

Flood exposure and settlement vulnerability in the Moldavian Plateau, Eastern Romania

Domenic-Raul BECICA^{1,*}, Mihai BARBACARIU¹, Marcel MÎNDRESCU¹

¹ Ștefan cel Mare University of Suceava, Faculty of History, Geography and Social Sciences, Geography Department, Universității Street, no. 13, Suceava, 720229, Romania

* Corresponding author: domenic.becica2@student.usv.ro

Received on 12-09-2025, reviewed on 14-11-2025, accepted on 30-11-2025

Abstract

This paper quantifies settlement-level exposure to centennial flood across the Moldavian Plateau (NE Romania) using a reproducible GIS workflow. Official flood-hazard bands were intersected with built-up limits and building footprints; rural housing was completed by manual digitization, while urban fabric relied on OpenStreetMap layer. Exposed population was estimated from household counts using the national average of 2.6 persons/household, with additional rules for apartment blocks. Results are reported at multiple scales—by river basins (Siret, Jijia including Buhai–Miletin–Bahlui–Bahluț, Bârlad and Prut/Chineja) and urban case studies (Iași, Bacău, Vaslui). The Siret basin concentrates the highest systemic exposure, Prut highlights transport-corridor vulnerability (DN/DJ roads and railway segments), while Bârlad exhibits dense, localized hot-spots. City-level estimates indicate approximately 68,750 exposed inhabitants in Iași, 36,756 in Bacău, and 2,550 in Vaslui under centennial flood scenario, together with clusters of socio-economic assets and critical infrastructure near the hazard band. Key limitations include potential under or over counts in recent developments, block-stairwell granularity, and reliance on census-based household averages. The findings support differentiated risk-reduction priorities: structural measures across Siret sub-basins, transport protection and redundancy along Prut, and targeted local actions in Bârlad. Periodic updates of hazard mapping using LiDAR and hydraulic modeling are recommended to refine exposure estimates and planning decisions.

Keywords: *flood risk, centennial flood, exposure mapping, GIS, Moldavian Plateau*

Introduction

The Moldavian Plateau in north-eastern Romania is a distinct geomorphological unit drained by a dense hydrographic network dominated by the Siret, Prut, and Bârlad rivers and their tributaries. The study sector spans these basins and is characterised by a dissected, predominantly hilly relief with moderate elevations and gentle south-eastern slopes. This natural configuration, combined with sustained settlement expansion along floodplains and lower river courses in recent decades, favors recurrent flooding and amplifies impacts on towns and villages.

The temperate-continental climate delivers roughly 450–750 mm of annual precipitation, concentrated mainly in spring and summer, which supports rapid runoff and flash-flood formation. Hydrological response is further intensified by widespread clayey–sandy and loess-derived soils that typically exhibit low permeability and heightened susceptibility to erosion. Over the last decade, the integration of hydraulic modelling (e.g. HEC-RAS) with LiDAR data and GIS workflows has proven effective for delineating flood extents and estimating exposure at settlement scale across north-eastern

Romania, motivating the approach adopted here (Chelariu et al., 2024; Devitt et al., 2023).

Operationally, flood risk is understood as the interaction between hazard, exposure, and vulnerability. In this study, the hazard component is represented by the 1% Annual Exceedance Probability (AEP) flood band, also referred to as the “centennial flood”, which underpins official mapping in line with the EU Floods Directive (2007/60/EC). A 1% AEP implies a 1% chance of occurrence in any given year, equivalent to about 26% over a 30-year horizon, a timeframe relevant to residential investment cycles. Exposure denotes built-up area and assets (households, infrastructure, and public services) intersecting this band, while vulnerability reflects their susceptibility to damage given construction typology, elevation relative to the channel, bank proximity, and access constraints (Tate et al., 2021; Pathak et al., 2020; Diaconu, 2022; Fischer et al., 2024).

The motivation for this work lies in the need for fine-scale, spatially comparable assessments across basins and across urban–rural contexts, given the persistence of floods and flash-floods on the Moldavian Plateau and the limitations of current administrative-scale.

Our approach overlays the 1% AEP band with built-up limits and buildings proxies to estimate exposure, and

then synthesizes the results across multiple scales—basin, sub-basin, and municipal case studies.

The overarching aim is to quantify the intravilan area intersecting the centennial flood and to estimate potentially affected population, households, and infrastructure, enabling comparisons between the Siret, Prut, and Bârlad basins and selected urban cases. In doing so, the study advances beyond a hazard-only perspective toward a decision-oriented flood-risk assessment with direct relevance for spatial planning and emergency management at local and regional scales (McDermott, 2022).

Data and methods

Study area

The study covers the Moldavian Plateau in north-eastern Romania, with a focus on the Siret and Jijia systems (including the Buhai–Miletin–Bahlui–Bahluet tributaries), the Bârlad Basin, and the analysed segment of the Prut Basin together with the Chineja tributary.

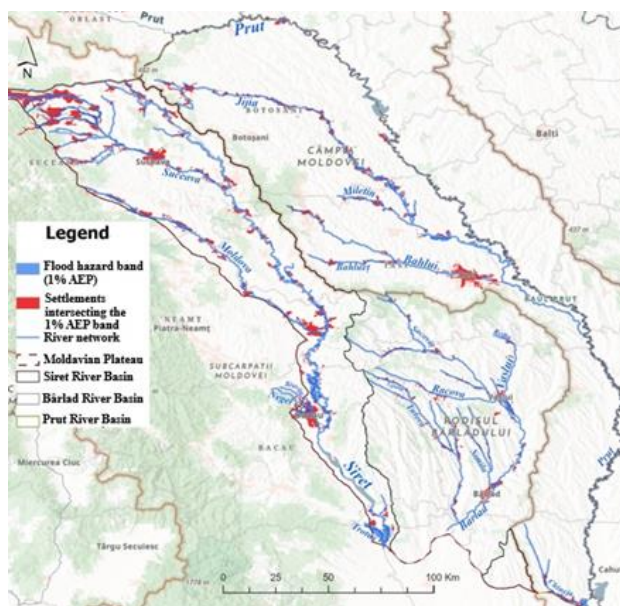


Figure 1: Study area and principal river basins in the Moldavian Plateau; flood hazard band (1% AEP) and settlements intersecting the band

Settlement exposure is assessed by intersecting the centennial flood with built-up area limits and building proxies (households/blocks). Transport exposure is reported as the lengths of national and county roads (DN/DJ) and railway segments intersecting the same 1% AEP band (Stefanidis et al., 2022).

We integrate the official 1% Annual Exceedance Probability (AEP) flood band with built-up boundaries and buildings proxies, complemented by demographics and transport networks (OpenStreetMap). Manual digitization was used to complete household and asset inventories where automated extraction (QuickOSM) was

insufficient. Exposed population in houses uses the national average of 2.6 persons/household; apartment blocks are treated via a compact rule (FEMA 2020; Tabasi et al., 2024).

Spatial processing and analysis steps

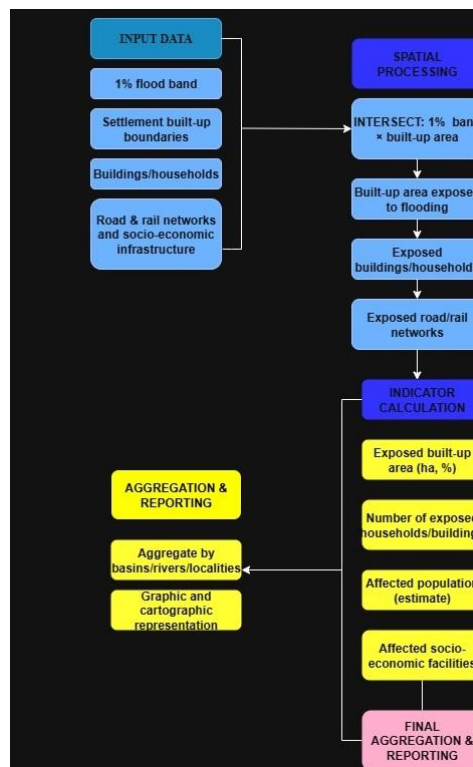


Figure 2: Exposure assessment workflow (1% AEP) - buildings, transport networks, population, facilities

All processing was performed in ArcGIS Pro. We intersected the centennial flood with settlement built-up polygons and assets (households, schools, churches, and industrial sites) to flag exposure. Exposed intravilan area (m²) and exposed share were computed as:

$$\text{Exposed share (\%)} = (\text{Exposed intravilan area m}^2 / \text{Total intravilan area m}^2) \times 100$$

Areas were converted to hectares by dividing m² by 10,000. Results were aggregated by basin and municipality.

