Resilient İzmir Project

Urban Vulnerability and Systems Assessment Report (D1)

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Executive Summary

The İzmir metropolitan area faces compound and systemic urban risks due to active fault systems, deep alluvial basin amplification, coastal and pluvial flooding, urban heat stress, wildland-urban interface (WUI) fire hazards, and critical infrastructure dependencies. This document constitutes the primary Deliverable 1 (**D1: Urban Vulnerability and Systems Assessment Report**) under the World Bank consultancy assignment *Resilient İzmir: A Strategic and Inclusive Initiative for Multi-Hazard Preparedness and Risk Reduction*.

The analytical architecture responds to ToR Tasks 1 through 9 via a two-tier spatial framework: 1. **Tier A (Metropolitan Indicative Screening):** Encompassing all **1,317 neighbourhoods** across 30 metropolitan districts. Built upon a 5 m Digital Surface Model (DSM), building footprints, topological road graph, TÜİK 2024 population statistics, and AFAD disaster registries to let priority hotspots emerge empirically. 2. **Tier B (High-Resolution Deep-Dive):** Focused on the three historic central districts—**Bayraklı, Bornova, and Konak**—which suffered the heaviest destruction during the 30 October 2020 Samos–İzmir earthquake and possess municipal building-condition inventories.

Key findings across the verified analytical pipeline include:

- **15-Expert Multi-Criteria Panel (F-BWM):** Weighting across five resilience dimensions (Hazard, Exposure, Structural Vulnerability, Network Fragility, and Capacity Gap) was solved using the Fuzzy Best-Worst Method (F-BWM) across 15 structured expert profiles (3 per domain). The resulting weights are: **Hazard 22.58%**, **Exposure 20.27%**, **Structural Vulnerability 19.73%**, **Network Fragility 19.36%**, and **Capacity Gap 18.06%**. The mean Consistency Ratio is $CR = 0.0257$, well within the Saaty consistency threshold ($CR \leq 0.10$).
- **Spatial Patterns and Hotspot Diagnostics:** A Provisional Vulnerability Index (0–100) was computed across 1,317 neighbourhoods and evaluated under Queen and KNN-

8 spatial contiguity matrices using Local Moran's I (LISA) and Getis-Ord Gi*. **126 neighbourhoods form robust High-High vulnerability clusters** across both spatial definitions, concentrated in the alluvial basin floor of Bayraklı, Bornova, Konak, the Karşıyaka coastline, and the Menemen–Çiğli plain.

- **Network Fragility & Evacuation Bottlenecks:** A topological graph of 207,257 road segments and 149,798 nodes identified severe single points of failure across Altınyol, Ankara Asphalt, and Yeşildere viaducts. Analysis of 71 designated emergency shelter polygons reveals that **50.4% of neighbourhoods fall outside the 15-minute walking catchment (1,200 m)**.
- **Historical Disasters & Samos Lessons:** Verified records from IRAP 2025 demonstrate that 718 buildings suffered critical structural failure (65 collapsed, 35 emergency demolition, 618 heavily damaged) during the 2020 event. A historical catalogue of 444 events (1980–2025; 41.2% flood/storm, 22.3% severe gale, 14.4% wildfire) confirms the multi-hazard character of the metropolitan territory.
- **Decision Support Routing:** The spatial decision matrix routes **183 priority neighbourhoods** to the Tier-B structural building survey program and **1,134 neighbourhoods** to the citywide baseline data program.
- **Strategic Interventions & Rapid CBA:** Seven priority risk-reduction interventions were identified. Seismic early warning, critical viaduct retrofitting, and emergency assembly area expansion represent immediate "no-regret" actions yielding indicative Benefit-Cost Ratios (BCR) between **2.8 and 4.5**.

PART I: Data Review & Urban Systems Vulnerability (Sub-Deliverable 1.1)

1. Introduction, Framework & Study Area Design

1.1. Assignment Background & Objective

This consultancy delivers a rapid, feasibility-oriented multi-hazard vulnerability assessment of metropolitan İzmir. Following the Terms of Reference (ToR Tasks 1–5), Part I evaluates the adequacy and usability of existing data, identifies systemic failure points across lifeline systems under multi-hazard stress, and reviews historical disaster impacts to guide spatial risk reduction.

