Integrating Multi-source Geospatial Datasets in Distributed Hydrological Modelling: A Case Study of the Podoniftis Basin (Athens)

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Abstract. Recent advances in geospatial data availability enable the integration of high-resolution terrain, land use, and soil information within distributed hydrological models. However, many flood assessment workflows still rely on lumped rainfall–runoff approaches, which do not fully exploit the information provided by modern geospatial datasets.

This study presents a distributed hydrological modelling framework applied to the Podoniftis basin (~80 km^2), a highly urbanized catchment in the metropolitan region of Athens, Greece. The modelling approach is based on an adaptation of the grid-based hydrological model DREAM, implemented at a spatial resolution of 10 × 10 m and a time step of 10 min. Multi-source geospatial datasets were processed within a unified GIS workflow to derive terrain parameters, soil hydraulic properties, and distributed model inputs. Design rainfall corresponding to a 100-year return period was generated and transformed into a basin-average hyetograph using an areal reduction factor.

Simulation results show a rapid increase in discharge, with a peak of approximately 658 m^3/s. Time-varying runoff maps are produced throughout the simulation; the map at peak conditions highlights higher runoff in urbanized areas and lower values in semi-natural zones, reflecting the combined influence of topography, land use, and imperviousness.

The study demonstrates how the integration of multi-source geospatial data and distributed modelling can support more reliable flood hazard assessment, providing gridded runoff outputs suitable for coupling with two-dimensional hydrodynamic simulations.

Keywords: Urban flood hazard · Distributed hydrological model · Geospatial data integration

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1 Introduction

In a changing environment, the non-stationarity of hydrological series demands robust distributed approaches to assess flood risk [1]. Building on decades of GIS-hydrology integration [2], high-resolution datasets such as DEMs, land cover, and soil data now enable physically consistent and spatially explicit representations of urban catchments.

With the increasing availability of digital terrain data and geospatial processing tools, high-resolution DEMs and geomorphic descriptors are now widely adopted in flood risk studies, showing high effectiveness in detecting flood-prone areas within ephemeral Mediterranean basins [3, 4].

In urban environments, hydrological response is driven by fine-scale heterogeneity [5]. High imperviousness and engineered drainage generate complex runoff patterns that aggregated approaches fail to represent. Here, processes operate at short time scales, making detailed distributed analysis of local terrain and surface properties essential [6].

However, many flood assessment workflows still rely on lumped or semi-empirical methods, such as the Curve Number [7] or unit hydrographs [8]. While computationally efficient, these approaches cannot fully exploit high-resolution geospatial datasets due to their reliance on basin-averaged parameters.

In contrast, distributed grid-based models overcome these limitations by discretizing the basin into fine-resolution cells. This allows for an explicit representation of the spatial variability of hydrological processes, allowing a more realistic description of runoff generation and flow concentration processes at the basin scale [9].

Within this framework, geomatics plays a central role in bridging data acquisition and environmental modelling. The integration of multi-source datasets, such as high-resolution DEMs, land cover, and soil databases, requires robust GIS workflows for harmonization, georeferencing, and parameter derivation. Far from being mere preparatory steps, these operations constitute the structural foundation of distributed hydrological modelling.

This study applies a distributed hydrological framework to the Podoniftis basin, Athens (Greece), using an adapted version of the DREAM model [10]. The model is implemented on a 10 m resolution grid for event-based simulations, driven by a 100-year design storm in accordance with the EU Floods Directive (2007/60/EC) and the Greek Flood Risk Management Plans (FRMP).

Applying distributed models in urban environments calls for careful consideration of the methodological choices involved. The selection of spatial resolution, for instance, reflects a balance between the model's ability to capture terrain variability and the inherent uncertainty of the available datasets. In this context, the distributed hydrological model is intended to provide gridded runoff inputs, while finer-scale urban flow processes can be addressed in subsequent hydrodynamic simulations (e.g., Runoff-On-Grid approaches, [11]). Likewise, the 10-min time step was chosen as a practical compromise: refined enough to represent the fast dynamics of intense events typical of Mediterranean basins, while still ensuring manageable computational effort.

The objective of the present study is to evaluate how a multi-source geomatics workflow can enhance the representation of distributed runoff through a consistent integration of terrain, land use, and soil information within a distributed hydrological model. Particular emphasis is placed on the role of GIS-based preprocessing in ensuring coherent

parameterization and on the ability of the model to generate physically consistent runoff fields. These outputs are intended to support urban flood hazard assessment and to provide suitable inputs for subsequent hydrodynamic modelling.

