[7], evaluates and identifies flash flood runoff accumulation areas in the

AlKhums region of Libya using the Topographic Wetness Index (TWI) and Geographic Information Systems (GIS), aiming to analyze the hydrological characteristics of wadis and generate accurate spatial maps based on a Digital Elevation Model (DEM) to pinpoint the zones most vulnerable to flooding, with results demonstrating that high concentrations of water accumulation are heavily concentrated along the coastal zone and adjacent to major and minor roads, causing traffic disruptions and damage to infrastructure, and recommending the leveraging of TWI as an essential tool in urban planning and stormwater management to support decision makers. Finally, the study by Uca *et al.* (2022)[8], addressed morphometric analysis and the Topographic Wetness Index (TWI) to determine flood runoff accumulation potential maps in the Mata Allo basin (South Sulawesi, Indonesia), demonstrating that high TWI areas are concentrated in intermontane plains and river floodplains, reflecting high susceptibility to floods in the event of excessive water flows.

Study Methodology

7.1 Materials and Datasets

To achieve the study's objectives in the data scarce environments of Suluq and Jardina, the methodology relied on terrain driven geospatial diagnostics rather than traditional hydrometeorological data. The following primary datasets were utilized:

- Four contiguous 1arcsecond (approximately 30m spatial resolution) raster tiles from the USGS Shuttle Radar Topography Mission (SRTM v3.0 / NASADEM) dataset covering the Suluq and Jardina study areas southwest of Benghazi, as well as the Al Rajma Escarpment and Al Jabal Al Akhdar headwaters, were acquired from the United States Geological Survey (USGS) EarthExplorer repository. Rather than assuming an ultra-high resolution surface, this standard 30 m grid was selected to optimize local topographic representation and capture regional macro gradients and prominent micro topographic drainage corridors within the constraints of freely available spatial data in an ungauged basin. All continuous spatial datasets and derived raster layers were projected under the Universal Transverse Mercator (UTM) coordinate system (Zone 34N), referenced to Libyan Geodetic Datum 2006 (LGD2006)[9] .
- Spatial vector data for the Suluq and Jardina areas southwest of Benghazi, extracted from Open Street Map (OSM) a collaborative digital map database of the world maintained and funded by the Open Street Map Foundation[10]. The acquired satellite imagery and spatial data were

processed using ArcGIS 10.8 to generate detailed shapefiles for roads, buildings, and public facilities. All spatial datasets were projected under the UTM coordinate system, referenced to the Libyan Geodetic Datum 2006 (Zone 34N).

- Geographic Information Systems (GIS) software (ArcGIS 10.8) was employed for all spatial processing, raster manipulation, and overlay analyses. GIS was chosen due to its robust capability to visualize flood prone areas and calculate spatial susceptibility accurately.

7.2 Data Preprocessing

Prior to hydrological modeling, the raw DEM data underwent spatial preprocessing within the GIS environment. The DEM was processed to generate fundamental topographic raster layers, specifically elevation and slope. Elevation data was classified to distinguish between the higher gradient headwaters and the flat coastal plains of the study area. Subsequently, the slope angle, which indicates the degree of inclination to the horizontal plane, was derived in degrees. Slope is a critical factor because it significantly impacts water flow direction and velocity; flat terrains slow water movement, thereby causing accumulation and increasing flood susceptibility. Furthermore, flow direction and flow accumulation grids were generated to determine the specific drainage pathways across the Suluq and Jardina suburban sectors[11].

7.3 Topographic Wetness Index (TWI) Computation

The Topographic Wetness Index (TWI) was selected as the primary analytical method to predict regions that experience saturated land surfaces and potential water carrying zones leading to overland flow. TWI measures the topographical influence on runoff generation and flow accumulation at any given location, describing the tendency of water to accumulate based on gravity. Higher TWI values indicate a higher level of moisture and a greater tendency for water accumulation (very flat slopes), whereas lower values indicate drier areas (steep slopes) [7].

By processing a Digital Elevation Model (DEM), spatial algorithms are applied to simulate the gravitational flow of water across the landscape. Sinks or artificial depressions within the DEM are initially filled to ensure a continuous flow path. Subsequently, the direction of flow for every pixel is calculated, which allows for the determination of flow accumulation the total number of upstream cells draining into a specific downward cell. When combined with the local slope gradient, the TWI is mathematically derived. The execution of this research is dependent upon the utilization of specialized spatial analysis tools and

mathematical algorithms within a GIS environment. The primary analytical engine employed is the Raster Calculator (Map Algebra), which is used to process the terrain data through a series of sequential mathematical transformations[12]:

1. Slope Conversion: The terrain slope, initially extracted in degrees, must be converted into radians to facilitate trigonometric calculations.
   $$Slope(rad) = Slope(deg.) \times \left(\frac{1.570796}{90}\right) \quad (1)$$
2. Slope Tangent and Zero-Value Handling: The tangent of the slope is calculated. To prevent mathematical errors associated with division by zero in completely flat cells, a conditional statement is applied to assign a minimal fractional value to zero-slopes.
   $$Tan\big(Slope(rad)\big) = con(Slope(deg.) > 0, Tan\big(Slope(rad)\big), 0.001) \quad (2)$$
3. Scaled Flow Accumulation(SFA): The raw flow accumulation raster (FA) is adjusted and scaled according to the spatial resolution (Cell Size) of the DEM to represent the specific catchment area per unit contour length.
   $$SFA = (FA + 1) \times (DEM\ Cell\ size) \quad (3)$$
4. Final TWI Calculation: The index is computed as the natural logarithm of the ratio between the scaled flow accumulation and the local slope tangent.
   $$TWI = \mathrm{Ln}\left(\frac{\mathrm{SFA}}{\mathrm{Tan(Slope(rad))}}\right) \quad (4)$$

   where:

   $Slope(rad)$= Terrain slope angle expressed in radians.

   $Slope(deg.)$ = Terrain slope angle derived directly from the DEM in degrees.

   $Tan\big(Slope(rad)\big)$= Adjusted local slope tangent representing ground inclination gradient (dimensionless).

   Con= Conditional Map Algebra operator in ArcGIS 10.8.

   SFA = Scaled specific catchment area per unit contour length .

   FA = Raw accumulation raster value (total number of upstream contributing cells).

   DEM Cell Size = Spatial resolution of the SRTM DEM grid.

   TWI = Topographic Wetness Index (dimensionless morphometric index).

It is crucial to clarify that the Topographic Wetness Index (TWI) is strictly a morphometric indicator designed to quantify potential surface moisture accumulation and overland flow routing based solely on local slope gradients and upslope contributing areas. The model does not incorporate dynamic meteorological variables such as rainfall intensity, storm duration, or infiltration capacity nor does it simulate hydraulic conveyance or actual runoff accumulation depth. Consequently, the derived classes represent relative topographic

susceptibility to water pooling and runoff accumulation rather than direct flood hazard or absolute runoff accumulation potential mapping.