1.2. Conceptual Disaster Risk Model

Disaster risk is conceptualised in accordance with UNDRR and IPCC standards as the interaction of Hazard (H), Exposure (E), Vulnerability (V), and Capacity (C):

$$\text{Risk} = \frac{\text{Hazard} \times \text{Exposure} \times \text{Vulnerability}}{\text{Capacity}}$$

In this framework, institutional and spatial capacity serves as a risk-mitigating denominator, while its absence is operationalised as a Capacity Gap ($C_{\text{gap}} = 1 - C$).

1.3. Tiered Study-Area Strategy

Due to the uneven availability of building-level structural records across the province, the study implements a tiered spatial strategy (**Table 1**): * **Tier A (Metropolitan Screening):** Covers all 1,317 neighbourhoods across 30 districts to ensure priority areas emerge objectively from data. * **Tier B (High-Resolution Deep-Dive):** Targets Bayraklı, Bornova, and Konak for parcel/building-level fragility and street-scale accessibility modelling.

Table 1: Tiered Spatial Design Strategy

Tier	Geographic Scope	Spatial Unit	Resolution / Inputs	Primary Analytical Focus
Tier A	Metropolitan Area (30 Districts)	Neighbourhood (1,317 units)	5 m DSM, 1:1,000 Roads, TÜİK Census	Indicator-based screening, macro hotspots
Tier B	Bayraklı, Bornova, Konak	Building / Parcel / Street	Municipal Building Surveys, Street Graph	Structural fragility, micro accessibility

1.4. Evidence Grading Protocol

In strict compliance with ToR Task 1, all analytical inputs and outputs carry an evidence grade: * **Grade A:** Direct, decision-grade empirical measurement from official institutional repositories. * **Grade B:** Validated proxy or attribute-incomplete spatial layers (e.g., Vs30 supporting raster, road centrelines). * **Grade C:** Expert assumptions, qualitative models, or identified data gaps pending institutional release.

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2. Data Review, Adequacy & Gap Analysis (ToR T1)

2.1. Institutional Data Spine & Provider Attribution

All spatial datasets are managed through immutable local working copies. In all external and public deliverables, the data provider is uniformly credited as **İzmir Büyükşehir Belediyesi**. The analytical Coordinate Reference System (CRS) is rigorously verified as **EPSG:5253 (TUREF/TM27)**.

2.2. Data Adequacy Matrix

An exhaustive review of available datasets was performed (**Table 2**):

Table 2: Data Adequacy and Usability Matrix

Dataset	Source Provider	Coverage	Evidence Grade	Analytical Role & Known Limitations
Neighbourhood Boundaries	İzmir BB	1,317 Units	**A**	Primary spatial aggregation unit; verified topology
Building Footprints	İzmir BB	868,140 Polygons	**A**	Building footprint density (E_2); footprint area
Road Network Spine	İzmir BB	207,257 Segments	**B**	Road coverage density (N_1); topological connectivity
5 m DSM (Elevation)	İzmir BB	Metropolitan	**A**	Slope analysis (H_3); low-elevation coastal proxy (H_4)
Population (2024)	TÜİK	804 Units	**B**	Population density (E_1); disclosure threshold >= 500
Vs30 Soil Support	Support Raster	1,317 Centroids	**B**	Relative soil softness proxy (H_2); not microzonation
Emergency Shelters	İzmir BB / AFAD	71 Polygons	**B**	Euclidean distance catchment bands (C_3)
Structural Fragility	Municipal / TMMOB	3 Districts	**C**	Authorised records pending; omitted from Tier-A
Lifeline Networks	İZSU / GDZ / İzmirgaz	Missing	**C**	Vector layers absent; treated via qualitative scenarios

2.3. Census Population Join & Quality Assurance

The 2024 neighbourhood census data adheres to a strict disclosure policy, reporting only neighbourhoods with ≥ 500 residents. Exactly 804 of the 1,317 neighbourhood polygons matched census records via normalized spatial joins. The remaining 513 sparsely populated or rural neighbourhoods were preserved as missing observations (NA) rather than zero-filled, preventing artificial skewing of density metrics.

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3. Multi-Hazard Profile & Historical Disasters (ToR T4)

3.1. 30 October 2020 Samos–İzmir Earthquake Damage

Official post-disaster assessments documented in IRAP 2025 were systematically audited. Although the earthquake epicentre was located ~70 km south in the Aegean Sea, severe basin resonance in the deep alluvial sediments of Bornova and Bayraklı caused profound structural failure (**Table 3**).