2 Study Area

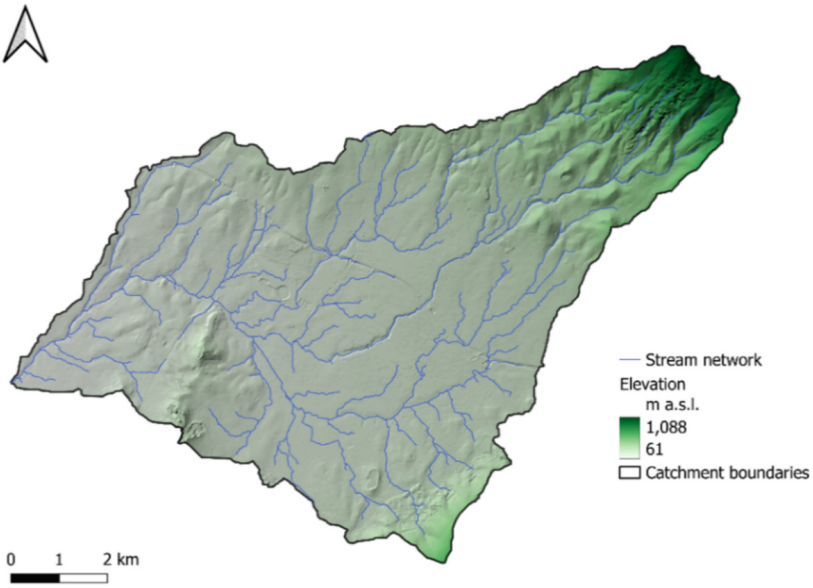

Fig. 1. Digital elevation model of the Podoniftis catchment and its stream network.

The Podoniftis basin is located in the metropolitan region of Athens, Attica, Greece. The total contributing area considered in this study is 77.59 km^2, with the outlet section defined upstream of the confluence with the Kifissos River (Fig. 1).

The basin originates from the Penteli massif and drains southwestward through a densely urbanized environment before joining the Kifissos system. The mean basin slope is approximately 14%, with steep upper slopes that transition to gentler gradients downstream.

A large portion of the catchment is highly urbanized, with impervious surfaces covering more than half of the total area, particularly in the central and downstream sectors. In several reaches, the stream channel is confined within engineered structures, reflecting the strong anthropogenic modification of the drainage network [12]. The basin is therefore characterized by a rapid hydrological response, with a time of concentration of approximately 2.7 h.

3 Geospatial Data and Processing Framework

All geospatial inputs used in this study were processed within a unified GIS-based preprocessing framework. A distinction is made between (i) model parameterization variables, including the Intensity–Duration–Frequency (IDF) curves [13], land cover classes, and soil-related parameters (e.g., root depth, Manning's n) [14, 15], and (ii) spatial input datasets, such as topography (DEM) and soil properties, summarized in Table 1.

Table 1. Spatial input datasets used for the model implementation.

Variable/Grid	Data set	Native resolution	Reference
Land use	CORINE Land Cover 2018	100 m	[16]
Soil type, Percentage of sand, Percentage of clay	LUCAS database	500 m	[17]
Organic matter	LUCAS database	500 m	[18]
Topography	DEM-LSO25	2 m	[19]

A common preprocessing workflow was applied. First, all geospatial inputs were reprojected into a common coordinate reference system (EPSG:2100 - Hellenic Geodetic Reference System 1987). The datasets were then clipped to the predefined domain covering the Podoniftis basin. Subsequently, all layers were resampled and aligned to a common computational grid with a spatial resolution of 10 m. The resampling procedure varied depending on the nature of the dataset (e.g., categorical versus continuous variables) and is described in detail in the following sections.

Vector datasets (e.g., land use) were rasterized, while continuous variables, such as soil properties, were interpolated or aggregated to the model grid. Finally, the processed layers were exported in ASCII raster format (.asc), which constitutes the input format required by the hydrological model.

3.1 Topographic Data and Terrain Processing

Basin delineation and topographic analysis relied on the high-resolution DEM-LSO25, a dataset provided by the National Observatory of Athens and based on the Large Scale Orthophotos (LSO25) project.