Block population estimation

This subsection provides a simple, reproducible approach to estimate population in apartment blocks, using defaults that match common Romanian typologies (P+4, P+8, P+10). The rules focus on residential floors and stairwell structure, avoiding commercial ground-floor complications.

Symbols

NS = number of stairwells

ApF = apartments per floor per stair

Nu = residential floors above ground level (e.g., 4 for P+4)

$\gamma_g \in \{0, 1\}$ = ground-floor residential factor (1 if residential, 0 if not)
 $\gamma_a \in \{0, 0.5, 1\}$ = attic factor (0 none; 0.5 partial; 1 full)
 \bar{p} = persons per apartment (use 2.6 by default)
 Effective residential floors: $N_f = N_u + \gamma_g + \gamma_a$
 Apartments per block: $Apt = NS \times ApF \times N_f$
 Population per block: $Pop = Apt \times \bar{p}$

Resolution/positional accuracy: small structures may be missed; precise alignment depends on georeferencing quality.

Despite these constraints, the workflow yields robust, policy-ready indicators of flood exposure across the Moldavian Plateau and a consistent basis for local and regional planning.

Results

Table 1: Block typologies and estimated population

Typology	NS	ApF (per stair)	N _u	γ_g	γ_a	N _f	Apt	Population
P+4 (1 stair, 4 ap/floor)	1	4	4	1	0	5	20	52
P+4 (2 stairs, 4 ap/floor/stair)	2	4	4	1	0	5	40	104
P+8 (1 stair, 3 ap/floor)	1	3	8	1	0	9	27	70
P+8 (2 stairs, 3 ap/floor/stair)	2	3	8	1	0	9	54	140
P+10 (2 stairs, 4 ap/floor/stair)	2	4	10	1	0	11	88	229
P+10 (1 stair, 6 ap/floor)	1	6	10	1	0	11	66	172

Basin-based organization of results

Outputs are structured by the main basins and tributaries: Siret (incl. Suceava, Moldova, Bistrița, Trotuș, etc.), Jijia (with Buhai, Miletin, Bahlui, Bahlueț), Bârlad (e.g., Vaslui, Racova, Tutova), and the analysed segment of the Prut with Chineja. Prut/Chineja are reported separately from Jijia/Bahlui due to their distinct hydrographic and management context (border river, extended floodplain, transboundary coordination). For each basin we report exposed intravilan area, households/blocks, population, and transport assets, enabling prioritisation of local interventions (bank stabilization, flood-protection works, evacuation planning).

Software and technical limitations

We used ArcGIS Pro for vectorisation, spatial analysis, and overlay of thematic layers (1% AEP band, household/block networks, critical infrastructure), with targeted QGIS/QuickOSM extraction in cities. Core tools (Intersect, Union, Clip) supported rapid identification and quantification of exposed entities (Bernardini et al., 2024).

Main limitations are represented by data currency: newly built houses may be missing from footprints/imagery → potential underestimation in fast-growing areas. Block granularity: multi-stairwell buildings treated as single units if stairwell data are missing → possible underestimation of residents.

Siret Basin

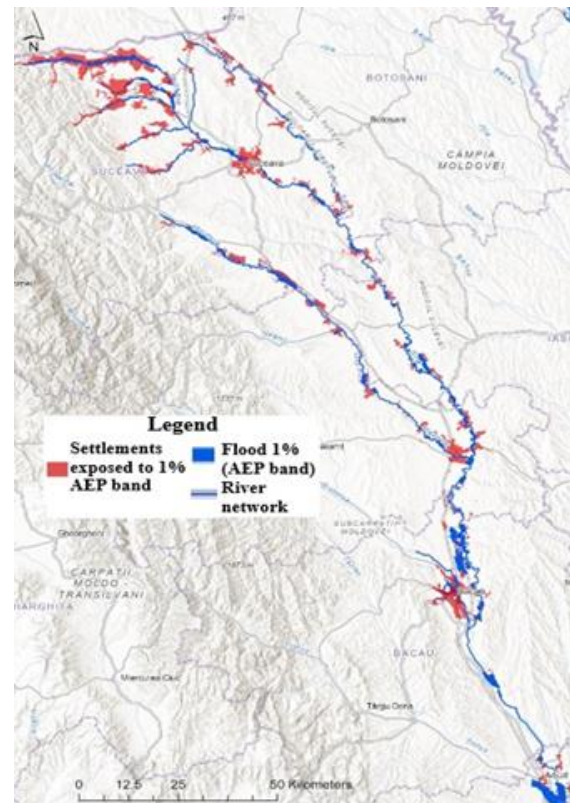


Figure 3: Settlements exposed to hazard 1% (AEP band) in Siret Basin

Across the 100 settlements intersecting the centennial flood in the Siret Basin (Siret, Trebeș, Negel and Trotuș network) the exposed built-up area totals 3,532 ha. In rural areas, we vectorised 4,993 households, which use 2.6 persons/household—yield an estimated exposed population of ~13,000 people (excluding the Bacău Municipality). The footprint spans both urban and rural settings, confirming substantial pressure on riparian communities during a centennial event.

Bacău is the most affected city in absolute terms, with 721 ha inside the centennial flood which represent 21.50% of its built-up area. The impacted footprint includes major residential districts (Miorița, Central Zone, C.F.R., Izvoare) and industrial areas. Based on the block rules the exposed population is ~37,000.

Adjud (at the Trotuș confluence) records 1 ha affected (0.22% of intravilan), 57 households lie in the band (~150 people) and 16 economic facilities are exposed,

underscoring functional risk despite the small areal share.

Several rural settlements show very high intravilan shares within the centennial flood: Schineni (57.62%), Șerbești (49.34%), Siretu (38.99%), Săucești (16.36%). Household counts typically fall between 114–200, implying ~300–600 residents at risk in each community (2.6 persons/household).

In the corridor between Cotu Grosului–Schineni and the NE of Săucești, the Siret (east bank) and Precista (west bank) centennial flood overlap the primary local roads. Built-up areas become encircled by the flood band, and all outward routes to county/national roads traverse floodable zones. Under a centennial flood, rapid isolation is likely for Șerbești, Siretu, Schineni and adjacent localities.