The normalized TWI raster was reclassified into distinct flood potential classes (e.g., Low, Moderate, High, and Very High) using the Reclassify tool in ArcGIS 10.8. This categorization was implemented because varying index thresholds correspond directly to localized surface saturation and runoff accumulation severity.

Finally, to assess urban susceptibility, a spatial overlay analysis was executed. The classified TWI flood accumulation zones were intersected with the OSM infrastructure layers. This integration quantified the spatial impact of runoff accumulation potential on regional assets, allowing for the direct identification of specific roads, reservoirs, and residential quarters in Suluq and Jardina that are situated within high risk accumulation pathways.

Runoff Accumulation Potential Mapping Using TWI for Suluq and Jardina, cities

The generation of runoff accumulation potential maps for Suluq and Jardina follows a systematic, hydro topographic modeling framework executed through spatial processing and map algebra within the ArcGIS10.8 software environment. The detailed workflow steps are illustrated below(Figure3):

- Four contiguous USGS Digital Elevation Model (DEM) rasters covering the southern Benghazi periphery were acquired. To generate a seamless elevation surface, the rasters were merged using the Mosaic tool .The resulting raster was clipped to the precise study boundaries of Suluq and Jardina using the Clip tool .To eliminate artificial terrain depressions and guarantee uninterrupted overland flow routing, the raster was hydrologically corrected using the Spatial Analyst Fill tool in ArcGIS 10.8. A critical methodological challenge in flat arid pediments like Suluq and Jardina is the handling of surface depressions. While standard hydrological preprocessing applies the ArcGIS Spatial Analyst Fill tool to remove all internal sinks and guarantee continuous flow routing, indiscriminate depression filling can inadvertently eliminate real, hydrologically significant depressions which act as primary natural terminal pooling nodes where surface water stagnates while correcting only for spurious elevation anomalies (Artifact Sinks) inherent to interpolation errors. In this study, to balance flow continuity with the preservation of micro topographic water holding structures, the Fill algorithm was executed either with a controlled vertical z-limit threshold or evaluated against local morphological

boundaries to prevent the artificial conversion of natural terminal sumps into continuous drainage channels. The distinction is vital: artifact sinks are artificial pits caused by radar shadow or coarse grid averaging that obstruct realistic overland flow routing, whereas real depressions in Suluq and Jardina constitute the actual physical locations of localized waterlogging and accumulation shown in the high TWI tiers. Consequently, the resulting accumulation and TWI grids successfully isolate these natural retention basins rather than purely hypothetical drainage lines.

- Using the hydro conditioned DEM, primary spatial layers were derived via the Spatial Analyst toolbox in ArcGIS 10.8 :Flow Direction was calculated (using the D8 algorithm) to determine the deterministic path of surface runoff across adjacent cells .Flow Accumulation was computed to measure the cumulative upstream catchment area contributing to each individual cell .Slope Angle was derived in degrees using the Slope tool to represent local ground inclination. For the regional macro scale scope of this study, D8 was selected because it preserves channel network continuity, prevents artificial flow dilution across low gradient boundaries, and maintains standard compatibility with the deterministic Map Algebra pipeline for TWI calculation in ArcGIS 10.8. Nevertheless, integrating MFD algorithms combined with higher resolution topographic data (e.g., LiDAR or drone derived DEMs) represents a promising direction for future micro topographic modeling to refine non channelized sheet flow dispersion.
- To execute the Topographic Wetness Index (TWI) model without division by zero errors in flat sub-urban terrain, Map Algebra expressions were processed in the ArcGIS 10.8 Raster Calculator :Slope angles were converted from degrees to radians .A conditional function(con) was applied in ArcGIS 10.8 to assign a minimum threshold of 0.001 to perfectly horizontal cells. Flow accumulation was scaled by cell spatial resolution and incremented by 1 to include localized cell area .The log transformed ratio of contributing catchment area to local slope tangent was derived using the natural logarithm (Ln) operator in ArcGIS 10.8 :to calculate the TWI .
- Using the Reclassify tool in ArcGIS 10.8, the continuous TWI surface was divided into five discrete runoff accumulation potential susceptibility classes :Very Low ،Low ،Moderate ،High ،and Very High .High TWI values correspond to low lying, flat zones with extensive upstream contributing areas, indicating high susceptibility to runoff accumulation and surface water pooling.

- Vector shape files representing built up areas, residential buildings, and transport networks were retrieved from Open Street Map (OSM) and integrated into ArcGIS 10.8. A spatial overlay analysis (intersection/spatial join) was conducted between the OSM infrastructure layers and the TWI susceptibility classes. This enabled the explicit spatial identification and quantification of critical urban assets, roads, and residential zones situated directly within high-risk runoff accumulation corridors.

All aforementioned findings and spatial runoff accumulation potential susceptibility classifications (DEM, Flow Direction, Flow Accumulation, Slope, Slope Conversion, Tangent Slope, Scaled Flow Accumulation, resulting Topographic Wetness Index (TWI), and TWI classification) are comprehensively illustrated in Figure 4 for the Suluq municipality and Figure 5 for the Jardina municipality.

The final spatial integration of the Topographic Wetness Index (TWI) runoff accumulation potential susceptibility classes with urban infrastructure and building footprints is comprehensively presented in Figure 6 for the Suluq municipality and Figure 7 for the Jardina municipality. These spatial overlays explicitly isolate the high and very high risk runoff accumulation potential zones, mapping their precise intersections with local building footprints, residential quarters, and road networks to pinpoint asset-level vulnerabilities across both study areas.

The quantitative distribution of the Topographic Wetness Index (TWI) runoff accumulation potential classes and their corresponding structural exposures are comprehensively summarized in Table1 for the Suluq municipality and Table2 for the Jardina municipality. The numerical data reveal that the vast majority of the terrain in both study sectors falls within the very low and low runoff accumulation potential classes, highlighting a generally favorable regional drainage regime. These numerical metrics validate that despite high overall drainage efficiency, localized micro topographic sinks present critical vulnerabilities demanding targeted municipal intervention.

The continuous output values of the Topographic Wetness Index (TWI) were reclassified into five discrete accumulation potential classes (Very Low, Low, Moderate, High, and Very High) utilizing the Jenks Natural Breaks Optimization algorithm in ArcGIS 10.8. The Natural Breaks method was selected because it is an intrinsically data driven statistical technique that identifies natural groupings and inherent variance discontinuities within the dataset. It maximizes homeogeneity within each class while maximizing differences between class boundaries. The

variations in absolute class thresholds between Suluq (e.g., -9.3, -6.3, -3.0, 0.37, 3.7, 9.3) and Jardina (e.g., -10.0, -6.5, -3.3, -0.24, 3.7, 13.0) are directly attributable to the distinct statistical distributions, sample sizes, and micro topographic range of each individual catchment. Because the objective of this study is to map relative local topographic accumulation susceptibility within each administrative basin rather than perform a direct pixel to pixel cross basin comparison, localized Jenks natural breaks provide a far more accurate representation of intra-basin micro-topographic variability than arbitrary or globally fixed class intervals.