The original dataset has a resolution of 2 m, allowing a detailed representation of the terrain morphology of the Podoniftis basin. The DEM was resampled to the model's 10 m computational grid using bilinear interpolation, a method that preserves the continuity of the elevation surface. The 10 m resolution represents a compromise between morphological detail, data uncertainty, and computational efficiency. While finer DEMs capture urban features more accurately, they may introduce artefacts that affect flow representation. A coarser grid reduces these effects and ensures a more robust and physically plausible hydrological response, while remaining suitable for distributed runoff modelling and subsequent hydrodynamic applications.

Prior to hydrological analysis, the DEM was hydrologically conditioned using depression filling to remove spurious pits and ensure the continuity of flow paths. Several terrain derivatives required for the hydrological model were calculated from the DEM, including local slope, flow direction, flow accumulation, and contributing drainage area.

3.2 Land Use Parametrization

Land use information was derived from the CORINE Land Cover 2018 dataset (Level IV). To adapt CORINE classes to the hydrological model structure, the following reclassification was implemented:

1. CORINE classes were first mapped into 17 intermediate categories following the WetSpa extension manual [14] and Hlavčová et al. [15];
2. Each intermediate class was assigned a Manning's roughness coefficient (n) and a root depth (D), according to literature sources;
3. The 17 categories were subsequently aggregated into the five macro-classes of DREAM model (Forest, Grass, Cropland, Bare soil, Impervious areas).

The procedure consisted of associating the CORINE land-cover classes and the root depth and Manning's roughness values in the shapefile. The resulting parameter layers were then rasterized and resampled to the 10 m computational grid using a nearest-neighbor approach to preserve categorical integrity; then, they were exported as ASCII grid files (.asc) for use in the hydrological model.

The Manning coefficient controls overland flow velocity within the kinematic routing component, whereas root depth regulates soil water storage capacity and runoff generation thresholds.

Although CORINE provides consistent land use information at the European scale, its 100 m resolution does not resolve the fine-scale structure of urban environments, including street canyons, small parks, narrow impervious corridors, and roof patterns. For distributed hydrological modelling, this implies that imperviousness is represented at a generalized level, potentially smoothing local contrasts that influence flow connectivity during intense rainfall. Nonetheless, at the catchment scale considered here, CORINE has been successfully used in previous urban hydrology studies and remains adequate for parameterizing roughness and vegetation-related processes [11].

3.3 Soil Data

Soil properties were derived from the LUCAS topsoil database, which provides point measurements of sand and clay fractions as well as organic matter content. In addition, a soil classification layer was used to define the dominant soil types across the basin.

The soil class map was resampled to the model grid using nearest-neighbour interpolation in order to preserve the categorical nature of the data. Continuous soil variables, including sand and clay percentages and organic matter content, were instead interpolated using bilinear interpolation and subsequently resampled to match the 10 m computational grid of the hydrological model. These inputs were then processed through pedotransfer functions [20] to define the soil hydraulic parameters governing infiltration and water storage.

It is important to note that the original resolution of the LUCAS dataset (500 m) is significantly coarser than the 10 m computational grid. As a result, the representation of soil parameters should be interpreted as indicative rather than locally accurate. Urban basins frequently exhibit highly heterogeneous soil conditions, including fill materials, compacted layers, and anthropogenic sealing, which are not captured in continental-scale soil databases. This limitation must be considered when interpreting infiltration dynamics.

3.4 Design Rainfall Modelling

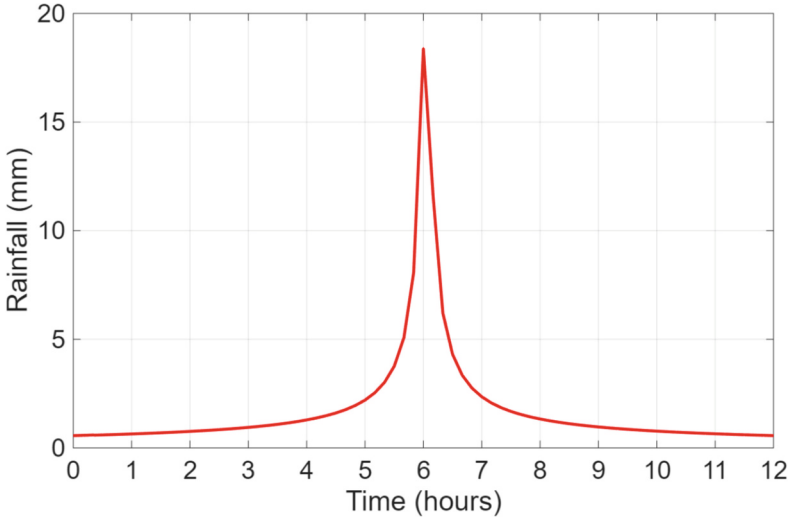

Fig. 2. Design rainfall hyetograph for a 100-year return period.