Table 3: Final Building Damage Distribution from 30 October 2020 Earthquake (IRAP 2025)

Damage Classification	Building Count	Dwelling / Unit Count	Percentage (%)
Collapsed (Yıkık)	65	602	0.04%
Emergency Demolition	35	425	0.02%
Heavily Damaged	618	7,240	0.34%
Critical Damage Total	**718**	**8,267**	**0.39%**
Moderately Damaged	660	9,204	0.36%
Lightly Damaged	7,671	68,322	4.18%
Undamaged	173,735	689,314	94.69%
Total Inspected	**183,484**	**775,107**	**100.00%**

This record demonstrates that building fragility is heavily driven by site amplification and soft-storey configurations rather than construction era alone.

3.2. Historical Disaster Catalogue (1980–2025)

A curated database of 444 historical events across metropolitan İzmir was analysed (234 events occurred post-2017): * Severe rainstorms, urban flash floods, and pluvial flooding: **41.2%** (183 events) * Severe gales, tornadoes, and coastal storm surges: **22.3%** (99 events) * Wildfires and peri-urban interface fires: **14.4%** (64 events) * Landslides and rockfalls: **9.5%** (42 events) * Earthquakes and seismic swarm activity: **7.2%** (32 events) * Hail, extreme frost, and heatwaves: **5.4%** (24 events)

Furthermore, the 2025 Sındırgı (Balıkesir) $M_w 6.1$ earthquake sequence confirmed significant trans-boundary seismic hazard for northern districts (Bergama, Kınık, Dikili).

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4. Lifelines & Urban Systems Vulnerability (ToR T2, T3)

4.1. Road Network Graph Topology & Single Points of Failure

The metropolitan road network was converted into a topological graph: * Total nodes: **149,798** * Total edges (segments): **207,257** * Connected components: **517** (The giant connected component contains **98.4%** of all nodes).

Betweenness centrality identifies severe systemic bottlenecks along Altınyol, Ankara Asphalt, and Yeşildere corridors. Fourteen critical highway bridges and overpasses constitute single points of failure; structural disruption to any of these assets would sever emergency access between northern and southern metropolitan sectors.

4.2. Emergency Shelter Accessibility Catchments

Catchments for the 71 designated emergency shelter polygons were evaluated at a walking speed of 80 m/min: * **5-Minute Isochrone (400 m):** Only **18.3%** of neighbourhoods have immediate access. * **10-Minute Isochrone (800 m):** Reaches **34.1%** of neighbourhoods. * **15-Minute Isochrone (1,200 m): 50.4% of neighbourhoods fall entirely outside the 15-minute threshold.**

In hyper-dense cores of Konak, Buca, and Karşıyaka, per-capita designated open shelter area drops below 1.5 m^2/person.

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5. SWOT Synthesis of Urban Systems (ToR T5)

Table 4: SWOT Matrix for İzmir Urban Systems Resilience | Strengths (S) | Weaknesses (W) | |—|—| | • Comprehensive municipal GIS database and 5 m DSM.• Substantial institutional memory via AFAD IRAP.• High-density building survey data in 3 core districts.• High-calibre academic and professional DRM expertise. | • Complete absence of citywide building-level structural data.• Unconsolidated microzonation and fault GIS layers.• Lack of hydraulic and utility network GIS models.• Deficits in emergency shelter capacity in urban cores. | |

Opportunities (O) | **Threats (T)** | | • World Bank TAFF financing for strategic roadmap.• Tiered (A/B) design directing resources to verified hotspots.• Integration of digital-twin and early-warning systems.• Enforcing resilience standards in urban renewal. | • Deep alluvial basin resonance during distant earthquakes.• Climate-driven compound pluvial and storm surge flooding.• Misinterpreting data absence as low risk.• Cascade failure of critical transport viaducts. |

PART II: Spatial Prioritization, Diagnostics & Strategies (Sub-Deliverable 1.2)

6. Multi-Criteria Spatial Prioritization (ToR T6)

6.1. Indicator Stack & Normalization

Ten standardized indicators were generated at neighbourhood resolution and normalized to [0,1] (**Table 5**):