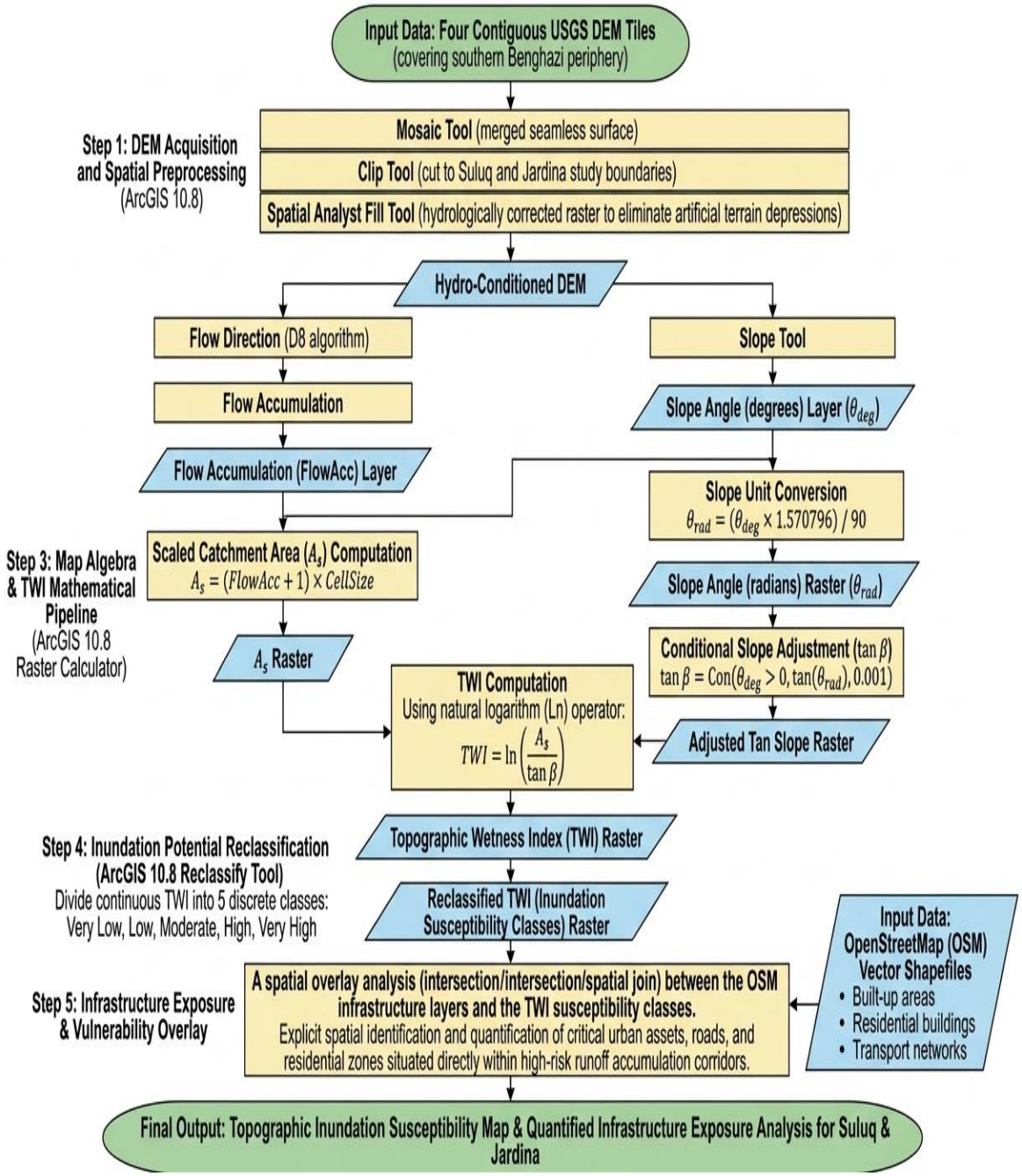


Figure 3: Conceptual framework for identifying potential runoff accumulation zones using TWI.