The selection of rainfall Depth-Duration-Frequency (DDF) formulations is a critical step, as it significantly affects the estimation of peak discharges in distributed modelling [21]. Design rainfall was derived following the procedure adopted in the national flood-risk assessment framework for Greece. The methodology is based on the probabilistic rainfall model proposed by Koutsoyiannis et al. [13], which describes the relationship between rainfall intensity, event duration, and return period.

In this study, the same formulation and parameterization used by Alexopoulos et al. [22] were adopted, where a design storm corresponding to a return period of 100 years was constructed using the Alternating Block Method [23].

Consistently with the reference study, the total storm duration was set to 12 h. However, the catchment considered in the present work differs slightly from that analysed in Alexopoulos et al. [22], as the diversion of the Penteli branch to Rafina was included in the delineation of the drainage area. As a result, the contributing basin area is larger than that adopted in the original study.

The design rainfall was then converted to spatially averaged rainfall over the basin using an areal reduction factor (ARF), computed according to the analytical formulation proposed by Koutsoyiannis and Xanthopoulos [24]. The ARF was calculated using the whole area of 77.59 km2 and applied to the point rainfall intensities to obtain the design hyetograph used in the hydrological simulations (Fig. 2).

4 Methodology

4.1 Model Structure

In this study, a grid-based hydrological model derived from the DREAM framework was used. While the original model operates at daily (D-DREAM) or hourly (H-REAM) scales, the latter was here adapted by discretizing the basin into a 10 × 10 m grid and a 10-min time step. This spatiotemporal resolution captures the high variability and rapid discharge fluctuations of the urbanized Podoniftis catchment while maintaining computational efficiency.

Each grid cell is conceptualized as a storage bucket whose capacity depends on soil type and root depth, and is governed by incoming and outgoing fluxes such as precipitation, evapotranspiration, surface runoff, subsurface flow, and groundwater recharge.

Soil moisture dynamics are described through a water balance equation accounting for precipitation inputs and losses. Vegetation intercepts part of the rainfall before it reaches the soil surface, while the remaining water may be temporarily stored in surface depressions. Effective precipitation is then partitioned into surface runoff and infiltration.

4.2 Initial Soil Moisture Condition

In the absence of discharge records for calibration, initial soil moisture represents the main state variable influencing runoff response under event-based simulation. Observations from streams in the Athens basin indicate that hydrological responses are strongly influenced by episodic high-intensity rainfall events and seasonal variability, with limited influence of persistent wet conditions [25].

In the model, soil water storage at time t is expressed as:

$$S_t = \theta_t * D \tag{1}$$

where D (m) is soil depth and θ_t (mm/m) is the volumetric water content. Rather than being calibrated against observed hydrographs, its initial value was treated as a physically admissible scenario parameter within the range bounded by wilting point (S_{wp}) and the maximum soil water storage capacity (S_{max}).

Considering the typically dry antecedent conditions of Mediterranean environments and the prevalence of event-driven responses, often associated with ephemeral flow regimes, a moderately dry initial state was assumed. Residual soil moisture from previous events and urban contributions was also considered. Specifically, an initial soil moisture equal to 20% of the storage interval between wilting point and field capacity (S_c) was

selected as a representative compromise between dry and partially replenished conditions (Eq. 2):

$$S_t = S_{wp} + \left(S_c - S_{wp}\right) * 0.2 \tag{2}$$

Antecedent soil moisture is known to be a dominant source of uncertainty in Mediterranean basins characterized by short-lived, high-intensity storm events. By assuming low initial soil moisture to avoid artificial pre-saturation, this configuration realistically captures rapid, saturation-driven runoff during intense storms within a basin characterized by shallow soils and limited storage capacity.

In the absence of streamflow observations, adopting a mid-to-low initial water content is physically reasonable, but alternative scenarios (e.g., wetter conditions following prior frontal systems) could substantially alter infiltration dynamics. A future sensitivity analysis could quantify the impact of these assumptions on simulated peak discharge.