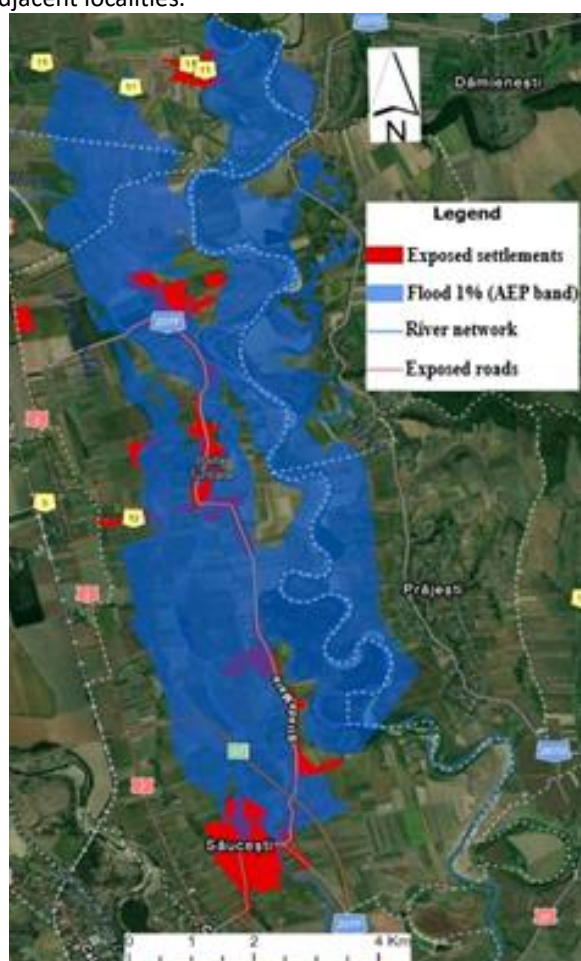


Figure 4: Settlements and roads exposed in Cotu Grosului – Săucești sector

2021 census data indicate ~2,700 people could be stranded or directly exposed in the absence of safe alternatives. The co-exposure of DN15D, DN2, DN11A and large sections of A7 (Lot 2) increases the logistical vulnerability of the area (access for emergency services, supply chains and evacuations).

GIS captures show alignment of exposed zones with urban-infrastructure nodes (bridges, rail, major roads, utilities). Past events on the Siret (e.g. 2008–2010 peaks

~2,884–4,650 m³/s) produced extensive flooding, reinforcing the basin's known vulnerability (Arseni et al., 2020; Romanescu & Stoleriu, 2013; 2017; PFRA, 2022).

Suceava Basin

The Suceava Basin, in the north-western Moldavian Plateau, shows substantial exposure where the centennial flood overlaps settlement limits across 34 localities. The total exposed intravilan exceeds ~1,700 ha, with marked variability between places. The Municipality of Suceava has a more limited, site-specific footprint, whereas exposure becomes critical in communes and villages distributed along the main stem and the tributaries Iaslovăț, Pozen, Solca, Soloneț, and Sucevița.

At Vicovu de Sus, about 120 ha—roughly 8% of the intravilan, fall within the centennial flood, affecting over 200 households (~520 people using 2.6 persons/household). Along the Straja–Frătăuții Vechi corridor, the centennial band intersects continuous built-up strips on both banks; estimates exceed 1,200 households and 3,000 residents potentially exposed.

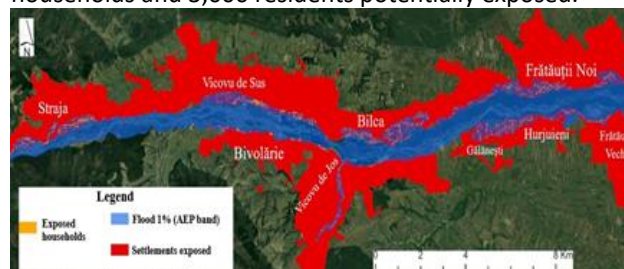


Figure 5: Floodable band and exposed households in Straja – Frătăuții Vechi sector

Satu Mare, located at the Pozen–Suceava confluence, presents very high relative exposure: more than 48% of its intravilan lies inside the band, with ~400 households and over 1,000 residents at risk, around half of the commune's population (2,136 in 2021, INS). Because the flood band also intersects the main access routes (DJ178B and DC41), a major flood could temporarily isolate the settlement, underscoring the need for contingency planning and redundant evacuation options.

In the Rădăuți area, the centennial flood footprint connects indirectly through the Pozen corridor. Horodnicu de Sus functions as a local collector of hillside runoff; inhabited sectors along the Pozen floodplain include more than 90 households (~240+ people) within the band. Although parts of Rădăuți benefit from river works, peri-urban stretches along the Pozen remain vulnerable, with >60 households, >50 economic facilities, and >150 residents exposed where intravilan expansion has outpaced protective measures.

Aggregating vectorised assets across the Suceava–Pozen–Solca–Soloneț–Iaslovăț system yields approximately 2,764 households and >200 economic facilities in the 1% AEP band, corresponding to ~7,200 potentially exposed residents, with a major cluster in

Straja, Vicovu de Sus, and Gălănești. The combination of large exposed areas and high household counts points to priorities such as strengthening dikes and channel works on critical reaches, tightening control of intravilan expansion in floodplains, and ensuring route redundancy and micro-plans for settlements where encirclement and isolation are plausible during a centennial event. (Rădoane et al., 2010; Săgeată et al., 2013; PFRA Suceava, 2022).

Moldova Basin

The Moldova River traverses over 100 km of the Moldavian Plateau, transitioning from a partially regulated mountain reach to hill and plateau sectors where flood volumes tend to accumulate and back up. The spatial analysis highlights pronounced vulnerability for settlements located along the active valley floor, with direct effects on intravilan footprints and adjacent households. Across 16 localities (e.g. Baia, Drăgușeni, Timișești, Vadu Moldovei), the built-up area intersecting the centennial flood totals ~290 ha. The distribution follows a classic pattern of development on low terraces and floodplains, where construction and agriculture have expanded onto hydraulically exposed surfaces. In Baia, approximately 100 ha of intravilan lie within the band (i.e., >14% of the settlement area). Household digitization confirms substantial residential presence inside the hazard zone: ~400 households, corresponding to ~1,000 residents using 2.6 persons/household. In Vadu Moldovei, the band covers ~50 ha, with ~180 households (~468 people) in direct exposure. In Drăgușeni, the affected area is smaller (~14 ha) and the share of intravilan is ~2.86%, but ~40 households (~100 people) remain inside the band.

Detailed maps and household vectors indicate that centennial flood intersects not only agricultural parcels but also local access roads and community infrastructure (secondary bridges, unimproved approaches), increasing the potential costs of a major flood. Where compact rural housing overlaps the band, tailored measures are warranted, bank stabilization, green buffer strips and updated building restrictions on flood-prone terraces.

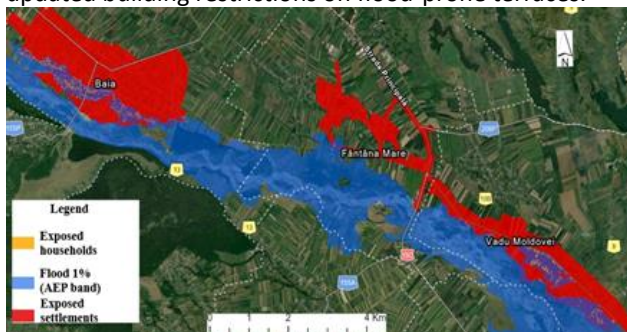


Figure 6: Exposed settlements and households in Baia – Vadu Moldovei sector

In sum, for the Moldova River we estimate ~290 ha of exposed intravilan, ~766 households, and an exposed

population of ~2,000 people. These findings align with the regional literature on Moldova Valley flood behaviour and underscore the value of pairing exposure mapping with downstream discharge monitoring to refine hydraulic modeling and prioritise structural mitigation along critical reaches. (Romanescu & Stoleriu, 2013).

Jijia Basin (excluding Bahlui)

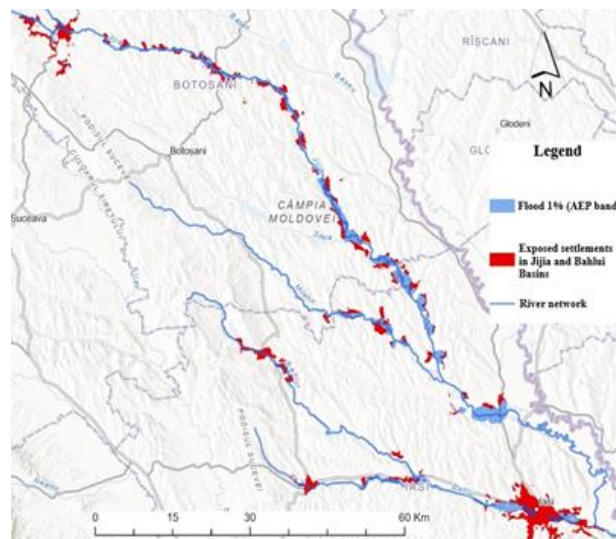


Figure 7: Exposed settlements in Jijia and Bahlui Basins

The Jijia Basin in the north-eastern Moldavian Plateau is among the most flood-prone areas due to its low floodplain, dense tributary network, and extensive settlement growth near channel margins. Overlaying the centennial flood on settlement (intravilan) limits indicates significant exposure across 60 localities, underscoring the basin’s importance for spatial planning and risk-reduction measures. Across the Jijia–Buhai–Miletin system (excluding Bahlui), the exposed intravilan exceeds ~630 ha, and vectorised households suggest ~2,500 people potentially exposed inside the centennial band.