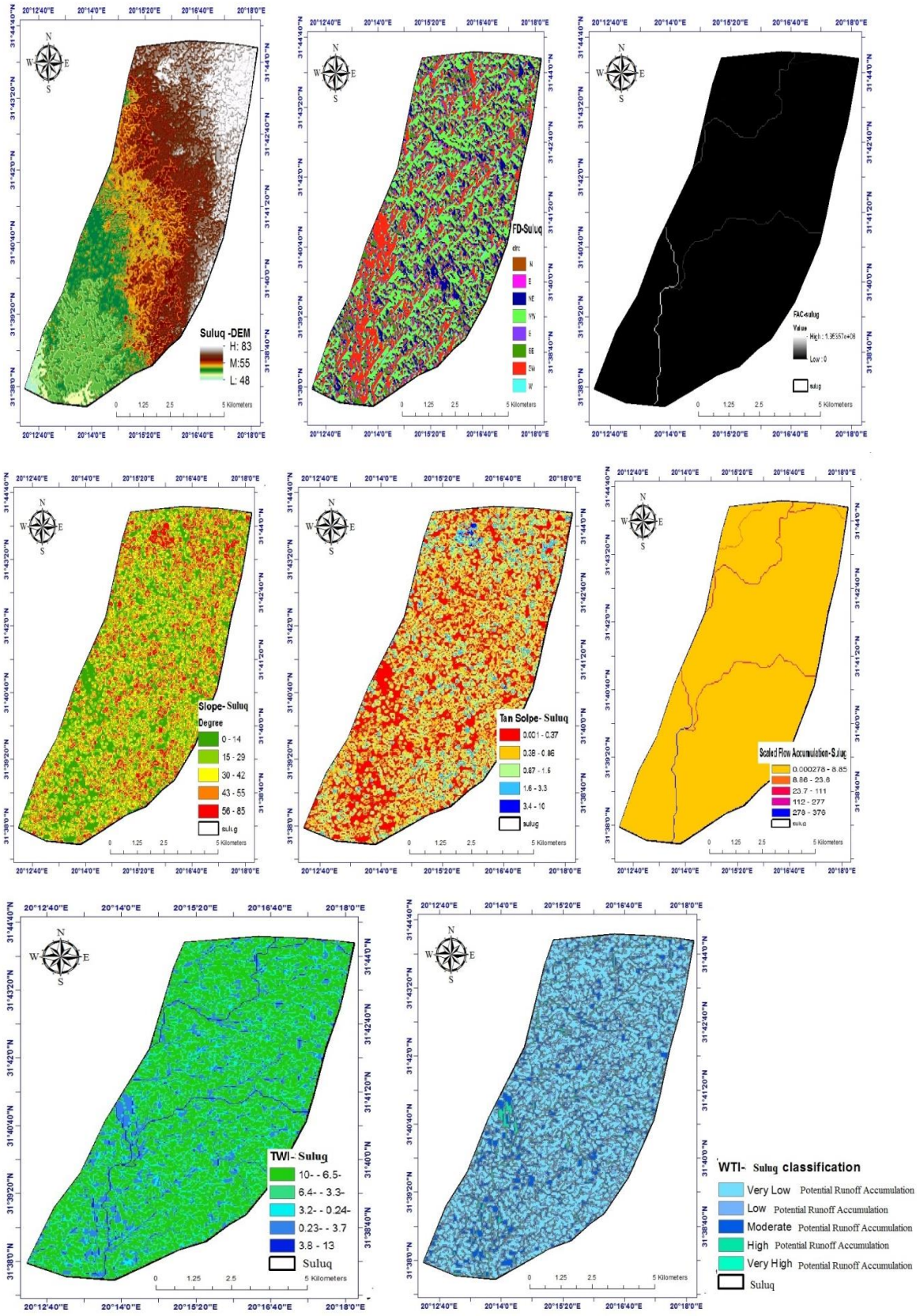


Figure.4: Sequential geospatial derivation of Topographic Wetness Index TWI (DEM, Flow Direction, Flow Accumulation, Slope, Slope Conversion, Tangent Slope, Scaled Flow Accumulation, resulting Topographic Wetness Index (TWI), and TWI classification) for the Suluq municipality.

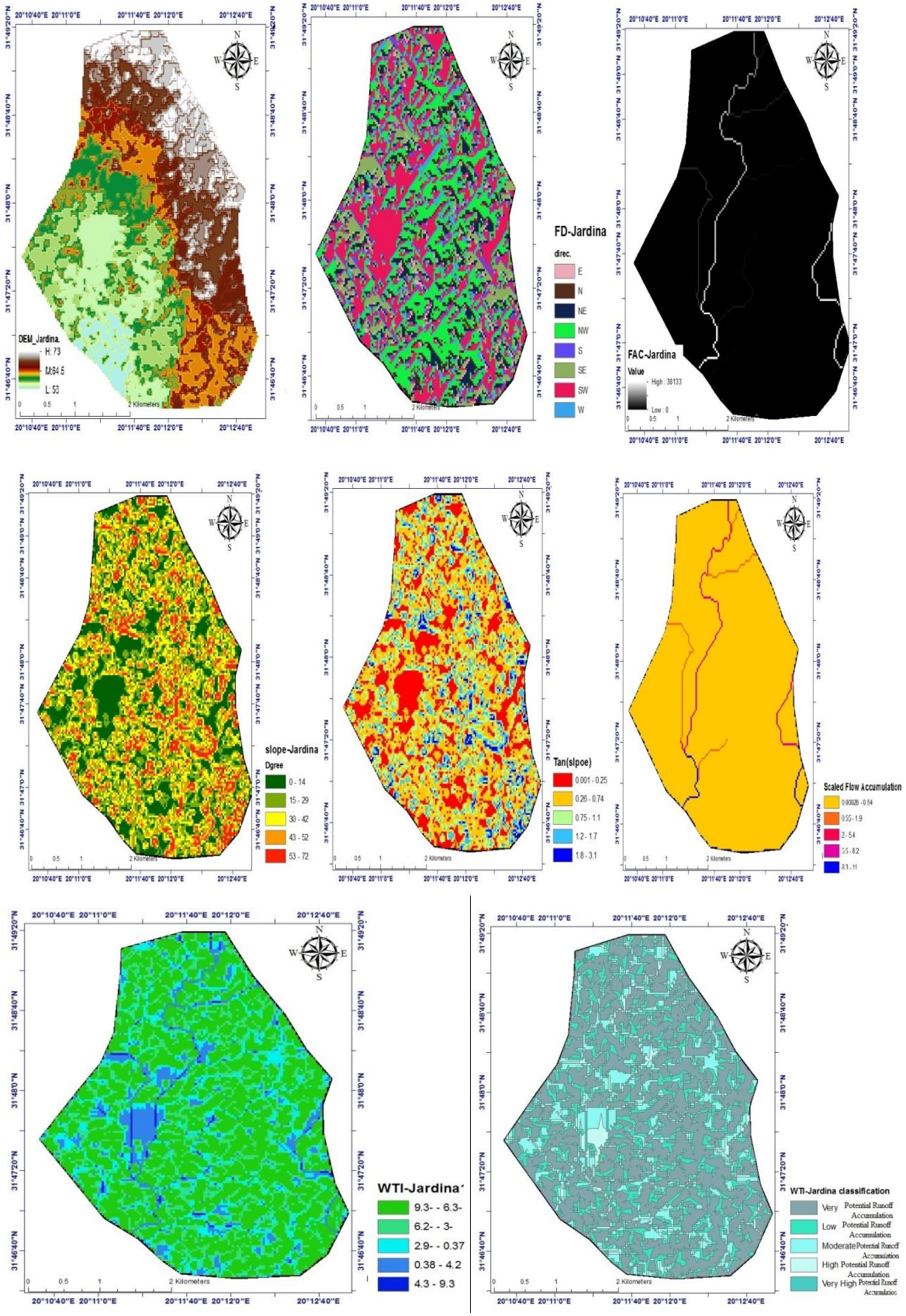


Figure5:. Sequential geospatial derivation of Topographic Wetness Index TWI (DEM, Flow Direction, Flow Accumulation, Slope, Slope Conversion, Tangent Slope, Scaled Flow Accumulation, resulting Topographic Wetness Index (TWI), and TWI classification) for the Jardina municipality.