4.3 Runoff Generation and Propagation

The model adopts a Dunnian runoff generation scheme based on saturation excess, following Manfreda et al. [10]. Under these conditions, rainfall exceeding the local storage capacity is converted into surface runoff. Subsurface runoff is generated when soil moisture exceeds the maximum storage capacity, and is computed as the corresponding excess. The total runoff is therefore obtained as the sum of surface and subsurface contributions.

Flow travel time is computed in a distributed manner based on local slopes and the drainage network structure, with flow velocities estimated using Manning's equation. Roughness and hydraulic radius are treated as static terrain properties. Following Manfreda et al. [10], a simplified routing scheme based on pure translation of runoff is adopted. While this assumption neglects attenuation and diffusion processes, as well as additional hydraulic complexities related to urban drainage infrastructure, it provides a parsimonious representation of flow routing and is considered appropriate for the present application, which focuses on capturing rapid runoff dynamics in a highly urbanized basin.

Total discharge at the basin outlet is obtained by summing the contributions from all grid cells, each delayed according to its travel time. The resulting hydrograph includes surface runoff, subsurface flow, and baseflow components.

5 Results

The simulated 100-year rainfall event produces a rapid hydrological response, with discharge rising sharply and peaking at 658.32 m^3/s, approximately one hour after the rainfall maximum (Fig. 3). This brief lag time, combined with a quick recession, is closely aligned with the estimated basin time of concentration ($t_c = 2.7$ h). Such timing reflects the fast hydrological response typical of urbanized catchments with limited buffering capacity. The dominance of rapid surface runoff processes is driven by the combined effect of steep upstream slopes and extensive impervious surfaces, which minimize soil storage and lead to a rapid synchronization of runoff contributions at the outlet.

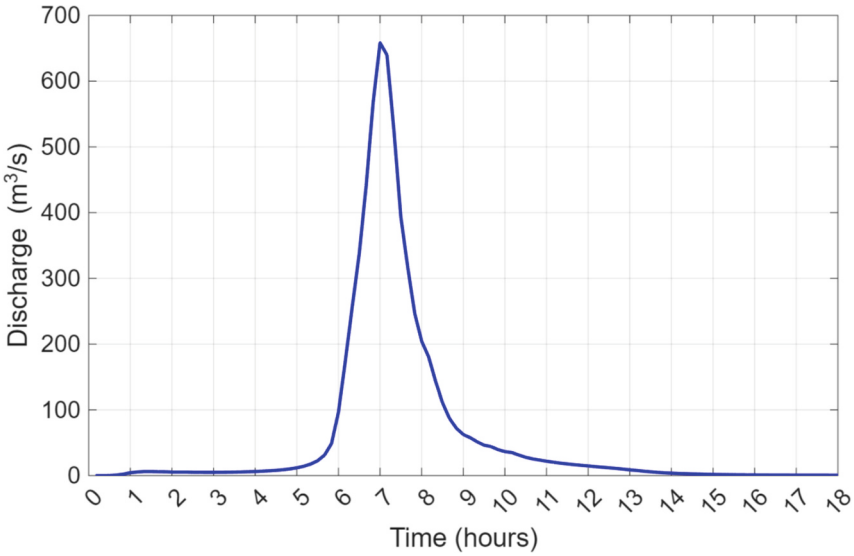

Fig. 3. Simulated hydrograph for a 100-year return period event.

The runoff map at the seventh hour (Fig. 4), corresponding to peak flow conditions, highlights a heterogeneous response across the basin, effectively capturing the transition from upstream areas to the urbanized outlet. Higher runoff depths (up to 8.6 mm) are clearly delineated along the drainage network, where flow accumulation is most prominent. In the downstream sectors, the high runoff values also reflect the impact of extensive impervious surfaces, which inhibit infiltration. Conversely, the fragmented pattern in the semi-natural areas exhibits significantly lower runoff, illustrating the variability in infiltration capacity and topographic control across the domain.