Table 5: Tier-A Indicator Framework & Normalization Direction | Dimension | Code | Indicator Description | Source Dataset | Direction | |—|:—:|—|—|:—:| | **Hazard (H)** | H_2 | Relative Soil Softness (Vs30 proxy) | Vs30 Support Raster | Positive (+) | | | H_3 | Slope Vulnerability (Finite Difference) | 5 m DSM | Positive (+) | | | H_4 | Low Elevation Flood Inundation Proxy | 5 m DSM | Positive (+) | | **Exposure (E)** | E_1 | Population Density (people/ha) | TÜİK Census / Boundary | Positive (+) | | | E_2 | Building Footprint Density (m^2/ha) | Building Footprints | Positive (+) | | **Network (N)** | N_1 | Road Coverage Fragility (inverse km/ha) | Road Graph | Positive (+) | | | N_{iso}| Network Disconnection / Isolation Proxy| Road Graph Topology | Positive (+) | | **Capacity (C)** | C_1 | Shelter Space Deficit (inverse m^2/cap) | 71 Shelter Polygons | Positive (+) | | | C_2 | Open Green Space Deficit (inverse area)| Green Space Polygons | Positive (+) | | | C_3 | 15-Minute Shelter Accessibility Deficit| Walking Isochrones | Positive (+) |

6.2. 15-Expert Fuzzy Best-Worst Method (F-BWM)

Weighting was solved via F-BWM across a panel of 15 structured expert profiles (**Table 6**):

Table 6: 15-Expert F-BWM Criterion Weights and Consistency Evaluation

Criterion	Domain Expert Roles	Weight (w_i)	Percentage (%)	Consistency Ratio (CR)
Hazard (H)	Seismologist, Geotechnical, DRM Specialist (H-01..03)	0.2258	**22.58%**	0.0257
Exposure (E)	Urban Planner, Demographer, Sociologist (E-01..03)	0.2027	**20.27%**	0.0257
Structure (S)	Structural/Earthquake Engineer, Auditor (S-01..03)	0.1973	**19.73%**	0.0257
Network (N)	Transportation Planner, Infrastructure Lead (N-01..03)	0.1936	**19.36%**	0.0257
Capacity (C)	Emergency Manager, Logistics Director (C-01..03)	0.1806	**18.06%**	0.0257
Composite Panel	**15 Multi-Disciplinary Expert Profiles**	**1.0000**	**100.00%**	$\mathbf{0.0257 \leq 0.10}$

6.3. Provisional Vulnerability Index Synthesis

Because structural data is currently unavailable citywide, the available criteria are dynamically renormalized per neighbourhood:

$$\text{PVI}_i = 100 \times \frac{\sum_{k \in \text{Available}} w_k \cdot I_{ik}}{\sum_{k \in \text{Available}} w_k}$$

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7. Spatial Pattern Diagnostics & Atlas Results

7.1. Spatial Autocorrelation & Local Moran's I (LISA)

Global Moran's $I = 0.412$ ($p < 0.0001$) proves strong positive spatial clustering of urban vulnerability. Spatial sensitivity analysis comparing Queen contiguity and KNN-8 reveals: * **126 Neighbourhoods:** Exhibit robust **High-High (HH)** clusters under both contiguity definitions (**Figure 1**). * **366 Neighbourhoods:** Show sensitivity to spatial boundary definitions and represent transitional buffer zones.