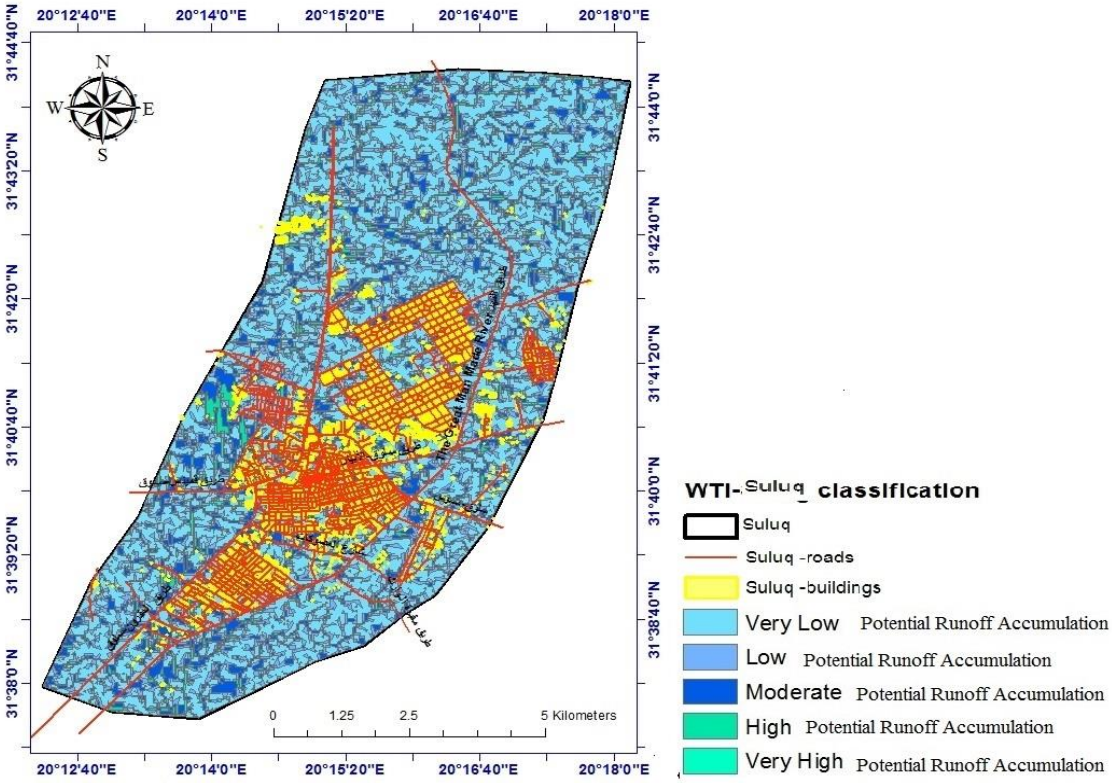


Figure **6:** Spatial overlay of Topographic Wetness Index (TWI) runoff accumulation potential classes with urban infrastructure and building footprints in the Suluq municipality.

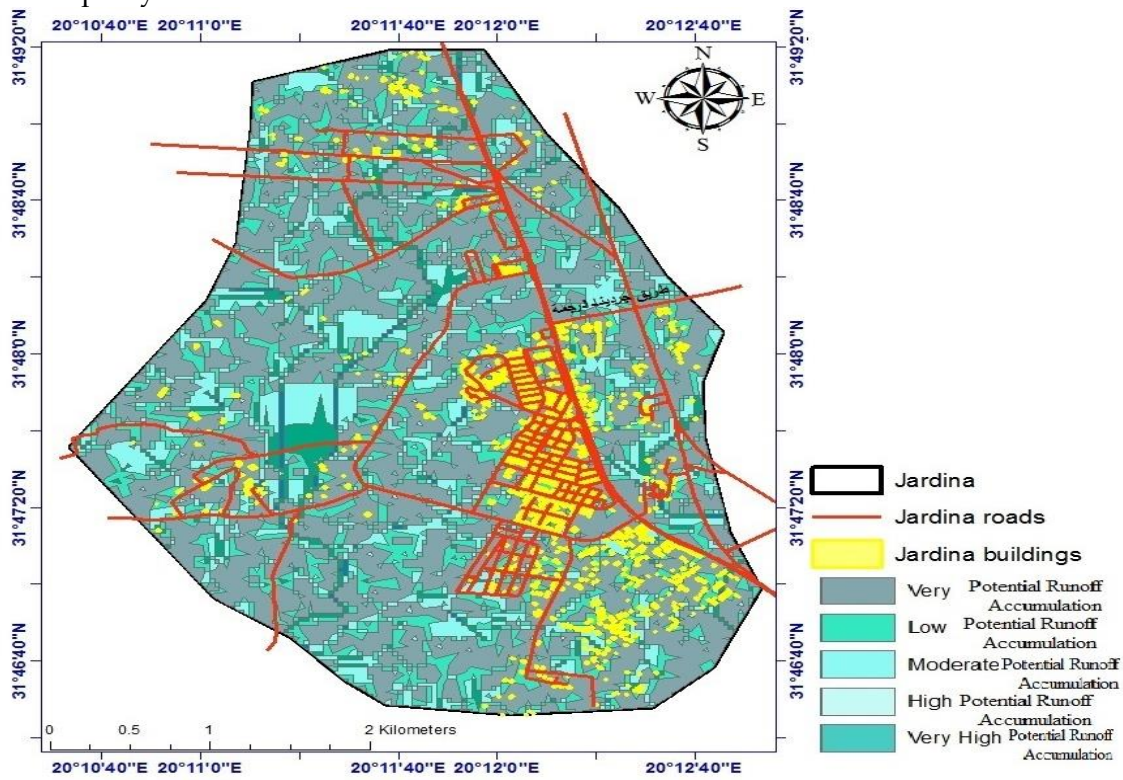


Figure**7:** Spatial overlay of Topographic Wetness Index (TWI) runoff accumulation potential classes with urban infrastructure and building footprints in the Jardina municipality.

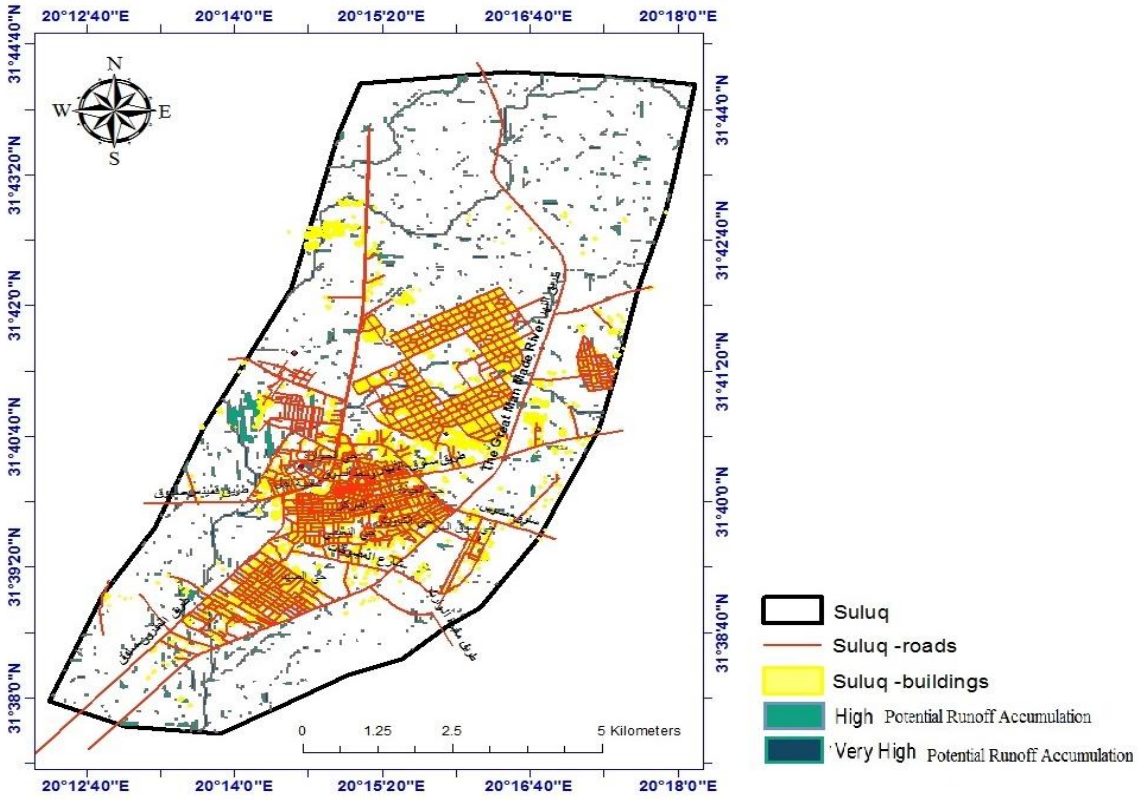


Figure**8:** Spatial isolation of High and Very High Topographic Wetness Index (TWI) runoff accumulation potential classes and their intersection with urban infrastructure and road networks in the Suluq municipality.