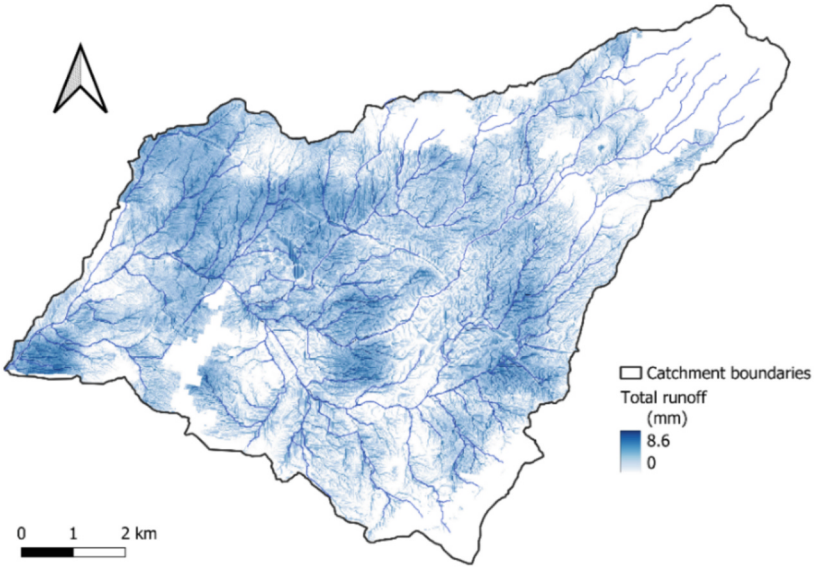

Fig. 4. Total runoff map for the seventh hour of the simulation.

6 Discussion

The grid-based implementation proves suitable for complex peri-urban systems where land use, soil, and topography vary significantly over short distances.

The results highlight three main aspects.

First, integrating multi-source geospatial datasets ensures a process-consistent parameterization, confirming the importance of geomatics-based workflows for urban modelling.

Second, the distributed modelling framework captures localized dynamics often undetected in traditional lumped schemes. The 10-m resolution provides time-varying runoff maps (Fig. 4) essential for street-scale hydraulic coupling and accurate urban flood reconstruction [26].

Third, urban imperviousness strongly accelerates runoff, producing steep rising limbs. While buildings are not explicitly treated as hydraulic obstacles in this study, this simplification can be addressed in subsequent 2D hydraulic simulations [27, 28].

Comparable discharge magnitudes were reported by Alexopoulos et al. [22], who used a 10-m hydraulic model on part of the Podoniftis basin. Their study evaluated several modelling configurations, including simulations with and without buildings represented as flow obstacles, the latter providing a more conservative scenario. Despite differences in modelling frameworks, such as the use of Curve Number approach, the resulting discharge estimates remain consistent with the peak flows obtained in the present study.

Despite the advantages of the distributed framework, several limitations should be acknowledged, mainly related to the level of process representation adopted. The model does not explicitly represent urban drainage infrastructure (e.g., pipes, inlets, culverts), which can significantly influence flow routing in densely built environments. In addition,

surface properties are parameterized in a simplified manner, and the resampling of the 2 m DEM to a 10 m grid smooths micro-topographic features that may affect local flow paths. Soil properties derived from coarse-resolution datasets provide only a generalized representation and do not fully capture the heterogeneity typical of urban environments. Furthermore, the absence of discharge observations prevents model calibration, and the use of a uniform design storm across the domain neglects rainfall variability.

These limitations are consistent with the scope of the present study, which focuses on the integration of multi-source geospatial data and on the generation of distributed runoff fields within a grid-based hydrological framework. In this context, the model is conceived as an intermediate layer, while finer-scale hydraulic processes can be addressed in subsequent hydrodynamic simulations. These aspects should be considered when interpreting the results and represent directions for future refinement and model coupling.

7 Conclusions

This study demonstrated the applicability of a fully distributed hydrological model to a highly urbanized Mediterranean basin in Athens. The grid-based implementation (10 × 10 m) enabled explicit representation of topographic controls and land-use heterogeneity, which govern runoff generation under extreme design rainfall.

Unlike traditional lumped approaches, this distributed framework identifies specific sub-catchment source areas and localized runoff concentrations that would be smoothed out by basin-wide averaging. Furthermore, it allows for a physically realistic parameterization of surface–subsurface interactions and antecedent soil moisture, which are known to significantly influence hydrograph shape and peak timing [11]. By accounting for soil water redistribution, this formulation accurately simulates saturation-driven processes and delayed subsurface contributions, which can generate runoff even after the rainfall event ends.

The resulting gridded, time-varying runoff fields are particularly suitable for coupling with 2D hydrodynamic models, supporting improved assessment of pluvial flood hazards in complex urban environments. Overall, the approach represents a robust and physically consistent tool for urban flood hazard assessment in Mediterranean catchments.

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