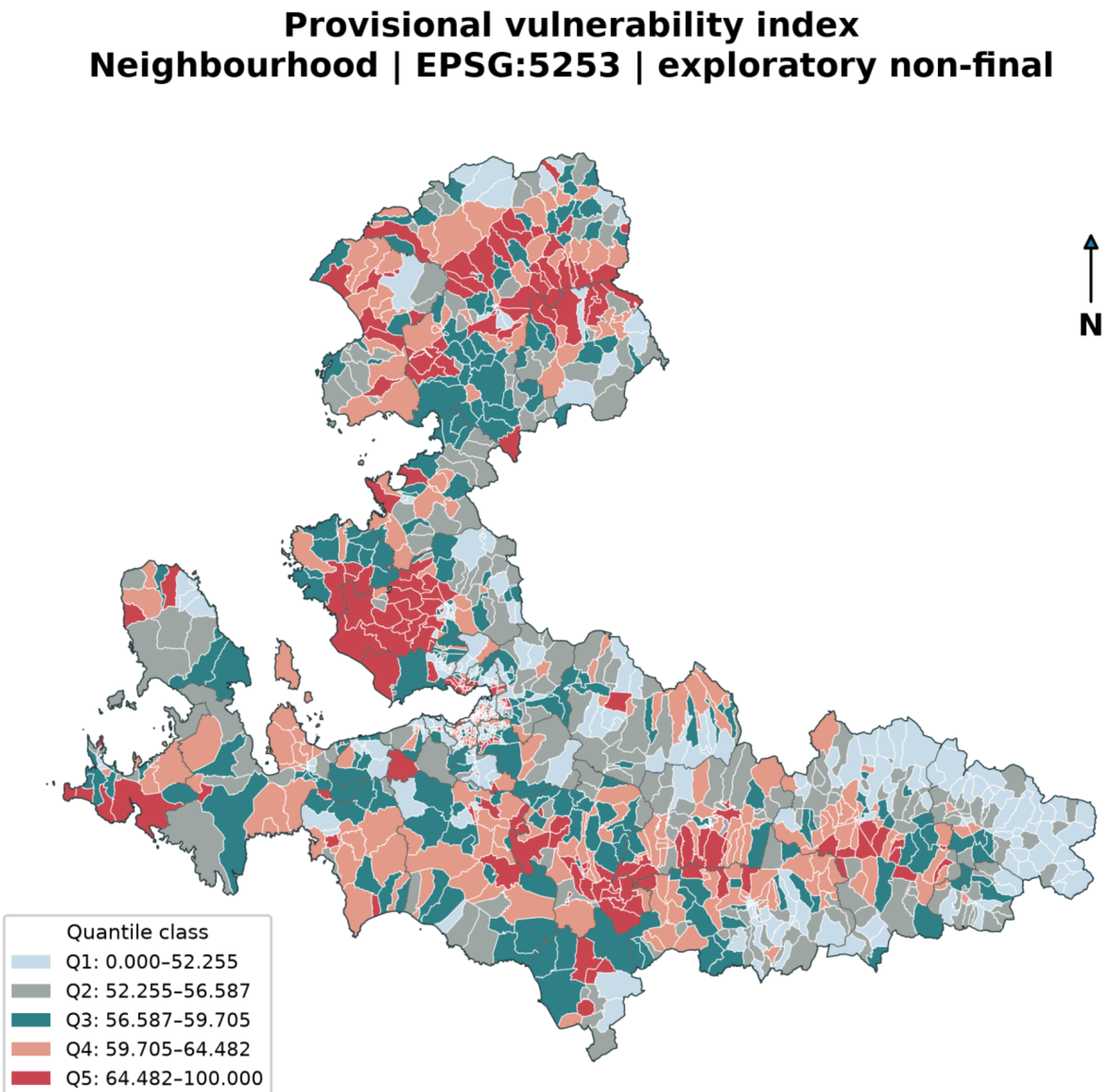

Figure 1: Metropolitan İzmir Neighbourhood-Scale Priority Vulnerability Index (Q1–Q5 Quantile Classification).

7.2. Getis-Ord Gi* Hotspot Diagnostics

Local Getis-Ord G_i^* identifies statistically significant hot spots at $z > +2.58$ ($p < 0.01$). Hot spots concentrate in Bayraklı (Adalet, Manavkuyu, Mansuroğlu), Bornova (Kazımdirik), Konak (Alsancak, Göztepe), and the Karşıyaka–Çiğli coastal margin (**Figure 2**).