Exposure is concentrated in Dorohoi, Andrieșeni, Răușeni, Pădureni, Broșteni where the share of settlements intersected frequently exceeds 10–13% and reaches >41% in Broșteni, especially on unprotected floodplain sectors. In Dorohoi, the affected intravilan totals 87 ha (9.57% of the city area), with 304 households and 53 economic facilities directly exposed; the estimated vulnerable population is ~790 residents, highlighting the need for targeted protection and updated contingency plans in a dense urban context. Along the Buhai, Pădureni emerges as a critical segment where the centennial flood follows the sinuous channel and directly affects 57 households. On the Miletin, exposure is emphasized in Chișcăreni and Șipote, and in Trușești the risk is amplified by local housing density and proximity of roads and farmland, even where the built-up percentage appears moderate. The flat geomorphology and low terraces of the Jijia floodplain favour water

ponding and prolonged inundation, increasing risk to households, crops, and transport links.

Recent evidence (HEC-RAS + LiDAR studies) (Huțanu et al., 2020) indicates that official hazard maps may underestimate true flood extents by ~10–20% on sections of the Jijia where lateral erosion and backwater effects occur, particularly where dikes are weakened. Field-aligned vector data in Glăvănești, Andrieșeni, Trușești support this finding, with the active hazard band occasionally exceeding traditional limits and intersecting newly built housing on the floodplain. These results reinforce the case for periodic hazard-map updates using high-resolution elevation data and hydraulic simulations, coupled with stricter controls on intravilan expansion in high-risk corridors.

Bahlui Basin

The Bahlui and its tributary Bahlueț traverse densely settled peri-urban and rural sectors, with gentle slopes and wide floodplains that favour inundation during intense rainfall. The total intravilan within the centennial flood is ~643 ha. Excluding the Iași Municipality, ~131 ha belong to small towns and villages, where the exposed stock includes >200 households and >600 residents.

Iași is the dominant hotspot: ~512 ha of intravilan lie in the 1% band, equivalent to 10.59% of the city area, spanning major residential districts (Dacia, Alexandru cel Bun, Mircea cel Bătrân, Cantemir–Podu Roș, Galata, Nicolina) and important industrial zones. The estimated exposed population exceeds ~68,750 people, reflecting the large urban footprint along the floodplain. In Podu Iloaiei, although only 0.62% of intravilan is affected, >50 households (≈>130 residents) fall inside the band, illustrating how small areal shares can still translate into meaningful headcounts. In Bădeni, the centennial band covers 9.27% of intravilan (27.5 ha), exposing 43 households (≈112 people). In Târgu Frumos, 3.25% (~18 ha) of intravilan is affected, with 23 households (≈>50 residents) at risk. Budai records the highest relative exposure (27.3%), consistent with floodplain-side housing and limited hydraulic protection.

Prior research (Boariu et al., 2013) shows that channel works on the Bahlui have altered hydrodynamics, enabling rapid conveyance but reducing natural storage and filtration; when design thresholds are exceeded, vulnerability can increase. The pattern observed here—urban expansion combined with engineered channels—argues for an integrated, cross-disciplinary approach that couples flood-risk analysis with water-quality monitoring and riverine ecosystem assessment, while updating zoning and structural measures where floodplain encroachment has intensified exposure.

Bârlad Basin

The Bârlad Basin includes medium-to-small tributaries (Vaslui, Stemnic, Racova, Bogdana, Simila, Studineț,

Tutova) with torrential behaviour and low, weakly consolidated floodplains. We identified 43 localities with high vulnerability, reflected by large intravilan shares intersecting the centennial band. In Vaslui (municipality), 16 P+4 blocks and 21 houses lie in the band; although the affected area is ~30 ha (~3.34% of intravilan), the urban context elevates risk, with ~2,550 residents potentially exposed and several administrative/economic facilities in danger. Codăești registers the highest relative exposure: 26.62% (68.52 ha) of intravilan, 142 households, >369 people, plus 10 economic facilities and an administrative building—confluence effects between Reditu and Dobrovăț further aggravate peaks. Muntenii de Jos (downstream of Vaslui): 24.86% (51.95 ha), 91 households, ~236 people, 8 facilities exposed—wide, low floodplain segments justify urgent reinforcement of protections. On Studineț, Hălărești and Siliștea exceed 17% intravilan affected; 78 households and >200 residents fall inside the band; on this tributary, ~126 households, >128 ha, and >320 residents are exposed—meandering planform and lack of continuous levees amplify risk. Ivești (Tutova): 9.46% (26.81 ha), 67 households, >174 residents exposed; local slopes and narrow sections produce rapid runoff, consistent with multicriteria GIS findings for the Tutova region (Stângă & Grozavu, 2012).

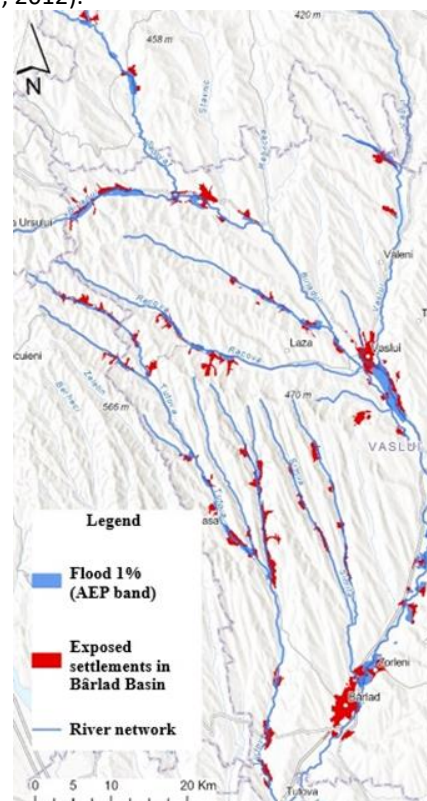


Figure 8: Exposed settlements in Bârlad Basin

On Simila, 16 households and ~40 residents are exposed over ~42 ha; absent major hydraulic works, risk remains persistent. On Bogdana, 92 households, >200 residents, and ~60 ha are in the band, with localities

showing 7.25–25.24% built-up areas affected. Overall across these tributaries, ~610 ha of intravilan, >800 households, and >2,700 residents are potentially exposed, with flash-flood style responses documented for hilly regions. The PMRI – ABA Prut–Bârlad (2022) confirms undersized/obsolete defenses in many rural reaches and calls for urgent interventions and urban-planning restrictions to curb floodplain encroachment (ABA Prut–Bârlad, 2022).

Prut River and Chineja sub-basin (analyzed segment)

Across the four analysed localities—Crasnăleuca, Rădăuți-Prut, Reditu, Românești, the intravilan intersected by the centennial flood totals ~188 ha, with substantial relative exposure ranging from ~9.36% (Crasnăleuca) to ~37.14% (Rădăuți-Prut). Household vectorisation identifies 139 households in the band, corresponding to an estimated ~360 residents (2.6 persons/household). The footprint indicates that extensive built-up strips lie on low floodplain surfaces; in Rădăuți-Prut, the high percentage of affected intravilan and the contiguity of exposed parcels suggest a priority need for reinforced local protection (levee maintenance and setback) and tighter construction controls.