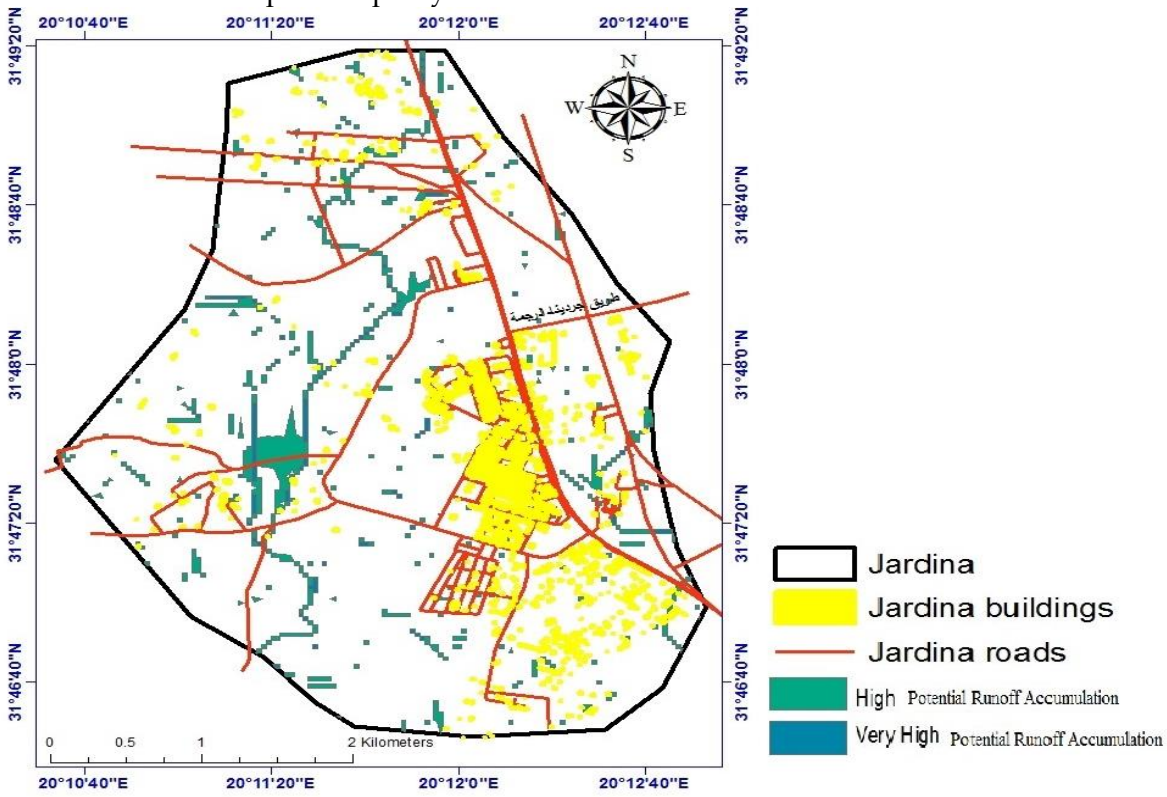


Figure**9:** Spatial isolation of High and Very High Topographic Wetness Index (TWI) runoff accumulation potential classes and their intersection with urban infrastructure and road networks in the Jardina municipality.

Table 1. Spatial Extent Of Topographic Wetness Index (TWI) Runoff Accumulation Potential Classes and Urban Infrastructure Exposure In Suluq.

TWI	class	Area ha	Area %	Number of building
-9.3 - -6.3	Very Low Accumulation Potential	3456.966	55.90%	5094
-6.2 - -3.0	Low Accumulation Potential	1409.953	22.80%	1426
-2.9 - 0.37	Moderate Accumulation Potential	996.9022	16.12%	637
0.38 – 3.7	High Accumulation Potential	228.7773	3.70%	91
3.8 – 9.3	Very High Accumulation Potential	89.97356	1.46%	29

Table 2. Spatial Extent of Topographic Wetness Index (TWI) Runoff Accumulation Potential Classes and Urban Infrastructure Exposure in Jardina.

TWI	class	Area ha	Area %	Number of building
-10 - -6.5	Very Low Accumulation Potential	722.317	56.24%	885
-6.4 - -3.3	Low Accumulation Potential	293.3801	22.84%	167
-3.2 - -0.24	Moderate Accumulation Potential	198.0411	15.42%	56
-0.23 – 3.7	High Accumulation Potential	59.49307	4.63%	7
3.8 - 13	Very High Accumulation Potential	11.1151	0.87%	4



Figure**10:** Field documentation of surface water pooling and infrastructure exposure across vulnerable residential quarters (Hay Al-Said, Hay Al-Jawhara, and Hay Al-Hawaza) and key transportation corridors in Suluq.