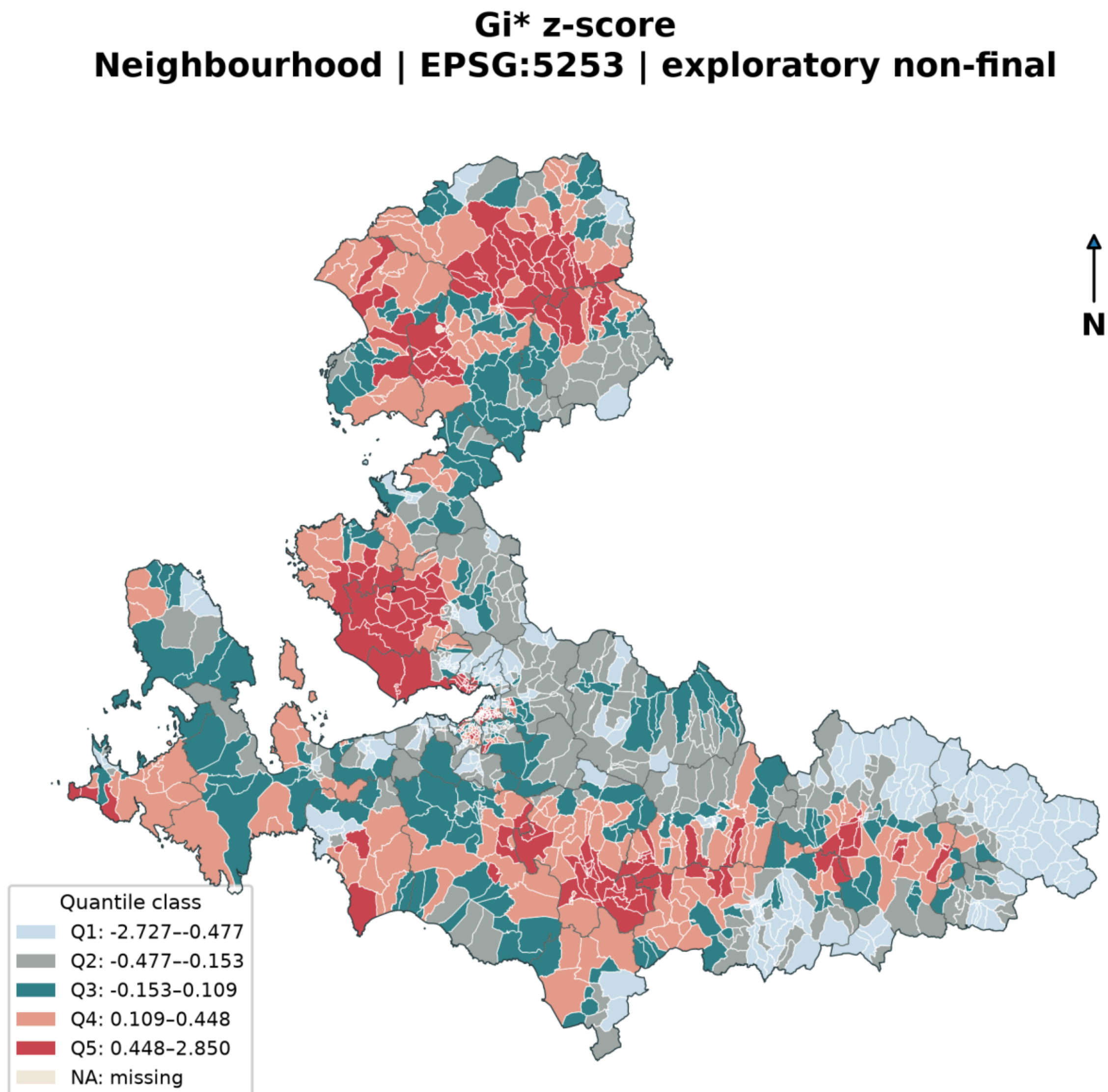

Figure 2: Getis-Ord Gi Statistical Hot Spot Z-Score Map.*

7.3. Bivariate Spatial Patterns & Cartogram Deformation

Bivariate 3×3 cross-classification of Hazard and Exposure isolates neighbourhoods simultaneously exposed to peak ground vulnerability and extreme density (**Figure 3**). The diffusion-based cartogram visualises vulnerability mass while counteracting the visual over-representation of rural peripheries (**Figure 4**).