Historical evidence corroborates the sector's severity: during the 2010 exceptional floods, discharges exceeded ~2,310 m³/s at the Rădăuți-Prut gauge, underscoring the magnitude and recurrence potential of high-impact events (Romanescu & Stoleriu, 2017). Recent work using Sentinel-1/2 shows that SAR/optical data can efficiently capture actual flood extents on the Prut and validate hazard maps for preparedness and response (Cîmpianu et al., 2021). Complementary regional analyses on flow estimation and flood routing point to a rising tendency of extremes, arguing for levee strengthening and region-adapted control structures. Taken together, the exposed built-up areas shares, the 2010 hydrological benchmark, and remote-sensing validation make a strong case for integrated measures: routine satellite-aided monitoring and real-time hydrometry, targeted levee upgrades (especially in Rădăuți-Prut, Reditu, Românești) and urban-planning restrictions to curb further encroachment of floodplain sectors.

In Galați County, the Chineja Basin shows pronounced exposure across Chirăfței, Fârtănești, Măstăcani, Târgu Bujor, Viile, where ~190 ha of built-up areas fall inside the centennial flood. We mapped 236 households in the band—~600+ residents at risk overall with Măstăcani standing out (135 households, ~351 residents) due to dense settlement on low floodplain levels. By contrast, Chirăfței and Fârtănești display comparable affected areas but fewer households and residents, reflecting lower residential density and more dispersed at-risk parcels. Hydrologically, tributaries such as Băneasa, Roșcani, Ijdileni, Bujorul can reinforce backwater effects

in the lower Chineja, a pattern consistent with observations from the 2010 Prut floods where even small tributaries intensified inundation via compound flooding (Romanescu & Stoleriu, 2017).

Risk-reduction priorities for the Chineja corridor include bank stabilization, selective minor retention/flow-control works and polder-style storage where feasible (as in analogous applications on Jijia at Țigănași), coupled with local planning controls to limit new construction in high-exposure zones. Given the sub-basin's compound-flood potential, periodic LiDAR/Sentinel-based updates of hazard extents and targeted maintenance of crossings and local levees are recommended.

Multidimensional analysis of flood exposure across the main basins of the Moldavian Plateau

The results show contrasts not only in spatial and demographic risk, but also in the vulnerability of critical transport assets and economic facilities. By synthesizing the key indicators—exposed built-up area, households and population, transport networks, and exposed facilities, we obtain a nuanced risk profile that is essential for management decisions and for prioritizing risk-reduction investments.

For comparability, results for the Jijia, Prut, and Chineja systems are aggregated under a single Prut Basin category. This integrated view is justified by their similar hydrologic and geomorphic settings, their compound-flood behaviour, and their shared institutional management context (PMRI Prut–Bârlad). Riverine settlements along these courses experience broadly similar flood and ponding mechanisms on low floodplains; the aggregation reflects on-the-ground realities and provides a sound basis for comparison with the Siret and Bârlad basins.

By total exposed settlements, Siret ranks first with 3,532 ha, followed by Prut (1,413 ha) and Bârlad (781 ha). These values reflect both basin size and network morphology—broad floodplains, urbanization on low terraces, and historical development in floodable zones. In Siret, spatial vulnerability is amplified by extensive settlement along the main stem and tributaries; in Prut, exposure is more fragmented; in Bârlad, the footprint is smaller but often coincides with densely inhabited sectors. Estimated exposed population follows the same order, with a clear peak in Siret (12,948 residents)—over three times the Prut (~4,000) and Bârlad (4,538). These counts—excluding major municipalities (Bacău, Iași, Vaslui)—highlight substantial exposure in rural and small-town settings, where early-warning systems and rapid-evacuation infrastructure are frequently limited. Household exposure reinforces the picture: Siret 4,993 households, Prut 1,573, Bârlad 1,405—a direct proxy for potential material losses and social costs during a centennial event.

Transport infrastructure introduces a distinct dimension of systemic risk. On rail, the Prut category has the greatest exposed length (57 km), ahead of Siret (16 km) and Bârlad (6.28 km), reflecting the concentration of key CFR alignments in the active floodplains of the Jijia–Bahlu–Bahluet corridor. Exposed CFR stations are likewise highest for Prut (8 stations, e.g. Dorohoi, Ungureni) versus Siret (1 station, Bacău), signaling major operational risk for passenger and freight flows during floods. On roads, all three basins show significant overlap of the 1% AEP band with national and county routes within intravilan: Siret leads with 15.58 km DN and 34.75 km DJ affected, followed by Prut (19.21 km DN, 21.53 km DJ) and Bârlad (5.72 km DN, 17.86 km DJ). Because these links underpin emergency access, evacuation, and service continuity, clustered exposures align with areas where settlements and base infrastructure concentrate on unprotected floodplains.

Economic facilities mirror these patterns: Siret 282, Prut 206, Bârlad 62 exposed sites, with notable differences in both absolute numbers and strategic importance (warehouses, farms, light industrial areas). This underscores the potential for regional economic disruption under severe flooding.

Overall, the integrated assessment indicates that Siret concentrates the highest systemic risk—spatial, demographic, and functional—impacting people, housing stock, and critical infrastructure. The Prut category shows elevated risk in transport, especially rail, alongside meaningful economic exposure, but its dispersion complicates targeted interventions. Bârlad registers lower absolute totals across indicators yet stands out for high local densities of population and housing within vulnerable reaches, calling for focused, site-specific measures and continuous hydrologic monitoring (Buruiană et al., 2013).

In conclusion, flood-risk governance should be tailored to basin specificities: major structural interventions and enforcement for Siret; functional/operational measures for transport networks in the Prut corridor (with emphasis on rail resilience and node protection); and precisely targeted protections and planning controls for vulnerable communities along the Bârlad. Across all basins, the integrated exposure profile argues for inter-institutional coordination, periodic LiDAR-based updates of hazard mapping, and coherent urban-planning and infrastructure policies to reduce flood vulnerability across the Moldavian Plateau.

Bacău Municipality – urban flood study case

The Municipality of Bacău, in the central-western Moldavian Plateau, is an emblematic case of urban exposure to multiple hydrologic risks driven by the interaction of dense neighborhood fabrics with nearby channels (Bistrița, Negel, Trebeș) and by historic expansion of built-up areas onto the floodplain. GIS overlays of buildings, infrastructure and social facilities

against the 1% AEP band indicate that Bacău is the region's second-largest urban hotspot, with >29,000 residents potentially exposed.

Within the city, Miorița is the dominant hotspot: 834 houses and 489 blocks intersect the 1% band, for an estimated 23,528 residents at risk—over three times the next neighborhood. Cornișa follows (23 houses, 162 blocks; 7,272 residents). Other sizeable exposures include Centru (5 houses, 33 blocks; 1,947 residents), Izvoare (165 houses, 20 blocks; 1,261 residents), C.F.R. (392 houses, 731 blocks; 1,100 residents), and the Central Zone (101 houses, 25 blocks; 1,097 residents), each exceeding 1,000 residents. The housing profile is dominated by dense single-family areas and P+4 apartment blocks—especially in Miorița, Cornișa and C.F.R.—with additional socio-economic vulnerabilities. Because some blocks were digitized as single units, true density may be underestimated; applying a +25% adjustment for multi-stairwell blocks lifts the citywide exposed population to >45,000 under a centennial scenario.

Administrative/social functions are also concentrated in exposed sectors. In Miorița alone we mapped 7 churches, 3 middle schools, 2 high schools and 1 clinic within or immediately adjacent to the band. A critical operational point is the ISU facility in Cornișa: its impairment or loss of access during a major flood would reduce response capacity and coordination, increasing systemic vulnerability city-wide.