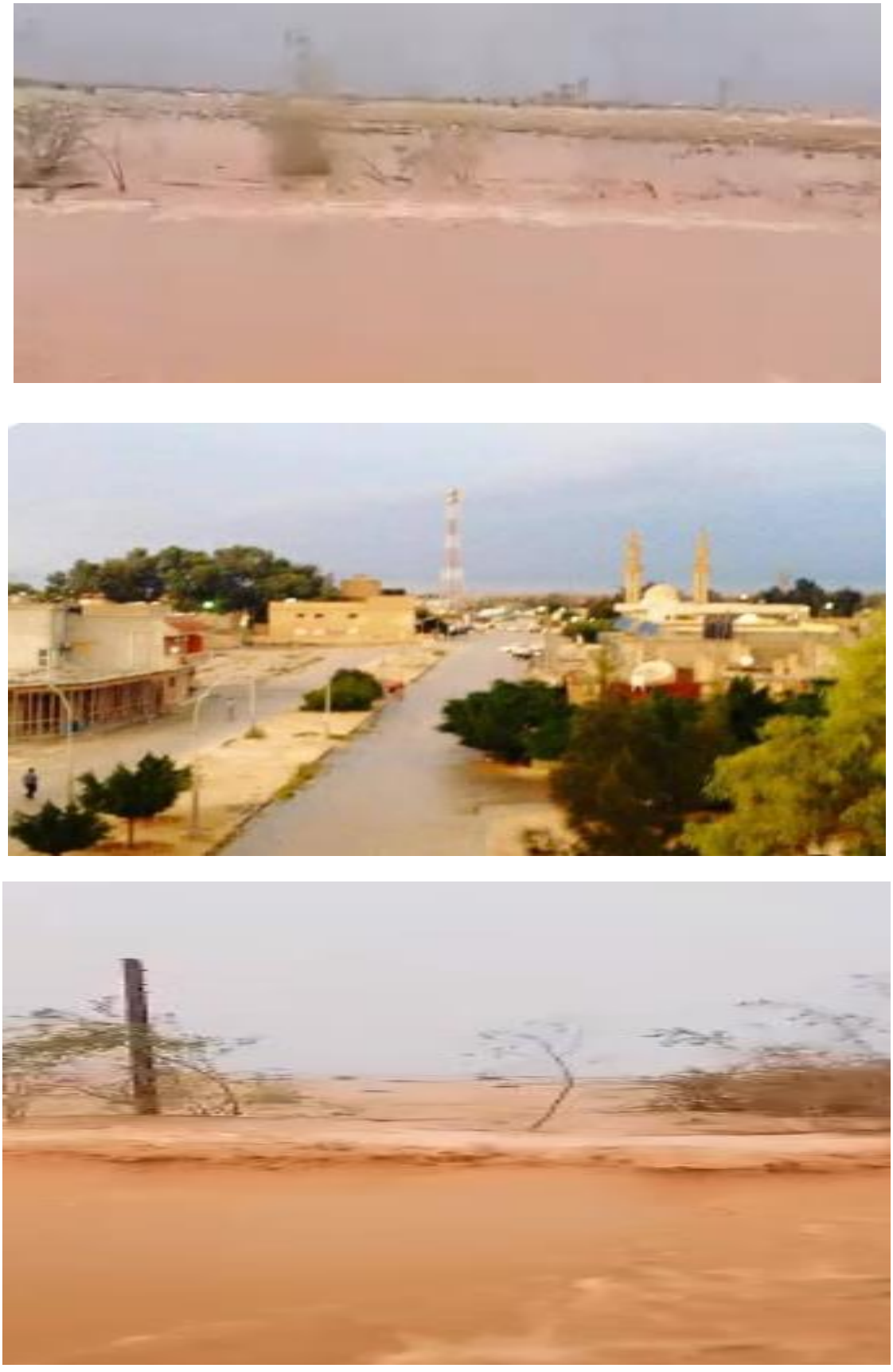


Figure**11:** Field documentation of surface water pooling and infrastructure exposure across vulnerable residential quarters, rural homesteads, and critical road infrastructure (including the Al-Kanawi road corridor and Benghazi–Suluq highway) in Jardina.

Results and Discussion

The objective of this study is to map and evaluate the runoff accumulation potential of the Suluq and Jardina areas using a hydrotopographic modeling approach. The spatial derivation of primary elevation data into sequential hydrological parameters provides a comprehensive understanding of overland flow dynamics and localized surface water stagnation risks in arid suburban plains.

The Digital Elevation Model (DEM) of the Suluq area illustrates a distinct regional elevation gradient, with highest elevations reaching 83 m above mean sea level in the northeastern sector, gradually descending to 48 m toward the south and southwest. This 35 m altitudinal differential dictates the primary gravitational routing of surface water across the area (Figure 4). In contrast, the Digital Elevation Model (DEM) of Jardina reveals a relatively restricted altitudinal range, characterized by a maximum elevation of 73 m in the northern and northeastern sectors, gradually descending to a minimum elevation of 56 m in the southern and southwestern zones, which directs gravitational surface runoff predominantly toward the south southwest (Figure 5).

Analysis of the derived slope map of the Suluq area confirms that the region is predominantly characterized by flat to gently undulating terrain, with the vast majority of the spatial extent falling within the 0° to 14° slope category. This low relief morphology is typical of arid plains and plays a crucial role in reducing runoff velocity while increasing the potential for localized water stagnation, whereas isolated occurrences of steeper gradients (up to 85°) likely correspond to localized micro reliefs, incised wadi banks, or anthropogenic earthworks (Figure 4). Similarly, the derived slope distribution model for the Jardina area is heavily dominated by the lowest slope category (0° to 14°). While isolated micro topographic variations exist reaching up to 72° in highly localized patches, the overarching flatness significantly attenuates runoff velocities, increasing the time of concentration and heavily promoting localized surface water stagnation during extreme precipitation events (Figure 5).

The deterministic path of surface runoff was modeled using the D8 Flow Direction algorithm for both study areas. The flow direction matrix for Jardina exhibits a complex, highly distributed spatial heterogeneity characteristic of a low-gradient topographic depression, heavily influenced by prominent South-West (SW) and North-West (NW) vector orientations. This configuration indicates that surface runoff is laterally dispersed across multiple micro-topographic facets before converging into the central-western terminal sink (Figure 5). In contrast, the Flow Direction model for Suluq demonstrates a more intricate, dendritic routing pattern characterized by a dense interweaving of North-West (NW), South-West (SW), and North-East (NE) directional vectors, where the prevalence of SW and NW routing paths aligns with the regional macro-gradient toward low-lying peripheral corridors (Figure 4). These flow direction matrices serve as the foundational computational grid for subsequent accumulation and wetness modeling. The

complex directional heterogeneity observed in both regions confirms that surface runoff experiences variable travel times depending on local vector continuity, making the identification of these precise flow paths essential for predicting overland flow concentration and enabling municipal engineers to design effective transverse drainage structures.

The Flow Accumulation (FAC) model effectively transitions this distributed flow into a concentrated drainage network. The model for Suluq records a maximum upslope contributing pixel value reaching 1.35357×10^6 against a minimum baseline of 0, illustrating a heavily concentrated, continuous primary drainage pathway traversing the western sector that indicates substantial volume convergence from surrounding low-relief facets (Figure 4). In contrast, the Flow Accumulation model for Jardina exhibits a maximum contributing cell value of 38133, revealing a more distributed, dendritic network of secondary accumulation lines converging toward the central and western zones where sheet flow transforms into defined channel flow (Figure 5).

The spatial distribution of runoff accumulation potential susceptibility derived through the categorization of the Topographic Wetness Index (TWI) synthesizes local slope gradients and upstream contributing areas into five tiers: Very Low, Low, Moderate, High, and Very High Runoff Accumulation Potential. The classified TWI map for Suluq indicates that the vast majority of the municipal boundary is dominated by Very Low and Low Runoff Accumulation Potential classes, signifying high regional drainage efficiency, though isolated dendritic corridors along the western longitudinal axis are classified under Moderate, High, and Very High categories (Figure 6). Similarly, the TWI classification map for Jardina demonstrates that the predominant surface area falls within the Very Low and Low Runoff Accumulation Potential classes, while successfully isolating scattered intermediate zones and localized high-risk pockets within the central-western depression where low local slopes intersect high upstream accumulation values (Figure 7).