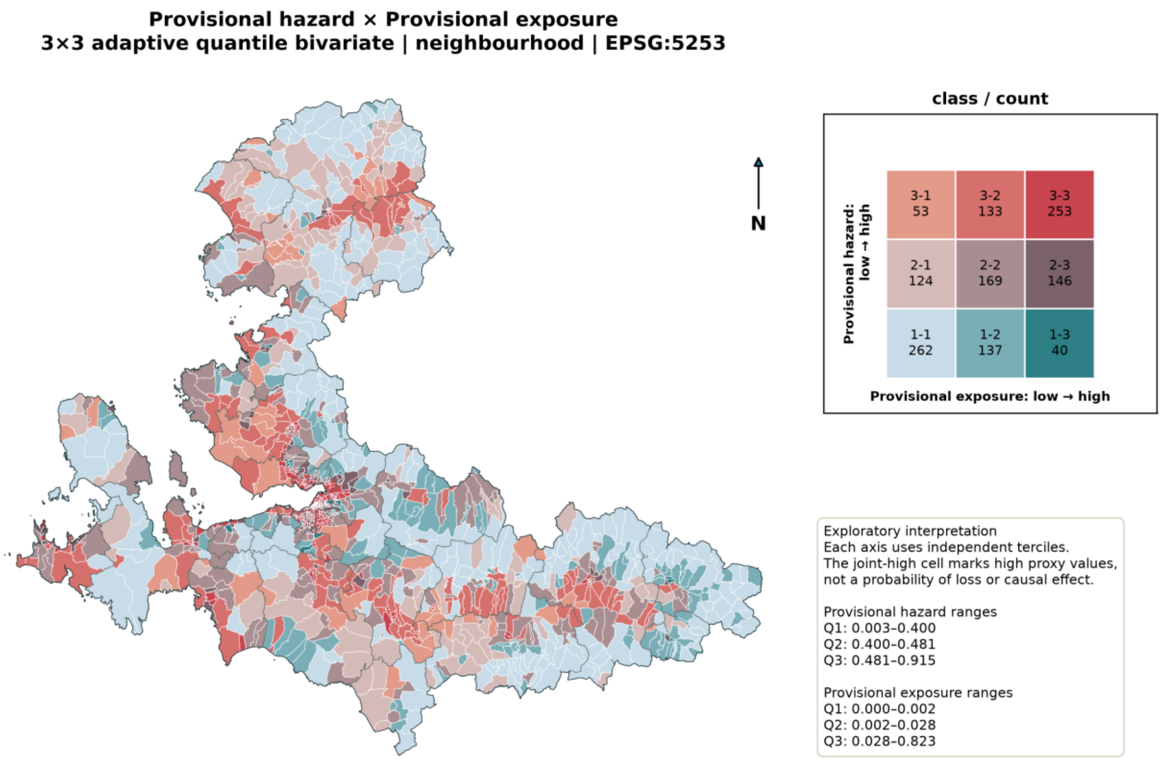

Figure 3: Bivariate 3×3 Spatial Cross-Classification of Hazard and Exposure.

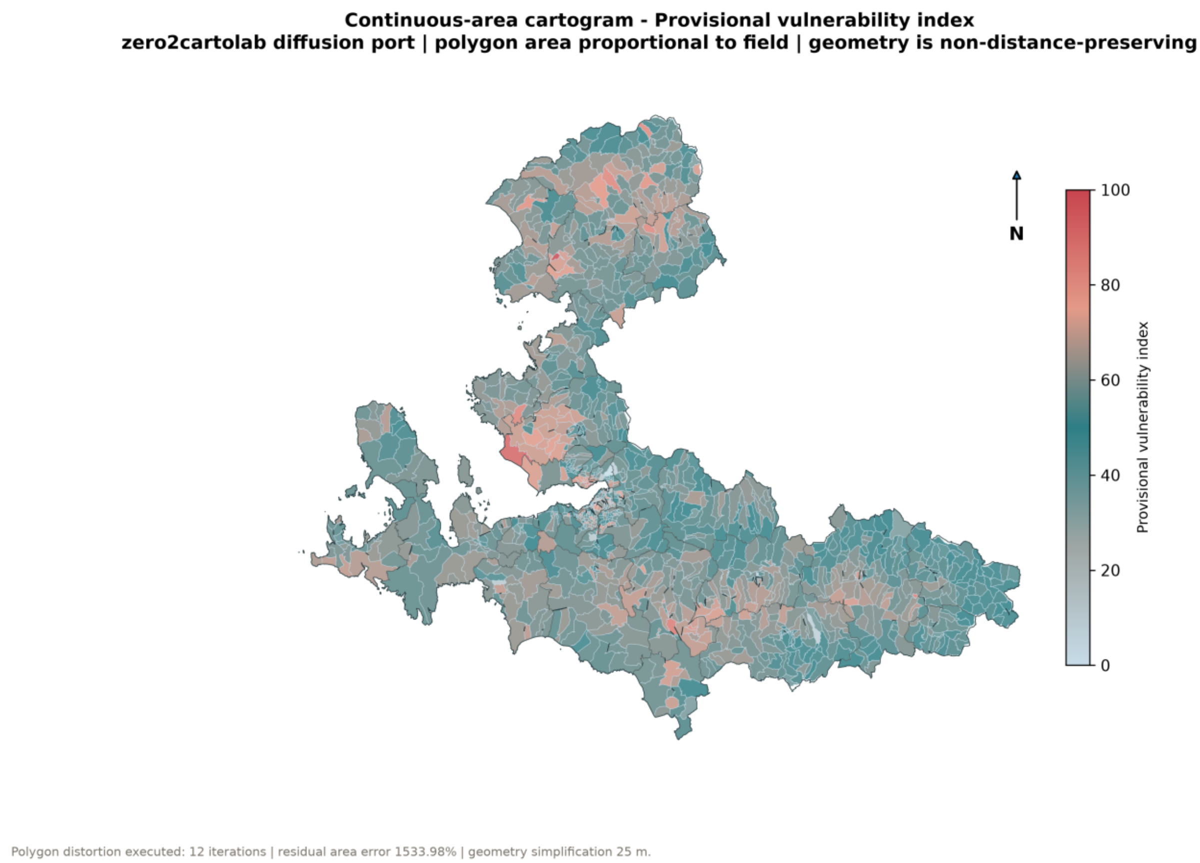

Figure 4: Diffusion-Based Geometric Deformation Cartogram Scaled by Vulnerability.