Economic exposure is substantial: Miorița and Industrial Zone 3 together account for 122 exposed facilities; Izvoare, Cornișa and C.F.R. each add another 19–32 units, indicating material loss potential during rapid or repeated events, particularly where engineered protections are limited. At the asset level, >3,200 buildings lie directly on the 1% band. Two proximity buffers capture near-band exposure: 0–50 m adds 630 buildings (higher proximity), and 50–100 m adds 543 buildings (moderate proximity), >1,100 additional buildings with elevated or moderate risk. Using such buffers is consistent with urban flood-risk literature, which shows substantial building and population exposure at very short distances from mapped hazard zones—and heightened vulnerability to isolation, limited access and fast hazard propagation during extreme events (Koks et al., 2015; Kreibich et al., 2017).

The Bacău results align with an independent multi-criteria GIS assessment for an extreme scenario involving partial failure of Izvorul Muntelui (Coca & Nilca, 2017): that study reports 3,870 houses and 425 blocks at risk, ~53.70% of intravilan exposed and a potential impact >€630 million. By comparison, our mapping identifies 1,462 blocks and 1,747 houses inside the centennial flood, corresponding to ~21.30% intravilan exposure. Differences reflect scenario design and methods, yet both approaches converge on the large urban vulnerability of Bacău. Together, they support differentiated planning by neighborhood for protection,

evacuation and post-disaster recovery, plus reinforcement of critical nodes (e.g. ISU access), routine monitoring of near-band areas, and updated planning

controls where expansion has pressed onto flood-prone terraces (Săgeată et al., 2013).

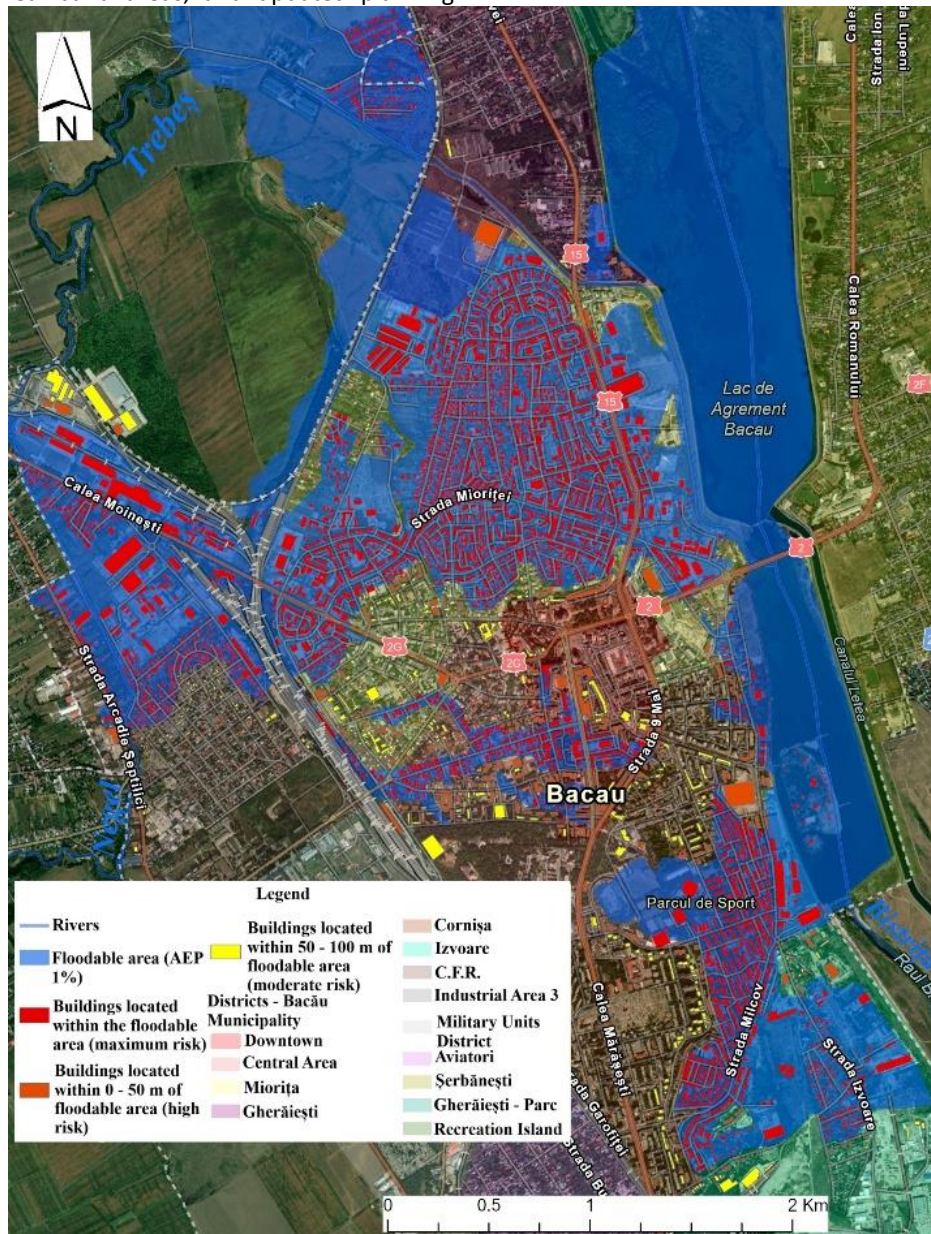


Figure 9: Zonation of Flood-Vulnerable Buildings in Bacău Municipality (1% AEP)

Iași Municipality – urban flood study case

The Municipality of Iași has a mixed urban fabric—large districts of collective housing alongside extensive single-family areas—aligned with the valleys of the Bahlui, Nicolina and smaller tributaries. Flood exposure was assessed by intersecting the 1% AEP band with digitised building footprints and by mapping vulnerable social and economic facilities.

Results show pronounced contrasts between neighborhoods in both exposed population and built-form. Alexandru cel Bun is the primary hotspot, with an estimated 31,348 residents at risk and 280 apartment blocks in the band, reflecting very high collective-housing density. Mircea cel Bătrân follows with ~10,691 residents,

106 blocks and 7 exposed facilities. In Cantemir–Podu Roș, exposure combines collective and single-family housing—~12,552 residents, 156 houses, 146 blocks and 34 facilities—indicating a high share of vulnerable social-economic functions. Galata (predominantly single-family) has ~5,668 residents exposed and 484 houses intersecting the band, while Dacia (block-dominated) has ~7,197 residents and 67 blocks affected. Nicolina and the Industrial Zone register lower exposed populations (~1,146 and ~65 residents, respectively) but the Industrial Zone concentrates 158 economic facilities, signaling heightened business-continuity risk even where headcounts are small. In Nicolina, 25 houses, 13 blocks and 14 facilities lie within the hazard band.



Figure 10: Zonation Map of Flood-Vulnerable Buildings in Iași Municipality (1% AEP)

At the asset level, 1,616 buildings are located directly on the 1% AEP band (maximum risk). Near-band proximity adds a further 559 buildings within 0–50 m (elevated risk) and 792 buildings within 50–100 m (moderate risk). This gradient underscores the need for tiered management—prioritizing hard protections and access continuity for on-band structures while adopting targeted measures (property-level resilience, micro-barriers, access safeguards) in the 0–100 m buffers where indirect impacts (encirclement, service disruption, rapid propagation) are likely.

Social infrastructure exposure is concentrated in dense districts, especially Alexandru cel Bun (3 churches, 3 kindergartens, 3 middle schools, 1 high school). Mircea cel Bătrân and Cantemir–Podu Roș each host multiple education facilities, while Galata includes a clinic and a rehabilitation hospital. This spatial pattern—critical services sited on or near flood-prone terraces—requires explicit inclusion in risk and evacuation planning, with redundancy for access routes and continuity plans for schools, health units and emergency functions.