As detailed in Table 1, the vast majority of the spatial extent is safely situated within favorable drainage tiers. Specifically, the Very Low Runoff Accumulation Potential class dominates the terrain, encompassing an expansive area of 3456.97 ha (representing 55.90% of the total municipal area) which houses 5094 buildings. This is complemented by the Low Runoff Accumulation Potential class, covering 1409.95 ha (22.80%) and containing 1426 structural units. Together, these two baseline tiers account for the overwhelming majority of both land area and urban assets, confirming a generally high regional drainage efficiency and macro-topographic stability. Conversely, transitional and high risk tiers isolate critical localized convergence zones where micro-depressions impede surface runoff. The Moderate Runoff Accumulation Potential class spans 996.90 ha (16.12%) with 637 buildings, marking a transitional threshold where sheet flow begins to decelerate due to subtle flattening of the local gradient. Most critically, the hazard-prone spectrum comprising the High Runoff Accumulation Potential and Very High

Runoff Accumulation Potential classes occupies a restricted geographic footprint of 228.78 ha (3.70%) with 91 buildings and 89.97 ha (1.46%) with 29 buildings, respectively. Although these severe classes represent a minor fraction of the total area, their direct intersection with exactly 120 vulnerable structures highlights severe asset-level exposure. These concentrated pockets pinpoint micro-topographic terminal sinks where unmitigated runoff pooling threatens municipal integrity, thereby providing municipal engineers with the precise empirical justification required to deploy targeted, cost-effective structural interventions rather than broad, indiscriminate regional drainage projects.

The spatial distribution of the High and Very High Runoff Accumulation Potential classes for the Suluq municipality (Figure 8), as visually delineated in the hazard map and quantified in the preceding analysis, reveals distinct micro-topographic vulnerabilities across the municipal boundary. Rather than forming an indiscriminate regional flood plain, the severe runoff accumulation potential zones exhibit a highly targeted spatial clustering governed by the area's subtle morphological depressions and local infrastructure barriers. The areas most susceptible to high and very high runoff accumulation potential are predominantly concentrated along the western to northwestern longitudinal corridors and localized terminal depressions within the municipal sector, where overland sheet flow converges from adjacent flat pediments. The spatial alignment of these pooling nodes with building footprints and regional road networks highlights critical asset-level exposure, demonstrating how unmitigated water accumulation disrupts key transportation and residential sectors within the low relief terrain. Neighborhoods such as Hay Al Said, Hay Al Jawhara, and Hay Al Hawaza, alongside critical transportation corridors including the initial segment of the Qaminis–Suluq road, the cemetery road, and the Al Magroun–Suluq road, emerge as the primary built-up sectors intersecting high and very high runoff accumulation potential susceptibility zones. These specific zones represent critical geometric convergence pathways where overland flow collects, intersecting directly with vulnerable building footprints and infrastructure elements, thereby exposing specific structural units to severe waterlogging hazards and prolonged surface pooling(Figure 10).

The quantitative distribution of the Topographic Wetness Index (TWI) runoff accumulation potential classes and their corresponding structural exposures for the Jardina municipality are comprehensively summarized in Table 2. The quantitative breakdown indicates that the vast majority of the spatial extent is safely situated within favorable drainage tiers. Specifically, the Very Low Runoff Accumulation Potential class dominates the terrain, encompassing an expansive area of 722.32 ha (representing 56.26% of the total municipal area) which houses 885 buildings. This is complemented by the Low Runoff Accumulation Potential class, covering 293.38 ha (22.85%) and containing 167 structural units. Together, these two baseline tiers account for the overwhelming majority of both land area and urban assets, confirming a generally high regional drainage efficiency and macro-topographic

stability. Conversely, transitional and high-risk tiers isolate critical localized convergence zones where micro-depressions impede surface runoff. The Moderate Runoff Accumulation Potential class spans 198.04 ha (15.42%) with 56 buildings, marking a transitional threshold where sheet flow begins to decelerate due to subtle flattening of the local gradient. Most critically, the hazard-prone spectrum comprising the High Runoff Accumulation Potential and Very High Runoff Accumulation Potential classes occupies a restricted geographic footprint of 59.49 ha (4.63%) with 7 buildings and 11.12 ha (0.87%) with 4 buildings, respectively. Although these severe classes represent a minor fraction of the total area, their direct intersection with exactly 11 vulnerable structures highlights targeted asset-level exposure. These concentrated pockets pinpoint micro-topographic terminal sinks where unmitigated runoff pooling threatens municipal integrity, thereby providing municipal engineers with the precise empirical justification required to deploy targeted, cost-effective structural interventions rather than broad, indiscriminate regional drainage projects.

Geographically, as illustrated in Figure 9, these critical accumulation pockets are predominantly concentrated along the central-western drainage axes and micro-topographic terminal sinks where overland sheet flow converges from adjacent flat pediments. The areas most susceptible to high and very high runoff accumulation potential are predominantly concentrated within the central-western sector of the study area, where surface runoff converges and becomes trapped in micro-topographic terminal sinks. The hazardous pooling zones extend through fragmented drainage pathways oriented toward the western and southwestern portions, where subdued topographic gradients and local infrastructure barriers impede natural sheet flow dissipation. Building upon the broader municipal assessment, the detailed spatial analysis of Jardina's northern, western, and southwestern agricultural and recently subdivided residential sectors reveals a distinct hydrological hazard profile. Specifically, the northern zones characterized by agricultural holdings and modern vertical land subdivisions aligned perpendicularly to the Benghazi–Suluq highway, alongside the expansive western, southwestern, and northwestern peripheries, encompass the primary clusters of high and very high runoff accumulation potential susceptibility, directly threatening critical infrastructure units, including scattered rural homesteads, the Al Kanawi road corridor, and secondary arterial branches diverging from the main ring road(Figure 11).

Conclusions and Recommendations

This study successfully bridges a critical methodological gap in hydrotopographic modeling for arid, low relief environments by integrating high resolution topographical derivatives with multi-tiered Topographic Wetness Index (TWI) classifications in the Suluq and Jardina suburban plains. Conventional hydrological models relying on standard resolution DEMs frequently fail to capture subtle micro topographic variations, resulting in distorted surface

saturation and runoff routing representations. The findings confirm that localized runoff accumulation risks are confined to restricted geographic footprints: the combined High and Very High accumulation tiers occupy 318.75 ha in Suluq and 70.61 ha in Jardina. At the asset level, these combined hazard tiers intersect a total of 120 structures in Suluq (91 structures in the High class and 29 in the Very High class) and 11 structures in Jardina (7 structures in the High class and 4 in the Very High class), underscoring the necessity of targeted structural interventions rather than broad regional projects.

Based on the findings and conclusions of this study, the following actionable recommendations are proposed for municipal planning and infrastructure management

1. Municipal authorities and civil planning directorates should abandon broad, capital intensive regional drainage schemes in favor of localized, cost effective structural measures focused strictly on identified high and very high risk convergence sinks in western Suluq and central western Jardina.
2. Drainage engineers must utilize the derived D8 flow accumulation and vector pathways to install optimized transverse culverts, local diversion channels, and protective berms across intersecting road networks where unmitigated runoff pooling disrupts critical transportation corridors.
3. Municipal planning frameworks should enforce strict zoning restrictions and elevation requirements for the 131 total exposed structures identified within the severe TWI tiers, preventing further urban encroachment into micro-topographic terminal depressions.
4. Future municipal expansions and infrastructure designs across arid Libyan suburban plains must systematically incorporate high resolution DEM based hydrotopographic modeling to pre-emptively identify surface water accumulation bottlenecks prior to development.

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