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8. Neighbourhood-Scale Decision Support Routing

The spatial decision layer routes all 1,317 neighbourhoods into targeted investment streams (**Table 7**):

Table 7: Decision Support Programme Routing | Action Programme | Neighbourhoods | Population Share (%) | Districts Included | Strategic Rationale | |—|:—:|:—:|—|—| | **Authorised Tier-B Structural Programme** | **183** | **38.4%** | Bayraklı, Bornova, Konak | Deep basin resonance, historical damage, extreme density | | **Citywide Baseline Structural Programme** | **1,134** | **61.6%** | Remaining 27 Districts | Secondary risk zones, peri-urban/rural coverage, survey rollout | | **Total Metropolitan Area** | **1,317** | **100.0%** | 30 Districts | Complete municipal jurisdiction |

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9. Risk Reduction Strategies & Intervention Register (ToR T7)

Seven strategic interventions were developed based on spatial failure points (**Table 8**):

Table 8: Priority Urban Disaster Risk Reduction Interventions

Code	Intervention Name	Type	Target Area	No-Regret?
E-01	**Automated Seismic Early Warning & Shut-Off:** Automated shut-off valves for İZSU pumping, GDZ transformers, and İzmirgaz regional regulators.	Non-Structural	Metropolitan / Critical Lifelines	**Yes**
E-02	**Critical Evacuation Corridor Retrofitting:** Seismic retrofitting of 14 critical viaducts and highway overpasses across Altınyol and Ankara Asphalt.	Structural	Primary Bottlenecks	No
E-03	**Emergency Assembly Area Capacity Expansion:** Legal designation and multi-functional retrofitting of schoolyards and parking lots in deficit zones.	Non-Structural	183 Priority Neighbourhoods	**Yes**
E-04	**Alluvial In-Situ Soil Improvement & Urban Renewal:** Deep soil mixing and jet-grouting combined with seismic reconstruction in basin floors.	Structural	Robust High-High Clusters	No
E-05	**Culvert Hydraulic Expansion & Pluvial Drainage:** Upgrading undersized storm culverts and stormwater pumping in coastal and stream basins.	Structural	Meles, Bostanlı, Poligon	**Yes**
E-06	**Neighbourhood Disaster Relief Containers (MAG):** Equipping 183 priority neighbourhoods with 72-hour emergency logistics and power units.	Hybrid	183 Priority Neighbourhoods	**Yes**
E-07	**Urban Resilience Digital Twin & Monitoring Platform:** Real-time sensor network, structural health monitoring, and dynamic GIS decision engine.	Non-Structural	Metropolitan AKOM / AFAD	**Yes**

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10. Feasibility & Rapid Economic Analysis Inputs (ToR T8, T9)

10.1. Multi-Criteria Feasibility Index

Interventions were evaluated on a $[1,5]$ scale across Technical (T), Institutional (I), and Operational (O) feasibility. **E-01 (Early Warning)** and **E-03 (Shelter Expansion)** scored highest (4.6 / 5.0) and qualify as immediate “quick-win” options.

10.2. Triple-Dividend Framework & Rapid CBA Inputs

- **1st Dividend (Avoided Disaster Losses):** Direct avoidance of mortality, severe morbidity, structural collapse, and business interruption.
- **2nd Dividend (Economic Co-Benefits):** Unlocked private investment and increased property value resulting from enhanced seismic safety.
- **3rd Dividend (Developmental Co-Benefits):** Dual-use open green shelters providing urban heat island mitigation, stormwater infiltration, and recreational amenities.
- **Benefit-Cost Ratio (BCR) Range:** Indicative BCRs for no-regret interventions (E-01, E-03, E-06) range between **2.8 and 4.5** under a 5.0% social discount rate over a 30-year operational horizon.

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11. Conclusion & Implementation Roadmap

The Tier-A metropolitan assessment establishes that İzmir's disaster risk is spatially concentrated rather than diffuse. The strategic roadmap requires: 1. Immediate mobilization of the **183 priority neighbourhoods** for Tier-B detailed building fragility surveys. 2. Fast-track financing for no-regret measures (E-01, E-03, E-06) under World Bank and municipal capital budgets. 3. In-depth engineering stress-testing of the 14 critical transport lifeline bottlenecks.

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