Overall, Iași exhibits substantial exposure of population, social services and economic activity, driven by dense urban structure and the co-location of critical functions in low-lying areas. The neighborhood-scale breakdown supports differentiated strategies: reinforced protections and access for Alexandru cel Bun and Cantemir–Podu Roș; business-continuity and node protection in the Industrial Zone; and property-level and micro-infrastructure measures in Galata, Dacia and Nicolina. These results also facilitate direct comparison with Bacău and Vaslui and argue for basin-coherent updates to hazard mapping and planning controls in the Bahlui corridor.

Vaslui Municipality – urban flood study case

The Municipality of Vaslui—though one of the three urban centres analysed—shows substantially lower exposure than Bacău or Iași in terms of population, critical infrastructure, and economic assets. Under the centennial flood scenario, the estimated exposed

population is ~2,550 residents, concentrated mainly in P+4 apartment blocks and smaller clusters of single-family housing.

We identified 16 P+4 blocks (most with two stairwells, consistent with local typologies) that account for the bulk of exposed residents, plus 21 single-family houses, confirming that even in exposed sectors the built form is predominantly collective housing. Compared with Bacău or Iași, both the density and absolute number of affected buildings are markedly lower.

Vulnerable social infrastructure includes one middle school, important for continuity of education and community support in a disaster. From an economic perspective, only six facilities were mapped within the risk band, implying a lower short-term business-continuity pressure at municipal scale.

By proximity tier, 44 buildings lie directly on the centennial flood (maximum risk), 85 buildings fall within 0–50 m (elevated risk), and 77 buildings within 50–100 m (moderate risk). Although the maximum-risk share is smaller than in the other cities, the near-band stock is non-trivial, raising vulnerability under extended flooding or extreme discharges. Risk management should therefore prioritise both on-band assets and the 0–100 m buffers, coupling hard protections and access safeguards with property-level resilience.

The Flood Risk Management Plan (PMRI) for the Prut–Bârlad Basin notes Vaslui’s susceptibility under 0.1% AEP conditions and highlights potential flood extents on the Vaslui River downstream of the Delea confluence. Proposed measures include increasing channel conveyance via levee and bridge rehabilitation and deploying “green” solutions (sediment management, channel restoration). In light of our mapping (16 blocks, 21 houses, 6 economic facilities, ~2,550 residents), these actions remain warranted: even a moderate present-day exposure calls for combined structural and non-structural interventions to avoid escalation under extreme scenarios.

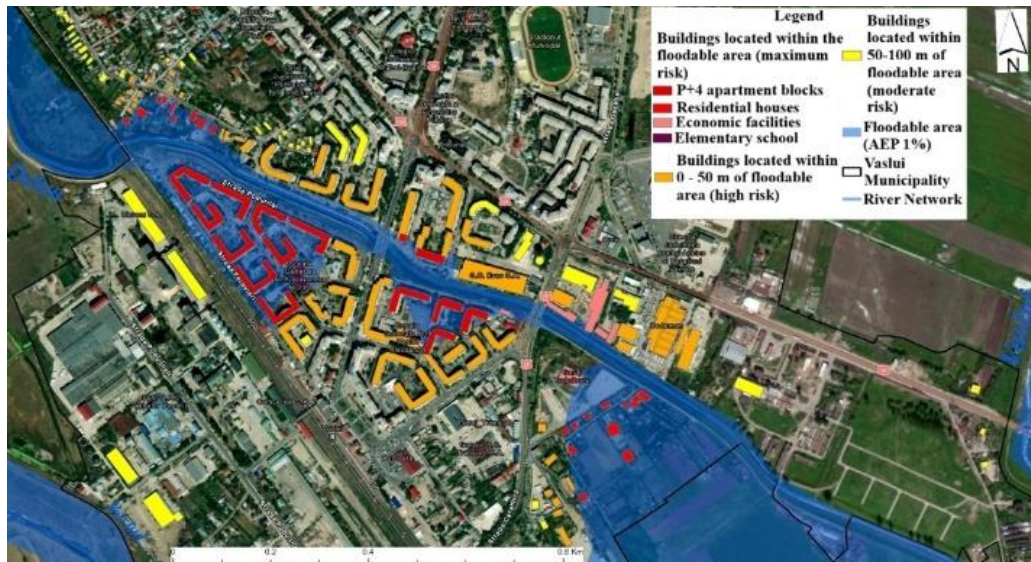


Figure 11: Zonation of Flood-Vulnerable Buildings in Vaslui Municipality (1% AEP)

Integrated Comparative Analysis of Flood Risk in the Municipalities of Bacău, Iași and Vaslui

The comparative analysis highlights not only quantitative contrasts but also structural particularities in how the built environment and population are exposed to flooding. A first notable aspect is the divergence between the number of exposed buildings and the estimated population at risk. In Bacău, the stock of exposed buildings is almost double that of Iași (Bacău: 1,747 houses + 1,462 blocks; Iași: 691 houses + 663 blocks). Yet the population at risk is roughly twice as large in Iași (~68,750 people) as in Bacău (~36,756 people). This discrepancy stems from housing structure: Iași concentrates a much larger share of high-capacity apartment blocks (P+4, P+10, often multi-stairwell and high density), whereas Bacău has more single-family housing and lower-density blocks within the mapped hazard.

Risk stratification using proximity buffers to the centennial flood (0–50 m and 50–100 m) further nuances the urban vulnerability profile. In Bacău, the count of maximum-risk buildings (located directly on the 1% band) is substantially higher (3,225) than in Iași (1,616), indicating more extensive urban fabric placed on the mapped hazard. Conversely, Iași shows a larger share in the near-band buffers (0–50 m; 50–100 m), signaling expansion into immediate floodplain proximity rather than the strict hazard footprint alone.

Vaslui records significantly smaller values across all categories—44 buildings at maximum risk, 85 at elevated risk (0–50 m), and 77 at moderate risk (50–100 m)—but, relative to city size, the local impact remains meaningful and warrants targeted attention.

Another key observation concerns built-form concentration. In Bacău, the density of single-family houses within the hazard zone elevates socio-economic risk for individual households. In Iași, collective risk is

amplified by large block estates (on the order of 80–100 residents/block on average), so smaller building counts can still translate into very large exposed populations.

In sum, differences between Bacău and Iași reflect not only demography but also urbanization trajectories, neighborhood morphology, and housing typologies. This is evident both in the population exposed and in the distribution across risk categories for each proximity buffer. Iași, despite fewer exposed buildings, concentrates a much larger at-risk population due to high-density block housing, whereas Bacău concentrates risk in individual houses and direct on-band exposure to the centennial flood footprint. These contrasts underscore the need for differentiated flood-risk strategies tailored to each urban context—combining structural measures, access and evacuation planning, and planning controls aligned with the specific spatial and socio-demographic profiles of Bacău, Iași and Vaslui (Jongman, 2021; Văculeșteanu et al., 2019; Rusu et al., 2020).

Discussions

Basin-level contrasts and urban patterns

The integrated basin analysis shows marked contrasts in how infrastructure and population are exposed to flooding across the Moldavian Plateau. The Siret Basin concentrates the highest systemic exposure—12,948 people and 4,993 households within the centennial flood—together with 282 exposed economic facilities. Transport vulnerability is likewise substantial, with 15.58 km of national roads, 34.75 km of county roads, and 15.94 km of railway intersecting the hazard band. The aggregated Prut category (Prut, Jijia, Bahlui, Chineja) registers ~4,000 people, 1,573 households, and 206 exposed facilities, but stands out for rail vulnerability: 57.02 km of exposed track and 8 at-risk stations linking Botoșani and Iași, alongside 19.21 km of national and

21.53 km of county roads. The Bârlad Basin shows more moderate totals—4,538 people, 1,405 households, 62 facilities, 6.28 km of railway, 5.72 km of national and 17.86 km of county roads—yet still requires targeted, locality-specific measures.

Urban comparisons underscore structural differences. Bacău totals 36,756 exposed residents, with Miorița (>23,500 people) and Cornișa (~7,200) as dominant hotspots; 1,747 houses and 1,462 blocks intersect the band. Iași has the largest exposed population (68,750), almost double Bacău's, despite fewer exposed buildings (691 houses, 663 blocks), due to high-capacity multi-stairwell blocks (P+4, P+10) and vertical density; the Industrial Zone adds 265 exposed facilities. Vaslui shows the smallest figures—~2,550 residents, 21 houses, 16 blocks, 6 facilities—yet its exposed assets warrant continuous monitoring and preventive upkeep. Risk stratification by proximity buffers confirms these patterns: Bacău leads in maximum-risk stock (3,225 buildings directly on the 1% band) versus 1,616 in Iași and 44 in Vaslui, while Iași carries a larger share in the 0–50 m and 50–100 m bands, signaling expansion into immediate floodplain proximity. Although Iași records the highest headcount at risk, Bacău's nodal position at the confluence of Siret–Bistrița–Trebeș–Negel elevates its systemic risk—particularly under 1%CC (centennial plus climate-change) conditions—where compound events could trigger disproportionate impacts on critical infrastructure and dense neighborhoods (Wang & Sebastian, 2021).

Comparison with other studies and reports

Scope and metrics vary widely across the literature. Coca & Nilca (2017) focus on urban vulnerability in Bacău, mapping multi-criteria risk rather than a citywide exposed population count. Albano et al. (2020) operate at national scale, estimating economic damages via flood–asset overlays rather than headcounts. Trif et al. (2023) analyse a small mountain basin (Valea Turcu), quantifying infrastructure/land losses without reporting exposed population. National-level risk profiles cite >2.5 million residents in floodable zones, indicating that the three cities here constitute a small fraction of the national total. Methodologically, our work derives building-scale exposure from local GIS, while other studies blend hazard maps with demographics, or emphasize hydraulic modeling and damage functions. Despite these differences, all converge on floodplain and low-terrace dominance of exposure. Numerically, our city-specific counts (Iași 68,750; Bacău 36,756; Vaslui 2,550 for 1% AEP) are directly comparable within this study's framework, while regional/national studies provide complementary context and scaling rather than like-for-like headcounts.

Limitations

Population estimates depend on data resolution. In the absence of official micro-statistics at stairwell/building scale, we used average occupancies (e.g. 2.6 persons/household) and typology rules for blocks (P+4, P+10), which can misstate local conditions; especially where functions are mixed or densities deviate from norms. Manual vectorisation from ortho/satellite imagery may omit small/temporary structures; multi-stair blocks were sometimes treated as single units, undercounting apartments and residents. For infrastructure, institutional datasets, INS and OpenStreetMap may lag local changes, affecting completeness. Hydrologically, we employed the centennial flood available on the national portal; F100CC (with climate-change adjustments) was not used and would likely enlarge affected areas, consistent with Floods Directive guidance. We also did not run 1-D, 2D urban hydraulic simulations or multi-probability scenarios (e.g., 5%, 0.1%), limiting micro-scale flow/encirclement insights. Finally, we did not integrate social vulnerability attributes (age, mobility, income, adaptive capacity), which would sharpen impact profiles for sensitive groups (Anwana & Owojori, 2023; Fox et al., 2024; Bates et al., 2021).

Implications for risk management and future directions

The outputs provide an actionable basis for prioritizing investments and targeting measures by basin, city and neighborhood. In the short term, exposure maps and statistics can feed civil-protection plans, rapid-response playbooks, drills and evacuation design; they can also guide placement/upgrade of levees, polders and green buffers, and inform road/rail/utility modernization. Neighborhood-level breakdowns support tailored communication with exposed residents and raise preparedness (Fischer et al., 2024; Rajib et al., 2023).

Over the medium to long term, we recommend: (i) continuous GIS updates; (ii) advanced hydraulic modeling (incl. 1D, 2D and multiple AEP's), with F100CC adoption; (iii) building-level socio-economic enrichments (stairwell/apartment granularity where feasible); and (iv) differentiated strategies per basin and municipality reflecting morphology and urban dynamics. Urban resilience hinges on inter-institutional coordination (local authorities - Inspectorates for Emergency Situations and Romanian Waters, utilities and communities), systematic data refresh, full digitisation of critical infrastructure and the building stock, and participatory planning to align household-level actions with citywide measures. Extending analyses to social, economic and environmental vulnerability layers, incorporating future climate scenarios, and assessing post-disaster response capacity will enable more effective, locally adapted public policies for flood-risk reduction across the Moldavian

Plateau (Haque et al., 2020; Fatemi et al., 2020; Török, 2018; Botezan et al., 2021; Anik et al., 2025).

Conclusions

The integrated assessment confirms clear systemic contrasts across the basins. The Siret Basin concentrates the highest flood risk—large volumes of exposed built-up areas, many vulnerable households and facilities, and the largest at-risk population—driven by compound influences along the main stem and tributaries. The Prut category (Prut–Jijia–Bahlui–Chineja) also shows substantial exposure of people and assets, but stands out for functional vulnerability in transport, especially rail. The Bârlad Basin posts lower totals overall, yet contains local hotspots that warrant targeted action.

At the urban scale, Bacău concentrates the largest absolute exposure on several indicators, amplified by its position at the Siret–Bistrița–Trebeș–Negel confluences. Iași registers the largest exposed population due to high-capacity, multi-stairwell apartment estates on low terraces along the Bahlui–Nicolina corridors. Vaslui shows comparatively modest figures, but assets near the Bârlad corridor remain relevant for preventive risk management.

Management implications differ by context. For Siret/Bacău, priorities include strengthening and extending levees, modernizing water-management infrastructure, protecting/raising critical crossings, and implementing rapid public warning with neighborhood-level micro-evacuation plans. For Prut/Iași, urban hydraulic works on Bahlui–Nicolina, hardening of road/rail nodes, and strict planning controls to limit further floodplain encroachment are essential. For Bârlad/Vaslui, site-specific works (bank stabilization, conveyance improvements), continuous monitoring, and rapid-response protocols for peak-flow events are appropriate.

The conclusions align with academic and institutional literature: building-scale, GIS-based accounting complements regional/national studies centered on hydraulic modeling and economic loss, and all converge on the dominance of exposure on floodplains and low terraces. Key limitations remain: using the F100 (1% AEP) band—rather than F100CC—likely underestimates future-oriented risk under climate change; average demographic proxies (2.6 persons/household) and block typology rules may bias local counts; manual digitization and infrastructure datasets can miss recent on-the-ground changes; multi-probability scenarios and 2D urban simulations were not run; and social-vulnerability layers were not integrated (Crenganiș et al., 2024).

Looking ahead, periodic LiDAR updates, 2D hydraulic modeling for multiple AEP's (including F100CC), finer socio-demographic detail at stairwell/apartment level, and differentiated strategies by basin and municipality—consistent with morphology and urban dynamics—will sharpen decisions. Operationally, early-warning and drill

regimes, neighborhood evacuation plans, full digitisation of critical assets, and sustained inter-institutional coordination (local authorities - Inspectorates for Emergency Situations, utilities and, communities) are pivotal. Overall, the study provides a basin- and city-specific evidence base for prioritizing investments and policy, and for building durable urban and regional resilience to major flood hazards across the Moldavian Plateau (Stoleriu et al., 2019; Rogers et al., 2025).

Funding

This research received no external funding.

Acknowledgements

The authors sincerely thank the anonymous reviewers for their detailed evaluations and highly constructive feedback, which substantially improved the quality and clarity of this paper. The authors are also deeply grateful to the editors of *Forum Geografic* for their continuous support, professionalism, and valuable coordination during the peer-review process.

Author contribution

Conceptualization, D.R.B. and M.M.; methodology, D.R.B. and M.M.; formal analysis, D.R.B. and M.M.; investigation, D.R.B. and M.B.; writing—original draft preparation, D.R.B.; writing—review and editing, D.R.B. and M.B.. All authors have read and agreed to the published.

Conflicts of interest

The authors declare no conflict of interest.

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